FACTFILE:
GCSE
Engineering and Manufacturing
3.3.1 Materials and their Applications

Rewarding Learning

Materials and their Applications

Learning outcomes

Students should be able to:

- demonstrate knowledge and understanding of the following materials and their applications:
  - ferrous metals and alloys (cast iron, stainless steel and low, medium and high carbon steel);
  - non-ferrous metals and alloys (copper, aluminium, brass, bronze and aluminium alloy);
  - thermosetting polymers (melamineformaldehyde and epoxy resins);
  - thermoplastic polymers (polythene, polypropylene, polyvinyl chloride (PVC), acrylic, nylon and polyester);
  - hardwood (balsa, beech, mahogany and oak);
  - softwood (pine, redwood and cedar);
  - manufactured board: (plywood, blockboard, chipboard, hardboard and MDF); and
  - composite materials: Glass Reinforced Plastic (GRP) and carbon composites.

Ferrous metals

These are metals which contain iron. They may have small amounts of other metals or other elements added, to provide specific properties. All ferrous metals are magnetic and are likely to corrode over time. Alloys are a mixture of two or more metals formed to create a new metal with improved properties and characteristics.

Alloying can:

- lower the melting point;
- increase hardness, ductility and strength;
- alter resistance to corrosion;
- modify electrical and thermal properties; and
- change the colour of the metal.

The following are ferrous metals, their characteristics and the kind of uses to which they are usually put:

Cast iron:

- used to manufacture items such as engine blocks and manhole covers;
- parts with complex shapes which can be made by casting; and
- carbon 2 – 6% and Iron at 94 to 98%. Very strong but brittle.

Stainless steel:

- used for the likes of cutlery and surgical instrumentation as it resists staining and corrosion; and
- made up of Iron, carbon, nickel and chromium.

Steel:

- steel is a very versatile material and is a commonly used alloy. It is obtained by alloying iron with carbon. Steel can be classified into three main groups.

Low carbon steel also known as mild steel:

- used for engineering purposes and in general, none specialised metal products, e.g. nails, screws, nuts and bolts;
- tough, ductile, malleable with a good tensile strength; and
- iron content of 99.7 – 99.9% and carbon content of 0.1 to 0.3%.

Medium carbon steel:

- used for car parts, e.g. axle shafts and crank shafts;
- good wear resistance; and
- composed of 0.3 to 0.6% carbon.

High carbon steel:

- used to make cutting tools such as drill bits, cutting tools and ball bearings; and
- carbon content of 0.6 to 1.4% and Iron content of 98.6 to 99.4%.

Non Ferrous Metals

A non-ferrous metal is a metal, including alloys, that does not contain iron. These are generally more expensive than ferrous metals. Non-ferrous metals are used because of desirable properties such as low weight (e.g. aluminium), higher conductivity (e.g. copper), non-magnetic property or resistance to corrosion (e.g. zinc).

These are the most common non ferrous metals.

Copper:

- is malleable and ductile;
- resistant to corrosion; and
- a good conductor of heat and electricity. This means that it can be used for electrical wiring, cooking utensils, tubing and pipe work.

Aluminium:

- good strength-to-weight ratio, light, soft, ductile, good conductor of heat and electricity;
- easily worked;
- used in aircraft manufacture, general cast components, window frames and some kitchen ware.

Brass:

- a combination of copper and zinc, usually in the proportions of 65% to 35% respectively;
- resistant to corrosion and a good conductor of heat and electricity;
- used for ornamental purposes and within electrical fittings.

Bronze:

- a mixture of copper and tin;
- harder than copper and resistant to corrosion;
- used for statues, musical instruments and medals.

Aluminium alloy sometimes called duralumin:

- composed of aluminium and a range of other materials such as copper silicon and manganese;
- lightweight and strong;
- used in a variety of products, e.g. aircraft parts and car wheels.

Thermosetting polymers

Thermosetting plastics (polymers) are synthetic materials that strengthen during a heating process, but cannot be remolded or reheated after their initial heatforming. This is in contrast to thermoplastics, which soften when heated and harden and strengthen after cooling. Some of the more common thermosets are listed below with their properties and uses.

Thermosetting plastics	Properties	Uses
Epoxy resin	Good electrical insulator, hard, brittle unless reinforced, resists chemicals well.	Used for casting and encapsulation, adhesives, bonding of other materials. Used for printed circuit boards (PCB's) and surface coatings.
Melamine formaldehyde	Stiff, hard, strong, resists some chemicals and stains.	Used for laminating work surfaces, electrical insulation, tableware.
Polyester resin	Stiff, hard, brittle unless laminated, good electrical insulator, resists chemicals well.	Used for casting and encapsulation, bonding of other materials, car bodies, boats.
Urea formaldehyde	Stiff, hard, strong, brittle, good electrical insulator.	Used for electrical fittings, handles and control knobs, adhesives.

Thermoplastic polymers

Thermoplastics can be heated and shaped many times. Thermoplastics will soften when it is heated and can be shaped when hot. The plastic will harden when cooled, but can be reshaped because there is no link between the polymer chains. Some of the more common thermosets are listed below with their properties and uses.

Thermoplastics	Properties	Uses
Polythene	Tough, good resistance to chemicals, flexible, and good electrical insulator.	Used for packaging, especially bottles, toys, packaging film and bags.
Polypropylene	Light, hard but can scratch easily, good resistance to chemicals, and tough.	Used for medical equipment, laboratory equipment, plastic seats, string, rope, kitchen equipment.
PVC	Stiff hard wearing.	Used for air and water pipes, shoe soles, blister packaging.
Acrylic	Stiff, durable but scratches easily, good electrical insulator, machines and polishes well.	Used for signs, covers of storage boxes, aircraft windows, wash basins and baths.
Nylon	Durable, tough, resistant to wear, low resistance and self lubricating.	Gears, bearings, washers and clothing.
Polyester	Durable, resistant to chemicals, resistant to stretching, shrinking and wrinkling.	Outdoor type clothing, fabric for conveyor and safety belts.

Hardwoods

Hardwoods come from deciduous or broad-leafed trees. They are generally slow growing which tends to make them harder and more expensive. Hardwoods are sold by the cubic metre then this is sawn to the size the customer requires. Some hardwoods are machined into sections for mouldings etc. Not all hardwoods are hard, balsa is very soft and is often used for model planes, however, it is a hardwood.

Hardwoods include Ash, Beech, Oak, Balsa, Teak and Mahogany. They:

- come from deciduous or broad-leafed trees;
- hardwoods can be identified by the structure of the wood grain and grow slower than softwoods so they are more expensive.

Hardwood	Properties	Uses
Balsa	A pale white to grey. It has a distinct velvety feel. It has exceptional strength to weight properties. It is the lightest and softest wood on the market.	Used for light work such as model making and model airplane construction.
Beech	A straight-grained hardwood with a fine texture. Light in colour. Very hard so is durable. Beech is also very easy to work with.	Used for furniture, toys, tool handles. Can be steam bent.
Mahogany	An easy to work wood which is reddish brown in colour. This wood is very expensive.	Used for expensive indoor furniture, shop fittings, veneers.
Oak	A very strong wood which is light in colour. Open grain. Hard to work with. When treated it has a good appearance.	Used for high class furniture, boats, beams used in buildings, veneers.

Softwoods

Softwoods grow faster than hardwoods and are cheaper in cost than hardwoods. They come from coniferous trees which have needles instead of leaves. They are easier to work with as they are softer than hardwoods. Softwoods are supplied in standard sections sawn and planed smooth.

- softwoods include Pine, Spruce, European redwood, and Cedar;
- softwoods come from coniferous trees, they don't lose their needles in autumn and winter;
- softwoods grow faster than hardwoods so are cheaper; and
- are used as building material.

Softwood	Properties	Uses
Pine	Knot free. Fairly strong and durable. Expensive. Pale yellow in colour with red/brown streaks.	Used for good quality knot free pine red / brown furniture such as doors and staircases.
European redwood	Quite strong, Lots of knots, durable when preserved. Cheap.	Used for general woodwork, cupboards, shelves, roofs.
Cedar	A pale yellow-coloured softwood with a fine even texture. Light in weight but stiff and stable.	Used for furniture, boat building, veneers, and model making.

Manufactured board

Manufactured boards are timber sheets which are mass produced mainly for industrial production by gluing wood layers or wood fibres together. Manufactured boards often make use of waste wood materials. Manufactured boards are made in very large sheets in varying thicknesses of consistent quality.

Manufactured boards:

- often make use of waste wood materials;
- saw dust held together with glue is used to make MDF and hardboard;
- manufactured boards are inexpensive and are often used instead of real woods; and
- manufactured boards are often covered with a thin layer of real wood called a veneer to improve appearance.

Manufactured Boards	Properties	Uses
MDF	Smooth, even surface. Easily machined and painted or stained. Also available in water and fire resistant forms.	Furniture and interior paneling due to its easy machining qualities.
Plywood	A very strong board constructed of layers of piles which are glued at 90 degrees to each other. Interior and exterior grades are available.	Used for strong structural paneling board used in building construction and furniture making. Some grades used for boat building and exterior work.
Chipboard	Made from chips of wood glued together. Usually veneered or covered in plastic laminate.	Used for kitchen and bedroom furniture usually veneered or covered with a plastic laminate. Also general DIY work.
Blockboard	Similar to plywood but the central layer is made from strips of timber. Good for shelves and worktops.	Used where heavier structures are needed. Common for shelving and worktops.
Hardboard	A very cheap particle board which sometimes has a laminated plastic surface.	Used for furniture backs, covering curved structures, door panels.

Composite materials

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties. When combined, these produce a material with characteristics very different from the individual components.

The new material may be preferred for many reasons including materials which are stronger, lighter, or less expensive when compared to traditional materials.

Typical engineered composite materials include:

- reinforced plastics, such as fiber-reinforced polymer;
- metal composites; and
- mortars and concrete.

There are two main categories of constituent materials, a matrix (binder) and a reinforcement. At least one portion of each type is required.

The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties.

Many commercially produced composites use a polymer matrix material often called a resin solution. There are many different polymers available depending upon the starting raw ingredients. There are several broad categories, each with numerous variations. The most common are known as polyester, vinyl ester, epoxy, phenolic, polyimide, polyamide, polypropylene, and others. The reinforcement materials are often fibres but also commonly ground minerals.

Composite	Properties	Uses
Steel Reinforced Concrete	Reinforced concrete has long steel rods passing through its length, adding great strength to the final composite material. Able to resist tensile forces.	Bridge building, skyscrapers and general large scale construction.
Glass Reinforced Plastic (GRP)	Polyester resin is added, followed by a catalyst (to speed up the reaction). Allowed to dry/cure. The resulting material is strong and light. Can be sanded and painted.	Canoes, car bodies, small swimming pools, water tanks, surfboards, small boat hulls.
Carbon Fibre Reinforced Polymer (CFRP)	Carbon fibre is woven into a textile material. Epoxy resin is added and allowed to cure. The resulting material is very strong and light. An improvement on glass fibre reinforced plastic, although much more expensive.	Aerospace, expensive sports cars, competition bicycles and motorbikes.
Kevlar	Kevlar® is a liquid, converted into a fibre and woven into a textile material. Extremely strong, lightweight, corrosion and heat resistant. Has a high tensile strength to weight ratio, far exceeding steel, carbon fibre and specialist alloys.	When combined with other materials: bullet proof jackets, armour for military vehicles and planes. Formula 1 fuel tanks.

Revision Questions

Q1. What are the properties of a ferrous metal?

Q2. What is the main problem with mild steel?

Q3. What is a metal alloy?

Q4. What properties does copper have that make it suitable for electronic cables?

Q5. Why are hardwoods expensive?

Q6. What is the difference between thermosetting plastics and thermoplastics?

Q7. What are manufactured boards made from?

Q8. List **three** benefits for the manufacturer in using manufactured boards.

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Q9. How can a manufactured board be made to look better?

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Q10. What are the benefits of using a composite material?

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Additional resources:

CDT: Technology – Collins – ISBN 0-00-327434-9

Design and Technology for AQA: Resistant Materials: Teachers resource file – Heinemann ISBN 0-435-41348-1

GCSE Design and Technology: Resistant Materials – CPG – ISBN 1-84146-792-8

www.design-technology.org/CDT10metalslesson.htm

www.bbc.co.uk/schools/gcsebitesize/design/resistantmaterials

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www.castlemetalseurope.com/blog/ferrous-nonferrous-metals-uses