Manufacturing Engineering

Year 1

SECTION

2

PROPERTIES OF MATERIALS

MATERIALS FOR MANUFACTURING

Properties of Materials

Introduction

In the field of manufacturing, selecting the right material for a given application is crucial; hence, understanding the properties of materials is fundamental. The characteristics of materials determine their suitability for different applications, influencing performance, durability, and efficiency. In this section, we will explore various properties that materials possess, including thermal, electrical, mechanical, and magnetic properties.

Thermal properties, such as thermal conductivity and specific heat capacity, are essential for managing heat in products. Electrical properties, including conductivity and resistivity, play a crucial role in the functioning of electronic devices. Mechanical properties, such as strength and ductility, determine how materials respond to forces, which is vital in construction and machinery. Lastly, magnetic properties, like permeability and retentivity, are important for applications involving magnetic fields.

By understanding these properties, learners will gain the knowledge needed to evaluate and select appropriate materials for different manufacturing tasks, ensuring that products are designed and produced to meet specific performance and safety standards.

Learning Indicators

- Explain thermal conductivity, specific heat capacity, thermal expansion, melting point, and thermal diffusivity as thermal properties of materials.
- Explain electrical conductivity, electrical resistivity, dielectric strength, and temperature coefficient of resistance as electrical properties of materials.
- Explain hardness, brittleness, ductility, strength, malleability, toughness, elasticity and plasticity as mechanical properties of materials.
- Explain permeability, retentivity, and reluctance as magnetic properties of materials.

Key Ideas

- The thermal conductivity of a material is a measure of how easily heat flows through it, while the specific heat capacity indicates how much energy is needed to raise the unit mass of a material by one degree Celsius.
- The melting point measures the stability of a material when heated, while thermal expansion describes how a material's size changes when heated or cooled.
- The thermal diffusivity of a material measures how heat spreads through it based on its level of thermal conductivity and specific heat capacity.
- Electrical properties refer to how materials behave in the presence of an electric current or electric field. Materials have different abilities in relation to electricity; some materials

allow current to flow through them serving as conductors while others on the other hand, prevent the flow of current. Knowledge of these properties helps select materials for electrical applications. Electrical conductivity, electrical resistivity, dielectric strength, and temperature coefficient of resistance are examples of the electrical properties of materials.

- Mechanical properties of materials are the characteristics that are seen in a material when a load or a force is applied to it. These properties determine how a material responds to different types of loads. They are essential in designing and analysing mechanical components, structures, and systems.
- Magnetic properties refer to the ability of a material to become magnetised (give magnetic properties to a material or to strongly respond) when exposed to an applied magnetic field. Magnetic materials can be classified into ferromagnetic, diamagnetic, and paramagnetic materials, with each type exhibiting different varying and behaviours in relation to magnetism. Magnetic properties are important for engineering applications that involve magnetic fields.

PROPERTIES OF MATERIALS

In this lesson, you will explore the thermal properties of materials. We have all encountered objects that are hot, warm, or cold at some point. This lesson focuses on understanding why materials heat up or cool down when exposed to heat sources. Thermal properties describe how materials absorb, transfer, and retain heat. Key thermal properties include thermal conductivity, specific heat capacity, thermal expansion, melting point, and thermal diffusivity.

A thorough understanding of these thermal properties is essential for future engineers, enabling them to understand how materials behave in different thermal conditions. This knowledge is crucial for selecting materials in manufacturing processes. Now, let's delve deeper into the thermal properties of materials commonly used in our communities and beyond.

Thermal Properties of Materials

Understanding the thermal properties of materials helps material scientists know the material's behaviour when exposed to heat and develop techniques for improving materials for existing and future applications. Some of the thermal properties include thermal conductivity, specific heat transfer, thermal expansion, and thermal diffusivity.

Thermal Conductivity

Thermal conductivity is a material property that measures the ability of a material to conduct heat. Conduction of heat means heat will move from one end of the material to another. You can observe this in a kitchen when heating a cooking pot, where the heat from the fire can be felt on the pot's lid. It measures how quickly heat energy moves through a material from a high temperature area to a low temperature one. The SI unit of thermal conductivity is watts per metre per Kelvin (W/m.K.). **Fig. 2.1** illustrates how heat could be conducted through a material's cross-sectional area, A, from a high temperature, T_2 section to a low temperature, T_1 section over the length, d, of the material.

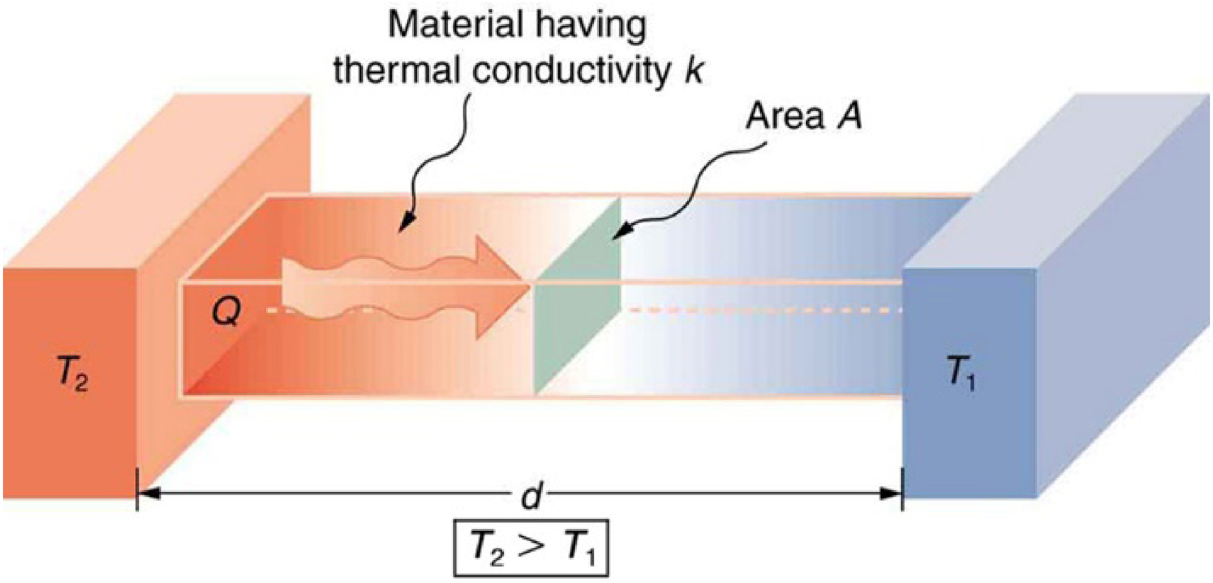


Fig. 2.1: Illustration of thermal conductivity of a material

Materials with high thermal conductivity, like metals, are good heat conductors, whereas materials with low thermal conductivity, like wood, plastic, and glass, are good insulators. For example, it is known that copper has a thermal conductivity of 401 W/mK. This means that a copper rod would be able to conduct heat energy of 401 joules per second through its cross-section if there was a temperature difference along its one-metre length. Thus, copper may be used in radiators and other cooling systems to help spread engine heat because of its high thermal conductivity. Copper is also used in the construction of heat exchangers to transfer heat from steam to cooling water.

Additionally, it is known that glass has a thermal conductivity of 1 W/mK. This also means that glass material can only conduct 1 joule per second through its crosssection if there is a temperature difference along its one-metre length. Hence, glass may be used as a thermal insulator in certain applications because it has very low thermal conductivity.

Specific Heat Capacity

The specific heat capacity of a material measures the amount of heat energy required to raise or increase the temperature of one-unit mass of the material by one degree Celsius or one Kelvin. Simply put, the value of a material's specific heat capacity indicates how much heat energy is needed to raise the temperature of the material. In **Fig. 2.2**, when two different spoons are placed in a saucepan, one may quickly become hot while the other remains warm. The spoon that becomes warm has a higher heat capacity because it requires more heat energy to raise its temperature to a higher level.

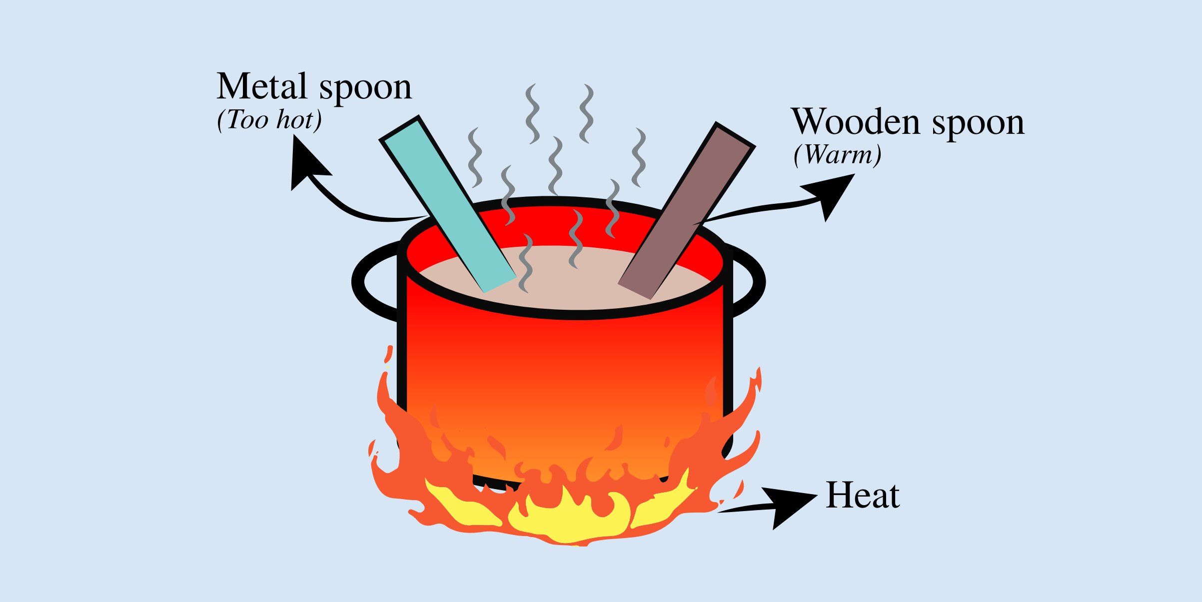


Fig. 2.2: Detecting the heat capacity of a metal spoon and wooden spoon in a saucepan.

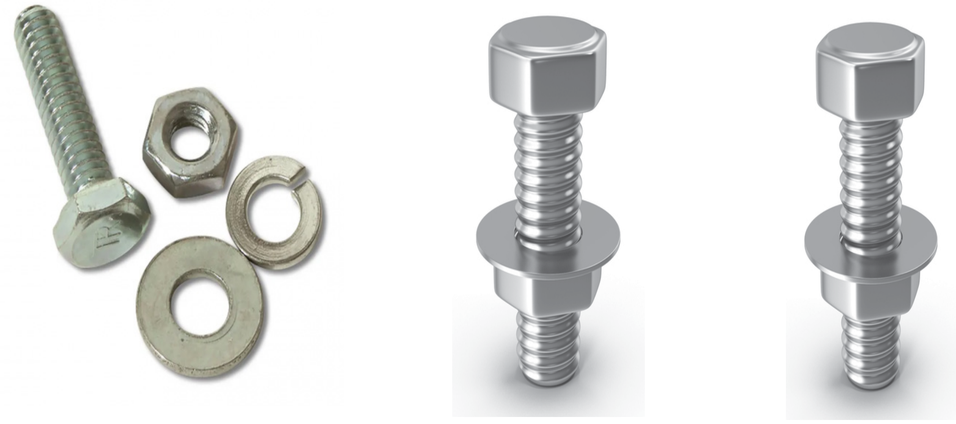
Metals typically have lower specific heat capacities compared to nonmetals, meaning they heat up and cool down more quickly. For instance, water has a specific heat capacity of 4184 J/kg·K. while that of copper is 385 J/kg·K. This means 4184 joules of heat energy are needed to raise the temperature of 1 kg of water by 1 kelvin, while 385 joules of heat energy are needed to raise the temperature of 1 kg of copper. Hence, it is more difficult to raise the temperature of 1 kg of water by 1 kelvin or degree Celsius than that of copper metal. Materials with higher specific heat capacities generally transfer heat more slowly than those with lower specific heat capacities. This explains why materials with high specific heat capacity, like water, can absorb and release large amounts of heat without undergoing significant temperature changes.

The concept of specific heat capacity is used in the design of thermal energy storage systems, refrigeration and air conditioning systems, renewable energy systems such as solar water heaters, and thermal insulators. It also has great applications in the food processing, metallurgy and materials processing, and medical industries.

Thermal Expansion

Thermal expansion is the change in length, area, or volume of a material due to the change in temperature of that material. Thermal expansion depends on the behaviour of the interatomic forces of a material. By increasing the temperature of a material, its particles gain kinetic energy and move more vigorously, increasing the space between the molecules and causing the material to expand. On the contrary, cooling a material would generally cause it to contract. The degree of thermal expansion varies among different materials and is measured by the material's coefficient of thermal expansion.

Generally, metals like aluminium and steel have a relatively high coefficient of thermal expansion, making them expand quickly with temperature changes. While nonmetals like ceramics and glass have a low coefficient of thermal expansion, making them more dimensionally stable under temperature variations, **Fig. 2.3** illustrates how a bolt, washer, and nut assemblage could be disoriented when thermal expansion occurs in the bolt. Thus, the diameter of the bolt increases after heating, and therefore the washer and nut cannot be fitted to the bolt.



(a) (b) (c)

Fig. 2.3: Illustration of thermal Expansion using bolt, washer and nut assemblage; (a) bolt, washer and nut, (b) the well-fitted assemblage before heating of bolt, and (c) unfitted or Disoriented assemblage after heating of bolt.

The concept of thermal expansion helps in the design of structures that can accommodate temperature-related damage, for instance, sign bridges, rail tracks, pipelines, and ducts used in the oil and gas industry.

Melting Point

The melting point of a material is the temperature at which it changes from a solid state to a liquid. The melting point of pure metal is constant, whereas that of alloys fluctuates. The melting point of a material is dependent on the forces that hold it together. The stronger the bonding force, the greater the melting point.

Metals usually have a very high melting point compared to non-metals. For example, titanium (Ti) has a melting point of 1668 °C, while the melting point of polystyrene is 240 °C. Additionally, materials held together by a strong network of covalent bonds melt at a higher temperature than those with ionic bonds. For instance, the melting point of silicon is 1414 °C, while that of NaCl is 801 °C. However, molecular covalent compounds generally have much lower melting points compared to ionic compounds, as the intermolecular forces (Van der Waals, hydrogen bonds) are weaker than ionic bonds. Thus, the melting point of ice (frozen water) is 0 °C while that of potassium chloride (KCl) has a melting point of about 770 °C. This means that ice can easily change to liquid (drinking water) than potassium chloride.

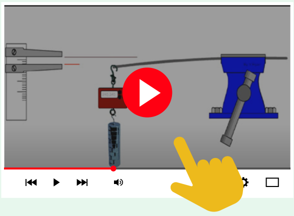
Materials with low melting points are used in the design of safety equipment such as fuse wire, fuse plugs, and boiler safety devices. Materials with high melting points ensure the structural integrity and performance of components in extreme thermal environments, such as valves, pistons in internal combustion engines, linings of furnaces, crucibles for melting metals, cutting tools, and refractory bricks.

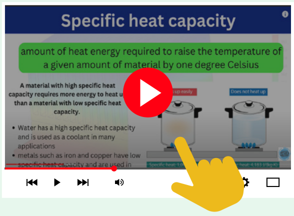
Thermal Diffusivity

Thermal diffusivity is the ratio of thermal conductivity to heat capacity. It measures the ability of a material to conduct heat energy relative to its ability to store heat energy. It describes how soon an amount of heat supplied to a material is uniformly distributed to all parts of the material. High diffusivity of a material means heat transfers rapidly through the material, while low diffusivity of a material means the material is capable of retaining heat. Materials with high thermal diffusivity adapt quickly to changes in the thermal environment to set up a steady-state condition. Aluminium has a thermal diffusivity of 9.7×10^{5} m^2/s while that of wood is 1.3×10^{-7} m^2/s. Wood has a lower thermal diffusivity than aluminium. This means aluminium can transmit heat at a faster rate than wood. Materials such as glass, concrete, wood, and plastics with low thermal diffusivity are used for thermal insulation, fire protection, cookware handles, and food storage. While materials such as copper and aluminum with high thermal diffusivity are used as heat sinks, heat exchangers, and cookware.

Activity 2.1

1. Search the internet for the thermal properties of materials or watch the following videos and complete both tasks (a) and (b):





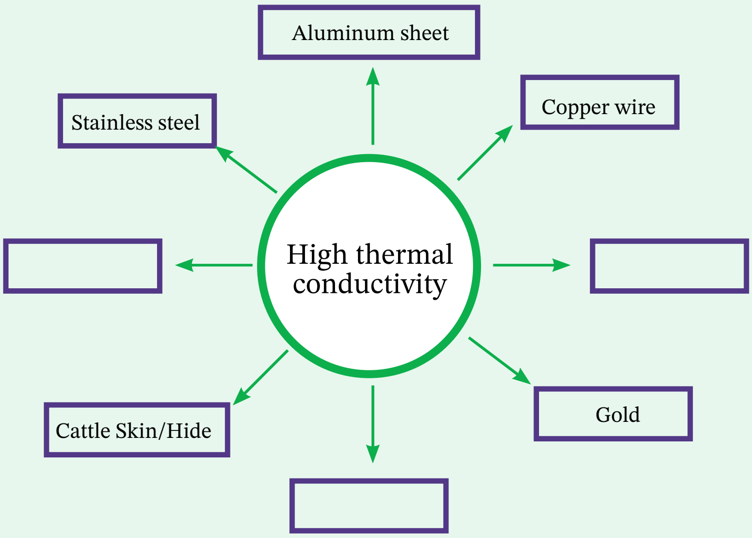
a. Use flashcards to display three (3) thermal properties and their corresponding meanings. An example is given below. **Note:** Do not repeat the property shown in the example.

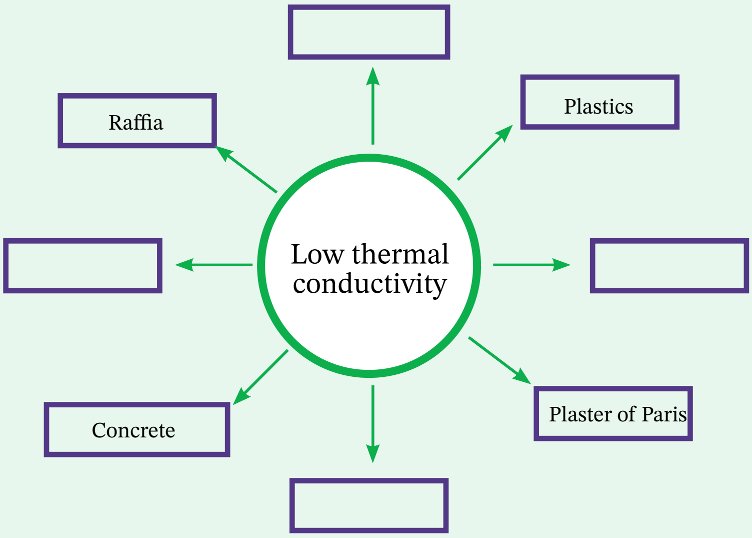
Thermal conductivity → Ability to conduct heat

b. Using the mind mapping technique, create six mind maps, each on A4 or A3 sheets, showing materials that exhibit high and low levels of the following thermal properties:

i. Thermal conductivity
ii. Thermal expansion
iii. Specific heat capacity
iv. Melting point
v. Thermal diffusivity

Each mind map (high and low) should include at least five materials. An example is given below.





Note: Complete the blank spaces in the examples provided and create your mind maps based on task (b) above.

Activity 2.2

Note: This activity (experiment) should be conducted under the supervision of a facilitator or teacher. In groups of three to five, perform experiments to determine the thermal properties of a metallic spoon and a wooden spoon. The thermal properties to be studied include thermal conductivity, specific heat capacity, thermal expansion, thermal diffusivity, and melting points. Follow these guidelines carefully:

1. Thermal conductivity test:

Materials needed: a candle, a metal spoon, a wooden spoon, and two similar thin metal plates.

Instruments/equipment needed: stopwatch/digital watch, dial thermometer or a gun thermometer, Bunsen burner, two pliers.

Steps involved:

a. Place the thin metal plate over the Bunsen burner (or a candle) at a reasonable height (say 8 cm) from the naked fire.
b. Light the burner, place one end of the metal spoon on the plate, and hold the other end with the pliers.
c. Measure the initial temperature of the metal spoon at the end, close to the plier, and record it.
d. Turn on the burner and record the new temperature every 30 seconds, between 10 to 15 times.
e. Repeat the process using the wooden spoon, the second pair of pliers, and the other thin metal plate.
f. Plot two graphs on the same graph sheet with temperatures on the y-axis and time on the x-axis.
g. Compare the curve of the metal spoon to the wooden spoon.
h. Record your findings in your notebooks.

2. Specific Heat Capacity Test

Materials needed: candle, metal spoon, wooden spoon, two similar thin metal plates

Instruments/equipment needed: stopwatch/digital watch, dial thermometer or gun thermometer, Bunsen burner, two pliers.

Steps involved:

a. Place the thin metal plate over the Bunsen burner (or a candle) at a reasonable height.
b. Measure and record the initial temperature of the spoon using the thermometer.
c. Place the metal spoon on the central portion of the plate and light the burner.

d. Start the stopwatch and stop it after three minutes (180 seconds) or more.
e. Simultaneously switch off the burner and record the exact time.
f. Pick up the spoon from the hot plate using the pliers.
g. Measure and record the final temperature of the metal spoon using the thermometer.
h. Repeat the process using the wooden spoon, the other thin metal plate, and the pliers.
i. Compare the final temperatures of the metal spoon after heating to that of the wooden spoon.
    - Which of the two spoons recorded a low rise in temperature?
    - Which of the spoons is likely to have a higher specific heat capacity?
j. Record your findings in your notebooks.

3. Thermal Expansion Test

Materials needed: candle, metal spoon, wooden spoon, two similar thin metal plates

Instruments/equipment needed: stopwatch/digital watch, dial thermometer or a gun thermometer, Bunsen burner, two pliers, Veneer callipers (a pair of compass and rule)

Steps involved:

a. Place the thin metal plate over the Bunsen burner (or a candle) at a reasonable height.
b. Measure the initial width and length of the metal spoon as well as its initial temperature.
c. Place the metal spoon at the central portion of the plate and light the burner.
d. Start the stopwatch and stop it after seven minutes (420 seconds) or more.
e. Switch off the burner and record the exact time at the same time.
f. Pick up the metal spoon from the hot plate using the pliers and measure its final width, length, and its final temperature.
g. Repeat the process using the wooden spoon, the other thin metal plate, and pliers.
h. Compare the dimensions before and after heating the metal spoon.
i. Compare the dimensions before and after heating the wooden spoon.
    - Which of the spoons recorded a higher expansion or elongation?
j. Record your findings in your notebooks.

4. Thermal Diffusivity Test

Materials needed: candle, metal spoon, wooden spoon, two similar thin metal plates

Instruments/equipment needed: stopwatch/digital watch, dial thermometer or gun thermometer, Bunsen burner, two pliers.

Steps involved:

a. Place the thin metal plate over the Bunsen burner (or a candle) at a reasonable height.
b. Measure and record the initial temperature of the spoon using the thermometer.
c. Place the metal spoon at the central portion of the plate and light the burner.
d. Start the stopwatch and stop it after five minutes (300 seconds) or more.
e. Simultaneously switch off the burner and record the time.
f. Pick up the metal spoon from the hot plate using the pliers.
g. Measure and record three different temperatures of the metal spoon at different locations.
h. Repeat the process using the wooden spoon, the other thin metal plate, and the pliers.
i. Compare the average temperatures for the metal spoon and the wooden spoon.
   - Which of the two spoons has a higher average temperature?
   - Which of the spoons has a higher thermal diffusivity?
j. Record your findings in your notebooks.

Activity 2.3

1. This experiment should be conducted under the supervision of a facilitator. In groups of three to five, perform experiments to determine which of the two spoons—metal or plastic—melts more easily. Follow these guidelines closely:

Experiment to Determine the Melting Time

Materials Needed: a candle, a metal spoon, a wooden spoon, and two similar thin metal plates.

Instruments/equipment needed: a stopwatch or a digital watch, a dial thermometer or a gun thermometer, Bunsen burner, two pliers

Steps involved:

a. Place the thin metal plate over the Bunsen burner (or a candle) at a reasonable height.
b. Measure and record the initial temperature of the spoon using the thermometer.
c. Place the metal spoon at the central portion of the plate and light the burner.
d. Start the stopwatch and continue to heat until one of the spoons begins to melt.
e. Simultaneously switch off the burner and record the melting time and temperature of two spoons.
f. Write a brief report on the melting times of the metal spoon and the plastic spoon. And make a presentation to your peers in class.

Extended Reading

1. Callister D. W. and Rethwisch D. G., 2018. Materials science and engineering, an introduction. John Wiley & Sons. Inc.–New York, USA. Read Chapter Nineteen.
2. Cverna, F. ed., 2002. ASM Ready Reference: Thermal properties of metals. Asm International.
3. Ashby, M.F. and Jones, D.R., 2022. Engineering materials 1: an introduction to properties, applications and design. Elsevier.

ELECTRICAL PROPERTIES OF MATERIALS

You can see that electricity is available for operating appliances like televisions and fans when you look around your house and the surrounding environment. These devices are made of materials with diverse electrical characteristics ranging from high electrical conductivity to resisting the flow of electricity, with some materials having both electrical and insulating properties based on their temperature. As such, knowledge of these properties will aid in selecting materials for electrical applications.

The electrical properties of a material refer to the material's ability to conduct electricity or the behaviour of the material when subjected to electrical current. The electrical properties of a material include electrical conductivity, electrical resistivity, dielectric strength, and temperature coefficient of resistance. Now let us discuss the electrical properties mentioned above.

Electrical Conductivity

The ***electrical conductivity*** of a material is the measure of its ability to conduct an electric current. Materials with high electrical conductivity are good conductors of electricity, while materials with low conductivity are insulators. Materials with high conductivity allow electricity or electric current to flow through them.

Most metals are known to have high electrical conductivity and are used for electric wires. Examples of materials that are good electrical conductors are copper, silver, lead, iron, tin, and aluminium.

Electrical Resistivity

Electrical resistivity is the direct opposite of electrical conductivity. It is the measure of a material's ability to resist the flow of an electric current. When you connect a material with high electrical resistivity to a source of electricity, the material will not allow current to flow through it; it serves as an insulator. Insulators are materials that prevent the flow of electricity through them. Examples of insulating materials are glass, rubber, and plastic.

A material's electrical resistivity depends on its temperature; therefore, the material may not always stop the flow of electricity. The electrical resistivity of a solid material changes with changes in the temperature of the material due to an increase or decrease in the electron flow of the material. The knowledge of this behaviour can be used to determine the temperature of a material by passing a specific amount of electric current through it.

Dielectric Strength

We know that electrically resistive materials do not allow electricity to pass through them. However, if we keep increasing the amount of electricity, the material will continue to resist the flow until the electricity is too much for the material to resist. At this point, the material allows current to flow through it, and its dielectric strength is broken.

Dielectric strength is a measure of the maximum electric field a material can withstand before it breaks down and becomes a conductor. When an insulating material is subjected to an electric field that exceeds its dielectric strength, the material's electrons can gain enough energy to break free from their atomic bonds, resulting in the material becoming conductive. Therefore, dielectric strength can also refer to the measure of the insulation capability of a material under high voltage conditions.

Different materials have different dielectric strengths. The dielectric strength of a material can be influenced by factors such as temperature, humidity, and the presence of impurities. Introducing impurities into an insulating material can cause an electron to be free, thereby making the material conductive. Examples of materials with high dielectric strength include glass, diamonds, polyethylene, porcelain (ceramic), distilled water, and mica.

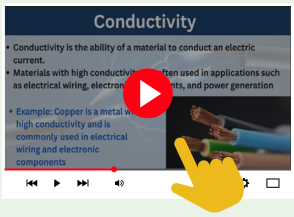
Temperature Coefficient of Resistance

We have learned that increasing the temperature of a material may cause the material to increase its electrical resistivity and reduce the flow of current through it. The amount of electricity allowed to flow through the material depends on how much temperature the material gains or loses, and the numerical value of the changes can be referred to as *the temperature coefficient of resistance*. The *temperature coefficient of resistance* is therefore a measure of how much the electrical resistance of a material changes with changes in temperature. It quantifies the rate at which the resistance of a material increases or decreases as the temperature changes and is expressed in terms of the percentage change in resistance per degree Celsius (or per kelvin) of temperature change.

The temperature coefficient of resistance is an important factor to consider in various electronic and electrical applications, as changes in temperature can impact the performance and accuracy of devices. For instance, in precision temperature measurement devices, materials with a low or well controlled temperature coefficient of resistance values, such as platinum and nickel iron alloys, are desirable to minimise errors caused by temperature variations. On the other hand, materials with a high temperature coefficient of resistance, such as tungsten and semiconductor devices, are used in components that require temperature compensation, such as resistors used in electronic circuits.

Activity 2.4

1. Click to watch video on the electrical properties of materials:



Electrical Properties of Materials

2. Now that you are done watching the videos, write a brief report on the different electrical properties of materials discussed in the videos, stating the importance of such properties in the manufacturing of parts of a machine. Use the headings below to guide you in writing your report.
   a. **Title:** A Report on the Electrical Properties of Materials.
   b. The electrical property (for example, electrical resistivity.)
   c. Definition.
   d. How do materials with such properties behave?
   e. The importance of this property.
   f. When does the property exhibit changes in a material?
   g. Conclusion

Activity 2.5

Match the electrical properties listed below with their definitions in the table provided:

a. Electrical conductivity
b. Electrical resistivity
c. Dielectric strength
d. Temperature coefficient of resistance

Electrical Property	Definition
	A measure of how much the electrical resistance of a material changes with changes in temperature.
	A measure of the maximum electric field a material can withstand before it breaks down and becomes a conductor.
	A measure of a material's ability to conduct an electric current.
	A measure of a material's ability to resist the flow of an electric current.

Activity 2.6

1. In a group of three, test the electrical conductivity of a plastic spoon and a metal spoon. The following materials will be needed for the experiment: a battery, a light bulb, a metal spoon, a plastic spoon, masking tape, and two short copper wires.
   a. Begin the experiment by wearing rubber gloves and then follow the steps given below.

Steps:

i. Connect the materials to each other as shown in Fig. 2.4 to form an open circuit.

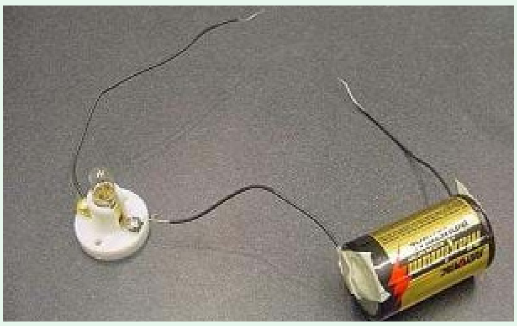


Fig. 2.4: Connecting materials to each other.

ii. Hold the plastic end of one of the wires and connect it to one end of the metal spoon as shown in Fig. 2.5.

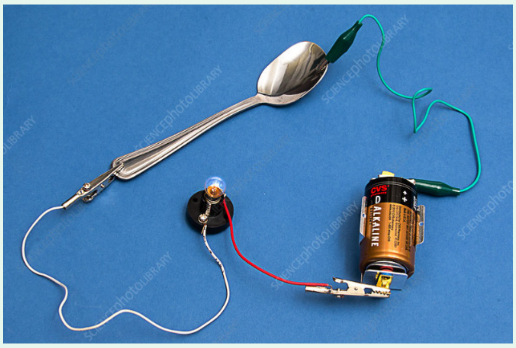


Fig. 2.5: Conductivity test. A battery and a light bulb are used to test the electric conductivity of metal spoons.

iii. Hold the plastic end of the second wire and connect it to the other end of the metal spoon to form an electric circuit.
iv. Disconnect the spoon and write down your observation.
v. Repeat steps 1 through 4 using the plastic spoon.

Activity 2.7

1. Write a short note explaining your observation during the experiment in Activity 2.6 and present it to your class. Use the points listed below as a guide to prepare your presentation.
   a. The title of the experiment
   b. The materials for the experiment
   c. Safety precautions taken
   d. Setup of the experiment
   e. Observations made
   f. Meaning of the observations
   g. Explain the electrical conductivity of metal and plastic.
   h. Conclusion

Extended Reading

For further experiments visit this site:

1. https://www.teachengineering.org/activities/view/cub_electricity_lesson04_activity1
2. https://youtu.be/lgJ51xt191Q (Why the resistance increases with temperature in conductor)
3. Callister, W. D., & Rethwisch, D. G., (2020). *Materials Science and Engineering: An Introduction*, 9th Edition, John Wiley & Sons. Chapter 18

MECHANICAL PROPERTIES OF MATERIALS

In this lesson, you will learn about the mechanical properties of materials. The mechanical properties of materials refer to the physical properties that a material exhibits when subjected to an applied load or force. They play a crucial role in selecting materials for specific uses and designing components that can withstand the intended applied force.

The mechanical properties help engineers and manufacturers understand how a material responds to external forces and deformations and performs in real-world applications.

Understanding the mechanical properties of a material offers manufacturers the best balance of properties required to meet the performance requirements of a particular product. This ensures the safety and reliability of the designed product. It determines how a material behaves under different conditions.

The mechanical properties of materials include hardness, brittleness, ductility, strength, malleability, toughness, elasticity, and plasticity.

Hardness

This is the ability of a material to resist indentation, scratching, or wear. This means that when the surface of a material is scratched, it does not leave a mark. A hardness test is conducted to determine the suitability of a material for a given application. The importance of hardness in manufacturing is to enable the production of durable, wear-resistant, and high-performance components. Diamonds, ceramics, hardened steel, and tungsten carbide are some examples of materials with high hardness. Rubber, plastics, wood, foam, and paper are examples of materials that have low hardness.

Brittleness

Brittleness is the ability of a material to break easily when a small load or force is applied. Materials that are brittle break easily under a small force or load and are generally hard in nature. For example, when a glass falls from a table, it breaks easily compared to when a spoon falls from the same table, making the glass brittle. In construction, brittle materials, such as glass and ceramics, are used for their strength and durability. Understanding the brittleness of materials can help engineers design products that are strong and durable. Examples of brittle materials include glass, bricks, eggshells, graphite, and alkali metals like magnesium.

Ductility

This is the ability of a material to undergo plastic deformation (a permanent change in shape) without fracturing. This means that ductile materials can be stretched into wires or bent without breaking. Engineering applications that require materials with high ductility include metal cables, stampings, and structural beams. Gold, copper, and steel are examples of ductile materials.

Strength

The strength of a material refers to the material's ability to withstand an applied load without failure or plastic deformation. It is one of the most important mechanical properties of materials and is often used as a measure of their quality. The strength of a material can be measured as tensile strength (resistance to pulling forces), compressive strength (resistance to crushing forces), or shear strength (resistance to sliding forces). Knowledge of the strength of materials helps in the design and manufacture of foundations, structures, load-bearing components for vehicles, power generation systems (turbines), and transmission systems.

Malleability

Malleability is the ability of a material to deform under compressive stress (pressure). It is the opposite of brittleness. This means that malleable materials can be beaten into shape, bent, or deformed without breaking. Malleability is an important property for engineering applications such as shaping, bending, stamping, and rolling, where plastic deformation is necessary for shaping the material. It is used to produce thin sheet metals used in the electronics industry. It is also used to manufacture roofing sheets, jewellery (wedding rings and chains, among other things), and packaging foils (aluminium foils for food packaging). Examples of malleable materials include gold, copper, aluminium, silver, brass, lead, etc.

Toughness

Toughness is the ability of a material to absorb energy and deform plastically without fracturing. This means that such materials can withstand shock or impact without breaking. For example, in the transportation industry, toughness is crucial for materials used in the manufacture of lorries, aeroplanes, submarines, and ships, as they need to endure collisions and other sudden forces. Similarly, materials used in machine parts like gears, shafts, and bearings must be tough enough to handle sudden loads and high stresses without breaking. Examples of tough materials used in engineering include manganese steel, wrought iron, and mild steel.

Elasticity

Elasticity is the ability of a material to return to its original shape after a load has been removed. It describes a material's capacity to deform under stress and then recover its original shape once the stress is released. This property is crucial in engineering applications where resistance to deformation is essential. Elasticity plays a significant role in the design of suspension systems, shock absorbers, brakes, tyres, seals, gaskets, bridges, buildings, aircraft, and many other applications. Examples of materials with high elasticity include rubber, spring steel, and silicon.

Plasticity

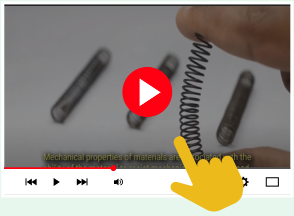
The plasticity of a material refers to its ability to undergo permanent deformation when subjected to an applied force or load without rupturing or breaking. This means that such materials can change shape and retain that shape even after the force applied is removed. Unlike elasticity, where a material returns to its original shape after the force is removed, plastic deformation results in a lasting change in the material's shape. Plastic deformation happens when the applied stress goes beyond a certain level, called the yield strength or yield point, of the material. Beyond this point, the material begins to exhibit plastic behaviour, and further deformation can occur even if the applied stress is reduced. This property is commonly observed in materials like metals and some nonmetallic materials under certain conditions. Plasticity has several applications in forming and shaping, machining, and metalworking.

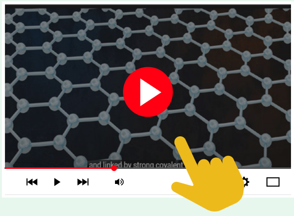
Table 2.1: Shows materials and their properties

Materials	Mechanical Property
Aluminium	Ductile, malleable
Copper	Ductile, malleable
Lead	Ductile, malleable
Zinc	Ductile, malleable
Thermoplastic	Ductile, malleable, elasticity, plasticity
Thermosetting plastic	Hard, brittle
Mild steel	Ductile, malleable tough
Cast iron	Hard, brittle
Medium carbon steel	Hard, tough
High Carbon steel	Hard, brittle
Rubber	Ductile, malleable, elasticity
Bamboo	Strength, tough
Wood	Strength, hard, elasticity

Activity 2.8

Using the provided links and book, conduct research on the following mechanical properties: hardness, brittleness, ductility, strength, malleability, toughness, elasticity, and plasticity.





Book: Callister WD, et al. (2014). *Materials Science and Engineering: An Introduction*, Chapter 6.

Now, define each property and match materials to their corresponding mechanical properties using flashcards.

For example:

Aluminium → **Malleable:** The ability of a material to be beaten into shape without breaking.

Copper → **Ductile:** The ability of a material to be stretched into thin wire without breaking

Following the example above, list at least six (6) materials of your choice and match them to their appropriate mechanical properties using flashcards.

Activity 2.9 – Group Work

In groups of three to five, perform an experiment to determine the strength, malleability, hardness, or brittleness of selected materials, such as plastic and bamboo. Create a video and PowerPoint presentations of your results, including the experiment details, and present it to the class or a friend for feedback.

Follow the procedures and steps below to conduct your experiment on the mechanical properties of bamboo and plastic materials. Ensure that you accurately report your observations.

1. Hardness Test:

This test is to show which of the materials can resist indentation or scratching.

Materials needed: plastic and bamboo.

Tools needed: hammer, veneer calliper, steel rule or measuring tape, goggles, centre punch, pen, and paper for recording observation.

Steps involved:

a. Ensure that both plastic and bamboo are of similar sizes and shapes.
b. Place samples on a flat surface and ensure that they are firmly held.
c. Place the centre punch on each material, one after the other, and gently apply hammer blows. To ensure consistency, use the same number of swings and a similar swing height during hammering.
d. Observe and record the resulting indentation or wear.
e. Measure the depth and width of the indentation on both materials using the veneer calliper or steel rule.
f. Compare the level of indentation. The material with less indentation is harder than the one with deeper indentation.

2. Test of strength:

This test is to show how much force or load a material can withstand without failing.

Materials needed: plastic and bamboo.

Tools needed: hammer, veneer calliper, steel rule or measuring tape, goggles, pen, and paper for recording observation.

Steps involved:

a. Ensure that both plastic and bamboo are of similar sizes and shapes.
b. Place samples on a flat surface and ensure that they are firmly held.
c. Gently apply hammer blows on both materials. Gradually increase the force applied as you observe the material response. To ensure consistency, use the same number of swings and a similar swing height during hammering.
d. Observe and record the number of hammer blows that caused defects (bending, cracking) in each material.
e. Observe and record the extent of the damage or failure.
f. Compare the amount of force each material withstood before failure. The material that withstands more hammer blows before failing is considered stronger because the one with less indentation is harder than the one with high indentation.

3. Malleability test:

This test is to show the ability of a material to deform or be beaten into shape without cracking.

Materials needed: plastic and bamboo

Tools needed: hammer, anvil, veneer callipers, steel rule or measuring tape, goggles, pen, and paper for recording observation.

Steps involved:

a. Ensure that both plastic and bamboo are of similar sizes and shapes.
b. Place samples on a flat surface and ensure that they are firmly held.

c. Gently apply hammer blows on both materials. To ensure consistency, use the same number of swings and a similar swing height during hammering.
d. Observe and record the resulting deformations and any other notable differences.
e. Compare the level of deformation to determine the malleability of plastic against bamboo. The one that deforms more easily without cracking is the malleable material.

4. Test for brittleness:

This test is to show which of the materials breaks easily when a force is applied without deformation.

Materials needed: plastic and bamboo

Tools needed: hammer, Veneer callipers, steel rule or measuring tape, goggles, centre punch, pen, and paper for recording observation.

Steps involved:

a. Ensure that both plastic and bamboo are of similar sizes and shapes.
b. Place samples on a flat surface and ensure that they are firmly held.
c. Gently apply hammer blows on both materials. To ensure consistency, use the same number of swings and a similar swing height during hammering.
d. Observe and record the sign of cracking, breaking, or shattering, including the force applied.
e. Observe and record the force at which each material cracks or shatters.
f. Compare the brittleness by noting which material broke or shattered easily under the same force.

Activity 2.10

In groups of three to five, generate ideas and discuss the importance of the mechanical properties of materials in developing a product.

1. Follow the guidelines below to generate ideas.

Prompts:

a. How do mechanical properties influence the choice of materials in manufacturing?
b. Why is it important to understand mechanical properties for ensuring product safety and reliability?
c. How can knowledge of mechanical properties lead to cost savings in manufacturing?
d. What are some real-world examples where mechanical properties have critically impacted a product's success or failure?

Based on the ideas generated and your discussion, write a report to your school maintenance officer on how to improve the strength and durability of the school desks using materials with better mechanical properties.

Extended Reading

1. Callister W D, et al (2014,). An Introduction to Materials Science and Engineering.

PROPERTIES OF MATERIALS

In this lesson, you will learn about the magnetic properties of materials. When magnets are brought closer to some objects, such as pins, coins, and some cooking utensils, the object becomes attracted to the magnet and moves to attach to the magnet. Some objects, on the other hand, do not react to the presence of a magnet and remain numb. Some engineering applications involve the exposure of materials to magnetic fields, and as such, it is important to learn the magnetic properties of materials to aid in the selection of materials for applications that involve magnetic fields.

Let us now look at the magnetic properties of materials.

Classifications of Magnetic Materials

Magnetism is the phenomenon by which materials exert an attractive or repulsive force on other materials. These materials can be referred to as magnetic materials. Magnetic materials can be classified into three categories: ferromagnetic, diamagnetic, and paramagnetic materials.

Ferromagnetic Materials

Ferromagnetic materials are strongly attracted by a magnetic field and retain the magnetism even when the magnetic field is removed. You can introduce an external magnetic field to the environment of a material by bringing a magnet close to it, as seen in **Fig. 2.6**.

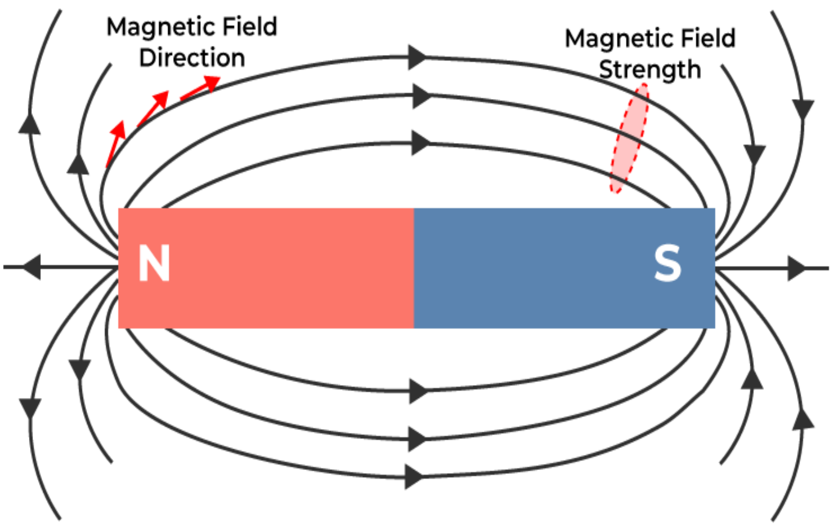


Fig. 2.6: A magnets showing the magnetic field lines

Examples of ferromagnetic materials include iron, nickel, cobalt, and steel. When you bring a magnet closer to these materials, the material will move to attach itself to the magnet, or the magnet will jump to attach the material and stick to it. Objects such as steel spoons, coins, and metal pliers have magnetic properties because they are made of ferromagnetic materials.

Diamagnetic materials

Diamagnetic materials are materials that produce negative magnetization when placed in an external magnetic field. Objects made from these materials are slightly repelled by the presence of a magnetic field. When you bring a magnet close to such material, the magnet will not be attracted to or pushed away, but rather will remain at the same location. Examples of diamagnetic materials are wood, glass, water, copper, and gold.

Paramagnetic materials

When you put a paramagnetic material in a magnetic field, it acquires a small net magnetic moment in the direction of the applied field, meaning paramagnetic materials are slightly attracted by the magnetic field. These materials do not retain their magnetization in the absence of an external magnetic field. Examples of paramagnetic materials include lithium, magnetic aluminium, and molybdenum. Table 2.3. shows the list of magnetic materials, their classifications, and their applications.

Now that you understand the classifications of magnetic materials, take a look at the magnetic properties of materials.

Magnetic Properties of Materials

The magnetic properties of materials describe the behaviour of individual materials when placed in a magnetic field. Examples of magnetic properties of materials include permeability, retentivity, and reluctance. These properties do not depend only on the material and material composition but also on specific conditions such as temperature, the presence of an external magnet, and the history of the material's magnetization.

Increasing the temperature of a solid material causes a misalignment in the magnetic dipole of the material, which leads to a reduction in the material's magnetism. This means that if you continue to heat a magnetic material, it will eventually lose its ability to attract other magnetic objects.

The presence of an external magnet creates a magnetic field, which causes the dipoles of the magnetic material to align with the magnetic field, creating a temporal magnetism in the material.

The history of a material's magnetism can significantly affect its magnetic properties, and this is known as magnetic hysteresis. A material that has been previously magnetised may retain some magnetization even after the external magnetic field is removed.

Permeability of Materials

Permeability is a magnetic property of materials that describes how easily a material can be magnetised when exposed to an external magnetic field. It is a measure of the material's ability to allow magnetic lines of flux to pass through it, as shown in **Fig. 2.7**. In other words, permeability indicates the degree to which a material can respond to and interact with an applied magnetic field by becoming magnetised itself. Different materials exhibit different permeability characteristics, which can have a significant impact on their magnetic behaviour and applications. It can be seen in **Fig. 2.7** that a nonmagnetic material such as wood does not affect the magnetic field.

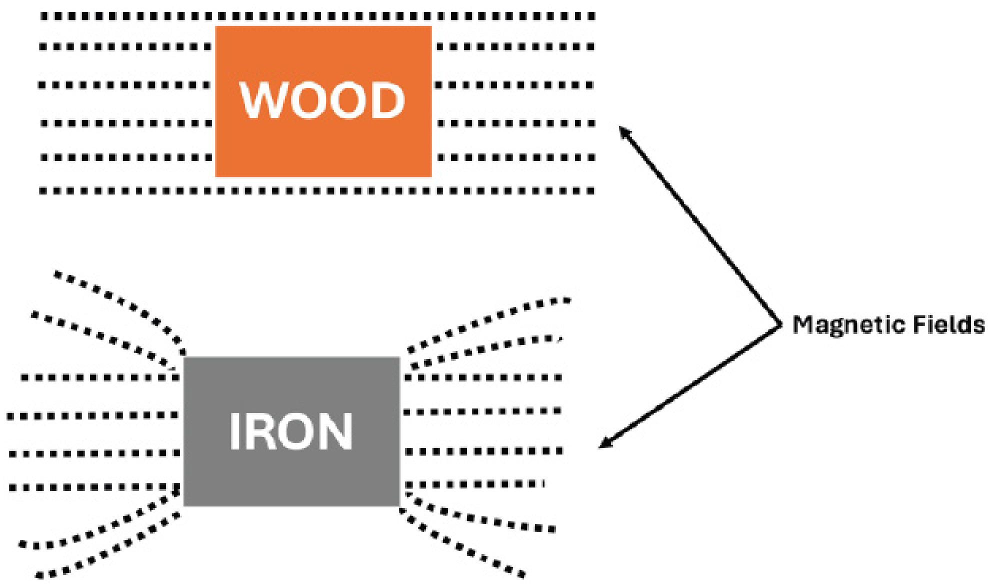


Fig. 2.7: Magnetic lines of flux in iron and wood

Ferromagnetic materials, such as iron, nickel, and cobalt, have relatively high absolute permeability due to the presence of magnetic domains that can align with external magnetic fields. This makes them ideal for applications in transformers, electromagnets, and magnetic storage devices.

Paramagnetic materials, such as copper, aluminium, and oxygen, have lower permeability compared to ferromagnetic materials, indicating a weak attraction to magnetic fields. However, they are used in magnetic resonance imaging (MRI) machines and sensors.

As shown in **Table 2.3**, diamagnetic materials, such as graphite, silver, mercury, and water, have permeabilities lower than those of paramagnetic materials, indicating a weak repulsion from magnetic fields. Although their magnetic response is very weak, they are used in levitation applications for experimental purposes.

Magnetic retentivity of materials

Magnetic retentivity is a property that measures the ability of a material to retain a level of magnetization even after the external magnetic field has been removed. Permanent magnets need to have high magnetic retentivity to ensure they retain their magnetic strength over time. This makes them suitable for applications in electric motors, generators, and speakers.

In magnetic storage media, like hard drives and magnetic tapes, magnetic retentivity allows data to be stored as magnetic patterns that persist over time, even when the external magnetic field is removed. Some examples of magnetic storage media are shown in **Table 2.2.**

Table 2.2: Some magnetic storage devices

Image	Magnetic storage device description
	Hard disk drives found in desktop computers, laptops, and CCTVs use magnetic storage technology.
	Magnetic tapes stored information such as music and voice recordings.
	A floppy disk was used as a storage device and to transfer data between computers.

Magnetic reluctance of materials

Magnetic reluctance is a property of a magnetic circuit that is similar to the concept of electrical resistance in an electrical circuit. It measures the opposition offered by a material to the flow of magnetic flux through it when subjected to a magnetic field. Magnetic flux, as seen in **Fig. 2.6**, is the number of magnetic field lines passing through a given closed surface. Magnetic reluctance quantifies the difficulty with which magnetic lines of flux pass through a material or a magnetic circuit.

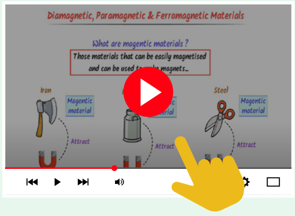
Magnetic reluctance depends on the length of the path of the magnetic flux, the cross-sectional area of the material, and the permeability of the material. It has applications in the design of magnetic circuits and magnetic sensors.

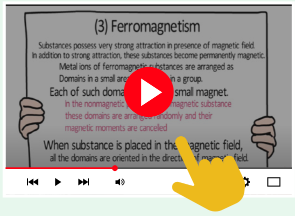
Table 2.3: List of magnetic materials, their classifications, and applications

Magnetic Classification	Material	Permeability	Retentivity	Reluctance	Application
Ferromagnetic	Iron	High	High	Low	Used in power generation and transmission, electronic devices, and data storage
	Nickel				Used in coinage, rechargeable batteries, and electric guitar strings
	Cobalt				Used in the manufacture of magnetic, wear-resistant, and high-strength alloys
	Steel				Used in automotive applications, kitchenware, and industrial equipment
Paramagnetic	Aluminium	Low	Low	High	Used in the manufacture of aircraft, automobiles, and packaging
Diamagnetic	Copper	Low	Low	High	Used in the manufacture of aircraft, automobiles, and packaging

Activity 2.11

1. Use the links below to watch videos on the magnetic properties of materials. Then perform the tasks in questions 2 and 3.





2. Now that you have watched the videos, look for more information on the magnetic properties of materials in a library. Visit your school or community library and look through the chapters on mechanics, physics, and materials for books that contain magnetic properties of materials. Politely ask the librarian for assistance in finding the books and the chapters.
3. Use the information you have gathered from your research to create study material with flashcards for matching material properties to their definitions and examples of materials.

   Materials needed: Two (2) A4 sheets and scissors.

   Follow the steps below to guide you through this activity:

Steps involved:

a. Fold the A4 sheets into two equal parts, with the folding line parallel to the longest edge of the sheet.
b. Now fold it parallel to the short edge and repeat. The sheets should now have lines dividing them into eight rectangles each.
c. Cut out the rectangles from the A4 sheet.
d. Write a magnetic property on one of the rectangles, as shown below. Repeat this for all three magnetic properties.

Retentivity

Fig. 2.8: Writing on paper cuttings

e. Write the definitions of magnetic properties on three other cuttings. Remember to write only the definition, not the property.
f. Write examples of materials that highly exhibit retentivity on one cutting. Do the same for permeability and reluctance.
g. Place the cuttings on a table and shuffle them.
h. Now match each magnetic property with its definition and examples.
i. Repeat steps 7 and 8 four more times.

Activity 2.12

Visualise magnetic fields using magnets and iron filings.

Materials needed: A bar magnet, a U-shaped magnet, a circular magnet, a small piece of wood, a plastic spoon, an A4 sheet, some iron filings, and a video camera (you can use a phone to take the video).

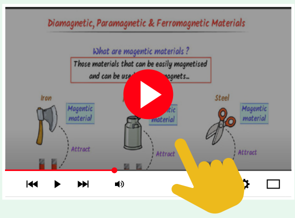
Use the steps below to guide you in your experiment:

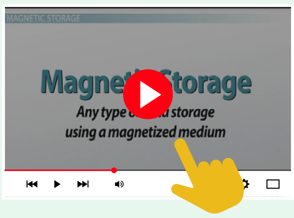
a. Place the U-shaped magnet on a flat, level table.
b. Put the A4 sheet on the magnet, ensuring the magnet is at the centre of the paper.
c. With one hand operating the camera, start recording the experiment with a focus on the A4 sheet.
d. Gently sprinkle the iron filings on the A4 sheet and simultaneously record the process with the camera.
e. Make three gentle taps on the edge of the A4 sheet and record your observations with the camera.
f. Pour the iron filings back into the container and remove the magnet.
g. Now that you have observed the behaviour of the U-shaped magnet, repeat steps 1 to 6 using a bar magnet, a circular magnet, a small piece of wood, and a plastic spoon.

After completing this experiment, present the video to your classmates and teacher for review.

Activity 2.13

Use the links below to learn about magnetic storage devices and write a report to present to your classmates.





Now that you've learned about magnetic storage devices, write a report using the points below as a guide:

a. What are magnetic storage devices?
b. What are the examples of magnetic storage devices?
c. How do magnetic storage devices function?
d. Which devices and machines use magnetic storage devices?
e. What are the flaws of magnetic storage devices?

f. Discuss the magnetic properties of the storage devices.
g. How does the magnetic field affect these storage devices?
h. How can these devices be improved in terms of protection from magnetic fields?

Extended Reading

1. Callister, W. D., & Rethwisch, D. G., (2020). Materials Science and Engineering: An Introduction, 9th Edition, John Wiley & Sons.
2. Tiwari, A., Murugan, N. A., & Ahuja, R. (2016). Advanced Engineering Materials and Modeling. John Wiley & Sons.
3. https://en.wikipedia.org/wiki/Magnetism

Suggested software

1. Visit these sites and use these suggested software for simulation exercises on the mechanical properties of materials under different loading conditions and analyse the results.
2. COMSOL (https://www.comsol.com/) to analyse the mechanical properties of materials under different loading conditions, which can aid in engineering applications
3. Materials Studio (https://www.3ds.com/products/biovia/materials-studio) can help learners visualise structures, perform simulations, and analyse results within an integrated environment.

Review Questions For Section 2

1. Identify one product in your community and state its uses and comment on how you think the thermal properties of the materials used to manufacture that product have positively influenced its performance.
2. How would the understanding of thermal properties guide you in designing a metal ladle with a wooden handle to be used in your kitchen?
3. You are given two liquids, X and Y, which are to be heated simultaneously to a temperature of 50 °C. Liquid X has a specific heat capacity of 2500 J/kg.K whilst Y has 4200 J/kg.K. Which of the liquids would hit the 50 °C temperature first if equal heat energy levels were applied? Justify your answer.
4. Due to the hot weather conditions in your community, especially during the afternoon, your father intends to construct a summer hut on the lawn of his house. He is unsure about the best roofing material to choose. He has three options: treated bamboo, tarpaulin, and aluminium. Assuming the cost of all three materials is the same, which material would you advise your father to select for the summer hut? Justify your choice.
5. You are required to select a material to be used to design an insulated container to keep food hot. What material will you select, and how will the selected material's thermal properties contribute to the designed container's effectiveness?
6. Perform the project work below.
   - Design a simple experiment to compare the thermal conductivities of a 12 mm diameter by 1000 mm long iron rod and a 16 mm diameter by 1000 mm long iron rod.
   - Outline the steps you will take in performing the experiment and how you will measure your results.
7. Explain the function of rubber as a covering for household electric cables.
8. Explain why household cables have metal in them.
9. Why do electrical technicians wear rubber gloves whenever they are repairing a problem on an electric pole?
10. Describe how impurities affect the conductivity of a dielectric material.
11. Evaluate the role electrical properties play in selecting materials for the design of power transmission lines.
12. Describe the importance of mechanical properties in the manufacturing of components. How will an understanding of the mechanical properties of materials enhance the work of local industries in the community?
13. Design an experiment to measure the tensile strength and hardness of steel and bamboo.

14. You are required to select either wood, metal, or a combination of wood and metal to design a desk for your school based on their mechanical properties. Justify the material you will select based on factors such as strength, hardness, and toughness.

15. You have been tasked with designing a desk for your school. Explain the mechanical properties you will consider in selecting the right materials that will ensure the durability of the desk.

16. Explain how the door of a refrigerator closes in relation to magnets.

17. Magnetic decorations used to decorate refrigerators begin to fall to the ground after some time. Explain the cause of this and recommend how the decoration can be made to stay on the doors.

18. When plywood is put between two magnets, the magnets do not stay apart but stick to the wood. Explain why this happens.

19. Explain the flux lines of a magnet.

Answers to Review Questions for Section 2

1. Thermos flask (also known as a vacuum flask)

   The thermos flask is used for keeping beverages hot or cold, storing food, and preserving temperature-sensitive medications or samples.

   a. **Double-walled Construction:** The flask has a double-walled design with a vacuum between the walls. This vacuum minimises heat transfer to reduce the rate at which the beverage inside the flask loses or gains heat from the external environment.
   b. **Aluminium reflective coating:** The inner surfaces of the walls are often coated with a reflective material, usually a thin layer of metal like aluminium. This reflective coating reduces heat transfer, keeping the contents at the desired temperature for a longer time.
   c. **Insulating materials:** They are good thermal insulators that help reduce heat transfer from the outer environment to the inner vacuum space.
   d. **Sealed lid:** The lid is designed to be airtight, preventing heat transfer through air leakage. This also helps in maintaining the temperature by minimising convective heat loss.

   These materials used for the manufacture of the thermos flask help it retain its temperature by slowing down heat transfer, allowing the flask to keep beverages hot or cold for many hours.

2. Understanding the thermal properties would help the designer to:

   a. Know that the metallic part would transfer heat at a faster rate to the user.
   b. Wood is a bad conductor and must be used to slow down the conduction of heat to the user.
   c. Based on this thermal information, the designer is convinced that using wood for the handles and metal for the blade and cup of the ladle would achieve the best results.

3. Liquid X would attain the 50 °C temperature first.

   This is because liquid X has a specific heat capacity of 2500 J/kg.K, which is less than that of liquid (4200 J/kg.K). Hence, it is easy for liquid X to be heated up to 50 °C.

4. Treated bamboo would most likely be the best material for the roofing of the summer hut.

   This is because it has low thermal conductivity and therefore, would be able to reduce heat transfer from the roof to the sitting area. Hence, it serves as a form of insulation shield from sun rays. It also has good low thermal diffusivity, slowing down the rate of heat distribution within the structural members of the roof.

5. Typical materials that would be good for such a container design are fibreglass, cotton wool, polystyrene foam, polyurethane, and natural fibres. The ideal materials that would be needed for such an insulating container should have the following properties:
   a. must have low thermal conductivity to prevent heat loss from the container to a cold environment.
   b. The material must have low thermal diffusivity to reduce the rate of heat distribution to other supporting parts of the container and also to nearby objects.
   c. The container material should have a very high specific heat capacity to ensure that it would take a long time for the wall of the container to be heated up by the hot food inside the container.
6. To conduct the thermal conductivities of a 12 mm diameter by 1000 mm long iron rod and a 16 mm diameter by 1000 mm long iron rod, refer to Activity 2.2 on the Thermal Conductivity Test. Replace the two spoons with the iron rods and follow the same procedure.
7. Rubber coverings on household wires protect people from shock if they come into contact with the wire. This is because rubber serves as an insulator and does not allow the current passing through the wire to pass through it.
8. The metal in the household cable serves as the electrical conductor, allowing electricity to flow through it to the place it's needed. Metals such as copper have high conductivity and, as such, are used as the electrical conductors of household cables.
9. The cables on electrical poles are used for electrical transmission, and a technician stands the risk of being electrocuted when they come into contact with a live wire. Technicians therefore wear rubber gloves, which have high resistivity, to protect them from electrical shock.
10. Impurities increase the conductivity of dielectric materials by introducing additional charge carriers, modifying the band structure, creating defects, and facilitating mechanisms such as hopping conduction and ionisation.
11. Power transmission lines are used to carry electrical power to different locations from the electrical power source or generator. The knowledge of electrical properties guides the selection of materials with high conductivity for the power lines. As the power lines spend time under the scorching sun, their temperature increases, thereby affecting their conductivity performance based on the material's temperature coefficient of resistance. This knowledge helps calculate the amount of electric power being transmitted through the power lines at different temperatures throughout the day.
12. Mechanical properties help engineers and manufacturers understand how a material responds to external forces and deformations and performs in real-world applications. It helps manufacturers select appropriate material that meets the job requirements, thereby ensuring the safety and reliability of the product

13.

(a) Hardness test on steel and bamboo

Materials needed: bamboo, steel

Tool needed: scriber, nail, hand gloves, G-clamp, F-clamp

Aim: This test is to show which of the materials can resist scratching.

Steps:

i. Ensure that both steel and bamboo are of similar sizes and shapes.
ii. Place samples on a flat surface and ensure that they are firmly held.
iii. Hold the scriber firmly and gently scratch the surface of the steel and bamboo.
iv. Apply moderate pressure and attempt to scratch the surfaces of both materials again.
v. Observe if the steel or bamboo surface shows any visible scratches or marks.
vi. Repeat the process on a different area of both materials if possible.
vii. Observe and record the resulting scratch or wear, and compare the level of scratch or wear. The material with fewer scratches or less wear is harder than the one with deeper scratches.

(b) Tensile strength test on steel and bamboo

Materials needed: bamboo, steel

Tool needed: scale, gloves, goggles rule, tape measure, bucket, and Veneer callipers.

Aim: This test is to show how much force or load a material can withstand without failing.

i. Ensure that both the steel and bamboo samples are of similar sizes and shapes.
ii. Place the samples on a flat surface and ensure they are firmly held.
iii. Measure and mark the initial length of each sample before applying the force. This measurement will be used to calculate elongation during the test.
iv. Measure the weight of the loads to be applied.
v. Attach a bucket to each sample to hold the loads.
vi. Gradually increase the load while observing the material's response. To ensure consistency, use the same load increments for each material.
vii. Observe and record the applied load and the corresponding elongation of the material samples during the test. The material that supports a higher load while exhibiting relatively shorter elongation before bending or fracturing has a higher tensile strength.

14. To ensure the safety and reliability of a school desk, a combination of wood and metal for the design is preferable. Both materials offer reliable strength, hardness, and toughness; this blend was selected after a careful review of their strength, hardness, and toughness. Using wood for the surface of the desk provides comfort and aesthetics, while incorporating metal for the frame and structural components enhances strength and durability. With this combination, the desk can withstand the daily impact of lifting, dropping, and pushing in the school environment while maintaining an appealing appearance and ensuring safety.

15. To be able to design safe, reliable, and long-lasting school desks, several mechanical properties must be considered.

    i. **The strength:** The strength of a material determines the amount of load it can take without fail. Selecting a material with high tensile strength properties promotes customer satisfaction since the product is reliable and can last longer.

    ii. Hard materials offer better resistance to scratching, dent wear, and other surface damages that happen with regular use. Selecting a hard material provides better resistance to such damage, ensuring the desk maintains its appearance and lasts longer.

    iii. **Toughness** refers to a material's ability to withstand shock or impact. School desks frequently endure various impacts from students. Therefore, toughness is crucial, as it allows the desk to absorb everyday wear and tear from student use.

16. The doors of refrigerators are lined with magnetic strips to ensure that they stay shut and that less effort is needed to close them. When the door is pushed closed, the magnet attracts the magnetic strip and pulls the door shut.

17. The decorations fall due to a weak magnetic force that occurs over time, thereby reducing the attraction between the magnet and the fridge. Other factors may also contribute to the weakness in the attraction, such as weight, moisture, extreme temperature changes, nonmagnetic coating on the fridge surface, and magnet size.

18. Magnets still attract each other when you put wood between them because wood is a non-ferrous material and does not interfere with magnetic fields.

19. Flux lines are imaginary lines that emerge from the North Pole and enter the South Pole of a magnetic.

Extended Reading

1. Callister, W. D., & Rethwisch, D. G., (2020). Materials Science and Engineering: An Introduction, 9th Edition, John Wiley & Sons.
2. Tiwari, A., Murugan, N. A., & Ahuja, R. (2016). Advanced Engineering Materials and Modeling. John Wiley & Sons.

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