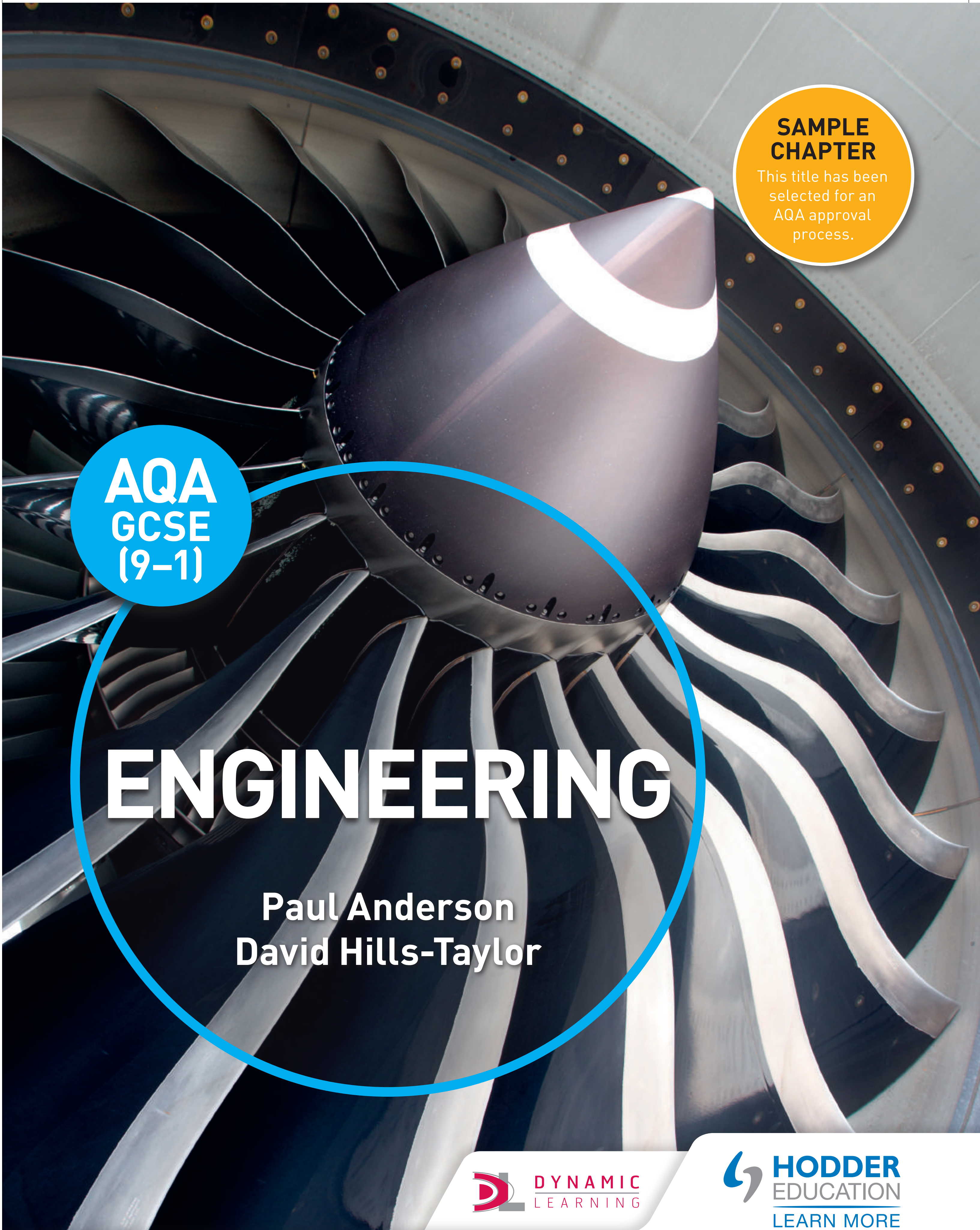

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AQA GCSE (9–1)

ENGINEERING

Paul Anderson
David Hills-Taylor

DYNAMIC LEARNING

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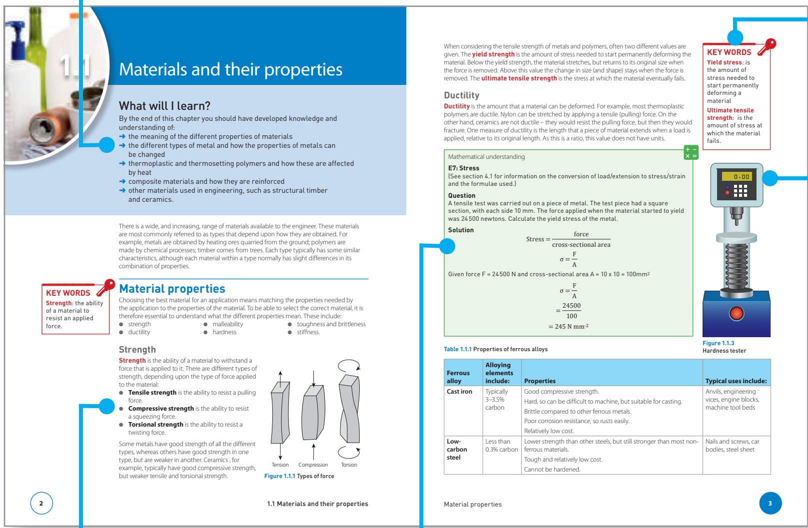

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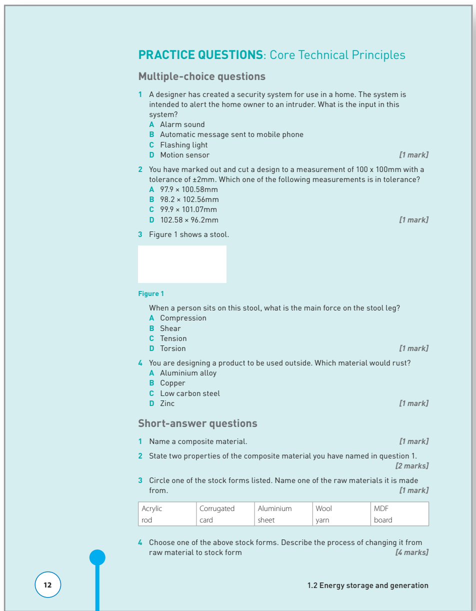

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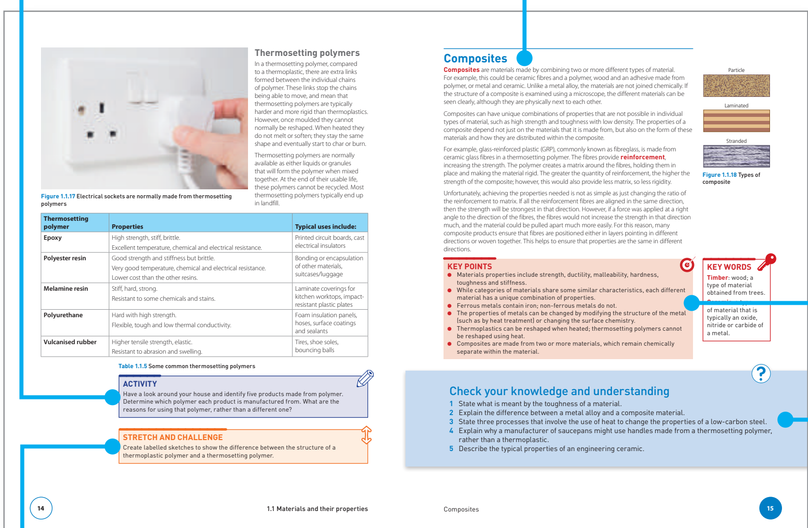

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1 Engineering materials

Successful engineered products do not just magically come into existence from nowhere. Normally, the needs that the product must meet are identified and researched; then considerable thought goes into choosing a material (or materials) that can meet these needs.

There are different categories of materials, such as metals, polymers and composites; and within each individual category, the different materials have unique combinations of properties, which make them the best for different applications.

This section includes the following topics:

At the end of this section you will find practice questions relating to engineering materials.

1.1 Materials and their properties

What will I learn?

By the end of this chapter you should have developed knowledge and understanding of:

- ➜ the meaning of the different properties of materials
- ➜ the different types of metal and how the properties of metals can be changed
- ➜ thermoplastic and thermosetting polymers and how these are affected by heat
- ➜ composite materials and how they are reinforced
- ➜ other materials used in engineering, such as structural timber and ceramics.

There is a wide, and increasing, range of materials available to the engineer. These materials are most commonly referred to as types that depend upon how they are obtained. For example, metals are obtained by heating ores quarried from the ground; polymers are made by chemical processes; timber comes from trees. Each type typically has some similar characteristics, although each material within a type normally has slight differences in its combination of properties.

KEY WORDS

Strength: the ability of a material to resist an applied force.

Material properties

Choosing the best material for an application means matching the properties needed by the application to the properties of the material. To be able to select the correct material, it is therefore essential to understand what the different properties mean. These include:

- strength
- ductility
- malleability
- hardness
- toughness and brittleness
- stiffness.

Strength

Strength is the ability of a material to withstand a force that is applied to it. There are different types of strength, depending upon the type of force applied to the material:

- **Tensile strength** is the ability to resist a pulling force.
- **Compressive strength** is the ability to resist a squeezing force.
- **Torsional strength** is the ability to resist a twisting force.

Some metals have good strength of all the different types, whereas others have good strength in one type, but are weaker in another. Ceramics , for example, typically have good compressive strength, but weaker tensile and torsional strength.

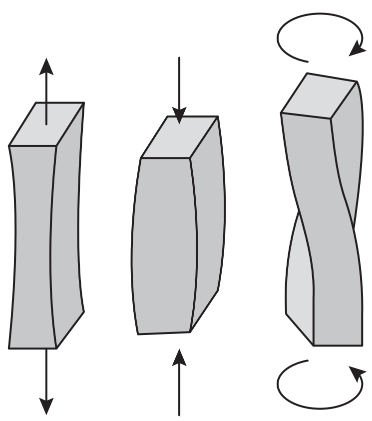

Figure 1.1.1 Types of force

When considering the tensile strength of metals and polymers, often two different values are given. The **yield strength** is the amount of stress needed to start permanently deforming the material. Below the yield strength, the material stretches, but returns to its original size when the force is removed. Above this value the change in size (and shape) stays when the force is removed. The **ultimate tensile strength** is the stress at which the material eventually fails.

The strength of a product (rather than a material) depends upon both the type of the material it is made from and the area of the product over which the load is applied. This means that an applied force that has no visible effect on a large product may be enough to cause a small product to break. This is because with a smaller area, the stress that the force creates within the product may exceed what the material can stand.

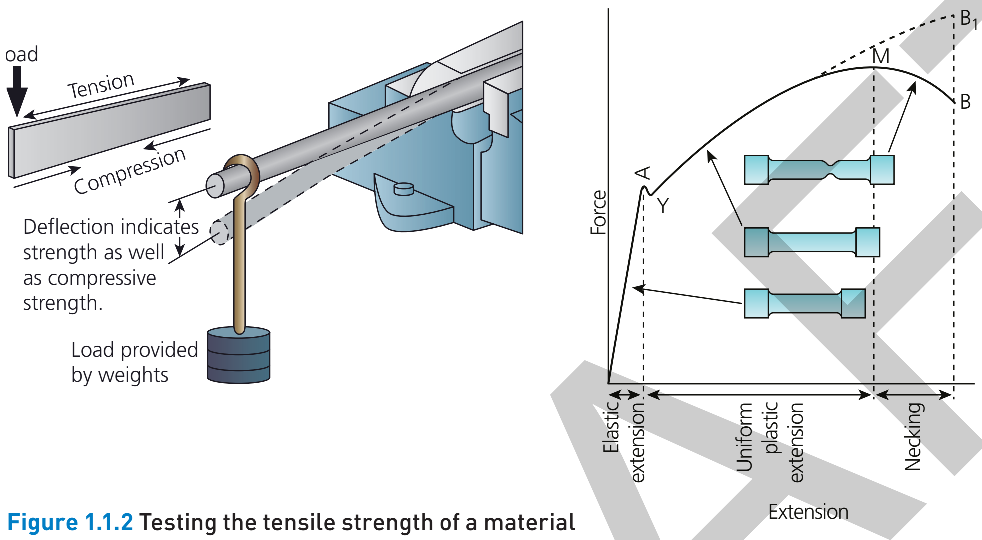

Figure 1.1.2 Testing the tensile strength of a material

KEY WORDS

Yield stress: is the amount of stress needed to start permanently deforming a material

Ultimate tensile strength: is the amount of stress at which the material fails.

Mathematical understanding

E7: Stress

(See section 4.1 for information on the conversion of load/extension to stress/strain and the formulae used.)

Question

A tensile test was carried out on a piece of metal. The test piece had a square section, with each side 10 mm. The force applied when the material started to yield was 24 500 newtons. Calculate the yield stress of the metal.

Solution

$$\text{Stress} = \frac{\text{force}}{\text{cross-sectional area}}$$

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

Given force F = 24 500 N and cross-sectional area A = 10 x 10 = 100mm^2

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

$$= \frac{24500}{100}$$

$$= 245 \text{ N mm}^{-2}$$

Ductility

Ductility is the amount that a material can be deformed. For example, most thermoplastic polymers are ductile. Nylon can be stretched by applying a tensile (pulling) force. On the other hand, ceramics are not ductile – they would resist the pulling force, but then they would fracture. One measure of ductility is the length that a piece of material extends when a load is applied, relative to its original length. As this is a ratio, this value does not have units.

MATHEMATICAL UNDERSTANDING

E8: Strain

(See section 4.1 for information on the conversion of load/ extension to stress/strain and the formulae used.)

Question

A metal bar is being used as part of the lifting gear in a crane. When there is no load, the bar is 2 m long. When the crane lifts the maximum load, the bar extends to a length of 2.03 m.

Calculate the strain in the bar at the maximum load.

Solution

$$\text{Strain} = \frac{\text{change in length}}{\text{original length}}$$

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

$$\varepsilon = \frac{0.03}{2} = 0.015 \text{ (or } 1.5 \times 10^{-2}\text{)}$$

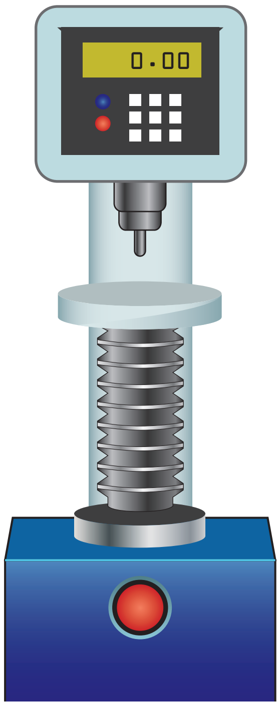

Figure 1.1.3
Hardness tester

Malleability

Malleability is the ability of a material to be deformed without rupturing. This means that the shape of the material can be changed without the material breaking. For example, modelling clay is very malleable; its shape can easily be changed by squeezing it with a hand. However, when it has dried out it is not malleable; attempting to reshape dried modelling clay results in it cracking and breaking.

Hardness

Hardness is the ability of a material to resist wear and abrasion. The harder a material, the more difficult it is to make a mark on its surface. It is also much more difficult to use saws or machines to cut the material. For example, if someone tries to scratch a piece of hard stainless steel, there may be at most only a tiny mark. If the same effort to scratch was applied to a piece of rubber, it would leave a much bigger indentation (mark).

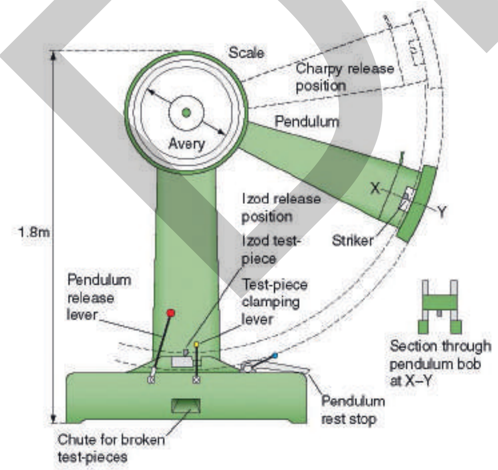

Figure 1.1.4 Toughness testing

Toughness/brittleness

Toughness is the ability of a material to withstand an impact without breaking. When it is hit with a hammer, a tough material might bend or be dented, but it will not crack. The opposite of toughness is **brittleness**. A brittle material will shatter in response to an impact. For example, glass is a brittle material. If a bowl made from glass is dropped it might smash. A similar bowl made from a tough metal might be dented when dropped.

Stiffness

Stiffness is the ability of a material to resist bending. In part, stiffness is related to the strength of the material – the stronger the material and the more it resists deforming, the stiffer it is. This is shown by the **Young's modulus** of the material. However, stiffness is also strongly affected by the shape of the material. For example, an I-beam is stiffer than a round bar of the same volume.

MATHEMATICAL UNDERSTANDING

E9: Young's Modulus

Question

A tensile test was carried out on a ceramic test piece. The test piece was cylindrical in shape with a radius of 29.3 mm.

At the point when the applied force was 270 kN, the strain in the test piece was calculated to be 2.5 x 10^{-4}.

Calculate the Young's modulus of the material.

Solution

Given

$$\text{Young's Modulus, } E = \frac{\text{stress, } \sigma}{\text{strain, } \varepsilon}$$

and

$$\text{Stress, } \sigma = \frac{\text{force, } F}{\text{cross-sectional area, } A}$$

$$\text{Cross-sectional area} = \pi r^2 = 2697 \text{ mm}^2$$

$$\text{Stress, } \sigma = \frac{270}{2697} \approx 0.1 \text{kN mm}^{-2}$$

$$\text{Young's Modulus, } E = \frac{0.1}{2.5 \times 10^{-4}} = 400 \text{kN mm}^{-2}$$

ACTIVITY

Identify five engineered products in your classroom or workshop. For each product, identify the properties that are important for the product to be able to carry out the task it was designed to do.

Metals and alloys

Metals are made from metal **ores**. The ores are rocks or minerals dug from quarries or mines then refined and processed, to turn the metal into usable forms.

Most metals are not used as pure chemical elements. They are typically mixed with other metals to improve their properties. A mixture of two or more metals is called an **alloy**. If should be noted that there are also a few non-metallic elements that can be added in small amounts to specific metals to form an alloy as well – for example, carbon in iron, or silicon in aluminium.

There are two main types of metals:

- **Ferrous** metals contain iron as their largest alloying element.
- **Non-ferrous** metals do not contain iron.

Figure 1.1.5 Pouring of liquid metal in a factory

KEY WORDS

Ductility: the amount that a material can be deformed.

Hardness: the ability of a material to resist wear and abrasion.

Toughness: the ability of a material to withstand an impact without breaking.

Brittleness: the opposite of toughness; the potential for a material to shatter when it experiences an impact.

Malleability: the ability of a material to be deformed without rupturing.

Stiffness: the ability of a material to resist bending.

Young's Modulus: the ratio of stress to strain of a material, showing how stiff it is.

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Ferrous metals and alloys

Pure iron is too soft for use in most engineered products. Ferrous metals typically contain a small percentage of carbon, which makes them into an alloy called carbon steel. The amount of carbon has a significant effect on the properties of the alloy. In general, the more carbon, the harder and stronger the ferrous metal. Carbon steels are the most widely used metals in the world.

Compared to non-ferrous metals, carbon steels typically cost less. However, they are prone to corrosion when they are exposed to water, which causes them to rust. Other elements can be added to a ferrous alloy to reduce corrosion, although this increases the cost of the metal. Alternatively, a surface finish can be used, such as a protective coating.

Table 1.1.1 Properties of ferrous alloys

Ferrous alloy	Alloying elements include:	Properties	Typical uses include:
Cast iron	Typically 3–3.5% carbon	Good compressive strength. Hard, so can be difficult to machine, but suitable for casting. Brittle compared to other ferrous metals. Poor corrosion resistance, so rusts easily. Relatively low cost.	Anvils, engineering vices, engine blocks, machine tool beds
Low-carbon steel	Less than 0.3% carbon	Lower strength than other steels, but still stronger than most non-ferrous materials. Tough and relatively low cost. Cannot be hardened.	Nails and screws, car bodies, steel sheet
High-carbon steel	0.8–1.4% carbon	Strong and hard, but not as tough as lower carbon steel. Difficult to form. Can be hardened.	Tools, such as saw blades, hammers, chisels
Stainless steel	At least 11.5% chromium	Strong and hard. Difficult to machine. Good corrosion resistance: does not rust. Relatively expensive.	Knives and forks, medical equipment, sinks

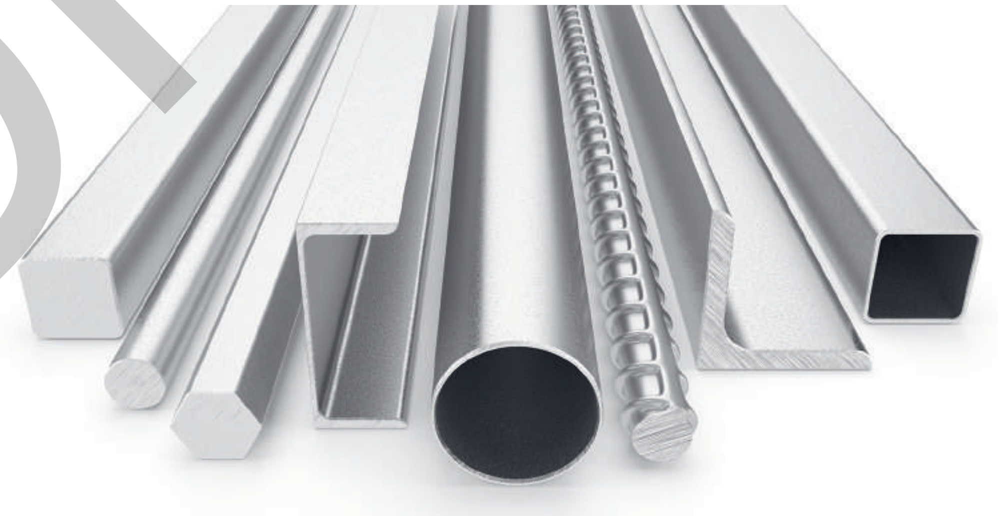

Figure 1.1.6 Forms of stainless steel

Non-ferrous metals and alloys

There are a wide range of metals and alloys that do not contain iron. Common non-ferrous metals and alloys include:

- aluminium and its alloys
- copper
- brass (an alloy of copper and zinc)
- bronze (an alloy of copper, tin and small amounts of other metals such as aluminium, zinc, lead and silicon)
- lead
- zinc.

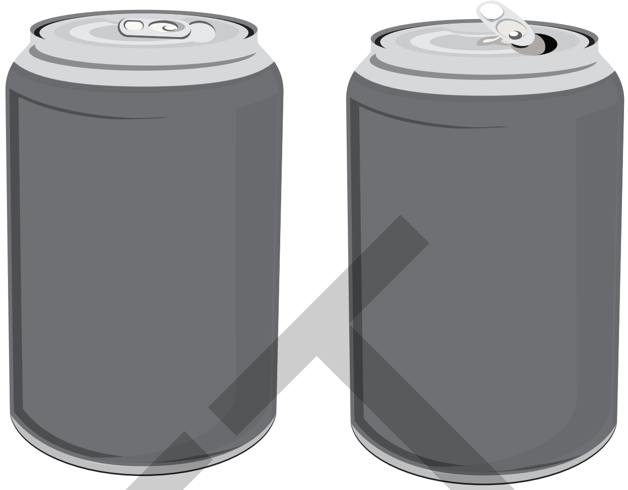

Figure 1.1.7 Aluminium drinks cans

Aluminium

Aluminium is one of the most commonly occurring elements on our planet. However, as a pure metal it is not as strong as steel, so it is normally alloyed to improve its properties. Compared to carbon steels, aluminium alloys cost more but have better resistance to corrosion. This makes them ideal for uses such as cans for soft drinks. Aluminium alloys also have lower density than steel; this means that aluminium products of the same size as steel products weight much less, so aluminium alloys are also used for applications such as the wings and body panels for aircraft.

Figure 1.1.8 Aluminium recycling symbol

Copper, brass and bronze

Copper is an excellent conductor of electricity and is also ductile, so it is often used to make electrical wires. Unlike many other metals, it is commonly used in its pure form, as alloying reduces its ability to conduct electricity; however, copper oxide can be added to make it stronger. Copper also has very good corrosion resistance, so its other most common use is to make water pipes.

Copper is also used to make the alloys bronze and brass. Bronze is an alloy of copper and tin, which is often used for cast products, including statues. Brass is an alloy of copper and zinc. It is difficult to cast, but can be machined to a high finish. Its uses include pressure-valve bodies, doorknobs and musical instruments.

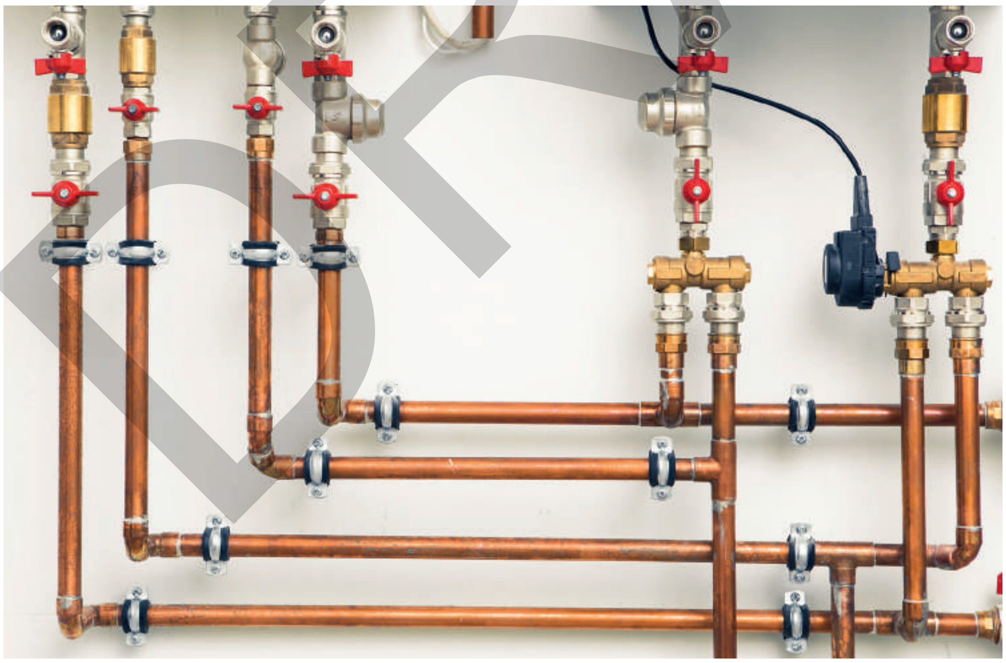

Figure 1.1.9 Copper pipes in a boiler room

KEY WORDS

Metal: a type of material typically made by processing an ore that has been mined or quarried.

Ores: typically an oxide of a metal, in the form of a rock.

Alloy: a mixture of two or more metals (or a metal with another element).

Ferrous: a material that contains iron.

Non-ferrous: a material that does not contain iron.

KEY WORDS

Cold working: repeatedly bending or hammering a metal.

Work hardening: an increase in the strength and hardness of a metal due to cold working.

Annealing: a heat treatment that makes a metal softer and easier to work.

Hardening: a heat treatment that increases the hardness and strength of a metal due to a change in the arrangement of the atoms within it.

Quenching: the rapid cooling of a hot metal by immersing it in a liquid, often oil or brine.

Tempering: a heat treatment to remove some of the brittleness in a hardened steel, at the cost of some hardness.

Lead

Lead is relatively soft, malleable and ductile and has very good resistance to corrosion. For these reasons lead sheets have often been used in the construction industry, for example to prevent water leaks around the edges of roofs. It also has a high density, so it is used for applications such as weights for diving belts and shielding for radiation in nuclear reactors. It used to be commonly used for water pipes in houses, but it was found that in the long term, exposure to lead can cause health problems in humans; nowadays, other materials which are less hazardous to humans are used for water pipes.

Zinc

Zinc has a low melting point compared to most metals (approximately 420°C). As this means it does not need as much energy (and therefore cost) to melt it, it is commonly used for die casting. Products that are commonly made from die-cast zinc include handles for car doors and camera bodies. It can be alloyed with aluminium to increase its strength.

ACTIVITY

Metals are used in a wide range of products. Using a table similar to the one below, try to identify the metals found in common products.

What properties make the metal suitable for use in that product?

Product	Metal	Important properties
Bicycle frame		
Kettle body		
Door key		
Car door		
Spoon		

Changing the properties of metal products

Alloying is a common way of creating a metal with the properties needed by a product. Compared to a pure metal, an alloy may offer, for example, higher strength, toughness or corrosion resistance, depending upon the alloying elements used. It typically involves melting two or more metals together, so they become mixed at a chemical level. In the microstructure of the metal, it is not normally possible to make out the different pure metals.

There are other ways in which the properties of metal products can be altered. These include:

- modifying the structure of the metal
- changing the surface chemistry.

Modifying the structure of the metal

If a metal product is examined under a microscope, it can be seen to be made of lots of grains of material pressed together. The size and shape of these grains affects the mechanical properties of the metal. In general, as the grain size reduces, the metal becomes harder and stronger; however, it also becomes less ductile and more brittle. This grain size can be affected by either **cold working** or heat treatment.

Further, in some metals different grains can have atoms arranged in different ways; these different arrangements typically also have different mechanical properties. In some metals these arrangements, and therefore the properties, can be changed by heat treatment.

Cold working

Many metals get harder as work is done to them – this is known as **work hardening**. It is why some metal parts get brittle and break after they have been repeatedly bent or hammered. When a metal is cold worked (i.e. not heated up before work is done to it), the grains in the affected area are deformed. They become stretched out, making them thinner, and effectively smaller, in that direction.

Further, within the metal grains there are many tiny flaws in how the atoms are arranged. These flaws are called dislocations. With repeated stressing, the atoms can move around within the grain, into the spaces left by these dislocations. In effect, the relocation of the atoms causes the dislocations to appear to move. However, when these moving dislocations meet up they can effectively 'pin' each other in place, stopping the atoms moving when stress is applied. This reduction in the ability of the atoms to move is what reduces the ductility and increases brittleness.

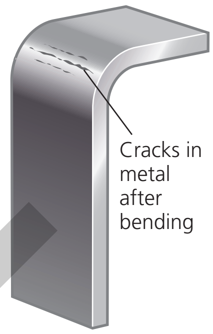

Figure 1.1.10 Metal failure after work hardening

Heat treatments to modify grain size

If a metal is heated to a suitable temperature, the grains within it can grow. This makes the metal softer and easier to work. This process is called **annealing** and is explained in detail in Section 2.6. It is often used to soften metal that has been work hardened, or to make metals easier to bend into complicated shapes.

Hardening and quenching

High-carbon steel, containing 0.8–1.4 per cent carbon, can be **hardened** by heat treatment; low-carbon steels cannot be hardened in this way. After heating, the steel is **quenched** by cooling it rapidly, and then **tempered**. This results in a steel which has a combination of hardness and toughness. This process is described explained in detail in Section 2.6.

Normalising

Normalising is carried out on steel that has been work hardened. It results in steel that is tough with some ductility. This is described in detail in Section 2.6.

KEY WORDS

Normalising: a heat treatment that results in metal that is tough with some ductility.

Corrosion: a reaction between the surface of a material and its environment that consumes some of the material.

Changing the surface chemistry

The properties of the surface of a metal product can be affected by its environment. For example, it may be damaged by corrosion or mechanical forces. For metal products, it is often possible to alter the effect of their environment by either managing corrosion or, for steels, by changing the structure of the surface through the addition (or subtraction) of carbon.

Corrosion

Corrosion is where the surface of the metal reacts with another substance in its environment. For example, this could be aluminium reacting with oxygen in the air to form aluminium oxide, or low-carbon steel reacting with rain water to form rust.

With aluminium, the oxide layer that forms protects the metal against further corrosion. The layer is so thin that it is not normally visible to the naked eye.

With steel, the corrosion can be progressive – over time more rust forms, slowly eating away the thickness of the material. Even a small amount of rust can have an aesthetic effect on a product, which may reduce how attractive it is to a user. However, as corrosion increases this results in a reduction in the thickness of the metal. If the metal has a force applied to it, for example a tensile load pulling it, this means

Figure 1.1.11 Corrosion on industrial pipes

that there is less metal to resist the force, so the stress in the metal is higher. If enough material has been corroded away, the stress can exceed the yield strength of the material, leading to permanent deformation or even failure. To avoid this, designers normally try to reduce or prevent corrosion. This can be achieved by, for example, stopping the surface of the steel coming in contact with water, by:

- painting
- applying a plastic coat by spraying or dipping
- applying a layer of another metal that does not react with the water – this is carried out either by dipping the product in molten metal or by electroplating, which involves placing the product in a chemical bath
- attaching a metal that the water will react with rather than reacting with the steel – the material is sacrificed to protect the steel (for example, zinc blocks are often used as a sacrificial material for offshore applications, such as the legs of oil rigs or boat hulls).

Corrosion is not desirable as it reduces the effective life of metal products; materials are often chosen to avoid it. However, in some cases manufacturers will use materials knowing that they will corrode, limiting the usable life of the product. This may be on cost grounds, as a material is much cheaper and easier to process than a more corrosion-resistant alternative, or it may be a result of planned obsolescence by the engineer.

Addition or subtraction of carbon in steels

Some products require a combination of the toughness of the low-carbon steel, with the hardness of high-carbon steel. For example, the gears used in train engines need to be tough so that they do not fracture; however, they also need to be hard so that they do not wear out where the teeth touch each other. This can be achieved by making the gear from a tough low-carbon steel then increasing the amount of carbon in the surface. This produces a hard skin that will resist wear. This process is known as case hardening.

KEY WORDS

Carburising: the addition of carbon to the surface of a low-carbon steel to improve hardness and strength.

The case hardening process is made up of two parts: **carburising** and hardening.

Carburising involves adding carbon to the outer surface of the steel. For a single part in a small workshop, this can be done by heating the steel part to red hot and then dipping it into carbon powder. Some of the carbon powder will be adsorbed into the surface by diffusion. This will normally be repeated two or three times. In an industrial situation, particularly when manufacturing quantities of parts, the methods used are:

- The steel part can be packed in charcoal granules and then heated to a temperature of about 900°C. This is then held at temperature for a few hours, to allow it to 'soak', so that the carbon can diffuse into the surface.
- Gas carburising: the steel part can be heated in a special furnace, where the atmosphere is controlled. This will normally contain a known proportion of carbon-rich gas, such as carbon monoxide. This is then allowed to soak at temperature for several hours, so that the carbon can diffuse into the surface.

Typically, gas carburising gives the most accurate control over the percentage of carbon in the surface, and dipping in carbon powder is the least accurate method.

Following carburising, the metal product is normally heated to red hot and quenched. This involves rapid cooling by dipping it in water, brine (salt water) or oil, as described in Section 2.6. As there is only a very thin skin of hard metal, the centre of the steel product will remain soft; this means that tempering is not needed.

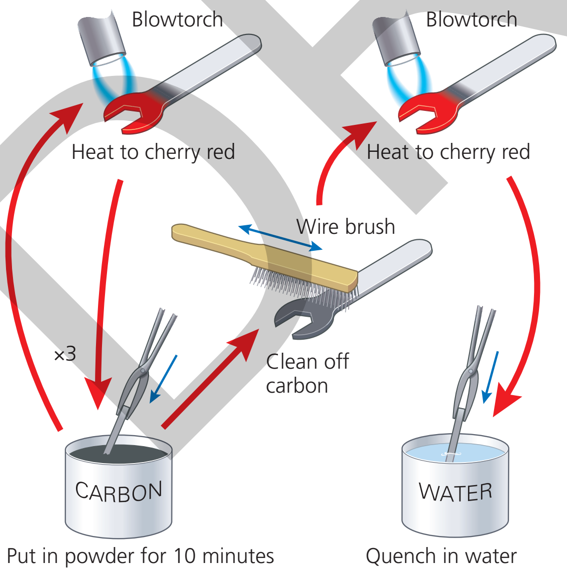

Figure 1.1.12 Case hardening of a low-carbon steel spanner

Available forms

Most metals are available in a wide range of standard forms and sizes:

- ingots (for melting to cast products)
- flat plates, sheets and strips
- bars and rods
- tubes and pipes
- standard section forms
- wire.

However, not all metals are available in every combination of size and shape, so engineers and manufacturers normally check what is available with their suppliers.

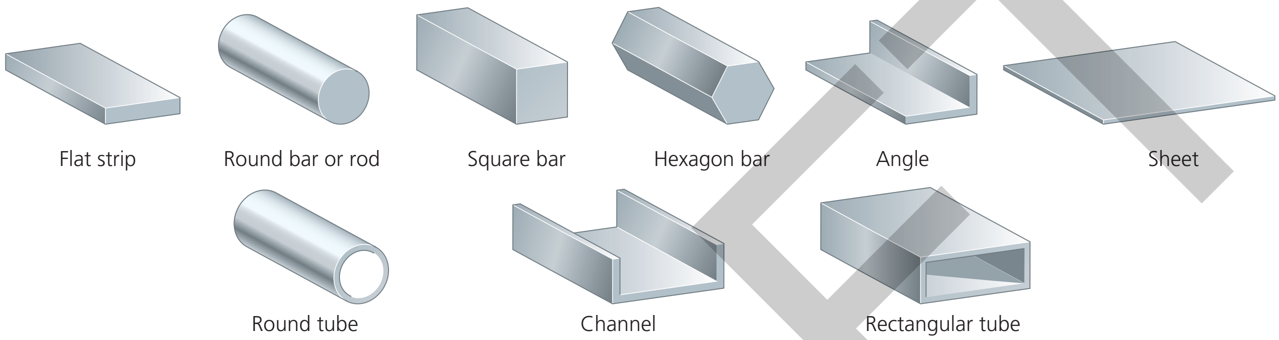

Figure 1.1.13 Standard metal forms

Metal	Bar	Flat	Tube	Shaped sections	Wires
Low-carbon steel	Round, square or hexagon	Plate, sheet or strip	Round, square or rectangular	L section (angle), U channel, H section, Tee section	
Aluminium alloy	Round, square or hexagon	Plate, sheet or strip	Round, square or rectangular	L section (angle), U channel, Tee section	0.5–3 mm thick
Copper	Round or square	Sheet or strip	Round		0.5–3 mm thick
Brass	Round, square or hexagon	Sheet or strip	Round	L section (angle)	0.5–3 mm thick

Table 1.1.2 Commonly available metal forms

Form	Characteristic	Standard sizes (mm unless otherwise stated)
Sheet	Width and length:	1 m x 1 m, 2 m x 1 m
	Thickness:	0.6, 0.8, 1.0, 1.2, 1.5, 2.0, 2.5, 3.0
Strip	Width and thickness:	10 x 3, 25 x 3, 50 x 3, 12 x 5, 20 x 5, 50 x 5, 12 x 6, 20 x 6, 50 x 6, 50 x 25, 100 x 50
Bar	Diameter of round section or side of square section:	3, 4, 5, 6, 8, 10, 12, 16, 18, 20, 22, 25, 30, 35, 40, 45, 50

Table 1.1.3 Typical standard sizes for some low-carbon steel forms

Polymers

Figure 1.1.14 Offshore oil rig

KEY WORDS

Polymer: a type of material made from a large number of similar, smaller chemical units that are bonded together.

Thermoplastic: a type of polymer that can be reshaped when heated.

Thermosetting polymer: a type of polymer with crosslinks between the polymer chains. It cannot be reshaped when heated.

Polymers are the most widely used type of material in commercial production. They comprise a large number of similar, smaller chemical units that are bonded together. Most polymers are synthetic, which means that they are man-made using chemical processes. Synthetic polymers are typically made from crude oil, which is obtained by drilling underground or under the sea. This is then processed in a chemical plant. However, there are an increasing number of natural polymers, made by processing plants. These include latex from trees, which is used to make natural rubber, and corn starch polymers, which are increasingly being used for disposable food packaging and cutlery.

There are two main types of polymer: **thermoplastics** and **thermosetting polymers**.

Figure 1.1.15 Water bottles formed by blow moulding thermoplastic tube

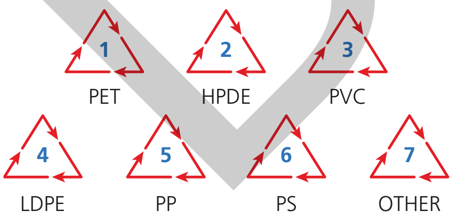

Figure 1.1.16 Recycling symbols on thermoplastics . The numbers and letters refer to different types of polymer.

Thermoplastics

Thermoplastics consist of long chains of repeating chemical parts. The individual chains are only weakly attached to each other. In some ways, a thermoplastic material resembles cooked spaghetti, in that the polymer chains overlap and entwine with each other to hold the material together. The weak links between the chains mean that thermoplastics are relatively ductile.

When thermoplastics are heated, they become softer and flexible. They can be shaped when hot and will harden into the new shape when cooled. If they are heated up again they can be reshaped. This property is a major reason that they are so widely used – it means that companies can buy sheets of polymers in standard sizes and easily change them into the shape required using heat, with processes such as vacuum forming or compression moulding. As well as being available in standard sheet sizes, they are also available as granules for use with moulding processes.

Thermoplastics can normally be recycled by melting them down. Many plastic products have markings to show the type of thermoplastic they are made from, to help them be sorted for recycling when they are thrown away.

Thermoplastic	Recycling symbol	Properties	Typical uses
Polyethylene terephthalate (PET)	1 PET	Clear, tough, shatter-resistant Good resistance to moisture	Drinks bottles, polyester fibres (polar fleece)
High-density polythene (HDPE)	2 HDPE	Hard, stiff Good chemical resistance Good impact strength	Bottles, buckets
Polyvinyl chloride (PVC)	3 PVC	Stiff, hard, tough, Good chemical and weather resistance	Window frames, guttering, pipes
Low-density polythene (LDPE)	4 LDPE	Tough, flexible, Electrical insulator Good chemical resistance	Detergent bottles, carrier bags
Polypropylene (PP)	5 PP	Hard Lightweight Good chemical resistance Good impact strength	Food containers, medical equipment
Polystyrene	6 PS	High Impact Polystyrene grades (HIPS) have good toughness and impact strength. Good for vacuum forming, injection moulding or extrusion.	Packaging, foam cups
ABS	9 ABS	Strong and rigid. Harder and tougher than polystyrene, but roughly twice the cost.	Plastic pipes, children's toys, keyboard keycaps
Acrylic	7 OTHER	Good optical properties – can be transparent. Hard wearing and will not shatter on impact.	Plastic windows, bath tubs, machine guards
Nylon	7 OTHER	Good resistance to wear. Low friction qualities. Ductile and durable.	Gear wheels, bearings
Polycarbonate	7 OTHER	High strength and toughness. Heat resistant. Excellent dimensional and colour stability.	Safety glasses, DVDs, exterior lighting fixtures

Table 1.1.4 Some common thermoplastics

Figure 1.1.17 Electrical sockets are normally made from thermosetting polymers

Thermosetting polymers

In a thermosetting polymer, compared to a thermoplastic, there are extra links formed between the individual chains of polymer. These links stop the chains being able to move, and mean that thermosetting polymers are typically harder and more rigid than thermoplastics. However, once moulded they cannot normally be reshaped. When heated they do not melt or soften; they stay the same shape and eventually start to char or burn.

Thermosetting polymers are normally available as either liquids or granules that will form the polymer when mixed together. At the end of their usable life, these polymers cannot be recycled. Most thermosetting polymers typically end up in landfill.

Thermosetting polymer	Properties	Typical uses include:
Epoxy	High strength, stiff, brittle. Excellent temperature, chemical and electrical resistance.	Printed circuit boards, cast electrical insulators
Polyester resin	Good strength and stiffness but brittle. Very good temperature, chemical and electrical resistance. Lower cost than the other resins.	Bonding or encapsulation of other materials, suitcases/luggage
Melamine resin	Stiff, hard, strong. Resistant to some chemicals and stains.	Laminate coverings for kitchen worktops, impact-resistant plastic plates
Polyurethane	Hard with high strength. Flexible, tough and low thermal conductivity.	Foam insulation panels, hoses, surface coatings and sealants
Vulcanised rubber	Higher tensile strength, elastic. Resistant to abrasion and swelling.	Tires, shoe soles, bouncing balls

Table 1.1.5 Some common thermosetting polymers

ACTIVITY

Have a look around your house and identify five products made from polymer. Determine which polymer each product is manufactured from. What are the reasons for using that polymer, rather than a different one?

STRETCH AND CHALLENGE

Create labelled sketches to show the difference between the structure of a thermoplastic polymer and a thermosetting polymer.

Composites

Composites are materials made by combining two or more different types of material. For example, this could be ceramic fibres and a polymer, wood and an adhesive made from polymer, or metal and ceramic. Unlike a metal alloy, the materials are not joined chemically. If the structure of a composite is examined using a microscope, the different materials can be seen clearly, although they are physically next to each other.

Composites can have unique combinations of properties that are not possible in individual types of material, such as high strength and toughness with low density. The properties of a composite depend not just on the materials that it is made from, but also on the form of these materials and how they are distributed within the composite.

For example, glass-reinforced plastic (GRP), commonly known as fibreglass, is made from ceramic glass fibres in a thermosetting polymer. The fibres provide **reinforcement**, increasing the strength. The polymer creates a matrix around the fibres, holding them in place and making the material rigid. The greater the quantity of reinforcement, the higher the strength of the composite; however, this would also provide less matrix, so less rigidity.

Unfortunately, achieving the properties needed is not as simple as just changing the ratio of the reinforcement to matrix. If all the reinforcement fibres are aligned in the same direction, then the strength will be strongest in that direction. However, if a force was applied at a right angle to the direction of the fibres, the fibres would not increase the strength in that direction much, and the material could be pulled apart much more easily. For this reason, many composite products ensure that fibres are positioned either in layers pointing in different directions or woven together. This helps to ensure that properties are the same in different directions.

Fibres are not the only form of reinforcement used in composites. The reinforcement can be layers of material (called plies or laminates), as in plywood, or even just particles, as in medium density fibreboard (MDF). In each case, the size and shape of the reinforcement will have an effect on the properties of the composite.

Most composites are made using moulding processes, where their different 'ingredients' are added together to form the required shape. For example, for fibreglass this could be sheets of fibre that are positioned in a mould and then impregnated or soaked with a polymer resin. For plywood and MDF, wood laminates or particles are compressed with adhesive to form sheets. These sheets can subsequently be machined into the shape needed using woodworking tools.

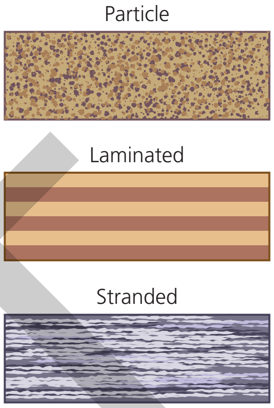

Figure 1.1.18 Types of composite

Figure 1.1.19 Sheets of carbon fibre, used to make composites

KEY WORDS

Composite: a type of material made by combining two or more different types of material. These remain physically distinct within its structure.

Reinforcement: the particles or fibre within a composite matrix that serve to increase its strength.

As it is very difficult to separate the different material types within the composite, they cannot normally be recycled. At the end of their usable life, many are disposed to landfill.

Composite	Properties	Typical uses include:
Carbon-fibre reinforced polymer (CRP)	Carbon fibres in a resin matrix. Extremely high strength and rigidity. Low density. Expensive to produce.	Aircraft structures, high-performance sports bicycles, helmets
Glass reinforced plastic (GRP)	Glass fibres in a resin matrix. High strength, low density. Good chemical resistance and thermal insulation. Lower cost than CRP but not as strong.	Canoes, small boat hulls, water tanks, surfboards
Plywood	Manufactured from layers of wood bonded together, at 90° to each other, using an adhesive. Smooth, even surface with good strength; often available in veneered form.	Furniture making, structural panelling; exterior grades used for boat building
Medium density fibreboard (MDF)	Manufactured from wood fibres and an adhesive matrix. Smooth, even surface with uniform properties. Easily machined and painted; often available in veneered form. Lower cost than plywood.	Furniture and internal panelling
Oriented strand board (OSB)	Manufactured from strands of wood compressed with adhesive matrix. Similar properties to plywood, but more uniform and lower cost.	Load bearing applications in construction, such as sheathing for walls and roof decking
Structural concrete	The most commonly used composite material. Concrete reinforced with steel bars to increase its tensile strength.	Bridges, high rise buildings

Table 1.1.6 Some common composite materials

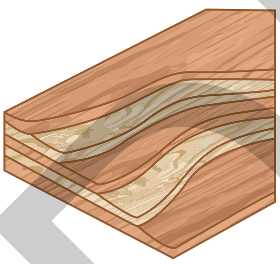

Figure 1.1.20
Structure of plywood

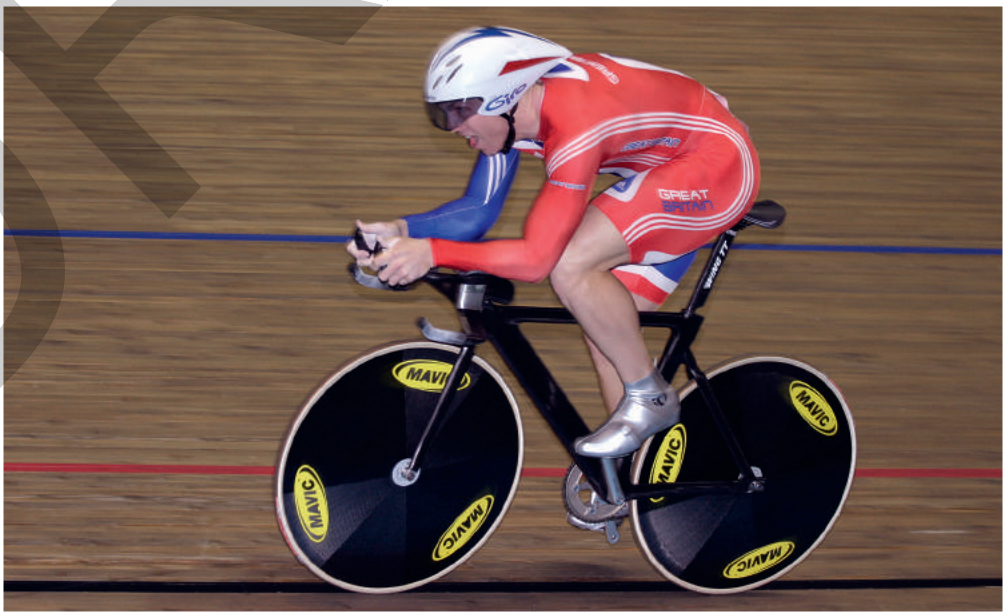

Figure 1.1.21 High-performance bicycle made from carbon fibre

Other materials

In addition to metals, polymers and composites, structural grades of timber and ceramic materials are also used for engineering applications.

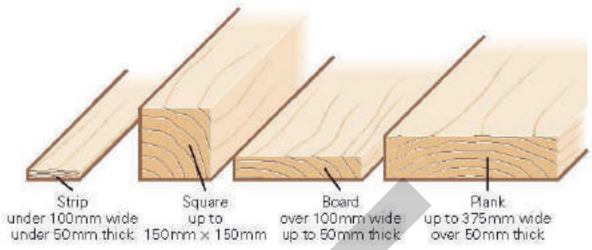

Figure 1.1.22 Standard timber sections

Timber

Timber is wood from trees. There are many types of wood available; however, within GCSE Engineering consideration only needs to be given to structural grades. These may be used, for example, to make the frames for wooden houses or gliders.

Timber used for structural applications is typically softwood, meaning that it is produced from coniferous trees which keep their leaves all year round. Examples include redwood (also known as scots pine) and western red, cedar and spruce. These are usually sawn into standard sizes and shapes. Rough sawn timber may also be planed to give it a smooth surface. Planing makes the wood approximately 3 mm smaller on each face than the sawn size. Planed timber is more expensive than sawn timber. However, it has a smoother finish and a more accurate size.

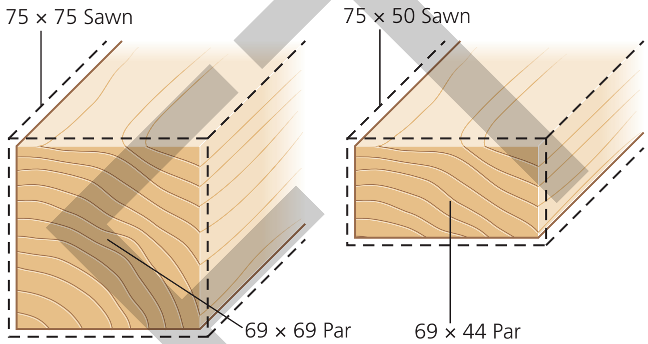

Figure 1.1.23 Typical planed timber sizes

Ceramics

The name **ceramic** comes from a Greek word meaning 'potter's clay'. However, ceramics are used for many more applications than just cups, plates and pots. In engineering their uses include:

- building materials, including concrete, bricks and plaster
- tools for cutting and grinding, made from tungsten carbide
- insulation for furnaces, made from alumina or aluminosilicates
- lenses, made from silicates.

Ceramic materials are typically oxides, nitrides or carbides of metals. They are usually harder than most other materials, meaning that they are very resistant to wear and scratches – hence their use for tools. They have excellent resistance to corrosion and are therefore used for chemical containers in laboratories.

Ceramics are very good insulators, for both electricity and heat, and can withstand high temperatures without softening. They also generally have good strength in compression. However, they have low tensile strength, very low ductility and are brittle. When they are subject to pulling forces they tend to crack and fall apart.

Due to their hardness, ceramics are very difficult to machine. They are often made by moulding processes, where very fine particles are either compressed together or held together by a liquid (like in clay). The moulded shapes are fired in furnaces at temperatures far above the melting point of most metals. This allows the ceramic particles to melt and join together. The use of moulding means that machining is not needed.

Figure 1.1.24 Stack of concrete masonry blocks

In theory, most ceramic materials could be recycled. However, due to the high temperatures required to melt them, this not normally cost effective. The exception to this is glass, which is used in very high quantities for bottles; the enormous numbers of bottles used each day mean that it is possible to get economies of scale to recycle them. Most other ceramics end up in landfill at the end of their usable life.

KEY WORDS

Timber: wood; a type of material obtained from trees.

Ceramic: a type of material that is typically an oxide, nitride or carbide of a metal.

KEY POINTS

- Materials properties include strength, ductility, malleability, hardness, toughness and stiffness.
- While categories of materials share some similar characteristics, each different material has a unique combination of properties.
- Ferrous metals contain iron; non-ferrous metals do not.
- The properties of metals can be changed by modifying the structure of the metal (such as by heat treatment) or changing the surface chemistry.
- Thermoplastics can be reshaped when heated; thermosetting polymers cannot be reshaped using heat.
- Composites are made from two or more materials, which remain chemically separate within the material.

Check your knowledge and understanding

1. State what is meant by the toughness of a material.
2. Explain the difference between a metal alloy and a composite material.
3. State three processes that involve the use of heat to change the properties of a low-carbon steel.
4. Explain why a manufacturer of saucepans might use handles made from a thermosetting polymer, rather than a thermoplastic.
5. Describe the typical properties of an engineering ceramic.

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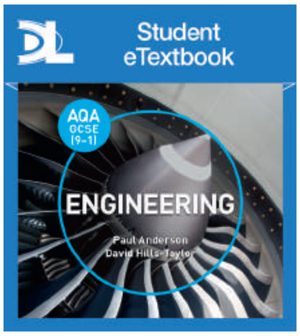

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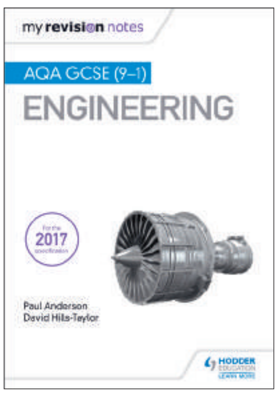

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