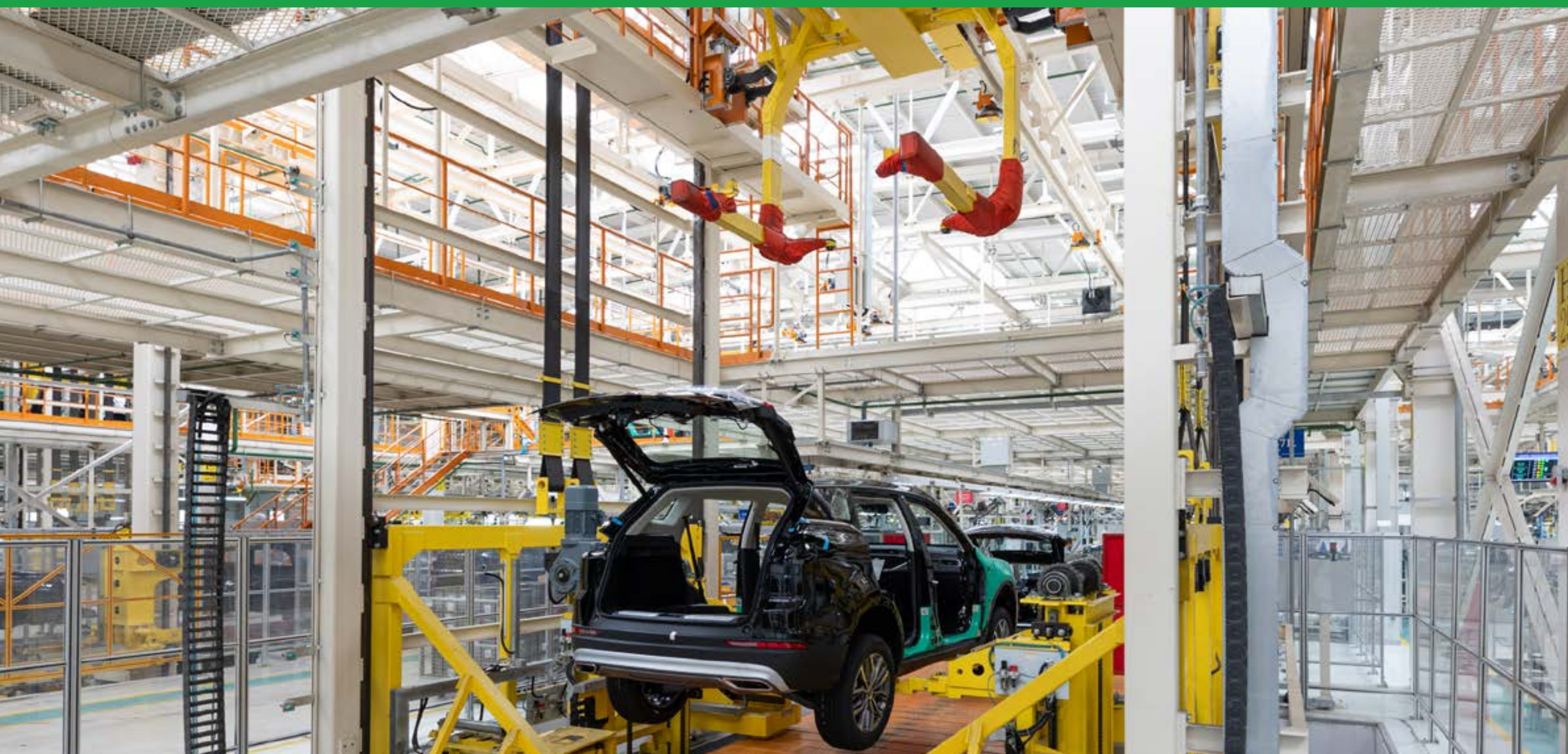
MINISTRY OF EDUCATION
GHANA ASSOCIATION OF SCIENCE TEACHERS

Manufacturing Engineering

for Senior High Schools

Year 2



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FOREWORD

Ghana's new Senior High School Curriculum aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, knowledge, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, progress to further studies and enter the world of work. This is the first time that Ghana has developed a Senior High School Curriculum which focuses on national values, attempting to educate a generation of Ghanaian youth who are proud of our country and can contribute effectively to its development.

The Ministry of Education is proud to have overseen the production of these Learner Materials which can be used in class and for self-study and revision. These materials have been developed through a partnership between the Ghana Education Service, teacher unions (Ghana National Association of Teachers- GNAT, National Association of Graduate Teacher -NAGRAT and the Pre-Tertiary Teachers Association of Ghana-PRETAG) and National Subject Associations. These materials are informative and of high quality because they have been written by teachers for teachers with the expert backing of each subject association.

I believe that, if used appropriately, these materials will go a long way to transforming our Senior High Schools and developing Ghana so that we become a proud, prosperous and values-driven nation where our people are our greatest national asset.

Haruna Iddrisu, MP
Minister for Education

SECTION

1

CLASSIFICATION OF MATERIALS ACCORDING TO THEIR CHEMICAL PROPERTIES, STRUCTURE, PROCESSING AND SYNTHESIS

MANUFACTURING MATERIALS AND TECHNOLOGIES

Classification of Materials

Introduction

In this section, we will explore the fundamentals of chemical changes and the classification of materials, which are essential concepts in the field of materials science. You will be introduced to the principles of chemical transformations that alter the identity of substances through the breaking and forming of chemical bonds. We will discuss how specific chemical properties, such as reactivity, flammability, and toxicity, manifest during these changes. You will also learn about the two main categories of materials: crystalline and amorphous. Understanding the distinct characteristics of these materials, including their atomic arrangements, will enhance your grasp of their physical properties and applications. Furthermore, we will delve into the various processing methods used in material classification, including shaping, property enhancement, and surface treatments. Hands-on activities will allow you to practice and apply your knowledge of these concepts, helping you understand the significance of synthesis methods and the diverse processes involved in creating materials, from natural occurrences to complex synthetic reactions.

By the end of this section, you will have a comprehensive understanding of chemical changes, material classifications, and their implications in real-world applications.

Key Ideas

- A chemical change is a transformation that modifies the identity of a substance by breaking and forming chemical bonds.
- During such changes, specific chemical properties are observed, including reactivity, flammability, and toxicity.
- Materials can be broadly categorised into two types, crystalline and amorphous. Crystalline materials possess a well-defined, orderly arrangement of atoms, which imparts distinct physical properties, amorphous materials lack this long-range order, resulting in different characteristics.
- Materials are also classified based on their processing methods, including shaping, enhancing properties, and surface treatments.
- A fundamental aspect of materials science is understanding how substances are grouped according to their synthesis method.
- The creation of materials ranges from naturally occurring substances to sophisticated synthetic chemical reactions.

EXPLAIN REACTIVITY, FLAMMABILITY AND TOXICITY AS CHEMICAL PROPERTIES OF MATERIALS

A chemical property of a material is revealed when it undergoes a chemical change, which fundamentally changes its identity through the breaking and forming of new chemical bonds. The chemical properties are determined by the material's atomic and molecular composition and structure, which significantly influence their behaviour in various environments. Understanding chemical properties such as reactivity, flammability, and toxicity is essential for developing safer manufacturing practices and minimising the environmental impact of industrial activities. **Figure 1.1** displays symbols representing reactivity, toxicity, and flammability.

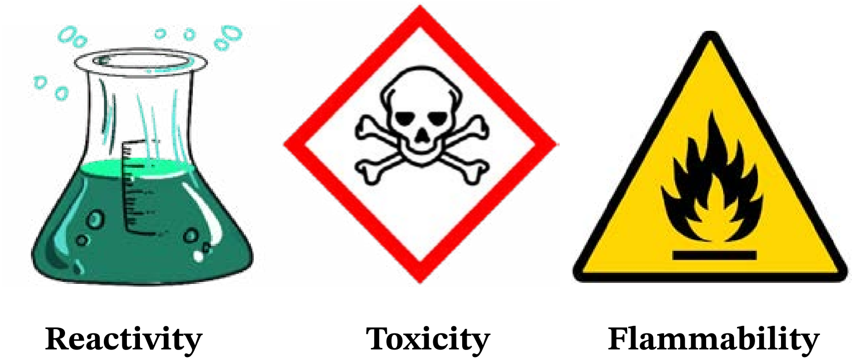


Figure 1.1: Reactivity, Toxicity and Flammability symbols.

Reactivity as a Property of Materials

Reactivity refers to the rate and extent to which a material engages in chemical reactions under specific conditions. As a property of materials in manufacturing, reactivity is crucial for determining the efficiency, safety, and performance of various processes and products. While reactivity is often a desirable trait that enables a wide range of applications, it can also pose significant workplace hazards. Many workplaces may store reactive chemicals without recognising their potential dangers.

Reactive materials must be properly identified and managed, as they can react under conditions such as heat, pressure, shock, friction, air, or water. Hazardous reactions may occur when two or more compounds are combined, leading to dangerous outcomes. Once an organisation has identified reactive materials in its environment, it must determine what information is necessary to control these hazards and what safeguards are required to mitigate risks.

In chemical manufacturing, reactivity can result in severe consequences, such as detonation or runaway reactions, underscoring the importance of thorough evaluations of raw materials and process streams to minimise risks. Overall, reactivity is a complex property that significantly impacts various aspects of manufacturing, influencing safety, efficiency, material optimisation, performance, and process outcomes.

Flammability as a Property of Materials

Flammability is a vital property in material manufacturing, significantly impacting safety, performance, and suitability for various applications. It describes a material's ability to ignite and sustain combustion when exposed to a flame or heat source. Flammability encompasses several factors, including the ease of ignition, the intensity of combustion, the rate of fire spread, and the generation of smoke and toxic byproducts during burning.

Several variables influence flammability, such as material composition, density, and thermal stability. For example, cellulose fibres can accelerate thermal degradation, whereas nano-fillers may enhance the thermal stability of composites. Due to its implications for safety, regulatory compliance, and performance, flammability is a critical consideration in material selection.

Materials that ignite easily and burn vigorously present heightened risks, often necessitating the incorporation of flame-retardant additives or modifications to their polymer structures to improve fire resistance. A thorough assessment of a material's flammability typically requires data from multiple laboratory tests, often supplemented by analytical methods or modelling to accurately interpret the results. Bench-scale flammability tests can determine various fire properties, including ignitability.

Testing methods, such as the cone calorimeter, are employed to evaluate parameters like heat release rate and mass loss, which are essential for understanding material behaviour in fire conditions. A comprehensive understanding of these diverse aspects of flammability enables manufacturers to develop materials that adhere to safety standards and perform reliably when exposed to fire.

Toxicity as a Property of Materials

Toxicity is an intrinsic property of materials that can result in harmful biological effects upon exposure to living organisms. This property indicates the potential for a material to cause damage or adverse reactions when it enters the body. The effects of toxicity can be categorised into two primary types: acute and chronic. Acute toxicity refers to the immediate harmful effects that occur due to short-term, high-concentration exposure to a toxicant, while chronic toxicity results from prolonged exposure to lower levels of a toxicant, leading to long-term health consequences.

Toxicity is influenced by various physicochemical characteristics of a material, including size, shape, surface area, and chemical composition, all of which can affect how the material interacts with biological systems. For example, nanomaterials, owing to their diminutive size and unique properties, can traverse cellular barriers and induce toxicity at the cellular level, thereby impacting tissues within the respiratory and gastrointestinal tracts.

The manifestations of toxicity can take several forms, such as cytotoxicity, immunotoxicity, and organ-specific toxicity, which can affect various bodily systems, including the central nervous system (CNS), lungs, heart, skin, and gastrointestinal tract. In the context of manufacturing, the toxicity of materials is a critical consideration, encompassing the potential adverse effects these materials may have on both biological systems and the environment. Sources of toxicity can include the inherent chemical composition of materials, the manufacturing processes employed, and the by-products generated during production and disposal.

For instance, in the toxic chemical industry, selecting materials requires a systematic approach to ensure sustainability and minimise toxicological impacts. Toxic entities can be classified into five categories: chemical, biological, physical, radiation, and behavioural toxicity. Examples of toxic chemicals include mercury, hydrogen sulfide, and chlorine gas. Understanding toxicity is essential for safeguarding human health and the environment in various industrial applications.

Activity 1.1 Presentation on chemical properties of materials

1. Make a search on the internet or watch the video or read from the textbook on the reactivity, flammability and toxicity as chemical properties of materials using the link and the book provided:
   a. https://www.youtube.com/watch?v=EAxgMS6QVaU
   b. https://www.youtube.com/watch?v=EB4ezvjtsD0
   c. https://study.com/academy/lesson/what-is-a-chemical-property-definition-examples.html
2. Prepare a PowerPoint presentation to be presented to your class highlighting the reactivity, flammability and toxicity as chemical properties of materials

Activity 1.2 Material Hunt

Take part in a “Material Hunt” in your classroom. Your teacher will allocate you to a group and assign your group a material type (metals, ceramics, or polymers). Your group is to collect samples of your assigned material type and create a poster that groups these materials based on their chemical properties, including reactivity, flammability, and toxicity. This task will help you to recall the basic properties of these materials and understand these concepts.

Activity 1.3 Safety Protocols

In your group research and develop a safety protocol for handling your assigned material type in a manufacturing setting, considering its reactivity, flammability, and toxicity. Your group will then present your safety protocols to the class. This task will help you to apply your knowledge in a real-world context and think critically about the implications of these chemical properties.

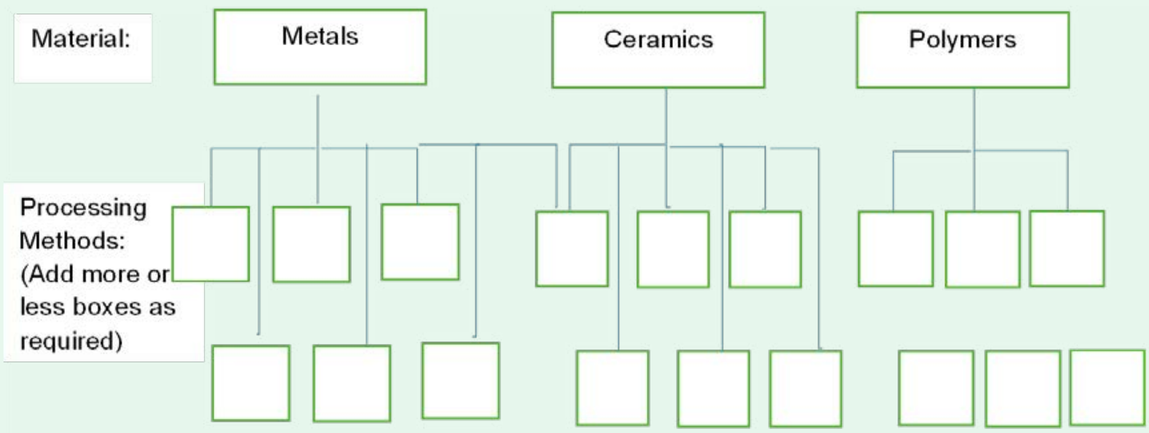
Activity 1.4 Classification of Processing Methods

In your group identify different materials processing methods and classify them based on the type of material they are most used for (metals, ceramics, polymers). You are then to create a flowchart or diagram to illustrate your findings.

Sample templates:

Materials	**Metals**	**Ceramics**	**Polymers**
Processing methods (*list all the different processing methods that can be used for each type of material*)			

Template for flowchart/diagram



Activity 1.5 Classification of synthesis methods

1. In your group research different synthesis methods for metals, ceramics, and polymers.
2. Classify these methods and present your findings to the class, explaining how the synthesis method impacts the chemical properties of the material.

GROUP MATERIALS ACCORDING TO THEIR CHEMICAL PROPERTIES

In manufacturing engineering, the classification of materials according to their chemical properties entails a comprehensive understanding of their composition, behaviour under varying conditions, and interactions with other substances. Manufacturers utilise sophisticated techniques, including machine learning, fuzzy logic, and clustering algorithms, to categorise materials based on these chemical properties.

Group Materials as Reactive and Non-Reactive Materials

Materials can be divided into two primary categories based on their chemical behaviour: reactive and non-reactive.

Reactive Materials

These materials undergo significant chemical transformations when exposed to specific conditions. They are engineered to release large amounts of energy through exothermic reactions, triggered by stimuli such as impact, friction, or heat. Reactive materials can be produced in various forms, including powders, multilayers, and structural composites, each designed for specific uses.

Non-Reactive Materials

In contrast, non-reactive materials are stable and do not readily participate in chemical reactions under typical conditions. Their stability makes them ideal for a wide range of industrial applications.

Understanding the distinction between reactive and non-reactive materials is crucial for selecting the right materials for various industrial and technological purposes. Refer to **Table 1.1** for a detailed classification of these materials.

Table 1.1: Classification of reactive and non-reactive materials

Material Category	Material	Reactivity Characteristics	Examples	Applications
Reactive Materials	Metals	They are highly reactive and can react with oxygen in the air, water, and acids.	Sodium, potassium, calcium, magnesium, aluminium, etc.	Used in various industries, including the manufacture of batteries and semiconductors
	Non-metals	They are very reactive and can combine other elements/ materials to form compounds/ new materials.	Fluorine, chlorine, and oxygen, etc.	Used in the production of various compounds for industrial applications
	Acids	They are reactive and can react with metals, bases and carbonates.	Hydrochloric acid, sulphuric acid, nitric acid, etc.	Used in various chemical processes in industries
	Reactive Polymers	They are macromolecules that possess specific chemical functional groups,	Polyethylene, polypropylene, polyvinyl chloride (PVC), Poly (β-hydroxybutyric acid),	Used in the manufacture of filled polymer compounds with enhanced mechanical properties, thermal stability, and chemical resistance
Non - Reactive materials	Noble gases	They are non-reactive or inert and do not readily form compounds with other elements/ materials.	Helium, neon, argon, krypton, xenon, and radon, etc	Used in various industries, including lighting, welding, and space exploration
	Noble Metals	They are highly resistant to corrosion and oxidation, making them non-reactive.	Gold and Platinum	used in the jewellery industry and in various industrial applications due to their resistance to corrosion and excellent conductivity

Material Category	Material	Reactivity Characteristics	Examples	Applications
	Inorganic Materials,	These materials are generally non-reactive and do not readily react with other substances.	Glass and Ceramics	used in various industries, including construction, electronics, and consumer goods
	Industrial Polymers/ Versatile Materials	These polymers are designed to avoid post-polymerisation reactions, which enhances their stability and performance in specific environments.	**Thermoplastics:** Polyethylene (PE), Polypropylene (PP**),** Polyvinyl Chloride (PVC) **Thermosetting plastics:** Epoxy Resins, Melamine Formaldehyde, Phenolic Resins	They find applications in the production of plastics, elastomers, man-made fibres, adhesives, and surface coatings
	Silicones	They are typically inert and do not readily react with other substances, which contributes to their stability and versatility in different environments	Polydimethylsiloxane (PDMS), phenyl Silicones, silicone Oil, silicone grease, silicone rubber, silicone resin, room temperature vulcanised silicones (RTV), liquid silicone rubber (LSR), fluorosilicone, etc	used as insulating materials, spreading agents, defoamers, parting agents, implants, matrices in drug delivery systems, adhesives, and sealants

Group Materials as Flammable and Non-Flammable Materials

Flammable Materials

Flammable materials are those that readily ignite and burn when exposed to an open flame, heat, or sparks. Common examples include wood, paper, and various construction materials, all of which present significant fire hazards in both residential and commercial environments. Their propensity to catch fire underscores the need for careful handling and storage.

Non-Flammable Materials

On the other hand, non-flammable materials are specifically engineered to resist ignition and inhibit the spread of fire, thereby enhancing safety in various applications. A range of compositions and technologies have been developed to create these materials. For example, a non-flammable agent can include a blend of borax, boric acid, alum, surfactants, calcium chloride, sodium silicate, copper sulphate, sodium oxide, silicon dioxide, iron oxide, caustic soda, alkali silicate, magnesium oxide, and magnesium carbonate. This combination has demonstrated excellent non-flammable performance across diverse material types and fire intensities.

Flammability Characteristics

Both flammable and non-flammable materials can exist in solid, liquid, or gaseous states. Their flammability is influenced by their chemical composition and physical properties, such as the flash point, the lowest temperature at which a material releases vapours capable of igniting.

A detailed classification of flammable and non-flammable materials can be found in **Table 1.2.**

Table 1.2: Classification of flammable and non-flammable materials

Material Category	Flammability Characteristics	Examples	Applications
Flammable materials	Burn readily, release heat and light when burning, and can leave ash or residue.	Wood	Used for construction, furniture, fuel (firewood)
		Paper	Used for writing, printing, packaging
		Cloth	Used for clothing, pen spark textiles, decoration
		Plastics	Used for packaging, construction, and various household items
		Rubber	Used for tyres, hoses, seals, toys
	Very volatile (evaporates easily), flammable vapours mix with air to create a combustible mixture and burn readily when ignited.	Gasoline	Fuel for vehicles
		Oil	Fuel for heating, cooking, lubrication
		Alcohol	Used in beverages, cleaning solutions, fuel
		Acetone	Solvent for paints and nail polish remover
	Odourless or have a faint odour, readily mix with air, can ignite with a spark or flame.	Paint	Used for coating and protecting surfaces

Material Category	Flammability Characteristics	Examples	Applications
		Propane	Fuel for cooking, heating, and grilling
		Natural gas	Fuel for heating, cooking, and electricity generation
		Butane	Fuel for lighters and portable stoves
		Hydrogen	Fuel for some vehicles and rockets
Non-flammable Materials	Do not easily ignite and may decompose or melt when heated	Metals	Used in construction, machinery, tools, electrical wiring
		Steel	Strong and durable metal used in buildings, bridges, and vehicles
		Aluminium	Lightweight metal used in cans, airplanes, and cookware
		Copper	Excellent conductor of heat and electricity, used in electrical wiring and plumbing.
		Minerals	Used in construction, fireproofing, and decoration
		Brick	Strong and fire-resistant building material.
		Concrete	Strong and durable building material
		Cement	Binds other materials together in concrete.
		Sand	Used in construction, glassmaking, and recreation.
		Glass	Hard, transparent material used for windows, bottles, and containers.
		Ceramics	Used for cookware, pottery, and electrical insulation
		Clay	Natural earth material used to make pottery and bricks.
		Porcelain	Fine, white ceramic used for dishes and figurines.
		Water	Essential for life, used for drinking, cleaning, and fire suppression

Group Materials as Toxic and Non-Toxic Materials

Toxic Materials

Toxic materials are substances that pose significant risks to human health and the environment. Exposure to these materials can result in a range of adverse health effects, including poisoning, cancer, and other serious medical conditions. The potential dangers associated with toxic materials necessitate stringent handling and usage precautions.

Non-Toxic Materials

In contrast, non-toxic materials are specifically designed to be safe for human contact and environmentally sustainable. These materials minimise health risks and contribute positively to ecological balance. For example, non-toxic and energy-efficient materials can be derived from expanded perlite, silica powder, and other benign raw materials, ensuring both safety and environmental responsibility.

A comparative grouping of toxic and non-toxic materials is presented in **Table 1.3**.

Table 1.3: Classification of toxic and non-toxic materials

Material Category	Material Characteristics	Examples	Applications
Toxic materials	Can cause harm to human health through inhalation, ingestion, or skin contact. Varying degrees of toxicity depend on the material and exposure level. May cause short-term or long-term health effects, including cancer, organ damage, and respiratory problems.	Arsenic Lead Mercury Benzene Cyanide Pesticides (e.g., DDT)	Used in industrial processes (e.g., lead in batteries, mercury in thermometers). Strict regulations and safety measures are essential due to their hazardous nature. Certain pesticides and herbicides used in agriculture and pest control (important to follow recommended usage guidelines). Some household products (e.g., strong cleaning agents and drain cleaners) require careful handling and storage, often with childproof closures

Material Category	Material Characteristics	Examples	Applications
Non-Toxic Materials	Do not pose a significant health risk under normal conditions. Generally safe for everyday use	Wood Cotton Steel Glass Water Food (excluding spoiled)	A wide range of everyday materials used in homes, offices, and schools. Construction materials (e.g., wood, concrete, steel). Food items (excluding spoiled or contaminated food). Clothing (made from natural or synthetic fibres). Natural materials (e.g., water, soil).

Activity 1.6 Discovering Material Properties

Using the internet, research and present your findings on the chemical properties of either metal, ceramic, or polymer. Focusing on:

1. **Reactivity**
   a. How does it react with air, water, acids, or bases?
   b. Are there any specific conditions that affect its reactivity?
   c. List at least two examples of such material
   d. List at least two places where such material is applicable
2. **Flammability**
   a. What is its flammability classification?
   b. Under what conditions can it ignite?
   c. List at least two examples of such material
   d. List at least two places where such material is applicable
3. **Toxicity:**
   a. Is it toxic?
   b. What health effects are associated with exposure?
   c. What are the safe handling practices?
   d. List at least two examples of such material
   e. List at least two places such material is applicable

Activity 1.7 Material Selection in the Marine Industry Discussion

Topic: The use of **aluminium and steel has been proposed** in the construction of marine vessels.

1. Your teacher will allocate you to a group. In this group explore the complexities of material selection in the marine industry and the role of chemical properties in material selection for the marine industry.
2. In your group generate responses to the following:
   - Why is aluminium a more suitable choice for marine industry applications than steel?
   - What chemical properties of aluminium make it more advantageous over steel for use in saltwater environments?
   - What challenges or considerations arise from aluminium's reactivity, toxicity, and flammability?
   - How does aluminium compare with steel in marine industry applications?

Activity 1.8 Classification of Materials

1. Bring into class different materials from your community. Then in your group classify these materials and group them into metals, ceramics, and polymers and discuss their chemical properties.
2. Your teacher will provide your group with a list of materials. In your group classify these materials into metals, ceramics, and polymers based on their chemical properties.

Activity 1.9 Chemical Properties of Materials

1. Your teacher will assign a to your group a specific material (metal, ceramic, or polymer).
2. In your group you should research the chemical properties of your assigned material, focusing on reactivity, flammability, and toxicity. Then present your findings to the class.

Activity 1.10 Case Study

1. Your teacher will give you a case study of a manufacturing process where the choice of material is crucial due to its chemical properties.
2. Analyse the case and discuss why the material was chosen and what considerations were made due to its chemical properties.

CLASSIFYING MATERIALS BASED ON THEIR STRUCTURE (CRYSTALLINE AND AMORPHOUS)

Materials can be categorised into crystalline and amorphous types based on their atomic arrangement and structural characteristics. Crystalline materials exhibit a highly ordered atomic structure with long-range periodic translational and orientation symmetries. This order gives rise to distinct mechanical, electrical, and optical properties, making them ideal for applications in semiconductors and photonics. Conversely, amorphous materials lack long-range order, presenting only short-range atomic arrangements. This structural disorder results in unique properties, such as isotropic atomic environments, numerous surface dangling bonds, and high unsaturation in coordination, which can enhance their electrocatalytic, optical, and mechanical performance. However, classifying and characterising amorphous materials is challenging due to their complex structure and absence of long-range order.

Classification of Materials According to their Crystal Structure, Such as FCC, BCC and HCP Crystal Structures

The crystal structure of a material consists of atomic arrangements held together by interatomic or intermolecular bonds, creating a systematic, three-dimensional pattern of atoms, ions, or molecules. This structure can be modified through several techniques:

1. **Extreme Heating**: Applying high temperatures to the material.
2. **Extreme Pressure**: Using significant force, such as impact loading or hammering, to deform the material.
3. **Laser Treatment**: Employing laser beams to alter the material's structure.

At the microscopic level, a metal's structure reveals the detailed arrangement of its components, primarily comprising crystalline grains. Each grain exhibits a periodic atomic arrangement, known as the crystal lattice, with atoms densely packed in a specific crystallographic orientation. Grain boundaries form at the intersections of different grains. Microscopic structures can be changed using various methods:

1. **Heat Treatment**: Controlled heating and cooling processes modify the microstructure.
2. **Mechanical Processing**: Techniques like rolling, forging, extrusion, and drawing induce plastic deformation, altering the microstructure.
3. **Alloying**: Introducing additional elements to the base material to enhance its properties.
4. **Phase Transformation**: Changes in temperature, pressure, or chemical composition can lead to alterations in crystal structure.
5. **Surface Treatment**: Methods such as shot peening, nitriding, and coatings modify the microstructure near the surface.

6. **Ion Implantation and Irradiation**: Bombarding the material with energetic particles introduces defects and alters both atomic and crystal structures for specialised applications, such as in semiconductors.

The macroscopic structure of a metal, observable to the naked eye or with low-magnification lenses, encompasses its grain size, shape, and arrangement, along with any visible defects. These characteristics are influenced by:

1. The manufacturing process.
2. The application of heat.
3. The alloy composition.

Materials are classified by their crystal structures, including Face-Centred Cubic (FCC), Body-Centred Cubic (BCC), and Hexagonal Close-Packed (HCP). Crystalline materials are characterised by a long-range ordered atomic arrangement. Upon solidification, atoms form a repeating three-dimensional pattern, bonding with nearest neighbours. This classification directly impacts physical properties, such as strength and conductivity. Many metals, ceramics, and some polymers develop crystalline structures during solidification, while non-crystalline or amorphous materials lack long-range atomic order. The properties of crystalline solids depend on their specific structures, which dictate the arrangement of atoms.

Crystal structures vary widely, with FCC, BCC, and HCP being the primary arrangements in metals, each defined by unique atomic configurations within the unit cell—the smallest repeating unit in a crystal lattice.

In crystalline structures, atoms (or ions) are modelled as solid spheres in the atomic hard-sphere model, where neighbouring spheres touch. The term “lattice” refers to a three-dimensional array of points corresponding to atomic positions, allowing the structure to be divided into unit cells.

Most unit cells are parallelepipeds or prisms, often depicted as cubes. A unit cell is chosen to represent the crystal’s symmetry, enabling the generation of all atomic positions in the crystal through translations along its edges. Thus, the unit cell serves as the fundamental building block of the crystal structure, defining its geometry and atomic arrangement.

Face-Centred Cubic Crystal (FCC) Structure

The crystal structure of many metals is characterised by a cubic unit cell, with atoms positioned at each corner and at the centres of all the cube faces. This configuration is known as the face-centred cubic (FCC) crystal structure. Notable metals exhibiting this structure include copper, aluminium, silver, and gold (refer to **Table 1.1** for more details).

Figure 1.1a illustrates a hard-sphere model of the FCC unit cell, while **Figure 1.1b** uses small circles to depict the atomic centres, enhancing the clarity of atomic positions. In **Figure 1.1c**, an aggregation of atoms represents a segment of a crystal comprising multiple FCC unit cells. In this arrangement, the atomic spheres or ion cores are in contact along the face diagonal. The relationship between the cube edge lengths a and the atomic radius R is given by the equation:

$$a = 2R\sqrt{2}$$

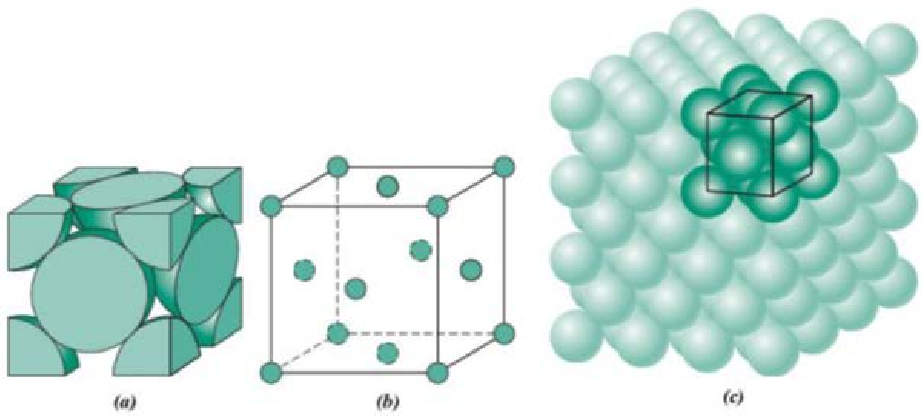


Figure 1.2: For the face-centred cubic crystal structure, (a) a hard-sphere unit cell representation, (b) a reduced sphere unit cell, and (c) an aggregate of many atoms.

Body-Centred Cubic Crystal Structure

Another prevalent metallic crystal structure features a cubic unit cell with atoms positioned at all eight corners and a single atom located at the centre of the cube. This configuration is referred to as the body-centred cubic (BCC) crystal structure. **Figure 1.2c** illustrates a collection of spheres representing this structure, while **Figure**s **1.2a** and **1.2b** present diagrams of BCC unit cells, with atoms depicted using hard-sphere and reduced-sphere models, respectively. In this arrangement, the central and corner atoms are in contact along the cube diagonals. The relationship between the unit cell length a and the atomic radius R is defined by the equation:

$$a = 4R\sqrt{3}$$

Chromium, iron, tungsten, and several other metals listed in **Table 1.3** exhibit a BCC structure.

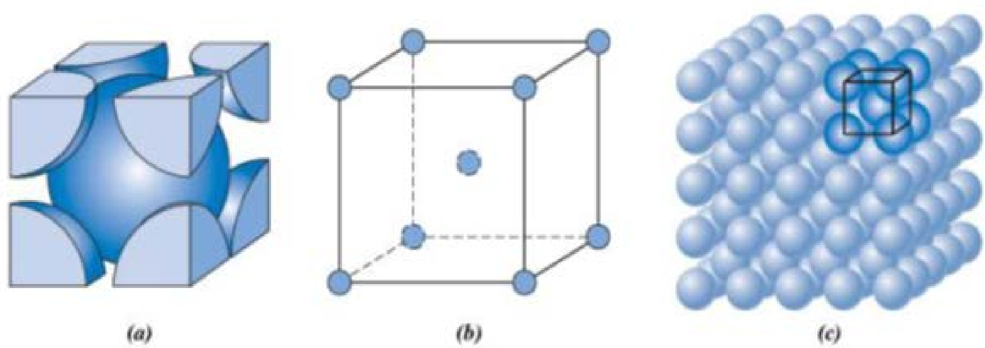
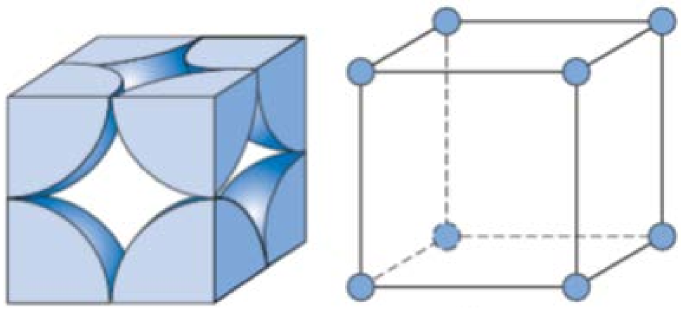


Figure 1.3: For the body-centred cubic crystal structure, (a) a hard-sphere unit cell representation, (b) a reduced sphere unit cell, and (c) an aggregate of many atoms.

Hexagonal Close-Packed Crystal Structure

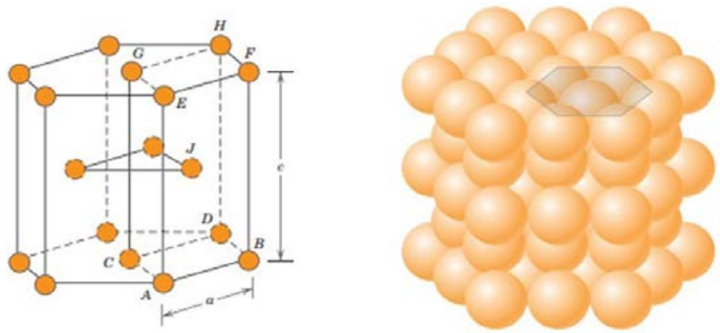
Not all metals possess unit cells with cubic symmetry; another common metallic crystal structure is hexagonal. **Figure 1.4a** illustrates a reduced sphere unit cell for this configuration, known as hexagonal close-packed (HCP). An assembly of several HCP unit cells is depicted in **Figure 1.4b**.

In the HCP unit cell, the top and bottom faces each contain six atoms arranged in regular hexagons, enclosing a single atom at the centre. Additionally, a midplane between the top and bottom faces contributes three more atoms to the unit cell. The atoms in this midplane have neighbouring atoms in both adjacent planes, enhancing the overall packing efficiency of the structure.



(a) *(b)*

Figure 1.4: For the simple cubic crystal structure, (a) a hard-sphere unit cell, and (b) a reduced-sphere unit cell.



(a) *(b)*

Figure 1.5: For the hexagonal close-packed crystal structure, (a) a reduced-sphere unit cell (a and c represent the short and long edge lengths, respectively), and (b) an aggregate of many atoms.

Table 1.3: Classification of materials according to their crystal structure.

Metal	Crystal Structure [a]	Atomic Radius [b] (nm)
Aluminium	FCC	0.1431
Cadmium	HCP	0.1490
Chromium	BCC	0.1249
Cobalt	HCP	0.1253

Metal	Crystal Structure [a]	Atomic Radius [b] (nm)
Copper	FCC	0.1278
Gold	FCC	0.1442
Iron (α)	BCC	0.1241
Lead	FCC	0.1750
Molybdenum	BCC	0.1363
Nickel	FCC	0.1246
Platinum	FCC	0.1387
Silver	FCC	0.1445
Tantalum	BCC	0.1430
Titanium (α)	HCP	0.1445
Tungsten	BCC	0.1371
Zinc	HCP	0.1332

FCC = face-centred cubic; HCP = hexagonal close-packed; BCC = body-centred cubic. Ananometre (nm) equals 10^{-9} m; to convert from nanometres to angstrom units (Å), multiply the nanometre value by 10

Amorphous, Polymorphism, Allotropy and Polycrystalline Solids

Non-crystalline solids lack a systematic and regular arrangement of atoms over relatively large distances. These materials are often referred to as amorphous, which literally means “without form,” or as supercooled liquids, due to their atomic structure resembling that of a liquid. Amorphous materials are characterised by a lack of long-range order in their atomic or molecular arrangements, setting them apart from crystalline materials that feature periodic atomic structures.

These materials are metastable, possessing only short-range order resulting from local intermolecular chemical bonding. This leads to unique structural features, including isotropic atomic environments, abundant surface dangling bonds, and highly unsaturated coordination. Such intrinsic disorder imparts specific characteristics to amorphous materials, such as intrinsic isotropy, varied defect distribution, and structural flexibility. These attributes make them particularly appealing for a range of applications, especially in electrochemical energy storage and conversion technologies, including lithium-ion batteries, lithium-metal batteries, and supercapacitors.

A comparison of the crystalline and non-crystalline structures of silicon dioxide (SiO_2) illustrates the amorphous condition. **Figure 1.6** presents two-dimensional schematic diagrams of both SiO_2 structures. Although each silicon ion bonds to three oxygen ions in both forms, the non-crystalline structure is significantly more disordered and irregular.

Amorphous materials are prevalent in everyday products such as glass, cement, and various food items like yoghurt and chocolate mousse. Despite their diverse appearances, these materials share many mechanical properties.

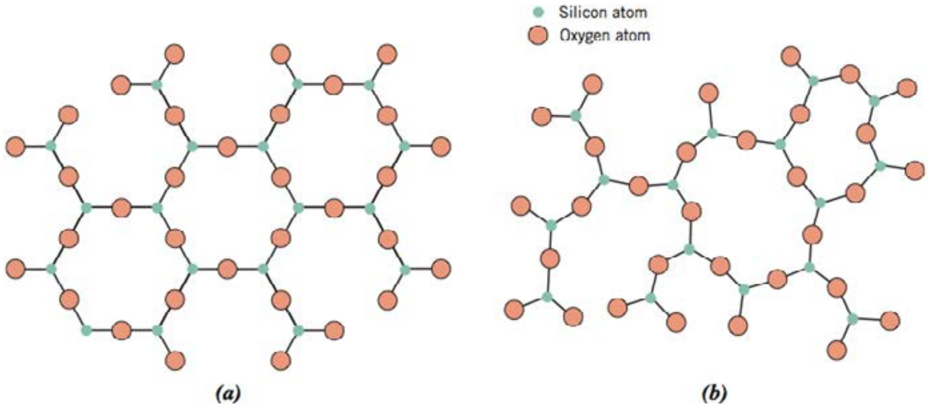


Figure 1.6: Two-dimensional schemes of the structure of (a) crystalline silicon dioxide and (b) non-crystalline silicon dioxide.

Polymorphism

Polymorphism in materials science and engineering refers to the phenomenon where a material can exist in multiple crystalline forms, each characterised by unique lattice structures and distinct properties. This characteristic is seen in various metals and nonmetals, illustrating the versatility of materials.

Polymorphism can be observed across a broad spectrum of materials, including crystalline substances, minerals, metals, alloys, and polymers, significantly impacting their functional properties. The formation of different polymorphic structures is often dictated by subtle variations in crystallisation conditions, which can make it difficult to control but simultaneously opens avenues for enhanced material performance.

The stability of a specific crystal structure is influenced by temperature and external pressure. A well-known example is carbon: graphite is the stable polymorph at room temperature, while diamond forms under extreme pressure. Similarly, pure iron exhibits a body-centred cubic (BCC) structure at room temperature, transitioning to a face-centred cubic (FCC) structure at 912°C (1674°F). These transitions are typically accompanied by modifications in density and other physical attributes.

Materials such as carbon, glycine, and silica exemplify the diverse manifestations of polymorphism. Understanding and harnessing polymorphism can lead to innovative applications and improved material properties, highlighting its crucial role in advancing materials science.

Allotropy

Allotropy is the phenomenon wherein a chemical element or elemental solid can exist in multiple distinct forms, known as allotropes, while maintaining the same physical state. This property is crucial because it enables materials to display varying physical and chemical characteristics based on their allotropic form. A prime example is iron, which showcases different crystal structures under varying temperatures and pressures. These transformations can be strategically manipulated to enhance key material properties such as strength and ductility, making allotropy a vital consideration in material design and engineering.

Several materials exemplify allotropy, including carbon—manifesting in forms such as diamond, graphite, graphene, fullerenes (like buckyball C-60), and carbon nanotubes. Other notable examples include oxygen (existing as dioxygen O_2 and ozone O_3), tin (exhibiting alpha and beta forms), and sulphur (displaying different allotropes like rhombic and monoclinic). Allotropy enhances our understanding of elemental behaviour and enables innovative applications across various fields, including materials science and nanotechnology, where the unique properties of different allotropes are utilised for advanced functionalities.

Polycrystalline Solids

Polycrystalline solids are materials composed of numerous small crystals or grains, each exhibiting the same crystal structure but differing in orientation. This unique arrangement is found in a variety of materials, including metals, ceramics, and certain polymers. The properties of polycrystalline solids are critically influenced by the size, shape, and distribution of these grains, collectively referred to as texture.

The synthesis of polycrystalline powders is a vital process in materials science. Various techniques, such as solid-state reaction, sol-gel synthesis, hydrothermal processes, and combustion methods, are employed to tailor properties like purity, grain size, crystallinity, and morphology. Grain boundaries play a significant role in determining the overall properties of polycrystalline materials. These boundaries are dynamic and influenced by interfacial energy, which drives processes such as grain growth and shrinkage. Over time, this leads to a coarsening effect that can significantly impact mechanical, electrical, and thermal properties.

Examples of polycrystalline solids include common metals like iron, copper, and aluminium, as well as ceramics, ice, galvanised steel, and silicon semiconductors. Understanding the behaviour and properties of polycrystalline materials is essential for advancements in technology and engineering applications, where performance and reliability are paramount.

Activity 1.11 Classification of Solids

Identify and bring five different materials from your community. Then classify these materials as crystalline or amorphous and discuss their structures.

Activity 1.12 Exploring Crystalline and Amorphous Materials

1. Make a search on the internet or watch the video or read from the textbook on Crystalline and Amorphous Materials using the link and the book provided.
   - https://www.youtube.com/watch?v=tbJy8Pap-_A
   - https://www.youtube.com/watch?v=VH9cRxXUNRA
   - https://www.youtube.com/watch?v=SQMrki3uX2s
2. Prepare a power point presentation to be presented to your class highlighting the structures and properties of crystalline and amorphous materials.

Activity 1.13 Crystal Structure

Your teacher will allocate you to a group of your classmates and each group will be assigned a specific material. You should research the crystal structure of your assigned material (FCC, BCC, or HCP) and present your findings to the class.

Activity 1.14 Case Study

1. Your teacher will present you with a case study of a manufacturing process where the choice of material is crucial due to its structure.
2. Analyse the case and discuss with peers why the material was chosen and what considerations were made due to its structure.

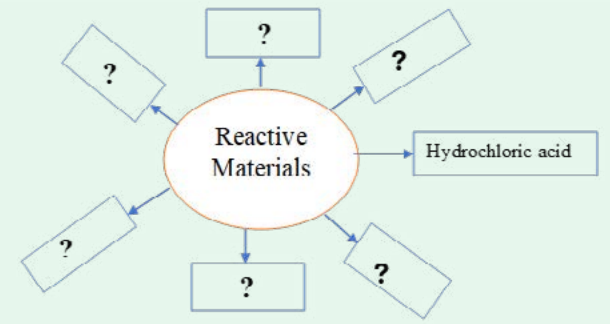
Activity 1.15 Grouping of Reactive, Toxic and Flammable Materials

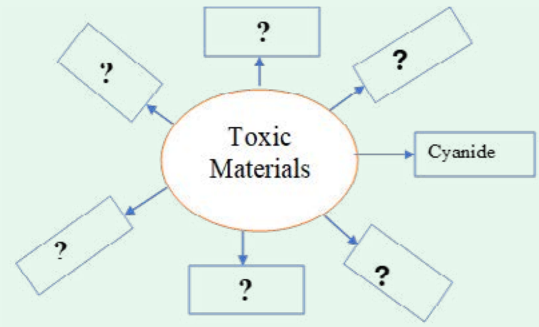
1. Create a table similar to the table below and identify at least five reactive materials, five toxic materials and five flammable materials that are available in your local community.

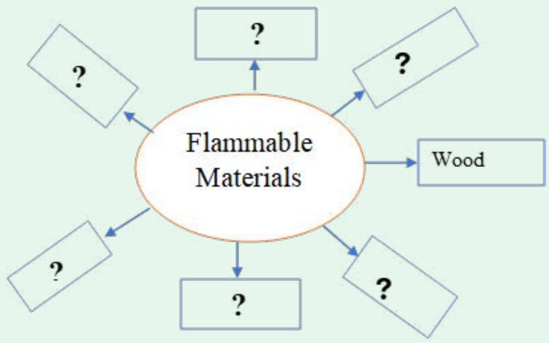
SN	Reactive material	Toxic Material	Flammable material
1	Hydrochloric acid	Cyanide	paper
2			

Make a mind map on a piece of hard card from the above table and present your report to your class for peer assessment. Sample of Mind maps:

Reactive materials







IDENTIFICATION OF MATERIAL PROCESSING METHODS

Understanding and identifying the diverse methods employed to process materials such as metals, ceramics, polymers, and composites—is critical in manufacturing engineering. These methods encompass techniques such as casting, forging, extrusion, machining, welding, and heat treatment. Each method possesses distinct parameters and considerations, including temperature, pressure, time, and environmental conditions, all of which can profoundly influence the properties and performance of the final product.

Processing methods can be categorised into three primary classifications: shaping processes, property-enhancing processes, and surface processing techniques. Shaping processes involve altering the geometry of materials, while property-enhancing processes focus on improving specific characteristics, such as strength or ductility. Surface processing techniques are aimed at modifying the surface properties of materials to enhance wear resistance, corrosion resistance, or aesthetic appeal.

Furthermore, advancements in technology, such as additive manufacturing (3D printing), have emerged as transformative methods in the field, allowing for more complex designs and efficient material usage. As engineers, it is important that we demonstrate a fair understanding of these processing methods to augment manufacturing practices and ensure the desired quality and performance of products are achieved.

Shaping Processes Such as Machining, Forming, Casting and Additive Manufacturing

Shaping processes are critical in manufacturing, transforming raw materials into specified forms and functional products. These methods are primarily divided into four categories: machining, forming, casting, and additive manufacturing.

Machining Processes

Machining is a subtractive manufacturing process that involves the use of cutting tools, discs, abrasive wheels, and more to remove excess material from a workpiece. This process is used to remove unwanted materials to achieve the desired product shape. This process can be further divided into conventional and non-conventional methods.

Conventional Machining includes techniques such as turning and milling, where cutting tools are employed to remove material systematically. In contrast, **non-conventional machining** methods—like Electrical Discharge Machining (EDM), Ultrasonic Machining (USM), and Laser Beam Machining (LBM)—utilise various forms of energy for material removal. These advanced techniques are particularly effective for intricate designs and hard materials.

Machining is indispensable for producing high-precision components, often involving abrasive methods like grinding, honing, lapping, and polishing to achieve tight dimensional tolerances and exceptional surface finishes. Additionally, machining is frequently necessary to refine components produced by other processes—such as casting, forging, welding, and extrusion—ensuring they reach their final, precise shape for effective assembly.

The use of cutting fluids in machining is crucial, as it reduces friction, minimises cutting temperatures, and prolongs tool life, ultimately enhancing the quality of the finished product.

Common machining operations include **turning**, **drilling**, and **milling**, each serving unique purposes in the production process. Visual representations of these operations further illustrate their specific applications and methods. Integrating various machining processes allows manufacturers to achieve the high precision and quality necessary for modern industrial production.

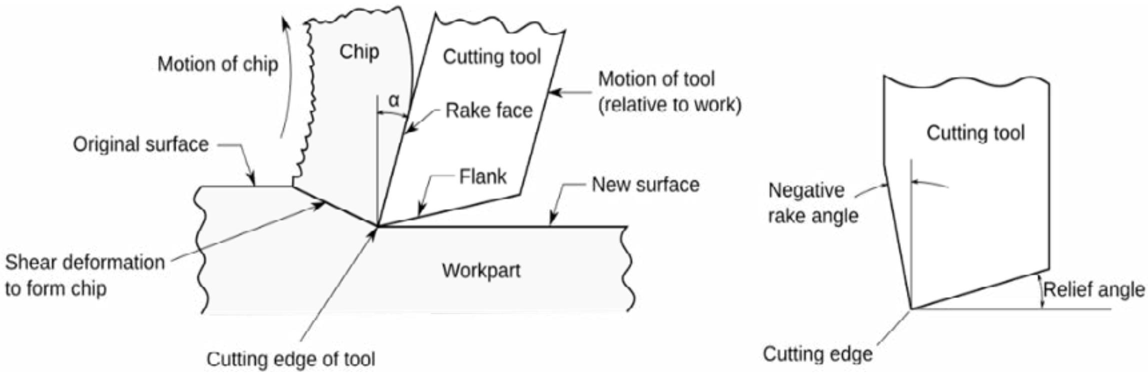


Figure 1.7: Cross-section of the machining process and tool with negative rake angle.

Turning

Turning is a machining process where a workpiece is rotated against a stationary cutting tool, allowing material to be removed from the workpiece surface to create a cylindrical shape. Turning can be performed manually using a traditional lathe that requires operator supervision, or it can be automated with computer numerical control (CNC). Turning utilises different types of lathes and turning machines, including turret lathes, engine lathes, etc. The turning process enables the fabrication of rotational parts with features like holes, grooves, threads, tapers, diameter steps, and contoured surfaces.

Drilling

Drilling is a process that involves creating cylindrical holes in a workpiece by using a cutting tool called a multi-point drill bit. The drill bits utilised in the drilling process typically have two spiral channels, known as flutes, which help evacuate swarf or chips from the hole as the drill bit advances into the material.

Moreover, the holes produced by the drill press play a crucial role in part assembly. The holes are also used for screws or aesthetic purposes. Moreover, it serves as a preparatory operation before tapping, reaming, or boring to establish threaded holes or achieve the desired dimension of a hole within an acceptable tolerance range. Drilling is a critical operation in the realm of machining processes.

Milling

Milling is a versatile machining process that utilises multi-point rotating cutters to remove material from a stationary workpiece. This process is capable of creating intricate shapes, grooves, and slots with exceptional precision. Like turning, milling can be performed manually and automated. When it comes to CNC milling, the CNC machine usually feeds the workpiece towards the cutting tool following the same direction as the tool's rotation. This differs from manual milling processes, where the workpiece is fed in the opposite direction relative to the rotation of the cutting tool.

The CNC-enabled milling machinery used in CNC milling is called mill machines or mills. The types of mills available include hand, plain, and universal milling machines. Milling machines utilise cutting tools that come in a variety of shapes and designs, leading to a wide range of milling operations. Examples include end milling, face milling, knee milling, and more, each tailored to specific cutting tool variations.

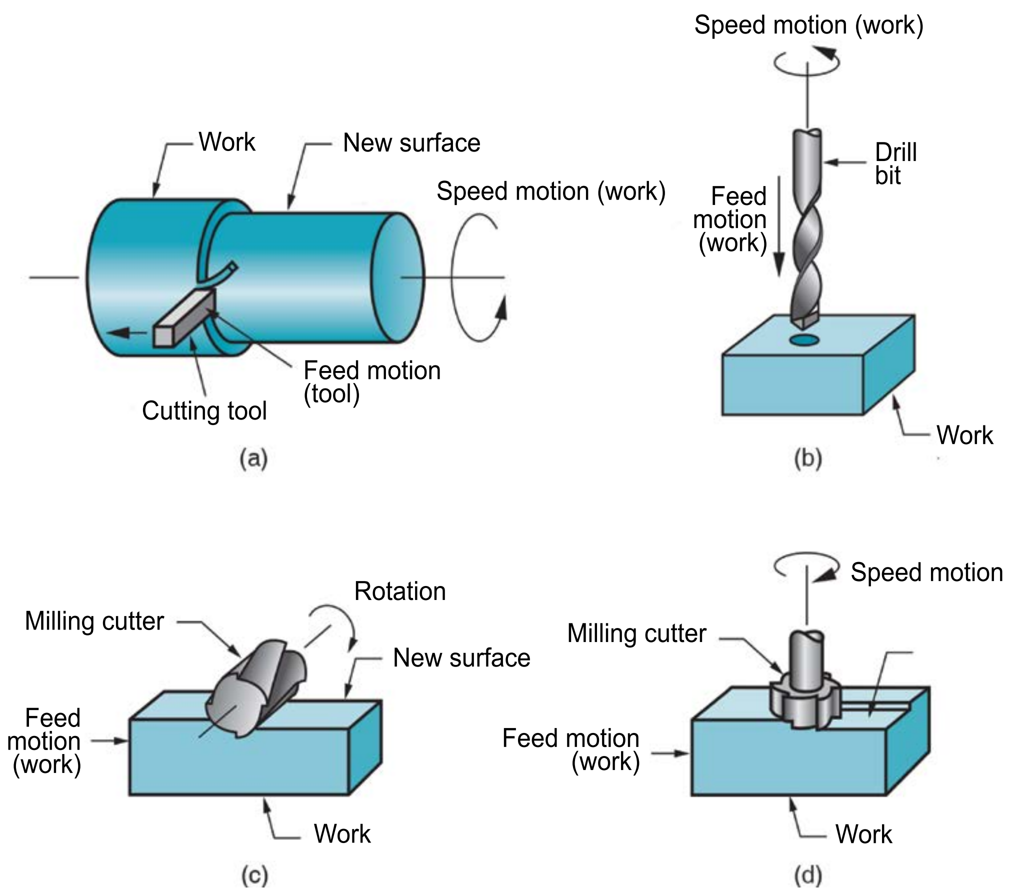


Figure 1.8: Types of machining operations

Forming Processes

Forming processes in manufacturing involve applying force and pressure to reshape material until the desired final product is achieved. These processes are remarkably versatile and can be employed with a variety of materials, including metals, polymers, and ceramics. Traditional forming methods encompass mechanical and thermomechanical deformation techniques. In these methods, solid material is shaped through processes such as stamping, drawing, forging, and extrusion.

Each technique has unique applications depending on the material properties and design requirements. A notable advancement in this field is Incremental Sheet Metal Forming (ISMF), a modern technique that enables the production of complex three-dimensional parts without the need for dedicated tooling. This flexibility makes ISMF particularly suited for low-volume production and mass customisation, allowing manufacturers to respond quickly to specific customer needs.

Another innovative approach merges additive manufacturing with traditional forming processes. For instance, using a laser-based directed energy deposition (DED-LB/M) module, manufacturers can enhance surface finish and material properties before applying a forming press. This combination opens new avenues for improving part performance and reducing waste.

Quality control is of utmost importance in forming processes, especially when producing sensitive materials like gelled propellants, where safety and precision are critical. Ensuring consistent quality not only minimises defects but also enhances the reliability of the final products.

Common metal forming processes include **bending**, **rolling**, **stamping**, **drawing**, **forging**, **extrusion**, and **deep drawing**. Each of these techniques plays a vital role in various industries, contributing to the creation of everything from automotive components to aerospace structures.

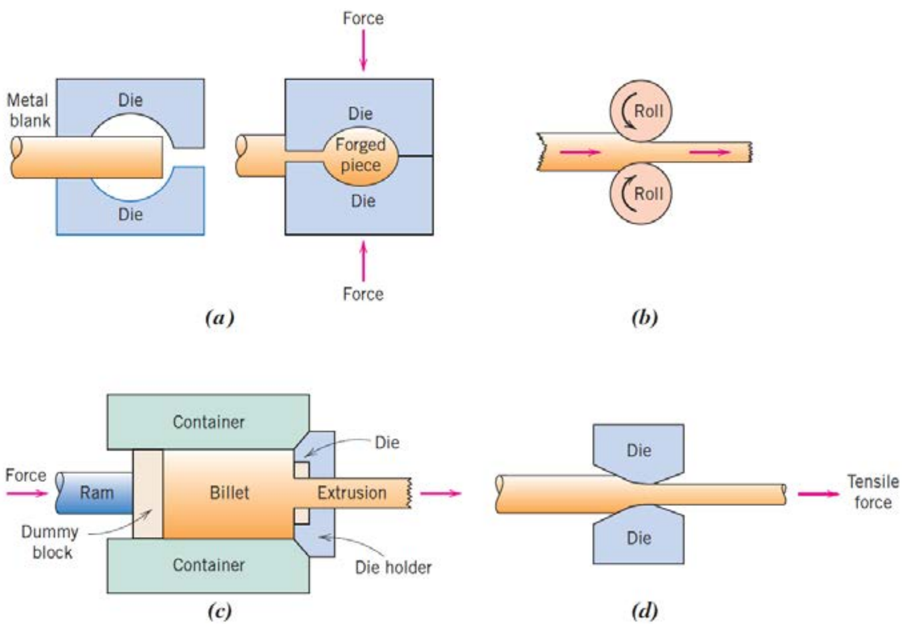


Figure 1.9: Metal deformation during (a) forging, (b) rolling, (c) extrusion, and (d) drawing

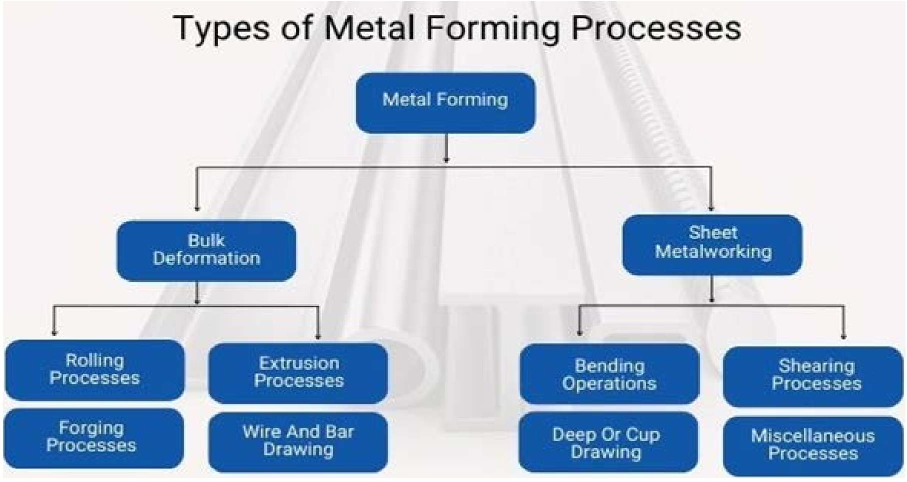


Figure 1.10: Chart of metal forming processes

Casting Processes

Casting processes are essential and varied techniques employed in the production of a wide array of metal components, ranging from intricate small parts to large-scale industrial machinery. The fundamental principle of casting involves pouring molten metal into a mould, which subsequently solidifies into the desired shape.

Numerous casting methods have been developed to enhance the properties and applications of the final products. Notably, semi-solid casting and squeeze casting techniques yield high-quality castings with exceptional mechanical properties, making them ideal for demanding applications. Traditional methods, such as sand casting, remain popular due to their versatility and cost-effectiveness; this process involves forming a mould from sand and pouring molten metal into it, allowing for efficient production even for complex geometries.

The initial material for casting is typically either in a liquid state or in a highly plastic condition, and the part is formed through the solidification of this material. Solidification processes can be categorised based on the type of engineering material being processed, including metals, ceramics (notably glasses), polymers, and polymer matrix composites (PMCs).

Furthermore, advancements in casting technology, such as investment casting and die casting, have expanded the capabilities of manufacturers to produce components with tighter tolerances and superior surface finishes. These innovations have made it possible to produce complex shapes and reduce post-processing requirements.

Quality control during casting is critical to ensure the integrity and performance of the final products, particularly in applications such as aerospace and automotive industries where safety is paramount.

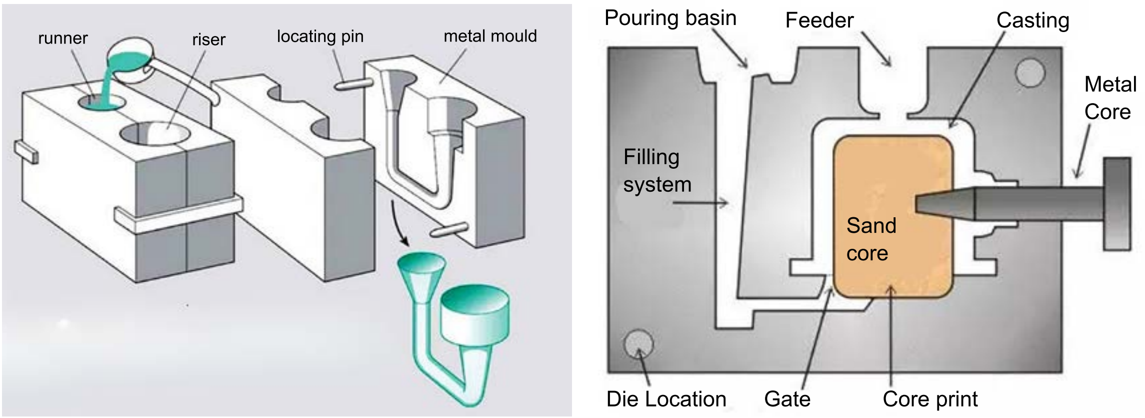


Figure 1.11: Casting of complex components into shape

Additive Manufacturing (AM) Processes

Additive Manufacturing (AM), commonly known as 3D printing, represents a groundbreaking shift in industrial production techniques. This method allows for the creation of parts and systems that are not only lighter but also stronger than those produced through traditional manufacturing methods. Unlike conventional approaches, which typically involve cutting away material from a larger block, AM constructs objects layer by layer, guided by a digital 3D model. This layer-by-layer process opens up new possibilities for intricate designs and complex geometries that were previously difficult or impossible to achieve. The main processes within Additive Manufacturing include:

- **Laser Powder Bed Fusion (L-PBF)**: Uses high-energy lasers to melt metal powder into solid parts.
- **Directed Energy Deposition (DED)**: Involves melting materials as they are deposited, often used for repairs or adding features to existing components.
- **Material Jetting**: Similar to inkjet printing, it deposits droplets of materials layer by layer.
- **Binder Jetting**: Utilises a liquid binding agent to adhere layers of powder together.
- **Sheet Lamination**: Involves bonding sheets of material together, which can then be cut into desired shapes.

Each of these processes has its own set of advantages and limitations, making them suitable for different applications. AM is particularly valuable in industries such as aerospace, automotive, biomedical, and consumer products. Its ability to produce complex geometries while minimising material waste significantly enhances efficiency. Moreover, AM technologies play a vital role in rapid prototyping and tooling, allowing manufacturers to quickly repeat designs and produce functional parts without extensive lead times. The range of materials used in Additive Manufacturing has also broadened. Beyond metals and polymers, AM now incorporates glass, ceramics, and composites, enabling manufacturers to customise properties to meet specific performance requirements through careful selection of materials and processes.

It must also be noted that Additive Manufacturing is not only reshaping the production landscape but also fostering innovation across various sectors, making it a key area of focus for future advancements in manufacturing technology.

Property Enhancing Processes

Property-enhancing processes are essential in manufacturing, playing a crucial role in improving the performance and quality of materials and products across various industries. These processes modify material properties using advanced manufacturing techniques and treatments, which include heat treatment, alloying, and surface hardening. Among these processes, heat treatment is one of the most significant and common processes of enhancing the properties of a metal. It encompasses a range of heating and cooling procedures designed to induce microstructural changes in a material, thereby influencing its mechanical properties. Heat treatment can be applied at different stages of the manufacturing process to achieve desired outcomes:

Basic heat treatment processes include hardening, annealing, normalising and tempering. Each has specific processes and reasons. For instance, annealing involves heating the metal to a specific temperature, maintaining that temperature for a designated period (known as soaking), and then allowing it to cool slowly. The process modifies the microstructure of the metal, which results in a decrease the hardness and brittleness to make the metal soft. This improves the metal machinability, allowing for easier cutting and shaping during subsequent manufacturing processes.

Apart from heat treatment, alloying and surface hardening are also critical property-enhancing processes. Alloying involves combining different elements to create alloys that exhibit superior properties compared to their individual components. This can lead to improved strength, corrosion resistance, and thermal stability. Surface hardening techniques, also known as case hardening (carburising or nitriding), enhance the surface properties of a material without significantly altering its core characteristics. These methods increase hardness and wear resistance, making components more durable and suitable for demanding applications.

Property enhancing processes such as heat treatment, alloying, and surface hardening are vital to modern manufacturing. They enable the optimisation of material properties to meet specific performance criteria, ultimately leading to the production of higher-quality and more reliable products across a wide range of industries. This helps engineers and manufacturers to innovate and improve the functionality of materials in their applications.

Surface Processing Techniques

Surface processing techniques such as coating and plating, polishing, ion implantation, and laser surface treatment are essential in contemporary manufacturing, significantly enhancing the mechanical and tribological properties of metallic components. These processes not only elevate performance but also prolong the lifespan of materials across a range of applications. Key techniques include:

Coating: This involves the application of a protective layer to a material's surface to prevent corrosion, wear, and oxidation. Common types of coatings include paints, varnishes, and polymer films, each designed to provide specific protective benefits.

Plating: Generally, refers to electroplating, a process where a metal layer (such as gold or nickel) is deposited onto a substrate. This enhances properties like electrical conductivity, corrosion resistance, and aesthetic appeal.

Polishing is a mechanical technique aimed at refining the surface of a material, enhancing its finish and minimising friction. Methods such as abrasive polishing and chemical mechanical polishing achieve a high gloss and precise tolerances, which are particularly crucial in industries such as optics and aerospace.

Ion implantation involves bombarding a material's surface with high-energy ions to modify its properties. This technique can significantly increase hardness, improve wear resistance, and enhance electrical characteristics without altering the bulk composition. It is predominantly utilised in semiconductor manufacturing.

Laser surface treatment employs concentrated laser beams to modify the surface characteristics of materials. Techniques include:

a. Laser Hardening: This method increases surface hardness through rapid heating and subsequent cooling.
b. Laser Cladding: This technique deposits additional material onto the surface to enhance wear resistance or to repair damaged components.
c. Surface Melting: In this process, the surface layer is melted and solidified to refine its microstructure and improve properties.

Surface processing techniques are critical in optimising the mechanical and tribological properties of materials within manufacturing. By enhancing attributes such as hardness, wear resistance, and surface finish, these processes significantly boost the performance and durability of components across various industries.

Activity 1.16 Discovering Material Processing Methods

1. This activity seeks to enhance your understanding of the various material processing methods through visuals and encourage critical thinking and discussion among peers.
2. Make a search on the internet or watch the video, or read from relevant materials/documents on the material processing methods using the link and the book provided.
   - https://www.youtube.com/watch?v=Um_g8sQ_p3Y
   - https://www.youtube.com/watch?v=BKYfnDn4hhE
   - https://www.iitg.ac.in/engfac/ganu/public_html/Metal%20forming%20processes_full.pdf
   - https://www.meadmetals.com/blog/5-common-types-of-metal-forming-processes-and-their-applications
   - https://www.rapiddirect.com/blog/types-of-machining-operations/
   - https://leadrp.net/blog/13-types-of-machining-processes/
   - https://www.iitg.ac.in/engfac/ganu/public_html/Metal%20casting%20processes_1.pdf
3. Prepare a handout that briefly describes each material's processing method featured in the videos and the lecture notes, and discuss with your class.

Activity 1.17 Classification of Material Processing Methods

Identify and classify material processing methods available in your community into shaping processes, property-enhancing processes, and surface processing operations.

Material Processing Methods in the community

Company name	Raw material(s) being processed	Classification of the process: • Shaping, • Property-enhancing • Surface-processing	Finished product

Activity 1.18 Industrial Visit (Field trip) and Workshop Practical

1. Visit a nearby Production/manufacturing industry for more practical on either shaping processes or property enhancement, or surface processing.
2. Put on all your safety clothing and abide by all safety precautions in order to prevent an accident.
3. Under the supervision of the workshop craft master, perform these three operations in the workshop.
   a. Casting and forming
   b. Annealing and hardening
   c. Coating and plating.
4. Ask someone to take a video or picture of you undertaking these practical sessions.

Activity 1.19 Material Processing Methods

1. Your teacher will allocate you to a group and will assign your group a specific material processing method (machining, forming, casting, additive manufacturing, heat treatment, alloying, surface hardening, coating, plating, polishing, ion implantation, or laser surface treatment).
2. In your group, you should research your assigned method and present your findings to the class.

Activity 1.20 Case Study on Material Processing Method Selection

Your teacher will allocate you to a group. In your group, select a case study that highlights either shaping processes or property enhancement or surface processing. For example, you could use the production of gears, crankshafts, or a suspension component that undergoes shaping or property enhancement or surface processing.

Case study: Choose a specific automotive component (like a forged gear or crankshaft). Your group must focus on one of the three processing methods.

1. Shaping: Explain how the component is formed (e.g., the forging process for gears).
2. Property Enhancement: Explore the heat treatment processes used to improve hardness.
3. Surface Processing: What coatings can be applied for corrosion resistance and wear reduction?

Ideas generation

1. Shaping Process Group: Discuss the advantages of the chosen shaping method and any limitations in application.
2. Property Enhancement Group: Analyse the effects of heat treatment or alloying on mechanical properties and performance.
3. Surface Processing Group: Evaluate the importance of surface treatments in prolonging component life and enhancing performance.

Present your findings on:

1. the specific processing method and its role in the component's performance.
2. the advantages and disadvantages of the chosen area
3. what other material processing method must be applied to enhance your chosen processing method?
4. any future trends in material processing and their implications for the manufacturing industry?

Activity 1.21 Classifying Materials

Look for a list of materials. Your task is to classify these materials as metals, ceramics, or polymers based on their processing methods. This activity can be done individually or in your group.

CLASSIFICATION OF MATERIALS ACCORDING TO THEIR PROCESSING METHODS

Materials can be classified based on how they are processed, and this classification can be divided into several main types, each with unique techniques and uses. One major way to classify manufacturing methods is by looking at the state of the raw materials and the final products. This distinction leads to two main approaches: **top-down** and **bottom-up**, which correspond to **subtractive manufacturing** (SM) and **additive manufacturing** (AM).

Subtractive manufacturing involves taking material away from a solid block to create a specific shape. This method is commonly seen in traditional machining processes. On the other hand, **additive manufacturing** builds objects by adding material layer by layer. This method includes techniques like 3D printing, which uses materials such as powders or resins. Another way to categorise materials is by specific processing techniques. For example, **powder metallurgy** (PM) is a cost-effective method that allows for the creation of complex shapes with minimal waste. PM includes processes like **press and sinter**, **liquid phase sintering**, and **high-velocity compaction**, all aimed at achieving nearly full density in the finished product.

Additionally, there are **functionally graded materials** (FGMs), which have varying properties throughout their volume. These materials can be produced using methods like **physical vapour deposition** and **chemical vapour deposition** for thin coatings, as well as **powder metallurgy** or **centrifugal casting** for larger quantities. Advanced processing methods, such as using a **laser beam** with controlled shielding gas flow, are employed to precisely melt and shape materials, improving the quality and properties of the final product.

For this section, we will classify materials based on the processing methods they undergo, which include **shaping**, **property enhancement**, and **surface processing**.

Materials that Undergo Shaping Processes

Various types of materials are shaped during manufacturing. Here are some examples:

Metals

Metals can undergo two main types of shaping processes:

1. **Cold Working Processes:** These include techniques such as press work, cold forging, rolling, and coining, which are performed at room temperature.
2. **Hot Working Processes:** These include methods like casting, hot forging, and powder forming, which are done at elevated temperatures to make shaping easier.

Thermosetting Polymers

These materials can be shaped using techniques like hot compression moulding and transfer moulding, which involve heating the material to set its shape permanently.

Thermoplastics

Thermoplastics can be formed through several processes, including:

1. Injection Moulding: Injecting melted plastic into a mould.
2. Extrusion: Forcing melted plastic through a shaped die.
3. Blow Moulding: Creating hollow plastic parts by inflating melted material.
4. Calendaring: Rolling the material into thin sheets.
5. Vacuum Forming: Shaping plastic sheets using heat and vacuum.

Ceramics

Ceramics are non-metallic, inorganic materials made by shaping and firing non-metal substances, like clay, at high temperatures. Examples include traditional ceramics such as pottery, bricks, and porcelain, as well as advanced ceramics like silicon carbide, boron nitride, alumina, and zirconia.

Thermoplastics

These versatile materials can be melted and reshaped when heated, returning to a solid state upon cooling. They include:

1. Amorphous Thermoplastics: These have a random molecular structure.
2. Semi-Crystalline Thermoplastics: These have a more organised molecular arrangement.

These materials and their shaping processes are essential for producing a wide range of products in manufacturing.

Materials that Undergo Property-Enhancing Processes

In manufacturing, several types of materials are treated to enhance their properties. Here are some examples:

Metals

Metals such as steel, aluminium, and titanium often undergo heat treatment processes. These include:

1. Annealing: Softening the metal.
2. Normalising: Refining the grain structure for better strength.
3. Carburising: Introducing carbon to the surface to increase hardness.
4. Hardening: Making the metal stronger.

Glasses

Glass materials can also be subjected to heat treatment. This process helps relieve internal stresses, improving their strength and making them less likely to break.

Powdered Metals and Ceramics

These materials can undergo a process called **sintering**. In this process, the powder is heated below its melting point, causing the particles to bond together and form a solid piece.

Super alloys

Super alloys are specially designed high-performance alloys that can withstand extreme temperatures and pressures. They often undergo heat treatment to enhance their mechanical properties, making them suitable for challenging applications.

Low-Carbon Steels

Low-carbon steels can be treated through a process known as **carburising**. In this method, carbon is introduced to the surface by heating the steel in a carbon-rich environment, which creates a hardened outer layer.

The choice of surface processing technique depends on the type of material being used and the specific properties desired in the final product.

Materials That Undergo Surface Processing

Several types of materials are treated through surface processing in manufacturing. Here are some examples:

Metals

Metals such as aluminium, steel, and titanium often undergo surface processing techniques. Common methods include:

- Electroplating: Applying a metal coating to enhance corrosion resistance and appearance.
- Anodising: Creating a protective oxide layer that improves corrosion resistance and wear resistance.
- Bluing: A chemical process that provides a layer of protection against rust while enhancing aesthetic appeal.

Plastics

Both hard and soft plastics can be treated using surface processing methods, such as:

- Vacuum Plating: Coating the plastic with a thin layer of metal (like aluminium, silver, or copper) to improve its appearance and durability.

Ceramics and Glass

These materials can also undergo various surface processing techniques, including:

- Vacuum Plating: This method enhances the appearance and durability of ceramics and glass.

Composite Materials

Composite materials can similarly benefit from vacuum plating to improve both their appearance and durability.

Additionally, there are various surface processing techniques available, such as mechanical abrasives, powder coating, and thermal spray coating. The choice of technique depends on the type of material and the desired properties of the final product.

Activity 1.22 Material Processing Methods

1. Make a search on the internet or watch the videos below.
2. Share your thoughts on different materials processing methods and present your findings to the class. You should include examples of metals, ceramics, and polymers that undergo these processes.
   - https://www.youtube.com/watch?v=AhS30ncmaTU&list=PLtt6ZgUFmMKyogHCUAmVv3mNyVklGQTm&index=2
   - https://www.youtube.com/watch?v=gBK0P4ASZ0o

Activity 1.23 Classification of Materials Using Processing Methods

Your teacher will facilitate a class discussion on the classification of materials according to the processing methods identified in activity 1.

Here are some discussion questions on the classification of materials according to different processing methods:

1. What are the key factors that determine how materials are classified according to processing methods? (e.g., material properties, processing conditions, desired final product)

2. How can material processing techniques like casting, forging, or additive manufacturing alter a material's microstructure and, consequently, its performance?
3. How does the classification of materials according to processing methods differ between metals, polymers, ceramics, and composites? Explore the differences in processing challenges and outcomes for each class.
4. In what ways do primary and secondary processing methods influence material selection for specific applications (e.g., automotive, aerospace, electronics)?
5. How does the method of material shaping (casting, extrusion, rolling, etc.) affect the cost-effectiveness and environmental sustainability of production?
6. What are the advantages and limitations of additive manufacturing (3D printing) compared with traditional methods like injection moulding or machining regarding material behaviour and processing complexity?
7. How does the processing route affect the material's ability to be recycled or reused? A discussion on sustainability and circular economies in materials processing.

Activity 1.24 Processing of Raw Materials into a Usable Form

1. Your teacher will allocate you to a small group and assign your group a raw material available in your community.
2. Your group should research how your assigned raw material is processed into a usable material and present your findings to the class.

Activity 1.25 Safety Clothing and Precautions

In the workshop under supervision with all the appropriate safety clothing and other safety precautions in place, prepare your own sand mould and cast any component of your choice using any material you find from your community as your project work.

GROUPING OF MATERIALS ACCORDING TO THEIR SYNTHESIS

The study of materials is a broad field that integrates chemistry, physics, engineering, and technology. A key part of this study is how materials are classified based on their synthesis (how they are made). This includes looking at different methods and processes from natural sources to complex chemical processes.

Bulk Materials

Bulk materials refer to large quantities of solid substances used in various applications. They can be categorised into different groups, such as sintered materials, single crystals, and solidified crystals, each serving unique purposes. For example, single crystals are often used to study the intrinsic properties of materials, such as the anisotropic behaviour of high-temperature superconductors (HTS).

Bulk materials also include organic metal compounds with nanostructured surfaces, which enhance their properties, such as improving hydrogen production and charge transfer rates, making them effective catalysts in electrochemical reactions. Additionally, bulk solids—composed of solid particles; are widely used in industries and are the second-most processed materials after water.

These materials possess distinctive characteristics, including density, surface area, flowability, compressibility, and compatibility, which require specialised techniques for characterisation. Handling and transporting bulk materials often involve advanced systems, such as conveyor belts with rotatable supports, to ensure efficient movement.

Production methods for bulk materials can vary, including techniques like foaming under heat, where materials are heated to specific temperatures to achieve desired properties and sizes. Examples of bulk materials include food items (sugar, salt, coffee, flour, cereals), building materials (sand, gravel, cement, topsoil), raw materials (rock salt, ore, coal), and industrial materials (cement, ash, chemicals).

Thin Films

Thin film materials play a crucial role in materials science and manufacturing engineering, distinguished by their unique properties that arise when substances are reduced to layers just a few nanometres to micrometres thick. Due to their large surface-to-volume ratio and quantum confinement effects, thin films exhibit distinct chemical, optical, electrical, magnetic, thermal, mechanical, and acoustic properties compared to bulk materials. These films are created by depositing atomic, molecular, or ionic species onto a substrate, forming a two-dimensional structure that contrasts with the three-dimensional nature of bulk materials. Various deposition techniques, including physical and chemical vapour deposition, sputtering, thermal evaporation, cathodic arc deposition, ion plating, and vapour-phase epitaxy, are used to manufacture thin films, depending on the material, intended application, and desired microstructure.

Thin films are essential in many applications, such as microelectronics, optics, aerospace, superconductivity, and photovoltaic cells, due to their low production temperatures, flexibility, transparency, and ability to produce high-quality, compact, and multi-coloured crystalline films. Properties like porosity, surface morphology, surface roughness, and crystallite size can be precisely controlled during deposition, enabling the development of innovative products while minimising waste compared with traditional manufacturing methods.

Thin films are vital for advancing optoelectronic, photonic, and magnetic devices, with their thermal stability and mechanical properties easily measured using techniques like nanoindentation. Their versatility extends to applications in semiconductor devices, wireless communications, integrated circuits, rectifiers, transistors, solar cells, light-emitting diodes, photoconductors, and micro-electromechanical systems (MEMS). Furthermore, thin films enable the creation of flexible and stretchable sensors and displays, with advanced deposition methods enhancing their durability and lifespan.

The ongoing development of thin film technology is driven by its potential to conserve materials and energy, making it an environmentally friendly option that supports the creation of innovative materials, such as room-temperature-grown diamonds and high-performance ferroelectric thin films.

Examples of thin film materials

a. Precursor Gases: Used in chemical vapour deposition processes to form thin films.
b. Sputtering Targets: Materials bombarded with ions that sputter atoms to create thin films on a substrate.
c. Evaporation Filaments: Employed in physical vapour deposition, where the material is heated until it evaporates and deposits as a thin film.
d. Metals: Gold and silver are often used to create thin films for applications like mirrors and electronic devices.
e. Oxides: Materials like silicon dioxide and titanium dioxide are used for optical coatings and solar cells.
f. Semiconductors: Silicon and gallium arsenide are used to form thin films for electronic devices and light-emitting diodes.

Nanomaterials

Nanomaterials are defined as materials with at least one dimension ranging from 1 to 100 nanometres. They have transformed materials science and manufacturing engineering due to their unique properties and diverse applications. Compared to their bulk counterparts, nanomaterials exhibit distinct physical, chemical, and mechanical characteristics, including enhanced solubility, reactivity, electrical and magnetic properties, and improved transport through membranes.

Nanomaterials can be classified based on their dimensions into four categories: zero-dimensional (quantum dots), one-dimensional (nanowires), two-dimensional (nanosheets), and three-dimensional (nanocrystals). Each type offers unique advantages, such as high surface-area-to-volume ratios and quantum confinement effects. The synthesis of nanomaterials can be achieved through two main approaches: top-down, which involves breaking down bulk materials into nanoscale particles, and bottom-up, which involves assembling materials from atomic or molecular precursors. These methods enable the production of nanomaterials with intricate shapes and structures, which are essential for various applications.

Nanomaterials play a vital role in multiple fields, including electronics, energy storage, photonics, diagnostics, and medical imaging, due to their exceptional properties. For example, two-dimensional materials like graphene have opened new avenues in optoelectronics and flexible nanoelectronics, demonstrating phenomena such as unconventional superconductivity and orbital magnetism. In the energy sector, nanomaterials are crucial for developing high-performance components for solid oxide fuel cells, offering superior properties compared to traditional materials.

The integration of nanomaterials into polymeric matrices has led to the creation of robust nanocomposites with enhanced physical and chemical properties, which are vital for various engineering, industrial, and medical applications.

Examples of nanomaterials include

a. **Carbon Nanotubes:** Cylindrical graphene tubes with unique properties, useful across various fields.
b. **Nanocomposites:** Hybrid structures combining different nanomaterials to enhance overall properties.
c. **Nanofibers:** Thin polymer threads used in applications such as filtration and tissue engineering.
d. **Nanowires:** Wire-like structures employed in electronic devices and sensors.
e. **Dendrimers:** Branched nanomolecules used in drug delivery systems.
f. **Quantum Dots:** Semiconducting nanocrystals applicable in solar cells and quantum computing.
g. **Fullerenes:** Carbon molecules shaped as hollow spheres, ellipsoids, or tubes.
h. **Nanocrystals:** Composed of quantum dots surrounded by semiconductor materials.
i. **Metals and Metal Oxides:** Inorganic nanomaterials, including nanoscale silver, gold, and titanium dioxide.
j. **Graphene:** A single layer of carbon atoms arranged in a two-dimensional honeycomb lattice.

Functional materials are advanced substances specifically engineered to perform designated functions, often featuring tailored properties and surface structures. These materials are essential across various innovative technologies and industries, including electronics, optoelectronics, catalysis, biomedicine, aerospace, and energy. They encompass a diverse range of materials, including functional inorganic compounds, polymers, metal powders, and composites, each exhibiting unique characteristics such as thermal stability, electrical conductivity, biocompatibility, and flame resistance.

The development of functional materials requires a comprehensive understanding of structure-property relationships, reliable characterisation methods, and efficient synthesis techniques, all of which are critical for their application in advanced technologies. A notable subset of functional materials is "multifunctional materials", which are designed to perform multiple functions simultaneously. This multifunctionality can lead to reduced weight, enhanced efficiency, and improved performance across various applications. These materials can respond to various stimuli, including heat, stress, electrical and magnetic fields, pH changes, moisture, and light, enabling capabilities such as self-healing, self-sensing, and shape memory.

Manufacturing processes for functional materials include self-assembly, wrapping, grafting, and one-pot synthesis, which are vital for achieving the desired properties and functionalities.

Examples of functional materials include

a. **Semiconductors:** Used in electronics for their ability to control electrical flow, with examples like silicon, germanium, and gallium arsenide.
b. **Piezoelectric Materials:** Generate electrical charge when subjected to mechanical stress, with examples including quartz, Rochelle salt (Potassium sodium tartrate tetrahydrate), and certain ceramics.
c. **Magnetocaloric Materials:** Change temperature in response to a magnetic field, applicable in magnetic refrigeration.
d. **Ferroelectric Materials:** Exhibit spontaneous electric polarisation that can be reversed with an external electric field, including barium titanate and lead zirconate titanate.
e. **Shape-Memory Alloys:** Return to their original shape upon heating after deformation, with examples like Nitinol (nickel-titanium) and copper-aluminium-nickel alloys.
f. **Multiferroic Materials:** Display multiple ferroic order parameters, such as ferromagnetism, ferroelectricity, ferroelectricity, or ferrotoroidicity.
g. **Biomaterials:** Compatible with the human body, used in medical applications, including titanium (for implants), collagen (for tissue engineering), and hydrogels (for drug delivery).
h. **Functional Oxides:** Materials like piezoelectric, where voltage application causes dimensional changes, or ferroelectrics, where it alters relative permittivity.
i. **Molecular Thin Films:** Developed for optoelectronic applications, noted for their low cost, lightweight nature, and ease of property modification through chemical synthesis.

Activity 1.26 Industry Visit/Field Trip

1. Visit a nearby material production/manufacturing industry for more practical experience on how materials are synthesised/produced to enhance mastery of the topic. Alternatively, watch these videos about material manufacturing:
   a. https://www.youtube.com/watch?v=XyP_7IZzpeI
   b. https://www.youtube.com/watch?v=laA9Aa4fnq4
   c. https://www.youtube.com/watch?v=HCfr0e1gE3A

2. After the visit or watching the videos, write a report detailing your observations and learnings from the visit.

Activity 1.27 Practical Exercise

1. Put on all your safety clothing and abide by all safety precautions in order to prevent accidents
2. Under the supervision of the laboratory master/workshop technician/ engineer, perform these three processes of synthesising materials:
   a. Bulk materials
   b. Nanomaterials
   c. Thin film
3. Ask someone to take a video or picture of you during these practical sessions.

Activity 1.28 Exploring Material Synthesis

1. Classify materials into bulk materials, nanomaterials, and thin films, and to explore methods of synthesis for each category.
2. Go to the internet, make a search, watch videos or read from relevant documents on Material Synthesis
   a. Define the following terms and explain why each type is important.
      - Bulk materials
      - Nanomaterials
      - Thin film

b. Fill out the table below with examples, applications, and methods of synthesis for each material type.

Material Type	Examples	Applications	Method of Synthesis
Bulk materials			
Nanomaterials			
Thin film			

Summarise your findings for each type of material, and present this to the class. The presentation should include:

- Definition
- Example and its application
- Synthesis method and key steps
- Reflect on how different synthesis methods influence material properties and uses.

3. The grouping of materials according to their synthesis.

Activity 1.29 Material Synthesis and Classification

1. In pairs, discuss and share your understanding of material synthesis and classify materials to be synthesised as bulk materials, nanomaterials, and thin films.
2. Provide examples of these materials and their methods of synthesis.

Review Questions

1. Name the chemical properties that should be considered when selecting a material for use in your local community.
2. What is polymorphism in terms of material structure?
3. Explain the difference between crystalline and amorphous solids. How do the properties of amorphous materials affect their processing? How different will the processing of crystalline materials be from amorphous materials?
4. Given a scenario where a metal part needs to be hardened, which process would you choose and why?
5. Describe one way in which the reactivity of metals differs from the reactivity of ceramics.
6. Explain how the reactivity of a metal could affect its use in manufacturing.
7. Based on a case study of a manufacturing company that experienced a fire due to the flammability of a material, analyse the contributing factors and propose a detailed plan for the company to prevent similar incidents in the future.
8. Explain why the processing of raw materials is important for product development.
9. Develop a flow chart illustrating the various processing steps involved in transforming a naturally occurring mineral (iron ore or bauxite, etc.) into a finished metal product.

Manufacturing Engineering

Year 2

SECTION

2

UNDERSTANDING MECHANICAL PROPERTIES OF MATERIALS

MANUFACTURING MATERIALS AND TECHNOLOGIES

Properties of Materials

Introduction

In this section, we will explore the loading of materials and the effects of loading, stress, and strain on them. Materials loading, stress, and strain are fundamental in understanding material behaviour under applied forces. You will understand the elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials and their contributions to the manufacturing of products. You will be able to explain the tensile properties of steel and link them to applications in the design and manufacturing of products that solve societal problems. You will also be taken through strain measurement using strain gauges as a fundamental technique in experimental stress analysis, which is widely applied across various fields such as the manufacturing, aerospace, automotive, agricultural, and medical industries. We shall explore why, when an external force acts on an object, the object tends to undergo some deformations. This will enhance your understanding that when materials are loaded within an elastic limit, the stress is proportional to the strain produced by the stress. By the end of this section, you will have a comprehensive understanding of the materials loading, the effect of loading, stress and strain on materials, and their implications in real-world applications.

Key Ideas

- Materials loading refers to the application of force on a material.
- Stress is defined as the internal force per unit area within a material.
- Strain is the measure of deformation representing the displacement between particles in the material body relative to a reference length.
- Elongation is the increase in the length of a material when it is subjected to a tensile force or stress.
- The ratio of the stress to the corresponding strain is a constant within the elastic limit. This constant is known as the Modulus of Elasticity or the Young's modulus and it is denoted by the letter E.

MATERIALS LOADING, STRESS AND STRAIN

The concepts of materials loading, stress, and strain are fundamental in understanding material behaviour under applied forces. Materials loading refers to the external forces such as gravity, pressure, tension, or thermal changes exerted on a material. How a material responds to these forces, its stress (force per unit area) and strain (deformation) determines its mechanical properties and is essential for designing durable and efficient structures.

Axial Loading (Tensile and Compressive), Bending, Torsional and Shear Loading

Axial, bending, torsional, and shear loading are fundamental forces that impact the behaviour and integrity of structural members in distinct ways.

Axial loading involves forces applied along the longitudinal axis of a structural member. These forces can be tensile (pulling apart) or compressive (pushing together). Tensile axial loads elongate the material, increasing its length, while compressive axial loads shorten it. Devices used to apply axial loads are crucial for ensuring accurate force application and measurement, which is vital in structural testing. **Figure 2.1** shows an example of an undeformed and deformed axially loaded rod.

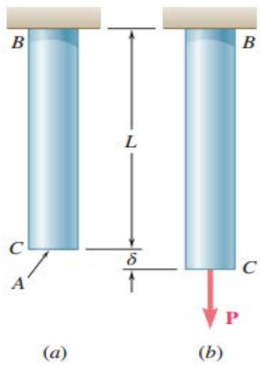


Figure 2.1: Undeformed and deformed axially loaded rod (Beer et al., 2020)

Bending occurs when a force or moment is applied perpendicular to the longitudinal axis, causing the member to bend. This induces tensile and compressive stresses across the cross-section, with the maximum stress occurring at the outermost portion of the material. Bending behaviour is critical in evaluating the strength and stability of beams and other structural elements. **Figure 2.3** shows the concept of bending behaviour in a shaft.

Torsional loading involves twisting a member around its longitudinal axis, generating shear stresses that vary across the cross-section. This is especially important in applications where torsional and axial loads are combined, such as in shafts or structural components subjected to simultaneous twisting and stretching/compression. **Figures 2.2** and **2.3** show the concept of torsional behaviour in a shaft.

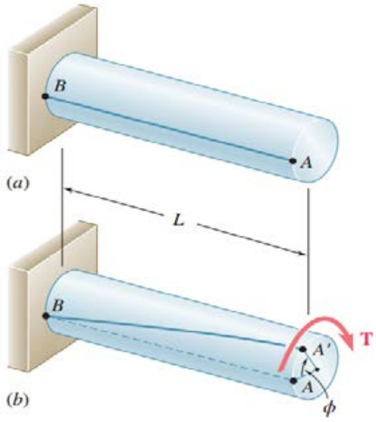


Figure 2.2: Shaft with fixed support and line AB drawn showing deformation under torsion loading: (a) unloaded (b) loaded (Beer et al., 2020)

Shear loading acts parallel to the structural member's cross-section, causing one part of the material to slide or deform relative to the adjacent part. This is particularly significant in the design of slender structures, like wires, which are often tested for shear strength through torsion and bending tests. Shear loading is also a key factor in the stability of beams under transverse loads. In reinforced concrete (RC) members, the interaction of these four loading types, axial, bending, shear, and torsion can be complex. RC members are often subjected to combined loading, requiring detailed analysis to understand how each type of stress contributes to the structure's overall behaviour and failure modes. **Figure 2.3** shows the concept of shear behaviour in a shaft.

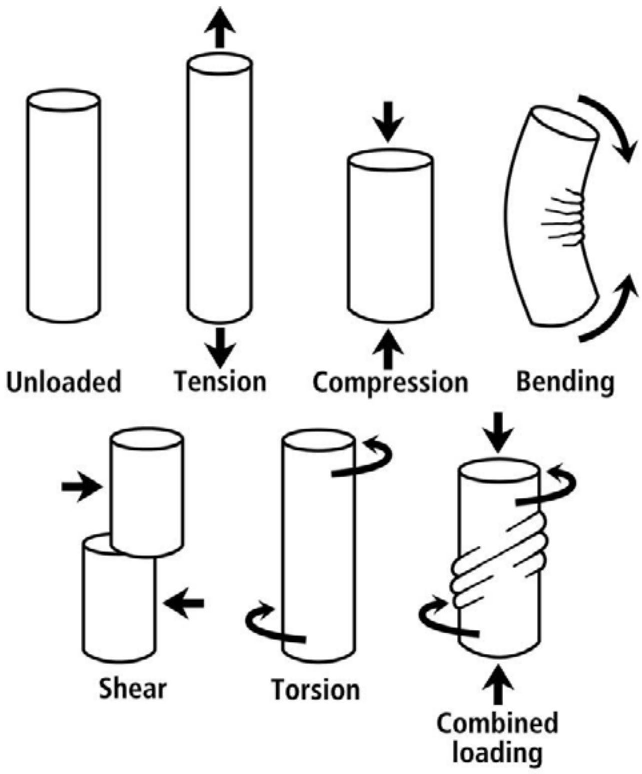


Figure 2.3: Axial loading (tensile and compressive), bending, torsional and shear loading

STRESS AND STRAIN OF MATERIALS

Stress and strain are core concepts in the study of material mechanics, describing how materials deform and ultimately fail under various loading conditions. Stress is the internal force per unit area within a material, while strain measures the material's deformation, specifically the relative displacement of its particles from a reference length.

In linear elasticity, stress and strain are governed by Hooke's Law, which asserts that strain is proportional to applied stress, provided the material's elastic limit is not exceeded. This relationship is vital for understanding the elastic behaviour of materials, where they return to their original shape once the stress is removed. However, materials in real-world conditions often display more complex responses. For example, plastic deformation occurs when stresses surpass the material's elastic limit, resulting in permanent deformation.

Measuring and predicting stress and strain are crucial for designing and maintaining engineering structures, as excessive stress or strain can lead to material failure. In granular materials, such as soils or powders, stress and strain must account for contact interactions and particle rotations, which are key to understanding their mechanical behaviour. Geomaterials like soils and rocks exhibit stress-strain responses influenced by strain rate, stress magnitude, and the interactions between solid, liquid, and gas phases—especially under dynamic loading conditions, such as blasts or seismic events.

Activity 2.1 Understanding Material Loading, Stress and Strain

1. Using the internet, research and present your findings on material loading, stress and strain (see suggested links below). Research the different types of loading and their effects on materials.
2. Use your research, focusing on stress and strain and their effects on materials, to create a presentation using these questions as section headings:
   - What is stress?
   - What is strain?
   - How do you calculate stress?
   - How do you calculate strain?
   - What happens to a material when it undergoes elastic deformation?
   - What happens when a material undergoes plastic deformation?
   - What is the elastic limit of a material?
   - What happens when the stress on a material exceeds its elastic limit?
   - What is the yield point?
   - What does the yield point indicate in a stress-strain curve?
   - What does the slope of the stress-strain curve represent?
   - How do you know when a material will fracture?

- What happens to a material under tensile stress?
- How does a material behave under compressive or shear stress?

These basic questions will help you understand how stress and strain work, how they are measured, and how they affect the behaviour of materials.

3. Watch this video to reinforce your understanding of stress and strain:

https://www.youtube.com/watch?v=X-zSlyM4JSQ

Some links to help you research understanding material loading, stress and strain:

- https://www.linearmotiontips.com/mechanical-properties-of-materials-stress-and-strain/
- https://www.xometry.com/resources/materials/stress-vs-strain/
- https://www.discoverengineering.org/stress-and-strain-in-materials/
- https://www.youtube.com/watch?v=aQf6Q8t1FQE

Activity 2.2 Axial Loading, Bending Loading, Torsional Loading, and Shear Loading

Join a small group of 3-4 of your classmates. In your group, perform an axial loading (compression and tension), bending loading, torsional loading, and shear loading experiment using readily available materials.

This experiment will allow you to observe how different forces affect materials and structures.

1. **Safety Considerations**
   a. Always secure the rods or beams in clamps to prevent them from moving unexpectedly when loaded.
   b. Be careful when applying torsional forces to avoid excessive twisting that might cause the material to break.
   c. Ensure weights are placed gradually to avoid sudden impacts.

2. **Axial Loading (Compression and Tension):**

Materials: Metal or wooden rods, spring scale, weights, clamps or vice (to hold rods in place), ruler or measuring tape

Procedure

a. Tension: Attach the spring scale to one end of a metal or wooden rod and apply a pulling force. Gradually add weights to the spring scale, measuring the force as the rod is pulled in tension.
b. Compression: Similarly, use the spring scale to apply a pushing force to the other end of the rod, compressing it. Measure the force applied during compression.

Observation: Measure the deformation of the rod when under tension and compression. You should observe elongation under tension and shortening under compression.

3. **Bending Loading**

Materials: Plastic or wooden beam, weights, ruler

Procedure

a. Place the beam horizontally on two supports (such as books or blocks) and apply weights in the middle of the beam to create bending. Measure the deflection at the centre of the beam using a ruler.
b. Vary the amount of weight and observe how the deflection increases with increasing force.

Observation: The beam should bend downwards under the applied weight. The amount of deflection depends on the weight, the length of the beam, and the material.

4. **Torsional Loading**

Materials: Metal or wooden rod, protractor, string or rope

Procedure

a. Attach the rod horizontally to a clamp or vice, leaving one end free. Wrap a string or rope around the free end of the rod.
b. Apply torque by rotating the string or rope and use the protractor to measure the angle of rotation.
c. Measure the amount of force applied to the string (you can use a spring scale to measure force).

Observation: As you twist the rod, you will see it rotate. The angle of rotation is related to the torque applied, and the amount of twist depends on the material and the amount of force.

5. **Shear Loading**

Materials: Wooden dowel or metal rod, cardboard or plastic sheet, weights

Procedure

a. Place a thin strip of cardboard or a plastic sheet on a flat surface and apply a vertical force (such as weights) at the centre of the sheet. Attach one end of the sheet to a fixed point, allowing it to shear as the force is applied.

b. Alternatively, a dowel can be placed on two supports with weights applied to the top to demonstrate shear at the points of contact.

Observation: The material will shear (break or deform) under the applied load. Measure the amount of displacement or deformation that occurs.

Activity 2.3 Analysis and Discussion

After the experiments in **Activity 2.2,** have a discussion on the following:

1. For each type of loading, you have measured the deformation (elongation, compression, deflection, rotation, shear displacement) as a function of the applied load.
2. Compare the behaviour of different materials (wood, metal, plastic) under the same type of loading.
3. Discuss the concepts of **stress** and **strain**, and how these relate to the properties of materials during or after manufacture.
4. For bending and torsion, discuss the relationship between the **modulus of elasticity** and the deformation observed.

Activity 2.4 Effects of Loading on Specific Materials

Your group will be allocated a type of loading (axial, bending, torsional, shear). In your group create a presentation demonstrating the effects of this loading on a specific material. Use these headings for your presentation:

1. Introduction to the type of loading (axial, bending, torsional, shear)
2. Understanding the material's behaviour under the type of loading allocated
3. Key Concepts in the type of loading allocated (Stress-Strain Relationship)
4. The loading experiment
5. Experimental Observations
6. Practical applications of that type of loading on your material
7. Summary

EFFECT OF LOADING, STRESS AND STRAIN ON MATERIALS

Materials are crucial in manufacturing engineering, as their properties dictate product quality, durability, and performance. Understanding how materials respond to stress and strain under different conditions is essential for designing reliable products. Excessive stress and strain caused by mechanical or thermal loading can lead to material failure, making their accurate measurement and prediction critical for designing and maintaining engineering structures.

Strain Measurement Using the Strain Gauge

Strain measurement using strain gauges is a core technique in experimental stress analysis, with extensive applications across industries such as manufacturing, aerospace, automotive, agriculture, and healthcare to measure the strain of objects. The device was invented by Edward E. Simmons and Arthur C. Ruge in 1938, The strain gauges consist of a variable resistor whose resistance value changes when a force is applied to the material, resulting in strain, A typical strain gauge consists of a metallic foil pattern mounted on a flexible insulating substrate, which is then bonded to the specimen using a suitable adhesive. When the specimen deforms under stress, the strain gauge deforms in tandem, changing its electrical resistance. This change is directly proportional to the strain experienced by the specimen, enabling accurate strain measurement.

Strain gauges are available in various forms, including wire, foil, and semiconductor types, offering distinct advantages for specific applications. For example, strain gauges can be arranged in a Rosette configuration to measure multi-directional strains, thus enhancing data accuracy and completeness. Advanced systems incorporating multiple strain gauges allow for rapid data collection, reducing random errors and improving precision through high-frequency sampling and arithmetic averaging. Capacitive strain gauges, which employ multiple electrodes and conductive guards, further improve accuracy by minimising errors and deviations from the basic measurement formula.

In specialised applications, such as crank measurement systems, strain gauges are strategically placed to measure bending, shear, and axial strains, providing detailed insights into forces, torque, and power exerted on the crank. The performance of strain gauges can be influenced by factors like temperature, which require careful selection and placement and is often determined using brittle coating techniques. Furthermore, innovative designs featuring flexible substrates and structured resistance layers enhance sensitivity and accuracy, optimising creep behaviour and reducing temperature coefficients and transverse sensitivity. **Figure**s **2.4** and **2.5** show images of strain gauge and strain gauge measurement (Rosette configuration)

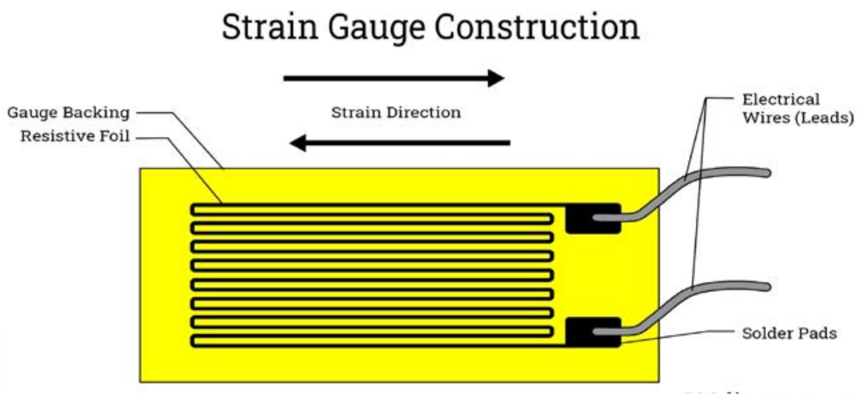


Figure 2.4: Strain gauge

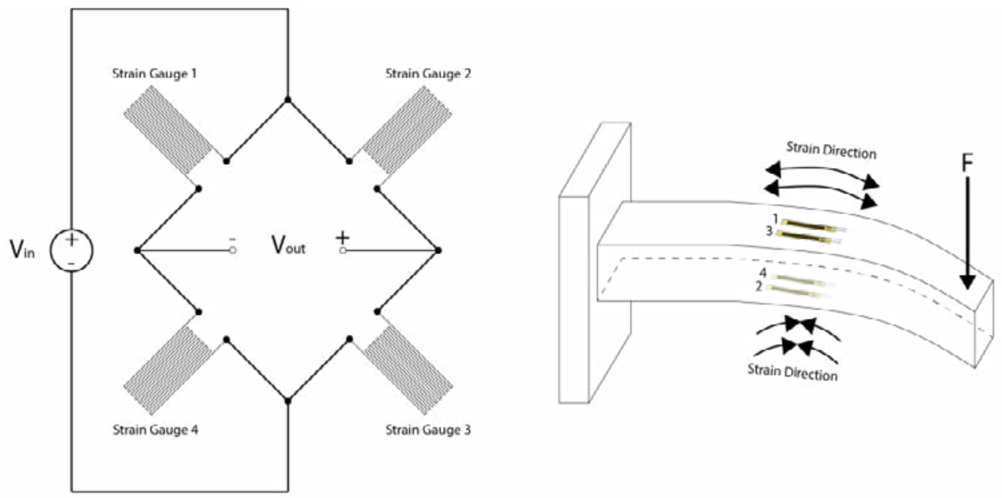


Figure 2.5: Strain gauge measurement (Rosette configuration)

Calculation of Stress and Strain of Materials Using the Modulus of Elasticity of Materials

Stress (σ) is the compression or tension per unit area and is defined as:

$$\sigma = \frac{F}{A} \qquad 2.1$$

Where, F is force, and A is the cross-sectional area where the force is applied. In the metric system, stress is commonly expressed in units of pascals (Pa), newtons per square metre (N/m^2) or newtons per square millimetre (N/mm^2).

When stress is applied to an object, the change in shape is called strain. In response to compression or tension, normal strain (ε) is given by the proportion:

$$\varepsilon = \frac{\Delta L}{L} \qquad 2.2$$

In this case, ΔL is the change in length, and L is the original length. Normal strain, or simply strain, is dimensionless.

Using the Young's modulus of elasticity formula

The modulus of elasticity equation is used only under conditions of elastic deformation from compression or tension. The modulus of elasticity is simply stress divided by strain

$$E = \frac{\sigma}{\varepsilon} \qquad 2.3$$

With units of pascals (Pa), newtons per square metre (N/m2) or newtons per square millimetre (N/mm^2). For most materials, elastic modulus is so large that it is generally expressed as megapascals (MPa) or gigapascals (GPa).

Example 2.1

To determine the modulus of elasticity of aluminium, observe the stress-strain curve and identify the region of elastic deformation, which applies to strains less than 0.5% ($\varepsilon = 0.005$). The corresponding stress at that point is $\sigma = 150\ N/mm^2$. Using the modulus of elasticity formula, calculate the modulus of elasticity for aluminium.

Solution:

The modulus of elasticity E is defined by the relationship:

$$E = \frac{\sigma}{\varepsilon} \qquad 2.4$$

From the question: $\sigma = 150\ N/mm^2$ and $\varepsilon = 0.005$ (since 0.5% strain is given)

Now, substitute these values into the modulus of elasticity formula:

$E = 150/0.005$

$E = 30{,}000\ N/mm^2$

So, the modulus of elasticity of aluminium is $30{,}000\ N/mm^2$ or 30 GPa

Try this:

A copper wire is subjected to a tensile test, and the stress-strain curve shows that the elastic deformation region applies to strains up to 0.2 percent ($\varepsilon = 0.002$). The corresponding stress at that point is $\sigma = 210\ N/mm^2$. Calculate the modulus of elasticity for copper.

Activity 2.5 Calculating the Stress and Strain on a Material

1. Search the internet, watch a video or read relevant materials/documents on the material processing methods using the link and the book provided.
   - https://www.youtube.com/watch?v=c6ndD5kTkP4
   - https://www.youtube.com/watch?v=aQf6Q8t1FQE
   - https://www.youtube.com/watch?v=WZIKjzOnZr8
   - https://byjus.com/physics/stress-and-strain/

2. Prepare posters that briefly describe stress and strain and discuss them with your class or peers.

Activity 2.6 Investigating Materials Loading, Stress and Strain

Materials needed

- Steel wire, rubber band, wood strip, plastic rod
- Spring scales (for measuring force)
- Ruler or callipers (for measuring elongation or deformation)
- Clamp stands (for holding materials)
- Protractor or angle ruler (if testing bending)
- Markers or chalk (for marking reference points)

Steps

1. **Set up material on clamp**
   a. Use steel wire for tensile loading, a rubber band for elastic deformation, and a wooden strip for bending.
   b. Make a reference mark on each material sample at the midpoint of each material to track deformation.
2. **For Tensile/Compressive (Axial loading)**
   a. Mount the spring scale to one end of the material and pull slowly while observing the elongation of the material.
   b. Measure the extension at different force intervals for tensile loading analysis. Record the force applied and the corresponding elongation (strain).
   c. Apply corresponding loads on the plastic spring and measure the corresponding compression.
   d. Use the data collected to plot a graph of force vs. elongation and discuss the relationship in a material's stress-strain. Compare the material's response with what you expect from Hooke's Law.
3. **Bending Test**
   a. Place the material on two supports, spaced at a specific distance (L) apart, usually given in terms of the sample length.

   b. Gradually apply a force (F) at the centre of the beam while recording the deflection (δ) at the midpoint. Increase the load step by step and record the corresponding deflection for each load increment.

4. **Elastic vs. Plastic Deformation**
   a. Fix one end of the rubber band or wire to a rigid point, say a table. Measure the initial length of the band/wire and record it as the reference length.
   b. Attach the first weight to the free end of the band/wire. Measure the stretch of the band/wire caused by the weight and record it.
   c. Since the elongation will be relatively small, the band/wire will return to its original length once the weight is removed.
   d. This demonstrates elastic deformation. The band/wire has stretched but will return to its original shape when the load is removed.
   e. Add more weight gradually. As the weight increases, you will notice that the band/wire begins to stretch more. A point will be reached where the band/wire does not return to its original length even after the weight is removed. This point marks the transition from elastic deformation to plastic deformation.
   f. Keep adding weight and observe how the band/wire deforms permanently. Once the band/wire is stretched beyond its yield point, it will not return to its original length, indicating plastic deformation.
   g. As the weight is increased too much, the rubber band/wire may eventually collapse, which occurs after significant plastic deformation.
5. **Group report:** After the experiments, prepare a group report outlining the effect of loading, stress and strain on these materials.

Activity 2.7 Simulating the Effect of Different Loads on a Material

Material and Setup

- Simulation tool (such as **ANSYS**, **SolidWorks Simulation**, or **COMSOL Multiphysics**)
- Steel (with yield strength of 250 MPa, Young's Modulus E=210 GPa)
- Length of the Beam: 6 metres
- Cross-sectional Area: Rectangular beam with width = 100 mm and height = 200 mm
- Support Conditions: The beam is fixed at both ends (simulating a simply supported beam).

- Loads: Apply three different load scenarios (uniformly distributed load, point load, and varying load) to see how the stress and strain respond.

Load Scenarios:

a. Uniformly distributed load: Load = 5000N, applied evenly across the beam (uniformly distributed load).

b. Point load: Load = 5000 N, applied at the centre of the beam.

c. Varying load: Load = Varying from 0 to 5000 N across the length of the beam.

Steps for Simulation for ANSYS/ SolidWorks Simulation/ COMSOL

1. Create a New Simulation Project:
   a. Open the software and create a new project.
   b. Select the type of simulation (structural analysis) and choose the material properties (steel).
   c. Input the dimensions of the beam: 6 metres (length), 100 mm (width), 200 mm (height).
2. Set Up Boundary Conditions: Define the fixed boundary conditions at both ends of the beam (simulating a simply supported beam).
3. Apply Load Conditions:
   a. For a uniformly distributed load: Apply a 5000 N load evenly along the beam.
   b. For a point load: Apply a 5000 N load at the centre of the beam.
   c. For varying load: Set a load that increases linearly from 0 to 5000 N along the length of the beam.
4. Mesh the Model: Create a mesh for the model. This divides the beam into small elements for the simulation to calculate the stress and strain more accurately.
5. Run the Simulation: Run the simulation for each loading scenario. The software will compute the resulting stress distribution and strain distribution throughout the beam.

Observe the Results: After the simulation, examine the following:

a. Stress distribution: Look for areas of the beam where stress exceeds the material's yield strength (250 MPa). These areas are more likely to fail under load.

b. Strain distribution: Identify the regions with the highest strain, which may indicate areas of high deformation.

The software will typically display results in colour-coded stress and strain maps, with red indicating areas of highest stress/strain and blue indicating the lowest.

Step 2: Record Observations

For each of the three loading scenarios (uniform, point, varying), record the following observations:

a. Maximum Stress: The highest stress value in the beam and where it occurs.
b. Maximum Strain: The highest strain value and the corresponding location in the beam.
c. Comparison between Scenarios:
   - How does the stress distribution change with a uniformly distributed load compared to a point load?
   - How does the varying load scenario affect the beam differently from the other two scenarios?
   - Did any areas exceed the yield strength of steel (250 MPa)? If so, what are the implications for design?
   - Discuss which loading condition resulted in the highest stress and strain.
   - Recommend which load conditions should be avoided or mitigated in a real-world scenario to prevent failure.

Activity 2.8 Case Study

A steel bridge component failed during operation due to excessive stress and strain. The component in question was a supporting beam, which had been designed to carry heavy loads. However, after several months of use, the beam experienced a disastrous failure. The cause of failure was found to stress and strain factors that exceeded the material's limits, leading to permanent deformation and fracture.

This case study illustrates the importance of considering stress, strain, material properties, and environmental conditions when designing structural components. You should understand how these factors contribute to failure and how improvements can be made in real-world applications

Failure Investigation and Analysis

Key Details of the Case:

- Material Used: Mild Steel (Yield Strength: 250 MPa, Modulus of Elasticity: 210 GPa)
- Component: Supporting beam of a bridge
- Dimensions of the Beam:
- Length: 8 metres
- Cross-sectional area: 200 mm x 300 mm
- Load: 5000 N, applied uniformly
- Environmental Conditions:

- The bridge is located in a coastal area with high humidity.
- The component was subjected to extreme temperature fluctuations.

Analysis of the Failure

Step 1

1. Calculation of Expected Stress and Strain

   Using the information provided, we can calculate the expected stress and strain under normal load conditions.

   Maximum Bending Moment (M) = $M = PL/4 = 10000$ N

   Where $P = 5KN = 5000N$

   $L = 8\,mL = 8$ m

2. Moment of Inertia (I) for Rectangular Section:

   $I = b\,h^3 / 12 = 5.4\times10^{-4}m^4$

   Where: $b = 200\,mm = 0.2\,mb = 200$ mm $= 0.2$ m

   $h=300\,mm = 0.3\,mh = 300$ mm $= 0.3m$

3. Distance from Neutral Axis to Outermost Fibre (c)

   $c = h/2 = 0.15m$

4. Bending Stress (σ): $\sigma = \quad M.c/I = 2.78\times107N/m^2 = 27.8MPa$
5. Strain (ε): From Hooks Law, $\varepsilon = \sigma/E = 1.32\times10^{-4}$

   From the above, the calculated stress (27.8 MPa) is far below the yield strength of mild steel (250 MPa), and the strain (1.32×10^{-4}) is relatively small, this means that the component will function without failure under these conditions.

Step 2: Cause of Failure

Though the calculated stress is far below the yield strength of mild steel, the beam failed. The failure occurred as a result of several contributing factors:

1. Fatigue Failure:
   - The bridge component was subjected to cyclic loads, which caused fatigue failure over time. Mild steel, though strong under static loading, can fail due to repeated stress cycles that cause small cracks to propagate.
   - Even though the stress was below the yield strength, cyclic loading caused the beam to experience repeated stress and strain, leading to fatigue cracks.

2. Environmental Factors:
   - The coastal environment introduced corrosion to the steel component. Over time, the steel's surface became weakened by rust, reducing its effective cross-sectional area and the ability to carry loads.
   - The combination of high humidity and extreme temperature fluctuations also led to thermal stresses that exacerbated the material's susceptibility to fatigue cracking.
3. Improper Material Selection:
   - Mild steel was selected for the component, which was not the most suitable choice for this environment. While mild steel is generally strong, it does not have the same level of corrosion resistance as materials such as stainless steel or galvanized steel.
   - Additionally, mild steel has a relatively low fatigue strength compared to high-strength alloys.
4. Design Flaw:
   - The component's design did not adequately account for the possibility of high dynamic loading (e.g., traffic movement, wind forces) that could induce higher stresses than the design loads.
   - The design did not consider adequate safety margins or factors like stress concentrators (e.g., bolt holes, weld joints), which can act as initiation points for fatigue cracks

Conclusion

The failure of the steel bridge component was primarily caused by a combination of material limitations (corrosion resistance and fatigue strength), environmental factors, and design flaws. By selecting more suitable materials, improving the design with adequate safety factors, and incorporating regular maintenance and inspection protocols, such failures can be prevented in the future.

Activity 2.9 Designing a Simple Support Beam

You are tasked with designing a simple support beam that is intended to carry a uniform load. The beam is subjected to a point load applied at its centre, and you need to calculate the expected stress and strain based on the modulus of elasticity of the material used.

The dimensions and material properties are provided below:

- Length of beam (L): 4 metres
- Point load (P): 5000 N (Newtons)
- Beam's cross-sectional area (A): 50 cm^2 (0.005 m^2)
- Material: Steel

- Modulus of Elasticity (E): 200 GPa (200×10^9 N/m^2)
- Moment of Inertia (I) for a rectangular section (beam cross-section): 8.33×10^{-6} m^4 (Assume a rectangular cross-section with width = 0.1 m and height = 0.05 m)

Calculate

1. the stress (σ) for the centre of the beam (where the load is applied)
2. the Strain (ε)
3. deflection at the Centre of the Beam (δ)

Procedure

1. the stress (σ) = P/A to calculate the stress in the beam

   where:
   P is the applied load
   A is the cross-sectional area of the beam

2. the Strain (ε) = σ /E to calculate the strain

   where:
   σ is the stress
   E is the modulus of elasticity

3. the deflection at the Centre of the Beam (δ) = PL^3 /48EI to calculate the deflection of the beam

   where:
   P is the applied load
   L is the length of the beam
   E is the modulus of elasticity
   I is the moment of inertia of the beam's cross-section

Justification of Material Choice (Steel): Based on your calculations, determine if steel is an appropriate material choice for this application, considering factors such as the expected stress and strain. Discuss if steel's high modulus of elasticity and strength make it suitable for the load conditions.

Compare the calculated stress with the yield strength of steel (approx. 250 MPa). If the stress is much lower than the yield strength, then steel would be a good material choice. Additionally, assess whether the strain and deflection are acceptable for the design.

ELONGATION, ELASTIC LIMIT, MODULUS OF ELASTICITY, YIELD STRENGTH AND TENSILE STRENGTH OF MATERIALS

As manufacturing engineers, we must understand the behaviour of materials when subjected to external forces. Understanding how materials respond to stress and strain enables engineers to make informed, optimal decisions in various applications. This includes selecting appropriate materials for product manufacturing, designing structural elements like bridges, and developing advanced technologies such as smartphones, among countless other critical applications.

Elongation

Elongation refers to the increase in length experienced by a material when subjected to a tensile force or stress. For instance, when a rubber band is stretched, it undergoes elongation. A stress-strain curve typically represents the relationship between the applied stress and the resulting strain (elongation). Elongation is a fundamental material property that significantly influences the performance, durability, and reliability of materials across various fields, including construction, manufacturing, and consumer products. A good understanding of how materials elongate under stress is essential for the design of safer, more efficient structures and products. Elongation is often quantified as a percentage of the material's original length, as described in equation 2.5. For example, if a wire originally measuring 10 cm is stretched to 11 cm, the elongation is 10%.

$$\text{Percentage elongation } (\Delta L) = \frac{\text{final length-original length}}{\text{original length}} \times 100\% \qquad \text{Eq. 2.5}$$

$$\text{Percentage elongation } (\Delta L) = \frac{11-10}{10} \times 100\%$$

$$\text{Percentage elongation } (\Delta L) = 10\%.$$

Elasticity and Elastic Limit

When an external force is applied to a material, the object typically undergoes deformation, which can manifest as a change in shape, size, or both. If the force is then removed and the material returns to its original shape and size, it is said to exhibit elasticity. Elasticity is the property of materials that allows them to recover their initial form after removing an applied force, provided the deformation remains within certain limits. This recovery occurs only if the applied force does not exceed a specific threshold known as the elastic limit. The elastic limit refers to the maximum amount of stress that a material can endure while still returning to its original dimensions once the external force is removed. Beyond this point, the material's ability to revert to its original state is compromised. If the applied force exceeds the elastic limit, permanent deformation occurs, and the material will not fully recover its original shape or size, even after the force is removed. This permanent change in shape is referred to as residual deformation.

Understanding the elastic limit in materials science is very important because it determines the boundaries within which a material can behave elastically. The material will maintain its structural integrity and functionality if the applied stress remains within the elastic limit. However, if the stress exceeds this limit, the material may suffer irreversible damage, affecting its performance and reliability. The elastic limit is thus a key parameter in material design, particularly in applications requiring materials to withstand repeated or high stresses without permanent deformation.

Modulus of Elasticity

When a material is subjected to a load within its elastic limit, the resulting stress is directly proportional to the strain it produces. This relationship is described by Hooke's Law, which states that within the elastic limit, the ratio of stress to strain remains constant. This constant, which defines the material's resistance to deformation under stress, is known as the Modulus of Elasticity (also referred to as Young's Modulus) and is represented by the symbol EEE.

The modulus of elasticity quantifies the stiffness of a material. Materials with a high modulus of elasticity are considered stiff, meaning they resist deformation more effectively when stress is applied. These materials require higher forces to produce a given amount of strain, indicating that they maintain their shape under stress. In contrast, materials with a low modulus of elasticity are more flexible, meaning they undergo greater deformation when subjected to the same amount of stress.

Mathematically, the modulus of elasticity can be expressed as:

$$\text{Modulus of elasticity (E)} = \frac{stress}{strain} = \frac{\sigma}{\varepsilon} \qquad 2.6$$

Where:

σ is the applied stress (force per unit area),

ϵ is the resulting strain (relative deformation).

The modulus of elasticity is a fundamental property in materials science, engineering, and structural design, as it plays an important role in determining how materials will behave under different loading conditions. High-modulus materials are ideal for applications where minimal deformation is required, such as in beams, bridges, and aircraft components. In contrast, low-modulus materials are better suited for applications that require flexibility, such as rubber seals or flexible polymers. This helps engineers to select the appropriate materials for specific applications, ensuring both safety and efficiency in design.

Different materials have different modulus of elasticity. **Table 6.1** shows the modulus of elasticity (Young's modulus) of some regular materials used in the manufacturing industry. These approximate values can vary depending on the specific grade, alloy, or material conditions.

Table 2.1: Modulus of elasticity (MOE) of typical materials used in the manufacturing industry

Material	Modulus of Elasticity (E) N/mm^2
Steel (Carbon)	200,000 – 210,000
Aluminium (Aluminium Alloy)	68,000 – 75,000
Copper	110,000
Titanium	100,000
Concrete (Reinforced)	25,000 – 30,000
Glass (Borosilicate)	60,000 – 75,000
Wood (Oak, Hardwood)	10,000 – 12,000
Rubber	0.01 – 0.1
Cast Iron	100,000 – 130,000
Polyethylene (HDPE)	800 – 1,200
Polycarbonate	2,200 – 2,500
Polyvinyl Chloride (PVC)	2,500 – 3,500
Brass	100,000
Carbon Fibre	70,000 – 150,000
Fibreglass	30,000 – 50,000

The unit of the modulus of elasticity is Pascal (Pa), but MPa (Megapascals) is the most common unit for expressing the modulus of elasticity in materials science and engineering.

$1 \text{ MPa} = 1 \text{ N/mm}^2$.

Materials like steel and titanium have high modulus values, which are very stiff and resist deformation under applied stress. Materials such as rubber and wood have lower modulus values, meaning they are more flexible and deform easily under stress.

The modulus of elasticity is an important parameter when selecting materials for engineering applications, as it helps determine how much a material will deform under a given load. Materials with a high modulus of elasticity (like steel or concrete) are preferred for their stiffness and load-bearing capacity for structural components. Materials with a lower modulus (like rubber or wood) are chosen for applications requiring flexibility.

Yielding and Yield Strength

In the design of materials, especially in engineering applications, most materials must undergo elastic deformation when subjected to external stresses. Elastic deformation allows the material to return to its original shape once the stress is removed. However, if a material undergoes plastic deformation, meaning it experiences a permanent change in shape, it may no longer function effectively within its intended design parameters; therefore, understanding the stress level at which plastic deformation begins is essential for material selection and design.

The point at which a material transitions from elastic to plastic deformation is called yielding. For metals, which typically undergo a gradual elastic-plastic transition, the point of yielding is often defined as the initial deviation from the linearity of the stress-strain curve. This point is sometimes called the proportional limit, representing the onset of plastic deformation at the microscopic level. However, determining the exact location of the proportional limit is challenging in real-world applications due to the gradual nature of the transition.

To address this, a conventional method has been established: a straight line is drawn parallel to the elastic portion of the stress-strain curve but offset by a specified strain value, usually 0.002 (or 0.2%). This line approximates the point where the material begins to yield. The intersection of this line with the stress-strain curve in the plastic region defines the yield strength (σy), which represents the stress at which permanent deformation begins. The yield strength is commonly expressed in megapascals (MPa).

The magnitude of the yield strength is a critical measure of a material's resistance to plastic deformation. Materials with higher yield strengths can withstand greater stresses before undergoing permanent changes in shape. For example, the yield strength of low-strength aluminium can be as low as 35 MPa, while high-strength steels may have yield strengths exceeding 1400 MPa. The yield strength is, therefore, a key property in determining the suitability of a material for structural and mechanical applications, where the ability to resist permanent deformation is essential for performance, safety, and longevity.

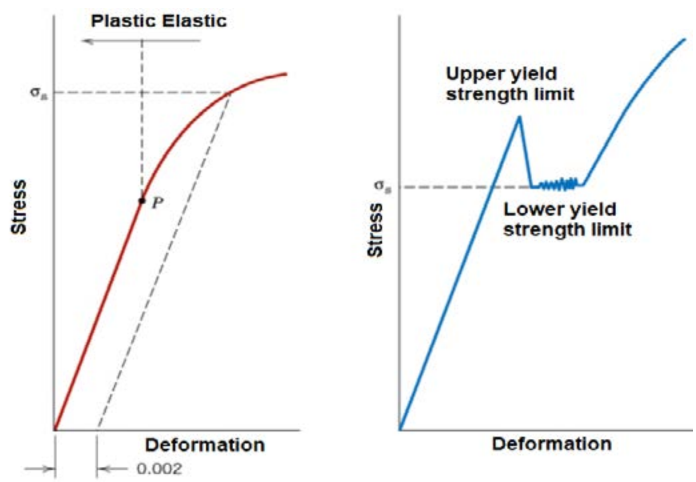


Figure 2.6: (a) Typical stress-strain behaviour for a metal showing elastic and plastic deformations, the proportional limit P, and the yield strength σy, as determined using the 0.002 strain offset method and (b) representative stress-strain behaviour found for some steels demonstrating the yield point phenomenon

Tensile Strength

Following the point of yielding, where the material begins to undergo plastic deformation, the stress required to continue deforming increases until it reaches a peak value. This maximum stress is known as tensile strength. The tensile strength represents the highest point on the engineering stress-strain curve (as shown in **Figure 2.7**) and corresponds to the greatest tensile stress a material can withstand before it begins to fail. After reaching the tensile strength, the stress required to continue deforming the material decreases, leading ultimately to fracture at the fracture point (F).

The tensile strength (TS) is a critical measure of a material's ability to resist failure under tensile (pulling or stretching) stress. It is when a material can no longer maintain its structural integrity and will eventually rupture or break. If stress equal to or greater than the tensile strength is applied to a material, it will ultimately lead to fracture, signifying the material's mechanical failure.

While tensile strength is an important material property, yield strength is typically used in structural application design calculations and material selection. This is because the material has already undergone significant plastic deformation by the time the stress reaches the tensile strength, which often means that the structure has lost much of its original functional integrity. At this point, the material is no longer considered suitable for use, even though it may still withstand further applied stress until fracture occurs.

In practice, materials are designed to resist yielding, and the yield strength ensures that the material can withstand the expected loads without undergoing permanent deformation. The tensile strength, on the other hand, provides insight into the material's ultimate strength. Still, it is less frequently used as a design parameter, as the material would typically be considered unusable once it has reached the point of maximum tensile stress.

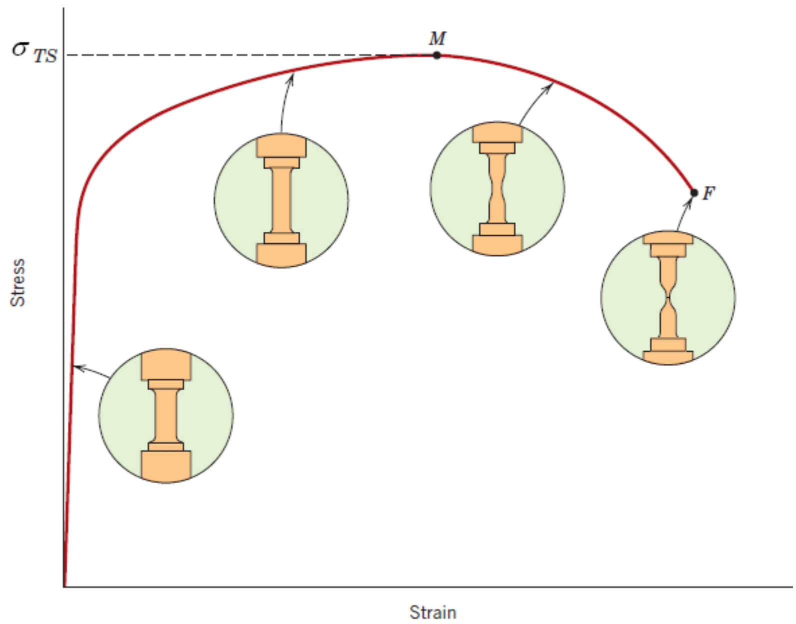


Figure 2.7: Typical engineering stress-strain behaviour to fracture, point F. The tensile strength (TS) is indicated at point M. The circular insets represent the geometry of the deformed specimen at various points along the curve.

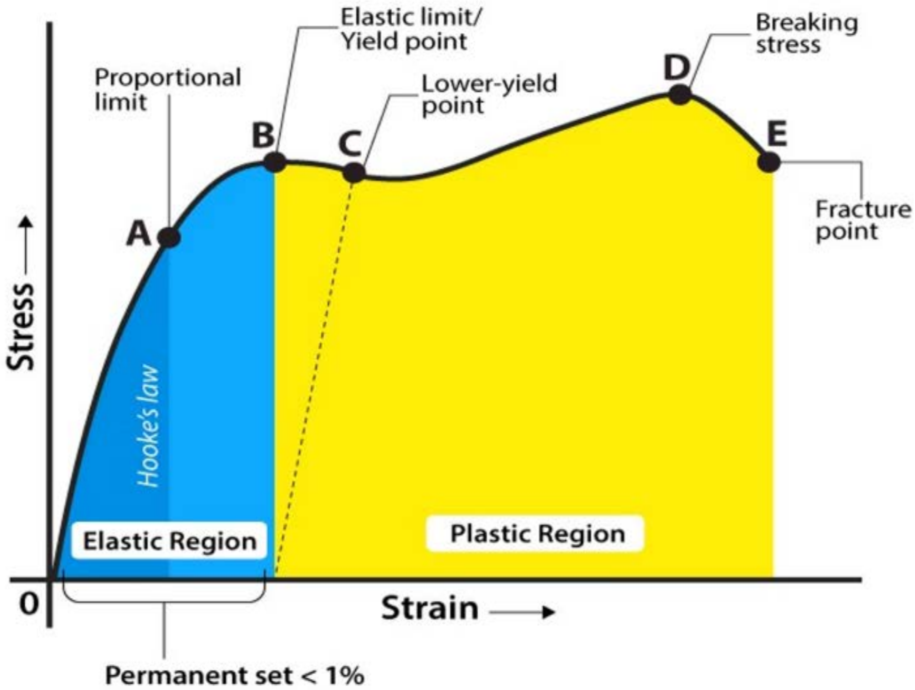


Figure 2.8: Stress-strain behaviour to fracture curve

Activity 2.10 Behaviour of Materials When Subjected to External Forces

1. Search the internet, watch the video, or read from relevant materials/ documents on the behaviour of materials when subjected to external forces using the link and the books provided.
   - https://www.youtube.com/watch?v=X-zSlyM4JSQ
   - https://www.youtube.com/watch?v=aQf6Q8t1FQE&t=59s
   - https://www.youtube.com/watch?v=eW5ICEtjN4w
   - https://themechanicalengineering.com/stress-and-strain/
   - https://core.ac.uk/download/pdf/47233878.pdf
   - https://byjus.com/physics/stress-and-strain/

2. Prepare a poster to be displayed in your class on how a material behaves when subjected to an external force.

Activity 2.11 Group Discussion

1. Join a small group to discuss elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials.
2. Then in your group share your understanding of these concepts with the whole class for feedback.

Activity 2.12 Flashcards Creation

1. Make flashcards that define elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials.
2. Educate someone on the importance of each concept on the flashcards.

Activity 2.13 Laboratory Work

1. Visit a nearby tensile testing laboratory or material testing laboratory for more mechanical tests/experiments of materials.
2. Wear all your safety clothing and follow all safety precautions to prevent accidents. Take a video or picture of yourself during the practical session.
3. Under supervision of a laboratory attendant, perform a typical stress-strain test, including:
    a. Elastic modulus (stiffness),
    b. Yield strength (the stress at which the material begins to deform plastically),
    c. Ultimate tensile strength (the maximum stress the material can withstand),
    d. Fracture strength (the stress at which the material breaks), and
    e. Strain at fracture (how much the material stretches before breaking).
4. Use the resulting data to plot a stress-strain curve.

TENSILE PROPERTIES OF STEEL

Tensile Test

The tensile test is the most common way to study how materials respond to stress and strain, especially metals. In this test, a force pulls the material, which makes it stretch and shrink in diameter, as shown in **Figure 2.9a**. The American Society for Testing and Materials (ASTM) sets the rules for how to prepare the test specimen and how to carry out the test. You can see the typical specimen and the general setup for the tensile test in **Figure 2.9** (b) and (c).

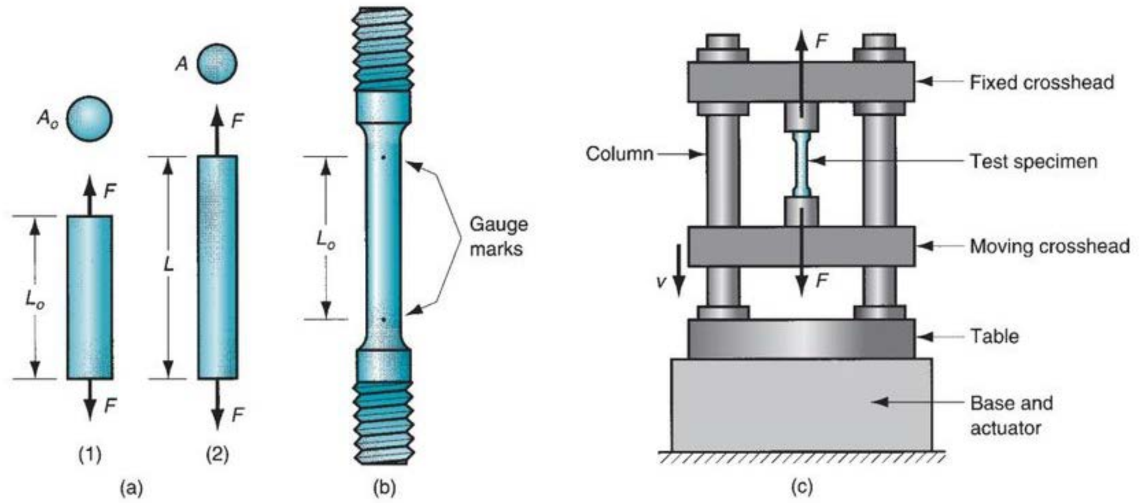


Figure 2.9: Tensile test (a) tensile force applied in (1) and (2) resulting elongation of material; (b) typical test specimen and (c) setup of the tensile test. (Groover, 2021)

The starting test specimen has an original length Lo and area Ao. The length is measured as the distance between the gauge marks, and the area is measured as the (usually round) cross-section of the specimen. During the testing of metal, the specimen stretches, then necks, and finally fractures, as shown in **Figure 2.10**. The load and the change in length of the specimen are recorded as testing proceeds to provide the data for the stress-strain relationship. There are two different types of stress-strain curves: (1) engineering stress-strain and (2) true stress-strain. The first is more important in design, and the second is more important in manufacturing.

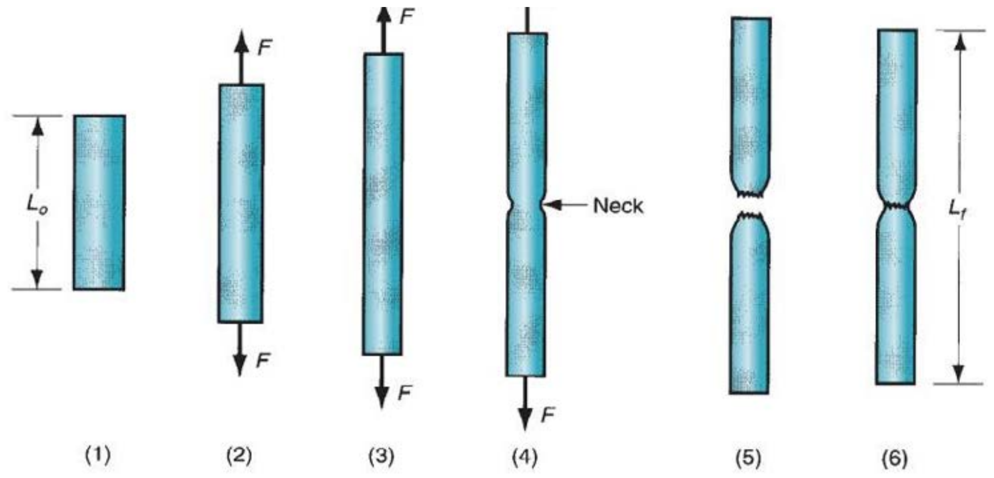


Figure 2.10: Typical progress of a tensile test: (1) beginning of the test, no load; (2) uniform elongation and reduction of the cross-sectional area; (3) continued elongation, maximum load reached; (4) necking begins, load begins to decrease; and (5) fracture. If pieces are put back together as in (6), the final length can be measured.

Tensile Test Experiment Using Tensile Test Machine

Objective: To determine the tensile strength, yield strength, Young's modulus, and percentage elongation of a steel rod using a tensile testing machine.

Materials and equipment needed

- Sample steel rod (sample as shown in **Figure 2.11**)
- Tensile testing machine (**Figure 2.12**)
- Vernier calliper or micrometre
- Extensometer
- Safety gear (gloves, goggles)

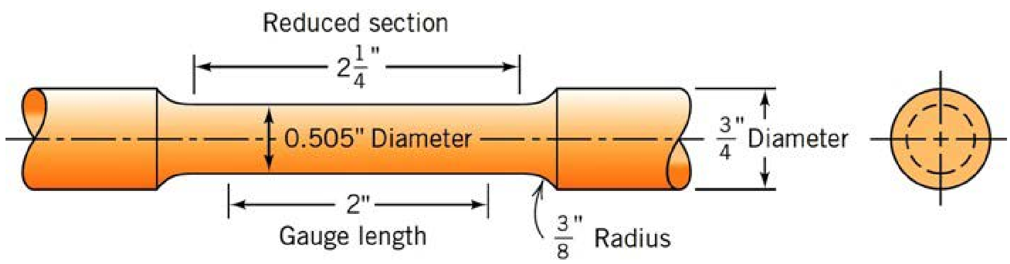


Figure 2.11: A standard tensile test specimen with circular cross-section

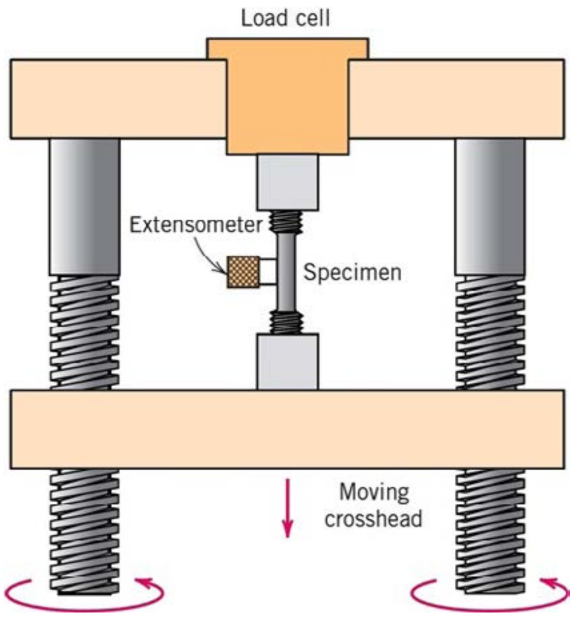


Figure 2.12: Set up of a universal tensile test machine for stress-strain test

Procedure

1. Preparation of Specimen:
   a. Measure the original length (L_0) and diameter (d_0) of the steel rod using a vernier calliper or micrometre.
   b. Mark the gauge length on the steel rod.
2. Setting up the Tensile Testing Machine:
   a. Secure the steel rod in the grips of the tensile testing machine.
   b. Attach the extensometer to the gauge length of the rod to measure the extension.
3. Conducting the Test:
   a. Start the tensile testing machine and gradually apply the tensile load.
   b. Record the applied load (F) and corresponding elongation (ΔL) at regular intervals.
   c. Continue the test until the rod fractures.
4. Recording Data:
   a. Note the maximum load (Fmax) before fracture.
   b. Measure the final length (L_f) and diameter (d_f) at the fractured section.

Data and observations

For the purposes of understanding, typical data recorded during a tensile test experiment will be used in this section.

Initial Measurements:

- Original Length (L_0): 50.8 mm
- Original Diameter (d_0): 12.8 mm

Calculations

- Cross-sectional Area (A): $A = \pi \frac{d_0^2}{4}$
- Stress (σ): $\sigma = \frac{F}{A}$
- Strain (ε): $\varepsilon = \frac{\Delta F}{A}$
- Young's Modulus (E): $E = \frac{\sigma}{\varepsilon}$
- Ultimate Tensile Strength (UTS):
- Percentage Elongation: $\%Elongation = \frac{L_f - L_0}{L_0} \times 100$

Table 2.2: Data from tensile test experiment

Load (N)	Length (m)	Elongation (m)	Strain	Stress (MPa)
0	0.0508	0	0	0
7330	0.050851	5.1E-05	0.001003937	56.95578553
15100	0.050902	0.000102	0.002007874	117.3304722
23100	0.050952	0.000152	0.002992126	179.4923118
30400	0.051003	0.000203	0.003996063	236.2149905
34400	0.051054	0.000254	0.005	267.2959102
38400	0.051308	0.000508	0.01	298.37683
41300	0.051816	0.001016	0.02	320.9104969
44800	0.052832	0.002032	0.04	348.1063017
46200	0.053848	0.003048	0.06	358.9846236
47300	0.054864	0.004064	0.08	367.5318766
47500	0.05588	0.00508	0.1	369.0859226
46100	0.056896	0.006096	0.12	358.2076007
44800	0.057658	0.006858	0.135	348.1063017
42600	0.05842	0.00762	0.15	331.0117958
36400	0.059182	0.008382	0.165	282.8363701
FRACTURE				

Results

- Stress-strain curve as shown in **Figure 2.13**
- Cross-sectional Area (A): 128.68 mm^2
- Young's Modulus (E): 5305.17 MPa
- Yield Strength: 285 MPa
- Ultimate tensile strength: 370 MPa
- Percentage Elongation: 16%

Conclusion

The tensile test showed important mechanical properties of the steel rod, including yield strength, ultimate tensile strength, Young's modulus, and percentage elongation. These properties are essential for engineering tasks and for choosing materials when designing and making products.

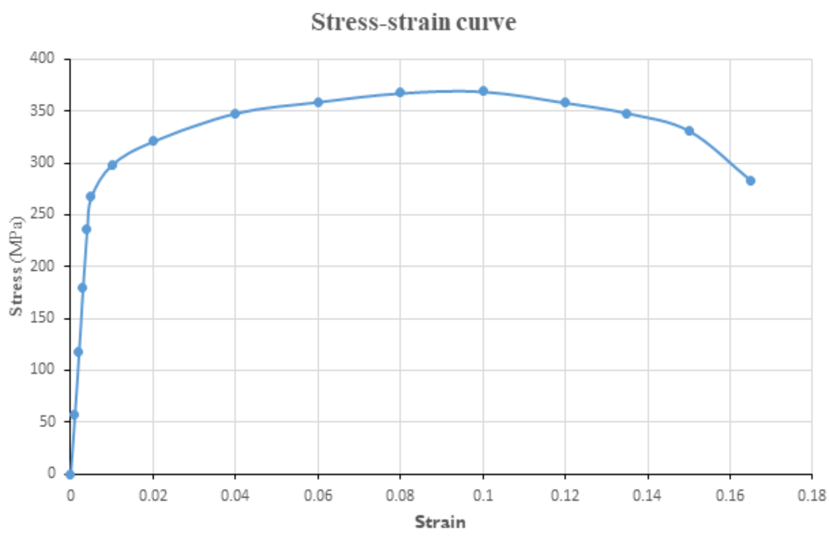


Figure 2.13: Stress-strain curve resulting from tensile test

Activity 2.14 The Tensile Test Experiment Using the Tensile Test Machine

Materials needed:

- Internet access
- Notebook or digital device for note-taking
- Access to a video-sharing platform (e.g., YouTube)

Steps:

1. Introduction to Tensile Testing: Begin by revising the previous learning in this Section (2) on loading, stress, strain, elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials for manufacturing.

2. Video Search: Search for educational videos on tensile testing. Suggested search terms include “tensile test experiment,” “tensile testing machine,” and “tensile strength test.”
   a. https://www.youtube.com/watch?v=FpO2KImasNo
   b. https://www.youtube.com/watch?v=lqR5cp2v1eQ
   c. https://www.youtube.com/watch?v=uWgnBNOy-rA
   d. https://www.youtube.com/watch?v=D8U4G5kcpcM&t=14s
   e. https://www.youtube.com/watch?v=hnkFR5J_Ifw&list=PLfIFNJ1DPG4nwAQAY8aEi2-1JPwCRj9Gq
   f. https://www.youtube.com/watch?v=BFPf0_-kRfM

3. Watching the videos:
   Take detailed notes on the following aspects
   a. The setup and components of the tensile testing machine.
   b. The materials being tested.
   c. The procedure followed during the test.
   d. The data collected and how it is analysed.
   e. Any safety precautions mentioned.

4. Summarise Findings:
   After watching the videos, summarise your findings in a report or presentation. The summary should include:
   a. A description of the tensile testing machine and its components.
   b. A step-by-step outline of the tensile testing procedure.
   c. Key observations and results from the videos.
   a. The importance of tensile testing in manufacturing engineering.

5. Class Discussion:
   a. Share your summaries and insights with your colleagues.
   b. Compare the videos you watched and discuss any procedure variations or results.
   c. Prepare a poster to be displayed in your class on your summaries and observations.

Activity 2.15 Laboratory work

Materials needed:

- Tensile testing machine
- Specimens of different materials [e.g., metal (steel), polymers, composites]
- Safety equipment (gloves, goggles, lab coats)
- Notebook or digital device for recording observations
- Data analysis software (optional)

Steps

1. Pre-Lab Preparation
    a. Introduction: Revise the previous learning in this Section (2) on loading, stress, strain, elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials for manufacturing.

    b. Safety Briefing: Review the safety procedures and ensure you have the necessary safety gear.
2. Understanding the Equipment
    a. Machine Overview: Ask the lab technician to provide you with a detailed explanation of the tensile testing machine, including its components and functions. Request a copy of the tensile testing machine's manual and study it.

    b. Demonstration: Conduct a demonstration of the machine setup and operation. Ensure you have properly mounted a specimen and calibrated the machine.
3. Experiment Setup
    a. Specimen Selection: Choose the different materials available in the laboratory for testing. Discuss the properties of each material and what you expect to observe.

    b. Machine Calibration: With the guidance of the laboratory technician, start the process of calibrating the tensile testing machine based on the specific specimens you want to test.
4. Conducting the Test
    a. Mounting the Specimen: Securely mount your specimens in the machine.

    b. Running the Test: Run the tensile test, ensuring they follow the correct procedure. Observe and record the behaviour of the material during the test.

c. Data Collection: Ensure you accurately record the data generated by the machine, such as the force applied and the elongation of the specimen.

4. Data Analysis

   a. Initial Observations: Make initial observations about the results, noting any visible changes in the specimen.

   b. Detailed Analysis: Use data analysis software or manual calculations to determine key properties such as tensile strength, yield strength, and elongation at break.

   c. Graphing Results: Plot stress-strain curves and interpret the graphs to understand the material behaviour.

4. Discussion and Reporting

   Group Discussion: Share your findings and compare results from different materials.

   Report Writing: Write a detailed lab report that includes:

   a. Introduction and objectives of the experiment
   b. Description of the materials and methods used
   c. Results and data analysis
   d. Discussion of the findings and their implications
   e. Conclusion and any recommendations for further study

Review Questions

1. Explain the difference between stress and strain.
2. If a material is subjected to a bending load, what might be the potential effects on the material
3. How does a strain gauge convert mechanical strain into an electrical signal?
4. Explain how a strain gauge works.
5. Describe a scenario where shear loading would be significant in a manufacturing process.
6. Discuss the importance of understanding stress, strain, and the modulus of elasticity in manufacturing engineering
7. A tensile test specimen has a starting gauge length = 50 mm and a cross-sectional area = 200 mm2. During the test, the specimen yields under a load of 32,000 N (this is the 0.2% offset) at a gauge length of 50.2 mm. The maximum load of 65,000 N is reached at a gauge length of 57.7 mm just before necking begins. Final fracture occurs at a gauge length of 63.5 mm. Determine (a) yield strength, (b) modulus of elasticity, (c) tensile strength, (d) engineering strain at maximum load, and (e) percentage elongation

SECTION

3

DRAW FOR MANUFACTURE

DESIGN AND PROTOTYPING

Design And Drawing For Manufacture

Introduction

This section is essential for understanding the foundational skills and techniques used in manufacturing engineering. Design and drawing are integral parts of the product development process. They serve as the bridge between conceptual ideas and tangible products. Mastering these skills allows engineers to effectively communicate their designs, ensure accuracy in manufacturing, and bring innovative ideas to life.

It builds on basic design principles and introduces advanced techniques essential for manufacturing. It prepares you for more complex product development and prototyping tasks, ensuring you have a solid foundation to tackle real-world engineering challenges. Before diving into this section, you should have a basic understanding of general design principles and familiarity with basic drawing tools and techniques. This background will help them grasp the more advanced concepts and applications discussed here.

By the end of this section, you will be equipped with the knowledge and skills to understand and apply freehand sketching in product design, utilise isometric projections to visualise designs in three dimensions, create accurate first angle orthographic projections for detailed views, implement sectioning, dimensioning, and tolerance in geometric drawings and develop detailed and assembly drawings for comprehensive product design and modelling. This comprehensive approach ensures that you are well-prepared to contribute effectively to the field of manufacturing engineering.

Key Ideas

- Freehand sketches are essential for quickly visualising and communicating design concepts. They help brainstorm and refine ideas before moving to detailed drawings.
- Use freehand sketches to explore different design options and iterate on ideas. They serve as a foundation for creating more detailed and precise technical drawings.
- Isometric projections provide a clear, three-dimensional view of a design. They help in understanding the spatial relationships and proportions of different components. Application of First Angle
- First-angle orthographic projections are used to create accurate, detailed views of each side of a design. They are essential for manufacturing as they provide precise measurements and specifications.
- Sectioning reveals the internal features of a design, which is crucial for understanding complex parts. Dimensioning ensures that all parts are manufactured to the correct size. Tolerances specify the allowable variations in dimensions, ensuring parts fit and function correctly.
- Detailed drawings provide comprehensive information about individual components. Assembly drawings show how different parts fit together, ensuring proper assembly and function of the final product.

IMPORTANCE OF FREEHAND SKETCH IN PRODUCT DESIGN

Freehand sketching is the technique of making a drawing without the use of drawing instruments like rulers or compasses for precision. It serves to represent ideas, capturing the designer's initial thoughts, concepts, and vision while emphasising form, composition, and key details. This technique is a valuable tool during the design creation and exploration stages, as it allows for smooth expression and effectively conveys thoughts. They provide a quick, low-cost way to explore various solutions to design problems so that the best choices can be made.

Investing too much time in creating a detailed layout before exploring your options through sketches can be costly. The degree of precision needed in each sketch depends on its use. Quick sketches to supplement verbal descriptions may be rough and incomplete. Sketches can be used to convey important and precise information when they are drawn and annotated. Freehand sketching requires only a pencil, paper, and an eraser. Mastering the techniques in this chapter to show quick single-view, oblique, perspective, and isometric drawings using good freehand line techniques will give you a valuable tool for communicating your ideas. The term freehand sketch does not mean a sloppy drawing.

As shown in **Figure 3.1**, a freehand sketch shows attention to proportion, clarity, and correct line widths. Sketches are also used to clarify information about changes in design or to provide information on repairing existing equipment.

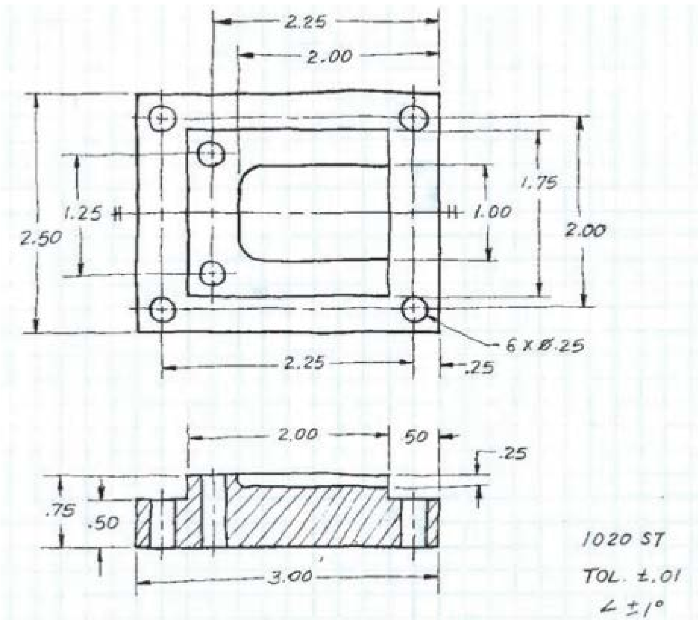


Figure 3.1: Sketch on Graph Paper (Technique of Lines)

The primary difference between a drawing and a freehand sketch lies in the nature and technique of the lines used. A good freehand line does not need to be perfectly straight or consistently uniform. Instead, it should demonstrate freedom and variety.

In contrast, lines created using CAD software or drawing instruments must be precise. However, it is still essential to differentiate between line patterns to ensure your drawing is legible. **Figure 3.2** illustrates examples of high-quality freehand lines, while **Figure 3.3** presents examples of both good and poor techniques.

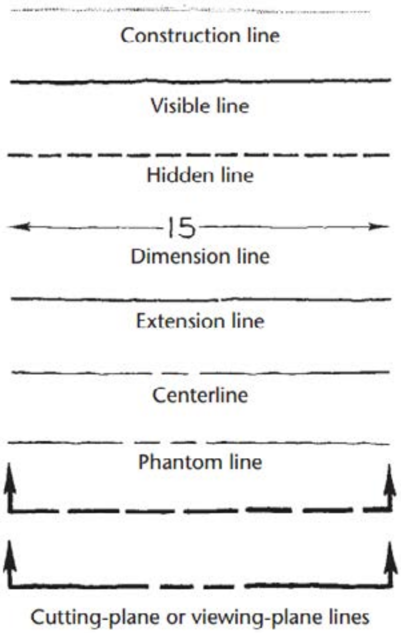


Figure 3.2: Freehand Alphabet of Lines (Full Size)

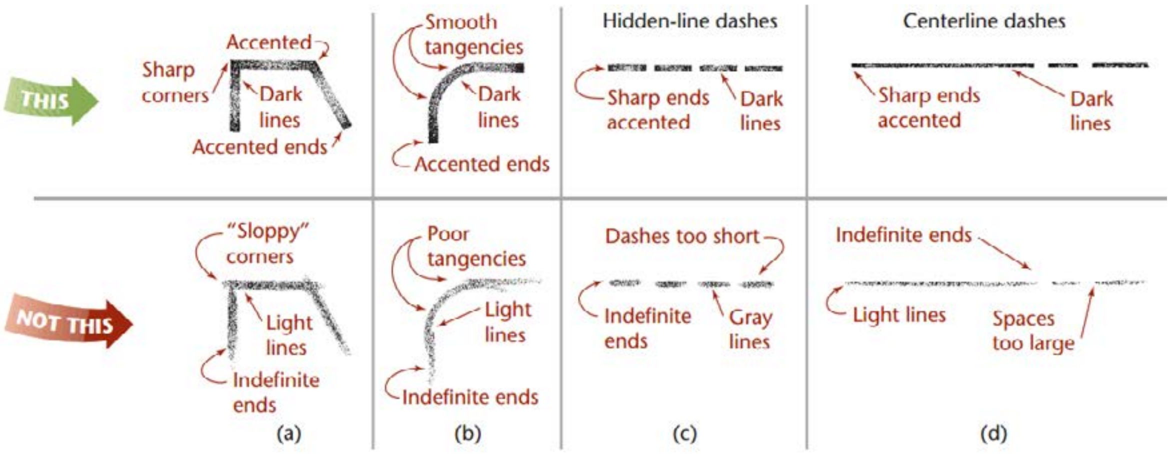


Figure 3.3: Technique of Lines (Enlarged)

Line weights

1. Make dimensions, extensions, and centrelines thin, sharp, and black.
2. Make hidden lines medium and black.
3. Make visible and cutting-plane lines thick and black.
4. Make construction lines thick and light.

Sketching Materials

The following materials are required for making good sketches:

1. A fairly soft pencil, particularly HB or H
2. A soft eraser
3. A suitable paper (e.g. A2, A3, A4, etc.)
4. A graph paper

When sketching, use a pencil with a conical point. Choose a good quality eraser that will not damage the paper. Depending on your project, you may use different types of paper for sketching. Beginners often use rectangular or square grid paper and isometric ruled paper. This helps them draw straight lines and maintain proper scale. You can start sketching on plain paper if you do not have specific paper available.

Note:
Even in freehand drawings, thick lines should be twice the width of thin lines. While the exact thicknesses don't need to be precise, there should be a clear distinction between thick and thin lines. Visible lines and cutting-plane lines are the two types of thick line patterns, and other lines should be noticeably thinner in comparison. To achieve thick and thin lines while drawing freehand, it can be helpful to keep two pencils on hand: one that is razor-sharp for creating thin lines and another that is dulled to produce thicker lines. As the sharp pencil becomes dull, switch it out with the dulled one and sharpen the other, ensuring you always have one sharp and one dull point ready for use. **Figure 3.4** *shows examples of line weight types.*

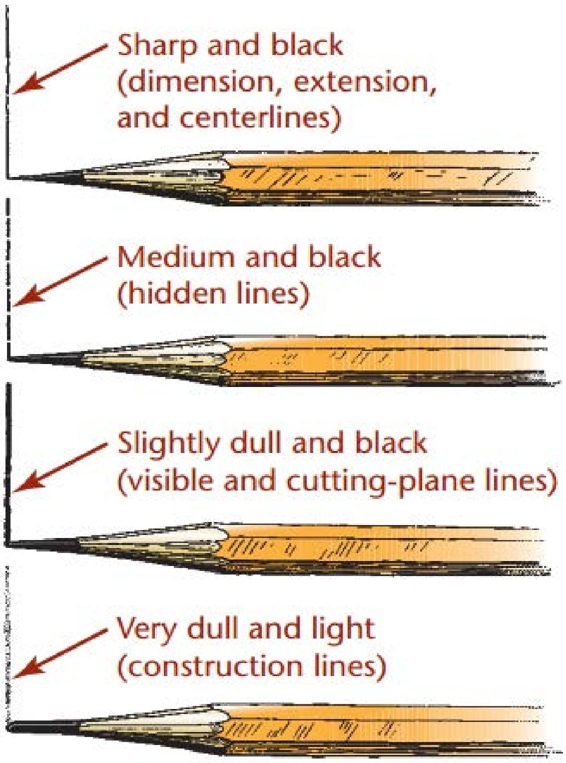


Figure 3.4: Examples of line weight types

Sketching Straight Lines

Most of the lines in an average sketch are straight lines. Your straight lines will naturally improve with practice, but these basics may help you improve quickly.

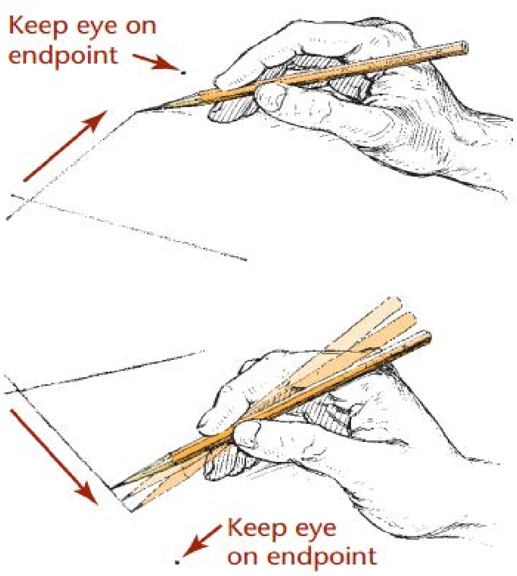
1. Hold your pencil naturally, about 1″ back from the point, and approximately at a right angle to the line to be drawn.
2. Draw horizontal lines from left to right with a free and easy wrist and arm movement.
3. Draw vertical lines downward with a wrist and arm movement.
4. Draw curved lines using finger and wrist movements.

Blocking in a Freehand Drawing

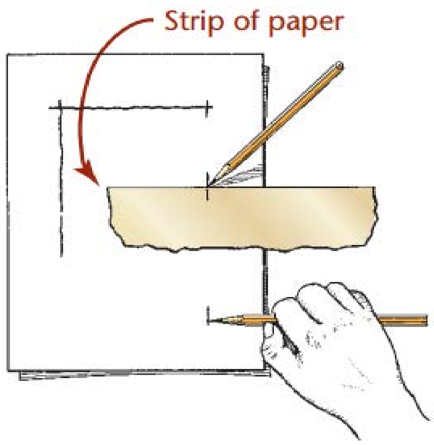
Over the years, freehand sketchers have developed techniques to draw faster and more accurately. Some useful methods include finding midpoints and quickly drawing straight vertical and horizontal lines. These techniques can help when you have a great idea or need to sketch quickly during a meeting or at a job site, especially when you do not have access to a CAD system or a ruler.

Note

1. Drawing Long Freehand Lines: To draw long, freehand lines, start by making light marks at each end. Then, gently move your pencil between them while focusing on the end mark. Once you are happy with the accuracy of your lines, press harder to create a dark line.



2. Blocking in a Border Freehand: Hold your hand and pencil steady. Slide your fingertips along the edge of the paper to create an even border.

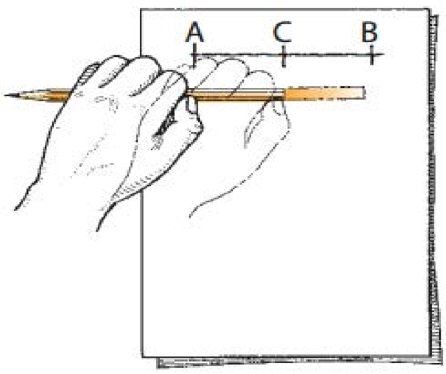


3. If your line looks like this, you might be holding your pencil too tightly or trying too hard to draw like a machine.

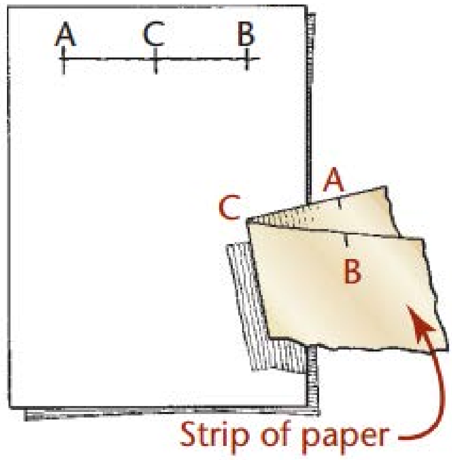
4. Slight wiggles are OK if the line continues on a straight path.

5. Occasional very slight gaps are fine and make it easier to draw straight.

6. Finding a Midpoint Freehand: Use your thumb to measure (guess) half the distance on your pencil. Test that distance on the other half. Keep adjusting until you find the centre, then mark it.



7. Folding a Paper to Find a Midpoint: To find the centre of a strip of paper, first mark the total distance along one edge. Then, fold the paper in half to create a crease that shows the centre. You can keep folding one half to find quarter points and smaller divisions.



The shape of an object has straight and curved surfaces, shown by straight and curved lines. These lines can be horizontal, vertical, or slanted. Move your wrist and forearm from left to right to draw horizontal lines. (These drawing instructions are for right-handed people, if you are left-handed the reverse applies to your drawing, thus from right to left for horizontal lines.) For vertical lines, use your fingers to draw downwards. Slanted lines that are almost horizontal go from left to right, while slanted lines that are nearly vertical are drawn downwards. The first step in drawing any straight line is to mark its endpoints. Then, draw a light line with one or more strokes connecting the endpoints. **Figure 3.5** illustrates how to sketch these lines to keep them straight.

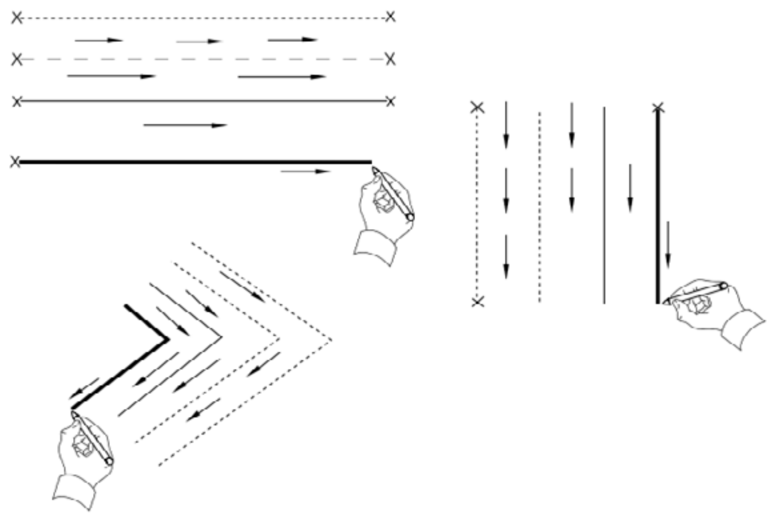


Figure 3.5: Sketching different kinds of lines

Sketching Circles

When drawing circles, small ones are usually easy to sketch in one or two strokes, while large ones require several strokes. To make drawing circles easier, a systematic approach is needed. The best way to sketch a circle is to find several points that the curve will go through. Remember, all points on a circle's edge are the same distance from its centre. Here are some common methods for sketching circles:

Methods for sketching small circles

Method I

a. Sketch horizontal and vertical centre lines and mark the centre of a circle.
b. Sketch a square with its side equal to a circle's diameter.
c. Sketch the diagonals of a square.
d. Along these diagonals, plot the points, one on each side of the centre, at a distance of a circle radius.
e. A smooth curve passing through these points results in the required circle. See **Figure 3.6**.

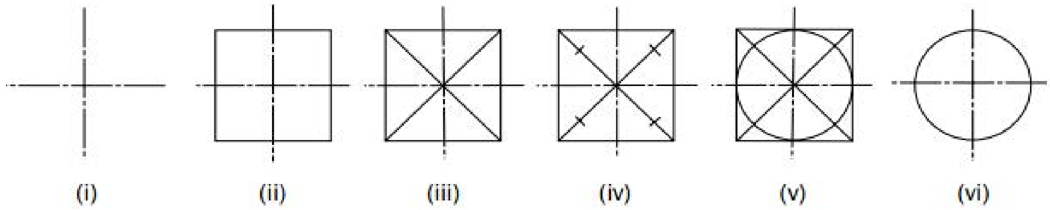


Figure 3.6: Sketching small circles (Method I)

Method II

a. Sketch radial lines, preferably eight in number, with the help of four straight lines.
b. Along each radial line, the circle's radius is estimated and marked off.
c. A smooth curve passing through these points results in the required circle. See **Figure 3.7**.

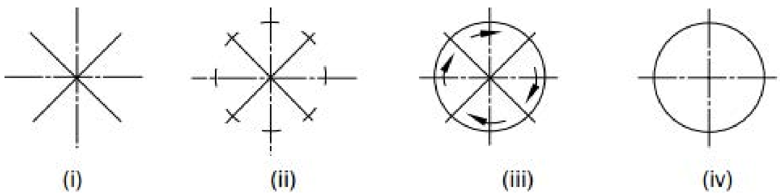


Figure 3.7: Sketching small circles (Method II)

Methods for sketching large circles

Method I (The Freehand Compasses)

It is an efficient and quick method of sketching a circle using the hand as a pair of compasses.

a. the little finger is used as a point at the centre, and the pencil is held stationary at the required radius from the centre.
b. Rotate the paper under the hand and pencil.
c. Complete the circle as shown in **Figure 3.8**.

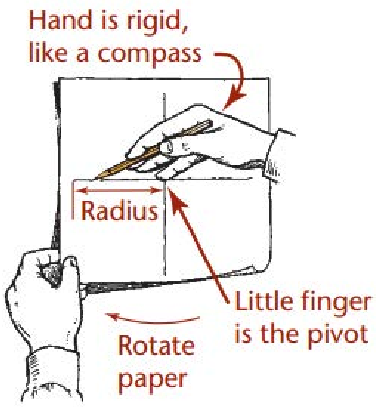


Figure 3.8: The freehand compass method

Method II (Paper Method)

It is a quick method of sketching a circle using a paper as a pair of compasses.

a. Mark the estimated radius on the edge of a card or a scrap of paper and set off as many points as desired from the centre.
b. Sketch the final circle through these points, as shown in **Figure 3.9**.

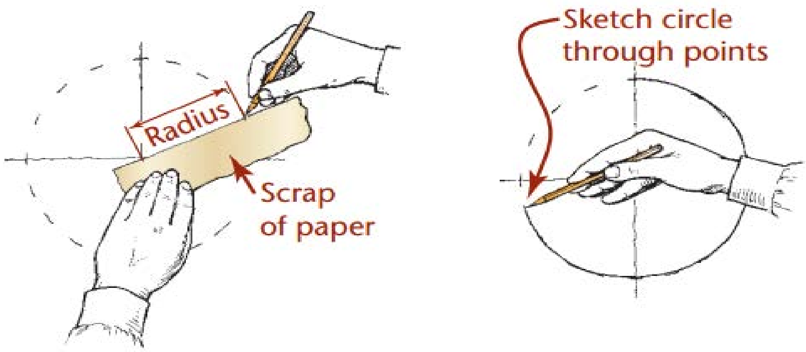


Figure 3.9: The paper method

Sketching an Ellipse

Following are the steps for sketching an ellipse in the orthographic views:

- Sketch horizontal and vertical centre lines and mark them by estimation, as well as the semi-major OA (= OB) and semi-minor OC (= OD) axes.
- Complete the rectangle with major and minor axes as sides.
- Sketch the axes tangentially at the mid-points of the sides, resulting in the required ellipse, as shown in **Figure 3.10.**

Additional points on the curve may be obtained for more accurate work, as shown in **Figures 3.11** and **3.12**.

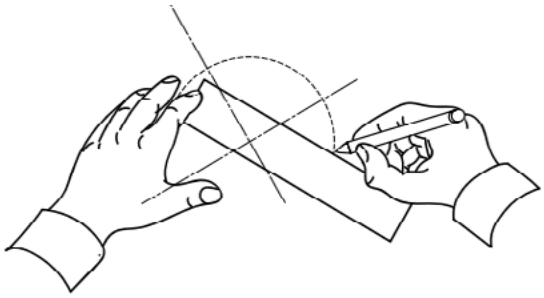


Figure 3.10: Sketching large circles (Method II)

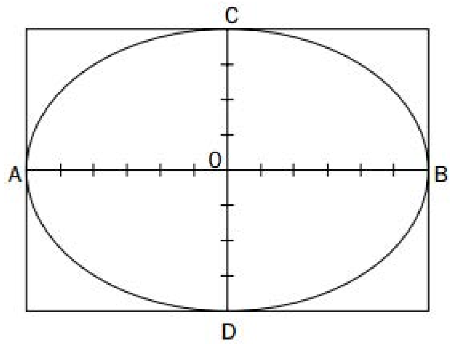


Figure 3.11: Sketching an ellipse

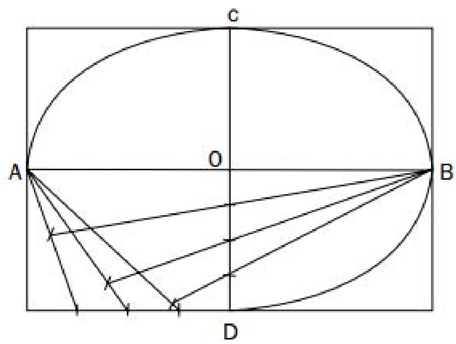


Figure 3.12: Method of obtaining additional points on the ellipse

Maintaining Proportions

Sketches are usually not made to a specific scale, though using a scale can be useful sometimes. The size of the sketch depends on how complex it is and the size of the paper you have. The most important rule in freehand sketching is to keep the sketch in proportion. This means accurately showing the size and position of each part in the whole sketch. No matter how good the technique or details, if the proportions are wrong, the sketch won't look right.

To maintain proportions, first determine the width and height in relation to one another and lightly outline them. You can mark a unit on a strip of paper or use your pencil to measure how many units wide and high the object is (as in **Figure 3.13**). Using grid paper can help you keep proportions by giving you a scale to work with (by counting squares). As you outline the medium-sized areas and add smaller details later, compare each new distance with the measurements you have already established.

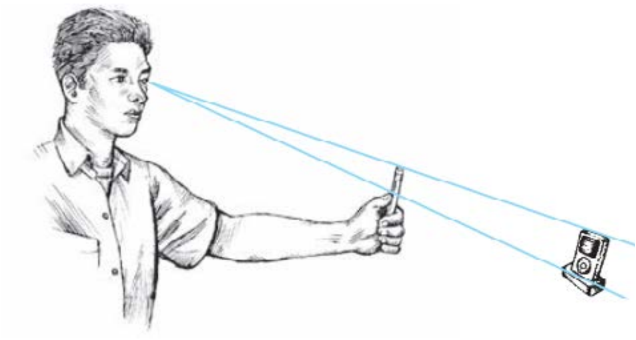
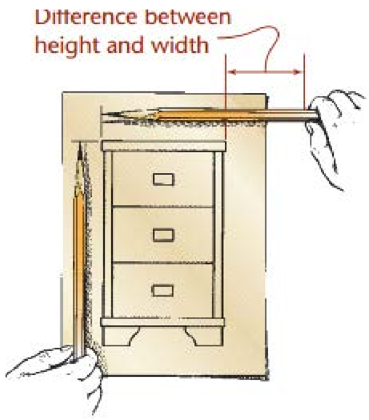


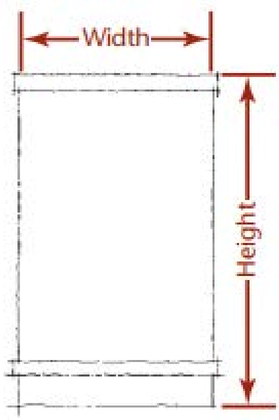
Figure 3.13: Estimating Dimensions

Maintaining Proportions in a Freehand Sketch

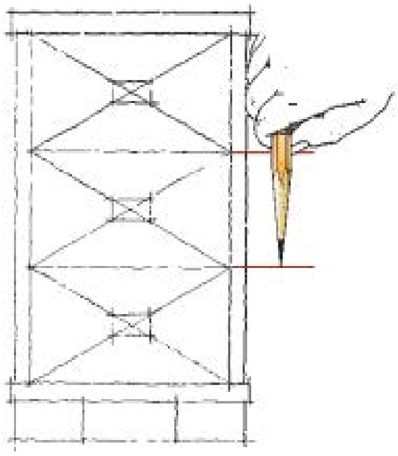
1. If you are working from a given picture, such as this utility cabinet, first establish the relative width compared with the height. One way is to use the pencil as a measuring stick. In this case, the height is about 1-3/4 times the width.



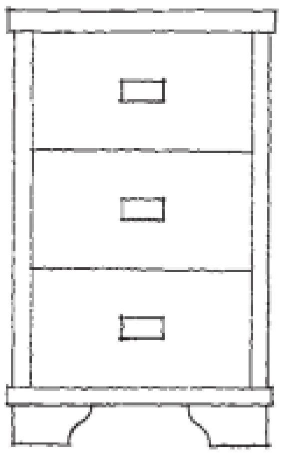
2. Sketch the enclosing rectangle in the correct proportion. This sketch is to be slightly larger than the given picture.



3. Divide the available drawer space into three parts with the pencil by trial. Hold your pencil about where you think one-third will be and then try that measurement. If it is too short or long, adjust the measurement and try again. Sketch light diagonals to locate the centres of the drawers and block in drawer handles. Sketch all remaining details.



4. Darken all final lines, making them clean, thick, and black.



Types of Freehand Sketches

The freehand sketches may be classified as follows:

1. Orthographic sketches
2. Isometric sketches

Product Design

Product design is the process of creating new products or improving existing ones. This involves using creativity, technical skills, and strategic thinking. Product design covers the entire lifecycle of a product, starting with ideas and development, moving through production, and ending with market introduction. It aims to meet user needs, solve problems, and create products that are functional, attractive, and marketable.

Freehand sketches play a crucial role in product design. They help turn abstract ideas into real items. Sketches allow designers to quickly share their concepts, making it easier to go from initial ideas to detailed designs. Designers can explore many options, refine their ideas, and keep a clear visual record of their thoughts with sketches. Even with the rise of digital tools, sketching remains important in design education and practice because it supports creativity and problem-solving.

Figures **3.14** to **3.16** display freehand sketches of bench plane, cameras, and staplers.

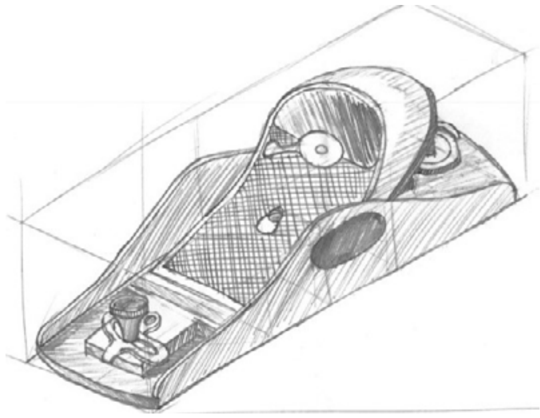


Figure 3.14: Bench plane

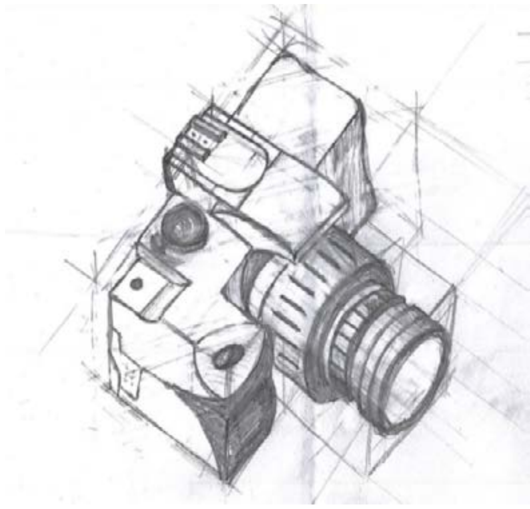


Figure 3.15: Camera

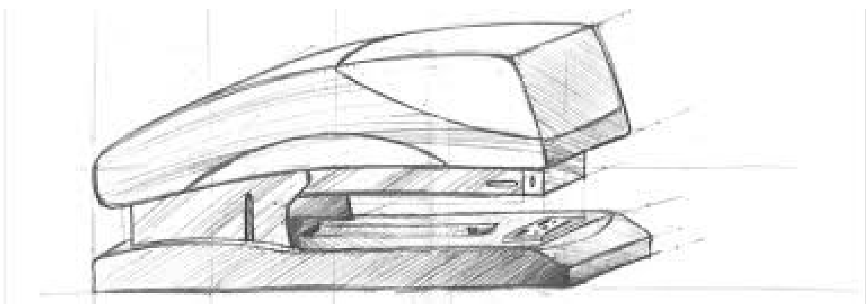


Figure 3.16: Stapler

Relevance of Freehand Sketch in Product Design

Freehand sketching is vital in product design because it helps develop and adjust ideas quickly. It allows designers to share complex concepts visually. This simple method is essential for brainstorming sessions, team discussions, and the early stages of design. Additionally, sketches create a visual base that can be improved with digital tools and prototyping. The importance of freehand sketches in product design can be summarised as follows:

Visual Communication

Freehand sketches help designers share their ideas, concepts, and details quickly and effectively. This visual way of communicating can be more straightforward and immediate than using words. Freehand sketching is still an essential tool in product design, serving as a main way to express ideas visually. Even with more digital tools available, sketches allow for quick expression and understanding of design concepts, promoting teamwork and creativity. This is especially helpful in the early design stages when sketches help present initial ideas and allow for fast changes.

The following sections will look at how freehand sketches play a role in visual communication in product design, using insights from different studies.

1. **Importance in Conceptual Design**

   Freehand sketches are important during the early stages of design. They help designers share and discuss their initial ideas easily. In Brainwriting sessions, sketches help team members understand and evaluate possible solutions, leading to better discussions and quicker proposal development. Despite the popularity of computer design tools, freehand sketching remains a key method for visualising ideas in design studios.

2. **Communication and Cognitive Processing**

   Sketches are important for communication among different stakeholders. Designers focus on representing visuals, while managers emphasise diagrams. This difference can impact how much effort people need to understand the information, showing the need for clear sketch communication. Freehand sketches help connect abstract ideas with concrete solutions, making it easier to understand design concepts.

3. **Transition to Digital Models**

   Sketches are an important part of creating 3D models. They help develop new products and improve existing ones. Sketches allow designers to change surfaces and create specific design effects. This shows their usefulness in the design's creative and technical parts.

4. **Educational and Creative Value**

   Sketching is a vital skill for engineers and manufacturers. It helps them communicate creative ideas and create clear diagrams. This straightforward way of expressing thoughts is key to developing and refining concepts. Because of this, sketching is important in engineering education.

Flexibility and Speed

Sketching by hand is quicker and more flexible than using digital tools. It allows for fast idea generation and exploration without being limited by software. Freehand sketches are crucial in product design because they let designers quickly create and communicate their ideas. These sketches connect the initial concept to the final product, enabling quick revisions. Combining freehand sketches with advanced computer tools increases their value in product design, making them essential in today's design process.

Here are the key ways that flexibility and speed in freehand sketches help in product design:

1. **Flexibility in Design**

   Freehand sketches let designers share their ideas freely, encouraging creativity and innovation. Tools like Sketch Edit help with editing sketches at a detailed level, allowing for accurate changes and flexibility during design adjustments.

2. **Speed in Development**

   Sketch-based modelling helps turn ideas into 3D models quickly. This speeds up prototyping and shortens the time it takes to bring products to market. Tools like Deep3DSketch+ use deep learning to transform sketches into detailed 3D models, making the design process much faster.

3. **Enhanced Communication**

   Freehand sketches are a simple way to share ideas between customers and manufacturers. They help connect the creative process with production. Using sketch-based systems feels natural, like using paper and pencil. This makes them easy to use for designers.

4. **Iterative Design and Analysis**

   Sketch-based interfaces help designers create and change 3D objects more easily. These tools allow designers to quickly modify their designs and analyse them for strength using finite element analysis. This process improves the structural integrity of the designs.

5. **Foundation for Development**

   Initial sketches are the starting point for further development. They provide a visual reference that can be improved in the next stages. Combining freehand sketches with Computer-Aided Design (CAD) software can greatly enhance product development. This combination blends the creative aspect of sketching with the accuracy of CAD. It allows for a smooth transition from early design ideas to detailed models, making the design process more efficient and creative. The following sections will discuss different ways and technologies that support this combination.

6. **Creativity and Spontaneity**

   Freehand sketching encourages creativity and quick thinking. It allows designers to try out different shapes and ideas without being limited by digital tools. Combining freehand sketches with computer-aided design (CAD) software can improve product development. This mix combines the easy, creative aspects of sketching and the precise, efficient features of digital tools. Using both methods can make the design process smoother and more innovative.

7. **Engagement and Collaboration**
   Sketching helps a design team and stakeholders work better together. It provides a clear and straightforward way to show ideas.

Ideation and Solutions to Design Problems Using Freehand Sketch

Freehand sketching plays a critical role in the ideation stage of product development. This includes:

1. **Brainstorming:** Sketching is an essential tool during brainstorming sessions, helping to quickly generate and capture a wide range of ideas and potential solutions.
2. **Problem-Solving:** By visually exploring different design possibilities, sketches help identify and solve design problems, often revealing issues and opportunities that might not be apparent through verbal or written descriptions.
3. **Concept Development:** Freehand sketches are instrumental in developing initial design concepts, allowing for exploring different forms, functions, and aesthetics.
4. **Iteration:** The ease and speed of sketching support rapid iteration, enabling designers to refine ideas through multiple versions and improvements.
5. **Visualisation:** Sketching helps visualise complex ideas and concepts, making it easier to understand and evaluate potential solutions to design problems.

Applications of Freehand Sketching in Product Design

Freehand sketches can be used as initial sketches that explore a concept or various design directions, more detailed sketches used for manufacturing a product, or refined sketches used for presentations to convey the design idea. Freehand sketches find its applications in the following areas:

1. **Design Exploration:** Freehand sketching explores various design options, enabling designers to experiment with different shapes, configurations, and styles without committing to a specific direction too early.
2. **Detailing and Refinement:** Freehand sketches can add details and refine concepts, focusing on specific aspects of the design, such as ergonomics, usability, and functionality.
3. **Prototyping and Mock-ups**: Freehand sketches can be transformed into prototypes and mock-ups, providing a tangible representation of the product for testing and evaluation.

4. **Client Communication:** Freehand sketches are a tool for communicating ideas to clients and stakeholders, making conveying design intentions and receiving feedback easier.
5. **Documentation and Reference:** Freehand sketches provide a visual documentation of the design process, serving as a reference for future development and ensuring that the evolution of ideas is well-recorded and understood.

Activity 3.1 The Relevance of Freehand Sketching in Product Design

Materials needed

- Flashcards (blank and pre-filled)
- Pencils and erasers
- Markers or coloured pens
- A3 drawing paper
- A set of objects or product ideas to base sketches on (e.g., a chair, bottle, phone case, kitchen gadget, etc.)

Steps

1. *Introduction*
   a. Start by reading the section of your learner manual that explains freehand sketching in product design.
   b. Look for examples in your manual or find images online of initial sketches and final product designs to see how sketches evolve into finished products.
2. *Creating Flashcards*
   a. Use blank flashcards to write down various reasons why freehand sketching is important in product design.
   b. Examples include enhancing creativity, allowing quick visualisation of ideas, facilitating communication of concepts and helping identify potential design flaws early
3. *Sketching Exercise*
   a. Choose a simple product idea you would like to design (e.g., a new type of chair, a kitchen gadget, or a smartphone accessory).
   b. Using an A3 drawing paper, quickly sketch your product idea. Focus on getting your ideas on paper rather than creating detailed drawings.
4. *Review and Reflect*
   a. Look at your sketch and think about how the initial sketch helps you understand and communicate your design concept.
   b. Consider any improvements or changes you might make based on your sketch.

5. *Flashcard Application*
   a. Match the points on your flashcards with aspects of your sketching exercise. For example, identify how freehand sketching enhanced your creativity or helped you spot a potential design flaw.
   b. Write down your insights.
6. *Conclusion*
   a. Summarise what you have learned about the importance of freehand sketching in product design.
   b. Reflect on how this activity has helped you understand the design process better.

Activity 3.2 Role of Freehand Sketching in Product Design

Introduction

Organise yourselves into groups of no more than five. In your groups, discuss the importance of freehand sketching in product design. Highlight how freehand sketches help designers quickly capture ideas, communicate with teams, and experiment with different design options.

Key Concepts	Justification/properties
Speed & Efficiency	How does freehand sketching speed up the design process?
Flexibility	Why is sketching useful in presenting multiple design options?
Creativity	How does sketching help refine a design idea?
Communication Tool	“How can freehand sketching communicate ideas quickly in a design team?

Key areas to generate ideas/discuss

1. Speed & Efficiency: Sketching allows designers to quickly translate ideas into visual form without relying on complex CAD software.
2. Flexibility: Freehand sketches let designers explore multiple concepts without getting bogged down in details.
3. Communication Tool: Sketches help explain ideas clearly to others, including clients or team members, during brainstorming or design reviews.
4. Creativity: Sketching helps foster creativity by quickly iterating designs and experimenting with different features and functions.

Activity 3.3 Flash Card on Freehand Sketching in Product Design

1. Use flashcards to explain the relevance of freehand sketching in product design

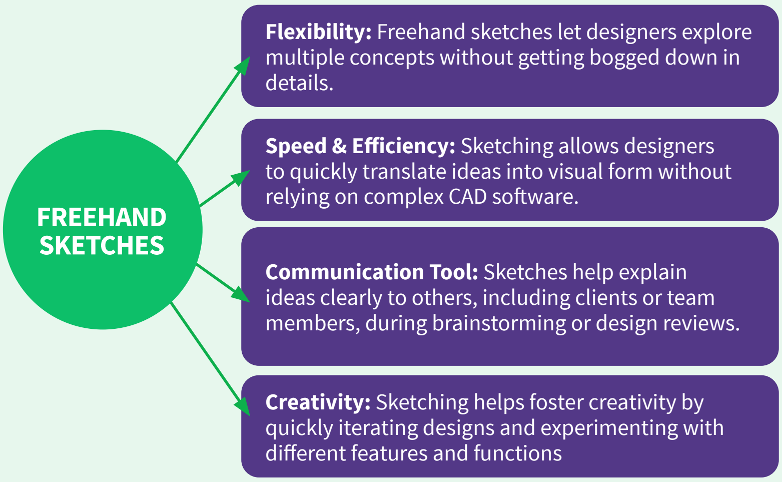


Figure 3.17: Sample Flash card

1. Now, make a flash card that explains the key features of freehand sketching in a product design. Consider the following features:
   a. Creativity
   b. Communication tools
   c. Flexibility
   d. Deed and efficiency

Activity 3.4 Watching Video on Freehand Sketching in Product Design

Materials needed

- Access to a device with the internet (computer, tablet, or smartphone)
- Access to video streaming platforms (e.g., YouTube, educational websites)
- A3 or A4 drawing paper
- Pencils and erasers
- Markers or coloured pens
- Design journal (optional)

Steps

1. Finding Videos
   a. Search for videos on freehand sketching in product design. Use keywords like “freehand sketching for product design,” “how to sketch products freehand,” or “product design sketching tutorial.”

b. Watch the videos on freehand sketching using the links provided below.

- https://www.youtube.com/playlist?list=PLbgj-zgqid54GYCrOXtzHYzOF3to1A2M_
- https://www.youtube.com/watch?v=Ess0dmJB2lo
- https://www.youtube.com/playlist?list=PL1xA-pZWMKpOMt3ew5vcn3keBxlqHKtlg
- https://www.youtube.com/watch?v=wF3fBFUCbPQ

2. Watching and Taking Notes
   a. Watch the videos, pay close attention to the techniques and tips shared by the instructor.
   b. Take notes on key points, such as line types, shading techniques, and tips for maintaining proportions and perspective.
   c. Repeat this step for the remaining videos, expanding your notes with additional tips and techniques.
3. Hands-on Sketching Task
   a. You should choose a simple everyday object or product (e.g., coffee mug, desk lamp, pen, chair, etc.). You can either be assigned a product or choose one yourself from a list provided.
   b. Sketch the chosen object from different perspectives (e.g., top view, side view, isometric view). Focus on quick sketches that capture the main features and proportions of the object, without worrying about perfection. Use light lines initially to outline the basic shape and refine as you go.

Note

Important Aspects to Focus on:

- Shape & Proportions: How the object looks from different angles.
- Functionality: How the object will be used, any ergonomic considerations.
- Design Variations: Start with one version, but also sketch alternative shapes, forms, or features (for example, a chair with different leg designs or armrests).

4. After the initial sketches, add basic details (e.g., buttons, texture, or structural elements).

   a. Consider the material and texture in their sketches by using shading and different line weights.
   b. Annotate sketches with brief labels or notes explaining design features.
5. Review and Reflect
   a. Look at your sketch and consider how the techniques from the videos helped you in visualising and improving your design.
   b. Write a brief reflection in your design journal about what you learned from the videos and how it influenced your sketching process.
6. Application and Improvement
   a. Watch the videos again if needed, focusing on any specific techniques you found challenging.
   b. Apply these techniques to a new sketch or refine your initial sketch further.
   c. Document your final sketches and notes in your design journal.
7. Conclusion
   a. Summarise what you have learned about freehand sketching in product design.
   b. Reflect on how watching videos and practising sketching have enhanced your understanding and skills.

IMPORTANCE OF ISOMETRIC DRAWING IN PRODUCT DESIGN

Isometric drawing plays a vital role in product design because it can represent three-dimensional (3D) objects on a two-dimensional plane, providing a clear and comprehensive visualisation essential for various design and manufacturing stages. This type of drawing is particularly valuable in the design process as it allows engineers to convey intricate details and spatial relationships without the distortion that can occur in other types of projections. The precision and clarity of isometric drawings facilitate effective communication of design intent, which is essential for ensuring that all stakeholders, including designers, manufacturers, and clients, have a unified understanding of the product. Moreover, isometric drawings are instrumental in reverse engineering, where accurate geometric and manufacturing information must be documented and utilised efficiently.

Isometric Drawing

Isometric drawing is a method of visually representing three-dimensional objects in two dimensions, where the three coordinate axes appear equally foreshortened, and the angles between any two of them are 120 degrees. This technique is widely used in various fields, such as architecture, engineering, and graphic design because it provides a clear and comprehensive view of complex structures. Isometric drawings are not just limited to geometric shapes but also include topological relations. They are crucial in Computer Aided Design (CAD) for tasks such as topology integrity authentication of piping systems through digital watermarking.

Isometric Projection

Isometric projection is a pictorial projection in which all three dimensions of an object are shown in one view. Unlike orthographic projection, isometric projection is simple to understand. It is the view obtained on a plane when the object is so placed that all three axes make equal angles with the plane of projection. This projection is more pleasing to the eyes than the oblique or perspective projection, as it is easier to draw because all edges are foreshortened equally (one scale). It aids in understanding an object's overall shape, size and appearance before production.

Positioning of an Object During Isometric Projection

1. Place a cube on the horizontal plane.
2. Rotate the cube 45°.
3. Tilt the cube either forward or backwards (35º 16') until the three meeting edges at the nearer corner are equally inclined to the plane of projection. See **Figure 3.18**.

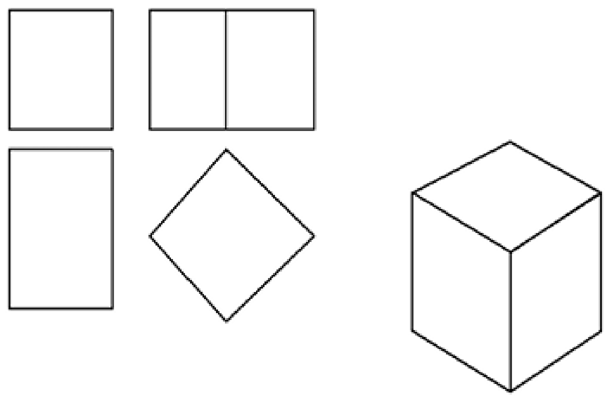


Figure 3.18: Positioning of an object during isometric projection

Isometric Scale

To obtain a True Isometric Projection, it would be required to apply the isometric scale:

1. Draw equal scaled vertical and horizontal lines.
2. Draw two lines inclined to a horizontal base line at 45° and 30° respectively.
3. On the vertical scale, enter the actual length of line (D).

4. Project it onto the 45° line (D).
5. Drop a vertical line and read the true isometric length on the 30° line.
6. It is based on an isometric scale (√ (2⁄3) = 0.8165).

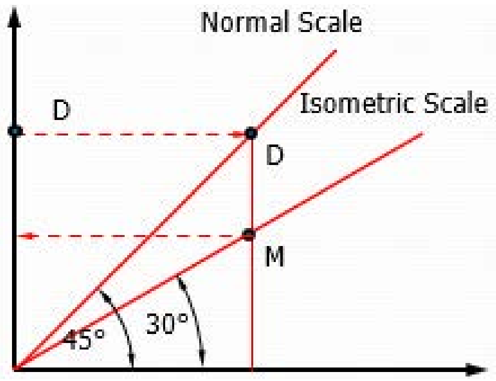


Figure 3.19: Isometric scale

If the foreshortening of the isometric lines in an **isometric projection** is disregarded and, instead, the true lengths are marked, the view obtained will be exactly of the same shape but larger in proportion (about 22.5%) than that obtained using the isometric scale, as shown in **Figure 3.20**. To avoid this tedious construction of isometric projection, the true lengths are laid out along the isometric axes, the view obtained is called an isometric drawing. It implies that the construction of an **isometric drawing** is much simpler compared with the isometric projection.

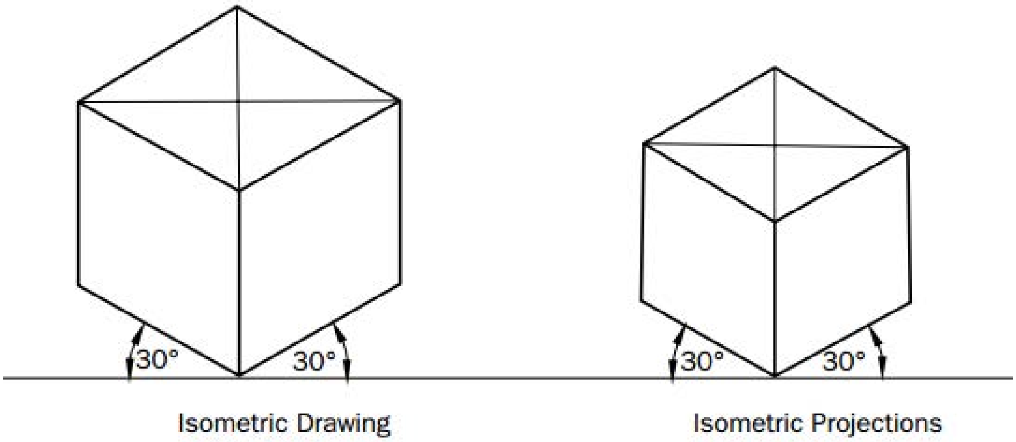


Figure 3.20: Isometric drawing is 22.5% larger than isometric projection

Isometric Dimensioning

The general rules for dimensioning will be discussed in detail in the subsequent subsection. All those rules hold good here too and in addition to those, the following rules must be taken care of:

1. Extension lines, dimension lines and numerals for the isometric projection must be placed in the isometric planes of the faces as shown in **Figure 3.21**.
2. If possible, apply the dimensions to visible surfaces.

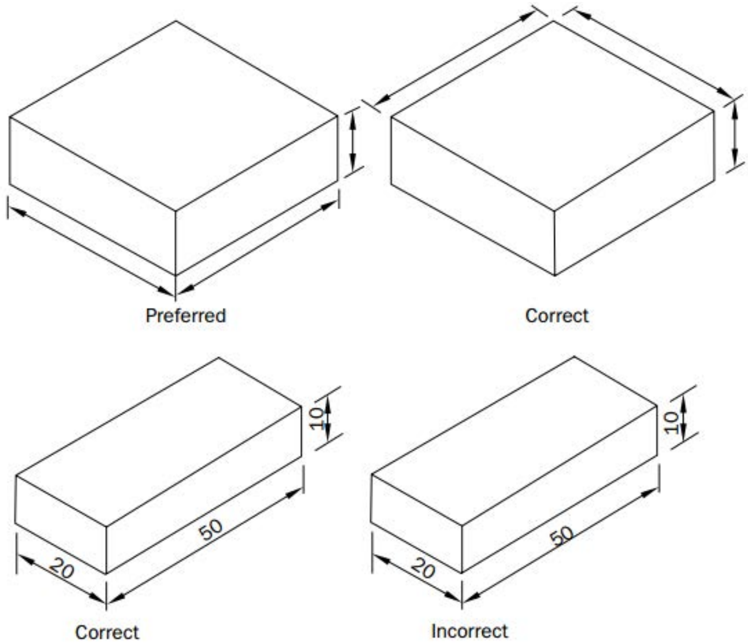


Figure 3.21: Isometric dimensioning

Hidden and Centre Lines on an Isometric Projection

It is a usual practice to omit the hidden lines unless they are needed to make the drawing clearer.

If an isometric projection is to be dimensioned and if it has holes, which must be located, centre lines must be drawn. The centre lines are placed on a plane in which the hole is shown and the dimensions are placed parallel to the planes. **Figure 3.22** shows the use of hidden and centre lines on an isometric projection.

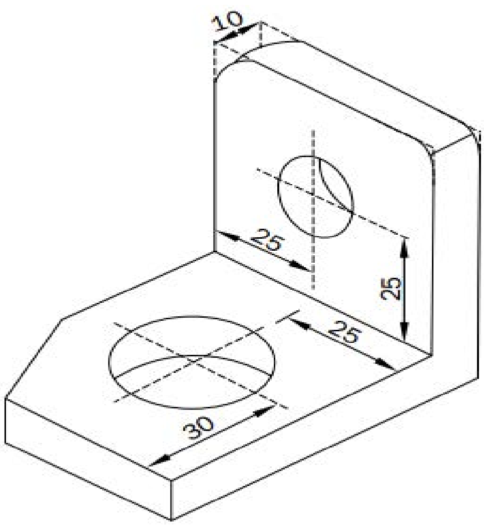


Figure 3.22: Use of centre lines for dimensioning

Isometric Drawing or Projection of Plane Figures

Draw an isometric drawing of a square lamina of 30 mm side.

Solution

Case I: Vertical Plane

1. Draw a line at 30° to the horizontal and mark the length on it.
2. Draw verticals at the ends of the line and mark the length on these parallel lines.
3. Join the ends of a straight line, which is also inclined at 30°. As shown in **Figure 3.23** there are two possible positions for the plane.

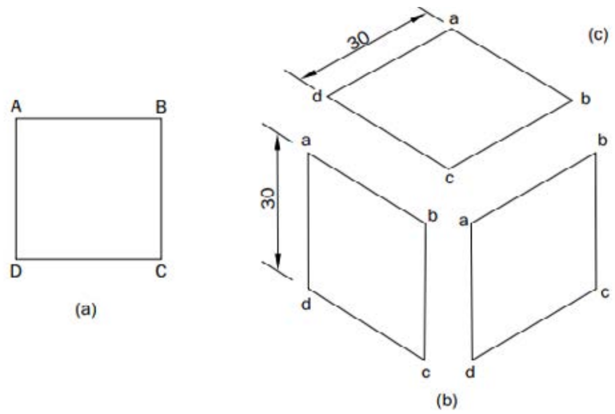


Figure 3.23: Solution to problem

Case II: Horizontal Plane

1. Draw two lines at 30° to the horizontal and mark the lengths along the same.
2. Complete the **Figure** by drawing 30° inclined lines at the ends until they intersect as shown in **Figure 3.23**. The shape of an isometric drawing of a square lamina is a rhombus.

Importance of Isometric Drawing in Product Design

Isometric drawing plays an important role in product design. The importance of isometric drawings include:

a. **Communication Tool**: Engineers use isometric drawings to convey information about dimensions, tolerances, surface finish, and other features needed in the machining process. They reduce misinterpretations and errors during manufacturing.

b. **Precision and Clarity**: Isometric drawings provide a more realistic representation of components, making it easier to visualise and understand critical features. They show the part to be fabricated, ensuring precision and accuracy in manufacturing.

c. **Visual intuition**: Unlike traditional orthographic projections, isometric drawings allow engineers and designers to convey design concepts. Lines parallel to the three principal axes appear in their true lengths, preserving angles and proportions.

d. **Assembly visualisation**: Isometric drawings help demonstrate how different parts fit together. In complex structures, they provide a visual roadmap for assembly.

Activity 3.5 Creating and Drawing 3D Shapes with Snap Cubes

Materials needed

- Snap cubes (or any similar connecting cubes)
- Isometric graph paper (you can print this from online resources) https://graphpapertemplates.com/dl/isometric-graph-paper
- Pencils and erasers
- Ruler (optional)
- Coloured pencils or markers (optional)

Steps

1. Building the 3D Shape: Build a 3D shape using the snap cubes. Experiment with different shapes like Cube, Rectangular prism, L-shaped or corner shape, Pyramid (a square base with a point) and a custom shape that includes multiple connected cubes.
2. Drawing the Shape on Isometric Paper
   a. Look closely at the shape you have built and its dimensions (e.g., length, width, and height). Use a pencil to start drawing the shape on isometric paper.
   b. Draw the front corner of the shape at the centre of the paper, making sure it aligns with the isometric grid.
   c. From the corner, draw the three main axes (length, width, and height) using the diagonal lines on the grid. All edges should be drawn at 30-degree angles from the horizontal axis.
   d. For each edge of the shape, extend the lines to the correct length, ensuring the proportionality of the object edges in the isometric view.
   e. Fill in the other edges, making sure the shape is connected properly and looks three-dimensional.

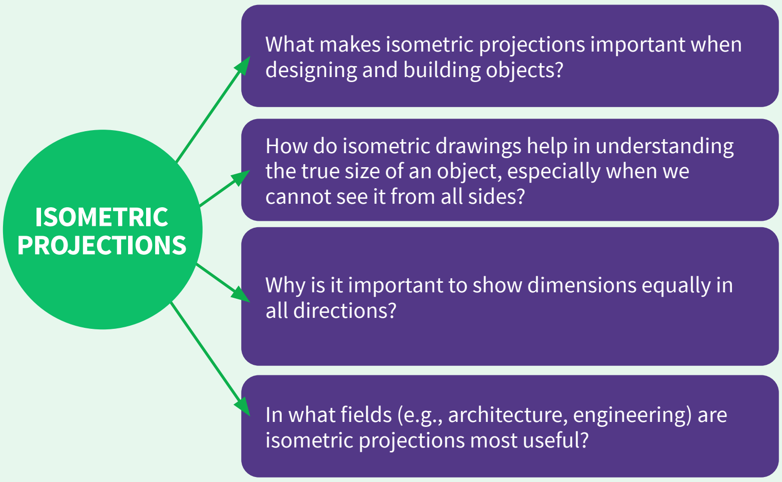
Note: *Use coloured pencils or markers to differentiate between faces of the shape for visual clarity.*

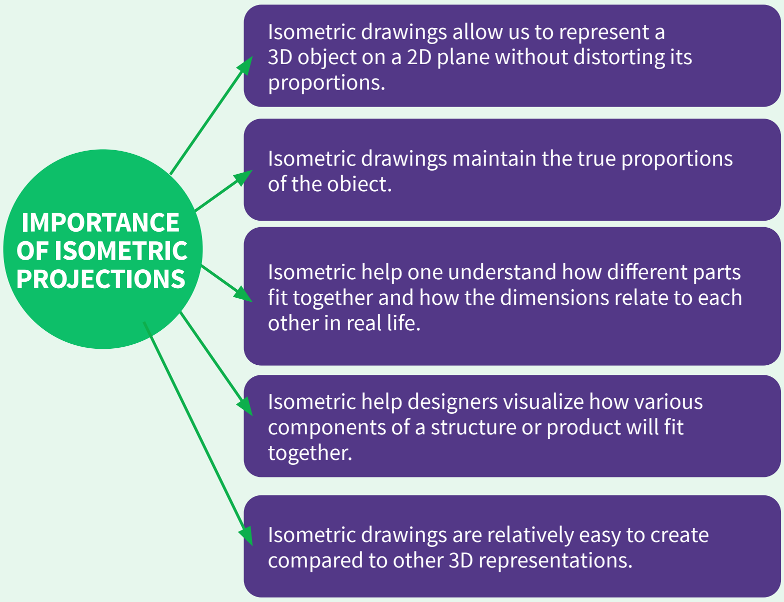
3. After the shapes have been drawn, invite colleagues (Peer Assessment) to compare their 3D snap cube model with their 3D isometric drawing.

4. **Extension Activities:** Challenge yourself to create a complex shape with snap cubes, like a building, a lamp, a bookshelf or a vehicle, and then draw it using isometric paper

Activity 3.6 Mind Maps and Concept Diagrams

Explore the importance of isometric projections by creating mind maps or concept diagrams.





Activity 3.7 Learning Isometric Drawing Using Videos

1. Search from the internet or watch the videos below using the links provided below
   - https://www.youtube.com/watch?v=LY5OqKhEP9k
   - https://www.youtube.com/watch?v=dY6HM1dfIPM
   - https://www.youtube.com/watch?v=Z6sjDv1DMXQ
   - https://www.youtube.com/watch?v=VExQl96VAiM

2. From the Knowledge and skills obtained from the videos, draw a cube and a pyramid in isometric form using the general principle of drawing object in isometric
   a. Draw three axes (X, Y, Z) at 120° to each other.
   b. Start with the front corner and project the other sides along the axes.
   c. Ensure dimensions are to scale
3. In drawing a cube,
   a. draw the first square at the intersection of the isometric axes (X, Y and Z).
   b. draw lines extending from the corners of the square along the three axes.
   c. complete the cube by drawing lines from the ends of the axes to form the sides and top faces.
4. In drawing a pyramid (or other simple shapes like cones or cylinders),
   a. start with the base shape (square or circle).
   b. use isometric lines to project the height and edges of the pyramid or cone.
   c. ensure all lines are at 120° angles from each other.
5. Main Practice: Drawing Physical Objects

   Select one of the following objects to draw in isometric projection:
   a. A simple furniture item like chair, small table or dining table
   b. A complex object like bookshelf,
   c. A complex geometric shape like an object with curved parts like a lamp.

APPLICATION OF FIRST ANGLE ORTHOGRAPHIC PROJECTION IN PRODUCT DESIGN

First-angle projection is a key method in product design, particularly in engineering graphics, where it is used to create detailed and accurate technical drawings. This method involves projecting the object onto the planes of a cube, which is then unfolded to create a 2D representation of the object. The first angle projection is beneficial in various applications, including the design of wide-angle projection objectives, which helps reduce the focal length of the projection objective, thus aiding in the miniaturisation of products like projectors and digital video equipment.

Projection

A projection represents an object viewed (perceived) from a specific angle. By systematically generating multiple projections from various perspectives, one can comprehensively describe the geometry and form of three-dimensional objects. Such representations can be rendered on various surfaces, including paper and digital screens, through drawing or photography. A practical demonstration of this concept can be observed by directing a beam of light from a flashlight onto an object, projecting its shadow onto a wall. To produce sketches and production drawings that are readily interpretable, it is imperative to adhere to established standard practices. This entails a comprehensive understanding of the appropriate views, including their correct orientation within the drawing and the effective representation of essential information, such as edges, surfaces, vertices, hidden lines, centrelines, and other vital details.

Importance of Orthographic Projection

1. Gives the true shape of the object,
2. The size of the image is proportional in size to the original object and
3. Multi-views provided are interrelated (i.e. when given two views, the third view can be derived and therefore provides a self-checking mechanism).

Understanding Projections

To create and interpret drawings effectively, one must grasp the principles of projections and the conventional arrangement of views. Familiarity with the geometry of solid objects is essential, as is the ability to visualise a three-dimensional object represented in a two-dimensional sketch or drawing. Recognising whether surfaces are normal, inclined, or oblique in orientation can enhance your visualisation skills. Common features such as vertices, edges, contours, fillets, holes, and rounds are represented in a standardised manner. This not only simplifies the drawing process but also helps prevent misinterpretations.

Factors Required in Projection

1. The object to be projected
2. The plane of projection
3. The projectors and
4. The observer's eye or station point

Views of Objects

A photograph captures an object as it appears to the observer but does not necessarily represent it accurately. Regardless of the distance or angle from which the photograph is taken, it cannot depict the exact shapes and sizes of the object's components. Consequently, creating a precise 3D model using only a photograph as a reference is impossible, as it provides merely one perspective.

Like photographs, drawings are also 2D representations, allowing for precisely recording sizes and shapes. In fields such as engineering, a complete and clear description of an object's shape and size is essential to ensure that it is manufactured according to the designer's specifications. To convey this information about a 3D object, multiple systematically arranged views are typically utilised, a method known as Multiview projection. Each view offers specific and definitive information; for instance, a front view illustrates the true shape and size of surfaces parallel to the object's front.

An example of a 3D object alongside its front view projection is depicted in **Figure 3.24**. **Figure 3.25** shows the same part with the six principal viewing directions, while **Figure 3.26** illustrates these six views of a house.

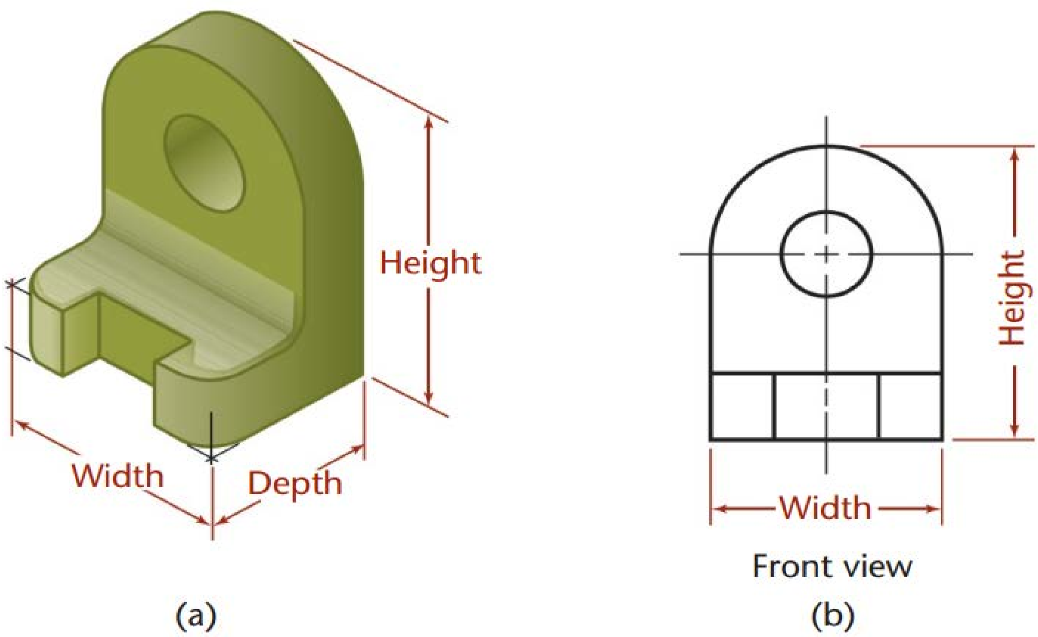


Figure 3.24: Front View of an Object

The Six Standard Views

Any object can be viewed from six mutually perpendicular directions, as shown in **Figure 3.25**. These are called the six principal views. You can think of the six views as what an observer would see by moving around the object. As shown in **Figure 3.26**, the observer can walk around a house and view its front, sides, and rear. You can imagine the top view seen by an observer from an aeroplane and the bottom, or worm's-eye view, as seen from underneath. The term plan may also be used for the top view. The term elevation is used for all views showing the height of the building. These terms are regularly used in architectural drawing and occasionally in other fields. To make drawings more straightforward to read, the views are arranged on the paper in a standard way. The views in **Figure 3.26** show the American National Standard arrangement. The top, front, and bottom views align vertically. The rear, left-side, front, and right-side views align horizontally.

To draw a view out of place is a serious error and is generally regarded as one of the worst mistakes in drawing. See **Figure 3.27** for an illustration of how to visualise the different views.

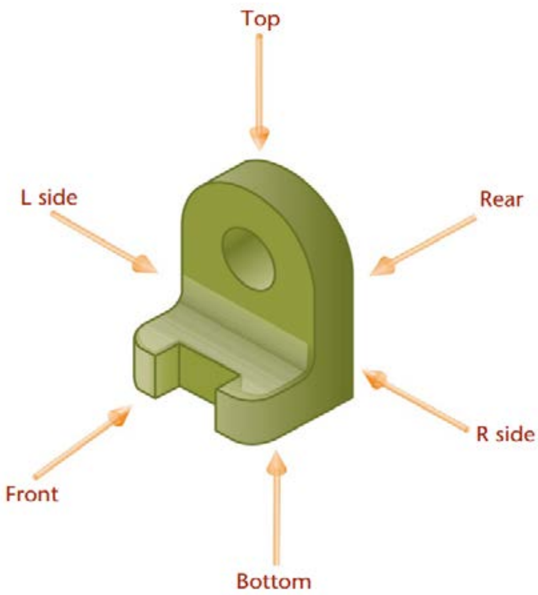


Figure 3.25: The six principal views

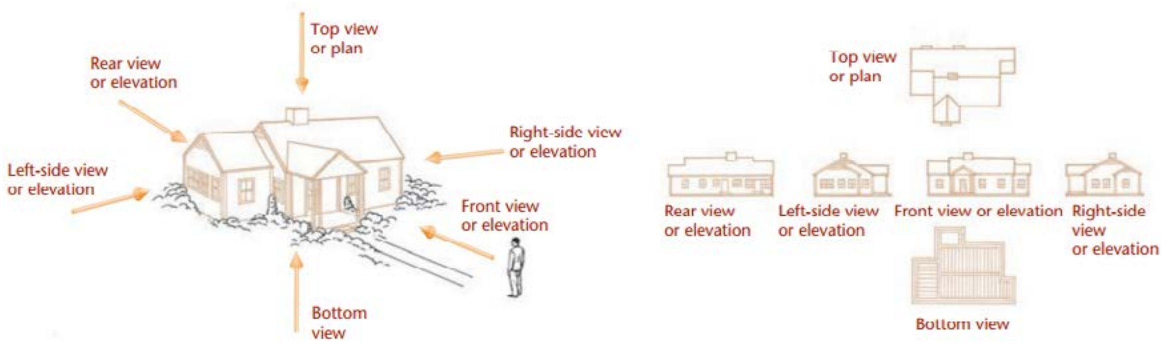


Figure 3.26: Six views of a house

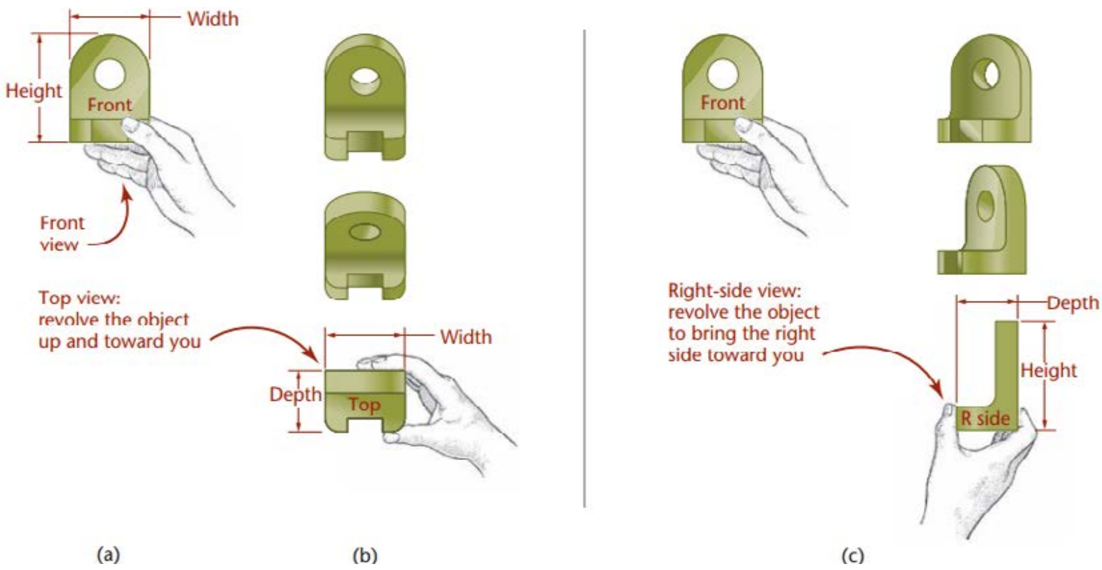


Figure 3.27: Revolving the Object to Produce Views

You can experience different views by revolving an object, as shown. (a) First, hold the object in the front view position. (b) To get the top view, tilt the object toward you to bring the top of the object into your view. (c) To get the right-side view, begin with the object's front view facing you and revolve it to bring the right side toward you. To see views of the rear, bottom, or left side, you would simply turn the object to bring those sides toward you.

Principal Dimensions

The three principal dimensions of an object are width, height, and depth (see **Figure 3.28**). These fixed terms are used for dimensions shown in certain views, regardless of the shape of the object. The terms length and thickness are not used because they may be misleading. The front view shows only the height and width of the object and not the depth. In fact, any principal view of a 3D object shows only two of the three principal dimensions; the third is found in an adjacent view. Height is shown in the rear, left-side, front, and right-side views. Width is shown in the rear, top, front, and bottom views. Depth is shown in the left-side, top, right-side, and bottom views.

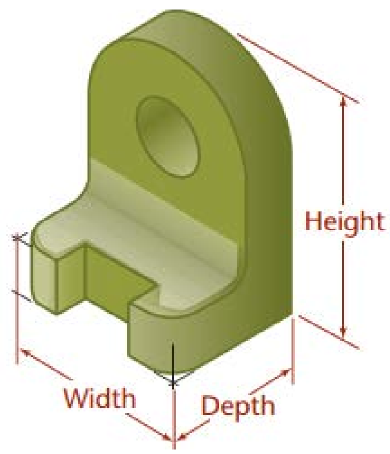


Figure 3.28: The Principal Dimensions of an Object

Projection Method

Figure 3.29 illustrates the front view of an object as represented in an orthographic projection. Imagine a sheet of glass placed parallel to the front surfaces of the object; this represents the plane of projection. The outline visible on this plane shows how the object appears to an observer. In orthographic projection, rays (or projectors) originating from all points on the edges or contours of the object extend parallel to each other and are perpendicular to the plane of projection. The term "orthographic" means "at right angles." Examples of top and side views are depicted in **Figure 3.30**. Specific names are assigned to the various planes of projection: the front view corresponds to the frontal plane, the top view corresponds to the horizontal plane, and the side view corresponds to the profile plane. **Figure 3.31** presents a flow chart illustrating the projection planes.

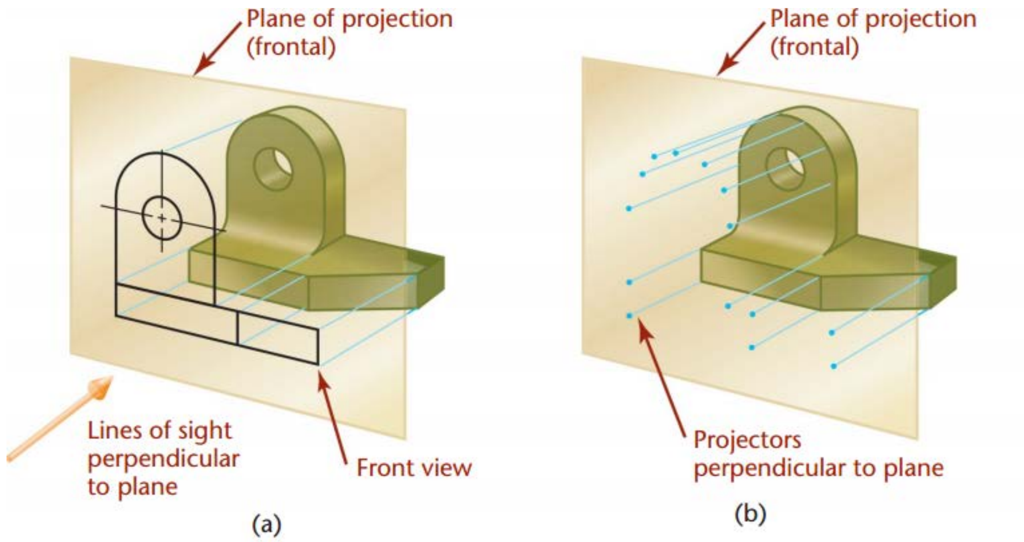


Figure 3.29: Projection of an Object

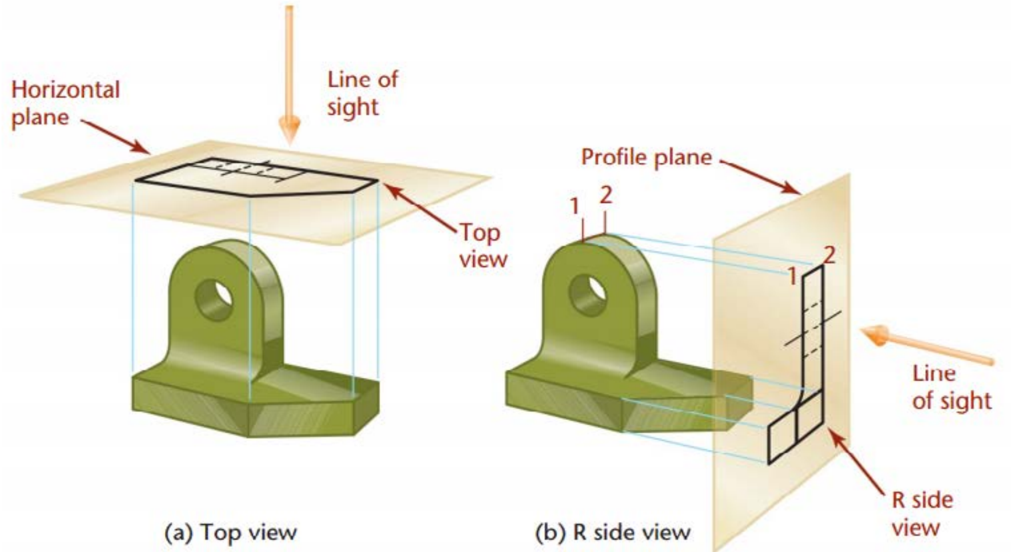


Figure 3.30 Horizontal and Profile Projection Planes

The orientations of a plane of projection give rise to various names including elevation, plan, side (left/ right) view, auxiliary view, principal planes, auxiliary planes and profile plane.

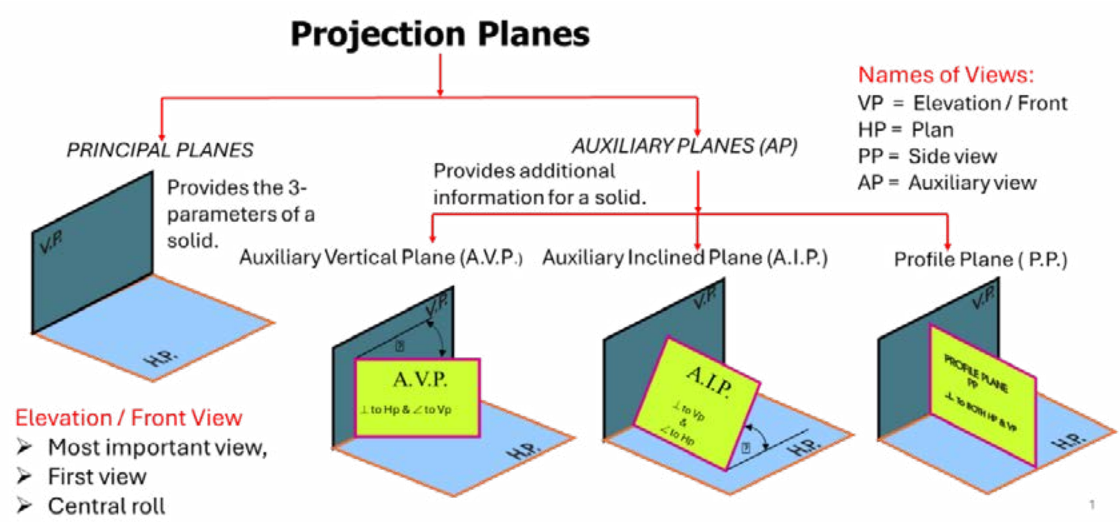


Figure 3.31: Flow chart of projection planes

The Glass Box

To understand the standard arrangement of views on a sheet of paper, imagine a glass box. If planes of projection were positioned parallel to each principal face of an object, they would create a box, as illustrated in **Figure 3.32**. An external observer would be able to see six standard views (front, rear, top, bottom, right side, and left side) of the object through the sides of this conceptual glass box.

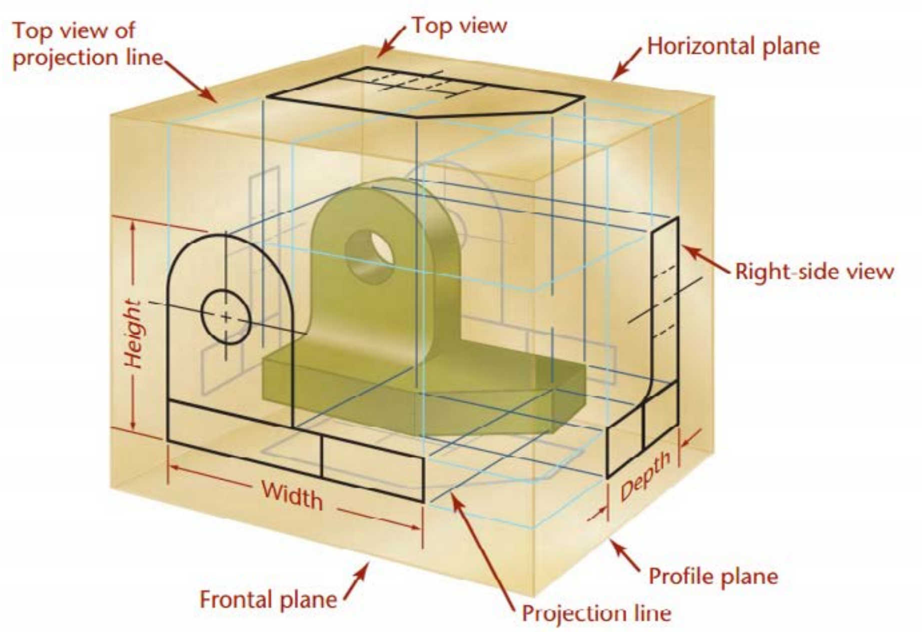


Figure 3.32: The glass box

To depict the views of a 3D object on a flat sheet of paper, envision the six planes of a glass box being unfolded to lie flat, as illustrated in **Figure 3.33**. Consider all planes, except for the rear plane, as being hinged to the frontal plane. Typically, the rear plane is hinged to the left-side plane. Each plane unfolds outward away from the frontal plane. The representation of the hinge lines of the glass box in a drawing is referred to as folding lines. The arrangement of these six planes after they have been unfolded is presented in **Figure 3.34**.

Identify each plane and its views based on the original position in the glass box. In **Figure 3.34**, lines connect one view to another within the glass box. These lines show how points in one view project to the same points in other views. The size and position of the object inside the glass box do not change. This is why the top view is the same width as the front view and is placed directly above it. The same goes for the front and bottom views.

Therefore, the front, top, and bottom views line up vertically and have the same width. The rear, left-side, front, and right-side views line up horizontally and share the same height. Since objects do not move in the box, the top view is the same distance from the folding line O/Z as the right-side view is from the folding line O/Y. Likewise, the bottom and left-side views are the same distance from their folding lines as the right-side and top views. The top, right-side, bottom, and left-side views are all the same distance from their folding lines and show the same depth.

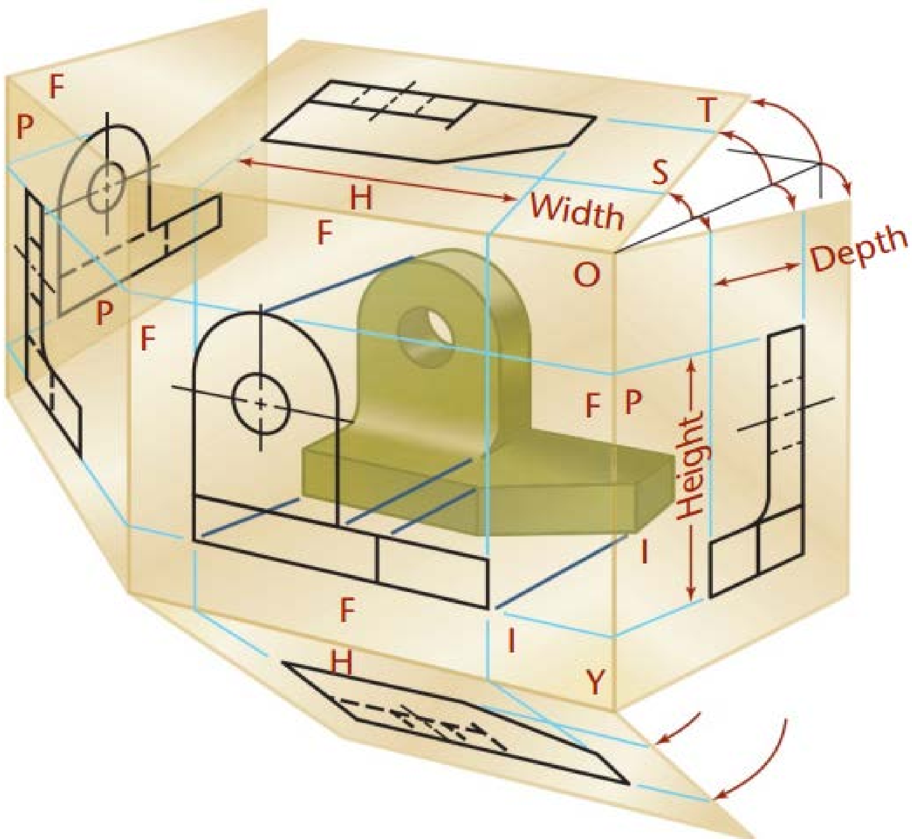


Figure 3.33: Unfolding the Glass Box

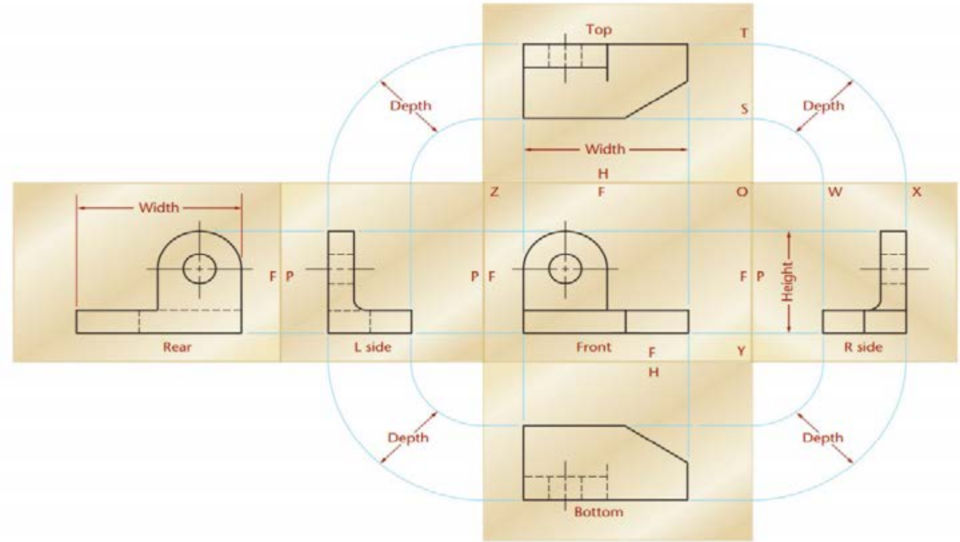


Figure 3.34: The Glass Box Unfolded

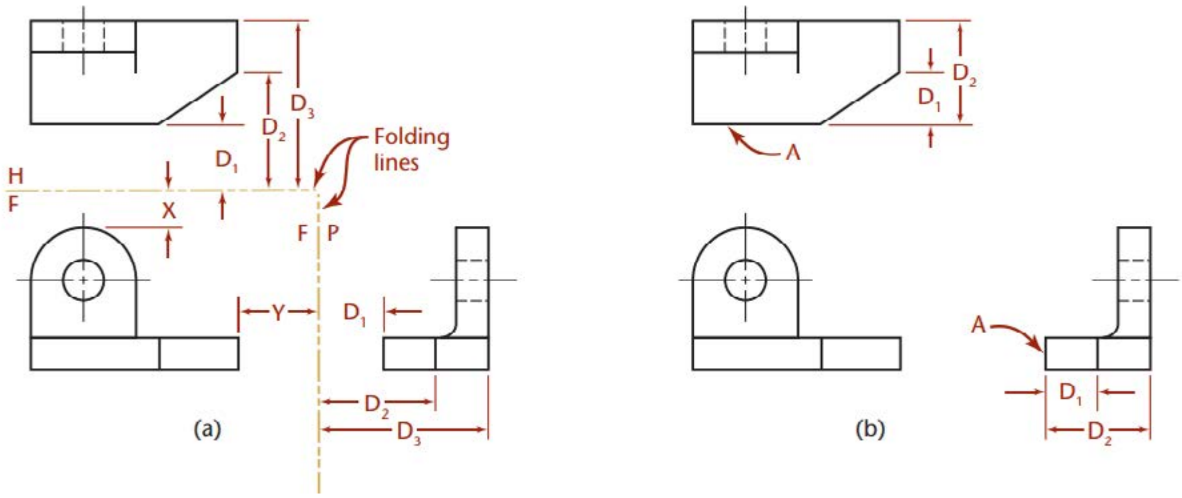


Figure 3.35: Views Shown with and without Folding Lines

The top, front, and right-side views of the object are shown in **Figure 3.35(a)**. Instead of a glass box, you will see folding lines between the views. These folding lines represent where the glass box would hinge. The H/F folding line between the top and front views shows where the horizontal and frontal planes meet. The F/P folding line between the front and side views shows where the frontal and profile planes meet. While understanding folding lines is helpful for solving problems in descriptive geometry, they are usually not included in the drawing, as shown in **Figure 3.35(b)**. Instead of using the folding lines to mark depth measurements in the top and side views, you can use the front surface (A) of the object as a reference line. Remember, D1, D2, and all other depth measurements match in both views as though you were using folding lines.

Spacing between Views

Spacing between views affects their appearance. Keep views spaced apart, but not too far, so they look related. You might need to leave some space to add dimensions.

Transferring Depth Dimensions

Make sure the depth dimensions in the top and side views match exactly. When you're using 2D CAD or measuring tools, be precise when transferring these distances. You can measure dimensions between the top and side views using dividers or a scale, as shown in the figures. Another helpful method is to mark the distances on a scrap of paper and use it like a scale to transfer the measurements to the other view. You might also find it useful to use a 45° mitre line to project dimensions between the top and side views. Drawing the mitre line at 45° allows you to transfer vertical depths from the top view to horizontal depths in the side view, and vice versa.

Measuring from a Reference Surface

To transfer a dimension from one view to a related view (which shares that dimension), measure from a plane that appears on edge in both views, as shown in **Figure 3.37**.

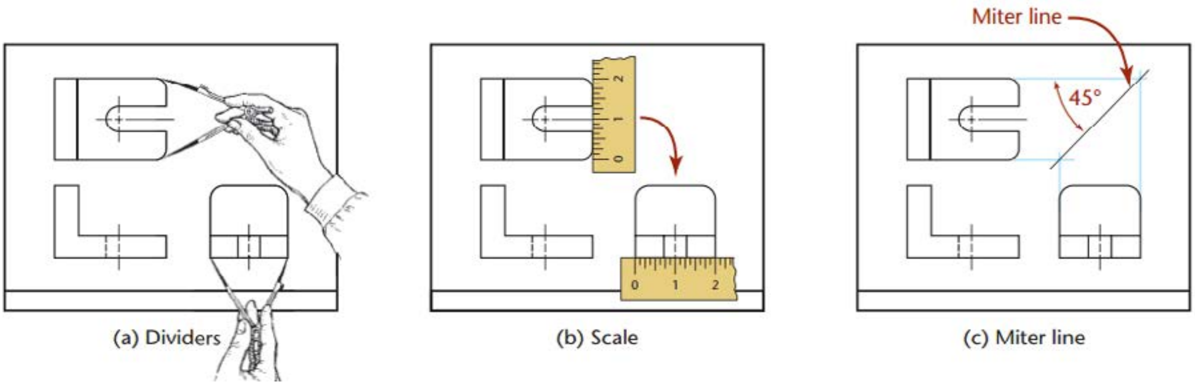


Figure 3.36 Transferring Depth Dimensions

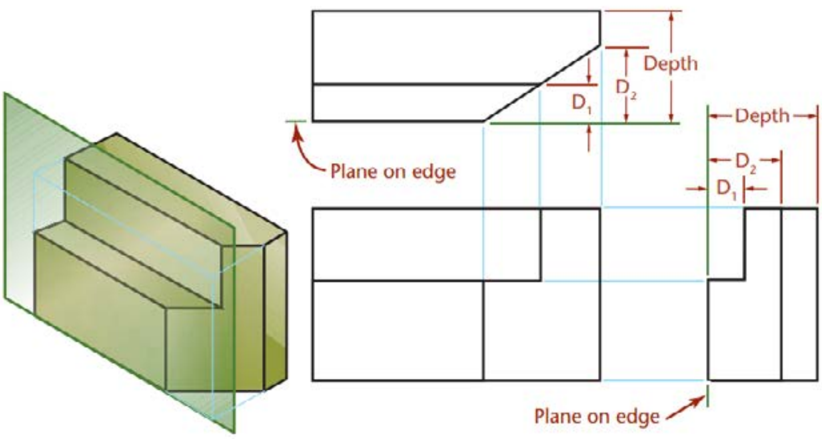


Figure 3.37: Transferring Depth Dimensions from a Reference Surface

Necessary Views

Figure 3.38 shows that the right and left side views of an object are mirror images of each other, with different hidden lines. Hidden lines are shown with a dashed pattern to indicate parts of the object not visible from a certain view. Typically, only the right-side view is drawn, which is also the case for top and bottom views, as well as front and rear views. The top, front, and right-side views are shown together in **Figure 3.39**. These views are called the three regular views because they are the most used.

A sketch or drawing should only show the views needed to clearly describe the object. These essential views are called necessary views. Choose views with the fewest hidden lines that display the main shapes clearly. Complicated objects may need more than three views or special partial views. Many objects can be described well with just two views. If the left-side and right-side views show the object equally, use the right-side view. If the top and bottom views are equally clear, choose the top view. If the top view and right-side view are both good options, pick the combination that best fits on your paper. Some examples are shown in **Figure 3.40.**

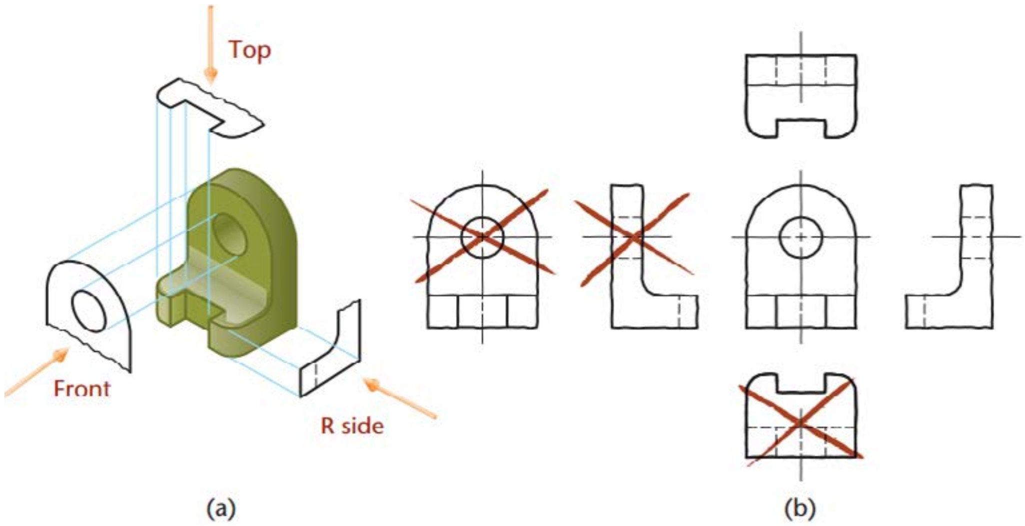


Figure 3.38: Opposite Views Are Nearly Identical

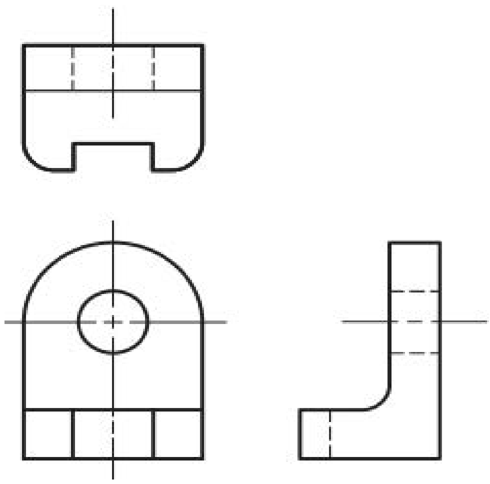


Figure 3.39: The Three Regular Views

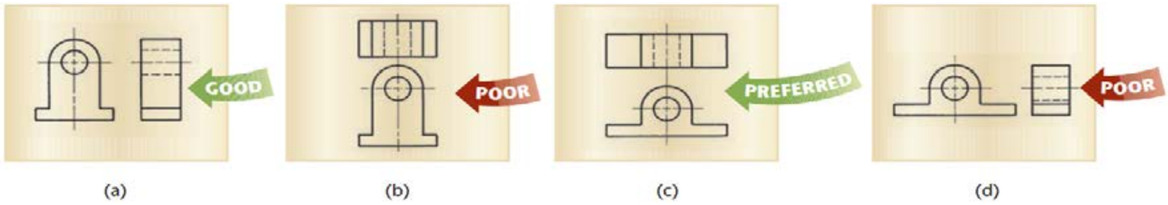


Figure 3.40: Choice of Views to Fit Paper

A single view, along with a note or lettered symbols, is usually enough, as shown in **Figure 3.41**. Objects that have a uniform thickness can often be displayed in one view. However, the connecting rod is an exception. It can still be shown in one view because of how it is dimensioned.

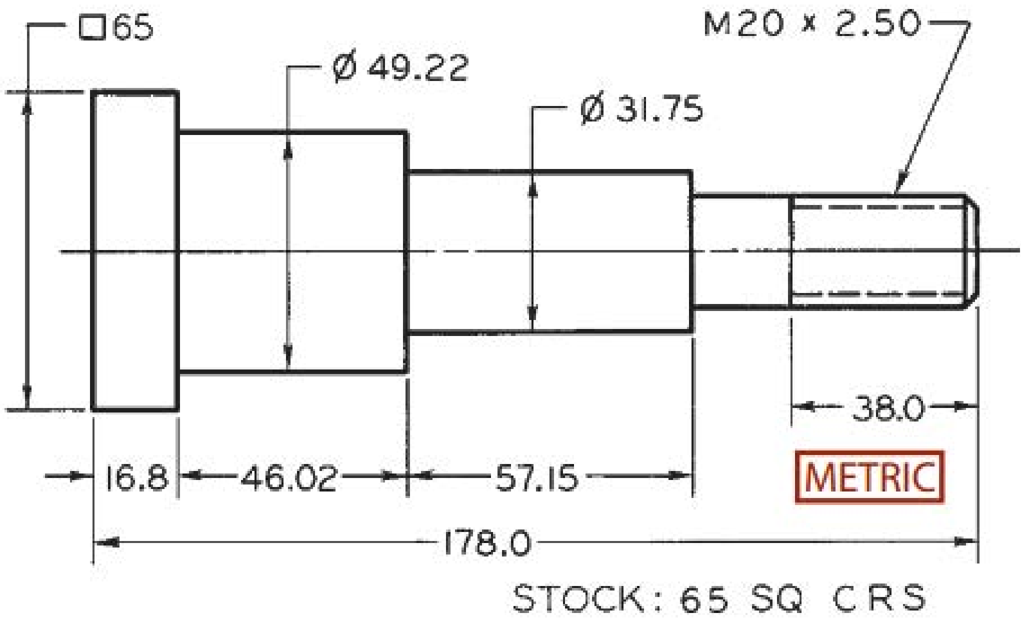


Figure 3.41: One-View Drawing of a Connecting Rod

Orientation of the Front View

Four views of a compact automobile are shown in **Figure 3.42**. The view chosen for the front view in this case is the side, not the front, of the automobile.

Note that;

- the front view should show a large surface of the part parallel to the front viewing plane.
- the front view should show the shape of the object clearly.
- the front view should show the object in a usual, stable, or operating position, particularly for familiar objects.
- when possible, a machine part is drawn in the orientation it occupies in the assembly.
- usually, screws, bolts, shafts, tubes, and other elongated parts are drawn in a horizontal position, as shown in **Figure 3.41**.

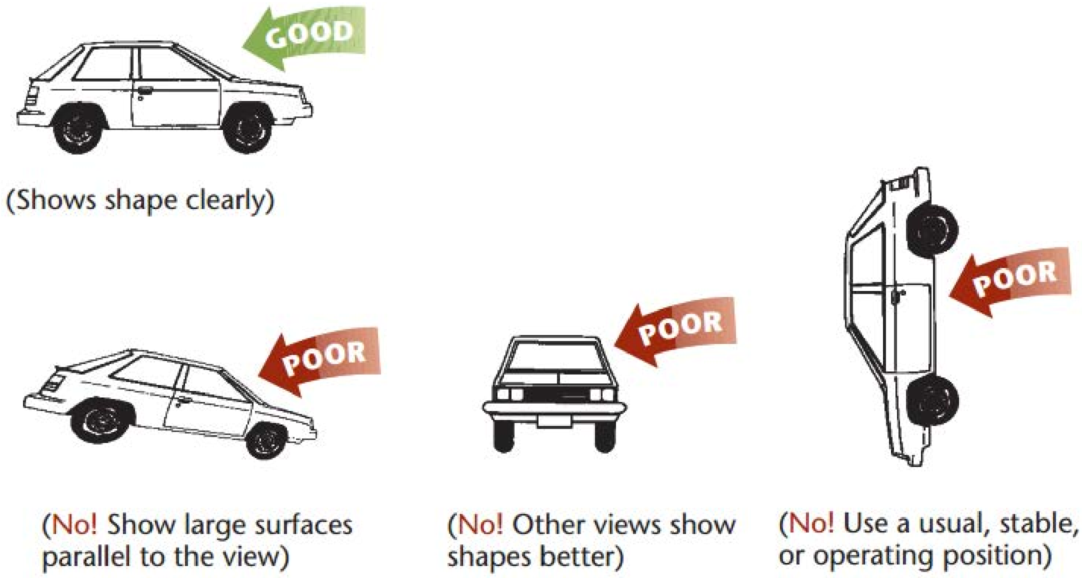


Figure 3.42: Choice of Front View

First and Third-Angle Projections

As mentioned earlier, you can think of projecting views as unfolding a glass box created by the viewing planes. There are two main systems used for this purpose: third-angle projection, which is commonly used in the United States, Canada, and a few other countries, and first-angle projection, which is mainly utilised in Europe and Asia. Confusion between first angle and third angle drawings can lead to difficulties in interpreting the drawings and manufacturing errors. Given the global nature of technical drawings, it is essential to have a solid understanding of both methods. **Figure**s **3.43** and **3.44** illustrate the orientation first angle and third-angle projections, along with the various types of projections.

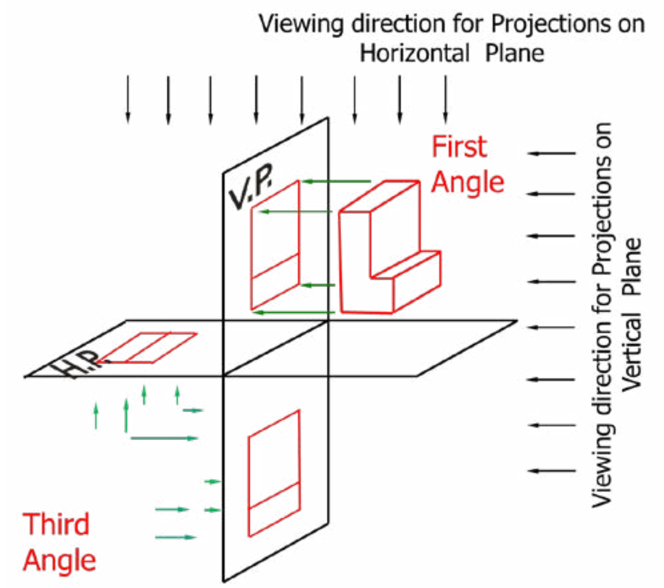


Figure 3.43 Orientation of first and third angle projections

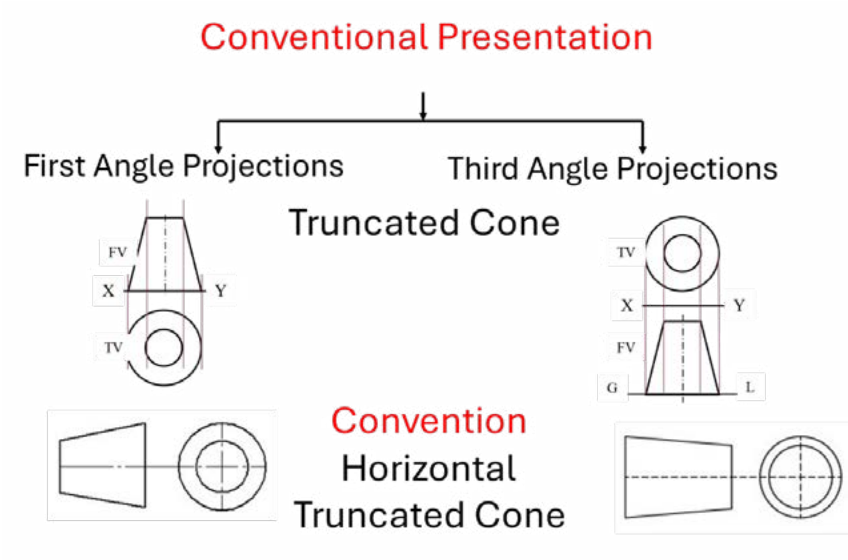


Figure 3.44: Types of orthographic projections

First Angle Projection

Alignment of planes and views

1. Consider a projection onto the VP, HP and PP is executed,
2. The first and most important view is the Front View (FV),
3. Aligning the other views to the Front View.

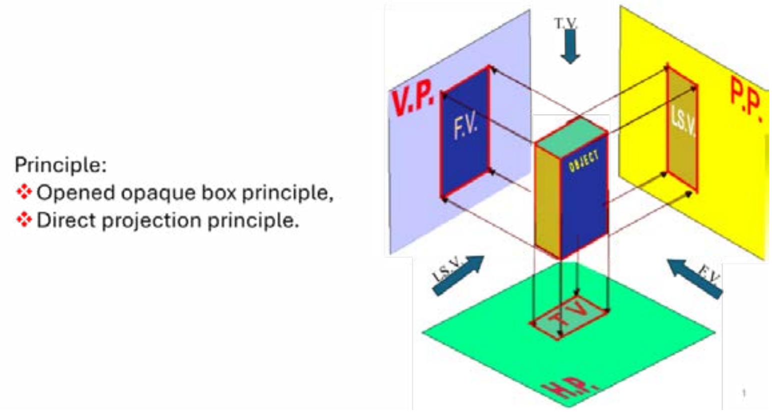


Figure 3.45: First angle projection

Characteristics of First Angle Projection Drawings

First angle projection places the object between the observer and the projection plane, which is behind the object. In contrast, third angle projection has the projection plane between the observer and the object. First angle projection follows the BS 8888:2011 standard, which is a guide for technical product documentation and specifications. This standard ensures that drawings are accurate and follow a consistent style, which is important for technical documentation. The method includes creating axonometric drawings, a kind of orthographic projection that rotates the object to show multiple sides. This technique is useful in engineering graphics because it accurately shows dimensions and spatial relationships. To create these drawings, the process involves forming the original graphic, projecting it onto a screen, and then adjusting it to achieve the desired shape and angles. This method makes sure that dimensions and angles are correct, which is critical for engineering and manufacturing. First angle projection drawings are important in technical and engineering fields as they provide a clear and consistent way to represent three-dimensional objects in two dimensions.

Key characteristics of first angle projections

1. Positioning of the Object
    a. The object is positioned in the first quadrant relative to the observer.
    b. This means that the object lies between the projection plane and the viewer.
2. Common Usage
    a. First angle projection is typically used in Africa, Europe, India, and Canada.
    b. It provides an alternative to third angle projection, which is more common in the United States and Canada.
3. Projection Plane
    a. The projection plane in first angle projection is opaque.
    b. Views (such as front, top, and side views) are projected onto this plane to create the engineering drawing.
4. Front Perspective Representation: In first angle projection, the top of the horizontal axis represents the front perspective of the object.

Selection of Views for a First Angle Projection

Views are selected in sequence according to their importance:

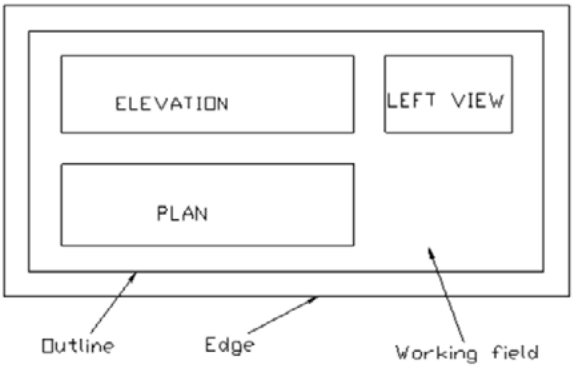
1. The rule of the most natural position.
2. The rule of stability.
3. The rule of the longest side or largest surface of an object.
4. The rule of minimum dash lines or hidden details.

Note

- The first two rules are for object orientation
- The last two rules help select the surfaces.

Spacing and Placing of Views for a first angle projection

1. Select the best views required to describe the object
2. Consider the sizes of the various views based on the intended scale
3. Consider the type of projection (First Angle)
4. Place the respective views at their respective positions
5. Maintain reasonable equal distances between views
6. Distances between views must be proportional to the size of the views.



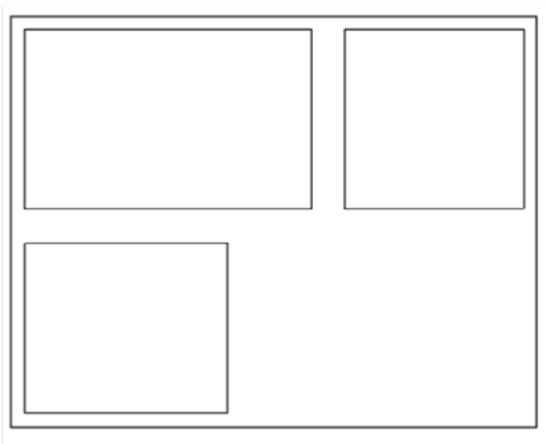


Figure 3.46: First angle projection (views placement/ positioning) on a drawing sheet

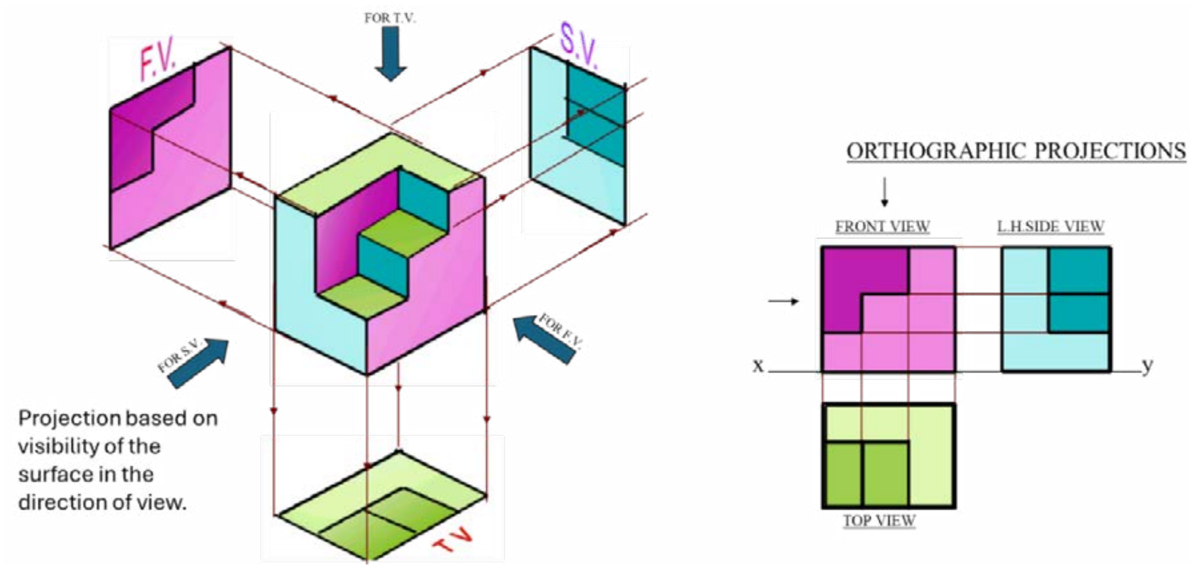


Figure 3.47: Views for first angle projection for sample component 1

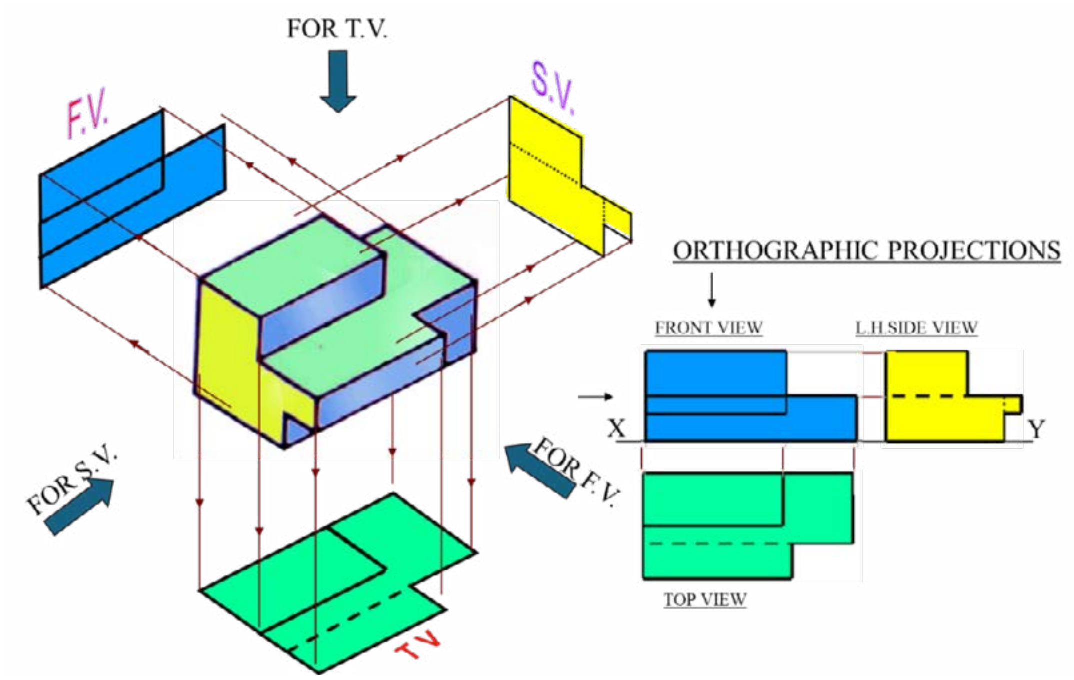


Figure 3.48: Views for first angle projection for sample component 2

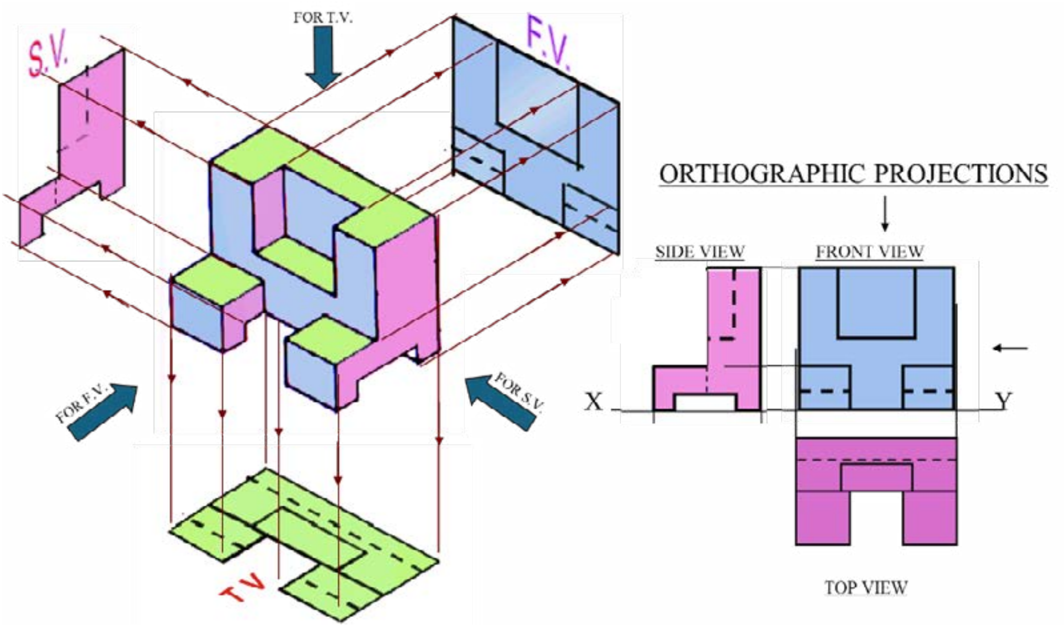


Figure 3.49: Views for first angle projection for sample component 3

Error Detections Within a Drawing

Errors in projections do occur. They could come in the form of:

1. Missing views required to completely describe the object.
2. Missing geometric object in a view.
3. Missing surface of a geometric object in a view.
4. Missing line of a geometric object in a view.

Application of first angle projection in product design

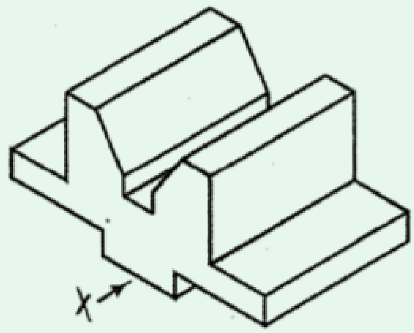
1. **Orthographic Projection System**
   a. First angle projection is one of the two primary methods used in orthographic projection systems. These systems represent three-dimensional objects in a two-dimensional plane.
   b. By projecting views (such as front, top, and side views) onto vertical and horizontal planes, engineers can visualise components' dimensions, connections, and relationships.
   c. This visualisation is essential during the design phase, allowing engineers to create prototypes, conduct tests, and manufacture the final product.
2. **Engineering Drawings**
   a. In first angle projection, the object is positioned in the first quadrant relative to the observer and the projection plane.
   b. The three main views used in first angle projection are:
      i. Front View: Represents the object as seen from the front.
      ii. Top View: Represents the object as viewed from above.
      iii. Side View: Provides additional information about the object's shape and features.
   c. These views help communicate design details, dimensions, and assembly instructions to manufacturers and other stakeholders.
3. **Product Design and Visualisation**
   a. First angle projection allows designers to create accurate representations of products, ensuring that all relevant features are captured.
   b. By combining front, top, and side views, designers can visualise how different components fit together and identify potential issues.
   c. This method ensures that the final product aligns with the intended design and meets functional requirements.

Activity 3.8 Orthographic Drawing

1. Search from the internet or watch the videos below that explain the concept of orthographic projection and demonstrate how to draw front, top, and side views of objects using the links provided.
2. Take notes on key techniques and tips.
   - https://www.youtube.com/watch?v=HQycdTP0orc
   - https://www.youtube.com/watch?v=Z-FC7ZKVz8w&list=PL9cRyfczUN_kFYV-dto_08-nfSuwIvXJ3

- https://www.youtube.com/watch?v=dKNnTxwSS-Q
- httpswww.youtube.com/watch?v=WG6H2pISUzQ&list=PLIhUrsYr8yHwe_ZgziK4FJIx4fmBJE://kIL
- Orthographic Projection_An Introduction_Engineering Drawing_Engineering Graphics_English - YouTube

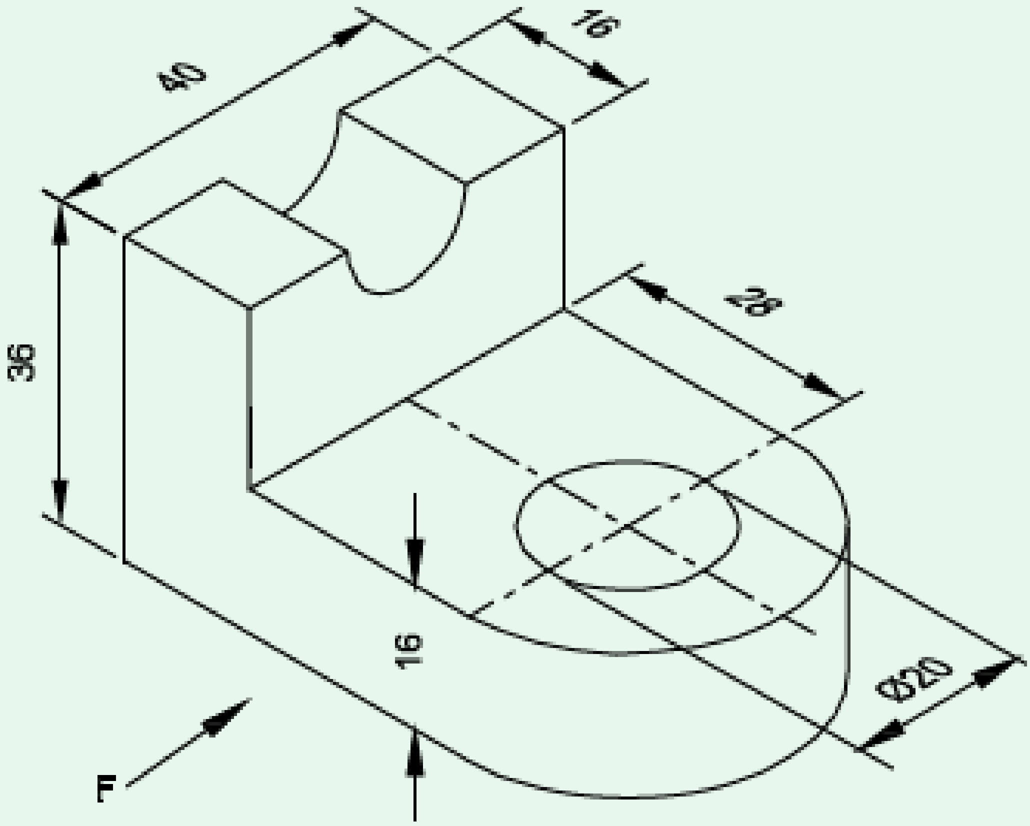
Activity 3.9 Using Images for Practice



1. Draw the front top and end views of the above two images.
2. Compare your drawings with the examples in the videos and the learner manual.
3. Identify areas for improvement and redraw the objects, focusing on those areas.
4. Present your work to your peers or family and discuss how orthographic views help convey accurate information about the shape and dimensions of the object

Activity 3.10 Orthographic Projection

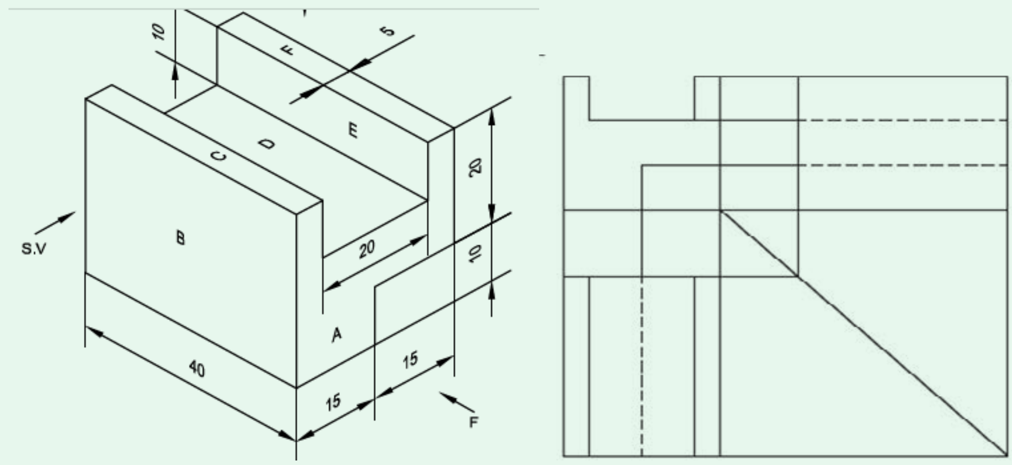
1. Looking at the direction of arrow F, draw in first angle projection the
   a. the front elevation
   b. the plan
   c. end elevation



2. Share your experience with your peers or family.

Activity 3.11 Orthographic projection

1. The figure below is a block drawn isometrically. Draw in first angle projection;
   a. the front elevation
   b. the plan
   c. end elevation



2. Discuss with friends the characteristics of first-angle projection drawings (e.g., placement of views, hidden lines, and dimensions).

IMPORTANCE OF SECTIONING, DIMENSIONING AND TOLERANCE

Various types of lines (continuous, non-continuous, thick and thin) are encountered in manufacturing drawings. Outlines of objects are represented by either thin dash lines or thick continuous lines depending on their visibility to the viewer. Reading and drawing of non-continuous lines, such as thin dash lines, are complicated and confusing. However, if these internal hidden features or outlines are made visible, they should be drawn by a thick, continuous line. They are easier to draw and read. Sectioning, dimensioning, and tolerance significantly aid in capturing the geometric details of a part.

Sectioning

Sectioning in drawing, design, and manufacturing is a complex process that involves creating cross-sectional views of objects to reveal their internal features. This technique facilitates accurate communication of design intent and optimises manufacturing processes. In technical drawing and CAD modelling, sections, or cross-sections, are essential for visualising the interior details of a part, including hidden lines, material composition, and dimensions. These details are crucial for both designers and manufacturers to fully understand the structure of the part.

The introduction of 3D CAD modelling software has significantly enhanced the role of sectioning. It allows for detailed mechanical calculations and optimisations, such as in the case of a shaft weakened by a keyway and supports the principles of additive manufacturing. In manufacturing, sectioning is integral to processes like extrusion and material shaping. For example, a section drawing device can ensure the straightness of aluminium bars by providing support during the drawing motion.

Similarly, section material shaping manufacturing technology involves heating and extruding aluminium bars through a die, followed by precise adjustments to achieve the desired section shape. This process reduces input costs and improves efficiency. Sectioning is also critical in 3D printing, where a central processor converts a 3D model into an STL file. This processor groups triangular patches using cutting planes and processes them in parallel to generate slice section data, ultimately enhancing the efficiency of 3D printing. A sectional view is obtained by imagining the object as if it has been cut by a plane, with the portion between the observer and the section plane removed. In this context, one can visualise an object with the cutting plane passing through it, with two halves drawn apart to expose the interior details.

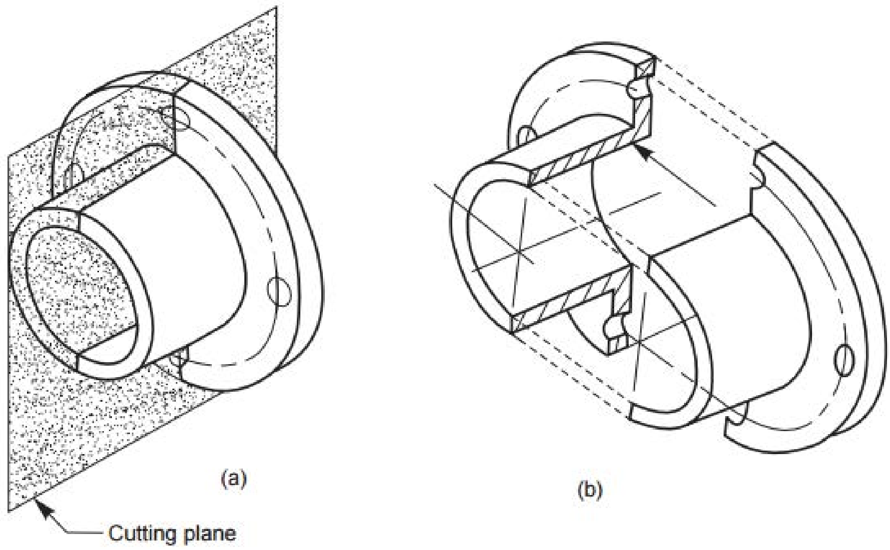


Figure 3.50: Principles of sectioning

Sections of Single Parts

If you have ever cut a melon in half, you have created a full section in real life (see **Figure 3.51**). To visualise a section of a single part is no different. Think of the part as being sliced through by the cutting plane, as if the plane were a giant cleaver. Once the object is cut, the closer half is pulled away, showing the inside construction of the part.

Figure 3.51: Full section of a Melon

Full Section

A sectional view obtained by assuming that the object is completely cut (fully in half) by a plane is called a full section or sectional view. The sectioned view (**Figure 3.52a**) provides all the inner details, better than the un-sectioned view with dotted lines for inner details (**Figure 3.52b)**. The cutting plane is represented by its trace in the view from the front (**Figure 3.52c**) and the direction of sight to obtain the sectional view is represented by the arrows. When the part is cut fully in half, the resulting view is called a full section, as shown in **Figure 3.52**. **Figure 3.53** shows a technical drawing of the part from **Figure 3.52** that does not use a section view. Notice how confusing all the hidden lines look. **Figure 3.54** shows the same drawing, but this time the right-side view is replaced with a right section view. Now it is much easier to understand.

In a drawing with a section view, the missing half is imagined to be removed and is not actually shown removed in any view except the section view. A line called the cutting-plane line provides the information necessary for understanding where the part was cut. The arrows at the ends of the cutting plane line indicate the direction of sight for the section view. In the section view, the areas that would have been in actual contact with the cutting plane (refer to the example shown in **Figure 3.52**) are shown with section lining. Those areas are crosshatched with thin parallel section lines.

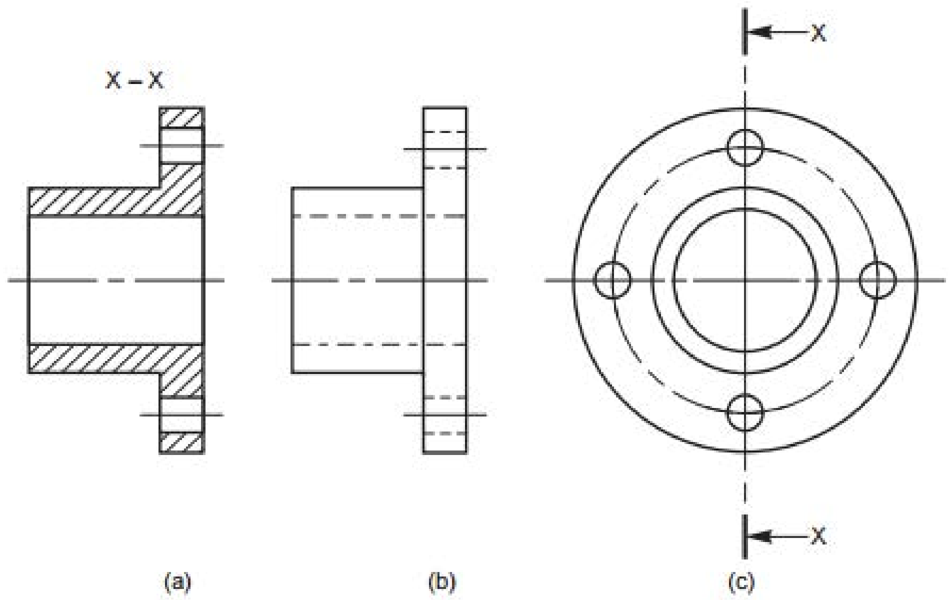


Figure 3.52: Sectioned and un-sectioned views

To create a sectional view, imagine that one half of the object is removed. However, this half isn't actually shown as removed; it is only represented in the sectional view. In this view, the parts of the object that the cutting plane intersects are marked with section lining or hatching. The view should also include the visible parts behind the cutting plane. **Figure 3.53** shows the correct and incorrect ways to create a sectional view. Sections mainly replace hidden line drawings, so avoid using hidden lines in sectional views.

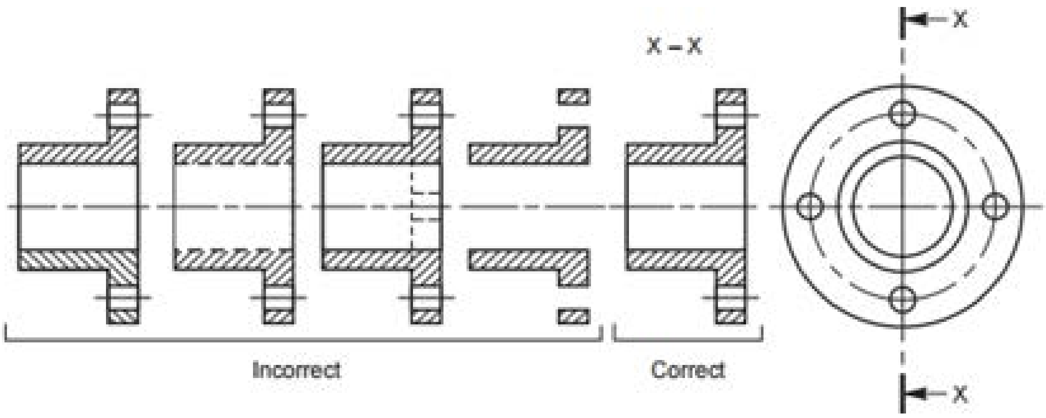


Figure 3.53: Incorrect and correct sections

Half Section

A half sectional view is often used for symmetrical objects. In a half section, the cutting plane removes only one quarter of the object. This view shows both the inside and outside details in the same illustration. It's best to leave out hidden lines even in half sectional views. **Figure 3.54a** displays an object with the cutting plane in place to create a half sectional view from the front, with the top half cut away. **Figure 3.54b** shows two parts separated to reveal the inner details of the sectioned area. **Figure 3.54c** shows the half sectional view from the front. A centre line separates the two halves in the half section. Students should also pay attention to how the cutting plane is represented in the view from above when creating the half sectional view from the front.

You can show symmetrical objects clearly with a half section view (see **Figure 3.55**). A half section reveals the inside of one half of the object while showing the outside of the other half. To create this view, you remove one quarter of the object. However, half sections are not often used for detail drawings that explain how to make a single part. This is because it can be hard to display all dimensions clearly when some internal features are only partially visible in the sectioned half as shown in **Figure 3.55b**.

In general,

- Omit hidden lines from both halves of a half section, whenever possible.
- Use a centreline to divide the sectioned half and the un-sectioned half, as shown in **Figure 3.55b**.

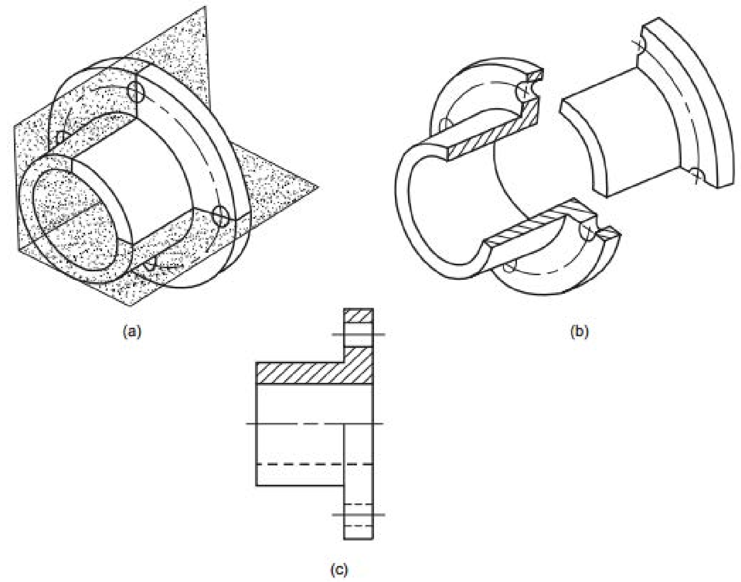


Figure 3.54: Method of obtaining half sectional view

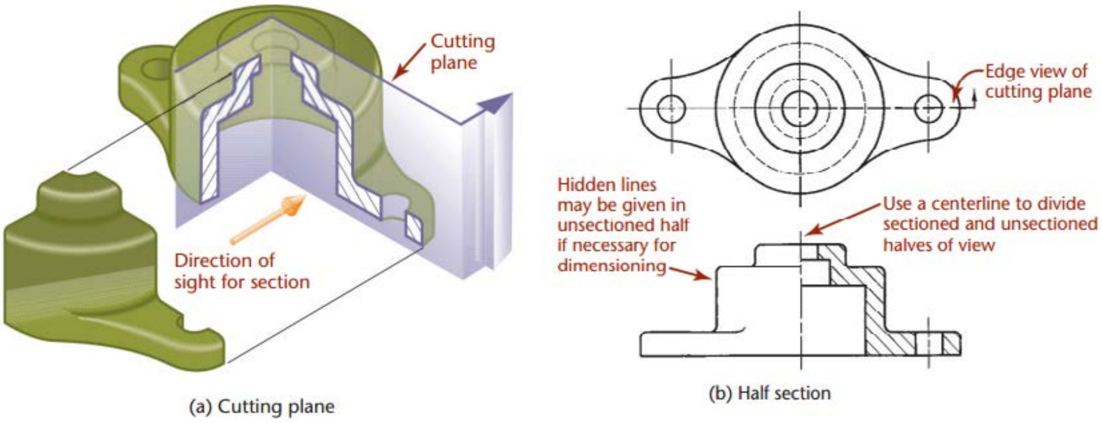


Figure 3.55: (a) Cutting Plane (b) Half section

Half-section drawings are particularly useful for displaying assemblies where it's important to illustrate both internal and external construction in a single view, typically without the need for dimensioning. In some cases, a broken-out section might be a better option. **Figure 3.56** shows an image of a half-section of a melon.

Figure 3.56: Half section of a melon

Auxiliary Sections

Auxiliary sections can be employed to enhance the principal views in orthographic projections. A sectional view projected onto an auxiliary plane, which is inclined to the main projection planes, reveals the cross-sectional shapes of features like arms, ribs, and similar elements. In **Figure 3.57**, the auxiliary cutting plane X-X is utilised to obtain the auxiliary section X-X.

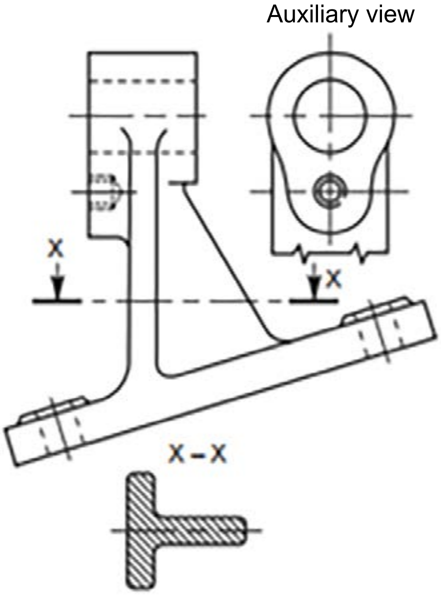


Figure 3.57: Auxiliary section

The Cutting Plane

The cutting plane is illustrated in a view adjacent to the section view, specifically the front view. In this view, the cutting plane is represented edgewise as a thick dashed line, known as the cutting-plane line. **Figure 3.58** shows an image depicting the cutting or slicing of a single part. The arrows at the ends of the cutting-plane line indicate the direction of sight for the section view, as demonstrated in **Figure 3.59**. These arrows point towards the section being viewed, as shown in **Figure**s **3.60** and **3.61**, rather than away from it, as seen in **Figure 3.62**. **Figure 3.63** highlights some previously hidden edges of a part that become visible in the section view.

Lines behind the Cutting Plane

The now-exposed visible edges of the object behind the cutting plane are shown, but they are not crosshatched with section lining, because they were not cut. **Figure 3.63** shows an example of object edges exposed by the cutting plane appearing as visible lines in the section view. In a full section, the location of the cutting plane is obvious from the section itself, so the cutting-plane line is often omitted. You will learn about other section types that require the cutting-plane line to be understood later in this chapter. Cutting-plane lines should be used wherever necessary for clarity.

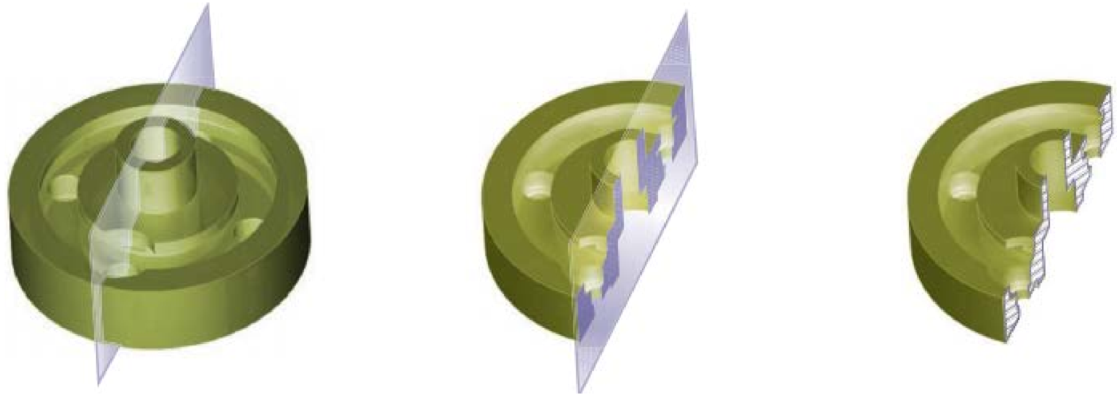


Figure 3.58: Slicing a Single Part

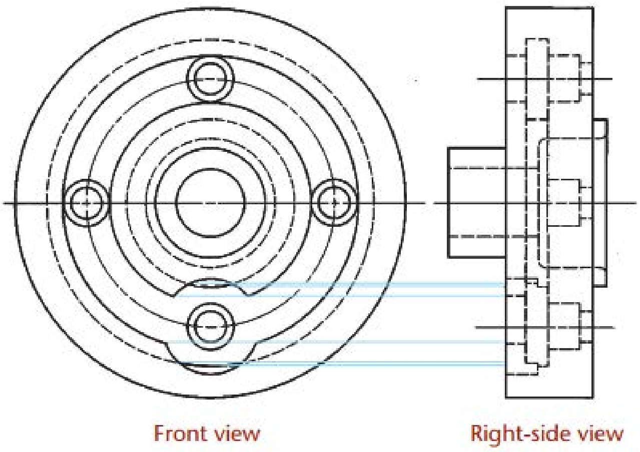


Figure 3.59: Front and Right-Side Views. Parts with a lot of interior detail may have so many hidden lines that their views are confusing

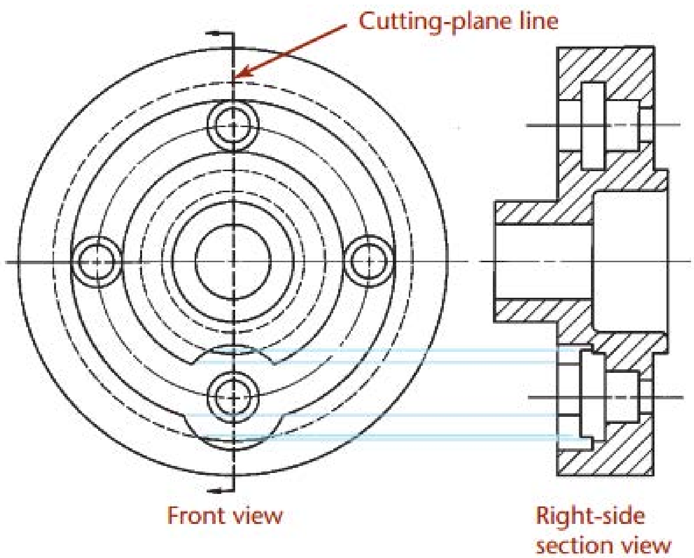


Figure 3.60: Front and Right-Side View in Full Section. Using a section view makes it easier to see interior details

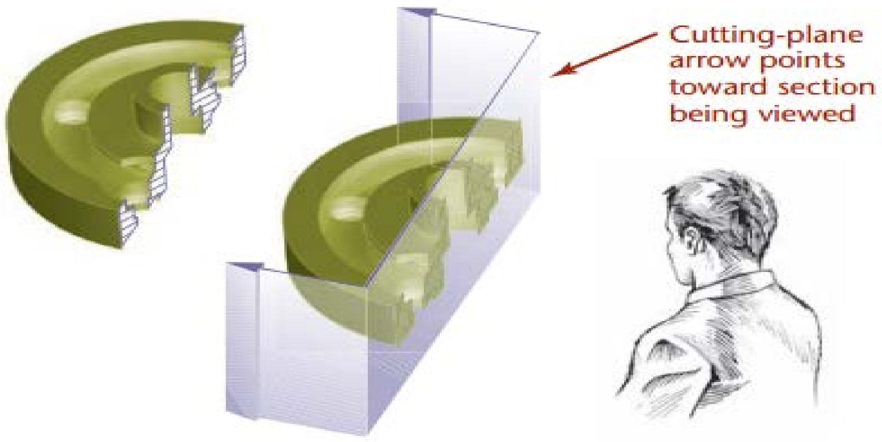


Figure 3.61: Cutting-plane Line Indicates Direction of Sight

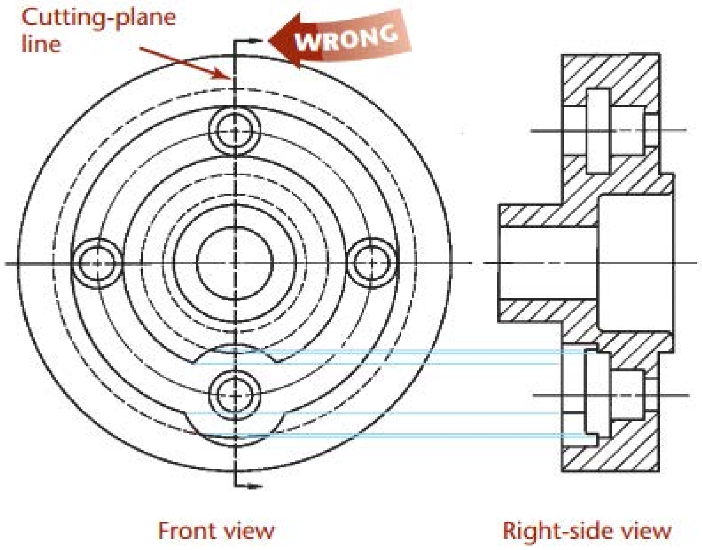


Figure 3.62: Arrows should not point to removed portion

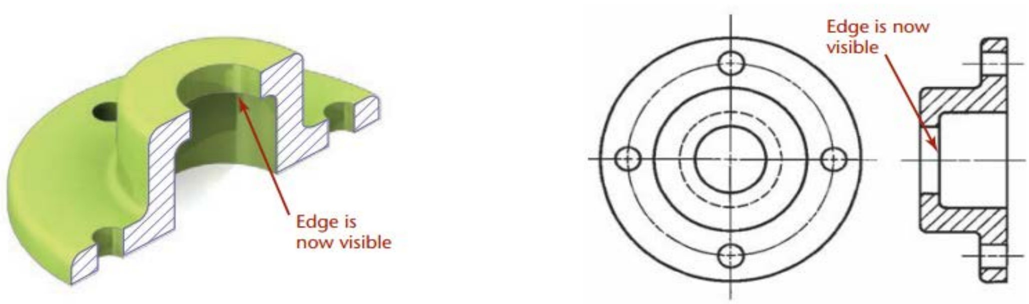


Figure 3.63: Some previously hidden edges of the part are visible in the section view

Visualising a Full Section

1. **Choose a Cutting Plane**

   This illustration **Figure 3.64** shows a collar that needs to be sectioned. To create a clear section showing both the counterbored recess and the smaller hole near the top, choose a cutting plane that goes through the vertical centreline in the front view. Imagine that the right half of the object is cut away.

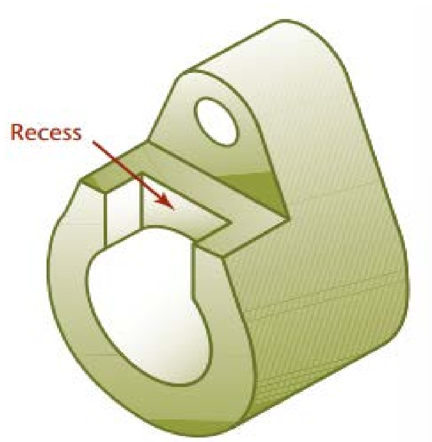


Figure 3.64: Collar that needs to be sectioned

2. **Identify the Surfaces**

   The pictorial drawing of the remaining half is shown below (see **Figure 3.65**). The first step in projecting the section view is making sure that you interpret the object correctly. Identifying the surfaces on the object can help. Surfaces R, S, T, U, and V have been labelled on the given views and the pictorial view.

   a. Which surface is R in the front view?
   b. Which surface is U in the top view?
   c. Are they normal, inclined, or oblique surfaces?
   d. Can you identify the counterbored recess in each view?

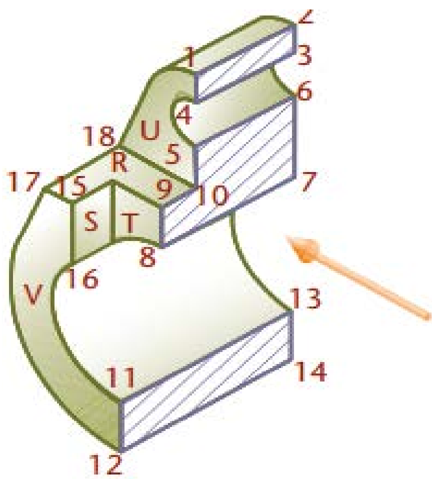


Figure 3.65: Remaining half

3. **Draw the Section View**

   To create a section view, leave out the part of the object in front of the cutting plane. Focus only on the part that is visible behind it. First, identify which solid areas the cutting plane will go through. Remember, the outer part of an object is always solid, unless the cutting plane goes through an opening that leads to the outside. In the example given (**Figure 3.66**), the points that form the section view are marked, connecting points 1-2-3-4, 5-6-7-8-9-10, and 13-14-12-11. These areas are shown with hatching. Each sectioned area is fully enclosed by lines that can be seen. The section view also displays all visible parts behind the cutting plane. There are no hidden lines included. However, note that the example in this step is missing some visible lines.

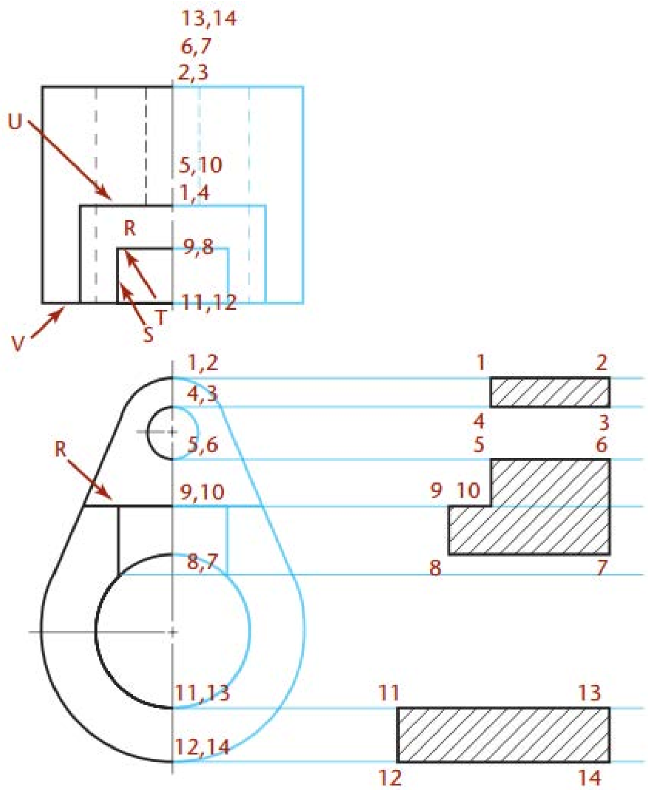


Figure 3.66: Section view

4. **Project the Visible Lines**

   From the direction the section is viewed, the top surface (V) of the object appears in the section as a visible line (12-11-16-15). The bottom surface of the object appears similarly as 14-13-7-6-3-2. The bottom surface of the counterbored recess appears in the section as line 19-20. Also, the back half of the counterbored recess and the drilled hole appear as rectangles in the section at 19-20-15-16 and 3-4-5-6. These points must also be projected. The finished view is shown below (**Figure** 3.67). Notice that since all cut surfaces are part of the same object, the hatching must all run in the same direction.

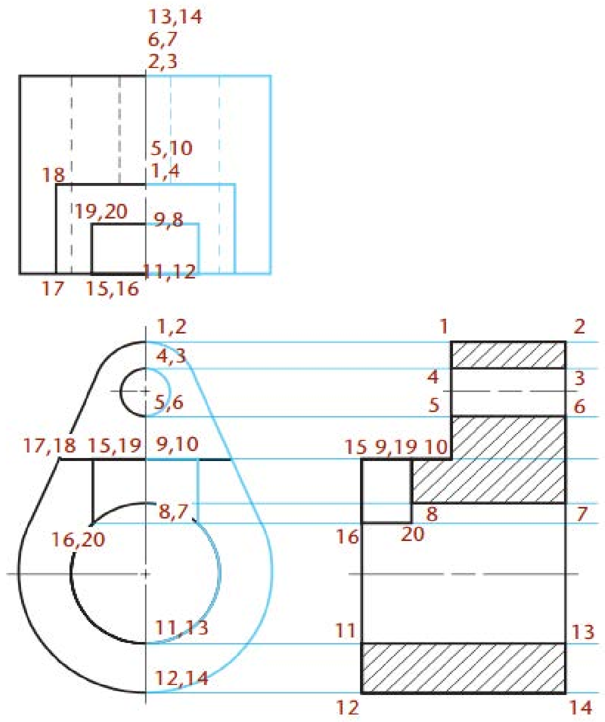


Figure 3.67: Visible lines

Placement of Section Views

Section views can replace the normal top, front, side, or other standard orthographic views in the standard view arrangement. **Figure 3.68** shows an example. In this drawing, the front view of the object is shown in the section. Only two views are necessary. The front view is shown as a section view, and the cutting plane line is shown in the right-side view.

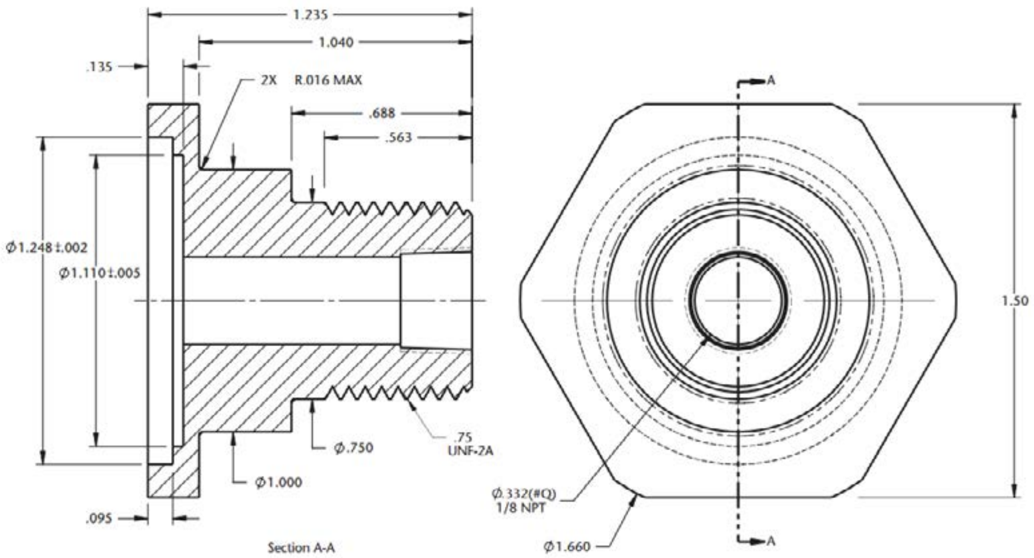


Figure 3.68: Section views can replace standard orthographic views

In **Figure 3.69**, the object is sectioned with a plane that is parallel to the front view, and the front half of the object is imagined to be removed. This results in a full section, which can be referred to as the "front view in section," since it occupies the same position as the front view. In **Figure 3.69b**, the cutting plane is horizontal, which appears as a line in the front view. In this case, the upper half of the object is imagined to be removed, and the resulting full section is displayed in place of the top view. When adding a section view to your drawing, remember that your goal is to document and convey information about your design, presenting it in the most effective way to achieve this objective.

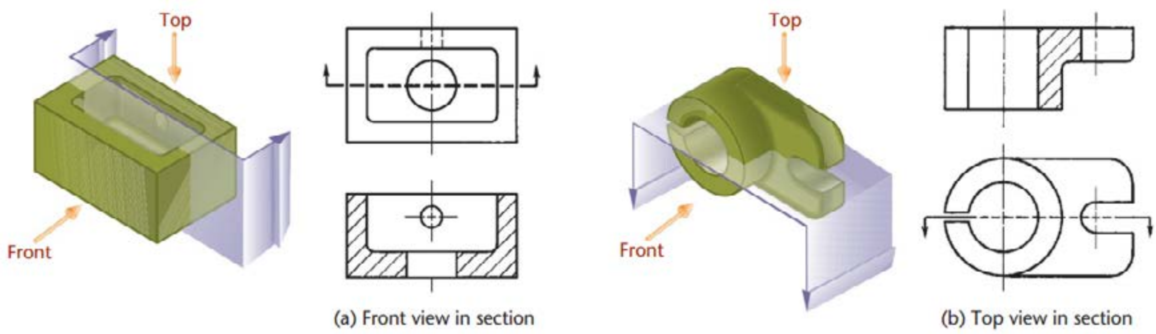


Figure 3.69: Front and Top Views in Section

Labelling Cutting Planes

In **Figure 3.70**, two cutting planes are illustrated: one is parallel to the front view, and the other is parallel to the side view. Both planes are shown edgewise in the top view. Each section is independent of the other and drawn without considering the presence of the other. For section A–A, the front half of the object is imagined to be removed. The back half is then observed from the direction indicated by the arrows to produce a front view of the section. For section B–B, the right half of the object is imagined to be removed, allowing the view of the left half from the direction of the arrows for a right-side view. The resulting section is represented as a right-side view in section. Typically, cutting-plane lines should be drawn through an exterior view (in this case, the top view shown) rather than through a section view. In **Figure 3.66**, the cutting-plane lines are included for illustration purposes only but are generally omitted when the location of the cutting plane is clear.

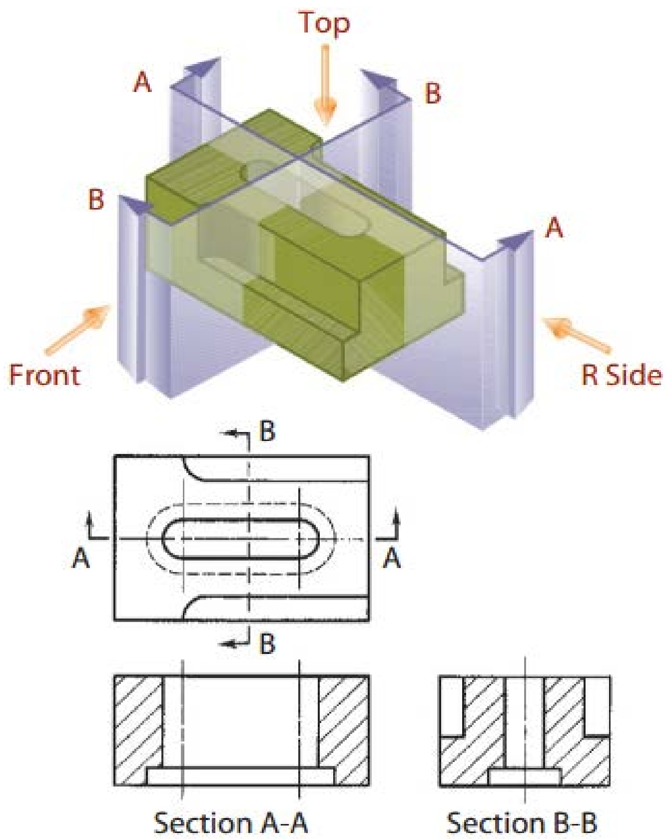


Figure 3.70: Front and Side Views in Section

Section-Lining Technique

1. The correct method of drawing section lines is shown in **Figure 3.61a**. When drawing by hand, use a sharp, medium grade pencil (H or 2H) to draw uniformly thin section lines, or hatching (a term meaning closely spaced parallel lines).
2. There should be a marked contrast between the thin section lines and the thick visible outlines of the part.
3. Draw section lines at 45° from horizontal unless they would be parallel or perpendicular to major edges of the part, in which case use a different angle. **Figure 3.61b** shows an example of section lines drawn at a different angle to prevent them from being parallel or perpendicular to visible outlines.
4. Space the lines as evenly as possible by eye (for most drawings, about 2.5 mm (110″) apart). The spacing interval depends on the size of the drawing or of the sectioned area, with larger drawings having wider spacing. In a smaller drawing the spacing interval may be as small as 1.5 mm (116″); in a large drawing, it may be 3 mm (18″) or more. As a rule, space the lines as generously as possible, yet close enough to clearly distinguish the sectioned areas.
5. Keep extension lines and dimension values off sectioned areas. If there is no alternative, omit the section lines behind the dimensions (**Figure 3.71c**).

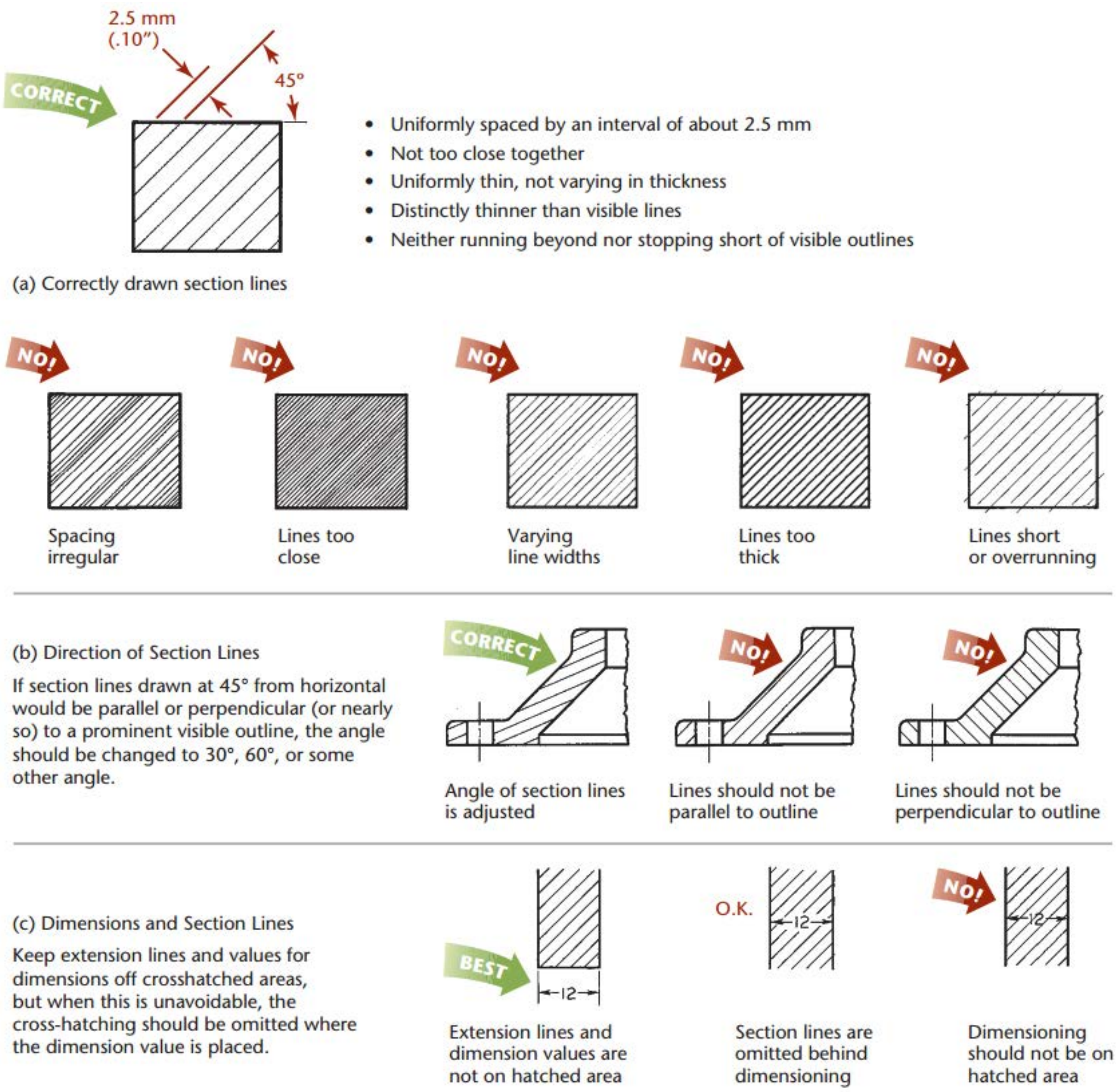


Figure 3.71: Correct and Incorrect Section-Lining Technique

Section-Lining Symbols

Section-lining symbols (see **Figure 3.72**) are used to indicate specific types of materials in technical drawings. These symbols represent general categories, such as cast iron, brass, and steel. However, due to the vast number of material variations—such as the hundreds of steel types—a general symbol is not sufficient. Therefore, a detailed specification listing the exact material must be provided, either as a note or within the title strip. The general-purpose section lining, which is the same as that for cast iron, can be used to represent any material in the detail drawing of a single part. Utilising different section-lining patterns can help differentiate various materials, particularly in assembly drawings. However, it is also acceptable to use the general-purpose symbol at different angles for different parts.

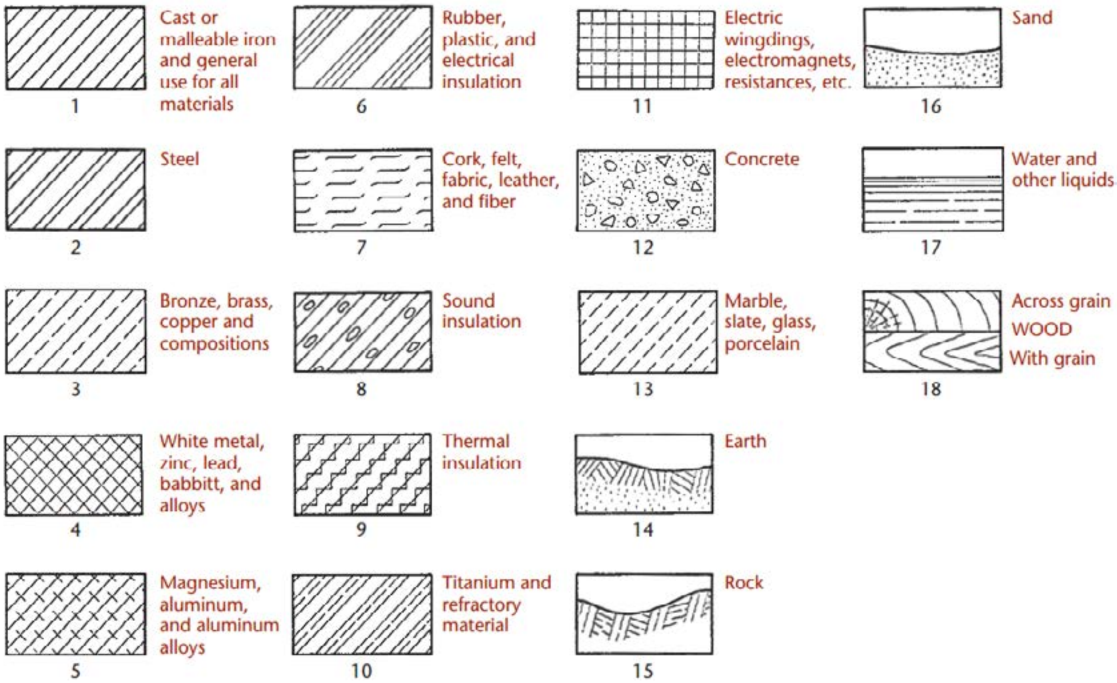


Figure 3.72: Symbols for Section Lining

Importance of Sectioning

The reduction in the number of hidden lines is achieved by sectioning. Sectioning of a drawing can be undertaken for the following reasons:

1. To expose internal features and thereby reduce the complexity of reading or producing a drawing involving hidden lines, and
2. To facilitate dimensioning by turning the undesirable hidden lines into visible lines required for dimensioning (**Figure 3.73**).

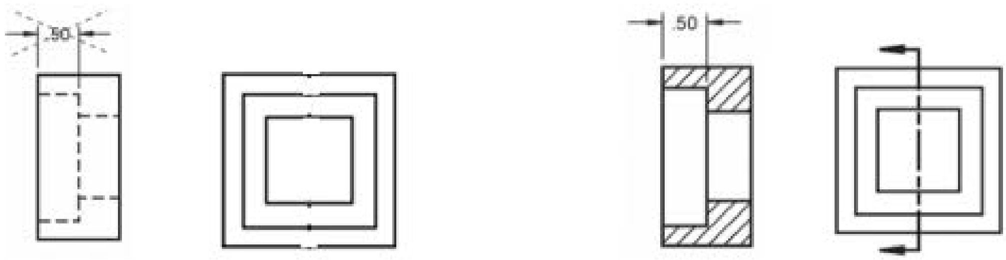


Figure 3.73: Sectioning facilitating dimensioning

Demonstration of Sectioning

Figure 3.74 shows an un-sectioned view of a block.

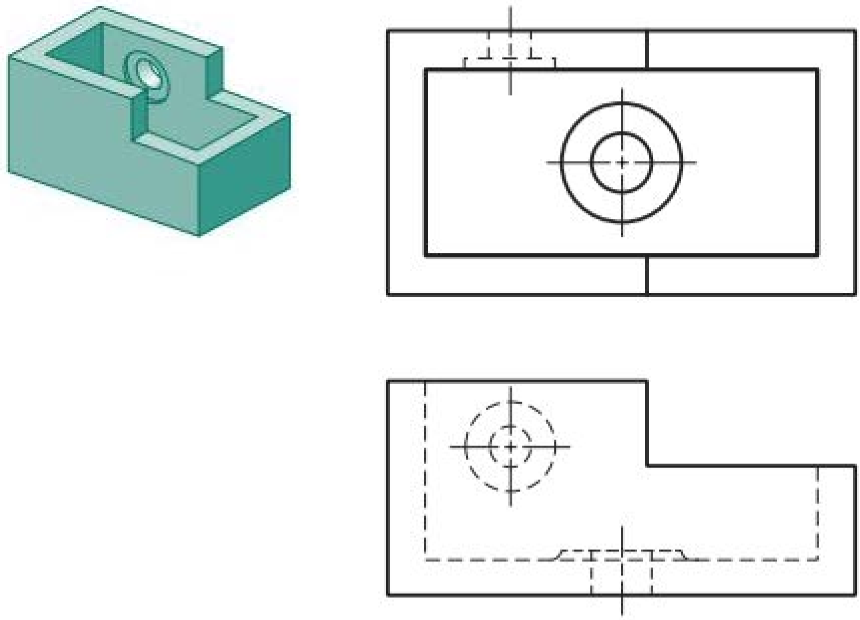


Figure 3.74: Un-sectioned view

Making a cut through the object with the aid of a cutting edge to expose the internal structures of the object as can be seen in **Figure 3.75**

- Object = block
- Knife = cutting plane
- Arrow = direction of viewing

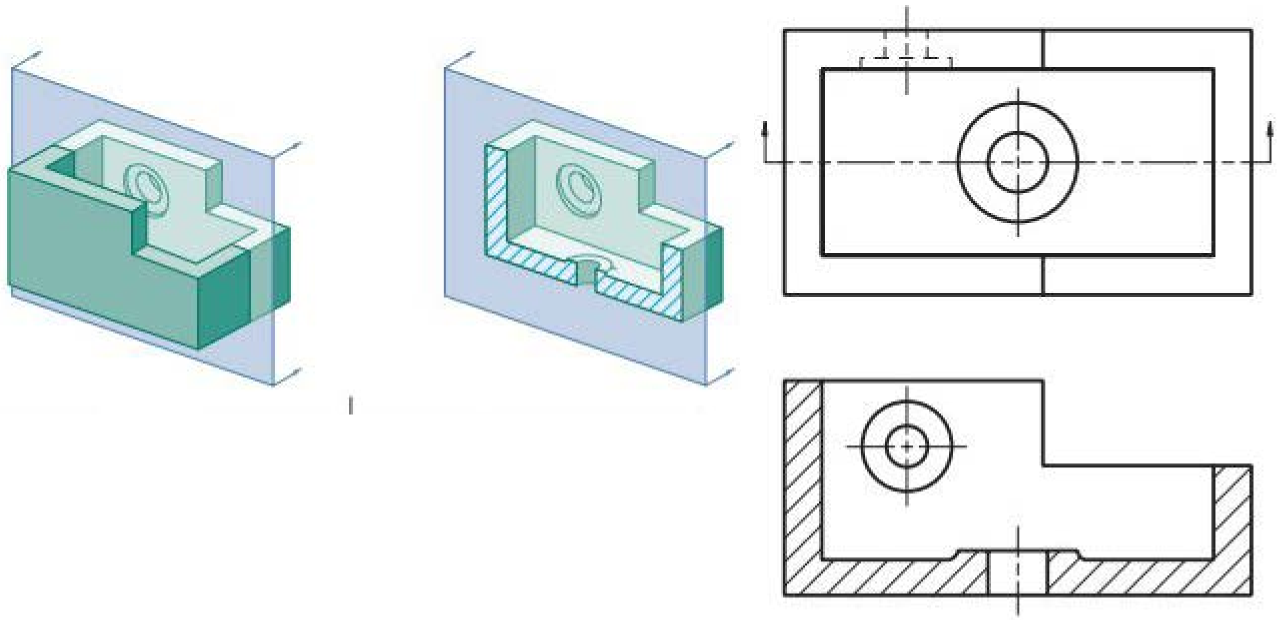


Figure 3.75: Sectioning of a block

Dimensioning

Dimensioning is art assigning dimensions, notes, and conventions to the views of an object or objects, such as to provide a clear and complete description of the object(s). Dimensioning in drawing, design, and manufacturing is a critical process that involves specifying the geometry, size, and allowable variations of parts and assemblies to ensure accurate communication among stakeholders, including

a. design engineers,
b. manufacturing personnel, and
c. quality inspectors.

This process is facilitated by Geometric Dimensioning and Tolerancing (GD&T), a symbolic language that provides a clear and concise technique for defining reference coordinates (datums) and dramatically reduces the need for extensive drawing notes. Dimensional measurement ensures that manufactured products conform to their designs within acceptable limits, acting as a vital link between design and manufacturing. Overall, dimensioning is a foundational aspect of technical drawing and manufacturing that ensures precision, quality, and effective communication across all stages of product development.

Aspects of Good Dimensioning

Dimensions are given in the form of distances, angles, and notes regardless of the dimensioning units being used. For both CAD and hand drawing, the ability to create good dimensioned drawings requires the following:

1. **Technique of dimensioning**

   The standards for the appearance of lines, spacing of dimensions, size of arrowheads, and so on, allow others to read your drawing. A typical dimensioned drawing is shown in **Figure 3.73**. Note the strong contrast between the visible lines of the object and the thin lines used for the dimensions. The dimensions are easily read because they follow the standards for dimensioning technique.

2. **Placement of dimensions**

   Use logical placement for dimensions according to standard practices so that they are legible, easy to find, and easy for the reader to interpret. Notice that when dimensions are placed between two views, it is easier to see how the dimension relates to the feature as shown in each view.

3. **Choice of dimensions**

   The dimensions you show affect how your design is manufactured. Dimension first for function and then review the dimensioning to see if you can make improvements for ease of manufacturing without adversely affecting the final result. 3D CAD models can be transmitted as all or part of a digital product definition, but this method still requires a thorough understanding of the sizes and relationships between the part features.

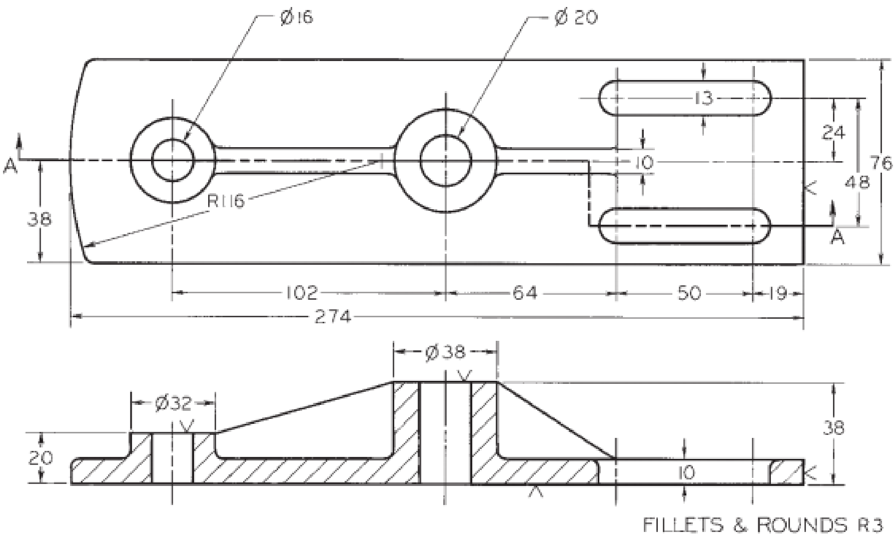


Figure 3.76: A drawing dimensioned in millimetres

A drawing released for production should show the object in its completed state and contain all necessary information for specifying the final part. As you select which dimensions to show, provide functional dimensions that can be interpreted to manufacture the part as you want it built.

Keep in mind:

- The finished piece.
- The function of the part in the total assembly.
- How you will inspect the final part to determine its acceptability.
- Production processes.

Also, remember the following points:

- Give dimensions that are necessary and convenient for producing the part.
- Give sufficient dimensions so that none must be assumed.
- Avoid dimensioning to points or surfaces inaccessible to the worker.
- Do not provide unnecessary or duplicate dimensions.

Geometric Breakdown

Engineering structures primarily consist of simple geometric shapes, such as prisms, cylinders, pyramids, cones, and spheres. These shapes can be classified as exterior (positive) forms or interior (negative) forms. For instance, a steel shaft represents a positive cylinder, while a round hole exemplifies a negative cylinder. The choice of these shapes is driven by design necessities, which prioritise simplicity, as well as the requirements of fundamental manufacturing processes. Forms with flat surfaces are typically created through operations such as planning, shaping, and milling. In contrast, shapes with cylindrical, conical, or spherical surfaces are produced using rotary operations like turning, drilling, reaming, boring, and countersinking. When dimensioning engineering structures, one approach involves two basic steps:

1. Give the dimensions showing the sizes of the simple geometric shapes, called size dimensions.
2. Give the dimensions locating these elements with respect to one another, called location dimensions.

It is important to note that a location dimension identifies a 3D geometric element rather than just a surface; if it were only about surfaces, all dimensions would need to be categorised as location dimensions. This geometric analysis process aids in determining the features of an object and how those features relate to each other. However, merely dimensioning the geometry is not sufficient. You must also consider the part's function within the assembly and the manufacturing requirements. This approach is similar to the methods used when modelling designs in 3D CAD.

Lines Used in Dimensioning

A dimension line is a thin, dark, solid line that is terminated by an arrowhead, indicating the direction and extent of a measurement (see **Figure 3.77**). In machine drawings, dimension lines are typically broken near the middle to allow space for the dimension value. In structural and architectural drawings, the dimension **Figure** is placed above an unbroken dimension line. As illustrated in **Figure 3.78**, the dimension line closest to the object outline should be spaced at least 10 mm (3/8″) away. All other parallel dimension lines should be at least 6 mm (1/4″) apart, and more if space permits. It is important that the spacing between dimension lines remains consistent throughout the drawing.

An extension line is a thin, dark, solid line that extends from a point on the drawing to which a dimension applies (refer to **Figure 3.78**). The dimension line meets the extension lines at right angles, except in special cases. A gap of approximately 1.5 mm (1/16″) should be left where the extension line joins the object outline. Additionally, the extension line should extend about 3 mm (1/8″) beyond the outermost arrowhead.

A centreline is represented by a thin, dark line with alternating long and short dashes. Centrelines are commonly used as extension lines to locate holes and other symmetrical features (see **Figure 3.79**). When extended for dimensioning, centrelines can cross over other lines in the drawing without creating gaps. Always finish centrelines with a long dash. Refer to **Figure**s **3.77–3.79** for examples of the different lines used in dimensioning.

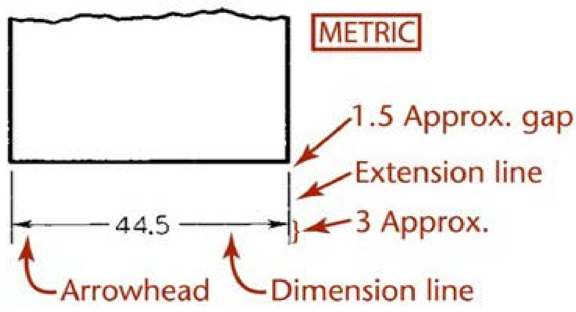


Figure 3.77: Dimension Line

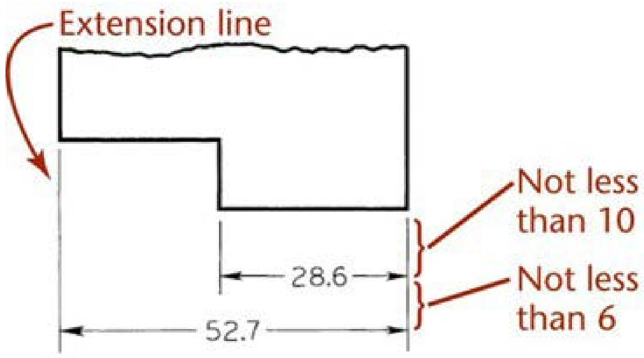


Figure 3.78: Extension Lines

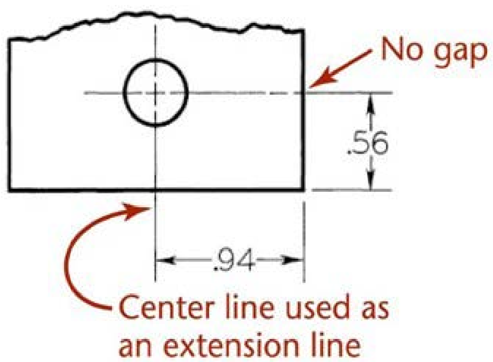


Figure 3.79: Centrelines

Dimensioning by Geometric Breakdown

To dimension the object shown in isometric at right, use the geometric breakdown as follows:

1. Consider the geometric features of the part (**Figure 3.80**). In this case, the features to be dimensioned include
   a. two positive prisms,
   b. one positive cylinder,
   c. one negative cone, and
   d. six negative cylinders.

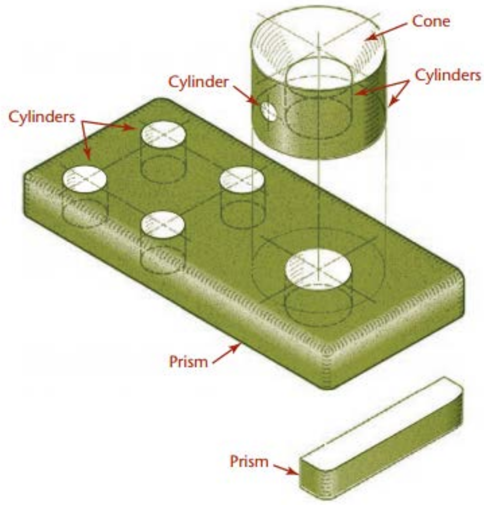


Figure 3.80: Geometric features

2. Specify the size dimensions for each feature by adding the dimension values as indicated in **Figure 3.81**. (In this illustration, the word "size" indicates the various dimension values.) Note that the four cylinders of the same size can be specified with one dimension.

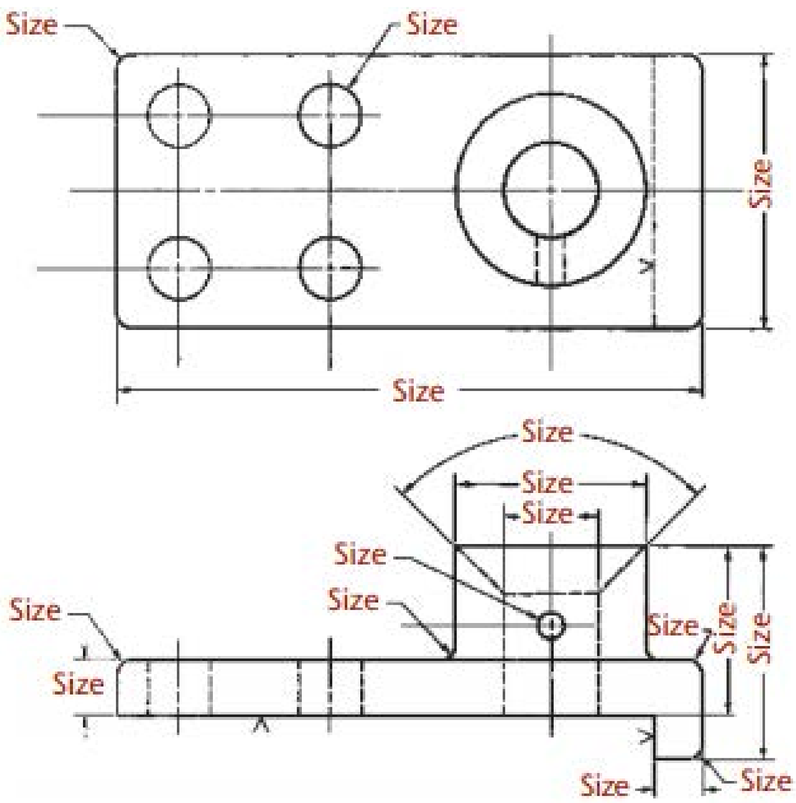


Figure 3.81: Size dimensions

3. Finally, locate the geometric features with respect to one another. (Actual values would replace the words "size" and "location" in this illustration, **Figure 3.82**.) Always check to see that the object is fully dimensioned.

Using Dimension and Extension Lines

Dimension lines and extension lines should adhere to the guidelines presented in **Figure 3.82 (a)**. Ensure that shorter dimensions are placed closest to the object's outline. Avoid having dimension lines cross extension lines, as shown in **Figure 3.82 (b)**, which occurs when shorter dimensions are positioned outside. It is acceptable to have extension lines cross each other as seen in **Figure 3.82 (b)**, but they should not be shortened (refer to **Figure 3.82 (b)**).

Additionally, a dimension line must never coincide with or extend from any line in the drawing (illustrated in **Figure 3.82 (b)**. Strive to avoid crossing dimension lines whenever possible. Dimensions should be aligned and grouped together as much as possible, as depicted in **Figure 3.82 (c)**, rather than arranged as in **Figure 3.82 (b)**. In many instances, extension lines and centrelines must intersect visible lines of the object (see **Figure 3.82 (a)**).

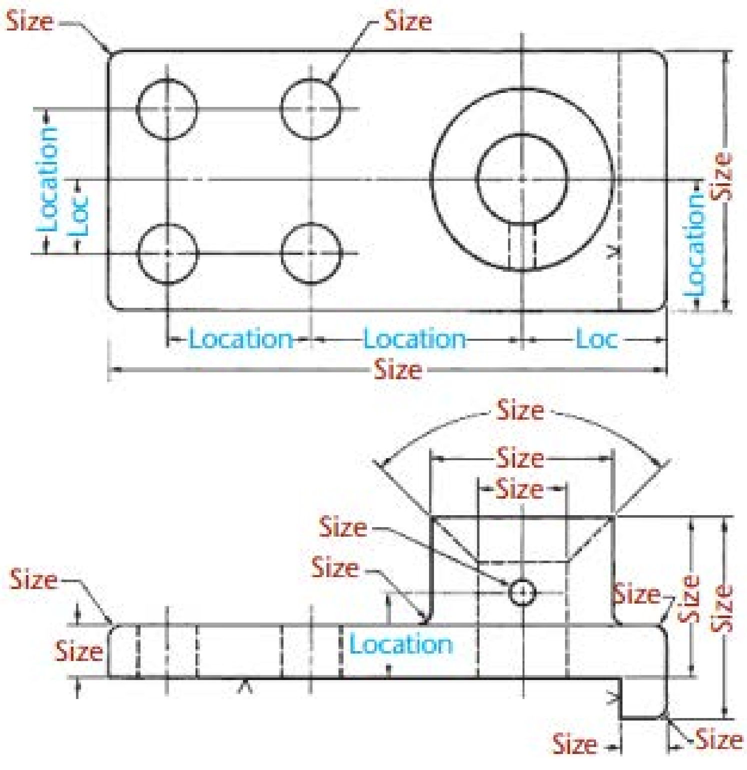


Figure 3.82: (a) Dimension and extension lines

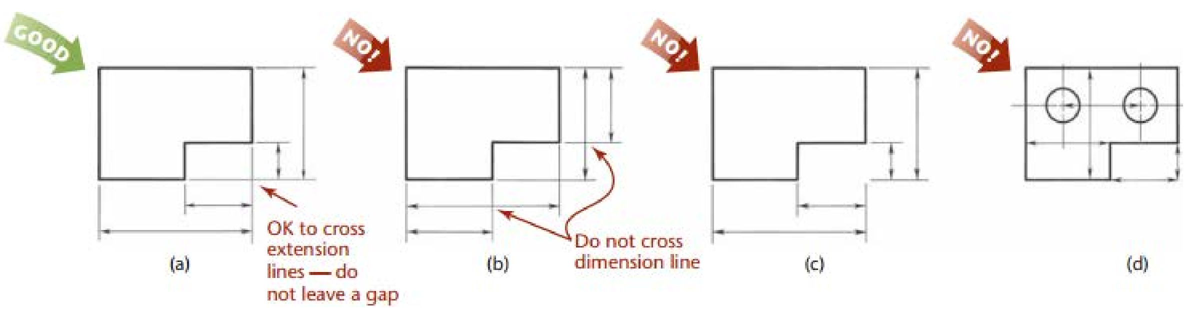


Figure 3.82: (b) Dimension and extension lines

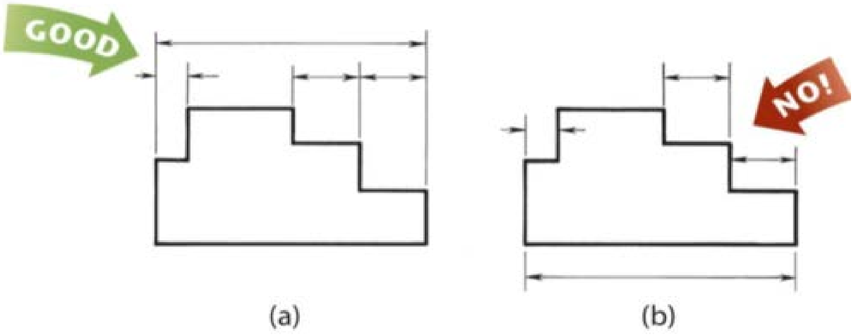


Figure 3.82: (c) Grouped Dimensions

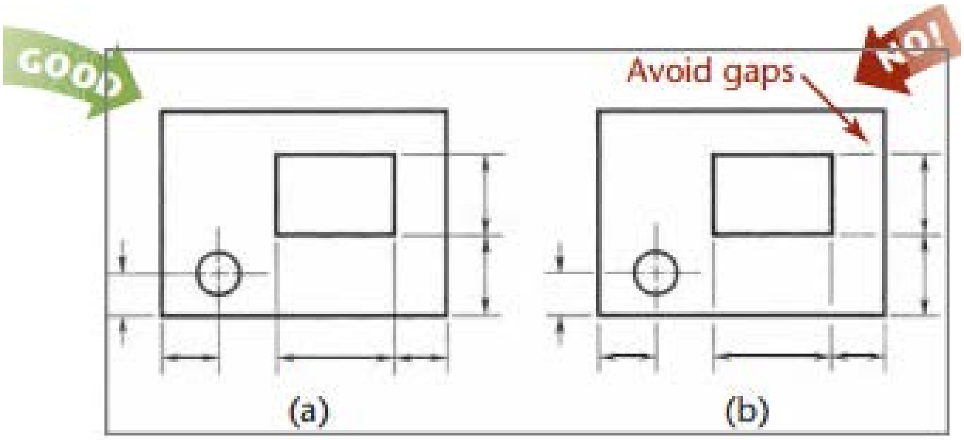
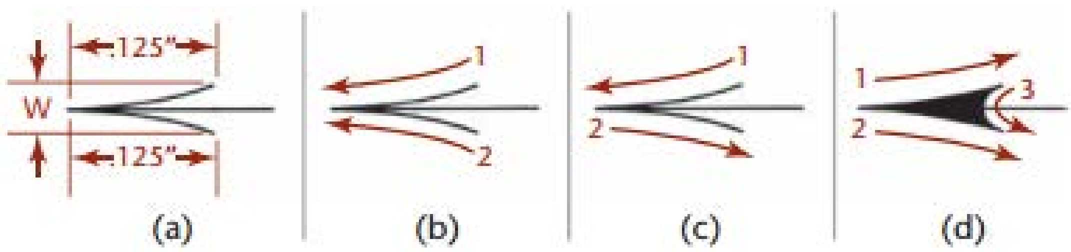


Figure 3.82: (d) Crossing Lines

Arrowheads

Arrowheads, as shown in **Figure 3.83**, indicate the extent of dimensions in a drawing. They should be uniform in size and style throughout the drawing, regardless of the drawing's overall size or the length of the dimensions. When sketching arrowheads freehand, ensure the length and width maintain a ratio of 3:1. The length of each arrowhead should be equal to the height of the dimension values, approximately 3 mm or 1/8 inch long. For optimal appearance, fill in the arrowhead as illustrated in **Figure 3.83 (d)**. **Figure 3.83** also displays the preferred arrowhead styles for mechanical drawings. Most CAD systems offer a variety of styles to choose from.



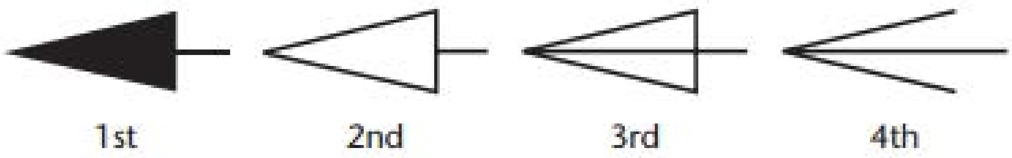


Figure 3.83: Arrowheads and order of preference for arrow styles

Leaders (Leader Lines)

A leader is a thin, solid line that directs attention to a note or dimension, beginning with either an arrowhead or a dot. The leader should be an inclined straight line drawn at a large angle, except for a short horizontal shoulder (approximately 3–6 mm or 1/8–1/4 inch) that extends from the centre of the first or last line of text associated with the note. When leading to a circle, the line should be radial, meaning it would pass through the centre of the circle if extended. Examples of leader lines can be seen in **Figure**s **3.84** (a)–(d). Use an arrowhead to start the leader when indicating a specific line in the drawing, such as the edge of a hole. Use a dot to begin the leader when locating something within the outline of the object, such as an entire surface (refer to **Figure**s **3.84** (e) and (f)).

For the Best Appearance, Make Leaders:

a. Near each other and parallel.
b. Across as few lines as possible.

Do not Make Leaders:

a. Parallel to nearby lines of the drawing.
b. Through a corner of the view.
c. Across each other.
d. Longer than needed.
e. Horizontal or vertical.

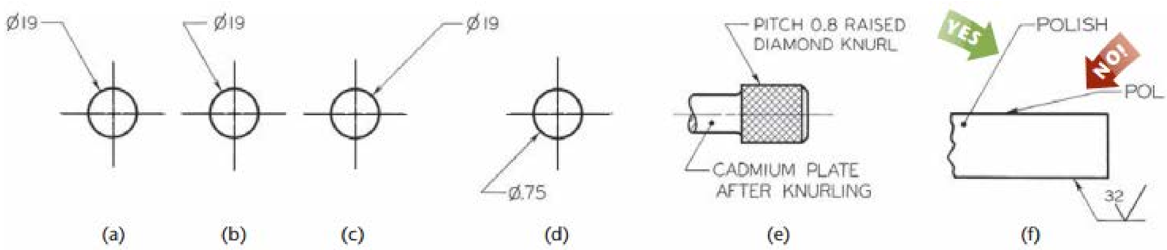


Figure 3.84: Leaders

Drawing Scale and Dimensioning

The scale is designed to help you visualise the object's size, but it should not be used to convey precise dimensions. Do not scale measurements from drawings to determine an unknown dimension. Many standard title blocks include a note stating, "DO NOT SCALE DRAWING FOR DIMENSIONS," as illustrated in **Figure 3.85**.

Draw a thick line under any dimension value that is not to scale (see **Figure 3.86**). Before CAD became common, if a change in a drawing was not important enough to update, people would just change the dimension value. If the dimension does not match the drawing, the part will be made according to the dimension, not the image. If you notice an error, many manufacturers will check to see if the drawing is correct. However, it is your job to clearly state what you want built. If the whole drawing is not to a standard scale, write "NONE" in the scale area of the title block.

The abbreviation "NTS," which stands for "not to scale," can be found on older drawings. When creating a drawing using CAD software, it is essential to define dimensions according to the appropriate standards. Since CAD drawings are easy to edit, it is advisable to adjust the drawing geometry when making changes rather than simply altering the dimension values. If you are using a digital model as the sole definition for the part, ensure that the model dimensions are accurately represented.

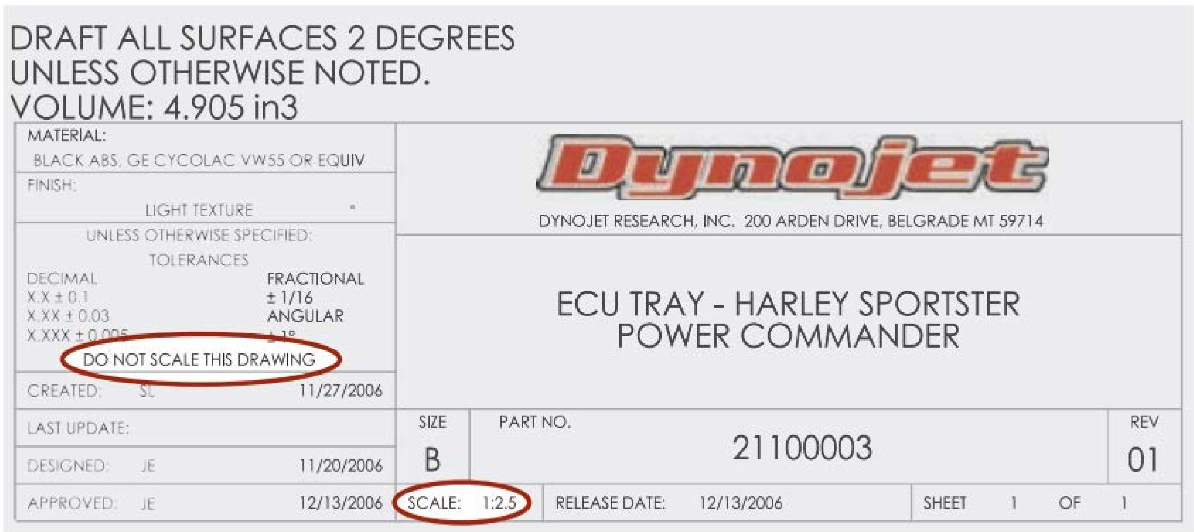


Figure 3.85: Drawing scale is noted in the title block. The drawing should not be scaled for dimensions

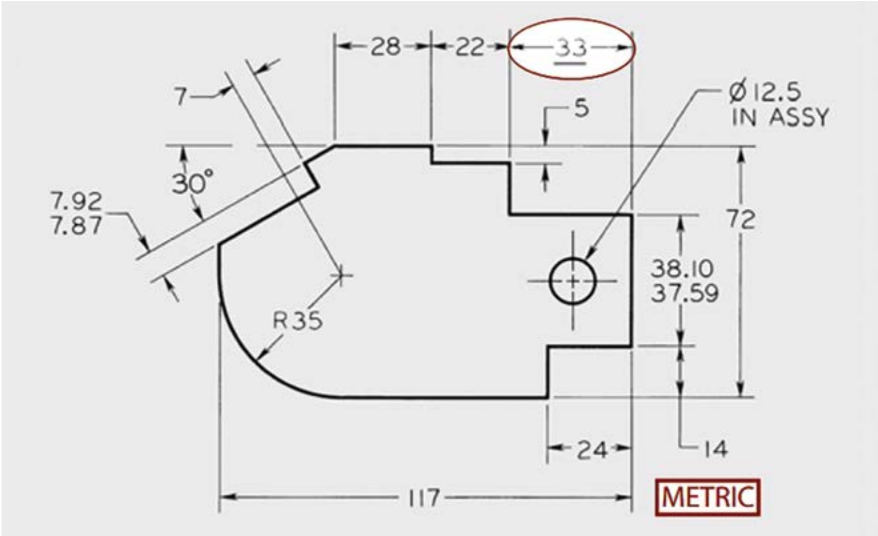


Figure 3.86: Draw a heavy line under any dimension value that is not to scale.

Keeping Dimensions and Lettering Legible at Smaller Scales

The lettering height, dimension line spacing, and similar elements should be represented at their actual size on the plotted sheet. If you plan to use reduced-size working prints, increase the size of the lettering, dimension arrows, and other components by approximately 50% (depending on the degree of reduction) to ensure they remain legible on the smaller print.

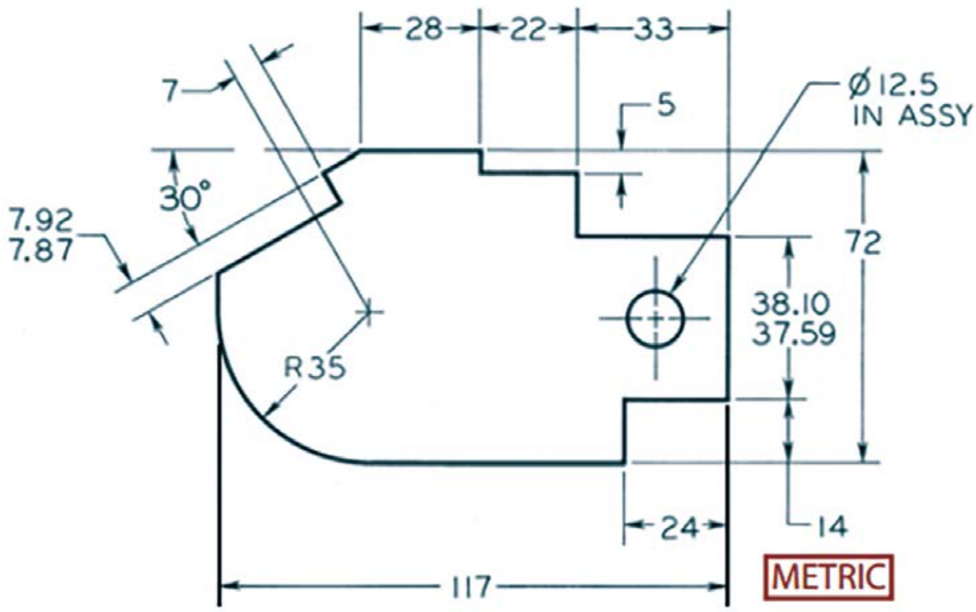


Figure 3.87: Unidirectional Dimension **Figure**s

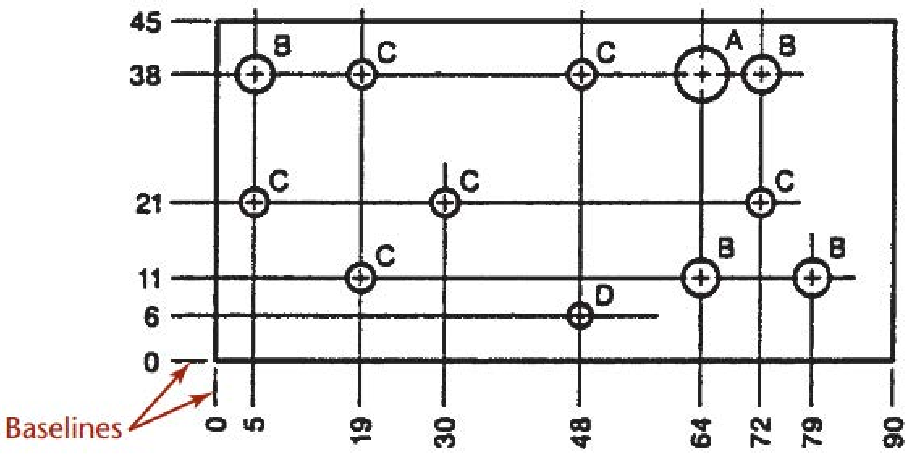


Figure 3.88: Rectangular coordinate dimensioning shows values reading from the right

Dimension Units

Dimension values are shown using metric or decimal-inch values. Millimetres and decimal inches can be added, subtracted, multiplied, and divided more easily than fractions. For inch–millimetre equivalents of decimal and common fractions, see the inside back cover of this book.

When a note stating ALL MEASUREMENTS IN MILLIMETRES or ALL MEASUREMENTS IN INCHES UNLESS OTHERWISE NOTED is used in the title block to indicate the measurement units, no units are needed with the dimension values. When indicating dimensions:

1. Millimetres are indicated by the lowercase letters mm placed to the right of the numeral, as in 12.5 mm.
2. Metres are indicated by the lowercase m, as in 50.6 m.
3. Inches are indicated by the symbol ″ placed slightly above and to the right of the numeral.
4. Feet are indicated by the symbol ′ similarly placed. It is customary in feet-inch expressions to omit the inch mark.

It is standard practice to omit millimetre designations and inch marks on drawings and note the units in the title block except when there is a possibility of misunderstanding. For example, 1 VALVE should be 1″ VALVE. Either metres or feet and inches and fractional inches are used in architectural and structural work where precision in the thousandths of an inch is not necessary, and the steel tape or framing square is used to make measurements. Commodities such as pipe and lumber are identified by standard nominal sizes that are close to the actual dimensions. In some industries, all dimensions, regardless of size, are given in inches; in others, dimensions up to and including 72″are given in inches, and dimensions greater than 72″ are given in feet and inches. In U.S. structural and architectural drafting, all dimensions of 1′ or more are usually expressed in feet and inches.

Notations of Dimensioning

Dimensioning involves assigning dimensions to a drawing under specific regulations and conventions. **Figure** 3.89 shows general information that can be found under dimensioning:

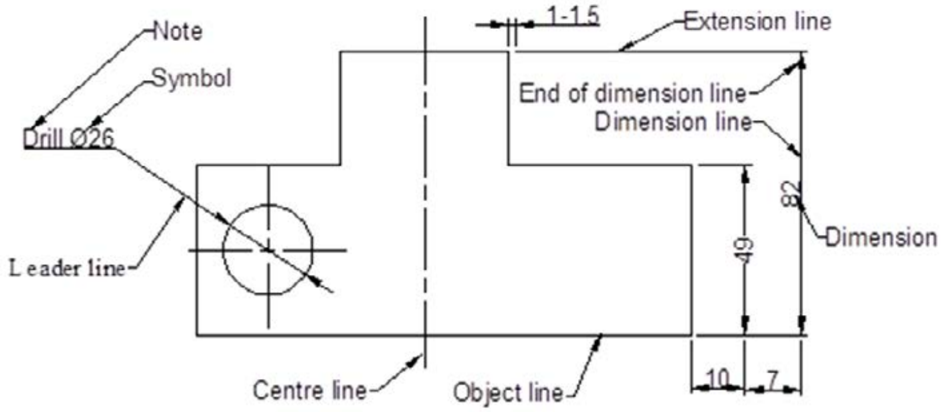


Figure 3.89: Notations of dimensioning

Dimensioning Symbols

A variety of dimensioning symbols are used to replace traditional terms or abbreviations (see **Figure** 3.90). The symbols are preferred because they take less space in the drawing, and they are internationally recognised and, therefore, do not have translation issues if the part is manufactured in a country where a different language is spoken. Traditional terms and abbreviations found in Appendix 2 can be used if necessary.

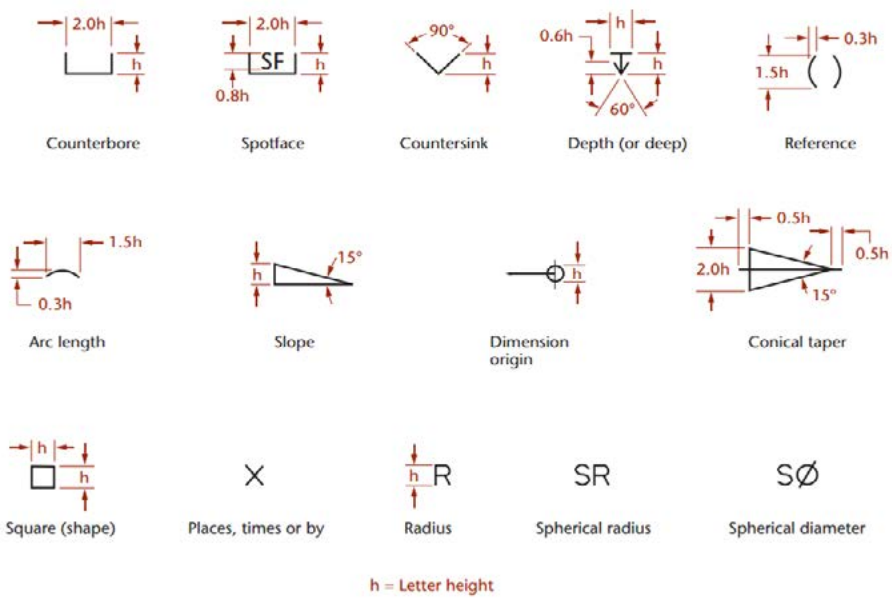


Figure 3.90: Form and Proportion of Dimensioning Symbols

Placing and Showing Dimensions Legibly

Rules for placing dimensions are essential for making your drawings clear and readable. They guide the location of dimensions in standard areas, ensuring that anyone manufacturing the part won't need to search through a complicated drawing to find the necessary information. While it's important to strive for these placement rules, there may be instances where you cannot follow them exactly. Always remember that the ultimate goal is to dimension the drawing clearly so that the parts are built to your specifications.

Rules for Placing Dimensions Properly

1. Never place a dimension value over any line on the drawing; if necessary, break the line.
2. In a group of parallel dimension lines, the dimension values should be staggered, as in **Figure** 3.91a, and not stacked up one above the other, as in **Figure 3.91b**.
3. Do not crowd dimension Figures into limited spaces, making them illegible. There are techniques for showing dimension values outside extension lines or in combination with leaders (**Figure 3.92**). If necessary, add a removed partial view or detail to an enlarged scale to provide the space needed for clear dimensioning.
4. Place dimensions between views, when possible, but attached to only a single view. This way, the dimension relates to the feature, which can be seen in more than one view.
5. When a dimension must be placed in a hatched area or on the view, leave an opening in the hatching or a break in the lines for the dimension values, as shown in **Figure 3.92b**.
6. Dimensions should not be placed on a view unless it promotes the clarity of the drawing, as shown in **Figure 3.93**.
7. In complicated drawings such as **Figure 3.93c**, it is often necessary to place dimensions on a view.
8. Avoid dimensioning to hidden lines (see **Figure 3.94**).
9. Do not attach dimensions to visible lines where the meaning is unclear, such as the dimension 20 in the top view shown in **Figure 3.95b**.
10. Notes for holes are usually placed where you see the circular shape of the hole, as in **Figure 3.94a**, but give the diameter of an external cylindrical shape where it appears rectangular. This way, it is near the dimensions of the length of the cylinder.
11. Give dimensions where the shapes are shown—where the object's contours are defined—as shown in **Figure** 3.**96**.
12. Locate holes in the view that show the shape of the hole clearly**.**

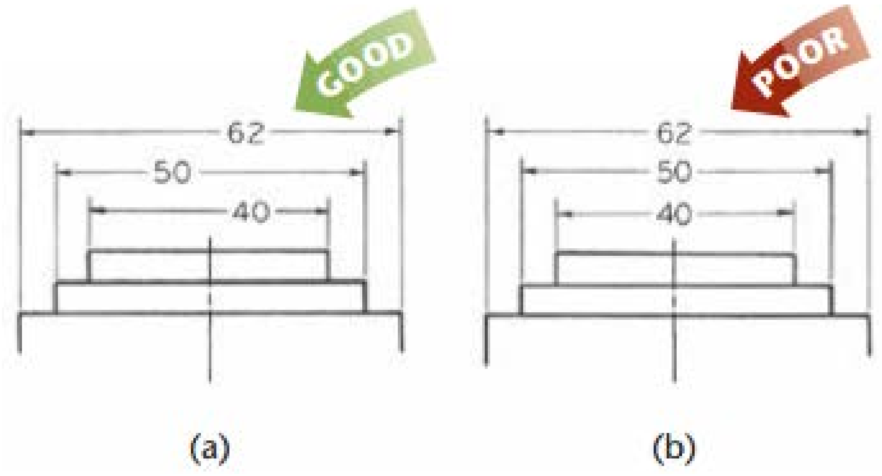


Figure 3.91: Staggered Numerals, Metric

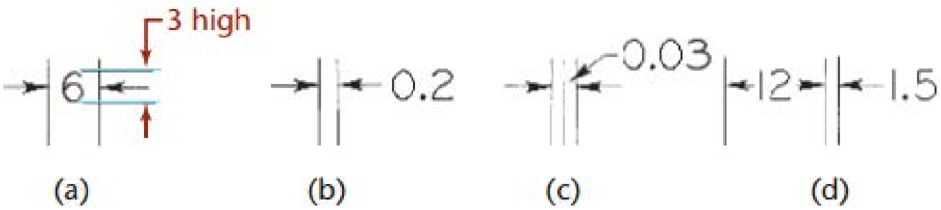


Figure 3.92: Fitting Dimension Values in Limited Spaces (Metric Dimensions)

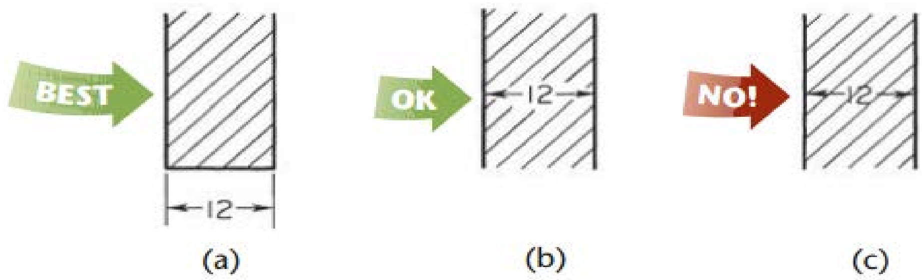


Figure 3.93: Dimensions and Section Lines

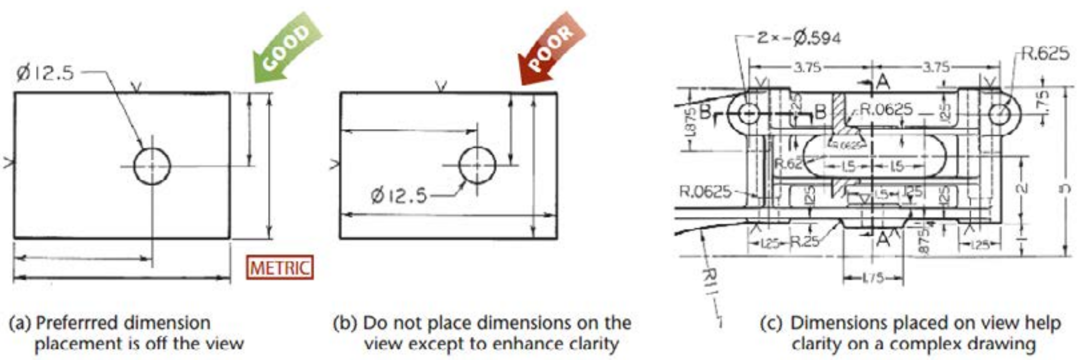


Figure 3.94: Place dimensions on view only when clarity is enhanced.

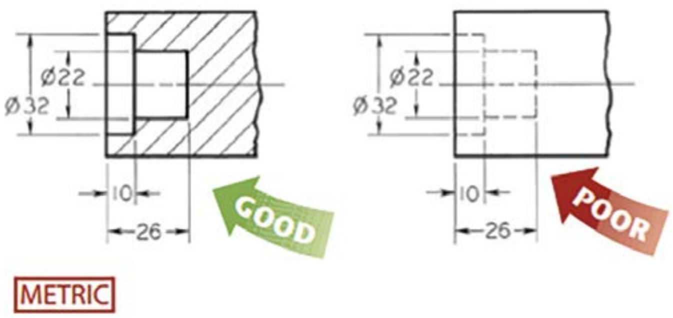


Figure 3.95: Placement of Dimensions

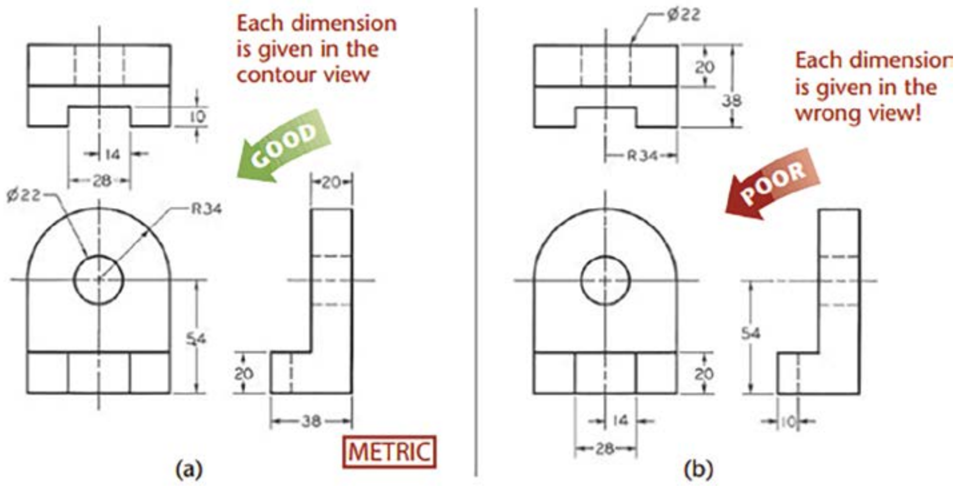


Figure 3.96: Place dimensions where the contours of the object are defined

Dimensioning Angles

Angles are dimensioned by specifying the angle in degrees and a linear dimension, as shown in **Figure 3.97a**. Coordinate dimensions can also be given for two legs of a right triangle, as shown in **Figure 3.97b**. The coordinate method is better when a high degree of accuracy is required. Variations in degrees of angle are hard to control because the amount of variation increases with the distance from the vertex of the angle. Methods of indicating angles are shown in **Figure 3.97**.

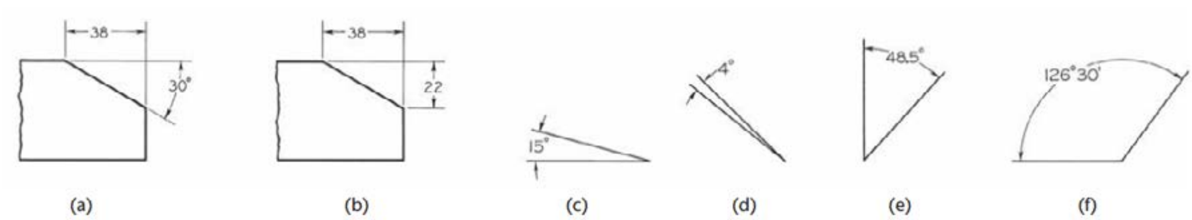


Figure 3.97: Dimensioning angles

Dimensioning Arcs

A circular arc is dimensioned in the view where its true shape is visible by indicating the radius value, preceded by the abbreviation "R" (see **Figure 3.98**). Small crosses mark the centres for clarity in the drawing, although this is not necessary for small or insignificant radii or for arcs that are not dimensioned. When there is sufficient space, both the radius value and the arrowhead are placed inside the arc. If space is limited, the arrowhead may remain inside while the radius value is moved outside.

Alternatively, both the arrowhead and the value can be positioned outside the arc. In cases where section lines or other lines obstruct the view, the value and leader can also be placed outside the crowded area. For longer radii, when the actual centre falls outside the available space, the dimension line should be directed toward the true centre. However, a false centre may be indicated with a "jogged" dimension line pointing to it (refer to **Figure 3.98f**).

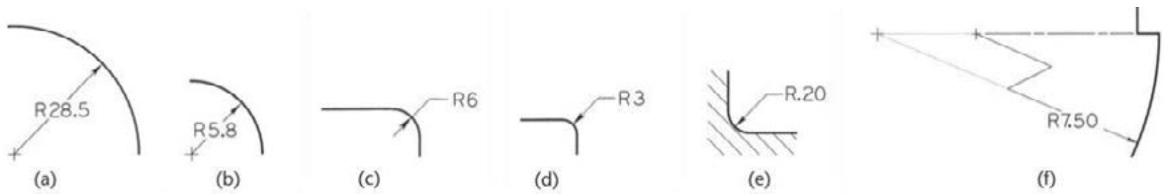


Figure 3.98: Dimensioning arcs

Fillets and Rounds

Individual fillets and rounds are dimensioned like other arcs. If there are only a few and they are obviously the same size, giving one typical radius is preferred. However, fillets and rounds are often numerous on a drawing, and they usually are some standard sizes, such as metric R3 and R6, or R.125 and R.250 when using decimal-inch dimensions. In this case, give a general note in the lower portion of the drawing, such as FILLETS R6 AND ROUNDS R3 UNLESS OTHERWISE SPECIFIED or ALL CASTING RADII R6 UNLESS NOTED or ALL FILLETS AND ROUNDS R6.

Size Dimensioning: Prisms

The right rectangular prism is one of the most common geometric shapes. The front and top views are dimensioned as shown in **Figure**s **3.99a** and **3.99b**. Typically, the height and width are indicated in the front view, while the depth is presented in the top view. When placing vertical dimensions, they can be positioned on either the left or right side, usually in line with the view. It is important to place the horizontal dimension between the views, rather than above the top view or below the front view. The front and side views should be dimensioned according to the examples in **Figure**s **3.99c** and 3.99d. Additionally, an example of size dimensions for a machine part composed entirely of rectangular prisms can be found in **Figure 3.100.**

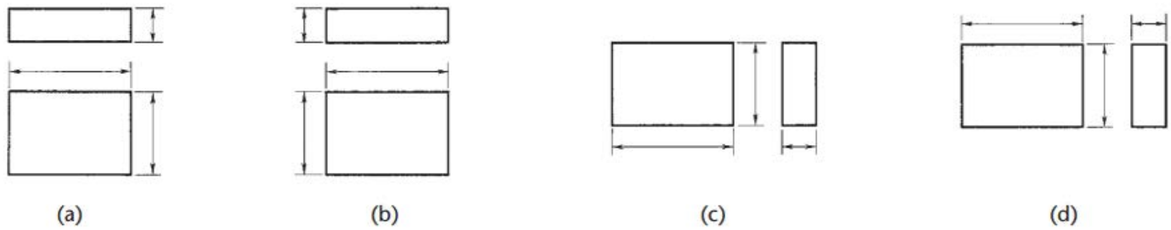


Figure 3.99: Dimensioning rectangular prisms

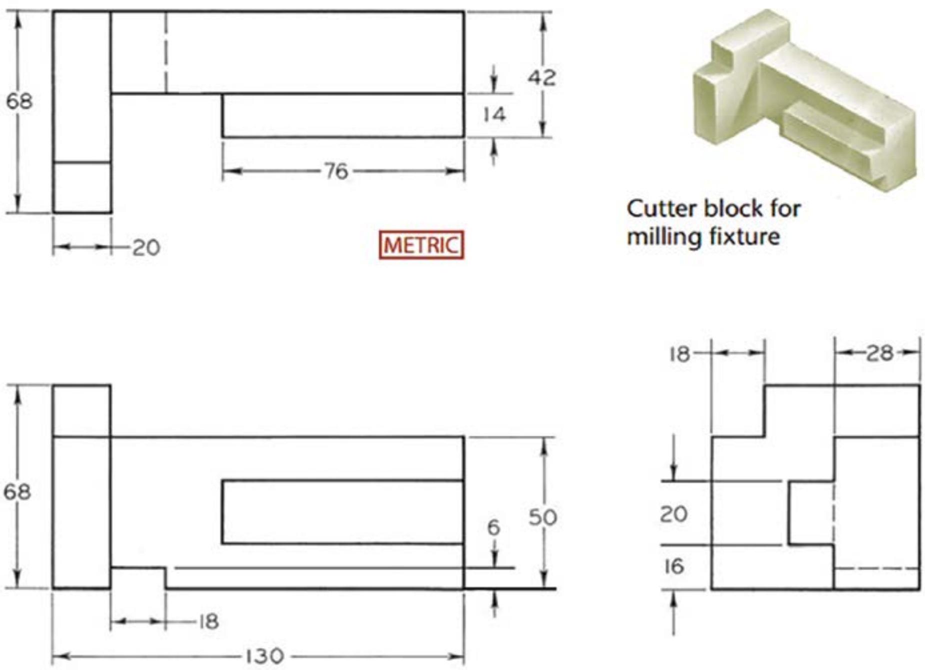


Figure 3.100: Dimensioning a machine part composed of prismatic shapes

Size Dimensioning: Cylinders

The right circular cylinder is one of the most common geometric shapes and is often seen as a shaft or a hole. Cylinders are typically dimensioned by providing the diameter and length, appearing as rectangles in technical drawings. When the cylinder is drawn vertically, indicate the length on the right or left side, as shown in **Figure**s **3.101** (a) and (b). Conversely, when the cylinder is drawn horizontally, the length should be provided above or below the rectangular view, as depicted in **Figure**s **3.101** (c) and (d). Avoid using diagonal diameters within the circular view unless it enhances clarity; multiple diagonal diameters at the same centre can lead to confusion.

It is important to note that the radius of a cylinder should not be provided, as measuring instruments like micrometres are designed to check diameters. For holes, dimensioning is typically done using notes that specify both the diameter and the depth, as illustrated in **Figure 3.104**. This can be done with or without additional manufacturing operations noted. Always use the diameter symbol (Ø) before all diameter dimensions, as shown in **Figure 3.103**a (ANSI/ASME Y14.5). In some instances, the symbol Ø may be used to replace the circular view, as indicated in **Figure 3.102**b. The abbreviation "DIA", following the numerical value, was commonly used in older decimal-inch drawings. If it is unclear whether a hole goes all the way through the part, include the note "THRU" after the value.

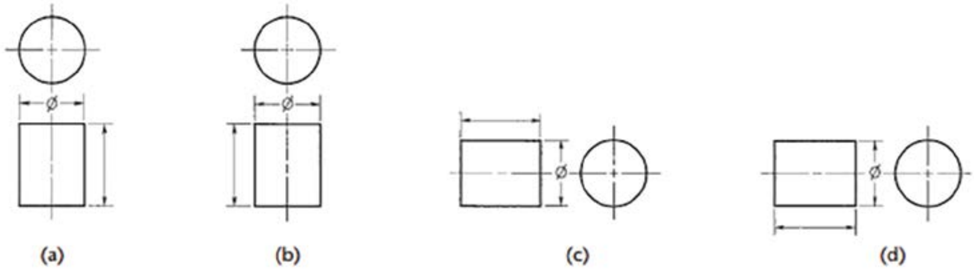


Figure 3.101: Dimensioning cylinders

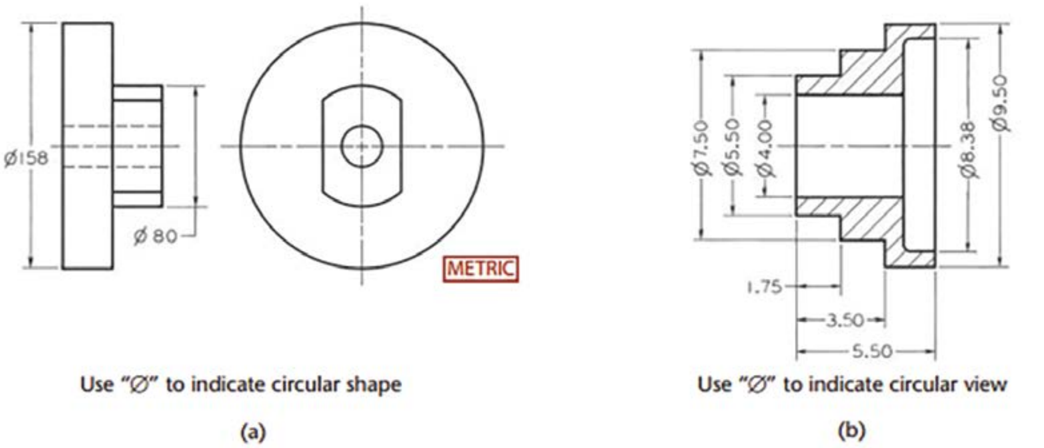


Figure 3.102: Use of ∅ in dimensioning cylinders

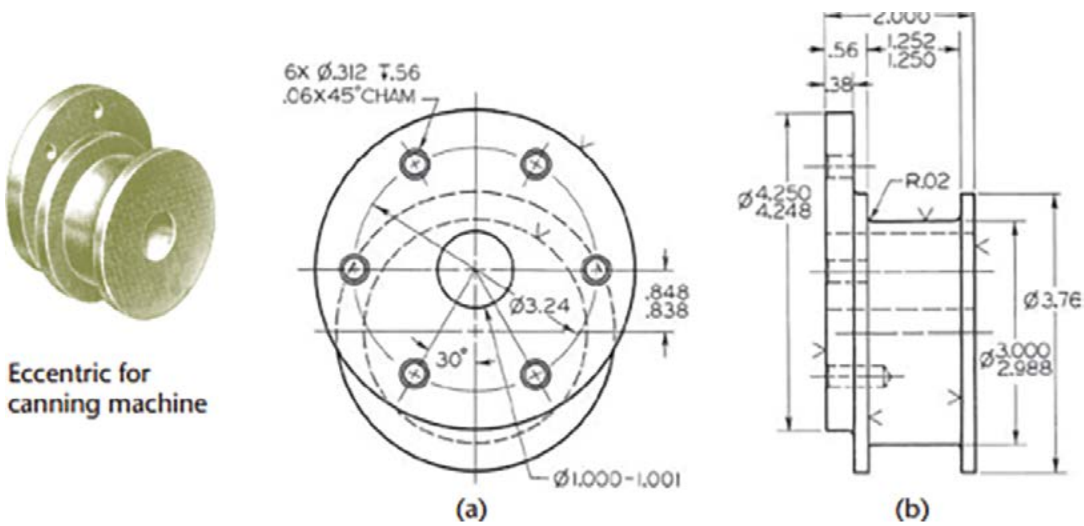


Figure 3.103: Dimensioning a Machine Part Composed of Cylindrical Shapes

Size Dimensioning: Holes

Figure 3.106 shows standard symbols used in dimensioning holes. The order of items in a note corresponds to the order of procedure in the shop in producing the hole. The leader of a note should point to the circular view of the hole, if possible. When the circular view of the hole has two or more concentric circles, such as counterbored, countersunk, spot faced, or tapped holes, the arrowhead should touch the outer circle. Draw a radial leader line, that is, one that would pass through the centre of the circle if it were extended. **Figure 3.105** shows good and bad examples of radial leader lines.

Countersunk, counterbored, spot-faced, and tapped holes are typically indicated using standard symbols or abbreviations, as illustrated in **Figure 3.106**. Multiple holes can be dimensioned with a single note by specifying the number of holes, as shown at the top of **Figure 3.106**. It is common to use decimal fractions for both metric and inch drill sizes, as depicted in **Figure 3.106b**. Metric drill sizes are always presented in decimal format and are not labelled with numbers or letters. When specifying hole dimensions, only the dimensions should be included—there is no need to indicate whether the holes are to be drilled, reamed, or punched, as shown in **Figure**s **3.106** (c) and **3.96** (d). It is usually the responsibility of the manufacturing technician or engineer to determine the most cost-effective process to achieve the required tolerance.

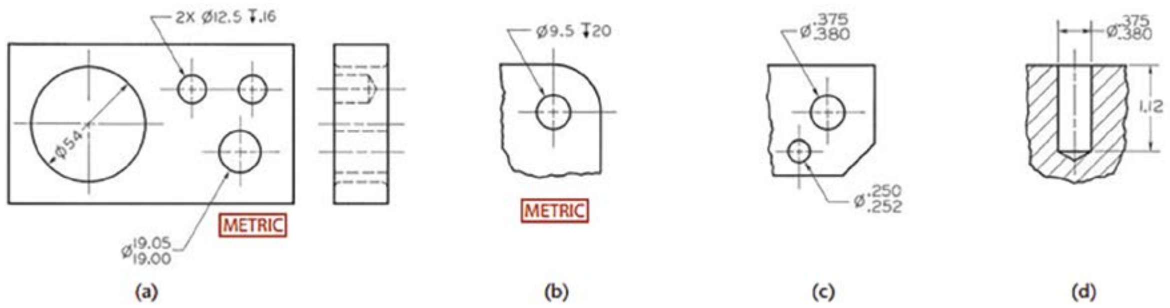


Figure 3.104: Dimensioning holes

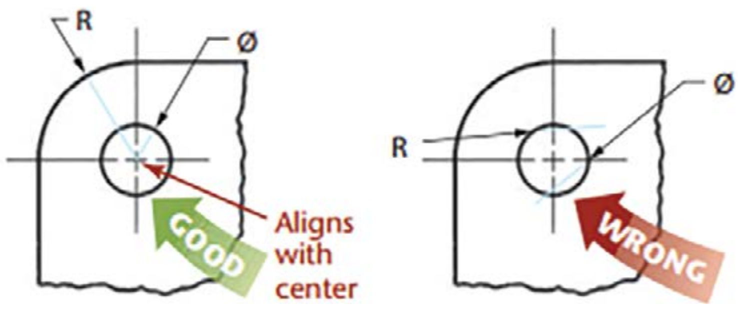


Figure 3.105: Good and bad examples of radial leader lines

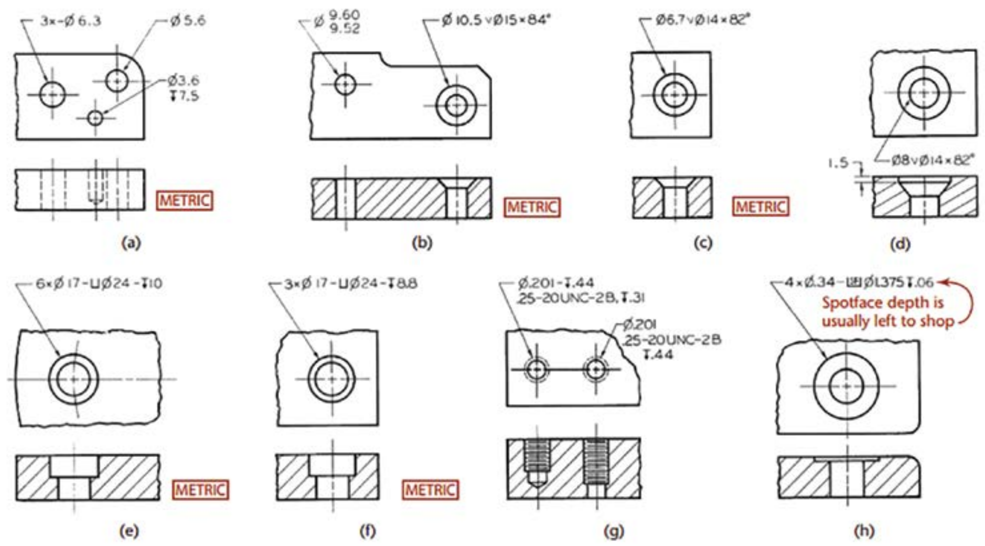


Figure 3.106: Standard symbols for hole dimensions

Importance of Dimensioning

1. Provides a clear (avoids inherit errors in drawing and reading of objects): Proper dimensioning ensures that there are no inherent errors in drawing or reading objects. Clear dimensions help convey accurate specifications, preventing misinterpretation.
2. Complements the description of an object: Dimensions enhance the description of an object. They provide essential information about size, shape, and tolerances, aiding in manufacturing and assembly processes.
3. Facilitates the end-use of a drawing: Accurate dimensioning allows end-users (such as machinists, fabricators, or engineers) to understand and work with the drawing effectively.

Tolerance

Tolerance in drawing, design, and manufacturing refers to the allowable limits of variation in a physical dimension or measured value. This ensures that parts can fit together and function correctly, despite the imperfections inherent in manufacturing processes. In mechanical design, tolerances are critical as they bridge the gap between the idealised geometry of components and the reality of manufacturing deviations, thereby ensuring reliable and cost-effective production.

Tolerance design is a multifaceted process that includes defining design requirements, identifying dimensions in a chain, and conducting variation analysis to guarantee that the final product meets quality standards while minimising costs. Robust designs that are insensitive to variations are essential for maintaining functional reliability under different conditions, and tolerance design plays a crucial role in achieving this robustness. In reverse engineering, tolerances are often overlooked, yet they are vital for ensuring that reproduced parts meet specifications and function as intended.

Specifying tolerances involves a decision-making process that considers both static factors, such as rules and standards, and dynamic factors, such as real-time manufacturing data, in order to optimise cost and quality. Advanced models, like the volumetric space envelope, help connect production variations to tolerances, especially for complex and deformable parts, thereby enhancing the accuracy and efficiency of tolerance analysis. In the realm of additive manufacturing (AM), traditional tolerance allocation methods must be adapted to account for the unique characteristics of AM processes, such as asymmetric error distributions and the significant impact that manufacturing parameters have on dimensional accuracy.

The use of CAD software and secondary development platforms can automate the adjustment and notation of form and position tolerances in engineering drawings, reducing human error and improving design efficiency. Overall, tolerance is a fundamental aspect of engineering and manufacturing, ensuring the functionality, reliability, and cost-effectiveness of products across various industries.

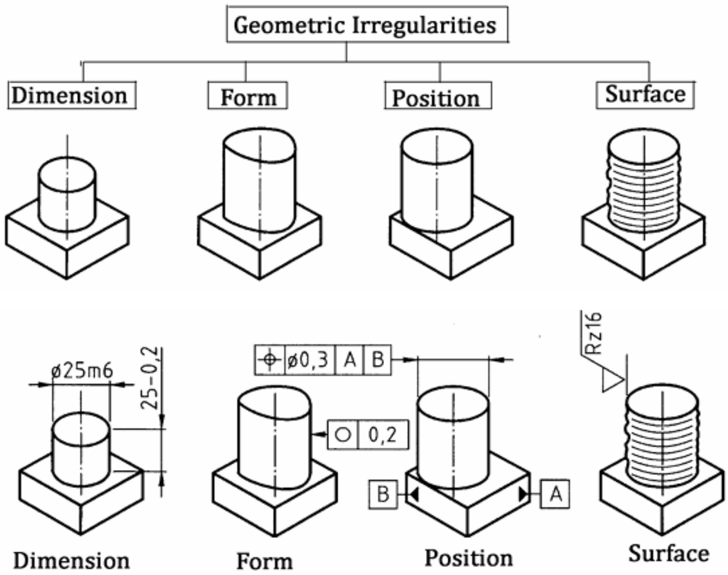


Figure 3.107: Tolerance

Purpose of Tolerancing

1. To indicate the close degree of exactitude required for a given length of size.
2. To specify liberal variations in size and assist its economical manufacture and interchangeability.

Classes of Tolerance

Three main classes of tolerance:

1. Tolerance for size (dimension tolerance),
2. Tolerance for a position (location), and
3. Tolerance for form.

These supplement those for size and define such characteristics as straightness, flatness, parallelism squareness or angularity and circularity. There are

a. Dimensional tolerance and
b. Geometric tolerance

Importance of Tolerance

1. Quality and Consistency: Tolerance enables designers and engineers to indicate the close degree of exactitude required for a given length size. Achieving an exact target consistently is nearly impossible due to manufacturing variations. By analysing tolerances during design, engineers can establish acceptable guidelines. Tighter tolerances generally lead to higher product quality, but drawbacks include slower production and increased costs.

2. Cost and yield Optimisation: Tolerance optimisation during design positively impacts manufacturing yields. Better yields directly affect product cost and quality. Engineers can avoid time-consuming iterations by understanding variations early in the design cycle.

3. Competitive Advantage: Product differentiation lies in design details in today's fast-paced market. Companies rely on tolerance analysis to gain a competitive edge. For instance, the electronics industry shrinks products while adding capabilities, emphasising a precise understanding of manufacturing variation and design tolerances.

Activity 3.12 Research and Presentation

1. Choose one of the under-listed topics to research
   a. Sectioning
   b. Dimensioning
   c. Tolerance

2. Use library resources, textbooks, or reliable online sources to gather information about your chosen topic.
3. Organise your notes into clear sections for your presentation. Your presentation should take this format:
   a. Introduction: Briefly introduce the topic and its importance in technical drawing and engineering.

   b. Key Concepts: Explain the main concepts related to your topic. For example:
      i. Sectioning: Types of sections, purposes, and techniques.
      ii. Dimensioning: Types of dimensions, rules, and best practices.
      iii. Tolerance: Types of tolerances, importance, and applications.

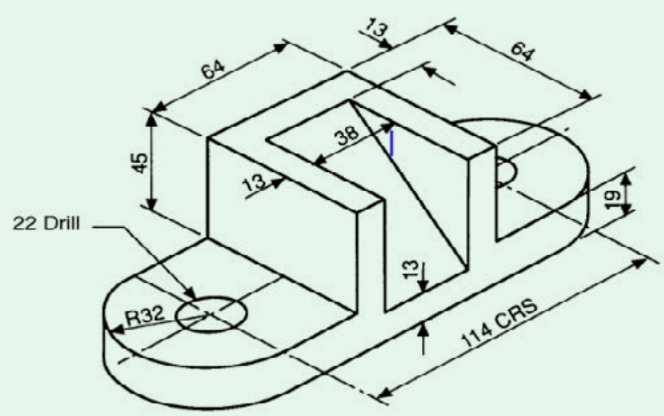
Note
- Include examples and diagrams to illustrate the concepts.
- Discuss how the topic is applied in real-world scenarios.

c. Conclusion: Summarise the key points and the importance of understanding the topic.

4. Prepare a PowerPoint presentation for your class or peers for further discussions.

Activity 3.13 Key Features of First-Angle Projection

1. Generate ideas using the following:
   a. Where do you think the front view should go in first-angle projection?
   b. What do the dashed lines represent?
   c. How are the dimensions positioned?
4. Share with friends or family on:
   a. how you will approach the first-angle projection of a given shape, like L-shaped object or a shape with a hole or a slanted surface.
   b. where to place the front, plan, and end views/elevations for the given shape.
   c. how to decide which view will be the front, top, or side.
   d. what you will do if certain features are not visible in a view? How would they be represented with dashed lines?
   e. what parts of the object might be hidden in each view?
6. Draws in the first-angle projection, the **Figure** below on a large piece of paper, ensuring to include:
   a. proper view placements (front, plan and end elevations).
   b. hidden lines for invisible features.
   c. dimensions to indicate size.



4. Upon completing your drawings, do a peer review to evaluate the final work.

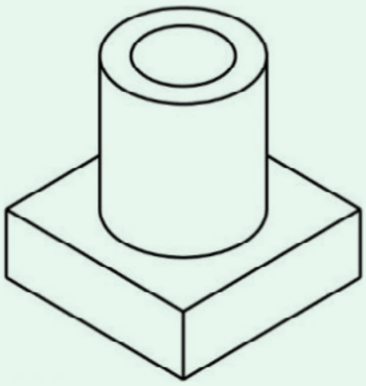
Activity 3.14 Dimensioning Practice in Technical Drawings

Generate ideas for the following questions

1. Why do we have to dimension objects in engineering drawings?
2. What are the types of dimensions?
3. What is the purpose of dimensioning technical drawings?
4. Why is it important to place dimensions clearly and accurately?
5. How are the dimensions placed?
6. What might happen if dimensions are not placed properly or are unclear?
7. What challenges might arise when dimensioning complex objects (like a part with holes or slanted surfaces)?

Activity 3.15 Dimensioning Practices

Dimension these objects using the principle of dimensioning



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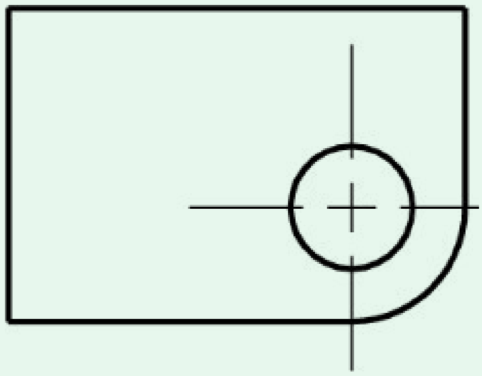


B

DETAILED DRAWINGS

Detailed and assembly drawings play an essential role in product design and manufacturing by providing comprehensive visual and informational representations of individual components and their integration within a product. Detailed drawings focus on the specifications of individual parts, including dimensions, materials, and manufacturing processes, ensuring that each component is accurately produced. On the other hand, Assembly drawings illustrate how these components fit together, often using exploded views to show the spatial relationships and assembly sequence, which is essential for understanding the overall structure and function of the product. Integrating Design for Assembly (DFA) principles into these drawings can significantly enhance the efficiency of the assembly process by optimising the design to facilitate easier and faster assembly, thereby reducing production costs and time.

Auxiliary views

Auxiliary views in product design and manufacturing are essential tools that provide additional perspectives and detailed insights into various aspects of a product. They facilitate a comprehensive understanding of the design process. These views are particularly crucial when designing and developing complex products, as multiple stakeholders often have different viewpoints, each focusing on specific aspects of the product and its development. For instance, multiple-view feature modelling supports different phases of product development by offering distinct views tailored to specific applications, such as conceptual design, assembly design, part detail design, and part manufacturing planning. This approach ensures that each phase of the product lifecycle is adequately addressed, promoting consistency and integration throughout the design process.

Additionally, incorporating concurrent engineering principles has led to the creation of intermediate models that modernise traditional CAD systems into feature-based modelling systems. This allows for the representation of various context-dependent product views, facilitating the consideration of lifecycle factors, such as manufacturing processes and quality control, during the design phase.

Furthermore, auxiliary tools, like the product design auxiliary tool, can automatically adjust the level of a countertop to ensure stability, providing practical support for designers and enhancing their ability to observe and interact with the product under different conditions. Similarly, auxiliary equipment that includes various dimension models corresponding to product features—like chamfers, holes, and embossed carvings—helps designers to reference and visualise the exterior size and details of the product. The use of multiple views also extends to the visualisation and analysis of design processes. An industrial case study with an engine company demonstrated how different visualisation techniques were employed to uncover hidden dependencies between the design artefact and its process.

Detailing techniques (chamfers, fillets, holes, threads, surface finishing)

Detailing techniques such as chamfers, fillets, holes, threads, and surface finishing play a crucial role in product design and modelling, ensuring functionality and aesthetics. Chamfers and fillets are essential for reducing stress concentrations and improving the durability of a product. Chamfers, which are bevelled edges, help ease the assembly of parts and enhance the visual appeal, while fillets, which are rounded edges, contribute to structural integrity by distributing stress more evenly across the part.

Holes and threads are fundamental for creating connections and assemblies in mechanical components. Holes can be used for fasteners, alignment, or weight reduction, and threads are necessary for screw connections, ensuring that parts can be securely fastened together. Surface finishing, including techniques like polishing, painting, and coating, is vital for a product's functional and aesthetic aspects. It can improve wear resistance, reduce friction, and enhance the product's appearance, making it more appealing to consumers. Using Computer-Aided Engineering (CAE) tools and CAD modelling techniques, such as wireframe, surface, and solid modelling, allows designers to efficiently create and evaluate these details in a virtual environment, ensuring precision and consistency across the design.

Additionally, parametric modelling techniques can automate the detailing process, preserving consistency across different levels of detail and reducing the potential for errors. Integrating these detailing techniques within the broader design context for manufacturability, usability, and environmental impact ensures that the final product is functional and aesthetically pleasing but also cost-effective and sustainable. The importance of these techniques is further highlighted in the automotive industry, where detailed modelling and innovative methods are crucial for developing complex products like experimental cars.

Moreover, physical models, such as clay models, can provide a tangible design evaluation, allowing for adjustments and refinements in the detailing phase. Overall, the systematic approach to detailing in the concept stage, considering aspects like surface, functional, structural, construction, aesthetic, manufacturability, and ergonomic details, ensures a well-rounded and successful product design. The effective use of these detailing techniques, supported by advanced tools and methods, ultimately creates high-quality products that meet both technical specifications and consumer expectations.

Detail Drawings

Detail drawings are used by manufacturing workers to illustrate each part involved in a product assembly. The only exceptions to this are standard parts, also known as purchased parts. These are items that can be acquired from external suppliers at a lower cost than they can be manufactured in-house. Examples of standard or purchased parts include common bolts, screws, pins, keys, and any other products readily available from vendors. Standard parts do not require a detailed drawing, as they can be clearly identified with a written description, as shown in **Figure 3.108.**

Detail drawings typically include some or all of the following items:

1. Necessary Multiview
2. Dimensional information.
3. Identity of the part, project name, and part number.
4. General notes and specific manufacturing information.
5. The material of which the part is made.
6. The assembly where the part fits.
7. Number of parts required for the assembly.
8. Name(s) of person(s) who worked on or with the drawing
9. Engineering changes and related information.

In general, detailed drawings have information that is classified into three groups:

a. **Shape description**, which shows or describes the shape of the part.
b. **Size description**, which shows the size and location of features on the part.
c. **Specifications** regarding items such as material, finish, heat treatment, and other manufacturing applications.

Figure 3.108 shows an example of a detailed drawing.

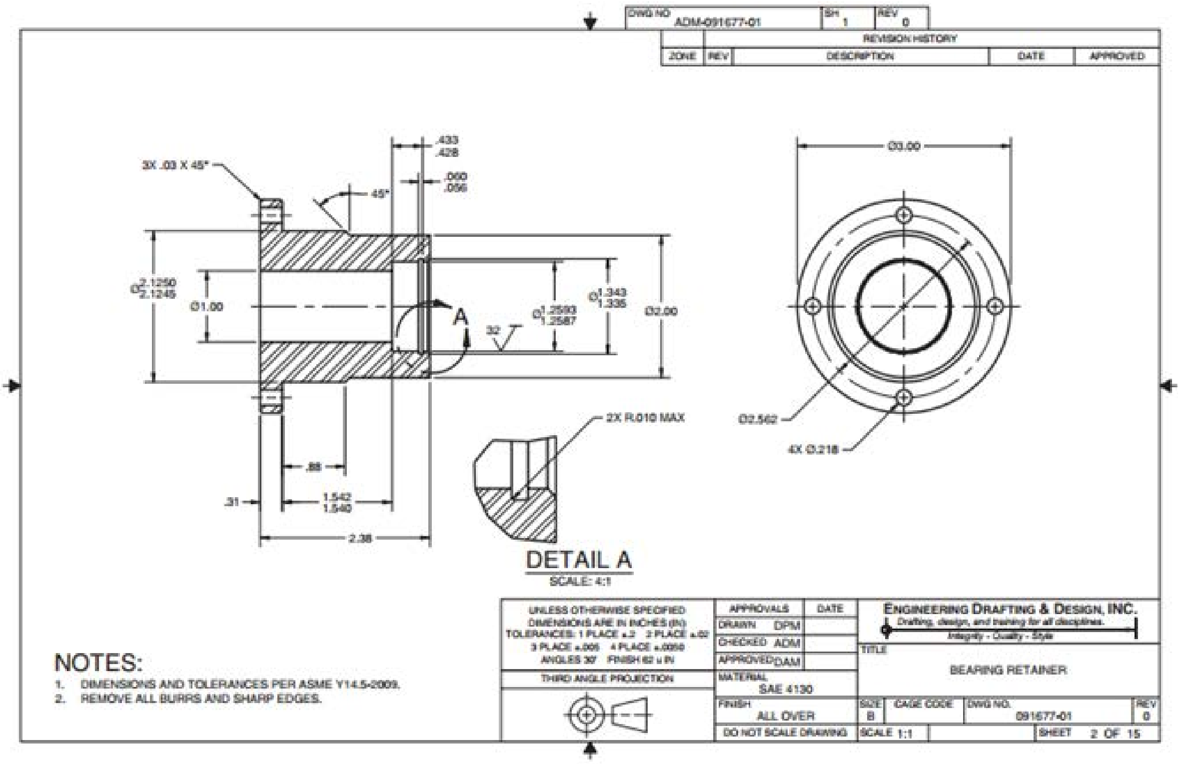


Figure 3.108: A monodetail drawing has one part per sheet. Dimension values in this **Figure** are in inches.

Monodetail and Multidetail Drawings

Detail drawings can be created in two primary formats: monodetail drawings and multidetail drawings. Monodetail drawings feature one part per sheet, as illustrated in **Figure** 3.98, while multidetail drawings group several parts onto a single sheet. The latter format is typically used for tool and fixture design, as well as structural details, where multiple parts are fabricated for assembly. The choice between these formats often depends on the individual company's standards. Most drawing assignments in this text follow the industry standard of one detail drawing per sheet. However, some companies prefer to include multiple details on a single sheet based on their specific applications and production processes.

One advantage of monodetail drawings is that each part is presented individually, allowing for easier distribution to manufacturing without including unrelated parts. Additionally, these drawings facilitate the use of parts across different assemblies. The sizes of the drawing sheets may vary based on the part size, scale, and information presented. When using the monodetail approach, a series of sheets are created, each detailing parts for a specific assembly. The sheet numbers indicate their relation to the assembly, and each part is keyed to the assembly. Furthermore, the sheets are numbered to specify their position within the set. For instance, if there are three pages in the working drawings, they would be numbered 1 of 3, 2 of 3, and 3 of 3.

In contrast, the advantage of multidetail drawings comes into play when multiple parts are manufactured or fabricated together for an assembly or structure. The drafter can include several parts on one sheet, depending on various factors such as the number and size of the parts, the scale used, and the relevant information associated with them. This approach allows companies to use a standard sheet size while maximizing the content on each sheet. **Figure 3.109** provides an example of a multi-detail drawing showcasing several detail drawings on one sheet.

Some companies employ both methods at different times, depending on the purpose of the drawings and the type of product. For example, it is more common to group the parts of a weldment on sheets rather than isolating each part, as the components can be fabricated together in one location within the shop.

Detail Drawing Manufacturing Information

Detail drawings are created to meet the specific needs of manufacturing processes. A detail drawing provides all the necessary information for manufacturing a part. For instance, casting and machining details can be combined into a single drawing. In some cases, a fully dimensioned machining drawing can be sent directly to the pattern or die maker. This pattern or die is fabricated with extra material where machining surfaces are specified.

When company standards require it, two detail drawings are prepared for each part. One drawing includes the views and dimensions necessary only for the casting or forging process. The other drawing omits the casting or forging dimensions and instead provides only the dimensions needed for machining operations on the part. Examples of these drawings can be found in the earlier sub-section which covers Dimensioning and Tolerancing.

Drawing conventions and standards

Drawing conventions and standards in product design and modelling ensures consistency, accuracy, and interoperability throughout various stages of the product development lifecycle. These standards include guidelines related to engineering design, manufacturing, quality control, and human-computer interaction. For example, using Computer-Aided Design (CAD) systems to establish new standards during the design process helps minimise the variety of component variants, ultimately optimising supply chain costs and storage requirements.

Activity 3.15 Research and Presentation on Detailed Drawings

1. Select one of the following topics to research on:
   a. Sectioning
   b. Dimensioning
   c. Tolerance
2. Go to the library or the internet and gather information about your chosen topic.
3. Take detailed notes on key concepts, definitions, and examples.
4. Look for diagrams, illustrations, or real-world applications to include in your presentation.
5. Consider the following structure in organising your findings
   a. Introduction: Briefly introduce the topic and its importance in technical drawing and engineering.
   b. Key Concepts. Explain the main concepts related to your topic. For example,
      i. Sectioning: Types of sections, purposes, and techniques.
      ii. Dimensioning: Types of dimensions, rules, and best practices.
      iii. Tolerance: Types of tolerances, importance, and applications.
   c. Include examples and diagrams to illustrate the concepts.
   d. Applications: Discuss how the topic is applied in real-world scenarios.
   e. Conclusion: Summarise the key points and the importance of the chosen area.
6. Present a PowerPoint presentation for your class. Ask a friend to take a picture of you while presenting.

Activity 2.16 Detailed Drawings of Simple Mechanical Components

1. Select simple mechanical components (e.g., gears, brackets, or fasteners).
2. Create detailed drawings for these components:
   a. Include orthographic views (front, top, side).
   b. Add dimensions, tolerances, and annotations.
   c. Consider assembly requirements.
3. Get someone to review your work and discuss best practices.

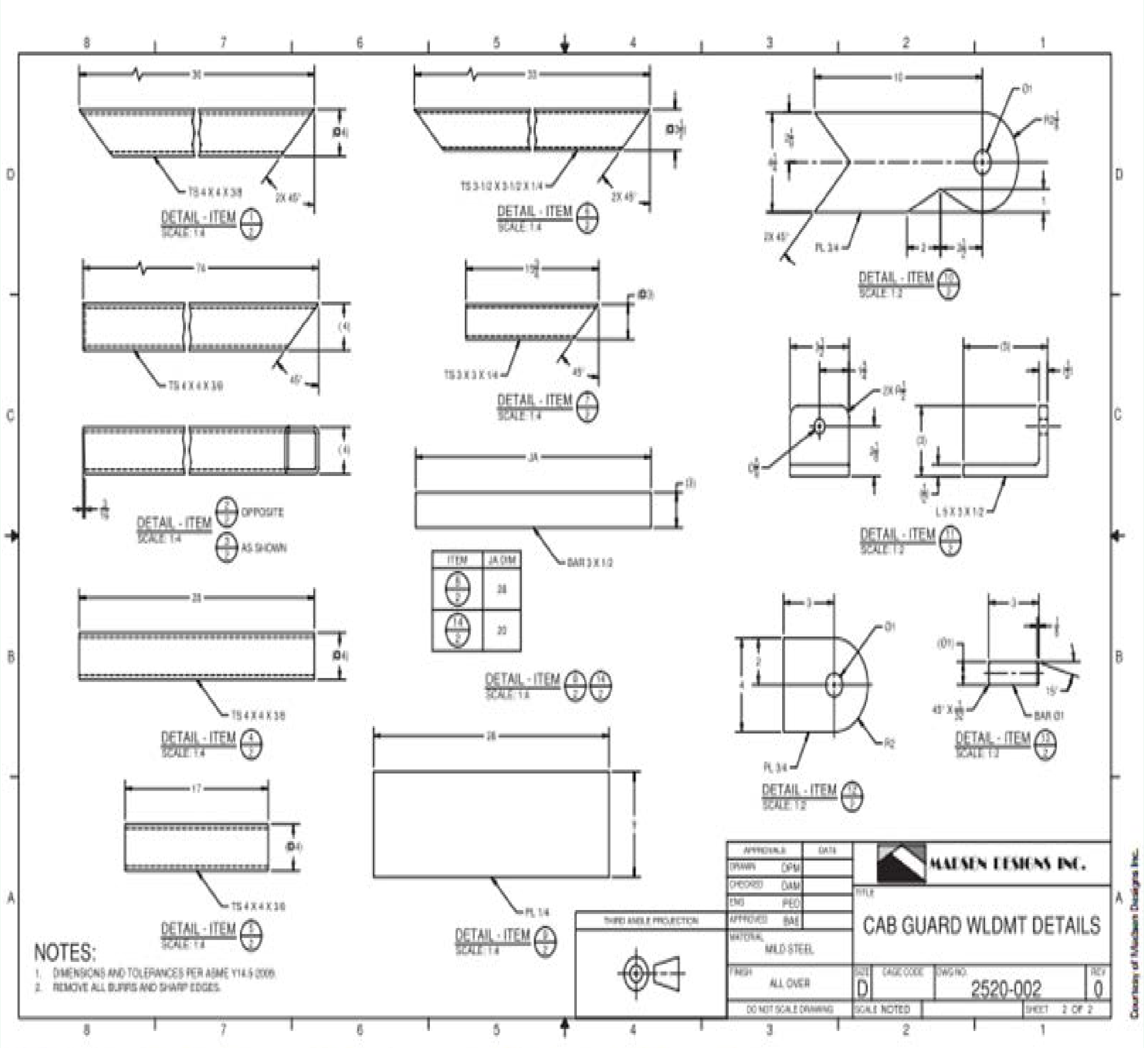


Figure 3.109: Example of a multidetail drawing with several detail drawings on one sheet

ASSEMBLY DRAWINGS

Detailed and assembly drawings are crucial in product design and modelling as they provide clear visual and informational representations of individual components and how they fit together within a product. Detailed drawings focus on the specifications of each part, including dimensions, materials, and manufacturing processes, ensuring that every component is produced accurately. In contrast, assembly drawings illustrate how these components come together, often using exploded views to show spatial relationships and the assembly sequence. This is essential for understanding the overall structure and function of the product. By integrating Design for Assembly (DFA) principles into these drawings, it is possible to enhance the efficiency of the assembly process. This approach helps reduce the number of parts and simplifies assembly operations, ultimately lowering production costs and improving product quality.

Sectional views

Sectional views play a crucial role in product design and modelling by providing detailed insights into a product's internal structures and components that are not visible in standard external views. These views are created by slicing through a 3D model along specified planes, revealing the interior features essential for verifying design integrity and functionality. There are different methods for generating sectional views. One approach automatically creates a cross-section structure chart based on user-defined parameters and line-drawing positions. This allows engineers to examine the sectional structures across various domains and ensure accurate product assembly processes and operational functionality.

Another method involves producing combined sectional views by obtaining section planes from multiple section lines and projecting specified elements to create a comprehensive view of the model. Integrating sectional views into product lifecycle management (PLM) systems is also significant. It supports consistency and the propagation of information changes across different stages of the product lifecycle, thereby enhancing the assembly-oriented design philosophy.

Assembly Drawings

Most products consist of several parts, and a drawing that illustrates how all these parts fit together is known as an assembly drawing. The amount of information provided in assembly drawings can vary, often depending on the complexity of the product. Typically, assembly drawings are multiview drawings. The objective in preparing assembly drawings is to use the fewest views necessary to clearly describe how each part fits together.

In many cases, a single front view is sufficient to depict the assembly (as shown in **Figure 3.110**). Full sections are often included in assembly drawings because they reveal most, if not all, of the internal features (see **Figure 3.111**). If a single view or section does not adequately convey how the parts connect, additional views or a combination of views and sections may be required.

In some instances, a front view or a group of views, combined with broken-out sections, effectively shows the external features while also exposing some internal features. It is crucial to make the assembly drawing clear enough for the assembly department to construct the product correctly. Assembly drawings differ from detail drawings in that they usually contain few or no hidden lines or dimensions. Hidden lines should be avoided unless they are necessary for clarity. Generally, the practice is to provide an exterior view to clarify outside features and a sectional view to reveal interior features.

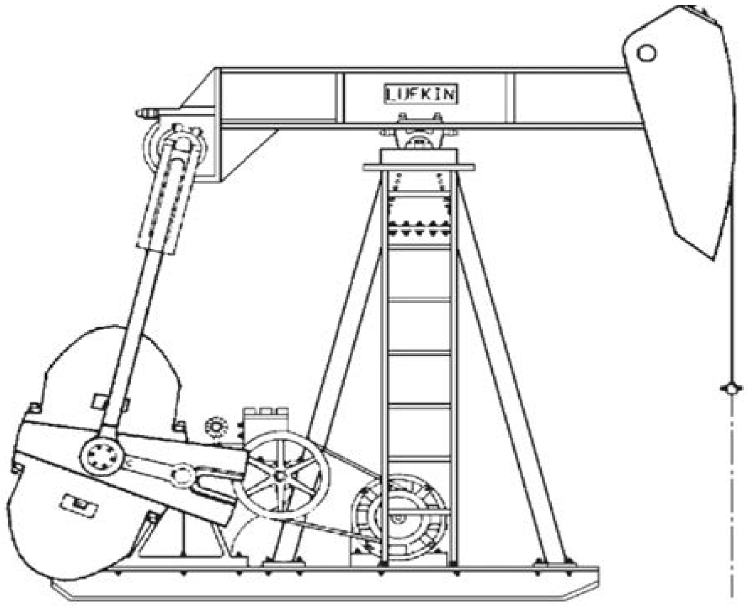


Figure 3.110: Assembly drawing with single front view

Dimensions on an assembly drawing are typically omitted unless they are needed to illustrate the relationship between individual parts. Assembly dimensions are only necessary when specific distances between parts must be maintained to ensure proper assembly. Machining processes and other specifications are usually not included on an assembly drawing unless a machining operation is required after two or more parts have been assembled. Other assembly notes may include specifications for bolt tightening, welding requirements, cleaning protocols, painting instructions, or decal placements that need to occur during or after the assembly process. For example, **Figure 3.113** shows a process note applied to an assembly drawing.

Some company standards or drafting practices may prefer assemblies to be represented with sectioned parts that do not include section lines. However, this is not a common practice and is not in line with ASME standards. When creating sectioned assemblies, objects like fasteners, pins, keys, and shafts are typically shown without section lines, even if the cutting plane passes through them and is parallel to their axes. **Figure 3.112** illustrates a full section assembly with parts that have been left un-sectioned.

Assembly drawings can contain some or all of the following information:

1. One or more views (auxiliary views are used as needed)
2. Sections necessary to show internal features, function, and assembly
3. Enlarged views necessary to show adequate detail
4. Arrangement of parts
5. Overall size and specific dimensions necessary for assembly
6. Manufacturing processes necessary for, during, or after assembly
7. Reference or item numbers that key the assembly to a parts list and to the details
8. Parts list or bill of materials.

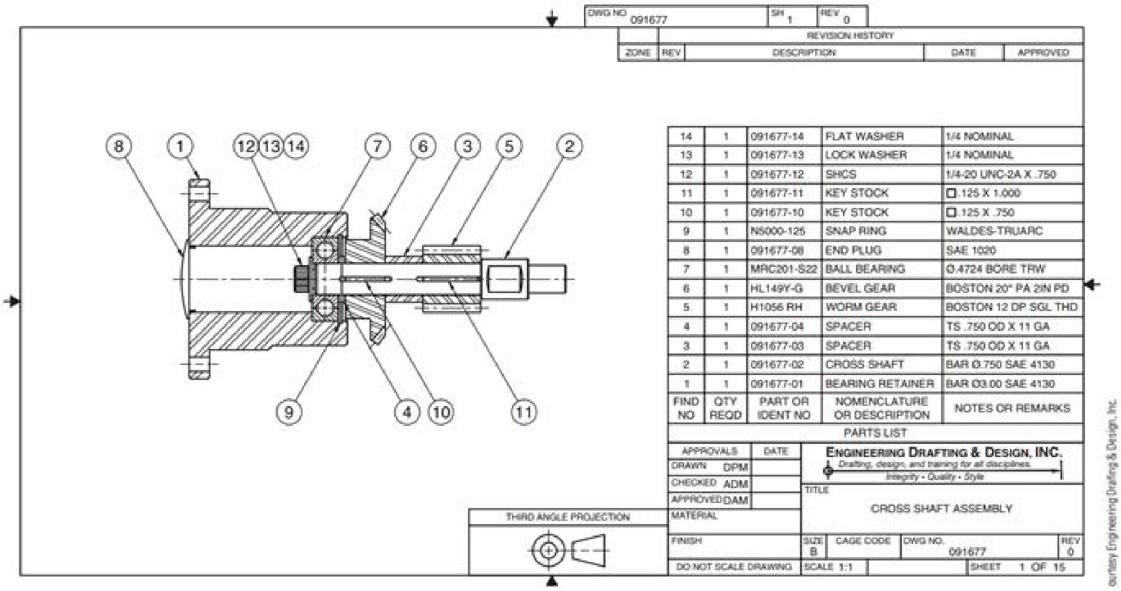


Figure 3.111: Assembly in full section

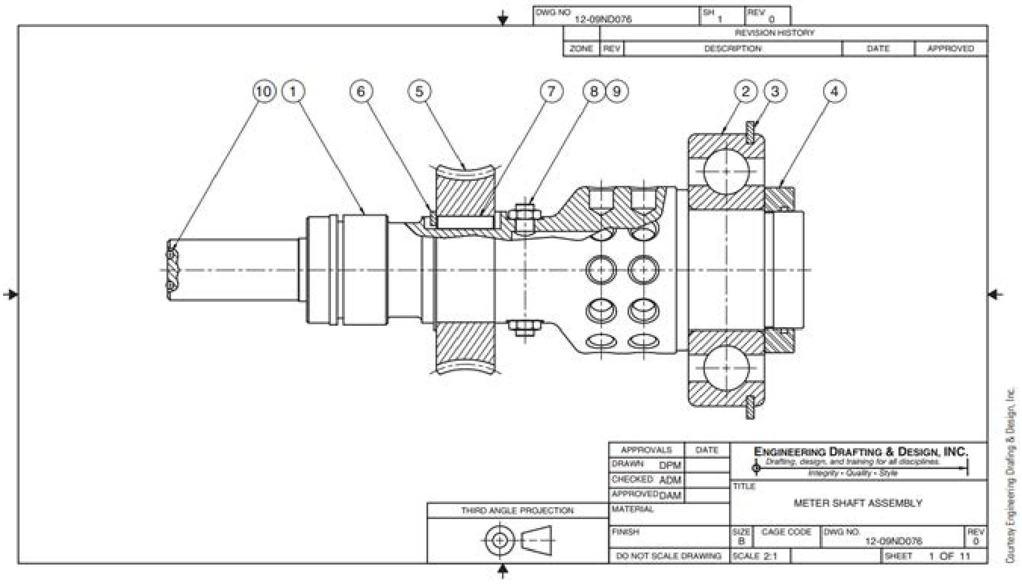


Figure 3.112: Assembly with broken-out section

Types of Assembly Drawings

There are several different types of assembly drawings used in industry. Let us explore some of them!

1. Layout or design assembly
2. General assembly
3. Working drawing or detail assembly
4. Erection assembly
5. Subassembly
6. Pictorial assembly.

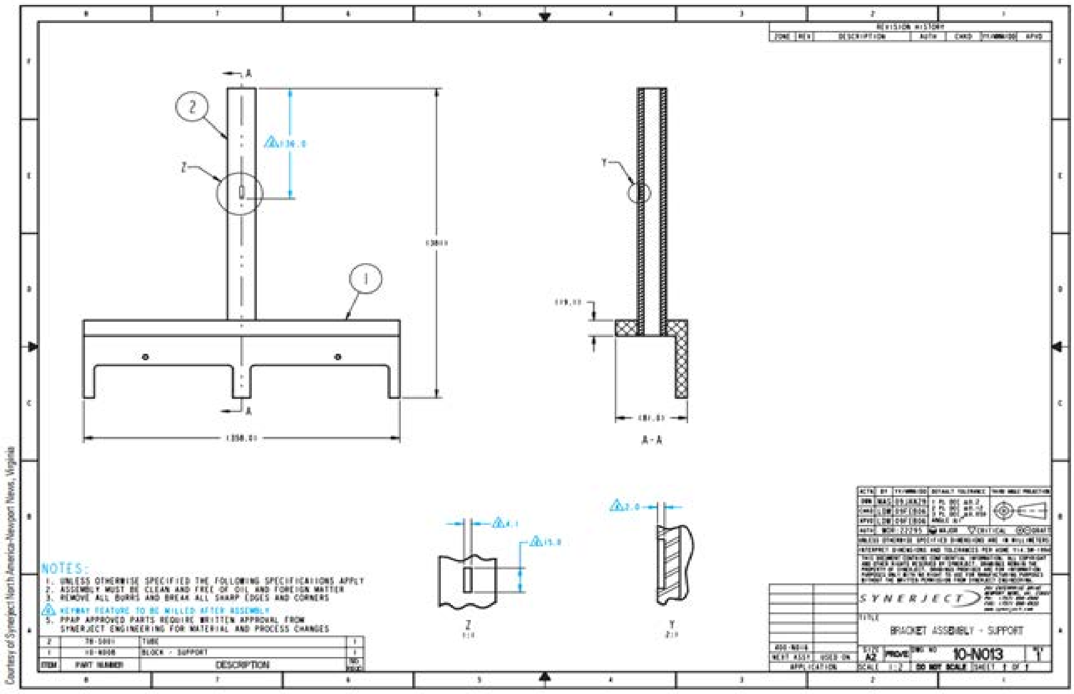


Figure 3.113: A process note applied to an assembly drawing. Dimension values in this **Figure** are in millimetres.

Layout Assembly

Engineers and designers can prepare a design layout in the form of a sketch or as an informal drawing. These engineering design drawings are used to establish the relationship of parts in a product assembly. From the layout, the engineer prepares sketches or informal detail drawings for prototype construction. This research and development (R&D) is the first step in the process of taking a design from an idea to a manufactured product. Layout, or design, assemblies can take any form, depending on the drafting ability of the engineer, the period for product implementation, the complexity of the product, or company procedures. In many companies, the engineers work with drafters who help prepare formal drawings from engineering sketches or informal engineering drawings. The R&D department is one of the most exciting places for a drafter to work, because this is where new ideas are developed. **Figure 3.114** shows a basic layout assembly of a product in the development stage. The limits of operation are shown using phantom lines.

General Assembly

General assemblies are the most common type of assembly used in a complete set of working drawings. A complete set of working drawings comprises three parts: detail drawings, an assembly drawing, and a parts list. The general assembly includes features such as multiviews, auxiliary views, detail views, and sectional views as needed for the specific product. Each part is identified using a balloon, which is a circle placed on the drawing that contains a part identification number. A leader line connects each balloon to its corresponding part. The balloon's identification number correlates with the same number in the parts list. This parts list identifies every component in the assembly. More information about balloons will be provided later in this section. A typical general assembly is illustrated in **Figure 3.115**.

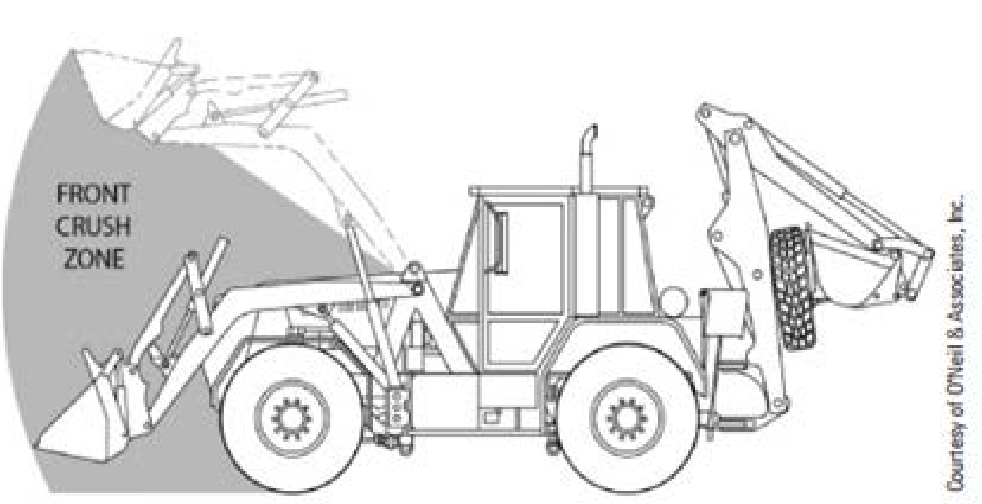


Figure 3.114: Layout assembly. The operation limits are shown with phantom lines and a shaded area

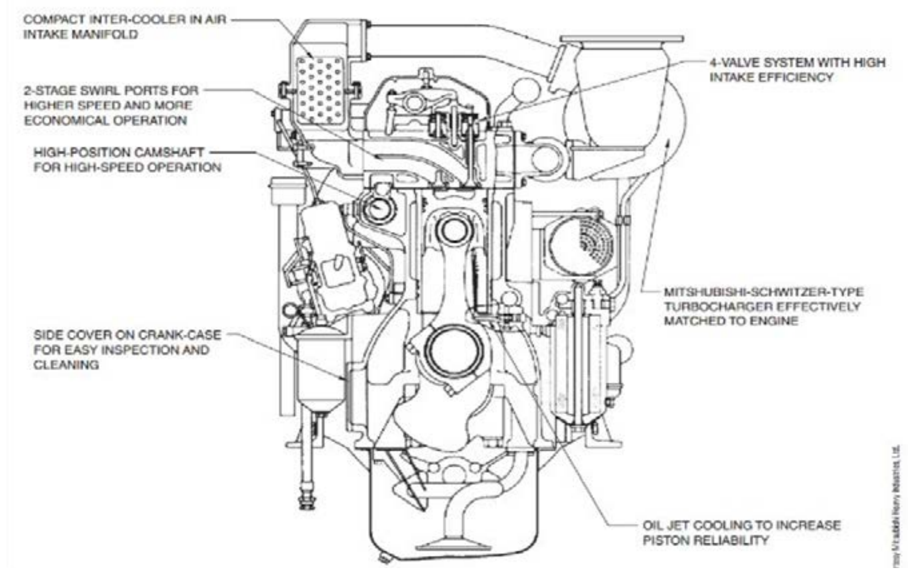


Figure 3.115: Full section assembly with section lines omitted

Detail Assembly

A detail assembly shows the details of parts combined on the same sheet with an assembly of the parts. This practice is also referred to as a working drawing assembly. Although this application is not as common as a general assembly, it is a practice used at some companies. The use of working-drawing assemblies can be a company standard, or this technique can be used in a specific situation even when it is not considered a normal procedure at a particular company. The detailed assembly can be used when combining the details and assembly on as few sheets as possible. An example can be a product with few parts produced only once for a specific purpose, as shown in **Figure**s **3.116**. and **3.117**.

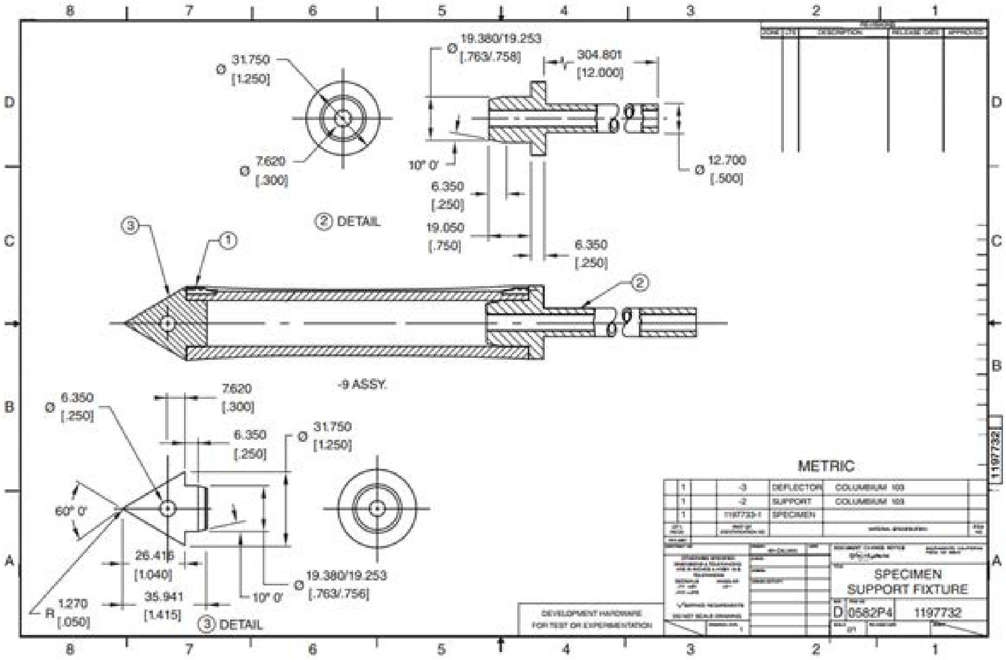


Figure 3.116: Working drawing assembly, also referred to as detail assembly

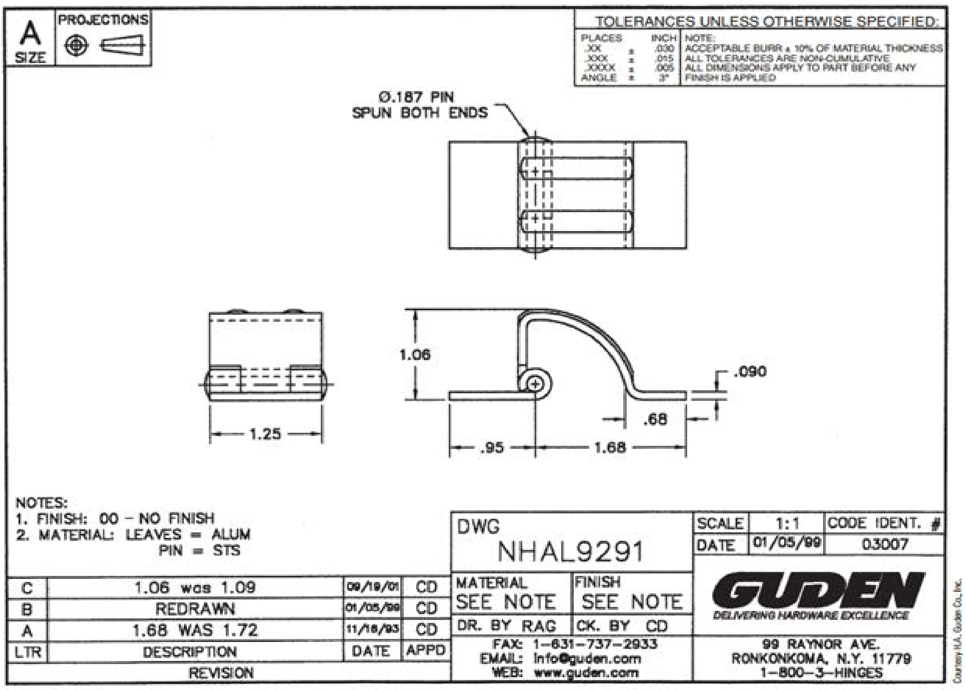


Figure 3.117: This product is an example of a detailed assembly with its component parts assembled in a manufacturer's catalogue. Dimension values in this Figure are in inches.

Erection Assembly

Erection assemblies usually differ from general assemblies in that dimensions and fabrication specifications are commonly included. Erection assemblies are used for fabrication and assembly, and they are typically associated with products made of structural steel or cabinetry. **Figure 3.118** shows an erection assembly with multiviews, fabrication dimensions, and an isometric drawing that displays how the parts fit together.

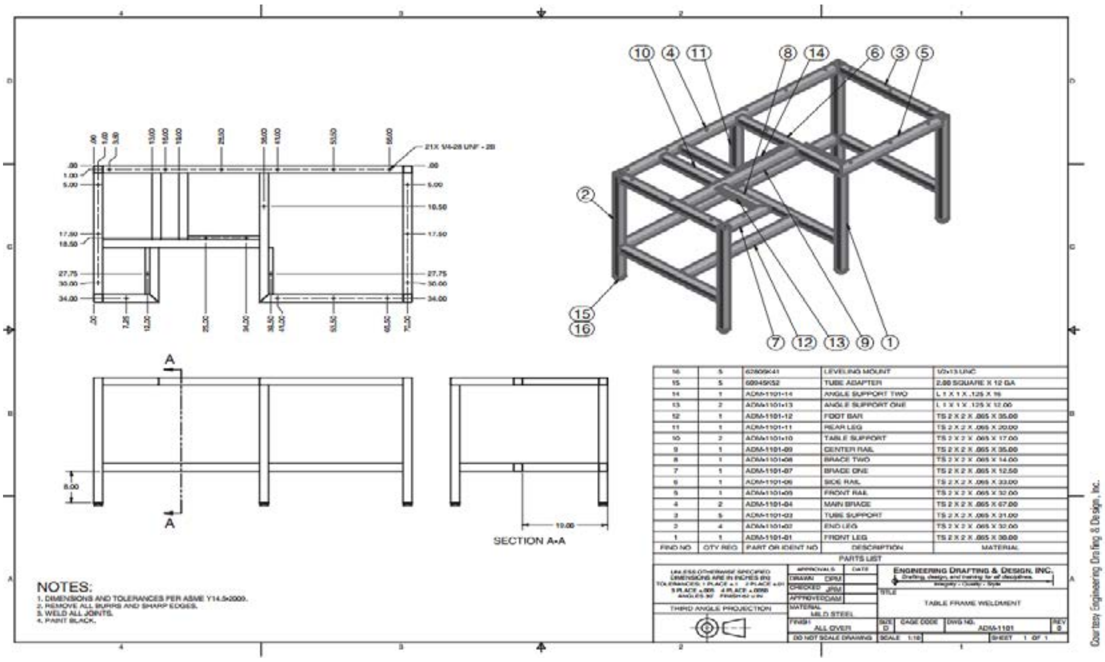


Figure 3.118: Erection assembly. Dimension values in this **Figure** are in inches.

Subassembly

The complete assembly of a product can be made up of several separate component assemblies. These individual unit assemblies are called subassemblies. A complete set of working drawings can have several subassemblies, each with its detailed drawings. The subassemblies are put together to form the general assembly. For example, the general assembly of an automobile includes the subassemblies of the drive components, the engine components, and the steering column, just to name a few. An assembly, such as an engine, can have other subassemblies, such as carburettor and generator.

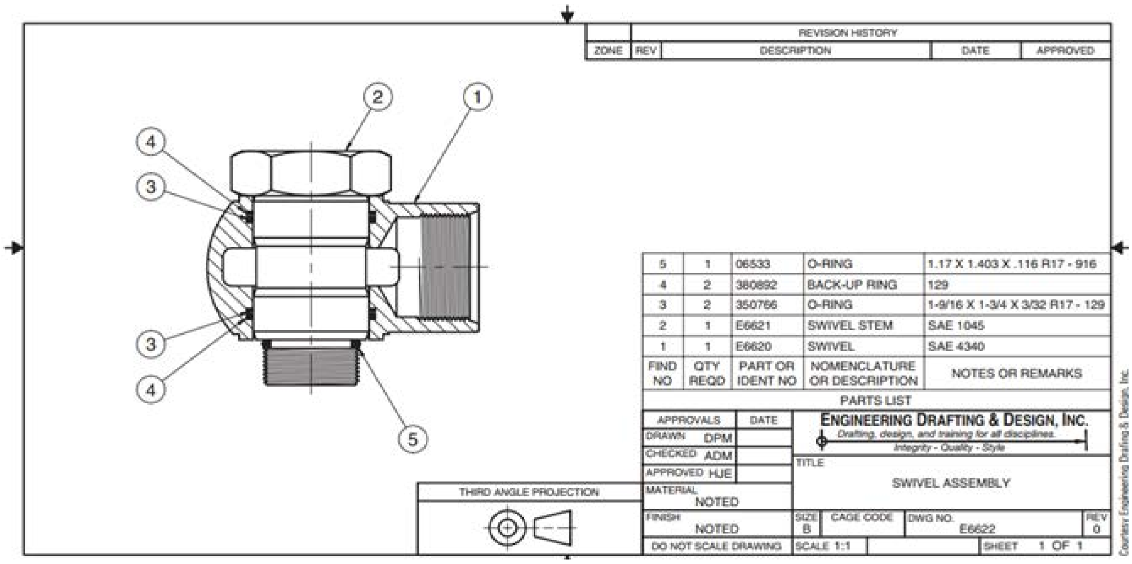


Figure 3.119: Subassembly with parts list

Pictorial Assembly

Pictorial assemblies are visual representations that showcase a product in a way that prioritises imagery over traditional multi-view drawings. These assemblies can be created using various methods, including photographs, artistic renderings, isometric drawings, or CADD models (Computer-Aided Design and Drafting). A simple example of a pictorial assembly is an isometric drawing, which aids workers in assembling the product. Pictorial assemblies are frequently found in product catalogues or brochures. They serve multiple purposes, such as sales promotion, guiding customers in self-assembly, or providing instructions for maintenance procedures. Additionally, pictorial assemblies may include exploded technical illustrations, often referred to as illustrated parts breakdowns. Exploded technical illustrations are used in catalogues, instruction manuals, and for maintenance or assembly instructions. These illustrations display the components of an assembly separated from one another, highlighting how the parts fit together. Each component in the exploded illustration is labelled with a balloon that corresponds to a parts list.

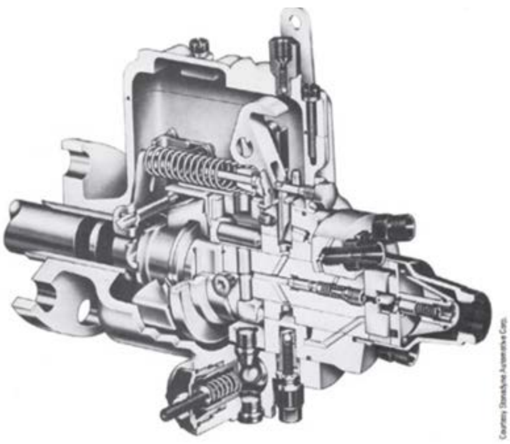


Figure 3.120: Pictorial assembly

Identification Numbers

Identification or item numbers are used to key the parts from the assembly drawing to the parts list. Identification numbers are generally placed in balloons. Balloons are circles connected to the related part with a leader line, as previously described. Several of the assembly drawings in this chapter show examples of identification numbers and balloons. Numbers in balloons are common, although some companies prefer to use identification letters. Balloons are drawn between .375 and 1 in. (10–25 mm) in diameter, depending on the size of the drawing and the amount of information that must be placed in each balloon. All balloons on the drawing are the same size. The leaders connecting the balloons to the parts are thin lines that can be presented in any one of several formats, depending on company standards.

Exploded views

Exploded views are a crucial aspect of product design and modelling, providing a detailed schematic representation that illustrates a product's components' spatial relationships and assembly sequence. These views are essential for various applications, including product instructional materials, repair and maintenance handbooks, and training manuals. Generating exploded views involves several sophisticated techniques to ensure clarity and efficiency. One method employs assembly constraints and collision detection to automatically generate hierarchical exploded views, reducing the number of attempted explosion operations and improving efficiency by determining explosion sequencing and layering of parts based on a three-dimensional assembly process.

Another approach involves determining test directions and blocking subsets for each part, using ray tracing to identify viable disassembly directions and creating exploded views that display relative displacements of parts. Collision-free paths are essential for assembly and disassembly, and novel methods like collision-free matrix representation help manage the increasing complexity as the number of components rises. The generation of exploded views can also be enhanced by extracting assembly contact information and geometric feasibility relations, simplifying the determination of disassembly sequences and levels.

Techniques like using a graphical tool to represent the hierarchical structure of an assembly and control explosion ratios further streamline the process. Automatic generation methods combine assembly modelling, sequence planning, and simulation technologies, utilising contact-connection and extension interference matrices to plan layering sequences and generate exploded views. Recursive search methods for multi-level assembly sequences and interference detection help manage complex products, ensuring exploded views are uniform, compact, and hierarchical.

Interactive methods also play a significant role, allowing users to create exploded views by categorising objects into layers based on size and using user-controlled probes to facilitate object selection, particularly useful in mobile-assisted manufacturing and repair environments.

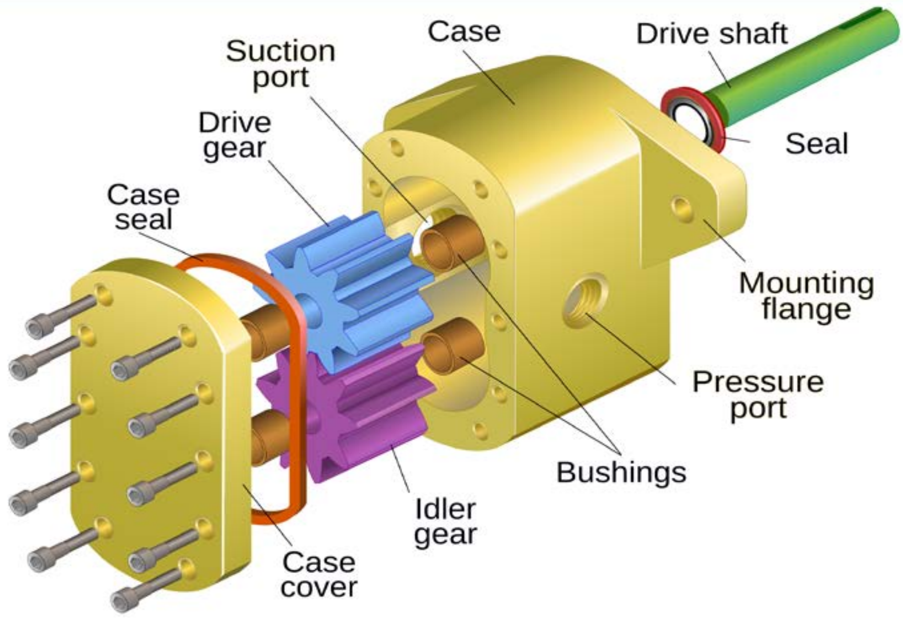


Figure 3.121: Exploded view of a gear pump

Parts List

The parts list, also known as a bill of materials (BOM) or list of materials, is usually combined with the assembly drawing. Still, it remains one of the individual components of a complete set of working drawings. The information associated with the parts list generally includes:

a. item number, also called find number—from balloons
b. quantity—the number of that particular part used on this assembly
c. part or drawing number, which is a reference back to the detail drawing
d. description, which is usually a part name or complete description of a purchase part or stock specification, including sizes or dimensions
e. material identification—the material used to make the part
f. information about vendors for purchase parts
g. sheet number.

Parts lists can include some or all of the previously mentioned information, depending on company standards. The first four elements are typically the most common items included. When all six elements are present, the parts list may also be referred to as a list of materials or a bill of materials.

When included on the assembly drawing, the parts list may be placed above or to the left of the title block, in the upper-right or upper-left corner of the sheet, or in a convenient location on the drawing field. The exact position is determined by company standards, with the most common placements being above or to the left of the title block. The parts list usually presents the first item number followed by consecutive item numbers. If the parts list becomes extensive and the columns fill the page, additional columns can be added next to the existing ones. Space on the parts list can also be expanded if more parts are added to the assembly. A parts list is typically prepared using CADD (Computer-Aided Design and Drafting) software or other database programs, allowing for easy retrieval and editing of information. When using a CADD or other electronic system, the contents of the parts list are usually displayed in a table format, making it simple to make updates as needed.

Additionally, when working drawings are created using a CADD system, the parts list can be parametrically linked to the details and assembly. This means that any changes made will be automatically reflected across all associated documents. However, the parts list is not always included on the assembly drawing itself. Some companies prefer to prepare parts lists on separate sheets, which allows for the use of spreadsheet software and more convenient filing. This approach also enables the parts list to be generated separately from the drawings on a computer, facilitating easier edits and updates.

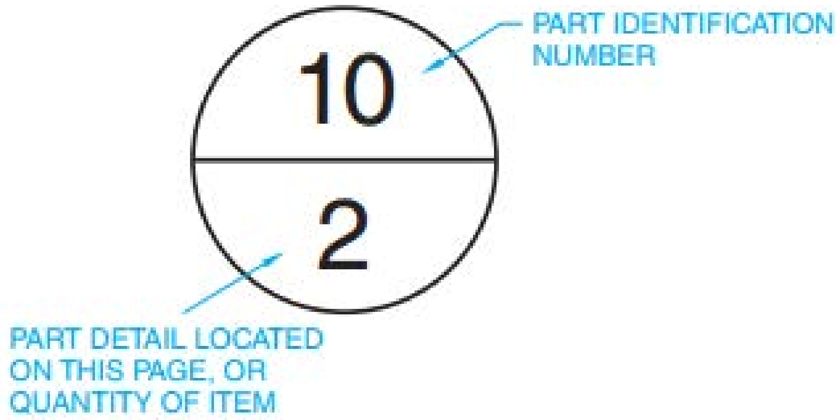
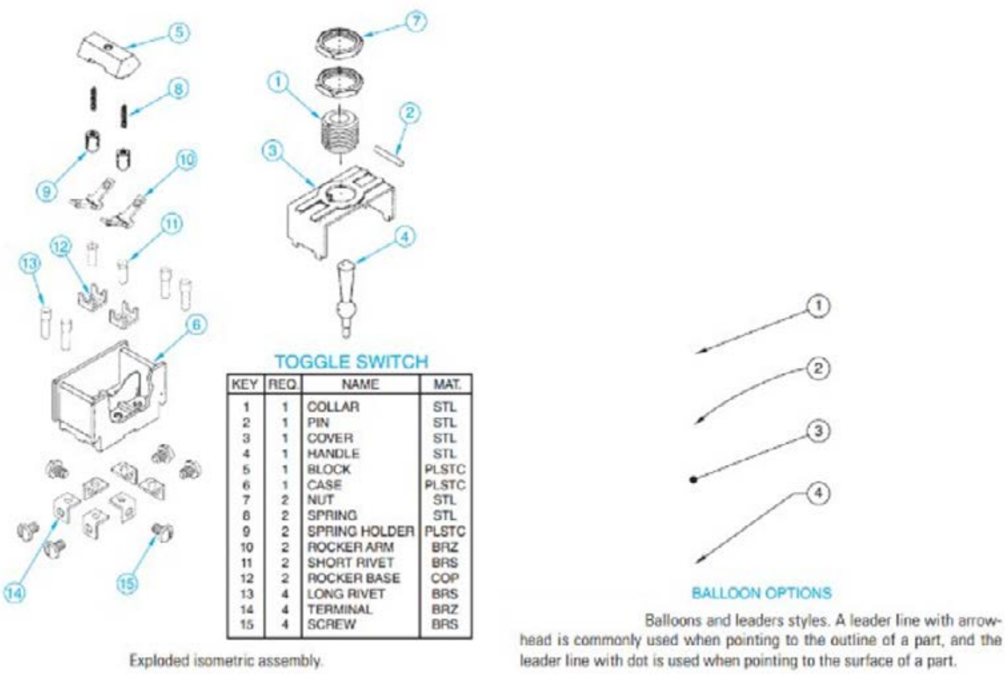


Figure 3.122: Balloon with page identification

Note: *An engineering change request (ECR) can require the removal of a component from the parts list.*

When a balloon and parts list number is deleted, it is common practice not to renumber the remaining items, as other documents may reference those numbers. Instead, the word “REMOVED” is added in the parts list next to the balloon number that has been deleted. However, not all companies follow this practice; some prefer to renumber the balloons and parts list and update all related documents accordingly.



KEY	REQ.	NAME	MAT.
1	1	COLLAR	STL
2	1	PIN	STL
3	1	COVER	STL
4	1	HANDLE	STL
5	1	BLOCK	PLSTC
6	1	CASE	PLSTC
7	2	NUT	STL
8	2	SPRING	STL
9	2	SPRING HOLDER	PLSTC
10	2	ROCKER ARM	BRZ
11	2	SHORT RIVET	BRS
12	2	ROCKER BASE	COP
13	4	LONG RIVET	BRS
14	4	TERMINAL	BRZ
15	4	SCREW	BRS

Figure 3.123: Exploded isometric assembly

Bill of materials

A Bill of Materials (BoM) is a comprehensive list detailing all the components, parts, and materials required to manufacture a product, often represented as a hierarchical diagram or tree structure. The BoM serves multiple critical product design and modelling functions, from material requirement planning (MRP) to product lifecycle management (PLM). The BoM is essential for ensuring accuracy and efficiency in the production process. For instance, an automatic checking method can improve the accuracy of a BoM by matching attribute information of each material to obtain standard material information, thus facilitating rapid checking and reducing errors.

Additionally, the BoM can be used to manage complex product data, such as in the commercial aircraft industry, where a unified BoM model integrates engineering and manufacturing data to enhance competitiveness and manage product complexity throughout the lifecycle. The BoM also plays a crucial role in forming product families by considering component commonality and the hierarchical assembly structure, which can optimise the assembly process and improve efficiency. Advanced methods for generating BoM data involve traversing data nodes and setting identifiers to accurately manage and adjust the product structure.

Moreover, the BoM can be generated by converting sales parameters into technical parameters, ensuring that each component's attribute information is accurately determined. In construction projects, an automated BoM system can provide cost estimates and improve efficiency, flexibility, and performance suitability, as demonstrated by a study using Microsoft Visual Studio and SQL Server for database management. Furthermore, the tactility of product materials, which influences user impressions and interactions, should be considered in the BoM to ensure the selection of appropriate materials for product design. The BoM's role extends to complex systems, where electronic documents are stored in standardised formats, and data fields are extracted and compiled to generate a comprehensive BoM.

Finally, innovative methods for controlling material deformation, such as using hydraulic presses and scales, can be integrated into the BoM to ensure precise material specifications and quality control. The BoM is a vital tool in product design and modelling, providing a structured approach to managing materials, components, and processes, thereby enhancing accuracy, efficiency, and overall product quality.

Benefits of a BoM

1. Organised production planning: A BoM helps ensure that the right materials are available when needed, improving production line efficiency.
2. Reduced waste: A BoM can help avoid over-ordering or under-utilising raw materials.
3. Better cost estimation: A BoM can help estimate cost, leading to more competitive pricing and budgeting.
4. Improved supply chain management: A BoM can help with strategic supply chain management, which can help a business respond more quickly to market changes.

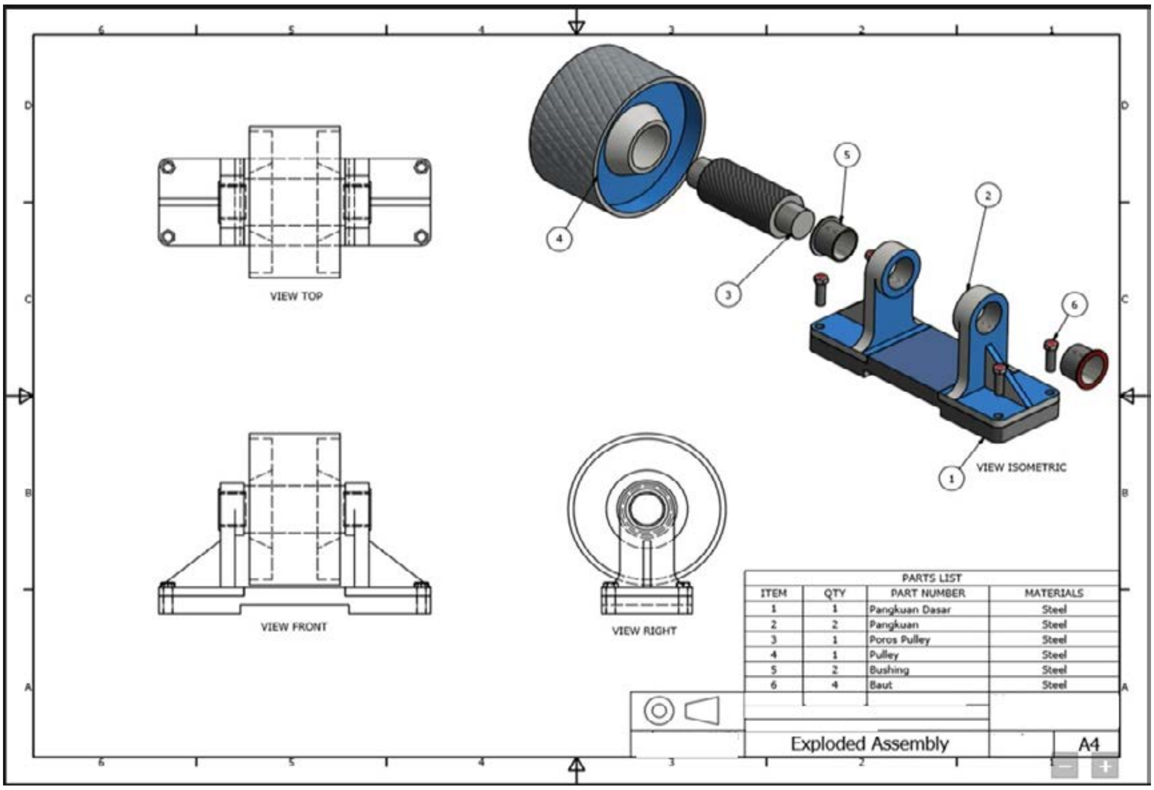
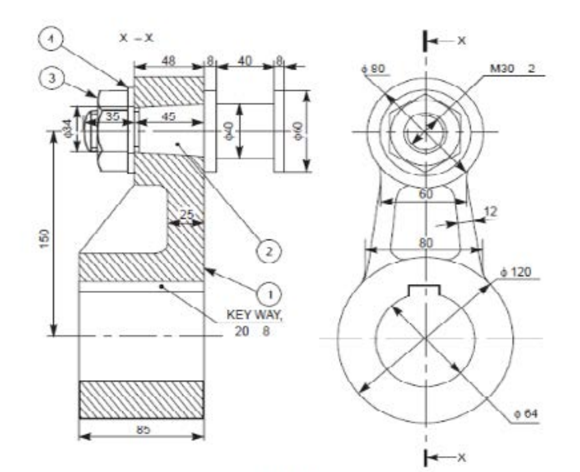


Figure 3.124: Exploded of a bearing assembly

Activity 3.16 Analysing Assembly Drawings

1. Analyse assembly drawings and charts and identify the characteristics unique to assembly drawings.

Below are sample assembly drawings and charts



Parts List

Part No.	Name	Material	Qty
1	Crank	Forged Steel	1
2	Crank Pin	45C	1
3	Nut	MS	1
4	Washer	MS	1

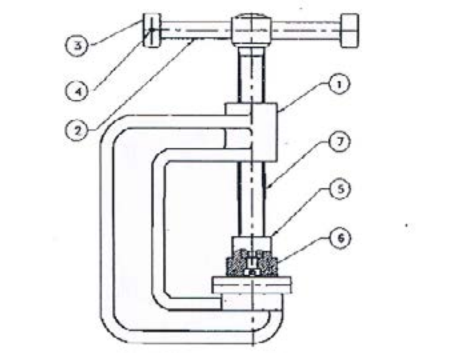


Fig. 1.26 C-clamp assembly.

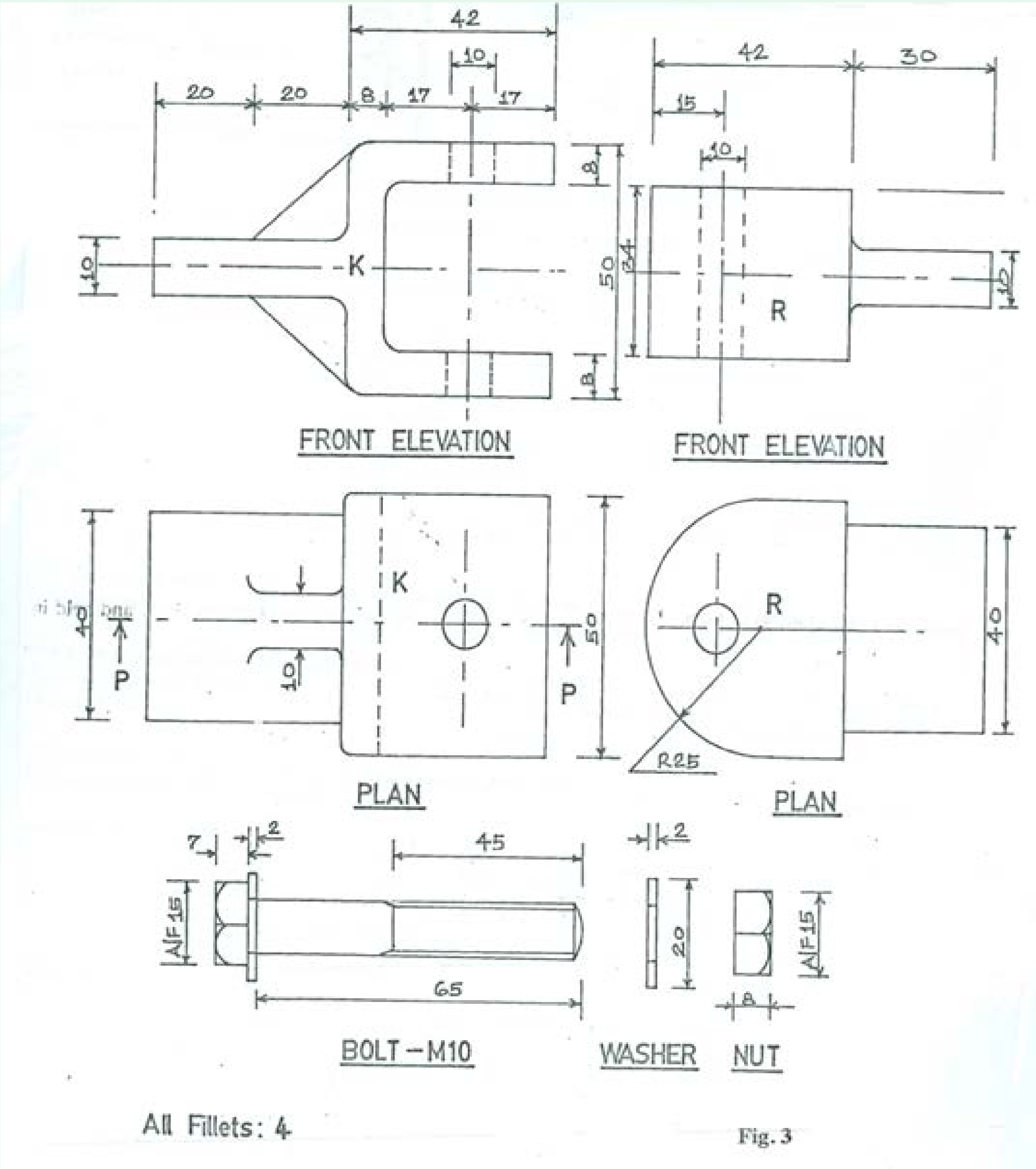
No.	Name of part	Material	Notes	Q
7	Screw rode	M.S.		1
6	Cap screw	M.S.		1
5	Jaw	Steel		1
4	Pin	M.S.		1
3	Collar	M.S.		1
2	Handle	M.S.		1
1	C-frame	C.S.		1

A **B**

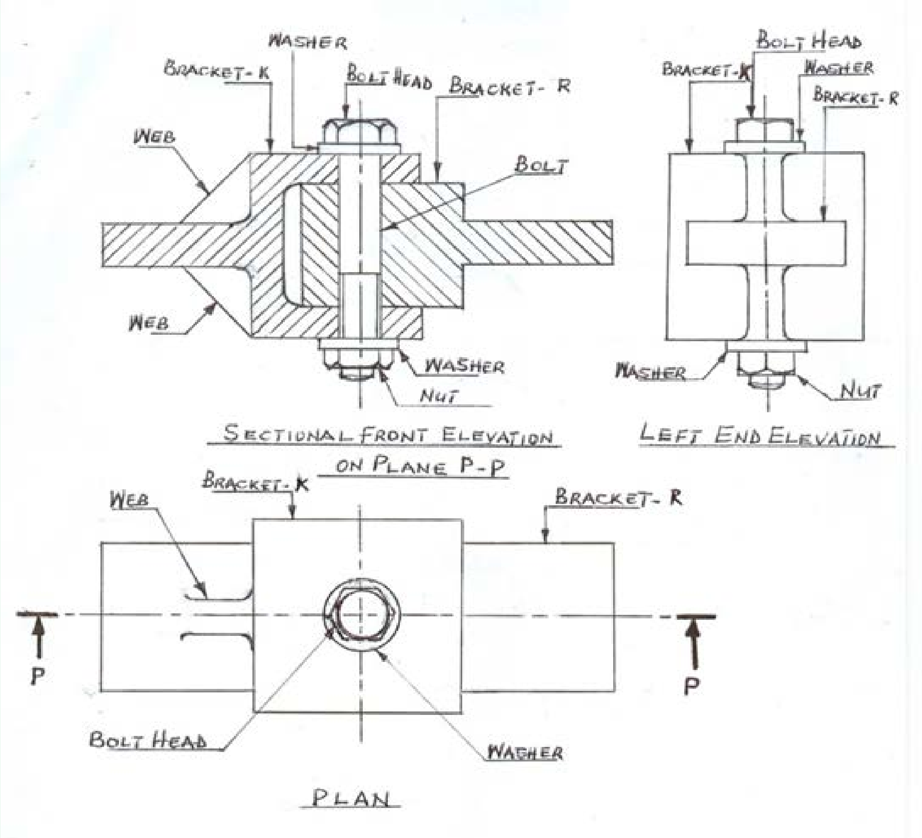
2. Reviewing the samples of assembly drawings and charts. Take notes on the key features and components shown in each drawing.
3. Analyse how the assembly drawing shows the relationship between individual parts.
4. Note how parts are connected, aligned, and interact with each other.
5. Identify any exploded views in the assembly drawings.
6. Observe how these views help in understanding the arrangement and assembly of components.
7. Look for the BOM in the assembly drawings.
8. Note how parts are listed, numbered, and described in the BOM.
9. Create a chart summarising the unique characteristics of assembly drawings based on your analysis, include columns for the following aspects:
   a. Drawing Title: Name of the assembly drawing.
   b. Relationship Between Parts: Description of how parts are connected and interact.
   c. Exploded Views: Presence and role of exploded views.
   d. Bill of Materials (BOM): Details of the BOM, including part numbers and descriptions.

Activity 3.17 Understanding Assembly and Detailed Drawings

1. Begin by reviewing sample assembly and detailed drawings provided in the learner manual or from reliable online sources.
2. Take notes on the key features, purposes, and levels of detail in each type of drawing.



Sample detailed drawing



Sample sectional assembly drawing

3. Revise the meaning of detailed and assembly drawings
4. Compare the level of detail in assembly drawings versus detailed drawings.
5. Discuss why detailed drawings require more precise information about individual components.
6. Identify scenarios where assembly drawings are most useful (e.g., during the assembly process, for understanding the overall structure).
7. Identify scenarios where detailed drawings are most useful (e.g., during manufacturing, for quality control).
8. Discuss how having both types of drawings can provide a comprehensive understanding up should follow this format:
   a. Introduction: Briefly introduce the importance of assembly and detailed drawings.
   b. Purpose: Explain the purpose of each type of drawing.
   c. Comparison: Present your comparison chart and discuss the differences in detail.
   d. Scenarios: Explain scenarios where each type of drawing is most useful.
   e. Conclusion: Summarise the key points and the overall importance of understanding both types of drawings. Reproduce the sample detailed and assembly drawing for mastery of content

Activity 3.18 Assembling and Drawing Mechanical Components

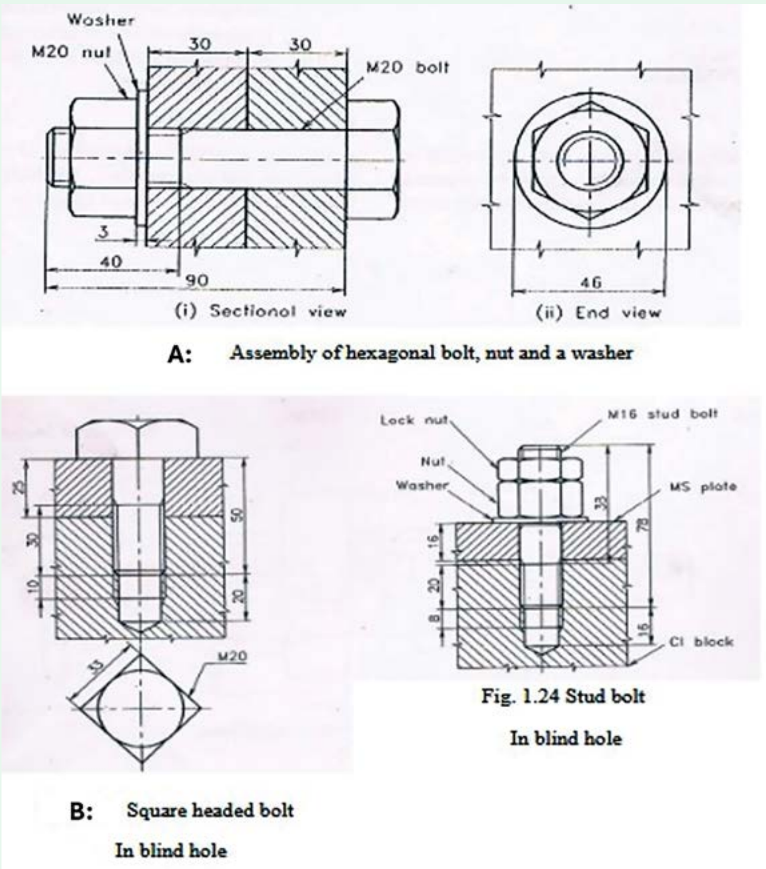
Materials Needed:

- Simple mechanical components (e.g., nuts, bolts, washers)
- Graph paper or plain paper
- Pencil and eraser
- Ruler
- Protractor
- Access to a device to watch instructional videos or view images

Steps

1. Gather Components:
   a. Collect simple mechanical components such as nuts, bolts, and washers.
   b. Ensure you have enough components to create a small assembly.

2. Assemble the Components:
   a. Physically assemble the mechanical components. For example, assemble a bolt with a washer and a nut as shown below



A: Assembly of hexagonal bolt, nut and a washer

B: Square headed bolt
In blind hole

Fig. 1.24 Stud bolt
In blind hole

2. Draw the front, top, and side views of the assembled components on graph paper.

   a. Use a ruler to ensure precise measurements and straight lines.
   b. Ensure that the views are aligned correctly and accurately represent the assembly.
   c. Label each part in your orthographic views (e.g., bolt, washer, and nut).
   d. Indicate the positions of each part clearly.
   e. Draw an exploded pictorial view of the assembled components, showing how each part fits together.
   f. Use lines to indicate the positions and relationships between the parts.

3. Ensure that the exploded view is clear and easy to understand.

Ball joint: assembled (a); exploded view (b): 1-cap, 2-spring, 3-bolt, 4-bowl, 5-body, 6-cover, 7-nut

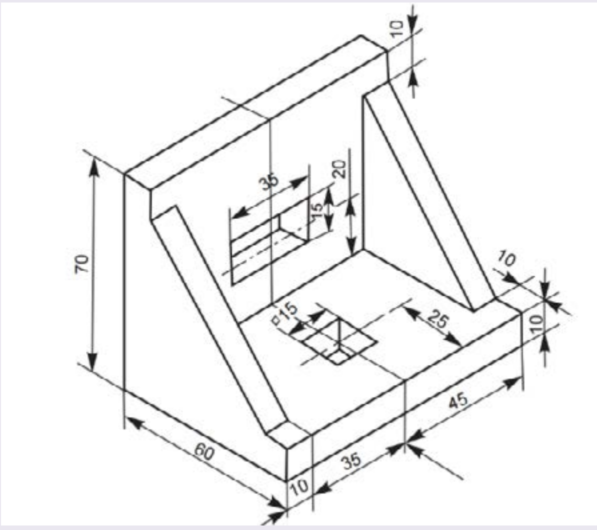
4. Compare your drawings to the example above.
5. Identify areas for improvement and redraw the assembly, focusing on those areas.
6. Include the following sections:
   a. Introduction: Briefly introduce the importance of assembly drawings.
   b. Exploded Views: Present your exploded view and discuss its role in showing component relationships.
   c. Annotations: Explain the importance of labelling parts and adding annotations.
   d. Conclusion: Summarise the key points and the importance of understanding assembly drawings.

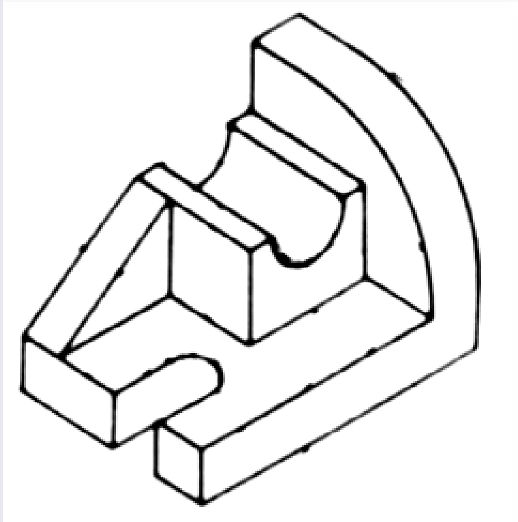
Review Questions

1. Draw a mug using freehand sketching techniques

2. Draw a phone charger using freehand sketching techniques

3. What makes isometric drawing an essential tool for product designers?
4. How does isometric drawing integrate with product design, manufacturing, and communication processes?
5. In what ways can isometric drawings minimise errors during the manufacturing process?
6. Using first angle projection, draw this component's views (the front elevation, the plan and the end elevation). Use reasonable measurements where necessary.





A **B**

7. How does tolerance affect manufacturing quality? Provide real-world examples to illustrate its impact.
8. How does sectioning in engineering drawings help reveal the internal details of a component?
9. What is the role of dimensioning in the manufacturing process?
10. What challenges are involved in creating accurate and clear detailed drawings for complex products?
11. What role do assembly drawings play in ensuring manufacturability and efficient assembly processes?
12. What are the best practices for creating clear and concise assembly drawings?

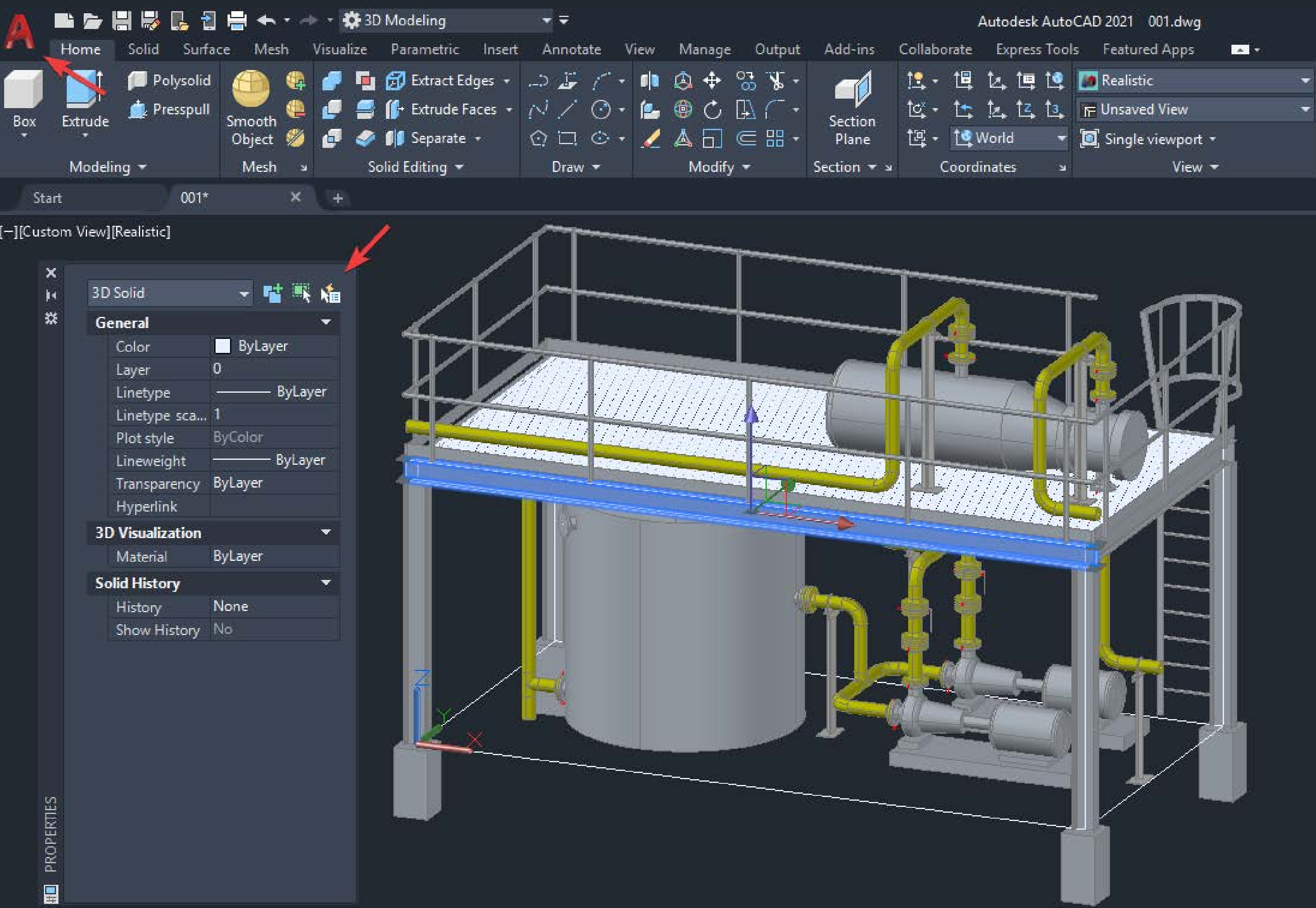
Manufacturing Engineering

Year 2

SECTION

4

MODELLING FOR MANUFACTURE



DESIGN AND PROTOTYPING

Manufacturing Tools And Equipment

Introduction

In this section, we will explore the use of AutoCAD in modelling and developed skills in creating both 2D and 3D models. The section aimed at equipping you with a comprehensive understanding and skills of how AutoCAD can be applied in various industries such as manufacturing, engineering, and design. Through hands-on activities and practical lessons, you will appreciate the essential commands and techniques required to create detailed and accurate models. By the end of this section, you would have understood the importance of AutoCAD in modelling and design, demonstrated proficiency in creating basic 2D shapes and drawings using AutoCAD, developed skills in converting 2D drawings into 3D models, applied advanced modelling techniques to create complex 3D objects and used layers, dimensions, and annotations to organise and detailed their drawings in AutoCAD.

Key Ideas

- AutoCAD is a powerful computer-aided design (CAD) software used by architects, engineers, and construction professionals to create precise 2D and 3D drawings.
- AutoCAD allows for customisation, enabling users to create personalised toolsets, automate tasks with scripts, and adjust the interface to meet specific project requirements.
- AutoCAD offers a comprehensive suite of features that make it an essential tool for professionals across a wide range of industries.
- In AutoCAD, a command is an instruction or action that tells the software to perform a specific task.
- AutoCAD offers a wide range of advanced drawing commands that enable users to create complex and precise designs. These commands are particularly useful for professionals who need to work with intricate geometries, intricate layouts, and high-level drafting.

IMPORTANCE OF AUTOCAD IN MODELLING

AutoCAD is a powerful computer-aided design (CAD) software used by architects, engineers, and construction professionals to create precise 2D and 3D drawings. It provides a comprehensive platform for designing, drafting, and annotating both simple and complex structures with accuracy and efficiency. With AutoCAD, users can create 2D geometry such as lines, arcs, and circles, as well as 3D models using solids, surfaces, and mesh objects. The software offers a range of tools for precise measurement, scaling, and editing, which are critical for producing high-quality, detailed designs.

In addition to drawing and modelling, AutoCAD also includes tools for adding annotations, dimensions, and text to drawings. This helps users communicate design intent and construction details clearly, making the software ideal for project documentation and coordination.

AutoCAD allows for customisation, enabling users to create personalised toolsets, automate tasks with scripts, and adjust the interface to meet specific project requirements. The software also supports various file formats, making it easy to share work with other professionals and integrate with different software applications

The advantages of AutoCAD are summarised below

- CAD drawings are easier to store and maintain
- The files are not susceptible to ageing.
- Revisions are relatively cheap and generally easier.
- Drawings can be reproduced and distributed faster

History of AutoCAD

AutoCAD, one of the most influential and widely used computer-aided design (CAD) software programs, was first released in December 1982 by Autodesk. This groundbreaking software ran on personal computers, utilising internal graphics controllers, a major departure from previous CAD systems that required expensive mainframe or minicomputers. Prior to AutoCAD, most commercial CAD programs were large, complex, and operated in dedicated computer rooms, where engineers or designers worked at specialised terminals. These systems were not only costly to implement but also limited in terms of accessibility, keeping them out of reach for smaller firms and independent professionals.

The creation of AutoCAD marked a turning point in the CAD industry, democratising access to advanced design tools. It was developed by Autodesk co-founder John Walker and a small team of software engineers, with the aim of building a CAD solution that was both affordable and user-friendly. The vision was to create a program that could run on a typical personal computer, allowing individual designers and small firms to harness the power of computer-aided design without the need for expensive, specialised hardware.

This vision became a reality when AutoCAD was first released. The software offered powerful design tools at a fraction of the cost of its competitors, making it accessible to a broader audience. For the first time, professionals in fields such as architecture, engineering, and construction could use CAD software without the high financial investment previously required. AutoCAD's affordability, combined with its intuitive interface, quickly made it the software of choice for many professionals.

The success of AutoCAD was due in large part to its versatility and extensive features, many of which were previously only available in much more expensive systems. The software allowed users to create detailed, precise drawings and models in two and three dimensions, and provided tools for drafting, editing, and visualising designs. AutoCAD's ability to produce high-quality designs without the need for advanced hardware made it revolutionary in the design world. AutoCAD's release in the 1980s was not only a milestone for Autodesk but for the entire field of computer-aided design. It laid the foundation for the widespread use of CAD technology in professional practice, transforming industries by making design processes faster, more accurate, and more accessible to professionals worldwide.

Over the years, AutoCAD has continued to evolve, incorporating new features and tools to meet the changing needs of its users. It has embraced advancements in hardware, software, and digital design technologies, ensuring that it remains one of the leading CAD programs in the market.

AutoCAD Screen Components

The AutoCAD interface is comprised of several integral components, each contributing to a streamlined and efficient design workflow. These components are as follows:

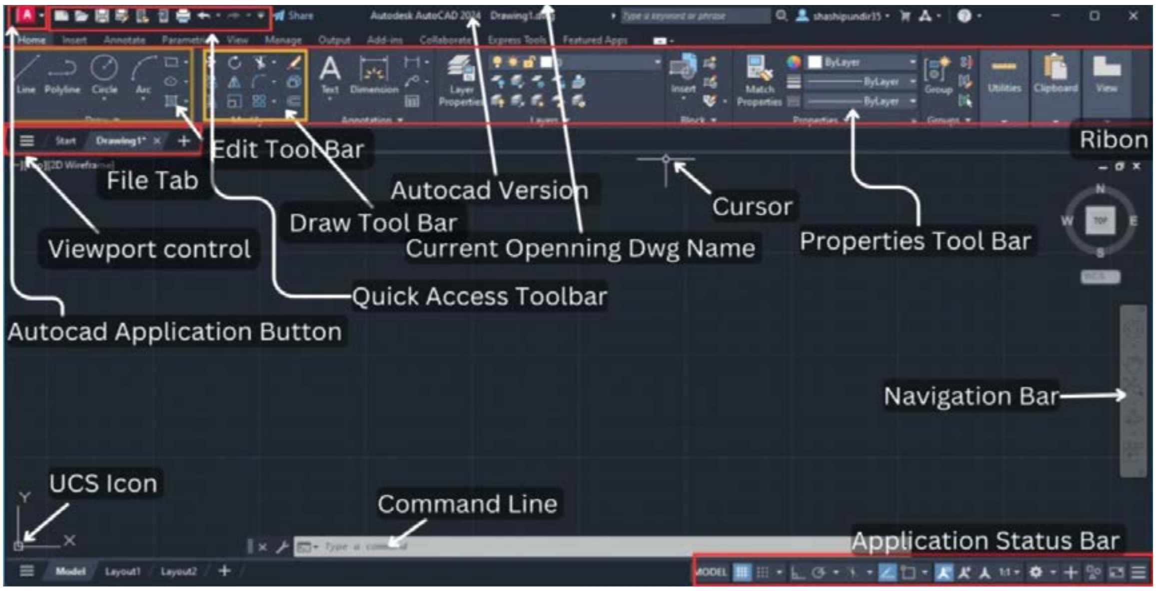


Figure 4.1: The drawing editor

1. **Title Bar**

   Positioned at the top of the screen, the title bar displays the name of the active drawing file and the version of AutoCAD in use, providing clear identification of the current project.

2. **Menu Bar**

   Located directly beneath the title bar, the menu bar offers a structured, drop-down interface through which users can access a wide array of commands, options, and settings organised into categories such as File, Edit, View, and Insert.

3. **Toolbars**

   AutoCAD provides a variety of toolbars. Each toolbar contains several icon buttons that can be PICKED to invoke commands for drawing or editing objects. Toolbars can be customised to suit user preferences and provide quick access to essential drawing functions.

4. **Command Window**

   The command window, situated at the lower portion of the screen, has the command prompt, is one of the most important areas of the AutoCAD editor. Any command that is entered or any prompt that is issued appears here. It serves as the primary interface for direct interaction with AutoCAD, offering real-time feedback on drawing operations and system responses.

5. **Drawing area**

   The central area of the AutoCAD screen is the graphics window, where objects are drawn using various commands. It displays lines, circles, and shapes, with the cursor marked by crosshairs. The coordinate system icon appears at the lower-left corner, and the window includes standard MS Windows controls like close, minimise, and scroll bars.

6. **Model Space**

   A specific area within the drawing environment where users create and manipulate the 2D or 3D model. Model space represents the actual design space, free from layout or annotation elements.

7. **Paper Space**

   A distinct area used to arrange the presentation of the model for printing or plotting. Paper space allows users to create layouts, position viewports, and add annotations, facilitating the creation of final drawing sheets.

8. **Status Bar**

   Found at the bottom of the interface, the status bar displays critical information about the current drawing state, such as the active drawing aids (e.g., snap, grid, ortho), and offers quick access toggles for these features.

9. **Viewport**

   Viewports in paper space are windows that display various perspectives of the model. They can be resized and repositioned to show different portions or views of the drawing, optimising the layout for printing.

10. **Drawing Tabs (Navigator)**

    Located near the bottom of the drawing area, these tabs allow for quick navigation between open drawing files. Each tab represents a different drawing, providing efficient switching between multiple projects.

Key Features

AutoCAD offers a comprehensive suite of features that make it an essential tool for professionals across a wide range of industries. From basic drafting to complex 3D modelling, AutoCAD capabilities cater to the diverse needs of designers, engineers, architects, and other technical professionals. Below are some of the key features that make AutoCAD a great and useful design software:

2D and 3D Drafting and Design

1. Precision Drawing: AutoCAD allows users to create highly detailed 2D drawings and 3D models with unparalleled accuracy. Its precision tools ensure that every design element is aligned, scaled, and positioned exactly as intended, meeting rigorous industry standards.
2. Advanced Geometry Tools: Whether you are creating simple sketches or intricate designs, AutoCAD provides robust tools for drawing and editing geometric shapes. You can easily manipulate lines, arcs, curves, and solids to craft complex designs or modify existing ones with high efficiency.

Automation Features

1. Task Automation: AutoCAD includes features to automate repetitive tasks, such as comparing drawings, inserting predefined blocks, and generating schedules. These automation tools reduce manual effort, streamline workflows, and help maintain consistency across multiple designs.
2. Increased Productivity: Automation not only speeds up common tasks but also enhances overall productivity by allowing users to focus on more complex aspects of the design process. With AutoCAD, you can reduce time spent on manual updates and revisions, leading to faster project delivery.

Industry-Specific Toolsets

AutoCAD is tailored to meet the unique needs of various industries. The software includes specialised toolsets that cater to the specific requirements of professionals working in different fields:

1. Architecture Toolset: AutoCAD provides a range of tools for architectural design, drafting, and documentation. Features like floor plans, building sections, and construction documentation templates help architects streamline their workflow and produce high-quality drawings.

2. Electrical Toolset: Designed for electrical engineers, this toolset allows users to create circuit layouts, panel drawings, and schematics with built-in electrical symbols and components, ensuring designs meet industry standards.
3. Map 3D Toolset: AutoCAD's GIS (Geographic Information System) tools allow users to plan, analyse, and manage infrastructure projects. The Map 3D toolset includes features for handling geospatial data, making it ideal for urban planning, environmental studies, and civil engineering projects.
4. Mechanical Toolset: This toolset is tailored for mechanical engineers and designers, offering tools for machine parts design, assemblies, and 2D and 3D modelling of mechanical components. It includes a library of standard parts and tools for dimensioning and tolerancing.
5. MEP Toolset (Mechanical, Electrical, and Plumbing): AutoCAD's MEP toolset provides comprehensive design and drafting tools for mechanical, electrical, and plumbing systems, making it easier for engineers to design, model, and document these systems in buildings.
6. Plant 3D Toolset: Designed for professionals working in the process plant and industrial facilities sectors, this toolset allows users to design piping, structures, and process equipment for oil and gas, chemical plants, and other industrial applications.
7. Raster Design Toolset: With Raster Design, users can convert scanned drawings and raster images (like JPEGs and TIFFs) into editable vector graphics, making it easier to update legacy drawings and incorporate scanned data into new projects.

Web and Mobile Applications

1. Access Anywhere: AutoCAD's web and mobile apps allow users to access their drawings and designs from virtually any location. Whether you're on-site, traveling, or working remotely, you can view, create, edit, and share CAD drawings from any device—be it a laptop, tablet, or smartphone.
2. Seamless Collaboration: The mobile and web versions of AutoCAD also enable collaboration on the go. Designers and engineers can share real-time updates, make changes to projects, and keep all team members aligned, ensuring smoother project execution and faster decision-making.

BASIC DRAWING COMMANDS

AutoCAD Command Line

The AutoCAD Command Line is a robust, text-based interface that offers an alternative means of interacting with the software, complementing the graphical user interface (GUI), which includes menus, ribbons, and toolbars. While the GUI is designed to be intuitive and accessible for beginners, many seasoned AutoCAD professionals prefer the Command Line for its efficiency, speed, and precision in executing commands.

By typing text commands directly into the Command Line, users can access a wide range of tools and functions with greater control and fewer steps than relying on the visual interface. For those familiar with AutoCAD's commands and syntax, the Command Line becomes an indispensable tool for optimising workflow and enhancing productivity.

Key Features and Benefits

Command Input

The Command Line serves as a direct interface for entering commands that execute a broad spectrum of AutoCAD functions. This includes tasks such as creating and modifying geometric shapes, inserting blocks, applying hatches, or executing more complex operations with precision. By typing the appropriate command, users can swiftly engage with the software's core capabilities, streamlining their workflow.

Command History

The Command Line features an integrated history function, which logs recently executed commands. This allows users to quickly repeat prior actions without re-entering the entire command. The command history is particularly useful for repetitive tasks, reducing the need for manual input and improving overall efficiency.

Autocompletion

As you begin typing a command, AutoCAD's autocompletion feature provides real-time suggestions, helping to complete the command more quickly. This not only speeds up the process but also reduces the risk of typographical errors, ensuring greater accuracy when entering commands. Autocompletion is an indispensable tool for both novice and advanced users, allowing them to work faster and more reliably.

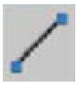
Customisation

The Command Line is highly customisable to suit individual preferences. Users can adjust the font size and colour, allowing for better visibility and a more personalised interface. Also, options like enabling or disabling autocompletion can be tailored to optimise workflow, providing a more efficient and comfortable user experience.

Customising the Command Line enhances usability, particularly for professionals who require a highly specific setup to match their working style.

Line Command in AutoCAD

The LINE command is one of the most fundamental tools in AutoCAD, allowing users to create precise 2D drawings by specifying exact points and controlling the direction and length of each line segment. Mastery of this command is essential for efficient drafting and design.

Draw Toolbar/Panel	Menu	Command (Alias)
	Draw ⟶ Line	LINE (L)

Steps in using the Line Command in AutoCAD

1. **Accessing the Command Line**

   At the bottom of the AutoCAD window, you'll find the command line interface, where you can type commands directly to interact with the software. This text-based interface provides a more efficient method for inputting commands, particularly for experienced users who prefer precise control over their workflow.

2. **Starting the LINE Command**

   To activate the LINE command, type 'LINE' into the command line and press 'Enter'. Alternatively, you can access the Line tool by navigating to the Home tab on the Ribbon and clicking on the Line icon. Both methods will initiate the same function, but using the command line can offer faster access for those familiar with AutoCAD's command syntax.

3. **Drawing a Line Segment**

   Once the LINE command is active, your cursor will change to a crosshair, indicating that AutoCAD is ready to receive input for the starting point of your line.

   a. Move your cursor to the desired starting point for the line segment.

   b. Left click to define the first point of your line. This is the anchor point where your line will begin.

4. **Drawing the Line**

   To draw the line segment,

   a. Move your cursor in the direction where you want the line to extend.

   b. Left click again to specify the second point, and AutoCAD will draw the line segment between these two points. The line is drawn based on the distance and direction between the two points you selected.

Example

Command: LINE

Specify first point: 10, 10

Specify next point or [Undo]: 50,100

(Press ENTER to exit the LINE command.)

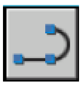
5. **Continuing or Ending the Line**

   After drawing your first line segment, the command line will prompt you with "Specify next point or [Undo]," indicating that AutoCAD is ready for you to either continue drawing or finish the command.

   a. To continue drawing, move your cursor to the next desired endpoint and left-click to define the next line segment.
   b. Repeat the process to create additional connected line segments, each defined by selecting new endpoints with each click.
   c. To end the LINE command and stop drawing, press 'Enter', right-click and choose Enter from the context menu, or type 'C' for Close to complete the current drawing and close the shape if applicable

Polyline Command in AutoCAD

The POLYLINE command is a highly flexible tool that allows AutoCAD users to create intricate shapes and continuous paths with ease. By combining straight lines and arcs into a single object, polylines simplify the design process and provide significant advantages when editing complex shapes. Whether you are working on architectural plans, mechanical parts, or any other design requiring connected segments, mastering the POLYLINE command is essential for efficient drafting and drawing management.

Draw Toolbar/Panel	Menu	Command	Alias
	Draw ⟶ Polyline	PLINE	pl

Steps in using the Polyline Command in AutoCAD

1. **Creating a Polyline**

   a. To initiate the POLYLINE command, type 'PLINE' or 'POLYLINE' in the command line and press 'Enter'.
   b. Alternatively, you can activate the Polyline tool from the Draw panel in the Home tab of the Ribbon. This provides a quick and intuitive method for starting the command from the graphical interface.

2. **Drawing Segments**

   Once the POLYLINE command is active, you can begin defining the vertices (corner points) of the polyline:

a. Click in the drawing area to place the first vertex. You can continue clicking sequentially to place each subsequent vertex.
b. Alternatively, you can use direct input methods such as absolute, relative, or polar coordinates to specify precise locations for each vertex. This provides flexibility and ensures accuracy when drawing complex shapes.

3. **Segment Types**

Within a single polyline, you can combine line segments and arc segments, allowing for greater design flexibility.

a. When creating a polyline, each segment can be either a straight line or a curve (arc), or a mixture of both. This is especially useful for creating smooth, flowing curves and sharp, angular segments in one continuous object.
b. To switch between segment types (from line to arc or vice versa), you can use the options available in the command line or the Ribbon. These tools allow you to specify whether the next segment should be a straight line or an arc.

4. **Editing Polylines**

Once a polyline is created, it can be easily modified using a variety of editing tools:

a. The PEDIT (Polyline Edit) command is a powerful tool for editing polylines. It allows users to add or remove vertices, change the type of segment (e.g., from line to arc), and adjust the position of individual vertices.
b. Polylines offer a unique advantage over individual lines and arcs because they remain as a single object, making them easier to manipulate without having to manage multiple entities. This makes it simpler to modify complex shapes, adjust dimensions, or refine curves.

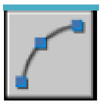
5. **Closing a Polyline**

To close a polyline (forming a closed shape), you have two options:

a. You can specify the same point as the starting point, thus connecting the last vertex to the first and completing the shape.
b. Alternatively, use the Close option available in the command line or the Ribbon. This automatically closes the polyline and ensures that all segments form a continuous, enclosed boundary.

Arc Command in AutoCAD

The ARC command in AutoCAD is an essential tool for creating arcs with precision and flexibility. By utilising different input methods, such as specifying centre points, radii, angles, chord lengths, and directions, users can create arcs that meet the exact requirements of their drawings. Whether you're designing smooth curves, transitions, or circular features, mastering the ARC command allows for a high degree of control and accuracy in your work.

Draw Toolbar/Panel	Menu	Command	Alias
	Draw ⟶ Arc	ARC	A

Steps in using the Arc Command in AutoCAD

1. **Centre, Start, and End Points**

   This method allows you to define an arc by specifying the centre, start point, and end point. This provides complete control over the arc's shape and positioning:

   a. To activate the ARC command, type 'ARC' in the command line and press 'Enter'.
   b. Specify the centre point of the arc by clicking on a location in the drawing area or entering the coordinates directly.
   c. Define the start point where the arc will begin.
   d. Finally, define the endpoint where the arc will finish, completing the curve.

2. **Radius and Angle**

   This method allows you to create an arc by specifying its radius and the included angle (the angle between the two radii extending from the centre point). This is particularly useful when you need a specific radius and angle:

   a. After starting the ARC command, specify the centre point of the arc (or any point on the arc's circumference).
   b. Enter the radius of the arc, which determines the curve's size.
   c. Specify the included angle between the two radii, which dictates the arc's span. This method creates an arc with a precise angle between its start and end points.

3. **Chord Length**

   You can also create an arc by defining its start point, end point, and chord length (the straight-line distance between the two endpoints of the arc):

   a. Start the ARC command and click the start point of the arc in the drawing area.
   b. Click the endpoint of the arc to define the other end of the curve.
   c. Enter the chord length, which defines the straight-line distance between the start and end points of the arc. This method ensures that the arc spans a specific chord length.

4. **Direction**

   By default, arcs are drawn in a counterclockwise direction. However, you can reverse this direction if needed:

   a. While drawing an arc, hold down the Ctrl key on your keyboard and drag the mouse in the opposite direction to create the arc clockwise. This feature provides additional flexibility when positioning arcs in your drawing.

5. **Tangent Arcs**

   AutoCAD also offers a method for automatically creating a tangent arc to another object, such as a line, polyline, or another arc:

   a. After drawing a line, arc, or polyline, press 'Enter' without specifying a point.

   b. AutoCAD will automatically generate an arc that is tangent to the last drawn object, ensuring a smooth, continuous transition between objects. This is particularly useful for creating seamless connections and smooth curves that blend into existing elements in your design.

   Example: Arc and Circle Command

   Command: ARC

   Specify start point of arc or [Centre]: (pick P1)

   Specify second point of arc or [Centre/End]: (pick P2)

   Specify end point of arc: pick P3)

   Command: CIRCLE «

   Specify centre point for circle or [3P/2P/Ttr(tan tan radius): 3,2 «

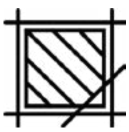
   Specify radius of circle or [Diameter] <current>: 1

ADVANCED DRAWING COMMANDS

AutoCAD offers a wide range of advanced drawing commands that enable users to create complex and precise designs. These commands are particularly useful for professionals who need to work with intricate geometries, intricate layouts, and high-level drafting. Here are some essential advanced drawing commands in AutoCAD, along with their functions and how the used.

HATCH

The HATCH command is an indispensable feature in AutoCAD, providing a quick and efficient way to apply visual fills to closed areas in a drawing. Whether you are working with architectural, mechanical, or other design drawings, the ability to apply hatch patterns, solid fills, or gradient fills adds clarity and detail to your work. By mastering the various options for choosing boundaries, modifying hatch patterns, and fine-tuning settings, you can create professional, high-quality drawings with enhanced visual appeal and clarity.

Draw Toolbar/Panel	Menu	Command (Alias)
	Draw ⟶ Hatch	HATCH/_BHATCH

Steps in using the HATCH Command in AutoCAD

1. **Choosing Boundaries**

   When using the HATCH command, the first step is to define the boundaries of the area you wish to fill. There are several methods to do this:

   a. Specify a Point: Click inside an enclosed area formed by intersecting objects. AutoCAD will automatically detect the boundary and apply the fill.

   b. Select Objects: Select the objects that form the boundary of the area you want to hatch. This option allows you to apply the hatch to complex, predefined shapes or closed loops.

   c. Pick Internal Point: Choose a point within a closed area, and AutoCAD will infer the boundaries from surrounding objects. This is especially useful for irregular or intricate shapes where manually selecting objects may be cumbersome.

   d. HATCH Draw Option: Use this option in the command line to manually specify boundary points, giving you more precise control over the hatch area. This can be beneficial for drawing complex or custom shapes.

   e. Drag from Tool Palette or Design Centre: For faster access to pre-defined hatch patterns, you can drag and drop a hatch pattern from the Tool Palette or Design Centre into the enclosed area. This method simplifies the process of applying commonly used patterns.

2. **Modifying Hatch Patterns**

   Once a hatch pattern is applied, AutoCAD offers several options for modifying or adjusting it:

   a. Remove Boundaries: If you wish to remove any hatch patterns added during the current HATCH command, you can do so using the Remove Boundaries option in the Hatch and Gradient dialog box. This allows you to reset the hatch area without starting from scratch.

   b. Add Boundaries: If you want to extend or adjust the hatch area, the Add Boundaries option allows you to include additional boundary objects after an initial hatch has been applied. This gives you the flexibility to modify the hatch pattern as needed.

   c. Undo: This option removes the most recent hatch pattern applied, allowing you to quickly correct mistakes or revert to a previous state in the current HATCH operation.

   d. Settings: The Settings button opens the Hatch and Gradient dialogue box, where you can fine-tune the properties of the hatch pattern. This includes adjusting the hatch pattern, scale, angle, and transparency. Customising these settings allows for greater control over the appearance and scale of the hatch, ensuring that it fits your drawing's requirements.

Steps to Add a Hatch Pattern

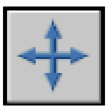
1. Click on the Home tab in the Ribbon.
2. Navigate to the Draw panel and click on Hatch or type 'HATCH' on the command line and press 'Enter'.
3. Specify the method to define the boundaries of the hatch (point, select objects, pick internal point, etc.).
4. Choose a hatch pattern from the options provided in the Hatch and Gradient dialogue box or select a predefined pattern from a tool palette.
5. Adjust settings such as scale, angle, and spacing as needed.
6. Click inside the enclosed area or select objects to apply the hatch pattern.

Tips for Using HATCH

- Ensure that the area you want to hatch is completely enclosed by objects or defined boundaries.
- Experiment with different hatch patterns and settings to achieve the desired visual effect.
- Use the Undo feature if you need to remove the last hatch pattern applied.

MOVE

When using the MOVE command, you can accurately reposition objects within your drawing, either by visually selecting the direction and distance or by entering precise coordinates. This flexibility allows for efficient modifications and refinements in your design work.

Draw Toolbar/Panel	Menu	Command (Alias)
	Modify » Move	MOVE (M)

Steps in Using the MOVE Command in AutoCAD

1. **Selecting Objects**
   a. Begin by clicking on the Home tab in the Ribbon.
   b. In the Modify panel, locate and click on the Move tool, or alternatively, type 'MOVE' in the command line and press 'Enter' to initiate the command.
   c. Select the objects you wish to move by clicking on them in the drawing area. After selecting all the objects, press 'Enter' to confirm your selection.
2. **Specifying the Base Point**
   a. After selecting your objects, AutoCAD will prompt you to specify a base point.

b. Click on a point within your drawing to define the base point, which acts as the anchor from which the objects will be moved. The base point serves as the reference point for the movement, allowing you to reposition objects accurately.

3. **Specifying the Second Point**

   After defining the base point, AutoCAD will prompt you to specify the second point—this is where the object will be relocated. You have two options for specifying the second point:

   a. Direct Distance and Direction. Click on a point in the drawing area that defines the distance and direction you want to move the objects. This point essentially serves as the endpoint of a vector extending from the base point.

   b. Using Coordinates: Alternatively, you can directly input the coordinates of the second point relative to the base point in the command line. Simply type the coordinates and press ‘Enter’ to finalise the movement.

ROTATE

When using the ROTATE command, you can efficiently reposition objects in your drawing at precise angles around a specific pivot point. This capability is crucial for adjusting the orientation of objects in technical drawings, architectural layouts, and engineering designs, ensuring that elements are aligned and proportioned correctly within your workspace.

Draw Toolbar/Panel	Menu	Command (Alias)
	Modify » Rotate	ROTATE (RO)

Steps in Using the ROTATE Command in AutoCAD

1. **Selecting Objects**

   a. Navigate to the Home Tab: First, click on the Home tab in the Ribbon.

   b. Activate the Rotate Command: In the Modify panel, locate and click on the Rotate button, or simply type ‘ROTATE’ into the command line and press ‘Enter’ to initiate the command.

   c. Select the Objects: Click on the objects you wish to rotate in the drawing area. After selecting all desired objects, press ‘Enter’ to confirm your selection and proceed.

2. **Specifying the Base Point**

   a. Define the Base Point: After selecting the objects, AutoCAD will prompt you to specify a base point.

   b. Click on the Base Point: This point acts as the pivot point around which the objects will rotate. Click on a location in the drawing area that will serve as the centre of rotation.

3. **Specifying the Rotation Angle**

   a. Enter the Rotation Angle: AutoCAD will then prompt you to specify the angle of rotation.

   b. Direct Angle Entry: You can directly type the desired angle of rotation (e.g., type '45' for a 45-degree rotation) and press 'Enter'.

   c. Using a Second Point for Rotation: Alternatively, you can specify the rotation angle by defining a second point. AutoCAD will calculate the angle relative to the base point you selected.

Additional Options

'C' for Copy: If you want to create a copy of the selected objects at the rotated position, type 'C' for Copy. This will duplicate the objects at the new angle while keeping the original objects in place.

'R' for Reference: Use the 'R' option for Reference rotation, which allows you to rotate objects from a specified angle to a new absolute angle. This is useful when you need to rotate objects to a precise orientation relative to their current position.

MIRROR

With the MIRROR command, you can create accurate and symmetrical reflections of objects, which is particularly useful for generating designs that require precise mirroring, such as in architectural plans, mechanical components, or any project where symmetry is crucial. This command provides flexibility in terms of mirror axis definition and the ability to retain or remove the original objects, giving you full control over the mirrored elements in your design.

Draw Toolbar/Panel	Menu	Command (Alias)
	Modify » Mirror	MIRROR(MI)

Steps in using the MIRROR Command in AutoCAD

1. **Selecting Objects**

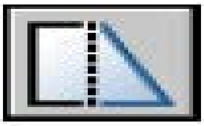
   a. Activate the MIRROR Command: Click on the Home tab in the Ribbon, then navigate to the Modify panel and click on Mirror. Alternatively, type 'MIRROR' in the command line and press 'Enter' to activate the command.

   b. Select Objects to Mirror: Click to select the objects you wish to mirror. Once all objects have been selected, press 'Enter' to confirm your selection and proceed to the next step.

2. **Specifying the Mirror Line**
    a. Define the Mirror Line: After selecting the objects, AutoCAD will prompt you to specify the first point of the mirror line.
    b. Set the First Point: Click on a point in the drawing area to define the starting point of the mirror line. This point marks the beginning of the axis along which the objects will be mirrored.
    c. Define the Second Point: Next, click to define the endpoint of the mirror line. This second point determines the direction and orientation of the mirrored objects. The line between these two points will act as the axis of reflection.
3. **Options for Erasing Source Objects**
    a. After defining the mirror line, AutoCAD will present you with an option regarding whether to erase the original objects once they have been mirrored:
    b. Erase Source Objects: AutoCAD will prompt you with the option to erase the original objects after creating their mirrored copy.
    c. 'Y' for Yes: Type 'Y' if you want to erase the original objects after mirroring them.
    d. 'N' for No: Type 'N' to retain the original objects in the drawing after the mirror operation.

STRETCH

The STRETCH command in AutoCAD is invaluable when making precise adjustments to the geometry of objects, such as modifying the length of walls in architectural drawings, resizing mechanical components, or altering curves in a design. By using a base point and selection window, you can maintain full control over which parts of the objects are stretched, ensuring accurate and efficient modifications.

Draw Toolbar/Panel	Menu	Command (Alias)
	**Modify»Stretch**	**STRETCH (S)**

Steps in using the STRETCH Command in AutoCAD

1. **Selecting Objects**
    a. Activate the STRETCH Command: Click on the Home tab in the Ribbon, then navigate to the Modify panel and select Stretch. Alternatively, type 'STRETCH' in the command line and press 'Enter' to activate the command.
    b. Select the Objects to Stretch: You must select the objects to be stretched by crossing them with a selection window or polygon.

c. Partially Enclosed Objects: Only the objects that are partially enclosed within the selection area will be stretched.
d. Fully Enclosed Objects: Objects fully enclosed within the window will not be stretched, but instead, will be moved along with the rest of the selection.
e. Individual Selection: If you individually select objects within the window, only those objects will be moved, not stretched.

2. **Specifying the Base Point**

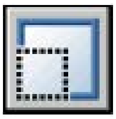
a. Define the Base Point: After selecting the objects, AutoCAD will prompt you to specify a base point.
b. Select a Base Point: Click on a point in the drawing area that will act as the origin for the stretch operation. This base point will determine the offset for the objects being stretched, and it can be placed outside the area being modified. This gives you full control over the direction and magnitude of the stretch.

3. **Performing the Stretch**

a. Define the Stretch Direction: Once the base point has been set, move your cursor in the direction in which you want to stretch the objects.
b. Set the Stretch Distance: Click to confirm the stretch operation and apply the defined distance. The objects within the selection window or polygon will stretch along the specified vector, while others will remain unaffected.

SCALE

The SCALE command in AutoCAD enables you to resize objects proportionally, maintaining their original shape and relative dimensions while changing their overall size. This command is essential for adjusting the scale of drawings, components, or elements within your project without distorting their proportions.

Draw Toolbar/Panel	Menu	Command (Alias)
	Modify» Scale	SCALE (SC)

Steps in using the SCALE Command in AutoCAD

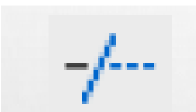
1. **Selecting Objects**

a. Activate the SCALE Command: Navigate to the Home tab in the Ribbon, then locate the Modify panel and click on Scale. Alternatively, you can type 'SCALE' into the command line and press 'Enter' to initiate the command.
b. Choose the Objects to Scale: Click on the objects you want to resize in the drawing area. Once you have selected all the desired objects, press 'Enter' to proceed to the next step.

2. **Specifying the Base Point**
   a. Define the Base Point: After selecting the objects, AutoCAD will prompt you to specify a base point.
   b. Choose the Base Point: Click on a point in the drawing area that will serve as the fixed point for scaling. This point will remain stationary, and all other selected objects will resize relative to this base point. It is crucial to choose a base point that represents a fixed reference in the design.
3. **Specifying the Scale Factor**
   a. Enter the Scale Factor: AutoCAD will prompt you to input a scale factor that determines the new size of the selected objects.
   b. Direct Scale Factor Input:
      i. Scale Factor Greater than 1: A scale factor greater than 1 will enlarge the selected objects proportionally. For example, entering ‘2’ will double the size of the objects.
      ii. Scale Factor Between 0 and 1: A scale factor between 0 and 1 will shrink the objects proportionally. For instance, entering ‘0.5’ will reduce the objects to half their original size.
   c. Using the ‘Copy’ and ‘Reference’ Options:
      i. Copy: If you want to create a duplicate of the objects before scaling them, use the ‘Copy’ option. Type ‘C’ on the command line and press ‘Enter’ to activate this option. This will allow you to create a scaled copy of the original objects while retaining the originals in place.
      ii. Reference: The ‘Reference’ option allows you to scale objects based on a known reference length. This is useful when you want to scale an object to a specific size. Type ‘R’ on the command line and press ‘Enter’. You will be prompted to specify the reference length (the original length you want to scale from), followed by the new length (the desired length after scaling).

TRIM

The TRIM command in AutoCAD is a powerful tool that enables you to remove portions of objects by trimming them to the nearest boundary. This operation is essential for refining and cleaning up drawings, especially when dealing with intersecting elements or excess geometry. AutoCAD offers two distinct modes for using the TRIM command. They are Standard Mode and Quick Mode.

Draw Toolbar/Panel	Menu	Command (Alias)
	Modify ⟶ Trim	TRIM/_TRIM

Steps in using the TRIM Command in AutoCAD

1. **Selecting Boundaries**
   a. Activate the TRIM Command: Click on the Home tab in the Ribbon, navigate to the Modify panel, and select Trim. Alternatively, type 'TRIM' in the command line and press 'Enter'.
   b. Define the Cutting Boundaries: In this step, you need to specify the objects that will act as the cutting edges (boundaries) for the trim operation. You can select multiple objects that will serve as boundaries. After selecting the boundaries, press 'Enter' to confirm.

2. **Trimming Objects**
   a. Select Objects to Trim: Once the boundaries are defined, AutoCAD prompts you to select the objects you wish to trim.
   b. Trim the Selected Objects: Click on the part of the object you want to remove. The portion of the object that extends beyond the nearest boundary will be trimmed off, ensuring a clean intersection with the boundary.

3. **Using All Objects as Boundaries**

   Apply All Objects as Cutting Edges: If you want all objects in the drawing to act as boundaries for the trim operation, simply press 'Enter' at the first "Select Objects" prompt without selecting any objects. Once done, proceed to select the objects you wish to trim as usual.

Quick Mode for Selecting Objects to Trim

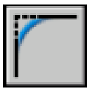
a. Activate the TRIM Command: Click on the Home tab in the Ribbon, navigate to the Modify panel, and click on Trim, or type 'TRIM' in the command line and press 'Enter'.
b. Automatic Boundaries: In Quick Mode, all objects in the drawing automatically act as cutting edges, so you do not need to manually define boundaries.
c. Select Objects to Trim: Simply select the objects you want to trim by clicking on them individually. You can also press and drag to create a freehand selection area or specify a crossing fence by picking two empty points in the drawing. If an object cannot be trimmed based on its geometry, it will be deleted instead of trimmed.

Additional Notes

1. Trim Operation: In both modes, trimming removes portions of objects that are outside the boundary, leaving only the part that intersects the cutting edge.
2. Undoing Trims: If you make an error, you can always Undo the trim operation using the 'Undo' command or by pressing Ctrl+Z.
3. Efficiency: While Standard Mode offers more control over which objects act as boundaries, Quick Mode is ideal for easily trimming multiple objects when you don't need to define specific boundaries.

FILLET

The FILLET command in AutoCAD is a versatile tool used to create a smooth, rounded transition between two objects. It is commonly employed to round the edges of lines, polylines, or other geometric entities, facilitating the creation of aesthetically pleasing, functional connections in your designs.

Draw Toolbar/Panel	Menu	Command (Alias)
	Modify» Fillet	FILLET(F)

Steps in using the FILLET Command in AutoCAD

1. **First Object Selection**
   a. Activate the FILLET Command: Start by clicking on the Home tab in the Ribbon, then navigate to the Modify panel and click on the Fillet button. Alternatively, you can type 'FILLET' into the command line and press 'Enter' to initiate the command.
   b. Select the First Object: Click on the first of the two objects you wish to fillet. Typically, these objects will be straight lines or segments of a polyline, but the FILLET command can be used with a variety of shapes and geometric entities.

2. **Second Object Selection**
   a. Select the Second Object: After selecting the first object, AutoCAD will prompt you to select the second object that you wish to connect via the fillet. Click on the second object to define the corner where the fillet will be applied.
   b. Arc Creation: Once both objects are selected, AutoCAD will automatically generate an arc that joins the two objects at their point of intersection, creating a smooth, rounded transition between them.

Other option for the FILLET Command

1. Radius Adjustment: The FILLET command allows you to adjust the radius of the rounded arc between the two objects. You can specify the radius either before selecting the objects (via the command line or dynamic input), or once you've selected the first object, AutoCAD will prompt you to input the desired radius.
2. Multiple Fillets: You can apply the FILLET command to multiple sets of objects without having to restart the command each time. After applying a fillet to one pair of objects, simply continue selecting additional pairs of objects to apply the same fillet radius.
3. Trim or Extend: The FILLET command also offers options to trim or extend the selected objects to ensure they meet precisely at the fillet. If the objects don't intersect, AutoCAD will either extend them to the point of intersection or trim them to the fillet arc, depending on the selected options.

Other Advanced Command Options

The FILLET command in AutoCAD comes with several advanced options that allow for precise control over how the rounded transitions are applied between objects. These options enable you to tailor the command to suit your specific design needs.

Undo

a. **Reverses the Last Action:** The Undo option allows you to quickly reverse the most recent action taken within the FILLET command. This is particularly useful if you make an error or wish to backtrack and restore the drawing to its previous state.

b. **How to Use:** Simply type 'U' after initiating the FILLET command to undo the last fillet operation. This will revert the selected objects back to their state before the fillet was applied.

Polyline

a. **Fillet All Vertices of a Polyline:** The Polyline option enables you to apply a fillet to every vertex of a selected 2D polyline, where two line segments meet. This results in creating rounded corners at each vertex along the polyline.

b. **How to Use:** After activating the FILLET command, type 'P' and select a polyline. The fillet will automatically be applied to all vertices where the line segments intersect.

Radius

a. **Defines the Radius of the Fillet Arc:** The Radius option sets the curvature of the fillet arc. The value you specify will become the default radius for all subsequent fillet operations in the current session.

b. **How to Use:** To set the fillet radius, type 'R' after initiating the FILLET command, input the desired radius value, and press 'Enter'. The specified radius will then be applied to the arc between the two selected objects.

Trim

a. **Controls Object Trimming to Fillet Arc:** The Trim option determines whether the fillet command will trim the selected objects to the endpoints of the fillet arc. When enabled, the edges of the objects will be trimmed to meet at the arc's endpoints, ensuring a cleaner intersection.

b. **How to Use:** To toggle trimming, type 'T' after initiating the FILLET command. When prompted, enter 'Yes' to enable trimming, or 'No' to leave the objects untrimmed after the fillet is applied.

Multiple

a. **Apply fillet to multiple object pairs:** The Multiple option allows you to apply the FILLET command to several sets of objects in a single command sequence, without needing to restart the command each time.

b. **How to use:** To use the Multiple option, type 'M' after starting the FILLET command. Then, select multiple pairs of objects, and AutoCAD will apply the fillet to each set sequentially. Press 'Enter' when finished.

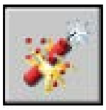
Edge

a. **Fillet a Single Edge:** The Edge option allows you to apply a fillet to a single edge, one at a time. You can continue to select and fillet additional edges until you decide to exit the command.

b. **How to Use:** To apply a fillet to a single edge, type 'E' after initiating the FILLET command, then select the edge you wish to fillet. Continue selecting edges until you are ready to finalise the operation by pressing 'Enter'.

EXPLODE

The EXPLODE command in AutoCAD is a powerful tool that allows you to break down complex objects into their individual components. This feature is particularly useful when you need to edit or manipulate specific parts of a compound object, such as a block, polyline, or other grouped entities. By using EXPLODE, you can access and modify the individual elements that make up a more intricate design.

Draw Toolbar/Panel	Menu	Command (Alias)
	Modify» Explode	EXPLODE (X)

Steps in using the EXPLODE Command in AutoCAD

1. **Activating the Command**

   a. Ribbon Method:
   - Click on the Home tab in the Ribbon.
   - Navigate to the Modify panel.
   - Click on the Explode icon.

   b. Command Line Method: Type 'EXPLODE' in the command line and press 'Enter'.

2. **Selecting Objects to Explode**

   c. Select the Compound Objects: Click on the objects you wish to break apart. This can include blocks, polylines, groups, or other compound objects.

   d. Confirm Selection: Once the objects are selected, press 'Enter' to confirm your selection and proceed with the explosion.

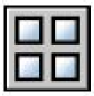
Important Notes on Using EXPLODE

- Block Explosions: When you explode a block, AutoCAD breaks it down into its components, such as lines, circles, and text, allowing you to modify them individually.

- Polyline Explosions: Exploding a polyline will break it into separate line or arc segments, depending on how the polyline was constructed.
- Groups: Exploding a group will disassemble the group into individual objects, which can then be manipulated separately.
- Caution: Once an object is exploded, it can no longer be treated as a single entity, so be sure to use this command carefully, especially for complex objects that may lose their grouped functionality after being exploded.

ARRAY

The ARRAY command in AutoCAD is an efficient tool that allows you to create multiple copies of selected objects in a specific arrangement or pattern. These patterns—referred to as arrays—can be rectangular, polar, or along a defined path. Each array type offers distinct ways to arrange the copies, giving you flexibility in how you structure your design. Whether you need to create a row of objects, arrange items around a central point, or align them along a curved path, the ARRAY command streamlines the process.

Draw Toolbar/Panel	Menu	Command (Alias)
	Modify» Array	ARRAT (AR)

Steps in using the ARRAY Command in AutoCAD

1. **Activating the Command**
   a. Ribbon Method:
      i. Click on the Home tab in the Ribbon.
      ii. Navigate to the Modify panel.
      iii. Click on the Array button.
   b. Command Line Method: Type 'ARRAY' in the command line and press 'Enter'.
2. **Selecting Objects**
   a. Select the Objects: Click to select the objects you want to replicate in the array.
   b. Confirm Selection: Press 'Enter' once you have selected all the objects you want to include in the array.
3. **Choosing the Array Type:** After selecting your objects, AutoCAD provides three array options, each suited for different design scenarios.
   a. **Rectangular Array**
      i. Choose 'Rectangular' from the array options.
      ii. Specify the number of rows and columns for the array.

iii. Define the spacing between each row and column, either by distance or by number of items in each direction.

This option is ideal when you need to replicate objects in a uniform grid pattern.

b. **Path Array**

iii. Select 'Path' from the array options.
iv. Choose the path along which the objects will be distributed (this can be a line, curve, or polyline).
v. Specify the number of items and adjust their alignment along the path, ensuring they fit precisely within the specified curve or line.

Path arrays are useful when objects need to follow a specific trajectory or curve, such as placing lights along a curved road or markers along a pathway.

c. **Polar Array**

i. Choose 'Polar' from the array options.
ii. Select the centre point around which the objects will be arranged.
iii. Enter the number of items and the angle between them.

The Polar array is perfect for creating circular patterns, such as evenly spaced bolts around a flange or lights arranged around a circular plaza.

Additional options and customisation

a. Associative arrays: When you create an array, you can make it associative, meaning changes to the array will automatically update the objects within the array. This can save time when making adjustments to the array pattern.

b. Adjusting the array after creation: You can edit the array by selecting it and using the array properties to modify the number of items, spacing, or the array type.

c. Array preview: As you define the array parameters, AutoCAD will show a real-time preview of how the objects will be arranged, making it easier to adjust the settings before finalising the array.

OFFSET

The OFFSET command in AutoCAD is a useful tool that enables the creation of parallel or concentric replicas of selected objects at a precise, user-defined distance. It is commonly employed to generate parallel lines, concentric circles, or offset curves within technical drawings, offering a quick and efficient method for duplicating geometric elements.

Draw Toolbar/Panel	Menu	Command (Alias)
	Modify » Offset	OFFSET(O)

Steps in using the OFFSET Command in AutoCAD

1. Initiate the Command
   a. Begin by navigating to the Home tab in the Ribbon.
   b. In the Modify panel, click on the Offset icon, or alternatively, type OFFSET in the command line and press Enter to activate the tool.
2. Define the Offset Distance
   a. Once the command is activated, you will be prompted to specify the offset distance.
   b. Input the desired distance and press Enter to confirm your selection.
3. Select the Object to Offset
   a. Click to select the object you wish to offset. This can be a line, arc, circle, polyline, or spline.
   b. Upon selecting the object, you will be prompted to choose the direction in which to place the offset copy.
4. Choose the Direction for the Offset
   a. Move your cursor to the side where you wish to position the offset copy.
   b. Click to define the location of the new, parallel object.

Activity 4.1 Discussion and Report Presentation

1. Search the internet, watch a video or read relevant materials/documents on the importance of AutoCAD in the manufacturing industry

   https://www.youtube.com/watch?v=snO_k57NXhU
   https://www.youtube.com/watch?v=_39brJN-POU

2. Explore the complexities of traditional drafting methods over AutoCAD. The role of AutoCAD in the manufacturing industry. Generate responses to the following during a small group discussion.
   a. Why is AutoCAD a more suitable choice for designing in the manufacturing industry?
   b. Why is AutoCAD more advantageous over traditional drafting methods in the manufacturing industry?
   c. What are the challenges associated with traditional drafting methods.
   d. In term of accuracy, speed, cost, precision, 3D modelling and visualisation, how does AutoCAD compare to traditional drafting methods in the manufacturing industry applications?

3. Prepare a brief two (2) pages report, a power point for presentation and discuss the findings on the above topic with your class or peers.

Activity 4.2 Drawing Simple Shapes Using AutoCAD

1. Watch the video below on how to draw basic shapes using AutoCAD using the link provided below
   - Source: https://www.youtube.com/watch?v=n1rxwDwQW2s
   - Source: https://www.youtube.com/watch?v=eMdCDFISkiw

2. After watching the videos, follow the steps below and draw the same figures.
   a. Introduce the drawing workspace in AutoCAD and the interface elements that you will use, such as the command line, drawing area, and toolbar.
   b. Draw a 2D Rectangle (Box): Use the RECTANGLE command and specify two opposite corners.
   c. Draw a 2D Circle: Use the CIRCLE command to define a circle by centre and radius.
   d. Draw a 3D Box: Use the BOX command to create a 3D rectangular box by specifying a corner, height, and width.
   e. Draw a 3D Cylinder: Use the CYLINDER command to draw a cylinder by defining the base radius and height.
   f. Show how to zoom, pan, and navigate in AutoCAD.

Note

Consider the following sequence used to draw a rectangle

Command: LINE

Specify first point: 1,1

Specify next point or [Undo]: @4,0 (4 units along the X-axis)

Specify next point or [Undo]: @0,3 (3 units along the Y-axis)

Specify next point or [Close/Undo]: @-4,0(4 units along the –ve X-axis)

Specify next point or [close/Undo]: @0,-3 (3 units along the –ve y - axis

Specify next point or [close/Undo]: (press enter)

CREATING 2D AND 3D MODELS USING AUTOCAD

2D Modelling in AutoCAD

AutoCAD is widely used to create accurate 2D drawings and models, vital for applications such as engineering schematics and manufacturing designs

Basic Workflow for 2D Modelling

1. **Setting Up the Drawing Environment**
   a. Configure Drawing Units: Use the UNITS command to set up drawing units (e.g., millimetres, inches) to ensure consistency in dimensions.
   b. Drawing Limits and Grid: Set the workspace limits and grid using the LIMITS and GRID commands to establish drawing boundaries and help with alignment.
   c. Template Selection: Choose a drawing template that matches the requirements of the project (e.g., architectural, mechanical, or civil).

2. **Using Basic Drawing Tools**
   a. Line (LINE): Draw straight lines by specifying a start and end point. Use dynamic input for quick coordinate entry.
   b. Circle (CIRCLE): Create circles by defining the centre point and either the radius or diameter.
   c. Rectangle (RECTANGLE): Draw rectangles by defining two opposite corners; can also use the AREA option for precise dimensions.
   d. Polyline (PLINE): Create continuous, connected lines, including both straight and curved segments. Useful for complex shapes.
   e. Arc (ARC): Draw arcs by specifying the start, centre, and end points, or use alternative arc creation methods (e.g., radius or angle).
   f. Ellipse (ELLIPSE): Create ellipses by specifying the centre, major, and minor axes. It's crucial for designs involving elliptical shapes.

3. **Editing Tools**
   a. Move (MOVE): Relocate selected objects by specifying a base point and second point for placement.
   b. Copy (COPY): Duplicate objects to another location, preserving the original.
   c. Rotate (ROTATE): Rotate objects around a specified base point, often used to adjust orientation.
   d. Scale (SCALE): Resize objects proportionally by specifying a base point and scale factor, useful for adjusting the size of components.
   e. Trim (TRIM): Cut off parts of objects that extend beyond a defined boundary. Use with precision to remove unwanted sections.
   f. Extend (EXTEND): Lengthen objects to meet the edges of other objects or boundaries, useful for connecting lines.

g. Offset (OFFSET): Create parallel lines or curves at a specified distance from the original, useful for maintaining consistent spacing.

4. **Creating Precise Geometry**
   a. Object Snaps (Osnap): Enable precise selection of geometric features such as endpoints, midpoints, and intersections. Key for accuracy in drawings.
   b. Grid and Snap Settings: Use the SNAP and GRID commands to align objects to the grid and lock to specified intervals for consistent spacing.
   c. Dynamic Input: Activate dynamic input to enter coordinate values, distances, and dimensions directly in the drawing area, speeding up the drafting process.

5. **Annotation and Dimensions**
   a. Text (TEXT, MTEXT): Add single-line or multi-line text annotations to the drawing for notes, labels, and explanations.
   b. Dimensions (DIM): Add linear, angular, radial, and diameter dimensions to indicate the size and relationships between objects. Use dimension styles for consistency.
   c. Leaders (LEADER, MLEADER): Create leader lines to annotate specific points in the drawing with text or symbols, ensuring clarity and communication.

6. **Layers and Layer Management**
   a. Layer (LAYER): Organise objects into layers, which help manage visibility, colour, line type, and line weight. This enhances control over the drawing elements.
   b. Layer Properties Manager: Use the LAYER tool to create, modify, and manage layer properties efficiently. Layers allow for better organisation, especially in complex drawings.

7. **Blocks and Attributes**
   a. Block (BLOCK, WBLOCK): Create reusable groups of objects (blocks) that can be inserted multiple times in a drawing. Blocks streamline repetitive tasks.
   b. Attributes (ATTDEF): Define attributes within blocks, such as part numbers, descriptions, or materials, which can be modified when the block is inserted into a drawing.

8. **Hatching and Fills**
   a. Hatch (HATCH): Apply hatching to fill closed areas with patterns, solid fills, or gradients to represent materials or designated zones. Essential for highlighting areas of interest.
   b. Boundary (BOUNDARY): Define closed boundaries for hatching, often used to fill irregular areas within a drawing. The BOUNDARY command simplifies this process.

Best Practices for 2D Modelling in AutoCAD

1. Maintain Clean Geometry
   a. Ensure all lines and shapes are accurately connected and closed.
   b. Avoid overlapping or duplicate objects to maintain drawing clarity.
2. Use Layers Effectively
   a. Organise different types of objects (e.g., walls, dimensions, annotations) on separate layers.
   b. Use meaningful layer names and assign appropriate properties (colour, line type, line weight) for better control.
3. Annotation Scaling: Use annotation scaling to ensure that text, dimensions, and hatches are appropriately sized for different drawing scales.
4. Regular Saving and Backup
   a. Save your work frequently and use incremental saves to prevent data loss.
   b. Maintain backup copies of important drawings.
5. Utilise Templates: Use templates to standardise settings and ensure consistency across multiple drawings.
6. Continuous Learning
   a. Stay updated with AutoCAD's new features and enhancements.
   b. Participate in training sessions, online tutorials, and forums to improve your skills

Demonstrative Example: Creating a 2D Flange in AutoCAD

1. **Setting up the drawing environment**
   a. Set Units:
      i. Command: UNITS
      ii. Choose "Decimal" for Type and "Millimetres" for Insertion Scale. Click OK.
   b. Set Limits
      i. Command: LIMITS
      ii. Specify the lower left corner as (0,0) and the upper right corner as (200,200) for a medium workspace.
   c. Turn on the Grid. Command: GRID
   d. Turn on Snap Mode. Command: SNAP
2. **Creating the Basic Shape of the Flange**
   a. Draw the Outer Circle
      i. Command: CIRCLE
      ii. Specify the centre point as (100,100) and the radius as 50.

b. Draw the Inner Circle (Hole)
   i. Command: CIRCLE
   ii. Specify the centre point as (100,100) and the radius as 20.

3. **Adding Bolt Holes**
   a. Draw a Bolt Hole
      i. Command: CIRCLE
      ii. Specify the centre point as (100,150) and the radius as 5.
   b. Array the Bolt Hole Around the Flange
      i. Command: ARRAYPOLAR
      ii. Select the bolt hole circle, press Enter. Specify the centre point of the flange (100,100). Enter the number of items as 6. Press Enter.
4. **Adding Dimensions**
   a. Add Diameter Dimension for Outer Circle
      i. Command: DIMDIAMETER
      ii. Select the outer circle. Place the dimension line outside the circle.
   b. Add Diameter Dimension for Inner Circle
      i. Command: DIMDIAMETER
      ii. Select the inner circle. Place the dimension line outside the circle.
   c. Add Radius Dimension for Bolt Holes
      i. Command: DIMRADIUS
      ii. Select one of the bolt holes. Place the dimension line outside the circle.
   d. Add Linear Dimension for Bolt Circle Diameter
      i. Command: DIMDIAMETER
      ii. Select the circle passing through the centres of the bolt holes. Place the dimension line outside the circle.
   e. Add Angular Dimension for Bolt Holes:
      i. Command: DIMANGULAR
      ii. Select the centre of the flange and one bolt hole. Place the angular dimension between the bolt holes.
5. **Annotating the Drawing:** Add Text for Labels
   a. Command: MTEXT
   b. Specify the start point for the text (e.g., 20,180). Enter the height of the text as 5. Enter the text “Flange”. Press Enter.
6. **Finalising the Drawing**
   a. Create Layers (Optional)
      ii. Command: LAYER

iii. Create layers such as "Flange", "Dimensions", and "Annotations" for better organisation and control over the drawing.

d. Save the Drawing

v. Command: SAVEAS

vi. Name the file as "Flange.dwg".

Commands Summary

UNITS -> Decimal, Millimetres

LIMITS -> 0,0 to 200,200

GRID -> ON

SNAP -> ON

CIRCLE -> Centre: 100,100, Radius: 50 (Outer Circle)

CIRCLE -> Centre: 100,100, Radius: 20 (Inner Circle)

CIRCLE -> Centre: 100,150, Radius: 5 (Bolt Hole)

ARRAYPOLAR -> Select Bolt Hole Circle, Enter, Centre: 100,100, Items: 6, Enter

DIMDIAMETER -> Select Outer Circle, Place Dimension

DIMDIAMETER -> Select Inner Circle, Place Dimension

DIMRADIUS -> Select Bolt Hole, Place Dimension

DIMDIAMETER -> Select Circle passing through Bolt Hole Centres, Place Dimension

DIMANGULAR -> Select Flange Centre and Bolt Hole, Place Dimension

MTEXT -> Start Point: 20,180, Height: 5, Text: "Flange"

SAVEAS -> Flange.dwg

3D MODELLING

Introduction to 3D modelling in AutoCAD

AutoCAD is a powerful tool for creating both 2D and 3D models. 3D modelling in AutoCAD enables designers to visualise their projects in three dimensions, enhancing their understanding of spatial relationships and refining the design process.

Setting Up the 3D Workspace

1. Switch to 3D Modelling Workspace: Go to the workspace switching button (usually at the bottom right corner) and select "3D Modelling."
2. Set up the view use the VIEWCUBE or NAVIGATION BAR to switch between different views (Top, Front, Isometric, etc.).
3. Set the view to an isometric perspective to better visualise the 3D space.

Basic 3D Modelling Commands

1. **Box**

   Command: BOX

   a. Creates a 3D box.
   b. Specify the corner points or dimensions (length, width, height).

2. **Cylinder**

   Command: CYLINDER

   a. Creates a 3D cylinder.
   b. Specify the centre point, radius, and height.

3. **Sphere**

   Command: SPHERE

   a. Creates a 3D sphere.
   b. Specify the centre point and radius.

4. **Cone**

   Command: CONE

   a. Creates a 3D cone.
   b. Specify the centre point, base radius, and height.

5. **Wedge**

   Command: WEDGE

   a. Creates a 3D wedge.
   b. Specify the corner points or dimensions (length, width, height).

6. **Torus**

   Command: TORUS

   a. Creates a 3D torus.
   b. Specify the centre point, radius of the torus, and tube radius.

Creating Complex Shapes

1. **Extrude**

   Command: EXTRUDE

   a. Converts 2D shapes into 3D objects by giving them height.
   b. Select a 2D object (like a polyline or circle) and specify the extrusion height.

2. **Revolve**

   Command: REVOLVE

   a. Creates 3D objects by revolving a 2D profile around an axis.
   b. Select a 2D profile, specify the axis, and the angle of revolution.

3. **Sweep**

   Command: SWEEP

   a. Creates 3D objects by sweeping a 2D profile along a path.
   b. Select a 2D profile and a path curve.

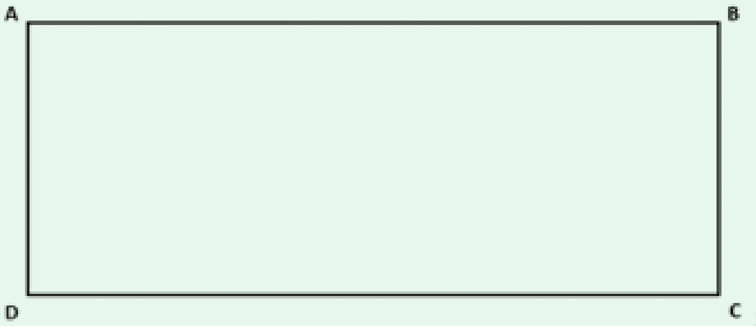
Drawing by Specifying Points in AutoCAD

In AutoCAD, drawing by specifying points is a simplified method for creating precise geometry. It involves defining object locations using coordinates or selecting points in the drawing area, ensuring accuracy in placing and connecting elements. This technique is essential for maintaining control over dimensions and alignment in complex designs. Table 4.1 explains how to specify points in AutoCAD drawing.

Table 4.1: Drawing by specifying point in AutoCAD

Interactive	pick	Select points in the drawing area with a mouse
Absolute coordinate	x,y	Type x and y coordinates relative to the origin (0,0)
Relative Rectangular	@x,y	Type x and y co-ordinates relative to the last point
Relative Polar	@ dist<angle	Type distance relative to last point and angle value relative to direction angles are measured from (east in counterclockwise direction withed fault setup).
Direct distance	dist, direction	Type a distance value relative to the last point, indicate direction with the cursor, then press Enter

Activity 4.3 Use Line Command to Construct a Rectangular Shape



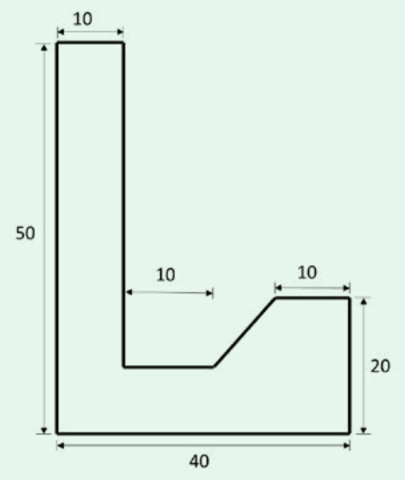
Steps in specifying points in AutoCAD

Point	**Absolute (x,y)**	**Incremental/Relative Rectangular (@x,y)**	**Relative Polar (@ distance<angle**
A	0,0	0,0	0,0
B	5,0	@5,0	@5<0
C	5,3	@0,3	@3<90
D	0,3	@-5,0	@-5<180
A	0,0	@-3,0	@-3<270

Activity 4.4 Understanding Line command

1. Watch the videos below on how to draw basic shapes using AutoCAD using the link provided below
   - Source: https://www.youtube.com/watch?v=n1rxwDwQW2s
   - Source: https://www.youtube.com/watch?v=eMdCDFISkiw

2. Make use of the command to construct shape below



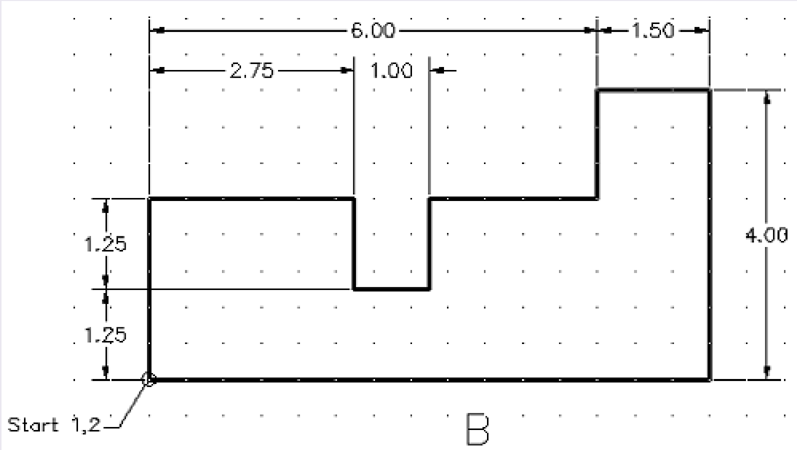
3. Steps in specifying points in AutoCAD

Point	**Absolute (x,y)**	**Incremental/Relative Rectangular (@x,y)**	**Relative Polar (@ distance<angle**
A	3,1	@3,1	3,1
B	7,1	@4,0	4<0
C	7,3	@0,2	2<90
D	6,3	@-1,0	1<180
E	5,2	@-1,-1	1.4<225
F	4,2	@-1,0	1<180
G	4,6	@4,0	4<90
H	3,6	@-1,0	1<180
A	3,1 /close	@-5,0/ close	5<270/ close

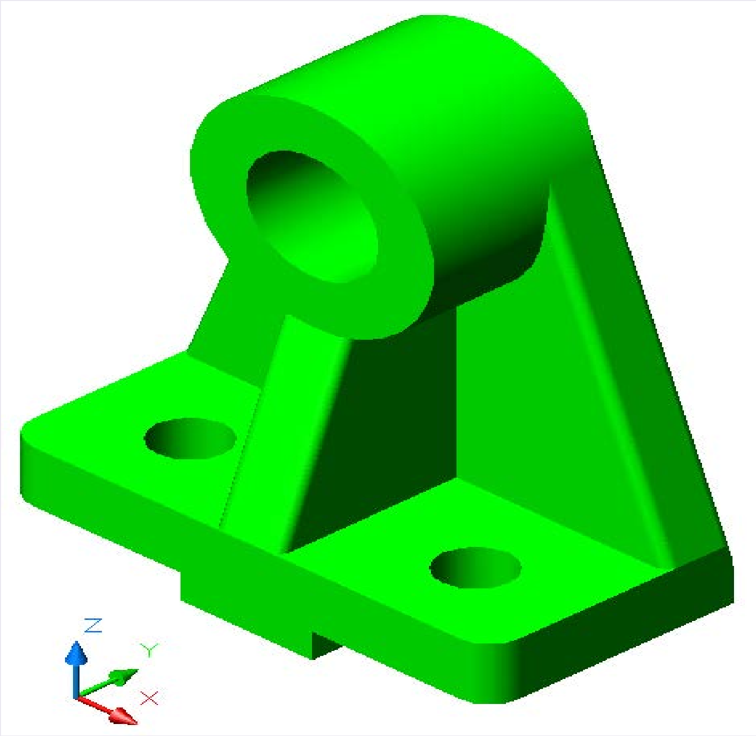
Now use AutoCAD to convert your 2D drawing into 3D.

Review Questions

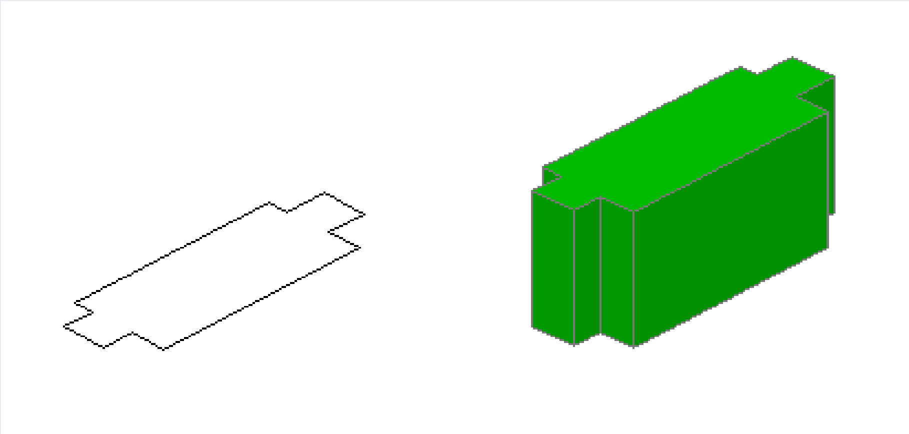
1. Using line command, try this on your own.



2. With the experience gained from this section use AutoCAD (3D Modelling) to design the figure below.



3. Using the extrude feature:



Steps

Command: **EXTRUDE**

Current wire frame density: ISOLINES=4

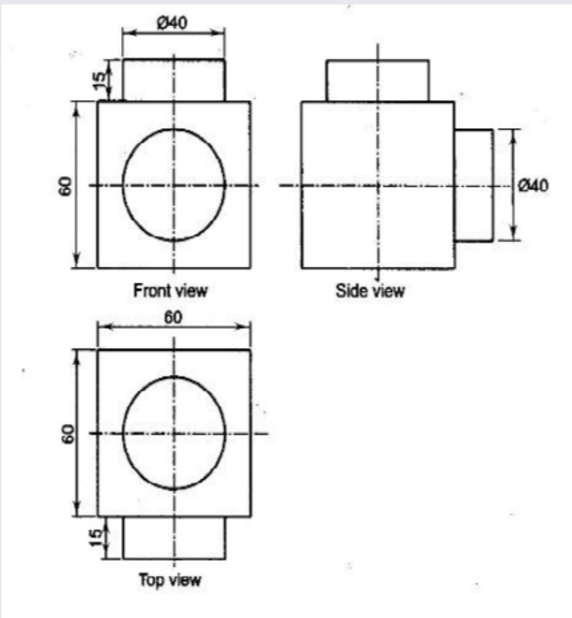
Select objects to extrude: 1 found

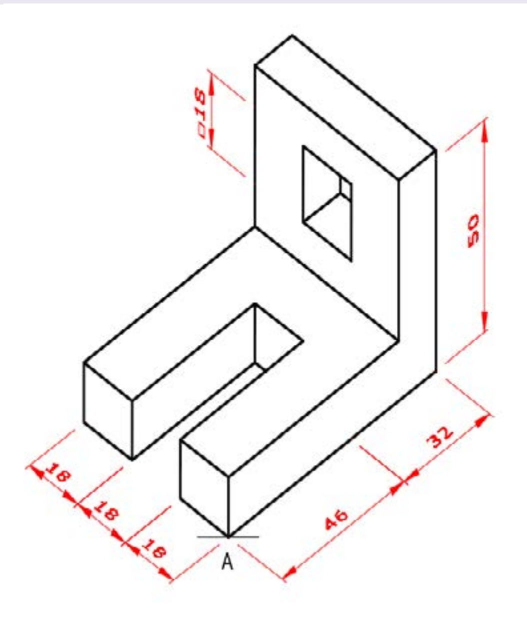
Select objects to extrude**: (Press enter key)**

Specify height of extrusion or [Direction/Path/Taper angle]

<338.7838>: 200

4. Using Solid Modelling techniques, model these objects shown:





A **B**

SECTION

5

MEASURING TOOLS AND HAND TOOLS

DESIGN AND PROTOTYPING

Manufacturing Tools And Equipment

Introduction

In this section, we will discuss in detail the differences between various essential measuring tools used in manufacturing to ensure the accuracy of workpieces. We will cover the correct usage of these tools, including their applications within the manufacturing process. You will be introduced to the principles behind essential instruments such as the ruler, Vernier calliper, and micrometre screw gauge. These tools are crucial for measuring linear dimensions and ensuring that parts meet the required tolerances and specifications. Additionally, we will differentiate between manual hand tools and power hand tools. Throughout this section, you will learn how to properly use each of these tools to measure workpieces, applying them in real-world manufacturing scenarios. Hands-on activities will allow you to practice measuring parts with these instruments, helping you develop the skills necessary to ensure that workpieces conform to precise dimensional requirements. By the end of this section, you will understand how to use these measuring tools to maintain accuracy, meet engineering tolerances, and ensure the overall quality of manufactured components.

Key Ideas

- **Accuracy describes how close** a measured value is to the true or accepted value.
- **Calibration involves adjusting** a measuring instrument to ensure it provides accurate readings.
- **Gauge is used to measure** or check the dimensions of a workpiece, such as a micrometre or Vernier calliper
- Measurement: the process of determining the size, length, or amount of something using specific tools.
- Precision: the degree to which repeated measurements under the same conditions show the same results.
- Tolerance: allowable variation in a physical dimension or measurement, ensuring that parts fit and function correctly despite slight differences.
- Workpiece: the object or material being measured, shaped, or processed in manufacturing.

DIFFERENCE BETWEEN MEASURING INSTRUMENTS

Measuring instruments are devices used to quantify physical properties such as length, angle, and surface features of objects. These tools play a crucial role in obtaining accurate and precise measurements, which are essential in fields like mechanical engineering, manufacturing, and construction. By converting physical attributes into measurable data, measuring instruments enable engineers and technicians to design, produce, and evaluate products according to exact specifications. Their function extends beyond mere measurement; they also ensure that components fit together correctly, operate as intended, and comply with safety and quality standards. The primary differences between measuring instruments are their precision, measurement range, and specific applications.

Precision

Precision refers to how consistent or reproducible measurements are. A measurement is deemed precise if repeated measurements taken under the same conditions yield very similar results. However, precision does not necessarily indicate that the measurement is correct (accurate); rather, it indicates the level of detail in the measurement. For instance, a micrometre screw gauge has high precision, as it can consistently measure small differences in size, such as 0.01 mm.

Range of Measurement

The range of measurement defines the span of values that a measuring instrument can accurately assess. It specifies the smallest and largest measurements the instrument can effectively capture. For example, a ruler typically has a range of 0 to 30 cm, while a micrometre may only measure smaller dimensions, such as from 25 mm to 50 mm. Understanding the range of a tool is essential because it ensures that the instrument can accurately measure the dimensions needed for the workpiece.

Application

The term “application” refers to the specific use or purpose for which a measuring instrument is employed. Different tools are designed for various applications based on their precision, range, and the types of measurements required. For example, a ruler is commonly used for basic tasks to measure length, while a Vernier calliper is employed for more precise measurements of internal and external dimensions. When extremely accurate measurements of small dimensions are needed, such as the thickness of a metal sheet, a micrometre is used.

LINEAR MEASUREMENT TOOLS

These are measuring instruments used to ascertain the distance between two points or quantify an object's dimensions along a linear path. These tools are essential in numerous engineering and manufacturing processes, providing critical accuracy and precision. Notable examples include the steel rule, Vernier calliper, and micrometre screw gauge, each serving a specific function in measuring length, width, and other linear dimensions with varying degrees of precision.

Steel Rule

Description: A steel rule is a fundamental measuring instrument, typically crafted from stainless steel or other durable metals. It features a straight edge and is calibrated with a scale, either in millimetres or inches, along its length. These markings enable the measurement of objects' length, width, and height across various applications.

Usage: Steel rules are commonly used for quick and rough measurements in various fields, including layout work, carpentry, metalworking, and general inspection. They are versatile tools that can be used to draw straight lines, measure the dimensions of flat surfaces, and quickly verify sizes during manufacturing and assembly processes.

Accuracy: Steel rules generally provide an accuracy of ±0.5 mm, although this can vary based on the quality of construction and manufacturing standards. Accuracy also depends on the user's skill in aligning the rule and correctly interpreting the scale. For tasks that require higher precision, it's better to use more advanced tools such as Vernier callipers or micrometres.

Steel rules are highly valued for their simplicity, durability, and practicality in various industrial and workshop settings where quick and reliable measurements are crucial. Their sturdy construction and straightforward design make them essential tools for tasks that require moderately precise measurements.

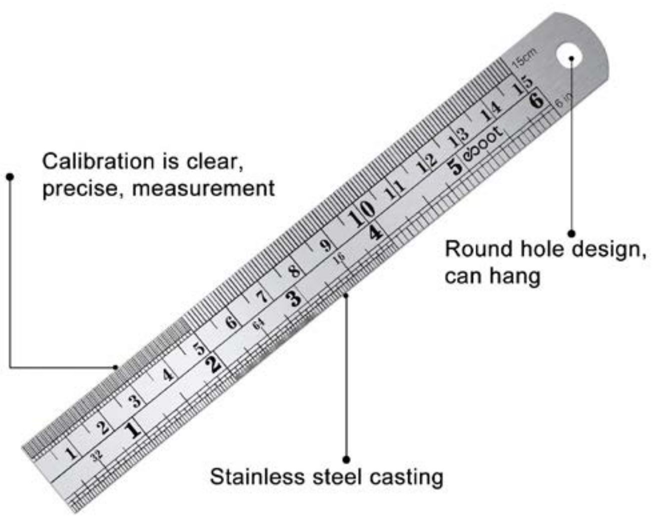


Figure 5.1: Steel rule

Vernier Calliper

Description: The Vernier calliper is a high-precision measuring tool that consists of a main scale and a sliding Vernier scale. The main scale is marked in either millimetres or inches, while the Vernier scale moves along the main scale to provide measurements with greater accuracy. This design enables the calliper to measure various dimensions with exceptional precision, including internal measurements (such as the internal diameter of a hole), external measurements (such as the diameter of a rod), and depth measurements. The calliper is equipped with both inside and outside jaws for measuring internal and external dimensions, respectively.

Additionally, it features a depth probe that extends from the bottom of the instrument for measuring the depth of holes or grooves. The fine adjustment screw allows for precise calibration, while the locking screw secures the calliper in place once a measurement is taken, preventing any unintended movement.

Usage: Vernier callipers are widely used in various fields, including machining, metalworking, mechanical engineering, and other industries where precise measurements are crucial. They play a vital role in quality control processes, ensuring that manufactured parts meet exact specifications. Additionally, vernier callipers are commonly used in workshops to measure and check the dimensions of components and verify tolerances.

Accuracy: Vernier callipers can provide an accuracy of up to 0.02 mm or better, depending on the quality of the instrument and the skill of the operator. Some higher-end models can achieve even finer precision, reaching as low as 0.01 mm or less. This high level of accuracy is possible due to the finely graduated Vernier scale, which allows for precise interpolation between the divisions of the main scale.

Vernier callipers are versatile and user-friendly instruments that combine high accuracy with ease of use. Their capability to provide precise measurements makes them essential tools in industries where stringent quality control, performance, and compliance with engineering standards are crucial.

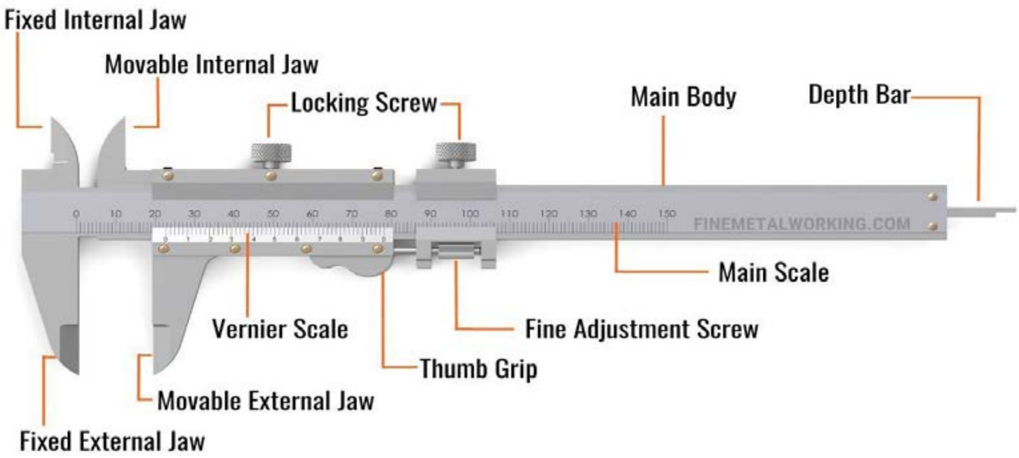


Figure 5.2: (a) Vernier Calliper

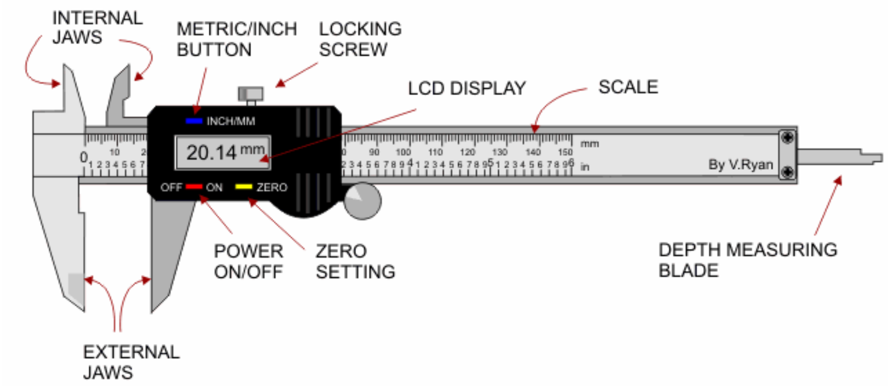


Figure 5.2: (b) Digital Vernier Calliper

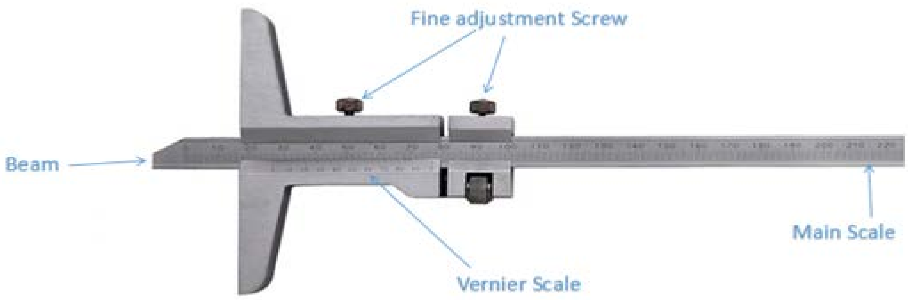


Figure 5.2: (c) Depth Vernier Calliper

Micrometre Screw Gauge

Description: The micrometre screw gauge is an exact measuring instrument designed to measure small distances, thicknesses, or diameters with exceptional accuracy. It operates using a calibrated screw mechanism, which converts small rotations of a finely threaded screw into precise linear measurements displayed on a graduated scale.

Usage: Micrometre screw gauges are ideal for measuring the dimensions of small components, such as wire thickness, rod diameters, or the depth of small holes and slots. They are widely employed in mechanical engineering, manufacturing, precision machining, and quality control, where extreme accuracy is critical. Various types of micrometres are available to cater for specific measurement needs, including:

- *Outside Micrometre:* Used for measuring external dimensions, such as the diameter of shafts or the thickness of materials.
- *Inside Micrometre:* Designed to measure internal dimensions, such as bores' diameter or slots' width.
- *Depth Micrometre:* Used for measuring the depth of holes, grooves, or other recesses

Accuracy: Micrometres provide an accuracy of up to 0.01 mm or better, depending on the quality of the instrument and the operator's expertise. Some high-precision micrometres can measure to an accuracy of 0.001 mm (1 micron) or finer. This level of precision is achieved through the finely pitched screw thread and the detailed graduation of the scale, which allows for precise interpolation and measurement.

The micrometre screw gauge is an indispensable tool for applications requiring meticulous measurements of small-scale components, ensuring both precision and reliability in various technical and engineering processes.

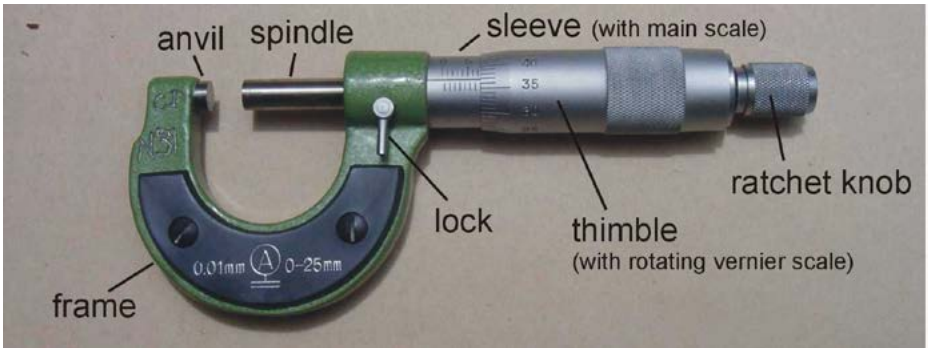


Figure 5.3: (a) Micrometre screw gauge

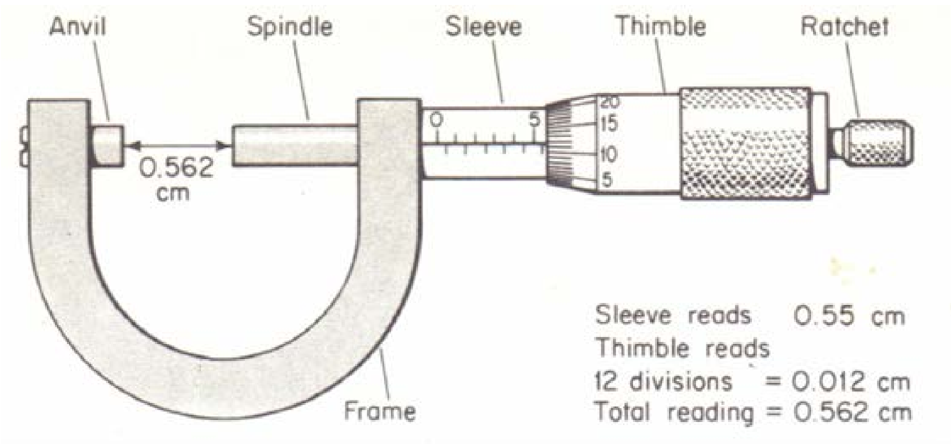


Figure 5.3: (b) External Micrometre screw gauge

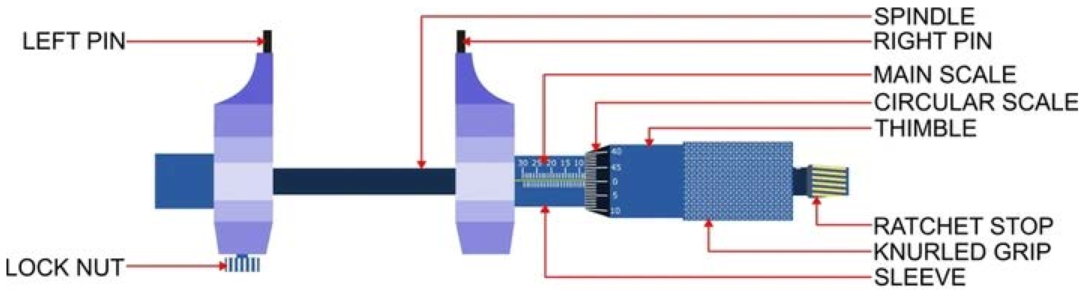


Figure 5.3: (c) Inside Micrometre screw gauge

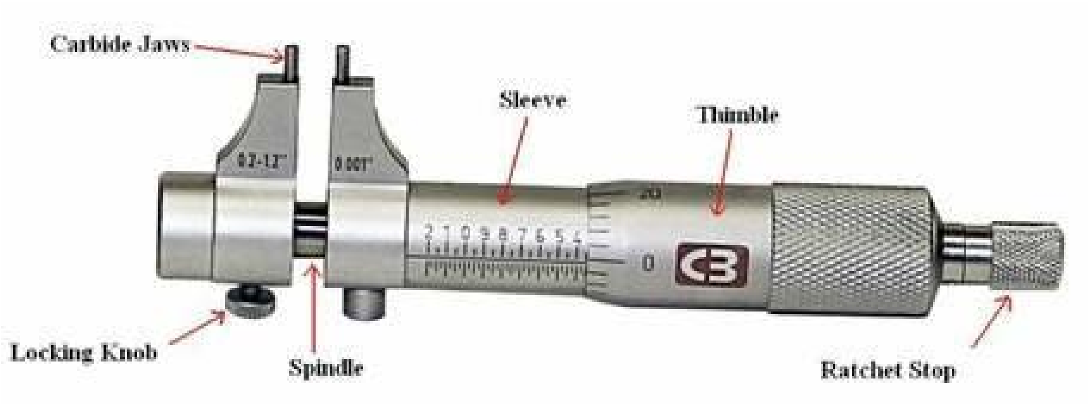


Figure 5.3: (d) Inside Micrometre screw gauge

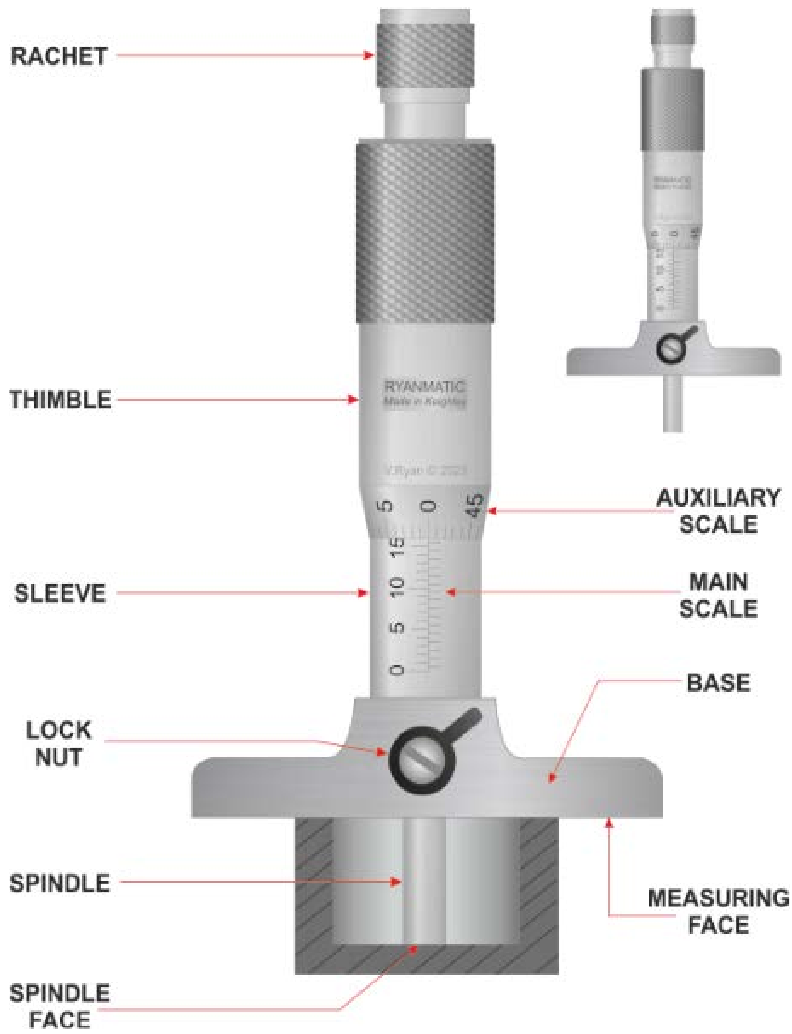


Figure 5.3: (e) Dept micrometre screw gauge

Comparing steel rule, vernier calliper and micrometre screw gauge

The differences between the steel rule, Vernier calliper, and micrometre screw gauge are primarily based on their measurement range, precision, accuracy, and the potential impact of environmental factors on measurement reliability. Table 5.1 outlines the key differences between these linear measuring instruments.

Table 5.1: Differences between steel rule, a vernier calliper and micrometre screw gauge

Property	Steel Ruler	Vernier Calliper	Micrometre Screw Gauge
Measurement range	It measures up to 300 mm, (normally).	Up to 200 mm.	Up to 250 mm.
Precision	Up to 1 mm.	Up to 0.02 mm.	Up to 0.01 mm.
Readability	Easy to read with simple scales marked on the tool.	It requires reading the main scale and the vernier scale together.	It requires reading the sleeve and thimble scales, sometimes with an additional vernier scale for extra precision.
Measurement type	Measures length, width and height.	Measures external dimensions, internal dimensions, and depths.	Measures external dimensions with high precision.
Accuracy	Lowest accuracy.	Moderately accurate.	Highest accuracy.
Usability	Simple and quick to use, requires no special skills.	Requires some skill to read correctly.	Requires careful handling and skill to use and read accurately.
Cost	Less expensive	Moderate pricing	Expensive
Application	Suitable for general measurement tasks where high precision is not required.	Suitable for tasks requiring moderate precision, such as mechanical and engineering applications.	Suitable for tasks requiring high precision, such as machining and quality control.
Environmental considerations	Not affected by environmental factors like temperature and dirt.	It can be affected by temperature variations and requires cleanliness for accurate readings.	Highly sensitive to temperature changes and must be kept clean for precise measurements.

ANGULAR MEASUREMENT TOOLS

Angular measurement tools are essential for determining the angles between two surfaces or lines. These instruments are crucial for ensuring the correct angular alignment of components and assemblies in various engineering processes. Examples include protractors, angle gauges, bevel protractors, and sine bars. These tools play a vital role in maintaining the proper angular orientation of parts and assemblies.

Protractors

Protractors are essential measuring tools typically made from plastic or metal. They feature a semicircular or circular scale marked in degrees. Protractors are primarily used to measure and construct angles in geometric drawings, drafting, and various educational and technical applications. They provide sufficient accuracy for moderate precision tasks in these areas. In educational settings, protractors are invaluable for teaching concepts in geometry and trigonometry. Moreover, they play a crucial role in engineering and architectural design by assisting in the layout of angles and geometric configurations. Generally, protractors are suitable for tasks where high precision is not necessary, offering accuracy within ±1 degree or slightly better, depending on the instrument's quality and the user's skill. This level of accuracy is adequate for many general-purpose applications where exact precision is not a critical requirement.

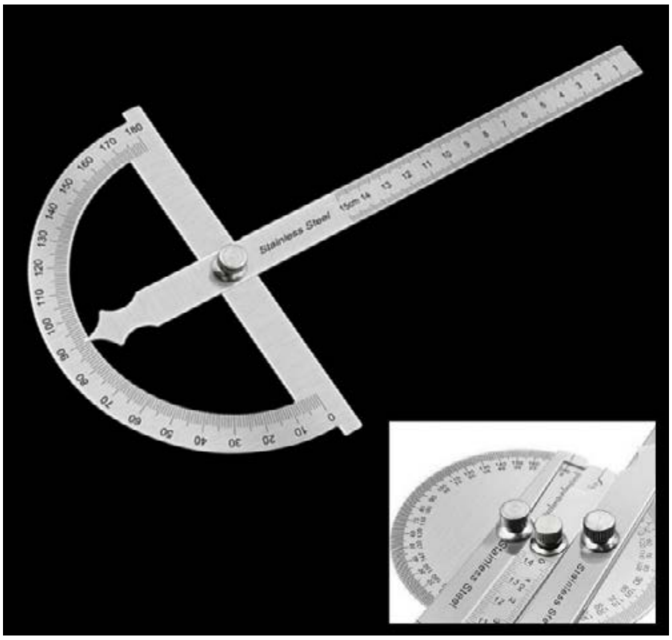


Figure 5.4: Steel protractor

Angle gauges

Angle gauges are high-precision instruments composed of a series of blades or blocks set to specific angular positions, typically with exceptional accuracy. These tools play a critical role in the setup and verification of machinery, the inspection of machined components, and the assurance of precision in various mechanical and manufacturing applications. Angle gauges are indispensable in industries where exact angular measurements are crucial, such as precision machining and assembly operations.

They are commonly used for aligning machine parts, calibrating cutting tools, and confirming the angular accuracy of machine configurations. By providing a fast and reliable means of measuring and verifying angles, angle gauges ensure that components are fabricated and assembled to exact specifications and tolerances. The degree of precision achievable with angle gauges is directly influenced by the quality of the gauge set. High-end angle gauges can deliver excellent angular measurements, often to fractions of a degree or even finer, thanks to their meticulously ground and calibrated blades or blocks. This high level of accuracy makes them indispensable for applications demanding stringent angular alignment.

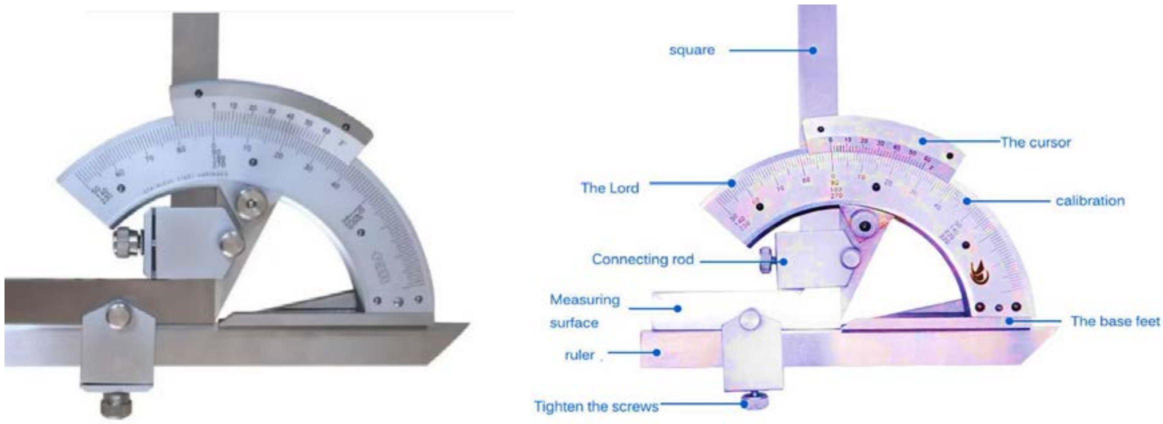


Figure 5.5: Angle gauge

Bevel Protractors

A bevel protractor is a highly accurate measuring tool that consists of a protractor head and an adjustable blade or arm. The protractor head typically features a circular scale graduated in degrees, which allows for precise measurement and marking of angles on various workpieces. Bevel protractors are widely used in machining, metalworking, and woodworking industries for tasks such as measuring, marking, and setting angles on a wide range of components. They are especially valuable for layout operations, machine setup, and verifying the angular alignment of parts during assembly. These instruments can measure angles with exceptional precision, often to fractions of a degree, depending on the quality of the tool and the skill of the user. This level of accuracy makes bevel protractors indispensable in precision machining and fabrication processes, where exact angular measurements are crucial for achieving high-quality results.

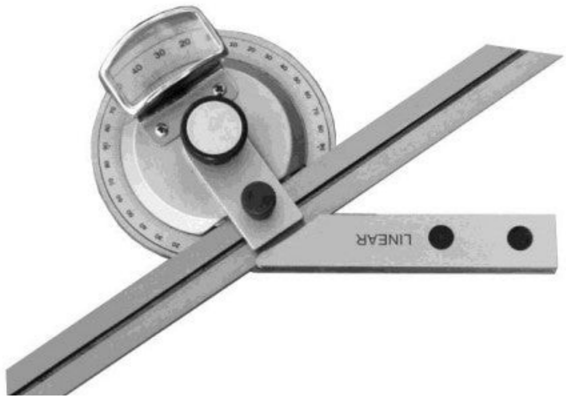
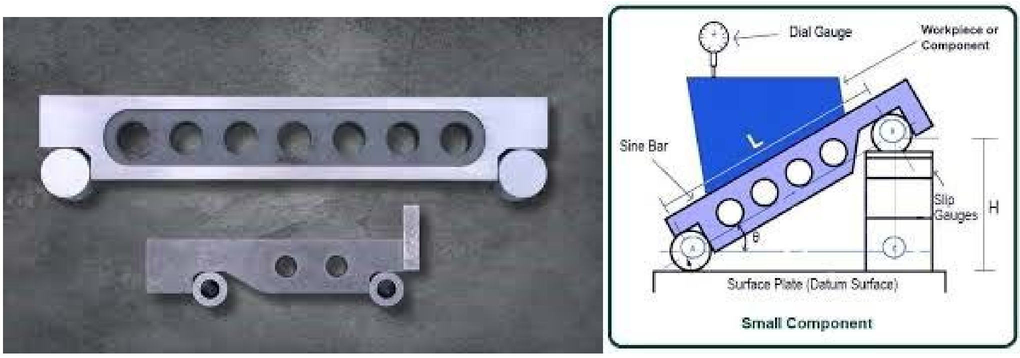


Figure 5.6: Bevel Protractor

Sine Bars

Sine bars are precision instruments that measure and set angles with exceptional accuracy based on trigonometric principles. They consist of a hardened steel bar with two precision-ground cylinders or blocks at each end, positioned at a specific distance apart. This configuration creates a fixed angle relative to the surface plate or worktable. Sine bars are primarily utilised in machining operations to verify and set exact angles, often in conjunction with gauge blocks. This combination allows for achieving the precise angular requirements needed for machining or inspection tasks. A sine bar used with slip gauge blocks enables accurate angular measurements. It is particularly effective for work that requires a high level of precision, such as milling, grinding, and inspection applications. Sine bars provide a reliable and highly accurate method for angular measurement and setup in precision engineering and manufacturing environments. The accuracy level depends on the quality of the sine bar and the precision of the gauge blocks employed. Typically, sine bars can achieve angular settings with exceptional precision, often within a few arc minutes or even finer. Their high level of accuracy makes them indispensable tools in machining operations where precise angular dimensions and tolerances are essential for the successful fabrication of components.



(a) *(b)*

Figure 5.7: (a) Sine bar and (b) Sine bar in use

Differences Between Protractors, Angle Gauges, Bevel Protractors and Sine Bars

The differences between protractors, angle gauges, bevel protractors, and sine bars lie in their measurement range, precision, accuracy, environmental suitability, and other factors. Table 5.2 details these distinctions among the various angle-measuring instruments.

Table 5.2: Differences between protractor, angle gauge, bevel protractor and sine bar

Property	Protractor	Angle gauge	Bevel protractor	Sine bar
Measure-ment range	Typically measures angles from 0 to 180°	Measures specific preset angles, often in a limited range	Measures angles from 0° to 360° with high precision	Indirectly measures any angle using trigonometric calculations
Precision	Moderate precision, generally up to 1°.	High precision for specific angles, often up to 0.1°.	High precision, often up to 0.083°.	Extremely high precision, depending on the accuracy of the gauge blocks used
Readability	Easy to read with clear degree markings.	Simple to use but limited to preset angles.	Requires reading vernier scales for precise measurements.	Indirect readability. Requires calculation based on height and length.
Set up time	Minimal setup time, ready to use immediately	Quick setup but limited to specific angles.	Requires some setup time for precise measurements.	Requires significant setup time with gauge
Usability	Simple to use, suitable for quick measurements.	Easy to use but limited to specific angles.	Requires some skill to read vernier scales accurately.	Requires setup with gauge blocks and calculations, needs more skill.
Cost	Generally cheap	Moderately priced, depending on precision and material.	Quite expensive due to precision.	Expensive due to high precision and materials

Property	Protractor	Angle gauge	Bevel protractor	Sine bar
Application	Used in general education, drafting, and simple layout tasks.	Used in machining, woodworking, and inspection.	Used in precision engineering, metalworking, and quality control.	Used in high-precision machining and inspection applications
Environmental considerations	Not affected by environmental conditions.	Sensitive to temperature and dirt, requires a clean environment.	Sensitive to temperature and dirt, requires careful handling	Highly sensitive to temperature changes, must be used in a controlled environment
Material for construction	Made of plastic, metal, or a combination of both.	Made of hardened steel or other durable materials.	Made of stainless steel or other high-quality metals.	Made of high-quality steel, often hardened and ground for precision.

SURFACE MEASUREMENT TOOLS

Surface measurement tools are used to assess materials' flatness, roughness, and other surface properties. These instruments are essential in quality control, ensuring that surfaces meet the specified standards and tolerances.

Surface Plates

Surface plates are precision-ground flat plates made from granite, cast iron, or other substances known for their excellent dimensional stability. These plates serve as reference surfaces for inspecting and measuring flatness and perpendicularity. In metrology and quality control, surface plates are essential for verifying surface flatness and establishing precise measurement setups. They provide a stable and accurate reference plane for measuring height gauges, dial indicators, and other precision instruments. Surface plates are meticulously flat, with deviations typically measured in micrometres (millionths of a metre). High-quality surface plates can achieve flatness tolerances as fine as a few micrometres across their entire surface, ensuring reliable and precise measurement results for quality assurance and advanced manufacturing operations.

Figure 5.8: Surface plate

Height Gauges

Height gauges are precision instruments that consist of a sliding measuring head mounted on a vertical column. They are specifically designed to measure vertical distances from a reference surface, such as a surface plate or worktable. These gauges are commonly used in machining, toolmaking, and metrology to determine heights, depths, and step dimensions. They are also essential for layout work, allowing users to mark lines at specific vertical positions on workpieces. Digital height gauges provide exceptional accuracy and often come with features for data output and statistical analysis. Some digital models can measure heights with an accuracy of up to 0.001 mm (1 micron) or finer, offering superior precision. Although mechanical height gauges are slightly less precise, they still deliver highly accurate measurements suitable for most industrial applications.

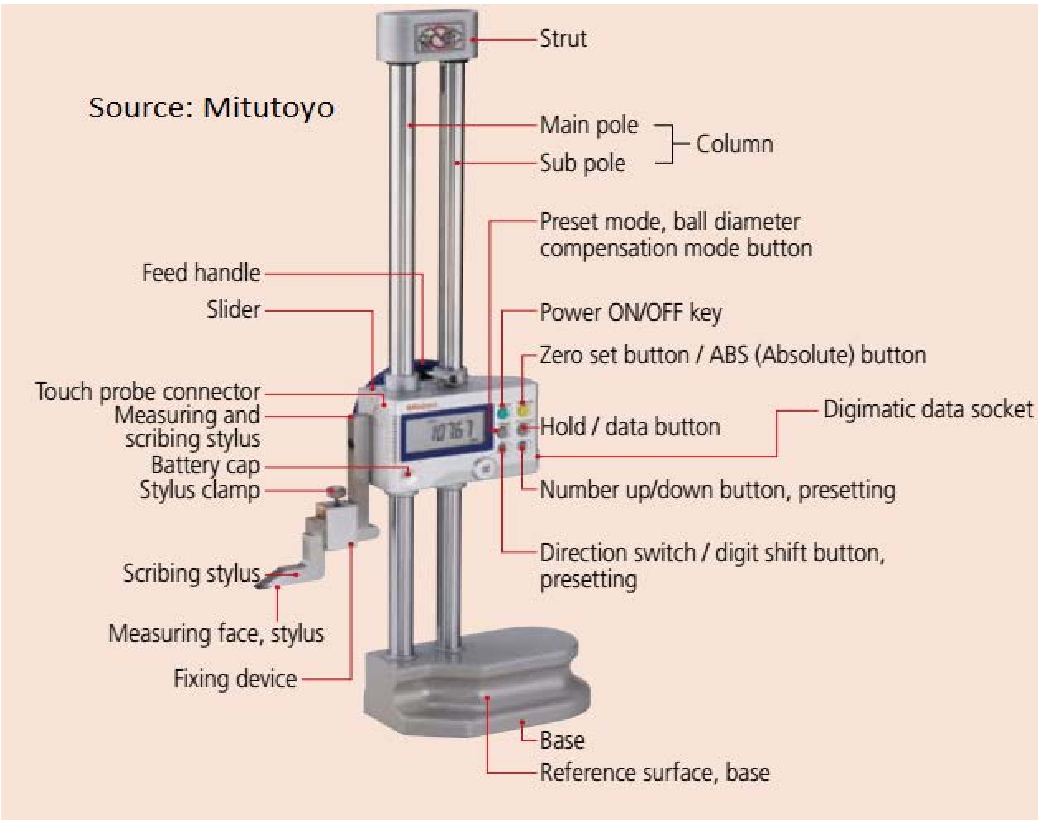


Figure 5.9: Digital Height gauge

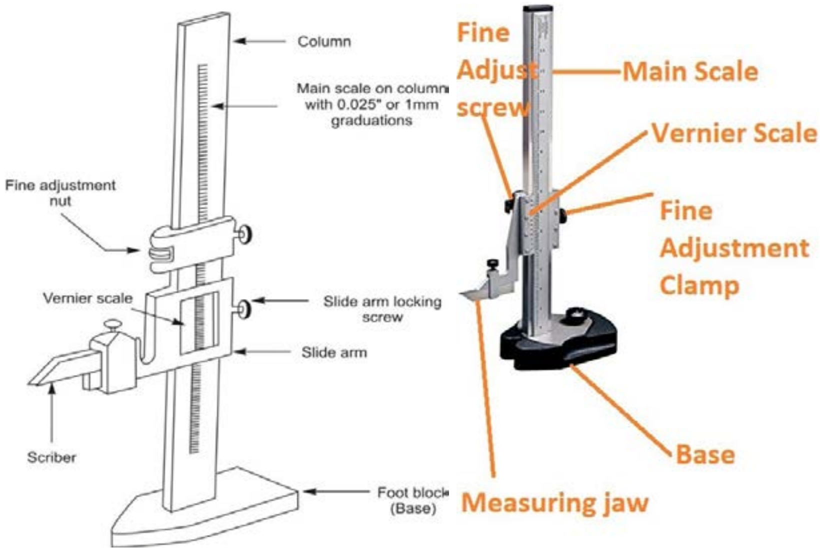


Figure 5.10: Vernier Height gauge

Surface Roughness Testers

Surface roughness testers are sophisticated electronic devices designed to measure the texture of surfaces accurately. They provide precise readings for roughness parameters, such as Ra (average roughness) and Rz (mean roughness depth). These testers play a crucial role in quality control and manufacturing by assessing the surface finish of machined components. Ensuring that surfaces meet the required roughness specifications is vital for their functionality, aesthetics, and performance. Surface roughness evaluations are particularly important in industries such as automotive, aerospace, and medical device manufacturing. These testers deliver highly accurate measurements of surface irregularities, which are typically expressed in micrometres (microns). This information offers valuable insights into the quality of surface finishes. Advanced models of surface roughness testers may also include features like graphical representations of surface profiles and the capability to conduct statistical analyses of roughness data, further enhancing the precision and depth of surface quality evaluation.

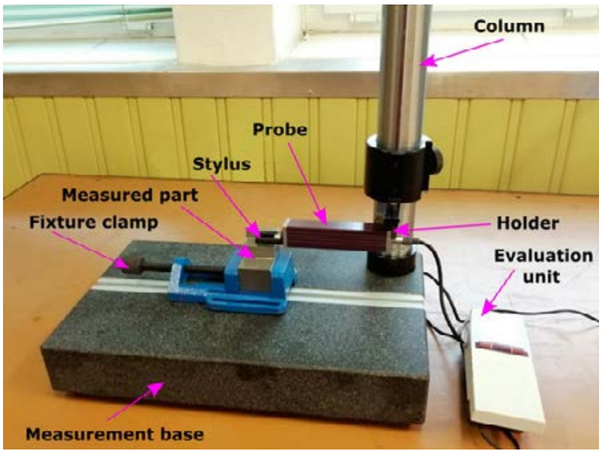


Figure 5.11: (a) Stylus-based surface roughness measurement using a surface tester

Figure 5.11: (b) Manual Column Stand Surface Roughness Tester

Comparing Surface Plates, Height Gauges and Surface Roughness Testers

The differences between surface plates, height gauges, and surface roughness testers lie in their measurement ranges, precision, accuracy, environmental suitability, and various other factors. Table 5.3 illustrates these differences among the surface measuring instruments.

Table 5.3: Differences between surface plates, height gauges and surface roughness testers

Property	Surface plates	Height gauges	Surface roughness testers
Measurement type	Do not measure directly but serve as a reference plane.	Measure height and vertical distance	Measure surface texture parameters.
Precision	Extremely flat with tolerances often in microns.	It can be up to 0.001 mm	High precision for surface texture measurements, often in microns.
Set up time	There is minimal setup time, but they must be placed on stable support.	Moderate setup time, especially if precise zeroing and adjustments are needed.	Minimal setup time, ready to use once calibrated and powered on.
Usability	Easy to use as a reference surface.	Requires some skill to use accurately.	Requires understanding of rough parameters and proper handling of the device.

Property	Surface plates	Height gauges	Surface roughness testers
Cost	It can be expensive due to the material and precision involved.	Moderate cost, depending on precision and features.	Often expensive due to sophisticated electronics and sensors
Application	Used in precision engineering, quality control, and laboratories.	Used in workshops, manufacturing, and quality control.	Used in machining, quality control, and material testing.
Environmental sensitivity	Sensitive to temperature changes and must be kept clean.	Sensitive to temperature and must be kept clean for accurate measurements.	Sensitive to surface contaminants and environmental conditions affecting electronic components.
Environmental considerations	Not affected by environmental conditions.	Sensitive to temperature and dirt, it requires a clean environment.	Sensitive to temperature and dirt, requires careful handling
Material for construction	Typically made from granite or cast iron	Made from stainless steel or other rigid metals.	Include electronic components and sensors, usually housed in a handheld or benchtop unit

Activity 5.1 Comparing Measuring Instruments

1. Using the internet, research, compare, and present your findings on the differences between measuring instruments according to their use, cost, precision, sensitivity and material of construction.
2. Focus on each of the following measuring instruments:
   a. Protractor
   b. Height Gauges
   c. Vernier calliper
   d. Digital callipers
   e. Micrometre screw gauge
   f. Angle gauge
3. Based on the research findings, prepare a presentation highlighting the differences between the assigned instruments. Your findings on each instrument must highlight each of the following:

a. Use/Application
b. Cost
c. Precision
d. Construction material
e. Range of Measurement
f. Usability

4. Present your findings to your class or peers for further discussion and feedback.

Activity 5.2 Comparing Measurement Instruments Based on Their Use

1. Search on the internet or watch the videos below on scale rule, vernier calliper, and micrometre screw gauge to measure different objects in a workshop.

The Steel Rule

https://www.youtube.com/watch?v=0KXPuBUdDtw&t=639s

Vernier Calipers (Principle & Description)

https://www.youtube.com/watch?v=ySRN3yuZUT0

How to use Micrometre Screw Gauge

https://www.youtube.com/watch?v=phFRSS7mH9Y&t=319s

2. After watching the videos, take a piece of:
   a. metal piece (e.g., a 10 cm long metal bar or block)
   b. cylindrical metal rod (approximately 1 cm in diameter, 10 cm long)
   c. thin metal sheet (like a sheet of aluminium foil or thin wire)

3. Use the instruments provided to measure the materials given and record their measurements.
4. Repeat each instrument measured three times and calculate the average. Gather your data and write a brief report for oral presentation
5. Write down all measurements taken during the activity and calculate the average for each tool and object.
6. Discuss with peers, which tool is most appropriate for each object (metal piece, cylindrical rod, thin metal sheet), challenges or difficulty faced while using the instruments and compare their accuracies (closeness to the true value) and precision (repeatability of measurements) of each instrument. Discuss why precision matters in specific tasks (e.g., measuring the thickness of a sheet accurately for fitting).

USING MEASURING TOOLS TO MEASURE WORK PIECES

Using the right instruments to take accurate measurements is significant in the manufacturing of products and quality control. The following highlights the importance of accurate measurement in production and quality control:

Why Accurate Measurement is Important

1. **Ensuring Product Quality:** Accurate measurement ensures products are made in the correct dimensions and within the required limits. This helps maintain consistent quality, prevent defects, and ensure each product meets the expected standards, essential for customer satisfaction and a strong brand reputation. It also helps maintain the product's function and reliability.

2. **Improving Efficiency:** When measurements are accurate, there's less need to fix mistakes or adjust. This saves time and resources, making the production process smoother. It reduces errors, ensuring parts fit together correctly the first time, leading to less downtime and more products being made in less time.

3. **Reducing Costs:** Accurate measures help avoid wasting materials and the need to redo work. This cuts down on costs. It also helps avoid expensive recalls or returns by ensuring products are made immediately.

4. **Compliance with Standards:** Accurate measurement is necessary to meet industry standards and regulations. Following these standards is necessary for legal reasons and for keeping certifications, which are essential for business operations.

5. **Ensuring Interchangeability:** Accurate measurement ensures that parts made by different manufacturers or at different times can be used together. This is important for assembly lines and large-scale production, helping maintain consistency and making repairs easier.

6. **Increasing Customer Satisfaction:** When products are accurately measured, they meet the required specifications and perform as expected. This leads to higher customer satisfaction, fewer complaints, and stronger customer loyalty. Accurate measurement ensures that customers receive products that match their expectations.

CONSTRUCTION, OPERATION AND READING THE SCALES OF MEASURING INSTRUMENTS

Vernier Callipers

Construction

- Main Scale: A long, straight ruler with marked measurements.
- Vernier Scale: A small, movable scale that slides along the main scale.
- Fixed Jaw: Attached to the main scale.
- Sliding Jaw: Attached to the vernier scale.
- Depth Rod: A thin rod that extends from the end of the calliper to measure depths.
- Locking Screw: Secures the sliding jaw in place.

Operation

- Zero Check: Ensure the calliper reads zero when the jaws are closed.
- Measuring External Dimensions: Place the object between the fixed and sliding jaws and gently close the jaws on the object.
- Measuring Internal Dimensions: Place the upper jaws inside the object.
- Measuring Depth: Extend the depth rod into the object.

Reading the Scales

- Main Scale Reading: Note the value on the main scale just before the zero of the vernier scale. In the example shown in **Figure 5.12a**, this is 23.
- Vernier Scale Reading: Identify the line on the vernier scale that aligns perfectly with a line on the main scale. This provides the decimal place; in the example shown in Fig. 5.12a, this is 6.
- Total Measurement: Add the main and vernier scales reading. In the example shown, this result is 23.6 mm.

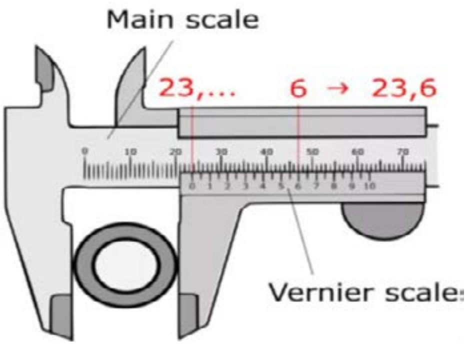


Figure 5.12: (a) Reading the scales of the vernier callipers

Example 5.1

The external measurement (diameter) of a round-section piece of steel is measured using a vernier calliper and, metric scale.

Mathematical Method

- The main metric scale is read first, and this shows that there are 13 whole divisions before the 0 on the hundredths scale. Therefore, the first number is 13.
- The' hundredths of mm' scale is then read. The best way to do this is to count the number of divisions until you get to the division that lines up with the main metric scale. This is 21 divisions on the hundredths scale.
- This 21 is multiplied by 0.02, giving 0.42 as the answer (each division on the hundredths scale is equivalent to 0.02mm).
- The 13 and the 0.42 are added together to give the final measurement of 13.42 mm (the diameter of the piece of round-section steel).

Commonsense Method

Alternatively, it is just as easy to read the 13 on the main scale and 42 on the hundredth scale. The correct measurement is 13.42mm.

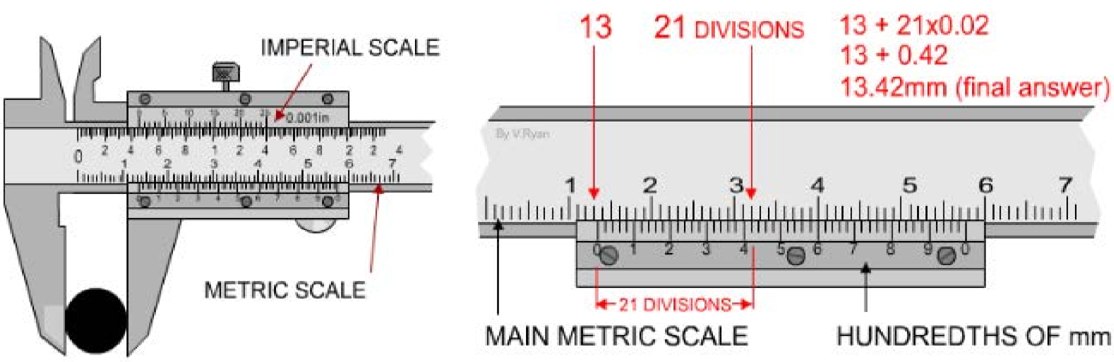


Figure 5.12: (b) Reading the vernier callipers

Example 5.2

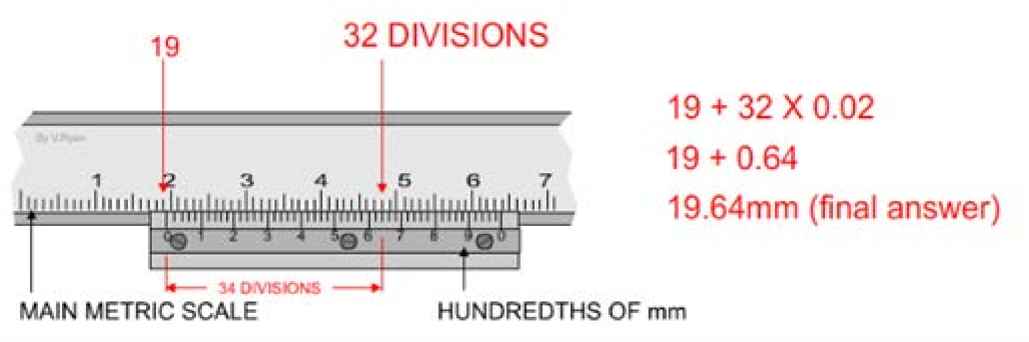


Figure 5.12: (c) Reading the vernier callipers

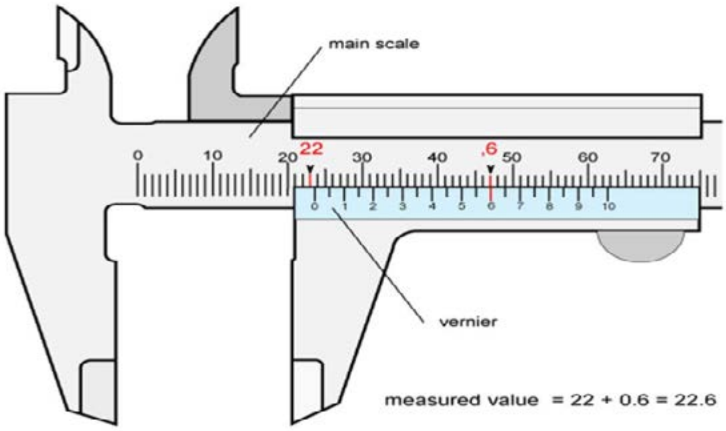


Figure 5.12: (d) Reading the vernier callipers

Micrometre Screw Gauge

Construction

- Frame: Provides a sturdy base for the anvil and spindle
- Anvil: A fixed measuring face
- Spindle: A movable measuring face that moves towards or away from the anvil
- Thimble: A cylindrical component that rotates to move the spindle
- Sleeve/Barrel: Has a linear scale etched onto it
- Ratchet Stop: Ensures consistent measuring pressure
- Lock Nut: Secures the spindle in place.

Operation

- Zero Check: Ensure the micrometre reads zero when the spindle is in contact with the anvil.
- Open the micrometre by turning the thimble or ratchet
- Place the object to be measured between the spindle and anvil.
- Close the spindle by turning the ratchet, not the thimble. The ratchet prevents excess pressure on the measured object, so you don't squash it and get a false reading.
- Now, read the scale.

Reading the Scales

- Sleeve Scale Reading: Note the last visible graduation on the sleeve.
- Thimble Scale Reading: Identify the line on the thimble that aligns with the sleeve's horizontal line.
- Total Measurement: Add the sleeve scale reading and the thimble scale reading.

How to read a Micrometre Screw Gauge

Example 5.3

Using **Figure 5.13a**

- Read off the millimetre mark to the left of the thimble
- Is there a half-millimetre mark before the millimetre mark to the left of the thimble? If there is an addition of 0.5 mm to your mm reading, so in this case 2.5 mm
- Read off the hundredths of a millimetre where the scale on the thimble meets the centre of the main scale. In this case, 0.38 mm.
- Add the readings together, so the thickness measured here is: 2.5 + 0.38 = 2.88 mm.

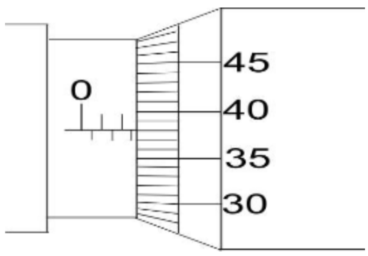


Figure 5.13: (a) Reading the micrometre screw gauge

Sleeve reading	=	2.50 mm
Thimble reading	=	0.38 mm
Total reading	=	2.88 mm

Example 5.4

Using **Figure 5.13b**

- Read the scale on the sleeve. The example shows 12 mm divisions.
- Still reading the scale on the sleeve, a further ½ mm (0.5) measurement can be seen on the bottom half of the scale. The measurement now reads 12.5mm.
- Finally, the thimble scale shows 16 full divisions (these are hundredths of a mm).
- The final measurement is 12.5mm + 0.16mm = 12.66

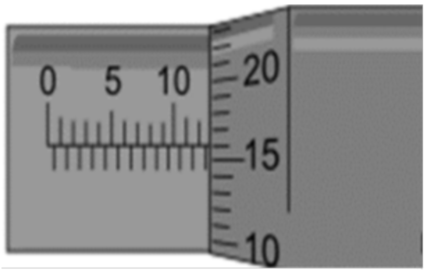


Figure 5.13: (b) Reading the micrometre screw gauge

Sleeve reading	=	12.50 mm
Thimble reading	=	0.16mm
Total reading	=	12.66 mm

Height Gauge

Construction

- Base: Provides stability and ensures the gauge is perpendicular to the surface.
- Beam/Column: A vertical scale for measuring height.
- Scriber/Probe: A pointed or flat tool that moves along the beam to mark the object or measure height.
- Vernier/ Digital Scale: For precise readings.
- Locking Screw: Secures the scriber/probe in place.

Operation

- Zero Check: Ensure the height gauge reads zero when the scriber/probe is at the base level.
- Measuring Height: Place the height gauge on a flat surface plate and move the scriber/probe to the top of the object.
- Locking: Use the locking screw to hold the scriber/probe in place.

Reading the Scales

- Main Scale Reading: Note the value on the main scale up to the zero of the vernier or digital scale.
- Vernier Scale Reading: Identify the line on the vernier scale that aligns perfectly with a line on the main scale.
- Digital Reading: Directly read the height measurement from the digital display if available.
- Total Measurement: Combine the main scale reading and the vernier scale reading for the final measurement.

Activity 5.3 Hands on applications measuring instruments

Use the following instruments scale rule, vernier calliper and micrometre screw gauge and measure the thickness, length and diameter of the following workpieces:

- Length metal piece
- Diameter of a cylindrical rod
- Thickness of a thin metal sheet
- Depth of a recess/hole and record your Figures.

Activity 5.4 How to Read the Vernier calliper

Calculate the measurement of the following Venier calliper readings

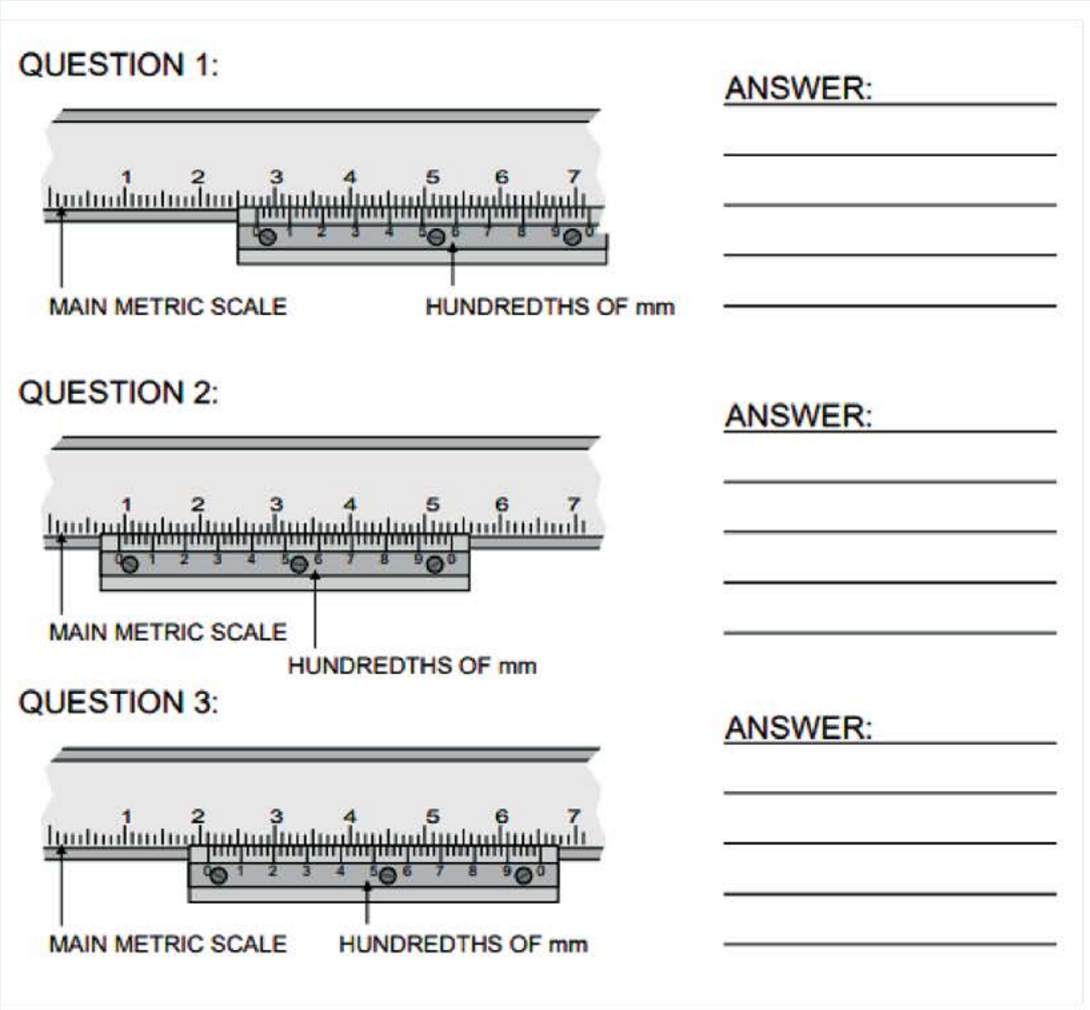


Figure 5.14: Reading of the Vernier calliper measurement

Activity 5.5 How to Read the Micrometre Screw Gauge

Calculate the measurement of the following micrometre readings

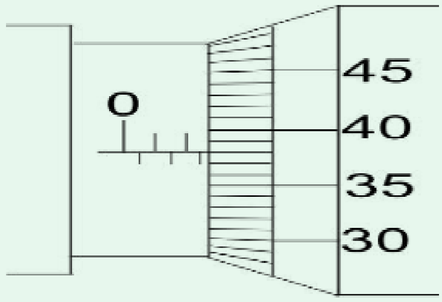


Figure 5.15: (a) Reading of the micrometre screw gauge measurement

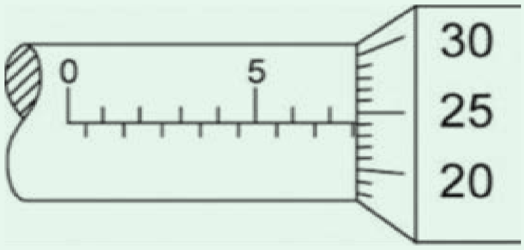


Figure 5.15: (b) Reading of the micrometre screw gauge measurement

DIFFERENCE BETWEEN MANUAL HAND TOOLS AND POWER HAND TOOLS

Hand tools are instruments used to perform a variety of tasks, such as cutting, shaping, fastening, and measuring. They can be either manually operated or powered by an external source. Unlike manual hand tools, which do not require any power source, power hand tools are powered by electricity, batteries, or compressed air.

Manual hand-tools

Manual hand tools are operated entirely by hand, without the need for external power sources. These tools depend on human effort and physical manipulation to complete tasks. Generally, they are simpler in design and construction compared with power tools. Manual hand tools include a wide range of implements, such as hammers, wrenches, screwdrivers, pliers, chisels, and hand saws. They are essential for tasks that require precision and control, including woodworking, crafting, minor repairs, and assembly work. Despite the increasing use of power tools, manual hand tools remain indispensable due to their reliability, ease of use, and capability to perform delicate and detailed work without requiring electricity or batteries.

Figure 5.16: Manual hand tools

Characteristics of Manual Hand Tools

- Simplicity: Manual hand tools have a simple design with few moving parts.
- Portability: They are generally lightweight and easy to transport.
- Durability: Often made from robust materials like steel, manual hand tools are built to withstand frequent use.
- Versatility: Suitable for various tasks, from precision work to heavy-duty applications.
- Control: Provide a high degree of control, allowing for precise and detailed work.

Advantages of Manual Hand Tools

- No Power Requirement: Can be used anywhere without the need for electricity or batteries.
- Cost-Effective: Typically, less expensive than their powered counterparts.
- Ease of Use: Simple to operate and often require minimal training.
- Low Maintenance: Require less maintenance compared with power tools, with no need for battery replacements or electrical repairs.
- Safety: Generally safer to use, as they operate at a lower speed and force, reducing the risk of accidents.

Limitations of Manual Hand Tools

- Physical Effort: Relying on human strength can be tiring and less efficient for large or repetitive tasks.
- Time-Consuming: Slower than power tools, which can affect productivity on large projects.
- Limited Power: This may not be suitable for very tough materials or heavy-duty applications where more power is needed.
- Speed: Manual tools are generally slower than power tools, making large-scale tasks more time-consuming.
- Precision: While effective for detailed work, they may lack the consistent accuracy that power tools can provide in some applications.

Examples of Manual Hand Tools

- **Cutting Tools**: Handsaws and utility knives, used for cutting wood, plastic, or other materials.
- **Gripping and Holding Tools**: Pliers and wrenches, used for gripping, twisting, or turning objects like wires or bolts.
- **Striking Tools**: Hammers and mallets, used for driving nails, breaking objects, or shaping materials.
- **Measuring and Layout Tools**: Tape measures and squares, used for measuring lengths or ensuring right angles and accurate alignment.
- **Fastening Tools**: Screwdrivers, used for inserting or removing screws to fasten objects.
- **Clamping and Holding Tools**: Clamps and vices, used for securing materials in place during work.

Power Hand-Tools

Power hand tools are powered either electrically or pneumatically and rely on an external power source for operation. They are designed to improve efficiency and productivity by automating tasks that would otherwise require considerable manual effort. Power hand tools can vary from compact handheld devices to larger stationary machines. Some common examples include drills, saws, grinders, sanders, and nail guns. While these tools can significantly enhance productivity and efficiency, they also require proper handling and safety precautions due to their greater power and speed compared to manual tools.

Figure 5.17: Power hand tools

Characteristics of Power Hand Tools

- Power Source: Operate using electricity (corded or battery-powered) or compressed air (pneumatic).
- Speed and Efficiency: Perform tasks much faster than manual tools due to their powered operation.
- Versatility: Available in various types for different applications, including cutting, drilling, grinding, and sanding.
- Complexity: Generally, it is more complex in design with multiple moving parts and electronic components.
- Portability: While some are portable, others may be heavier and less convenient to transport than manual tools.

Advantages of Power Hand Tools

- Increased Productivity: Significantly speeds up tasks, making them ideal for large and repetitive projects.
- Reduced Physical Effort: Minimises the physical strain on the user, allowing for more extended periods of work without fatigue.
- Precision and Consistency: Provides more consistent results and can achieve higher precision in cutting, drilling, and sanding tasks.
- Enhanced Capabilities: Can handle tougher materials and more demanding tasks that would be difficult or impossible with manual tools.

Limitations of Power Hand Tools

- Dependency on Power Supply: These tools rely on a continuous power source, which poses a challenge in remote or outdoor environments lacking electricity.
- Expense: They tend to be more costly than manual tools, both in terms of initial investment and ongoing maintenance.
- Maintenance Requirements: Regular upkeep is necessary, including battery replacements for cordless models and servicing of motors or compressors.
- Safety Risks: There is an increased risk of accidents and injuries due to the high power and speed of operation, necessitating strict adherence to safety protocols.

Examples of Power Hand Tools

Cutting Tools

1. Circular saws: Used for making straight cuts in wood, metal, plastic, and other materials
2. Jigsaws: For making curved cuts and intricate wood, metal, and plastic designs.
3. Band saws: Used for cutting irregular or curved shapes in wood, metal, and other materials.

4. Tile cutters: Designed specifically for cutting tiles, whether ceramic, porcelain, or stone.

Drilling and Fastening Tools

1. Power Drills: Used for drilling holes in various materials like wood, metal, and masonry.
2. Impact Drills: Powerful drills designed to drive screws or drill into tough materials like concrete or masonry.
3. Hammer Drills: A type of drill that combines rotary motion with a hammering action to drill into hard materials like concrete and brick.
4. Cordless Screwdrivers: Used for driving screws without the need for a direct power source, offering portability and convenience

Grinding and Polishing Tools

1. Angle Grinders: Used for grinding, polishing, and cutting materials like metal, stone, and concrete.
2. Rotary Tools: Versatile tools with various attachments used for cutting, grinding, sanding, and polishing in small or detailed areas.
3. Bench Grinders: Stationary grinding tools used for sharpening and shaping tools or materials.
4. Polishing Machines: Used for giving a smooth, shiny finish to surfaces such as metal, wood, or plastic

Sanding Tools

1. Random Orbit Sanders: Used for smoothing surfaces without leaving swirl marks, great for wood and other materials.
2. Belt Sanders: Powerful tools for quickly smoothing large areas of wood and other materials using a sanding belt.
3. Detail Sanders: Small, handheld tools used for sanding in tight corners and detailed areas.
4. Palm Sanders: Lightweight sanders ideal for smaller sanding tasks, providing control and smooth finishes.

Routing and Milling Tools

1. Routers: Used for hollowing out an area in wood or other materials, or for shaping edges and grooves.
2. Electric Planers: Used to smooth or level wood surfaces, removing layers of material to adjust thickness.
3. Trim Routers: Smaller routers are designed for precision work, such as trimming edges or creating decorative shapes.
4. Compact Routers: Similar to trim routers but designed for more detailed and controlled routing in smaller, finer projects.

Sawing Tools

1. Reciprocating Saws: Used for demolition, cutting through wood, metal, and plastic with a back-and-forth motion.
2. Mitre Saws: Specialised for making precise crosscuts and angled cuts, typically in wood and plastic.
3. Table Saws: Stationary saws used for cutting large boards, providing straight, accurate cuts.
4. Scroll Saws: Used for making intricate, curved cuts in wood, metal, and other materials.

Cutting and Welding Tools

1. Plasma Cutters: These are used for cutting through metal using a high-temperature plasma arc.
2. Welding Machines: These are used for fusing metal pieces together by applying heat and sometimes pressure.
3. Oxy-Acetylene Torches: Used for welding, cutting, and brazing metals with the heat produced by burning a mix of oxygen and acetylene gas.
4. MIG Welders: Metal Inert Gas (MIG) welders are used for welding by feeding a wire into the weld pool, ideal for thin to medium metal projects.

Safety and Maintenance of Hand Tools

Hand tools are essential for various tasks. However, improper use and lack of maintenance can lead to accidents, reduced tool effectiveness, and costly repairs. Ensuring safety and proper upkeep of hand tools is crucial to avoiding injuries, extending the tools' lifespan, and maintaining optimal performance. Regular inspection, cleaning, and correct usage are key to keeping hand tools in good condition and safe to operate.

Safety of Hand Tools

1. Always wear appropriate personal protective equipment (PPE), including safety glasses, gloves, and hearing protection, depending on the tool and task.
2. Check for any damage, wear, or defects in the tool that could affect its performance or safety.
3. Use the right tool for the job to avoid overexertion or potential hazards.
4. Carry tools securely with sharp edges and points facing away from your body.
5. Never carry tools up a ladder without a proper tool belt or container.
6. Follow the manufacturer's instructions and guidelines for safe operations.
7. Keep hands and fingers away from moving parts or cutting edges.
8. Ensure the work area is well lit and free from clutter or obstacles that could cause accidents.

9. Use tools in well-ventilated areas when working with chemicals or dust-producing materials.
10. Store tools in a clean, dry place where they are protected from damage.
11. Transport tools safely in a toolbox or case to prevent injury or damage to the tool.
12. Keep tools clean and free of dirt, grease, and debris.
13. Inspect tools regularly for wear and tear and replace or repair damaged tools promptly

Maintenance of Hand Tools

1. Wipe down tools to remove dust, dirt, and moisture after each use.
2. Use appropriate cleaning agents and lubricants to prevent rust and corrosion.
3. Sharpen cutting tools regularly to maintain effectiveness and reduce the risk of accidents.
4. Adjust tools, such as wrenches and pliers, to ensure they operate smoothly and securely.
5. Store tools in a way that prevents them from rubbing against each other or falling.
6. Use tool organisers or racks to keep tools organised and easily accessible.
7. Replace worn-out or damaged tools rather than attempting to repair them if they compromise safety or functionality.
8. Use only genuine replacement parts recommended by the manufacturer.
9. Follow the manufacturer's instructions for charging and storing batteries.
10. Replace batteries when they no longer hold a charge or show signs of wear.
11. Conduct periodic inspections of tools to identify any issues early.
12. Test tools for proper operation and functionality before each use.

Differences Between Manual Hand Tools and Power Hand Tools

The differences between manual hand tools and power hand tools are shown in Table 5.4.

Table 5.4: Differences between manual hand tools and power hand tools

Criteria	Manual Hand Tools	Power Hand Tools
Power Source	Operated by physical force, no electricity or batteries	Powered by electricity, batteries, or air
Ease of Use	Requires more physical effort, slower	Requires less effort, faster work
Precision	Provides greater control and precision	Can be less precise but improved with newer models

Criteria	Manual Hand Tools	Power Hand Tools
Speed and Efficiency	Slower, more labour-intensive	Faster and more efficient, ideal for large tasks
Cost	Generally, less expensive	Typically, more expensive due to the complex components
Maintenance	Minimal maintenance, mainly cleaning and sharpening	Regular maintenance, including motor and battery care
Portability	Lightweight, portable	Can be heavier and less portable due to power sources

Activity 5.6 Discussion on Manual and Power Hand Tools

1. In a small group, explore and compare manual hand tools and power hand tools across various factors (precision, control, safety, use, portability, accessibility, efficiency, and speed.
2. In your group present your responses on the following in a whole class presentation:
   a. How does the precision of a task differ when using a manual hand tool compared to a power hand tool?
   b. Which type of tool—manual or power—offers more control during use, especially in intricate or detailed tasks?
   c. What are the potential safety risks associated with using power hand tools compared with manual hand tools?
   d. Are manual tools generally safer for beginners, and if so, why?
   e. In which types of projects or tasks are manual hand tools more suitable than power hand tools?
   f. In situations where portability of equipment is key, would you choose manual or power tools, and why?
   g. On remote sites without workshop infrastructure which would you choose, Manual or power tools and why?
   h. How do power tools impact the speed of completing tasks compared with manual tools?
   i. How does the efficiency of manual tools compare with power tools in terms of time and energy spent on a project?

Activity 5.7 Performing Drilling Operations with Hand Drills

Materials needed

- Manual hand drills (Brace and bit)
- Power hand drills (cordless or corded)
- Drill bits of various sizes
- Workpieces (e.g., pieces of wood, metal, or plastic)
- Measuring tools (ruler or calliper)
- Safety equipment (goggles, gloves, ear protection)

Steps

1. Organise yourselves into groups of no more than five. Each group will drill a hole of a specified depth and diameter into a workpiece using both the manual hand drill and the power hand drill.
2. Use the manual hand drill to drill a hole. Focus on how the drill feels, how much effort is needed, and the accuracy of the hole.
3. Use the power hand drill to drill a hole. Pay attention to how the power tool feels in comparison, including ease of use, speed, and how much effort is required.
4. Measure and compare the depth and diameter of the holes drilled with both tools.
5. Take notes on their experiences, paying attention to precision, control, safety, speed, and efficiency.
6. At your group level, generate ideas to the following questions:
   a. How did each tool perform in terms of precision and control?
   b. Which tool was easier to use, and why?
   c. What safety precautions were important when using each tool?
   d. Did you notice a difference in the speed of completing the task?
   e. Which tool felt more efficient in terms of effort and time?
7. Your oral presentation report should include:
   a. Introduction: Briefly describe the tools used and the tasks performed.
   b. Comparison: Discuss the differences between manual and power drills across various factors such as precision, control, safety, speed, portability, efficiency, and accessibility. Use personal observations from the hands-on activity to support your argument.
   c. Conclusion: Which tool would be preferable for different tasks and why, based on your experience?

APPLICATION OF HAND TOOLS IN MANUFACTURING

Hand tools play a crucial role in many manufacturing processes, especially where precision, control, and detailed craftsmanship are essential. Even with the prevalent use of power tools in modern manufacturing, hand tools remain vital across various industries. They are especially suited for tasks that require careful control and delicate handling, providing unique advantages in situations where power tools may be less effective or impractical.

IMPORTANCE OF HAND TOOLS IN VARIOUS INDUSTRIES

Hand tools are essential in various industries, offering specific applications that improve productivity, precision, and safety. The use of hand tools in several industries is explained below:

Construction Industry

Manual Hand Tools: Essential tools in the construction industry include hammers, screwdrivers, wrenches, and pliers. These tools are used for various tasks such as framing, wiring, plumbing, and structural assembly. They offer craftsmen a high level of control and the ability to make precise adjustments, ensuring accuracy throughout the construction process.

Power Hand Tools: Power tools such as drills, saws, sanders, and nail guns greatly improve productivity by minimising the time and effort required for labour. These tools allow workers to handle challenging materials and complete large-scale projects more easily, resulting in significant enhancements in both speed and effectiveness.

Automotive Industry

Manual Hand Tools: Wrenches, socket sets, screwdrivers, and pliers are essential for engine repairs, component replacements, and routine maintenance. These tools provide the precision necessary to work with complex automotive parts, ensuring meticulous attention to detail in repairs and adjustments.

Power Hand Tools: Impact wrenches, electric ratchets, and drills greatly enhance the speed and efficiency of mechanical repairs and maintenance. These power tools enable the quick removal and installation of parts, minimising downtime and improving overall workflow efficiency.

Manufacturing Industry

Manual Hand Tools: Callipers, micrometres, and gauges are essential tools for precision measurement and quality control in manufacturing. These instruments ensure that components comply with exact specifications and tolerances, which helps maintain high standards of accuracy and consistency.

Power Hand Tools: Grinders, drills, and torque wrenches are widely used in assembly lines and fabrication processes. These power tools not only increase production rates but also ensure that each component is manufactured with consistent quality. This contributes to the overall efficiency and reliability of the manufacturing process.

Woodworking Industry

Manual Hand Tools: Saws, chisels, hand planes, and carving tools are essential for artisans who create intricate cuts, shapes, and finishes. These tools are vital for producing high-quality craftsmanship in fine woodworking and cabinetry, providing the precision and control necessary for detailed and refined work.

Power Hand Tools: Electric saws, routers, sanders, and drills enhance the cutting, shaping, and finishing processes. These power tools allow woodworkers to efficiently manage larger projects and execute intricate designs, greatly improving productivity without sacrificing quality.

Electrical Industry

Manual Hand Tools: Wire strippers, pliers, screwdrivers, and multimeter are essential tools for installing and repairing electrical systems. These tools allow for the precision and safety needed to work with delicate electrical components, ensuring they function properly while minimising the risk of damage or accidents.

Power Hand Tools: Cordless drills, impact drivers, and power screwdrivers enhance the installation of fixtures, wiring, and electrical panels. These tools greatly improve efficiency, enabling electricians to complete tasks more quickly and easily, particularly in complex or large-scale projects.

Plumbing Industry

Manual Hand Tools: Pipe wrenches, pliers, tube cutters, and plungers are essential tools for installing and maintaining plumbing systems. These tools enable plumbers to work effectively in tight spaces and carry out detailed tasks, providing the necessary leverage and control for secure fittings and repairs.

Power Hand Tools: Electric pipe cutters, power augers, and cordless drills significantly enhance the speed and efficiency of cutting, fitting, and clearing pipes. These power tools minimise manual effort and improve workflow, allowing plumbers to tackle larger tasks and more demanding projects with greater effectiveness.

HVAC Industry

Manual Hand Tools: Wrenches, screwdrivers, pipe cutters, and tubing benders are essential tools for installing and servicing heating, ventilation, and air conditioning (HVAC) systems. These tools enable accurate fittings and secure connections, ensuring efficient and reliable operation of HVAC systems.

Power Hand Tools: Power saws, drills, and refrigerant recovery machines greatly improve the installation and maintenance of Heating, Ventilation and Air conditioning (HVAC) systems. These tools allow technicians to handle complex tasks more efficiently, saving time and effort while ensuring high standards of accuracy and performance.

Aerospace Industry

Manual Hand Tools: Torque wrenches, callipers, and specialised fasteners are essential for the assembly and maintenance of aircraft components. These tools guarantee the precision needed for critical applications, where even the slightest mistake can significantly affect safety and performance.

Power Hand Tools: Pneumatic drills, rivet guns, and grinders are crucial tools in aircraft assembly and repair. These power tools enhance efficiency and accuracy, ensuring the structural integrity of components while meeting the stringent demands of the aerospace industry.

Medical Industry

Manual Hand Tools: Surgical instruments, forceps, and precision tools are essential in medical procedures and the production of medical equipment. These tools require the highest levels of precision, sterility, and reliability, as they directly impact patient outcomes and the effectiveness of medical devices.

Power Hand Tools: Battery-operated surgical drills and saws are increasingly utilised in orthopaedic and other surgical procedures. These tools enhance control and precision, reduce operation time, improve surgical efficiency, and minimise patient recovery time.

Home Improvement

Manual Hand Tools: Hammers, screwdrivers, pliers, and saws are essential for various home repairs and improvement projects. These tools allow homeowners to complete a wide range of tasks independently.

Power Hand Tools: Cordless drills, power saws, and sanders simplify DIY projects, enabling more complex and professional-quality results.

Applications of Manual Hand Tools

Manual hand tools are used for many implications. Some selected manual hand tools and their applications are listed below:

- **Hammer**: The hammer is primarily used to drive nails into wood, metal, or other materials. Its claw end is essential for extracting nails. In metalworking, hammers are employed to shape, forge, and manipulate metal components, ensuring precise alterations.
- **Screwdriver:** Designed to insert, tighten, and remove screws, the screwdriver is a fundamental tool for fastening components in various materials, including wood, metal, and plastic. It is also utilised for loosening screws during disassembly or maintenance.
- **Wrench**: A key tool for applying torque to bolts, nuts, and other fasteners. Wrenches (spanners) are essential for tightening or loosening mechanical connections, ensuring secure fittings in both industrial and domestic applications.
- **Pliers**: Pliers are used for gripping, manipulating, and securely holding objects. Many pliers come with built-in cutting edges, allowing them to cut wires, nails, or small metal components. They are also essential for bending, shaping, and crimping metal wires and parts.
- **Handsaw**: The handsaw is used to make straight, controlled cuts in wood, plastic, and some metals. It is also effective for pruning branches and cutting smaller pieces of lumber, offering a manual solution for precise, straight-line cutting.
- **Chisel**: Chisels are tools used for carving and shaping wood. They can remove small pieces of wood or other materials to create detailed designs.
- **File**: Files are used to smooth rough edges and surfaces of metal, wood, and plastic. They can also shape and fine-tune the dimensions of various materials.
- **Clamp**: Clamps are used to secure workpieces during operations such as cutting, glueing, or assembly. They apply consistent pressure to hold materials steady, ensuring accurate alignment and aiding in the proper curing of adhesives during the bonding process.
- **Hand Plane**: A hand plane is used for smoothing, flattening, and levelling wooden surfaces. It is essential in carpentry to achieve a fine finish, remove irregularities, and create an even, level surface.
- **Hand Drill**: A manual hand drill is used to create accurate holes in wood, plastic, and light metals. It provides better control and precision for detailed drilling tasks.
- **Mallet**: It is used to strike chisels and other tools without damaging them. It also assists in assembling joints without marring the surface of the wood or material.

Applications of Power Hand Tools

Below are some power hand tools and their respective applications:

- **Electric Drill**: It is used to drill holes in various materials, including wood, metal, and plastic. With the appropriate bits, it can also drive screws into these materials.
- **Circular Saw**: Perfect for making straight cuts in wooden materials, it can also cut metal sheets and plastics with the appropriate blade.
- **Angle Grinder**: It is utilised to grind metal surfaces and to remove rust or paint. Additionally, it can cut through metal, stone, and concrete when equipped with the appropriate disc.
- **Jigsaw**: It is ideal for making detailed and curved cuts in wood, metal, and plastic.
- **Power Sander**: It is used to sand surfaces to smooth them before painting or finishing. It effectively removes paint, varnish, or rust from surfaces.
- **Impact Driver**: It produces high torque for driving screws and bolts into tough materials and is effective in removing stubborn screws.
- **Nail Gun**: It quickly and efficiently drives nails into wood and other materials.
- **Power Planer**: It is used to remove thin layers of wood to create a smooth surface.

Comparative Applications

Table 5.5 compares the advantages and applications of selected power hand tools and manual hand tools used in manufacturing.

Table 5.5: Comparisons of the applications of manual and power hand tools

Manual Hand Tool	Application	Advantages	Power Hand Tool	Application	Advantages
Hammer	Driving nails manually	Simple, no power needed, suitable for precision work	Nail Gun	Driving nails rapidly using compressed air or electricity	Fast, consistent, reduced physical effort
Screw driver	Manually driving screws	Simple, no power needed, good for delicate work	Electric Screwdriver	Quickly driving screws using a motor	Faster, less physical effort handles tougher materials

Manual Hand Tool	Application	Advantages	Power Hand Tool	Application	Advantages
Handsaw	Manual cutting wood or other materials	No power needed, precise, good for small cuts	Circular Saw	Rapidly cutting wood, metal, or plastic using a motor	Fast, efficient, handles larger and tougher materials
Hand Drill	Manually drilling holes in wood, plastic, and light metals	No power is needed, simple, portable	Electric Drill	Quickly drilling holes using a motor	Fast, can handle tougher materials, multiple speed settings
Pliers	Gripping, bending, and cutting wires, and small components	Simple, precise, versatile	Power Pliers	Quickly crimping electrical connectors/ terminals	Fast, consistent, reduce physical effort
Hand Plane	Manual smoothing and shaping wood surfaces	Precise, good for detailed work, no power needed	Power Planer	Quickly smoothing and shaping wood surfaces using a motor	Fast, handles larger surfaces, less physical effort
Utility Knife	Manually cutting materials like cardboard, plastic, drywall	Simple, precise, portable	Jigsaw	Cutting intricate shapes and curves using a powered blade	Fast, handles tougher materials, can make complex cuts
Wrench	Manually turning nuts, bolts, and other fasteners	Simple, precise, no power needed	Impact Wrench	Quickly turning nuts, bolts, and fasteners using a motor	Fast, handles high-torque applications, reduces physical effort
Chisel	Manually carving, cutting, or shaping wood, stone, metal	Precise, good for detailed work, no power needed	Rotary Tool	Cutting, carving, grinding, polishing using a motor	Versatile, fast, handles intricate work with multiple attachments

Manual Hand Tool	Application	Advantages	Power Hand Tool	Application	Advantages
File	Manually smoothing and shaping material surfaces	Simple, precise, good for detailed work	Belt Sander	Rapidly smoothing and shaping material surfaces using a motor	Fast, efficient, handles larger surfaces

Activity 5.8 Design and Make a Metal/Wooden Box at the Workshop

Materials/Tools needed

- Wood, metal, or plastic (depending on the product to be created)
- Hammer
- Screwdrivers
- Wrenches
- Pliers
- Handsaw or Circular Saw
- Jigsaw
- Power drill or electric drill
- Angle grinder (if working with metal or concrete)
- Power sander
- Safety equipment (gloves, goggles, ear protection, etc.)

Steps

- In a small group, choose a product to create (e.g., a simple wooden shelf, a small toolbox, or a metal box).
- Sketch a detailed design, outlining the dimensions and required materials for the project.
- Outline the sequence of steps, identifying which tools (manual and power hand tools) are required for each stage of the product creation.
- Use manual tools such as handsaws and files, to begin preparing the materials (e.g., cutting wood or smoothing edges).
- Use manual hand tools like hammers, screwdrivers, wrenches, and pliers to assemble the components of the product.
- Now use power hand tools like an electric drill to make precise holes, a circular saw for cutting larger pieces of wood or plastic, or a jigsaw for intricate cuts.
- Where necessary, use power sanders or angle grinders to smooth the surfaces and refine the product for quality finishes.

- Assemble your product using a combination of manual and power hand tools to secure fasteners and joints. Ensuring that joints are stable and screws are tight.
- Final touches such as sanding and smoothing any rough edges or surfaces.
- Evaluate both the aesthetic and structural integrity of the product.
- Discuss the process and reflect on the tools used in a whole class discussion.
- Which tasks were best suited for manual hand tools?
- Which tasks were more efficiently completed using power hand tools?
- How did the combination of tools contribute to the overall success of the product?
- Which safety considerations were important when using power tools?

Review Questions

1. Match these instruments to their primary function:

A	B
Vernier Calliper	Measures small dimensions with high precision
Micrometre screw gauge	Measures angles
Steel Ruler	Measures internal and external dimensions
Protractor	Measures straight lengths

   Explain one key difference between a vernier calliper and a micrometre screw gauge in terms of precision

2. You are to measure the internal diameter of a small pipe and the thickness of thin wire. Describe the steps you would take to measure both accurately, specifying which instruments you would use and why.
3. Calculate the reading of the measurement shown below (**Figure 5.18**)

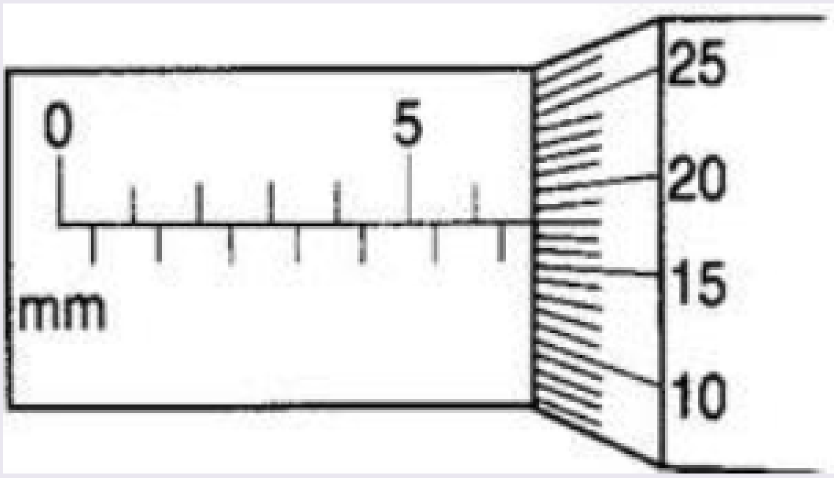


Figure 5.18: Reading of the micrometre screw gauge measurement

4. Analyse the safety considerations one must consider when using power hand tools compared to manual hand tools.
5. Discuss two potential drawbacks of relying solely on power tools in the manufacturing industry

Manufacturing Engineering

Year 2

SECTION

6

CASTING AND JOINING PROCESSES

MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES

Manufacturing Processes

Introduction

This section delves into the essential manufacturing processes of casting and joining, highlighting their significance in the production of engineering products. It begins with exploring the importance of casting, emphasising its ability to create complex shapes and its widespread use in various industries. The sand-casting process is then detailed, outlining the steps and materials involved. The section also covers both non-permanent and permanent joining methods, comparing their applications and benefits. Finally, practical techniques for joining components using screws, bolts, nuts, and welding processes are discussed, along with the necessary safety practices. By the end of this section, you will have a comprehensive understanding of casting and welding processes and their applications in manufacturing engineering.

Key Ideas

- Casting is a fundamental manufacturing process used to create complex shapes by pouring molten material into a mould.
- Casting offers several advantages, including the ability to produce large and intricate parts, cost-effectiveness for mass production, and versatility in material selection.
- Casting is widely used in various industries, such as automotive, aerospace, and machinery, to produce components like engine blocks, turbine blades, and machine frames.
- Sand-casting is a popular method that involves creating a mould from sand and pouring molten metal into it to form a part. The sand-casting process
- It processes involves several steps: pattern making, mould preparation, pouring, cooling, and finishing. It is suitable for a wide range of materials, including metals and alloys, making it a versatile and widely used process in manufacturing.
- Non-permanent joining methods, such as bolting, screwing, and riveting, allow for easy disassembly and reassembly of components.
- Permanent joining methods, including welding, brazing, and soldering, create strong, durable bonds that cannot be easily undone.
- Choosing the right joining method depends on factors like the required strength, the need for disassembly, and the materials being joined.
- Screws, bolts, and nuts are essential fasteners used to join components in a variety of applications, offering ease of assembly and disassembly.
- Welding techniques, such as MIG, TIG, and arc welding, create strong, permanent joints between metal parts.
- Safety practices are crucial when performing joining processes, including using personal protective equipment (PPE) and proper handling of tools and materials.

IMPORTANCE OF CASTING IN MANUFACTURING ENGINEERING PRODUCTS

Casting is a fundamental manufacturing process in which a liquid material, usually metal or alloy, is poured into a mould that has a hollow shape of the desired product. Once the material cools and hardens, it forms a part called a casting and is then taken out of the mould to finish the process. This method is widely used for creating complex shapes and large quantities of parts. There are two main types of casting processes: expendable mould processes and permanent mould processes. The choice of which process to use depends on the material, the desired properties of the product, the production volume, the cost, and how the final product will be used. Knowing how the casting process works is important for making different types of parts.

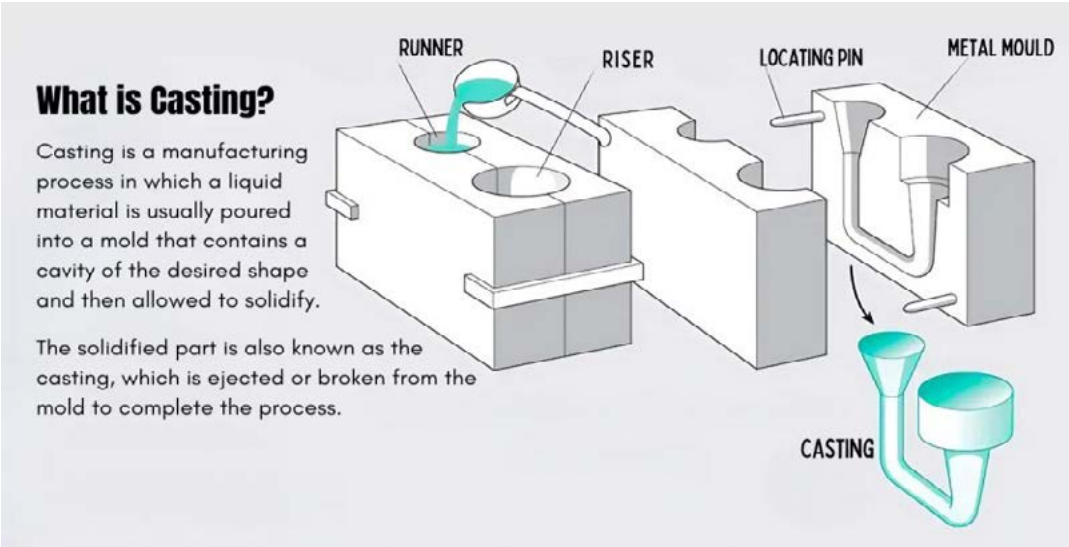


Figure 6.1: Sand-casting process

Applications of Casting

Casting is a versatile manufacturing process with various applications across various industries. It plays an important role in manufacturing engineering due to its numerous benefits, especially for products that need specific designs and structural integrity Table 6.1 presents some of the key applications of casting.

Table 6.1: Applications of casting

Industrial Sector	Casting Application
Transport	Casting is widely used to manufacture parts for automobiles, aerospace, railways and shipping.
Heavy Equipment	Used in building heavy equipment for construction, farming and mining industries

Industrial Sector	Casting Application
Machine Tools	Used in various machine tools involved in machining, casting, plastics moulding, forging, extrusion and forming use parts made through casting.
Plant Machinery	Used in chemical, petroleum, paper, sugar, textile, steel and thermal plant parts.
Defence	Used in vehicles, artillery, munitions, storage and supporting equipment.
Art and Jewellery	Used in smaller items like dental crowns, jewellery and statues.
Home and Kitchen Appliances	Used in products like wood-burning stoves, frying pans and pipes.
Engine Components	Used in the manufacture of engine blocks and heads for automotive vehicles.

Advantages and Disadvantages of Casting

Advantages of Casting

- **Include complex internal cavities**: It is particularly useful for producing components with fine details, thin walls, and internal structures that would be difficult or impossible to achieve with other methods.
- **Design Flexibility**: The casting process is highly adaptable and can accommodate nearly any design, whether it involves intricate external or internal features. This flexibility makes it ideal for a wide range of applications.
- **Material Efficiency**: Casting can make effective use of low-cost materials, such as scrap iron, steel, or even milling debris, which helps reduce material costs and supports recycling practices.
- **Cost-Effectiveness**: Compared with many other manufacturing processes, casting equipment is relatively inexpensive. This makes casting a cost-effective solution, especially for high-volume production runs.
- **Wide Range of Materials**: Almost any material, from metals like iron, steel, and aluminium to non-metals, can be cast. This versatility allows casting to be used for various industrial applications, regardless of material type.
- **Precision and Consistency**: Casting is capable of producing parts with high accuracy, ensuring consistency across large production runs. This is crucial in industries that require reliable, repeatable performance from their components.
- **Good Surface Finish**: The casting process can provide smooth, high-quality surface finishes, often requiring little additional processing. This reduces the need for post-casting finishing operations, saving both time and cost.

- **Strength and Durability**: Cast parts are typically strong and capable of withstanding high levels of stress and strain. The process allows for the creation of robust components suited to demanding applications, such as automotive and aerospace.
- **Production of Large Parts**: Casting is well-suited for producing large and heavy parts. Unlike other manufacturing methods that may have size limitations, casting can create components of virtually any size and weight.
- **Reduced Need for Machining:** Since cast parts are produced close to their final shape, there is minimal need for further machining. This not only reduces material waste but also shortens production time, making casting an efficient process for large-scale manufacturing.

Disadvantages of Casting

- **Dimensional Accuracy**: Due to the shrinkage that occurs during solidification, castings may face challenges in achieving precise dimensional accuracy. This shrinkage, along with the potential for defects such as misalignment or warping, can compromise the overall precision of the final part.
- **Surface Finish**: Cast parts often have a rough surface finish, which typically requires additional finishing operations. Secondary machining processes are often necessary to achieve the desired smoothness and quality, adding time and cost to production.
- **Strength**: Cast components generally have lower intrinsic strength compared with forged parts. Their load-bearing capacity is reduced, and they exhibit lower fatigue strength, which makes them less suitable for applications that demand high endurance under repeated stress.
- **Porosity**: One common issue in casting is the formation of porosity. Air pockets or voids within the material can reduce the part's overall strength and structural integrity, making them less reliable in high-stress environments.
- **Challenging Production Environment**: The casting process takes place in a harsh production environment, involving extremely high temperatures and potentially hazardous working conditions. The emission of toxic gases, the creation of dust, and the high labour intensity all contribute to the difficult and often unsafe working conditions in casting operations.
- **Inefficiency for Low-Volume Production**: While casting is highly effective for mass production, it is not cost-efficient for low-volume production. The setup costs, including mould creation, make casting less economical when only a small number of parts are required.
- **Safety Hazards**: The casting process presents significant safety risks to workers. Handling molten metals exposes workers to the danger of burns, metal splashes, and inhalation of harmful fumes, posing potential health and safety concerns during manufacturing operations.

Activity 6.1(a) Exploring the Casting Process (Physical Visit)

1. Visit a nearby foundry where you can observe the casting process in real time to have a hands-on understanding of the casting process.
2. Under the supervision of the Foundry Manager, you will be taken through the following checklist:
   a. Types of moulds used (e.g., sand moulds, permanent moulds): Are there any special features of the mould design? (e.g., complex shapes, internal cavities)
   b. Melting process and equipment: What equipment is used to heat the metal? (e.g., furnace, induction heater), How is the molten metal poured into the mould?
   c. Pouring process
   d. Cooling and solidification methods: What cooling techniques are used? (e.g., air cooling, water cooling). What safety equipment is used to handle molten metal? (e.g., protective gloves, face shields, heat-resistant clothing)
   e. Defects and Quality Control: What steps are taken to ensure the quality and integrity of the final product? Are there any casting defects (e.g., cracks, porosity, and shrinkage)?
   f. Safety measures and PPE used: What safety precautions are taken in the foundry? How do workers protect themselves from the molten metal and hazardous fumes?
3. Prepare a written report to be presented to your class teacher for assessment. Your report should include:
   a. Title: Observation of the Casting Process.
   b. Introduction: Briefly describe what casting is and why it is an important manufacturing process.
   c. Casting Process: Summarise the steps involved in the casting process, as observed in the foundry or video. Describe the key stages (e.g., mould preparation, pouring, cooling, etc.).
   d. Materials and Equipment: Describe the materials used in the casting process. What types of metals or alloys were observed, and what equipment is used to handle them?
   e. Casting Defects: Discuss any defects you observed in the castings, such as porosity or shrinkage. How were these defects addressed or prevented?
   f. Safety Measures: What safety precautions were in place? Describe the steps taken to ensure the safety of workers in the foundry or the precautions shown in the video.

g. Real-World Applications: Reflect on the products or industries where casting is used. For example, automotive parts, industrial machinery, or aerospace components.

h. Personal Insights: Share your thoughts on the casting process. What did you find most interesting? What challenges did you think might arise during the process?

Activity 6.1(b) Understanding the Casting Process (Virtual)

1. Where physical tour is not possible, watch the following videos on casting processes to build foundational knowledge using the links provided below.
   - https://www.youtube.com/watch?v=DuOMrOqs86s
   - https://www.youtube.com/watch?v=M9Lvrr1bw5s
   - https://www.youtube.com/watch?v=54gu4u_2NaM
   - https://www.youtube.com/watch?v=NMBtpbhaQI0
   - https://www.youtube.com/watch?v=ALzXQJAWp5c
   - https://www.youtube.com/watch?v=ckbpq6OoiEY

2. Take notes to covers key stages of casting, including
   a. Types of moulds used (e.g., sand moulds, permanent moulds)
   b. Melting process and equipment
   c. Pouring process
   d. Cooling and solidification methods
   e. Finishing processes
   f. Safety measures and PPE used

3. Write a report summarising your observations and reflections.

Activity 6.2 The Role of Casting in Engineering Manufacturing

1. In a group generate a response to the following:
   a. What is casting?
   b. Why is casting used in manufacturing?
   c. Why do engineers use casting to manufacture products?
   d. What are the advantages of casting compared with other manufacturing processes (e.g., machining, forging)?
   e. In what types of engineering products is casting commonly used?
2. After the discussion, the summarise your groups findings and, create flashcards to explain the relevance of casting in manufacturing engineering.

ADVANTAGES OF CASTING

- Casting can make effective use of low-cost materials, such as scrap iron, steel, or even milling debris, which helps reduce material costs and supports recycling
- Casting is capable of producing parts with high accuracy, ensuring consistency across large production runs
- Cast parts are typically strong and capable of withstanding high levels of stress and strain.
- Useful for producing components with fine details, thin walls, and internal structures that would be difficult or impossible to achieve with other methods.

DISADVANTAGES OF CASTING

- Due to the shrinkage that occurs during solidification, castings may face challenges in achieving precise dimensional accuracy
- The casting process presents significant safety risks to workers. Handling molten metals exposes workers to the danger of burns, metal splashes, and inhalation
- One common issue in casting is the formation of porosity. Air pockets or voids within the material can reduce the part's overall strength and structural integrity
- Cast parts often have a rough surface finish, which typically requires additional finishing operations.

Activity 6.3 Foundry Observations Presentation

1. Organise yourselves into groups of no more than five. In your groups, use any of these presentation formats to cater for different learning styles PowerPoint and Poster
   a. Types of moulds used (e.g., sand moulds, permanent moulds)
   b. Melting process and equipment
   c. Pouring process
   d. Cooling and solidification methods
   e. Finishing processes
   f. Safety measures and PPE used
2. Compile your observations and prepare your presentations. Use digital tools or templates to organise and design the presentation.
3. Present your findings to the class, highlighting the key aspects of the casting process. Ensure that there is creativity and clarity in your presentations.

SAND-CASTING PROCESS

The sand-casting process is a long-established and extensively utilised technique for producing metal components and structures, renowned for its affordability and adaptability. This method encompasses a series of essential steps and elements, each playing a pivotal role in determining the final quality of the cast product. At its essence, sand-casting involves the creation of a mould from sand, into which molten metal is poured to form the desired part.

The process begins with the preparation of the sand mould, typically crafted from a blend of sand, clay, and water, referred to as green sand. The quality of the green sand is of paramount importance, as it directly influences the strength of the mould, as well as the surface finish and dimensional precision of the finished casting. The mould is constructed by compacting the sand around a pattern—an exact replica of the intended product. Once the pattern is removed, a cavity is left behind in the sand, replicating the shape of the part to be cast. Additionally, the mould may incorporate cores, which are used to create internal voids within the casting.

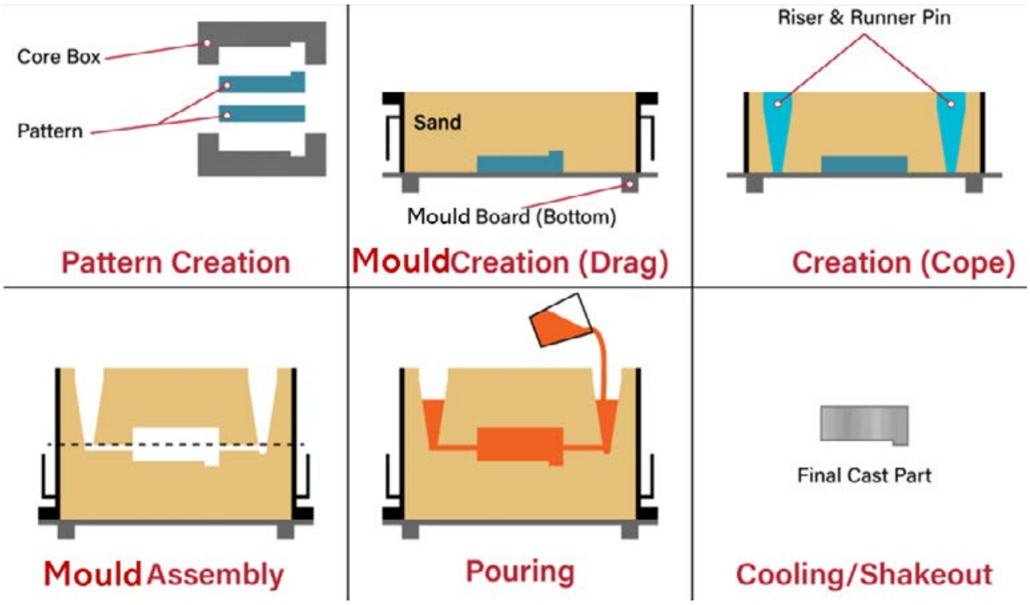


Figure 6.2: Sand-casting process

Fundamentals of Sand-Casting Technology

Sand-casting is a fundamental and time-honoured manufacturing process that has been in use for thousands of years. It remains the most widely employed casting technique, representing the majority of total casting tonnage. Virtually all casting alloys can be processed through sand-casting, and it is one of the few methods suitable for metals with high melting points, such as steel, nickel, and titanium. A flow chart of the casting process and casting diagram is depicted in **Figure 6.3**. The following outlines the key steps and principles that govern sand-casting technology:

- **Pattern Creation**: The process begins with the creation of a pattern, which is an exact replica of the external shape of the intended casting. This pattern is made from a durable material and is intentionally oversized to compensate for material shrinkage during solidification. The pattern also incorporates the necessary metal pathways, including gating and risers, to direct the molten metal to the desired areas of the casting.
- **Mould Formation**: To create the mould, sand is packed around the pattern, which is then separated into two halves. After the pattern is removed, the two halves of the mould are carefully reassembled to restore the cavity that mirrors the shape of the part to be cast.
- **Metal Pouring**: The molten metal is poured into the mould cavity. The mould must possess sufficient strength to withstand the weight of the liquid metal and must be resistant to any chemical reaction with the metal during the pouring process.
- **Cooling and Solidification**: Once the molten metal has been poured, it undergoes cooling and solidification. After the metal has fully solidified, the mould is broken open to reveal the cast part.

- **Finishing**: Following the casting process, the part typically undergoes additional surface finishing operations to improve its quality, remove any imperfections, and ensure it meets the required specifications.

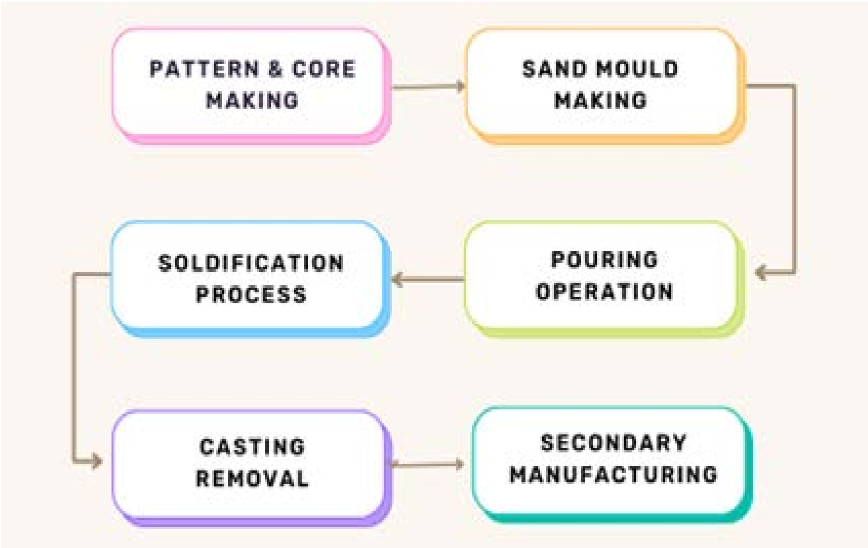


Figure 6.3: (a) Sand-casting process

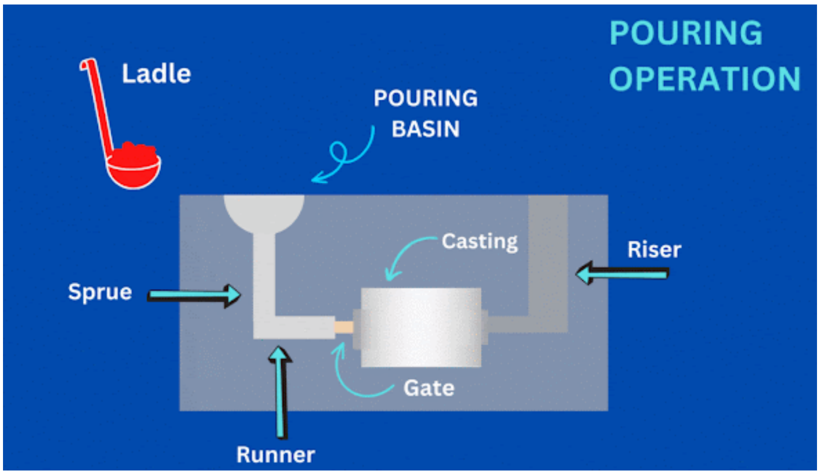


Figure 6.3: (b) Sand-casting diagram

Patterns

A pattern is a full-scale model of the part to be cast, intentionally enlarged to account for both shrinkage during solidification and any allowances required for machining the final casting. Common materials used to create patterns include wood, plastics, and metals. Wood is frequently chosen as a pattern material due to its ease of shaping and availability. While metal patterns are more costly to produce, they offer greater durability and longevity. Plastics strike a balance between the affordability of wood and the durability of metal. The selection of an appropriate pattern material is influenced by the anticipated production volume of the castings. Patterns can be classified into several types, including solid, split, match-plate, and cope-and-drag patterns. The solid pattern is the simplest to fabricate and mirrors the exact geometry of the casting, with adjustments made for shrinkage and machining allowances. However, solid patterns are not ideal for use in the sand moulding process and are generally suited only for low-volume production due to their limited flexibility. **Figure 6.4** illustrates a typical pattern arrangement for the sand-casting process.

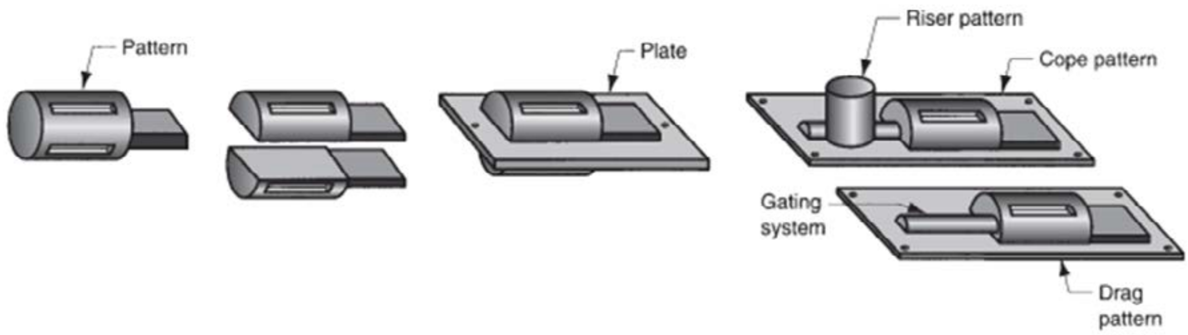


Figure 6.4: Pattern arranged for sand-casting process

Cores

A core is a full-scale model of the internal surfaces of a part, designed to be placed within the mould cavity before the molten metal is poured. This allows the metal to flow and solidify between the core and the mould cavity, thereby forming both the external and internal features of the casting. Cores are typically made from sand, which is compacted into the desired shape. Like patterns, cores must be sized with allowances for both shrinkage during solidification and any necessary machining. To ensure the core remains correctly positioned during pouring, supports known as chaplets are used to hold it in place within the mould cavity. **Figure 6.5** provides an illustration of a typical sand cast mould containing a core.

The mould

A mould is composed of two primary halves:

1. Cope: The upper half of the mould.
2. Drag: The lower half of the mould.

These two halves are enclosed in a box known as a flask, and they separate along a parting line. The mould cavity is formed by compacting sand around a pattern that mirrors the shape of the final part. Once the pattern is removed, the remaining cavity in the packed sand reflects the desired shape of the casting. To account for metal shrinkage during solidification and cooling, the pattern is typically made oversized. The sand used for the mould is kept moist and contains a binder to maintain its structural integrity and shape throughout the casting process.

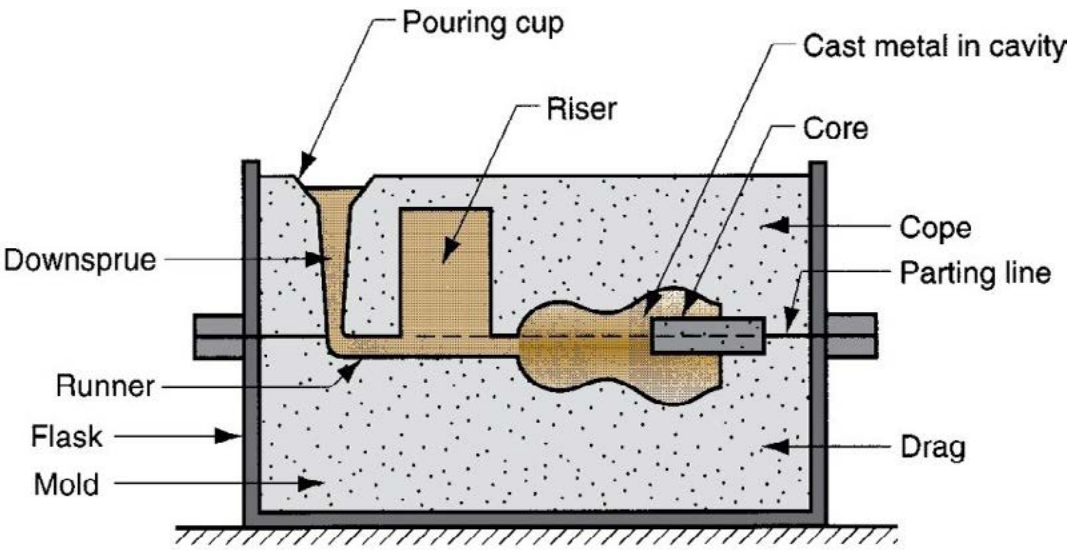


Figure 6.5: Sand-casting mould showing the various mould parts

Cope and Drag: The upper and lower components of a casting arrangement are referred to as the cope and drag, respectively. These are typically framed structures, often made of wood, that house the mould halves.

Riser: Also known as a feeder, the riser is a reservoir and passage within the mould that compensates for metal shrinkage during solidification. It ensures the casting receives a continuous supply of molten metal, preventing voids and defects.

Runner: A runner is a channel with a reduced diameter that directs the flow of molten metal towards the mould cavity, facilitating an even and controlled metal distribution.

Mould: The mould is a cavity formed by a pattern, which is a replica of the final desired casting. In sand-casting, the pattern is typically made from sand, creating a negative impression of the part.

Core: In sand-casting, the core is an insert placed within the mould cavity to create internal features, such as holes or passages, in the final casting.

Gate: The gate is the entry point through which molten metal flows into the mould cavity, initiating the filling process.

Base Sand: Also known as foundation sand, base sand is the purest form of sand, typically composed of silica, used as the primary material for mould formation.

Binders: Binders are agents that hold the sand particles together in the mould. The most commonly used binders include clay and water, oil, resin, and sodium silicate, each chosen for its ability to provide the necessary strength and cohesion to the sand.

Sand-casting Process

The sand-casting process consists of several essential stages, including the creation of a pattern, mould formation, pouring of molten metal, cooling and solidification, cleaning, and final finishing

Detailed Steps in Sand-Casting Process

1. **Pattern Creation:** The process of sand-casting begins with the creation of a pattern, a replica of the external shape of the intended casting. The pattern must be made from a stable material and is intentionally oversized to account for the shrinkage that occurs as the metal cools and solidifies. In addition to forming the external shape, the pattern includes the necessary metal pathways, known as gating and risers, which direct the flow of molten metal into the mould and compensate for material shrinkage. Sand cores are used to form internal features such as holes or intricate designs within the casting. Careful consideration must be given to the pattern's material, geometry, withdrawal method, and the expected distortions and shrinkage during the casting process.

2. **Mould Making:** Mould making is the next step, where a mould is formed around the pattern using various combinations of sand, additives, binders, and water. The mould structure typically includes the cope (top half), drag (bottom half), flask, and gating system. Mould preparation can be done manually (hand moulding) or using automated machinery (machine moulding). There are three primary types of sand moulds used in casting:

   a. Green-sand moulds: a mixture of sand, clay, and water, where the term "green" refers to the moisture content at the time of pouring.

   b. Dry-sand moulds: use organic binders instead of clay and are baked to improve strength and durability.

   c. Skin-dried moulds: are green-sand moulds where the surface of the cavity is dried to a depth of 10 to 25 mm using torches or heating lamps. The sand mixture typically consists of about 90% sand, 3% water, and 7% clay, but other bonding agents such as phenolic resins, sodium silicate, and phosphate can also be used to enhance the strength and permeability of the mould. The mould is created by packing the sand around the pattern, then separating the two halves and removing the pattern. The two mould halves are then reassembled for pouring.

3. **Pouring Molten:** Metal Once the mould is prepared, molten metal is poured into it. The mould must be robust enough to withstand the weight of the molten metal and resistant to chemical reactions with the metal. One challenge in pouring molten metal is the buoyancy of the liquid metal, which can displace the sand core, leading to defects in the casting. To prevent this, the pouring rate must be controlled carefully. The molten metal must flow into all regions of the mould, especially the main cavity, before solidifying. Factors such as pouring temperature, pouring rate, and turbulence are critical to ensuring a successful pour, with the metal filling the mould without causing disruptions or defects.

4. **Cooling and Solidification:** After the molten metal is poured into the mould, it begins to cool and solidify. Solidification is the process where the molten metal transitions back to a solid state, forming the desired casting. The rate and nature of solidification can vary depending on whether the metal is a pure element or an alloy, and these factors influence the final casting's properties. Once the metal has solidified and cooled sufficiently, the mould is broken open to release the casting.

5. **Cleaning (Shakeout) and Inspection:** Once the casting has cooled and solidified, the next step is to clean it by removing any residual sand, oxide layers, and gating or riser systems. This is often done through a process known as shakeout, where mechanical vibration is used to break the mould and free the casting. After the shakeout, the casting undergoes a series of inspections to detect any potential defects. Inspection methods can include visual inspection, magnetic testing, non-destructive testing (NDT), Ultrasonic testing, geometrical dimensioning and tolerance checks, Pressure testing, Radiographic testing or metallurgical control. These inspections ensure the casting meets the desired specifications and is free from internal or external defects.

6. **Finishing Operations**: After the cleaning and inspection process, the casting often requires finishing to achieve the desired surface quality and dimensional accuracy. Common finishing operations include grinding, turning, milling, lapping, honing, welding, repairs, CNC machining. These processes remove any roughness, correct dimensional deviations, and refine the surface for functionality or aesthetic purposes.

7. **Heat Treatment:** To improve the metallurgical properties of the casting, heat treatment may be applied. This process involves controlled heating and cooling to alter the microstructure of the metal, improving its strength, hardness, and other physical properties. Heat treatment can include processes such as annealing, tempering, hardening, and normalising, depending on the material used and the intended application of the final casting.

Together, these stages combine to create high-quality, precise castings suitable for a variety of applications. Whether producing a small part or a large component, each step in the sand-casting process plays a critical role in determining the casting's quality, performance, and durability.

Figure 6.6: Detailed steps in sand-casting process

Desirable Mould Properties

1. **Strength** – The mould must possess sufficient strength to retain its shape during the casting process and resist erosion caused by molten metal.
2. **Permeability** – The mould should have the ability to allow the passage of hot gases and air through the voids in the sand, ensuring proper venting during casting.
3. **Thermal Stability** – The mould must be able to withstand high temperatures without cracking when it comes into contact with molten metal, maintaining its integrity throughout the casting process.
4. **Collapsibility** – The mould should exhibit the capacity to collapse or give way as the casting cools and shrinks, preventing the casting from cracking due to thermal contraction.
5. **Reusability** – The sand used in the mould should be reusable, allowing it to be reclaimed and repurposed for the creation of new moulds after the casting is removed.

Figure 6.7: Desirable mould properties

Activity 6.4 Experiential Learning on Sand-casting Process

1. Surf the internet and watch the video below using the links provided.
   - Sand Casting: https://www.youtube.com/watch?v=pwaXCko_Tkw
   - Die Casting: https://www.youtube.com/watch?v=iSyBsdJkQu8
   - Showcasing the basics of casting: https://www.youtube.com/watch?v=2CIcvB72dmk&t=181s
   - Die Casting: https://www.youtube.com/watch?v=_V9oyvWovHQ

2. After watching the videos, think about the steps involved in the sand-casting process. Pair up with a classmate to discuss the steps. Work together as a team to summarise the casting process.
3. Present your summary orally to your class for discussion and feedback.

Activity 6.5 Casting Simple Components Using Sand-casting

Materials needed

- Modelling clay or play-dough (to create patterns)
- Sand (green sand or a similar casting sand)
- Clay and water (for sand mixture)
- Small metal objects or aluminium pieces (to be melted and poured)
- Moulds or containers (such as small boxes for moulding)
- Pouring ladles (or containers to hold molten metal)
- Safety equipment (gloves, goggles, aprons, etc.)
- Paper, pens, and notebooks for documentation
- Digital cameras or phones for taking process photos (optional)
- Metal melting equipment (e.g., a small furnace, torch, or heating setup) – if available
- Sandblasting or cleaning tools for cleaning the castings
- Trimming tools (for removing excess material)

Note: *Observe all safety measures to avoid any accidents.*

Steps

1. Create Simple Patterns: The pattern could be a basic shape like a small gear, mobile phone cover, or a knife. The pattern should be made from modelling clay or play-dough to mimic a metal pattern.
2. Mould Making: Mix sand, clay, and water to create a suitable moulding mixture. The typical mix for green sand-casting is about 90% sand, 3% water, and 7% clay.
3. Pouring Molten Metal: Use a small furnace or torch to melt metal, like aluminium. Ensure that the metal is heated to the correct pouring temperature.
4. Cooling and Finishing: Wait for the metal to reach room temperature before attempting to remove the mould. Allow the metal to cool and solidify
5. Shakeout, Cleaning, and Trimming: Remove any remaining sand or oxide layers using shot blasting, wire brushing, or other cleaning methods. If the casting has excess metal or leftover sprues, runners, or risers, you will trim these off using appropriate tools like grinders, saws, or trimming presses.
6. Write a simple report summarising all the activities you went through.

NON-PERMANENT JOINING PROCESSES

Non-permanent joining processes in manufacturing engineering are techniques that enable the assembly and disassembly of components without causing any permanent damage to the parts involved. These methods are crucial in situations where regular maintenance, repair, or reconfiguration of assemblies is required. Unlike permanent joining techniques, such as welding or soldering, non-permanent joining does not involve the fusion or alteration of the materials, thereby allowing for the easy separation of components when necessary. A prevalent example of a non-permanent joining process is mechanical fastening, which encompasses the use of screws, nuts, bolts, and washers. These fasteners are designed for easy removal and reuse, making them ideal for applications where future disassembly is anticipated. Image of fasteners is displayed in **Figure 6.8**.

Figure 6.8: Fasteners

MECHANICAL FASTENING WITH SCREWS, BOLTS, NUTS, RIVETS, PINS AND CLIPS

Screws, Bolts, and Nuts

Screws and bolts are both types of threaded fasteners that feature external threads, but they differ in their technical applications. While the distinction between a screw and a bolt is often blurred in everyday usage, it is important to note their specific functions. A screw is an externally threaded fastener designed to be inserted into a blind threaded hole, where it engages with internal threads. In contrast, a bolt is an externally threaded fastener that passes through holes in the components being joined and is secured by a nut on the opposite side. A nut is an internally threaded fastener with standard threads that correspond to those on bolts of the same diameter, pitch, and thread form. The typical assemblies formed by the use of screws and bolts are illustrated in **Figure 6.9**.

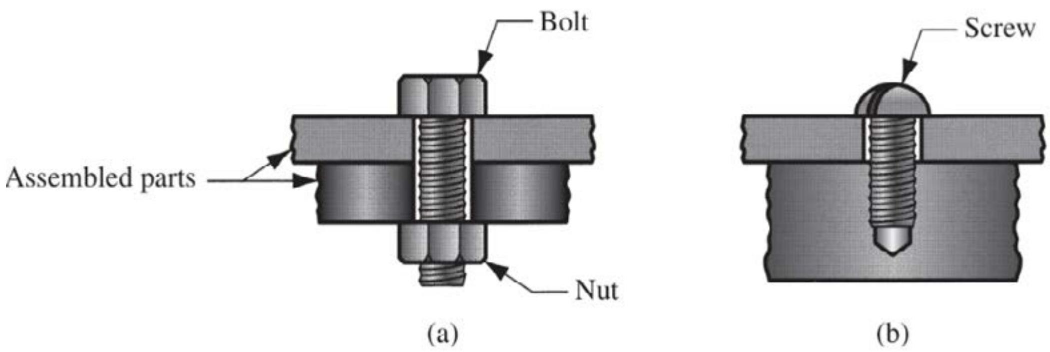


Figure 6.9: Typical assemblies using (a) bolt and nut and (b) screw

Screw Thread Terms

The following definitions apply to screw threads in general and are illustrated in **Figure 6.10**. For additional information regarding specific Unified and metric screw thread terms and definitions, refer to the appropriate standards.

- Screw thread: A ridge of uniform cross section in the form of a helix on the external or internal surface of a cylinder.
- External thread: A thread on the outside of a member, as on a shaft.
- Internal thread: A thread on the inside of a member, as in a hole.
- Major diameter: The largest diameter of a screw thread (for both internal and external threads). Minor diameter: The smallest diameter of a screw thread (for both internal and external threads).
- Pitch: The distance from a point on a screw thread to a corresponding point on the next thread measured parallel to the axis. In the United States, the pitch is equal to 1 divided by the number of threads per inch.
- Pitch diameter: The diameter of an imaginary cylinder passing through the threads where the widths of the threads and the widths of the spaces would be equal.
- Lead: The distance a screw thread advances axially in one turn.
- Angle of thread: The angle between the sides of the thread measured in a plane through the axis of the screw.
- Crest: The top surface joining the two sides of a thread.
- Root: The bottom surface joining the sides of two adjacent threads.
- Side: The surface of the thread that connects the crest with the root.
- Axis of screw: The longitudinal centreline through the screw.
- Depth of thread: The distance between the crest and the root of the thread measured normal to the axis.
- Form of thread: The cross-section of thread cut by a plane containing the axis.
- Series of thread: The standard number of threads per inch for various diameters.

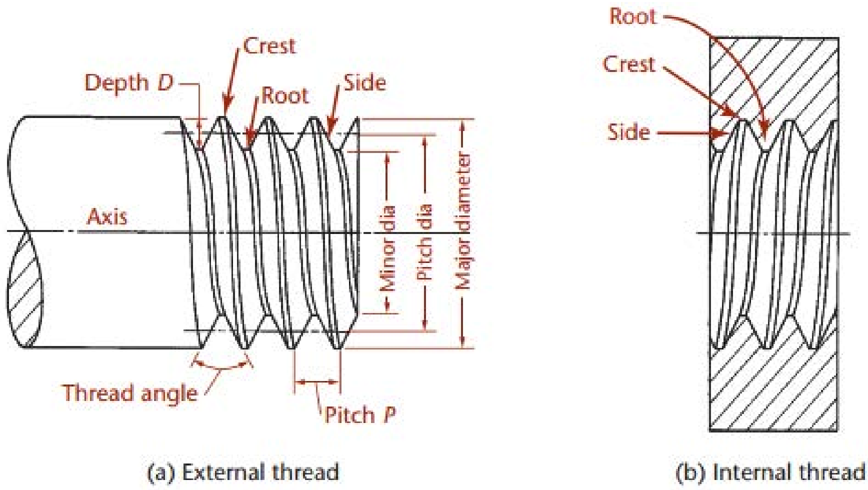


Figure 6.10: Screw thread nomenclature

Figure 6.11: Closeup view of a threaded nut and bolt

Screws and bolts are available in a wide range of standard sizes, thread configurations, and shapes. **Table 6.2** presents a selection of commonly used threaded fastener sizes according to the metric system, as defined by the International Standards Organisation (ISO). The metric specification is typically denoted by the nominal diameter in millimetres, followed by the pitch in millimetres. For instance, a specification of M12 × 1.25 means a metric thread of nominal diameter of 12 mm and a pitch of 1.25 mm. Both coarse and fine pitch standards are provided in **Table 6.2**. Further technical information regarding these and other standard threaded fastener sizes can be found in relevant design texts and engineering handbooks.

Table 6.2: Selected standard threaded fastener sizes in metric units

Nominal Diameter, mm	Coarse Pitch, mm	Fine Pitch, mm
2	0.4	
3	0.5	
4	0.7	
5	0.8	

Nominal Diameter, mm	Coarse Pitch, mm	Fine Pitch, mm
6	1.0	
8	1.25	
10	1.5	1.25
12	1.75	1.25
16	2.0	1.5
20	2.5	1.5
24	3.0	2.0
30	3.5	2.0

It should be noted that differences among threaded fasteners have tooling implications in manufacturing. To use a particular type of screw or bolt, the assembly worker must have tools that are designed for that fastener type. For example, there are numerous head styles available on bolts and screws, the most common of which are shown in **Figure 6.12.** The geometries of these heads, as well as the variety of sizes available, require different hand tools (e.g., screwdrivers) for the worker. One cannot turn a hex-head bolt with a conventional flat-blade screwdriver.

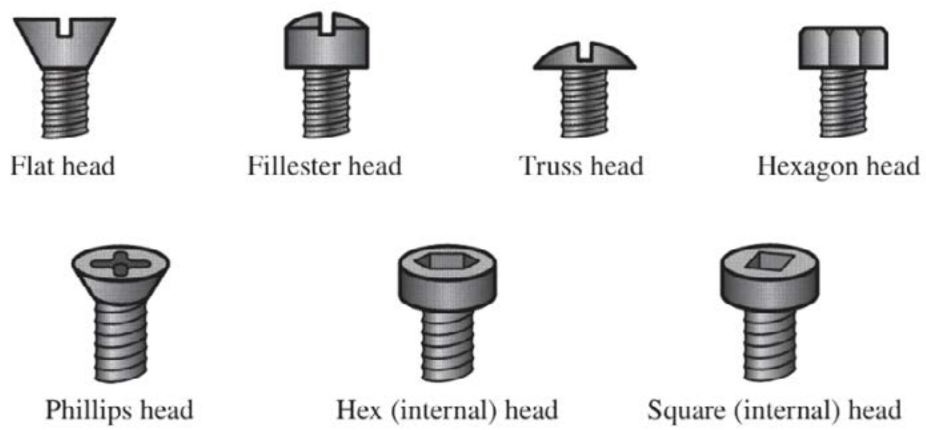


Figure 6.12: Some head styles available on screws and bolts

Screws come in a greater variety of configurations than bolts, since their functions vary more. The types include machine screws, cap screws, setscrews, and self-tapping screws. Machine screws are the basic type, designed for assembly into tapped holes. They are sometimes assembled into nuts, and in this usage, they overlap with bolts. Cap screws have the same geometry as machine screws but are made of higher strength metals and to closer tolerances. Setscrews are hardened and designed for assembly functions such as fastening collars, gears, and pulleys to shafts, as shown in **Figure 6.13a.** They come in various geometries, some of which are illustrated in **Figure 6.13b.**

A self-tapping screw is designed to form or cut threads in a pre-existing hole into which it is being rotated. **Figure 6.14** shows two of the typical thread geometries for self-tapping screws. Most threaded fasteners are produced by thread rolling. Some are machined but this is usually a more expensive thread-making process. A variety of materials are used to make threaded fasteners, steels being the most common because of their good strength and low cost. These include low and medium carbon as well as alloy steels.

Fasteners made of steel are usually plated or coated for superficial resistance to corrosion. Nickel, chromium, zinc, black oxide, and similar coatings are used for this purpose. When corrosion or other factors deny the use of steel fasteners, other materials must be used, including stainless steels, aluminium alloys, nickel alloys, and plastics (however, plastics are suited to low-stress applications only).

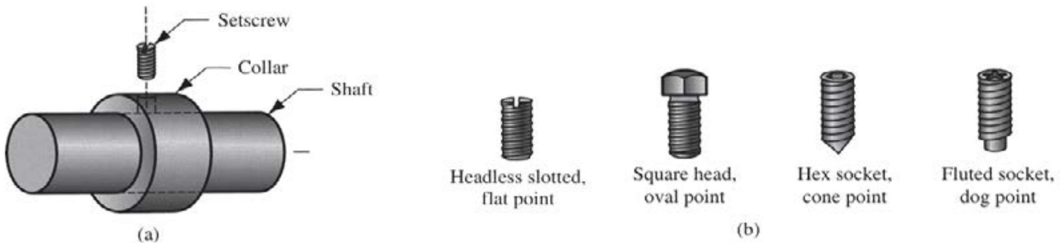


Figure 6.13: (a) Assembly of collar to shaft using a setscrew; (b) various setscrew geometries (head types and points)

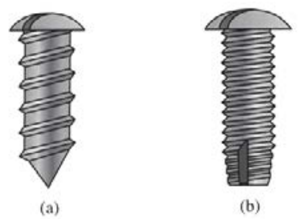


Figure 6.14: Self-tapping screws: (a) thread-forming and (b) thread-cutting

Other Threaded Fasteners and Related Hardware

Additional threaded fasteners and related hardware include studs, screw thread inserts, captive threaded fasteners, and washers. A stud (in the context of fasteners) is an externally threaded fastener but without the usual head possessed by a bolt. Studs can be used to assemble two parts using two nuts, as shown in **Figure 6.15a**. They are available with threads on one end or both, as in **Figure 6.15 (b)** and **(c)**.

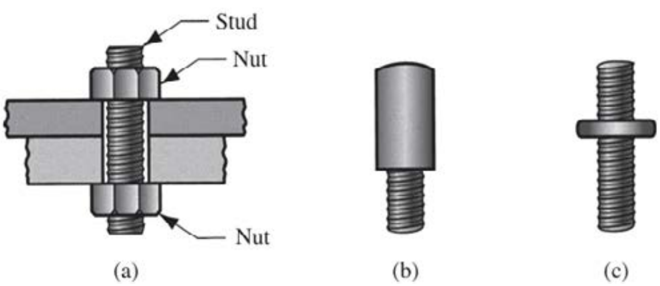


Figure 6.15: (a) Stud and nuts used for assembly. Other stud types: (b) threads on one end only and (c) double-end stud (Groover, 2021).

Screw thread inserts are internally threaded plugs or wire coils made to be inserted into an unthreaded hole and to accept an externally threaded fastener. They are assembled into weaker materials (e.g., plastic, wood, and lightweight metals such as magnesium) to provide strong threads. There are many designs of screw thread inserts, one example of which is illustrated in **Figure 6.16.** Upon subsequent assembly of the screw into the insert, the insert barrel expands into the sides of the hole, securing the assembly.

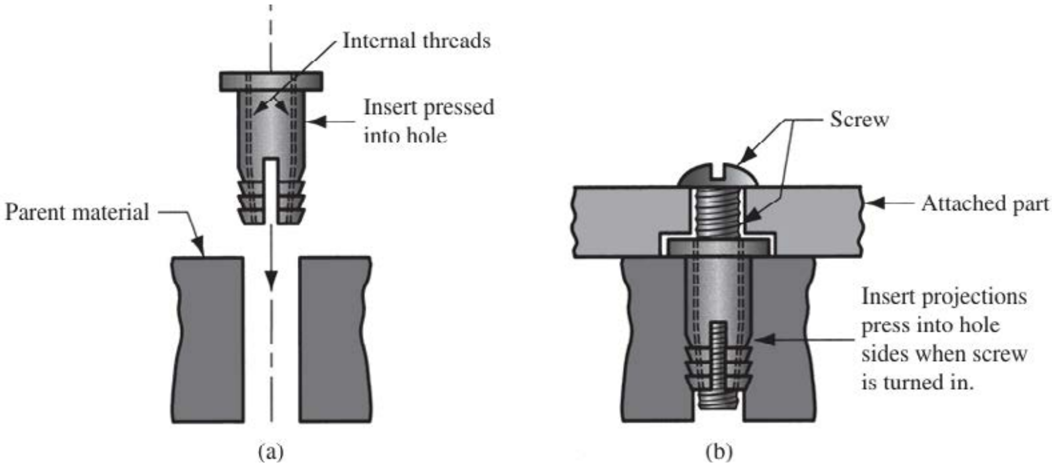


Figure 6.16: Screw thread inserts: (a) before insertion and (b) after insertion into hole and screw is turned into the insert (Groover, 2021).

Captive threaded fasteners are threaded fasteners that have been permanently preassembled to one of the parts to be joined. Possible preassembly processes include welding, brazing, press fitting, or cold forming. Two types of captive threaded fasteners are illustrated in **Figure 6.17.** A washer is a hardware component often used with threaded fasteners to ensure tightness of the mechanical joint; in its simplest form, it is a flat thin ring of sheet metal. Washers serve various functions. They (1) distribute stresses that might otherwise be concentrated at the bolt or screw head and nut, (2) provide support for large clearance holes in assembled parts, (3) increase spring tension, (4) protect part surfaces, (5) seal the joint, and (6) resist inadvertent unfastening.

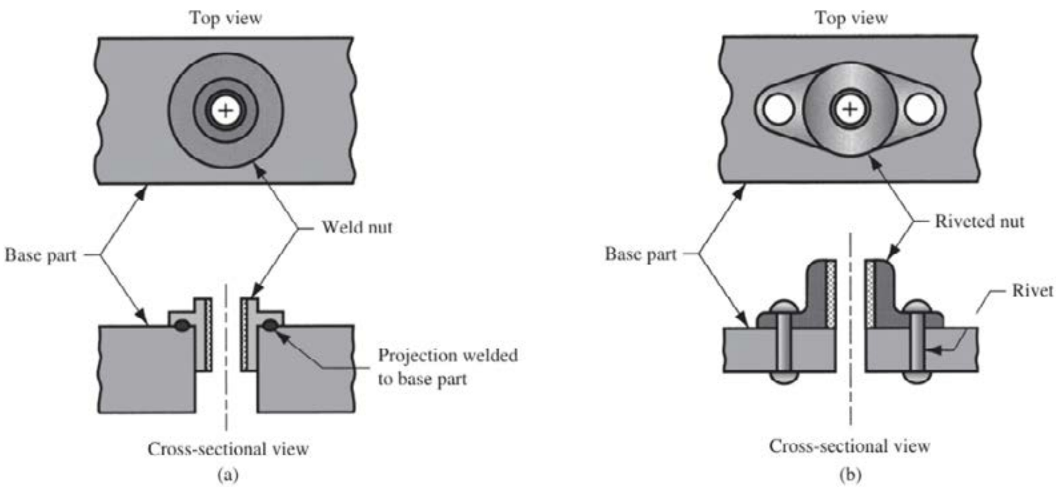


Figure 6.17: Captive threaded fasteners: (a) weld nut and (b) riveted nut

Rivets and Eyelets

Rivets are extensively employed to create permanent mechanical joints. Riveting is a fastening technique known for its high production efficiency, simplicity, reliability, and cost-effectiveness. However, despite these advantages, its use has diminished in recent years, largely supplanted by threaded fasteners, welding, and adhesive bonding. Nevertheless, riveting remains a fundamental fastening method in the aircraft and aerospace industries, where it is commonly used to attach skins to channels and other structural components. A rivet is an unthreaded, headed pin that joins two or more parts by passing through holes in the components and forming a second head on the opposite side through a process known as upsetting. This deformation can be carried out either hot or cold, using methods such as hammering or steady pressing.

Once the rivet is deformed, it becomes permanent, and the joint cannot be undone without breaking one of the heads. Rivets are classified by several key parameters: length, diameter, head type, and rivet geometry. Rivet types refer to five basic geometries that influence how the rivet will be deformed to create the second head, as illustrated in **Figure 6.18.** Additionally, there are specialised rivets designed for particular applications. Rivets are predominantly used in lap joints. The clearance hole into which the rivet is inserted should be close to the rivet's diameter. If the hole is too small, insertion becomes difficult, thereby slowing the production process. Conversely, if the hole is too large, the rivet may fail to fill the hole properly and could bend or compress during the formation of the second head.

To ensure proper fit and function, rivet design tables are available to specify the optimal hole sizes for various applications.

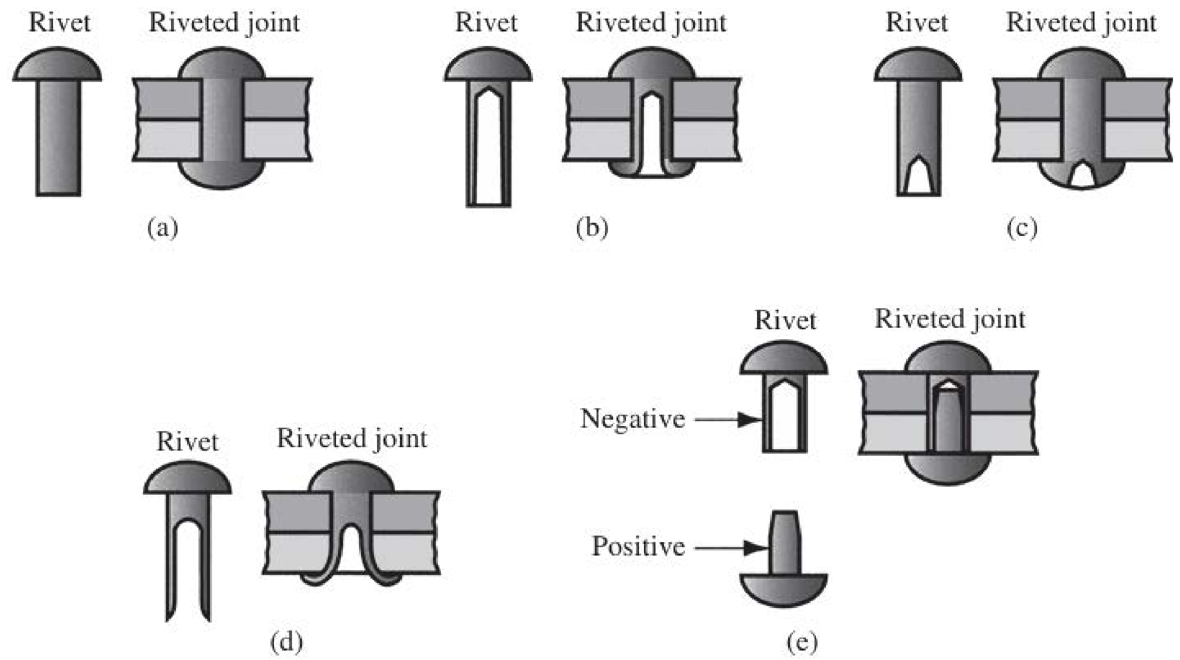


Figure 6.18: Five basic rivet types, also shown in assembled configuration: (a) solid, (b) tubular, (c) semi tubular, (d) bifurcated, and (e) compression

An eyelet is a small ring, typically made from metal, rubber, or plastic, designed to reinforce or strengthen holes punched into thin materials, such as fabrics. Eyelets are primarily used to prevent damage to materials by reinforcing the holes, protecting them from abrasion or tearing. They are commonly applied in textiles, sheet metal, and other thin, fibrous materials. Without eyelets, delicate fabrics are prone to tearing around the hole, but the eyelet acts as a protective barrier, enhancing the material's durability.

In addition to providing reinforcement, eyelets are used to create a permanent lap joint between two or more flat components. They are often substituted for rivets in low-stress applications, offering advantages in terms of material savings, weight reduction, and cost efficiency. During the fastening process, the eyelet is inserted through the holes in the parts, and the straight end of the eyelet is deformed, or "set," over the material. This setting process involves opposing tools that secure the eyelet in place while curling the extended portion of its barrel, ensuring a secure and durable attachment.

(a)

(b)

Figure 6.19: Fastening with an eyelet: (a) the eyelet and (b) An eyelet assembly

Adhesive Fastening with Liquid Adhesives, Tapes, Hot Melts, and Structural Adhesives

Adhesive fastening is the process of joining two or more materials using a bonding agent rather than mechanical fasteners like screws or bolts. The various types of adhesives and bonding methods offer unique benefits and are widely used across industries such as automotive, aerospace, construction, and packaging. Liquid adhesives, tapes, hot melts, and structural adhesives each offer unique benefits suited to specific applications. While liquid adhesives provide high-strength bonds for various materials, tapes offer quick, clean, and easy bonding solutions. Hot melts are excellent for high-speed applications, and structural adhesives are ideal for heavy-duty, high-strength applications. The choice of adhesive depends on factors like material compatibility, strength requirements, curing time, and environmental conditions.

Figure 6.20: Liquid Adhesives

Types of Adhesives

1. Liquid Adhesives Liquid adhesives are one of the most useful and commonly used forms of adhesives. They can bond a wide range of materials and are typically used for precision applications.
2. Tapes Adhesive tapes are flexible materials coated with a layer of adhesive on one or both sides. They are available in a variety of forms, such as single-sided and double-sided.
3. Hot Melts Hot melt adhesives are thermoplastic materials that are applied in a molten form and then cool to form a solid bond. They are used in both manual and automated assembly processes.
4. Structural Adhesives Structural adhesives are high-strength bonding agents designed to carry significant loads and are used in demanding applications where mechanical fasteners may not be feasible. These adhesives are typically two-component systems, consisting of a resin and a hardener that cure to form a rigid bond.

Table 6.3 shows the various types of adhesive fasteners, their descriptions, examples and applications.

Table 6.3: Adhesive fastening with descriptions and examples

Type of Adhesive Fastener	Description	Examples	Applications
Liquid Adhesives	Liquid adhesives are versatile and can bond a wide range of materials, including metals, plastics, and composites. They are typically applied in a liquid form and cure to form a strong bond.	Epoxy Resins: Used in automotive repairs for bonding metal parts. Cyanoacrylate (Super Glue): Commonly used for quick repairs in household items. Polyurethane Adhesives: Used in construction for bonding wood and concrete.	Automotive: Bonding parts like trim, panels, and glass. Construction: Flooring, wall panels, and insulation. Electronics: Assembling components and securing wires.
Adhesive Tapes	Adhesive tapes consist of a backing material coated with an adhesive. They are available in various forms, including double-sided, foam, and specialty tapes.	Double-Sided Tape: Used in mounting posters and lightweight objects. Foam Tape: Used in automotive applications to reduce vibrations. Electrical Tape: Used for insulating electrical wires.	Packaging: Securing boxes and packages. Electronics: Mounting components and heat sinks. Automotive: Attaching trim and emblems.
Hot Melts	Hot melt adhesives are thermoplastic materials that are applied in a molten state and solidify upon cooling. They are commonly used in industrial and consumer applications.	Hot Glue Sticks: Used in crafting and DIY projects. Polyolefin Hot Melts: Used in packaging for sealing boxes. EVA (Ethylene Vinyl Acetate) Hot Melts: Used in bookbinding.	Packaging: Sealing cartons and boxes. Furniture: Assembling parts and edge banding. Textiles: Bonding fabrics and attaching labels.
Structural Adhesives	Structural adhesives are designed to provide high strength and durability, often used in load-bearing applications. They include epoxies, polyurethanes, and acrylics.	Epoxy Adhesives: Used in aerospace for bonding composite materials. Acrylic Adhesives: Used in automotive for bonding metal and plastic parts. Polyurethane Adhesives: Used in construction for bonding concrete and steel.	Aerospace: Bonding aircraft components. Automotive: Assembling chassis and body panels. Construction: Securing structural elements.

Interference fitting: Press fits, shrink fits, snap fits etc.

Several assembly methods rely on mechanical interference between two mating parts to securely join them. This interference, which occurs either during the assembly process or after the parts are joined, ensures that the components remain fixed together. These methods include press fitting, shrink and expansion fits, snap fits, and retaining rings.

Press Fitting

A press fit assembly involves two components that have an interference fit, meaning one part is slightly larger than the hole it is inserted into. A common example is pressing a cylindrical pin, with a specific diameter, into a hole that is slightly smaller in diameter. Standard pin sizes are commercially available for a range of functions, including: (1) locating and locking components; used to assist threaded fasteners by holding multiple parts in precise alignment; (2) serving as pivot points, allowing one part to rotate around another; and (3) acting as shear pins, which are designed to fail under a sudden or excessive shearing load to protect the rest of the assembly. Pins used for locating and locking, or as pivot points, are generally hardened for durability, whereas shear pins are made from low-strength materials to facilitate their breakage under stress.

Additional applications of press fitting include the assembly of collars, gears, pulleys, and similar components onto shafts. The pressures and stresses involved in an interference fit can be estimated using various relevant formulas. For example, in the case where a round solid pin or shaft is inserted into a collar or similar component, as shown in **Figure 6.21**, and both parts are made of the same material, the forces and stress distribution can be calculated accordingly.

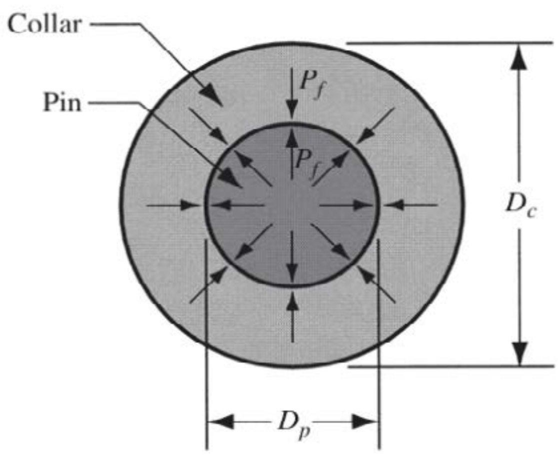


Figure 6.21: Cross section of a solid pin or shaft assembled to a collar by interference fit.

Dc = diameter of collar hole, Dp = diameter of pin

Shrink and Expansion Fits

The terms refer to the process of assembling two components that initially have an interference fit at ambient temperature, with one part experiencing a controlled temperature change, either through cooling to contract or heating to expand, just prior to assembly. A typical example of this technique is the insertion of a cylindrical pin or shaft into a collar. In shrink fitting, the external part is heated to expand, while the internal component remains at room temperature or is cooled to contract. The parts are then assembled, and as they return to ambient temperature, the external component contracts and, if previously cooled, the internal component expands, thereby generating a robust interference fit.

Expansion fitting involves the cooling of only the internal component, causing it to contract before the assembly process. Once the internal part is inserted into the mating component, it warms to ambient temperature and expands, forming the required interference fit. These methods are frequently employed to securely attach gears, pulleys, sleeves, and other components to both solid and hollow shafts.

Snap Fits and Retaining Rings

Snap fits represent a specific category of interference fit, where two components temporarily interfere during initial assembly, causing the mating elements to elastically deform in response. As the parts are pressed together, the features flex to absorb the interference and then interlock, securing the assembly. An example of this process is depicted in **Figure 6.22,** where the components are pressed together, the mating features flex to accommodate the interference, and subsequently snap into place. Once fully assembled, the components are mechanically secured, making disassembly challenging. The design typically ensures that a slight interference remains even after the assembly process, reinforcing the connection.

The key advantages of snap-fit assemblies include:

- The ability to design self-aligning components.
- Elimination of the need for specialised tooling.
- The potential for rapid assembly.

While snap-fit technology was originally developed for use in industrial robotics, its simplicity has made it highly advantageous for human assembly as well, with ease of assembly shared by both automated and manual processes.

A retaining ring, also known as a snap ring, is a fastener designed to fit into a circumferential groove on a shaft or tube, creating a shoulder to either hold or restrict the movement of mounted parts. This is illustrated in **Figure 6.23.** Retaining rings are generally available in two types: external (shaft) and internal (bore). Constructed from either sheet metal or wire stock, retaining rings are typically heat-treated to enhance their hardness and stiffness. Installation of a retaining ring involves the use of a specialised set of pliers, which temporarily deform the ring, enabling it to fit over the shaft or into the bore. Once positioned, the ring snaps into the groove, securing the assembly.

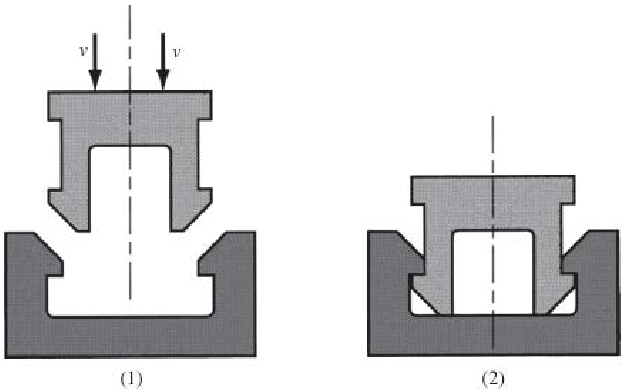


Figure 6.22: Snap fit assembly, showing cross sections of two mating parts: (1) before assembly and (2) parts snapped together

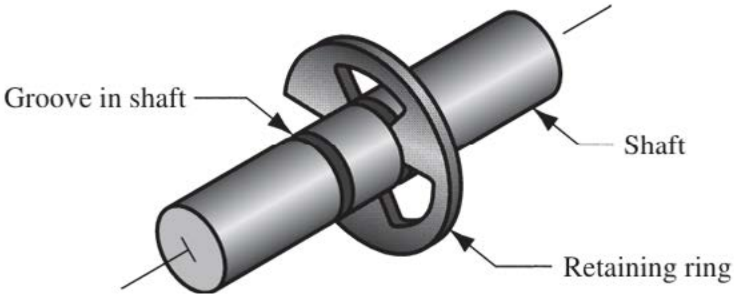


Figure 6.23: Retaining ring assembled into a groove on a shaft

Temporary fasteners: Clevis pins, cotter pins, quick-release fasteners, etc.

A clevis pin is a reusable, cylindrical, non-threaded fastener available in various designs, used to secure components between its head and the end of the pin. These pins are ideal for quickly connecting or disconnecting equipment in both temporary and permanent applications, particularly in situations where precise alignment is not critical. The basic structure of a clevis pin includes the head, shank, and shank end, with key dimensions including the diameter, shank length, effective length, and head diameter. **Figure**s **6.24** and **6.25** illustrate a clevis pin and its typical applications.

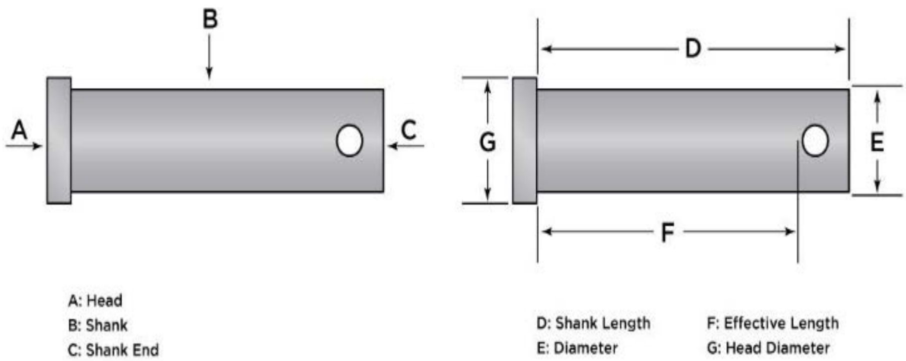


Figure 6.24: Clevis pin

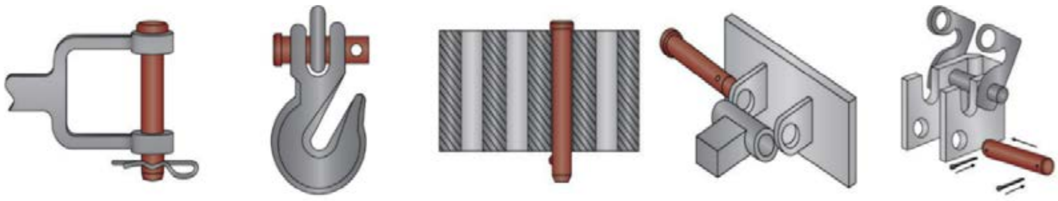


Figure 6.25: Clevis pin fastener process

Cotter Pins

Cotter pins are fasteners formed from half-round wire into a single two-stem pin, as in **Figure 6.26.** They vary in diameter, ranging between 0.8 mm and 19 mm, and in point style, several of which are shown in the Figure. Cotter pins are inserted into holes in the mating parts and their legs are split to lock the assembly. They are used to secure parts onto shafts and similar applications.

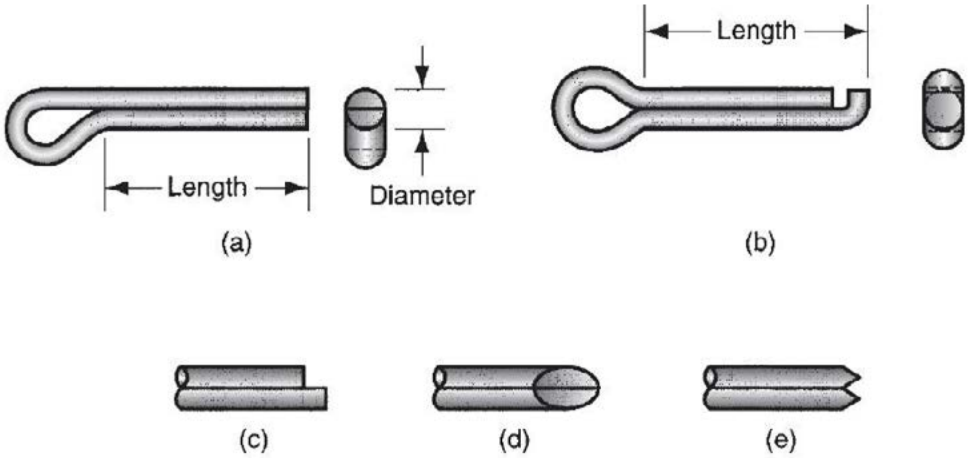


Figure 6.26: Cotter pins: (a) offset head, standard point; (b) symmetric head, hammerlock point; (c) square point; (d) metered point; and (e) chisel point.

Quick-release fasteners

Quick release pins are fastening devices featuring a mechanism that enables rapid and effortless pin removal, commonly utilised in machinery, electronics, and vehicles. These pins offer an efficient and straightforward solution for both securing and releasing components. Quick release pins are essential in various industries, particularly in applications that demand frequent access or where ease of disassembly is critical for maintenance or repair operations. An illustration of a quick release pin is shown in **Figure 6.27**.

Figure 6.27: Quick-release fastener

Working principles, advantages, and limitations of each joining process

Table 6.4 shows the various types of fasteners, their working principles, advantages and limitations of each joining process

Type of Fasteners	Working principles	Advantages	Limitations
Threaded Fasteners (Screws, Bolts, and Nuts)	Threaded fasteners use helical threads to convert rotational force into linear force, creating a strong clamping force between materials. Screws typically have a pointed end for driving into materials, while bolts require a nut to secure the joint.	• Easy to install and remove. • Reusable and adjustable. • Available in various sizes and materials.	• Can loosen under vibration. • Requires precise alignment of holes. • May need washers to distribute load and prevent damage
Rivets and Eyelets	Rivets are cylindrical fasteners with a head on one end and a tail that is deformed to create a second head, securing materials together. Eyelets are small rings used to reinforce holes in thin materials.	• Permanent and strong joints. • Resistant to vibration and shear forces. • Suitable for thin materials.	• Not easily removable. • Requires access to both sides of the joint. • Limited to specific applications
Adhesive fasteners	Adhesives bond materials by creating a chemical or physical bond. They come in various forms, including liquid adhesives, tapes, hot melts, and structural adhesives.	• Can bond dissimilar materials. • Distributes stress evenly. • Provides a clean and smooth finish.	• Requires surface preparation. • Longer curing times for some types. • Limited temperature and chemical resistance
Interference Fitting: Press Fits, Shrink Fits, and Snap Fits	Interference fits rely on the tight fit between parts, achieved by pressing, heating, or cooling components to create a secure joint.	• Strong and permanent joints. • No additional fasteners are required. • Suitable for high-stress applications.	• Difficult to disassemble. • Requires precise manufacturing tolerances. • Potential for material deformation

Type of Fasteners	Working principles	Advantages	Limitations
Shrink and Expansion Fits	Shrink fits involve heating one component to expand it before fitting it over another component, which contracts upon cooling. Expansion fits use cooling to contract one component before fitting it into another, which expands upon warming.	• Creates very tight and secure joints. • No additional fasteners are needed. • Suitable for high-load applications.	• Requires precise temperature control. • Limited to materials that can withstand thermal expansion. • Difficult to disassemble
Snap Fits and Retaining Rings	Snap fits use flexible features that snap into place to hold components together. Retaining rings fit into grooves on shafts or inside bores to secure components axially.	• Quick and easy assembly. • No tools required for assembly. • Reusable and adjustable.	• Limited to specific applications. • May not withstand high loads. • Requires precise design and manufacturing
Temporary Fasteners (Clevis Pins, Cotter Pins, Quick-Release Fasteners)	Temporary fasteners are designed for easy installation and removal. Clevis pins are secured with cotter pins, while quick-release fasteners use mechanisms like detents or spring-loaded balls.	• Easy to install and remove. • Reusable. • Suitable for temporary or adjustable joints	• Limited load-bearing capacity. • May loosen under vibration. • Requires precise alignment

Factors to be considered when selecting non-permanent joining processes

Table 6.5: presents the criteria for selecting non-permanent joining processes.

Criteria	Parameter	Description
Material Compatibility	Material Types	Ensure the joining process is compatible with the materials being joined (e.g., metals, plastics, composites).
	Surface Conditions	Consider the surface finish and cleanliness required for effective joining.
Load Requirements	Load Type	Determine the type of load the joint will experience (e.g., tensile, shear, compressive).
	Load Magnitude	Assess the maximum load the joint must withstand without failure.

Criteria	Parameter	Description
Environmental Conditions	Temperature	Evaluate the operating temperature range and its impact on the joint.
	Corrosion and Chemical Resistance	Consider exposure to corrosive environments or chemicals.
	Vibration and Shock	Assess the joint's ability to withstand dynamic loads and vibrations.
Assembly and Disassembly	Ease of Assembly	Consider the simplicity and speed of the assembly process.
	Ease of Disassembly	Evaluate how easily the joint can be disassembled for maintenance or repair.
	Tool Requirements	Identify any special tools or equipment needed for assembly and disassembly.
Cost Considerations	Material Costs	Account for the cost of fasteners and any additional materials required
	Labour Costs	Consider the labour involved in the assembly and disassembly processes.
	Tooling Costs	Evaluate the cost of any specialised tools or equipment needed.
Joint Accessibility	Access to Joint	Ensure there is sufficient access to the joint for assembly and disassembly.
	Space Constraints	Consider any space limitations that may affect the joining process.
Reusability	Fastener Reusability	Determine if the fasteners can be reused without compromising joint integrity.
	Component Reusability	Assess if the joined components can be reused after disassembly.
Aesthetic and Functional Requirements	Appearance	Consider the visual impact of the joining method on the final product.
	Functionality	Ensure the joining process does not interfere with the functionality of the components.
Safety and Compliance	Safety Standards	Ensure the joining process complies with relevant safety standards and regulations.
	Risk of Failure	Evaluate the potential risks associated with joint failure and implement appropriate safeguards.

Criteria	Parameter	Description
Production Volume	Batch Size	Consider the production volume and its impact on the cost-effectiveness of the joining process.
	Scalability	Assess the scalability of the joining process for different production volumes.

Activity 6.6 Exploring Non-Permanent Joining Processes

Materials needed

- Nonfunctional standing fan, kitchen knife, door locks, standing fan ceiling fan, furniture, bicycles, toys and some metal containers.
- A variety of fasteners (e.g., screws, bolts, nuts, washers).
- A selection of materials to be joined (e.g., wood, metal sheets, plastic parts).
- Hand tools (e.g., screwdrivers, wrenches, drills)
- Measuring tools (e.g., rulers, callipers).

Steps

- Bring to class components that have been joined together like kitchen knife, door locks standing fan ceiling fan, furniture, bicycles, toys and some metal containers. Separate, them into those with permanent and non-permanent joints, and discuss the non-permanent joining processes.
- Disassemble the standing fan, ceiling fan and other non-permanent devices and identify parts that are permanent and non-permanent
- Try to assemble the components as one complete appliance. Assemble a simple joint using the given materials, such as joining two pieces of wood or metal with screws and bolts and nuts
- Engage in a class discussion to discuss the advantages and disadvantages of non-permanent joints.
- Prepare a report or a presentation on your learnings and present this to the class for feedback.

PERMANENT JOINING PROCESSES

Permanent joining processes are fundamental techniques employed in manufacturing to create connections that are intended to endure for the lifetime of a product or structure. These methods are vital for ensuring the structural integrity, durability, and reliability of a wide range of assemblies, spanning from everyday consumer goods to critical infrastructure and aerospace components. Common examples of permanent joining processes include welding, soldering, and brazing.

WELDING PROCESSES

Welding is a process that joins two or more pieces of similar metals by heating them to a temperature sufficient to soften or melt the material. The weld zone is where the materials fuse, allowing their grain structures to merge seamlessly from one piece to the other. Once welded, the parts form a unified structure, and a properly executed weld can be as strong as, or even stronger than, the original material. Welding can be carried out with or without applying pressure to the materials, with some processes relying solely on pressure to achieve the fusion. Most welding techniques involve filling the heated joint with molten metal.

There are several common types of welding, including arc welding, MIG (Metal Inert Gas) welding, TIG (Tungsten Inert Gas) welding, and gas (Oxy-Acetylene) welding, each suited to different materials, applications, and environments. Welding typically requires specific equipment such as welding machines, electrodes, and protective gear like helmets and gloves to shield workers from heat, ultraviolet light, and fumes.

This method is widely utilised for fastening adjacent parts in various manufacturing sectors, including automotive production, aerospace, electronics, and shipbuilding. The advantages of welding over other fastening methods include increased strength, improved weight distribution, potential reductions in the size of required castings or forgings, and possible time and cost savings in manufacturing. Welding also provides a more permanent, durable bond compared with other methods such as mechanical fastening, which may loosen or wear over time. However, welding may require additional post-weld processes such as grinding or inspection to ensure the quality and integrity of the joint.

Types of Welding Processes

The American Welding Society (AWS) is a leading organisation in the field of welding, and it plays a key role in setting standards, providing education, and promoting the welding industry. AWS recognises seven primary welding processes, which are essential techniques used to join metals and materials in various manufacturing, construction, and repair applications. Each of these processes is distinct, using different methods of heat generation and material handling to create durable, reliable joints. These welding processes are classified into two main categories: (1) fusion welding and (2) solid-state welding. The most common methods are oxygen gas welding, shielded metal arc welding, gas tungsten arc welding, and gas metal arc welding, as shown in **Figure 6.28**.

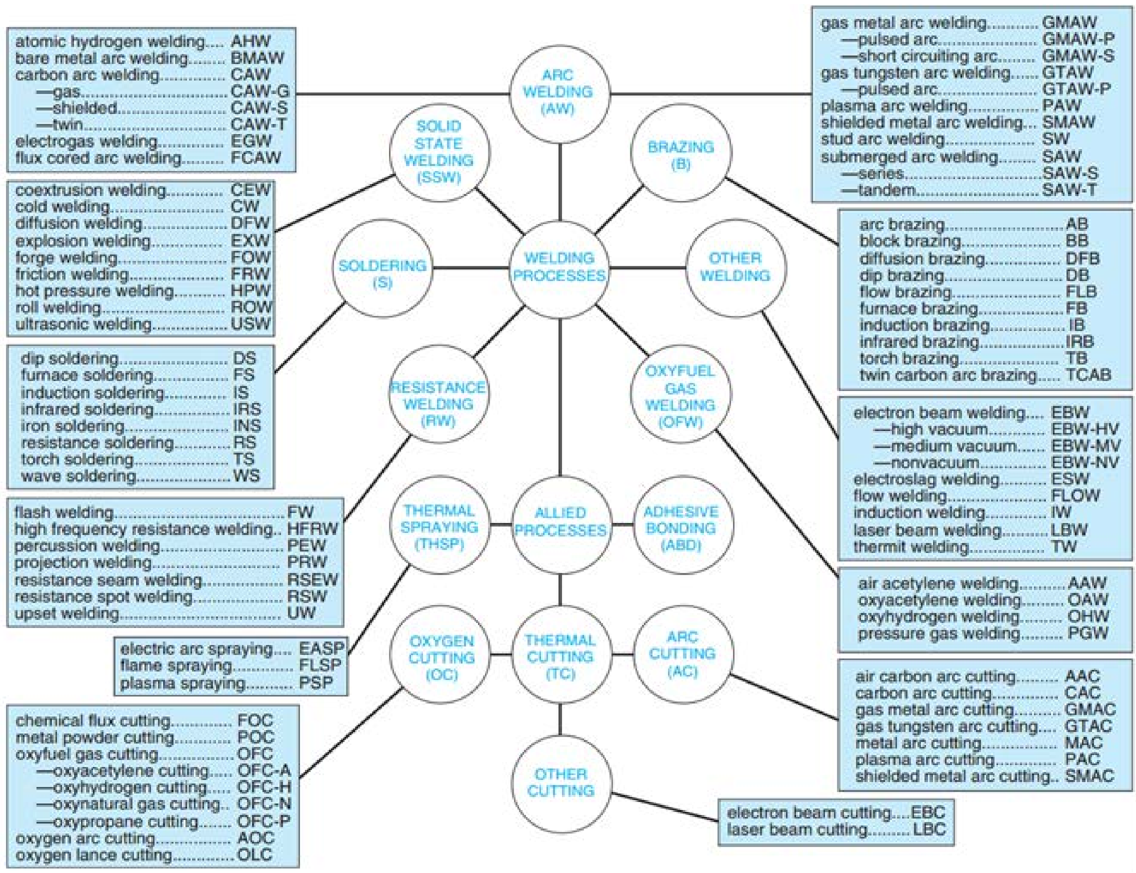


Figure 6.28: Master chart of welding and allied processes

Other Standard-Setting Bodies in the World

There are many different standard-setting bodies across the world for welding, but the most influential are:

- The American Welding Society (AWS)
- International Organisation for Standardisation (ISO) (HQ: Geneva, Switzerland)
- American Society of Mechanical Engineers (ASME) (HQ: USA)
- European Committee for Standardisation (CEN) (HQ: Brussels, Belgium)

Although, regional organizations like BS (British Standard), JIS (Japanese Industrial Standards) and CSA (Canadian Standards Association) play critical roles in their respective areas.

Fusion Welding

These welding processes utilise heat to melt the base metals, facilitating the formation of a joint. In numerous welding applications, a filler metal is introduced into the molten pool, enhancing the process and contributing to the strength of the welded joint. When no filler metal is employed, the weld is referred to as an autogenous weld. The fusion welding category encompasses the most prevalent welding techniques, which can be classified into four primary types: arc welding, gas welding, resistance welding, and high-energy welding. **Table 6.5** provides comprehensive details of these categories, including specific examples and their respective applications.

Table 6.5: Fusion Welding Categories

Category	Example	Description	Application
Arc Welding	Shielded Metal Arc Welding (SMAW)	Shielded Metal Arc Welding (SMAW), commonly known as stick welding, is a manual arc welding process that uses a consumable electrode coated in flux to create a weld.	Uses an electric arc between a consumable electrode and the workpiece to melt the metals. Commonly used in construction and repair work.
	Gas Metal Arc Welding (GMAW/ MIG)	Gas Metal Arc Welding (GMAW), also known as Metal Inert Gas (MIG) welding, is a type of arc welding process that uses an electric arc between a metal electrode and the workpiece to fuse metals together. The process is shielded from the atmosphere by a gas, typically a mixture of argon and carbon dioxide	Uses a continuous wire feed as an electrode and an inert gas to shield the weld. Widely used in automotive and manufacturing industries
	Gas Tungsten Arc Welding (GTAW/TIG)	Gas Tungsten Arc Welding (GTAW), also known as Tungsten Inert Gas (TIG) welding, is a type of arc welding process that uses a non-consumable tungsten electrode to create an arc between the electrode and the workpiece. The process is shielded from the atmosphere by a gas, typically a mixture of argon or helium.	Uses a non-consumable tungsten electrode and an inert gas for shielding. Known for producing high-quality welds, often used in aerospace and automotive industries.

Category	Example	Description	Application
Arc Welding	Flux-Cored Arc Welding (FCAW)	Flux-Cored Arc Welding (FCAW), also known as Submerged Arc Welding (SAW), is a type of arc welding process that uses a tubular electrode filled with a flux. The flux is a material that melts and forms a slag covering over the weld, protecting it from the atmosphere and improving the weld quality.	Similar to GMAW but uses a flux-cored wire, which provides its own shielding gas. Suitable for outdoor welding and heavy-duty applications (welding thick materials in shipbuilding and structural applications).
Gas Welding	Oxy-Fuel Welding (OFW)	These joining processes use an oxyfuel gas, such as a mixture of oxygen and acetylene, to produce a hot flame for melting the base metal and filler metal, if one is used.	Uses a flame produced by burning a fuel gas (usually acetylene) with oxygen. Often used for welding thin materials and in repair work.
	Oxyacetylene Welding (OAW)	Oxyacetylene welding is a fusion welding process performed by a high temperature flame from combustion of acetylene and oxygen.	**Automotive Repair:** • Exhaust Systems: Repairing and fabricating exhaust systems. • Body Panels: Fixing fenders and body panels. • Frames: Repairing vehicle frames1. **Metal Fabrication:** • Structures: Creating metal structures, from simple brackets to intricate machinery components. • Pipelines: Welding steel pipes and tubing.

Category	Example	Description	Application
Gas Welding	Oxyacetylene Welding (OAW)	Flame is directed by a welding torch. Filler metal is sometimes added. Pressure is occasionally applied in OAW between the contacting part surfaces.	**Artwork:** • Sculptures: Used by sculptors for creating metal art due to the ability to control the heat and flame size. • Decorative Items: Crafting intricate designs and decorative metal pieces. **Maintenance and Repair:** • Industrial Equipment: Repairing and maintaining industrial machinery and equipment. • Agricultural Tools: Fixing and fabricating agricultural tools and machinery. **Construction:** • Steel Structures: Welding small-sized structural steel shapes and bars. • Reinforcements: Joining steel reinforcements in construction project.
Resistance Welding	Spot Welding	Resistance welding process in which fusion of faying surfaces of a lap joint is achieved at one location by opposing electrodes.	Uses pressure and electric current to join overlapping metal sheets. Commonly used in the automotive industry for assembling car bodies.
	Seam Welding	Uses rotating wheel electrodes to produce a series of overlapping spot welds along lap joint. Can produce air-tight joints.	Similar to spot welding but produces a continuous weld along a seam. Used in manufacturing fuel tanks and pipe

Category	Example	Description	Application
High-Energy Welding	Laser Beam Welding (LBW)	Laser Beam Welding (LBW) is a type of welding process that uses a focused laser beam to melt and join metals together. The laser beam is generated by a laser source, such as a solid-state laser or a gas laser.	Uses a high-powered laser to melt and join materials. Known for precision and used in aerospace, electronics, and medical device manufacturing.
	Electron Beam Welding (EBW)	Electron Beam Welding (EBW) is a type of welding process that uses a focused beam of high-energy electrons to melt and join metals together. The electrons are generated in a vacuum chamber and accelerated to high speeds before being focused onto the workpiece.	Uses a beam of high-velocity electrons to melt the materials. Performed in a vacuum and used for high-precision application

Solid-State Welding

Solid-State Welding (SSW) is a technique used to join materials without the need to melt them. Unlike fusion welding, which relies on heat to melt the materials and then cools them to form a bond, SSW employs pressure, often combined with heat, to create a strong and durable connection. The core principle of SSW is to apply sufficient pressure to bring the surfaces of the materials into direct contact, facilitating atomic bonding across the interface. The introduction of heat can further aid this process by enhancing atomic mobility, which promotes better intermixing of the surfaces. For a detailed overview of the various types of SSW, along with examples and applications, refer to **Table 6.6.**

Table 6.6: Solid State Welding Category

Example	Description	Application
Cold Welding (CW)	Joins materials at room temperature using pressure.	Electrical connections: Joining wires and electrical components, especially in the aerospace industry. Nanotechnology: Joining ultrathin metal wires and components
Diffusion Welding (DFW)	Uses heat and pressure to bond materials through atomic diffusion.	Aerospace: Joining turbine blades, rocket engine components, and aircraft structures. Automotive: Fabricating exhaust systems, fuel cells, and engine components

Example	Description	Application
Explosion Welding (EXW)	Uses explosive force to bond materials.	Shipbuilding: Cladding aluminium plates to carbon steel for ship hulls. Petrochemical industry: Bonding stainless steel or titanium to carbon steel in pressure vessels
Forge Welding (FOW)	Involves heating and hammering materials	Blacksmithing: Creating tools, weapons, and decorative items. Manufacturing: Joining steel pipes, creating cookware, and making armour
Friction Welding (FRW)	Uses frictional heat and pressure to join materials.	Automotive: Welding drive shafts, gear levers, and brake spindles. Aerospace: Joining turbine blades, rotors, and combustion chambers
Hot Pressure Welding (HPW)	Combines heat and pressure to bond materials.	Aerospace: Joining high-strength metals like titanium and aluminium alloys. Automotive: Joining sheet metals and various types of alloys
Roll Welding (ROW)	Uses pressure from rolling to join materials.	Cladding: Applying stainless steel to mild steel for corrosion resistance. Manufacturing: Producing bimetallic strips and sandwich strips for coins
Ultrasonic Welding (USW)	Uses high-frequency ultrasonic vibrations and pressure to bond materials.	Medical devices: Assembling filters, masks, and other medical components. Electronics: Joining components in electronic devices and armature windings

Oxygen Gas Welding

Oxygen gas welding, also known as oxyfuel welding or oxyacetylene welding, can utilise a variety of fuel gases, including natural gas, propane, and propylene. This technique is primarily employed for working with thin materials such as sheet metal and lightweight pipes or tubing. It is also commonly used for repairs and metal cutting. One notable advantage of oxyfuel welding is its relatively low cost in terms of both equipment purchase and operation, compared with other welding methods. However, advancements in other welding technologies have made them faster, cleaner, and less likely to cause material distortion.

Oxyfuel welding and cutting equipment, as shown in **Figure 6.29**, are frequently used in many industries. Related processes such as soldering, brazing, and braze welding are more focused on bonding than welding since the base material remains solid while a filler metal melts into the joint. Soldering occurs at temperatures below 840°F (450°C), whereas brazing takes place at higher temperatures. Different alloys are chosen based on their melting points: solder is typically an alloy of tin and lead, while brazing often involves a copper-zinc alloy.

Brazing joins two closely fitting metals by heating them to a temperature where the filler metal flows into the joint through capillary action, creating a strong bond. Braze welding, on the other hand, fills the joint with filler metal without relying on capillary action. Another oxyfuel-based process is flame cutting, which involves using a high-temperature flame to preheat the metal. Once the metal reaches the desired temperature, a stream of pure oxygen is directed onto the material, allowing it to be cut through efficiently.

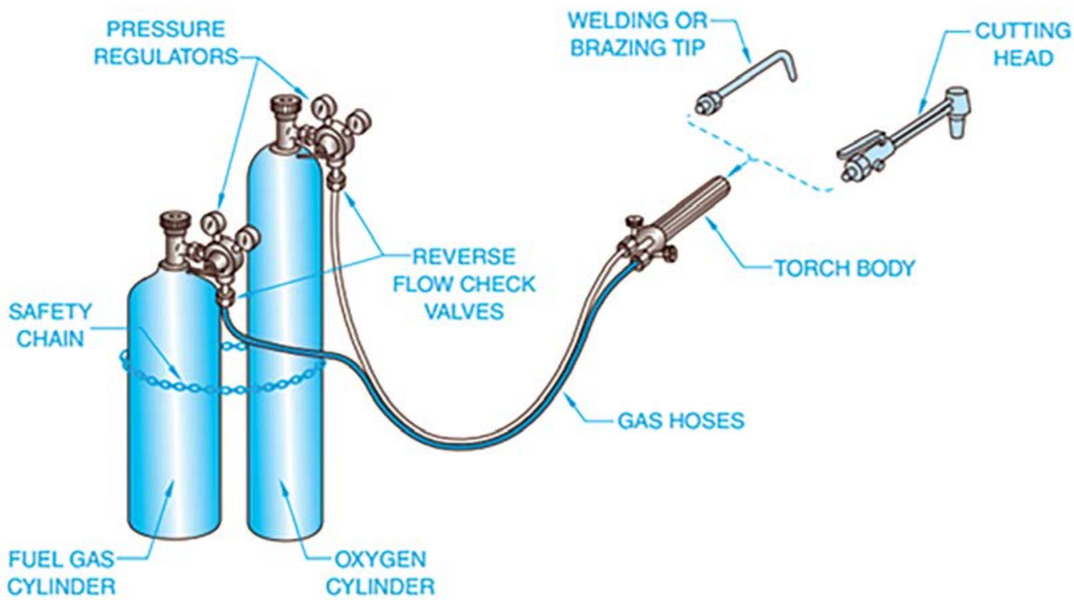


Figure 6.29: Oxyfuel welding and cutting machine

Shielded Metal Arc Welding

Stick Electrode Welding, also known as Shielded Metal Arc Welding (SMAW), is a widely used and traditional welding method that provides strong, reliable welds across a variety of metals and thicknesses. This technique utilises a coated metal electrode through which an electrical current passes, creating an arc that melts both the electrode and the base material. The molten metal from the electrode merges with the base material to form a solid, durable weld. SMAW is preferred for its low-cost equipment and materials, as well as its flexibility, portability, and versatility. A typical SMAW setup is illustrated in **Figure 6.30.**

Gas Tungsten Arc Welding (GTAW), commonly known as Tungsten Inert Gas Welding (TIG) or Heliarc (a trademark of Union Carbide Corporation), utilises a non-consumable tungsten electrode that does not degrade during the welding process. The electrode is shielded from contamination by an inert gas, such as argon or helium, which helps to produce clean and high-quality welds. GTAW offers the ability to work on a broader range of materials than SMAW, making it suitable for applications that require precise, high-strength welds. This process is particularly effective for welding thin materials, small parts, or applications where superior weld quality is essential. However, GTAW is typically slower than other welding methods, and both the equipment and materials tend to be more expensive. **Figure 6.31** provides a visual of a GTAW setup.

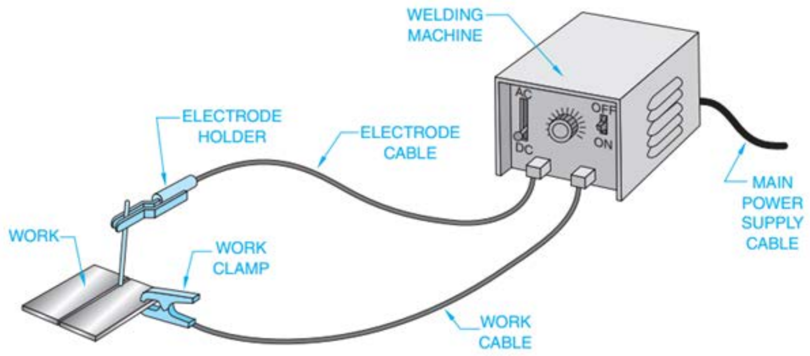


Figure 6.30: Shielded metal arc welding equipment

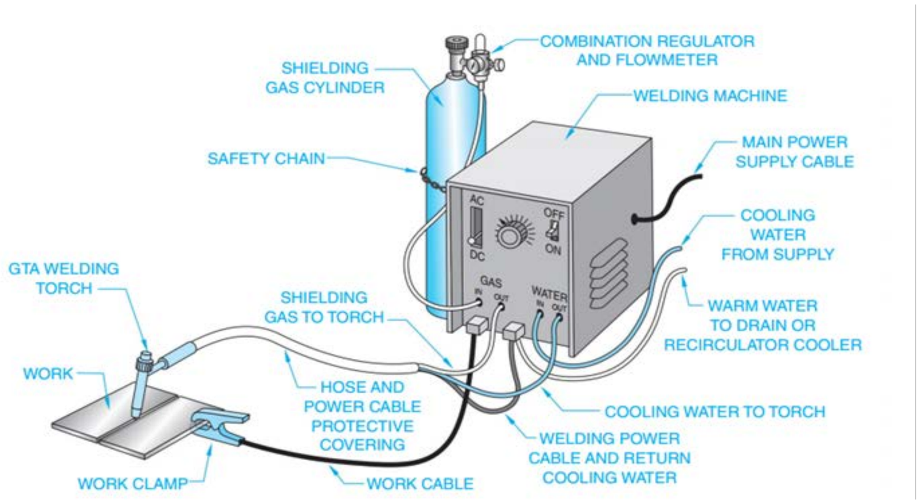


Figure 6.31: Gas tungsten arc welding equipment

Gas Metal Arc Welding

Gas Metal Arc Welding (GMAW), commonly referred to as MIG welding, is an efficient and cost-effective method for producing clean, high-quality welds. It is versatile enough to be used on both thin materials and thick plates. Initially developed for welding aluminium with a metal inert gas (MIG) shield, GMAW involves feeding a continuous wire electrode into the joint, through which an electric current is passed to create the weld. This process is widely employed in various industries, particularly in automated and robotic systems, which enable rapid production of consistent welds in any position. While the initial investment in equipment can be substantial, the increasing adoption of GMAW has led to a decrease in costs. **Figure 6.32** illustrates the typical setup for gas metal arc welding.

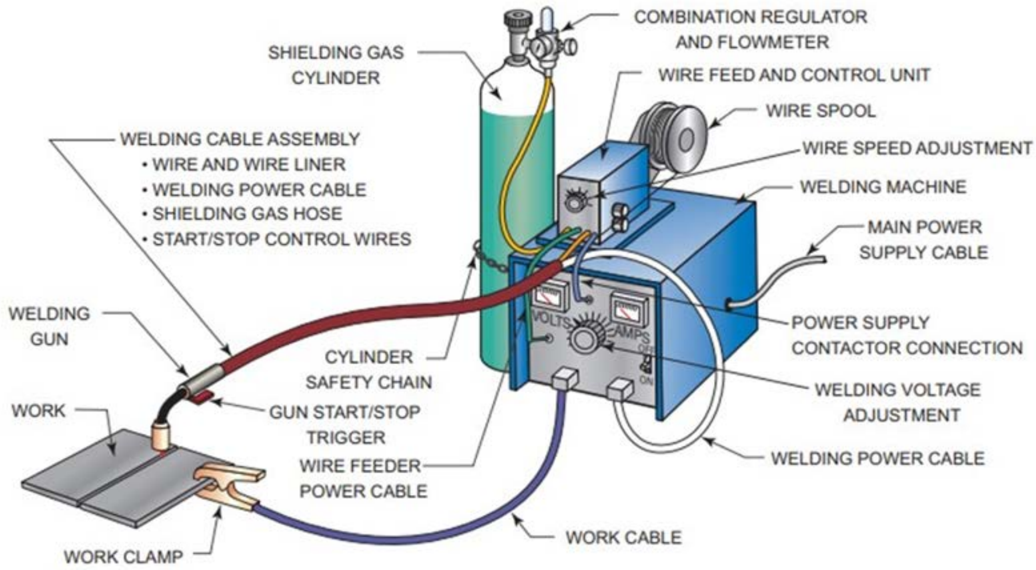


Figure 6.32: Gas metal arc welding machine

Elements of Welding Drawings

Welding drawings are made up of several parts to be welded together. These drawings are usually called weldments, welding assemblies, or subassemblies. The welding assembly typically shows the parts together in a multiview with all the fabrication dimensions, types of joints, and weld symbols. Welding symbols identify the location of the weld, the welding process, the weld's size and length, and other information. The weld symbol indicates the type of weld and is part of the welding symbol. The welding assembly has a list of materials that generally provides a key to the assembly, the number of each part, part size, and material. **Figure 6.33** shows a welding subassembly. When additional parts must be specified, then detailed drawings of each part are prepared, as shown in **Figure 6.34.**

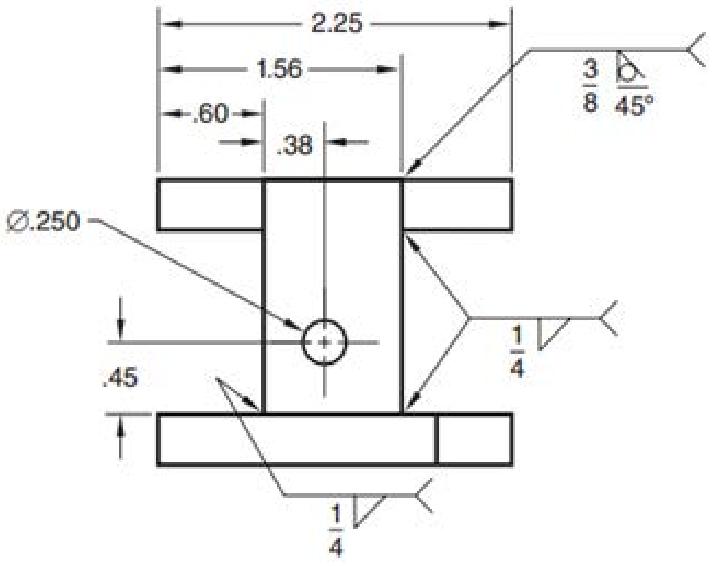


Figure 6.33: Welding subassembly

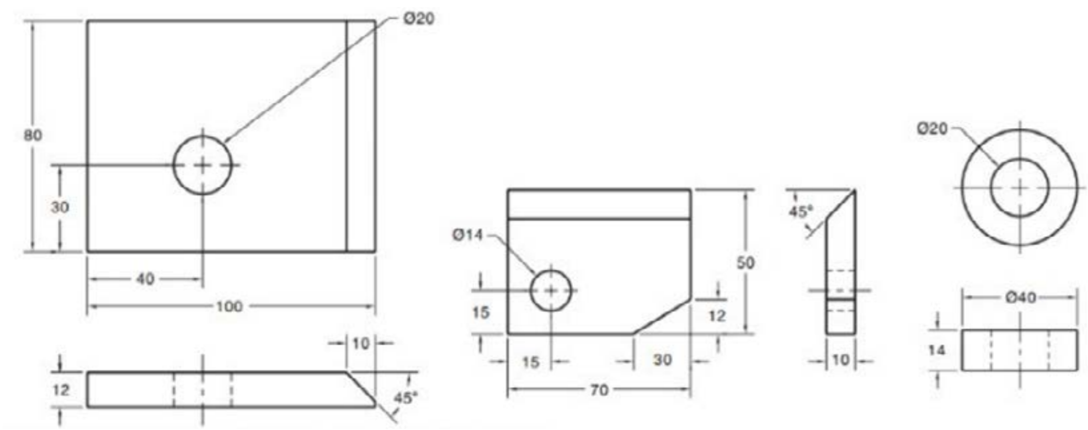


Figure 6.34: Drawings of each part of the welded subassembly

Welding and Weld Symbols

A welding symbol has a few basic parts: the reference line, tail, and leader, which are all drawn as thin lines, as shown in **Figure 6.35.** The reference line is usually the first part of the welding symbol to appear on the drawing. The leader connects to the reference line and follows the same rules as leaders for notes. You can draw leaders at any angle but avoid angles less than 15 degrees or more than 75 degrees. Leaders for notes typically connect directly from the shoulder to the feature. This also applies to welding leaders. However, sometimes welding leaders may bend to reach hard-to-access areas or when multiple leaders come from the same reference line, as shown in **Figure 6.36.** Keep in mind that this bending is not allowed for leaders drawn according to ASME standard dimensioning.

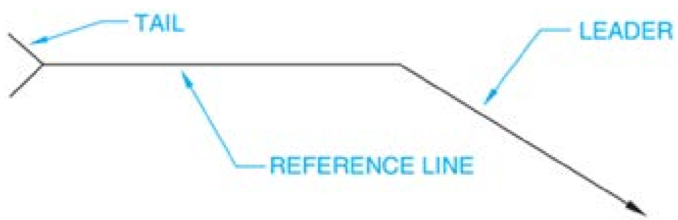


Figure 6.35: Welding symbols: reference line, tail and leader

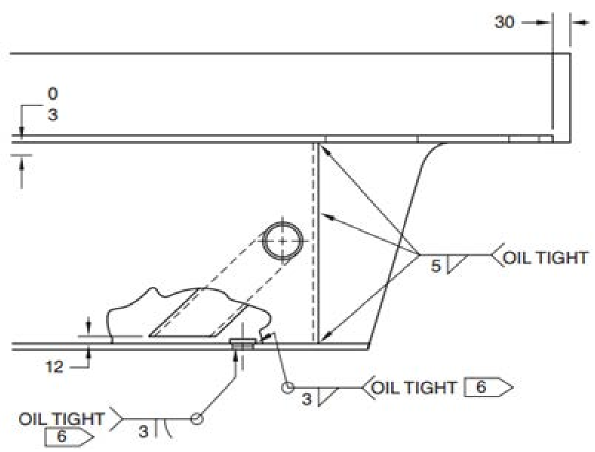


Figure 6.36: Welding symbol leader use

After the reference line has been established, additional information is placed on the reference line to continue the weld specification. **Figure 6.37** shows the standard location of welding symbol elements as related to the reference line, tail, and leader. As previously introduced, the weld symbol indicates the type of weld and is part of the welding symbol. Weld symbols are generally drawn on or near the centre of the reference line of the welding symbol. Typical weld symbols are shown in **Figure 6.37**.

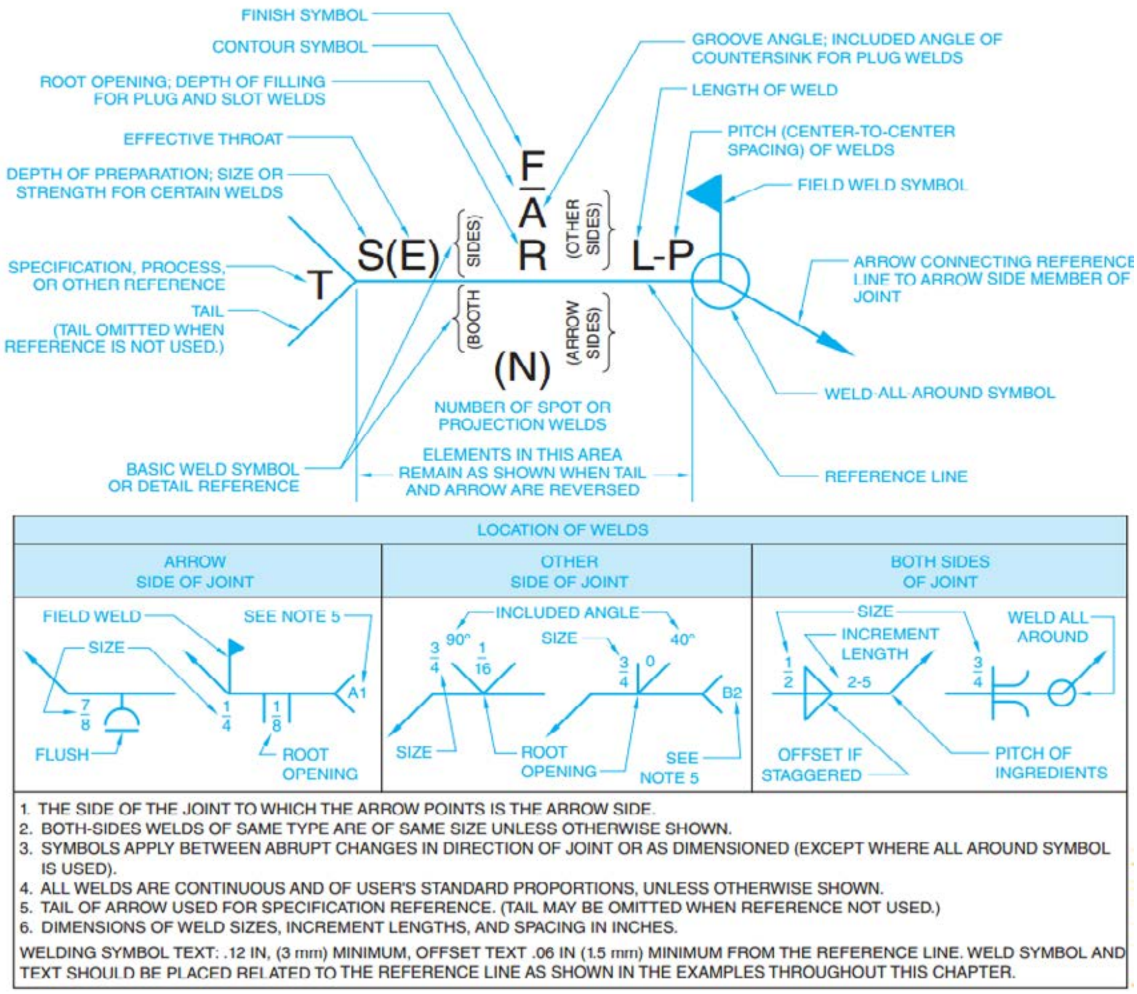


Figure 6.37: Typical weld symbols

Types of Weld Joints

Welds come in different types, and each type is chosen based on what is needed for the job, the properties of the materials, and how strong the joint needs to be. The type of weld can affect how well the joint works and how long it lasts. The main types of welds are **fillet welds**, **butt welds**, and **cruciform welds**. Each type has its own features and uses. Many industries, including construction and manufacturing, use these welds, selecting them based on the specific needs of the structure.

1. **Fillet Welds**: Fillet welds are commonly used in T-joints, lap joints, and corner joints. They are characterised by their triangular cross-section and are typically used where high strength is not the primary requirement. Fillet welds are easier to perform and require less preparation compared with other types of welds.
2. **Butt Welds**: Butt welds join two pieces of metal along a flat surface. They are strong and cause less distortion, making them good for demanding tasks. Common uses include pipeline construction and structural work, where joints need to handle a lot of stress. To keep the joint strong, it is important to prepare and align the pieces carefully.
3. **Corner Joint**: This joint is created when two pieces meet at a right angle, forming an L-shape. It's often used in frame construction.
4. **Edge Joint**: This joint is made when the edges of two pieces are placed side by side. It is typically used for sheet metal and thin materials1.
5. **Lap Joint**: This joint is formed when two pieces overlap each other. It's commonly used in automotive and structural applications1.
6. **T-Joint**: This joint is created when one piece is perpendicular to another, forming a T-shape. It's often used in structural and fabrication work
7. **Cruciform Welds**: Cruciform welds are made by joining two plates at right angles to form a cross shape. These welds are used when a joint needs to support loads from different directions. They are complex and need careful attention to how stress is distributed to avoid failure.

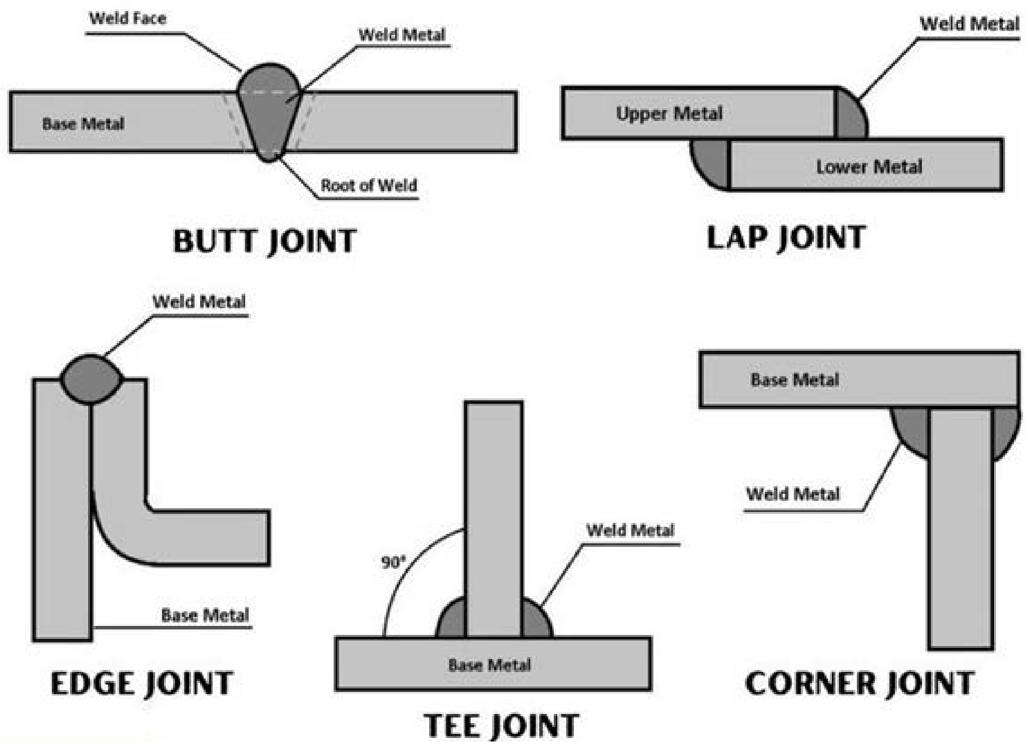


Figure 6.38: Type of weld joints

Welding Standards

Welding standards are essential guidelines that ensure the quality, safety, and reliability of welding processes across various industries. These standards provide a framework for the design, execution, and inspection of welds, ensuring that they meet specific criteria for performance and safety. Welding standards are developed by various organisations and are crucial for maintaining consistency and dependability in welding practices. Below are key aspects of welding standards.

Importance of Welding Standards

- Welding standards are pivotal in ensuring uniformity and reliability in fabrication processes. They help validate welder competency and credibility, leading to improved weld quality, reduced defects, and enhanced safety.
- Standards like the British Standard (BS) 7570:2000 and BS EN 50504:2008 are used to calibrate welding equipment, ensuring that machines operate within acceptable parameters to produce high-quality welds.

Types of Welding Standards

1. Different industries have specific standards tailored to their needs. For instance, the nuclear power industry in China uses distinct standards for carbon steel welding materials, which are being unified to reduce costs and improve efficiency.
2. The American Petroleum Institute (API) has developed standards for in-service welding, such as API Standard 1104, which includes guidelines for welding pipelines while they remain operational.
3. American Welding Society (AWS): AWS sets industry-wide best practices for welding quality and qualifications. They publish over 240 codes, recommended practices, and guides, such as AWS D1.1 for structural welding (steel) and AWS D1.2 for structural welding (aluminium).
4. American Society of Mechanical Engineers (ASME): ASME's Boiler and Pressure Vessel Code (BPVC) includes explicitly related to welding, such as Section IX for welding and brazing qualifications.
5. Occupational Safety and Health Administration (OSHA): OSHA provides standards for welding, cutting, and brazing to ensure workplace safety in general industry, maritime, and construction.
6. International Standards: Various international standards, such as ISO 9606 for welder qualification testing and EN 1011 for welding recommendations, are also widely used.

Application and Challenges

1. Welding standards are applied in various sectors, including construction, where they dictate the size and specifications of welds to prevent issues like weld cracking due to rapid cooling.

2. Challenges in standardisation include the need for ongoing updates and the harmonisation of different standards to avoid unnecessary costs and inefficiencies.

Development and Evolution

1. Developing welding standards involves carefully considering factors such as welding parameters, material properties, and environmental conditions. For example, standards for hydrogen-assisted cold cracking require specific test parameters and indexes to ensure reliable data comparison.

2. New standards are being developed to better align weld quality criteria with structural performance, such as fatigue strength, which can lead to more reliable and lighter structures.

Welding standards are important for ensuring quality and safety. However, they come with challenges, such as the need for regular updates and the need to align different standards across industries. These challenges show that welding standards are always changing, and there are ongoing efforts to improve and adapt them to meet the needs of various sectors.

Soldering

Soldering is a process used to join metal parts together. It involves heating a filler metal that has a melting point no higher than 450°C. This metal melts and flows into the spaces between the parts, helping to create a strong bond without melting the actual parts being joined. Like brazing, soldering requires clean surfaces. Before you begin, make sure to clean the surfaces to remove any dust, oil, or oxides.

Next, apply a flux to these surfaces and heat them. The filler metal, called solder, is then added. It fills the gaps between the parts. Sometimes, one or both surfaces are pre-coated with solder in a process known as tinning, regardless of whether the solder contains tin. Typical gaps in soldering range from 0.075 mm to 0.125 mm. If the surfaces are tinned, the gap is about 0.025 mm. After the solder cools and hardens, any leftover flux needs to be cleaned off. Soldering is commonly used in electronics assembly but can also be used for mechanical joints. However, it's not suitable for joints that will face high stress or high temperatures.

The benefits of soldering include:

- requiring less energy than brazing or welding,
- offering various heating methods,
- providing good electrical and thermal connections,
- creating seals that keep out air and liquids, and
- being easy to fix or modify.

The downsides of soldering are weak joint strength unless reinforced and the possibility of the joint weakening or melting at high temperatures. **Figure 6.40** shows the soldering of an LED to a circuit board.

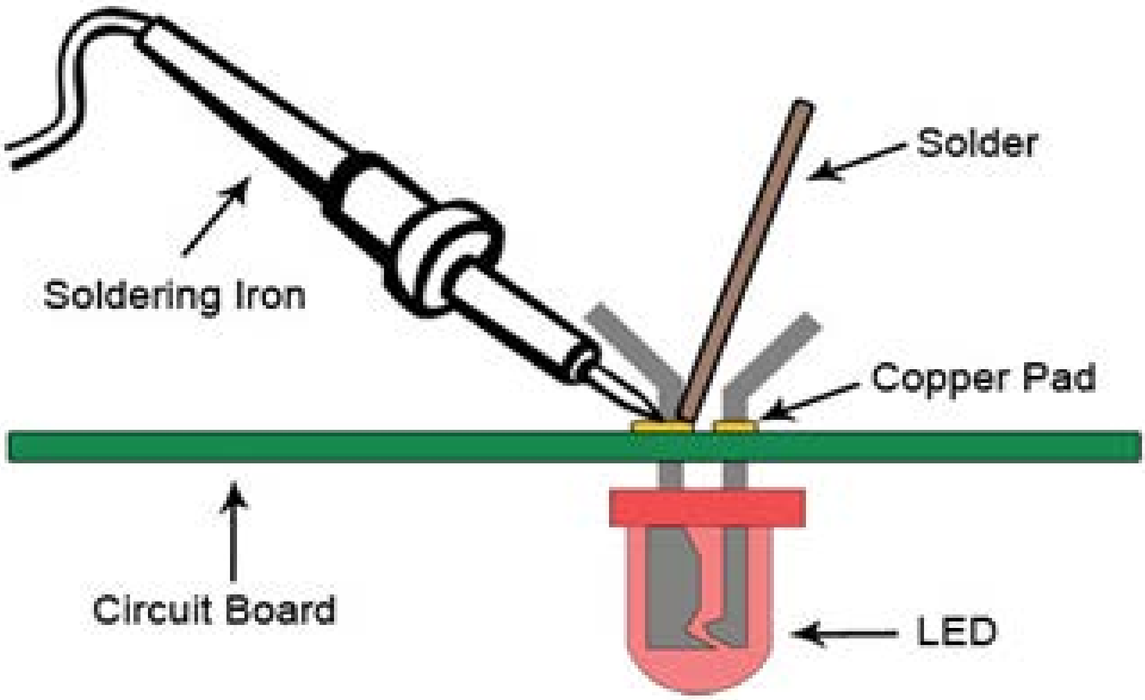


Figure 6.39: Soldering of an LED to a circuit board

Brazing

Brazing is a method of joining metal parts using a filler metal that melts but does not affect the base metals. The filler metal melts at a temperature above 450°C but below the melting point of the metals being joined. If the joint is designed well and brazing is done correctly, the joint will be stronger than the filler metal when it cools. This happens because of the tight fit between the parts, the bonding between the base and filler metals, and the shape of the parts. Common filler metals used for brazing are nickel, silver, copper and gold.

Brazing has several benefits (advantages) over welding

1. It can join any metal, even dissimilar ones.
2. Some brazing methods are fast and consistent, allowing for quick production and automation.
3. Certain techniques can join multiple joints at once.
4. It works for thin-walled parts that can't be welded.
5. It generally requires less heat and power than welding.
6. It reduces issues with heat affecting the base metal near the joint.
7. It can connect hard-to-reach areas because the filler metal is drawn into the joint by capillary action.

However, there are some drawbacks (disadvantages) associated with brazing

1. The strength of a brazed joint is usually less than that of a welded joint.
2. Although a good, brazed joint is stronger than the filler metal, it may be weaker than the base metals.
3. High temperatures can weaken a brazed joint.
4. The colour of the brazed joint may not match the base metal, which can be a visual issue.

Brazing is widely used in many industries. In automotive, it joins tubes and pipes. In electrical equipment, it connects wires and cables. In cutting tools, it attaches cemented carbide inserts to shanks, and in jewellery making, it joins metal pieces. The chemical processing industry and plumbing contractors often use brazing to join metal pipes. It is also a common choice for repairs and maintenance work in almost every industry. **Figure 6.40** shows a diagram of the brazing process.

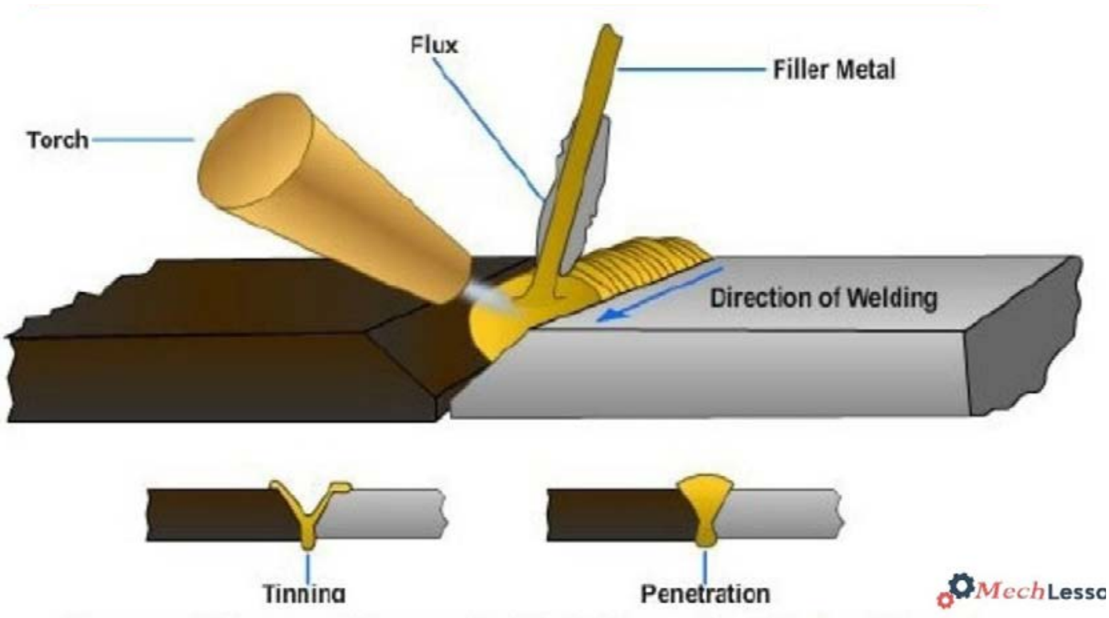


Figure 6.40: Diagram of brazing process

Working Principles, Advantages and Limitations of Welding

Table 6.7 displays details of an explanation of the working principles, advantages, and limitations of welding.

Table 6.7: Explanation of the working principles, advantages, and limitations of welding

Types of Permanent Joining Process	Working principles	Advantages	Limitations
Welding	Welding involves melting the base materials (usually metals) to be joined and a filler material to form a strong joint upon cooling. The process typically uses high heat and sometimes pressure.	Strong Joints: Welded joints are typically very strong and can withstand high stresses. Versatility: Can be used on a wide range of materials and thicknesses. Permanent: This creates a permanent bond that is often stronger than the base materials.	High Heat: High temperatures are required, which can cause distortion or weakening of the base materials. Skill Required: Requires skilled labour and proper safety measures. Equipment Cost: Welding equipment can be expensive.
Soldering	Soldering involves melting a filler metal (solder) with a lower melting point than the base materials. The filler metal flows into the joint by capillary action and solidifies to form a bond.	Low Temperature: Uses lower temperatures, reducing the risk of damaging the base materials. Precision: Ideal for delicate and precise work, such as electronics. Ease of Use: Generally easier to perform than welding.	Weaker Joints: The joints are not as strong as welded joints and unsuitable for high-stress applications. Limited Materials: Typically used for joining metals with similar melting points. Corrosion: Soldered joints can be prone to corrosion if not properly protected.
Brazing	Brazing is similar to soldering but uses a higher temperature. The filler metal (often a copper alloy) melts and flows into the joint by capillary action, creating a strong bond upon cooling.	Strong Joints: Stronger than soldered joints and can join dissimilar metals. Low Distortion: Lower temperatures than welding, reducing the risk of distortion. Leak-Proof: Can create leak-proof joints, ideal for plumbing and HVAC applications.	Temperature Sensitivity: Requires precise temperature control to avoid damaging the base materials. Surface Preparation: Requires clean surfaces for a strong bond. Cost: Filler materials can be expensive.

Criteria for Selecting Permanent Joining Processes

Table 6.8 shows details of the criteria for selecting permanent joining processes.

Table 6.8: Criteria for selecting permanent joining processes

Criteria	Parameter	Description
Material Type	Material Types	Ensure the joining process is compatible with the materials being joined (e.g., metals, plastics, composites).
	Surface Conditions	Consider the surface finish and cleanliness required for effective joining.
Joint Strength Requirements	Load Type	Determine the type of load the joint will experience (e.g., tensile, shear, compressive).
	Load Magnitude	Assess the maximum load the joint must withstand without failure.
Operating Environment	Temperature	Evaluate the operating temperature range and its impact on the joint.
	Corrosion and Chemical Resistance	Consider exposure to corrosive environments or chemicals.
	Vibration and Shock	Assess the joint's ability to withstand dynamic loads and vibrations.
Precision and Size of Components	Ease of Assembly	Consider the simplicity and speed of the assembly process.
	Ease of Disassembly	Evaluate how easily the joint can be disassembled for maintenance or repair.
	Tool Requirements	Identify any special tools or equipment needed for assembly and disassembly.
Cost Considerations	Budget and Equipment Availability	Account for the cost of fasteners and any additional materials required
	Labour Costs	Consider the labour involved in the assembly and disassembly processes.
	Tooling Costs	Evaluate the cost of any specialised tools or equipment needed.
Heat Sensitivity	Heat Impact	If the base materials are sensitive to high temperatures, soldering or brazing might be preferred over welding to avoid distortion or damage.

Criteria	Parameter	Description
Joint Design and Accessibility	Design Complexity	The design of the joint and accessibility can influence the choice. Welding might be challenging in tight or complex spaces, where soldering or brazing could be more feasible
Production Volume	Batch Size	For high-volume production, methods that offer faster processing times and ease of automation, like soldering, might be preferred

Advantages of Non-Permanent and Permanent Joining Processes

Table 6.9 shows the advantages of non-permanent and permanent joining processes.

Table 6.9: Criteria for selecting permanent joining processes

Joining Processes	Advantages	Disadvantages
Non-permanent	Ease of Disassembly: Components can be easily dismantled without damaging them, making it ideal for applications requiring frequent assembly and disassembly	Lower Strength: Typically, these joints are as strong as permanent joints.
	Inspection and Maintenance: Simplifies inspection, repair, and maintenance since parts can be separated without breaking	Not Leak-Proof: Often, they do not provide a leak-proof seal, which can be a limitation in specific applications.
	Cost-Effective: Generally, more cost-effective for applications where joints need to be frequently inspected or replaced	Potential for Loosening: Non-permanent joints may loosen over time, especially under dynamic loads.
	Flexibility: Allows for flexibility in design and modifications	
Permanent	High Strength: Provides strong and durable joints, suitable for heavy load applications	Irreversibility: Disassembly: Once joined, the parts cannot be easily separated without damaging them, making repairs or modifications challenging

Joining Processes	Advantages	Disadvantages
Permanent	Leak-Proof Joints: Sealing: Properly executed permanent joints can be leak-proof, making them ideal for applications involving fluids and gases	Heat Affected Zone (HAZ): Material Properties: The heat generated during processes like welding can alter the properties of the base materials, potentially weakening the joint
	Weight Reduction: Material Efficiency: These processes can reduce the need for additional fasteners or overlapping materials, leading to lighter structures	Residual Stresses: Distortion: The cooling of welded joints can introduce residual stresses, leading to distortion or warping of the components
	Aesthetic and Functional Design: Seamless Appearance: Permanent joining can create smooth, continuous surfaces, which are both aesthetically pleasing and functionally beneficial in reducing stress concentrations	Defects: Quality Control: Welding and other processes can introduce defects such as porosity, cracks, and incomplete fusion, which may not be easily detectable and can compromise the strength of the joint
	Versatility: Material Compatibility: They can join a wide range of materials, including dissimilar metals and non-metals, expanding their applicability across different fields	Skill Requirement: Operator Skill: High skill levels are often required to perform these processes correctly, which can increase labour costs and the potential for human error
	Cost-Effectiveness: Long-Term Savings: Despite higher initial costs, the durability and reliability of permanent joints can lead to lower maintenance and repair costs over time	

Activity 6.7 Creating Non-Functional Object Using Permanent Joining

Materials Tools and equipment needed:

- Metal rods, sheets, pipes (for welding, brazing, riveting)
- Copper, aluminium, or steel items (for brazing, soldering)
- Soldering irons, welding machines, brazing torches
- Rivets, screws, bolts, nuts, adhesives, hammers, drills, and other non-permanent joining tools

- Safety equipment: goggles, gloves, aprons, face shields
- Printed step-by-step instructional guides
- Visual guides for each process
- Workbenches, clamps, soldering irons, welding machines, brazing torches, heat sources, cleaning tools

Steps:

1. In your group choose your desired object (such as a coal pot, dustpan, bucket) and decide which joining methods you will use.
2. Create a simple sketch of the chosen object, identifying where permanent and non-permanent joining methods will be used.
3. Review the printed step-by-step instructional guide and visual guides for each process for a better understanding of the chosen method.
4. Outline the materials to be used like mild steel, wood, copper and the joining techniques for each part like welding for a frame, riveting for handles.
5. Practice the joining techniques on scrap material to get hands-on experience before applying them to the main project for example try soldering small copper pieces or welding simple metal joints.
6. In your group prepare a PowerPoint presentation on your object to the class. The presentation should include:
   a. Explain the object you have created and its purpose (functional or decorative describe the joining methods used
   b. Explain a particular joining technique that was chosen for each part of the object.
   c. Discuss any challenges faced during construction and how they were overcome.
   d. Include visual aids like diagrams or photos of the joining processes
   e. Explain the joining processes used, the reasons for your choices, and any challenges faced.
7. Reflect on your group's performance and individual contributions.

JOIN COMPONENTS USING SCREWS, BOLTS, NUTS AND WELDING PROCESSES

In manufacturing engineering, joining components effectively is key to making strong products. Common methods include using screws, bolts, nuts, and welding. These techniques are important in many industrial applications because they help ensure the structure lasts over time. Screws and bolts allow for easy assembly and disassembly. Choosing the right fastener depends on the materials used and how much load they need to support. On the other hand, welding creates a permanent bond by melting materials together, which is important for applications that require strength. Engineers must master these joining techniques to ensure that products perform well and meet safety standards. **Figure 6.41** presents a flow diagram of the mechanical joining methods using screws, bolts, nuts and welding processes

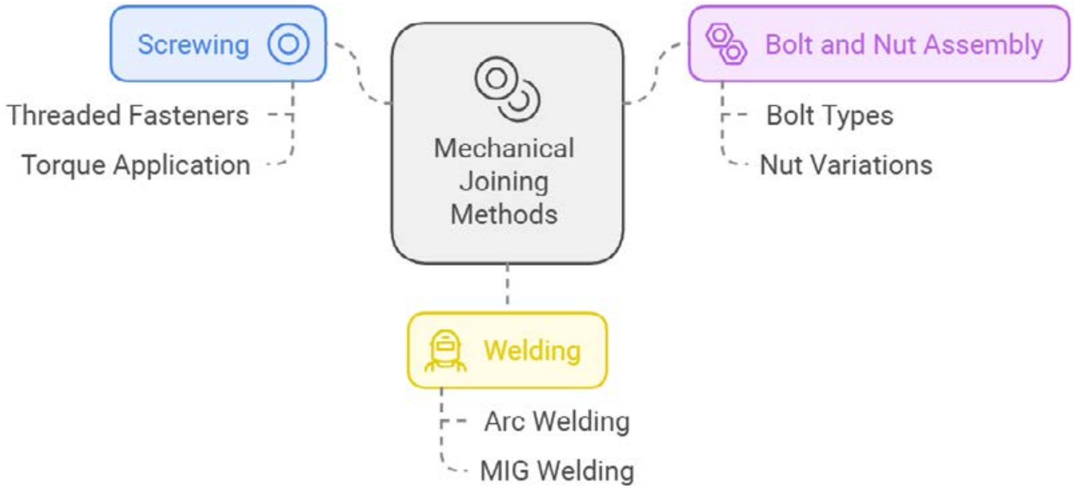


Figure 6.41: Mechanical joining methods

APPLYING SCREWS, BOLTS AND NUTS TO JOIN COMPONENTS

Technical Considerations

- **Determine the type of joint**: Decide whether you need a temporary or permanent joint. Permanent joints often use bolts and nuts, while temporary joints might use screws.
- **Select the appropriate fasteners**: Choose screws, bolts, and nuts that are the right size and material for the components you are joining. Consider factors like the thickness of the materials, the required load, and the desired appearance.
- **Prepare the components**: Ensure the surfaces to be joined are clean and free of dirt, grease, or other contaminants. If necessary, drill pilot holes for the screws or bolts.

- **Thread direction**: Ensure that the threads on the screw or bolt match the threads on the nut.
- **Washers**: Use washers to distribute the load and prevent the fastener from sinking into the material.
- **Torque**: If necessary, use a torque wrench to ensure the fasteners are tightened to the correct specifications.
- **Locking mechanisms**: Consider using locking mechanisms (e.g., lock washers, thread lock) to prevent the fasteners from loosening over time.

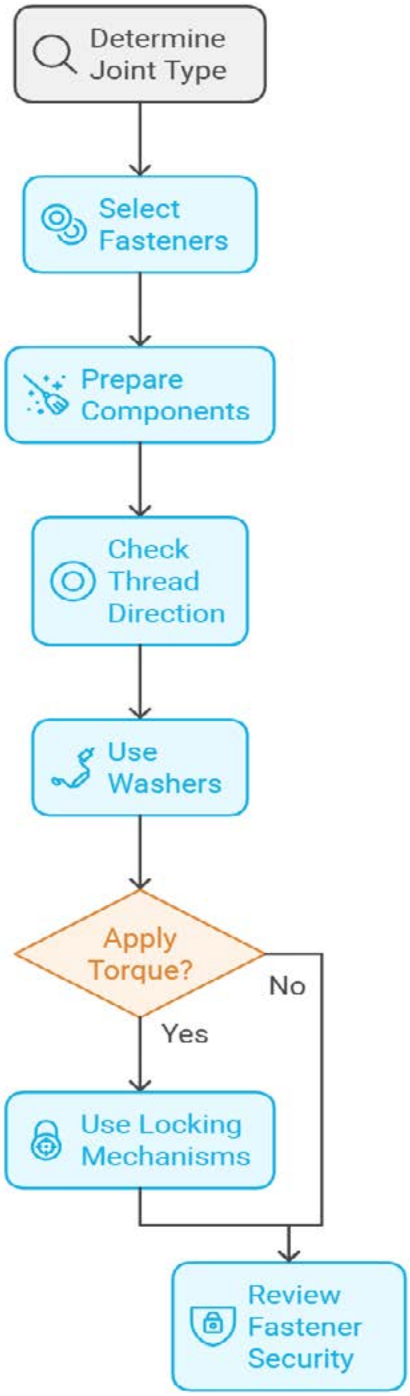


Figure 6.42: Technical considerations of applying screws, bolts and nuts to join components

Sequence of Applying Screws, Bolts and Nuts to Join Components

1. **Preparation**
   a. Gather Materials: Ensure you have all necessary components, including screws, bolts, nuts, washers, and the parts to be joined.
   b. Instrument and Tools Required: Collect the required tools such as measuring tap, marker, screwdrivers, wrenches, spanners, drill bits and a drill if holes need to be made.
2. **Marking and Drilling Holes**
   a. Measure and Mark: Accurately measure and mark the locations where the screws or bolts will be inserted.
   b. Drill Holes: Use a drill to create holes at the marked locations. Ensure the holes are the correct size for the screws or bolts being used.
3. **Aligning Components**
   a. Position Parts: Align the components to be joined, ensuring that the holes in each part match up perfectly.
   b. Clamp Parts (if necessary): Use clamps to hold the parts in place to prevent movement during the joining process.
4. **Inserting Screws**
   a. Select Screws: Choose screws of the appropriate length and diameter for the materials being joined.
   b. Insert Screws: Place the screw into the hole and use a screwdriver to drive it in. Ensure the screw is tight but avoid over-tightening, which can strip the threads or damage the material.
5. **Applying Bolts and Nuts**
   a. Select Bolts and Nuts: Choose bolts and nuts that are suitable for the thickness and type of materials being joined.
   b. Insert Bolts: Insert the bolt through the aligned holes of the components.
   c. Add Washers (if necessary): Place a washer on the bolt before adding the nut. Washers help distribute the load and prevent damage to the material.
   d. Thread the Nut: Thread the nut onto the bolt by hand until it is finger tight.
   e. Tighten the Nut: Use a wrench or spanner to tighten the nut. Hold the bolt head with another wrench to prevent it from turning. Tighten until the components are securely joined but avoid over-tightening to prevent damage.
6. **Final Checks**
   a. Inspect the Joint: Check that the components are securely joined and that there are no gaps or misalignments.
   b. Test the Assembly: If applicable, test the assembled parts to ensure they function as intended.

7. **Clean Up**
   a. Remove Clamps: If clamps were used, carefully remove them.
   b. Clean Work Area: Clear away any debris, tools, and unused materials.

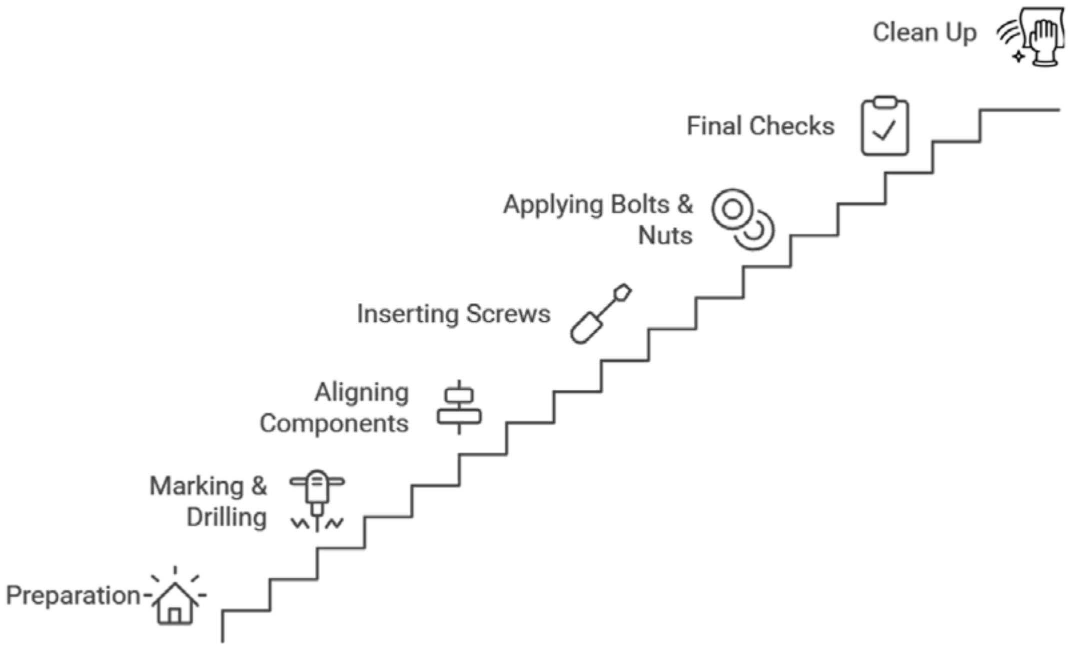


Figure 6.43: Sequence of applying screws, bolts and nuts to join components

Using the Welding Process to Join Components

1. **Preparation**
   a. Gather Materials: Ensure you have all necessary materials, including the components to be welded, welding rods or wire, and any filler materials.
   b. Tools Required: Collect the required tools such as a welding machine (MIG, TIG, or stick welder), welding helmet, gloves, protective clothing, and safety glasses.

2. **Safety Precautions**
   a. Wear Protective Gear: Put on a welding helmet, gloves, protective clothing, and safety glasses to protect yourself from sparks, UV radiation, and hot metal.
   b. Ventilation: Ensure the welding area is well-ventilated to avoid inhaling harmful fumes.
   c. Fire Safety: Remove any flammable materials from the welding area and have a fire extinguisher nearby.

3. **Prepare the Components**
   a. Clean the Surfaces: Clean the surfaces to be welded to remove any rust, paint, oil, or dirt. Use a wire brush or grinder if necessary.
   b. Align the Components: Position the components to be welded and secure them with clamps or fixtures to prevent movement during welding.

4. **Set Up the Welding Machine**
   a. Select the Welding Method: Choose the appropriate welding method (MIG, TIG, or stick welding) based on the materials and the type of weld required.
   b. Adjust Settings: Set the welding machine to the correct voltage, current, and wire feed speed (for MIG welding) or current (amps) (for stick and TIG welding) according to the material thickness and type.

5. **Tack Welding**
   a. Strike the arc
   b. Touch the electrode to the workpiece: Gently touch the electrode to the workpiece to create an arc.
   c. Maintain the arc: Move the electrode along the joint steadily, maintaining a consistent arc length.
   d. Add filler metal (if necessary): If using a filler metal, feed it into the weld pool as needed.
   e. Tack Weld: Apply small tack welds at intervals along the joint to hold the components in place. This helps prevent warping and ensures proper alignment.

6. **Perform the Weld**
   a. Start the Weld: Begin welding at one end of the joint. Hold the torch at the correct angle and maintain a consistent distance from the workpiece for MIG and TIG welding. For stick welding, strike an arc and maintain a steady hand.
   b. Move Along the Joint: Move the welding torch or electrode steadily along the joint, maintaining a consistent speed and angle. Ensure the weld pool is properly formed and that the filler material is being deposited evenly.
   c. Control the Heat: Monitor the heat input to avoid overheating and warping the components. Adjust the welding speed and settings as needed.

7. **Complete the Weld**
   a. Finish the Weld: Continue welding until the entire joint is completed. For long joints, you may need to stop and reposition yourself or the workpiece.
   b. Inspect the Weld: Check the weld for any defects such as cracks, porosity, or incomplete fusion. If necessary, perform additional passes to fill any gaps or reinforce the joint.

8. **Post-Weld Treatment**
   a. Clean the Weld: Remove any slag, spatter, or oxidation from the weld using a wire brush or grinder.
   b. Inspect the Weld: Conduct a thorough inspection of the weld to ensure it meets the required standards and specifications.

9. **Final Checks**
   a. Test the Joint: If applicable, test the welded joint for strength and integrity. This may involve mechanical testing or visual inspection.

   b. Remove Clamps: Carefully remove any clamps or fixtures used to hold the components in place.

10. **Clean Up**
   a. Turn Off Equipment: Turn off the welding machine and disconnect it from the power source.
   b. Remove slag: Remove any slag from the weld using a chipping hammer or wire brush.
   c. Grind or polish (if necessary): If desired, grind or polish the weld to improve its appearance.
   d. Store Tools and Materials: Clean and store all tools and materials properly.
   e. Dispose of Waste: Dispose of any waste materials, such as used welding rods or wire, in accordance with safety regulations.

Note: Welding is a skilled trade that requires proper training and practice. Always prioritise safety and follow the manufacturer's instructions for your specific welding equipment.

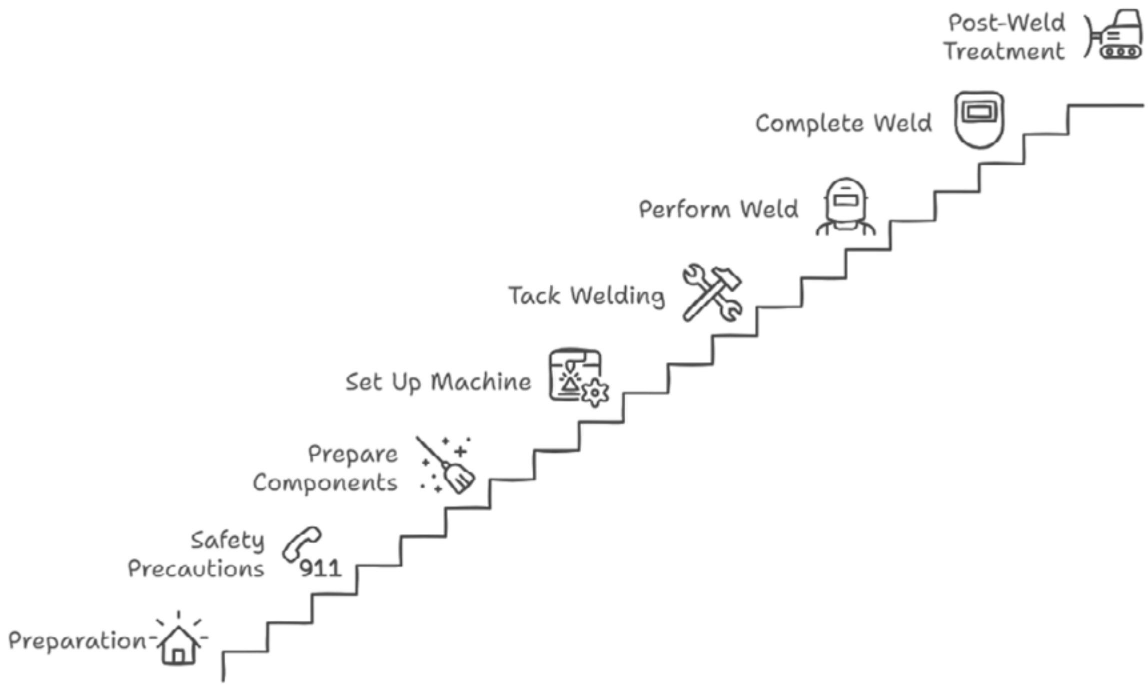


Figure 6.44: Using the welding process to join components

Activity 6.8 Assembling a Non-Permanent Joint

Materials Tools and equipment needed

- Bolts (variety of sizes, preferably 4 to 6 bolts)
- Nuts (matching sizes to bolts)
- Screws (different sizes)
- Screwdrivers (flathead and Phillips)
- Wrenches (adjustable or fixed)/spanner
- Wood pieces (2 or 3 wooden blocks of similar size)
- Drills (different sizes)
- Measuring tape or ruler
- Pencil
- Washers

Steps

1. In a group, perform the following operations to assemble the components
    - Mark the positions for the holes on both workpieces. These holes are to take the bolts. Ensure that both holes are aligned perfectly. Ensure that the space between the holes is sufficient and that the plates remain securely joined when the bolts are tightened. (5–10 cm between the centres)
    - Put on safety clothing (PPE) to protect yourself. Drill through the marked positions, start with a pilot hole. Ensure that the holes are straight and of the correct diameter to fit the bolts. Drill slowly to prevent splintering.
    - Aligning the workpiece to the holes. Pass bolts through the aligned holes of the two plates. Put washers on the bolts followed by the nuts. Tighten the nuts onto the bolts until the pieces are securely joined together. Ensure that they are firmly secured but not over-tightened to avoid damaging the material.
    - Once the assembly is complete, test the joint by applying slight pressure on the pieces. The joint should hold without coming loose.
    - If the joint feels loose, re-tighten the bolts or adjust the placement of the washers or nuts.
2. In your group, perform the following operations to disassemble the components
    - Disassemble the joint by loosening the nuts using a wrench/spanner and removing the bolts.
    - Repeat steps 1c, 1d, 1e, and 2a to ensure that all your group members get a chance to practice this session.
3. Present your assembled work to the class for discussion and feedback and share your reflections from the process.

Activity 6.9 Joining Manufactured Parts Using Welding

Materials Tools and equipment needed

- Two or more pieces of metal such as mild steel plates or rods
- Welding machine and its accessories.
- Welding electrodes or filler rods
- Personal Protective Equipment like welding gloves, goggles, face shields, flame-resistant aprons, ear protection, and welding jackets
- Clamps or welding jigs (to hold parts in place)
- Grinder or wire brush (for cleaning metal surfaces)
- Steel wire brush or grinder (for cleaning the joint area)
- Metal ruler or tape measure
- Chalk or marker (for marking weld areas)
- Welding inspection tools (e.g., visual inspection for weld quality)

Steps

In a group, perform the following operations to weld components together

1. Depending on the equipment available at the school workshop, choose a welding process (Stick, MIG, TIG). Ensure you and all your group are wearing the proper safety gear:
2. Clean the surfaces of the metal that will be welded. The surfaces of both pieces must be free of rust, paint, or other contaminants.
3. Ensure that the workpieces are well aligned and securely positioned for welding.
4. Set up the welding machine by adjusting to the right current (amps) and voltage for the materials being welded.
5. Insert the welding rod or electrode (for Stick or MIG welding) into the machine or prepare the filler rod for TIG welding.
6. Clamp the metal parts securely in place using clamps or a welding jig, ensuring they will stay in position while welding.
7. Hold the welding torch or electrode holder properly. For MIG, maintain a steady hand to guide the torch along the joint. For Stick welding, move the electrode along the joint in a smooth motion. Strike the arc for Stick welding) and begin the welding process by starting at one end of the joint.
8. Focus on overlapping the welds to ensure a strong, continuous joint. Create a proper bead, ensuring that the weld pool is smooth and uniform. Pause periodically to check the weld for consistency and quality.
9. Allow the joint to cool naturally before touching or handling it, visually inspect the weld for evenness of the bead, proper fusion between the two parts, absence of cracks or gaps, strength of joined components.
10. Clean up excess spatter and smooth the weld bead if necessary.

11. Subject the welded joint to a physical test to check the strength of the weld by applying slight pressure to the joint to ensure it holds or using a hammer to gently tap the joint and check for signs of weakness.
12. Discuss the potential reasons why a weld might fail like poor technique, improper settings, or contamination.
13. To appreciate the durability of the weld, try to break the joint manually or with a small hammer, and inspect the break.
14. Reflect on the group's performance and individual contributions.
15. Discuss what was learned from the practice sessions and how your group worked together.
16. Present your work to the class for discussion and feedback.

Review Questions

1. Imagine a scenario where a manufacturing company needs to produce a large quantity of identical high-strength alloy components for an engineering application. Analyse the advantages of using casting for this purpose compared with forging or extrusion. Discuss how casting can influence the mechanical properties, production efficiency, and cost-effectiveness of the components. Provide examples to support your analysis and conclude whether casting would be the optimal choice for this situation.
2. What are the key factors that influence the quality of a casting process, such as pouring temperature, mould design, and cooling rate? How can these factors lead to defects in the casting, and what measures can be taken to minimise these issues?
3. A manufacturing company is considering using sand-casting to produce a new product. What factors should they consider when making their decision?
4. A manufacturing company is designing a new product that requires a non-permanent joint. What factors should they consider when selecting the appropriate method?
5. In a case study where a bridge construction used welding, identify the reasons why welding was chosen over other joining processes.
    a. Strength of the joint
    b. Cost-effectiveness
    c. Speed of assembly
    d. Ease of disassembly

Manufacturing Engineering

Year 2

SECTION

7

SAFETY IN MANUFACTURING

MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES

Manufacturing Processes

Introduction

In this section, we will be discussing the types of hazard controls, effects of manufacturing on the environment, the benefits of using environmentally friendly processes and products in manufacturing and research trends in the local manufacturing industry. You will be introduced to Levels of hazard control including elimination, substitution, engineering controls, administrative controls, and personal protective equipment. Manufacturing has a negative effect on the environment including pollution from industrial processes, resource depletion, waste generation, high energy consumption and emissions, impact on biodiversity and ecosystems and climate change. Throughout this section, you will learn how using environmentally friendly processes and products in manufacturing results in reduced environmental impacts, cost savings and efficiency, improved health and safety of workers, resilience and risk management.

Key Ideas

- The manufacturing environment presents numerous hazards that can impact the health and safety of workers
- Hazard control involves all the necessary steps needed to protect workers from exposure to hazards.
- Levels of hazard control include elimination, substitution, engineering controls, administrative controls, and personal protective equipment
- Manufacturing has negative effects on the environment including pollution from industrial processes, resource depletion, waste generation, high energy consumption and emissions, impact on biodiversity and ecosystems and climate change.
- Using environmentally friendly processes and products in manufacturing results in reduced environmental impacts, cost savings and efficiency, improved health and safety of workers, resilience and risk management

HAZARD CONTROLS

The manufacturing environment contains a variety of hazards that can significantly affect the health and safety of workers. It is important to understand these potential risks and implement effective control measures to mitigate their impact, ensuring a safe and efficient workplace. A fundamental aspect of maintaining safety in manufacturing settings is fostering a safety culture that prioritises the well-being of every employee. This concept, known as hazard control, encompasses a comprehensive approach to identifying, assessing, and managing risks to prevent harm. Mastery of hazard control principles is vital in cultivating a safer manufacturing environment and ensuring the protection of the workforce. **Figure 7.1** shows a fishbone diagram which outlines hazard control strategies to ensure safety in manufacturing environments.

Figure 7.1: Enhancing safety in manufacturing environments

Levels of hazard control

The levels of hazard control refer to a systematic approach for identifying and prioritising measures designed to protect workers from workplace hazards. These levels are arranged in a hierarchy, ranging from the most effective to the least effective. Often referred to as the hierarchy of hazard controls, the levels include elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE). In practice, a combination of these control methods is frequently employed to offer the most comprehensive protection for workers, ensuring optimal safety in the workplace. **Figure 7.2** is a pyramid that shows the hierarchy of hazard control. The pyramid shows the first and most important hazard control as elimination, followed by substitution, engineering controls, administrative controls and personal protective equipment.

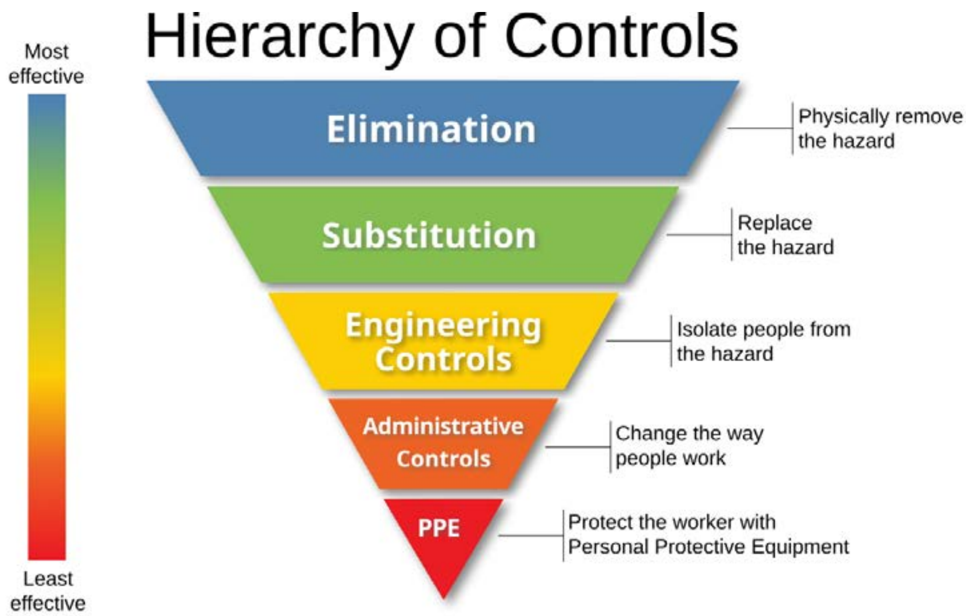


Figure 7.2: Pyramid of the hierarchy of hazard control

Elimination

The most effective method of hazard control is to entirely eliminate the hazard, thereby removing the associated risk. This can be achieved by altering work processes in a way that completely eradicates the danger. Examples include switching to non-toxic chemicals, modifying tasks to be performed at ground level instead of at heights, or discontinuing the use of hazardous, noisy processes. **Figure 7.3** depicts the process of elimination as a hazard control level.

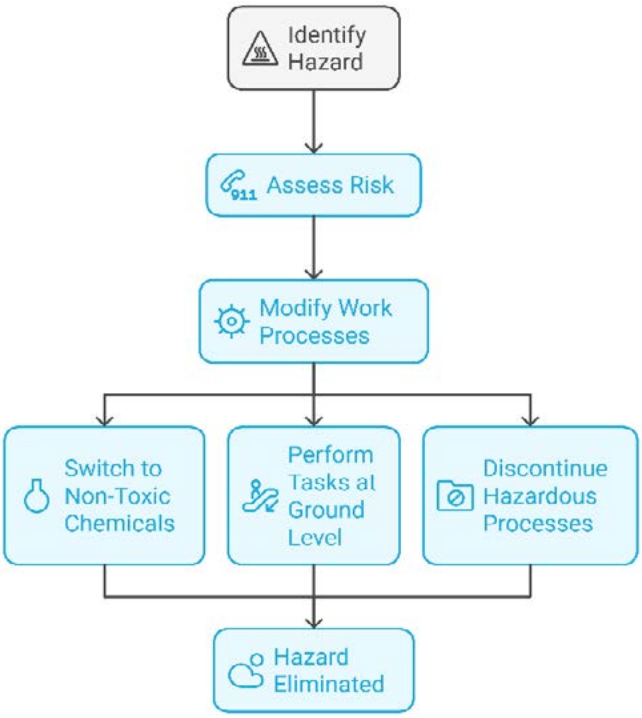


Figure 7.3: Elimination process

Substitution

When elimination is not feasible, the next best approach is substitution, which involves replacing a hazardous substance or process with one that is either non-hazardous or significantly less harmful. This might include replacing a toxic chemical with a safer alternative, opting for a less hazardous chemical, or employing processes that operate at lower force, speed, temperature, or electrical current to reduce risk. **Figure 7.4** shows an image of substitution as a hazard control level.

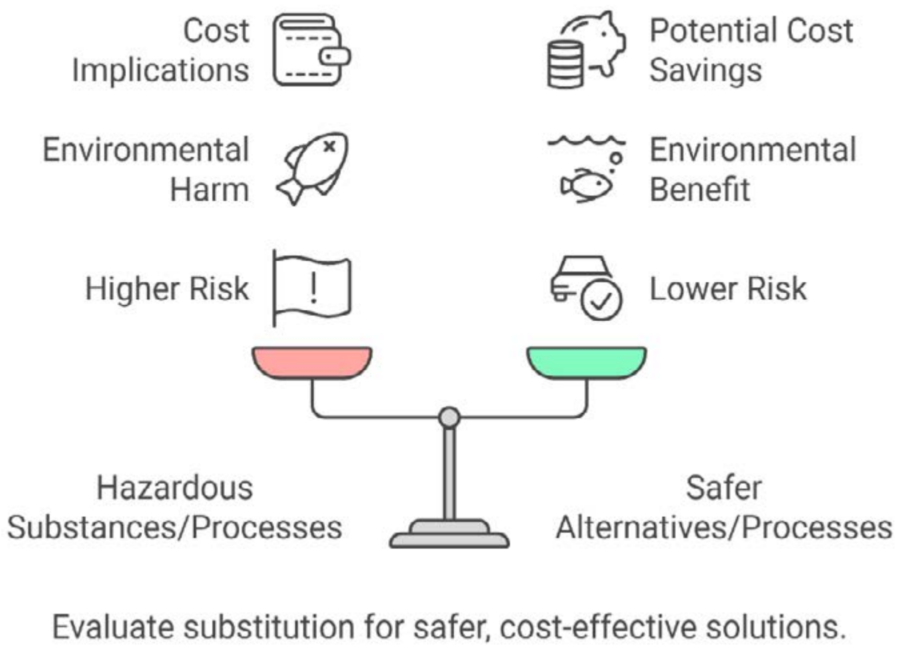


Figure 7.4: Substitution as level of hazard control

Engineering Controls

When elimination or substitution is not possible, engineering controls provide an effective means of preventing exposure to hazards. These controls aim to isolate workers from the hazard or to mitigate its impact. Examples include the use of noise-reduction technologies to lower sound levels, enclosing chemical processes in protective barriers such as Plexiglas “glove boxes,” implementing mechanical lifting devices to reduce manual handling, and installing local exhaust ventilation systems that capture airborne contaminants before they can enter the worker’s breathing zone. **Figure 7.5** shows a fishbone diagram which outlines engineering hazard control strategies to ensure safety in manufacturing environments.

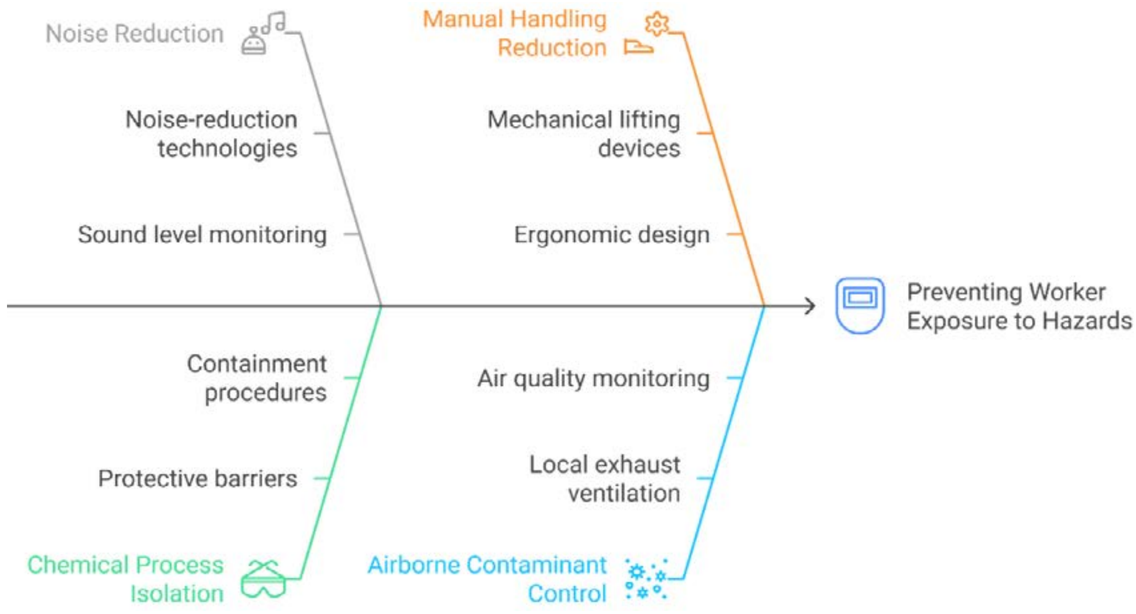


Figure 7.5: Engineering controls for hazard prevention

Administrative Controls

When engineering controls cannot be immediately implemented, administrative controls serve as an alternative approach. These controls focus on modifying work practices or providing workers with essential information to improve safety. Typically employed alongside more robust hazard control measures, administrative controls encompass:

- **Procedures**: This includes systematic approaches such as regular equipment inspections, preventive maintenance schedules, checklists, lockout/tag-out/try-out procedures, infection prevention and control practices, adjustments to work schedules, pre- and post-task reviews, and job rotation to minimise exposure to hazards.
- **Training**: Employees should receive training on various safety topics, such as hazard communication, permit-required confined space entry, lockout/tagout/try-out protocols, and safe work practices to ensure they are well-informed and equipped to handle risks.
- **Warnings**: Effective warning systems include the use of signs, backup alarms, smoke detectors, computer notifications, mirrors, horns, labels, and clear instructions to alert workers of potential hazards and guide them toward safe practices.

Figure 7.6 displays a diagram which outlines administrative control strategies to ensure safety in manufacturing environments.

Figure 7.6: Administrative controls for hazard prevention

Personal Protective Equipment

Personal protective equipment (PPE) serves as a "last resort" measure for controlling hazards by directly safeguarding workers' bodies. While higher-level controls may not always be immediately applicable, PPE can be essential when used in conjunction with other safety measures to ensure comprehensive protection. Examples of PPE include respirators, gloves, protective clothing, safety footwear, hard hats, goggles, and earplugs, all designed to mitigate exposure to specific workplace hazards and enhance worker safety. **Figure 7.7** shows a diagram of the various PPEs used to ensure safety in manufacturing environments.

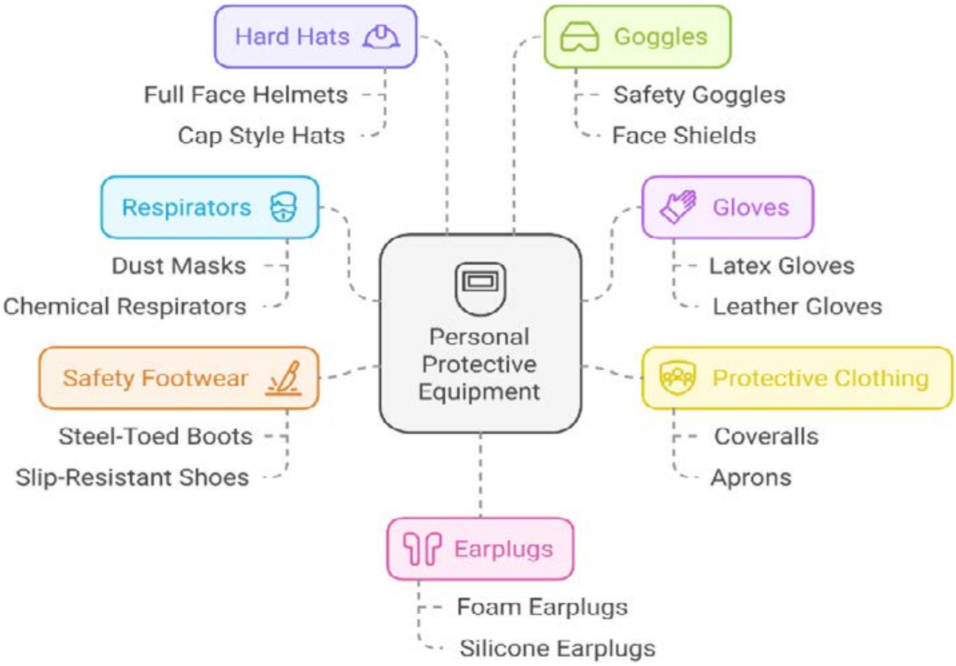


Figure 7.7: Personal protective equipment

RISK ASSESSMENT AND HAZARD CONTROL PLANNING

Risk assessment and hazard control planning are fundamental practices for ensuring a safe and efficient manufacturing environment. These processes involve identifying potential hazards, assessing the risks they pose, and implementing effective strategies to control or eliminate these risks. A thorough understanding of these concepts is vital for safeguarding the health and well-being of all workers while maintaining optimal productivity. **Figure 7.8** shows a diagram of risk assessment and hazard control planning.

Figure 7.8: Risk assessment and hazard control planning

Risk Assessment

Risk assessment is a systematic process that involves identifying potential hazards, evaluating the risks they present, and determining the most effective strategies to mitigate or eliminate those risks. This approach ensures that appropriate measures are taken to safeguard the health and safety of individuals in the workplace. **Figure 7.9** shows a diagram of risk assessment in the workplace.

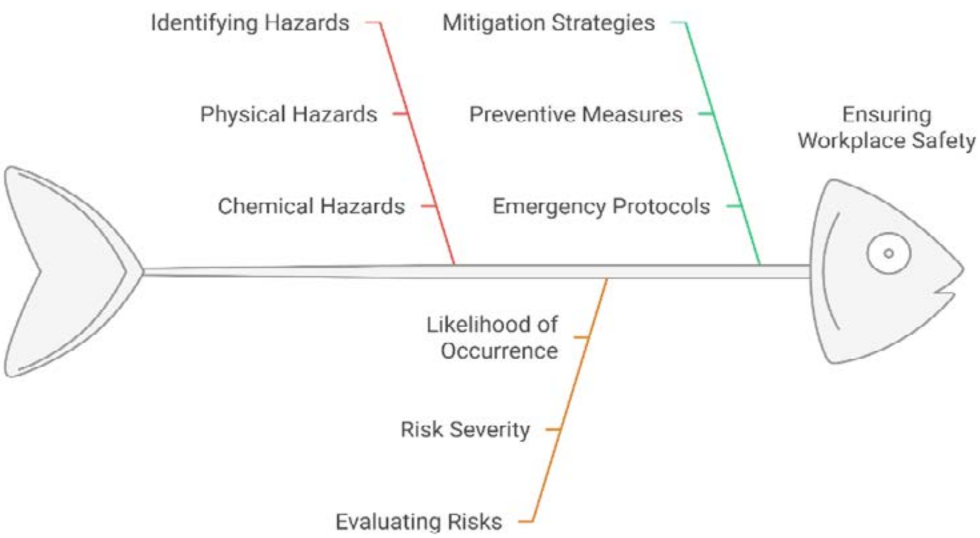


Figure 7.9: Risk assessment in the workplace

Steps in Risk Assessment

The process of conducting a risk assessment involves the following key steps:

1. **Hazard Identification**: Identify the potential hazards or risks that could affect the project, organisation, or system.
2. **Assess Risk Level**: Assess the level of risk associated with each hazard, by determining the likelihood (probability) of the hazard occurring and the severity (impact) of its consequences.
3. **Risk Analysis**: Assess the likelihood and severity of harm resulting from the identified hazards.
4. **Risk Evaluation**: Evaluate the significance of each risk and prioritise hazards based on their potential impact.
5. **Risk Control**: Formulate and implement strategies to effectively manage and mitigate the identified risks.
6. **Monitor and Review**: Monitor the effectiveness of the risk controls and review the risk assessment periodically.

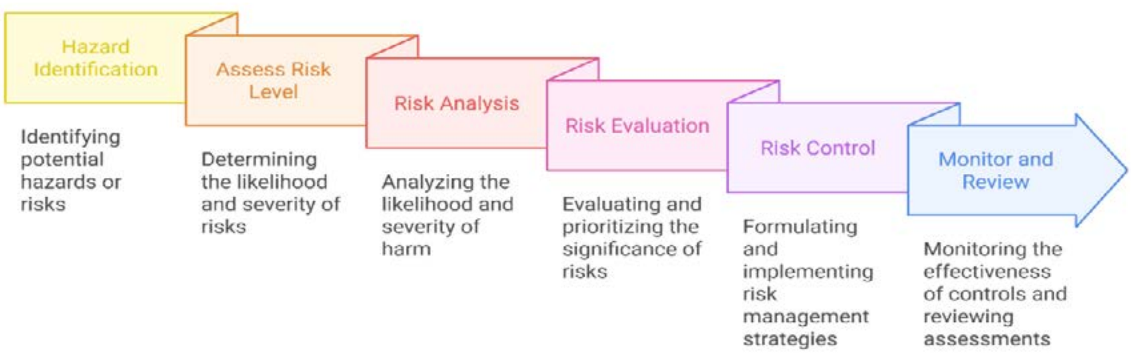


Figure 7.10: Steps in risk assessment

Techniques for Risk Assessment

- **Checklists**: Pre-designed lists to systematically identify hazards in specific processes based on industry standards and best practices. Used in routine inspections, particularly in industries like healthcare, construction, and aviation. Ensures consistency and completeness in identifying hazards.
- **What-If Analysis**: Brainstorming technique that explores potential hazards by asking "what if" questions to consider unlikely scenarios. Ideal for new projects or complex systems lacking historical data. Commonly used in high-risk sectors like aerospace and chemical industries to anticipate catastrophic events.
- **Failure Mode and Effects Analysis (FMEA)**: Evaluates potential failure modes in a system, assessing their causes, effects, and likelihood to prioritise risks. Common in automotive, aerospace, and healthcare for improving system reliability. Helps identify critical failure points, preventing accidents in industries like automotive manufacturing.
- **Hazard and Operability Study (HAZOP)**: Systematic analysis of process deviations to identify operational hazards using guidewords like "more" and "less." Primarily used in chemical, oil, and gas industries to identify potential hazards before they arise. Prevents major incidents by addressing process deviations in complex systems.

All these techniques are valuable tools in a comprehensive risk assessment strategy. They can be used individually or in combination depending on the complexity and specific requirements of the process or system being assessed. **Figure 7.11** shows a diagram of techniques of risk assessment.

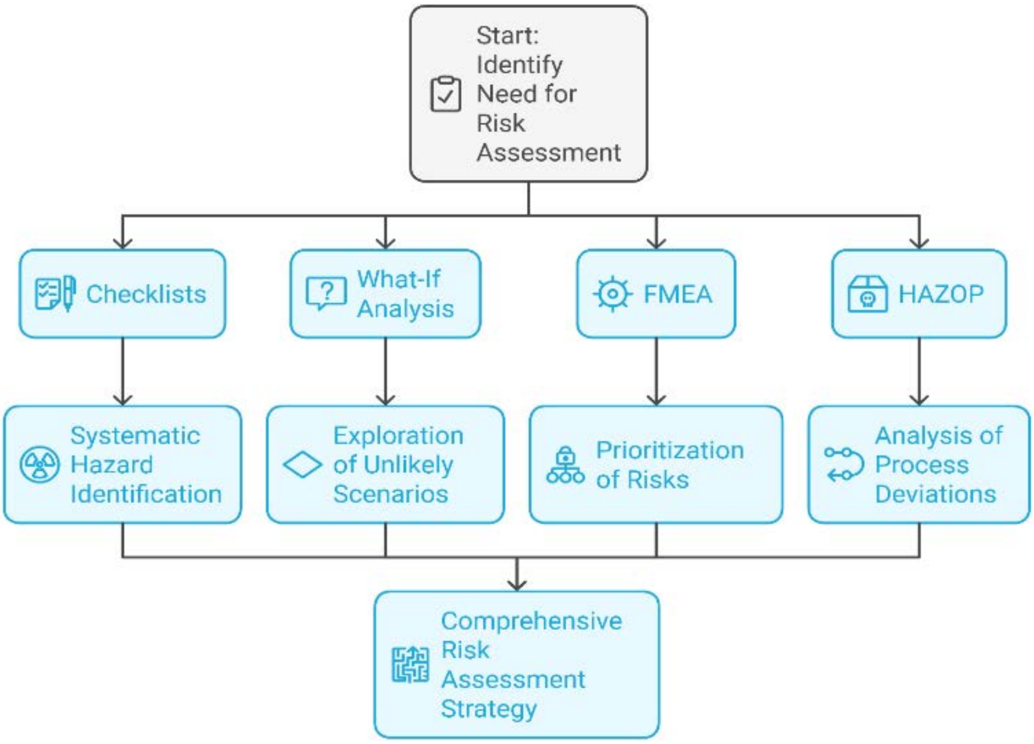


Figure 7.11: Techniques of risk assessment

Hazard Control Planning

Hazard control planning is the strategic process of formulating and executing measures to mitigate risks associated with identified hazards in the workplace. This approach entails a comprehensive and systematic evaluation to implement effective control strategies aimed at minimising the likelihood of accidents, injuries, and health issues. It includes hierarchy-of-control methods, such as elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE), to ensure optimal risk reduction.

Effective hazard control planning has been shown to significantly reduce workplace injuries. According to the Occupational Safety and Health Administration (OSHA), workplaces that implement a structured hazard control plan experience a decrease in injury rates and increased overall safety performance. **Figure 7.12** shows a diagram of hazard control planning.

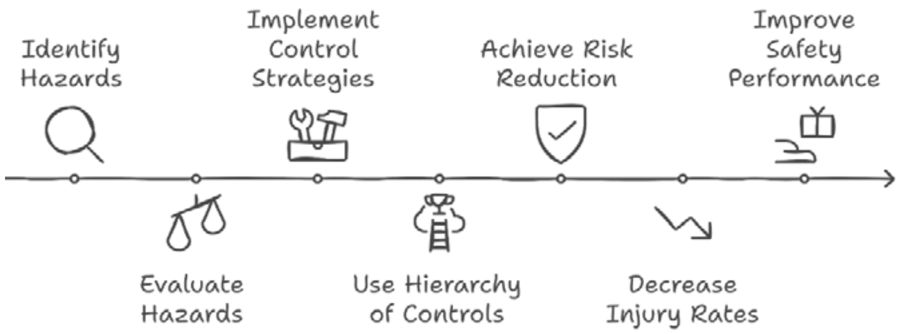


Figure 7.12: Hazard control planning process

Steps in Hazard Control Planning

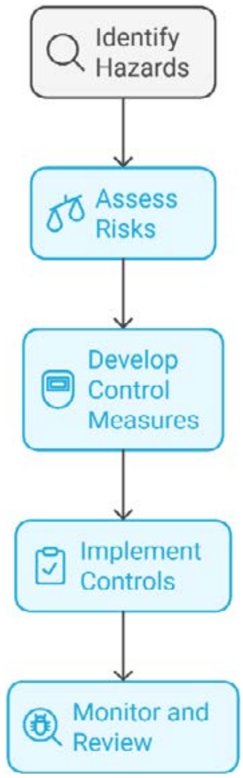


Figure 7.13: Steps in hazard control planning

1. **Identify Hazards**: The initial step involves systematically identifying potential hazards that could pose risks to health and safety. These hazards may be physical, chemical, biological, or ergonomic in nature. A comprehensive hazard assessment considers both immediate and latent threats within the workplace environment.
2. **Assess Risks**: Once hazards are identified, the next step is to assess the associated risks by evaluating the probability and potential severity of harm. This risk assessment helps to prioritise hazards, enabling resources to be focused on those that present the greatest threat to employee well-being.
3. **Develop Control Measures**: In this phase, appropriate control measures are designed to eliminate or mitigate the identified risks. The hierarchy of controls—ranging from elimination, substitution, and engineering controls to administrative controls and personal protective equipment (PPE)—guides decision-making in selecting the most effective interventions.

4. **Implement Controls**: This step involves the active deployment of the selected control measures. It requires ensuring that all employees are fully trained on the new procedures and are compliant with the safety protocols. Communication, training, and enforcement are essential to ensure the controls are effectively applied across the workforce.
5. **Monitor and Review**: Ongoing monitoring and evaluation of the implemented controls are necessary to assess their effectiveness. This step involves collecting data, conducting audits, and adjusting control measures where required. Regular reviews ensure that hazard control plans remain dynamic and aligned with evolving risks and workplace conditions.

Organisations can create a robust hazard control plan that reduces risks, enhances workplace safety, and ensures compliance with regulatory standards.

Examples of Hazard Control Measures in Manufacturing

Table 7.1 shows typical hazard control measures as can be applied in a manufacturing environment

Table 7.1: Hazard control measures

Control parameter	Hazard	Control measure
Noise control	High noise levels from machinery	Install soundproof enclosures around noisy equipment, provide earplugs or earmuffs, and schedule regular maintenance to keep machinery running smoothly.
Chemical safety	Exposure to toxic chemicals.	Substitute with less harmful chemicals, use proper ventilation systems, store chemicals safely, and provide appropriate PPE such as gloves, coveralls, aprons, face shields, rubber boots and respirators.
Improvement in ergonomics	Repetitive strain injuries from poor workstation design.	Redesign workstations to be more ergonomic, provide adjustable chairs and tables, use mechanical lifting aids, and implement job rotation to reduce repetitive motions.
Elimination of explosions.	Explosion from high pressure components and systems.	Regular maintenance and inspection of parts, provision of proper training to the individuals, PPEs and first aid kit.

Importance of Hazard Control Planning

- **Protects Workers**: Hazard control planning is fundamental in safeguarding the health and well-being of employees by systematically mitigating risks and preventing accidents and injuries. Through proactive hazard identification and control measures, the likelihood of workplace incidents is significantly reduced, ensuring a safer work environment.
- **Legal Compliance**: Effective hazard control planning ensures adherence to occupational health and safety regulations, thereby helping organisations avoid potential legal liabilities and penalties. By complying with relevant safety standards, companies not only meet regulatory requirements but also enhance their operational credibility and reduce exposure to legal risks.
- **Improves Efficiency**: A well-structured hazard control plan fosters a safer work environment, which directly correlates with improved operational efficiency. By minimising workplace accidents, organisations can reduce downtime, lower absenteeism, and optimise resource utilisation, leading to enhanced productivity and sustained business performance.
- **Enhances Reputation**: Demonstrating a commitment to worker safety through effective hazard control planning reinforces a company's reputation as a responsible and ethical employer. This commitment not only attracts top talent but also boosts employee morale, fostering a culture of safety that contributes to long-term organisational success.

Figure 7.14: Importance of hazard control planning

Case Study: Hazard Control in Ameen Sangari Company Ltd.

Company Overview

Ameen Sangari Company Ltd is a well-established company located in Cape Coast, Ghana, specialising in the processing of palm nuts to produce high-quality soap. Founded over 50 years ago, the company has built a reputation for delivering affordable and effective soap products to local regional and national markets. The company operates a sizable facility, employing approximately 300 workers, and produces over 500 tonnes of soap monthly, contributing significantly to the local economy.

The manufacturing process at Ameen Sangari begins with the extraction of palm oil from palm nuts, followed by the refining and mixing of the oil with other ingredients like caustic soda and fragrances to produce soap. This multi-stage process involves several complex operations, including heavy lifting, exposure to chemicals, and the use of high-temperature equipment. Despite its success, the company faced challenges related to workplace safety, as the production environment posed various hazards such as machinery-related injuries, chemical exposure, fire risks, and ergonomic concerns. To mitigate these risks and improve the overall well-being of its workers, Ameen Sangari Company Ltd embarked on a comprehensive hazard control plan to enhance workplace safety, reduce accidents, comply with occupational health and safety standards, and foster a more efficient production process

Hazard Identification: Ameen Sangari Company Ltd conducted a thorough hazard assessment of its production facility. The primary hazards identified included:

1. **Physical Hazards**
    a. Exposure to moving parts in machines such as the palm nut extractors and soap mixers.
    b. Risk of crushing, entanglement, and other injuries associated with improperly guarded equipment.
    c. Exposure to high temperatures (e.g. during boiling of palm but).
    d. High noise levels
2. **Chemical Hazards**
    a. The use of caustic soda and other chemicals in the soap-making process, leads to potential chemical burns and respiratory issues.
    b. Fumes from chemicals used in soap production.
3. **Ergonomic Hazards**
    a. Repetitive lifting of heavy bags of palm nuts and constant stirring in soap mixers.
    b. Poor workstation design that led to musculoskeletal strain.
4. **Fire Hazards:** High-risk environment due to the use of flammable materials like oils, caustic soda, and other chemicals, combined with high temperatures during the soap-making process.
5. **Slips, Trips, and Falls:** Wet floors in the production area, increasing the risk of slip and fall accidents.

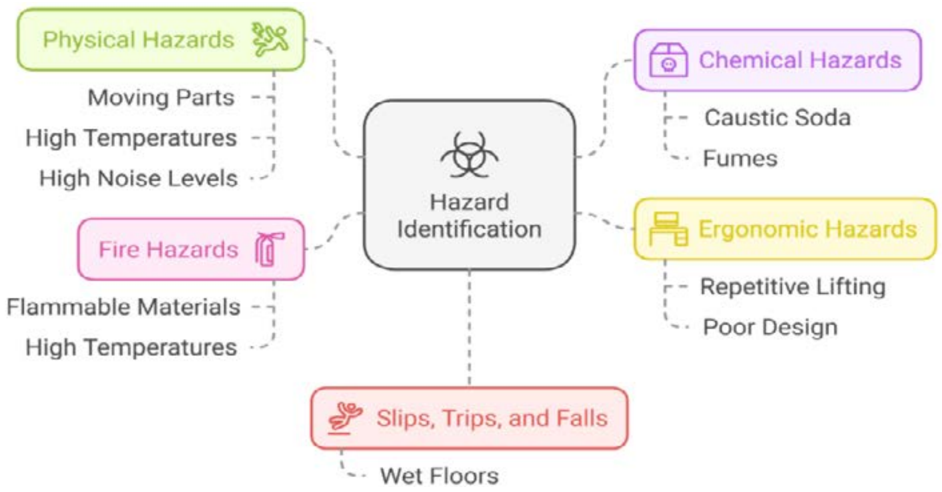


Figure 7.15: Hazard identification

Hazard Assessment: The company's risk assessment process included the following steps:

- **Task Analysis**: Detailed review of every department's process to identify specific risks linked to each job.
- **Exposure Monitoring**: Measurements of chemical exposure, noise levels, and ergonomic assessments to evaluate risk.
- **Health and Safety Audits**: Ongoing safety inspections and audits to ensure compliance and track effectiveness of implemented controls.

Hazard Control Measures: Based on the hazard assessment, Ameen Sangari Company Ltd introduced the following control measures, using the hierarchy of controls:

1. **Elimination**
   a. Automated certain hazardous and repetitive tasks in the soap-making process to reduce manual intervention.
   b. Simplified processes to remove unnecessary steps that created safety risks.

2. **Substitution**
   a. Replaced toxic chemicals like certain solvents with less harmful alternatives in the soap production process.
   b. Substituted noisy machinery with quieter, more efficient models to reduce noise pollution in the facility.

3. **Engineering Controls**
   a. Installed machine guards and safety interlocks to prevent accidental contact with moving parts.
   b. Upgraded ventilation systems to efficiently remove fumes and airborne chemical contaminants.
   c. Re-designed workstations to improve ergonomics, including adjustable workbenches and mechanical lifting aids.

4. **Administrative Controls**
   a. Implemented mandatory training on hazard recognition, safety protocols, and safe machine operation.
   b. Established job rotation systems to minimise repetitive strain injuries and reduce fatigue.
   c. Developed standard operating procedures (SOPs) for each task to ensure consistent and safe practices.
5. **Personal Protective Equipment (PPE)**
   a. Provided workers with appropriate PPE such as gloves, goggles, face shields, and respirators for handling chemicals.
   b. Issued ear protection to employees working in high-noise areas and flame-resistant clothing for those exposed to heat.

Practical Applications and Results

- **Machine Hazards**: The installation of machine guards and emergency stop buttons reduced machine-related injuries by 50%. Routine maintenance ensured that equipment was operating safely and efficiently.
- **Chemical Exposure**: By substituting safer chemicals and improving ventilation, the company reduced chemical-related incidents by 35%. Workers handling chemicals were provided with adequate PPE, significantly reducing the risk of burns and respiratory problems.
- **Ergonomics**: The redesign of workstations and introduction of adjustable equipment and lifting aids reduced ergonomic injuries by 40%. The implementation of job rotation also helped reduce musculoskeletal disorders.
- **Fire Hazards**: The addition of fire suppression systems and improved storage for flammable materials helped the company avoid fire-related incidents. Workers were trained in fire safety protocols, contributing to a safer environment.
- **Slips, Trips, and Falls**: Improved floor drainage and anti-slip coatings on wet surfaces led to a 45% reduction in slip-and-fall incidents. Regular housekeeping practices also helped maintain a safer working environment.

Activity 7.1 On-Site Hazard Assessment and Hazard Control Plan

1. Visit a nearby manufacturing company. Observe various processes and interactions, focusing on (If you are unable to visit a manufacturing company you should undertake this same activity based on your school laboratories and workshops.):
   a. How risks are identified in the manufacturing process.
   b. How hazard control plans are developed and implemented.
   c. How hazards are managed through controls (e.g., equipment, PPE, or administrative procedures).

2. Take notes and ask questions about the company's safety protocols, risk assessment processes, and the effectiveness of the control measures in place.
3. Organise yourselves into groups of no more than five. In your groups, collaborate and reflect on observations, exchange ideas, and produce a detailed report on:
   a. What types of hazards were identified in the observed department(s)?
   b. How were these hazards assessed in terms of severity and likelihood?
   c. What hazard control measures were implemented, and how effective do they seem?
   d. Did the company follow the hierarchy of controls? If so, how? If not, what could be improved?
4. As a group create your own hazard control plans based on the observations. These plans should:
   a. Identify and assess hazards in the observed department.
   b. Suggest control measures according to the hierarchy of controls.
   c. Address how to implement and monitor these measures.
5. Prepare a written report that summarises:
   a. The observations made during the site visit.
   b. A description of the identified hazards.
   c. An assessment of the risks and control measures observed.
   d. A developed hazard control plan, including suggested improvements if necessary
6. Prepare a power point presentation and present this to your class for discussion and feedback.

Activity 7.2 Case Study and Role Play on Hazard Control Plan

Materials/data needed:

- Pen and paper or digital tools (Word Processor/Spreadsheet/ Presentation Software)
- Access to safety regulations (e.g., OSHA guidelines)
- Sample workplace layouts or descriptions (can be provided by the instructor)
- Case study or real-world example of a manufacturing company (can be fictional or based on actual data)

Role-Playing Case Study: Manufacturing Safety Simulation

Objective

You will engage in a role-playing exercise to identify hazards, develop control measures, and demonstrate safety procedures in a manufacturing environment. You will be evaluated based on your understanding and implementation of workplace safety measures.

Company Overview

SteelTech Manufacturing Ltd. is a mid-sized manufacturing company specialising in the production of precision metal components for the automotive and aerospace industries. The facility operates heavy machinery, chemical processing units, and assembly lines. The company employs a diverse workforce, including machine operators, engineers, quality control specialists, and logistics personnel. Due to the nature of its operations, workplace safety is a top priority, requiring strict adherence to safety regulations and protocols.

Roles

Your group will consist of the following stakeholders:

- Safety Officer: Oversees safety protocols, ensures compliance, and guides the team on hazard control measures.
- Worker: Performs the assigned task while adhering to safety guidelines and reporting concerns.
- Manager: Balances productivity with safety requirements and ensures all protocols are followed.
- Observer/Evaluator: Assesses the team's adherence to safety protocols and provides feedback.

Scenarios

Your group will be assigned two of the following scenarios and must develop a hazard control plan:

- Noisy Environment: Workers are exposed to high levels of noise from heavy machinery.
- Handling Toxic Chemicals: Employees deal with hazardous substances requiring proper safety procedures.
- Using Sharp-End Machinery: Workers operate or maintain cutting tools and machines with exposed sharp edges.
- Working with Fumes: Employees work in an environment where fumes are generated, requiring ventilation and protective measures.

Safety Equipment Available

- Personal Protective Equipment (PPE) (e.g., gloves, goggles, ear protection, respirators)

- Safety signage and hazard communication materials
- Emergency response kits (e.g., eyewash stations, first aid kits)
- Ventilation systems and fume hoods
- Noise-cancelling barriers

Step 1: Hazard Identification

1. Organise yourselves into groups of no more than five. In your groups, embark on a hazard identification exercise based on the provided information about the manufacturing company. Potential hazards could include:
   a. Machinery (moving parts, sharp edges)
   b. Chemical exposure (fumes, spills, dust)
   c. Physical hazards (slips, trips, falls)
   d. Ergonomic concerns (repetitive strain, heavy lifting)
   e. Biological (e.g., exposure to bacteria or mould)
2. You should use real-world examples or potential scenarios to identify where these hazards might occur in the workplace.

Step 2: Assess the risk associated with each hazard by considering:

1. The likelihood of the hazard occurring (High, Medium, Low)
2. The severity of its potential impact (High, Medium, Low)

Note: Prioritise hazards based on the combination of likelihood and severity to determine which ones pose the greatest risk to workers.

Step 3: Hazard Control Methods

Propose control measures for the most significant hazards identified.

Follow control strategies such as:

1. Elimination: Removing the hazard entirely (e.g., automating a process to avoid human exposure to harmful chemicals).
2. Substitution: Replacing a hazardous material with a safer alternative.
3. Engineering Controls: Redesigning the workspace or machinery (e.g., machine guards, ventilation systems).
4. Administrative Controls: Changing work practices or procedures (e.g., job rotation to minimise repetitive motion).
5. Personal Protective Equipment (PPE): Providing gloves, masks, safety goggles, etc.

Note: All suggested controls for their identified hazards, must follow safety regulations and best practice.

Step 4: Creating the Hazard Control Plan

Generate a Hazard Control Plan document. This plan should include:

1. An introduction to the company and its operations.
2. A list of identified hazards with descriptions.
3. The risk assessment for each hazard.
4. Control measures proposed for each hazard.
5. An implementation timeline (when and how these controls will be put in place).
6. A monitoring and review plan (how the effectiveness of controls will be assessed and adjusted over time).

Step 5: Evaluation of the Hazard Control Plan creation

Evaluation Rubric:

Criteria	**Excellent (5)**	**Good (4)**	**Satisfactory (3)**	**Needs Improvement (2)**
Hazard Identification	Clearly identifies all hazards in the scenario	Identifies most hazards with some detail	Identifies some hazards but lacks depth	Identifies a few hazards but misses major risks
Control Measures	Proposes comprehensive and effective safety measures	Proposes effective but slightly incomplete measures	Proposes basic safety measures	Proposes limited and ineffective measures
Implementation	Demonstrates clear and thorough safety procedures	Demonstrates procedures with minor errors	Follows procedures but lacks clarity	Partially follows procedures
Role-Playing Engagement	Fully engages in the role with realistic responses	Engages with minor inconsistencies	Somewhat engages but lacks realism	Minimal engagement in role
Team Collaboration	Excellent teamwork and communication	Good teamwork with minor lapses	Basic teamwork but needs improvement	Minimal teamwork and coordination

Step 6: Group presentation

In your group prepare a PowerPoint presentation on your hazard control plan. Present this to the class for discussion and feedback. In the presentation, you should explain:

1. How you identified and assessed the risks.
2. Why you chose specific control measures for each hazard.
3. How you plan to monitor and review the success of your controls.
4. How each role contributed to ensuring workplace safety.
5. Improvements that could be made to enhance safety in your scenario.
6. The importance of hazard control plans in real-world environments.

Activity 7.3 Analysis of the Risks Posed by a Common Chemical

Materials/data needed:

- Pen and paper or digital tools (Word Processor/Spreadsheet/ Presentation Software)
- A sample Material Safety Data Sheet (MSDS) for a particular common chemical

Steps

1. In a small group, discuss the MSDS provided and identify all the important information contained about this chemical in the different sections of the MSDS. Discuss and agree in your group:
    a. How this chemical should be stored in order to minimise the risks to both human and environmental safety.
    b. How this chemical should be used in order to minimise the risks to both human and environmental safety.
    c. How this chemical should be disposed of after being used in order to minimise the risks to both human and environmental safety.
2. Create a PowerPoint presentation to explain your group's analysis to the rest of your class for discussion and feedback.

EFFECT OF MANUFACTURING ON THE ENVIRONMENT

Manufacturing activities are a significant contributor to environmental degradation, serving as a primary source of pollution across air, water, and soil. The pollutants released during industrial processes can have extensive and enduring impacts on ecosystems, public health, and the global climate. Key forms of pollution stemming from manufacturing include atmospheric contamination, waterborne pollutants, and soil degradation, each posing distinct threats to the environment and human well-being.

Air Pollution

Air pollution resulting from manufacturing arises when detrimental substances are released into the atmosphere during industrial production processes. These pollutants, which encompass gases, particulate matter, and hazardous chemicals, contribute significantly to a range of environmental and public health issues.

Types of Air Pollutants

- **Carbon Dioxide (CO_2)**: A primary greenhouse gas emitted through the combustion of fossil fuels in industries such as steel manufacturing, cement production, and energy generation. CO_2 is a major driver of climate change.
- **Sulphur Dioxide (SO_2)**: Released from the burning of coal or oil in power plants and industrial processes such as metal smelting. SO_2 is a precursor to acid rain, which can severely damage forests, soil, and aquatic ecosystems.
- **Nitrogen Oxides (NO_x)**: Emitted by vehicles, power plants, and industrial operations. NO_x contributes to the formation of ground-level ozone, leading to smog and exacerbating respiratory conditions.
- **Volatile Organic Compounds (VOCs)**: Released from the use of solvents, paints, and chemical manufacturing processes. VOCs play a crucial role in smog formation and can cause a range of health problems, including headaches, dizziness, and respiratory irritation.
- **Particulate Matter (PM)**: Fine particles produced by industries such as cement manufacturing, mining, and construction. These particles can penetrate deep into the lungs, leading to respiratory and cardiovascular diseases.

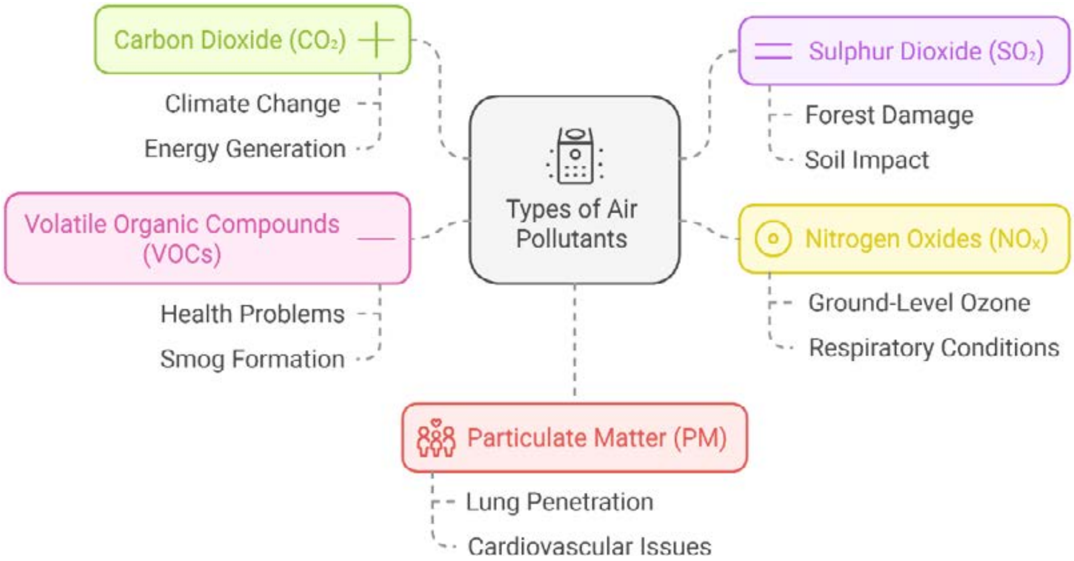


Figure 7.16: Types of air pollutants

Examples of Air Pollution in Manufacturing

1. **Cement Manufacturing:** The production of cement is a significant source of CO_2 emissions, which exacerbate global warming. In addition, the grinding and heating processes release substantial amounts of dust and particulate matter, further deteriorating air quality.

2. **Oil Refineries:** During the refining of crude oil into petroleum products, oil refineries emit a range of pollutants, including SO_2, NO_x, and VOCs. These emissions contribute to the formation of smog and acid rain, with harmful effects on both the environment and human health.

3. **Steel Production:** The steel manufacturing process is a major source of CO_2 and particulate matter emissions, primarily due to the combustion of coke and other fossil fuels in blast furnaces. These pollutants contribute to air pollution and are detrimental to both environmental and public health

4. **Power Generation:** Power plants, particularly those that burn coal or natural gas, emit large quantities of CO_2, SO_2, and NO_x. These emissions are primary contributors to climate change, acid rain, and smog, negatively impacting both air quality and public health.

5. **Chemical Manufacturing:** The production of chemicals, such as plastics, fertilisers, and pesticides, releases a wide array of volatile organic compounds (VOCs), as well as hazardous air pollutants like benzene and formaldehyde. These substances contribute to smog formation, air toxicity, and respiratory illnesses.

6. **Textile Production:** The textile industry emits various pollutants, including VOCs from dyes and solvents, as well as particulate matter from the use of cotton and synthetic fibres. These emissions degrade air quality and can cause significant health problems for workers and nearby communities.

7. **Mining Operations:** Mining activities, particularly coal and metal mining, release dust and particulate matter into the atmosphere. The combustion of fossil fuels used in mining equipment also adds to CO_2 emissions, further contributing to air pollution.

8. **Pulp and Paper Industry:** This industry emits sulphur compounds, including SO_2, as well as VOCs during the pulping process. These pollutants contribute to air quality degradation and can lead to respiratory and cardiovascular problems for workers and surrounding population

Water Pollution

Water pollution arises when industrial processes release harmful substances into water bodies such as rivers, lakes, and oceans. These pollutants may include toxic chemicals, heavy metals, and untreated wastewater, all of which contribute to the contamination of water sources and pose significant threats to aquatic ecosystems and biodiversity.

Types of Water Pollutants

- **Heavy Metals**: Elements such as lead, mercury, cadmium, and arsenic are often released into water from industrial processes like metal plating, mining, and the production of batteries. These metals are highly toxic to marine life and can accumulate in the food chain, posing serious health risks to both wildlife and humans.
- **Chemical Contaminants**: A wide range of industrial chemicals, including solvents, dyes, and pesticides, are frequently discharged into rivers, lakes, and oceans. This contamination can taint drinking water supplies and cause significant harm to aquatic ecosystems, disrupting the balance of marine life.
- **Nutrient Pollution**: Excessive amounts of nutrients, particularly nitrogen and phosphorus, are introduced into water bodies from agricultural runoff and wastewater from food processing plants. These nutrients promote the growth of algae, leading to eutrophication; a process that creates oxygen-depleted "dead zones" where most marine life cannot survive.
- **Oil and Grease**: Oil spills and leaks, especially from the petroleum industry, release harmful oils and greases into water systems. These pollutants coat marine organisms, destroy coastal habitats, and disrupt the overall health of aquatic ecosystems.
- **Plastic Pollution**: Plastics, including micro plastics, are widespread in aquatic environments, often originating from littering, industrial waste, or the breakdown of larger plastic items. These pollutants are ingested by marine life, causing physical harm and introducing toxic chemicals into the food chain.
- **Pharmaceuticals and Personal Care Products (PPCPs)**: These substances, which include medications, hormones, and chemicals found in personal care products, are often released into water bodies through wastewater discharges. They can disrupt aquatic ecosystems and contribute to the development of antibiotic-resistant bacteria.

- **Radioactive Contaminants**: Radioactive substances, such as those from nuclear power plants or medical waste, can contaminate water sources. These pollutants pose long-term health risks, including cancer, and can affect ecosystems for extended periods.
- **Thermal Pollution**: The discharge of hot water from industrial processes, power plants, or cooling systems can raise the temperature of water bodies. This disrupts the natural temperature balance, harming aquatic life that is sensitive to temperature changes, and reducing oxygen levels in the water.

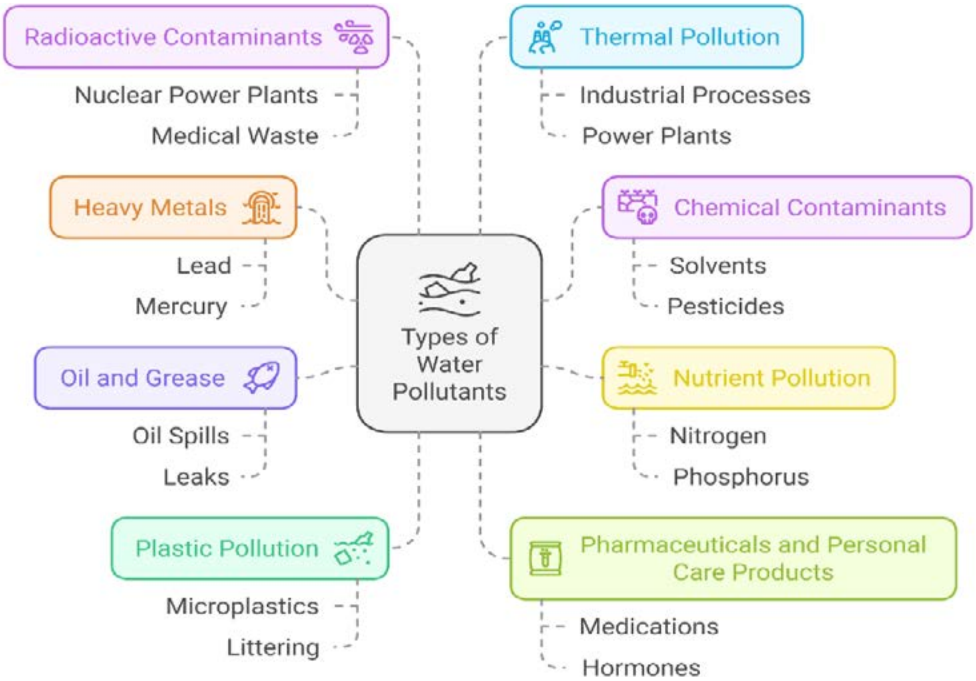


Figure 7.17: Types of water pollutants

Examples of Water Pollution in Manufacturing

1. **Textile Manufacturing**: In textile production, factories often release a variety of harmful substances, including synthetic dyes, chemicals, and heavy metals, into nearby water sources. The disposal of these pollutants not only degrades water quality but also poses significant risks to aquatic ecosystems, disrupting biodiversity and potentially contaminating drinking water supplies.

2. **Electronics Manufacturing**: The production of electronics generates wastewater laden with hazardous heavy metals such as lead, mercury, and cadmium. These toxic substances can seep into water bodies, leading to contamination that endangers both human health and the well-being of aquatic organisms, often resulting in long-term environmental damage.

3. **Food Processing**: Water used in food processing plants often contains high levels of organic waste, nutrients, and various chemicals. When released into nearby rivers or lakes, this wastewater contributes to nutrient pollution, fuelling the process of eutrophication. This leads to oxygen-depleted "dead zones," where aquatic life struggles to survive, disrupting local ecosystems

4. **Mining Operations**: Mining, especially for metals and minerals, generates wastewater laden with harmful substances such as heavy metals, cyanide, and sulphuric acid. The runoff from mining activities can pollute nearby rivers, lakes, and groundwater, causing long-term environmental damage and posing serious health risks to both wildlife and humans who rely on contaminated water sources.
5. **Oil and Gas Production**: In the extraction and processing of oil and gas, large amounts of wastewater, containing hydrocarbons, heavy metals, and toxic chemicals, are often released into nearby water bodies. This type of pollution can lead to oil spills, disrupt aquatic ecosystems, and negatively affect the health of communities relying on local water sources for drinking and irrigation.
6. **Textile Dyeing**: In addition to general textile manufacturing, dyeing processes are particularly polluting, releasing large amounts of coloured wastewater filled with toxic chemicals such as azo dyes and formaldehyde. These pollutants can stain water bodies, severely affecting both aquatic life and human health.
7. **Automobile Manufacturing**: The automotive industry contributes to water pollution through the discharge of oils, paints, solvents, and other chemicals used in the production and finishing of vehicles. These contaminants can enter water sources through improper disposal, leading to severe ecological and health impacts.

Soil Pollution

Soil pollution occurs when harmful chemicals, heavy metals, and other toxic substances from industrial activities contaminate the soil. This contamination can lead to a significant decline in soil quality, harm to plant life, and the contamination of food crops, ultimately affecting ecosystems and human health.

Types of Soil Pollutants

- **Heavy Metals**: Industries such as mining, battery production, and metal plating release toxic heavy metals, including lead, cadmium, and arsenic, into the soil. These metals are highly persistent, remaining in the soil for extended periods. They can be absorbed by plants, thereby entering the food chain and posing serious health risks to both wildlife and humans.
- **Pesticides and Herbicides**: The production and use of agricultural chemicals, such as pesticides and herbicides, can lead to soil contamination through spills, leaks, and improper disposal. These chemicals disrupt the balance of soil microorganisms, reducing biodiversity and fertility, which can ultimately degrade soil health and crop productivity.
- **Industrial Waste**: The improper disposal of industrial waste, including hazardous chemicals, plastics, and other toxic materials, contributes to soil pollution. These contaminants can poison the soil, inhibit plant growth, and harm both terrestrial and aquatic life. Over time, the degradation of soil quality can lead to the loss of arable land and negatively impact agricultural systems.
- **Solvents and Chemicals from Manufacturing**: Many manufacturing processes, especially in the chemical, paint, and pharmaceutical industries,

release solvents and synthetic chemicals into the environment. These pollutants can seep into the soil, contaminating it with toxic substances that persist for years. These chemicals can degrade soil structure, hinder plant growth, and contaminate groundwater.

- **Radioactive Waste**: Some industries, such as mining, nuclear power plants, and research laboratories, may dispose of radioactive materials improperly. These radioactive contaminants can remain in the soil for thousands of years, posing long-term environmental risks and affecting plant, animal, and human health through radiation exposure.
- **Construction and Demolition Debris**: Construction activities often result in the accumulation of debris, including cement, bricks, and other building materials, which, if not disposed of correctly, can lead to soil contamination. These materials can alter the physical properties of the soil, reduce its ability to retain water, and introduce hazardous substances like asbestos or lead into the soil.
- **Oil and Petrochemical Waste**: Spills and leaks from the oil and petrochemical industries, including used oils, lubricants, and refinery by-products, can contaminate the soil. These substances can poison plants and animals, degrade soil quality, and pose a long-term threat to ecosystems by preventing plant growth and affecting soil structure.
- **Plastics**: The accumulation of plastic waste, particularly microplastics, in soil is an emerging environmental concern. Plastics break down very slowly, and as they degrade, they can leach harmful chemicals into the soil. These pollutants can impact soil fertility, disrupt the activity of soil organisms, and enter the food chain through crops.

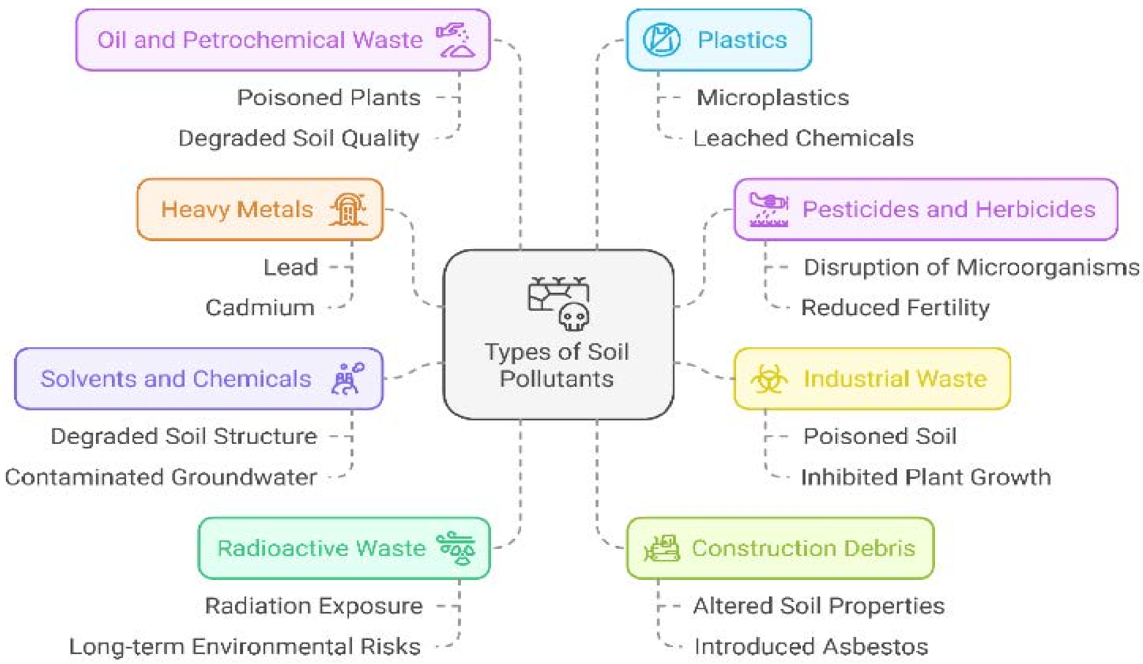


Figure 7.18: Types of soil pollutants

Examples of Soil Pollution from Manufacturing

1. **Battery Manufacturing**: The production and improper disposal of batteries can result in the contamination of soil with toxic heavy metals such as lead and cadmium. These metals can leach into the soil over time, creating long-lasting environmental hazards and posing serious risks to human health, wildlife, and plant life.
2. **Mining Activities**: Mining operations often introduce heavy metals and toxic chemicals, such as cyanide and sulphuric acid, into the soil. These pollutants can degrade soil quality, disrupt ecosystems, and prevent the growth of vegetation, leading to long-term ecological damage and the loss of fertile land.
3. **Chemical Manufacturing**: The production of chemicals can release a wide array of hazardous wastes and toxic substances into the soil. These contaminants can persist for extended periods, severely impacting soil health, reducing agricultural productivity, and threatening human health through the ingestion of contaminated crops and water.
4. **Plastic Manufacturing**: The production of plastics involves the use of various chemicals, including solvents, dyes, and additives, which can contaminate the surrounding soil if waste is not disposed of properly. These chemicals, along with plastic waste itself, can accumulate in the soil, reducing its quality and impacting plant and animal life.

Resource Depletion

Resource depletion refers to the exhaustion of natural resources due to human activities, particularly those associated with industrial and manufacturing processes. As the global demand for goods and services continues to grow, industries increasingly consume raw materials and energy resources, leading to significant environmental and ecological consequences.

Raw Material Extraction

Manufacturing industries are heavily reliant on the extraction of raw materials from the earth, such as minerals, metals, fossil fuels, and biomass. The unsustainable extraction of these resources can lead to the depletion of natural reserves, environmental degradation, and the loss of biodiversity.

Types of Raw Material Depletion

1. **Minerals and Metals**: The mining sector extracts large volumes of minerals and metals, including iron, copper, aluminium, and rare earth elements, which are essential for the production of goods such as electronics and automobiles. Over-extraction of these materials can result in the depletion of mineral reserves, making these resources scarcer and more difficult to access for future generations.

2. **Fossil Fuels**: Energy-intensive manufacturing industries, such as steel production, cement manufacturing, and chemical processing, consume enormous quantities of fossil fuels, including coal, oil, and natural gas. The excessive use of these non-renewable energy sources not only accelerates their depletion but also contributes to global environmental challenges, such as climate change and air pollution.
3. **Forests and Biomass**: Industries like paper manufacturing, furniture production, and construction rely heavily on wood and other forms of biomass. The extensive deforestation required to meet these demands leads to habitat destruction, a reduction in carbon sequestration, and the disruption of ecosystems, further exacerbating biodiversity loss and climate change.

Examples of Raw Material Depletion in Manufacturing

1. **Electronics Manufacturing**: The production of electronic devices is heavily reliant on rare earth metals such as lithium, cobalt, and neodymium. The extraction of these metals through resource-intensive mining practices leads to the gradual depletion of natural reserve, while also contributing to significant environmental damage, including habitat destruction and pollution.
2. **Cement Production**: Cement manufacturing consumes vast quantities of limestone and other essential minerals. The continuous extraction of these materials not only threatens the long-term availability of limestone reserves but also results in the degradation of natural landscapes, disrupting ecosystems and altering local environments.
3. **Paper Industry**: The paper manufacturing sector is heavily dependent on wood as its primary raw material. Large-scale logging operations, designed to meet the industry's needs, accelerate deforestation, which in turn depletes forest ecosystems, reduces biodiversity, and exacerbates the impacts of climate change through the loss of carbon sequestration capacity.
4. **Steel Manufacturing**: Steel production requires significant amounts of iron ore, coal, and limestone. The constant extraction of iron ore from mines can deplete ore reserves, while coal mining for energy-intensive production processes exacerbates the depletion of fossil fuel resources. Additionally, mining activities can lead to soil erosion and pollution of surrounding water sources.
5. **Plastic Production**: The creation of plastic products heavily depends on petroleum, a non-renewable resource. The increasing demand for plastic has led to the depletion of oil reserves, while the environmental impact of plastic waste further exacerbates resource depletion, as plastics can take hundreds of years to break down.

Energy Consumption in Manufacturing

Manufacturing processes are inherently energy-intensive, drawing upon both renewable and non-renewable energy sources. The disproportionate reliance on non-renewable energy, such as fossil fuels, accelerates the depletion of these finite resources. Additionally, this excessive energy consumption significantly contributes to environmental degradation, including the exacerbation of climate change through increased greenhouse gas emissions and the depletion of natural resources that are crucial for sustaining future generation

Types of Energy Depletion

Non-Renewable Energy: Manufacturing industries rely heavily on fossil fuels—such as coal, oil, and natural gas—to power machinery, transport goods, and drive production processes. The excessive consumption of these finite resources accelerates their depletion, while simultaneously contributing to the release of greenhouse gases, exacerbating global climate change and environmental degradation.

Water Resources: Certain manufacturing processes, including textile dyeing, food processing, and chemical production, require substantial quantities of water. The over-extraction of water, particularly in regions already facing water scarcity, can lead to the depletion of vital aquifers and the degradation of aquatic ecosystems, threatening both local communities and biodiversity.

Renewable Energy: Although renewable energy sources like solar, wind, and hydroelectric power are more sustainable alternatives, their large-scale implementation necessitates significant land use, material extraction, and energy input. Without careful management, this can lead to the depletion of natural resources and create new environmental challenges, undermining the very sustainability they are intended to promote.

Hydropower: Although hydropower is often classified as renewable, it can contribute to resource depletion when large-scale dams disrupt local ecosystems and water cycles. The construction and maintenance of these dams can deplete water resources, affect biodiversity, and displace local communities, leading to long-term environmental consequences.

Natural Gas: While considered a "cleaner" fossil fuel compared with coal and oil, natural gas is still a non-renewable resource. Its extraction for manufacturing processes, heating, and power generation can deplete reserves, and the environmental impact of methane leaks and carbon emissions from natural gas extraction and use continues to contribute to global warming.

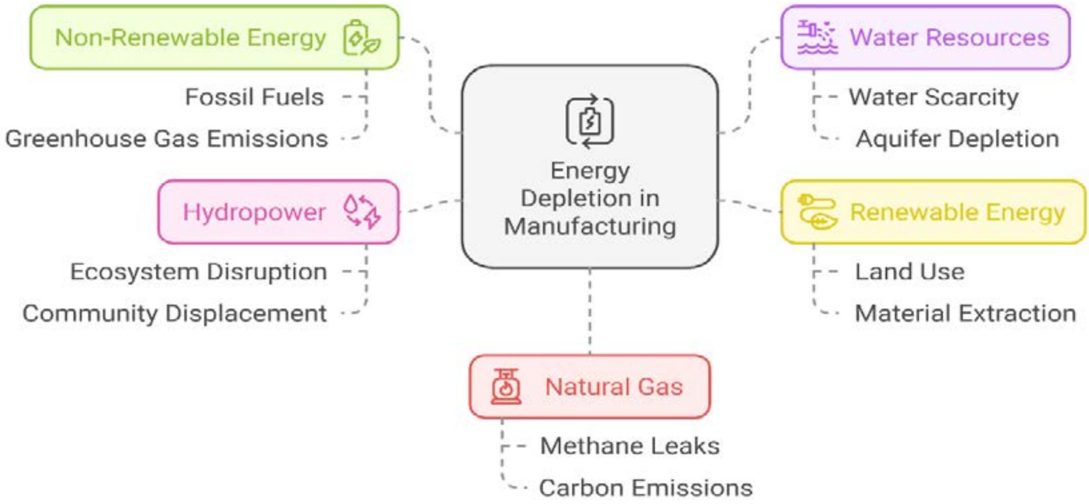


Figure 7.19: Types of energy depletion

Examples of Energy Consumption in Manufacturing

1. **Steel Manufacturing**: The steel industry stands as one of the most energy-intensive sectors, predominantly relying on coal and natural gas for its production processes. The ongoing reliance on these fossil fuels not only accelerates the depletion of non-renewable energy resources but also significantly contributes to air pollution and climate change through the emission of harmful greenhouse gases.

2. **Textile Industry**: The textile industry is notoriously water-intensive, requiring substantial volumes of water for processes such as dyeing, printing, and finishing. In regions where water resources are already scarce, this excessive consumption can lead to the depletion of local water supplies, thereby straining both human communities and surrounding ecosystems.

3. **Petrochemical Industry**: The production of plastics, fertilisers, and various chemicals within the petrochemical industry demands enormous quantities of fossil fuels, both as raw materials and as energy sources. The relentless extraction and consumption of oil and natural gas in this sector drive the depletion of these finite resources, compounding the environmental challenges associated with fossil fuel dependency.

4. **Aluminium Production**: Aluminium manufacturing is extremely energy-intensive, primarily relying on electricity to power the electrolysis process that separates aluminium from its ore, bauxite. This process is highly dependent on non-renewable energy sources, particularly coal and natural gas, leading to significant energy consumption, resource depletion, and substantial greenhouse gas emissions.

5. **Cement Industry**: The cement industry is a major consumer of energy, with the production of cement requiring the continuous burning of fossil fuels like coal and natural gas to heat kilns to high temperatures. This energy-intensive process depletes non-renewable energy resources and generates large quantities of carbon dioxide, a key contributor to global warming.

6. **Food and Beverage Processing**: The food and beverage industry consumes large amounts of energy for processes such as cooking, refrigeration, and packaging. The reliance on both electricity and fossil fuels for these processes leads to considerable energy consumption, further depleting non-renewable resources and contributing to environmental degradation.

7. **Mining and Extraction Industries**: Mining operations for minerals, metals, and other raw materials are highly energy intensive. These industries rely on vast amounts of energy, often derived from non-renewable sources like coal and natural gas, to power heavy machinery, transportation, and extraction processes. The continuous use of these resources accelerates their depletion while contributing to environmental degradation, including habitat destruction and increased carbon emissions.

Land Use and Habitat Degradation

Manufacturing industries frequently require vast expanses of land for the establishment of factories, mining operations, and waste disposal sites. The extensive appropriation and alteration of land for industrial purposes can lead to significant habitat degradation, loss of biodiversity, and alterations in land use patterns, which have profound ecological and environmental consequences.

Types of Land Use and Degradation

- **Deforestation**: Industries that depend on wood and other forest resources, such as paper and furniture manufacturing, contribute directly to deforestation. The clearing of forests for raw material extraction or to make space for industrial infrastructure leads to the destruction of vital habitats for numerous species, while also diminishing the land's capacity to sequester carbon, thereby exacerbating climate change.
- **Land Degradation**: Mining and quarrying operations involved in raw material extraction are major contributors to land degradation. The removal of topsoil, along with the erosion and contamination caused by mining processes, can render the affected land infertile and uninhabitable, rendering it unsuitable for agriculture and disrupting natural ecosystems.
- **Urbanisation and Industrialisation**: The growth of manufacturing industries often spurs urbanisation, transforming natural landscapes into sprawling industrial zones. This expansion results in habitat fragmentation, the loss of agricultural land, and escalating pressure on local resources, further compounding environmental stresses and diminishing the land's capacity to support diverse ecosystems.
- **Coastal Development and Industrial Expansion**: Manufacturing industries, particularly those involved in shipping, petrochemicals, and heavy industries, often expand into coastal areas. This leads to habitat destruction, such as the loss of wetlands, mangroves, and coral reefs, which play crucial roles in biodiversity, water filtration, and carbon storage. These developments also increase the risk of coastal erosion and disrupt marine ecosystems.

- **Waste Accumulation and Landfills**: Manufacturing industries that produce large quantities of waste, such as electronics or plastic products, often rely on landfills for disposal. The accumulation of industrial waste in landfills can lead to soil and groundwater contamination, and the ongoing need for landfill space exacerbates land depletion, ultimately degrading the surrounding environment and ecosystems.

Figure 7.20: Types of land use and degradation

Examples of Land Use and Habitat Degradation in Manufacturing

- **Mining Operations**: The extraction of metals such as iron, copper, and bauxite requires extensive land clearance, resulting in deforestation, soil erosion, and the destruction of natural habitats. For instance, bauxite mining in tropical regions has led to widespread deforestation of rainforests, displacing local communities and causing irreversible ecological damage, threatening both biodiversity and the livelihoods of indigenous populations.
- **Oil and Gas Extraction**: The process of extracting oil and natural gas frequently necessitates large-scale land clearing for drilling sites, pipelines, and related infrastructure. This land use not only disrupts natural habitats but also heightens the risk of catastrophic oil spills, which have devastating long-term effects on ecosystems, waterways, and wildlife, compounding environmental harm.
- **Urban Sprawl**: As manufacturing facilities expand in urban areas, large tracts of natural land are converted into industrial zones. This urban sprawl leads to habitat fragmentation, the reduction of vital green spaces, and an increase in the urban heat island effect, which exacerbates temperatures in cities, further disrupting local ecosystems and diminishing the quality of life for residents.

Waste Generation and Management

The manufacturing sector is a major contributor to waste generation, which has significant environmental consequences. Manufacturing processes produce a wide array of waste, including solid, liquid, hazardous, and non-hazardous materials. The effective management of this waste is critical to mitigating its harmful effects on the environment, public health, and surrounding ecosystems. Without proper waste treatment and disposal strategies, manufacturing waste can contaminate water supplies, degrade soil quality, and contribute to air pollution, underscoring the need for sustainable practices and comprehensive waste management systems.

Types of Waste Generated in Manufacturing

Manufacturing industries produce a diverse range of waste materials, depending on the specific processes and raw materials involved. The primary categories of waste include:

1. **Solid Waste**: This encompasses scrap materials, packaging waste, industrial by-products, and defective products. Solid waste can be classified as either non-hazardous or hazardous, based on its chemical composition and the potential risks it poses to the environment. The improper disposal of solid waste can lead to soil contamination and long-term ecological damage.

2. **Liquid Waste**: Manufacturing operations often generate liquid waste, including wastewater, coolants, solvents, and cleaning agents. These liquids may contain harmful substances such as oils, heavy metals, and toxic chemicals, making their treatment and safe disposal particularly challenging. Improper management of liquid waste can lead to groundwater contamination and pollution of water courses and water bodies (surface water).

3. **Gaseous Waste**: Manufacturing processes also produce gaseous emissions, including carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic compounds (VOCs), and particulate matter (PM). These gases contribute significantly to air pollution, posing serious risks to human health and the environment by exacerbating respiratory conditions, smog formation, and global warming.

4. **Hazardous Waste**: Hazardous waste includes materials that are toxic, corrosive, flammable, or chemically reactive. Examples include solvents, acids, heavy metals, and radioactive substances. Due to their potential to cause severe environmental and health hazards, hazardous waste requires specialised handling, treatment, and disposal methods to mitigate the risk of contamination and protect ecosystems and communities.

5. **E-Waste**: Electronic waste (e-waste) is generated by industries involved in the manufacturing of electronic devices and components. E-waste contains harmful substances, such as lead, mercury, cadmium, and brominated flame retardants. Improper disposal or recycling of e-waste can lead to significant environmental damage and pose serious health risks, particularly in developing regions where such waste is often handled informally.

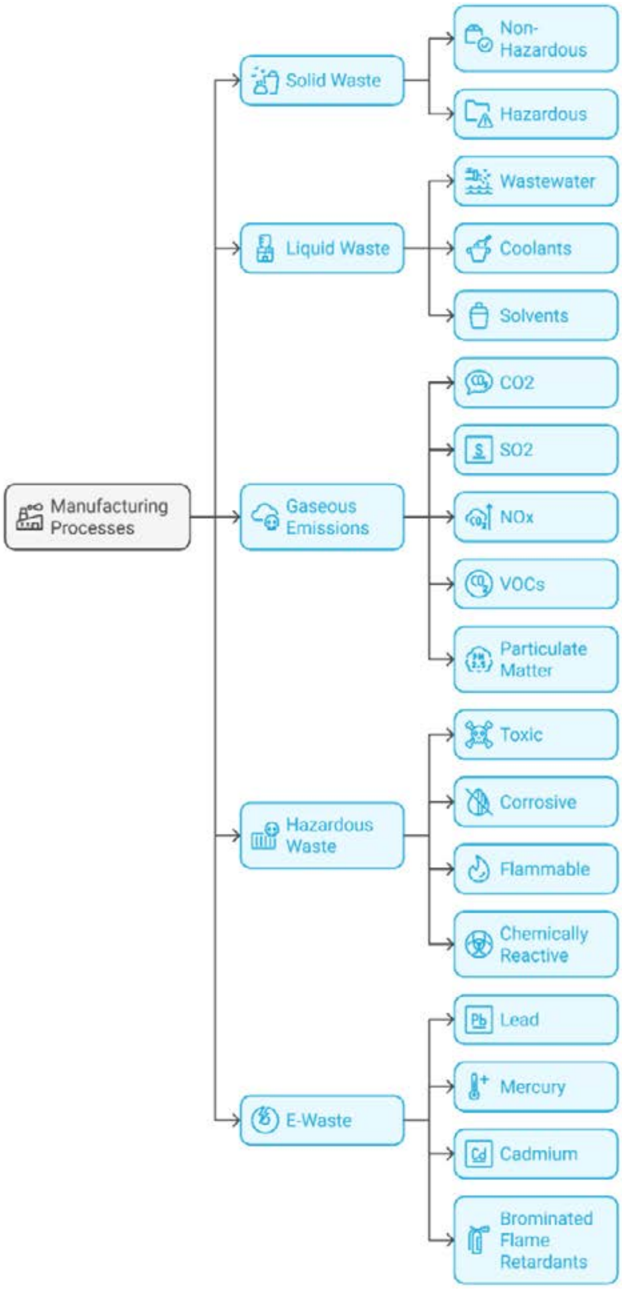


Figure 7.21: Types of waste generated in manufacturing

Waste Management Strategies in Manufacturing

Effective waste management in manufacturing is key for minimising environmental impact and fostering sustainability. The following strategies encapsulate key approaches for managing waste in industrial operations:

Waste Minimisation: The primary objective of waste minimisation is to curtail the volume of waste generated at its source. This can be accomplished through the optimisation of production processes, the substitution of materials, and the enhancement of manufacturing techniques. For instance, an electronics manufacturer might redesign its products to incorporate fewer hazardous substances or adopt more sustainable materials, significantly reducing the creation of e-waste.

Recycling and Reuse: Recycling and reuse involve extracting valuable materials from waste products for incorporation into new manufacturing processes, thereby reducing the reliance on virgin raw materials and minimising the environmental footprint associated with waste disposal. For example, in the automotive industry, metals, plastics, and glass retrieved from decommissioned vehicles are recycled and reintroduced into the production of new cars, lowering the need for new materials and promoting a circular economy.

Treatment and Disposal: Waste that cannot be minimised, recycled, or reused must undergo treatment to mitigate its environmental consequences before disposal. Treatment methodologies include incineration, neutralisation, and biological treatment. A chemical manufacturing facility, for example, might treat wastewater to eliminate harmful pollutants before it is released into natural water bodies, thereby safeguarding aquatic ecosystems and minimising the risk of water contamination.

Hazardous Waste Management: Hazardous waste necessitates specialised handling, storage, and disposal procedures to prevent ecological harm. Adherence to stringent regulatory frameworks and the application of advanced technologies are essential for the safe management of such waste. For example, a pharmaceutical company generating hazardous chemical byproducts may rely on secure containment and advanced disposal methods, such as high-temperature incineration or dedicated hazardous waste landfills, to prevent adverse environmental effects.

E-Waste Management: E-waste management refers to the responsible collection, recycling, and disposal of electronic products, with an emphasis on recovering valuable materials and properly managing hazardous components. For example, an electronics manufacturer might institute a comprehensive e-waste recycling program, enabling consumers to return outdated devices. This program would focus on recovering valuable materials, such as precious metals, while ensuring the safe disposal of toxic substances like lead or mercury.

Figure 7.22: Waste management strategies in manufacturing

ENERGY CONSUMPTION AND EMISSIONS

Energy consumption and emissions are critical factors in manufacturing that have far-reaching environmental implications. Manufacturing processes are inherently energy-intensive, often relying on fossil fuels as the primary source of energy. This reliance results in the release of numerous pollutants into the atmosphere, including greenhouse gases such as carbon dioxide, nitrogen oxides, and particulate matter. These emissions significantly contribute to pressing global environmental challenges, including climate change, air quality degradation, and the accelerated depletion of finite natural resources. The environmental impact of energy consumption in manufacturing highlights the urgent need for more sustainable energy practices and the adoption of cleaner, renewable energy sources.

Energy Consumption in Manufacturing

Manufacturing is an inherently energy-intensive sector, with energy usage varying significantly depending on the nature of the manufacturing processes, production scale, and materials involved. The energy consumed in manufacturing can be broadly categorised into several types:

- **Electricity**: Electricity is crucial for powering machinery, lighting, heating, and cooling systems within manufacturing facilities. Typically generated from fossil fuels such as coal, natural gas, or oil, electricity production from these sources remains a major contributor to carbon emissions, exacerbating environmental concerns.
- **Fossil Fuels**: Direct combustion of fossil fuels—such as coal, oil, and natural gas—is prevalent in manufacturing processes requiring high temperatures, such as steel production, cement manufacturing, and glass production. These fuels are significant sources of greenhouse gas (GHG) emissions, particularly carbon dioxide (CO_2).
- **Renewable Energy**: In an effort to mitigate the environmental impact of energy use, some manufacturing sectors are increasingly integrating renewable energy sources, including solar, wind, and biomass. Despite this progress, the adoption of renewable energy remains limited relative to the widespread reliance on fossil fuels.

Energy-Intensive Manufacturing Industries

- **Steel Manufacturing**: The steel industry is among the most energy-demanding, utilising vast quantities of coal in blast furnaces to convert iron ore into iron. This energy-intensive process results in substantial carbon dioxide (CO_2) emissions, making steel production a key contributor to global warming.
- **Cement Production**: Cement manufacturing requires the use of high temperatures during the calcination process, where limestone and other raw materials are heated in kilns. This process is highly energy-consuming and is responsible for significant CO_2 emissions, contributing to both environmental degradation and climate change.

- **Chemical Manufacturing**: The production of chemicals—such as ammonia, fertilisers, and plastics—demands considerable energy, typically derived from natural gas and other fossil fuels. These processes are energy-intensive and, therefore, significant contributors to both energy consumption and greenhouse gas emissions.

Emissions from Manufacturing

The emissions generated by manufacturing can be classified into several broad categories, each posing unique environmental and health risks. The emissions from manufacturing, particularly from energy-intensive industries, are a significant source of environmental degradation.

Greenhouse Gas Emissions

- **Carbon Dioxide (CO_2)**: The principal greenhouse gas emitted from the combustion of fossil fuels. CO_2 is the primary driver of global warming and climate change, with long-term environmental consequences.
- **Methane (CH_4)**: Released during the extraction and transport of fossil fuels, as well as from certain industrial processes like chemical manufacturing. Methane is a potent greenhouse gas, possessing a global warming potential far greater than CO_2.
- **Nitrous Oxide (N_2O)**: Emitted from industrial activities, particularly in the production of fertilisers and chemicals. Nitrous oxide is a powerful greenhouse gas with a prolonged atmospheric presence, contributing to long-term environmental harm.
- **Air Pollutants Sulphur Dioxide (SO_2)**: Emitted from the combustion of fossil fuels containing sulphur, such as coal and oil. SO_2 contributes to acid rain, which harms ecosystems, corrodes infrastructure, and impacts human health.
- **Nitrogen Oxides (NOx)**: Produced through high-temperature combustion processes, particularly in manufacturing facilities. NOx is a precursor to ground-level ozone and smog, which can severely affect respiratory health.
- **Volatile Organic Compounds (VOCs)**: Released from the use of solvents, paints, and other chemicals in industrial operations. VOCs contribute to the formation of ozone and smog, causing respiratory and neurological health problems.
- **Particulate Matter (PM)**: Fine particulate matter is emitted from industrial activities, combustion processes, and material handling. PM can penetrate deep into the lungs and bloodstream, leading to respiratory and cardiovascular diseases.

Toxic and Hazardous Emissions

- **Heavy Metals**: Industries such as metal plating, battery production, and electronics manufacturing release toxic heavy metals like lead, mercury, and cadmium into the environment. These metals accumulate in the food chain, posing severe health risks to humans and wildlife.
- **Dioxins and Furans**: By-products of certain industrial processes, including waste incineration and chemical manufacturing, these compounds are highly toxic. Dioxins and furans are known carcinogens and can cause reproductive and developmental issues, as well as immune system damage.
- **Persistent Organic Pollutants (POPs)**: Chemicals used in various industrial processes that persist in the environment and accumulate in living organisms. POPs, such as polychlorinated biphenyls (PCBs) and certain pesticides, have detrimental effects on both human health and ecosystems, leading to long-term ecological damage.

Emissions from Specific Manufacturing Industries

- **Cement Manufacturing**: The cement sector is a significant contributor to CO_2 emissions, primarily due to the energy-intensive calcination process and the combustion of fossil fuels in rotary kilns. Beyond carbon dioxide, cement plants also release a variety of pollutants, including particulate matter, sulphur dioxide (SO_2), and nitrogen oxides (NOx), all of which exacerbate air quality issues and pose serious risks to respiratory health.
- **Petrochemical Industry**: The petrochemical industry, responsible for producing chemicals such as plastics, fertilisers, and synthetic materials, is a major source of volatile organic compounds (VOCs), nitrogen oxides, and other hazardous air pollutants. These emissions play a critical role in the formation of ground-level ozone, contribute to smog, and adversely affect both public health and environmental quality through contamination of air and water resources.
- **Automobile Manufacturing**: The automotive manufacturing sector is a substantial emitter of carbon dioxide and other greenhouse gases, driven by the energy-intensive processes involved in vehicle production. Additionally, the use of solvents, paints, and coatings in the manufacturing of automobiles releases significant amounts of VOCs and hazardous air pollutants, which contribute to air pollution and pose long-term health risks.
- **Pulp and Paper Industry**: The pulp and paper sector is notorious for its environmental impact, with the pulping process releasing sulphur compounds, particulate matter, and volatile organic compounds (VOCs) into the atmosphere. In addition, the wastewater discharged by paper mills often contains a complex mixture of chemicals, organic pollutants, and heavy metals, which can severely degrade water quality and harm aquatic ecosystems.
- **Steel Manufacturing**: The steel industry is a major source of carbon dioxide and other greenhouse gases, particularly due to the high energy consumption involved in the production process, including the use of coke in blast furnaces. Additionally, steel production emits particulate matter, sulphur dioxide,

nitrogen oxides, and volatile organic compounds, which contribute to both air and water pollution and can negatively impact human health.

- **Mining Industry**: The mining sector, particularly in the extraction of metals and minerals, is a major emitter of carbon dioxide, methane, and other greenhouse gases. Additionally, the process of mining and refining metals such as copper, gold, and aluminium releases particulate matter, sulphur dioxide, nitrogen oxides, and heavy metals, leading to both air and water pollution. Mining operations can also result in land degradation and habitat destruction.

Climate Change Mitigation and Adaptation in Manufacturing

Mitigation strategies within the manufacturing sector are essential for reducing greenhouse gas (GHG) emissions and minimising its environmental footprint. These strategies primarily focus on improving energy efficiency, adopting cleaner technologies, and shifting towards renewable energy sources.

Enhancing Energy Efficiency: Boosting energy efficiency in manufacturing processes is an effective method for significantly curbing GHG emissions. This can be achieved through the modernisation of equipment, streamlining production workflows, and upgrading facility infrastructure. For example, the automotive sector has successfully integrated energy-efficient practices by installing LED lighting systems in production facilities, optimising heating, ventilation, and air conditioning (HVAC) systems, and utilising energy management systems to track and reduce overall energy consumption.

Transition to Renewable Energy: Shifting towards renewable energy sources such as solar, wind, and hydropower plays a pivotal role in drastically reducing the carbon footprint of manufacturing operations. By harnessing these cleaner energy alternatives, the manufacturing sector can move away from fossil fuels, which are a primary source of greenhouse gas emissions.

Carbon Capture and Storage (CCS): Carbon Capture and Storage technologies represent a critical innovation in the fight against climate change. CCS systems capture carbon dioxide (CO_2) emissions from manufacturing processes and store them underground or repurpose them for other applications. This prevents the release of CO_2 into the atmosphere, mitigating its contribution to global warming.

Waste Minimisation and Recycling: Reducing waste production and enhancing recycling efforts are essential components of a sustainable manufacturing strategy. By minimising waste and increasing the recycling of materials, manufacturers can lower the need for raw material extraction and reduce the energy required to process these materials. A notable example is the paper manufacturing industry, which uses recycled paper in its production process, reducing the demand for virgin pulp, thereby saving energy and cutting emissions.

Climate Change Adaptation Strategies in Manufacturing

As the effects of climate change intensify, manufacturing companies must implement robust adaptation strategies to safeguard the continuity and resilience of their operations. Adaptation involves modifying processes, infrastructure, and supply chains to effectively respond to evolving environmental challenges.

Building Resilient Supply Chains: Climate change poses significant risks to the stability of supply chains, potentially disrupting the availability of raw materials, altering transportation routes, and delaying production timelines. To mitigate these risks, manufacturing firms must cultivate resilient supply chains capable of adjusting to these shifting environmental conditions. This includes diversifying suppliers, investing in logistics flexibility, and integrating advanced risk management practices.

Adapting Infrastructure: Manufacturing facilities must be redesigned or relocated to withstand climate-induced hazards such as rising sea levels, extreme weather events, or escalating temperatures. Retrofitting buildings to meet new environmental standards, elevating infrastructure to protect against flooding, and implementing climate-resilient technologies are critical steps to ensure operational continuity in the face of these threats.

Enhanced Water Management: Water scarcity is a growing concern linked to climate change, requiring manufacturing companies to adopt more efficient water usage practices. This includes improving water efficiency, recycling wastewater, and sourcing water from sustainable and local sources to reduce dependence on increasingly scarce resources. Implementing water stewardship programs will be vital for mitigating the impact of droughts and ensuring a stable water supply.

Developing Flexible Production Systems: To maintain agility in the face of unpredictable environmental changes and shifts in market demand caused by climate change, manufacturing companies should develop flexible production systems. These systems should be capable of quickly adapting to supply disruptions, variations in resource availability, and changes in consumer preferences. The incorporation of modular manufacturing techniques and adaptive scheduling technologies can help companies remain competitive and resilient in a rapidly changing world.

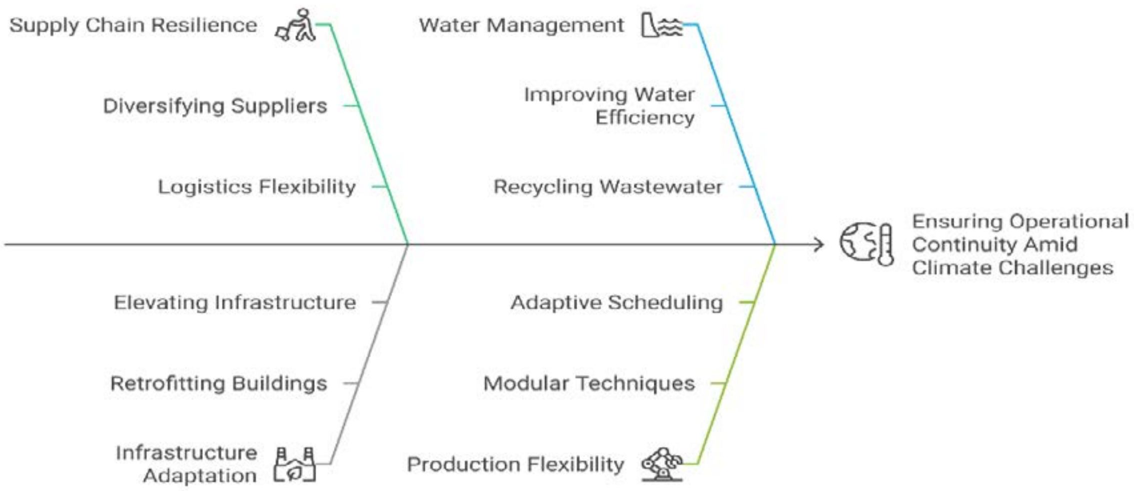


Figure 7.23: Climate change adaptation strategies in manufacturing

Activity 7.4 Impact of Manufacturing on the Environment

1. Join a small group. Each group chooses an industry that involves significant manufacturing processes like:
   a. Textile Industry
   b. Automobile Manufacturing
   c. Electronics Production
   d. Food Processing
   e. Mining and Metal Extraction
   f. Plastic Manufacturing
2. Research your assigned industry and answer the following questions:
   a. What are the key environmental impacts of this industry? (Consider air pollution, water pollution, waste generation, resource depletion, etc.)
   b. What are the primary raw materials used, and how do they affect the environment?
   c. How does the manufacturing process contribute to global warming and climate change?
   d. Identify at least two real-world examples of environmental damage caused by manufacturing in this industry.
   e. Describe the environmental issues caused by manufacturing in their assigned industry.
   f. Provide real-world examples of damage caused by industrial activities.
   g. Share any efforts that have been made to reduce environmental harm in this industry (e.g., sustainable practices, new technologies, recycling).

3. In your groups, brainstorm and come up with at least three solutions for how industries can reduce environmental impact (e.g., using renewable energy, recycling materials, adopting cleaner technologies, reducing water use).

Activity 7.5 A Visit to a Local Manufacturing Company

1. Visit a nearby manufacturing company (If you are unable to visit a local manufacturing company watch these videos. Links have been provided at the end of this activity).
2. Observe the waste management system, focusing on:
   a. Types of waste generated (solid, liquid, or air pollutants).
   b. Raw materials used and how they might affect the environment.
   c. Waste disposal or recycling processes.
   d. Any sustainable practices that are being implemented.
3. In a small group collaborate and reflect on observations, exchange ideas, and produce a detailed report on:
   a. What types of types of waste, raw materials, and waste management practices?
   b. Types of waste generated (solid, liquid, or air pollutants). Raw materials used and how they might affect the environment.
   c. Waste disposal or recycling system.
   d. Any sustainable practices that are being implemented. Take notes and ask questions about the company's waste management strategies.
4. Prepare a written report that summarises the following. You can also use flashcards, charts or mappings to make your presentation interesting.
   a. The observations made during the site visit.
   b. A description of the identified hazards.
   c. An assessment of the risks and control measures observed.
   d. A developed hazard control plan, including suggested improvements if necessary
5. Present your report to the class for discussion and feedback.

   Video links if you are unable to visit a local manufacturing company:

   - https://www.youtube.com/shorts/zewegWZD0dU
   - https://www.youtube.com/watch?v=r-q5V6LDxEY
   - https://www.youtube.com/watch?v=tdPmQTnb2-g
   - https://www.youtube.com/shorts/AuFAIlz597c
   - https://www.youtube.com/shorts/U9HdopsQMo4
   - https://www.youtube.com/watch?v=U3KUJTDPsSE
   - https://www.youtube.com/watch?v=uxtvgkhgwQA

Activity 7.6 Research on Climate Change Strategies

1. Use the internet or read the following relevant documents on one of these sub-strands:
   a. Climate change and its impact on manufacturing
   b. Mitigation strategies in manufacturing (e.g., energy efficiency, renewable energy, waste reduction)
   c. Adaptation strategies in manufacturing (e.g., climate-resilient infrastructure, sustainable water management, supply chain resilience)
   d. Positive and negative environmental impacts of different manufacturing activities
      - (http://creativecommons.org/licenses/by-nc-nd/4.0/)
      - https://www.climateguide.fi/articles/impacts-of-climate-change-on-industrial-production
      - https://www.open.edu/openlearn/money-business/leadership-management/supply-chain-sustainability/content-section-2.2
      - file:///C:/Users/Fatorma/Downloads/14976-Article%20Text-45352-1-10-20160613.pdf
      - https://ros.edu.pl/images/roczniki/2022/022_ROS_V24_R2022.pdf

2. Note down your findings and present this to your class or family for discussion and feedback.

BENEFITS OF USING ENVIRONMENTALLY FRIENDLY PROCESSES AND PRODUCTS IN MANUFACTURING

As industries around the world strive to meet the challenges of today's world the importance of using environmentally friendly processes and products in manufacturing has grown. These practices not only help protect the environment but also provide significant benefits to businesses, workers, and society. By adopting sustainable manufacturing methods, companies can reduce their environmental impact, lower costs, improve worker safety, and become more prepared for future challenges.

Reduced Environmental Impacts

Environmentally friendly manufacturing processes and products are designed to minimise harm to the environment. These methods help reduce waste, lower emissions, and conserve natural resources, which all play a key role in combating climate change, protecting ecosystems, and preserving biodiversity. By reducing their environmental impact, manufacturing companies can support global sustainability goals and avoid penalties related to environmental regulations. For instance, using renewable energy sources such as solar or wind power in production can significantly lower greenhouse gas emissions compared to traditional fossil fuels. Moreover, practices like recycling and reusing materials reduce the need for raw resource extraction, which helps prevent environmental damage.

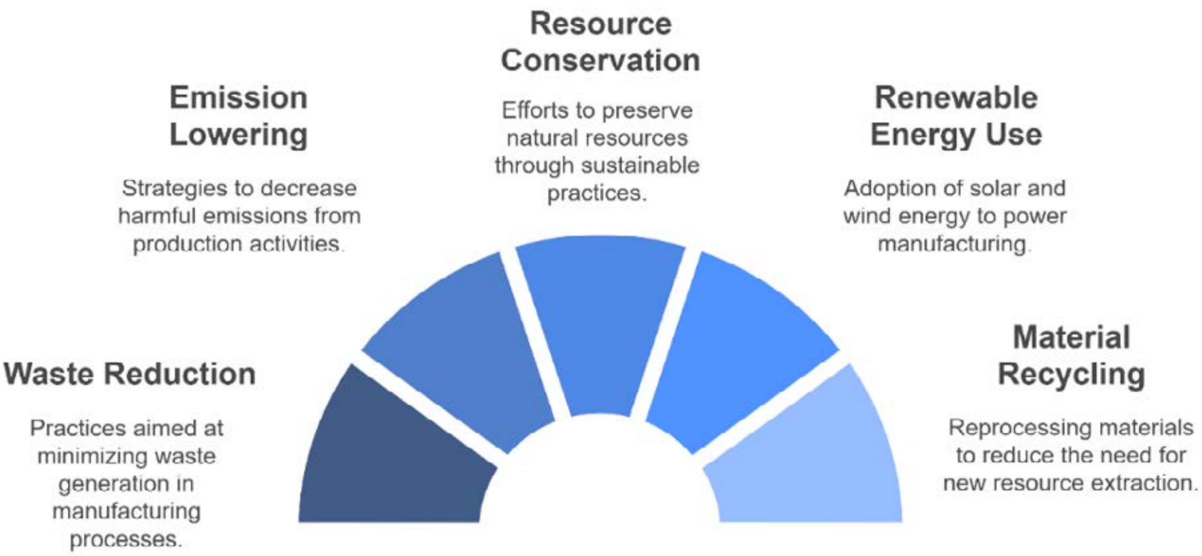


Figure 7.24: Reduced environmental impacts

Cost Savings and Efficiency

Adopting environmentally friendly practices in manufacturing can lead to significant cost savings and enhanced operational efficiency. While the initial investment in green technologies may be higher, the long-term advantages often far outweigh these upfront costs. For example, energy-efficient machinery uses less power, resulting in reduced utility expenses. Likewise, minimising waste and optimising resource utilisation lowers material costs and cuts disposal fees. Lean manufacturing techniques, which focus on waste reduction and process optimisation, are prime examples of eco-friendly practices that drive efficiency. By improving operational performance, companies can boost profitability while simultaneously reducing their environmental footprint.

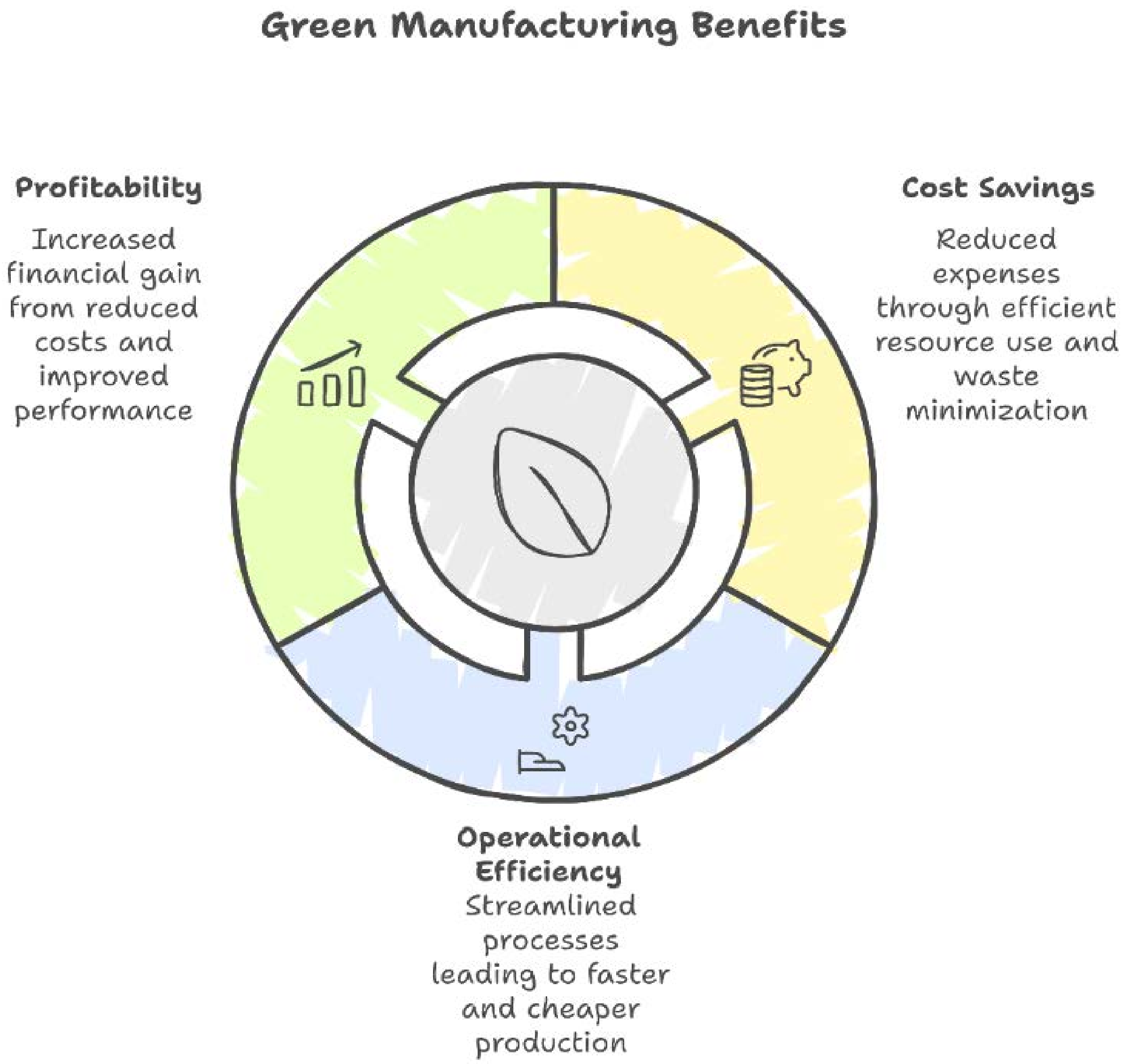


Figure 7.25: Cost savings and efficiency

Health and Safety

Environmentally responsible manufacturing processes typically involve the use of non-toxic materials and safer practices, which contribute to improved health and safety for both workers and consumers. Replacing hazardous chemicals with safer alternatives reduces the risk of exposure to harmful substances, resulting in fewer workplace accidents and health issues. Furthermore, the production of eco-friendly products, such as biodegradable packaging or non-toxic cleaning agents, minimises the potential harm to consumers and the environment. A strong focus on health and safety can also enhance a company's reputation, fostering greater customer trust and loyalty.

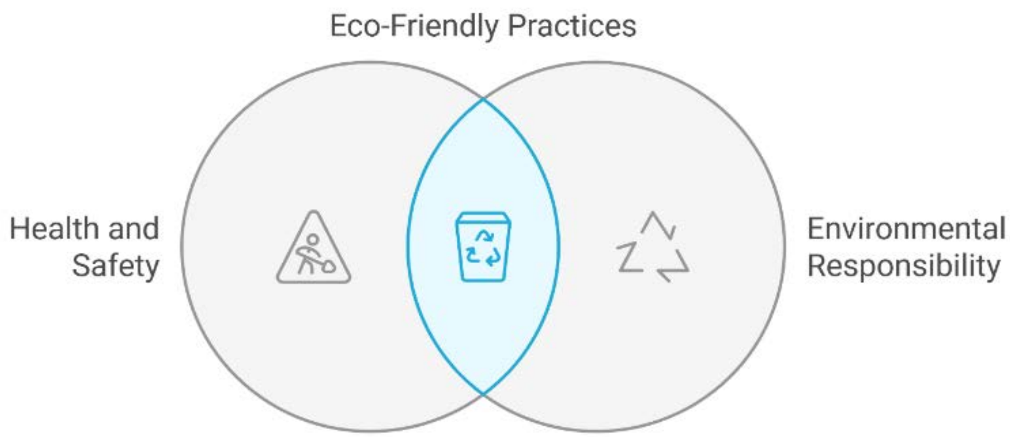


Figure 7.26: Health and safety

Resilience and Risk Management

The adoption of sustainable manufacturing processes can strengthen a company's resilience and enhance its risk management strategies. Environmentally friendly practices often involve diversifying energy sources, materials, and supply chains, making companies less vulnerable to disruptions caused by resource shortages, regulatory changes, or environmental disasters. For example, businesses investing in renewable energy become less exposed to the volatility of fossil fuel prices. Additionally, reducing dependence on scarce or environmentally harmful resources allows companies to better navigate future regulatory shifts and avoid supply chain interruptions. This resilience enables businesses to maintain stable operations and remain competitive in a market that increasingly prioritises sustainability.

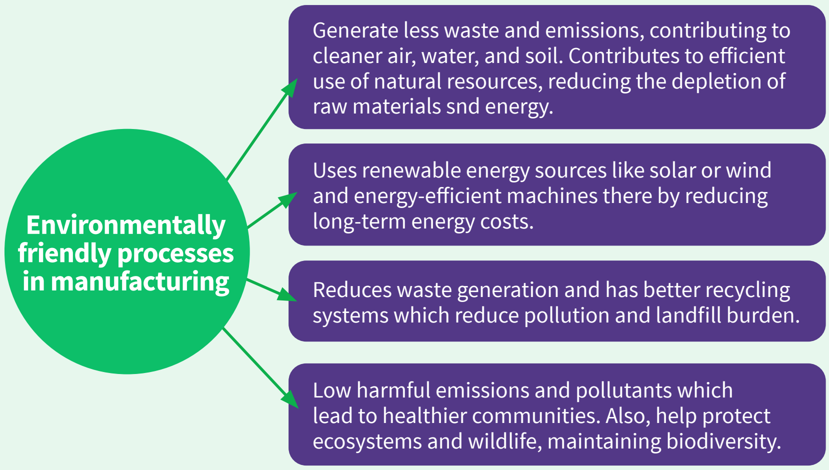
Figure 7.27: Resilience and risk Management

Activity 7.7 Impacts of Eco-Friendly Manufacturing Processes

1. Search the internet or watch the following videos or read from the documents on the environmentally friendly processes and products in manufacturing using the links and the documents provided.
    - https://www.youtube.com/watch?v=orTlPy-LIIE
    - https://www.youtube.com/watch?v=D7JpgfyinN8
    - https://www.youtube.com/watch?v=5T77wFoUeCE
    - https://www.youtube.com/watch?v=bIDjABY6Mis
    - https://eliteformmanufacturing.com/eco-friendly-manufacturing-processes/
    - https://green.org/2024/01/30/eco-friendly-manufacturing-processes/
    - https://www.scirp.org/pdf/ti_2024022715075775.pdf
    - https://greenly.earth/en-us/blog/ecology-news/what-was-the-industrial-revolutions-environmental-impact
    - https://earth.org/fast-fashion-companies/
2. As you research, make notes and prepare a presentation highlighting the benefits and importance of environmentally friendly processes and products in manufacturing.
3. Present this to your class for discussion and feedback.

Activity 7.8 Comparing Eco-Friendly vs. Conventional Manufacturing

1. In a small group, brainstorm the following:
   a. The concept of manufacturing processes and their impact on the environment and workers' health taking into consideration the sustainability, carbon footprint, pollution and health risks
   b. Types of manufacturing process: Company using environmentally friendly practices and the other on a company using conventional processes
2. Now watch these videos using the links below for better understanding
   - https://www.youtube.com/watch?v=61DW4G7pF1w
   - https://www.youtube.com/watch?v=B6FVwNiR1XI
   - https://www.youtube.com/watch?v=H_szMx1pVp0
   - https://www.youtube.com/results?search_query=1.5+bottle+recycle
3. After watching the videos, in your groups, discuss the following:
   a. Company using renewable energy sources, waste recycling, low-emission technologies, low energy consumption and less production cost.
   b. Company with traditional manufacturing processes such as high emissions, use of harmful chemicals, and poor worker conditions and pollution.
   c. The benefits of using eco-friendly practices over conventional ones?
4. Based on your discussion, develop a presentation and present this to your class for feedback.
   a. **Slide 1**
      Advantages of environmentally friendly processes and products in manufacturing on:
      i. waste and emissions
      ii. renewable energy sources
      iii. waste generation
      iv. harmful emissions and pollutants



b. **Slide 2**

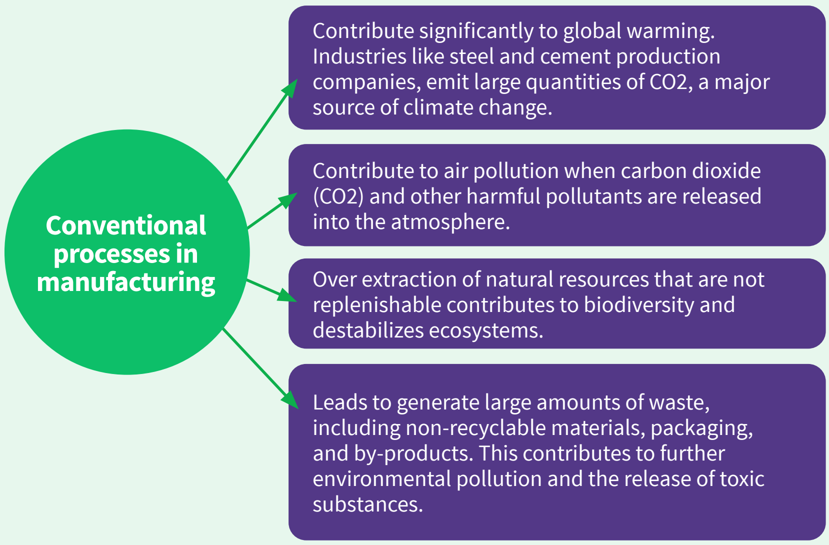
Effects of conventional processes and products in manufacturing on:

i. global warming

ii. air pollution and CO_2

iii. extraction of natural resources

iv. the amounts of waste and non-recyclable materials.



Activity 7.9 Benefits of Environmentally Friendly Processes

1. Organise yourselves into groups of no more than five. Brainstorm on the connection between manufacturing practices and global challenges like climate change, resource depletion, and pollution and the importance of sustainable manufacturing, focusing on how environmentally friendly processes and products help mitigate climate change and contribute to sustainability.
2. Use the internet or read from a variety of sources (textbooks, online articles, charts, or case studies) to gather information on the benefits of using

environmentally friendly processes and products in manufacturing. Focus on these areas:

a. Cost Benefits: Energy savings, waste reduction, and efficient use of resources.
b. Environmental Benefits: Reduced carbon footprint, conservation of natural resources, waste management.
c. Social Benefits: Health improvements, community impact, worker safety.
d. Business Benefits: Enhanced brand image, marketability, regulatory compliance.
e. Innovation and Long-term Viability: Sustainability as a driver of innovation and business longevity.

3. Discuss benefits of environmentally friendly processes. Ensure that the discussion is evidence-based and inclusive.
4. Prepare a report summarising the benefits of using environmentally friendly processes and products in manufacturing. You can present your report to the class for discussion and feedback. You can use the structure below for your report:

   a. Title: The Benefits of Environmentally Friendly Processes in Manufacturing: A way to Sustainability).

   b. Introduction: Introduce the concept of sustainable manufacturing and its significance. Briefly mention the importance of adopting environmentally friendly processes in combating climate change.

   c. Body of the Report:
      i. Cost Benefits: Explain how processes like energy efficiency and waste reduction save costs for manufacturers.
      ii. Environmental Benefits: Describe how sustainable practices, such as reduced emissions and resource conservation, protect the environment.
      iii. Social Benefits: Discuss how environmentally friendly processes contribute to health and safety and improve community well-being.
      iv. Business and Innovation Benefits: Analyse how sustainable practices enhance a company's reputation, open new markets, and foster innovation.
      v. Climate Change Mitigation Strategies: Discuss specific strategies to reduce manufacturing's impact on climate change and promote adaptation to climate-related challenges.

   d. Conclusion: Summarise the main benefits of adopting environmentally friendly processes. Provide a recommendation or a call to action for manufacturers to embrace sustainable practices.

RESEARCH TRENDS IN THE LOCAL MANUFACTURING INDUSTRY

The local manufacturing industry is undergoing continuous transformation, shaped by a variety of global and technological influences. These changes are primarily driven by factors such as globalisation, rising energy costs, heightened environmental consciousness, advancements in manufacturing technologies, the increasing emphasis on sustainability, and the transition toward digitalisation and Industry 4.0. This section explores these key drivers and examines their implications for the local manufacturing sector.

Globalisation

Globalisation has profoundly reshaped the manufacturing landscape, extending the reach of local manufacturers beyond domestic markets and placing them in direct competition on the global stage. This increased competition has compelled local manufacturers to enhance operational efficiency, reduce production costs, and uphold high product quality standards to remain competitive. In recent years, local manufacturers have placed a strong emphasis on optimising supply chains to ensure timely delivery and cost-effectiveness. The integration of global supply chains has become increasingly prevalent, necessitating advanced logistics and inventory management systems. To further reduce costs, many local manufacturers outsource production to countries with lower labour costs. This trend has spurred research focused on maintaining quality control and mitigating risks associated with outsourcing.

Additionally, adherence to international quality and environmental standards, such as ISO certifications, has become essential for local manufacturers seeking access to global markets. Research in this domain explores the impact of these standards on local manufacturing practices and product design. **Figure 7.28** shows the globalisation's impact in manufacturing.

Figure 7.28: Globalisation's impact in manufacturing

Rise in Energy Costs

The rising cost of energy presents a significant challenge for manufacturers, particularly in energy-intensive sectors. As energy prices fluctuate and environmental regulations become more stringent, manufacturers are under increasing pressure to adopt more energy-efficient processes. In response, local manufacturers are focusing on developing production methods that consume less energy. This includes utilising advanced materials that require lower energy inputs for processing and optimising existing manufacturing technologies. Additionally, the exploration of renewable energy sources such as solar and wind for manufacturing operations is gaining momentum. This trend is driven by the dual need to reduce reliance on fossil fuels and mitigate the financial impact of rising energy costs. **Figure 7.29** shows a diagram of rising energy costs.

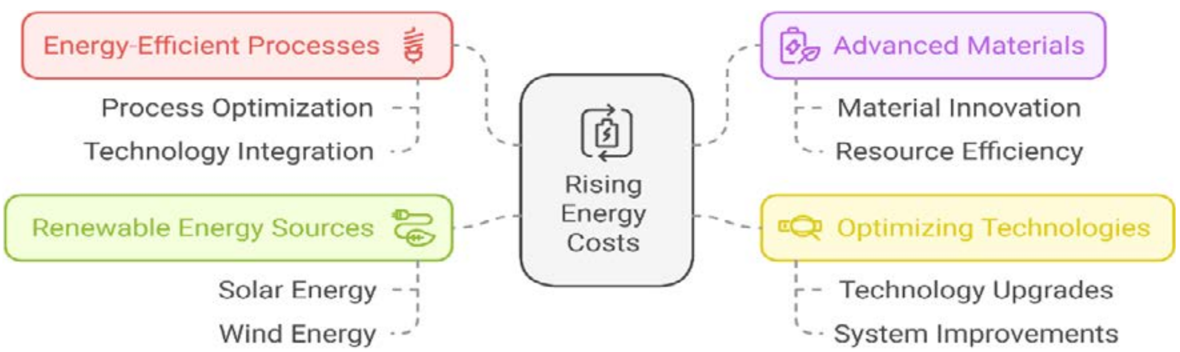


Figure 7.29: Rising energy costs

Increase in Environmental Awareness

Heightened environmental awareness among consumers, governments, and manufacturers has led to substantial changes in manufacturing practices. As a result, environmental sustainability has become a key priority in the industry. Local manufacturers are prioritising the reduction of environmental impacts through cleaner production techniques, which include minimising waste, reducing emissions, and using non-toxic materials.

Furthermore, there is an increasing focus on designing products that are environmentally friendly throughout their entire lifecycle, from raw material extraction to end-of-life disposal. This includes utilising recyclable materials and designing products that are easier to disassemble and recycle. Moreover, compliance with evolving environmental regulations has become essential, requiring manufacturers to adapt their production processes and materials to meet these stricter standards. **Figure 7.30** depicts overview of environmental awareness.

Figure 7.30: Environmental awareness

Advanced Manufacturing Technologies

Technological advancements are driving a revolution in the manufacturing sector. Cutting-edge manufacturing technologies such as automation, robotics, and additive manufacturing (3D printing) are enabling manufacturers to produce more complex products with greater precision and efficiency. The integration of robotics and automated systems has resulted in substantial increases in productivity and significant reductions in labour costs. Additive manufacturing, particularly 3D printing, allows for the creation of intricate geometries that would be either impossible or prohibitively expensive to achieve using traditional manufacturing methods. Manufacturers are exploring the potential applications of 3D printing across various industries. Additionally, the development of new materials with enhanced properties, such as lightweight composites and high-strength alloys, is crucial for improving the performance and efficiency of manufactured products. **Figure 7.31** shows details of advanced manufacturing technologies used in the manufacturing industry.

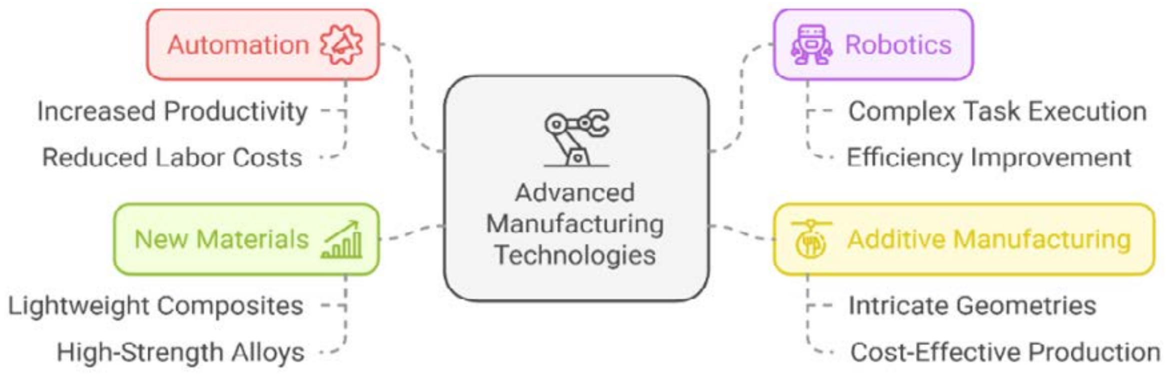


Figure 7.31: Advanced manufacturing technologies

Sustainable Manufacturing

Sustainable manufacturing focuses on producing goods in a way that minimises negative environmental impacts while conserving energy and natural resources. It also seeks to ensure the safety of workers and communities while maintaining economic viability. To achieve these objectives, most manufacturers conduct lifecycle assessments to understand the environmental impact of a product from raw material extraction through to production, use, and disposal. These assessments help identify opportunities to reduce environmental footprints at each stage of the product lifecycle.

Additionally, research efforts are concentrated on minimising the use of raw materials and energy in manufacturing processes, developing techniques that produce less waste, and recycling materials within the production cycle to ensure resource efficiency. Sustainable manufacturing is also often closely linked to corporate social responsibility (CSR) initiatives, where companies commit to ethical practices that benefit both society and the environment. **Figure 7.32** shows the various aspects of sustainable manufacturing.

Figure 7.32: Sustainable manufacturing

Digitalisation and Industry 4.0

The digital transformation of manufacturing, commonly referred to as Industry 4.0, involves the integration of advanced digital technologies into manufacturing processes. This shift is transforming the industry by enabling real-time data collection, analysis, and decision-making. Research in this area includes the use of the Internet of Things (IoT), big data, and smart manufacturing. IoT facilitates the connection of machines, devices, and systems within the manufacturing environment, enabling real-time monitoring and control for predictive maintenance, quality assurance, and process optimisation. Big data analytics plays a critical role in leveraging the vast amounts of data generated by digital manufacturing systems to enhance production efficiency, reduce downtime, and improve product quality. Techniques such as machine learning and artificial intelligence are employed to extract actionable insights from this data. Furthermore, smart manufacturing involves the use of digital technologies to create highly flexible, efficient, and sustainable production systems. This encompasses the development of smart factories that can rapidly adapt to changes in demand and production requirements. **Figure 7.33** shows a diagram of the interplay between digital manufacturing and industry 4.0.

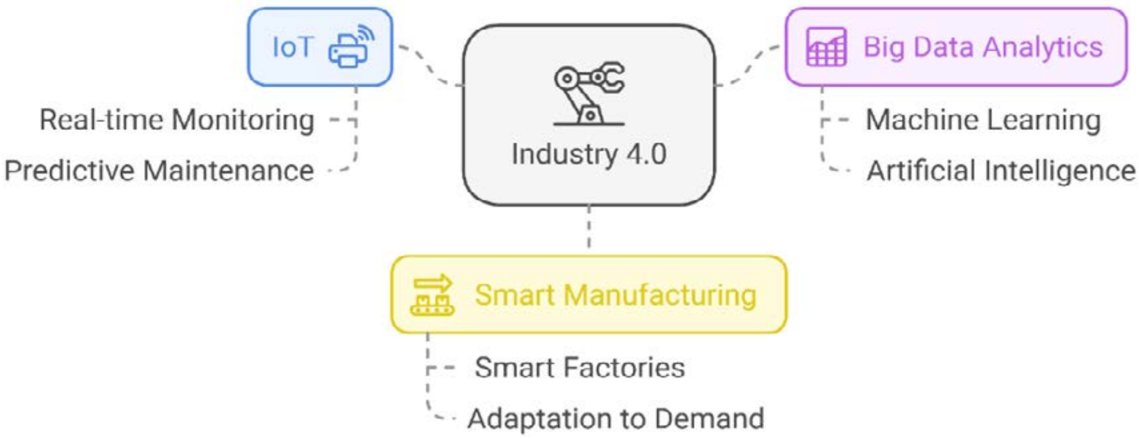


Figure 7.33: Digital manufacturing and industry 4.0

Activity 7.10 Research and Development in Manufacturing industry

1. Visit nearby research and development centres of selected manufacturing companies in your locality. Or a representative of their R&D team may visit your school to explain what they are doing to improve their manufacturing processes.
2. Observe and interact with the research team to learn about the projects being undertaken to improve manufacturing processes. You can ask them the following questions:
   a. What types of research has the company conducted? (Process improvement, product innovation, sustainability efforts, and automation.)

b. How do these research efforts aim to improve manufacturing processes?
c. What Technologies or equipment are being tested in their research and development department?
d. What projects and technologies are being researched and how the research will impact local manufacturing and the economy?
e. How can the research lead to improvements in local manufacturing (e.g., efficiency, quality, cost reduction, sustainability)?
f. What innovations does the research seeks to provide?
g. How sustainable are the company's practices and manufacturing plan?

3. After your visit (or the talk), organise yourselves into small groups of no more than five. In your groups, brainstorm the following:
   a. What is the importance of Research and Development in the manufacturing industry.
   b. How does Research and Development drive innovation, improve processes, enhance product quality, and promote sustainability.
4. Compile your observations, and analyse the potential impacts of the research on the local manufacturing sector.
5. Prepare a presentation based on your findings and present this to the class for discussion and feedback. Focus on the research, its potential impact on the local manufacturing sector, and how these innovations could improve practices in the community

Activity 7.11 Understanding Research in Local Manufacturing Industry

1. Use the internet, watch a video or read on the following areas using the links provided below
   a. Benefits of research in manufacturing.
   b. The impact of rising energy costs on manufacturing.
   c. Advanced manufacturing technologies.
   d. The rise of sustainable manufacturing practices.
   e. Digitalisation and Industry 4.0.
   f. Climate change mitigation and adaptation strategies for manufacturing
      - https://www.njmep.org/blog/why-manufacturers-need-research-development/
      - https://mslindia.net/blog/the-pivotal-role-of-research-and-development-in-manufacturing

2. Make notes as you research and share your findings with the class. Engage in a whole class discussion on the important of research in the local manufacturing industry.

Activity 7.12 Research and Trends in Improving Local Manufacturing

1. Organise yourselves into groups of no more than five. In your groups, discuss the following:
   a. How do rising energy costs affect the competitiveness of local manufacturers?
   b. Can digitalisation help manufacturers reduce their environmental footprint?
   c. What role does Industry 4.0 play in improving efficiency and reducing waste in manufacturing?
2. Make notes as you discuss and prepare a presentation based on your group's findings. The presentation should address:
   a. The benefits of research and innovation in improving local manufacturing.
   b. The impact of trends such as rising energy costs, digitalisation, and sustainability on the local community and the nation.
   c. Specific examples of how advanced manufacturing technologies and Industry 4.0 are transforming manufacturing.
   d. Climate change mitigation and adaptation strategies for the manufacturing sector
3. Present this to the class for discussion and feedback.

Extended Reading

1. A study on sustainable manufacturing practices in RMG industries of Bangladesh. Chowdhury, Nasif and Yasmin, Jarin City University, City University 30 May 2018. Online at https://mpra.ub.uni-muenchen.de/87104/ MPRA Paper No. 87104, posted 24 Jul 2018 10:42 UTC
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6. https://greenly.earth/en-us/blog/ecology-news/what-was-the-industrial-revolutions-environmental-impact
7. https://jewellinstruments.com/support/how-does-a-strain-gauge-work/?gad_source=2&gclid=EAIaIQobChMI773EoKrMiQMVm5tQBh28USuFEAAYASABEgI8bfD_BwE
8. https://math.ucr.edu/~res/math153-2021/week09unit11/Vernier%20caliper.pdf
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12. https://static.sdcpublications.com/pdfsample/978-1-63057-339-3-1-cw77gw9lwo.pdf
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16. https://www.encardio.com/blog/strain-gauge-principle-types-features-and-applications#
17. https://www.iitg.ac.in/engfac/ganu/public_html/Metal%20casting%20processes_1.pdf
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24. https://www.njmep.org/blog/why-manufacturers-need-research-development/
25. https://www.salesiancollege.com/uploaded/MainFolder/documents/hitthegroundrunning/Lectures/Resources/Physics_4_Micrometers_and_Calipers_Guide.pdf
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Additional Reading

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2. Callister, William D. "Materials Science and Engineering: An Introduction", 8th Edition, New York: John Wiley & Sons, 2010.
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Review Questions

1. Describe the difference between a hazard and a risk.
2. What are the five main levels of control measures used to mitigate hazards
3. Given a scenario where there is a chemical spill in a factory, outline the steps you would take to control this hazard.
4. Explain how you would prioritise hazards if multiples of them are identified in a risk assessment.
5. Describe one way in which manufacturing can contribute to resource depletion
6. Analyse how climate change can be influenced by manufacturing activities. What role do emissions play?
7. How can manufacturing companies reduce their impact on biodiversity? Provide two examples.
8. Why is it important for manufacturers to consider the environment when producing goods?
9. Discuss how research in environmental awareness has led to changes in manufacturing practices. Provide an example.

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GLOSSARY

WORD	MEANING
2D modelling:	Creating flat shapes and drawings on a computer using lines, circles, and other shapes.
3D modelling:	Making 3D objects on a computer that you can rotate and view from all sides.
Absolute coordinate:	A way of describing a point in a drawing by how far it is from a fixed starting point (0,0).
Accuracy:	The degree to which a measured value or result is close to the true or correct value. It indicates how closely a measurement or operation matches the intended or target specification.
Adhesive bonding:	A process in which two surfaces are joined using an adhesive material (such as glue or epoxy).
Administrative Controls:	Policies, procedures, and practices implemented to reduce the risk of hazards through changes in work procedures or schedules.
Annotating:	Adding notes, labels, and measurements to a drawing to explain things more clearly.
Arc Welding:	A welding process in which an electric arc is used to melt the base material and form a bond.
Assembly drawings:	Drawings that illustrate how components fit together, often using exploded views to show spatial relationships and assembly sequences.
AutoCAD command:	Special instructions you type into AutoCAD to make it do something, like drawing a line or changing a shape.
AutoCAD:	A software program used to make detailed drawings and models, often in architecture or engineering.
Auxiliary views:	Additional perspectives in drawings that provide detailed insights into various aspects of a product, essential for understanding complex designs.
Bead:	A raised line of weld metal formed during welding that joins two parts together.
Binder:	Materials used in sand-casting to hold sand grains together to form a mould.
Brazing:	Similar to soldering but uses a higher melting point filler metal to join parts.

WORD	MEANING
Butt Joint:	A type of joint where two pieces of material are joined end-to-end, commonly used in welding.
CAD (Computer-Aided Design):	Software used for creating precision drawings or technical illustrations.
Carbon footprint:	The total amount of greenhouse gases emitted into the atmosphere as a result of manufacturing activities, typically measured in equivalent tons of CO_2.
Casting:	A manufacturing process in which a liquid material, typically metal or plastic, is poured into a mould and allowed to solidify into a desired shape. Common methods include sand-casting, die casting, and investment casting.
Cavity:	The hollow space within a mould into which molten material is poured. The cavity determines the final shape of the cast part. A cavity can also refer to unintended voids within a part due to porosity.
Centrifugal casting:	A casting process where molten metal is poured into a rotating mould, allowing centrifugal force to shape the material.
Circular economy:	An economic model aimed at eliminating waste and continually using resources by reusing, recycling, and repairing materials and products.
Climate change adaptation:	Adjusting practices and processes to minimise the negative effects of climate change.
Climate change mitigation:	Efforts to reduce or prevent the emission of greenhouse gases to slow or reverse climate change.
Clinching:	A joining method that involves pressing two metal sheets together to form a mechanical interlock without the need for fasteners or welding.
Collapsibility:	The ability of a mould or core material to collapse or break apart easily once the casting has solidified. This helps facilitate the removal of the casting without damaging it.
Command window:	The area in AutoCAD where you type commands to tell the program what to do.
Computer-Aided Design (CAD):	Using a computer program to design things like buildings, machines, or parts.
Construction lines:	Light lines are used as guides to help construct the drawing.
Core:	A pre-formed insert placed in a mould to create internal features or voids in the cast part.

WORD	MEANING
Corporate Social Responsibility (CSR):	A business model in which companies integrate environmental, social, and economic concerns into their operations and interactions with stakeholders.
Cross-Sectional Views:	Views that show the interior details of an object as if it has been cut by a plane.
Cutting Plane:	An imaginary plane that slices through an object to create a sectional view.
Design for Assembly (DFA):	Principles aimed at optimizing the design to facilitate easier and faster assembly, reducing production costs and time.
Detailed drawings:	Drawings that focus on the specifications of individual parts, including dimensions, materials, and manufacturing processes.
Die casting:	A casting process in which molten metal is forced into a mould under high pressure.
Dimensioning:	The process of adding measurements to a drawing to specify the size and location of features.
Energy efficiency:	The use of less energy to produce the same amount of output, achieved through optimised manufacturing processes or the use of energy-saving technologies.
Engineering controls:	Physical changes to the workplace or equipment designed to reduce or eliminate hazards at the source.
Environmental Awareness:	The understanding and knowledge of environmental issues, including the effects of human
Environmental Regulations:	Laws and guidelines set by governments to regulate the environmental impact of manufacturing processes.
Exploded Views:	Drawings that show the components of an assembly separated but in positions that indicate their relationships.
Fastening:	The process of using fasteners like bolts, screws, or nuts to mechanically join parts together.
Fillet Weld:	A type of weld used to join two parts at right angles to each other, typically in corner joints.
Flux:	A chemical substance used in soldering, brazing, or welding to prevent oxidation of the metal and help the filler material flow.
Form:	The shape and structure of a design.
Freehand Sketching:	The technique of drawing without using precision instruments like rulers or compasses, capturing initial ideas and concepts.

WORD	MEANING
Friction Stir Welding:	A solid-state welding process in which a rotating tool generates heat and causes materials to join without melting.
Full Section:	A sectional view obtained by cutting an object completely in half.
Fusion Zone:	The area of material where the molten base metal is fused together during welding.
Globalisation:	The integration of national economies through the exchange of goods, services, and labour across borders.
Green Manufacturing:	Manufacturing processes that reduce environmental impact by using environmentally friendly materials, technologies, and energy sources.
Half Section:	A sectional view where only one quarter of the object is removed, showing both inside and outside details.
Hand tools:	Manual tools powered by human effort rather than electricity or machinery. They are typically used for various tasks in construction, repair, or other manual work, such as hammers, screwdrivers, pliers, and wrenches.
Heat Affected Zone (HAZ):	The area of material adjacent to a weld that is affected by the heat from the welding process, potentially changing the material properties.
Heat Treatment:	A process used to alter the physical and mechanical properties of a metal through controlled heating and cooling. Heat treatment can improve hardness, strength, and other material characteristics.
Hierarchy of Controls:	A system used to determine the most effective control method to reduce or eliminate hazards, prioritising elimination, substitution, engineering controls, administrative controls, and PPE.
HVAC systems:	Heating, Ventilation, and Air Conditioning systems regulate indoor environments by controlling temperature, humidity, and air quality.
Industry 4.0:	The integration of digital technologies (e.g., IoT, AI, robotics) into manufacturing to create smarter, more efficient, and environmentally sustainable production processes.
Investment casting:	A casting process where a wax pattern is coated with a ceramic shell, which is then melted away before the metal is poured.
Isometric drawing:	A method of visually representing three-dimensional objects in two dimensions, where the three coordinate axes appear equally foreshortened, and the angles between any two of them are 120 degrees.
Laser welding:	A welding process that uses a laser beam to melt and join parts, providing high precision and minimal heat-affected zones.

WORD	MEANING
Local Manufacturing Sustainability:	Efforts to make local manufacturing processes environmentally sustainable and economically viable in response to rising costs, environmental regulations, and consumer demand for eco-friendly products.
Manual:	It refers to a type of operation carried out by hand instead of automated or machine-driven processes.
Menu Bar:	The part at the top of AutoCAD where you can find different options like "File" and "Edit."
Metallurgy:	The science and technology of metals, including their extraction, alloying, casting, and processing. Metallurgy focuses on understanding the properties and behaviours of metals during manufacturing.
Mould:	A hollow form into which molten material is poured to create a part. The mould shapes the material as it solidifies.
Necessary Views:	The essential views needed to clearly describe an object in a drawing, chosen to minimise hidden lines and display the main shapes clearly.
Oblique drawing:	A type of drawing that shows an object with one face parallel to the drawing plane and the other faces receding at an angle.
Orthographic Projection:	A method of representing three-dimensional objects in two dimensions, using multiple views to show different sides of the object.
Overlap:	A type of welding defect where the weld metal extends beyond the base material.
Pattern:	A model of the part to be cast, typically made of metal, wood, or plastic, used to form the mould.
Patternmaking:	The process of creating the pattern or model for casting, usually from materials like wood or metal.
Permanent Mould Casting:	A casting process that uses durable moulds, usually made of metal, which can be reused for multiple castings.
Permeability:	The ability of a material, such as a mould or core, to allow gases to pass through it. Permeability is important in casting, as it helps prevent the formation of defects caused by trapped gases.
Personal Protective Equipment (PPE):	Equipment worn by workers to protect them from exposure to hazards that cannot be fully controlled through administrative or engineering means.

WORD	MEANING
Perspective drawing:	A technique used to represent three-dimensional objects on a two-dimensional surface, showing depth and space.
Pneumatic:	Pertaining to the use of compressed air or gas to perform mechanical work. Pneumatic systems are commonly used in tools, machines, and equipment where air pressure is used to power motors, actuators, and other components to perform specific tasks.
Porosity:	The presence of small holes or voids in a cast part, often caused by trapped gas or air during solidification. Porosity can weaken the final product and affect its strength and appearance.
Power consumption:	The amount of energy used in the manufacturing process, including electricity, gas, and other fuel sources.
Precision and Clarity:	The quality of drawings that provide a realistic representation of components, making it easier to visualize and understand critical features.
Precision:	The degree to which repeated measurements or operations yield the same result. In engineering and manufacturing, precision refers to the consistency and exactness with which a tool or process can perform a task.
Processing of Raw Materials:	The process of transforming raw materials into finished products through physical, chemical, or mechanical processes.
Prototyping:	Creating a preliminary model of a product to test and refine its design.
Readability:	The ease with which information can be understood or interpreted. In instruments and displays, readability refers to how the measurements or data can be read, including font size, contrast, and clarity.
Refrigerant:	A substance, typically a fluid, used in refrigeration and air conditioning systems to absorb and release heat.
Relative Polar:	A way of creating shapes by choosing an angle and distance from a starting point instead of using exact numbers.
Resource Efficiency:	Using fewer raw materials, water, and energy to produce goods without compromising quality
Reusability:	The ability of a material, such as sand in a mould, to be reused after a casting is completed. Reusability is important for cost-effectiveness and sustainability in casting.
Rise in Energy Costs:	The increase in the price of energy sources like electricity, gas, and oil.

WORD	MEANING
Riveting:	A mechanical joining process where a metal pin (rivet) is inserted through holes in parts and deformed to hold the parts together.
Sand-casting:	A casting process where a mould is made using sand, often used for larger parts.
Shakeout:	The process of removing the solidified casting from the mould, usually after it has cooled down. Shakeout involves breaking apart the mould material to retrieve the finished part.
Shell:	A thin, rigid outer layer created in investment casting, which supports the molten metal during pouring and solidification.
Shrinkage:	The reduction in volume of a material as it cools and solidifies, which can lead to dimensional changes in the cast part.
Software Programs:	Applications that run on a computer to do specific tasks, like AutoCAD for drawing and designing.
Soldering:	A joining process where a filler metal (solder) with a lower melting point is used to join two base materials, typically used for electrical components.
Solidification:	The process by which molten metal cools and transitions from a liquid to a solid state.
Spot Welding:	A welding process that uses heat and pressure to join small areas of materials, typically used for sheet metal.
Status Bar:	The section at the bottom of AutoCAD that shows useful info, like drawing settings and tools you are using.
Substitution:	Replacing a hazardous substance or process with a less dangerous one.
Sustainable Manufacturing:	Manufacturing processes designed to minimise environmental impact, reduce energy consumption, and use resources efficiently.
Tack Welding:	A temporary welding technique used to hold parts together before final welding.
Technological Innovation:	The development and application of new technologies to improve manufacturing efficiency and reduce environmental impact.
Tensile Strength:	The maximum stress a material can withstand before breaking, often a key property in joined materials.
Texture:	It refers to the feel, smoothness, roughness, or pattern on the surface, affecting both functionality and aesthetic appeal.

WORD	MEANING
Threading:	A process of creating helical grooves (threads) on a part's surface, often used to allow it to be screwed into another part.
Title Bar:	The bar at the top of the AutoCAD window that shows the name of the current drawing or project.
Tolerance:	The permissible limit of variation in a physical dimension, ensuring parts fit together correctly.
Toolbars:	Groups of buttons or icons in AutoCAD that give you quick access to tools for drawing or editing
Ultrasonic Welding:	A process in which high-frequency ultrasonic vibrations are used to generate heat and join materials, typically for plastics.
Waste Disposal:	The process of handling, recycling, or safely disposing of manufacturing byproducts and waste materials.
Welding:	A joining process in which two or more parts are fused together by melting the workpieces and adding a filler material.