



MINISTRY OF EDUCATION

MANUFACTURING ENGINEERING

For Senior High Schools

TEACHER MANUAL



YEAR TWO



**NATIONAL COUNCIL FOR
CURRICULUM & ASSESSMENT
OF MINISTRY OF EDUCATION**

MINISTRY OF EDUCATION



REPUBLIC OF GHANA

Manufacturing Engineering

For Senior High Schools

Teacher Manual

Year Two



**NATIONAL COUNCIL FOR
CURRICULUM & ASSESSMENT
OF MINISTRY OF EDUCATION**

MANUFACTURING ENGINEERING TEACHER MANUAL

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INTRODUCTION

The National Council for Curriculum and Assessment (NaCCA) has developed a new Senior High School (SHS) curriculum which aims to ensure that all learners achieve their potential by equipping them with 21st Century skills, competencies, character qualities and shared Ghanaian values. This will prepare learners to live a responsible adult life, further their education and enter the world of work.

This is the first time that Ghana has developed an SHS 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.

This Teacher Manual for Manufacturing Engineering is a single reference document which covers all aspects of the content, pedagogy, teaching and learning resources and assessment required to effectively teach Year Two of the new curriculum. It contains information for all 24 weeks of Year Two including the nine Key Assessments required for the Student Transcript Portal (STP).

Thank you for your continued efforts in teaching our children to become responsible citizens.

It is our belief that, if implemented effectively, this new curriculum 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.

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SECTION 1: CLASSIFICATION OF MATERIALS ACCORDING TO THEIR CHEMICAL PROPERTIES, STRUCTURE, PROCESSING AND SYNTHESIS

STRAND: MANUFACTURING MATERIALS AND TECHNOLOGIES

Sub-Strand: Classification of materials

Learning Outcome: *Classify materials as metals, ceramics and polymers based on their chemical properties, structure, synthesis and processing methods*

Content Standards

1. *Demonstrate knowledge and understanding of the chemical properties and structure of materials*
2. *Demonstrate knowledge and understanding of how to classify materials according to their use*

HINT



- *Remind learners to create a portfolio to show performance progress in the academic year.*
- *Refer to appendix A for details on how the portfolio should be organised and submitted in week 20.*
- *Give group project to learners in week 3, which will be submitted in week 20.*
- *Refer to Appendix B at the end of this section for details of how the group project should be organized.*

Introduction and Section Summary

In this section, learners will be introduced to the classification of materials based on their chemical properties, structure, synthesis, and processing methods. They will understand how to classify materials as crystalline and amorphous and identify material processing methods. Furthermore, learners will be able to classify materials according to their synthesis. By understanding these fundamental concepts, learners will gain insights into creating tailor-made products that enhance our quality of life and meet global standards. At the end of this section, students can classify materials into three main categories: metals, ceramics, and polymers. These classifications are essential for understanding how different materials impact product manufacturing.

The weeks covered by the section are:

Week 1: Classification of materials based on their chemical properties, structure, synthesis, and processing methods

Week 2: Classification of materials as crystalline and amorphous materials

Week 3: Identification of material processing methods

Week 4: Classification of materials according to their synthesis

Summary of Pedagogical Exemplars

Considering the diverse backgrounds, learning capacities, and styles of learners, it is vital to employ a comprehensive range of pedagogical approaches within the classroom. These alternatives include experiential learning through nature walks, collaborative learning, explorative learning, and discussion-based approaches. Organising field trips to local materials processing sites within the community can enhance their understanding. Encourage collaborative discourse among learners to explore various processes, classify materials based on chemical properties, structure, synthesis, and processing methods, and differentiate between crystalline and amorphous materials. Furthermore, learners can identify material processing techniques and classify materials according to their synthesis. In mixed-ability groups, learners can apply these concepts to address societal challenges

Assessment summary

A range of assessment methods should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions following a visit to a materials processing company; written responses of various difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Learners should be able to classify materials based on their chemical properties, structure, synthesis and processing methods and identify their processing methods. These should contribute to learners' formative assessment.

Teachers can refer to Teacher Assessment Manual and Toolkits (NaCCA, 2023) for further information on modes of assessment

WEEK 1

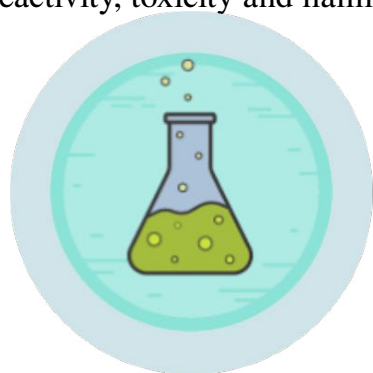
Learning Indicators

1. Group materials as metals, ceramics and polymers based on their chemical properties
2. Explain the chemical properties of materials as reactivity, flammability and toxicity

Focal Area 1: Explain reactivity, flammability, and toxicity as chemical properties of materials

Introduction

A chemical property of a material that is observed when a substance undergoes a chemical change. A chemical change is a type of change that also changes the identity of a substance due to the breakage and formation of new chemical bonds. The chemical properties of materials are fundamental to their functionality and application across various fields, including chemistry, biomedical engineering, mechanical and materials science. These properties are determined by the material's composition and structure at atomic and molecular levels, influencing their behaviour in different environments. Understanding the chemical properties of materials, such as reactivity, flammability, and toxicity, is essential in developing safer manufacturing practices and reducing the environmental impact of industrial activities. Figure 1.1 shows images of reactivity, toxicity and flammability symbols.



Reactivity



Toxicity



Flammability

Figure 1.1: *Reactivity, toxicity and flammability symbols*

Explain reactivity as a property of materials

Reactivity refers to the rate and extent to which a material undergoes chemical reactions under specified conditions. Reactivity, as a property of materials in manufacturing, plays an essential role in determining the efficiency, safety, and performance of various processes and products. Reactivity is a desirable quality in many chemicals, allowing them to be used in a variety of applications. However, it is also a property that can also turn a substance into a workplace hazard. A workplace may store several chemicals, without realising that they are reactive, and potentially hazardous. Reactive materials in the workplace must be identified and controlled. Reactive materials are generally classified as those that can react by themselves when exposed to heat, pressure, shock, friction, air or water. Reactive interactions occur when two or more compounds are combined to cause a hazardous result. When an organisation has identified the

reactive materials in their workplace, they must then decide what data they need to control the hazard. They can then identify what safeguards they need to control the hazard.

In chemical manufacturing, reactivity can lead to hazardous outcomes such as detonation or runaway reactions, necessitating thorough evaluation of raw materials and process streams to mitigate risks. Overall, reactivity is a multifaceted property that influences various aspects of manufacturing, from safety and efficiency to optimising material properties, performance and process outcomes.

Explain flammability as a property of materials

Flammability is a critical property in material manufacturing, influencing safety, performance, and application suitability. It refers to the ability of a material to ignite and sustain combustion when exposed to a flame or heat source. Flammability can also be defined as the ease with which a material is ignited, the intensity with which it burns and releases heat once ignited, its propensity to spread fire, and the rate at which it generates smoke and toxic combustion products during gasification and burning. Various factors affect flammability, including material composition, density, and thermal stability. For instance, cellulose fibres can accelerate thermal degradation, while nano-fillers can enhance thermal stability in composites. Flammability significantly influences material selection in manufacturing due to its impact on safety, regulatory compliance, and performance. Materials that are easily ignitable and burn intensely pose higher risks, necessitating flame-retardant additives or modifications to the polymer structure to enhance fire resistance. A comprehensive evaluation of a material's overall flammability may require data from several laboratory tests, perhaps combined with some form of analysis or modelling, to interpret the results properly. Several fire properties, like ignitability, can be determined from bench-scale flammability tests. Flammability testing, such as using a cone calorimeter, helps assess parameters like heat release rate and mass loss, which are crucial for understanding material behaviour under fire conditions. Understanding these diverse flammability aspects helps manufacturers develop materials that meet safety standards and perform reliably under fire exposure.

Explain toxicity as a property of materials

Toxicity is an inherent property of materials that can lead to adverse biological effects when organisms are exposed to them. Toxicity means a property that can cause damage or cause harm to a living organism if it enters. When a toxic material enters the body, it affects the body, and the effect of toxic material is of two types. This property is influenced by various factors, including the material's physicochemical characteristics, such as size, shape, surface area, and chemical composition, which can affect their interaction with biological systems. For instance, nanomaterials, due to their small size and unique properties, can penetrate cellular barriers and cause toxicity at the cellular level, impacting tissues in the respiratory and gastrointestinal tracts. The toxicity of materials can manifest in different forms, such as cytotoxicity, immunotoxicity, and organ-specific toxicity, affecting systems like the central nervous system (CNS), lungs, heart, skin, and gastrointestinal tract. Toxicity in materials used in manufacturing is a critical property that encompasses the potential harmful effects these materials can have on biological systems and the environment. This toxicity can arise from various sources, including the inherent chemical composition of the materials, the manufacturing processes, and the by-products generated during production and disposal. For instance, selecting materials in the toxic chemical industry requires a systematic approach to address sustainability and minimise toxicological impacts.

Toxic material can have two types of effects, namely acute and chronic. Acute toxicity means that it has an adverse effect on a living organism because of its short-term high concentration exposure to a toxicant. Chronic toxicity is harmful and has an adverse effect on a living organism as a result of long-term exposure to a toxicant. There are 5 types of toxic entities: chemical, biological, physical, radiation and behavioural toxicity. Examples of toxic chemicals are mercury, hydrogen sulphide and chlorine gas.

Learning Tasks

1. Organise a “Material Hunt” in the classroom. Divide the class into groups and assign each group a material type (metals, ceramics, or polymers). Each group will collect samples of their 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 learners recall the basic properties of these materials and understand these concepts.
2. Conduct a “Material Debate”. Each group will represent a material type (metals, ceramics, or polymers) and prepare arguments to debate the advantages and disadvantages of their material type based on its reactivity, flammability, and toxicity. This task will help learners apply their understanding of these chemical properties in a practical context and synthesise information from various sources.
3. Implement a “Material Safety Protocol” project. Each group will research and develop a safety protocol for handling their assigned material type in a manufacturing setting, considering its reactivity, flammability, and toxicity. The groups will present their safety protocols to the class. This task will help learners apply their knowledge in a real-world context and think critically about the implications of these chemical properties.
4. Learner groups will identify different materials processing methods and classify them based on the type of material they are most used for (metals, ceramics, polymers). They will create a flowchart or diagram to illustrate their findings.
5. Learner groups will research different synthesis methods for metals, ceramics, and polymers. They will classify these methods and present their findings to the class, explaining how the synthesis method impacts the chemical properties of the material.

Pedagogical Exemplars

Collaborative Learning

Learners can be divided into small groups and given the task of categorising different materials, such as metals, ceramics, and polymers, based on their chemical properties. Each group can be assigned a specific property (reactivity, flammability, or toxicity) to focus on. This encourages learners to work together, share ideas, and learn from each other. To ensure differentiation, the teacher can form groups considering the learners’ readiness, interests, and learning styles. The complexity of the task can be varied based on the group’s readiness level. For instance, advanced groups can be given additional materials to categorise or asked to explain why certain materials fall into a specific category.

Talk for Learning

The teacher can initiate a class discussion on the chemical properties of materials. Learners can be encouraged to share their understanding of reactivity, flammability, and toxicity. They

can discuss how these properties influence the categorisation of materials into metals, ceramics, and polymers. Differentiation can be incorporated by allowing learners to express their understanding in various ways. For instance, some learners prefer to draw diagrams, while others prefer to write a paragraph or give a verbal explanation.

Remember to consider socio-emotional learning by encouraging respectful and open communication among learners. Promote gender equality and social inclusion by ensuring that all learners, regardless of gender or social background, are given equal opportunities to participate in the discussion. Lastly, incorporate national core values in your teaching by relating the discussion to real-life scenarios or issues relevant to Ghana.

Key Assessment

Assessment Level 1

1. What chemical property determines how a material reacts with other substances?
 - A) Reactivity
 - B) Flammability
 - C) Toxicity
 - D) All of the above
2. **True or False:** Ceramics are generally more reactive than metals.
3. **Fill in the blank:** _____ is a chemical property that describes a substance's potential to undergo a chemical change with another substance.

Assessment Level 2

1. List the steps you would take to test the flammability of a material.
2. List the reactivity, flammability, and toxicity of metals, ceramics, and polymers.
3. Describe one way in which the reactivity of metals differs from the reactivity of ceramics.

Assessment Level 3

1. Analyse how the chemical properties of materials impact their use in manufacturing, providing examples to support your analysis.
2. 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.
3. Create a detailed presentation that evaluates how a material's chemical properties influence its use in manufacturing, providing specific examples and recommendations.
4. Compare the flammability of different materials and explain your method for testing this property.

Focal Area 2: Group materials according to their chemical properties

Introduction

Grouping materials according to their chemical properties in manufacturing engineering involves understanding their composition, behaviour under different conditions, and interaction with other substances. Manufacturers classify materials based on chemical properties using advanced techniques that leverage machine learning, fuzzy logic, and clustering algorithms. These diverse methodologies collectively enhance the ability of manufacturers to accurately classify materials based on their chemical properties, ensuring efficiency and precision in industrial applications.

Group materials as reactive and non-reactive materials

Materials can be broadly categorised into reactive and non-reactive types based on their chemical behaviour and applications. Reactive materials include those that undergo significant chemical changes under specific conditions. Reactive materials are a class of materials designed to release substantial amounts of energy through exothermic reactions when initiated by stimuli such as impact, friction, or heat. These materials can be engineered in various forms, including powders, multilayers, and structural composites, each tailored for specific applications. Non-reactive materials do not readily engage in chemical reactions under normal conditions, making them highly stable and suitable for various industrial applications. Thus, classifying reactive and non-reactive materials is important for selecting appropriate materials for specific industrial and technological applications. Table 1.1 shows the classification of reactive and non-reactive 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, sulfuric acid, nitric acid, etc.	Used in various chemical processes in industries

Reactive Materials	Reactive Polymers	They are macromolecules that possess specific chemical functional groups, which enhance their reactivity and prevent phase separation in polymer mixtures, thereby imparting new chemical, biophysical, physicochemical, or optoelectronic properties to the polymers	Polyethylene, polypropylene, polyvinyl chloride (PVC), Poly (β -hydroxybutyric acid), Polyethylene glycol, polyester, etc.	Used in the manufacture of filled polymer compounds with enhanced properties. They find applications in packaging, automotive industries, electronics, coatings, and biomedical materials
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
	Gold and Platinum	They are highly resistant to corrosion and oxidation, making them non-reactive.	-	used in the jewellery industry and in various industrial applications due to their resistance to corrosion and excellent conductivity
	Glass and Ceramics	These materials are non-reactive and do not readily react with other substances.	-	used in various industries, including construction, electronics, and consumer goods
	Industrial Polymers	These polymers are designed to avoid post-polymerisation reactions, which enhances their stability and performance in specific environments.	-	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), fluor silicone, 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 can easily ignite and burn when exposed to an open flame, heat, or spark. These materials include common items such as wood, paper, and various construction materials, which pose significant fire hazards in residential and commercial settings. On the other hand, non-flammable materials are designed to resist ignition and prevent the spread of fire, thereby enhancing safety. Various compositions and technologies have been developed to create non-flammable materials. For instance, a non-flammable agent composition comprising 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 have been shown to exhibit excellent non-flammable performance across different types of materials and fire strengths. Flammable and non-flammable materials can be solids, liquids, or gases, and their flammability depends on their chemical composition and physical properties like flash point (the lowest temperature at which they release vapours that can ignite). Classification of flammable and non-flammable materials is presented 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
		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 and non-toxic materials are categorised based on their potential harm to human health and the environment. Toxic materials contain materials that can cause adverse health effects, such as poisoning, cancer, or other serious health issues upon exposure. In contrast, non-toxic materials are designed to be safe for human contact and environmentally friendly. For instance, non-toxic and energy-saving materials can be made from expanded perlite, silica powder, and other harmless raw materials, ensuring safety and environmental sustainability. Some toxic and non-toxic materials have been grouped and 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.
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 or contaminated food)	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).

Learning Tasks

1. Let learners identify and bring different materials from their community. They should then group these materials into metals, ceramics, and polymers and discuss their chemical properties.
2. Provide learners with a list of materials. They classify these materials into metals, ceramics, and polymers based on their chemical properties. This activity can be done individually or in groups.

3. Assign learners in mixed ability groups a specific material (metal, ceramic, or polymer). They should research the chemical properties of their assigned material, focusing on reactivity, flammability, and toxicity. Each student will then present their findings to the class.
4. Present learners with a case study of a manufacturing process where the choice of material is crucial due to its chemical properties. Learners should analyse the case and discuss why the material was chosen and what considerations were made due to its chemical properties.

Pedagogical Exemplars

Explorative Learning

Let learners go around their community and bring to the classroom different materials available in their communities. Encourage learners to bring materials that are relevant to their interests or current learning topics. For example, a learner interested in botany might bring different types of leaves or flowers, while a learner interested in geology might bring different types of rocks or soil.

Collaborative Learning

Learners in mixed ability groups identify and group materials into metals and non-metals, such as polymers and ceramic materials. Learners think-pair share and write the chemical properties (composition, microstructure and corrosion resistance) that distinguish metals from non-metals and relate these properties to their processing and use. Learners mention any considerations when processing metals in a specific environment due to their chemical properties. Group learners based on their readiness, interests, and learning styles. For example, you could group learners who have a strong interest in materials science together, or group learners who learn best through hands-on activities together.

Key Assessment

Assessment Level 1

1. List the materials available in your community based on their reactivity.
2. List the materials available in your community based on their flammability.
3. List the materials available in your community based on their toxicity.
4. Name the chemical properties that should be considered when selecting a material for use in your local community.
5. True or False: Metals are more reactive than ceramics.
6. Fill in the blank: _____ is a chemical property that describes a substance's potential to undergo a chemical change.
7. Which of the following is a polymer? a) Iron b) Aluminium c) Polyethylene d) Copper
8. What is toxicity in terms of chemical properties?

Assessment Level 2

1. How will you relate metals, polymers, and ceramics to the chemical properties of materials?
2. If you were to design a fire-resistant material, which of the following properties would be most important? a) Reactivity b) Flammability c) Toxicity d) Electrical conductivity

3. Explain how the reactivity of a metal could affect its use in manufacturing.
4. Given a list of materials, classify them into metals, ceramics, and polymers based on their chemical properties.
5. How would you determine the flammability of a material?

Assessment Level 3

1. Analyse and categorise materials based on their reactivity, flammability, and toxicity, and justify your classification criteria. Discuss potential applications or risks associated with these materials in real-world scenarios.
2. Identify and analyse the chemical properties relevant to selecting materials for community use, requiring students to evaluate and make informed decisions based on their analysis.

HINT



*The recommended mode of assessment for week 1 is **class exercise**. Use focal area 1 level 2 question 3 as a sample question.*

WEEK 2**Learning Indicator:** Classify materials based on their structure (Crystalline and amorphous)**Focal Area 1: Classification of materials as crystalline and amorphous materials****Introduction**

Materials can be broadly classified into crystalline and amorphous categories based on their atomic arrangement and structural properties. Crystalline materials are characterised by a highly ordered atomic structure with periodic translational and orientational symmetries extending over long ranges. This order results in distinct mechanical, electrical, and optical properties, making them suitable for various technological applications, including semiconductors and photonics. In contrast, amorphous materials lack long-range order, exhibiting only short-range atomic arrangements. This structural disorder imparts unique properties such as isotropic atomic environments, abundant surface dangling bonds, and highly unsaturated coordination, which can enhance their electrocatalytic, optical, and mechanical performance. Classifying and characterising amorphous materials is challenging due to their complex structure and lack of long-range order.

Classification of materials according to their crystal structure such as FCC, BCC and HCP crystal structures

Solid materials may be classified according to the regularity with which atoms or ions are arranged concerning one another. A crystalline material is one in which the atoms are situated in a repeating or periodic array over large atomic distances - that is, long-range order exists, such that upon solidification, the atoms position themselves in a repetitive three-dimensional pattern in which each atom is bonded to its nearest neighbour atoms. Classification of materials according to their crystal structure is important as it directly influences the material's physical properties, including its strength, ductility and conductivity and so on.

All metals, many ceramic materials, and certain polymers form crystalline structures under normal solidification conditions. For those that do not crystallise, this long-range atomic order is absent and is classified as non-crystalline or amorphous materials. Some of the properties of crystalline solids depend on the crystal structure of the material - how atoms, ions, or molecules are spatially arranged. There is an extremely large number of crystal structures with long-range atomic order; these vary from relatively simple structures for metals to exceedingly complex ones, as displayed by some ceramic and polymeric materials. The three most common crystal structures found in metals are Face-Centred Cubic (FCC), Body-Centred Cubic (BCC), and Hexagonal Close-Packed (HCP) (Figure 2.1). Each structure is defined by a unique arrangement of atoms within the unit cell, the smallest repeating unit in a crystal lattice.

When describing crystalline structures, atoms (or ions) are considered solid spheres with well-defined diameters. This is termed the atomic hard-sphere model in which spheres representing nearest-neighbour atoms touch one another. An example of the hard-sphere model for the atomic arrangement found in some of the common elemental metals is displayed in Figure 2.1c. In this case, all the atoms are identical. Sometimes the term lattice is used in the context of crystal structures; in this sense, lattice means a three-dimensional array of points coinciding with atom positions (or sphere centres). The atomic order in crystalline solids indicates that small groups of atoms form a repetitive pattern. Thus, in describing crystal structures, it is often convenient to subdivide the structure into small repeating entities called unit cells. Unit cells

for most crystal structures are parallelepipeds or prisms with three sets of parallel faces; one is drawn within the aggregate of spheres (Figure 2.1c), which is a cube. A unit cell is chosen to represent the symmetry of the crystal structure, wherein all the atom positions in the crystal may be generated by translations of the unit cell integral distances along each of its edges. Thus, the unit cell is the basic structural unit or building block of the crystal structure and defines the crystal structure by its geometry and the atom positions within.

Face-Centred Cubic Crystal (FCC) Structure

The crystal structure found for many metals has a unit cell of cubic geometry, with atoms located at each corner and the centres of all the cube faces. It is aptly called the face-centred cubic (FCC) crystal structure. Some familiar metals with this crystal structure are copper, aluminium, silver, and gold (see also Table 2.1). Figure 2.1a shows a hard-sphere model for the FCC unit cell, whereas in Figure 2.1b the atom centres are represented by small circles to provide a better perspective on atom positions. The aggregate of atoms in Figure 2.1c represents a section of crystal consisting of many FCC unit cells. These spheres or ion cores touch one another across a face diagonal; the cube edge length a and the atomic radius R are related through

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

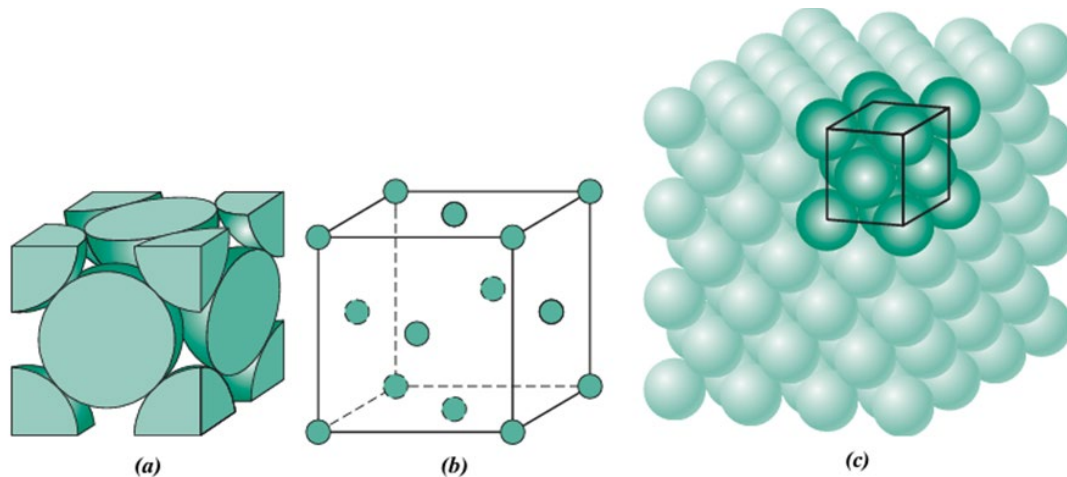


Figure 2.1: For the face-centred cubic crystal structure, (a) a hard-sphere unit cell representation, (b) a reduced sphere unit cell, and (c) an aggregate of many atoms.

Body-Centred Cubic Crystal Structure

Another common metallic crystal structure has a cubic unit cell with atoms at all eight corners and a single atom at the cube centre. This is called a body-centred cubic (BCC) crystal structure. A collection of spheres depicting this crystal structure is shown in Figure 2.2c, whereas Figures 2.2a and 2.2b are diagrams of BCC unit cells with the atoms represented by hard-sphere and reduced-sphere models, respectively. Centre and corner atoms touch one another along cube diagonals, and unit cell length a and atomic radius R are related through

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

Chromium, iron, tungsten, and several other metals listed in Table 3.1 exhibit a BCC structure.

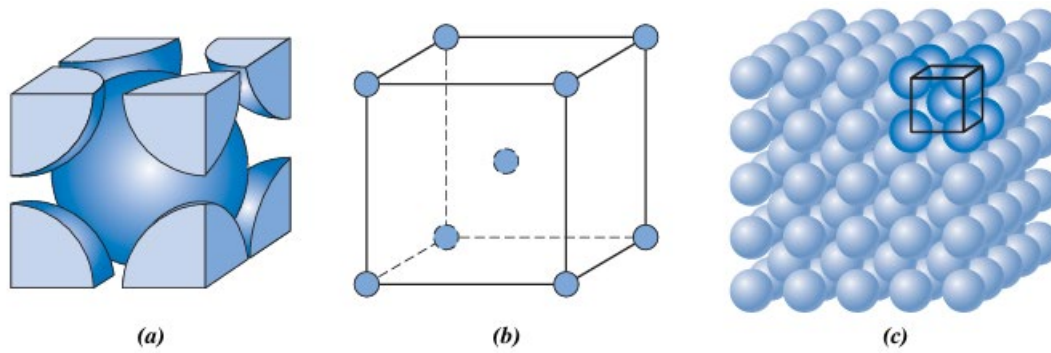


Figure 2.2: For the body-centred cubic crystal structure, (a) a hard-sphere unit cell representation, (b) a reduced sphere unit cell, and (c) an aggregate of many atoms.

Hexagonal Close-Packed Crystal Structure

Not all metals have unit cells with cubic symmetry; the final common metallic crystal structure to be discussed has a unit cell that is hexagonal. Figure 2.3a shows a reduced sphere unit cell for this structure, which is termed hexagonal close-packed (HCP); an assemblage of several HCP unit cells is presented in Figure 2.4b.1 The top and bottom faces of the unit cell consist of six atoms that form regular hexagons and surround a single atom in the centre. Another plane that provides three additional atoms to the unit cell is situated between the top and bottom planes. The atoms in this midplane have as nearest neighbours' atoms in both adjacent two planes.

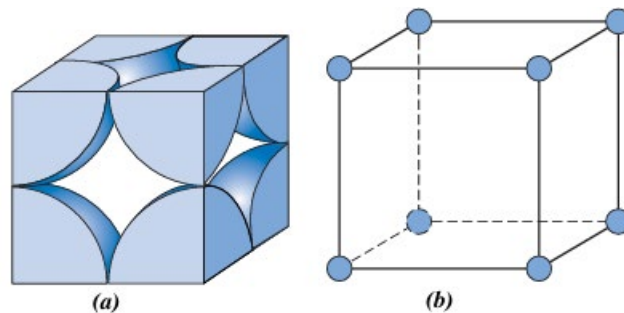


Figure 2.3: For the simple cubic crystal structure, (a) a hard-sphere unit cell, and (b) a reduced-sphere unit cell.

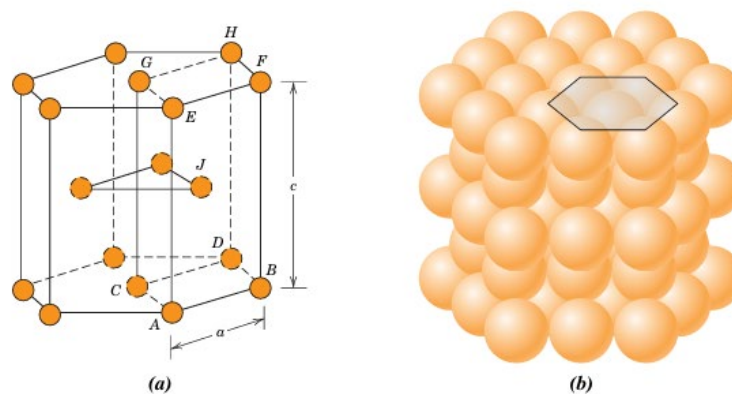


Figure 2.4: For the hexagonal close-packed crystal structure, (a) a reduced-sphere unit cell (a and c represent the short and long edge lengths, respectively), and (b) an aggregate of many atoms.

[Figure 2.2 (c) from W. G. Moffatt, G. W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. I, Structure, p. 51. Copyright © 1964 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.] (Callister, 2014)

[Figure 2.4(b) from W. G. Moffatt, G. W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. I, Structure, p. 51. Copyright © 1964 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.] (Callister, 2014)

Table 2.1: Classification of materials according to their crystal structure

Metal	Crystal Structure ^a	Atomic Radius ^b (nm)	Metal	Crystal Structure	Atomic Radius (nm)
Aluminium	FCC	0.1431	Molybdenum	BCC	0.1363
Cadmium	HCP	0.1490	Nickel	FCC	0.1246
Chromium	BCC	0.1249	Platinum	FCC	0.1387
Cobalt	HCP	0.1253	Silver	FCC	0.1445
Copper	FCC	0.1278	Tantalum	BCC	0.1430
Gold	FCC	0.1442	Titanium (α)	HCP	0.1445
Iron (α)	BCC	0.1241	Tungsten	BCC	0.1371
Lead	FCC	0.1750	Zinc	HCP	0.1332

^aFCC = face-centred cubic; HCP = hexagonal close-packed; BCC = body-centred cubic.

^bA nanometre (nm) equals 10^{-9} m; to convert from nanometres to angstrom units ($\text{\AA}$), multiply the nanometre value by 10

Amorphous, polymorphism, allotropy, and polycrystalline solids

Amorphous Materials

Non-crystalline solids lack a systematic and regular arrangement of atoms over relatively large atomic distances. Sometimes such materials are also called amorphous (meaning literally “without form”) or supercooled liquids, since their atomic structure resembles that of a liquid. Amorphous materials are a class of solids characterised by a lack of long-range order in their atomic or molecular arrangements, distinguishing them from crystalline materials that exhibit periodic atomic structures. These materials are metastable and possess only short-range order due to local intermolecular chemical bonding, resulting in unique structural features such as isotropic atomic environments, abundant surface dangling bonds, and highly unsaturated coordination. This intrinsic disorder imparts amorphous materials with specific characteristics like intrinsic isotropy, defect distribution, and structural flexibility, making them highly attractive for various applications, particularly in electrochemical energy storage and conversion technologies such as Li-ion batteries, Li-metal batteries, and supercapacitors. An amorphous condition may be illustrated by comparing the crystalline and non-crystalline structures of the ceramic compound silicon dioxide (SiO_2), which may exist in both states. Figures 2.5a and 2.5b present two-dimensional schematic diagrams for both structures of SiO_2 . Even though each silicon ion bonds to three oxygen ions for both states, beyond this, the structure is much more disordered and irregular for the non-crystalline structure. Amorphous materials can be found in everyday items like glass, cement, and even food products like yoghurt and chocolate mousse, and they share many mechanical properties despite their diverse appearances.

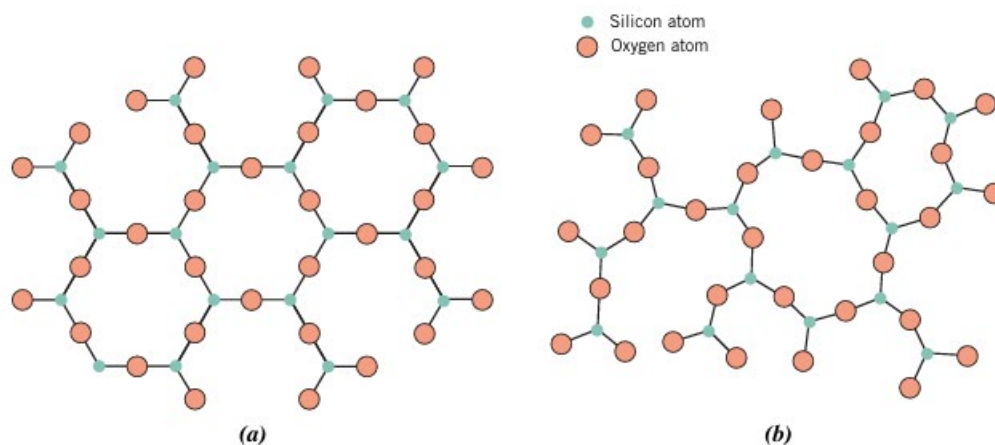


Figure 2.5: Two-dimensional schemes of the structure of (a) crystalline silicon dioxide and (b) non-crystalline silicon dioxide

Polymorphism

Polymorphism in materials science and engineering refers to the ability of a material to exist in more than one crystalline form, each with distinct lattice structures and properties. Some metals and nonmetals may have more than one crystal structure, a phenomenon known as polymorphism. Polymorphism can be observed in a wide range of materials such as crystalline substances, minerals, metals, alloys, and polymers, and it plays an important role in determining the functional properties of these materials. The occurrence of different polymorphic forms is often influenced by slight changes in crystallisation conditions, making it challenging to control but also offering opportunities for enhanced material functionalities. The prevailing crystal structure depends on both the temperature and the external pressure. One familiar example is found in carbon (graphite is the stable polymorph at ambient conditions, whereas diamond is formed at extremely high pressures). Also, pure iron has a BCC crystal structure at room temperature, which changes to FCC iron at 912°C (1674°F). Most often a modification of the density and other physical properties accompanies a polymorphic transformation. Carbon, glycine, and silica are some of the materials which exhibit polymorphism.

Allotropy

Allotropy refers to the phenomenon where a chemical element/ elemental solid can exist in two or more different forms, known as allotropes, in the same physical state. This property is significant because it allows materials to exhibit different physical and chemical properties depending on their allotropic form. For instance, iron exhibits different crystal structures at various temperatures and pressures, which can be manipulated to enhance material properties such as strength and ductility. Materials exhibiting allotropy are carbon (diamond, graphite, graphene, fullerenes, buckyball (C-60) and carbon nanotubes), oxygen, tin, and sulphur materials.

Polycrystalline Solids

Polycrystalline solids are characterised by their composition of numerous small crystals or grains, each with identical crystal structures but different orientations. These materials, which include metals, ceramics, and certain polymers, exhibit properties critically dependent on the size, shape, and orientation distributions of their grains, collectively known as texture. The synthesis of polycrystalline powders is a crucial step in materials science, with various methods such as solid-state reaction, sol-gel, hydrothermal, and combustion being employed to achieve

desired purity, grain size, crystallinity, and morphology. The properties of polycrystalline materials are influenced by the dynamic nature of grain boundaries, which are driven by interfacial energy causing some grains to grow while others shrink and vanish, leading to a coarsening process that affects mechanical, electrical, and thermal properties. Some examples of polycrystalline solids include metals (iron, copper, aluminium), ceramics, ice, galvanised steel, and silicon semiconductors.

Learning Tasks

1. Have learners identify and bring different materials from their community. They should then classify these materials as crystalline or amorphous and discuss their structures.
2. Divide the class into mixed-ability groups. Each group should visit the library to research crystalline and amorphous materials. They should then prepare a presentation explaining the difference between these two types of materials based on their structure.
3. Assign learners in mixed ability groups a specific material. They should research the crystal structure of their assigned material (FCC, BCC, or HCP) and present their findings to the class.
4. Present learners with a case study of a manufacturing process where the choice of material is crucial due to its structure. Learners should analyse the case and discuss why the material was chosen and what considerations were made due to its structure.

Pedagogical Exemplars

Collaborative Learning: Put learners into mixed-ability groups and let them visit the library and read about crystalline and amorphous materials. Learners think-pair-share and explain the difference between crystalline solids and amorphous materials based on their structure and present their results to the class. Group learners based on their readiness, interests, and learning styles. For example, you could group learners who have a strong interest in materials science together, or group learners who learn best through hands-on activities together. Anticipate that some learners may struggle with certain concepts and plan for additional support or resources to help these learners.

Talk for Learning: Learners group materials available in the local community based on their reactivity, flammability and toxicity using tables. Use questioning for learners to talk about the various materials. Use mind mapping to organise learners' thoughts. Allow learners to demonstrate their understanding in different ways. For example, some learners could present their findings to the class, while others could create a report or a mind map.

Key Assessment

Assessment Level 1

1. List examples of crystalline materials available in your community. Identify some amorphous materials found in your community.
2. **True or False:** All metals have a crystalline structure.
3. **Fill in the blank:** _____ is a type of crystalline structure.
4. Match the following materials with their structures:
Iron (), Glass (), Polyethylene ().

5. Multiple choice: Which of the following is an amorphous material?

- a) Iron b) Aluminium c) Polyethylene d) Copper

6. What is polymorphism in terms of material structure?

Assessment Level 2

1. Explain the difference between crystalline and amorphous solids a. How do the properties of amorphous materials affect their processing? b. How different will the processing of crystalline materials be from amorphous materials?
2. If you were to design a material for a high-temperature application, which type of structure would be most suitable? a) FCC b) BCC c) HCP d) Amorphous
3. Explain how the structure of a material could affect its use in manufacturing.
4. Given a list of materials, classify them into FCC, BCC, HCP, and amorphous based on their structure.
5. How would you determine if a material is crystalline or amorphous?
6. Briefly explain the difference between crystalline and amorphous materials with at least two examples each.

Assessment Level 3: Can crystalline material change to amorphous? Explain.

HINT



*The recommended mode of assessment for week 2 is **homework**. Use the level 2 question 6 as a sample question.*

WEEK 3

Learning Indicator

1. Identify types of materials processing methods
2. Classify materials as metals, ceramics and polymers according to their processing methods

Focal Area 1: Identification of material processing methods

Introduction

Understanding and identifying the various methods used to process materials, from metals and ceramics to polymers and composites, is essential in manufacturing engineering. These methods include casting, forging, extrusion, machining, welding, heat treatment, etc. Each method has its own unique set of parameters and considerations, such as temperature, pressure, time, and environment, which can significantly affect the properties and performance of the final product. The classifications of processing methods include shaping processes, property-enhancing processes and surface processing.

Shaping processes such as machining, forming, casting and additive manufacturing

Shaping processes in manufacturing are diverse and essential for transforming raw materials into desired forms and functional products. These processes can be broadly categorised into machining, forming, casting and additive manufacturing.

Machining Processes

Machining processes involve the removal of material to achieve desired shapes, sizes, and surface finishes of parts, and they are integral to both small and large-scale industrial production. These processes can be broadly categorised into conventional and non-conventional methods. Conventional machining includes turning and milling, which utilise cutting tools to remove material, while non-conventional methods such as electrical discharge machining (EDM), ultrasonic machining (USM), and laser beam machining (LBM) employ various energy sources for material removal. The machining process is essential for producing precise and high-precision parts, especially from hard materials and often involves abrasive machining techniques like grinding, honing, lapping, and polishing, which are used for final finishing operations to achieve tight dimensional tolerances and fine surface finishes. Additionally, machining is often required to bring parts made by other manufacturing processes, such as casting, forging, welding, and extrusion, to their final net shape, ensuring accurate and precise assembly. Cutting fluids is important in machining to reduce friction, lower cutting temperatures, and extend tool life, thereby enhancing the quality of the final product. Figure 3.1 shows a cross-section of the machining process and tool with a negative rake angle

The three most common types of machining operations are turning, drilling, and milling. Figure 3.2 displays the various machining operations.

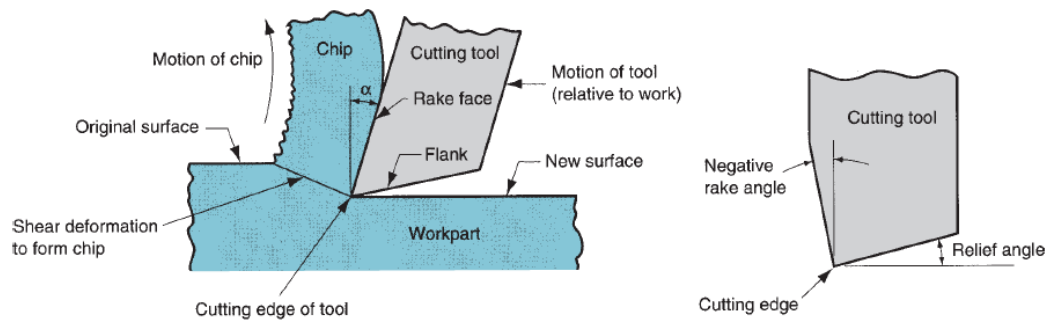


Figure 3.1: Cross-section of the machining process and tool with negative rake angle

Turning

In turning, a cutting tool with a single cutting edge is used to remove material from a rotating workpiece to generate a cylindrical shape. The speed motion in turning is provided by the rotating work-part, and the feed motion is achieved by the cutting tool moving slowly in a direction parallel to the axis of rotation of the workpiece.

Drilling

Drilling is used to create a round hole. It is accomplished by a rotating tool that typically has two cutting edges. The tool is fed in a direction parallel to its axis of rotation into the work part to form the round hole.

Milling

In milling, a rotating tool with multiple cutting edges is fed slowly across the work material to generate a plane or straight surface. The direction of the feed motion is perpendicular to the tool's axis of rotation.

The speed motion is provided by the rotating milling cutter. The two basic forms of milling are peripheral milling and face milling.

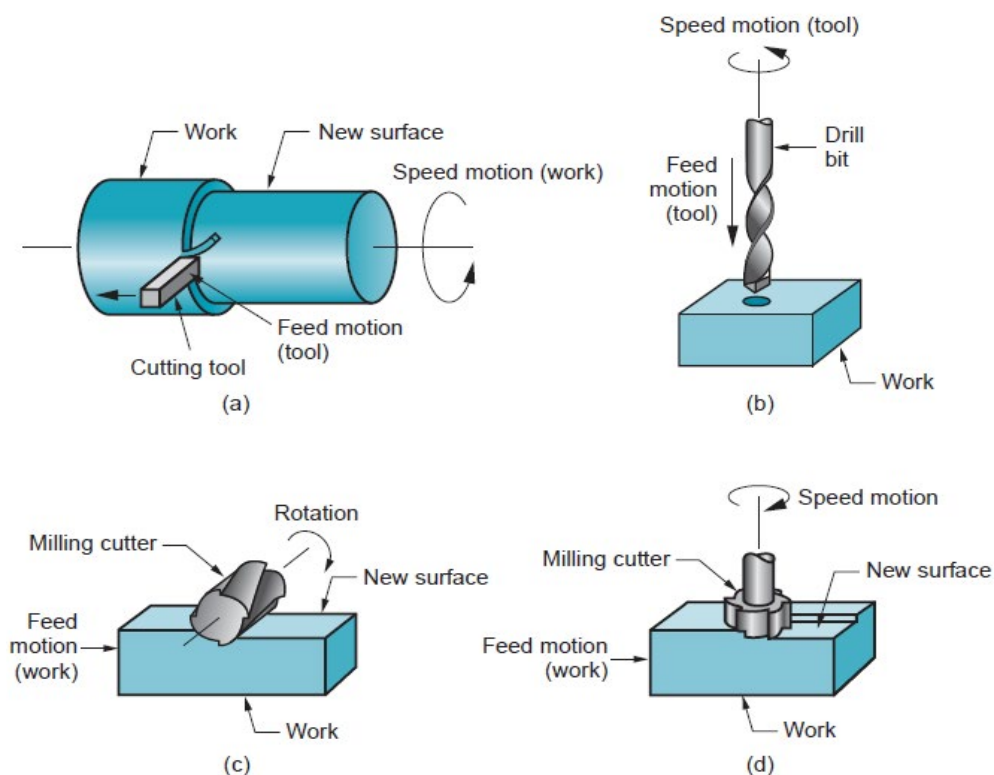


Figure 3.2: Types of machining operations

Forming Processes

Forming processes in manufacturing involve the application of force and pressure to modify the shape of a material part until the final product is obtained. These processes are highly versatile and can be applied to various materials, including metals, polymers, and ceramics. Traditional forming methods include mechanical and thermomechanical deformation, where a solid piece of material is shaped through stamping, drawing, forging, or extrusion. Incremental sheet metal forming (ISMF) is a modern technique that allows for the creation of complex three-dimensional parts without the need for component-specific tools, making it ideal for low-volume production and mass customisation. Another innovative approach combines additive manufacturing with forming processes, such as using a laser-based directed energy deposition (DED-LB/M) module followed by a forming press to enhance surface finish and material properties. Quality control in forming processes is crucial, especially in the production of energetic materials like gelled propellants, where safety and precision are paramount. Some common metal forming processes include bending, rolling, stamping, drawing, forging, extrusion, and deep drawing. Figure 3.3 shows some of the forming processes.

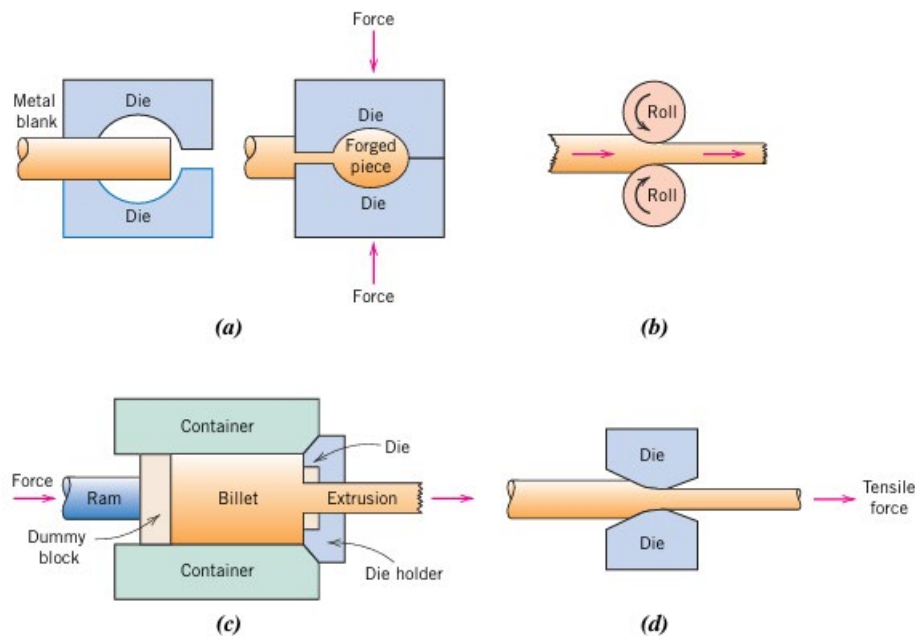


Figure 3.3: Metal deformation during (a) forging, (b) rolling, (c) extrusion, and (d) drawing

Casting Processes

Casting processes are diverse and integral to producing various metal components, from small intricate parts to large industrial machinery. Casting involves pouring molten metal into a mould that solidifies into the desired shape. Various casting methods have been developed to optimise the properties and applications of the final products. For instance, semi-solid and squeeze casting processes produce high-quality castings with superior mechanical properties. Traditional methods like sand casting, which involves creating a mould from sand and pouring molten metal into it, are still widely used due to their versatility and cost-effectiveness. The starting work material for casting is either a liquid or is in a highly plastic condition, and a part is created through the solidification of the material. Solidification processes can be classified according to engineering material processed (metals, ceramics (specifically glasses), polymers and polymer matrix composites (PMCs)). Figure 3.4 shows the classification of the solidification processes.

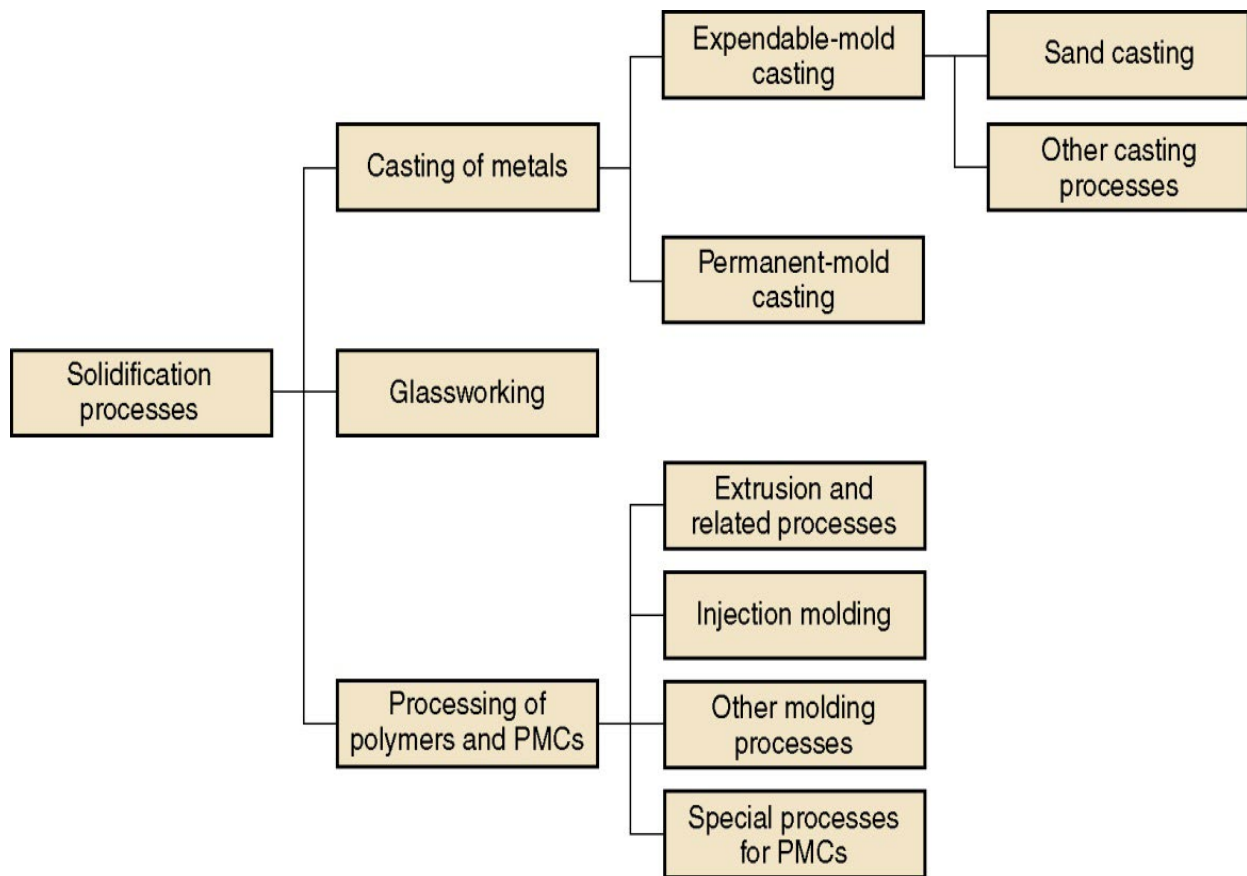


Figure 3.4: *Classification of the solidification processes*

Additive Manufacturing (AM) Processes

Additive Manufacturing (AM), also known as 3D printing, is a transformative approach to industrial production that enables the creation of lighter, stronger parts and systems. Unlike traditional manufacturing processes that often involve subtracting material from a larger block, AM builds objects layer by layer from a digital 3D model, allowing for unprecedented design freedom and complexity. The primary AM processes include laser powder bed fusion (L-PBF), directed energy deposition (DED), material jetting, binder jetting, and sheet lamination, each with unique operational concepts, advantages, and limitations. For instance, L-PBF and DED are widely used for metal parts, utilising high-energy beams to melt and solidify materials, which can be in the form of powders or thin wires. These processes are particularly beneficial in industries such as aerospace, automotive, biomedical, and consumer products due to their ability to produce complex geometries and reduce material waste. AM technologies have also been instrumental in rapid prototyping and tooling, significantly enhancing productivity in traditional manufacturing processes like casting. The materials used in AM have expanded beyond metals and polymers to include glass, ceramics, and composites, allowing for tailored properties through careful selection of processing types and material compositions. Despite its advantages, AM faces challenges such as ensuring the reliability and quality of the produced components, which are influenced by processing parameters like energy density, scan speed, hatch distance, and layer thickness.

Property-enhancing processes such as heat treatment, alloying, surface hardening

Property-enhancing processes in manufacturing are critical for improving the performance and quality of materials and products across various industries. These processes involve modifying the material properties through advanced manufacturing techniques and treatments. Property-enhancing processes include heat treatment, alloying and surface hardening. The most important property-enhancing operations involve heat treatments. Heat treatment involves various heating and cooling procedures performed to effect microstructural changes in a material, which in turn affect its mechanical properties. It can be applied at different stages of the manufacturing process. For instance, it can be applied before shaping to soften the metal so that it can be more easily formed while hot. It can also be used to relieve the effects of strain hardening that occurs during the manufacturing process. In some cases, heat treatment is accomplished at or near the end of the sequence to achieve the final strength and hardness required in the product. One common type of heat treatment is annealing. This process involves heating the metal to a suitable temperature, holding at that temperature for a certain time (called soaking), and then slowly cooling. Annealing is performed on a metal for several reasons which are to reduce hardness and brittleness, to alter the microstructure so that desirable mechanical properties can be obtained, to soften metals for improved machinability.

Surface processing such as coating and plating, polishing, ion implantation, laser surface treatment

Property-enhancing processes in manufacturing, such as heat treatment, alloying, and surface hardening, play a crucial role in improving the mechanical and tribological properties of metallic components. Heat treatment processes, including induction hardening and laser hardening, are widely used to enhance surface behaviour and wear resistance without affecting the core microstructure of the material. Induction hardening, for instance, uses an alternating current to generate a magnetic field, inducing eddy currents that heat the surface rapidly, making it an energy-efficient and cost-effective method. Laser hardening, on the other hand, offers precise control over the treated area, optimising hardness and extending the service life of components like turbine blades and automotive parts. Alloying, such as the addition of niobium (Nb) to rolled homogeneous armour (RHA) steels, can significantly enhance performance by refining grain structures and increasing strength and impact resistance without raising production costs. Surface hardening techniques, including thermally assisted methods like warm shot peening and laser shock peening, further improve surface and subsurface hardness, fatigue life, and wear resistance by inducing compressive residual stresses and unique microstructures through the synergistic effects of thermal energy and high-strain-rate plastic deformation.

Learning Tasks

1. Show learners videos of different material processing methods. After watching, have a class discussion where learners identify the types of materials processing methods they observed in the videos.
2. Have learners identify and classify material processing methods available in their communities into shaping processes, property-enhancing processes, and surface processing operations.

3. Assign learners in groups a specific material processing method (machining, forming, casting, additive manufacturing, heat treatment, alloying, surface hardening, coating, plating, polishing, ion implantation, or laser surface treatment). They should research their assigned method and present their findings to the class.
4. Present learners with a case study of a manufacturing process where the choice of material processing method is crucial. Learners should analyse the case and discuss why the method was chosen and what considerations were made.
5. Provide students with a list of materials. Their task is to classify these materials as metals, ceramics, or polymers based on their processing methods. This activity can be done individually or in groups.

Pedagogical Exemplars

Experiential Learning: Show learners videos of material processing methods. Lead learners to classify material processing methods available in their communities into shaping processes, property-enhancing processes, and surface processing operations. Anticipate that some learners may struggle with certain concepts, such as the difference between shaping processes, property-enhancing processes, and surface processing operations, and plan for additional support or resources to help these learners.

Collaborative Learning: Let learners in mixed-ability groups identify, from the video, the types of materials processing methods such as shaping processes, property-enhancing processes, and surface processing operations. Allow learners to demonstrate their understanding in different ways. For example, some students could present their findings to the class, while others could create a report or a model.

Key Assessment

Assessment Level 1

1. List examples of materials processing methods in your community.
2. **True or False:** Ceramics can be processed through heat treatment.
3. **Fill in the blank:** _____ is a type of shaping process that involves adding material layer by layer.
4. Define coating
5. Define plating

Assessment Level 2

1. Classify materials processing methods in your community into shaping processes, property-enhancing processes, and surface processing operations
2. Given a scenario where a metal part needs to be hardened, which process would you choose and why?
3. Explain the process of laser surface treatment.
4. List five advantages and disadvantages of different shaping processes.
5. What is the difference between coating and plating?

Focal Area 2: Classification of materials according to their processing methods

Introduction

The classification of materials according to their processing methods can be broadly categorised into several key types, each with distinct techniques and applications. One primary classification is based on the state of raw materials and the final products, which divides manufacturing into top-down and bottom-up approaches, or subtractive manufacturing (SM) and additive manufacturing (AM). As seen in traditional machining processes, subtractive manufacturing involves removing material from a solid block to create the desired shape. In contrast, additive manufacturing builds objects layer by layer from materials such as powders or resins, exemplified by 3D printing technologies. Another classification method focuses on specific techniques, such as powder metallurgy (PM), which is cost-effective for creating complex shapes with minimal waste. PM techniques include press and sinter, liquid phase sintering, and high-velocity compaction, aiming to achieve near-full density in the final product. Functionally graded materials (FGMs) represent another category where properties vary across the material's volume. FGMs can be produced using methods like physical vapour deposition, chemical vapour deposition for thin coatings, and powder metallurgy or centrifugal casting for bulk materials. Additionally, advanced material processing methods such as laser beam application with controlled shielding gas flow are used to melt and shape materials precisely, enhancing the quality and properties of the final product. However, for the context of this lesson, materials will be classified based on the processing methods they are subjected to, which include shaping, property-enhancing, and surface processing processes.

Materials that undergo shaping processes

There are several types of materials that undergo shaping processes in manufacturing. Examples of materials which undergo shaping processes are;

1. **Metals:** Metals can undergo both cold working processes (such as press work, cold forging, rolling, and coining) and hot working processes (like casting, hot forging and powder forming).
2. **Thermosetting Polymers:** These materials can be shaped through hot compression moulding and transfer moulding.
3. **Thermosetting Polymers:** These polymers can be shaped through various processes such as injection moulding, extrusion, blow moulding, calendaring, and vacuum forming.
4. **Ceramics:** Ceramics are non-metallic, inorganic materials that are typically made by shaping and then firing a non-metal, such as clay, at high temperatures. Examples of ceramics include traditional ceramics like pottery, bricks, stoneware, porcelain, and tiles, and advanced ceramics such as silicon carbide, boron nitride, alumina, and zirconia.
5. **Thermoplastics:** Thermoplastics are versatile materials that can be melted and moulded when exposed to heat and revert to a solid state upon cooling. Examples of thermoplastics include amorphous thermoplastics, which have a disordered or random molecular structure, and semi-crystalline thermoplastics, which have a more ordered and structured molecular arrangement.

Materials that undergo property-enhancing processes (with examples)

There are several types of materials that undergo property-enhancing processes in manufacturing. Examples of materials which undergo property-enhancing processes are;

1. **Metals:** Metals, including steel, aluminium, and titanium, often undergo heat treatment processes such as annealing, normalising, carburising, and hardening to enhance their properties.
2. **Glasses:** Glasses can also undergo heat treatment to relieve internal stresses and improve mechanical properties.
3. **Powdered Metals and Ceramics:** These materials can undergo a process called sintering, which involves heating the powder below its melting point until its particles adhere to each other.
4. **Superalloys:** Superalloys, high-performance alloys designed to withstand high temperatures and pressures, can also undergo heat treatment to enhance their mechanical properties.
5. **Low-Carbon Steels:** Low-carbon steels can undergo a process called carburising, where carbon is introduced into the material's surface by heating it in a carbon-rich environment, forming a hardened layer.

Materials that undergo surface processing

There are several types of materials that undergo surface processing in manufacturing. Examples of materials which undergo surface processing are;

1. **Metals:** Metals such as aluminium, steel, and titanium often undergo surface processing techniques like electroplating, anodising, and bluing. These processes can enhance corrosion resistance, wear resistance, and aesthetic appeal.
2. **Plastics:** Hard and soft plastics can undergo surface processing methods like vacuum plating. This process involves coating the plastic with a thin metal layer (such as aluminium, silver, or copper) to improve its appearance and durability.
3. **Ceramics and Glass:** Ceramics and glass can undergo various surface processing techniques, including vacuum plating. This process can enhance the appearance and durability of these materials.
4. **Composite Materials:** Composite materials can also undergo vacuum plating to improve their appearance and durability.

In addition, various surface processing techniques are available, including mechanical abrasives, powder coating, thermal spray coating, and more. The choice of surface processing technique depends on the material and the desired properties of the final product

Learning Tasks

1. Ask learners to research different materials processing methods and present their findings to the class. They should include examples of metals, ceramics, and polymers that undergo these processes.
2. Facilitate a class discussion on the classification of materials according to their processing methods. Encourage students to share their thoughts and ask questions.

3. Divide the class into small groups and assign each group a different raw material available in their community. The groups should research how their assigned raw material is processed into a usable material and present their findings to the class.

Pedagogical Exemplars

Experiential Learning: Let learners watch online videos (YouTube) and share their thoughts about material processing (e.g., sawmill, foundry etc.) to observe the processing of raw materials into materials that can be used to manufacture products. Anticipate that some learners may struggle with certain concepts, such as the different stages of material processing, and plan for additional support or resources to help these learners.

Collaborative Learning: Learners in mixed-ability groups identify raw materials available in their community. For example, timber, cocoa, rubber, cotton leather, gold, iron ore etc., and the materials they can be processed into (for example, Timber into wood, cocoa into cocoa powder, cotton into fabric, iron ore into steel etc.). Provide different levels of activities based on learners' readiness. For example, some learners could work on identifying basic raw materials and their processed forms, while others could explore more complex materials.

Talk for Learning: Learners to identify the processes used in converting a raw material into a processed material. e.g., sawing process to convert timber into wood, smelting process to turn iron ore into steel, spinning and weaving process to turn cotton into fabric etc. Allow learners to demonstrate their understanding in different ways. For example, some learners could present their findings to the class, while others could create a report or a model.

Key Assessment

Assessment Level 1

1. Classify materials in your community as metals, ceramics, and polymers based on their processing methods.
2. What are the three main types of materials used in manufacturing?
3. Name at three materials that undergoes a shaping process?
4. What is a property-enhancing process? Give an example.
5. Name a material that undergoes surface processing.
6. List some common materials processing methods?

Assessment Level 2

1. Relate the processing of materials to the technology used.
2. Explain why the processing of raw materials is important for product development.
3. How can the raw materials in your community be processed for useful industrial applications?
4. How would you classify steel: as a metal, ceramic, or polymer? Why?
5. What are some differences between materials that undergo shaping processes and those that undergo property-enhancing processes?
6. Compare and contrast two materials that undergo different types of processing methods?
7. How does surface processing affect the properties of a material?

8. Why is it important to understand the processing methods of materials in manufacturing engineering?

Assessment Level 3: Compare and contrast two materials processing practices in your community.

Assessment Level 4: Develop a flow chart illustrating the various processing steps involved in transforming a naturally occurring mineral (e.g. Gold, bauxite etc.) into a finished metal product.

HINT



*The recommended mode of assessment for week 3 is **poster**. Use the level 4 question 1 as a sample question.*

WEEK 4

Learning Indicator: Group materials according to their synthesis

Focal Area: Grouping of materials according to their synthesis

Introduction

The study of materials is a diverse field that intersects multiple disciplines, from chemistry and physics to engineering and technology. One of the key aspects in this field is understanding how materials are grouped according to their synthesis. This involves examining the methods or processes used to create these materials, which can range from natural occurrence to complex chemical reactions.

Bulk materials

Bulk materials refer to large quantities of solid materials used in various forms and applications. These materials can be categorised into different groups, such as sintered, single, and solidified crystals, each serving distinct purposes. For instance, single crystals are often utilised to investigate the intrinsic properties of materials, such as the anisotropic behaviour of high-T_c superconductors (HTS). Bulk materials can also include bulk organic metal compounds, characterised by nanostructured surfaces that enhance their properties, such as hydrogen production reaction activity and charge transfer kinetics, making them suitable as catalysts in electrochemical reactions. Additionally, bulk solids, which are assemblies of solid particles, are extensively used in industrial applications, being the second-most manipulated material after water. These materials exhibit unique properties like density, surface area, flowability, compressibility, and compatibility, which require specialised characterisation techniques. Bulk materials handling and delivery often involve sophisticated mechanisms, such as conveyor systems with rotatable support and drive mechanisms to ensure efficient material transport. Production methods for bulk materials can vary, including processes like foaming under heat, where materials are heated to specific temperatures to achieve desired properties and sizes. Some examples of bulk materials are food (sugar, salt, coffee, flour, and cereals), building materials (sand, gravel, cement, topsoil (humus)), raw materials (road salt, ore, and coal) and industrial materials (cement, ash, salt, and chemicals).

Thin films

Thin film materials are a pivotal component in material science and manufacturing engineering, characterised by their unique properties that emerge when materials are reduced to thin layers ranging from a few nanometres to micrometres. Due to the large surface-to-volume ratio and quantum confinement effects, these materials exhibit distinct chemical, optical, electrical, magnetic, thermal, mechanical, and acoustic properties compared with their bulk counterparts. Thin films are created by condensing atomic, molecular, or ionic species onto a substrate, forming a two-dimensional material that contrasts with bulk three-dimensional materials. The manufacture of thin films involves various deposition techniques such as physical and chemical vapour deposition, sputtering, thermal evaporation, cathodic arc deposition, ion plating, and vapour-phase epitaxy, each chosen based on the material, intended function, and desired microstructure. These films are integral to numerous applications, including microelectronics, optics, space science, aircraft, superconductivity, and photovoltaic cells, due to their lower production temperatures, flexible and transparent nature, and the ability to produce high-

quality, compact, and multi-shaded crystalline films. The properties of thin films, such as porosity, surface morphology, surface roughness, and crystallite size, can be engineered through precise control of deposition conditions, enabling the development of new products and minimising waste compared to conventional manufacturing techniques. Thin films are essential in advancing optoelectronic, photonic, and magnetic devices, and their integration into various devices is facilitated by their thermal stability and mechanical properties, which can be measured using techniques like nanoindentation. The versatility of thin films extends to applications in semiconductor devices, wireless communications, telecommunications, integrated circuits, rectifiers, transistors, solar cells, light-emitting diodes, photoconductors, and micro-electromechanical systems (MEMS). Additionally, thin films are essential for creating flexible, bendable, and stretchable sensors and displays, with advanced metallic thin film deposition methods enhancing their robustness and longevity. The continuous development of thin film technology is driven by its potential to save materials and energy, making it an environmentally benign technology that supports the creation of innovative and exotic materials, such as room-temperature grown diamonds and high-performance ferroelectric thin films. Some examples of thin film materials are as follows:

1. **Precursor Gases:** These are used in chemical vapour deposition processes to form thin films.
2. **Sputtering Targets:** These materials are bombarded with ions to sputter atoms that then deposit as a thin film on a substrate¹.
3. **Evaporation Filaments:** These are used in physical vapour deposition processes, where the material to be deposited is heated to a high temperature, causing it to evaporate and deposit as a thin film on the substrate.
4. **Metals:** Metals such as gold and silver can be used to form thin films. These are often used in applications like mirrors and electronic devices.
5. **Oxides:** Oxides like silicon dioxide and titanium dioxide can be used to form thin films. These are often used in applications like optical coatings and solar cells.
6. **Semiconductors:** Semiconductors like silicon and gallium arsenide can be used to form thin films. These are often used in applications like electronic semiconductor devices and light-emitting diodes.

Nano materials

Nanomaterials, defined as materials with at least one dimension of 1 to 100 nanometres, have revolutionised material science and manufacturing engineering due to their unique properties and vast applications. These materials exhibit distinct physical, chemical, and mechanical characteristics compared with their bulk counterparts, including enhanced solubility, reactivity, electrical and magnetic properties, and transport through membranes. The classification of nanomaterials is based on their dimensions, including zero-dimensional (quantum dots), one-dimensional (nanowires), two-dimensional (nanosheets), and three-dimensional (nanocrystals) forms, each offering unique advantages such as high surface-area-to-volume ratios and quantum confinement effects. The synthesis of nanomaterials can be achieved through top-down approaches, which involve breaking down bulk materials into nanoscale particles, or bottom-up approaches, which assemble materials from atomic or molecular precursors. These methods enable the production of nanomaterials with complex shapes and structures, essential for various applications. Nanomaterials are integral to numerous fields, including electronics, energy storage, photonics, diagnostics, and medical imaging, due to their exceptional properties.

For instance, two-dimensional materials like graphene have opened new avenues in optoelectronics and flexible nanoelectronics, showcasing phenomena such as unconventional superconductivity and orbital magnetism. In the field of energy, nanomaterials are pivotal in the development of high-performance components for solid oxide cells, offering superior properties compared with conventional materials. The integration of nanomaterials into polymeric matrices has led to the creation of robust nanocomposites with improved physical and chemical characteristics, which are crucial for engineering, industrial, and medical applications. The following are examples of nano materials;

1. **Carbon Nanotubes:** These cylindrical graphene tubes have unique properties, making them useful in various fields.
2. **Nanocomposites:** These are hybrid nanostructures combining different nanomaterials to enhance their properties.
3. **Nano fibres:** These thin polymer threads can be used in applications like filtration and tissue engineering.
4. **Nanowires:** These are wire-like nanostructures that can be used in electronic devices and sensors.
5. **Dendrimers:** These are branched nano-molecules that can be used in drug delivery systems.
6. **Quantum Dots:** These are semiconducting nanocrystals that can be used in solar cells and quantum computing.
7. **Fullerenes:** These are carbon molecules in the form of a hollow sphere, ellipsoid, or tube.
8. **Nanocrystals:** These are composed of a quantum dot surrounded by semiconductor materials.
9. **Metal and Metal Oxides:** These inorganic-based nanomaterials include nano-scale silver, gold, and titanium dioxide.
10. **Graphene:** This is a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice.

Functional materials

Functional materials are advanced materials specifically designed and synthesised to perform particular functions, often with tailored properties and surface morphologies. These materials are integral to numerous innovative technologies and industries, including electronics, optoelectronics, catalysis, biomedicine, aerospace, and energy sectors. They encompass a wide range of materials, such as functional inorganic materials, polymers, metal powders, and composites, each offering unique properties like thermal, electrical, biocompatible, and flame-retardant characteristics. The development of functional materials involves a deep understanding of structure-property relationships, reliable characterisation, and superior synthesis pathways, which are crucial for their application in advanced technologies. Multifunctional materials, a subset of functional materials, are designed to perform multiple responsibilities simultaneously, which can lead to reduced weight, higher efficiency, and superior properties in various applications. These materials can respond to different stimuli such as heat, stress, electrical, magnetic, pH, moisture, and light, enabling functionalities like self-healing, self-sensing, and shape memory. The manufacturing processes of functional materials include self-assembly, wrapping, grafting, and one-pot synthesis, which are essential for achieving the desired properties and functionalities. Examples of functional materials are;

1. **Semiconductors:** These are often used in electronics due to their ability to control the flow of electricity. Examples include silicon, germanium, and gallium arsenide.
2. **Piezoelectric Materials:** These materials generate an electric charge in response to mechanical stress. Examples include quartz, Rochelle salt, and certain types of ceramics.
3. **Magnetocaloric Materials:** These materials change temperature under the influence of a magnetic field and are used in magnetic refrigeration.
4. **Ferroelectric Materials:** These materials have a spontaneous electric polarisation that can be reversed by applying an external electric field. Examples include barium titanate and lead zirconate titanate.
5. **Shape-memory Alloys:** These materials can return to their original shape after being deformed when heated. Examples include Nitinol (nickel-titanium) and copper-aluminium-nickel alloys.
6. **Multiferroic Materials:** These materials exhibit more than one primary ferroic order parameter, such as (anti-)ferromagnetism, ferroelectricity, ferro elasticity, or ferrotoroidicity.
7. **Biomaterials:** These are used in medical applications for their compatibility with the human body. Examples include titanium (for implants), collagen (for tissue engineering), and hydrogels (for drug delivery).
8. **Functional Oxides:** These are materials such as piezoelectric, where the application of a voltage causes a change in dimensions, or ferroelectrics, where the application of a voltage causes a change in the relative permittivity.
9. **Molecular Thin Films:** These are developed for optoelectronic applications due to their low cost, low weight, and the possibility to modify their properties easily through the insertion of functional groups by chemical synthesis.

Learning Tasks

1. Organise a field trip to a local materials processing company. After the trip, ask students to write a report detailing their observations and learnings.
2. Ask learners to research different methods of material synthesis from the library and present their findings to the class. They should include examples of bulk materials, thin films, nano materials, and functional materials that undergo these synthesis processes.
3. Facilitate a class discussion on the grouping of materials according to their synthesis. Encourage learners to share their thoughts, comment on presentations, and tolerate others' views.
4. In pairs, let learners discuss and share their understanding of material synthesis and classify materials to be synthesised as bulk materials, nanomaterials, and thin films. They should provide examples of these materials and their methods of synthesis.
5. Divide the class into small groups and assign each group a different material. The groups should research how their assigned material is synthesised and present their findings to the class.

Pedagogical Exemplars

Collaborative Learning: Learners, in mixed-ability groups read from the library and present to the class on how materials can be synthesised to form new materials. Encourage them to comment on presentations and tolerate others' views. Allow learners to demonstrate their understanding in different ways. For example, some learners could present their findings to the class, while others could create a report or a model.

Talk for Learning: In pairs, let learners discuss and share their understanding of material synthesis and classify materials to be synthesised as bulk materials, nanomaterials, and thin films. Learners provide examples of bulk materials, nanomaterials, thin films, and their methods of synthesis. Monitor learner progress and adjust your approach as needed. For example, if a pair is struggling, you could provide additional support or modify the activity.

Key Assessment

Assessment Level 1

1. Identify bulk and nanomaterials that are used in your community.
2. What does material synthesis mean?
3. **True or False:** Bulk materials use the same methods as nanomaterials for synthesis.
4. **Fill in the blank:** Thin films are often synthesised using _____.
5. State two examples of a functional material.

Assessment Level 2

1. Relate the synthesising of materials to the processing of materials Explain why materials are synthesised.
2. How can you use the information gained on material synthesis to develop new ways of processing the materials available in your community?
3. Explain the process of synthesising a nanomaterial.
4. Explain the relationships between different materials and their synthesis methods

Assessment Level 3

1. Construct a concept map showing the relationships between different materials and their synthesis methods.
2. As a material engineer relate the synthesising of materials to the processing of materials and explain why materials are synthesised with clear examples.

HINT



The recommended mode of assessment for week 4 is **discussion**. Use the level 3 question 2 as a sample question.

Section 1 Review

1. Chemical properties of materials are fundamental to their functionality and application across various fields, including chemistry, biomedical engineering, mechanical and materials science.
2. Materials can be classified into crystalline and amorphous categories based on their atomic arrangement and structural properties.
3. Materials are characterised by their classification of processing methods, including shaping, property-enhancing, and surface processing.
4. Bulk materials exhibit unique properties like density, surface area, flowability, compressibility, and compatibility.

Appendix for Rubrics for the Class Exercise Assessment, Homework & Poster

Criteria	Excellent (5 marks)	Very good (4 marks)	Good (3 marks)	Fair (2 marks)
Clear and scientific explanation for metals	Provides scientific explanation with all the key words. Metals possess metallic bonds that facilitate electron loss, making them reactive with oxygen, water, and acids. This results in metal oxides, metal hydroxides (with water), and salts (with acids), releasing hydrogen gas.	Provides explanation with omission of 1 keyword. Metals lose electrons easily due to metallic bonding, reacting with oxygen, water, and acids to form oxides, hydroxides, and salts, often releasing hydrogen gas...	Provides explanation with the omission of 2 key words. Metals react with oxygen, water, and acids, forming oxides, hydroxides, and salts, and releasing hydrogen gas.	Provides explanation with the omission of 3 key words, Metals react with oxygen, water, and acids, forming oxides, hydroxides, and salts, and producing hydrogen.
Clear and scientific explanation on ceramics	Explaining ceramic with all the key words present. Ceramics have strong ionic or covalent bonds that make them highly resistant to chemical reactions, especially acids, due to their stability.	Explaining ceramic with 1 key word missing. Ceramics are resistant to acids because their strong ionic or covalent bonds prevent dissolution	Explaining ceramic with 2 key word missing Ceramics resist acid reactions due to their strong bonds.	Explaining ceramic with 3 key word missing Ceramics are resistant to acid due to their strong bonds.

Rubrics for the Homework Assessment

Criteria	Excellent	Very good	Good	Fair
Clear and scientific explanation Crystalline Materials.	Provides scientific explanation with all key words. They are materials that have highly ordered atomic or molecular structure, forming distinct, well-defined crystals with regular, repeating pattern. (5 Marks).	Provides explanation with the omission of 1 keyword. These are materials having an ordered structure, forming well-defined crystals with a repeating pattern. (4 Marks).	Provides explanation with the omission of 2 keywords. Are materials with an ordered atomic or molecular structure and form crystals with a repeating pattern. (3 Marks).	Provides explanation with the omission of 3 keywords. Are materials with ordered atomic structure and crystal formation, definition of crystals. (2 Marks).
Examples of Crystalline Materials.	Give at least two example like Steel, quartz and diamond, (2 Marks).	Give only one example like steel. (1 Marks).	Give wrong example like Nylon. (0 Marks).	Give no example, (0 Marks).

<i>Clear and scientific explanation of Amorphous Materials.</i>	<i>Ceramics have strong ionic or covalent bonds that make highly resistant to chemical reactions, especially acids, due to their stability. (5 Marks).</i>	<i>Ceramics are resistant to acids because their strong ionic or covalent bonds prevent dissolution. (4 Marks).</i>	<i>Ceramics resist acid reactions due to their strong bonds. (3 Marks).</i>	<i>Ceramics are resistant to acid due to their strong bonds. (2 Marks).</i>
<i>Examples of Amorphous Materials</i>	<i>Give at two examples like glasses, plastics (2 Marks).</i>	<i>Give only one example like plastic. (1 Marks).</i>	<i>Give wrong example like Nylon. (0 Marks).</i>	<i>Give no example. (0 Marks).</i>

Rubrics for the Poster Assessment

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
<i>Understanding of the Process</i>	<i>Includes all key steps (extraction, smelting, refining, casting, finished metal product :) in proper order.</i>	<i>Omit 1 key step in correct order. (Extraction, smelting, refining, casting and shaping)</i>	<i>Includes key steps, but the sequence is incomplete, casting, refining, extraction, smelting,</i>	<i>Omits key steps, extraction, casting, refining,</i>
<i>Clarity and Logical Flow</i>	<i>The flowchart is clear, easy to follow, and well-organised. Arrows and connections make the progression logical.</i>	<i>The flowchart is mostly clear, with minor issues with connection of flow.</i>	<i>The flowchart is somewhat lacking connections progression but with arrows to follow.</i>	<i>The flowchart is difficult to follow, with no arrow and connections</i>
<i>Symbol and Formatting Usage</i>	<i>Uses correct flowchart symbols (rectangles, diamonds, Hexagonal) and follows standard flowchart conventions (arrows pointing to the next step/object).</i>	<i>Mostly correct use of flowchart symbols, but may have minor formatting errors.</i>	<i>Uses some flowchart symbols incorrectly</i>	<i>Incorrect or no use of flowchart symbols. Formatting is confusing.</i>
<i>Creativity and Presentation</i>	<i>Visually appealing and well-organised. Uses colours, labels, and spacing effectively to enhance understanding.</i>	<i>Presentation is clear with some use of colours or spacing.</i>	<i>The flowchart is functional, but lacks visual appeal and effective use of space or color.</i>	<i>Presentation is hard to read, as symbols are not labeled, coloured and with irregular spacing.</i>

Refer to Appendix C for correct flow chat diagrams in steel production with design elements and symbols.



APPENDIX A: PORTFOLIO ORGANISATION

Portfolio Assessment

Portfolio assessment for the academic year commences in Week 2 and is to be submitted in Week 20. The portfolio assessment structure should include a diverse collection of artefacts.

1. The Portfolio Assessment should include the following

- a) Exercise from week 1 -19
 - i. case study
 - ii. homework
 - iii. presentations
- b) Project works from week 1 - 19
 - i. individual project
 - ii. group project work
 - iii. Poster/artefact
- c) Reports on practical exercises (if any)
- d) Mid semester and end of semester paper(s)
- e) Awards (if any)
- f) Other relevant documents.

2. Structure and organisation of the Portfolio Assessment

A file with all collected items should include the following components:

- a) **Cover Page:** Full name, class and academic year, (e.g. 2024/2025 academic year) which entails the learner's name, class, subject and period (date).
- b) Table of Contents which has the list of items included with page numbers.
- c) A glossary, on the page with new terminologies learnt throughout the year

3. Mode of Administration

Remind and prompt learners throughout the academic year, which exercise are included in the portfolio (reminders have been provided at various sections in the PLC handbook)

4. Mode of Submission

- a) Communicate the final deadline for portfolio submission to all learners to ensure timely and complete submissions.
- b) Learners can submit their completed portfolios either as a physical or through the school's online submission system.
- c) Ensure the portfolio includes all required elements: assignments, projects, tests, class participation records, mid semester and end of semester.
- d) Learners should organise their portfolios clearly and logically, with each component clearly labeled and easy to access.
- e) For digital submissions, learners should upload their portfolios as a single file or in clearly marked folders within the online portal.

5. Sample Portfolio Assessment and rubrics

<i>Learner's works</i>	<i>Score</i>
<i>homework/Exercises</i>	<i>10 marks</i>
<i>Projects/Case studies</i>	<i>10 marks</i>
<i>Tests</i>	<i>10 marks</i>
<i>Posters/artefact</i>	<i>5 marks</i>
<i>Mid-semester and End-of-semester Papers</i>	<i>5 marks</i>
<i>Total marks</i>	<i>40 marks</i>

Rubrics for the Portfolio Assessment

<i>Criteria</i>	<i>Excellent (10)</i>	<i>Very Good (8)</i>	<i>Good (6)</i>	<i>Fair (4)</i>
<i>Organisation & Structure</i>	<i>The portfolio is organised in neat file with the inscription; Full name, class and academic year. Table of Contents and a glossary</i>	<i>The portfolio is organised in file with the inscription; Full name, class and academic year. Table of Contents but without a glossary</i>	<i>The portfolio is organised in an envelope without glossary, and table of content.</i>	<i>The portfolio is poorly organised with only the Full name, class</i>
<i>Contents</i>	<i>All supporting documents/ content are available Homework/Exercises Projects/Case studies Tests Posters/artefact Mid-semester and End-of-semester Papers</i>	<i>Few supporting documents/contents missing. Homework/Exercises Tests Mid-semester and End-of-semester Papers</i>	<i>Some supporting documents/ content missing. Homework/ Exercises Tests and End-of- semester Papers</i>	<i>Most of the supporting documents/ content missing. Homework/ Exercises. Tests End-of-semester Papers</i>
<i>Glossary</i>	<i>Glossary is comprehensive with clear definitions for all key terms, abbreviations, and concepts used.</i>	<i>Glossary includes definitions for most key terms, abbreviations, and concepts.</i>	<i>Glossary do not some definitions some terms or concepts.</i>	<i>Glossary is incomplete, with several terms or concepts missing definitions.</i>



APPENDIX B: STRUCTURE OF A GROUP PROJECT

DESIGN AND FABRICATE A POROTYPE. OF NET POST HOLDER/LAMP (MARKING OUT, CUTTING, FILING BENDING AND JOINING PROCESSES)

Task

In a mixed ability group, work collaboratively on a group project to design, fabricate, and present prototype a net post clamp for holding table tennis net. After completing the project, each group member should write a brief reflection of not more than 200 words, stating some valuable skills that you have learned, the challenges you faced, and things you can do to improve upon your teamwork and project management skills in future projects.

Project Components

1. Project Proposal (including objectives, methodology, and expected outcomes)
2. Research and Data Collection (Fabrication Techniques, Design Considerations, Material Selection, cost analysis)
3. Development Process (Project Planning, Conceptual Design, Analysis,
4. Design Documentation, (Introduction, purpose, scope, and objectives of the design, design concepts, discussion of results, conclusion and recommendations)
5. Final Product/Outcome (photos and descriptions of the completed project or implemented solution).
6. Group Presentation (slides, scripts, and any other presentation materials)
7. Individual Reflections (not more than 200 words each) on the project journey, skills learned, challenges faced, and areas for improvement

Structure and Organisation of the Project Report

As part of the structure of the project report, groups should include the following details:

Cover Page (Title, Group members' names, Class, Date of submission).

1. Table of Contents.
2. Project Proposal.
3. Research and Data Collection.
4. Design Documentation.
5. Development Process.
6. Final Product/Outcome.
7. Group Presentation.
8. Individual Reflections

Rubrics

1. Cover page.....2 marks
2. Table of Contents.....2 marks
3. Project Proposal.....5 marks

4. Research and Data Collection5 marks
5. Design Documentation5 marks
6. Development Process.....5 marks
7. Final Product/Outcome10 marks
8. Group Presentation10 marks
9. Individual Reflections5 marks
10. Demonstration of creativity and teamwork ...1 mark

How to administer assessment task

1. Explain the group project requirements and objectives to the learners.
2. Assign the group project in week 3 of the first semester.
3. Schedule regular check-ins to monitor progress and provide feedback.
4. By the 18th week, instruct groups to finalise their project and prepare their presentations.
5. Group projects should be submitted and presented in the 22nd week at a time agreed on by both teacher and learners.
6. Refer to Teacher Assessment Manual and Toolkit (TAMT) page 143-149 for more information on how to use group projects as an assessment strategy

Feedback

1. Review the project report and provide feedback, highlighting strengths and areas for improvement.
2. Evaluate the group presentation and provide constructive feedback.
3. Share the results of the project with the learners and commend their efforts.
4. Encourage learners to reflect on their group work experience and keep records for future reference

Rubrics for the Discussion Assessment

Criteria	Excellent	Very good	Good	Fair
<i>Relationship between synthesising and processing of materials</i>	<i>Provides five relationships between Synthesis and processing create materials with tailored properties by combining elements in a controlled way, while processing shapes these materials into final products using techniques like molding or heat treatment. (10 Marks).</i>	<i>Provides 4 relationship with. Synthesis forms materials with specific properties by combining elements, and processing shapes these materials into products through methods like molding or heat treatment. (8 Marks).</i>	<i>Provides 3 relationship though, but with slight omissions or lack of detail. Synthesis creates new materials by combining elements, and processing shapes them into final products using techniques like molding or heat treatment. (6 Marks).</i>	<i>Provides 2 relationship but lacks some specific detail Synthesis combines elements to create materials, and processing shapes them into products using methods like molding or heat treatment. (4 Marks).</i>

<i>Examples synthesised materials.</i>	<i>Give at least three examples (Nylon. Polyethylene Fiberglass, Carbon Fiber Reinforced Polymer, stainless steel (3 Marks).</i>	<i>Give at least two examples (Nylon. Fiberglass, Carbon Fiber Reinforced. (2 Marks).</i>	<i>Give at only one example (Nylon) (1 Marks).</i>	<i>Gives incorrect or wrong example (wood) (0 Marks).</i>
<i>Why materials are synthesising</i>	<i>Provide clear and understandable reason like; To create materials with specific characteristics that are not found in naturally occurring materials and also for the emerging technological advancement needs. (5 Marks).</i>	<i>Provided clear and understandable reason with few omissions; To develop materials with distinct characteristics that are not available in nature, facilitating advancements in technology and application (4 Marks).</i>	<i>Provided a reason that is incomplete; To create materials with specific properties that don't exist in natural materials, expanding potential uses in various industries (2 Marks).</i>	<i>Provided a reason with unclear thought; To make materials with properties that aren't found in nature, allowing for new applications and improvements. (1 Marks).</i>

SECTION 2: UNDERSTANDING MECHANICAL PROPERTIES OF MATERIALS

STRAND: MATERIALS FOR MANUFACTURING

Sub-Strand: Properties of materials

Learning Outcome: *Explain and measure the tensile properties of materials*

Content Standards

1. *Demonstrate knowledge and understanding of loading, stress and strain of materials*
2. *Demonstrate knowledge and understanding of loading, stress and strain of materials*

HINT



- Remind learners of Mid semester examination in week 6
- Refer to the Appendix D for more sample task and the Table of Specification

Introduction and Section Summary

In this section, learners will be introduced to materials loading and the effect of loading, stress and strain on materials. Learners will understand the elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials and their contributions to the manufacturing of products. Learners 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. The weeks covered by the section are:

Week 5: Materials loading and effect of loading, stress and strain on materials

Week 6: Elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials

Week 7: Tensile properties of steel

Summary of Pedagogical Exemplars

Given the diversity in learners' backgrounds, learning capacities, and learning styles, employing a broad spectrum of pedagogical approaches that cater to learners' varied abilities within the classroom is vital. Pedagogical alternatives include employing strategies such as experiential learning, talk for learning, project-based learning, research-based learning and collaborative learning. In this section, consider providing learners the opportunity to view a video demonstration of materials loading and the effect of loading, stress and strain on materials. Allow learners to articulate their experiences through collaborative discourse to define elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials.

In mixed ability groups, allow learners to design experiments to measure and compute the elongation, elastic limit, modulus of elasticity, yield strength and tensile strength and use the knowledge gained to suggest ways of improving materials for specific applications.

Assessment summary

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in this section. Oral responses can be elicited in class discussions after watching video demonstrations of materials loading and the effect of loading, stress and strain on materials. written responses of various difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Learners should be able to understand and explain the elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials and apply the knowledge gained in the design and manufacturing of products.

WEEK 5

Learning Indicator

1. Explain loading, stress and strain of materials for manufacturing
2. Outline the effect of loading, stress and strain in materials

Focal Area 1: Materials loading, stress and strain

Introduction

Materials loading, stress, and strain are fundamental concepts in understanding the behaviour of manufactured products. They play a vital role in understanding how materials behave under various conditions and are essential in designing and manufacturing safe and efficient structures and products. Materials Loading refers to the application of force on a material. This force can be due to various factors such as gravity, pressure, tension, or even temperature changes. The way a material responds to this force is a key aspect of its mechanical properties.

Axial loading (tensile and compressive), bending, torsional and shear loading

Axial loading, bending, torsional, and shear loading are fundamental forces that structural members can experience, each affecting the member's behaviour and integrity in distinct ways. Axial loading involves forces applied along the longitudinal axis of a structural member, which can be either tensile (pulling apart) or compressive (pushing together). Tensile axial loads stretch the material, increasing its length, while compressive axial loads shorten it. Devices designed to apply axial loads ensure precise application and measurement of these forces, highlighting their importance in structural testing. Bending occurs when a moment or force is applied perpendicular to the longitudinal axis, causing the member to curve. This type of loading induces both tensile and compressive stresses across the cross-section, with the outer fibres experiencing the maximum stress. Torsional loading, on the other hand, involves twisting a member around its longitudinal axis, generating shear stresses that vary along the radius of the member's cross-section. This type of loading is particularly relevant in applications involving combining torsional and compressive/tensile stress waves for synchronised loading. Shear loading acts parallel to the cross-section of the member, causing one part of the material to slide past the adjacent part. This type of loading is critical in the design of slender geometries, such as wires, which are often tested for shear and compressive stress-strain curves through torsion and bending tests. The interaction of these loads can be complex, as seen in reinforced concrete (RC) members subjected to combined axial, bending, shear, and torsion loading.

Stress and strain of materials

Stress and strain are fundamental concepts in the study of the mechanical behaviour of materials, describing how materials deform and fail under various types of loading. Stress is defined as the internal force per unit area within a material, while strain is the measure of deformation representing the displacement between particles in the material body relative to a reference length. In the context of linear elasticity, stress and strain are related through Hooke's Law, which states that the strain in a material is proportional to the applied stress, provided the material's elastic limit is not exceeded. This relationship is critical for understanding the elastic behaviour of materials, where they return to their original shape upon the removal of stress.

However, real-world materials often exhibit more complex behaviours. For instance, plastic deformation occurs when materials are subjected to stresses beyond their elastic limit, leading to permanent deformation. The measurement and prediction of stress and strain are essential for the design and maintenance of engineering structures, as high stress and strain can lead to material failure. In granular materials, stress and strain definitions must consider contact couples and independent particle rotations, which are critical for understanding their mechanical behaviour. Geomaterials, such as soils and rocks, exhibit stress-strain behaviour that depends on factors like strain rate, stress level, and the interaction among solid, liquid, and gas phases, especially under dynamic loading conditions like blasts.

Learning Tasks

1. Divide the class into mixed-ability groups and let each group perform axial loading (compression and tension), bending loading, torsional loading, and shear loading using readily available materials.
2. After the loading tests, facilitate a class discussion where learners explain loading, stress, and strain. Guide learners to understand that stress and strain are used to deduce the properties of materials during or after manufacturing.
3. Ask students to research different types of loading and their effects on materials. They should present their findings to the class, including examples of materials that undergo these types of loading.
4. Assign each group a different type of loading (axial, bending, torsional, shear) and ask them to create a presentation demonstrating the effects of this loading on a specific material. This task encourages collaborative learning and application of knowledge

Pedagogical Exemplars

Experiential Learning

Place learners into mixed-ability groups and let each group perform axial loading (compression and tension), bending loading, torsional loading and shear loading using readily available materials. Use your knowledge of your learners and your creativity to adapt the activity as needed. For example, you could incorporate elements of gamification, or use technology tools to enhance learning.

Talk for Learning

Learners explain loading, stress and strain from the loading tests performed earlier. Guide learners to understand that stress and strain are used to deduce the properties of materials during or after manufacturing. Allow learners to demonstrate their understanding in different ways. For example, some learners could present their understanding to the class, while others could create a report or a model.

Key Assessment

Assessment Level 1

1. List materials in your community that undergo tension, compression, or torsion during their everyday use.
2. **True or False:** Axial loading includes both tensile and compressive loading.
3. **Fill in the blank:** _____ loading is a type of loading where a twisting force is applied to an object.

4. What is the term used to describe the deformation of a material under stress?
5. Which of the following is not a type of loading?
a) Axial b) Bending c) Torsional d) Elastic
6. A material is subjected to a force that causes it to twist. What type of loading is this?
a) Axial b) Bending c) Torsional d) Shear

Assessment Level 2

1. Relate the failure of some materials in your community with the type of load applied to it.
2. Explain the difference between stress and strain.
3. If a material is subjected to a bending load, what might be the potential effects on the material?
4. Describe a scenario where shear loading would be significant in a manufacturing process.

Assessment Level 3

1. Compare and contrast the effects of tensile and compressive loading on a ductile material.
2. How can you use the knowledge of stress and strain to prevent failure in the everyday use of materials in your community?
3. Discuss the effects of different types of loading on the stress and strain of materials in manufacturing.
4. Investigate the properties of a specific material around you and how they change under different types of loading.
5. Present a case study of a real-world manufacturing process, identifying the types of loading involved and their effects on the materials used.
6. Debate: Argue for or against the statement: “Understanding the effects of loading on materials is crucial for efficient and safe manufacturing.”

Focal Area 2: Effect of loading, stress and strain on materials

Introduction

Materials form the cornerstone of manufacturing engineering. Their properties and behaviour under various conditions dictate the quality, durability, and efficiency of the products we engineer. Hence, a profound understanding of how materials respond to different conditions is paramount for designing and manufacturing robust and efficient products. The effects of loading, stress, and strain on materials are multifaceted and significantly influence their mechanical properties and behaviour. Stress and strain, resulting from mechanical or thermal loading, can lead to material failure due to the generation of high stress and strain values, making their measurement and prediction crucial for the design and maintenance of engineering structures.

Strain measurement using the strain gauge

Strain measurement using strain gauges is a fundamental technique in experimental stress analysis, widely applied across various fields such as manufacturing, aerospace, automotive, agriculture, and medical industries. A strain gauge typically consists of a metallic foil pattern mounted on a flexible insulating substrate bonded to the specimen using a suitable adhesive. When the specimen deforms under stress, the strain gauge also deforms, causing a change in its electrical resistance. This change in resistance is proportional to the strain experienced by the specimen, allowing for precise strain measurement. Strain gauges come in various types, including wire, foil, and semiconductor strain gauges, each with specific applications and advantages. For instance, the strain gauge system can be configured in a Rosette arrangement to measure multi-directional strains, enhancing the accuracy and comprehensiveness of the data collected. Advanced strain gauge systems, such as those incorporating multiple strain gauges, can collect large amounts of data rapidly, reducing random errors and improving measurement precision through high-frequency sampling and arithmetic averaging. Additionally, capacitive strain gauges, which use several electrodes and conductive guards, offer improved accuracy by minimising error occurrence and deviation from the basic formula. In specific applications like crank measurement systems, strain gauges are strategically placed to measure bend, shear, and axial strains, providing comprehensive data on force, torque, and power applied to the crank. The strain gauge's performance can be influenced by factors such as temperature, which necessitates careful selection and placement of the gauges, often determined using techniques like brittle coating. Moreover, innovative designs, such as those with flexible substrates and structured resistance layers, enhance the strain gauge's sensitivity and accuracy by adjusting the creep behaviour and minimising temperature coefficients and transverse sensitivity.

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:

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

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/m²) or newtons per square millimetre (N/mm²).

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:

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

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:

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

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

Example

To determine the modulus of elasticity of steel, for example, first identify the region of elastic deformation in the stress-strain curve, which you now see applies to strains less than 1 percent, or $\varepsilon = 0.01$. The corresponding stress at that point is $\sigma = 250 \text{ N/mm}^2$. Therefore, using the modulus of elasticity formula, the modulus of elasticity of steel is

$$E = \frac{\sigma}{\varepsilon} = \frac{250}{0.01} = 25000 \text{ N/mm}^2$$

Learning Tasks

1. In mixed ability groups ask learners to research different materials used in manufacturing and their respective modulus of elasticity. They should prepare a group report outlining the effect of loading, stress, and strain on these materials.
2. Using a software simulation tool, learners can simulate the effect of different loads on a material and observe the resulting stress and strain. They should record their observations and present them to the class.
3. Provide learners with a real-world case study where a particular material failed due to stress and strain. Ask them to analyse the case, identify the causes of failure, and suggest improvements.
4. Challenge learners to design a component with a specific load requirement. They should calculate the expected stress and strain using the modulus of elasticity and justify their material choice based on these calculations.
5. In mixed ability groups Learners will prepare a group presentation on the topic of 'Effect of loading, stress, and strain on materials. They should use examples and case studies to illustrate their points.

Pedagogical Exemplars

Experiential Learning

Learners measure the strain of materials in the laboratory using the strain gauge and determine the stress of the materials according to the applied strain. Display lab work for others to critique.

Project-based Learning

Put learners into mixed-ability groups and let them use the strain gauge to measure the strain and calculate the stress induced in a steel metal using the modulus of elasticity of mild steel as available in textbooks. Learners share their findings with the class and receive feedback.

Key Assessment

Assessment Level 1

1. List the instrument that can be used to measure the strain in a material.
2. True or False: The modulus of elasticity is used to calculate stress and strain.
3. Fill in the blank: The _____ gauge is a device used to measure strain.
4. Which of the following is not a type of loading? a) Axial b) Bending c) Torsional d) Elastic
5. What is stress?

Assessment Level 2

1. How does a strain gauge convert mechanical strain into an electrical signal?
2. Explain how a strain gauge works.

Assessment Level 3

1. A metal bar is subjected to a tensile load. Explain how you would determine the modulus of elasticity of the material.
2. How will you use the strain gauge to find the stress induced in a material?
3. Discuss the importance of understanding stress, strain, and the modulus of elasticity in manufacturing engineering.
4. Investigate the properties of a specific material and how they change under different types of loading.
5. Present a case study of a real-world manufacturing process, identifying the types of loading involved and their effects on the materials used.
6. Perform axial loading bending loading and torsional loading test using readily available materials.

HINT



The recommended mode of assessment for week 5 is **demonstration**. Use the level 3 question 6 as a sample question.

WEEK 6

Learning Indicator: Explain elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials

Focal Area: Elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials

Introduction: This lesson discusses some key properties that are important in understanding how materials behave under different forces and conditions. By the end of this lesson, learners will be able to explain the following terms: elongation, elastic limit, modulus of elasticity, yield strength, and tensile strength. An understanding of these properties is important in the manufacturing and engineering fields. Knowledge of how materials respond to stress and strain helps us make informed decisions for everyday applications such as selecting materials for the manufacturing of a product, designing bridges, manufacturing smart phones and many such applications.

Elongation

It refers to the increase in length of a material when it is subjected to a tensile force or stress. When a rubber band is pulled, it stretches. This stretch is the elongation. The relationship between the applied force (stress) and the elongation (strain) can be seen on a stress-strain curve. Elongation is a critical property in material science, affecting the durability and performance of materials in construction, manufacturing, and everyday products. Understanding how materials elongate under stress helps in designing safer and more efficient structures and products. Elongation is typically measured as a percentage of the original length as shown in equation (6.1). For example, if a 10 cm long wire stretches to 11 cm, the elongation is 10%.

Percentage elongation (ΔL)

$$= \frac{\text{final length} - \text{original length}}{\text{original length}} \times 100\%$$

Elasticity and Elastic Limit

When an external force acts on an object, the object tends to undergo some deformation. If the external force is removed and the object comes back to its original shape and size, the object is known as an elastic object. This property, by which certain materials return to their original position after the removal of the external force, is called elasticity. The object will regain its previous shape and size only when the deformation caused by the external force, is within a certain limit. Thus, there is a limiting value of force up to and within which, the deformation completely disappears on the removal of the force. The value of stress corresponding to this limiting force is known as the elastic limit of the material. If the external force is so large that the stress exceeds the elastic limit, the material loses, to some extent, its elastic property.

If the force is now removed, the material will not return to its original shape and size and there will be a residual deformation in the material.

Modulus of Elasticity

When a material is loaded within an elastic limit, the stress is proportional to the strain produced by the stress. This is referred to as Hooke's Law, and it explains that 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. The modulus of elasticity describes the stiffness of a material. A material with high modulus of elasticity shows

that the material is stiff and can resist deformation upon the application of a stress. A material with low modulus of elasticity shows that it is more flexible and deforms easily upon the application of an external stress. Mathematically, the modulus of elasticity can be expressed as shown in equation (6.2).

$$\text{Modulus of elasticity (E)} = \frac{\text{Stress } (\sigma)}{\text{Tensile strain } (e)}$$

The unit of the modulus of elasticity is the Pascal (Pa). Since the modulus of elasticity often deals with large values, it is commonly expressed in gigapascals (GPa) or megapascals (MPa). Different materials have different modulus of elasticity. Table 6.1 shows the modulus of elasticity of some regular materials used in the manufacturing industry.

Table 6.1: *Modulus of elasticity of typical materials used in the manufacturing industry*

Material	Modulus of elasticity (GPa)
Steel	200 – 210
Aluminium	69 – 70
Copper	110 – 130
Titanium	110 – 120
Brass	90 – 105
Concrete	25 – 30
Glass	50 – 90
Wood	10 – 16

Yielding and Yield Strength

Most materials are designed to undergo elastic deformation when external stress acts on them. A material that undergoes plastic deformation (experiences a permanent change in shape) is not capable of performing its intended functions. It is therefore desirable to know the stress level at which plastic deformation begins. The onset of plastic deformation in materials is referred to as yielding. For metals that experience gradual elastic-plastic transition, the point of yielding may be determined as the initial departure from the linearity of the stress-strain curve. This is sometimes called the proportional limit and represents the onset of plastic deformation on a microscopic level. In real applications, the position of the proportional limit (P) is difficult to measure precisely. Therefore, a convention has been established by which a straight line is constructed parallel to the elastic portion of the stress-strain curve at some specified strain offset, usually 0.002 as shown in Fig. 6.1(a). The stress corresponding to the intersection of this line and the stress-strain curve as it bends over in the plastic region is defined as the yield strength s_y . The unit of yield strength is MPa. The magnitude of the yield strength for a metal is a measure of its resistance to plastic deformation. Yield strength may range from 35 MPa, for low-strength aluminium, to greater than 1400 MPa for high-strength steels.

Some materials exhibit the tensile stress-strain behaviour shown in Figure 6.1(b). With such materials, the elastic-plastic transition is very well defined and occurs abruptly in what is termed as the yield point phenomenon. At the upper yield point, plastic deformation is initiated with an apparent decrease in engineering stress. Continued deformation fluctuates slightly about a constant stress value, termed the lower yield point; stress subsequently rises with increasing strain. For metals that display this effect, the yield strength is taken as the average stress that is associated with the lower yield point because it is well-defined and relatively insensitive to the testing procedure.

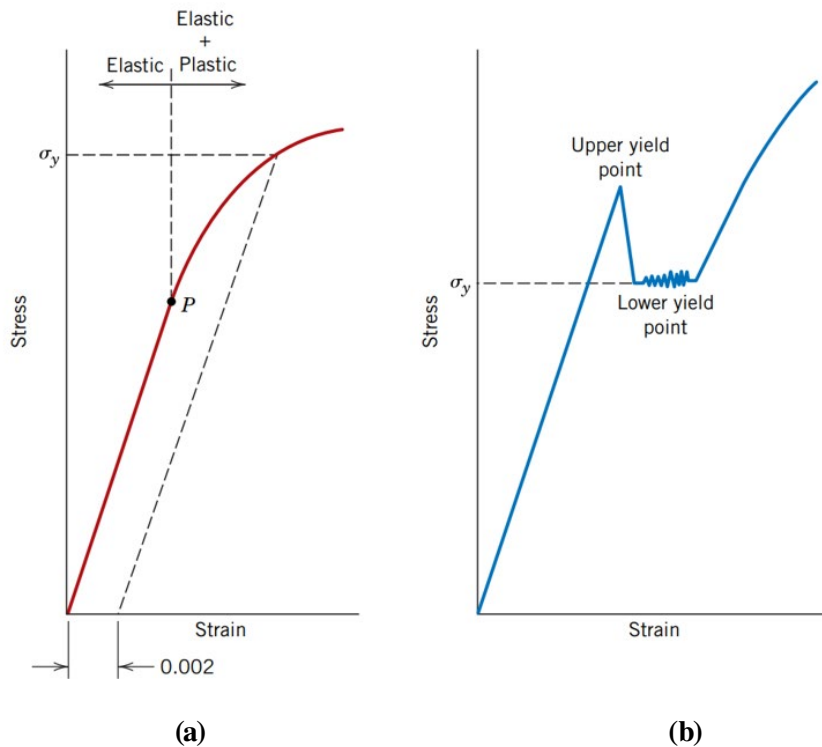


Figure 6.1(a): Typical stress-strain behaviour for a metal showing elastic and plastic deformations, the proportional limit P , and the yield strength σ_y , as determined using the 0.002 strain offset method (Callister, 2014).

Figure 6.1(b): Representative stress-strain behaviour found for some steels demonstrating the yield point phenomenon (Callister, 2014).

Tensile Strength

After yielding, the stress necessary to continue plastic deformation in metals increases to a maximum point (M) known as the tensile strength. The stress decreases after the tensile strength to the eventual fracture, point F. The tensile strength (TS) is the maximum stress on the engineering stress-strain curve as shown in Figure 6.2, and it corresponds to the maximum stress that can be sustained by a material in tension. If this stress is applied and maintained on a material, fracture will occur.

Typically, when the strength of a material is cited for design purposes, the yield strength is used because by the time a stress corresponding to the tensile strength has been applied, often a structure has experienced so much plastic deformation that it is not worth using anymore.

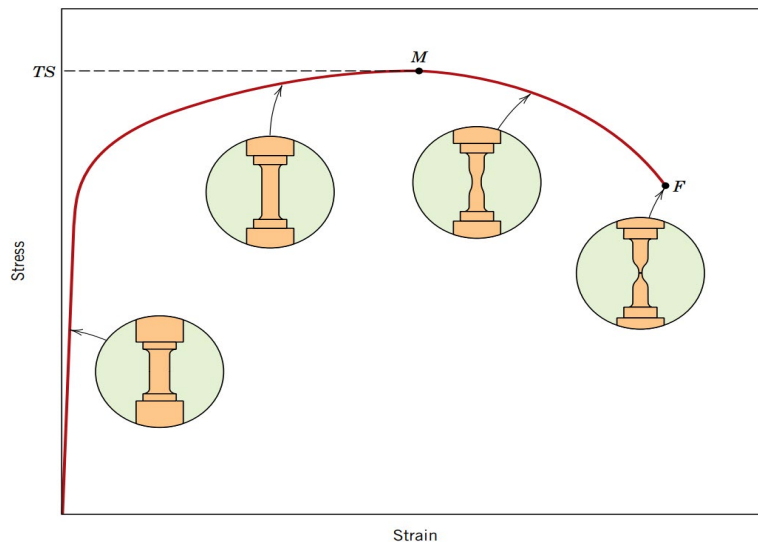


Figure 6.2: Stress-strain behaviour to fracture curve (Callister, 2014)

Learning Tasks

1. Learners discuss elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials before sharing their understanding of these concepts with the class for feedback.
2. Learners make flashcards that define elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials.
3. Learners perform experiments using materials such as rubber bands and weights to observe elongation, elastic limit and plastic deformation.

Pedagogical Exemplars

1. **Talk for learning:** Lead learners to discuss elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials. Encourage learners to discuss in pairs before sharing with the whole class. Allow learners who may not be vocal to contribute to the discussion through writing. Encourage all learners to contribute to the discussion while ensuring that a few learners do not dominate the discussion session. Develop communication and discussion skills to facilitate learning.
2. **Research-based learning**
 - a. Learners read from the library and the internet on elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials. Learners use flashcards to define elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials with examples, and share their results in class. Encourage learners to share their findings with each other to promote collaborative learning. Let advanced learners find more complex examples relating to each concept.
 - b. Let learners in mixed-ability groups perform experiments to observe and understand elongation, elastic limit, modulus of elasticity, yield strength and tensile strength using materials such as rubber bands and weights. Let learners measure and record the elongation of the material at different weights, record video presentations of their results and discuss it in class for feedback. Encourage more proficient learners to compare the modulus of elasticity with theoretical values.

Key Assessment

Assessment Level 1

1. Define elongation in the context of material science.
2. What is meant by the elastic limit of a material?
3. What does the modulus of elasticity measure?

Assessment Level 2

From the tensile stress-strain behaviour for the brass specimen shown in Figure 6.3, determine the following:

- (a) The modulus of elasticity.
- (b) The yield strength at a strain offset of 0.002.
- (c) The maximum load that can be sustained by a cylindrical specimen having an original diameter of 12.8 mm.

- (d) The change in length of a specimen originally 250 mm long that is subjected to a tensile stress of 345 MPa.

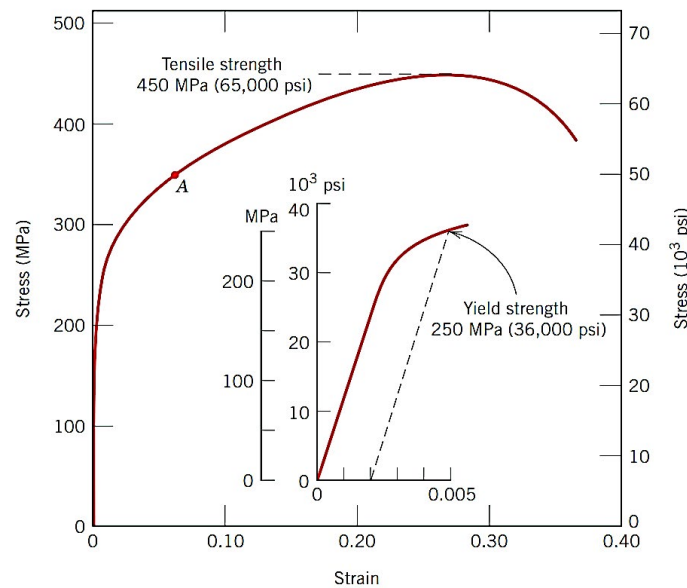


Figure 6.3: Stress-strain behaviour for brass (Callister, 2014)

Assessment Level 3

1. Compare the implications of using a material with high modulus of elasticity against one with low modulus of elasticity for the construction of a bridge.
2. Given two materials with the same yield strength but different tensile strengths, which material would be more suitable for an application requiring high resistance to fracture and why?
3. Outline the steps you would take to perform a simple experiment to measure the yield strength of a metal wire. Discuss the key considerations in your experimental setup and describe how you would process the collected data to determine the yield strength.

HINT



- The recommended mode of assessment for week 6 is **Mid semester examination**.
- Refer to the Appendix C for more sample task and the Table of Specification

WEEK 7

Learning Indicator: Measure the tensile properties of steel using the tensile test

Focal Area: Tensile properties of steel

Introduction

This lesson introduces the tensile test, which is a fundamental experiment used to measure the tensile properties of materials such as elongation, yield strength and tensile strength. The tensile test is a hands-on test conducted using a tensile test machine. The test helps in understanding how steel behaves under different types of stress, providing essential insights into its applications in engineering and manufacturing. This lesson will equip learners with the knowledge and skills to perform and analyse tensile tests, bridging the gap between theory and practice.

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

1. Sample steel rod (sample as shown in Fig. 7.1)
2. Tensile testing machine (Fig. 7.2)
3. Vernier calliper or micrometre
4. Extensometer
5. Safety gear (gloves, goggles)

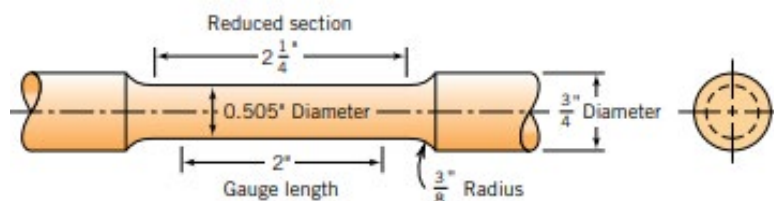


Figure 7.1 A: standard tensile test specimen with circular cross-section (Callister, 2014)

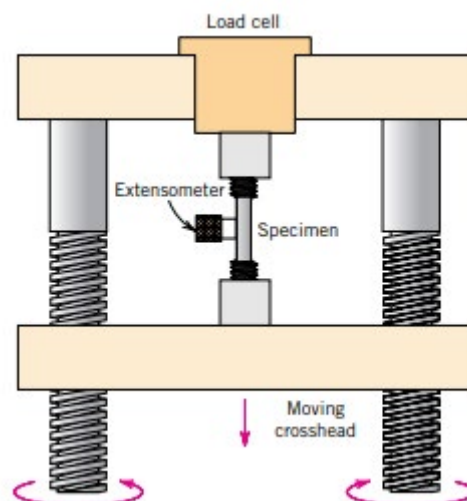


Figure 7.2: Set up of a universal tensile test machine for stress-strain test

Procedure

1. Preparation of Specimen

- Measure the original length (L_0) and diameter (d_0) of the steel rod using a vernier calliper or micrometer.
- Mark the gauge length on the steel rod.

2. Setting up the Tensile Testing Machine

- Secure the steel rod in the grips of the tensile testing machine.
- Attach the extensometer to the gauge length of the rod to measure the extension.

3. Conducting the Test

- Start the tensile testing machine and gradually apply the tensile load.
- Record the applied load (F) and corresponding elongation (ΔL) at regular intervals.
- Continue the test until the rod fractures.

4. Recording Data

- Note the maximum load (F_{max}) before fracture.
- Measure the final length (L_f) and diameter (d_f) at the fractured section.

Data And Observations

For the purposes of understanding, a 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): $A = \pi \frac{d_o^2}{4}$
- Stress (σ): $\sigma = \frac{F}{A}$
- Strain (ϵ): $\epsilon = \frac{\Delta L}{L_o}$
- Young's Modulus (E): $E = \frac{\sigma}{\epsilon}$
- Ultimate Tensile Strength (UTS): $UTS = \frac{F_{max}}{A}$
- Percentage Elongation: $\%Elongation = \left(\frac{L_f - L_o}{L_o} \right) \times 100$

Table 7.1 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 Fig. 7.3
- Cross-sectional Area (A): 128.68 mm²
- Young's Modulus (E): 5305.17 MPa
- Yield Strength: 285 MPa
- Ultimate tensile strength: 370 MPa
- Percentage Elongation: 16%

CONCLUSION

The tensile test provided essential mechanical properties of the steel rod, including yield strength, ultimate tensile strength, Young's modulus, and percentage elongation. These values are critical for engineering applications and material selection during the design and manufacturing of products.

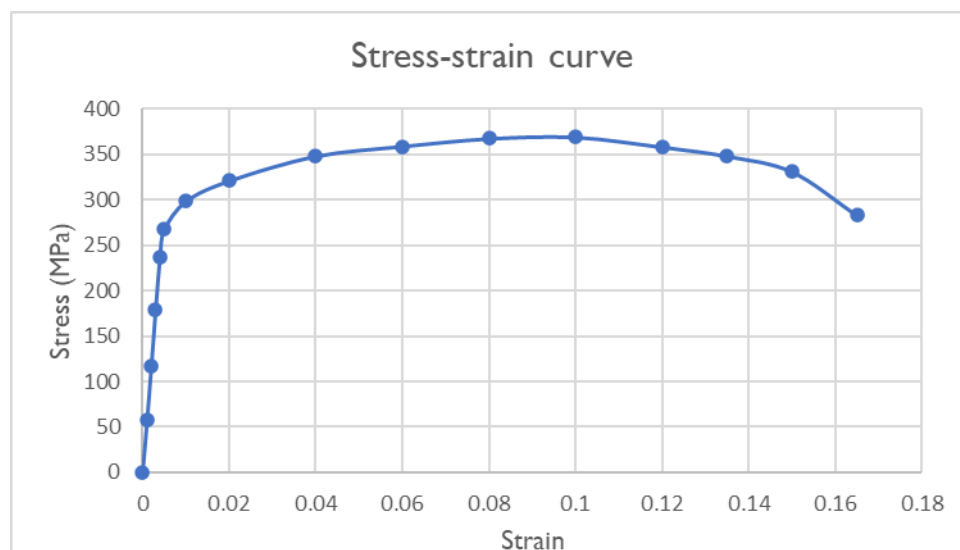


Figure 7.3: Stress-strain curve resulting from tensile test

Learning Tasks

Learners perform tensile test on a steel material in the laboratory and present their reports to the class for feedback.

Pedagogical Exemplars

Experiential/collaborative learning: Using diagrams, detailed written instructions, videos and additional reading materials explain the tensile test setup and procedure. Let learners in mixed-ability groups perform the tensile test in the laboratory using steel. Let learners in their mixed-ability groups plot the stress-strain graph from the tensile test of the mild steel and use it to determine the tensile properties of the mild steel. Assign specific roles to learners to ensure that all learners fully participate in the experiment. Let learners decide on the mode of presentation such as written reports, oral presentation or video presentations and receive feedback. Encourage more proficient learners to find the Young modulus, yield strength and ultimate tensile strength of steel from the experiment and compare it with theoretical values reported in literature.

Key Assessment

Assessment Level 1

1. What is the purpose of a tensile test?
2. Define tensile strength.
3. What is elongation in the context of a tensile test?

Assessment Level 2

1. Describe the steps involved in setting up a tensile test machine for testing a steel sample.
2. Explain how you would determine the yield strength from a stress-strain curve obtained during a tensile test.
3. Calculate the modulus of elasticity if a steel sample with an initial length of 50 mm stretches to 51 mm under a stress of 300 MPa.

Assessment Level 3

1. Compare the implications of selecting either a material with high yield strength or high tensile strength for the construction of a bridge.
2. Design an experiment to test the tensile properties of a newly developed composite material and outline the test procedure and equipment needed.

HINT



The recommended mode of assessment for week 7 is **peer/self**. Use the level 3 question 6 as a sample question.

Section 2 Review

1. Materials loading, stress, and strain are fundamental concepts in understanding the behaviour of manufactured products.
2. Strain measurement using strain gauges is a fundamental technique in experimental stress analysis, widely applied across various fields such as manufacturing, aerospace, automotive, agriculture, and medical industries.
3. When an external force acts on an object, the object tends to undergo some deformation.
4. When materials are loaded within an elastic limit, the stress is proportional to the strain produced by the stress.

Rubrics for the Demonstration Assessment

Criteria	Excellent (5 points)	Very Good (4 points)	Good (3 points)	Fair (2 points)
Setting Up the Experiment	Sets up the experiment. Test setup is stable and aligned with excellent control of environmental factors	Setup is stable but with minor issues in alignment or control of factors. .	Test setup is somewhat unstable, or there are significant issues with environmental control	Test setup is unstable, with major alignment or environmental control issues. .
Execution of Demonstration	Performs all loading tests (compression, tension, bending, torsion, shear) accurately and smoothly using appropriate materials. Torque is applied smoothly; Shear strength is accurately determined and matches theoretical or expected values. Twist angle is measured accurately	Performs most loading tests accurately. Torque is applied steadily with minor inconsistencies in measurement, Shear strength is accurately determined but slightly deviates from expected values. Twist angle is measured with minor discrepancies.	Performs basic tests. Torque application shows some errors in measurement. Shear strength is measured but deviates significantly from expected values. Twist angle is somewhat unclear, with noticeable measurement errors. .	Performs tests with significant issues in accuracy. Torque application is highly inconsistent, with significant errors in measurement. Shear strength is inaccurately determined or not measured. Twist angle is not measured or is highly inaccurate
Material Behavior (Elasticity)	Material exhibits clear elastic behavior; returns to original shape after load is removed. .	Material shows mostly elastic behavior, with slight permanent deformation.	Material shows partial elastic behavior, with some noticeable permanent deformation.	Material shows significant plastic deformation or does not return to original shape.
Failure Point	Failure occurs at the expected load level, demonstrating strong material strength.	Failure occurs within a reasonable range of expected values, showing acceptable performance.	Failure occurs slightly below the expected range, indicating some weakness in material strength.	Failure occurs well below expected levels, indicating significant material weakness.
Strain/Stress Analysis	Clear analysis of stress and strain throughout the test; material's response well documented.	Good analysis of stress and strain, but some aspects of material response are unclear.	Limited or unclear analysis of stress and strain, with some missing key details.	Analysis of stress and strain is missing or incomplete.

Marking Scheme for the Peer/Self-Assessment.

Step	Operation	Tools/Equipment	Marks
1	Cut the specimen to standardised dimensions (e.g., dog-bone shape).	Cutting tools, micrometer, calipers, jig for consistency.	5
2	Prepare the specimen's surface (smooth and defect-free).	Sandpaper, polishing tools, cleaning materials.	4
3	Calibrate the universal testing machine (UTM).	Universal Testing Machine (UTM), calibration equipment.	6
4	Ensure correct alignment of specimen in the testing machine.	Visual inspection, laser alignment tools.	4
5	Attach appropriate grips/clamps to hold the specimen securely.	Pneumatic/manual/hydraulic grips, composite material grips.	4
6	Attach an extensometer to measure strain (optional).	Extensometer (contact or laser), mounting fixtures.	4
7	Apply tensile load gradually at a constant rate.	Universal Testing Machine (UTM) with load cell.	5
8	Monitor force and displacement during the test.	UTM with data acquisition system, extensometer, software (LabVIEW, TestWorks).	6
9	Identify failure mode (fracture, delamination, etc.).	Optical microscope, scanning electron microscope (SEM), fractography tools.	4
10	Calculate tensile strength using force and specimen area.	Data analysis software (Excel, MATLAB), force measurement data.	4
11	Document and present results, including stress-strain curve and failure mode.	Lab report templates, data analysis software.	3
Total Marks			45



APPENDIX D: TABLE OF TEST SPECIFICATION (MID-SEMESTER 1)

Week	Focal Area (F)	Type of Question	Depth of Knowledge			
			L1	L2	L3	Total
1	F1. Explain reactivity, flammability and toxicity as chemical properties of materials. F2. Group materials according to their chemical properties.	Multiple Choice	2	2	1	5
2	Classification of materials as crystalline and amorphous materials	Multiple Choice	1	1	1	3
3	F1. Identification of material processing methods F2. Classification of materials according to their processing methods	Multiple Choice	2	2	1	5
4	Grouping of materials according to their synthesis	Multiple Choice	1	1	1	3
5	F1. Materials loading, stress and strain F2. Effect of loading, stress and strain on materials	Multiple Choice	1	2	1	4
Total			7	8	5	20

SECTION 3: DRAW FOR MANUFACTURE

STRAND: DESIGN AND PROTOTYPING

Sub-Strand: Design and drawing for manufacture

Learning Outcome: *Explain the importance of freehand sketch, projection of objects, detailed and assembly drawings in product design and manufacturing*

Content Standards

1. *Demonstrate skills in freehand sketching for product design*
2. *Demonstrate knowledge and understanding of the projection of objects in product design*
3. *Demonstrate that detailed and assembly drawings are significant for product design and manufacturing*

HINT



- Remind learners of the End of Semester Examination in Week 12
- Refer to Appendix E at the end of this section for the Table of Specifications.

Introduction and Section Summary

In this section, learners will be introduced to the importance and application of isometric drawing and first-angle projection in product design. Learners will understand the importance of sectioning, dimensioning and tolerance and their importance to the manufacturing of products. Learners will be able to explain the concepts and application of detailed and assembly drawings in product design and modelling.

The weeks covered by the section are:

Week 8: Importance and application of isometric drawing and first-angle orthographic projection in product design

Week 9: Importance of sectioning, dimensioning and tolerance

Week 10: Importance of sectioning, dimensioning and tolerance

Week 11: Detailed drawings

Week 12: Assembly drawings

Summary of Pedagogical Exemplars

Considering the diversity in learners' backgrounds, learning capacities, and learning styles, employing a broad spectrum of pedagogical approaches that cater to learners' varied abilities within the classroom is vital. Pedagogical alternatives include employing strategies such as talk for learning, practice-based learning, research-based learning and collaborative learning.

In this section, consider providing learners with the opportunity to view a video or images of real-world objects (e.g., tables, chairs, or other products) and the importance of capturing multiple orthographic views (front, top, and side) for these objects. Allow learners to articulate their experiences through collaborative discourse to define and explain isometric drawing, sectioning, dimensioning, tolerance, detailed drawing and assembly drawing. In mixed ability groups, allow learners to identify the characteristics of assembly drawing and detailed drawing using sample drawings and charts and use the knowledge gained to suggest ways in which they can be employed in product design.

Assessment summary

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in this section. Oral responses can be elicited in class discussions after watching videos or images of isometric drawings, first-angle projections, detailed and assembly drawings. Written responses of various difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Learners should be able to understand and explain the isometric drawing, first-angle orthographic projections, sectioning, dimensioning, tolerance, detailed drawing and assembly drawing and apply the knowledge gained in the design and manufacturing of products.

WEEK 8

Learning Indicators

1. State the importance of freehand sketch in product design
2. Apply freehand sketch in product design

Focal Area 1: Importance of freehand sketch in product design

Introduction

Freehand sketching involves drawing by hand without the aid of tools like rulers or compasses for precision. It's a way to represent ideas, capturing the designer's initial thoughts, concepts, and vision, emphasising form, composition, and key details. Freehand sketching is an important tool in the design creation and exploration stage due to its smoothness and ability to convey thoughts effectively.

Product design

Product design is the process of creating new products or improving existing ones through a combination of creativity, technical skills, and strategic thinking. It encompasses the entire lifecycle of a product, from conceptualisation and development to production and market introduction. Product design aims to meet user needs, solve problems, and create functional, aesthetically pleasing, and marketable products.

Freehand sketches play a crucial role in product design by bridging the gap between abstract ideas and tangible outcomes. They provide a means for designers to quickly and effectively communicate their concepts, facilitating the transition from initial inspiration to detailed design. Through sketches, designers can explore a wide range of possibilities, iterate ideas, and refine solutions, all while maintaining a clear visual record of their thought processes.

Relevance of freehand sketch in product design

The relevance of freehand sketching in product design lies in its ability to support the rapid and flexible development of ideas. It serves as a foundational tool for visual communication, enabling designers to convey complex concepts in a simple manner. This quick and easy use makes freehand sketching indispensable for brainstorming sessions, collaborative discussions, and the early stages of design development. Moreover, sketches provide a visual foundation that can be further developed and refined using digital tools and prototyping methods. The relevance of freehand sketches in product design can be summarised as follows:

1. **Visual Communication:** Freehand sketches allow designers to quickly and effectively communicate ideas, concepts, and details. This visual form of communication can be more intuitive and immediate than words.
2. **Flexibility and Speed:** Sketching by hand is faster and more flexible than digital tools, enabling rapid iteration and exploration of ideas without the constraints of software.
3. **Foundation for Development:** Initial sketches serve as a foundation for further development, providing a visual reference that can be refined and elaborated upon in subsequent stages.
4. **Creativity and Spontaneity:** Freehand sketching fosters creativity and spontaneity, allowing designers to experiment with shapes, forms, and functions without the limitations imposed by digital tools.

5. **Engagement and Collaboration:** Sketching can facilitate better engagement and collaboration within a design team and with stakeholders by providing a tangible, easily understandable representation of 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 the exploration of 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 in visualising complex ideas and concepts, making it easier to understand and evaluate potential solutions to design problems.

Focal Area 2: 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 the manufacturing of a product, or refined sketches used for presentations to convey the design idea. Freehand sketches find their applications in the following areas:

1. **Design Exploration:** Freehand sketching is used to explore various design options, enabling designers to experiment with different shapes, configurations, and styles without committing to a specific direction too early in the process.
2. **Detailing and Refinement:** Freehand sketches can be used to add details and refine concepts, focusing on specific aspects of the design such as ergonomics, usability, and functionality.
3. **Prototyping and Mockups:** Freehand sketches can be transformed into prototypes and mockups, providing a tangible representation of the product for testing and evaluation.
4. **Client Communication:** Freehand sketches serve as a tool for communicating ideas to clients and stakeholders, making it easier to convey design intentions and receive feedback.
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.

Learning Tasks

1. Learners use flash cards to explain the relevance of freehand sketching in product design
2. Learners make sketches of a design idea (eg. Smart phone, a desk, a tool etc.) using their freehand.

Pedagogical Exemplars

Talk for learning: In mixed-ability groups, learners discuss and summarise the relevance of free hand sketches in product design using flash cards, mind maps, concept maps, poster boards, power points etc. Provide specific instructions to the groups to guide the discussions and to prevent the possibility of only one learner doing all the talking. Encourage learners to simply and clearly articulate their points and listen to others during the discussions. Make room for non-vocal learners to contribute to the group discussions through writing.

Project-based learning: In mixed-ability groups learners provide freehand sketches of a new product such as smart phone, a desk, a tool etc. Learners discuss the freehand sketch from each member of the group and suggest refinements based on the features of the new product. Let learners present the final sketch of their design to the class using any suitable method for feedback. Assign specific roles to learners to ensure that all learners participate in the project and are challenged according to their understanding and skills in freehand sketching. Also, develop a peer mentoring system in the mixed-ability groups to encourage more advanced learners to support their colleagues in understanding and effectively applying freehand sketching during product designs.

Key Assessment

Assessment level 1

1. What is freehand sketching in the context of product design?
2. Name one benefit of freehand sketching in product design.

Assessment level 2

1. How can freehand sketching help in the initial stages of product design?
2. Describe a scenario in which freehand sketching would be more advantageous than using computer-aided design (CAD) software.

Assessment level 3

1. Discuss two areas where freehand sketching is more effective than using digital drawing tools
2. Evaluate the role of freehand sketching in identifying and solving design problems early in the product development process.

Assessment level 4

1. Write an essay on the limitations of relying solely on freehand sketching in the product design process and suggest ways to overcome these limitations.
2. Design a product that could significantly improve an aspect of your school. Create a detailed freehand sketch of your product, and provide a comprehensive explanation of its features and functionality. Justify your design choices by evaluating how the product addresses specific needs or challenges in the school environment and propose a plan for its implementation and potential impact assessment.

HINT



The recommended mode of assessment for week 8 is **display and exhibition**. Use the level 4 question 2 as a sample question.

WEEK 9

Learning Indicators

1. Outline the importance of isometric projections in product design
2. Explain the application of first-angle orthographic projection in product design

Focal Area 1: Importance of isometric drawing in product design

Introduction

Isometric drawing plays a vital role in product design due to its ability to represent three-dimensional (3D) objects on a two-dimensional plane, providing a clear and comprehensive visualisation that is essential for various stages of design and manufacturing. 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 the reverse engineering process, 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, due to its ability to provide a clear and comprehensive view of complex structures. Isometric drawings are not just limited to geometric shapes but also include topological relations, making them 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 type of 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 the three axes make equal angle with the plane of projection. This projection is more pleasing to the eyes than oblique or perspective projection, as it is easier to draw because all edges are foreshortened equally (one scale). It aids in understanding the overall shape, size and appearance of an object before its 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 backward ($35^\circ 16'$) until the three meeting edges at the nearer corner are equally inclined to the plane of projection (Figure 9.1).

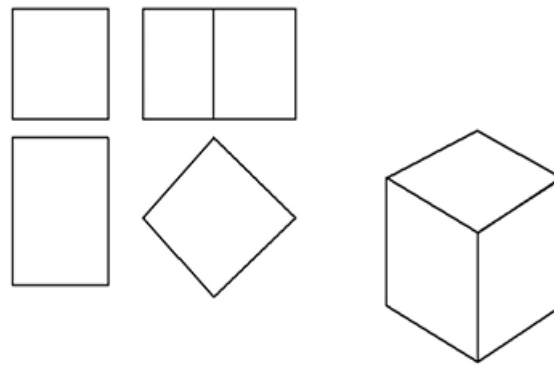


Figure 9.1: Positioning of an object during isometric projection

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 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 isometric scale ($\sqrt{2/3}=0.8165$).

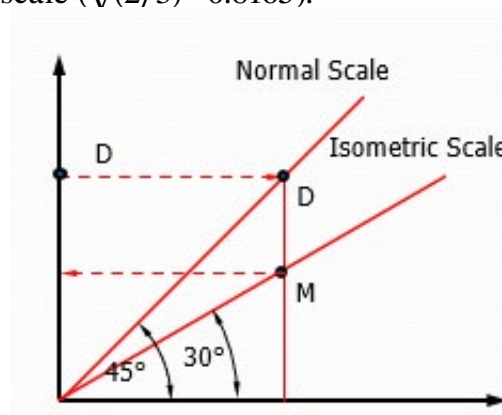


Figure 9.2: Isometric scale

Importance of isometric drawing in product design

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

1. **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.
2. **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.
3. **Visual intuition:** Unlike traditional orthographic projections, isometric drawings allow engineers and designers to convey design concepts clearly. Lines parallel to the three principal axes appear in their true lengths, preserving angles and proportions.

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

Learning Task

1. Learners create 3D shapes using the snap cubes and draw the shapes they've created using isometric graph paper.
2. Learners discuss the following: the ability of isometric projections to provide 3D views of objects and how isometric drawings help convey dimensions accurately.
3. Learners draw physical objects (e.g., a chair, a table, or more complex shapes) in isometric projections.

Pedagogical Exemplars

Collaborative learning

Learners in mixed-ability groups freely create shapes using snap cubes (or similar building blocks) and draw the shapes created using isometric papers and share them with partners. Ask them to draw the shapes they've created using isometric graph paper. Encourage learners to share their drawings with their partners. Provide isometric drawing templates with varying difficulty levels for learners with different prior knowledge. Allow learners to choose between building simple or more complex shapes. Offer learners the option to present their isometric drawings on paper or digitally using software.

Talk for learning

Discuss with learners the importance of isometric projections, emphasising their ability to provide 3D views of objects, showing how isometric drawings help convey dimensions accurately and how components fit together. Organise thoughts using mind maps or concept diagrams. Tailor the discussion's depth based on learners' understanding. Use simpler explanations for beginners and delve deeper for advanced learners. Offer mind map templates or graphic organisers to cater for different learning styles (visual vs. kinesthetic). Allow learners to choose between creating a mind map, concept diagram, or a written summary of key points.

Project-based learning

Show learners physical objects, such as chair, table, etc., and some advanced shapes. Let learners draw these shapes in isometric projections using drawing instruments and drawing sheets. Provide drawing instruments (rulers, pencils, etc.) and isometric drawing sheets. Instruct learners to draw these objects in isometric projections. Encourage creativity and attention to detail. Learners display drawings and receive feedback from colleagues in a tolerant manner. Have learners display their drawings and receive constructive feedback from colleagues. Provide a variety of objects with varying levels of complexity (simple shapes vs. furniture) for learners to draw. Offer differentiated instruction sheets with step-by-step guides for isometric drawing for approaching proficiency learners, while encouraging proficient and highly proficient learners to explore advanced techniques. Let learners choose between traditional drawing tools like pencils and rulers or allow them to explore using digital drawing software.

Key Assessment

Assessment Level 1

1. Complete the following sentences.
 - a) In first angle projection the front elevation is drawn
 - b) One key advantage of using isometric projections in product design is their ability to provide a clear visual representation that helps in complex ideas and designs.
 - c) In isometric drawings, the angles between the axes are typically set at degrees.
2. Which of the following statements is true about isometric drawings?
 - a) They show only one flat view of an object
 - b) They show three sides of an object in proportion
 - c) They are used for artistic sketches
3. Is isometric drawing a good way to show the dimensions of a product design? (True/False)
4. Which type of projection provides a 3D view of an object using equal angles for all three axes?
 - a) Isometric projection
 - b) Orthographic projection
 - c) Perspective projection
 - d) Oblique projection
5. Isometric drawings accurately represent the dimensions of an object. (True/False)

Assessment Level 2

1. Why is isometric drawing a useful tool for product designers? (Short answer)
2. Explain the difference between isometric projection and orthographic projection in terms of their applications in product design.
3. Describe how isometric drawing is related to product design, manufacturing, and communication.
4. Explain how isometric drawings can help in reducing errors during the manufacturing process.

Assessment Level 3

1. Given a rectangular prism, create an isometric drawing that accurately represents its dimensions. Label the edges and vertices.
2. Describe a scenario where an isometric drawing would be more useful than an orthographic projection for communicating design details.

Focal Area 2: Application of first-angle projection in product design

Introduction

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, where it helps reduce the focal length of the projection objective, thus aiding in the miniaturisation of products like projectors and digital video equipment.

Characteristics of first-angle projection drawings

The primary characteristic of first-angle projection is that the object is placed between the observer and the projection plane, resulting in the projection plane being behind the object. This contrasts with third-angle projection, where the projection plane is between the observer and the object. The first-angle projection is consistent with the BS 8888:2011 standard, which is a comprehensive guide for technical product documentation and specification. This standard ensures that the drawings are precise and adhere to a specific style, which is crucial for maintaining consistency and accuracy in technical documentation. The method involves creating axonometric drawings, which are a type of orthographic projection where the object is rotated along one or more of its axes to reveal multiple sides. This technique is particularly useful in engineering graphics, where it is essential to convey the exact dimensions and spatial relationships of the object being depicted. Creating these drawings involves several steps, including forming the original graphic on a forming face, projecting it onto a screen, and then deforming the original graphic to achieve the desired shape and angles. This method ensures that the angles and dimensions are accurately represented, which is critical for engineering and manufacturing applications. First-angle projection drawings are a vital tool in technical and engineering fields, providing a standardised and precise method for representing three-dimensional objects in two dimensions. A summary of the key characteristics of first-angle projections are:

1. Positioning of the Object

- The object is positioned in the first quadrant relative to the observer.
- This means that the object lies between the projection plane and the viewer.

2. Common Usage

- First-angle projection is typically used in Africa, Europe, India, and Canada.
- It provides an alternative to third-angle projection, which is more common in the United States and Canada.

3. Projection Plane

- The projection plane in first-angle projection is opaque.
- 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.

Application of first-angle projection in product design

1. Orthographic Projection System

- 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.
- By projecting views (such as front, top, and side views) onto vertical and horizontal planes, engineers can visualise the dimensions, connections, and relationships of components.
- This visualisation is essential during the design phase, allowing engineers to create prototypes, conduct tests, and eventually manufacture the final product.

2. Engineering Drawings

- In first-angle projection, the object is positioned in the first quadrant relative to the observer and the projection plane.
- The three main views used in first-angle projection are:
 - * **Front View:** Represents the object as seen from the front.
 - * **Top View:** Represents the object as viewed from above.
 - * **Side View:** Provides additional information about the object's shape and features.
- These views help communicate design details, dimensions, and assembly instructions to manufacturers and other stakeholders.

3. Product Design and Visualisation

- First-angle projection allows designers to create accurate representations of products, ensuring that all relevant features are captured.
- By combining front, top, and side views, designers can visualise how different components fit together and identify potential issues.
- This method ensures that the final product aligns with the intended design and meets functional requirements.

Learning Task

1. Learners watch videos or images of real-world objects (e.g., tables, chairs, or other products) and the importance of capturing multiple orthographic views (front, top, and side) for these objects.
2. Learners discuss how orthographic views help convey accurate information about the shape and dimensions of the object.
3. Learners draw the front, top, and side views of sample objects (either physical objects or images) using first-angle projection.
4. Learners discuss the characteristics of first-angle projection drawings (e.g., placement of views, hidden lines, and dimensions).

Pedagogical Exemplars

Experiential Learning

Show learners videos or images of real-world objects such as tables or chairs and their corresponding first-angle orthographic views i.e. front, top and side views. Highlight the importance of capturing multiple orthographic views (front, top, and side) for these objects. Discuss how these views help convey accurate information about the shape and dimensions of the object. Provide videos or images with varying levels of complexity (simple shapes vs. furniture) for learners with different prior knowledge. Offer learners a choice between analysing real-world objects or virtual representations (images). Allow learners to present their findings through a written report, a sketch, or a 3D model.

Project-based learning

Provide learners with sample objects (either physical objects or images). Instruct them to draw the front, top, and side views of these objects using first-angle projection. Encourage attention to detail and accuracy. Allow learners to compare their drawings with reference orthographic views. Provide a variety of sample objects with varying difficulty levels for learners to draw. Offer differentiated instruction sheets with step-by-step guides for beginners, while encouraging more advanced learners to explore advanced techniques like dimensioning. Allow learners to choose between traditional drawing tools or digital software to create their multi-view drawings.

Talk for learning

Share examples of first-angle projection drawings with learners. Discuss with learners the characteristics of drawings (e.g., placement of views, hidden lines, and dimensions) in first-angle projection using samples of first-angle projection drawings. Learners think-pair-share and provide, in turns, the first-angle orthographic projection of shapes created from snap cubes. Let them share their drawings with colleagues for comments. Tailor the discussion's depth based on learners' understanding. Use simpler explanations for beginners and delve deeper into concepts like hidden lines for advanced learners. Incorporate a "Think-Pair-Share" activity where learners ponder individually, then discuss in pairs, before sharing their interpretations of first-angle projections with the whole class.

Key Assessment

Assessment Level 1

1. Which type of orthographic projection places the front view above the top view?
 - a) First-angle projection
 - b) Third angle projection
 - c) Isometric projection
 - d) Oblique projection
2. In first-angle projection, the top view is positioned below the front view. (True/ False)
3. Match the following terms:

View Parameter	Description
First-angle projection	Places the top view below the front view
Third angle projection	Places the top view above the front view
Front view	Represents the object's shape in the XY plane
Top view	Represents the object's shape in the XZ plane
Side view	Represents the object's shape in the YZ plane

Assessment Level 2

1. Explain the purpose of hidden lines in first-angle projection drawings. Provide an example.
2. Given an object with complex features, create a first-angle projection drawing that includes front, top, and side views. Highlight any hidden lines.
3. Compare and contrast first-angle projection and third-angle projection. When would you choose one over the other in product design?
4. Discuss the advantages and limitations of using first-angle projection in engineering design. How does it impact manufacturing processes and assembly instructions?

Assessment Level 3

1. In a collaborative design project, analyse the strengths and weaknesses of first-angle, third-angle, isometric, and oblique projections. Based on these analyses, argue which type of projection would be most suitable for effectively communicating the overall shape and dimensions of a new product to team members. Support your choice with specific examples and considerations of the design project's needs.
2. Explore advancements in digital tools for creating first-angle projection drawings. Discuss how computer-aided design (CAD) software has transformed the field of product design.

Assessment Level 4

1. Design a complex mechanical assembly using first-angle projection. Include detailed views, section cuts, and annotations. Explain your design choices and how they enhance manufacturability.
2. Imagine you are a product design consultant. Create a first-angle projection drawing for a client's innovative product concept.

HINT



The recommended mode of assessment for week 9 is **questioning**. Use the focal area 1, level 1 question 1 as a sample question.

WEEK 10

Learning Indicators: Outline the importance of sectioning, dimensioning, and tolerance of geometric objects

Focal Area: Importance of sectioning, dimensioning and tolerance

Introduction

In manufacturing drawing, various types of lines (continuous, non-continuous, thick and thin) are encountered. 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, for example thin dash lines, are complicated and confusing. However, if these internal hidden features or outlines are made visible, then they are supposed to 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 multifaceted process that involves creating cross-sectional views of objects to reveal internal features, facilitate accurate communication of design intent, and optimise manufacturing processes. In technical drawing and CAD modelling, sections or cross-sections are essential for visualising the interior details of a part, such as hidden lines, material composition, and dimensions, which are crucial for both designers and manufacturers to understand the complete structure of the part. The advent of 3D CAD modelling software has significantly enhanced the role of sections, enabling detailed mechanical calculations and optimisations, such as in the case of a shaft weakened with a keyway, and supporting the principles of additive manufacturing. In manufacturing, sectioning is integral to processes like extrusion and shaping of materials. For instance, a section drawing device can ensure the straightness of aluminium bars by pressing and supporting them during the drawing motion. Similarly, a section material shaping manufacturing technology involves heating and extruding aluminium bars through a die, followed by precise adjustments to achieve the desired section shape, thereby reducing input costs and improving efficiency. The sectioning method is also pivotal in 3D printing, where a central processor converts a 3D model into an STL file, groups triangular patches by cutting planes, and processes them in parallel to generate slice section data, ultimately improving the efficiency of 3D printing.

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 10.1).



Figure 10.1: *Sectioning facilitating dimensioning*

Demonstration of Sectioning

Figure 10.2 shows an unsectioned view of a block.



Figure 10.2: *Unsectioned 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 10.3:

1. Object = block
2. Knife = cutting plane
3. Arrow $\Rightarrow$ direction of viewing

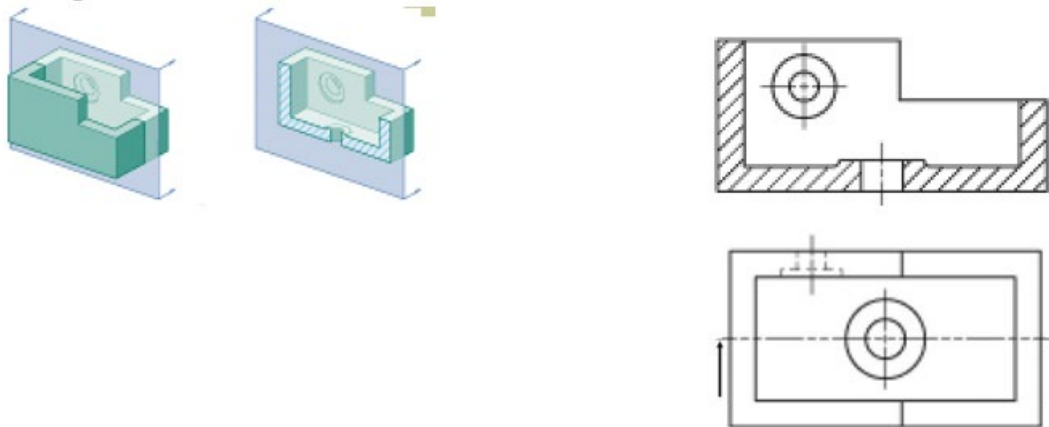


Figure 10.3: *Sectioning of a block*

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 design engineers, manufacturing personnel, and 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. GD&T standards, such as

ASME Y14.5, have been developed to streamline manufacturing activities, reduce costs, and ensure high-quality production, although their adoption has been inconsistent across industries. The complexity of GD&T, due to its rule-based system, makes it challenging to teach and learn, prompting the development of educational techniques that allow students to visualise geometric tolerances and tolerance zones using tools like portable coordinate measuring machines (CMMs) and parametric solid modelling software. Dimensional measurement ensures that manufactured articles 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.

Notations of Dimensioning

Dimensioning involves assigning dimensions to a drawing under specific regulations and conventions. Figure 10.4 shows general information that can be found under dimensioning:

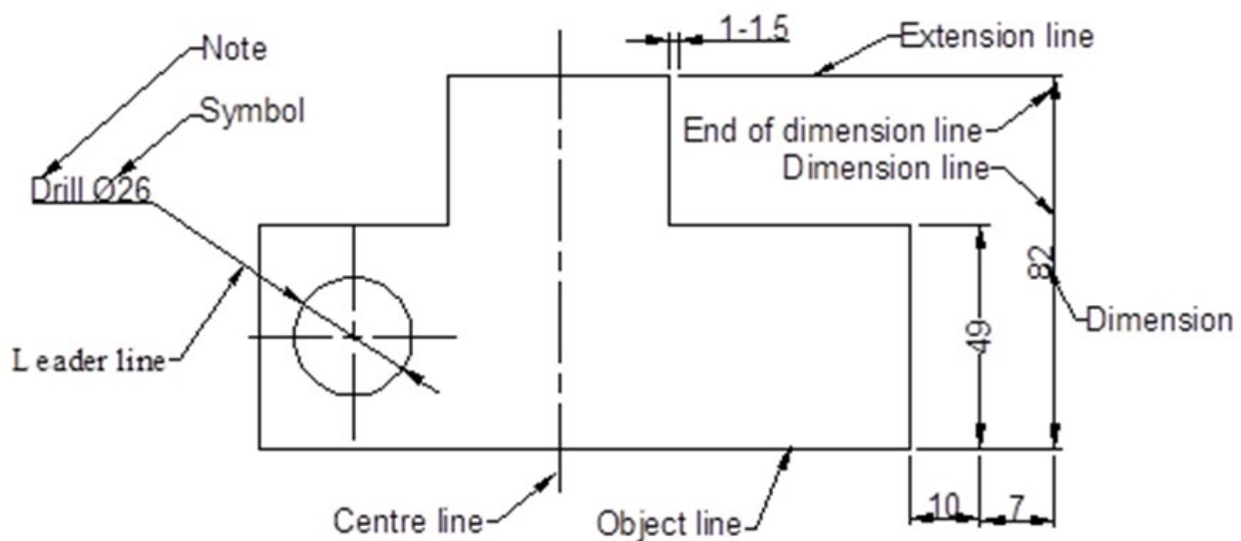


Figure 10.4: *Notations of dimensioning*

Importance of Dimensioning

1. Provides clarity (avoids inherent 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 permissible limits of variation in a physical dimension or measured value, which ensures that parts fit together and function correctly despite inherent imperfections in manufacturing processes. In mechanical design, tolerances are critical as they bridge the gap between the idealised perfect geometry of components and the reality of manufacturing deviations, ensuring reliable and cost-effective

production. Tolerance design is a multifaceted process that involves defining design requirements, identifying dimension chains, and performing variation analysis to ensure that the final product meets quality standards while minimising costs. Robust designs, which 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 the necessary specifications and function as intended. The specification of 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, to optimise cost and quality. Advanced models, like the volumetric space envelope, help link production variations to tolerances, especially for complex and deformable parts, thereby enhancing the accuracy and efficiency of tolerance analysis. In the context of additive manufacturing (AM), traditional tolerance allocation methods need to be adapted to account for the unique characteristics of AM processes, such as asymmetric error distributions and the significant impact of manufacturing parameters 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 that ensures the functionality, reliability, and cost-effectiveness of products across various industries.

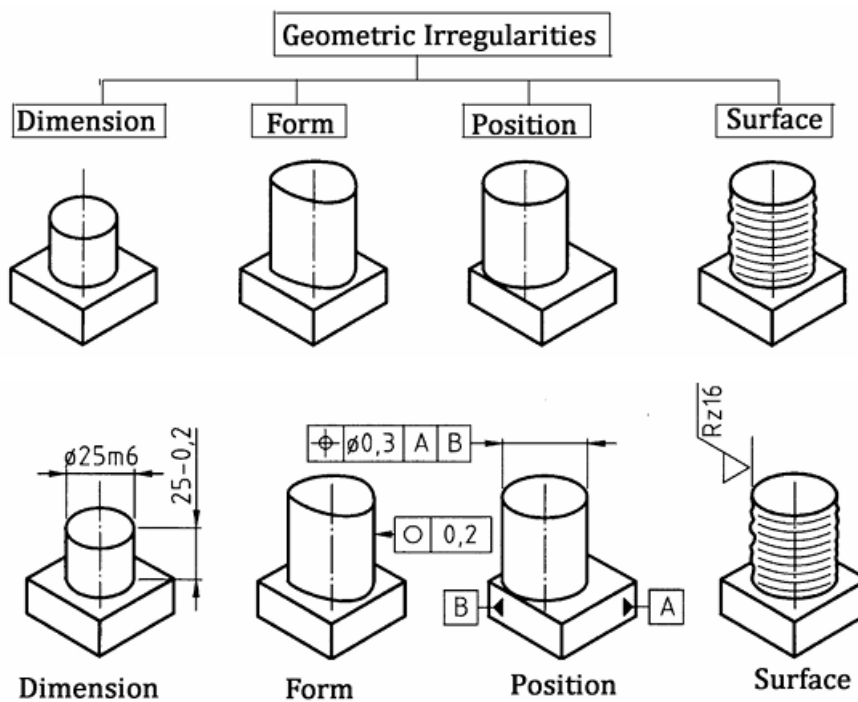


Figure 10.5: Tolerance

Purpose of Tolerancing

1. To indicate the close degree of exactitude required for a given length of size.
2. To specify liberal variations on the size and hence assist its economical manufacture and inter-changeability.

Classes of Tolerance

Three main classes of tolerance

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

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

1. Dimensional tolerance and
2. 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 they come with drawbacks like 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. By understanding variations early in the design cycle, engineers can avoid time-consuming iterations.
3. **Competitive Advantage:** In today's fast-paced market, product differentiation lies in design details. Companies rely on tolerance analysis to gain a competitive edge. For instance, the electronics industry shrinks products while adding capabilities, emphasising precise understanding of manufacturing variation and design tolerances.

Learning Task

1. Learners to research concepts of sectioning, dimensioning, or tolerance from library resources or relevant materials and create a presentation summarising their findings.
2. Learners discuss the importance of the following aspects of engineering drawing:
Sectioning: Highlighting how it reveals internal details (e.g., cross-sections).
Dimensioning: how it ensures consistent measurements.
Tolerance: Its impact on manufacturing quality.
3. Learners with sample drawings of geometric objects (e.g., mechanical components) create accurate section views and add appropriate dimensions (linear, angular, and tolerances) taking into consideration functional requirements (fit, clearance, interference).

Pedagogical Exemplars

Collaborative learning

In mixed-ability group, let learners read on sectioning, dimensioning and tolerance of geometric objects from the library, make presentations of their findings in class and receive feedback. Assign each group a topic: sectioning, dimensioning, or tolerance. Instruct learners to research

these concepts from library resources or relevant materials. Conduct in-class presentations, allowing learners to share their insights. Provide constructive feedback to enhance their understanding. Assign topics based on learner readiness. Beginners might research sectioning, while advanced learners explore tolerance. Offer learners a choice between researching from library resources or online sources. Allow learners to choose between a traditional presentation, a digital infographic, or a video explaining their assigned topic.

Talk for learning

Share sample engineering drawings with learners. Lead a discussion on the importance of each aspect:

1. **Sectioning:** Highlight how it reveals internal details (e.g., cross-sections).
2. **Dimensioning:** Discuss how it ensures consistent measurements.
3. **Tolerance:** Explain its impact on manufacturing quality.

Tailor the discussion's depth. Briefly explain sectioning for beginners, then delve deeper into dimensioning and tolerance for advanced learners. Incorporate a "jigsaw" activity. Learners can research all three aspects (sectioning, dimensioning, tolerance) in expert groups, then come together in mixed groups to teach each other, ensuring everyone grasps all concepts.

Practice-based learning

Provide learners with sample drawings of geometric objects (e.g., mechanical components). Ask them to:

1. Create accurate section views.
2. Add appropriate dimensions (linear, angular, and tolerances).
3. Consider functional requirements (fit, clearance, interference).

Review their work collectively and discuss best practices.

Provide a variety of geometric object drawings with varying complexity levels to match learner skillsets. Beginners might work on simpler shapes, while advanced learners tackle more intricate mechanical components. Offer differentiated instruction sheets with step-by-step guides for beginners, while encouraging advanced learners to explore advanced techniques like applying different tolerance levels. Allow learners to submit their work digitally or on paper. Advanced learners can include a written analysis explaining their design choices based on functional requirements.

Key Assessment

Assessment Level 1

1. Which of the following statements is true about sectioning in engineering drawings?
 - a) It reveals internal details.
 - b) It ensures consistent measurements.
 - c) It impacts manufacturing quality.
 - d) It is used for aesthetic purposes.
2. Dimensioning ensures _____ measurements in engineering drawings.
3. Tolerance refers to the allowable variation in dimensions for a manufactured part (True/False)

Assessment Level 2

1. You are designing a mechanical component. Which type of dimension (linear, angular, or tolerance) would you use to specify the fit between two mating parts?
 - a) Linear dimension
 - b) Angular dimension
 - c) Tolerance
 - d) None of the above
2. Explain how sectioning helps reveal internal details in an engineering drawing.

Assessment Level 3

1. Given a sample drawing of a gear, calculate the appropriate tolerance for its diameter based on functional requirements (e.g., fit, clearance, interference).
2. Discuss the impact of tolerance on manufacturing quality. Provide examples from real-world scenarios.
3. In an automotive assembly line, a part with tight tolerances is causing delays. How would you address this issue?
 - a) Adjust the manufacturing process
 - b) Redesign the part
 - c) Change the tolerance specifications
 - d) Implement statistical process control
4. How can improper use of sectioning, dimensioning and tolerance affect the assembly process of a machine?

Assessment Level 4: Investigate how different industries (e.g., aerospace, automotive, medical devices) handle dimensioning and tolerance in their engineering drawings. Present your findings.

HINT



The recommended mode of assessment for week 10 is **research**. Use the level 3 question 4 as a sample question.

WEEK 11

Learning Indicator: Explain the application of detailed and assembly drawings in product design and modelling

Focal Area: Detailed drawings

Introduction

Detailed and assembly drawings play an important role in product design and modelling 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. Assembly drawings, on the other hand, 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. The integration of 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 modelling are essential tools that provide additional perspectives and detailed insights into various aspects of a product, facilitating a comprehensive understanding and effective design process. These views are particularly crucial in the design and development of complex products, where multiple actors with different viewpoints are involved, each focusing on specific aspects of the product and its development process. For instance, the use of 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 across the design process. Additionally, the integration of concurrent engineering principles has led to the development of intermediate models that upgrade traditional CAD systems to feature-based modelling systems, allowing for the representation of different context-dependent views of the product. These models facilitate the simultaneous consideration of various lifecycle factors, such as manufacturing processes and quality control, during the design phase. Furthermore, auxiliary tools like the product design auxiliary tool, which automatically adjusts the levelness of a counter top to maintain stability, provide practical support for designers, enhancing their ability to observe and interact with the product under different conditions. Similarly, auxiliary equipment comprising various dimension models corresponding to different product features, such as chamfers, holes, and embossed carvings, aid designers in referencing and visualising the exterior size and details of the product. The use of multiple views also extends to the visualisation and analysis of design processes, as demonstrated in an industrial case study with an engine company, where 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 both 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 in easing the assembly of parts and enhancing the visual appeal, while fillets, which are rounded edges, contribute to the 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 both the functional and aesthetic aspects of a product. It can improve wear resistance, reduce friction, and enhance the product's appearance, making it more appealing to consumers. The use of 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. The integration of these detailing techniques within the broader context of design for manufacturability, usability, and environmental impact ensures that the final product is not only 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, the use of physical models, such as clay models, can provide a tangible evaluation of the design, 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 leads to the creation of high-quality products that meet both technical specifications and consumer expectations.

Drawing conventions and standards

Drawing conventions and standards in product design and modelling are essential for ensuring consistency, accuracy, and interoperability across various stages of the product development lifecycle. These standards encompass a wide range of guidelines, including those for engineering design, manufacturing, quality control, and human-computer interaction. For instance, the use of Computer-Aided Design (CAD) systems in establishing new standards during the design process helps in reducing the diversity of component variants, thereby optimising supply chain costs and storage requirements.

Learning Task

1. Learners research a topic related to detailed drawings (e.g., sectioning, dimensioning, or tolerance) using library resources or relevant materials and create a presentation summarising their findings.
2. Learners discuss the following aspects of assembly drawings:
 - a. How assembly drawings represent the relationship between individual parts.

- b. The role of exploded views in showing component arrangement.
 - c. Bill of materials (BOM) and part numbering conventions.
3. Learners create detailed drawings of simple mechanical components (e.g., gears, brackets, or fasteners) components including orthographic views (front, top, side), dimensions, tolerances, annotations while considering assembly drawing requirements.

Pedagogical Exemplars

Collaborative/ Research-based learning

In mixed-ability groups, let learners read about sectioning, dimensioning and tolerance of geometric objects from the library, make presentations of their findings in class and receive feedback. Assign each group a topic related to detailed drawings (e.g., sectioning, dimensioning, or tolerance). Conduct in-class presentations, allowing learners to share insights and receive feedback.

Assign topics based on learner readiness. Beginners might research sectioning, while advanced learners explore tolerance or delve into Bill of Materials (BOM) conventions. Offer learners a choice between researching from library resources, online sources, or a combination of both. Allow learners to choose between a traditional presentation format, creating an infographic, or a video explaining their assigned topic.

Talk for learning

Share sample assembly drawings with learners (e.g., exploded views of mechanical components).

Lead a discussion on the following:

1. How assembly drawings represent the relationship between individual parts.
2. The role of exploded views in showing component arrangement.
3. Bill of materials (BOM) and part numbering conventions.

Tailor the discussion's depth. Briefly explain assembly drawings and exploded views for beginners. For advanced learners, delve deeper into BOM and part numbering conventions. Incorporate a "gallery walk" activity. Learners create posters showcasing key aspects of assembly drawings (exploded views, BOM, etc.). They then rotate around the classroom to learn from each other's presentations.

Practice-based learning

Provide learners with simple mechanical components (e.g., gears, brackets, or fasteners). Instruct them to create detailed drawings for these components:

1. Include orthographic views (front, top, side).
2. Add dimensions, tolerances, and annotations.
3. Consider assembly requirements.

Review their work collectively and discuss best practices.

Provide a variety of mechanical components with varying complexity levels to match learner skillsets. Beginners might work on simpler gears, while advanced learners tackle more intricate components like brackets with detailed features. Offer differentiated instruction sheets with step-by-step guides for beginners on creating orthographic views and adding basic dimensions.

Challenge advanced learners with exploring advanced tolerancing techniques and incorporating assembly considerations into their drawings. Allow learners to submit their work digitally or on paper. Advanced learners can include a written analysis explaining their design choices and how they considered assembly requirements.

Key Assessment

Assessment Level 1

1. Which type of drawing represents the relationship between individual parts in an assembly?
 - a) Detailed drawing
 - b) Exploded view
 - c) Orthographic view
 - d) Isometric view
2. The Bill of Materials (BOM) lists all the _____ used in an assembly.
3. Detailed drawings typically include annotations such as dimensions and tolerances. (True/False)

Assessment Level 2

1. You are designing a complex mechanical assembly. Explain the role of exploded views in your assembly drawing.
2. Describe the purpose of part numbering conventions in assembly drawings.

Assessment Level 3

1. Given an assembly drawing, identify any missing dimensions or annotations that are critical for manufacturing.
2. Discuss the challenges of creating accurate and clear assembly drawings for complex products. Consider factors like scale, perspective, and communication with manufacturing teams.
3. As a manufacturing engineer, discuss the role of exploded view in designing and assembling of complex mechanical components like the gearbox of a car.
4. In a product design team, there is a disagreement about the tolerances specified in an assembly drawing. How would you resolve this issue?
 - a) Consult with the manufacturing team
 - b) Adjust the tolerances based on personal judgment
 - c) Follow industry standards
 - d) Seek input from senior engineers

Assessment Level 4: Investigate how different industries (e.g., automotive, aerospace, consumer electronics) handle detailed and assembly drawings. Present your findings.

HINT



*The recommended mode of assessment for week 11 is **discussion**. Use the level 3 question 3 as a sample question.*

WEEK 12

Learning Indicator: Explain the application of detailed and assembly drawings in product design and modelling

Focal Area: Assembly drawings

Introduction

Detailed and assembly drawings play a vital role in product design and modelling 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. Assembly drawings, on the other hand, 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. The integration of Design for Assembly (DFA) principles into these drawings can significantly enhance the efficiency of the assembly process by reducing part count and simplifying assembly operations, thereby lowering production costs and improving product quality.

Sectional views

Sectional views are essential aspects of product design and modelling, providing detailed insights into the internal structures and components of a product that are not visible in standard external views. These views are generated by cutting through a 3D model along specified planes to reveal the interior features, which is essential for verifying design integrity and functionality. The method for generating sectional views can vary; for instance, one approach involves automatically creating a cross-section structure chart based on user-input parameters and line-drawing positions, allowing engineers to observe the sectional structures of different domains and verify the correct formation of electric fields and operational functionality. Another method involves producing combined sectional views by obtaining section planes based on multiple section lines and projecting specified elements to create a comprehensive view of the model. The integration of sectional views into the product lifecycle management (PLM) systems is also significant, as it supports the consistency and propagation of information changes across different stages of the product lifecycle, enhancing the assembly-oriented design philosophy.

Exploded views

Exploded views are a crucial aspect of product design and modelling, providing a detailed schematic representation that illustrates the spatial relationships and assembly sequence of a product's components. These views are essential for various applications, including product instructional materials, repair and maintenance handbooks, and training manuals. The process of 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 both 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 the use of 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 matrices like the 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 that exploded views are uniform, compact, and clearly 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, which is particularly useful in mobile-assisted manufacturing and repair environments.

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. In product design and modelling, the BoM serves multiple critical 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 both 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 manage and adjust the product structure accurately. 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.

Learning Tasks

1. Learners analyse assembly drawings and charts and identify the characteristics unique to assembly drawings.

2. Learners discuss the following aspects of assembly and detailed drawings:
 - a. Purpose of each type of drawing.
 - b. Comparison between the level of detail in assembly drawings versus detailed drawings.
 - c. Scenarios where each type is most useful.
3. Learners assemble simple mechanical components (e.g., nuts, bolts, washers) physically, create assembly drawings including orthographic views (front, top, side) of the assembled components. Learners then complete the following: label the parts, indicate their positions and use exploded pictorial views to show component relationships.

Pedagogical Exemplars

Collaborative Learning

Learners in mixed-ability groups identify the characteristics of assembly drawing and detailed drawing using sample drawings and charts. Provide sample assembly drawings and charts. Instruct learners to analyse these materials and identify the characteristics unique to assembly drawings. Encourage discussion within the groups.

Provide different levels of complexity in sample drawings and charts. Beginners might focus on basic assembly features, while advanced learners analyse more intricate details. Offer learners a choice between analysing physical models alongside drawings or focusing solely on visual materials. Allow learners to present their findings in a way that suits their strengths. Options could include a group written report, a collaborative digital mind map, or a short video explaining key characteristics.

Talk for Learning

Share additional sample drawings (both assembly and detailed). Lead learners to discuss the purpose, differences and applications of assembly drawing and detailed drawing using sample drawings and charts.

Tailor the discussion to learner understanding. Briefly explain the basics of assembly and detailed drawings for beginners. For advanced learners, delve deeper into specific applications and the benefits of each drawing type. Incorporate a “Think-Pair-Share” activity. Learners ponder the purpose and differences independently, then discuss in pairs, before coming together as a class to share their insights and engage in a guided discussion led by you.

Practice-Based Learning

Learners practice the principles of assembling components and preparing assembly drawings and detailed drawings using sectional views or exploded pictorial views of component parts. Provide learners with simple mechanical components (e.g., nuts, bolts, washers). Instruct them to assemble these components physically. Then, guide them in creating assembly drawings: include orthographic views (front, top, side) of the assembled components, label parts and indicate their positions and use exploded pictorial views to show component relationships.

Offer a variety of mechanical component sets with varying complexity levels. Beginners might work with simple nut-and-bolt assemblies, while advanced learners tackle more intricate components requiring detailed exploded views.

Provide differentiated instruction sheets with step-by-step guides for beginners on assembly and basic assembly drawing creation. Advanced learners can explore more complex techniques

through online tutorials or self-directed learning. Allow learners to submit their work digitally or on paper. Advanced learners can include a written analysis explaining their assembly process and how their drawings reflect the component relationships.

Key Assessment

Assessment Level 1

- Which type of drawing provides detailed views of individual components, including dimensions and annotations?
 - Assembly drawing
 - Detailed drawing
 - Isometric drawing
 - Exploded view
- Assembly drawings focus on showing how individual parts fit together to create a whole product. (True/ False)
- Match the following terms

Drawing Parameter	Description
Assembly drawing	Shows the relationship between components
Detailed drawing	Provides dimensions and specifications for manufacturing
Exploded view	Illustrates how parts are positioned during assembly
Bill of materials (BOM)	Lists all components and quantities needed for assembly

Assessment Level 2

- Explain the purpose of an exploded view in an assembly drawing. Provide an example.
- In a large-scale manufacturing project, which type of drawing would be most useful for communicating the assembly sequence to production line workers?
 - Assembly drawing
 - Detailed drawing
 - Exploded view
 - Isometric drawing

Assessment Level 3

- Compare and contrast assembly drawings and detailed drawings. When would you use each type in the product design process?
- Discuss the role of assembly drawings in ensuring manufacturability and efficient assembly processes. How do they impact quality control and production planning?

Assessment Level 4

- Given a complex mechanical assembly, create a detailed drawing for one of the components. Include necessary dimensions and annotations.
- Investigate best practices for creating clear and concise assembly drawings. Present your findings in a report, emphasising industry standards and guidelines.

HINT

- The recommended mode of assessment for week 12 is **end of semester examination**.
- Refer to Appendix E at the end of this section for Table of specification.

Section 3 Review

1. Product design is the process of creating new products or improving existing ones through a combination of creativity, technical skills, and strategic thinking.
2. The relevance of freehand sketching is visual communication, flexibility and speed, foundation for development, creativity and spontaneity, engagement and collaboration.
3. Isometric drawing plays a vital role in product design due to its ability to represent three-dimensional (3D) objects on a two-dimensional plane, providing a clear and comprehensive visualisation that is essential for various stages of design and manufacturing.
4. Characteristics of first-angle projections are the positioning of the object, common usage, projection plane and front perspective representation.
5. Sectioning, dimensioning and tolerance significantly aid in capturing the geometric details of a part.
6. Detailed and assembly drawings play an important role in product design and modelling by providing comprehensive visual and informational representations of individual components and their integration within a product.

Marking Scheme for the Questioning Assessment & Rubrics for the Display and Exhibition Assessment

Marking Scheme for the Questioning

The correct responses are:

1. on top of the plan.....2 marks
2. communicating.....2 marks
3. 120°.....2 marks

Rubrics for the Display and Exhibition Assessment

Criteria	Excellent (10)	Very Good (8)	Good (6)	Fair (3)
1. Creativity and Innovation	The design demonstrates a high level of originality with unique features that enhance the user experience. It presents new concepts or innovative solutions.	The design is creative and introduces some innovative features, building on existing concepts with distinct improvements or new elements.	The design is functional but lacks significant innovation, closely resembling existing designs without introducing major new features or ideas.	The design lacks originality and does not provide unique solutions. It follows conventional ideas without addressing specific challenges.
2. Sketch Quality	The sketch is clear, highly detailed, and accurately shows all relevant parts of the design, including dimensions, materials, and mechanisms. Clean and polished.	The sketch is well-drawn and easy to understand, with the main features of the design presented clearly. Some minor details or annotations may be missing.	The sketch is somewhat unclear or rough, with missing details. Some aspects of the design are not clearly shown, making it difficult to understand the full scope.	The sketch lacks clarity or is incomplete. Key parts of the design are missing, and the overall presentation is difficult to interpret.
3. Functionality and Practicality	The design is highly functional, addressing all user needs with ease. It is durable, easy to use, and solves the problem efficiently. Realistic for regular use.	The design is functional and mostly practical but has small areas that could be improved for better usability or durability. Meets most user needs with minor limitations.	The design is functional but has significant drawbacks in terms of usability, durability, or practicality. Some user needs are addressed, but there are notable areas for improvement.	The design is not practical, with many limitations. It does not address key user needs or is overly complicated, difficult to use, or not durable.

Criteria	Excellent (10)	Very Good (8)	Good (6)	Fair (3)
4. Explanation and Justification	The explanation thoroughly justifies each design choice, clearly linking features to specific user needs and the product's functionality. Every component of the design (e.g., materials, shape, functionality) is explained with evidence of research or clear reasoning. For example, padding material is chosen to prevent damage to the table, and the clamping mechanism is explained with respect to ease of use and durability.	The explanation justifies most design choices, with a clear focus on practicality and user needs, but some elements may require more depth. For instance, the adjustment mechanism is explained as easy to use, but further details on why that particular mechanism is best suited for users (e.g., adjustable, lightweight) might be lacking. There is a clear connection to user requirements, but not all aspects are fully explored.	The explanation is somewhat vague or lacks solid justification for key design choices. While some features are linked to functionality, many decisions (e.g., the choice of material, specific adjustments, or the clamping process) are not thoroughly explained. The link between design choices and the users' needs or the intended functionality of the product is unclear or underdeveloped.	The explanation is unclear, does not justify design choices, or lacks reasoning for why the design will meet user needs. Key components (e.g., why the clamp mechanism is chosen, or how the materials impact usability) are not addressed. There is little to no explanation as to how the design will solve the identified problem or meet user expectations.
5. Relevance to School Needs	The design is highly relevant to school needs, solving a clear issue or significantly improving an aspect of the school environment. Practical and useful.	The design is relevant to school needs and addresses an issue, but could have more direct impact. It may need more refinement to fully suit school requirements.	The design is somewhat relevant to school needs but does not directly address or improve a major aspect of the school environment. Its impact on the school is limited.	The design is not relevant to the needs of the school. It does not address a clear problem or provide a useful solution to the school environment.
6. Presentation and Clarity	The presentation is clear, well-organised, and visually appealing. The design is easy to understand, with logical flow and excellent clarity.	The presentation is clear and mostly organised, with minor issues in structure or clarity. The design is easy to follow, though a few parts may need more explanation.	The presentation is somewhat disorganised or unclear, making it harder to understand the design. Some parts of the explanation or visuals are missing or unclear.	The presentation is disorganised or unclear, making it difficult to follow. The design is not explained clearly, and the overall flow is confusing.

Rubric for Research Assessment**(Sectioning, Dimensioning, and Tolerancing in Machine Assembly)**

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
<i>Fit and Assembly Issues</i>	<i>Components are precisely dimensioned, ensuring a perfect fit and smooth assembly with no misalignment. Assembly is efficient, and machine functionality is not affected.</i>	<i>Components mostly fit well, with only minor misalignments that require minimal adjustments. The assembly process remains relatively smooth.</i>	<i>Some components have alignment or fit issues, requiring additional time for adjustments. Misalignment could cause slight functionality issues.</i>	<i>Components do not fit properly, causing significant delays in assembly, misalignment, or severe functionality issues that affect machine performance.</i>
<i>Tolerance Problems</i>	<i>Tolerances are correctly defined, with no excessive play in moving parts. Components fit together perfectly, reducing the risk of failure and ensuring smooth operation.</i>	<i>Tolerances are mostly appropriate, but there may be slight play or minor adjustments needed during assembly. No significant impact on machine performance.</i>	<i>Tolerances are either too tight or too loose, leading to minor operational issues and requiring rework or adjustments during assembly.</i>	<i>Tolerances are poorly defined, either causing excessive play or overly tight fits. This increases the risk of failure and delays the manufacturing process.</i>
<i>Increased Costs</i>	<i>No rework or scrap is needed, and the assembly process is efficient. The machine is produced with minimal costs, and production time is optimised.</i>	<i>Some minor rework or scrap is needed, leading to slight increases in cost and minor delays in assembly.</i>	<i>Significant rework or scrap is required, increasing overall manufacturing costs. Assembly time is extended, reducing efficiency.</i>	<i>Frequent rework and scrap result in high manufacturing costs, with long assembly times and low overall efficiency.</i>
<i>Functionality Issues</i>	<i>Components fit and function exactly as intended, leading to optimal machine performance and no safety concerns. The machine operates efficiently and safely.</i>	<i>Minor functional issues may be present but do not compromise overall machine performance or safety.</i>	<i>Functional inefficiencies exist, leading to potential safety concerns or reduced machine performance.</i>	<i>Misfitting or malfunctioning components cause significant operational issues, safety risks, or complete failure of the machine.</i>

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
Communication Breakdowns	Technical drawings are clear, accurate, and detailed, ensuring no ambiguity. All teams communicate effectively, and there are no misunderstandings or errors.	Most technical drawings are clear, but minor ambiguities could lead to slight miscommunication or minor assembly delays.	Drawings have noticeable ambiguities or inconsistencies that lead to occasional misunderstandings and minor errors in the assembly process.	Technical drawings are unclear, leading to frequent miscommunication and errors, significantly impacting the assembly process and final product quality.
Overall Assembly Efficiency	The design and documentation result in a highly efficient assembly process, with minimal delays, rework, or errors. The machine is produced quickly and with high-quality standards.	The assembly process is efficient, but minor adjustments or clarifications are needed. There may be slight delays or rework, but overall efficiency is maintained.	The assembly process is moderately efficient, but issues with fit, tolerance, or unclear drawings lead to frequent delays and rework.	The assembly process is slow and inefficient, with constant delays, rework, and errors due to poor dimensioning, tolerance issues, or unclear technical drawings.

Rubric for the Discussion Assessment.

(Design and Assembly of Complex Mechanical Components)

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
Enhanced Visualisation	Provides a highly detailed, clear view of how parts fit together with all relationships easily understandable.	Provides a clear overview with most part relationships visible, though some minor details might be hard to interpret.	Shows basic relationships but lacks clarity in certain areas, Only closer components are visible while inner components do not fit well.	Provides very unclear, with many parts poorly placed, making it hard to understand the assembled components.
Assembly & Disassembly	Provides a comprehensive step-by-step guide with clear part orientation and exact sequence of assembly.	Clear step-by-step guidance, though some steps may not be as detailed or some orientations may be ambiguous.	Part of the assembly sequence is unclear, and some parts are not properly oriented or need additional explanation.	Missing key assembly steps, with unclear part orientations, leading to potential errors or confusion.

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
<i>Interference Identification</i>	<i>Clearly shows and highlights all potential interferences or clearance issues, with specific notes on solutions.</i>	<i>Identifies most major interference points, but some minor issues or potential conflicts are overlooked.</i>	<i>Identifies some major interference issues, but many smaller conflicts or clearance issues are not highlighted.</i>	<i>Does not address interference or clearance issues, or overlooks key conflicts between parts.</i>
<i>Part Identification</i>	<i>Every part is clearly labeled and identified with part numbers, aiding in easy sourcing and inventory management.</i>	<i>Most parts are labeled, but a few might lack clear identification or proper part numbers, causing minor sourcing issues.</i>	<i>Some parts are not labeled or identified, which could lead to confusion in procurement or assembly.</i>	<i>Many parts are not labeled or identified, making sourcing and inventory management difficult.</i>



APPENDIX E: TABLE OF TEST SPECIFICATION (END OF SEMESTER 1)

Week	Focal Area	Type of Question	Depth of Knowledge				
			L1	L2	L3	L4	Total
1	F1. Explain reactivity, flammability and toxicity as chemical properties of materials. F2. Group materials according to their chemical properties.	Multiple Choice Essay	1	1	1	1	4 1
2	Classification of materials as crystalline and amorphous materials	Multiple Choice Essay	1	2	1 1	1	4 1
3	F1. Identification of material processing methods F2. Classification of materials according to their processing methods	Multiple Choice Essay	1	2	1 1		4 1
4	Grouping of materials according to their synthesis	Multiple Choice Essay	1	2	1 1		4 1
5	F1. Materials loading, stress and strain F2. Effect of loading, stress and strain on materials	Multiple Choice	1	2	1		4
6	Elongation, elastic limit, modulus of elasticity, yield strength and tensile strength of materials.	Multiple Choice Essay	1	1	1 1		3 1
7	Tensile properties of steel	Multiple Choice	1	1	1		3
8	F1. Importance of freehand sketch in product design. Applications of freehand sketching in product design	Multiple Choice Essay	1	2	1	1	4 1
9	F1. Importance of isometric drawing in product design F2. Application of first-angle projection in product design	Multiple Choice	1	2	1		4
10	Importance of sectioning, dimensioning and tolerance	Multiple Choice	1	1	1		3
11	Detailed drawings	Multiple Choice	1	1	1		3
Total Multiple Choice			12	17	11	1	40
Total Essay			0	0	3	2	5

SECTION 4: MODELLING FOR MANUFACTURE

STRAND: DESIGN AND PROTOTYPING

Sub-Strand: Manufacturing tools and equipment

Learning Outcome: *Create geometric figures using AutoCAD*

Content Standard: *Demonstrate the application of computer graphics in modelling*

HINT



- Assign learners Individual projects in week 13, which will be submitted in week 22.
- Refer to Appendix E at the end of this section for more information on individual project.

Introduction and Section Summary

This section discusses the significance of AutoCAD in the modelling, with a focus on creating both 2D and 3D models. By the end of the lesson, learners are expected to have a comprehensive understanding of the role that AutoCAD plays in the manufacturing, engineering, and design industries. Learners will be equipped with proficiency in using essential AutoCAD commands to create detailed and accurate models, transitioning from basic 2D sketches to more complex 3D structures.

The weeks covered by the section are:

Week 13: Importance of AutoCAD in modelling

Week 14: Creating 2D and 3D models using AutoCAD

Summary of Pedagogical Exemplars

Given the diversity in learners' backgrounds, learning capacities, and learning styles, it is crucial to employ a broad spectrum of pedagogical approaches that cater for students' varied abilities within the classroom. Pedagogical alternatives to explore include employing strategies such as the experiential learning, project-based learning collaborative learning and talk for learning. In this section, consider providing learners the opportunity to read from a textbook or the internet and view a video detailing the use of AutoCAD to make 2D and 3D drawings. Allow learners to articulate their experiences through collaborative discourse to identify the importance of using AutoCAD in modelling and learn the commands used in making 2D and 3D drawings in AutoCAD. Finally, a research project can be considered so learners can use AutoCAD to produce 2D and 3D drawings.

Assessment summary

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions after reading textbooks and watching videos on the importance of AutoCAD in modelling; written responses of various difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Learners should be able to explain the importance of AutoCAD in modelling and should be able to 2D and 3D drawings using AutoCAD. These should contribute to learners' formative assessment.

WEEK 13

Learning Indicator: Explain the importance of AutoCAD in creating geometrical figures

Focal Area: Importance of AutoCAD in modelling

Introduction

AutoCAD is computer-aided design (CAD) software that architects, engineers, and construction professionals rely on to create precise 2D and 3D drawings. It is a powerful tool that allows for the drafting, annotation, and design of 2D geometry and 3D models using solids, surfaces, and mesh objects.

History of AutoCAD

AutoCAD was first released in December 1982 as a desktop application running on microcomputers with internal graphics controllers. Before the advent of AutoCAD, most commercial CAD programs operated on mainframe computers or minicomputers, with each CAD operator working at a dedicated graphics terminal. This setup made CAD systems expensive and less accessible.

The development of AutoCAD marked a significant shift in the CAD industry. The first version of AutoCAD was developed by Autodesk co-founder John Walker and a small team of developers. Their goal was to create a CAD program that was affordable, easy to use, and capable of running on personal computers. This vision led to the creation of a software that democratised access to CAD technology, allowing smaller firms and individual professionals to leverage CAD capabilities without the need for expensive hardware.

AutoCAD quickly became one of the most widely used CAD programs due to its affordability and ease of use. It offered a range of features that were previously available only in much more expensive systems, making it a popular choice across various industries including architecture, engineering, and construction.

The release of AutoCAD represented a major milestone in the history of computer-aided design, paving the way for the widespread adoption of CAD technology in everyday professional practice. Over the years, AutoCAD has continued to evolve, incorporating advanced features and keeping pace with technological advancements to remain a leader in the CAD software market.

Key Features

1. 2D and 3D Drafting and Design
 - a. Create detailed 2D drawings and 3D models with high precision.
 - b. Use tools to draw and edit geometry accurately.
2. Automation
 - a. Automate repetitive tasks such as comparing drawings, adding blocks, and creating schedules.
 - b. Enhance productivity with automated features.

3. Industry-Specific Toolsets

- a. **Architecture:** Tools for architectural design, drafting, and documentation.
- b. **Electrical:** Tools for electrical design, including circuit layouts and panel drawings.
- c. **Map 3D:** GIS mapping tools for planning and managing infrastructure.
- d. **Mechanical:** Tools for mechanical engineering, including machine parts design.
- e. **MEP (Mechanical, Electrical, Plumbing):** Tools for MEP design and drafting.
- f. **Plant 3D:** Tools for designing process plant facilities.
- g. **Raster Design:** Tools for editing scanned drawings and converting raster images to vector.

4. Web and Mobile Apps

- a. Access AutoCAD on the go with web and mobile apps.
- b. View, create, edit, and share CAD drawings from any device.

Basic drawing commands

AutoCAD Command Line

The AutoCAD command line is a powerful text-based interface that provides an alternative method for interacting with the software, in addition to the menus and ribbons. While the graphical user interface (GUI) is user-friendly, many experienced AutoCAD users consider the command line to be a more efficient way to work.

Key Features and Benefits

1. **Command Input:** The command line allows you to enter commands to execute a wide range of AutoCAD functions, including creating and modifying geometric shapes, inserting blocks, and applying hatches to objects.
2. **Command History:** The command line maintains a history of recently used commands, which can be beneficial when you need to repeat a prior action.
3. **Autocompletion:** As you begin typing a command, AutoCAD offers suggestions for completing the command. This feature can save time and prevent typos.
4. **Customisation:** The command line can be tailored to your preferences. You can adjust the font size and colour, and you can enable or disable autocompletion to optimise your workflow.

Line Command in AUTOCAD

1. Accessing the Command Line

- a) At the bottom of the AutoCAD window, you'll see the command line interface where you can type commands directly.

2. Starting the LINE Command

- a) Type 'LINE' and press 'Enter' in the command line. Alternatively, you can activate the Line tool from the Home tab on the Ribbon by clicking on the Line icon.

3. Drawing a Line Segment

- a) After activating the LINE command, your cursor will change to a crosshair shape indicating that AutoCAD is ready to accept points for drawing.
- b) Move your cursor to the desired starting point for your line segment.
- c) Left-click to specify the first point.

4. Drawing the Line

- a) Move your cursor in the direction you want the line to extend.
- b) Left-click again to specify the second point of the line segment.
- c) The line segment will be drawn between these two points.

5. Continuing or Ending the Line

- a) After defining the first line segment, the command line will prompt you with Specify next point or [Undo:
- b) Move your cursor to define the next endpoint of another line segment and left-click to place it.
- c) Repeat this process to continue drawing additional line segments.
- d) If you want to end the LINE command, you can press 'Enter' or right-click and choose Enter from the context menu, or type 'C' for Close in the line

POLYLINE Command in AutoCAD

The POLYLINE command in AutoCAD allows users to create a single object composed of one or more connected line segments or arcs. This feature is particularly useful for creating complex shapes or continuous paths within drawings. Here are the key aspects to understand:

1. Creating a Polyline

- a) To start the POLYLINE command, you can type 'PLINE' or 'POLYLINE' on the command line and press 'Enter'.
- b) Alternatively, you can find the Polyline tool in the Draw panel on the Home tab of the Ribbon.

2. Drawing Segments

- a) Once the command is active, specify the points where you want to place vertices (corners) of the polyline.
- b) You can use direct coordinates (absolute, relative, or polar) or click in the drawing area to place each vertex sequentially.

3. Segment Types

- a) Within a single polyline, you can create line segments, arc segments, or a combination of both.
- b) To switch between segment types while drawing a polyline, you can use the options provided in the command line or the Ribbon.

4. Editing Polylines

- a) After creating a polyline, you can edit it using various commands such as PEDIT (Polyline Edit), which allows you to add or remove vertices, change segment types, adjust vertex positions, etc.

- b) Polylines offer flexibility in editing and adjusting shapes without breaking them into separate objects.
- 5. **Closing a Polyline:** To close a polyline (creating a closed shape), you can either specify the same point as the starting point or use the Close option in the command line or Ribbon.

ARC Command in AutoCAD

The ARC command in AutoCAD allows you to create arcs using various methods and specifying different parameters such as centre, endpoint, start point, radius, angle, chord length, and direction. Here's how you can create arcs using some common methods:

1. Centre, Start, and End Points

- a) This method allows you to specify the centre of the arc, the start point (where the arc begins), and the endpoint (where the arc ends).
- b) To start the ARC command, type 'ARC' on the command line and press 'Enter'.
- c) Specify the centre point of the arc.
- d) Specify the start point of the arc.
- e) Specify the endpoint of the arc.

2. Radius and Angle

- a) You can create an arc by specifying its radius and the included angle.
- b) After starting the ARC command, specify the centre point or any point on the arc's circumference.
- c) Enter the radius of the arc.
- d) Specify the included angle (the angle between the two radii extending from the centre point).

3. Chord Length

- a) You can create an arc by specifying its start point, endpoint, and the chord length (the straight-line distance between the two endpoints of the arc).
- b) After starting the ARC command, specify the start point of the arc.
- c) Specify the endpoint of the arc.
- d) Enter the chord length.

- 4. **Direction:** By default, arcs are drawn in a counter clockwise direction. You can hold down the Ctrl key while dragging the mouse to draw the arc in a clockwise direction.

5. Tangent Arcs

- a) If you press 'Enter' without specifying a point after drawing a line, arc, or polyline, AutoCAD automatically creates an arc tangent to the last drawn object.
- b) This is useful for creating smooth transitions and connections between objects.

Advanced drawing commands

HATCH

The HATCH command in AutoCAD is used to fill an enclosed area or selected objects with a hatch pattern, solid fill, or gradient fill. Here's an overview of how to use the HATCH command and its various options:

1. Choosing Boundaries

- a) **Specify a point:** Click within an enclosed area formed by objects.
- b) **Select objects:** Choose objects that enclose an area.
- c) **Pick internal point:** Determine boundaries from existing objects around a specified point.
- d) **HATCH Draw option:** Specify boundary points using command-line options for more control.
- e) **Drag from the tool palette or Design Centre:** Drag a predefined hatch pattern into an enclosed area.

2. Modifying Hatch Patterns

- a) **Remove Boundaries:** Removes hatch patterns added during the current HATCH command. Available in the Hatch and Gradient dialog box.
- b) **Add Boundaries:** Switches from Remove Boundaries mode to add more hatch patterns.
- c) **Undo:** Removes the last hatch pattern inserted during the current HATCH command.
- d) **Settings:** Opens the Hatch and Gradient dialog box where you can change settings like hatch pattern, scale, angle, and more.

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 dialog 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

1. Ensure that the area you want to hatch is completely enclosed by objects or defined boundaries.
2. Experiment with different hatch patterns and settings to achieve the desired visual effect.
3. Use the Undo feature if you need to remove the last hatch pattern applied.

MOVE

The MOVE command in AutoCAD allows you to move objects from one location to another by specifying a base point (starting point) and a second point (endpoint or vector direction). Here's how you can use the MOVE command effectively:

1) Selecting Objects

- a) Click on the **Home** tab in the Ribbon.
- b) Navigate to the **Modify** panel and click on **Move**, or type 'MOVE' on the command line and press 'Enter'.

- c) Select the objects you want to move by clicking on them in the drawing area. Press 'Enter' when you have selected all objects.

2) Specifying the Base Point

- a) After selecting objects, AutoCAD prompts you to specify a base point.
- b) Click on a point in the drawing area that will serve as the starting point (base point) from which the objects will be moved.

3) Specifying the Second Point

- a) After specifying the base point, AutoCAD prompts you to specify the second point.
- b) You can specify the second point in two ways:
 - i. Direct Distance and Direction: Click on a point in the drawing area that indicates the distance and direction in which you want to move the objects. This point acts as the endpoint of a vector from the base point.
 - ii. Coordinates: Alternatively, you can type the coordinates of the second point relative to the base point directly on the command line and press 'Enter'.

COPY

The COPY command in AutoCAD allows you to create copies of selected objects at a specified distance and direction from a base point. Here's a detailed explanation of how to use the COPY command effectively:

1. Selecting Objects

- a) Click on the **Home** tab in the Ribbon.
- b) Navigate to the **Modify** panel and click on **Copy**, or type 'COPY' on the command line and press 'Enter'.
- c) Select the objects you want to copy by clicking on them in the drawing area. Press Enter when you have selected all objects.

2. Specifying the Base Point

- a) After selecting objects, AutoCAD prompts you to specify a base point.
- b) Click on a point in the drawing area that will serve as the base point from which the objects will be copied.

3. Specifying the Second Point or Displacement

- a) After specifying the base point, AutoCAD prompts you to specify the second point or enter options such as Displacement, Mode, or Array.
- b) **Displacement:** Enter coordinates to specify a relative distance and direction for the copy. For example, '@5,3' would copy the objects 5 units horizontally and 3 units vertically from the base point.
- c) **Mode:** Controls whether the command repeats automatically. You can toggle this using the 'Mode' option.
- d) **Array:** Creates multiple copies arranged in a linear array. Specify the number of copies and the displacement between them.
- e) **Fit:** Redefines the array so that the last copy is located at the specified displacement, fitting the copies between the original and final positions.

ROTATE

The ROTATE command in AutoCAD allows you to rotate objects around a specified base point by a specified angle. Here's how you can effectively use the ROTATE command:

1. Selecting Objects

- a) Click on the **Home** tab in the Ribbon.
- b) Navigate to the **Modify** panel and click on **Rotate**, or type 'ROTATE' on the command line and press 'Enter'.
- c) Select the objects you want to rotate by clicking on them in the drawing area. Press 'Enter' when you have selected all objects.

2. Specifying the Base Point

- a) After selecting objects, AutoCAD prompts you to specify a base point.
- b) Click on a point in the drawing area that will serve as the base point around which the objects will rotate.

3. Specifying the Rotation Angle

- a) AutoCAD prompts you to specify the rotation angle.
- b) You can enter the rotation angle directly (e.g., '45' for 45 degrees).
- c) Alternatively, you can specify a second point to define the angle of rotation relative to the base point.
- d) Other options include:
 - i. **'C' for Copy:** Creates a copy of the selected objects at the rotated position.
 - ii. **'R' for Reference:** Rotates objects from a specified angle to a new absolute angle.

MIRROR

The MIRROR command in AutoCAD allows you to create a mirrored copy of selected objects across a specified line. Here's how you can effectively use the MIRROR command:

1. Selecting Objects

- a) Click on the **Home** tab in the Ribbon.
- b) Navigate to the **Modify** panel and click on **Mirror**, or type 'MIRROR' on the command line and press 'Enter'.
- c) Select the objects you want to mirror by clicking on them in the drawing area. Press 'Enter' when you have selected all objects.

2. Specifying the Mirror Line

- a) After selecting objects, AutoCAD prompts you to specify the first point of the mirror line.
- b) Click on a point in the drawing area to define the starting point of the mirror line.
- c) Then, click on another point to define the end point of the mirror line. This line will act as the axis across which the objects will be mirrored.

3. Options for Erasing Source Objects

- a) After specifying the mirror line, AutoCAD prompts you with options regarding the source objects:
 - i. **Erase:** Determines whether the original objects are erased after being mirrored. Type 'Y' to erase or 'N' to retain them.

STRETCH

The STRETCH command in AutoCAD allows you to stretch objects that are crossed by a selection window or polygon. Here's a detailed explanation of how to use the STRETCH command effectively:

1. Selecting Objects

- a) Click on the **Home** tab in the Ribbon.
- b) Navigate to the **Modify** panel and click on **Stretch**, or type 'STRETCH' on the command line and press 'Enter'.
- c) Select the objects you want to stretch by crossing them with a selection window or polygon. Objects partially enclosed will be stretched, while fully enclosed objects or individually selected objects will be moved.

2. Specifying the Base Point

- a) After selecting objects, AutoCAD prompts you to specify a base point.
- b) Click on a point in the drawing area that will serve as the base point from which the offset for the stretch operation will be calculated. This base point can be outside the area being stretched.

3. Performing the Stretch

- a) After specifying the base point, you can move your cursor to define the stretching direction and distance.
- b) Click to confirm the stretch operation.

SCALE

The SCALE command in AutoCAD allows you to resize objects while keeping their proportions consistent. Here's how to use the SCALE command effectively:

1. Selecting Objects

- a) Click on the **Home** tab in the Ribbon.
- b) Navigate to the **Modify** panel and click on **Scale**, or type 'SCALE' on the command line and press 'Enter'.
- c) Select the objects you want to scale by clicking on them in the drawing area. Press 'Enter' when you have selected all objects.

2. Specifying the Base Point

- a) After selecting objects, AutoCAD prompts you to specify a base point.
- b) Click on a point in the drawing area that will serve as the base point for the scaling operation. This point will remain stationary while the selected objects are resized around it.

3. Specifying the Scale Factor

- a) AutoCAD prompts you to specify the scale factor.
- b) Enter a scale factor directly
 - i. A scale factor greater than '1' enlarges the objects.
 - ii. A scale factor between '0' and '1' shrinks the objects.
- c) You can also use the 'Copy' and 'Reference' options for more control:
 - i. **Copy:** Creates a copy of the selected objects for scaling. Type 'C' on the command line and press 'Enter' to use this option.
 - ii. **Reference:** Scales the selected objects based on a reference length and a specified new length. Type 'R' on the command line and press 'Enter' to use this option. You will then need to specify the reference length and the new length.

TRIM

The TRIM command in AutoCAD allows you to trim objects to meet the edges of other objects. It provides two modes: Standard Mode and Quick Mode. Here's a detailed explanation of how to use the TRIM command:

Standard Mode

1. Selecting Boundaries

- a) Click on the **Home** tab in the Ribbon.
- b) Navigate to the **Modify** panel and click on **Trim**, or type 'TRIM' on the command line and press 'Enter'.
- c) Select the objects that will act as the cutting edges (boundaries). You can select multiple objects. After selecting the boundaries, press 'Enter'.

2. Trimming Objects

- a) Select the objects you want to trim. Click on the part of the object that you want to remove. The selected portion of the object will be trimmed to meet the nearest boundary.

3. Using All Objects as Boundaries

- a) To use all objects in the drawing as boundaries, press 'Enter' at the first "Select Objects" prompt without selecting any objects. Then select the objects to be trimmed as usual.

Quick Mode

Selecting Objects to be Trimmed

1. Click on the **Home** tab in the Ribbon.
2. Navigate to the **Modify** panel and click on **Trim**, or type 'TRIM' on the command line and press 'Enter'.
3. In Quick Mode, all objects automatically act as cutting edges.
4. Select the objects you want to trim by clicking on them individually, pressing and dragging to start a freehand selection path, or picking two empty locations to specify a crossing fence. Objects that cannot be trimmed will be deleted instead.

FILLET

The FILLET command in AutoCAD is used to round the edges of objects by creating an arc between two objects. This can be particularly useful for creating smooth transitions between lines or polyline segments. Here's a detailed breakdown of how to use the FILLET command and its various options:

1. First Object

- a) Click on the **Home** tab in the Ribbon.
- b) Navigate to the **Modify** panel and click on **Fillet**, or type 'FILLET' on the command line and press 'Enter'.
- c) Select the first of the two objects you want to fillet.

2. Second Object

- a) Select the second object to define the fillet.

Command Options

1. **Undo:** Reverses the previous action taken in the FILLET command. This is useful if you make a mistake or want to revert to the previous step.
2. **Polyline:** Applies the fillet to all vertices of a selected 2D polyline where two-line segments meet. This creates a rounded corner at each vertex.
3. **Radius**
 - a) Defines the radius of the fillet arc. The value entered becomes the current radius for all subsequent FILLET commands.
 - b) To set the radius, type 'R' after initiating the FILLET command, enter the desired radius value, and press 'Enter'.
4. **Trim**
 - a) Controls whether the FILLET command trims the selected edges to the endpoints of the fillet arc.
 - b) To toggle trimming, type 'T' after initiating the FILLET command. Enter 'Yes' to enable trimming or 'No' to disable it.
5. **Multiple**
 - a) Allows you to fillet multiple sets of objects in one command sequence.
 - b) To use this option, type 'M' after initiating the FILLET command, and then select multiple pairs of objects to fillet.
6. **Edge:** Select a single edge for filleting. You can continue to select single edges until you press 'Enter'.

EXPLODE

The EXPLODE command in AutoCAD is used to break down a compound object into its individual components. This is useful when you need to make detailed modifications to the individual elements that make up a more complex object.

1. Activate the Command

- a) Click on the **Home** tab in the Ribbon.

- b) Navigate to the **Modify** panel and click on **Explode**, or type 'EXPLODE' in the command line and press 'Enter'.

2. Select Objects

- a) Select the compound objects that you want to explode.
- b) Press 'Enter' to confirm your selection.

ARRAY

The ARRAY command in AutoCAD allows you to create multiple copies of selected objects arranged in a specific pattern. These patterns, known as arrays, can be rectangular, path, or polar. Each type of array arranges the copies in a different way, providing flexibility for various design needs.

How to Use the ARRAY Command

1. Activate the Command

- a) Click on the **Home** tab in the Ribbon.
- b) Navigate to the **Modify** panel and click on **Array**, or type 'ARRAY' in the command line and press 'Enter'.

2. Select Objects

- a) Select the objects you want to duplicate.
- b) Press 'Enter' to confirm your selection.

3. Choose Array Type

- a) Rectangular Array
 - i. Select 'Rectangular' from the options.
 - ii. Specify the number of rows, columns, and the spacing between them.
- b) Path Array
 - i. Select 'Path' from the options.
 - ii. Select the path you want to use for the array.
 - iii. Specify the number of items and their alignment along the path.
- c) Polar Array
 - i. Select 'Polar' from the options.
 - ii. Specify the centre point of the array.
 - iii. Enter the number of items and the angle between them.

OFFSET

The OFFSET command in AutoCAD is used to create parallel or concentric copies of selected objects at a specified distance. This tool is particularly useful for creating features like parallel lines, concentric circles, or offset curves in your drawings.

How to Use the OFFSET Command

1. Activate the Command

- a) Click on the **Home** tab in the Ribbon.

- b) Navigate to the **Modify** panel and click on **Offset**, or type 'OFFSET' in the command line and press 'Enter'.
2. **Specify Offset Distance**
 - a) After activating the command, you will be prompted to specify the offset distance.
 - b) Enter the desired distance and press 'Enter'.
3. **Select Object to Offset**
 - a) Select the object you want to offset. This can be a line, arc, circle, polyline, or spline.
 - b) After selecting the object, you will be prompted to specify the side to offset to.
4. **Specify Side for Offset:** Move your cursor to the side where you want the offset copy to be created and click to place the offset object.

Learning Tasks

1. Learners discuss and present reports on the importance of using AutoCAD over traditional drafting methods.
2. Learners draw simple shapes such as boxes, cylinders etc. using AutoCAD.

Pedagogical Exemplars

Talk for learning: Let learners read about what AutoCAD is, its history and application from textbooks or online. Lead learners to discuss the primary functions and key features of AutoCAD such as drawing, editing and annotation tools and commands. Have learners use flashcards and mappings to illustrate the importance of AutoCAD and present results to class. Provide specific instructions to the groups to guide the discussions and to prevent the possibility of only one learner doing all the talking. Encourage learners to simply and clearly articulate their points and listen to others during the discussions. Make room for non-vocal learners to contribute to the group discussions through writing.

Project-based learning: In mixed-ability groups each learner uses AutoCAD to draw simple objects such as boxes, cylinders etc. Learners discuss the drawings in their groups and present their final drawing to the class using any suitable method and emphasising the importance of using AutoCAD compared to the traditional drawing methods. Assign specific roles to learners to ensure that all learners participate in the project and are challenged according to their understanding and skills on the use of AutoCAD. Also, develop a peer mentoring system in the mixed-ability groups to encourage more advanced learners to support their colleagues in understanding and effectively using AutoCAD to draw. Challenge proficient learners to try drawing complicated figures using AutoCAD.

Key Assessment

Assessment Level 1

1. What is AutoCAD?
2. List two features of AutoCAD.
3. Name one industry that commonly uses AutoCAD.

Assessment Level 2: Explain how AutoCAD improves efficiency in design compared to manual drafting.

Assessment level 3

1. What are the benefits of using AutoCAD for collaborative projects?
2. How does AutoCAD help in visualising complex designs?
3. Discuss the potential challenges of learning and using AutoCAD for new users.
4. Discuss the three main basic drawing commands of AutoCAD

Assessment level 4: Analyse the impact of AutoCAD on reducing material waste in manufacturing.

HINT



*The recommended mode of assessment for week 13 is **check list**. Use the level 3 question 4 as a sample question.*

WEEK 14

Learning Indicator: Use AutoCAD to create 2D and 3D models

Focal Area: Creating 2D and 3D models using AutoCAD

2D modelling in AutoCAD

Introduction

AutoCAD is widely used for creating precise and detailed 2D drawings and models. These 2D models are essential for various applications, including engineering schematics and manufacturing designs. Understanding the tools and techniques for 2D modelling in AutoCAD is crucial for producing accurate and professional drawings.

Basic Workflow for 2D Modelling

1. Setting Up the Drawing Environment

- a. Start by configuring the drawing units (e.g., millimetres, inches) using the **UNITS** command.
- b. Set up the drawing limits and grid to define the workspace using the **LIMITS** and **GRID** commands.
- c. Choose an appropriate template that suits the type of drawing you are creating.

2. Using Basic Drawing Tools

- a. **Line (LINE):** Draw straight lines by specifying start and end points.
- b. **Circle (CIRCLE):** Create circles by specifying the centre point and radius or diameter.
- c. **Rectangle (RECTANGLE):** Draw rectangles by defining opposite corners.
- d. **Polyline (PLINE):** Create continuous lines that can include both straight and curved segments.
- e. **Arc (ARC):** Draw arcs by specifying start, centre, and end points or using other arc creation methods.
- f. **Ellipse (ELLIPSE):** Create ellipses by defining the centre, major axis, and minor axis.

3. Editing Tools

- a. **Move (MOVE):** Relocate objects by specifying a base point and a second point.
- b. **Copy (COPY):** Duplicate objects to a specified location.
- c. **Rotate (ROTATE):** Rotate objects around a base point.
- d. **Scale (SCALE):** Resize objects by specifying a base point and a scale factor.
- e. **Trim (TRIM):** Cut off parts of objects that extend beyond specified boundaries.
- f. **Extend (EXTEND):** Lengthen objects to meet the edges of other objects.
- g. **Offset (OFFSET):** Create parallel lines or curves at a specified distance from the original.

4. Creating Precise Geometry

- a. **Object Snaps (Osnap):** Enable precise selection of geometric features such as endpoints, midpoints, centres, and intersections.
- b. **Grid and Snap Settings:** Use the SNAP and GRID commands to control the alignment of objects to the grid.
- c. **Dynamic Input:** Enable dynamic input to enter coordinate values and dimensions directly on the drawing.

5. Annotation and Dimensions

- a. **Text (TEXT and MTEXT):** Add single-line or multi-line text annotations to the drawing.
- b. **Dimensions (DIM):** Add various types of dimensions, such as linear, angular, radial, and diameter dimensions, to specify the size and relationships of objects.
- c. **Leaders (LEADER or MLEADER):** Create leader lines with text or symbols to annotate specific points.

6. Layers and Layer Management

- a. **Layer (LAYER):** Organise your drawing by assigning objects to different layers. Layers help manage visibility, colour, linetype, and lineweight properties.
- b. **Layer Properties Manager:** Use the Layer Properties Manager to create, modify, and control layers efficiently.

7. Blocks and Attributes

- a. **Block (BLOCK and WBLOCK):** Create reusable groups of objects (blocks) that can be inserted multiple times in a drawing.
- b. **Attributes (ATTDEF):** Define attributes for blocks to include variable text information, such as part numbers or descriptions.

8. Hatching and Fills

- a. **Hatch (HATCH):** Fill closed areas with patterns, solid fills, or gradients to indicate different materials or areas.
- b. **Boundary (BOUNDARY):** Define boundaries for hatching using closed loops.

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, linetype, lineweight) 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

Command: UNITS

Choose “Decimal” for Type and “Millimeters” for Insertion Scale. Click OK.

- b) Set Limits

Command: LIMITS

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

Command: CIRCLE

Specify the centre point as (100,100) and the radius as 50.

- b) Draw the Inner Circle (Hole)

Command: CIRCLE

Specify the centre point as (100,100) and the radius as 20.

3. Adding Bolt Holes

- a) Draw a Bolt Hole

Command: CIRCLE

Specify the centre point as (100,150) and the radius as 5.

- b) Array the Bolt Hole Around the Flange

Command: ARRAYPOLAR

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

Command: DIMDIAMETER

Select the outer circle. Place the dimension line outside the circle.

- b) Add Diameter Dimension for Inner Circle

Command: DIMDIAMETER

Select the inner circle. Place the dimension line outside the circle.

- c) Add Radius Dimension for Bolt Holes

Command: DIMRADIUS

Select one of the bolt holes. Place the dimension line outside the circle.

- d) Add Linear Dimension for Bolt Circle Diameter

Command: DIMDIAMETER

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:

Command: DIMANGULAR

Select the centre of the flange and one bolt hole. Place the angular dimension between the bolt holes.

5. Annotating the Drawing

- a) Add Text for Labels

Command: MTEXT

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)

Command: LAYER

Create layers such as "Flange", "Dimensions", and "Annotations" for better organisation and control over the drawing.

- b) Save the Drawing

Command: SAVEAS

Name the file as "Flange.dwg".

Commands Summary

UNITS -> Decimal, Millimeters

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 versatile tool for creating both 2D and 3D models. 3D modelling in AutoCAD allows designers to visualise their designs in three dimensions, which helps in understanding the spatial relationships and improving the overall design process. The notes below explain how to create 3D models in AutoCAD.

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
 - a) Use the VIEWCUBE or NAVIGATION BAR to switch between different views (Top, Front, Isometric, etc.).
 - b) 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

- c) Creates a 3D torus.
- d) 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.

Learning Tasks

1. Learners create 2D drawings using AutoCAD
2. Learners create 3D drawings using AutoCAD

Pedagogical Exemplars

1. **Experiential learning:** Let learners read from textbooks, charts, the internet or watch videos on how to make 2D and 3D drawings. Afterwards, organise a seminar on the creation of 2D and 3D drawings using AutoCAD and let learners, in mixed-ability groups, practice their knowledge on the use of AutoCAD. Assign specific roles to learners to ensure that all learners fully participate. Create a peer-to-peer mentoring system to help learners having difficulties receive help from colleagues. Encourage more proficient learners to try difficulty figures.
2. **Project-based learning:** Let learners create 2D drawings such as flanges, bolts etc. using AutoCAD. Afterwards, let learners use the 3D commands in AutoCAD to transform their 2D drawings into 3D drawings and present their results to the class for feedback. Allow learners to choose their preferred mode of presentation. Let learners with difficulties receive help from proficient learners and encourage proficient learners to draw complicated figures.

Key Assessment

Assessment Level 1

1. What is AutoCAD and what is it used for?
2. What command would you use to draw a circle in AutoCAD?
3. How do you switch to the 3D Modelling workspace in AutoCAD?

Assessment Level 2

1. Describe the difference between 2D and 3D modelling in AutoCAD.
2. Explain the steps to create a simple 2D rectangle in AutoCAD.
3. How do you use the EXTRUDE command to create a 3D object from a 2D shape?
4. Describe the purpose of the OFFSET command and provide an example of its use.
5. What is the purpose of using layers in AutoCAD, and how do you create a new layer?

Assessment level 3

1. Create a flange using AutoCAD. Describe each step.
2. Explain how to use the ARRAYPOLAR command to create a pattern of holes in a circular flange.
3. How do you apply dimensions and annotations to a 2D drawing in AutoCAD? Provide specific commands and steps.
4. Describe the steps to create a 3D model of a cylinder with a hole through its centre.
5. Explain how to use the LOFT command to create a 3D object from multiple cross-sectional profiles. Provide an example.

Assessment Level 4

1. Develop a detailed 3D model of a mechanical part, such as a gear, including all necessary dimensions and annotations. Describe the complete workflow.
2. Describe the process of converting a 3D model into 2D orthographic views for manufacturing purposes. Include commands and steps.
3. Use AutoCAD software to design and create a 3D model of a cylinder with a hole through its centre.

HINT



*The recommended mode of assessment for week 14 is **practical**. Use the level 4 question 3 as a sample question.*

Section 4 Review

This section explored the use of AutoCAD in modelling and developed skills in creating both 2D and 3D models. The section aimed to equip learners with a comprehensive understanding of how AutoCAD can be applied in various industries such as manufacturing, engineering, and design. Through hands-on activities and practical lessons, learners will learn the essential commands and techniques required to create detailed and accurate models. At the end of the section, learners 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.

Marking Scheme for the Check List Assessment

Basic drawing commands in AutoCAD.

Criteria	Yes (1 point)	No (0 points)	Comments
<i>Understanding of Commands</i>			
<i>Can explain the purpose of the Line command.</i>			
<i>Can explain the purpose of the Circle command.</i>			
<i>Can explain the purpose of the Rectangle command.</i>			
<i>Application of Commands</i>			
<i>Successfully uses the Line command in a drawing.</i>			
<i>Successfully uses the Circle command in a drawing.</i>			
<i>Successfully uses the Rectangle command in a drawing.</i>			
<i>Accuracy</i>			
<i>Drawings created with the Line command are accurate in length and direction.</i>			
<i>Drawings created with the Circle command have correct radius/diameter.</i>			
<i>Drawings created with the Rectangle command are accurate in dimensions.</i>			
<i>Creativity and Effort</i>			
<i>Demonstrates creativity in the use of drawing commands.</i>			
<i>Shows effort in completing the task thoroughly.</i>			



APPENDIX E: STRUCTURE OF AN INDIVIDUAL PROJECT

INDIVIDUAL PROJECT

Individual project should be given to learners in week 13. Final submission of the individual project should be by the 22nd week of the academic year

Task Example

Project Topic: Problem Identification

Given that several households in Ghana rely on manual methods of cutting vegetables which are often time-consuming and unsafe. Design and make a cost-effective, efficient and user-friendly vegetable cutter tailored for the average Ghanaian household.

Structure and Organisation of the Project:

As part of the structure of the individual project, the report, should include the following details:

1. **Defining the Problem:** Describe the problem faced by Ghanaian households when manually cutting vegetables. Highlight specific issues related to time consumption and safety hazards.
2. **Understanding the Problem:** Describe key methods of gathering and keeping data/information. Provide any background information on similar products or existing solutions and how they informed your design. Summarise key findings from your investigation. Mention any specific feedback from stakeholders (e.g., households, market insights).
3. **Brainstorming Potential Solutions:** Generation at least three conceptual designs with annotated notes.
4. **Choosing the final Solution:** List the evaluation criteria such as functionality, manufacturability, safety, cost) used to evaluate conceptual ideas Explain why you selected the final design concept. Justify your decision based on the evaluation criteria
5. **Developing the chosen unit:** Provide detailed specifications for your chosen design, including dimensions, materials, tolerances, and performance criteria. Produce a final design using AutoCAD
6. **Making a Prototype of the Solution (Realisation):** Explain the manufacturing processes you chose and why they were suitable for your design. Describe how you built the prototype. Include details about the materials used and why they were selected.
7. **Testing and evaluation of the Prototype:** Describe the tests conducted on the prototype (e.g., safety tests, performance under various conditions).
Summarise the results of the tests, highlight how the prototype performed in terms of functionality, safety, and efficient.
8. **Evaluation report:** This report is the outcome of the testing and evaluation. Prepare a report (1-2- page(s) that includes:
 - a. An introduction
 - b. Function.
 - c. Material.

- d. Construction
- e. Safety
- f. Conclusion
- g. Recommendations

Submission Requirements

Each learner will submit a completed prototype of a vegetable cutter and a report (1-2 page(s) detailing the outcome after testing and evaluation

How to administer individual project:

- i. Explain the project requirements and objectives to the learners.
- ii. Assign the individual project in week 13 of the second semester.
- iii. Schedule regular check-ins to monitor progress and provide feedback.
- iv. By the 21st week, instruct groups to finalise their project.
- v. Group projects should be submitted in the 22nd week at a time agreed on by both teacher and learners.

Specific Rubric for Assessing the Vegetable Cutter Design

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
Functionality	Cutter is highly efficient, quickly cutting a variety of vegetables with minimal effort and producing consistent, clean cuts. Safety mechanisms (blade guards, stable base) work flawlessly.	Cutter performs well on most vegetables, but may require moderate effort on harder or denser vegetables. Safety features are present but not as effective as ideal.	Cutter works but requires considerable effort or produces uneven cuts. Safety mechanisms are not intuitive or may not fully prevent accidents.	Cutter is inefficient and difficult to operate. Cuts are inconsistent or messy, and the product lacks effective safety features.
Affordability	Very cost-effective to produce and priced well within the budget of the average Ghanaian household. Comparable in price to local alternatives.	Priced reasonably, but could be slightly higher than expected for some households. Still affordable for most users.	Price may be too high for some households, making it less accessible than comparable manual cutters.	Price is excessive for the target market. Production or retail costs are too high for average households to afford.

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
<i>Durability and Materials</i>	<i>High-quality materials (e.g., rust-resistant stainless-steel blades, durable plastic or wood body) that withstand regular use. Easy to clean and maintain, and lasts over time.</i>	<i>Materials are sturdy and perform well, but may show slight wear with heavy use. Cleaning and maintenance are easy, but not as convenient as ideal.</i>	<i>Materials are average quality, may deteriorate over time with frequent use. Cleaning may be difficult, and maintenance is somewhat cumbersome.</i>	<i>Materials are poor quality, likely to break down with use. Difficult to clean or maintain, leading to frequent replacements.</i>
<i>User-Centered Design</i>	<i>Ergonomic and intuitive design that is comfortable for users of all abilities (e.g., easy grip, simple operation). Requires little to no physical strength to use effectively.</i>	<i>Handle and design are comfortable for most users, with minimal effort required for cutting. May require brief learning curve or adjustment for comfort.</i>	<i>Design is not intuitive for all users. Uncomfortable to use, or requires more effort to operate than necessary. User instructions are unclear.</i>	<i>Uncomfortable to hold or use. Design is awkward or causes strain. Difficult to use without technical knowledge or guidance.</i>
<i>Innovation</i>	<i>The cutter features innovative solutions, such as interchangeable blades, a crank mechanism, or multi-purpose functionality. It stands out from traditional cutters.</i>	<i>The cutter includes some unique features, but is not radically different from existing products. Adds value but doesn't introduce major innovations.</i>	<i>Cutter is similar to existing products without offering new features or improvements over traditional methods.</i>	<i>The cutter is not innovative and lacks features that improve on traditional cutting methods. No unique selling points.</i>
<i>Impact on Daily Life</i>	<i>Cutter significantly saves time and effort compared to manual chopping. Greatly improves kitchen safety and reduces injury risk. Users find it transformative for everyday tasks.</i>	<i>Cutter saves some time and effort, though not drastically compared to manual methods. Improves safety to some extent but still requires caution during use.</i>	<i>Cutter offers limited time savings and doesn't significantly improve safety. It may still require careful attention to avoid accidents.</i>	<i>Cutter does not save time or improve safety. It may even introduce additional difficulties compared to traditional methods.</i>

Rubrics for the Practical Assessment

(3D Model of a Cylinder with a Hole in AutoCAD)

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
Correct Use of Commands	Uses all relevant AutoCAD commands correctly (e.g. CYLINDER, SUBTRACT, EXTRUDE,) to create the model with no errors. Efficient and effective application of each command for specific tasks.	Commands such as CYLINDER, SUBTRACT are used correctly for the most part, with minor inefficiencies (e.g., unnecessary extra steps). Commands are applied mostly correctly, but may lack optimisation.	Some commands like CYLINDER or SUBTRACT are used improperly or inefficiently, resulting in extra or unnecessary steps that make the process longer or more complicated.	Incorrect or incomplete use of basic AutoCAD commands (e.g., using the wrong command for cutting or extruding), leading to inefficient or incorrect results.
Creativity & Complexity	The design includes advanced features such as additional filleting or chamfering on the edges for aesthetics or smoother functionality. The hole design is creatively integrated.	The design includes basic refinement, such as rounded edges, but no advanced features (e.g., additional fillets).	The design is functional but lacks refinement or extra features. It follows a basic approach with no added complexity beyond the hole.	The design is basic and overly simplistic without any enhancements or extra features. The hole and edges are just cut without considering aesthetic improvements.
Presentation & Visual Quality	The model is presented with clear viewports, perfect rotations, and visibility of all relevant parts. No extraneous lines or artifacts appear in the drawing. It is easy to understand and looks polished.	The model is mostly clear, with good presentation but may include slight errors in viewpoint or extra lines. Visibility is generally good, but could be improved.	The model presentation is cluttered, with unclear viewports, or extra lines that obscure important features. The model looks incomplete or not well-organised.	The model's presentation is poor, with significant issues in clarity, alignment, or use of viewports. There are multiple artifacts or unnecessary lines, making it hard to understand.
File Organisation	The drawing file is well-organised, using appropriate layers, naming conventions, and proper grouping. Files are easily navigable, and the structure is logical.	The file organisation is good, with minor inconsistencies in layer usage or naming. It's still mostly clear and easy to navigate.	The file lacks clear organisation; some layers may be unnamed or improperly structured, making it more difficult to navigate or understand.	The file is disorganised, with poorly named layers or no layers at all, making it difficult to work with or navigate.

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
<i>Error-Free Model</i>	<i>The model is free of errors such as misalignments, gaps, or overlaps. The cut is clean, and no unintended gaps or overlaps exist. Model can be easily modified or adjusted if necessary.</i>	<i>The model contains minor errors such as slight misalignments or a small gap that doesn't significantly affect the overall structure. It is still functional.</i>	<i>Some noticeable errors or misalignments are present, such as small gaps, overlap, or uneven cuts, that need fixing for the model to be fully functional.</i>	<i>The model has major errors, such as overlapping or misaligned components, which will require significant revisions to work properly.</i>
<i>Understanding of CAD Tools</i>	<i>Demonstrates excellent proficiency with AutoCAD's 3D modeling tools and commands, including the use of advanced features. Model is complex, clean, and exhibits advanced technical skills.</i>	<i>Demonstrates good understanding of AutoCAD tools, with some minor errors or limitations. The model shows functional use of 3D tools but lacks full proficiency.</i>	<i>Displays basic understanding of AutoCAD tools, with limited use of advanced features. The model is functional but lacks advanced techniques.</i>	<i>Shows limited understanding of AutoCAD tools, often relying on basic 2D commands or incorrect techniques, which makes the model less efficient or inaccurate.</i>

SECTION 5: MEASURING TOOLS AND HAND TOOLS

STRAND: DESIGN AND PROTOTYPING

Sub-Strand: Manufacturing tools and equipment

Learning Outcome: *Apply measuring instruments and hand tools to manufacture engineering components*

Content Standard: *Demonstrate knowledge and understanding of using measuring tools*

Introduction and Section Summary

This section examines the critical aspects of measuring instruments and hand tools used in manufacturing. Understanding the differences between various measuring instruments and how to use them effectively is fundamental for precision and quality control in any manufacturing process. Additionally, distinguishing between manual hand tools and power hand tools, along with their applications, is crucial for selecting the appropriate tools for different tasks and ensuring efficiency and safety in the workshop. This section aims to equip learners with understanding the difference between measuring instruments and using measuring tools to measure work pieces, and the difference between manual hand tools and power hand tools and application of hand tools in manufacturing. The section will help learners to know the key differences between manual and power hand tools, select the appropriate measuring instrument or hand tool for a specific task and use manual and power hand tools correctly and safely.

The weeks covered by the section are:

Week 15: Difference between measuring instruments and using measuring tools to measure work pieces

Week 16: Difference between manual-hand tools and power hand tools and application of hand tools in manufacturing.

Summary of Pedagogical Exemplars

Understanding that learners have different backgrounds, learning capacities, and learning styles, it is crucial to employ a broad spectrum of pedagogical approaches that cater for students' varied abilities within the classroom. Pedagogical alternatives to explore include employing strategies such as the experiential learning, project-based learning, collaborative learning and talk for learning. In this section, consider providing learners the opportunity to read from a textbook or the internet and watch a video on different measuring tools and manual and power hand tools in operation in a workshop. Allow learners to discuss their experiences through collaborative discourse to identify the differences between the measuring instruments or tools and the manual and power hand tools. Finally, a project can be considered so learners can use the measuring instruments and tools and the manual and power hand tools to ascertain the practical differences of using these tools in the manufacturing industry.

Assessment summary

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions after reading textbooks and watching videos on the different types of measuring tools and manual and power hand tools; written responses of various difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Learners should be able to explain the differences between measuring instruments, and manual and power hand tools. Learners should also be able to use the right measuring instruments and tools for specific works in the workshop. These should contribute to learners' formative assessment.

WEEK 15

Learning Indicators

1. Explain the difference between measuring tools such as rule, a vernier calliper and a micrometer screw gauge for measuring work pieces
2. Apply measuring tools for the measurement of work pieces

Focal Area 1: Difference between measuring instruments

Introduction

Measuring instruments are tools used to determine physical quantities related to the length, angle, and surface characteristics of objects. These instruments are essential in providing accurate and precise measurements, which are critical in fields like mechanical engineering, manufacturing, and construction. By converting physical properties into quantifiable data, measuring instruments enable engineers and technicians to design, create, and inspect products with exact specifications. Their purpose extends beyond simple measurement; they also ensure that parts fit together correctly, function as intended, and meet safety and quality standards.

Linear measurement tools

They are used to determine the distance between two points or the size of an object along a straight line. These tools are fundamental in various engineering and manufacturing applications. Examples include steel rule, vernier calliper and micrometer screw gauge.

Steel Rule

Description: A steel rule is a basic measuring tool typically made from stainless steel or other metals. It is straight-edged and marked with a scale in either millimetres or inches along its length. The markings on the rule allow for measurements of length, width, and height of objects in various applications.

Usage: Steel rules are commonly used for quick and rough measurements in layout work, carpentry, metalworking, and general inspection tasks. They are versatile tools that can be used to mark straight lines, measure the dimensions of flat objects, and quickly verify sizes during manufacturing and assembly processes.

Accuracy: Steel rules are generally accurate to within ± 0.5 mm, although this can vary depending on the quality and manufacturing precision of the rule itself. The accuracy also depends on the skill and technique of the user in aligning the rule correctly and reading the scale accurately. For more precise measurements, especially when higher accuracy is required, more advanced measuring tools such as Vernier callipers or micrometres would be used.

Steel rules are valued for their simplicity, durability, and ease of use in a wide range of industrial and workshop settings where quick measurements are needed. Their straightforward design and robust construction make them indispensable tools for tasks where precise, albeit not ultra-high precision, measurements are sufficient.

Vernier Calliper

Description: The Vernier calliper is a precision measuring instrument consisting of a main scale and a sliding Vernier scale. The main scale is marked in millimetres or inches, while the Vernier scale slides along the main scale and provides readings to a finer resolution. This allows the calliper to measure internal dimensions (like the inside diameter of a hole), external dimensions (like the diameter of a rod), and depth measurements with high accuracy. Vernier callipers have inside and outside measurement Jaws that are used for measuring internal and external dimensions, respectively. They have depth probes that extends from the bottom of the calliper for measuring depths of holes or grooves. The fine adjustment screw allows for precise adjustment and zeroing of the calliper and the locking screw secures the calliper in position once a measurement is taken to prevent accidental movement.

Usage: Vernier callipers are extensively used in machining, metalworking, mechanical engineering, and other fields where precise measurements are critical. They are indispensable for tasks such as quality control in manufacturing, where parts must meet exact specifications, and in workshop environments for accurately sizing components and checking tolerances.

Accuracy: Vernier callipers can measure to an accuracy of 0.02 mm or better, depending on the quality of the instrument and the skill of the operator. Some models can achieve even higher levels of precision, such as 0.01 mm or finer. The accuracy is achieved by the fine graduation of the Vernier scale, which allows for precise interpolation between the main scale divisions.

Vernier callipers are versatile instruments that combine ease of use with high accuracy, making them essential tools in industries where precise measurements are essential for ensuring product quality, performance, and compliance with engineering standards.

Micrometer Screw Gauge

Description: The micrometer screw gauge is a precision measuring instrument designed for measuring small distances, thicknesses, or diameters with high accuracy. It consists of a calibrated screw mechanism that translates small rotations of a finely threaded screw into precise measurements displayed on a scale.

Usage: Micrometer screw gauges are ideal for measuring the dimensions of small parts, such as the thickness of wires, the diameter of rods, or the depth of small holes or slots. They are widely used in mechanical engineering, manufacturing, precision machining, and quality control environments where extreme precision is required. Different types of micrometres include:

- **Outside Micrometer:** Used for measuring external dimensions, such as the diameter of shafts or the thickness of plates.
- **Inside Micrometer:** Designed for measuring internal dimensions, such as the diameter of bores or the width of slots.
- **Depth Micrometer:** Used for measuring depths of holes, slots, or other recesses.

Accuracy: Micrometres can measure to an accuracy of 0.01 mm or better, depending on the quality of the instrument and the skill of the operator. Some micrometres can achieve even higher accuracies, down to 0.001 mm (1 micron) or finer. The accuracy is achieved through the precise pitch of the screw thread and the finely graduated scale, which allows for exact measurement readings.

Differences between steel rule, vernier calliper and micrometer screw gauge

The differences between steel rule, vernier calliper and micrometer screw gauge lies in their measurement range, precision, accuracy and even environmental effect on the accuracy in measurement. Table 15.1 provides the differences between these linear measuring instruments.

Table 15.1 : *Differences between steel rule, vernier calliper and micrometer screw gauge*

Property	Steel Ruler	Vernier Calliper	Micrometer Screw Gauge
Measurement range	Measures up to 300 mm.	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 tool.	Requires reading the main scale and the vernier scale together.	Requires reading the sleeve and thimble scales, sometimes with an additional vernier scale for extra precision.
Measurement type	Measures lengths, widths and heights.	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.	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.
Material for construction	Typically made of metal, plastic, or wood.	Usually made of stainless steel or hardened steel.	Constructed from high-quality steel or carbide for precision and durability.

Angular measurement tools (e.g. Protractors, angle gauges, bevel protractors, sine bars)

Angular measurement tools are used to measure the angle between two surfaces or lines. These tools are essential for ensuring the correct angular orientation of parts and assemblies.

Protractors

Protractors are simple measuring tools typically made of plastic, metal, or other materials, featuring a semicircular or circular scale marked in degrees. They are used to measure and draw angles in geometric constructions, drafting, and various educational and technical applications. They are commonly used in drafting and basic angular measurements where moderate accuracy is sufficient. They are especially useful in educational settings for teaching geometry and trigonometry concepts, as well as in engineering and architectural drawings for laying out angles and geometric shapes. Protractors are suitable for less precise measurements, typically accurate within ± 1 degree or slightly better, depending on the quality of the protractor and the skill of the user. This level of accuracy is adequate for many general-purpose applications where exact precision is not critical.

Angle Gauges

Angle gauges are precision tools that consist of a set of blades or blocks set at specific angles, typically calibrated to high precision. They are used for setting up machinery, checking the angles of machined parts, and ensuring accuracy in various mechanical and manufacturing processes. They are essential in precision machining and assembly operations where exact angles are critical. They are commonly used for aligning components, setting cutting tools, and verifying the angular accuracy of machine setups. Angle gauges provide a quick and reliable method for ensuring that parts are machined and assembled according to specified angles and tolerances. The accuracy of angle gauges depends on the quality of the gauge set. High-quality angle gauges can achieve very precise angular measurements, often within fractions of a degree or better. The blades or blocks are precisely ground and calibrated to ensure consistent and accurate angle readings, making them suitable for demanding applications where precise angular alignment is necessary.

Bevel Protractors

A bevel protractor is a precision measuring tool that features a protractor head and a movable blade or arm. The protractor head typically has a circular scale marked in degrees, allowing for precise measurement and marking of angles on workpieces. They are widely used in machining, metalworking, and woodworking industries for measuring, marking, and setting angles on various workpieces. They are particularly useful for layout work, setting up machinery, and checking the angular alignment of components during assembly. Bevel protractors can measure angles to within minutes of a degree, depending on the quality of the instrument and the skill of the user. They provide a high level of accuracy suitable for most precision machining and fabrication tasks where precise angular measurements are required.

Sine Bars

Sine bars are precision measuring tools used in conjunction with gauge blocks to measure and set angles based on trigonometric principles. A sine bar consists of a hardened steel bar with two precision-ground cylinders (or blocks) at each end. These cylinders are set at a specific distance apart, creating a fixed angle relative to the surface plate or worktable. Sine bars are

primarily used in machining operations for checking and setting precise angles. They are placed on a surface plate or machine table and used in combination with gauge blocks to establish specific angles required for machining or inspection tasks. Sine bars provide a reliable and accurate method for angular measurement and setup in precision engineering and manufacturing environments. Sine bars are highly accurate measuring instruments, with measurements depending on the precision of the sine bar itself and the gauge blocks used. They can achieve very precise angular settings, typically within a few arc minutes or better. The accuracy of sine bars makes them indispensable tools for ensuring angular precision in machining processes where accuracy is critical to achieving desired part dimensions and tolerances.

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 considerations and many more. Table 15.2 provides the differences between these angle measuring instruments.

Table 15.2: *Differences between protractor, angle gauge, bevel protractor and sine bar*

Property	Protractor	Angle gauge	Bevel protractor	Sine bar
Measurement 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 blocks and calculations.
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.

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 the flatness, roughness, and other surface characteristics of objects. These tools are critical in quality control to ensure that surfaces meet the required specifications.

Surface Plates

Surface plates are flat, precision-ground plates made from granite, cast iron, or other materials with high dimensional stability. They serve as a reference surface for the inspection and measurement of flatness and perpendicularity. Surface plates are used in metrology and quality control for checking the flatness of surfaces and setting up precision measurements. They provide a stable and accurate reference plane against which measurements can be made using height gauges, dial indicators, and other precision instruments. Surface plates are extremely flat, with deviations typically measured in micrometres (millionths of a metre). High-quality surface plates can have flatness tolerances as tight as a few micrometres over their entire surface area. This level of accuracy ensures reliable measurement results in quality assurance and precision manufacturing processes.

Height Gauges

Height gauges are tools equipped with a sliding measuring head mounted on a vertical column. They are used to measure vertical distances from a reference surface, such as a surface plate or worktable. Height gauges are commonly used in machining, toolmaking, and metrology for measuring heights, depths, and step dimensions. They are also used in layout work to mark lines at specific heights or depths on workpieces. Digital height gauges provide precise measurements and often include features for data output and statistical analysis. Height gauges offer high precision, with digital models capable of measuring heights to an accuracy of 0.001 mm (1 micron) or better. Mechanical height gauges, while slightly less precise, still provide accurate measurements suitable for most industrial applications.

Surface Roughness Testers

Surface roughness testers are electronic devices designed to measure the texture of a surface, providing quantitative data on surface roughness parameters such as Ra (average roughness) and Rz (mean roughness depth). Surface roughness testers are used in quality control and

manufacturing to assess the surface finish of machined parts. They ensure that surfaces meet specified roughness parameters required for functionality, aesthetics, and performance. Surface roughness measurements are crucial in industries such as automotive, aerospace, and medical device manufacturing. Surface roughness testers provide detailed measurements of surface irregularities, typically in micrometres (microns). They can measure roughness parameters with high accuracy, offering precise insights into the quality of surface finishes. Advanced models may also provide a graphical representation of surface profiles and statistical analysis of surface roughness data.

Differences between surface plates, height gauges and surface roughness testers

The differences between surface plates, height gauges and surface roughness testers lie in their measurement range, precision, accuracy, environmental considerations and many more. Table 15.3 provides the differences between these surface measuring instruments.

Table 15.3: *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.	Can be up to 0.001 mm	High precision for surface texture measurements, often in microns.
Set up time	Minimal setup time, but they must be placed on a 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 roughness parameters and proper handling of the device.
Cost	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.
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.

Learning Tasks

1. Learners discuss and make presentations on the differences between measuring instruments according to their use, cost, precision, sensitivity and material of construction.
2. Learners in mixed-ability groups use scale rule, vernier calliper and micrometer screw gauge to measure the length of a metal piece, diameter of a cylindrical rod and the thickness of a thin metal sheet respectively at the workshop. Learners write a report to discuss the differences between the measuring instruments according to their use.

Pedagogical Exemplars

1. **Talk for learning:** In mixed-ability groups, learners discuss and make presentations on the difference in measuring instruments according to their use, cost, precision, sensitivity and material of construction using flash cards, mind maps, concept maps, poster boards, power points etc. Provide specific instructions to the groups to guide the discussions and to prevent the possibility of only one learner doing all the talking. Encourage learners to simply and clearly articulate their points and listen to others during the discussions. Make room for non-vocal learners to contribute to the group discussions through writing. Encourage learners to help colleagues who have difficulties differentiating between the measuring instruments and challenge learners who are proficient to provide individual reports.
2. **Collaborative learning:** Using diagrams, detailed written instructions, videos and additional reading materials explain the use of measuring instruments at the workshop. Let learners in mixed-ability groups use scale rule, vernier calliper and micrometer screw gauge to measure the length of a metal piece, diameter of a cylindrical rod and the thickness of a thin metal sheet respectively at the workshop and observe/discuss the differences in the use of the measuring instruments for presentation. Assign specific roles to learners to ensure that all learners fully participate. Let learners decide on the mode of presentation such as written reports, oral presentation or video presentations and receive feedback. Encourage more proficient learners to find the differences between the measuring instruments in respect of their cost, sensitivity, precision, readability and setup time.

Key Assessment

Assessment Level 1

1. Which of the following is used to measure the diameter of a small metal rod with high precision?
 - a. Ruler
 - b. Vernier Calliper
 - c. Micrometer Screw Gauge
 - d. Protractor
2. A vernier calliper can measure both internal and external dimensions. (True/False)
3. What is the primary use of a micrometer screw gauge?

Assessment Level 2

1. Match the instrument to its primary function:

Vernier Calliper	Measures angles
Micrometer screw gauge	Measures small dimensions with high precision
Ruler	Measures internal and external dimensions
Protractor	Measures straight lengths

2. Explain one key difference between a vernier calliper and a micrometer screw gauge in terms of precision.
3. Label the main parts of a vernier calliper and a micrometer screw gauge on provided diagrams.

Assessment level 3

1. Describe a scenario in which you would choose a micrometer screw gauge over a vernier calliper for measurement.
2. Compare the measurement range of a standard vernier calliper and a micrometer screw gauge.
3. You are given a thin sheet of metal that needs to be measured with high precision. Which instrument would you choose, and why?

Assessment level 4

1. Analyse the advantages and disadvantages of using a vernier caliper compared to a micrometer screw gauge for measuring the thickness of a piece of plastic.
2. Discuss the importance of precision in manufacturing and how the choice of measuring instruments affects product quality.
3. You are to measure the internal diameter of a small pipe and the thickness of a thin wire. Describe the steps you would take to measure both accurately, specifying which instruments you would use and why.

Focal Area 2: Using measuring tools to measure work pieces

Introduction

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:

Ensuring Product Quality: Accurate measurement ensures that products meet specified dimensions and tolerances, leading to consistent quality. It prevents defects and ensures that each product adheres to the desired specifications, which is crucial for customer satisfaction and brand reputation. This helps in maintaining the integrity and performance of the final product.

Enhancing Efficiency: Accurate measurements reduce the need for rework and adjustments, thus saving time and resources. It streamlines the production process by minimising errors and ensuring that components fit together correctly the first time to ensure reduction in downtime and increased throughput.

Cost Reduction: Accurate measurements result in the reduction of material waste and the need for rework or scrap, contributing to cost savings. It also helps in avoiding costly recalls or returns by ensuring that products are produced correctly the first time.

Compliance with Standards: Accurate measurement is essential for compliance with industry standards and regulations. Meeting these standards is necessary for legal compliance and maintaining certifications, which can be crucial for business operations.

Ensuring Interchangeability: Accurate measurement ensures that parts produced by different manufacturers or at different times are interchangeable, which is vital for assembly lines and large-scale production. This interchangeability is crucial for maintaining consistency in production and for servicing and repairing products in the field.

Enhancing Customer Satisfaction: Accurate measurement results in high-quality products that meet specifications and perform reliably leading to greater customer satisfaction and loyalty. Accurate measurement ensures that the final product matches the customer's expectations, reducing complaints and enhancing the overall customer experience.

Construction, operation and reading the scales of the measuring instruments

Vernier Callipers

Construction

1. **Main Scale:** A long, straight ruler with marked measurements.
2. **Vernier Scale:** A small, movable scale that slides along the main scale.
3. **Fixed Jaw:** Attached to the main scale.
4. **Sliding Jaw:** Attached to the vernier scale.
5. **Depth Rod:** A thin rod that extends from the end of the calliper for measuring depths.
6. **Locking Screw:** Secures the sliding jaw in place.

Operation

1. **Zero Check:** Ensure the calliper reads zero when the jaws are closed.
2. **Measuring External Dimensions:** Place the object between the fixed and sliding jaws, and gently close the jaws on the object.
3. **Measuring Internal Dimensions:** Use the upper jaws and place them inside the object.
4. **Measuring Depth:** Extend the depth rod into the object.

Reading the Scales

1. **Main Scale Reading:** Note the value on the main scale just before the zero of the vernier scale. In the example shown in Fig. 15.1, this is 23.
2. **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, and in the example shown in Fig. 15.1, this is 6.

3. **Total Measurement:** Add the main scale reading and the vernier scale reading. In the example shown, this results in 23.6.

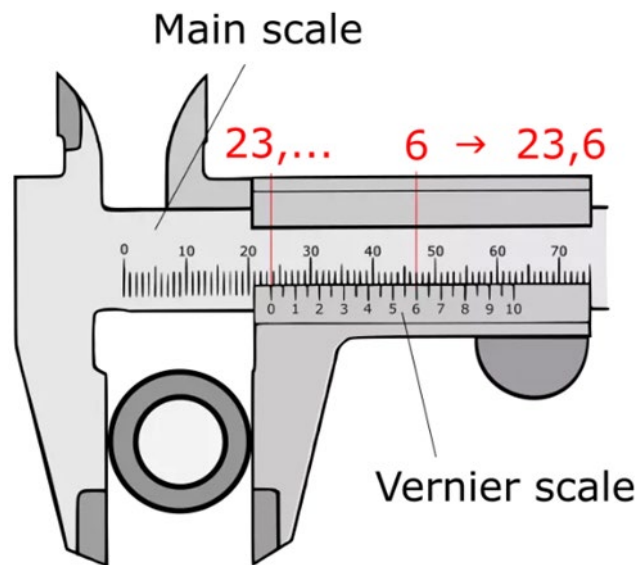


Figure. 15.1: Reading the scales of the vernier callipers (aci, 2024)

Micrometer Screw Gauge

Construction

1. **Frame:** Provides a sturdy base for the anvil and spindle.
2. **Anvil:** A fixed measuring face.
3. **Spindle:** A movable measuring face that moves towards or away from the anvil.
4. **Thimble:** A cylindrical component that rotates to move the spindle.
5. **Sleeve/Barrel:** Has a linear scale etched onto it.
6. **Ratchet Stop:** Ensures consistent measuring pressure.
7. **Lock Nut:** Secures the spindle in place.

Operation

1. **Zero Check:** Ensure the micrometer reads zero when the spindle is in contact with the anvil.
2. **Measuring Thickness/ Diameter:** Place the object between the anvil and spindle, and gently rotate the thimble until the spindle touches the object.
3. **Consistent Pressure:** Use the ratchet stop to apply consistent pressure.

Reading the Scales

1. **Sleeve Scale Reading:** Note the last visible graduation on the sleeve.
2. **Thimble Scale Reading:** Identify the line on the thimble that aligns with the sleeve's horizontal line.
3. **Total Measurement:** Add the sleeve scale reading and the thimble scale reading.

Height Gauge

Construction

1. **Base:** Provides stability and ensures the gauge is perpendicular to the surface.
2. **Beam/Column:** A vertical scale for measuring height.
3. **Scriber/Probe:** A pointed or flat tool that moves along the beam to mark the object or measure height.
4. **Vernier/ Digital Scale:** For precise readings.
5. **Locking Screw:** Secures the scriber/probe in place.

Operation

1. **Zero Check:** Ensure the height gauge reads zero when the scriber/probe is at the base level.
2. **Measuring Height:** Place the height gauge on a flat surface plate and move the scriber/probe to the top of the object.
3. **Locking:** Use the locking screw to hold the scriber/probe in place.

Reading the Scales

1. **Main Scale Reading:** Note the value on the main scale up to the zero of the vernier or digital scale.
2. **Vernier Scale Reading:** Identify the line on the vernier scale that aligns perfectly with a line on the main scale.
3. **Digital Reading:** Directly read the height measurement from the digital display if available.
4. **Total Measurement:** Combine the main scale reading and the vernier scale reading for the final measurement.

Learning Task

Learners measure the length of a metal piece, diameter of a cylindrical rod and the thickness of a thin metal sheet at the workshop using scale rule, vernier calliper and micrometre screw gauge respectively.

Pedagogical Exemplars

Experiential learning: Let learners in mixed-ability groups use scale rule, vernier calliper and micrometer screw gauge to measure the length of a metal piece, diameter of a cylindrical rod and the thickness of a thin metal sheet respectively at the workshop and take notice of the correct procedure for taking the measurements to ensure accuracy. Assign specific roles to learners to ensure that all learners fully participate. Let learners decide on the mode of presentation such as written reports, oral presentation or video presentations and receive feedback. Encourage more proficient learners to use height gauges to take measurements of work pieces.

Key Assessment

Assessment Level 1

- Which tool would you use to measure the thickness of a metal sheet?
 - Protractor
 - Vernier Calliper
 - Ruler
 - Micrometer Screw Gauge
- A ruler can measure both the length and the diameter of a cylindrical object. (True/False)

Assessment Level 2

- Match the tools in A with their primary function in B

A	B
Vernier Calliper	Measures angles
Micrometer Screw Gauge	Measures small, precise dimensions
Height Gauge	Measures internal and external dimensions and depths
Protractor	Measures the height of objects

- Explain why a micrometer screw gauge is more precise than a ruler.
- Describe the steps to measure the internal diameter of a pipe using a vernier caliper.

Assessment level 3

- Compare and contrast the uses of a vernier caliper and a height gauge.
- As a manufacturing engineer, you needed to measure the thickness of a piece of paper and a roofing sheet for comparison. What instrument would you use, and why?

Assessment Level 4

- Discuss the importance of using accurate measuring tools in quality control during manufacturing processes.
- Given a set of measurements (length, width, height) of a block, demonstrate how you would accurately measure and record these dimensions using the appropriate tools.
- Evaluate the impact of temperature changes on the accuracy of measurements taken with a vernier caliper and a micrometer screw gauge. How would you mitigate these effects?
- A manufacturer reports inconsistencies in their product dimensions. Propose a systematic approach to identify and resolve measurement inaccuracies using appropriate measuring tools.
- You are tasked with ensuring that all parts of a mechanical assembly fit together perfectly. Describe the process you would follow, including the tools you would use, to measure and verify each component's dimensions.

HINT



The recommended mode of assessment for week 15 is **essay**. Use the level 3 question 2 as a sample question.

WEEK 16

Learning Indicators

1. Differentiate between manual-hand tools (e.g. hacksaw, cold chisels, screw drivers, taps, dies, engineer's hammer, etc.) and power-hand tools (e.g. grinding, drilling, screw, etc.) in manufacturing
2. Apply hand tools to manufacturing engineering

Focal Area 1: Difference between manual hand tools and power hand tools

Introduction

Hand tools are manually operated, or power operated instruments used to perform various tasks such as cutting, shaping, fastening, and measuring. Unlike power tools, hand tools do not require an external power source to operate. Common examples include hammers, screwdrivers, wrenches, pliers, chisels, and saws.

Manual hand-tools

Manual hand tools are operated solely by hand without the assistance of external power sources. These tools rely on human effort and physical manipulation to perform tasks. They are typically simpler in design and construction compared with power tools. Manual hand tools include a wide variety of implements, such as hammers, wrenches, screwdrivers, pliers, chisels, and hand saws. They are essential for tasks requiring precision and control, such as woodworking, crafting, small repairs, and assembly work. Despite the growing prevalence of power tools, manual hand tools remain indispensable for their reliability, ease of use, and ability to perform delicate and detailed work without the need for electricity or batteries.

Characteristics of manual hand tools

1. **Simplicity:** Manual hand tools have a simple design with few moving parts.
2. **Portability:** They are generally lightweight and easy to transport.
3. **Durability:** Often made from robust materials like steel, manual hand tools are built to withstand frequent use.
4. **Versatility:** Suitable for a wide range of tasks, from precision work to heavy-duty applications.
5. **Control:** Provide a high degree of control, allowing for precise and detailed work.

Advantages of manual hand tools

1. **No Power Requirement:** Can be used anywhere without the need for electricity or batteries.
2. **Cost-Effective:** Typically, less expensive than their powered counterparts.
3. **Ease of Use:** Simple to operate and often require minimal training.

4. **Low Maintenance:** Require less maintenance compared to power tools, with no need for battery replacements or electrical repairs.
5. **Safety:** Generally safer to use, as they operate at a lower speed and force, reducing the risk of accidents.

Limitations of manual hand tools

1. **Physical Effort:** Relying on human strength can be tiring and less efficient for large or repetitive tasks.
2. **Time-Consuming:** Slower than power tools, which can affect productivity on large projects.
3. **Limited Power:** May not be suitable for very tough materials or heavy-duty applications where more power is needed.

Examples of manual hand tools

Examples of manual hand tools include cutting tools such as handsaws and utility knives, gripping and holding tools such as pliers and wrenches striking tools such as hammers and mallets, measuring and layout tools such as tape measures and squares, fastening tools such as screwdrivers clamping and holding tools such as clamps and vices.

Power hand-tools

Power hand tools are electrically or pneumatically powered and require an external power source to operate. They are designed to enhance efficiency and productivity by automating tasks that would otherwise require significant manual effort. Power hand tools can range from compact handheld devices to larger, stationary machines. Examples include drills, saws, grinders, sanders, and nail guns. While power tools can significantly boost productivity and efficiency, they require proper handling and safety precautions due to their increased power and speed compared with manual tools.

Characteristics of power hand tools

1. **Power Source:** Operate using electricity (corded or battery-powered) or compressed air (pneumatic).
2. **Speed and Efficiency:** Perform tasks much faster than manual tools due to their powered operation.
3. **Versatility:** Available in various types for different applications, including cutting, drilling, grinding, and sanding.
4. **Complexity:** Generally, more complex in design with multiple moving parts and electronic components.
5. **Portability:** While some are portable, others may be heavier and less convenient to transport compared to manual tools.

Advantages of power hand tools

1. **Increased Productivity:** Significantly speeds up tasks, making them ideal for large projects and repetitive tasks.
2. **Reduced Physical Effort:** Minimises the physical strain on the user, allowing for longer periods of work without fatigue.

3. **Precision and Consistency:** Provides more consistent results and can achieve higher precision in tasks like cutting, drilling, and sanding.
4. **Enhanced Capabilities:** Can handle tougher materials and more demanding tasks that would be difficult or impossible with manual tools.

Limitations of power hand tools

1. **Dependence on Power Source:** Requires a constant power supply, which can be a limitation in remote or outdoor locations without electricity.
2. **Cost:** Generally, more expensive than manual tools, both in initial purchase price and maintenance costs.
3. **Maintenance:** Requires regular maintenance, including battery replacements for cordless tools and servicing of motors or compressors.
4. **Safety Risks:** Higher risk of accidents and injuries due to the power and speed at which they operate, requiring strict adherence to safety guidelines.

Examples of power hand tools

Examples of power hand tools include cutting tools such as circular saws and jigsaws, drilling and fastening tools such as power drills and impact drills, grinding and polishing tools such as angle grinders and rotary tools, sanding tools such as random orbit sanders and belt sanders, routing and milling tools such as routers and electric planers, sawing tools such as reciprocating saws and mitre saws, and cutting and welding tools such as plasma cutters and welding machines.

Safety and maintenance of hand tools

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 manufacturer 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 after each use to remove dust, dirt, and moisture.
2. Use appropriate cleaning agents and lubricants to prevent rust and corrosion.
3. Sharpen cutting tools regularly to maintain their 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 manufacturer 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 16.1.

Table 16.1 Differences between manual hand tools and power hand tools

Criteria	Manual Hand Tools	Power Hand Tools
Precision and Control	Ideal for tasks requiring precise, fine control	Efficient for rapid completion of tasks, less control for precision
Portability and Accessibility	Portable, accessible in remote areas without power sources	Require power source, less portable, more suitable for fixed sites
Safety and Ease of Use	Safer, easier for beginners, less risk of accidents	Higher risk due to power requires proper training and precautions
Efficiency and Speed	Slower, suitable for detailed work	Faster, ideal for large-scale projects and heavy-duty tasks
Heavy-Duty tasks	Limited for tough materials or high-volume work	Excellent for tough materials, high-volume tasks
Versatility and Capability	Versatile across various industries	Versatile, suitable for diverse applications

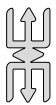
Learning Tasks

1. Learners discuss and make presentations on the differences between manual hand tools and power hand tools according to their precision, control, safety, use, portability, accessibility, efficiency and speed of operations.

2. Learners in mixed-ability groups use manual hand drills and power hand drills to perform drilling operations at the workshop. Learners write a report to discuss the differences between the manual hand drills and the power hand drills.

Pedagogical Exemplars

1. **Talk for learning:** In mixed-ability groups, learners discuss and make presentations on the difference in manual hand tools and power hand tools according to their precision, control, safety, use, portability, accessibility, efficiency and speed of operations. Let learners use the presentation format they are comfortable with such as flash cards, mind maps, concept maps, poster boards, power points, video presentations etc. Provide specific instructions to the groups to guide the discussions and to prevent the possibility of only one learner doing all the talking. Encourage learners to simply and clearly articulate their points and listen to others during the discussions. Make room for non-vocal learners to contribute to the group discussions through writing. Encourage learners to help colleagues who have difficulties differentiating between manual hand tools and power hand tools. Challenge proficient learners to provide individual reports.
2. **Experiential learning:** In mixed-ability groups, have learners use the manual hand drill and power hand drills to perform drilling operations at the workshop and compare the difference in the two hand tools according to their ease of use, precision, control, safety, portability, accessibility, efficiency and speed of operations. Let learners write a report and present their results to the class for feedback. Encourage groups to accept and tolerate feedback given by peers.



Note

Teacher should ensure health and safety protocols are adhered to before, during and after the work

Key Assessment

Assessment Level 1

1. Which of the following is a power hand tool?
 - a) Hammer
 - b) Screwdriver
 - c) Electric Drill
 - d) Wrench
2. Manual hand tools do not require an external power source to operate. (True/False)

Assessment Level 2

1. Name two advantages of using power hand tools over manual hand tools.
2. Explain the main difference between a manual screwdriver and an electric screwdriver.
3. Label the parts of an electric drill and a manual hammer in provided diagrams.

Assessment level 3

1. Compare and contrast the uses of a manual saw and a power saw. Provide at least two differences.

2. In what situation would you prefer to use a manual hand tool over a power hand tool? Explain your reasoning.
3. You are given a task to assemble a piece of furniture. List the manual and power hand tools you would use and explain why you would choose each tool.

Assessment level 4

1. Analyse the safety considerations one must consider when using power hand tools compared to manual hand tools.
2. Discuss the impact of technological advancements on the development of power hand tools and how they have changed the construction industry.
3. Evaluate the environmental impact of using manual hand tools versus power hand tools. Consider factors such as energy consumption, materials used, and long-term sustainability.

Focal Area 2: Application of hand tools in manufacturing

Importance of hand tools in various industries

Hand tools play a crucial role in numerous industries with specific applications that enhance productivity, precision, and safety. The use of hand tools in some industries are explained below:

1. Construction Industry

- a. **Manual Hand Tools:** Essential tools like hammers, screwdrivers, wrenches, and pliers are used for tasks such as framing, wiring, plumbing, and assembling structures. These tools allow for precise control and adjustments.
- b. **Power Hand Tools:** Drills, saws, sanders, and nail guns increase efficiency and reduce labour time, enabling workers to handle tough materials and large-scale projects with ease.

2. Automotive Industry

- a. **Manual Hand Tools:** Wrenches, socket sets, screwdrivers, and pliers are indispensable for tasks such as engine repairs, part replacements, and routine maintenance. These tools provide the accuracy needed for working with intricate components.
- b. **Power Hand Tools:** Impact wrenches, electric ratchets, and drills enhance the speed and efficiency of mechanical repairs and maintenance, allowing for quick removal and installation of parts.

3. Manufacturing Industry

- a. **Manual Hand Tools:** Calipers, micrometers, and gauges are used for precision measurement and quality control. These tools ensure that components meet exact specifications and tolerances.
- b. **Power Hand Tools:** Grinders, drills, and torque wrenches are used in assembly lines and fabrication processes, increasing production rates and ensuring consistent quality.

4. Woodworking Industry

- a. **Manual Hand Tools:** Saws, chisels, hand planes, and carving tools allow craftsmen to create detailed and precise cuts, shapes, and finishes. These tools are essential for fine woodworking and cabinetry.
- b. **Power Hand Tools:** Electric saws, routers, sanders, and drills expedite the cutting, shaping, and finishing processes, enabling woodworkers to handle larger projects and complex designs efficiently.

5. Electrical Industry

- a. **Manual Hand Tools:** Wire strippers, pliers, screwdrivers, and multimeters are used for installing and repairing electrical systems. These tools provide the precision and safety required for working with electrical components.
- b. **Power Hand Tools:** Cordless drills, impact drivers, and power screwdrivers speed up the installation of fixtures, wiring, and electrical panels.

6. Plumbing Industry

- a. **Manual Hand Tools:** Pipe wrenches, pliers, tube cutters, and plungers are vital for installing and repairing plumbing systems. These tools enable plumbers to work in tight spaces and perform detailed tasks.
- b. **Power Hand Tools:** Electric pipe cutters, power augers, and cordless drills facilitate the cutting, fitting, and clearing of pipes, improving job efficiency and reducing manual labour.

7. HVAC Industry

- a. **Manual Hand Tools:** Wrenches, screwdrivers, pipe cutters, and tubing benders are used for installing and servicing heating, ventilation, and air conditioning systems. These tools ensure precise fitting and connections.
- b. **Power Hand Tools:** Power saws, drills, and refrigerant recovery machines enhance the installation and maintenance of HVAC systems, allowing technicians to handle complex tasks with ease.

8. Aerospace Industry

- a. **Manual Hand Tools:** Torque wrenches, callipers, and specialised fasteners are used for assembling and maintaining aircraft components. These tools provide the precision necessary for high-stakes applications.
- b. **Power Hand Tools:** Pneumatic drills, rivet guns, and grinders are used in the assembly and repair of aircraft, increasing efficiency and ensuring the structural integrity of the components.

9. Medical Industry

- a. **Manual Hand Tools:** Surgical instruments, forceps, and precision tools are used in medical procedures and equipment manufacturing. These tools require the highest levels of precision and cleanliness.
- b. **Power Hand Tools:** Battery-operated surgical drills and saws are used in orthopaedic and other surgeries, providing control and accuracy while reducing operation time.

10. Home Improvement

- a. **Manual Hand Tools:** Hammers, screwdrivers, pliers, and saws are essential for various home repairs and improvement projects. These tools enable homeowners to perform a wide range of tasks independently.
- b. **Power Hand Tools:** Cordless drills, power saws, and sanders make DIY projects faster and easier, allowing for 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:

1. **Hammer:** Used for driving nails into wood or other materials. The claw end is used for pulling out nails. It is also used in metalworking to shape or forge metal pieces.
2. **Screwdriver:** Used to insert and tighten screws into various materials. It is also used for loosening and removing screws.
3. **Wrench:** Used to turn bolts, nuts, and other fasteners.
4. **Pliers:** It is used to grip, hold, and manipulate objects. Some pliers have built-in cutters for cutting wires. Pliers are useful for bending and shaping metal wires and components.
5. **Handsaw:** It is used to make straight cuts in wood and other materials. It is sometimes used for cutting branches and pruning trees.
6. **Chisel:** It is used for carving and shaping wood. It can be used to remove small pieces of wood or other materials to create detailed designs.
7. **File:** It is used to smooth rough edges and surfaces of metal, wood, and plastic. It can be used to shape and fine-tune the dimensions of various materials.
8. **Clamp:** It is used to hold workpieces securely in place during cutting, gluing, or assembly. It provides even pressure during the drying or setting of glue.
9. **Hand Plane:** It is used to smooth and flatten wood surfaces.
10. **Hand Drill:** Used to manually drill holes in wood, plastic, and light metals.
11. **Mallet:** It is used to strike chisels and other tools without damaging them. It also helps 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

1. **Electric Drill:** It is used to drill holes in wood, metal, plastic, and other materials. With appropriate bits, it can drive screws into various materials.
2. **Circular Saw:** Ideal for making straight cuts in wooden materials. It can also cut metal sheets and plastics given the right blade.
3. **Angle Grinder:** It is used to grind metal surfaces and remove rust or paint. It can also cut through metal, stone, and concrete with the appropriate disc.
4. **Jigsaw:** It is perfect for making intricate and curved cuts in wood, metal, and plastic.

5. **Power Sander:** It is used to sand down surfaces to smoothen them before painting or finishing. It efficiently removes paint, varnish, or rust from surfaces.
6. **Impact Driver:** It delivers high torque for driving screws and bolts into tough materials. It is effective in removing screws that are difficult to loosen.
7. **Nail Gun:** It drives nails into wood and other materials quickly and efficiently.
8. **Power Planer:** It is used to remove thin layers of wood to create a smooth surface.

Comparative applications

Table 15.2 compares the advantages and applications of selected power hand tools and manual hand tools as used in manufacturing.

Table 15.2: 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, good for precision work	Nail Gun	Driving nails rapidly using compressed air/ electricity	Fast, consistent, reduces physical effort
Screwdriver	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
Handsaw	Manually 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, light metals	No power needed, simple, portable	Electric Drill	Quickly drilling holes using a motor	Fast, can handle tougher materials, multiple speed settings
Pliers	Gripping, bending, cutting wires, and small components	Simple, precise, versatile	Power Pliers	Quickly crimping electrical connectors/ terminals	Fast, consistent, reduces physical effort
Hand Plane	Manually 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
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

Learning Tasks

Learners make a product at the workshop using manual hand tools and power hand tools.

Pedagogical Exemplars

Project-based learning: In mixed-ability groups learners make a simple wooden box at the workshop using only manual hand tools. Learners again use only power hand tools to make a similar wooden box and discuss the differences in the processes of making the wooden box using the manual and power hand tools. Let learners present their findings to the class using any suitable method for feedback. Assign specific roles to learners to ensure that all learners participate in the project and are challenged according to their understanding and skills on the use of hand tools. Also, develop a peer mentoring system in the mixed-ability groups to encourage more advanced learners to support their colleagues in using the hand tools during the project. Challenge more proficient learners to individually use the hand tools in making a similar product.

Key Assessment

Assessment Level 1

1. Define a manual hand tool and state two examples.
2. State two advantages of using power hand tools.

Assessment Level 2

1. Explain the main difference between a manual screwdriver and an electric screwdriver.

Assessment level 3

1. Describe a situation where using a hand saw would be more appropriate than using a circular saw.
2. Compare the efficiency of using a manual hand drill versus an electric drill in a manufacturing process.

Assessment Level 4

1. Evaluate the impact of using power tools on productivity and worker fatigue in a manufacturing setting.
2. Discuss two potential drawbacks of relying solely on power tools in manufacturing.
3. Propose a maintenance schedule for a set of commonly used power tools in a manufacturing workshop.

Assess the environmental impact of using power tools versus manual tools in manufacturing.

HINT



The recommended mode of assessment for week 16 is **homework**. Use the level 4 question 4 as a sample question.

Section 5 Review

The section discussed the differences between various measuring instruments and the correct use of these tools to measure work pieces, as well as the distinctions between manual hand tools and power hand tools, along with their applications in manufacturing. Using various pedagogies designed to ensure differentiation, learners will be equipped with understanding the differences and proper use of measuring instruments and manual and power hand tools. They will also experience hands-on skills essential for future manufacturing tasks.

Rubric for the Essay Assessment

Evaluating Instrument Selection for Measuring Thickness of Paper and Roofing Sheet

Criteria	Excellent (5)	Very Good (4)	Good (3)	Fair (2)
Instrument Choice for Paper	Micrometer is selected, demonstrating full understanding of the required precision (0.01mm) for measuring the thin, flexible paper.	Vernier Caliper or Digital Caliper is chosen, demonstrating understanding of precision needed for paper (within 0.1mm) but less accurate than a micrometer.	Caliper or Ruler selected, but they lack the precision required for paper, and may result in measurement errors.	Instrument selected (e.g., ruler, micrometer for thick materials) is inappropriate for the precise measurement of paper thickness.
Instrument Choice for Roofing Sheet	Vernier Caliper, Digital Caliper, or Ultrasonic Thickness Gauge is chosen, based on material properties and required precision (0.1mm or better).	Vernier Caliper or Digital Caliper is selected, suitable for most roofing sheet thicknesses, but may not be ideal for extreme thickness variations (e.g., very thick sheets).	Thickness gauge or caliper selected, but it might struggle with more robust or thicker roofing materials, lacking the precision for accurate measurements.	Instrument selected (e.g., paper micrometer or inappropriate gauge) is unsuitable for measuring roofing sheet thickness.
Precision and Accuracy Consideration	Demonstrates excellent understanding of precision (e.g., micrometer for paper at 0.01mm, Vernier caliper or digital caliper for roofing sheet at 0.1mm), ensuring highly accurate measurements.	Instrument choice shows good understanding of the need for precision, but may not fully meet the required precision levels for both materials (e.g., 0.05mm precision for paper, 0.2mm for roofing sheet).	Instrument choice demonstrates limited understanding of the required precision, failing to meet 0.01mm precision for paper and 0.1mm for roofing sheet, leading to potential errors.	Instrument does not align with the required precision for either material, causing potential measurement inaccuracies (e.g., greater than 0.5mm error).
Suitability of Instrument for Material	Instrument is perfectly suited for the material properties: micrometer for paper's flexibility and calipers or ultrasonic gauge for the rigidity of roofing sheets.	Instrument is suitable but may not be optimal for all material types (e.g., good for typical paper and roofing sheet, but struggles with extreme variations).	Instrument is somewhat suitable for material, but there could be handling issues with paper or roofing sheet, leading to minor measurement inaccuracies.	Instrument is unsuitable for the material type (e.g., using a micrometer designed for thicker materials on paper, or improper gauges for roofing sheet).

SECTION 6: CASTING AND JOINING PROCESSES

STRAND: MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES

Sub-Strand: Manufacturing processes

Learning Outcome: Explain casting and welding processes used in manufacturing engineering products

Content Standards

1. Demonstrate understanding of Casting
2. Demonstrate understanding of joining Processes

HINT



- Remind learners of **Mid semester examination** in Week 18.
- Refer to the Appendix F for more sample task and the Table of Specification

Introduction and Section Summary

In this section, learners will be introduced to the importance of casting in manufacturing engineering products. They will understand the processes involved in sand casting and its relevance in manufacturing. Learners will also understand the concepts of non-permanent and permanent joining processes. Learners will be introduced to the process of assembling components using screw, bolt and nut and welding processes. The section covers the following weeks:

Week 17: Importance of casting in manufacturing engineering products

Week 18: Sand casting process

Week 19: Non-permanent and permanent joining processes

Week 20: Join components using screw, bolt and nut and welding processes

Summary of Pedagogical Exemplars

Given the diversity in learners' backgrounds, learning capacities, and learning styles, it is vital to employ a broad spectrum of pedagogical approaches that cater for students' varied abilities within the classroom. Pedagogical alternatives to explore include employing strategies such as experiential learning, collaborative learning and talk for learning. In this section, consider providing learners the opportunity to visit a foundry to understand the casting processes, and to familiarise themselves with the technologies used in casting. Also, let learners discuss the importance of casting in the manufacturing of engineering products. Allow learners to articulate their experiences through collaborative discourse to identify the permanent and non-permanent joints, explain their working principles, advantages, and limitations and explain the criteria for

selecting non-permanent joining processes. Finally, in mixed-ability groupings, learners should be given the opportunity to learn and practice different permanent and non-permanent joining processes and their applications at the workshop.

Assessment summary

A range of assessment methods should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions following a visit to a manufacturing company; written responses of various levels of difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Learners should be able to explain casting, the sand casting process, the importance of casting in manufacturing of engineering product, identify and describe permanent and non-permanent joints. These should contribute to learners' formative assessment.

WEEK 17

Learning Indicator: Outline the importance of casting in manufacturing of engineering products

Focal area: Importance of casting in manufacturing engineering products

Introduction of the casting process

Casting is a manufacturing process in which a liquid material is usually poured into a mould, which contains a hollow cavity of the desired shape, and then allowed to solidify. The solidified part is also known as a casting, which is ejected or broken out of the mould to complete the process. The term **casting** also applies to the part made in the process. Casting processes in manufacturing engineering are diverse and integral to producing a wide range of metal components. There are two main types of casting processes, and they are expendable mould processes and permanent mould processes. The choice of casting process depends on the material, desired properties, production volume, cost considerations and application of the final product. Knowledge of the casting process is helpful in the manufacture of many parts. Figure 17.1 shows molten metal being poured into a mould.



Figure 17.1: Casting process

Applications of casting

Casting is a versatile manufacturing process with various applications across various industries. Table 17.2 presents some of the key applications of casting.

Table 17.2: 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
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

1. **Complex Shapes:** Casting can manufacture workpieces with complex shapes, especially complicated internal cavities. It allows for producing intricate components with internal cavities and thin walls.
2. **Versatility:** Casting is versatile in design and can be used to create any intricate shape, either internal or external.
3. **Material Efficiency:** The casting process can utilise low-cost iron and steel scrap, milling debris, etc.
4. **Cost-Effective:** Casting equipment is relatively low-cost compared with other manufacturing processes. It is generally inexpensive.
5. **Material Variety:** It is practically possible to cast any material.
6. **Accuracy and Consistency:** Casting can produce parts with high accuracy and consistency.
7. **Surface Finish:** Casting can provide a good surface finish.
8. **Strength:** Castings are generally strong.
9. **Large Parts:** The size and weight are almost unrestricted with metal casting workpieces.
10. **Reduced Machining:** The shape and size of the castings are very close to the workpiece, reducing the amount of further machining work and saving metal materials.

Disadvantages of casting

1. **Dimensional Accuracy:** Due to shrinkage in the casting, the dimensional accuracy might be at risk. The casting workpieces are more prone to take with casting defects.
2. **Surface Finish:** Casting often gives a poor surface finish and requires additional surface finish operations. It requires secondary machining operations to improve the surface finish.
3. **Strength:** The intrinsic quality of castings is weaker, and the load-bearing capacity is less than that of forgings. Castings have lower fatigue strength compared with forging.
4. **Porosity:** Castings can have high porosity compared to a machined part, which can affect their strength.

5. **Production Environment:** The casting process involves a challenging production environment with high temperature, dust, emission of poisonous gases and high labour intensity.
6. **Not Suitable for Low-Volume Production:** Casting is not economical for low-volume production.
7. **Safety Hazards:** There are safety hazards to humans when processing hot molten metals (splash of molten metals, inhalation of poisonous gases, etc.).

Learning Tasks

1. Learners embark on a tour to a foundry nearby to observe the casting of engineering products after which they write a report on their observations. If a physical tour isn't possible, learners can watch videos and interactive simulations to show the casting process and afterwards write a report on what they learned.
2. Learners discuss the importance of casting in the manufacturing of engineering products and use mind maps to summarise what they learned.
3. Learners present their observations at the foundry, emphasising the types of moulds used for casting, melting of the metal to be used for the casting, pouring of the molten metal into the mould, and freezing the molten metal in the mould.

Pedagogical Exemplars

1. **Experiential learning:** Take learners on a tour to a foundry nearby to observe the casting of engineering products and share their observations with the class. Provide background materials (articles, videos) on casting processes to ensure all learners have a basic understanding before the tour. Create an observation checklist to guide learners on what to look for during the tour or video. This can include specific questions about the types of moulds, the melting process, and safety measures. Also, offer different formats for the report, such as written reports, video diaries, or digital presentations, to cater to different learning preferences. Organise a peer review session where learners exchange their reports and provide feedback to each other.
2. **Talk for learning:** Lead learners to discuss the importance of casting in the manufacturing of engineering products. Let them add to what others say and summarise using mind maps. Use a fishbowl discussion format where a small group discusses while others observe, then rotate roles. This ensures all voices are heard. Provide mind map templates or digital tools (like Microsoft Visio, Mind Meister or Lucid chart) to help learners organise their thoughts visually. Assign roles (e.g., facilitator, note-taker, summariser) to different learners to ensure active participation. Prepare a set of scaffolded questions to guide the discussion, starting with basic concepts and moving to more complex ideas.
3. **Collaborative learning:** Learners in mixed-ability groups make presentations on their observations at the foundry, making emphasis on the types of moulds used for casting, melting of the metal to be used for the casting, pouring of the molten metal into the mould, and freezing of the molten metal in the mould. Assign specific roles within each group (e.g., researcher, presenter, designer) to leverage individual strengths and ensure balanced participation. Allow groups to choose their presentation format (e.g., PowerPoint, poster, video) to cater for different learning styles. After presentations, organise feedback sessions where peers and the teacher provide constructive feedback. Use rubrics to guide the feedback process.

Key Assessment

Assessment Level 1

1. What is the primary purpose of casting in manufacturing?
 - a) To shape metals into desired forms
 - b) To melt metals
 - c) To cool metals
 - d) To paint metals
2. _____ involves pouring molten metal into a mould to create a specific shape.
3. Which of the following is NOT a step in the casting process?
 - a) Melting the metal
 - b) Pouring the molten metal into a mould
 - c) Painting the metal
 - d) Freezing the molten metal in the mould

Assessment Level 2

1. Which of the following statements correctly identifies an advantage of casting compared to other manufacturing processes?
 - a) Casting allows for the production of parts with high dimensional accuracy without the need for machining.
 - b) Casting is ideal for producing parts with complex geometries and intricate details.
 - c) Casting is the most cost-effective method for producing small quantities of parts.
 - d) Casting produces parts with superior surface finish compared to forging and machining.
2. Which of the following points would be most important to include in a presentation on the importance of casting in the manufacturing industry?
 - a) The history of casting and its development over centuries.
 - b) The role of casting in producing large quantities of identical parts.
 - c) The environmental impact of casting compared to other processes.
 - d) Real-world examples of products made using casting and their benefits.

Assessment Level 3

1. Evaluate the suitability of casting for producing a batch of automotive engine components that require complex geometries and high dimensional accuracy. Discuss the advantages and disadvantages of using casting for this application compared to other manufacturing processes such as machining or forging, and justify your recommendation.
2. 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.

WEEK 18

Learning Indicator: Explain the sand-casting process in manufacturing

Focal area: Sand casting process

Introduction

The sand-casting process is a traditional and widely used method for creating metal parts and structures, characterised by its cost-effectiveness and versatility. This process involves several key steps and components, each contributing to the final quality of the cast product. At its core, sand casting involves creating a mould from sand and pouring molten metal to form the desired part. The process begins with preparing the sand mould, typically made from a mixture of sand, clay, and water, known as green sand. The quality of the green sand is crucial, as it affects the mould's strength and the final casting's surface finish and dimensional accuracy. The mould is formed by packing the sand around a pattern, a replica of the final product. This pattern is removed, leaving a cavity in the sand that mirrors the shape of the part to be cast. The mould may also include cores, which create internal cavities in the casting.

Fundamentals of sand-casting technology

Sand casting is a fundamental manufacturing process used for thousands of years. Sand casting is the most widely used casting process, accounting for most of the total tonnage cast. Nearly all casting alloys can be sand cast. Sand casting is one of the few processes that can be used for metals with high melting temperatures, such as steels, nickels, and titanium. Figure 18.1 shows a flow chart of the casting process. Here are the key steps and principles involved in sand casting technology:

1. **Creating the Pattern:** The process begins with a pattern, a replica of the external shape of the casting. It's made of a stable material and is oversized to accommodate shrinkage. The pattern also includes the metal pathways that will feed the desired cast product design with appropriate gating and risers.
2. **Mould Making:** A mould is made by packing sand around the pattern. The mould is then separated into two halves, and the pattern is removed. The two halves of the mould are then reassembled.
3. **Pouring:** The liquid metal is poured into the mould. The mould must be strong enough to hold the weight of the molten metal during casting and resistant to reaction with the metal.
4. **Cooling and Solidification:** After the metal has cooled and solidified, the mould is broken open, and the part is removed.
5. **Finishing:** The casting often requires additional surface finish operations.

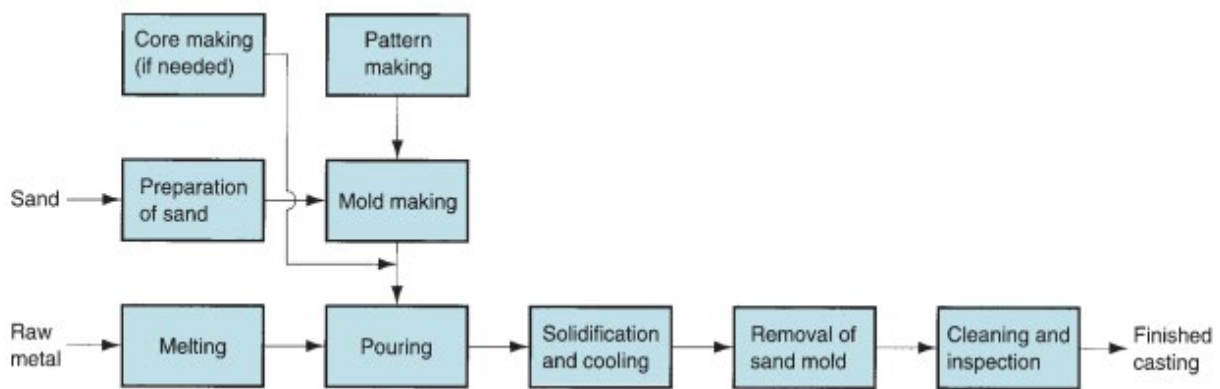


Figure 18.1: Sand casting process

Patterns

A pattern is a full-sized model of the part, enlarged to account for shrinkage and machining allowances in the final casting. Materials used to make patterns include wood, plastics, and metals. Wood is a common pattern material because it is easily shaped. Metal patterns are more expensive to make, but they last much longer. Plastics represent a compromise between wood and metal. Selection of the appropriate pattern material depends on the total quantity of castings to be made. Patterns may be classified into solid, split, match-plate, and cope-and-drag patterns. Solid pattern is the easiest to fabricate. It has the same geometry as the casting, adjusted in size for shrinkage and machining. Solid patterns are not easy to use in making the sand mould. Solid patterns are generally limited to very low production quantities. Figure 18.2 shows a typical pattern arranged for the sand casting process.

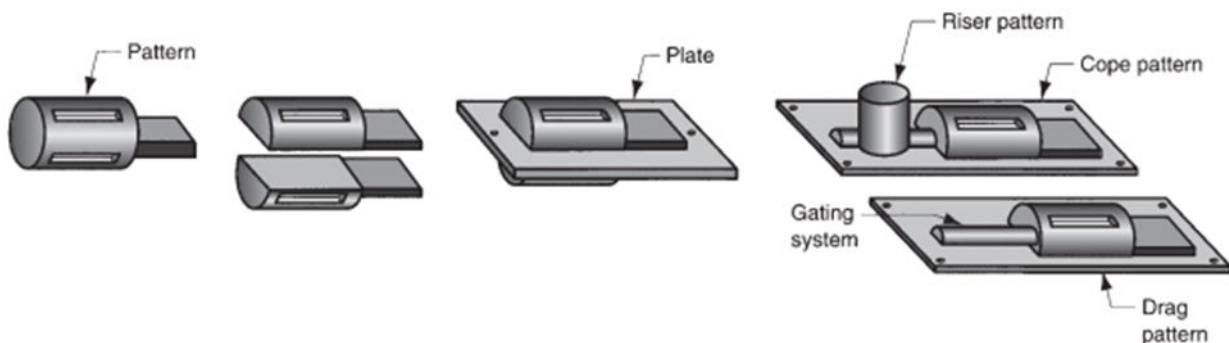


Figure 18.2: Pattern arranged for sand casting process

Cores

A core is a full-scale model of the interior surfaces of the part, which is inserted into the mould cavity prior to pouring so that the molten metal will flow and solidify between the mould cavity and the core to form the casting's external and internal surfaces. The core is usually made of sand and compacted into the desired shape. The actual size of the core must include allowances for shrinkage and machining. Supports, called chaplets, hold the part in the mould cavity during pouring. Figure 18.3 shows an image of a typical sand cast mould with a core.

The mould

Mould consists of two halves:

1. **Cope:** the upper half of mould and
2. **Drag:** the bottom half

The mould halves are contained in a box, called a flask. The two halves separate at the parting line. A mould cavity is formed by packing sand around a pattern, which has the shape of the part. When the pattern is removed, the packed sand's remaining cavity has the cast part's desired shape. The pattern is usually oversized to allow for metal shrinkage during solidification and cooling. Sand for the mould is moist and contains a binder to maintain its shape.

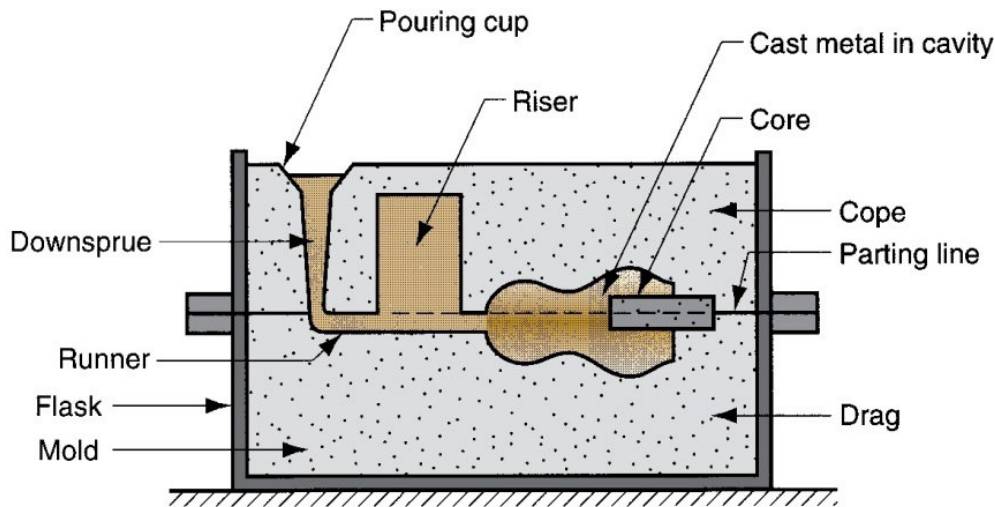


Figure 18.3: Sand casting mould showing the various mould parts

Using a Core in the mould cavity

The mould cavity provides the external surfaces of the cast part. In addition, a casting may have internal surfaces, determined by a core, placed inside the mould cavity to define the interior geometry of part. In sand casting, cores are generally made of sand. An image of the core can be seen in Figure 18.3.

Gating system

It is the channel through which molten metal flows into the cavity from the outside of mould. It consists of a down sprue, through which metal enters a **runner** leading to the main cavity. At the top of the down sprue, a **pouring cup** is often used to minimise splash and turbulence as the metal flows into the down sprue. Figure 18.3 shows an image of a typical sand mould which also displays the gating system.

Riser System

The riser is a reservoir in the mould, which is a liquid metal source to compensate for the shrinkage of the part during solidification. The riser must be designed to freeze after the main casting to satisfy its function. Figure 18.3 shows an image of a typical sand mould displaying the riser. A riser is used in a sand-casting mould to feed liquid metal to the casting during freezing to compensate for solidification shrinkage. To function, the riser must remain molten until after the casting solidifies. The riser also represents waste metal that will be separated from the cast part and re-melted to make subsequent castings. It is desirable for the volume of metal in the riser to be a minimum. The geometry of the riser is normally selected to maximise the Volume (V) / Area (A) ratio, this tends to reduce the riser volume as much as possible.

Sand casting process

Detailed steps in the sand-casting process

1. **Creating the Pattern:** The process begins with a pattern, which is a replica of the external shape of the casting. It's made of a stable material and is oversized to accommodate shrinkage. The pattern also includes the metal pathways that will feed the desired cast product design with appropriate gating and risers. Sand cores form internal features like holes. Care should be taken in pattern making, considering pattern material, geometry, withdrawal method, distortion, and shrinkage.
2. **Mould Making:** The purpose of this step is to create a mould using various types of sand, additives, binders, and water. The mould structure includes the cope, drag, flask, and gating system. Methods for mould preparation can be manual (hand moulding) or automated (machine moulding). There are three main types of sand moulds. These sand moulds are green-sand mould (a mixture of sand, clay and water. "Green" means mould contains moisture at the time of pouring), dry-sand mould (organic binders rather than clay. This mould is baked to improve strength) and skin-dried mould (drying mould cavity surface of a green-sand mould to a depth of 10 to 25 mm, using torches or heating lamps). The sand preparation for making the sand cast mould depends on the type of sand cast mould selected and the type of part to be cast. Sand is held together by a mixture of water and bonding clay. A typical mix of the sand for casting is 90% sand, 3% water and 7% clay. Other bonding agents also used in sand moulds are organic resins (e.g., phenolic resins) and inorganic binders (e.g., sodium silicate and phosphate). Additives are sometimes combined with the mixture to increase strength and/or permeability. A mould is made by packing sand around the pattern. The mould is then separated into two halves, and the pattern is removed. The two halves of the mould are then reassembled.
3. **Pouring:** The liquid (molten) metal is poured into the mould. The mould must be strong enough to hold the weight of the molten metal during casting and resistant to reaction with the metal. During pouring, the buoyancy of the molten metal tends to displace the core, which can cause the casting to be defective. Hence, care should be taken to control the pouring rate to prevent the core's displacement. For the pouring step to be successful, a metal must flow into all regions of the mould, most importantly the main cavity, before solidifying. The pouring temperature, pouring rate, and turbulence govern the successful pouring of molten metal.
4. **Cooling and Solidification:** After the metal has cooled and solidified (solidification is the transformation of molten metal back into a solid state), the mould is broken open, and the part is removed. The solidification processes may differ depending on whether the metal is a pure element or an alloy.
5. **Cleaning (Shakeout) and inspection of casting:** The cast part is cleaned and inspected for defects. The gating and riser systems are separated from the cast parts at this stage. Inspection methods include visual inspection, magnetic testing, non-destructive testing (NDT), ultrasonic testing, eddy current inspection, geometrical dimensions, pressure testing, radiographic testing, metallurgical control, and inspection.
5. **Finishing:** The casting often requires additional surface finish operations. Finishing operations such as grinding, turning, milling, lapping, honing, welding, repairing, and CNC machining can be employed.
6. **Heat treatment:** The cast parts may be heat treated to improve their metallurgical properties.

Desirable Mould Properties

1. **Strength** - to maintain shape and resist erosion
2. **Permeability** - to allow hot air and gases to pass through voids in sand
3. **Thermal stability** - to resist cracking on contact with molten metal
4. **Collapsibility** - the ability to give way and allow casting to shrink without cracking the casting
5. **Reusability** - can sand from broken mould be reused to make other moulds?

Learning Tasks

1. Learners watch videos of an industry-based sand-casting process, summarise the casting process and present their results to the class.
2. Using sand casting, learners cast simple components in the laboratory and document the process.

Pedagogical Exemplars

1. **Experiential learning:** Show learner's videos of an industry-based sand-casting process and let learners, in think-pair-share groups, summarise the casting process and present their results to the class. Provide videos with varying levels of complexity. For advanced learners, include detailed videos with technical jargon. For beginners, use simpler videos with basic explanations. Offer supplemental reading materials or infographics for learners who prefer text-based information. Allow learners to choose how they want to summarise the process: written summaries, diagrams, or oral presentations. Ensure mixed-gender groups to promote inclusivity. Provide positive feedback and support to build confidence and encourage participation.
2. **Project-based learning:** Learners in mixed-ability groups cast simple components in the laboratory using sand casting. Provide detailed instructions and step-by-step guides for beginners. Offer advanced resources and challenges for more experienced learners, such as designing complex components. Allow learners to choose their roles within the group based on their strengths and interests (e.g., designing the mould, preparing the sand, pouring the metal). Provide options for documenting the process: written reports, photo journals, or video logs. Promote teamwork and collaboration by assigning group roles and responsibilities. Provide opportunities for reflection and feedback to improve group dynamics and individual contributions. Address any biases or stereotypes that may arise during group work. Emphasise the importance of responsibility, diligence, and respect for others' contributions during the project.

Key Assessment

Assessment Level 1

1. What is the primary material used in the sand-casting process?
 - a) Plastic
 - b) Sand
 - c) Wood
 - d) Glass

2. True/False: The sand-casting process involves pouring molten metal into a mould made of sand.
3. What is the purpose of using a core in sand casting?
4. Which of the following is NOT a step in the sand-casting process?
 - a) Pattern making
 - b) Mould making
 - c) Injection moulding
 - d) Pouring molten metal

Assessment Level 2

1. If a casting has a rough surface finish, which part of the sand-casting process might need improvement?
 - a) Pattern making
 - b) Sand quality
 - c) Pouring temperature
 - d) Shakeout process
2. A foundry worker is preparing to cast a metal part. Which of the following steps would be the most important to ensure a successful casting?
 - a) Using the correct type of sand
 - b) Pouring the molten metal quickly
 - c) Leaving the mould to cool overnight
 - d) Using a large, heavy pattern
3. Create a step-by-step flowchart of the sand-casting process, including all major steps from pattern making to heat treatment.
4. Describe the role of the gating system in the sand-casting process.
5. Explain the difference between a green sand mould and a dry sand mould.
6. Describe the sand-casting process in detail, including the steps involved and the equipment used.

Assessment Level 3

1. A manufacturing company is considering using sand casting to produce a new product. What factors should they consider when making their decision?
2. Compare and contrast sand casting with other casting methods, such as die casting and investment casting.

Assessment Level 4: Design and create a functional sand-cast object, documenting the process and challenges encountered.

HINT



- The recommended mode of assessment for week 18 is **Mid-semester examination**.
- Refer to the Appendix F for more sample task and the Table of Specification

WEEK 19

Learning Indicator: Identify and explain the difference between non-permanent and permanent joining processes

Focal area: Non-permanent joining processes

Introduction

Non-permanent joining processes in manufacturing engineering refer to methods that allow components to be assembled and disassembled without causing damage to the parts involved. These processes are essential in applications where assemblies' maintenance, repair, or reconfiguration is required. Unlike permanent joining methods, such as welding or soldering, non-permanent joining does not involve the fusion of materials, allowing for the separation of components when needed. One common non-permanent joining method is mechanical fastening, which includes the use of screws, nuts, bolts, and washers. These fasteners can be easily removed and reused, making them ideal for applications where disassembly is anticipated.

Mechanical fastening with Screws, bolts, nuts, rivets, pins, clips etc.

Screws, Bolts, and Nuts

Screws and bolts are threaded fasteners that have external threads. There is a technical distinction between a screw and a bolt that is often blurred in popular usage. A screw is an externally threaded fastener that is generally assembled into a blind threaded hole. A bolt is an externally threaded fastener that is inserted through holes in the parts and "screwed" into a nut on the opposite side. A nut is an internally threaded fastener having standard threads that match those on bolts of the same diameter, pitch, and thread form. The typical assemblies that result from the use of screws and bolts are illustrated in Figure 19.1.

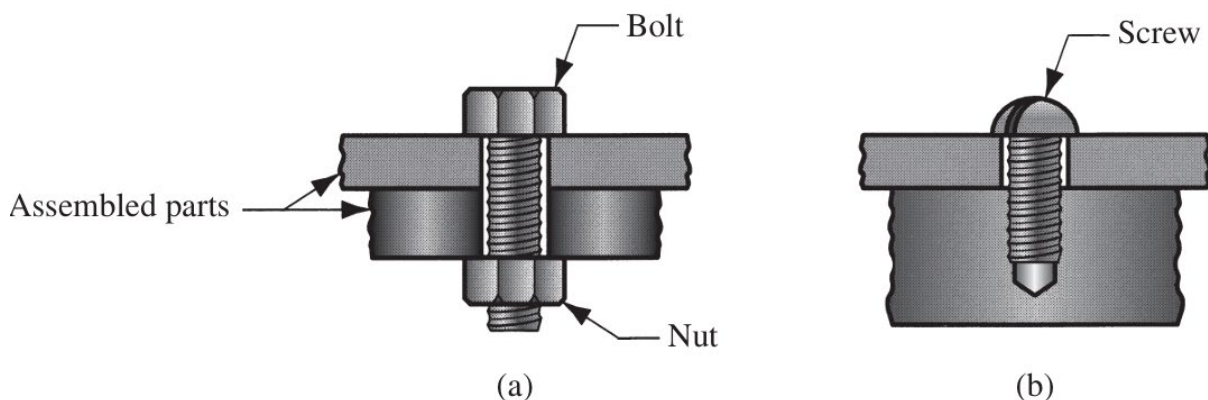


Figure 19.1: Typical assemblies using (a) bolt and nut and (b) screw

Screws and bolts come in a variety of standard sizes, threads, and shapes. Table 19.1 provides a selection of common threaded fastener sizes in metric units (International Standards Organisation (ISO) standard). The metric specification consists of the nominal major diameter, mm, followed by the pitch, mm. For example, a specification of 4×0.7 means a 4.0-mm major diameter and a pitch of 0.7 mm. Both coarse pitch and fine pitch standards are given in Table

19.1. Additional technical data on these and other standard threaded fastener sizes can be found in design texts and handbooks.

Table 19.1: *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	
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 19.2. 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.

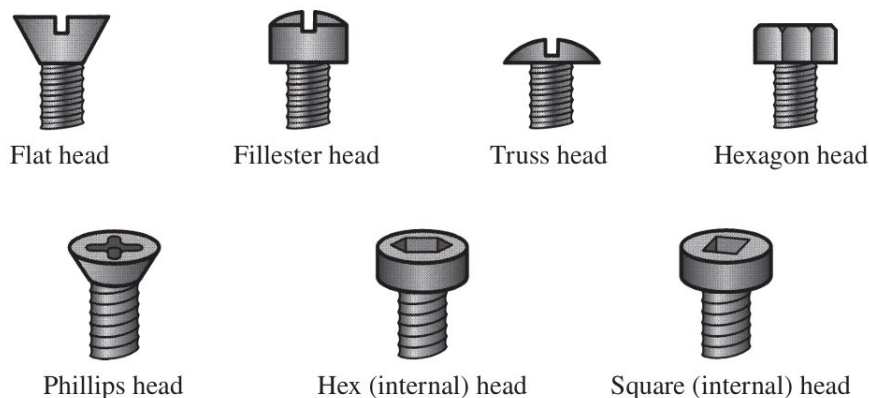


Figure 19.2: *Some head styles available on screws and bolts*

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 to 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 19.3(a). They come in various geometries, some of which are illustrated in Figure 19.3(b). A self-tapping screw is designed to form or cut threads in a pre-existing hole into which it is being rotated. Figure 19.4 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).

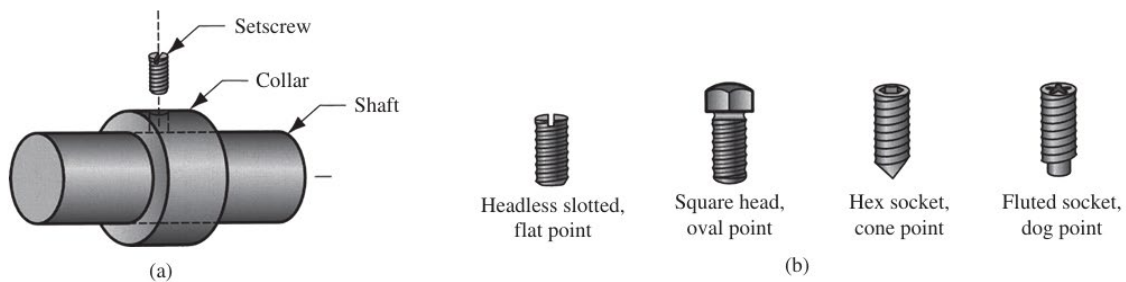


Figure 19.3 (a): Assembly of collar to shaft using a setscrew; **(b)** various setscrew geometries (head types and points)

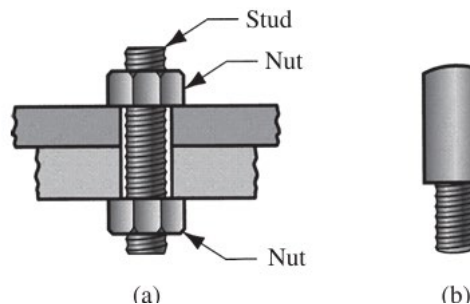


Figure 19.4: Self-tapping screws: **(a)** thread-forming and **(b)** thread-cutting

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 19.5(a). They are available with threads on one end or both, as in Figure 19.5 (b) and (c).

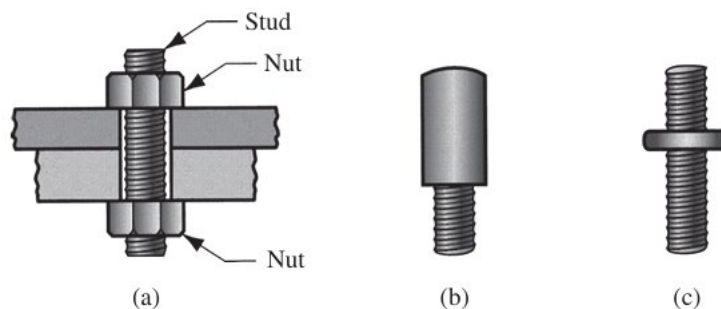


Figure 19.5: (a) Stud and nuts used for assembly. Other stud types: (b) threads on one end only and (c) double-end stud

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 19.6. Upon subsequent assembly of the screw into the insert, the insert barrel expands into the sides of the hole, securing the assembly.

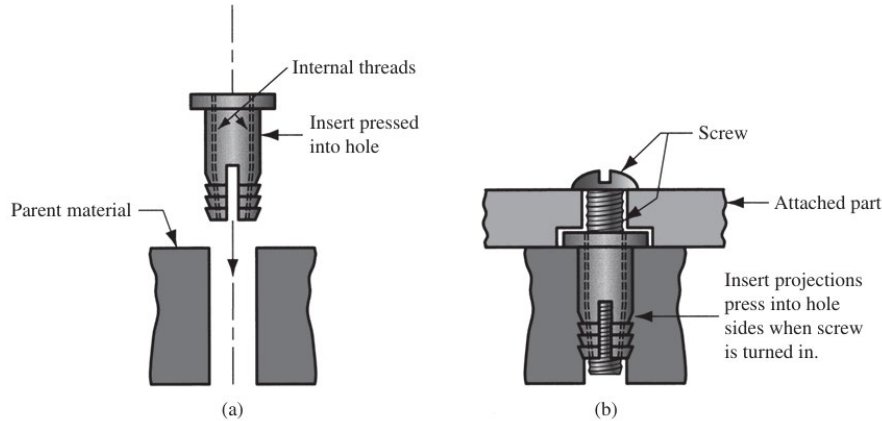


Figure 19.6 Screw thread inserts: (a) before insertion and (b) after insertion into hole and screw is turned into the insert

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 19.7. 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.

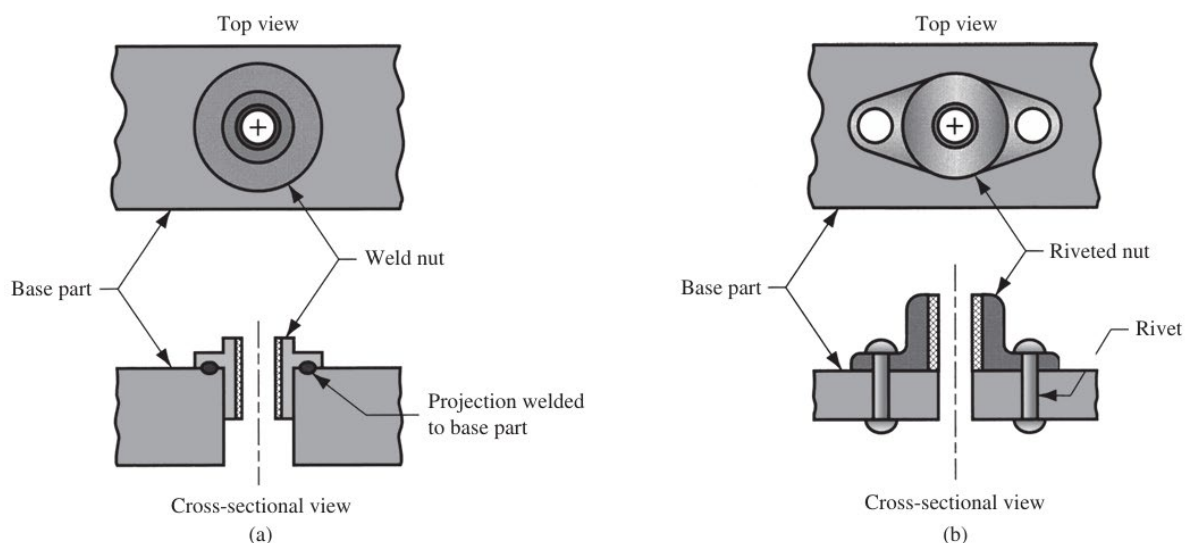


Figure 19.7: Captive threaded fasteners: (a) weld nut and (b) riveted nut

Rivets and Eyelets

Rivets are widely used for achieving a permanent mechanically fastened joint. Riveting is a fastening method that offers high production rates, simplicity, dependability, and low cost. Despite these apparent advantages, its applications have declined in recent decades in favour of threaded fasteners, welding, and adhesive bonding. Riveting is one of the primary fastening processes in the aircraft and aerospace industries for joining skins to channels and other structural members. A rivet is an unthreaded, headed pin used to join two (or more) parts by passing the pin through holes in the parts and then forming (upsetting) a second head in the pin on the opposite side. The deforming operation can be performed hot or cold (hot working or cold working) and by hammering or steady pressing. Once the rivet has been deformed, it cannot be removed except by breaking one of the heads. Rivets are specified by their length, diameter, head, and type. Rivet type refers to five basic geometries that affect how the rivet will be upset to form the second head. The five types are defined in Figure 19.8. In addition, there are special rivets for special applications. Rivets are used primarily for lap joints. The clearance hole into which the rivet is inserted must be close to the diameter of the rivet. If the hole is too small, rivet insertion will be difficult, thus reducing production rate. If the hole is too large, the rivet will not fill the hole and may bend or compress during formation of the opposite head. Rivet design tables are available to specify the optimum hole sizes.

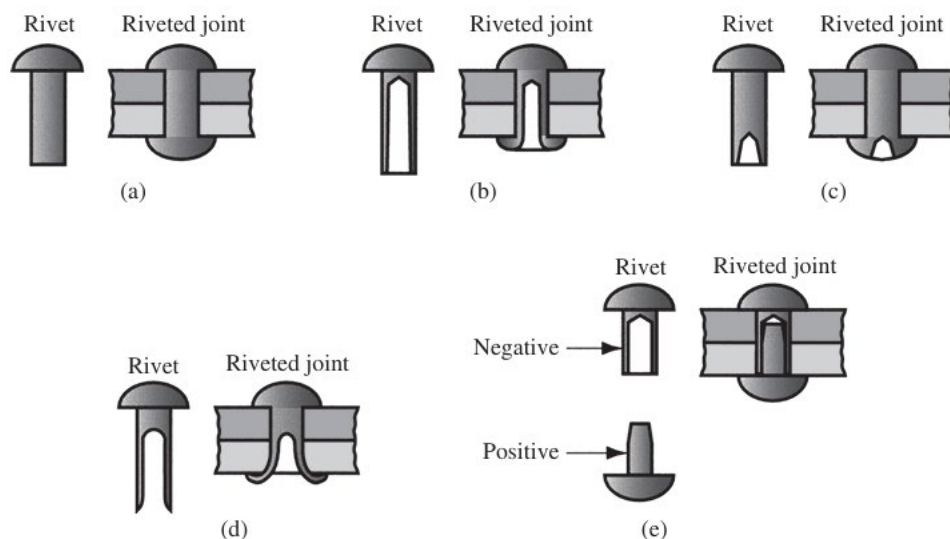


Figure 19.8 : Five basic rivet types, also shown in assembled configuration: (a) solid, (b) tubular, (c) semi tubular, (d) bifurcated, and (e) compression

Eyelets are thin-walled tubular fasteners with a flange on one end, usually made from sheet metal, as in Figure 19.9 (a). They are used to provide a permanent lap joint between two (or more) flat parts. Eyelets are substituted for rivets in low-stress applications to save material, weight, and cost. During fastening, the eyelet is inserted through the part holes, and the straight end is formed over to secure the assembly. The forming operation is called setting and is performed by opposing tools that hold the eyelet in position and curl the extended portion of its barrel. Figure 19.9 (b) illustrates the sequence for a typical eyelet design. Applications of this fastening method include automotive subassemblies, electrical components, toys, and apparel.

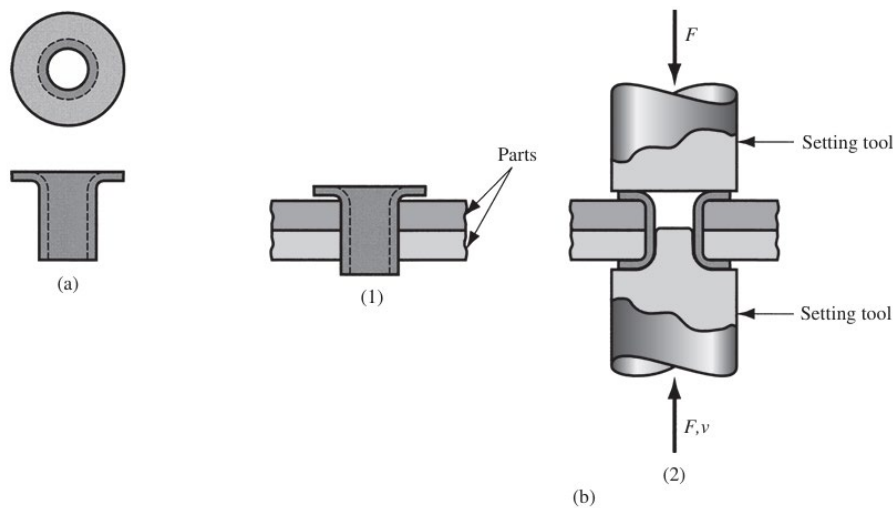


Figure 19.9: Fastening with an eyelet: (a) the eyelet and (b) assembly sequence: (1) inserting the eyelet through the hole and (2) setting operation

Adhesive fastening with liquid adhesives, tapes, hot melts, structural adhesives etc.

Adhesive fastening offers a range of solutions for different applications, each with its own set of advantages and limitations. Choosing the right adhesive depends on the specific requirements of the project, including the materials involved, the desired bond strength, and the environmental conditions. Table 19.2 shows the various types of adhesive fasteners, their descriptions, examples and applications.

Table 19.2: Adhesive fastening with liquid adhesives, tapes, hot melts, structural adhesives

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 are based on mechanical interference between the two mating parts being joined. This interference, which occurs either during assembly or after the parts are joined, holds together the parts. The methods include press fitting, shrink and expansion fits, snap fits, and retaining rings.

Press Fitting

A press fit assembly is one in which the two components have an interference fit between them. The typical case is where a pin (e.g., a straight cylindrical pin) of a certain diameter is pressed into a hole of a slightly smaller diameter. Standard pin sizes are commercially available to accomplish a variety of functions, such as (1) locating and locking the components—used to augment threaded fasteners by holding two (or more) parts in fixed alignment with each other; (2) pivot points, to permit rotation of one component about the other; and (3) shear pins. Except for (3), the pins are normally hardened. Shear pins are made of low-strength metals and are designed to break under a sudden or severe shearing load in order to save the rest of the assembly. Other applications of press fitting include assembly of collars, gears, pulleys, and similar components onto shafts. The pressures and stresses in an interference fit can be estimated using several applicable formulas. If the fit consists of a round solid pin or shaft inside a collar (or similar component), as depicted in Figure 19.10 and the components are made of the same material.

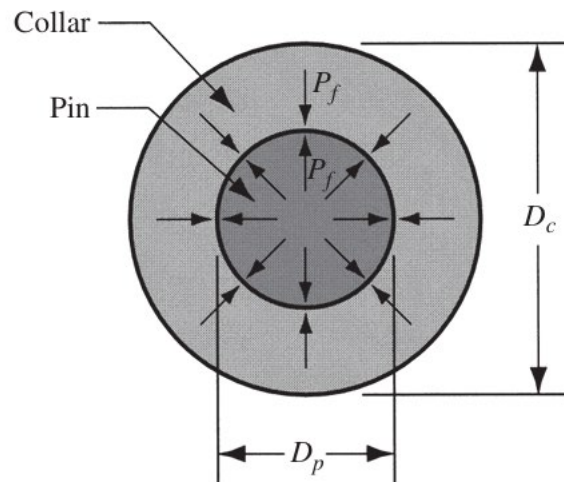


Figure 19.10: Cross section of a solid pin or shaft assembled to a collar by interference fit.

D_c = diameter of collar hole, D_p = diameter of pin

Shrink and Expansion Fits

These terms refer to the assembly of two parts that have an interference fit at room temperature, but one of the parts is either cooled to contract it or heated to expand it just before assembly. The typical case is a cylindrical pin or shaft inserted into a collar. To assemble by shrink fitting, the external part is heated to enlarge it by thermal expansion, and the internal part either remains at room temperature or is cooled to contract its size. The parts are then assembled and brought back to room temperature, so that the external part shrinks, and if previously cooled, the internal part expands, to form a strong interference fit. An expansion fit is when only the internal part is cooled to contract it for assembly; once inserted into the mating component, it warms to room temperature, expanding to create the interference. These assembly methods are used to fit gears, pulleys, sleeves, and other components onto solid and hollow shafts.

Snap Fits and Retaining Rings

Snap fits are variations of interference fits. A snap fit consists of joining two parts in which the mating elements possess a temporary interference while being pressed together, but once assembled, they interlock to maintain the assembly. A typical example is shown in Figure 19.11: As the parts are pressed together, the mating elements elastically deform to accommodate the interference, subsequently allowing the parts to snap together; once in position, the elements become connected mechanically so that they cannot easily be disassembled. The parts are usually designed so that a slight interference exists after assembly.

Advantages of snap fit assembly include:

- 1) the parts can be designed with self-aligning features
- 2) no special tooling is required, and
- 3) assembly can be accomplished very quickly. Snap fitting was originally conceived as a method that would be ideally suited to industrial robotics applications; however, it is no surprise that assembly techniques that are easier for robots are also easier for human assembly workers.

A retaining ring, also known as a snap ring, is a fastener that snaps into a circumferential groove on a shaft or tube to form a shoulder, as in Figure 19.12. The assembly can be used to locate or restrict the movement of parts mounted on the shaft. Retaining rings are available for both external (shaft) and internal (bore) applications. They are made from either sheet metal or wire stock, heat treated for hardness and stiffness. To assemble a retaining ring, a special plier's tool is used to elastically deform the ring so that it fits over the shaft (or into the bore) and then is released into the groove.

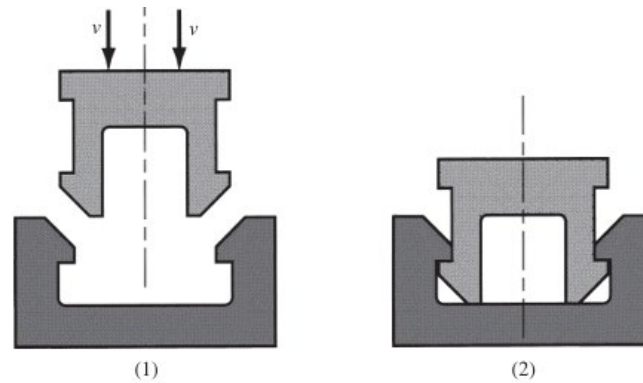


Figure 19.11: Snap fit assembly, showing cross sections of two mating parts: (1) before assembly and (2) parts snapped together

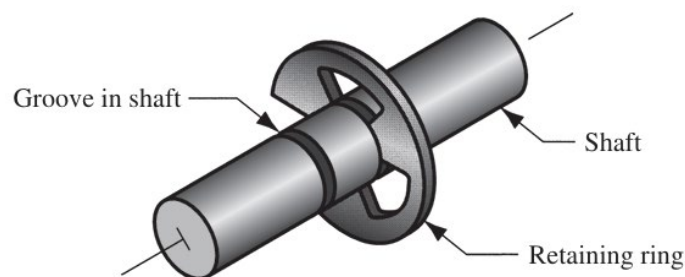


Figure 19.12: Retaining ring assembled into a groove on a shaft

Temporary fasteners: Clevis pins, cotter pins, quick-release fasteners, etc.

A clevis pin is a reusable, cylindrical, non-threaded pin available in a variety of styles that secure components between the head and the end of the pin. They are ideal for quickly connecting or disconnecting equipment in temporary or permanent applications, especially those that do not require precise alignment. In its most basic structure, a clevis pin consists of a head, shank, and shank end, with the most pertinent measurements being the diameter, shank length, effective length, and head diameter. Figures 19.13 and 19.14 show images of a clevis pin and how it is used,

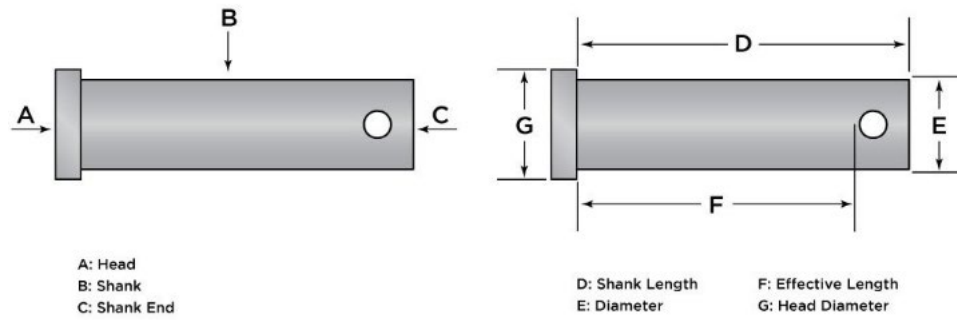


Figure 19.13: *Clevis pin*

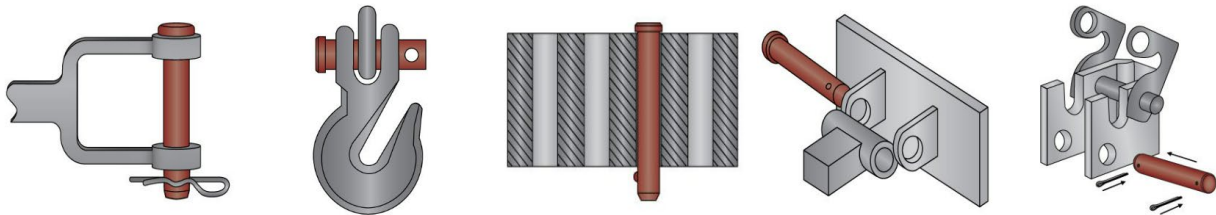


Figure 19.14: *Clevis pin fastener process*

Cotter Pins

Cotter pins are fasteners formed from half-round wire into a single two-stem pin. They vary in diameter, ranging between 0.8 mm and 19 mm, and in point style. 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 19.15 presents images of cotter pins.

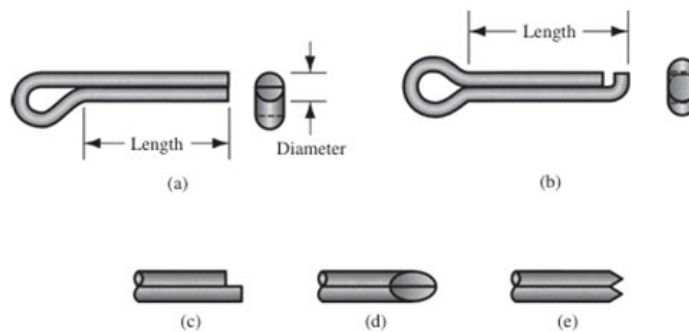


Figure 19.15 Cotter pins: (a) offset head, standard point; (b) symmetric head, hammerlock point; (c) square point; (d) mitred point; and (e) chisel point.

Quick-release fasteners

Quick release pins are fastening devices equipped with a mechanism that facilitates quick and easy pin release, commonly employed in hardware such as machinery, electronics, and vehicles. They provide a simple and efficient means to both secure and release machinery parts. Quick release pins play a vital role in numerous industries and are frequently used in applications requiring frequent access or where easy disassembly is crucial for maintenance or repair Learning Tasks. An image of a quick-release fastener is displayed in **Figure 19.16**.



Figure 19.16: Quick-release fastener

Explanation of the working principles, advantages, and limitations of each joining process

Table 19.3 shows the various types of fasteners, their working principles, advantages and limitations.

Table 19.3: Explanation of the 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 required. Suitable for high-stress applications.	Difficult to disassemble. Requires precise manufacturing tolerances. Potential for material deformation
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 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

Criteria for selecting non-permanent joining processes

Table 19.4 presents the criteria for selecting non-permanent joining processes.

Table 19.4: *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.

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.
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.

Learning Tasks

Learners identify non-permanent joints (e.g., mechanical fastening with screws, bolts, and nuts), explain their working principles, advantages, and limitations and explain the criteria for selecting non-permanent joining processes.

Pedagogical Exemplars

Collaborative learning: Learners in mixed-ability groups bring to class components that have been joined together and separate them into components with permanent joints and those with non-permanent joints. Learners identify the non-permanent joints (e.g., mechanical fastening with screws, bolts, and nuts), explain their working principles, advantages, and limitations and explain the criteria for selecting non-permanent joining processes. Provide tiered reading materials on non-permanent joining processes, ranging from basic to advanced levels. Let learners demonstrate their understanding through various formats such as written reports, oral presentations, video demonstrations, or creating infographics. Encourage creative representations like models or posters.

Key Assessment

Assessment Level 1

1. Which of the following is a non-permanent joining process?
 - a) Welding
 - b) Brazing
 - c) Screwing
 - d) Adhesive bonding
2. **True/False:** Bolts and nuts are examples of non-permanent joining processes.

Assessment Level 2

1. Explain the working principle of a bolt and nut as a non-permanent joining process.
2. A technician needs to join two metal plates together temporarily for a repair. Which of the following non-permanent joining methods would be the most suitable?
 - a) Welding
 - b) Bolting
 - c) Gluing
 - d) Riveting

Assessment Level 3

1. Describe the various types of non-permanent joining processes, including their advantages and disadvantages.
2. A manufacturing company is designing a new product that requires a non-permanent joint. What factors should they consider when selecting the appropriate method?
3. Create a concept map categorising five non-permanent joining processes and their applications.

Focal Area 2: Permanent joining processes

Introduction

Permanent joining processes are fundamental techniques in manufacturing, designed to create joints that are intended to remain intact for the lifetime of the product or structure. These processes are vital in ensuring the structural integrity, durability, and reliability of various assemblies, ranging from everyday consumer products to critical infrastructure and aerospace components. Examples of permanent joining processes include welding, soldering and brazing.

Welding processes

Types of Welding Processes

Fifty (50) different types of welding operations have been catalogued by the American Welding Society. They use various types or combinations of energy to provide the required power. The welding processes can be divided into two major groups: (1) fusion welding and (2) solid-state welding.

Fusion Welding

These processes use heat to melt the base metals. In many fusion welding operations, a filler metal is added to the molten pool to facilitate the process and provide bulk and strength to the welded joint. A fusion-welding operation in which no filler metal is added is referred to as an autogenous weld. The fusion category includes the most widely used welding processes, which can be organised into the following general groups: arc, gas, resistance and high energy welding. Table 19.5 displays details of these categories, which include examples and applications.

Table 19.5: *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.
	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. Flame is directed by a welding torch. Filler metal is sometimes added. Pressure is occasionally applied in OAW between the contacting part surfaces.	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 tubing². 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 pieces³. Maintenance and Repair: Industrial Equipment: Repairing and maintaining industrial machinery and equipment. Agricultural Tools: Fixing and fabricating agricultural tools and machinery⁴. 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
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 category of welding processes that join materials without melting them, relying instead on pressure, and sometimes heat, to achieve a bond. This method contrasts with fusion welding, where the materials are melted and then solidified to form a joint. The fundamental principle of SSW is the application of sufficient pressure to bring the surfaces of the materials into intimate contact, allowing atomic bonding to occur. This process can be enhanced by the application of heat, which increases atomic mobility and facilitates diffusion across the interface. Table 19.6 displays details of SSW categories, which include examples and applications.

Table 19.6: SSW 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
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 ¹
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
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Soldering

Soldering is similar to brazing and can be defined as a joining process in which a filler metal with a melting point (liquidus) not exceeding 450°C is melted and distributed by capillary action between the faying surfaces of the metal parts being joined. As in brazing, no melting of the base metals occurs, but the filler metal wets and combines with the base metal to form a metallurgical bond. Details of soldering are similar to those of brazing, and many of the heating methods are the same. Surfaces to be soldered must be precleaned so they are free of oxides, oils, and so on. An appropriate flux is applied to the faying surfaces, and the surfaces are heated. Filler metal, called solder, is added to the joint and distributes itself between the closely fitting parts. In some applications, the solder is precoated onto one or both of the surfaces—a process called tinning, irrespective of whether the solder contains any tin. Typical clearances in soldering range from 0.075 mm to 0.125 mm, except when the surfaces are tinned, in which case a clearance of about 0.025 mm is used. After solidification, the flux residue must be removed. As an industrial process, soldering is most closely associated with electronics assembly (Chapter 30). It is also used for mechanical joints, but not for joints subjected to elevated stresses or temperatures. Advantages of soldering include (1) low energy input relative to brazing and fusion welding, (2) variety of heating methods available, (3) good electrical and thermal conductivity in the joint, (4) capability to make air-tight and liquid-tight seams for containers, and (5) easy to repair and rework. The biggest disadvantages of soldering are (1) low joint strength unless reinforced by mechanical means and (2) possible weakening or melting of the joint in elevated-temperature service.

Brazing

Brazing is a joining process in which a filler metal is melted and distributed by capillary action between the faying surfaces of the metal parts being joined. No melting of the base metals occurs in brazing; only the filler melts. In brazing, the filler metal (also called the brazing metal) has a melting temperature (liquidus) that is above 450°C but below the melting point (solidus) of the base metal(s) to be joined. If the joint is properly designed and the brazing operation has been properly performed, the brazed joint will be stronger than the filler metal out of which it has been formed upon solidification. This rather remarkable result is due to the small part clearances used in brazing, the metallurgical bonding that occurs between base and filler metals, and the geometric constrictions that are imposed on the joint by the base parts.

Brazing has several advantages compared with welding:

- (1) Any metals can be joined, including dissimilar metals;
- (2) certain brazing methods can be performed quickly and consistently, thus permitting high cycle rates and automated production;
- (3) some methods allow multiple joints to be brazed simultaneously;
- (4) brazing can be applied to join thin-walled parts that cannot be welded;
- (5) in general, less heat and power are required than in fusion welding;

- (6) problems with the heat-affected zone in the base metal near the joint are reduced; and
- (7) joint areas that are inaccessible by many welding processes can be brazed, since capillary action draws the molten filler metal into the joint.

Disadvantages and limitations of brazing include

- (1) joint strength is generally less than that of a welded joint;
- (2) although strength of a good brazed joint is greater than that of the filler metal, it is likely to be less than that of the base metals;
- (3) high service temperatures may weaken a brazed joint; and
- (4) the colour of the metal in the brazed joint may not match the colour of the base metal parts, a possible aesthetic disadvantage.

Brazing as a production process is widely used in a variety of industries, including automotive (e.g., joining tubes and pipes), electrical equipment (e.g., joining wires and cables), cutting tools (e.g., brazing cemented carbide inserts to shanks), and jewellery making. In addition, the chemical processing industry and plumbing and heating contractors join metal pipes and tubes by brazing. The process is used extensively for repair and maintenance work in nearly all industries.

Explanation of the working principles, advantages, and limitations of welding.

Table 19.7 displays details of explanation of the working principles, advantages, and limitations of welding.

Table 19.7: *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, along with 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: Creates a permanent bond that is often stronger than the base materials.	High Heat: Requires high temperatures, 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 are not suitable 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.
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Criteria for selecting permanent joining processes

Table 19.8 shows details of criteria for selecting permanent joining processes.

Table 19.8: *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
	Labor 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
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 19.9 shows the advantages of non-permanent and permanent joining processes

Table 19.9: *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 certain applications.
	Cost-Effective: Generally, more cost-effective for applications where joints need to be frequently inspected or replaced	Potential for Loosening: Over time, non-permanent joints may loosen, 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
	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

Permanent	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	

Learning Tasks

Learners in mixed-ability groups learn and practice different permanent joining processes (e.g., welding, brazing, soldering) and their applications at the workshop.

Pedagogical Exemplars

1. Project-based learning: Learners in mixed-ability groups learn and practice different permanent joining processes and their applications at the workshop. Learners create functional or non-functional objects (e.g. coal pots, buckets, door handles, dust pans etc.) using permanent and non-permanent joining techniques. Each group presents their project, explaining the joining processes used and the reasons for their choices. Assess learners' prior knowledge and skills related to joining processes. Group learners with varying levels of expertise to ensure peer learning. Allow learners to choose the type of object they want to create based on their interests (e.g., household items, tools, decorative pieces). Provide resources in multiple formats (videos, diagrams, written instructions) to cater for different learning preferences. Anticipate potential challenges and provide scaffolding, such as step-by-step guides for complex processes or additional support for learners who need it.

Key Assessment

Assessment Level 1

- Which of the following is a permanent joining process?
 - Bolting
 - Welding
 - Screwing
 - Clamping
- True/False:** Soldering is a non-permanent joining process.

3. Define a permanent joining process
4. Which of the following is NOT a characteristic of permanent joining processes?
 - a. Creates a strong bond
 - b. Can be easily disassembled
 - c. Often involves heat
 - d. Used in structural applications

Assessment Level 2

1. If you need to join two metal parts permanently for a high-stress application, which process would you choose?
 - a) Welding
 - b) Bolting
 - c) Clamping
 - d) Taping
2. Explain why brazing is considered a permanent joining process.
3. Which permanent joining process would be most suitable for joining two metal plates in a car chassis, and what are the key factors that make it suitable?

Assessment Level 3

1. Compare and contrast welding and soldering in terms of their applications and processes.
2. Create a concept map that shows the different types of permanent joining processes and their characteristics.
3. Discuss the advantages and disadvantages of using welding over brazing in manufacturing.
4. 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) Ease of disassembly
 - d) Speed of assembly

Assessment Level 4

1. In a scenario where a spacecraft needs to have parts joined permanently, which process would be most suitable and why?
 - a) Welding
 - b) Brazing
 - c) Soldering
 - d) Riveting
2. Create a model or prototype using various permanent joining processes. Document the steps and techniques used.

3. How significantly do non-permanent and permanent joining processes influence the efficiency and sustainability of manufacturing practices?

HINT



*The recommended mode of assessment for week 19 is **debate**. Use the level 4 question 3 as a sample question.*

WEEK 20

Learning Indicator: Apply screw, bolt and nut, and welding processes to assemble manufactured parts together

Focal area: Join components using screw, bolt and nut and welding processes

Introduction

In manufacturing engineering, effective component joining is crucial for producing durable products. Techniques such as screws, bolts, nuts, and welding are foundational to numerous industrial applications, ensuring structural integrity and longevity. Fasteners like screws and bolts enable versatile assembly and disassembly, with their selection based on material compatibility and load requirements. Conversely, welding offers a permanent bond through material fusion, critical for high-strength applications. Mastery of these joining techniques is essential for engineers to ensure optimal performance and compliance with safety standards.

Apply screws, and bolts and nuts to join components

Technical Considerations

1. **Determine the type of joint:** Decide whether you need a temporary or permanent joint. Permanent joints often use welding, or rivets, while temporary joints might use screws, or nuts and bolts.
2. **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.
3. **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.
4. **Thread direction:** Ensure that the threads on the screw or bolt match the threads on the nut.
5. **Washers:** Use washers to distribute the load and prevent the fastener from sinking into the material.
6. **Torque:** If necessary, use a torque wrench to ensure the fasteners are tightened to the correct specifications.
7. **Locking mechanisms:** Consider using locking mechanisms (e.g., lock washers, thread lock) to prevent the fasteners from loosening over time.

Sequence of applying screws and 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.

Use 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 amperage (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

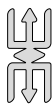
- a. **Clean the Weld:** Remove any slag, spatter, or oxidation from the weld using a wire brush or grinder.
- b. **Inspect the Weld:** Conduct a thorough inspection of the weld to ensure it meets the required standards and specifications.

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.

Learning Tasks

1. Learners form non-permanent joints using screws, bolts, and nuts.
2. Learners join manufactured parts using any available welding process.

Pedagogical Exemplars

Experiential learning: Learners in mixed-ability groups practice the joining of components in the workshop to form non-permanent joints using screws, bolts, and nuts. Learners take turns in mixed-ability groups to join manufactured parts using any available welding process. Provide varied complexity of tasks based on learners' readiness. For example, beginners can work on simpler joints, while advanced learners can tackle more complex assemblies. Offer multiple ways to learn, such as hands-on practice, instructional videos, and step-by-step guides. Allow learners to demonstrate their understanding through different formats, such as written reports, oral presentations, or practical demonstrations.

Key Assessment

Assessment Level 1

1. Which tool is commonly used to tighten bolts and nuts?
 - a) Hammer
 - b) Wrench
 - c) Screwdriver
 - d) Pliers
2. **True/False:** Screws are used to create permanent joints.
3. Name two types of welding processes.

Assessment Level 2

1. If you need to join two wooden parts temporarily, which fastener would you use?
 - a) Nail
 - b) Screw
 - c) Bolt and Nut
 - d) Weld
2. Explain the difference between a screw and a bolt.
3. Given a set of components (two plates, screws, bolts, nuts), describe the steps you would take to join them using screws and bolts.
4. Describe a situation where welding would be preferred over using screws or bolts.

Assessment Level 3

1. Discuss the advantages and disadvantages of using welding versus screws and bolts for assembling manufactured parts.
2. Given a case study of a manufacturing scenario, identify the best joining method (screws, bolts, or welding) and justify your choice.

Assessment Level 4

1. Design and build a small structure using a combination of screws, bolts, and welding, documenting the process and challenges faced.
2. In a scenario where you need to assemble a metal frame for a heavy-duty application, which joining method would you choose and why?

- a) Screws
 - b) Bolts and Nuts
 - c) Welding
 - d) Adhesives
3. Design and build the assembly of two separate components using the following methods of joining (rivets, screws, studs, bolts, and nuts).

HINT



*The recommended mode of assessment for week 20 is **display and exhibition**. Use the level 4 question 3 as a sample question.*

Review of Section 6

This section introduced learners to the importance of casting, sand casting processes, permanent and non-permanent joining processes and their relevance in manufacturing products. The important lessons learnt from the section are summarised below:

1. Casting is a manufacturing process in which a liquid material is usually poured into a mould, which contains a hollow cavity of the desired shape, and then allowed to solidify.
2. Sand casting is the most widely used casting process, accounting for most of the total tonnage cast.
3. Non-permanent joining processes are essential in applications where assemblies' maintenance, repair, or reconfiguration is required.
4. Welding processes can be divided into two major groups: (1) fusion welding and (2) solid-state welding.

RUBRICS FOR THE DEBATE ASSESSMENT

Criteria	Exemplary (4 points)	Proficient (3 points)	Satisfactory (2 points)	Needs Improvement (1 point)
Understanding of Concepts	Non-permanent joining processes (e.g., adhesives, snap-fits, and mechanical fasteners) that allow for easy disassembly, and permanent joining methods (e.g., welding, brazing, and soldering) that create lasting bonds,	Shows a good understanding of both types of joining methods but may lack depth in discussing specific techniques or fail to connect them clearly to their applications.	Displays a basic understanding of joining methods with significant gaps, such as confusing non-permanent and permanent processes or not addressing their industrial relevance.	Lacks understanding of key concepts related to joining processes, such as not distinguishing between non-permanent and permanent methods or their applications.
Applications	Applications of non-permanent joints in consumer electronics, modular furniture, and automotive components where repairability is important, and permanent joints in construction, aerospace, and automotive manufacturing where safety and reliability are critical.	Identifies some applications but may not fully explore their relevance or impact in various industries, such as mentioning examples without detailing how they benefit specific sectors.	Provides limited applications, with minimal connection to joining processes discussed, lacking examples or explanations of their significance in manufacturing.	Fails to identify relevant applications or their significance in manufacturing, neglecting to illustrate how joining processes are used in practical scenarios.
Depth of Analysis	Non-permanent joints can significantly reduce assembly time (up to 50%), while permanent joints provide exceptional structural integrity for high-stress applications and lower maintenance costs over time due to their longevity.	Provides a reasonable analysis but may miss some important aspects or implications, such as not fully addressing how the choice of joining method affects overall manufacturing processes.	Basic analysis with minimal depth, lacking detail on implications of the processes, such as only mentioning that joining methods exist without discussing their impact.	Analysis is superficial or lacks relevant insights into efficiency and sustainability, failing to connect the benefits of joining methods to real-world outcomes in manufacturing.
Conclusion Quality	Both non-permanent and permanent joining processes are vital in manufacturing, each offering distinct benefits suited to specific needs, thus helping manufacturers optimise production and meet market demands.	Summarises key points but may lack a strong concluding perspective on overall significance, missing a final statement that reinforces the importance of understanding joining processes.	Provides a basic conclusion but misses the significance of understanding joining processes, with a vague or generic closing statement.	Conclusion is weak or missing, failing to summarise key points or relevance, leaving the reader without a clear understanding of the topic's importance.

Rubric for the Display and Exhibition

(Joining Methods, Presentation, and Documentation)

Criteria	Exemplary (4 points)	Proficient (3 points)	Satisfactory (2 points)	Needs Improvement (1 point)
Selection of Joining Methods	Clearly identifies and justifies the choice of joining methods (e.g., rivets, screws, bolts, nuts, studs) with strong, specific examples tailored to material, load-bearing, environment, and assembly method. Clear rationale for each choice with real-world applications.	Identifies appropriate joining methods, but with some generalisation. Justification is adequate but lacks depth, with limited exploration of material properties, load requirements, or environments.	Provides a basic selection of joining methods, but explanations are vague and lack key details about material properties or environmental factors. Some methods may not be fully suitable for the given application.	Fails to identify suitable joining methods, or provides incorrect or mismatched methods with little or no rationale. Missing key justifications for choice or understanding of the application.
Presentation Quality	Presentation is well-organised with clear visuals (diagrams, CAD models) and engaging explanations. Effectively explains the assembly process, highlighting the advantages of each joining method used. Visuals are labeled, professional, and add value.	Presentation is organised and clear, but may lack in visual clarity or engagement. Minor issues in flow, and some visuals may not be fully clear or well-labeled. Explanations are solid but lack depth in engagement.	Basic presentation lacking clarity or engagement. Visuals are minimal or not well-explained. The explanation may lack sufficient details about the assembly process, making it harder for the audience to follow.	Presentation is disorganised, with poor visuals or no supporting diagrams/models. The explanation is unclear, incomplete, or fails to properly describe the assembly and joining methods used.
Documentation and Display	Comprehensive and well-organised documentation includes step-by-step assembly process with detailed labels, materials used, and clear explanations of the role of each joining method. The display is professional, visually appealing, and informative, helping the audience understand the process.	Documentation is organised, with a basic step-by-step process and some labels, but may lack complete details (e.g., material properties or deeper justification for joining methods). The display is neat but could use more clarity or detail.	Minimal documentation, with basic steps outlined. Lacks clarity in explaining the joining methods or missing key steps of the assembly process. Labels and content are unclear, making it difficult for the audience to understand.	No clear documentation provided, or poorly organised. The process is difficult to follow, and the display lacks any meaningful labels or explanations, making it confusing for the audience.



APPENDIX F: TABLE OF TEST SPECIFICATION (MID-SEMESTER 2)

There are 20 objective test items. Each item is followed by four alternatives, A-D. Read each item carefully and select the best option that bears the correct answer.

Week	Focal Area	Type of Question	Depth of Knowledge			
			L1	L2	L3	Total
13	Importance of AutoCAD in modelling	Multiple Choice	1	2	1	4
14	Creating 2D and 3D models using AutoCAD	Multiple Choice	2	1	1	4
15	F1. Difference between measuring instruments F2. Using measuring tools to measure work pieces	Multiple Choice	1	2	1	4
16	F1. Difference between manual hand tools and power hand tools Introduction. F2, Application of hand tools in manufacturing	Multiple Choice	1	2	1	4
17	Importance of casting in manufacturing engineering products	Multiple Choice	1	2	1	4
Total			6	9	5	20

SECTION 7: SAFETY IN MANUFACTURING

STRAND: MANUFACTURING TOOLS, EQUIPMENT AND PROCESSES

Sub-Strand: Manufacturing processes

Learning Outcome: *Discuss methods of applying different types of hazard controls*

Content Standards

1. *Demonstrate knowledge of the various types of hazard controls (administrative, engineering, personal protective **equipment**)*
2. *Demonstrate an understanding of ways in which the manufacturing industry affects the **environment**.*

HINT



- *Remind learners to submit their Individual projects in week 22.*
- *Remind learners of the end of semester examination in week 24*
- *Refer to Appendix G at the end of this section for Table of specification.*

Introduction and Section Summary

In this section, learners will be introduced to hazard controls in the manufacturing industry. They will understand the various types of hazard control and the effects of manufacturing on the environment. Learners will also understand the benefits of using environmentally friendly processes and products in manufacturing and be able to explain the various research being undertaken by local manufacturing industries to ensure sustain manufacturing practices.

The section covers the following weeks:

Week 21: Types of hazard control

Week 22: Effect of manufacturing on the environment

Week 23: Benefits of using environmentally friendly processes and products in manufacturing

Week 24: Research trends in the local manufacturing industry

Summary of Pedagogical Exemplars

Given the diversity in learners' backgrounds, learning capacities, and learning styles, it is crucial to employ a broad spectrum of pedagogical approaches that cater to students' varied abilities within the classroom. Pedagogical alternatives to explore include employing strategies such as experiential learning, collaborative learning and talk for learning. In this section, consider providing learners the opportunity to visit a manufacturing industry to understand the

hazard controls used, and to ascertain the kind of research being undertaken to ensure sustainable manufacturing. Also, let learners view a video of the effect of manufacturing on the environment. Allow learners to articulate their experiences through collaborative discourse to identify hazard controls, the effect of manufacturing on the environment and research trends in the local manufacturing industry. In mixed ability groupings, learners should be given the opportunity to outline the benefits of using environmentally friendly processes and products in manufacturing. Finally, consider giving learners case study of risk assessment and hazard control planning for manufacturing companies available in the community.

Assessment summary

A range of assessment modes should be considered to ensure that learners across all proficiency levels have the chance to demonstrate their comprehension of the principal themes presented in the section. Oral responses can be elicited in class discussions following a visit to a manufacturing company; written responses of various levels of difficulties appropriate for the class can also be requested from learners relative to the major concepts in this section. Learners should be able to explain the types of hazard controls, the effect of manufacturing on the environment, the benefit of using sustainable manufacturing processes and various research that can be undertaken to ensure sustainable manufacturing. These should contribute to learners' formative assessment.

WEEK 21

Learning Indicator: Demonstrate knowledge of the various types of hazard controls (administrative, engineering, personal protective equipment)

Focal area: Types of hazard controls

Introduction

The manufacturing environment presents numerous hazards that can impact the health and safety of workers. Understanding these hazards and knowing how to control them is essential to ensure a safe and productive workplace. Ensuring safety in manufacturing environments involves creating a culture of safety that prioritises the well-being of all workers. This is referred to as hazard control, and it involves all the necessary steps needed to protect workers from exposure to hazards. Knowledge of hazard control is helpful in contributing to a safer manufacturing environment.

Levels of hazard control

The “levels of hazard control” is a method used to identify and rank safeguards to protect workers from hazards. They are arranged from the most effective to the least effective and are also called the hierarchy of hazard controls. The levels of hazard control include elimination, substitution, engineering controls, administrative controls and personal protective equipment. One must most often combine the methods of hazard control to provide the best protection for workers.

Elimination

The best way to control a hazard is to eliminate it and remove the danger. This can be done by changing a work process in a way that will get rid of a hazard. Examples include using a non-toxic chemical, having workers perform tasks at ground level rather than working at heights, stopping the use of noisy processes and many more.

Substitution

The next best way to control a hazard is to substitute something else in its place that would be non-hazardous or less hazardous to workers. Examples include replacing a toxic chemical with a non-toxic chemical or a less toxic chemical, switching to a process that uses less force, speed, temperature, or electrical current and many more.

Engineering controls

In cases where a hazard cannot be eliminated or substituted with a safer option, the next best method is to use an engineering control to prevent the hazard from reaching the worker. Examples of such approaches include using noise dampening technologies to reduce noise levels, enclosing a chemical process in a Plexiglas “glove box”, using mechanical lifting devices, using local exhaust ventilation that captures and carries away contaminants before they get in the breathing zone of workers.

Administrative controls

If engineering controls cannot be implemented right away, administrative controls should be considered. Administrative controls change the way work is done or give workers more information by providing workers with relevant procedures, training, or warnings. They're often used together with higher-level controls and include

1. Procedures such as equipment inspections, planned preventive maintenance, checklists, lockout/tagout/try-out, infection prevention and control practices, changing work schedules, pre- and post-task reviews, and rotation of workers.
2. Training on topics such as hazard communication, permit-required confined space entry, lockout/tagout/try-out, and safe work procedures.
3. Warnings such as signs, backup alarms, smoke detectors, computer messages, mirrors, horns, labels, and instructions.

Personal Protective Equipment

The use of personal protective equipment (PPE) is a way of controlling hazards by placing protective equipment directly on workers' bodies. Higher-level controls are not always feasible, and PPE might be needed in conjunction with other control measures to ensure the safety of workers. Examples of personal protective equipment include respirators, gloves, protective clothing, protective shoes, hard hats, goggles, and ear plugs.

Fig. 21.1 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.

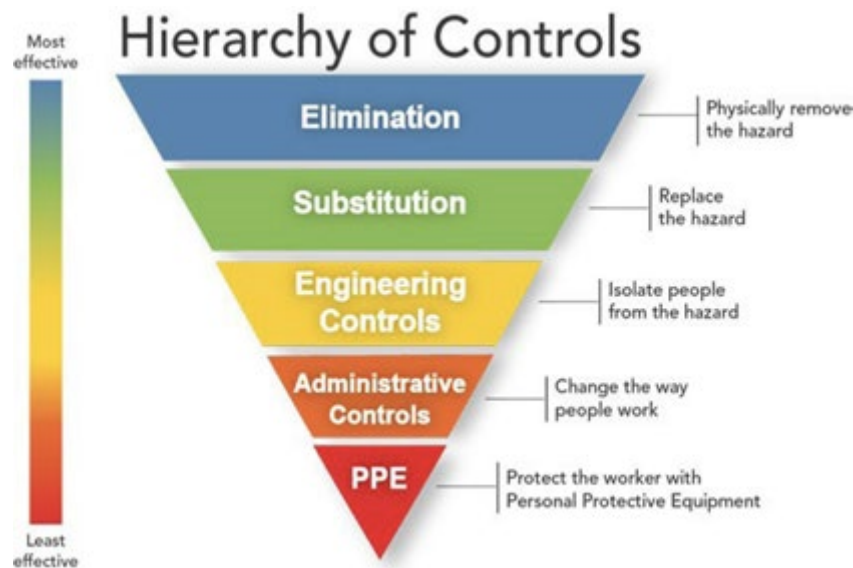


Fig. 21.1 Pyramid of the hierarchy of hazard control

Risk assessment and hazard control planning

Risk assessment and hazard control planning are essential components of maintaining a safe and productive manufacturing environment. These processes help identify potential hazards, evaluate the risks associated with them, and implement effective measures to control or eliminate those risks. Understanding these concepts is crucial for ensuring the safety and well-being of all workers.

Risk Assessment

Risk assessment is the systematic process of identifying hazards, evaluating the associated risks, and determining appropriate ways to eliminate or control the risks.

Steps in Risk Assessment

The following steps can be undertaken when performing risk assessment:

1. **Hazard Identification:** Recognise potential sources of harm.
2. **Risk Analysis:** Evaluate the likelihood and severity of harm from identified hazards.
3. **Risk Evaluation:** Determine the significance of the risk and prioritise the hazards.
4. **Risk Control:** Develop and implement strategies to manage the identified risks.

Techniques for Risk Assessment

The following techniques can be used to undertake risk assessment

1. **Checklists:** Use pre-designed lists to identify hazards in specific processes.
2. **What-If Analysis:** Brainstorm potential hazards by asking “what if” questions.
3. **Failure Mode and Effects Analysis (FMEA):** Analyse the potential failures in a system and their consequences.
4. **Hazard and Operability Study (HAZOP):** Examine deviations in operational processes that could lead to hazards.

Hazard Control Planning

Hazard control planning refers to the process of developing and implementing measures to minimise the risks associated with identified hazards in the workplace. This involves a systematic approach to ensure that all potential dangers are addressed appropriately to prevent accidents and injuries.

Steps in Hazard Control Planning

1. **Identify Hazards:** The first step is to identify potential hazards that could cause harm. This can include physical, chemical, biological, and ergonomic hazards.
2. **Assess Risks:** Evaluate the likelihood and severity of harm from each identified hazard. This helps prioritise which hazards need immediate attention.
3. **Develop Control Measures:** Determine the most effective ways to control or eliminate the hazards. Use the hierarchy of controls as a guide.
4. **Implement Controls:** Put the planned control measures into action. Ensure all employees are aware of and adhere to these controls.
5. **Monitor and Review:** Continuously monitor the effectiveness of the control measures and adjust as necessary. Regularly review the plan to ensure it remains effective and up to date.

Examples of Hazard Control Measures in Manufacturing

Table 21.1 shows typical hazard control measures as can be applied in a manufacturing environment.

Table 21.1: *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, faceshields, 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

1. **Protects Workers:** Ensures the health and safety of employees by reducing the risk of accidents and injuries.
2. **Legal Compliance:** Helps the company comply with occupational health and safety regulations to avoid legal penalties.
3. **Improves Efficiency:** Creates a safer work environment, which can lead to higher productivity and lower absenteeism.
4. **Enhances Reputation:** Demonstrates a commitment to worker safety, which can improve the company's reputation and employee morale.

Case Study: Hazard Control in a Manufacturing Environment

Manufacturing environments present various hazards, including physical, chemical, ergonomic, and biological risks. Implementing effective hazard control measures is crucial to ensure the safety and well-being of workers. This case study examines a mid-sized manufacturing facility that produces metal components for the automotive industry, detailing the hazard identification, assessment and control.

Company Background

1. **Company Name:** AutoParts Manufacturing Inc.
2. **Industry:** Automotive
3. **Location:** Kumasi
4. **Number of Employees:** 73

5. **Facility Size:** 8000 m²
6. **Products:** Metal components for automotive assembly

Hazard Identification

AutoParts Manufacturing Inc. conducted a comprehensive hazard assessment to identify potential risks in the facility. Key hazards identified include:

1. **Physical Hazards**
 - a. Machinery with moving parts (e.g., lathes, milling machines)
 - b. High noise levels
 - c. Exposure to high temperatures (e.g., during welding and forging)
2. **Chemical Hazards**
 - a. Use of solvents and lubricants
 - b. Welding fumes
 - c. Metal dust and particulates
3. **Ergonomic Hazards**
 - a. Repetitive tasks
 - b. Manual lifting and handling of heavy materials
 - c. Poor workstation design
4. **Biological Hazards**
 - a. Limited exposure to biological hazards, primarily through contact with contaminated surfaces or materials

Hazard Assessment

The risk assessment process involved the following steps:

1. **Task Analysis:** Detailed examination of tasks performed in each department to identify specific hazards associated with each job.
2. **Exposure Monitoring:** Measurement of noise levels, air quality (e.g., dust and fume concentrations), and ergonomic assessments.
3. **Health and Safety Audits:** Regular inspections and audits to identify potential hazards and ensure compliance with safety regulations.

Hazard Control Measures

Based on the hazard assessment, AutoParts Manufacturing Inc. implemented a range of control measures, following the hierarchy of controls: elimination, substitution, engineering controls, administrative controls, and personal protective equipment (PPE).

1. **Elimination**
 - a) Automated repetitive and hazardous tasks where possible, reducing the need for manual intervention.
 - b) Modified production processes to eliminate unnecessary steps that posed hazards.

2. Substitution

- a) Replaced hazardous solvents and lubricants with less toxic alternatives.
- b) Installed quieter machinery and equipment to reduce noise levels.

3. Engineering Controls

- a) Installed guards on all machinery with moving parts to prevent accidental contact.
- b) Upgraded ventilation systems to effectively remove welding fumes, dust, and other airborne contaminants.
- c) Redesigned workstations to improve ergonomics, including adjustable workbenches and lift-assist devices.

4. Administrative Controls

- a) Implemented comprehensive training programs on hazard recognition, safe work practices, and proper use of PPE.
- b) Introduced job rotation schedules to minimise repetitive strain injuries.
- c) Developed and enforced standard operating procedures (SOPs) for all tasks, with a focus on safety.

5. Personal Protective Equipment (PPE)

- a) Provided earplugs for employees exposed to high noise levels.
- b) Issued appropriate respirators for workers in areas with high concentrations of fumes or dust.
- c) Supplied gloves, safety glasses, and flame-resistant clothing to protect against physical and chemical hazards.

Practical Applications and Results

- 1. Noise Control:** Installation of soundproof enclosures around high-noise machinery and regular maintenance to ensure optimal operation. This resulted in the reduction of noise levels by 25%, decreasing the risk of hearing loss among workers.
- 2. Air Quality Improvement:** Installation of local exhaust ventilation systems at welding stations and dust collection systems in machining areas. This resulted in significant reduction in airborne contaminants, leading to improved respiratory health for employees.
- 3. Ergonomic Enhancements:** Introduction of height-adjustable workstations and mechanical lifting aids to reduce the physical strain on workers. This resulted in lower incidence of musculoskeletal disorders and increased productivity.
- 4. Chemical Safety:** Substitution of hazardous chemicals with safer alternatives and implementation of proper storage and handling procedures resulted in reduced exposure to toxic substances and fewer chemical-related incidents.
- 5. Safety Culture:** Regular safety meetings, incentive programs for reporting hazards, and continuous safety training. This resulted in increased employee engagement in safety practices and a noticeable decline in workplace accidents.

Learning Tasks

1. Learners write a report on the hazard control plans implemented in a manufacturing company.
2. Learners develop a hazard control plan for a local manufacturing company.

Pedagogical Exemplars

1. **Experiential learning:** In mixed-ability groups, let learners visit a manufacturing company and observe how risk assessment is performed and how hazard control plan is developed for a typical manufacturing environment. Let learners present a report on their findings using any format of their choice. Ensure peer-to-peer collaboration in the mixed-ability groups to foster exchange of ideas and provision of assistance to one another. This will promote skill development and peer-to-peer learning. Encourage proficient learners to develop their own hazard control plans based on the observations made in the manufacturing company.
2. **Collaborative learning:** Provide learners with role-playing scenario handouts, safety equipment and evaluation rubrics. Let learners in mixed-ability groups play the role of different stakeholders (such as safety officer, worker, manager etc.) in a manufacturing environment. Given different scenarios of a manufacturing environment (such as noisy environment, handling of toxic chemicals, using sharp end machinery, working in an environment that produces fumes etc.) to each group, learners develop and implement a hazard control plan for their scenario and perform their roles to demonstrate their hazard control measures for evaluation and feedback. Provide specific instructions and roles to learners to ensure that all learners participate in the activity. Foster peer-to-peer discussions to help learners who are less proficient to understand their role play. Encourage proficient learners to submit report on the role play activities.
3. **Experiential Learning:** Show learners a sample MSDS of a particular common chemical and let them identify the various important information about the chemical from the material. Learners discuss the various sections of an MSDS. Let them add to what others say and summarise their views using webbing, or similar. Provide specific instructions to the groups to guide the discussions and to prevent the possibility of only one learner doing all the talking. Encourage learners to simply and clearly articulate their points and listen to others during the discussions. Make room for non-vocal learners to contribute to the group discussions through writing.
4. **Talk for learning:** Let learners watch a demonstration video or read from a textbook on hazard control and planning in a typical manufacturing environment. Lead learners to discuss the levels of hazard control such as elimination, substitution, engineering controls, administrative controls, personal protective equipment. Offer additional resources, such as visual aids, to learners who may have difficulties understanding the concept to reinforce understanding the levels of hazard control. Also, encourage learners to engage in collaborative discussions, allowing for peer teaching and learning to promote deeper understanding of where they can share insights and perspectives on the levels of hazard control, allowing opportunities for peer teaching and learning, and promoting a deeper understanding of hazard control. Moderate the discussions to ensure that a few members in the class do not control the discussions. Encourage non-vocal learners to contribute to the discussions through writing.
5. **Research-based learning:** Learners in mixed-ability groups visit a local manufacturing company to observe their operations, potential risks and hazards and develop a hazard control plan for the local manufacturing company. Learners present their report to the class

for feedback. Ensure peer-to-peer collaboration in the mixed-ability groups to foster exchange of ideas and provision of assistance to one another. This will promote skill development and peer-to-peer learning. Encourage proficient learners to develop their own hazard control plans based on the observations made in the manufacturing company.

6. **Research-based learning:** Let learners in mixed-ability and gender groups research and produce an MSDS for a sample chemical substance and present their findings to the class and receive feedback. Assign specific roles to learners to ensure that all learners participate in the project and are challenged according to their understanding and skills.

Key Assessment

Assessment Level 1

1. What is a hazard?
2. Give an example of a hazard you might find in a manufacturing environment.
3. What is the first step in hazard control?
4. Why is it important to control hazards in a manufacturing environment?

Assessment Level 2

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. Explain what a risk assessment involves.
4. List two examples of engineering controls in hazard control.

Assessment Level 3

1. Given a scenario where there is a chemical spill in a factory, outline the steps you would take to control this hazard.
2. How would you conduct a risk assessment for a new piece of machinery in a manufacturing plant?
3. Create a basic hazard control plan for a small manufacturing workshop. Include identification of hazards, risk assessment, and control measures.
4. Explain how you would prioritise hazards if multiples of them are identified in a risk assessment.

Assessment Level 4

1. Evaluate the effectiveness of different hazard control measures in a specific manufacturing environment.
2. Compare and contrast the hazard control approaches that can be used in a chemical manufacturing industry and food processing industry.
3. Design a comprehensive hazard control program for an automotive parts manufacturing company. Include all necessary elements such as hazard identification, risk assessment, control measures, training, and monitoring.

HINT



The recommended mode of assessment for week 21 is **questioning**. Use the level 1 question 3 as a sample question.

WEEK 22

Learning Indicator: Analyse the effects that various manufacturing activities have on the environment (e.g., the effects of waste disposal, power consumption, processing of raw materials.)

Focal area: Effect of manufacturing on the environment

Introduction

Manufacturing activities are one of the primary sources of environmental pollution, contributing to the degradation of air, water, and soil quality. The pollution from manufacturing processes can have far-reaching consequences for ecosystems, human health, and the climate. The types of pollution caused by manufacturing include air pollution, water pollution and soil pollution.

Air Pollution

Air pollution from manufacturing occurs when harmful substances are released into the atmosphere during production processes. These pollutants can include gases, particulate matter, and toxic chemicals, which contribute to various environmental and health problems.

Types of Air Pollutants

1. **Carbon Dioxide (CO₂):** A major greenhouse gas emitted from the combustion of fossil fuels in industries such as steel manufacturing, cement production, and power generation.
2. **Sulphur Dioxide (SO₂):** Released from burning coal or oil in power plants and industrial processes like metal smelting. SO₂ contributes to acid rain, which can harm forests and aquatic ecosystems.
3. **Nitrogen Oxides (NO_x):** Emitted from vehicles, power plants, and industrial facilities. NO_x can lead to the formation of ground-level ozone and contribute to smog and respiratory problems.
4. **Volatile Organic Compounds (VOCs):** Emitted from the use of solvents, paints, and chemical manufacturing processes. VOCs contribute to the formation of smog and can cause various health issues, including headaches and respiratory irritation.
5. **Particulate Matter (PM):** Fine particles released from industries such as cement manufacturing, mining, and construction. PM can penetrate deep into the lungs and cause respiratory and cardiovascular diseases.

Examples of Air Pollution in Manufacturing

1. **Cement Manufacturing:** The production of cement releases significant amounts of CO₂, contributing to global warming. Additionally, dust and particulate matter are released during the grinding and heating processes, leading to air quality degradation.
2. **Oil Refineries:** Refineries emit SO₂, NO_x, and VOCs during the refining of crude oil into petroleum products. These emissions contribute to smog formation and acid rain.
3. **Steel Production:** The steel industry is a major emitter of CO₂ and particulate matter due to the combustion of coke and other fossil fuels in blast furnaces.

Water Pollution

Water pollution occurs when manufacturing processes discharge harmful substances into water bodies, including rivers, lakes, and oceans. These pollutants can include chemicals, heavy metals, and untreated wastewater, leading to the contamination of water sources and harm to aquatic life.

Types of Water Pollutants

1. **Heavy Metals:** Metals like lead, mercury, cadmium, and arsenic are released from industries such as metal plating, mining, and battery manufacturing. These metals are toxic to aquatic life and can accumulate in the food chain.
2. **Chemical Contaminants:** Industrial chemicals, including solvents, dyes, and pesticides, are often discharged into water bodies, leading to the contamination of drinking water sources and harm to aquatic ecosystems.
3. **Nutrients:** Excess nutrients like nitrogen and phosphorus are released from agricultural processing plants and food manufacturing facilities. These nutrients can cause eutrophication, leading to algal blooms and dead zones in water bodies.
4. **Oil and Grease:** Oil spills and leaks from manufacturing plants, particularly in the petroleum industry, can contaminate water bodies, harming aquatic life and coastal ecosystems.

Examples of Water Pollution in Manufacturing

1. **Textile Manufacturing:** Textile factories discharge dyes, chemicals, and heavy metals into nearby water bodies, leading to the contamination of rivers and lakes. The use of synthetic dyes and chemicals in textile processing can have toxic effects on aquatic life and pollute drinking water.
2. **Electronics Manufacturing:** Wastewater from electronics manufacturing often contains heavy metals like lead, mercury, and cadmium, which can contaminate water bodies and pose serious health risks to both humans and wildlife.
3. **Food Processing:** Wastewater from food processing plants often contains organic matter, nutrients, and chemicals, leading to water pollution and contributing to eutrophication in nearby rivers and lakes.

Soil Pollution

Soil pollution occurs when hazardous chemicals, heavy metals, and other pollutants from manufacturing processes contaminate the soil. This can result in the degradation of soil quality, harm to plant life, and the contamination of food crops.

Types of Soil Pollutants

1. **Heavy Metals:** Industries such as mining, battery manufacturing, and metal plating can release heavy metals like lead, cadmium, and arsenic into the soil. These metals can persist in the soil for long periods and can be absorbed by plants, entering the food chain.
2. **Pesticides and Herbicides:** Manufacturing of agricultural chemicals often leads to soil contamination due to spills, leaks, and improper disposal of these chemicals. These pollutants can harm soil microorganisms and reduce soil fertility.

3. **Industrial Waste:** Improper disposal of industrial waste, including chemicals, plastics, and hazardous materials, can lead to soil contamination and harm to plant and animal life.

Examples of Soil Pollution from Manufacturing

1. **Battery Manufacturing:** The production and disposal of batteries can lead to soil contamination with heavy metals like lead and cadmium. These metals can leach into the soil, posing risks to human health and the environment.
2. **Mining Activities:** Mining operations can result in soil contamination with heavy metals and chemicals used in the extraction process. This can lead to the destruction of vegetation and the degradation of the soil's ability to support plant life.
3. **Chemical Manufacturing:** Chemical factories may release hazardous waste and toxic chemicals into the soil, leading to long-term contamination. This can affect agricultural productivity and pose risks to human health through the consumption of contaminated crops.

Resource Depletion

Resource depletion refers to the exhaustion of natural resources due to human activities, particularly industrial and manufacturing processes. As manufacturing industries continue to grow to meet global demand, the consumption of raw materials and energy resources has intensified, leading to significant environmental consequences.

Raw Material Extraction

Manufacturing relies heavily on the extraction of raw materials from the earth, such as minerals, metals, fossil fuels, and biomass. The over-extraction of these resources can lead to the depletion of natural reserves, habitat destruction, and loss of biodiversity.

Types of Raw Material Depletion

1. **Minerals and Metals:** The mining industry extracts large quantities of minerals and metals, such as iron, copper, aluminium, and rare earth elements, for use in manufacturing products ranging from electronics to automobiles. Over-extraction can lead to the depletion of mineral reserves, making them less available for future generations.
2. **Fossil Fuels:** Manufacturing processes, especially those in energy-intensive industries like steel, cement, and chemical production, consume vast amounts of fossil fuels, including coal, oil, and natural gas. The excessive use of fossil fuels leads to the depletion of these non-renewable resources and contributes to environmental issues like climate change.
3. **Forests and Biomass:** Industries such as paper manufacturing, furniture production, and construction rely on wood and other biomass. Deforestation for raw material extraction leads to habitat loss, reduced carbon sequestration, and disruption of ecosystems.

Examples of Raw Material Depletion in Manufacturing

1. **Electronics Manufacturing:** The production of electronic devices requires significant amounts of rare earth metals like lithium, cobalt, and neodymium. These metals are extracted through intensive mining processes, which can deplete natural reserves and cause environmental degradation.

2. **Cement Production:** Cement manufacturing is a major consumer of limestone and other minerals. The continuous extraction of these materials can lead to the depletion of limestone reserves and the destruction of natural landscapes.
3. **Paper Industry:** The paper manufacturing industry heavily depends on wood as a raw material. Large-scale logging operations for paper production contribute to deforestation, leading to the depletion of forests and the loss of biodiversity.

Energy Consumption

Manufacturing processes are highly energy-intensive, relying on both renewable and non-renewable energy sources. The excessive use of energy, particularly from non-renewable sources, leads to the depletion of these resources and contributes to environmental degradation.

Types of Energy Depletion

1. **Non-Renewable Energy:** Manufacturing industries consume large amounts of fossil fuels (coal, oil, and natural gas) to power machinery, transportation, and production processes. The overuse of these non-renewable energy sources leads to their depletion and contributes to greenhouse gas emissions.
2. **Water Resources:** Some manufacturing processes, such as textile dyeing, food processing, and chemical production, consume significant amounts of water. Over-extraction of water resources, especially in water-scarce regions, can lead to the depletion of aquifers and the degradation of water ecosystems.
3. **Renewable Energy:** While renewable energy sources like solar, wind, and hydroelectric power are more sustainable, their deployment still requires significant land, materials, and energy, which can lead to resource depletion if not managed properly.

Examples of Energy Consumption in Manufacturing

1. **Steel Manufacturing:** The steel industry is one of the largest consumers of energy, primarily relying on coal and natural gas for production. The continuous use of fossil fuels in steel production leads to the depletion of these resources and contributes to air pollution and climate change.
2. **Textile Industry:** The textile industry is highly water-intensive, using large volumes of water for dyeing, printing, and finishing processes. In regions with limited water availability, this can lead to the depletion of local water resources and impact both human populations and ecosystems.
3. **Petrochemical Industry:** The production of plastics, fertilisers, and other chemicals in the petrochemical industry requires vast amounts of fossil fuels as both raw materials and energy sources. The continuous extraction and consumption of oil and natural gas contribute to the depletion of these non-renewable resources.

Land Use and Habitat Degradation

Manufacturing industries often require large areas of land for the construction of factories, mining operations, and waste disposal sites. The extensive use of land can lead to habitat degradation, loss of biodiversity, and changes in land use patterns.

Types of Land Use and Degradation

1. **Deforestation:** Manufacturing industries that rely on wood, such as paper and furniture production, contribute to deforestation. The clearing of forests for raw materials or to make space for industrial facilities can lead to the loss of habitat for countless species and reduce carbon sequestration.
2. **Land Degradation:** Mining and quarrying activities for raw material extraction can cause significant land degradation. The removal of topsoil, erosion, and contamination from mining operations can render the land unsuitable for agriculture or natural ecosystems.
3. **Urbanisation and Industrialisation:** The expansion of manufacturing industries often leads to urbanisation and the conversion of natural landscapes into industrial zones. This can result in the fragmentation of habitats, loss of agricultural land, and increased pressure on local resources.

Examples of Land Use and Habitat Degradation in Manufacturing

1. **Mining Operations:** The mining of metals like iron, copper, and bauxite requires large-scale land use, leading to deforestation, soil erosion, and habitat destruction. For example, bauxite mining in tropical regions has led to the deforestation of rainforests and the displacement of local communities.
2. **Oil and Gas Extraction:** The extraction of oil and natural gas often involves the clearing of land for drilling sites, pipelines, and infrastructure. This can lead to the destruction of natural habitats and increased risk of oil spills, which further harm the environment.
3. **Urban Sprawl:** The expansion of manufacturing facilities in urban areas can lead to the conversion of natural land into industrial zones. This urban sprawl can disrupt local ecosystems, reduce green spaces, and contribute to the heat island effect in cities.

Waste Generation and Management

Waste generation is a major by-product of manufacturing processes, leading to significant environmental impacts. The waste produced by manufacturing industries includes a wide range of materials, from solid and liquid waste to hazardous and non-hazardous substances. Effective waste management is crucial to mitigate the adverse effects on the environment, public health, and ecosystems.

Types of Waste Generated in Manufacturing

Manufacturing industries generate various types of waste depending on the processes and materials used. The primary types of waste include:

1. **Solid Waste:** This includes scrap materials, packaging waste, industrial by-products, and defective products. Solid waste can be non-hazardous or hazardous, depending on its chemical composition and potential environmental impact.
2. **Liquid Waste:** Manufacturing processes often produce liquid waste, such as wastewater, coolants, solvents, and cleaning agents. This waste may contain harmful chemicals, oils, and heavy metals, making it difficult to treat and dispose of safely.
3. **Gaseous Waste:** Emissions from manufacturing processes can include gases such as carbon dioxide (CO₂), sulphur dioxide (SO₂), nitrogen oxides (NO_x), volatile organic compounds

(VOCs), and particulate matter (PM). These emissions contribute to air pollution and have adverse effects on human health and the environment.

4. **Hazardous Waste:** Hazardous waste includes materials that are toxic, corrosive, flammable, or reactive. Examples include solvents, acids, heavy metals, and radioactive materials. Hazardous waste requires special handling, treatment, and disposal to prevent environmental contamination.
5. **E-Waste:** Electronic waste (e-waste) is generated by industries involved in the production of electronic devices and components. E-waste contains hazardous materials such as lead, mercury, cadmium, and brominated flame retardants, which can be harmful to the environment and human health if not properly managed.

Environmental Impacts of Waste Generation

The waste generated by manufacturing industries has various environmental impacts, including pollution, resource depletion, and ecosystem disruption. These impacts can be categorised based on the type of waste and its interaction with the environment:

1. **Land Pollution:** Manufacturing industries that produce solid waste, such as the textile, automotive, and construction sectors, often contribute to land pollution. Landfills used for waste disposal can contaminate soil and groundwater, especially if hazardous materials are not properly contained. Improper disposal of solid waste can lead to soil degradation, loss of arable land, and contamination of water sources. Land pollution also affects local biodiversity and can pose health risks to nearby communities.
2. **Water Pollution:** Industries like chemical manufacturing, oil refining, and metal plating generate liquid waste that can contaminate water bodies. For instance, wastewater from textile dyeing processes often contains toxic dyes, heavy metals, and organic pollutants that can harm aquatic ecosystems. Water pollution from industrial waste can lead to the degradation of freshwater and marine ecosystems, affecting aquatic life and human populations that rely on these water sources. Contaminated water can also lead to the bioaccumulation of toxins in the food chain.
3. **Air Pollution:** Manufacturing industries such as cement production, power generation, and petroleum refining release significant amounts of gaseous pollutants into the atmosphere. These include greenhouse gases (GHGs), such as CO₂ and methane, as well as harmful pollutants like SO₂, NO_x, and VOCs. Air pollution contributes to global warming, acid rain, and respiratory health problems in humans. It also affects vegetation and can lead to the formation of smog and ground-level ozone, which are harmful to both human health and the environment.
4. **Toxic Waste and Hazardous Substances:** The electronics industry generates large amounts of e-waste, which contains hazardous materials like lead, mercury, and cadmium. These substances can leach into the environment if not properly managed, leading to soil and water contamination. Hazardous waste poses significant risks to human health and the environment. It can cause long-term contamination of soil and water, leading to ecosystem damage and health issues such as cancer, neurological disorders, and reproductive problems.

Waste Management Strategies in Manufacturing

Effective waste management in manufacturing is essential to reduce environmental impact and promote sustainability. Waste management strategies can be categorised into the following approaches:

- 1. Waste Minimisation:** The goal of waste minimisation is to reduce the amount of waste generated at the source. This can be achieved through process optimisation, material substitution, and improved manufacturing techniques. A company in the electronics industry might redesign its products to use fewer hazardous materials or switch to more sustainable materials, thereby reducing the generation of e-waste.
- 2. Recycling and Reuse:** Recycling and reuse involve the recovery of materials from waste products to be used in new production processes. This reduces the demand for raw materials and minimises the environmental impact of waste disposal. For example, the automotive industry often recycles metals, plastics, and glass from end-of-life vehicles. These materials can be reused in the production of new vehicles, reducing the need for virgin materials.
- 3. Treatment and Disposal:** Waste that cannot be minimised, recycled, or reused must be treated to reduce its environmental impact before disposal. Treatment methods include incineration, neutralisation, and biological treatment. For instance, a chemical manufacturing plant might treat its wastewater to remove harmful chemicals before discharging it into a water body. This reduces the risk of water pollution and protects aquatic ecosystems.
- 4. Hazardous Waste Management:** Hazardous waste requires special handling, storage, and disposal methods to prevent environmental contamination. Companies must comply with regulations and use appropriate technologies to manage hazardous waste safely. For example, a pharmaceutical company that generates hazardous chemical waste may use specialised containment and disposal methods, such as secure landfills or incineration facilities, to prevent environmental contamination.
- 5. E-Waste Management:** The management of electronic waste involves the collection, recycling, and safe disposal of electronic products. This includes recovering valuable materials and safely disposing of hazardous components. An electronics manufacturer may implement an e-waste recycling program that collects used products from consumers, recycles valuable materials, and safely disposes of hazardous substances.

Energy Consumption and Emissions

Energy consumption and emissions are two significant aspects of manufacturing that have profound effects on the environment. Manufacturing processes typically require large amounts of energy, which is often sourced from fossil fuels, leading to the release of various pollutants into the atmosphere. These emissions contribute to global environmental issues, such as climate change, air pollution, and the depletion of natural resources.

Energy Consumption in Manufacturing

Manufacturing is an energy-intensive sector, with energy consumption varying significantly depending on the type of manufacturing process, the scale of production, and the materials used. The energy consumed in manufacturing can be categorised into different types:

- 1. Electricity:** Used to power machinery, lighting, heating, and cooling systems in manufacturing plants. Electricity is often generated from fossil fuels like coal, natural gas, or oil, which are major sources of carbon emissions.
- 2. Fossil Fuels:** Direct burning of fossil fuels, such as coal, oil, and natural gas, is common in manufacturing processes that require high temperatures, such as in steelmaking, cement production, and glass manufacturing. These fuels are a major source of greenhouse gas (GHG) emissions.

3. **Renewable Energy:** Some manufacturing industries are increasingly adopting renewable energy sources, such as solar, wind, and biomass, to reduce their carbon footprint. However, the adoption of renewable energy in manufacturing is still relatively low compared with fossil fuels.

Energy-Intensive Manufacturing Industries

1. **Steel Manufacturing:** The steel industry is one of the most energy-intensive industries, consuming large amounts of coal in blast furnaces to produce iron from iron ore. This process generates significant carbon dioxide (CO₂) emissions.
2. **Cement Production:** Cement manufacturing requires high temperatures for the calcination process, which involves heating limestone and other raw materials in kilns. This process is energy-intensive and contributes to substantial CO₂ emissions.
3. **Chemical Manufacturing:** The production of chemicals, such as ammonia, fertilisers, and plastics, requires significant amounts of energy, primarily from natural gas and other fossil fuels.

Emissions from Manufacturing

The emissions from manufacturing can be broadly classified into several categories, each with distinct environmental impacts:

1. Greenhouse Gas Emissions

- a. **Carbon Dioxide (CO₂):** The primary greenhouse gas emitted from the combustion of fossil fuels. It is the leading contributor to global warming and climate change.
- b. **Methane (CH₄):** Released during the extraction and transportation of fossil fuels, as well as from industrial processes like chemical manufacturing. Methane is a potent greenhouse gas with a global warming potential much higher than CO₂.
- c. **Nitrous Oxide (N₂O):** Emitted from industrial activities, including the production of fertilisers and chemicals. Nitrous oxide is a potent greenhouse gas with a long atmospheric lifespan.

2. Air Pollutants

- a. **Sulphur Dioxide (SO₂):** Produced from the burning of fossil fuels containing sulphur, such as coal and oil. SO₂ contributes to acid rain, which harms ecosystems, corrodes buildings, and affects human health.
- b. **Nitrogen Oxides (NO_x):** Emitted from combustion processes in manufacturing plants, particularly from high-temperature operations. NO_x contributes to the formation of ground-level ozone and smog, which have detrimental effects on respiratory health.
- c. **Volatile Organic Compounds (VOCs):** Released from the use of solvents, paints, and other chemicals in manufacturing. VOCs contribute to the formation of ground-level ozone and smog and can cause respiratory and neurological health problems.
- d. **Particulate Matter (PM):** Tiny particles emitted from industrial processes, combustion, and material handling. PM can penetrate deep into the lungs and bloodstream, causing respiratory and cardiovascular diseases.

3. Toxic and Hazardous Emissions

- a. **Heavy Metals:** Industries such as metal plating, battery manufacturing, and electronics production release heavy metals like lead, mercury, and cadmium into the environment. These metals are toxic and can accumulate in the food chain, posing serious health risks.
- b. **Dioxins and Furans:** By-products of industrial processes, such as waste incineration and chemical manufacturing. These compounds are highly toxic and can cause cancer, reproductive and developmental problems, and damage to the immune system.
- c. **Persistent Organic Pollutants (POPs):** Chemicals used in industrial processes that persist in the environment and can cause adverse effects to human health and ecosystems. Examples include polychlorinated biphenyls (PCBs) and certain pesticides.

Examples of Emissions from Specific Manufacturing Industries

1. **Cement Manufacturing:** The cement industry is one of the largest emitters of CO₂ due to the calcination process and the burning of fossil fuels in kilns. Additionally, cement plants emit particulate matter, sulphur dioxide, and nitrogen oxides, contributing to air pollution and respiratory health issues.
2. **Petrochemical Industry:** The production of plastics, fertilisers, and other chemicals in the petrochemical industry results in the release of volatile organic compounds, nitrogen oxides, and hazardous air pollutants. These emissions contribute to smog formation, respiratory problems, and environmental contamination.
3. **Automobile Manufacturing:** The automotive industry emits significant amounts of CO₂ and other greenhouse gases from energy-intensive manufacturing processes. Additionally, the use of solvents, paints, and coatings in vehicle production releases VOCs and hazardous air pollutants.
4. **Pulp and Paper Industry:** This industry is a major source of air and water pollution. The pulping process releases sulphur compounds, particulate matter, and VOCs into the atmosphere, while wastewater from paper mills can contaminate water bodies with chemicals, organic pollutants, and heavy metals.

Climate Change Mitigation and Adaptation

Mitigation strategies in manufacturing aim to reduce the sector's greenhouse gas emissions and overall environmental impact. These strategies include improving energy efficiency, adopting cleaner technologies, and transitioning to renewable energy sources.

1. **Energy Efficiency Improvements:** Enhancing energy efficiency in manufacturing processes can significantly reduce GHG emissions. This can be achieved through upgrading equipment, optimising production processes, and improving facility insulation. For instance, the automotive industry has implemented energy-efficient practices such as using LED lighting in factories, optimising heating and cooling systems, and employing energy management systems to monitor and reduce energy consumption.
2. **Renewable Energy Adoption:** Transitioning to renewable energy sources, such as solar, wind, and hydroelectric power, can significantly reduce the carbon footprint of manufacturing operations.

3. **Carbon Capture and Storage (CCS):** CCS technologies capture CO₂ emissions from manufacturing processes and store them underground or use them in other applications, preventing them from entering the atmosphere.
4. **Waste Reduction and Recycling:** Reducing waste and increasing recycling rates in manufacturing can lower the demand for raw materials and the energy required to produce them, thereby reducing GHG emissions. For instance, the paper manufacturing industry can use recycled paper in their production processes. This reduces the need for virgin pulp, saving energy and lowering emissions.

Climate Change Adaptation Strategies in Manufacturing

As climate change impacts become more pronounced, manufacturing companies must adopt adaptation strategies to ensure the resilience of their operations. Adaptation involves adjusting processes, infrastructure, and supply chains to cope with changing environmental conditions.

1. **Resilient Supply Chains:** Climate change can disrupt supply chains by affecting the availability of raw materials, transportation routes, and production schedules. Manufacturing companies must develop resilient supply chains that can adapt to these changes.
2. **Infrastructure Adaptation:** Manufacturing facilities may need to be retrofitted or relocated to cope with climate-related risks, such as rising sea levels, extreme weather events, or increased temperatures.
3. **Water Management:** Water scarcity is a growing concern due to climate change, and manufacturing companies must adapt by improving water use efficiency, recycling wastewater, and sourcing water from sustainable sources.
4. **Flexible Production Systems:** Manufacturing companies can develop flexible production systems that can quickly adapt to changing environmental conditions or shifts in demand due to climate change.

Learning Tasks

1. Learners use mappings to illustrate the effects of manufacturing on the environment.
2. Learners write reports on climate change mitigation and adaptation strategies to ensure sustainable manufacturing.

Pedagogical Exemplars

Experiential Learning: Take learners on a tour to different local manufacturing companies to observe the effect the manufacturing activities have on the immediate environment. Find out about the waste management system; types of raw materials used and products of that industry and relate their findings to environmental safety. Let learners report on the effect of the various manufacturing industries on the environment using flashcards, charts, mappings or any other suitable method familiar to learners. Offer additional support to learners who may not understand the concept while encouraging learners who easily understand the concept to provide more detailed reports. Also, consider and make room for persons with a disability during the tour.

Talk for learning: Let learners read from textbooks, charts or internet sources on climate change mitigation and adaptation strategies to ensure a safe and sustainable manufacturing environment. Lead learners to discuss the strategies that can be used to mitigate the effect of manufacturing on climate change, including the positive and negative activities of various

manufacturing activities on the environment. Have learners write reports on climate change mitigation and adaptation strategies in the manufacturing industries. Learners may struggle to articulate their thoughts or express themselves clearly during discussions. Therefore, provide clear instructions on effective communication skills, such as active listening, paraphrasing, and using evidence to support their views. Model effective communication and provide constructive feedback to help students improve their verbal and non-verbal communication skills. Let learners who have difficulties contributing to the oral discussions write their thoughts to be shared with the class. Also, encourage proficient learners to write detailed reports on climate change mitigation and adaptation strategies for sustainable manufacturing.

Key Assessment

Assessment Level 1

1. What is pollution?
2. List two ways in which manufacturing can harm the environment.
3. What does “waste generation” mean in the context of manufacturing?

Assessment Level 2

1. Explain how manufacturing can lead to air pollution.
2. Describe one way in which manufacturing can contribute to resource depletion.
3. How does waste from manufacturing affect water bodies?

Assessment Level 3

1. Compare the effects of energy consumption and emissions from a cement manufacturing company and a food processing company.
2. How can manufacturing companies reduce their impact on biodiversity? Provide two examples.
3. Analyse how climate change can be influenced by manufacturing activities. What role do emissions play?

Assessment Level 4

1. Evaluate the effectiveness of current waste management strategies in manufacturing industries. What improvements can be made?
2. Discuss the long-term impact of manufacturing on ecosystems if no changes are made to current practices.
3. Propose a sustainable manufacturing plan that minimises resource depletion and pollution. Justify your choices.
4. Read the case below

A textile manufacturing plant near a river has been discharging untreated wastewater into the river for years. The wastewater contains dyes, chemicals, and heavy metals from the dyeing and finishing processes. Over time, the water has become discoloured, and fish populations have significantly declined. Local farmers now struggle with poor crop yields, as the contaminated water is used for irrigation. Residents report health problems, such as skin rashes and stomach issues, due to using the polluted water for drinking and bathing.

Despite existing wastewater treatment facilities at the plant, they are outdated and ineffective, leading to severe environmental and public health concerns

How does the discharge of untreated wastewater from the textile manufacturing plant affect the river's water quality, local ecosystems, and public health, and what actions should be taken to address these issues?

HINT



*The recommended mode of assessment for week 22 is **case study**. Use the level 4 question 4 as a sample question.*

WEEK 23

Learning Indicator: Explain the benefits of using environmentally friendly processes and products in the manufacturing process

Focal Area: Benefits of using environmentally friendly processes and products in manufacturing

Introduction

As industries around the world strive to meet the challenges of today's world, the importance of environmentally friendly processes and products in manufacturing has increased. These practices do not only protect the environment, but they also offer significant benefits to businesses, workers, and society. The adoption of sustainable manufacturing methods, will help companies reduce their environmental footprint, cut costs, enhance worker safety, and build resilience against future risks.

Reduced Environmental Impacts

Environmentally friendly manufacturing processes and products are designed to minimise harm to the environment. These processes reduce waste, lower emissions, and conserve natural resources, which in turn help mitigate climate change, protect ecosystems, and preserve biodiversity. By reducing the environmental footprint, manufacturing companies can contribute to global sustainability goals and avoid penalties associated with environmental regulations. For example, using renewable energy sources like solar or wind power in manufacturing can significantly reduce greenhouse gas emissions compared to relying on fossil fuels. Additionally, adopting practices like recycling and reusing materials reduces the need for raw resource extraction, thereby decreasing environmental degradation.

Cost Savings and Efficiency

Implementing environmentally friendly practices can lead to significant cost savings and increased efficiency in manufacturing. While the initial investment in green technologies may be higher, the long-term benefits often outweigh these costs. For instance, energy-efficient machinery consumes less power, resulting in lower utility bills. Similarly, reducing waste and optimising resource use can decrease material costs and minimise disposal expenses. Lean manufacturing techniques, which emphasise waste reduction and process optimisation, are examples of environmentally friendly practices that enhance efficiency. By improving operational efficiency, manufacturing companies can increase their profitability while also reducing their environmental impact.

Health and Safety

Environmentally friendly manufacturing processes often involve the use of non-toxic materials and safer practices, which can lead to improved health and safety for workers and consumers. For instance, replacing hazardous chemicals with safer alternatives reduces the risk of exposure to harmful substances, leading to fewer workplace accidents and health issues. Moreover, the production of environmentally friendly products, such as biodegradable packaging or non-toxic cleaning agents, reduces the potential for harm to consumers and the environment. This focus

on health and safety can also enhance a company's reputation, leading to greater customer trust and loyalty.

Resilience and Risk Management

Adopting environmentally friendly processes can increase a company's resilience and improve its risk management. Sustainable practices often involve the diversification of energy sources, materials, and supply chains, making companies less vulnerable to disruptions caused by resource shortages, regulatory changes, or environmental disasters. For example, companies that invest in renewable energy are less susceptible to fluctuations in fossil fuel prices. Additionally, by reducing their reliance on scarce or environmentally damaging resources, companies can better navigate future regulatory changes and avoid supply chain disruptions. This resilience can help companies maintain steady operations and remain competitive in an increasingly sustainability-focused market.

Learning Tasks

1. Learners use flashcards, mappings and charts to illustrate the benefits of using environmentally friendly processes and products in manufacturing.
2. Learners write reports on the benefits of using environmentally friendly processes and products in manufacturing.

Pedagogical Exemplars

1. **Experiential Learning:** Let learners watch videos of manufacturing companies that use environmentally friendly processes and products and that of those who use conventional processes and products. Let learners observe the effect of the processes of these manufacturing companies on the environment and the health of workers and use flashcards, charts and mappings to illustrate same. Offer additional support to learners who may not understand while encouraging learners who easily understand to provide more detailed report.
2. **Talk for learning:** Let learners read from textbooks, charts or internet sources on the benefits of using environmentally friendly processes and products in manufacturing. Lead learners to discuss these benefits and have them write reports on the benefits of using environmentally friendly processes and products in manufacturing. Therefore, provide clear instructions on effective communication skills, such as active listening, paraphrasing, and using evidence to support their views to ensure a fruitful discussion. Let learners who have difficulties contributing orally write their thoughts. Also, encourage proficient learners to write detailed reports on climate change mitigation and adaptation strategies for sustainable manufacturing.

Key Assessment

Assessment Level 1

1. What does “environmentally friendly” mean in the context of manufacturing?
2. List two examples of environmentally friendly processes or products used in manufacturing.
3. Why is it important for manufacturers to consider the environment when producing goods?

Assessment Level 2

1. Explain how using environmentally friendly processes can lead to cost savings for a manufacturing company.

2. Discuss how the adoption of environmentally friendly products in manufacturing can improve worker health and safety.
3. Compare the environmental impacts of traditional manufacturing processes with those of sustainable processes.

Assessment Level 3

1. Propose a strategy for a manufacturing company to transition to environmentally friendly processes while maintaining efficiency.
2. Critically assess the role of risk management in adopting environmentally friendly manufacturing processes.
3. As a production engineer in a manufacturing company, how would you assess and manage waste generation in a production process? Discuss the methods and tools you would use to evaluate and reduce waste.

HINT



*The recommended mode of assessment for week 23 is **puppet show**. Use the level 3 question 3 as a sample question.*

WEEK 24

Learning Indicator: Describe recent trends in the local manufacturing industry (e.g., globalisation, rise in energy costs, increase in environmental awareness) and their effect on the local community or the nation

Focal Area: Research trends in the local manufacturing industry

Introduction

The local manufacturing industry is continuously evolving due to various global and technological factors. These changes are driven by factors such as globalisation, the rise in energy costs, increased environmental awareness, advancements in manufacturing technologies, the push for sustainable practices, and the shift towards digitalisation and Industry 4.0. This section discusses these key factors and their implications for the local manufacturing sector.

Globalisation

Globalisation has fundamentally altered the landscape of the manufacturing industry. Local manufacturers are no longer confined to domestic markets but now compete on a global stage. This increased competition has forced local manufacturers to enhance efficiency, reduce production costs, and maintain high product quality to remain competitive. In recent times, local manufacturers focus on optimising supply chains to ensure timely delivery and cost-efficiency. They are increasingly integrating global supply chains, requiring advanced logistics and inventory management systems. Additionally, to reduce costs, local manufacturers often outsource production processes to countries with lower labour costs. This trend has led to research on maintaining quality control and minimising risks associated with outsourcing. Furthermore, adhering to international quality and environmental standards (such as ISO certifications) is crucial for local manufacturers to access global markets. Research in this area examines the impact of these standards on local manufacturing practices and product design.

Rise in Energy Costs

The rise in energy costs poses a significant challenge for manufacturers, particularly in energy-intensive industries. As energy prices fluctuate and environmental regulations become stricter, manufacturers are under pressure to adopt more energy-efficient processes. Local manufacturers are, therefore, focusing on developing manufacturing processes that consume less energy. This includes the use of advanced materials that require less energy to process and the optimisation of existing manufacturing technologies. The exploration of renewable energy sources, such as solar and wind, for manufacturing operations is also a growing area. This trend is driven by the need to reduce dependency on fossil fuels and mitigate the impact of rising energy costs.

Increase in Environmental Awareness

Environmental awareness among consumers, governments, and manufacturers has led to significant changes in manufacturing practices. As a result, environmental sustainability has become a priority in the industry. Local manufacturers are focused on reducing the environmental impact of manufacturing through cleaner production techniques. This includes minimising waste, reducing emissions, and using non-toxic materials. There is also an increasing emphasis

on designing products that are environmentally friendly throughout their lifecycle, from raw material extraction to end-of-life disposal. This includes the use of recyclable materials and the design of products that are easier to disassemble and recycle. Furthermore, compliance with environmental regulations has become a necessity. Manufacturers must adapt to evolving environmental laws and standards, which often require significant changes in production processes and materials.

Advanced Manufacturing Technologies

Technological advancements are revolutionising the manufacturing industry. Advanced 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 use of robotics and automated systems in manufacturing has led to significant increases in productivity and reductions in labour costs. Additive manufacturing allows for the creation of complex geometries that would be impossible or cost-prohibitive with traditional manufacturing methods. Manufacturers are exploring the application of 3D printing in various industries. Furthermore, the development of new materials with enhanced properties, such as lightweight composites and high-strength alloys is important for improving the performance and efficiency of manufactured products.

Sustainable Manufacturing

This is concerned with creating products in a manner that reduces negative environmental impacts while conserving energy and natural resources. It also aims to ensure the safety of workers and communities and to maintain economic viability. Most manufacturing companies, therefore, perform lifecycle analysis to understand the environmental impacts of a product throughout its entire lifecycle ie. from raw material extraction to production, use, and disposal. This helps in the identification of opportunities to reduce the environmental footprint at each stage. Further research attention is given to minimising the use of raw materials and energy in the manufacturing process by developing processes that produce less waste, and the recycling of materials within the production cycle to ensure resource efficiency. Additionally, sustainable manufacturing is often linked with corporate social responsibility initiatives, where companies commit to ethical practices that benefit society and the environment.

Digitalisation and Industry 4.0

The digitalisation of manufacturing, often referred to as Industry 4.0, involves the integration of digital technologies into manufacturing processes. This trend 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. The internet of Things (IoT) helps connect machines, devices, and systems within a manufacturing environment, enabling real-time monitoring and control to ensure predictive maintenance, quality control, and process optimisation. Big data and analytics help in the use of the vast amount of data generated by digital manufacturing systems to improve production efficiency, reduce downtime, and enhance product quality. This involves the use of advanced analytics techniques, such as machine learning and artificial intelligence, to derive actionable insights from data. Furthermore, smart manufacturing involves the use of digital technologies to create highly flexible, efficient, and sustainable production systems. It involves the development of smart factories that can quickly adapt to changes in demand and production requirements.

Learning Tasks

1. Learners write reports on the research trends of the manufacturing companies in the locality.
2. Learners use flashcards, mappings and charts to illustrate the benefits of research in manufacturing.

Pedagogical Exemplars

1. **Experiential Learning:** Let learners visit research and development centres of some manufacturing companies in the community to familiarise themselves with the research works they are undertaking to enhance manufacturing. Let learners in mixed-ability groups write reports on their observations after the trip, indicating the research these companies are undertaking and how they will improve the local manufacturing sector. Allow learners to select their preferred mode of presentation. Offer additional support to learners who may not understand the concept while encouraging learners who easily understand to provide individual reports.
2. **Talk for learning:** Let learners read from textbooks, charts or internet sources on the benefits of research in improving the local manufacturing industry. Lead learners to discuss these benefits and recent trends and have them write reports on them, focusing on the effects of those trends on the local community and the nation as a whole, the rise in energy costs, the increase in environmental awareness, advanced manufacturing technologies, sustainable manufacturing, digitalisation and Industry 4.0. Provide clear instructions to ensure that few learners do not control the discussion. Encourage learners who have difficulties contributing orally to write their contributions to be read to the class. Also, encourage proficient learners to write detailed reports on climate change mitigation and adaptation strategies for sustainable manufacturing.
3. **Research-based learning:** Let learners in mixed-ability groups read from the library, internet sources or textbooks on the benefit of research in boosting the local manufacturing industry. Let learners write a report using flashcards, mappings and charts to illustrate these benefits. Provide clear instructions and responsibilities to learners to ensure that all learners partake in the assignment. Ensure that less proficient learners in each group receive help from their colleagues and encourage proficient learners to write detailed reports for publication in the school's magazine.

Key Assessment

Assessment Level 1

1. What is globalisation, and how does it impact local manufacturing?
2. Name one benefit of research in sustainable manufacturing.

Assessment Level 2

1. Explain how rising energy costs influence research in manufacturing.
2. Describe the role of digitalisation in modern manufacturing.

Assessment Level 3

1. Analyse the potential impact of advanced manufacturing technologies on a local manufacturing company.

2. Discuss how research in environmental awareness has led to changes in manufacturing practices. Provide an example.

Assessment Level 4

1. Evaluate the long-term benefits of sustainable manufacturing research on both the environment and the economy.
2. Propose a research project that could help a local manufacturing company adapt to Industry 4.0 trends. Explain its potential benefits.

HINT



- *The recommended mode of assessment for week 24 is **End of second semester examination**.*
- *Refer to Appendix G at the end of this section for Table of specification.*

Review of Section 7

This section introduced learners to 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. The important lessons learnt from the section are summarised below:

1. Levels of hazard control include elimination, substitution, engineering controls, administrative controls, and personal protective equipment.
2. 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.
3. 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.
4. Various research that focuses on globalisation, reduction in energy costs, increased environmental awareness, advanced manufacturing technologies. sustainable manufacturing. digitalisation and industry 4.0 are being undertaken by local manufacturing industries to ensure sustainable manufacturing.

Marking scheme for the Questioning Assessment & Rubrics for the Case Study Assessment.

Marking Scheme for Questioning

The correct response is “. Elimination”. Effort to modified production processes to eliminate unnecessary factors that posed hazards, etc.

Rubrics for the Case Study Assessment

Criteria	Exemplary (4 points)	Proficient (3 points)	Satisfactory (2 points)	Needs Improvement (1 point)
Understanding Waste Hazards	Demonstrates a deep understanding of multiple waste hazards from manufacturing, including chemical pollutants (e.g., heavy metals, solvents), nutrient overloads (e.g., phosphorus), and thermal pollution. Provides clear examples of each hazard type.	Identifies a range of hazards but may lack depth in explaining specific types of pollutants (e.g., doesn't explain the impact of heavy metals in detail) or their sources.	Shows basic understanding of waste hazards but provides few examples or fails to distinguish between types of pollutants (e.g., mixing all pollutants together).	Fails to identify key waste hazards or provides incorrect or overly simplistic explanations of pollutants and their types.
Effects of Waste	Provides a comprehensive analysis of how manufacturing waste impacts aquatic ecosystems (e.g., loss of biodiversity, eutrophication, habitat degradation) and human health (e.g., waterborne diseases like cholera, heavy metal poisoning, long-term cancers). Uses specific examples and data.	Discusses the effects of waste on ecosystems and human health but lacks specific examples or detailed explanations (e.g., only mentions "diseases" without specifics).	Mentions the effects on water bodies but lacks depth in the discussion or fails to link waste directly to specific environmental and health impacts (e.g., generalised impacts without examples).	Fails to discuss the effects of waste on ecosystems and human health or provides incorrect information.
Proposed Control Measures	Proposes highly effective, detailed control measures for each identified hazard, such as advanced treatment systems (e.g., reverse osmosis, activated carbon filters), industrial recycling initiatives, and compliance with strict regulatory standards (e.g., EU environmental directives). Explains how each measure will mitigate specific hazards.	Suggests reasonable control measures but lacks specificity in how these measures will address specific hazards (e.g., general references to "better treatment" without details).	Provides basic control measures (e.g., "reduce waste" or "treat water") but lacks detail or doesn't connect them to the specific hazards identified earlier.	Fails to propose practical or relevant control measures, or provides vague recommendations without explanation or connection to specific waste hazards.

Criteria	Exemplary (4 points)	Proficient (3 points)	Satisfactory (2 points)	Needs Improvement (1 point)
Recommendations	Provides clear, actionable recommendations such as strict enforcement of waste management protocols, investment in advanced treatment technologies (e.g., biological treatment, chemical precipitation), promoting cleaner production practices (e.g., zero waste production), and enhancing regulatory oversight (e.g., stricter pollution limits). Justifies recommendations with solid reasoning and clear examples.	Provides valid recommendations such as improving treatment systems or enforcing regulations but lacks detailed justifications or clear action plans.	Suggests basic recommendations (e.g., "improve waste management") without detailed explanation or clear steps for implementation. May fail to fully address the problem.	Fails to propose meaningful or actionable recommendations, or offers recommendations that are not relevant to the issue of manufacturing waste.
Clarity and Structure of Argument	The response is exceptionally clear, well-organised, and logically structured. Each point is supported by detailed examples and evidence, with smooth transitions and no ambiguity.	The argument is generally well-organised but may have minor clarity issues or gaps in linking evidence to claims. Some points may not be fully elaborated.	The argument lacks clear organisation or coherence in some areas. Some points are weakly supported or unclear, making the response harder to follow.	The argument is poorly organised, lacking clear structure. Key points are either missing, unsupported, or overly vague, making it difficult to understand the response.

Rubric for the Puppet Show Assessment (Report on Waste Generation in Manufacturing)

Criteria	Excellent (5)	Very Good (4)	Good (3))	Fair (2)
Understanding of Waste Generation	Clearly defines waste as excess raw materials, defective products, off-cuts, and damaged goods that do not contribute to the final product...	Defines waste as excess raw materials, defective products, and off-cuts.	Basic definition of waste as excess materials and damaged products.	Vague or incomplete definition of waste as wasted materials,
Type of Waste Identified and Analysed	. Provides clear examples overproduction of parts, excess scrap, and poor material handling practices, with clear links to increased costs and resource depletion.	Identifies most types of waste as scrap material and damaged products, but the connection to costs and resource depletion was missing	Provides waste as scraps but no connection to costs or production efficiency.	Fails to identify key waste types or provides generic examples
Relevance of Points to the Manufacturing Context	All points are directly relevant to the manufacturing process, illustrating how each waste type contributes to increased costs, delayed production, and environmental damage.	Most points are relevant to manufacturing but may lack strong connection to costs, efficiency, or environmental sustainability.	Some points are relevant but loosely connected to manufacturing practices. Focus on general waste, with limited manufacturing context.	Points fail to connect to the manufacturing context and waste generation.
Effectiveness of Examples in Illustrating the Concept	Provides clear, real-world examples of waste on costs and production efficiency (e.g., overproduction causing material waste or energy inefficiencies leading to higher costs).	Good examples, but some lack direct relevance or depth in demonstrating their impact on costs or efficiency.	Provides weak examples that are not clearly tied to waste generation or its effects on costs and efficiency.	No examples, or examples are irrelevant and do not show the impact of waste on manufacturing processes.
Application of Lean Manufacturing and Waste Reduction Strategies	Clearly explains how Lean Manufacturing principles like 5S, Kaizen, JIT, and Kanban help eliminate material, time, and energy waste. Demonstrates specific outcomes (e.g., reduced downtime, material savings, energy optimisation).	Mentions Lean principles, but with limited examples or detailed explanation of how they reduce waste in practice.	Mentions Lean principles but does not fully explain how they reduce waste or improve efficiency. Lacks real-world application or specific examples.	Does not mention Lean principles or lacks any detailed strategy for reducing waste in manufacturing.



APPENDIX G: TABLE OF TEST SPECIFICATION (END OF SECOND SEMESTER EXAMINATION)

Week	Focal Area	Type of Question	Depth of Knowledge				
			L1	L2	L3	L4	Total
13	Importance of AutoCAD in modelling	Multiple Choice	2	1	1		4
14	Creating 2D and 3D models using AutoCAD	Multiple Choice Theory	2	2	1		4 1
15	F1. Difference between measuring instruments F2. Using measuring tools to measure work pieces	Multiple Choice	1	2	1		4
16	F1. Difference between manual hand tools and power hand tools Introduction. F2, Application of hand tools in manufacturing	Multiple Choice	1	2	1		4
17	Importance of casting in manufacturing engineering products	Multiple Choice Theory	1	2	1 1		4 1
18	Sand casting process	Multiple Choice Theory	2	1	1		3 1
19	F1. Non-permanent joining processes F2. Permanent joining processes	Multiple Choice Theory	1	1	1 1		3 1
20	Join components using screw, bolt and nut and welding processes	Multiple Choice Theory	1	2	1 1		4 1
21	Types of hazard controls	Multiple Choice	1	1	1		3
22	Effect of manufacturing on the environment	Multiple Choice	2	1		1	4
23	Benefits of using environmentally friendly processes and products in manufacturing.	Multiple Choice	1	1	1		3
Total Multiple Choice			15	15	10	0	40
Theory			0	0	4	1	5

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