# WJEC LEVEL 2 ENGINEERING

# REVISION BOOKLET FOR THE UNIT 3 EXAM.

**Unit 3 Solving Engineering Problems**



**Name**

Plympton Academy
Inspiring Success

# Learning Outcome 1: Effects of engineering achievements

## Introduction to engineering industry

Engineering is a very exciting, creative and interesting subject to study. There is much to learn but most of this can be covered through practical designing and making activities. Engineering involves:

- Designing products, through drawing, modelling and testing
- Selecting the materials to be used
- Planning making activities
- Making products using a wide range of different equipment, ranging from hand tools, to machine tools, to automated equipment.

There are many different types of engineering industry today ranging from chemical engineering to automotive and electrical, however, to simplify things down this course requires you to look at three different sectors in detail.

| Structural Engineering | Mechanical Engineering | Electronic Engineering |
|---|---|---|
| • Buildings<br>• Bridges<br>• Dams | • Vehicles<br>• Cranes<br>• Aircraft | • Mobile phones<br>• Personal Computers<br>• Televisions |
| • Arup<br>• Balfour Beatty<br>• Skanska AB | • Airbus<br>• Ford<br>• BMW | • Apple<br>• Samsung<br>• Dyson |

## Environmental Issues

In the past the engineering industry has contributed significantly to pollution and environmental damage. One of the main reasons for this is that we, as a society, placed more importance on our needs for material progress rather than environmental issues. This means that we were more concerned with having larger cars, mobile phones and the comforts we associate with modern life than the environmental impact of making, using and disposing of these products. Engineering companies were more concerned with generating profit than reducing environmental impact. Another reason is that we may not have been fully aware of the environmental impact of our manufacturing activities.

As environmental issues have become more pressing, their relative importance to society has increased. This has placed increasing moral and legal responsibilities on engineering companies. A number of different approaches are being used to minimise the impact of their activities on the environment. These include:

- Modifying the design of products
- Recycling materials and components at the end of the products useful life
- Reducing energy requirements to make the products

| The 6 Rs of Sustainability | | |
|---|---|---|
| **Reduce**<br>Using less material and energy | **Repair**<br>Extend the life of products rather than disposal | **Recycle**<br>Reduce use of resources and energy by reprocessing |
| **Reuse**<br>Don't dispose of a product if it could be used to fulfil the same use again or a different use | **Rethink**<br>Review if the need is necessary and the features of the design | **Refuse**<br>Decline to use products that are not environmentally friendly |

**Reducing material usage and energy consumption**
Engineered products are made from materials and components bought from suppliers in standard shapes and sizes. The production of these materials uses both energy and raw materials. For example, most metals are made from metal ores mined from the ground and plastics are made from oil, both of which are finite materials. Changing the form of these raw materials into useful products uses a lot of energy to power the manufacturing processes.

Designing products that use less material or reduce the amount of materials or components needed in a product can help to reduce environmental impact. Products that use electrical systems to operate are designed to be more energy efficient. In addition industries can use more recycled materials in their products, which can help reduce energy consumption as not as much power is required to process recycled materials compared with producing materials from raw materials.

**Extending product life**
Many products have a limited life span and are usually more expensive to repair than to buy a new product. This means that manufacturers protect their future sales by designing built-in obsolescence into their products.

Extending product life can be achieved by using materials with improved properties. For instance, using coatings to improve the corrosion resistance of products that are exposed to the elements or extremes in temperatures extends their life span. The ability to repair a product can also extend the products life as worn or damaged parts can be replaced.

**Disposal**
All engineered products today must comply with strict environmental legislation to reduce their environmental impact. For example, the End of Life of Vehicles Directive came into force in Europe in 2000. It gives legal targets for what proportion of a vehicle has to be reused or be suitable for recycling. These targets meant that by 2015, 85% by weight of the materials used in the car had to be suitable for recycling. The responsibility for achieving this target is placed on the company producing the vehicle.

**Reuse**
Using a component again is preferable to recycling as no energy is required to change the form of the part. Scrap yards are a well established source of parts to repair cars. This is because it is cheaper to buy parts second hand than to buy them new.

**Recycling**
Recycling involves breaking down or melting material and changing it into a different shape so that it can be used for a different application. Recycling applies to both products at the end of their useful life and to waste generated during the manufacture of the product. Metals, glass and different types of plastic are routinely recycled and are usually marked to indicate which material they are.

Recycling products made from just one material is fairly straightforward, however, most products contain several different materials that need to be taken apart before they can be recycled. Many products can be difficult to separate, which makes recycling difficult. For example, composite materials are a very fine mixture of two or more different types of material that are not normally suitable for recycling.


**Energy use in engineering**
Engineering industries use large amounts of energy during the production and transportation of the their products. Much of this energy is generated by burning fossil fuels such as oil, gas and coal which in turn releases carbon dioxide and contributes to global warming. To reduce their environmental impact many engineering companies have tried to adopt some of the following strategies:

Increasing process efficiency to reduce the amount of energy actually used by powering down or turning off electrical equipment when not in use. This can include machines, computers and lighting. Replacing old machines with more efficient new machines. Insulating the facilities used to heat-treat products, which can reduce the energy needed to heat them by 20%.

Switching from non-renewable energy sources to renewables such as solar, tidal or hydroelectric power.  Investing in carbon capture schemes which are designed to offset the carbon produced by planting trees.

## Learning Outcome 2: Properties of Engineering Materials

When choosing engineering materials or components it is important to consider the mechanical or physical properties to ensure that the materials will perform their task. The table below shows the most common properties you need to know and their application.

| Property | Description & Application |
|---|---|
| **Tensile Strength** | **The ability to withstand stretching forces.** Structural steel is used in many modern buildings to provide a framework for other building materials. |
| **Hardness** | **Resistance to scratching, cutting, denting and wear.** High speed steel is very hard and so is suitable for use in high speed machining operations. |
| **Toughness** | Resistance to sudden shock without breaking or deforming. Many plastics are very tough that is why they are used to produce products such as wheelie bins, classroom chairs and buckets. |
| **Malleability** | **The ability to be permanently deformed in all directions without fracture.** Precious metals like silver and gold can be formed into shape by hammering and beating . |
| **Ductility** | **The ability to be stretched and permanently deformed without breaking.** Mild steel is used in the production of car bodies as it can resist the stretching involved in forming processes. |
| **Conductivity** | **The ability to conduct electricity and heat.** Copper is used to produce electrical wiring and water pipes as it is an excellent conductor. |
| **Corrosive resistance** | **Resistance to oxygen and water in the air.** Tinplate is used to package beans and other food products as it is resistant to corrosion. |
| **Environmental degradation** | **The ability to withstand environmental conditions.** Zinc is used as coating on steel buckets, screws and roofing sheets as it is extremely resistant to corrosion from moisture and other environmental conditions. |
| **Elasticity** | **The ability to regain its original shape after it has been deformed.** Plastic or rubber based materials are used on handles as they provide a comfortable grip on sporting products. |

## Industrial Material Testing

Before selecting materials for use with engineering products it is important to know if they are suitable for the environment they will be used in and if they are suited to the function they have to perform. Tyre companies such as Michelin will run tyres on vehicles to establish wear-rates in use.

## Destructive Testing

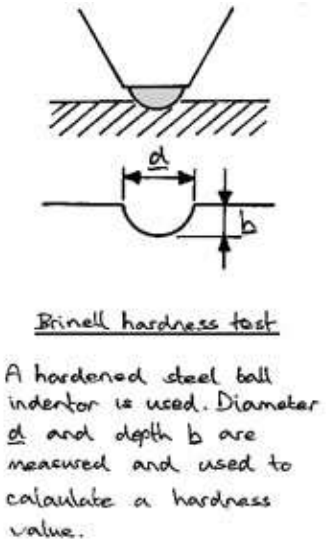
Destructive Testing refers to a range of tests that ultimately results in the destruction of a standard size piece of material. Hardness test pieces will have small indentations after testing, while impact testing will cause test pieces to bend or break completely.

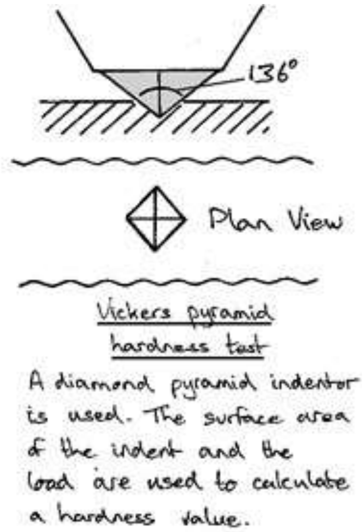
## Hardness Tests

Hardness is the ability of a material to resist abrasive wear, indentation or deformation. Hardness is a by-product of strength, so generally the stronger the material the harder it is. Opposite are two basic tests that are used for testing hardness:

The Brinell hardness test forces a steel ball into the material's surface by means of a suitable load. The surface area of the indent is measured and used to calculate the hardness number.

The Vickers test uses a diamond pyramid to indent the material. This is again measured using a microscope to give the hardness value.



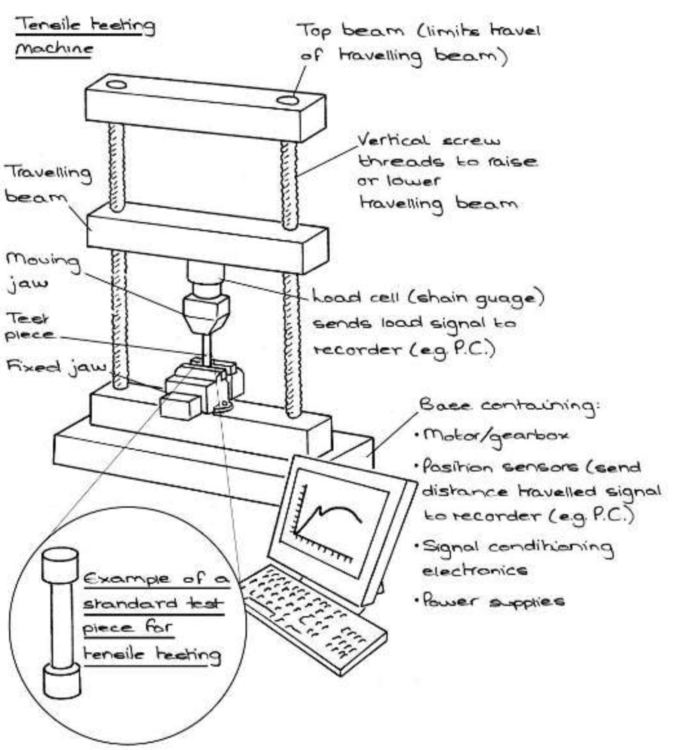



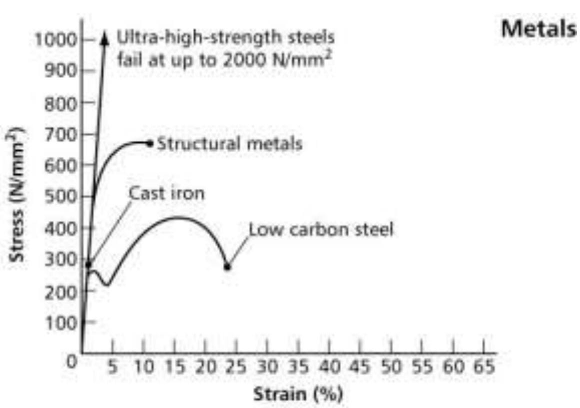

### Tensile Tests

Tensile testing involves putting material under tension by stretching to provide information regarding tensile strength, elasticity and plastic properties, such as ductility and malleability.

A standard test piece is held between two grips. One of the grips is fixed and the other is moved at a constant speed by a motor until the material either breaks or stretches beyond the elastic limit of the machine.

A number of materials are tested in this way including rubber, steel and fabric. The rope making industry tests the strength of the fibres used in their ropes and in the clothing industry test the strength of their fabrics.



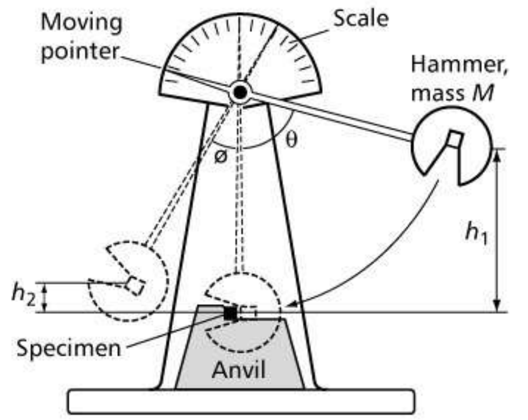
## Impact Tests

Impact tests indicate the toughness of a material and, in particular, its resistance to mechanical shock. There are three main methods of impact testing:

- Izod test
- Charpy test
- Houndsfield test

Test pieces are standardised for each test and the more the test piece absorbs the impact the tougher the material is.

**Izod/charpy impact test equipment**



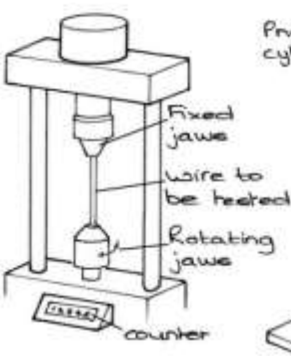

## Wear Resistance

Materials that need to resist constant wear can be tested by weighing a sample piece before and after the test, which involves rubbing the material with an abrasive. The difference in weight is used to determine the materials resistance to wear.

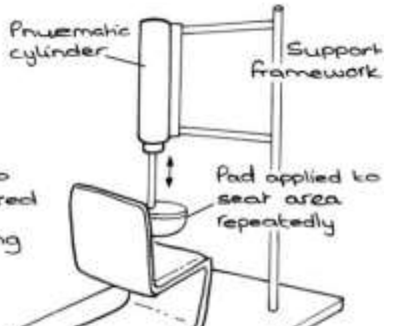
## Fatigue Testing

Two methods of testing fatigue are shown opposite. The first involves twisting steel wire in different materials over time until the sample breaks.

Chairs can be tested by repeatedly applying a force or weight to the seating area representing a person sitting on the chair.




Fatigue testing steel wires




Cantilever chair being fatigue tested

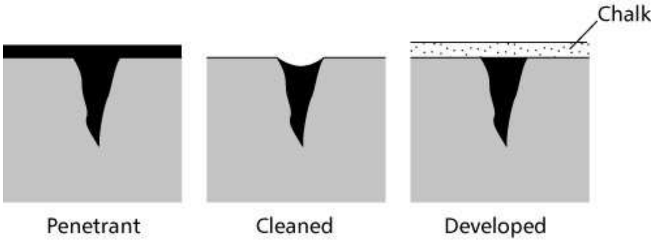
## Non-destructive Testing

These tests use methods that do not damage or destroy the material or product. They are usually used on the final product to test for surface or near surface faults or flaws. Welded joints on car chassis and engine castings in the car industry are tested in this way.

## Surface Crack Detection

A simple way of testing for surface cracks is to visually check the surface. Touch can also be used to sense any faults directly on the surface of the product.

Ringing is used in the casting and pottery industries to test for faulty products as a bell cannot ring if it is cracked.



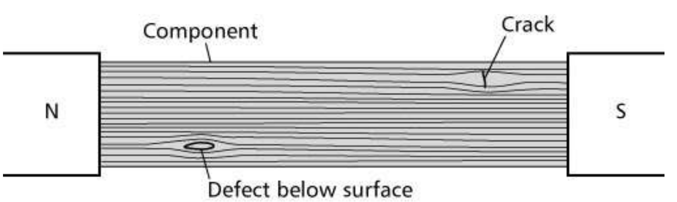

**Crack detection**

## Liquid Penetrant

In this process a liquid is sprayed onto the surface of the product. Once the excess has been removed only the penetrant in the cracks will remain. To make the cracks clearer a light dusting of chalk is applied.

## Magnetic Testing

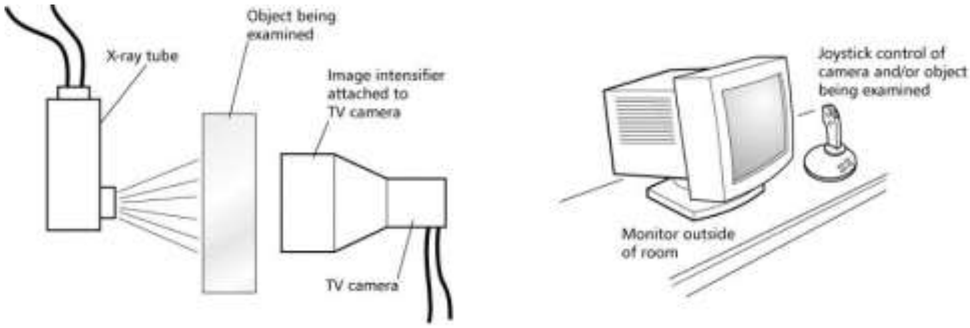
A component can be magnetised in an electromagnetic circuit. Iron particles are dusted over the area and highlight where the magnetic lines of force are broken by a defect. It is particularly useful when trying to find defects just below the surface.



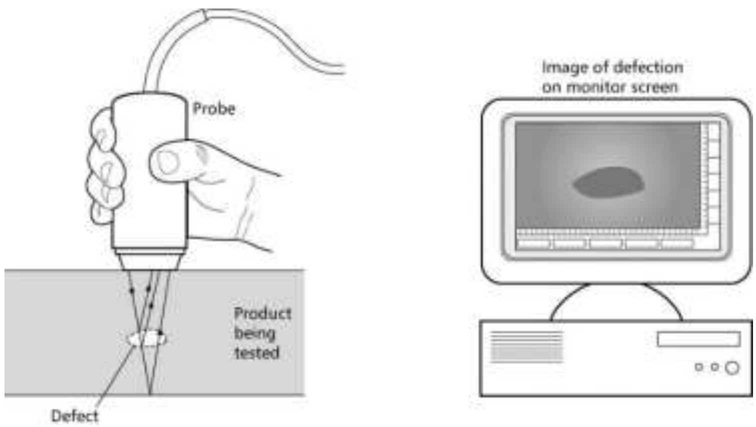

**Component within a magnetic circuit**

**Internal Defect Detection**

**X-ray Testing**
X-rays are used to detect defects under the surface of a product or material. An x-ray tube emits radiation through the product and forms an image through an image intensifier and camera to a monitor. As x-rays travel faster through cavities they produce a darker image on the screen. This is useful for detecting if products have been formed together correctly.




**Ultrasonic Testing**
Very high frequency sound vibrations can be used to precisely locate internal defects. A probe is passed over the component transmitting the high frequencies. Under normal conditions the vibrations pass through the material and are reflected back through the bottom surface of the material. The probe receives this and an amplifier converts the vibrations into blips on a monitor. This process is ideal to test sheet, plate and strip materials making it ideal into the inspection of aircraft and pipelines.

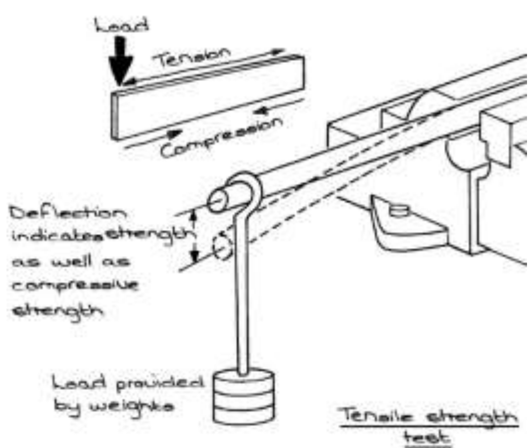



***Example Question***
*You have been asked to measure the ability of a length of steel bar to resist bending.*

*Describe using notes and sketches how you could perform a simple test in a workshop to measure the steel bar's ability to resist bending.*

**As each weight is added, the sample is reviewed and comments recorded.**

**As the sample weight reaches 1Kg a reading is taken using a metal rule.**



## Engineering Materials

### Metals
Metal ores are mined from the ground  and the metal is extracted from the rocks, this is a finite resource, so has to be managed carefully. All metals can be recycled, however, which should reduce the demand on raw materials. There are three main types of metal: ferrous, non-ferrous and alloys.

Ferrous metals consist of iron, carbon and other elements. Most ferrous metals are prone to rusting and are magnetic. Non-ferrous metals do not contain any iron, so they are not magnetic and do not rust when exposed to moisture. However, they do tarnish and oxidise. Alloys are metals that contain two or more elements which are combined to enhance the properties of the material. For example, improving the strength to weight ratio in vehicles or improving resistance to corrosion.

**Stock forms/types**
Metals used in industry are generally available in standard forms as they are easier to handle and transport, in addition they are cheaper than special sizes as they can be manufactured in large quantities.

Construction beams are used in the construction industry to carry large loads across a gap. The most common is the I beam which has large flanges to spread load over larger areas. Other beams are shown below and are used in different applications.

Bar has a solid cross-section  and is available in square, round, hexagonal, flat, angle and channel. It is used in general purpose construction work.

Sheet comes as flat sheets ranging in thickness from 0.6-3mm and is used to manufacture washing machine casing and radiators among other products. Plate is sheet metal with a thickness greater than 3mm and is used in heavy duty work, for instance building ship hulls.

Pipe and tube has a hollow section and is available in square, rectangular, round and hexagonal. It is used in general construction work where reduced weight is important.

## Ferrous Metals

| Name | Description | Application |
|---|---|---|
| Cast Iron | • Re-melted pig iron with some small quantities of other metals<br>• Typically 93% iron with 4% carbon<br>• Very strong in compression, but brittle | • Metal work vices and machinery bases<br>• Brake discs and drums<br>• Car cylinder blocks |
| Mild Steel | • Iron mixed with about 0.3% carbon<br>• Ductile and malleable with a high tensile strength<br>• Rusts very quickly if exposed to moisture | • Nuts and bolts<br>• Car body panels<br>• Gates and girders |
| Tool Steel | • Known as medium or high carbon steel<br>• Up to 1.5% carbon content<br>• Strong and very hard | • Hand tools<br>• Garden tools and springs |
| High Speed Steel | • Contains a high content of tungsten, chromium and vanadium<br>• Brittle but resistant to wear<br>• Used in high speed machining operations | • Drill bits<br>• Lathe tools<br>• Milling cutters |
| Stainless Steel | • An alloy of iron with 18% chromium and 8% nickel<br>• Very resistant to wear and corrosion | • Kitchen sinks<br>• Cutlery and teapots<br>• Surgical equipment |

## Non-Ferrous Metals

| Name | Description | Application |
|---|---|---|
| Aluminium | • A light grey colour that can be polished to a mirror-like appearance<br>• Light in weight, ductile and malleable<br>• Can be anodised to protect the surface and give it colour | • Cooking foil and packaging<br>• Saucepans<br>• Window frames<br>• Ladders |
| Copper | • Reddish brown, but can turn green after exposure to oxygen<br>• Ductile and malleable<br>• An excellent conductor of heat and electricity | • Plumbing and electrical components<br>• Domed roofs (copper covered) |
| Tin | • Bright silver in colour<br>• Ductile and malleable<br>• Resistant to corrosion<br>• Tinplate is steel with a tin coating | • Used as a coating on food cans and packaging |
| Zinc | • Very weak<br>• Extremely resistant to corrosion from moisture | • Used as a coating on steel buckets, screws and roofing sheets (galvanized steel) |
| Gold and Silver | • Precious metals<br>• Very ductile and malleable<br>• Silver tarnishes, but gold isn't affected by oxidation | • Jewellery<br>• Plated onto electrical wires to improve contact and reduce resistance |

| Alloys | | |
|---|---|---|
| **Name** | **Description** | **Application** |
| Brass | • A hard yellow material<br>• An alloy of 65% copper and 35% zinc<br>• Often cast and machined, then chromium plated | • Decorative metal work, like door handles and boat fittings<br>• Plumbing accessories |
| Pewter | • A lead-free alloy than can be easily cast as it has a low melting point<br>• An alloy of 92% tin, 6% antimony and 2% copper<br>• Polishes to a bright mirror-like finish | • Drinking tankards<br>• Jewellery<br>• Picture frames |
| Casting Alloy | • Mainly aluminium with 3% copper and 5% silicon<br>• Looks like pure aluminium but far easier to cast | • Die casting and sand casting processes |
| Duralumin | • An aluminium alloy with 4% copper and 1% manganese and magnesium<br>• Almost as strong as steel but only 30% of the weight | • Aircraft bodies<br>• Car body panels |

**Heat treatment**

The crystalline structure of a metal affects how it reacts to working and cutting. The size of the grains is important and can be changed by **annealing** or softening the metal. By hardening and annealing metals we can make them malleable enough to form into shapes or hard enough to cut all other metals.

If a metal becomes deformed by working (hammering or bending) it becomes **work hardened** and continuing to work the metal will make it brittle. If the metal is annealed the heating allows the grains to re-form. On cooling the metal will have returned to its original condition and working can continue.

When a **ferrous metal** is annealed it becomes very soft and workable. It can be annealed in the following way:

1) Heat it to bright cherry red (725°C) and soak it in the heat for a few minutes.
2) Cool it very slowly to allow the grains to grow.

A **non-ferrous metal** can be annealed in the following way:

1) Heat it to dull red (500°C).
2) Either quench in cold water or allow it to cool slowly.

The scale or oxide on the surface of the metal can be cleaned off with acid or an abrasive.

**Hardening**

If high carbon or tool steel is hardened, it is at its maximum hardness and able to cut other steels. Steel can be hardened in the following way:

1) Heat the metal to cherry red (720°C).
2) Soak the metal in the heat for a few minutes.
3) Quickly quench it in water or oil.

**Tempering**

Hardening makes steel very hard, so it will not wear away, but it leaves it brittle and liable to crack. Tempering reduces the hardness a little until a workable balance is found between hardness and brittleness (toughness).

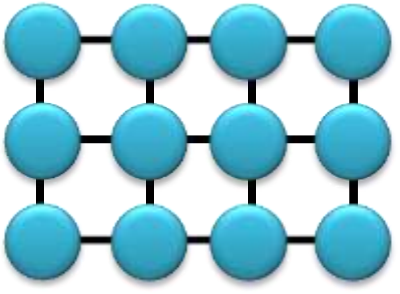
1) Clean the metal so its colour can be seen
2) Reheat the steel until its between 230°C and 300°C depending on the toughness you need for the metal (see the colour chart below).
3) As soon as the correct colour is seen, stop the heating and quench the metal.

Mild steel doesn't have enough carbon in it to be hardened, but it can be case hardened. This involves giving a thin outer layer of hardened steel by soaking it in a bed of red hot carbon for several hours at 950°C.

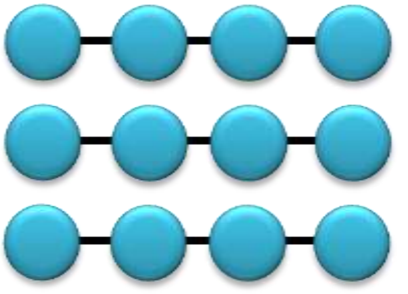
| Colour | Hardness | Temperature | Application |
|---|---|---|---|
| Pale straw | Hardest | 230°C | Lathe tools and scribers |
| Straw | | 240°C | Drills and milling cutters |
| Dark straw | | 250°C | Taps and die punches |
| Brown | Tough and hard | 260°C | Plane irons, shears and chisels |
| Brown/purple | | 270°C | Scissors and knives |
| Purple | | 280°C | Cold chisels and saws |
| Dark purple | | 290°C | Screwdrivers |
| Blue | Toughest | 300°C | Springs, spanners and needles |

**Polymers**

Polymers are the most widely used materials in commercial production. They are created from two main sources. Natural polymers include materials such as amber, which is fossilised tree resin and latex which is a form of rubber. Synthetic polymers are chemically manufactured from carbon-based materials, such as crude oil, coal and natural gas. Synthetic polymers are manufactured using a process known as polymerisation.



Thermosetting Polymer Bonds



Thermoplastic Polymer Bonds

**Stock forms/types**

Plastics used in industry are generally available in a variety of different forms depending on the process they will be used in, for instance when injection moulding, plastic granules are used and sheet materials are used when vacuum forming. They can also come in a variety of other forms similar to metals. There are two different types of plastics:

Thermosetting Polymers are heated and moulded into shape. They cant soften if heated because the polymer chains become interlinked during the moulding process. Individual monomers are joined together to form a massive polymer.

Thermoplastic Polymers soften when they are heated and can be shaped when hot. The plastic will harden when it is cooled, but can be reshaped if heated again.

| **Thermosetting Polymers** | | |
|---|---|---|
| **Name** | **Description** | **Application** |
| Melamine Formaldehyde MF | • Heat resistant polymer<br>• Used as a surface finish on manufactured boards | • Tableware<br>• Electrical installations<br>• Decorative work tops |
| Epoxy Resign ER | • A resin and a hardener mixed to produce a casting | • Castings<br>• Printed circuit boards( PCBs)<br>• Surface coating |
| Polyester Resin PR | • Polymerises at room temperature<br>• A resin and hardener mixed together<br>• Often reinforced with GLASS FIBRE | • Laminated to form GRP (Glass Reinforced Plastic) castings<br>• Car bodies and boat hulls |
| Phenol Formaldehyde | • Hard, brittle plastic with dark colour<br>• Glossy finish<br>• Resists heat | • Electrical fittings<br>• Parts for domestic appliances, e.g. kettle and saucepan handles |
| Urea Formaldehyde | • A colourless polymer with artificial pigments to produce a wide range of different colours | • Door and cupboard handles<br>• Electrical switches and fittings |

| Thermoplastics | | |
|---|---|---|
| **Name** | **Description** | **Application** |
| High Density Polythene HDPE | • Stiff and strong plastic<br>• Softens at 120-130°C | • Pipes and bowls<br>• Milk crates<br>• Buckets |
| Low Density Polythene LDPE | • Weaker and softer and more flexible than HDPE<br>• Softens at 80°C | • Packaging and film carrier bags<br>• Toys<br>• Detergent bottles |
| Polypropylene PP | • High impact strength<br>• Can be flexed many times without breaking<br>• Softens at 150°C | • Bottle crates<br>• Medical equipment and syringes<br>• Food containers |
| High Impact Polystyrene HIPS | • Light but strong plastic<br>• Widely available in sheet<br>• Softens at 95°C | • Outer casings of products |
| Nylon | • Hard material- good resistance to wear and tear<br>• Solid nylon has low friction qualities and high melting point. | • Combs<br>• Clothing<br>• Gear wheels and bearings |
| Rigid Poly Vinyl Chloride PVC | • Stiff and hard wearing<br>• Plasticiser can be added to create a softer more rubbery material | • Air and water pipes<br>• Chemical tanks<br>• Window frames |
| Acrylic Polymethyl-methacrylate | • Trade name – Perspex<br>• Glass like transparency or opaque<br>• Can be coloured with pigments<br>• Hard wearing, will not shatter | • Display signs<br>• Baths<br>• Roof lights<br>• Machine guards |
| Acrylonitrile butadiene styrene ABS | • Excellent impact strength<br>• Lightweight<br>• Hard and durable | • Computer casings<br>• Mobile phones<br>• Safety helmets<br>• Car bumpers |
| Styrofoam™ Extruded polystyrene | • Lightweight and buoyant<br>• Good insulator<br>• Easily shaped | • Fast food packaging<br>• Insulation<br>• Modelling material |

## Composite Materials

Composites are produced by mixing together two or more different materials providing enhanced properties for the final composite material. For example, by adding strands (fibres) of glass to polyester resins, a very tough, rigid, lightweight material can be produced, fibre glass.

Composite materials have gained popularity (despite their generally high cost) in high-performance products that need to be lightweight, yet strong enough to take harsh loading conditions such as:

- Aerospace components (tails, wings, fuselages, propellers)

- Boat and scull hulls, bicycle frames and racing car bodies. Other uses include fishing rods and storage tanks.


A resin being added to a glass fibre
Mat.

**Arrangement of Kevlar fibres**

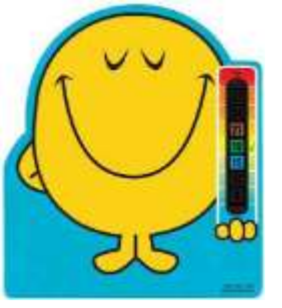
| **Composites** | | |
|---|---|---|
| **Name** | **Description** | **Application** |
| Glass-reinforced Plastic GRP | • Polyester resin reinforced by the addition of strands of spun glass fibres<br>• Light weight, hard wearing and durable<br>• Corrosion resistant | • Car body building<br>• Boat hulls |
| Carbon Fibre | • A very high strength to weight ratio<br>• Impact resistant<br>• Expensive to produce | • High performance vehicles<br>• Aircraft<br>• Sports equipment |
| Kevlar | • A very high strength to weight ratio<br>• High toughness and cut resistance<br>• Flame resistant and self extinguishing | • Bullet proof vests and helmets<br>• Sports equipment<br>• Run flat tyres |
| Reinforced Concrete | • Cement mixed with water, sand and aggregates and reinforced by adding steel bars<br>• A dense material that is very strong under compression but also flexible to resist tensile forces | • Construction industry<br>• Buildings<br>• Bridges |

**Smart Materials**

Smart materials react to outside stimuli and change their properties as a result, for instance they become different shapes or colours. They are often integrated into or onto products in the form of a coating or finish.

Shape Memory Alloy used in spectacle frames


Phosphorescent Pigments used in safety signage

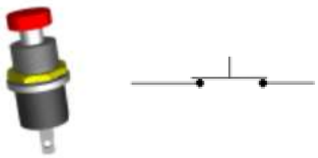


Thermochromic Pigments used in a child's thermometer

| Smart Materials | | |
|---|---|---|
| **Name** | **Description** | **Application** |
| Shape Memory Alloys SMA | • Made from nickel-titanium or copper-zinc-aluminium alloys<br>• Use heat to return to their original shape | • Spectacle frames<br>• Triggers or switches<br>• Bioengineering and surgical procedures |
| Polymorph | • Tough polymer material<br>• Softens at 62°C and becomes easy to mould<br>• Hardens on cooling | • Model making and prototyping |
| Thermochromic Pigments | • React to changes in temperature<br>• Combined with polymers during moulding | • Temperature indicators on electrical products<br>• Baby feeding products |
| Phosphorescent pigments | • Replaced radioactive materials<br>• Absorb large amounts of light<br>• Re-emits light energy over a period of time<br>• Available as a powder which can be mixed with paints | • Emergency warning signage<br>• Watch faces |
| Quantum Tunnelling Composite QTC | • A flexible polymer which contains tiny metal particles<br>• Normally an insulator but if it is squeezed it becomes a conductor. | • Membrane switches<br>• Pressure sensors<br>• Speed controllers |

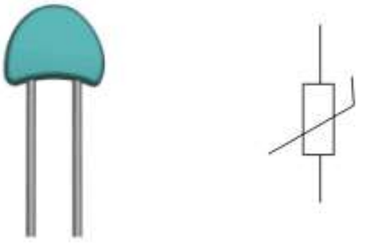
**Electronic Components**

Electronic components are used in electronic devices to make them work, from switches to microcontrollers. You need to know some basic components for your course, however, further research is recommended to increase your understanding of how a number of electronic components and devices operate.



**Push to Make Switch**
Allows current to flow through it when pressed.

**Light Dependent Resistor**
Has a resistance that changes depending on the light level, e.g. street lights.



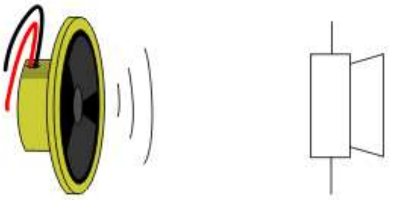
**Thermistor**
Has a resistance that changes depending on the temperature, e.g. home central heating.


**Microcontroller**
A small computer on an integrated circuit that can be preprogramed to provide functionality such as timing, counting and decision making.

**Resistor**
Limits the flow of electrical current in a circuit, used to protect delicate components, e.g. LED.

**Buzzer**
Produces a buzzing sound when current flows through it., e.g. audible warnings.

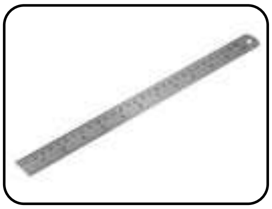

**Light Demitting Diode (LED)**
Produces light when current flows through it, e.g. home lighting and visual warnings/notifications.



**Speaker**
Turns electronic signals into sounds.

**Measuring & Marking**

There are a number of tools used in engineering for measuring and marking out. You will need to be able to identify and know how to use them for practical tasks to ensure accuracy in your work.



### Steel Rule

A steel rule is used to measure lengths and to set odd-legs and dividers

### Engineering Square

An engineering square is used to:

Mark lines at 90° from the edge of the material

To check square components or corners

### Engineering Bevel

An engineering bevel is an adjustable angle marker that can be set to any angle.

### Surface Plate

A surface plate is a very flat surface used to accurately mark out materials.

### Surface Gauge

A surface gauge is used with a surface plate to accurately mark parallel lines on materials.

### Scriber

A scriber is a sharp tool used for marking accurate lines on metals and polymer materials.

## Odd-Leg Callipers

Odd-Leg Callipers are used to scribe lines parallel to a straight edge. The notched leg slides along the edge of the metal while the scriber point marks a line.

## Dividers

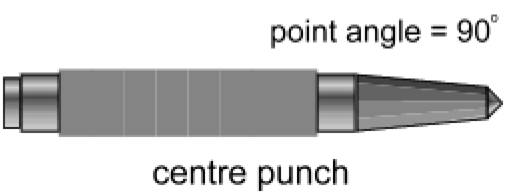
Dividers are used to mark circles or arcs. One point digs into the material whilst the other point scribes a line into the surface of the material.

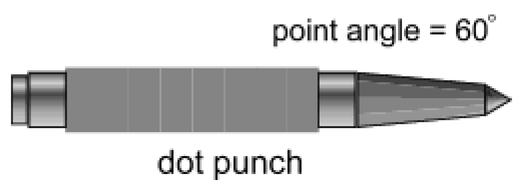
**Dot Punch**

A dot punch has a conical point ground to 60° that is used for marking the positions of drill holes.

**Centre Punch**

A centre punch has a conical point ground to 90° that is used for marking the centre of holes for drilling.

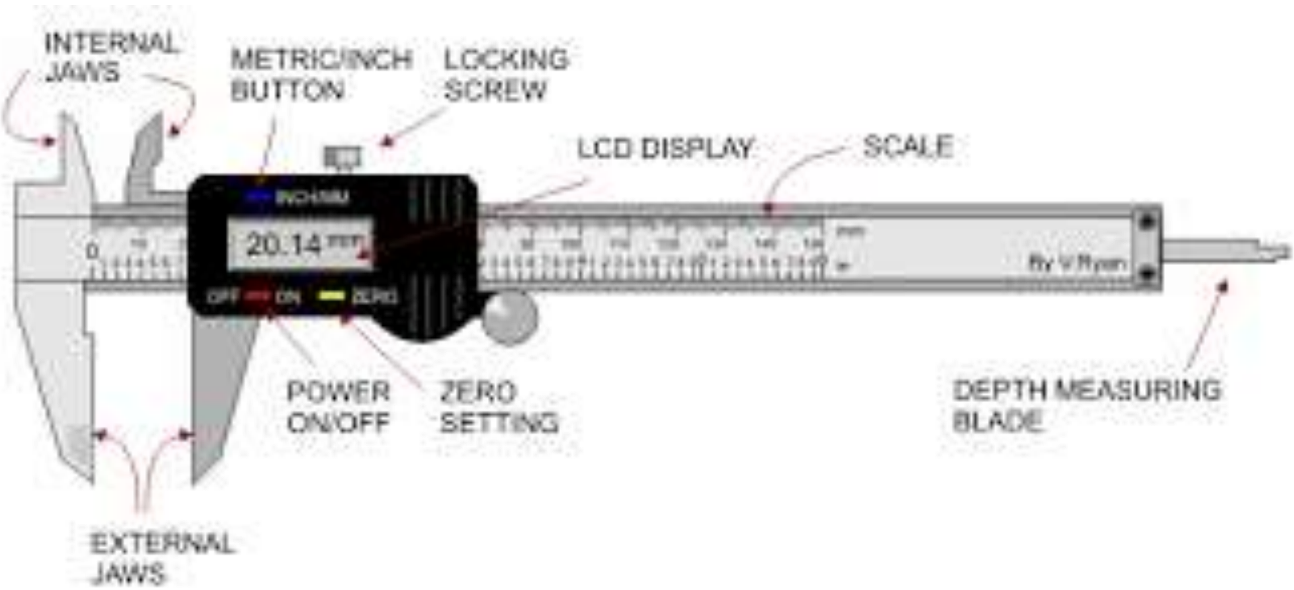



**The Digital Vernier Calliper**

The Vernier Calliper is a precision instrument that can be used to measure internal and external distances extremely accurately. The example shown below is a digital Vernier calliper as the distances are read from an LCD display.

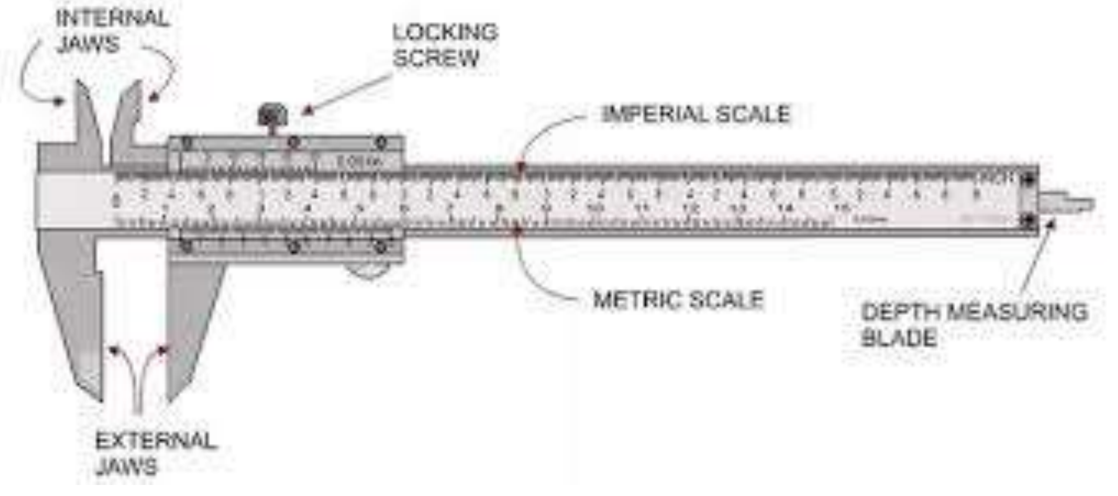
Digital Vernier callipers are easier to use as the measurement is clearly displayed and also, by pressing the inch/mm button the distance can be read as metric or imperial.



**The Vernier Calliper – Manual Version**

The Vernier Calliper is a precision instrument that can be used to measure internal and external distances extremely accurately. The example shown below is a manual calliper. Measurements are interpreted from the scale by the user. This is more difficult than using a digital Vernier calliper which has an LCD digital display on which the reading appears. The manual version has both an imperial and metric scale.

Manually operated Vernier callipers can still be bought and remain popular because they are much cheaper than the digital version. Also, the digital version requires a small battery whereas the manual version does not need any power source.




**How to read a measurement from the scales**

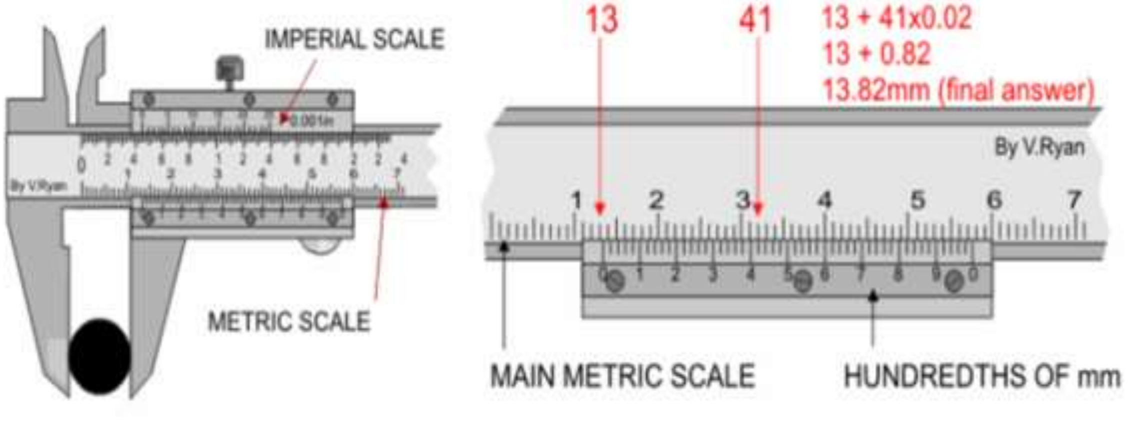
The external measurement (diameter) of a round section piece of steel is measured using a Vernier calliper, metric scale.

A. The main metric scale is read first and this shows that there are 13 whole divisions before the 0 on the hundredths scale. Therefore, the first number is 13.

B. The' hundredths of mm' scale is then read. Only one division on the main metric scale lines up with a division on the hundredths scale below it, whilst others do not. In the example below, the 41st division on the hundredths scale lines up exactly with a division on the metric scale above.

C. This 41 is multiplied by 0.02 giving 0.82 as the answer (each division on the hundredths scale is equivalent to 0.02mm).

D. The 13 and the 0.82 are added together to give the final measurement of 13.82mm (the diameter of the piece of round section steel).



**Measuring Internal Distances**

The example below shows a Vernier callipers being used to measure the internal diameter of a piece of copper tube. The internal jaws are adjusted carefully until they touch the internal 'sides'. The locking screw is tightened so that an accurate measurement can be made even if the jaws are 'knocked' against the sides as the jaws are removed from the hole. The measurement is shown on the LCD display.

**Measuring Depths**

Measuring the depth of a hole can be very difficult. However, using a Vernier calliper makes this task easy. The base of the Vernier calliper rests on the top of the hole and the depth measuring blade is adjusted until it touches the bottom of the hole. The locking screw is tightened and the measurement can be read on the LCD display.

**The Micrometre**

The micrometre is a precision measuring instrument, used by engineers. Each revolution of the ratchet moves the spindle face 0.5mm towards the anvil face. The object to be measured is placed between the anvil face and the spindle face. The ratchet is turned clockwise until the object is 'trapped' between these two surfaces and the ratchet makes a 'clicking' noise. This means that the ratchet cannot be tightened any more and the measurement can be read.

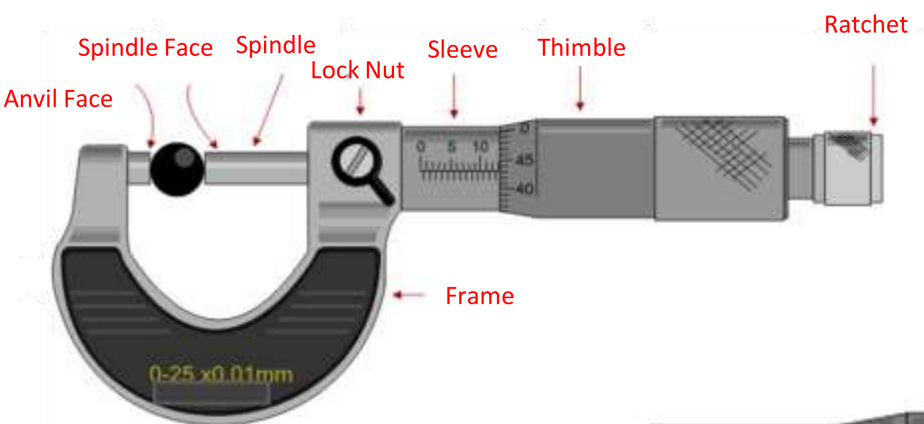
**How to read a measurement from the scales**

1. Read the scale on the sleeve. The example clearly shows 12 mm divisions.

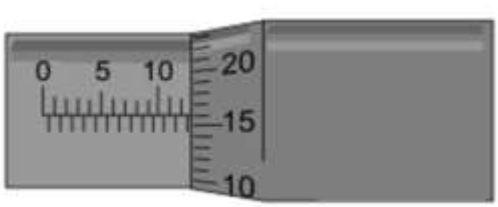
2. Still reading the scale on the sleeve, a further ½ mm (0.5) measurement can be seen on the bottom half of the scale. The measurement now reads 12.5mm.

3. Finally, the thimble scale shows 16 full divisions (these are hundredths of a mm).

The final measurement is 12.5mm + 0.16mm = 12.66

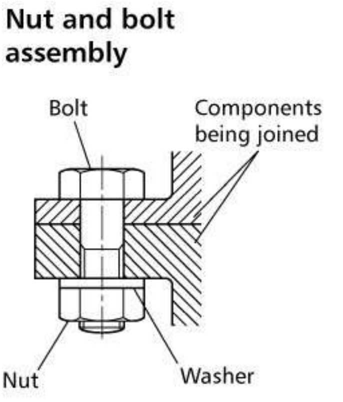



**Sleeve Reads full mm = 12.00**
**Sleeve Reads ½ mm = 0.50**
**Thimble Reads = 0.16**
**Total Measurement = 12.66mm**



## Joining Metals

All materials can be joined using either temporary or permanent joining processes. Temporary fixings allow components to be disassembled whereas permanent joining processes do not usually allow for disassembly.



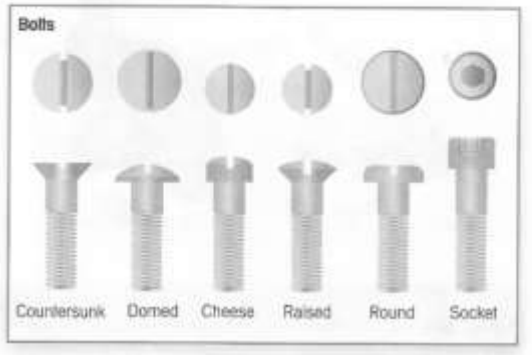

### Temporary Fixings

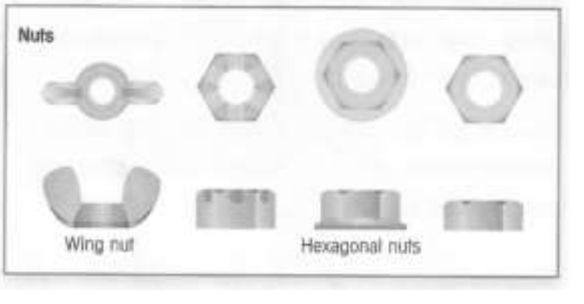
**Nuts and Bolts**

There are many different types of nuts, bolts and washers. Bolts are made with different heads for use in different applications. Countersunk and cheese head screws are tightened with a screwdriver. Hexagonal heads are tightened with a spanner and socket heads are tightened with an allen key.

Threads also vary in size, but metric threads are mostly used today. They are available in many lengths, typically 20-100mm. Smaller bolts are called machine screws and have the thread over the entire length. Nuts need to match the same thread as the bolt. Wing nuts are tightened by hand and are useful for temporary joints. Hexagonal heads are tightened with a spanner.

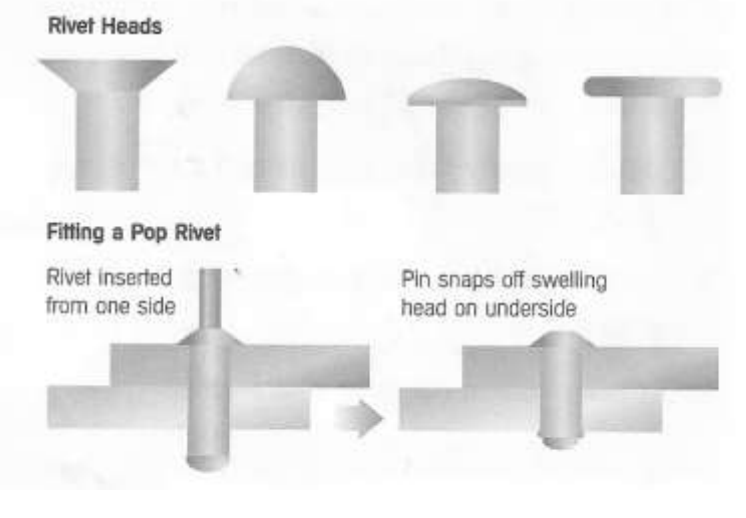
A washer is used under the nut to spread the pressure and protect the surface of materials being joined together. These are usually plain ring washers, although spring washers are used to stop the nut vibrating loose.




**Rivets**

Rivets are used to make a more permanent joint than nuts and bolts. They hold the material together by forming a head on both sides of the material.. Pop rivets are fitted using a rivet gun from one side of the material. They come with a variety of heads and are normally made from mild steel, copper or aluminium.

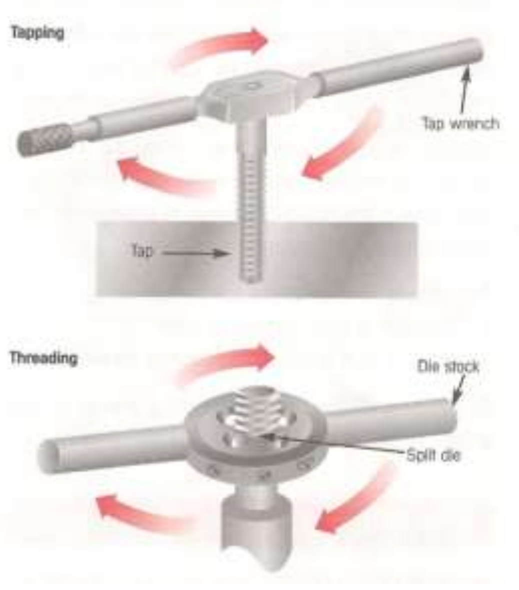


**Tapping and Threading**

Screw cutting can be carried out on most metals. A tapping hole, smaller that the thread, must be drilled in the metal before an internal thread can be cut.

Internal or female threads are usually cut with a tap, held in a tap wrench. A tap is a very hard steel tool which makes its own thread as its twisted into a hole drilled into the material.

Threading is the cutting of an external or male thread. The tool is called a split die and is held in a die stock so that it can be turned.




**Permanent Processes**

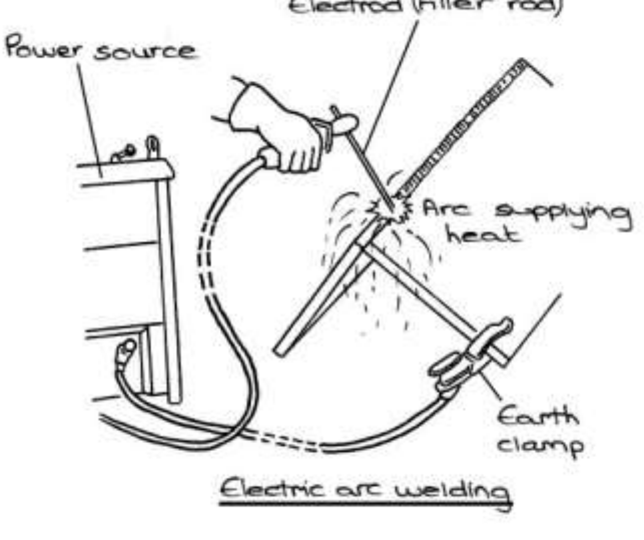
Heat can be used to join metals together. Welding uses heat to melt the edges of the metals being joined. This forms a pool of molten metal that when cooled forms the joint. Soldering uses a bonding alloy to form a joint and the parent metals do not melt. The surface is cleaned with flux and heat is applied using a gas torch. The solder is applied, which melts and runs between the two parent materials.

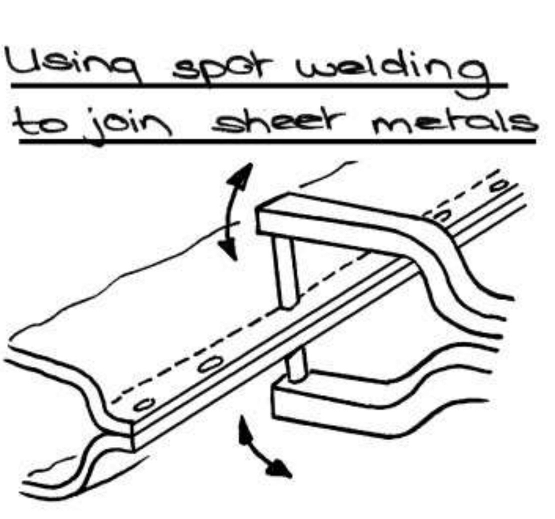
**Welding**

Gas welding uses an acetylene torch to heat up the joint. A mixture of acetylene gas and oxygen produces a very small, hot flame which melts both the filler rod and the surrounding metal.

Metal Inert Gas (MIG) welding is another method where an electrical spark creates the heat by arcing between the electrode and the work-piece. The electrode melts and is fed in from a roll of steel wire. The area is cooled with a gas mixture of argon and carbon dioxide. Tungsten Inert Gas (TIG) welding is used to weld non-ferrous metals. Its like MIG welding, nut the electrode doesn't melt.

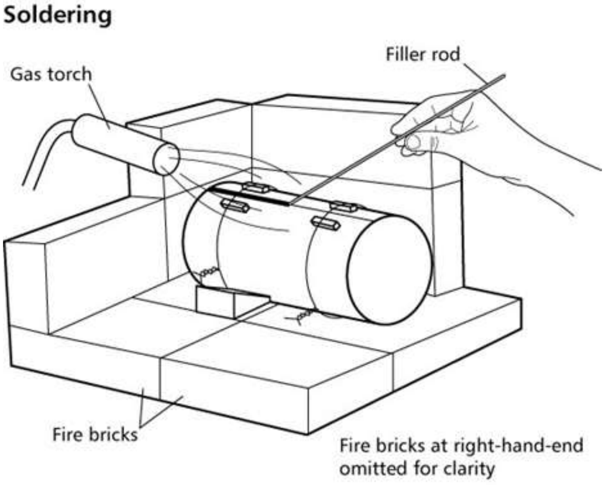
Spot welding is a form of resistance welding and is used for melting thin sheet steel together, e.g. car body panels. Copper electrodes sandwich the metal together and a current is passed between them. The resistance creates the heat to bond the two metals in a tiny spot.



**Soldering**

Soft soldering joins metal parts together using a lead free alloy. It is used for light applications, e.g. electrical connections and plumbing joints. Flux is applied to the join to clean it, the fluxed joint is heated using a gas torch or metal soldering bit. Hard soldering or brazing is used for heavier applications as the joint is much stronger. The brass bonding alloy (spelter) melts at a much higher temperature than soft solder. Its used for joining mild steel and copper.
Silver soldering is like brazing but it uses a silver based alloy. Its used on brass, copper and guilding metal as the silver alloy melts at a lower temperature than brazing spelter.



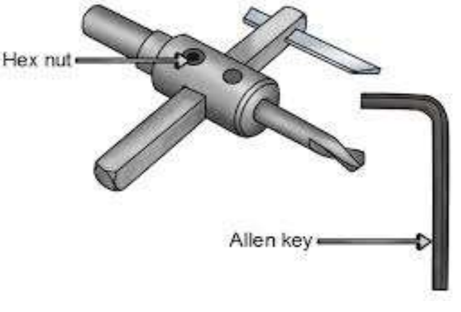

## Cutting metal

**Shearing and bending**

Sheet metal fabrication is used in many engineering industries for and machine processes. Cutting sheet metal is usually achieved by using a shearing action.
Two methods include using tinsnips to cut small pieces of sheet metal and using bench mounted shears for thicker sheets as they provide greater leverage.
Sheet metal can also be bent using either folding bars or bending machines.

Tinsnips

Bench-mounted shears




Tank Cutter

**Drilling**

Drill bits are usually made from carbon steel or high speed steel. Twist drills or jobber drills are used for drilling holes in metals and polymers. Larger holes can be cut using a tank cutter or a hole saw.

**Sawing**

Sawing is one of the oldest methods of cutting materials. Teeth are triangular and shaped do that they remove a small amount of material on the forward stroke. Metal cutting saws have small teeth on a blade supported in a frame.

The hacksaw is the main saw used for cutting in engineering. Teeth are available in different teeth per inch (TPI) with 20 TPI being usual for bench work. The blade is tensioned by turning a wingnut and can be changed when worn down.

For thin metals a junior hacksaw is used. Teeth are usually 32TPI and the blade is tensioned by the spring in the steel frame. A piercing saw is a very fine toothed saw is normally used in jewellery making.

Junior Hacksaw

Hacksaw

Powered Hacksaw

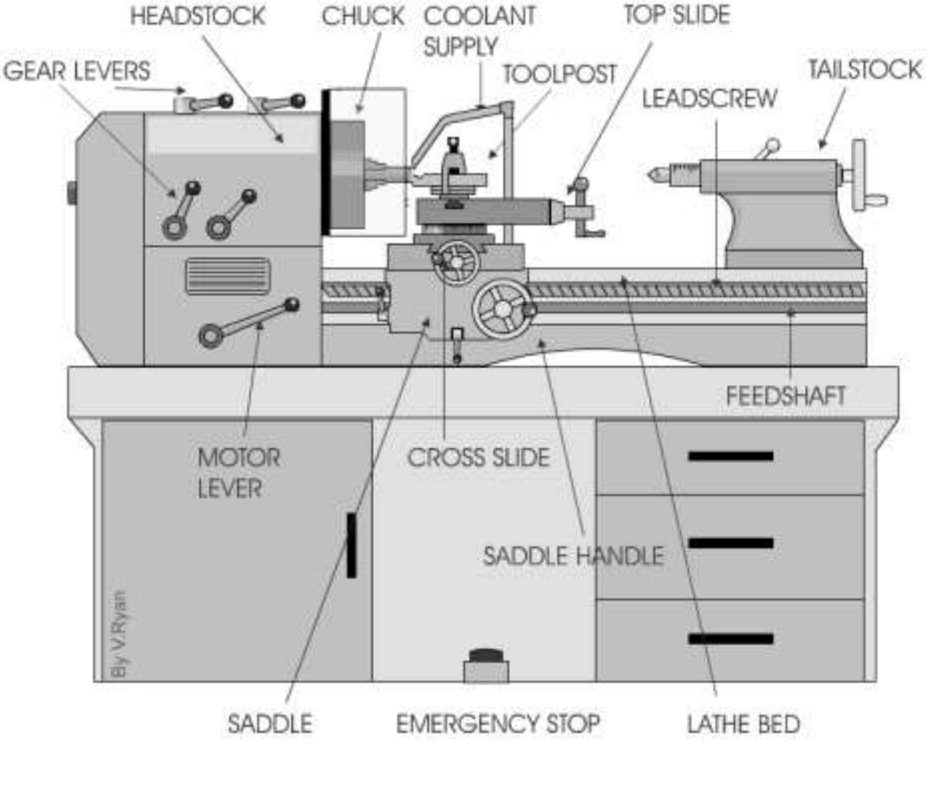

Machine saws use the same action as a manual version but are more accurate as the material is clamped in position.

Laser and plasma cutting are used to cut metals and polymers when larger volumes and accuracy is required. They are both driven by design produced using computer aided design packages.

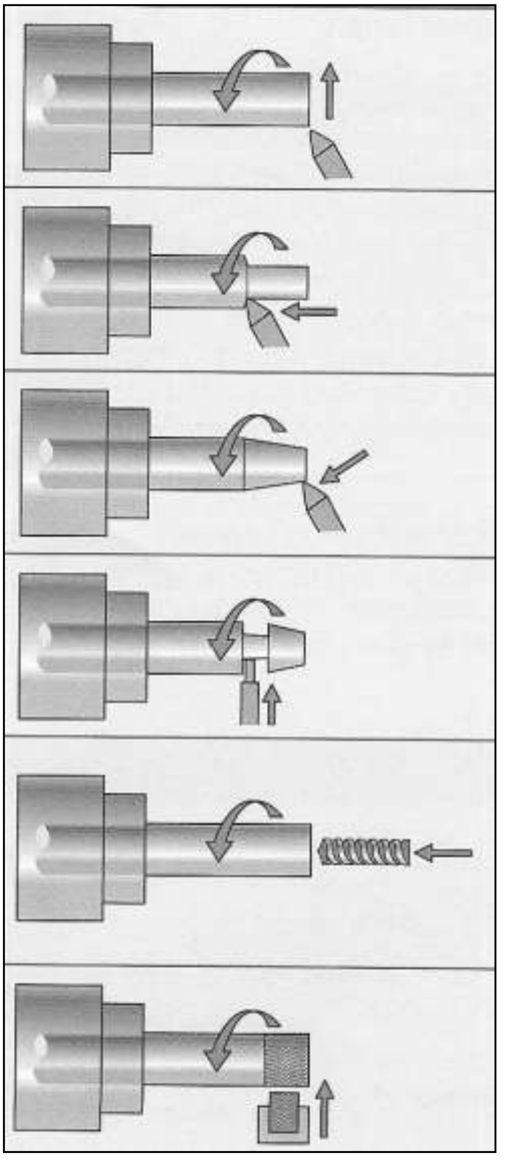
**Turning**

A centre lathe is used to produce parts by holding the work in a chuck and rotating the work towards the cutter. The cutter can be moved left and right (X axis) and forwards and backwards (Y axis). A variety of tools can be used to create the desired shape in the work and the tailstock can be fitted with a drill chuck for drilling holes into the end of the material.

A manual lathe is shown below. When producing large volumes of identical parts computer numerically controlled (CNC) lathes are used which produce parts following instructions from a CAD programme. This is extremely accurate and is much faster than a manual operator.



## Turning Operations



### Facing
The tool is moved at right angles to the axis, facing the end surface.

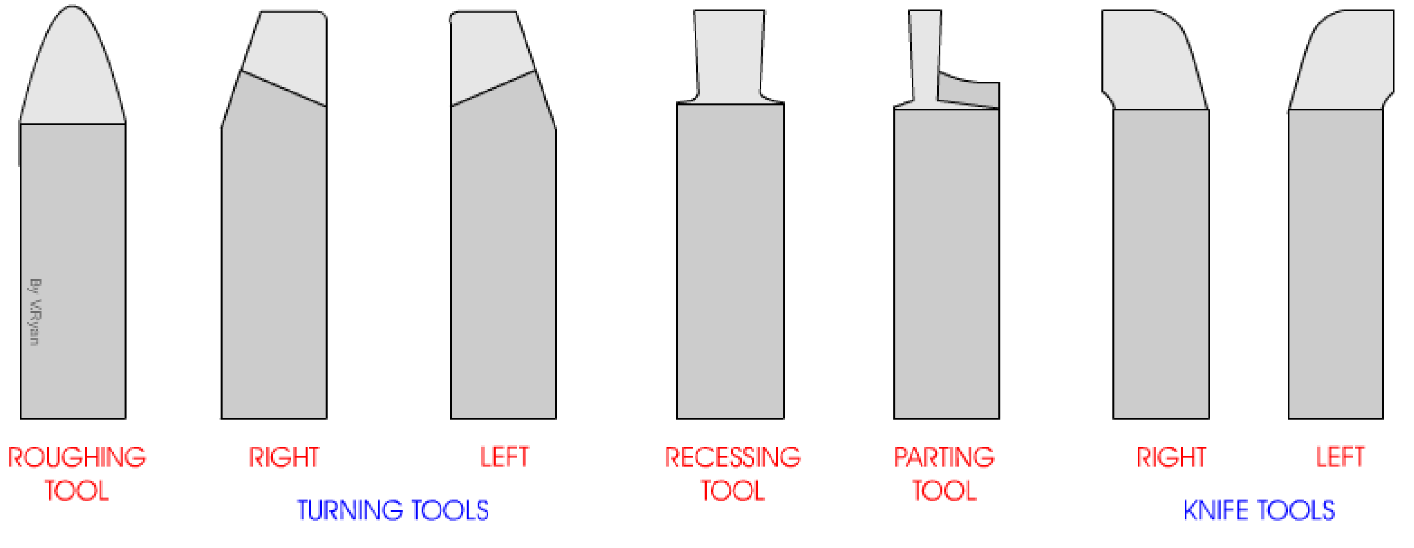
### Parallel Turning
The tool is moved parallel to the axis to form a cylinder while reducing the diameter.

### Taper Turning
The tool at an angle to the axis to produce a taper.

### Parting
A narrow tool is fed into the work to trim to length or part off work from stock bar.

### Drilling
The tail stock is used to hold a chuck into which a drill can be placed; as work rotates the drill is fed into the work.

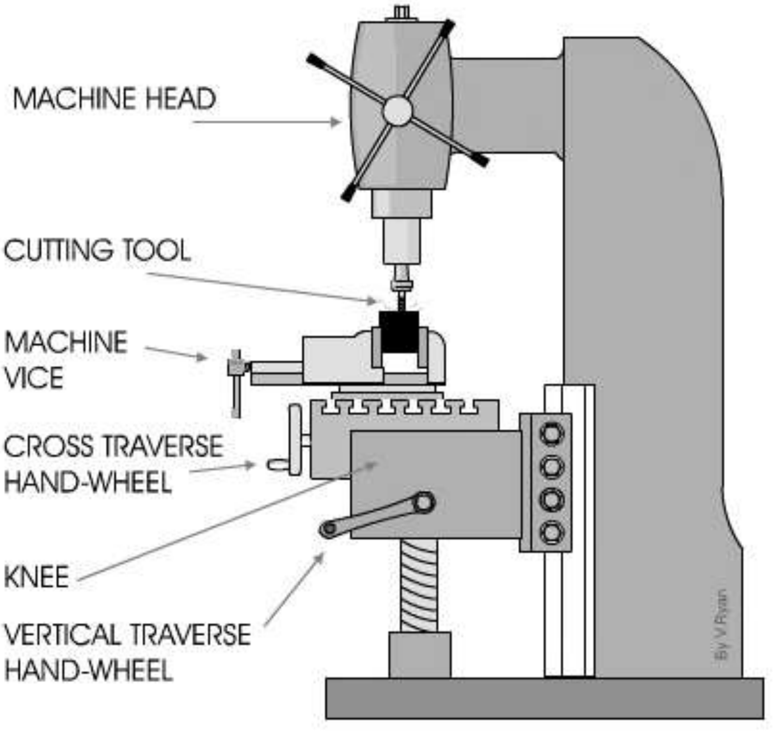
### Knurling
A hardened steel wheel is pressed into the rotating work to produce a straight or diamond pattern.



**Milling**

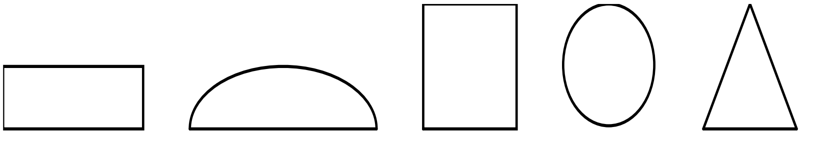
A variety of engineering materials can be shaped using a revolving, multi-toothed cutter which moves over the material.  A manual machine can be moved left and right (X axis) and forwards and backwards (Y axis).  A variety of tools can be used to create the desired shape in the work.

A manual milling machine is shown below. When producing large volumes of identical parts computer numerically controlled (CNC) millers are used which produce parts very accurately following instructions from CAD programmes.




**Surface Finishes**

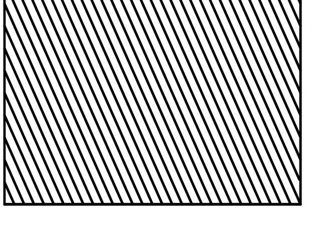
Files are used to smooth and shape the surface of metals and hard plastics by pressing and dragging the hundreds of small teeth on the file across the material. They are made from hardened and tempered cast steel, so they will cut other metals. Files come in a variety of shapes flat, half round, square, round and three square.

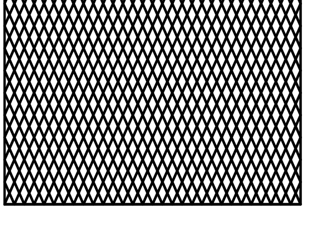


**Hand Flat** **Half Round** **Square** **Round** **3 Square**

Files also have different sized teeth and are used depending on the amount of material to be removed.  Different techniques  are used:

- Cross filing removes metal quickly with the file moving from end to end to bring the rough material to shape.
- Draw filing involves moving from side to side which removes less material and leaves a finer surface ready for abrasives.



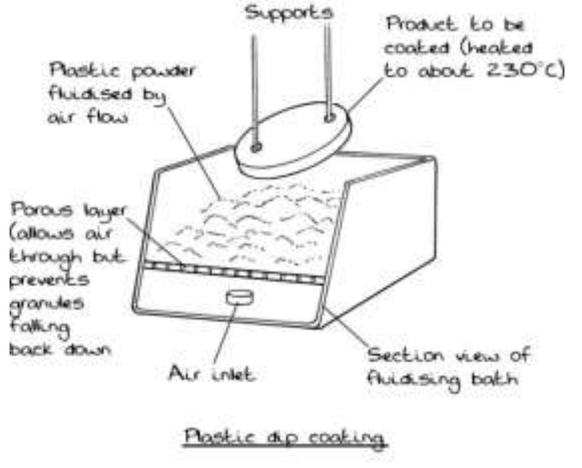


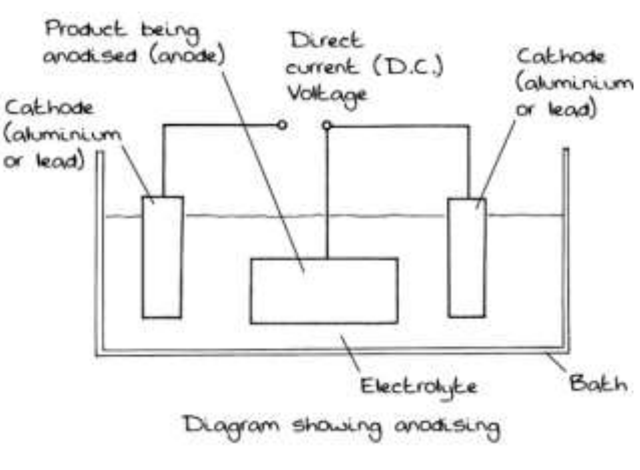
**Single Cut** **Double Cut**

**Abrading**
To make abrasive paper, small chips of abrasive material are glued onto a paper or cloth backing sheet. The abrasive material is usually silicon carbide or emery. Each sheet is numbered, with the lowest number being the coarsest sheet. Emery cloth is used on metals and polymers and can be used in a two handed manner or wrapped around a flat file. A linisher (sanding machine) can also be used.

**Polishing**
Metal polish is always slightly abrasive because it relies on cutting away the surface of the metal until its very smooth. Metal polishes can be used in liquid form, which is applied with a cloth or as a wax bar applied to a buffing wheel.

| Coatings | |
|---|---|
| **Plastic dip-coating**<br>Polythene is the most common thermoplastic powder used for dip-coating. It is commonly used on dishwasher racks, coat hooks and tool handles.<br><br>• Air is blown through the powder to make it behave like a liquid.<br>• Metal, pre-heated to 180°C, is dipped in the fluidised powder.<br>• The metal is returned to the oven where the plastic coating melts to form a smooth finish. | **Powder coating**<br>Powder coating is an industrial finish that is a more sophisticated version of dip-coating. The powder is prayed onto the products which then pass through an oven.<br>This process provides a very hard paint-like finish and is available in all colours as well as translucent.<br>This finish makes the products very durable and is suited to those that are exposed to the environment, such as outdoor furniture and wheel trims. |




**Industrial Surface Finishes**

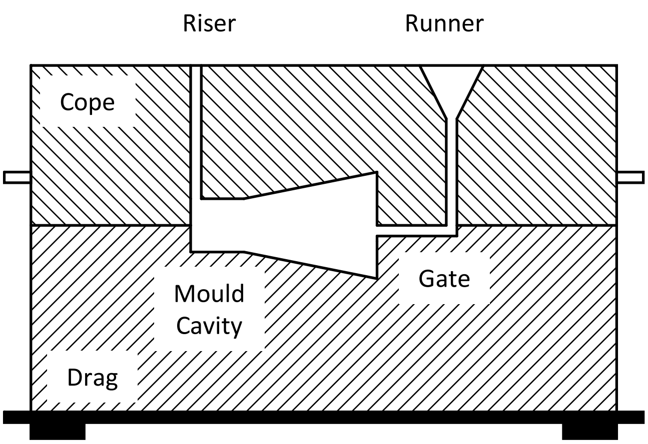
**Anodising** is used on aluminium to provide a durable, corrosion resistant finish. It involves electrolysis, which involves acids and electric currents. Sports equipment, window frames and electrical products are often anodised.

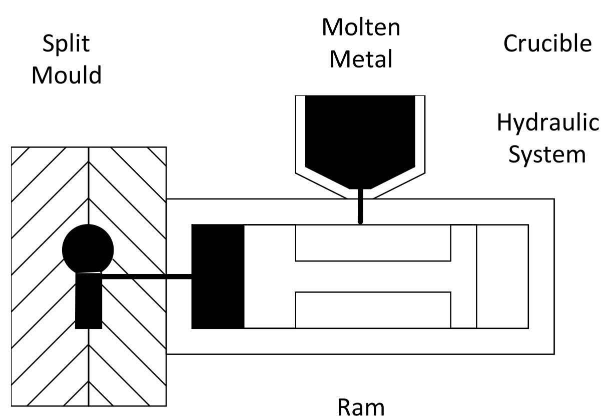
**Plating** also uses electrolysis. There are many forms, although chromium plating is the most widely recognised. The thin layer of metal on the surface provides a durable finish that is corrosion resistant.

**Galvanising** involves dipping the metal (usually mild steel) into a bath of molten zinc. Although it isn't very attractive, the zinc provides a very corrosion resistant surface. Car body panels are usually galvanized prior to further paint finishes being added.

**Industrial Processes**

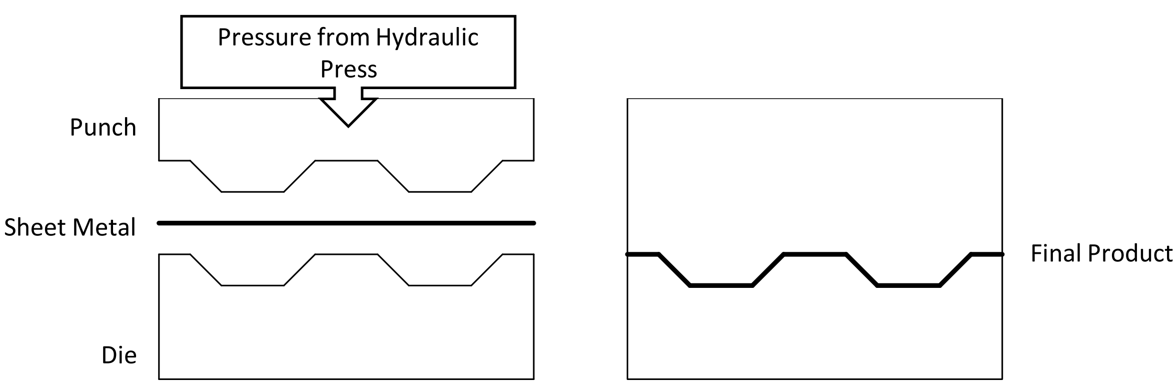
| Sand Casting | Die Casting |
|---|---|
| Sand casting is used to shape metals, e.g. cast iron, aluminium and brass. It is not used to produce very large quantities of products.<br><br>1) A pattern is made from wood or MDF in two halves and attached to a board.<br>2) The pattern is sandwiched between open boxes called a cope and drag.<br>3) A special oil-bound sand is used to fill each box. One of the boxed also contains two tapered wooden pegs or sprues, which form the pouring spout (runner) and the riser to let the air out.<br>4) The pattern is removed and the space left is filled with molten metal.<br>5) Once cooled further machining is normally carried out before the final product is complete. | Die casting is very similar to injection moulding and is used to manufacture large quantities of metal products. Alloys with a low melting point, e.g. pewter, aluminium and zinc alloys can be used.<br>The mould is created by a spark eroding the form required into two blocks of steel. These moulds are water cooled to control the temperature.<br><br>1) The metal is heated in a crucible until molten.<br>2) A hydraulic ram pushes a quantity of the molten metal into the mould.<br>3) Pressure is maintained until the metal has cooled enough for the mould to be opened. |




**Pressing**

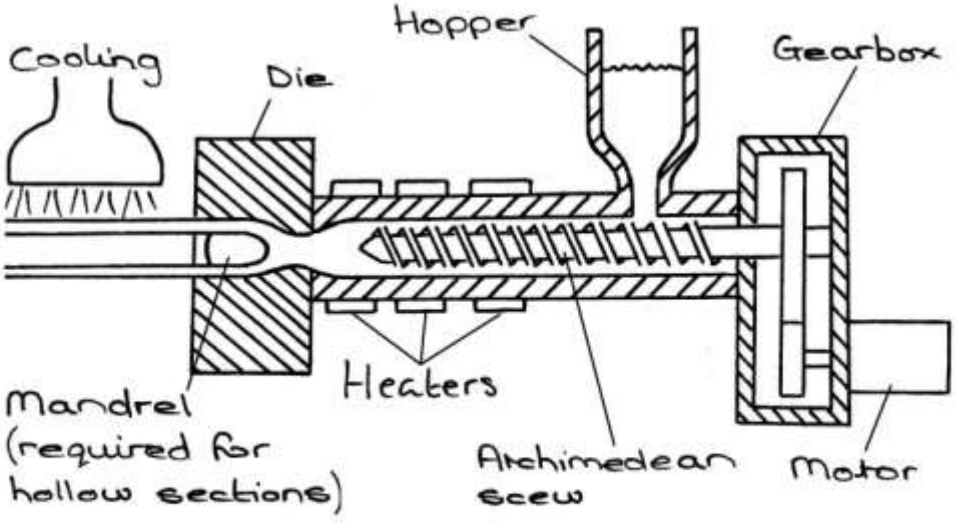
In industry presses are used to bend and form sheet metal to make car body panels and radiators for example. Presses are controlled by hydraulic rams, which create massive pressure. Sheet metal is stamped and pressed cold.



**Extrusion**

Extrusion is a process that produces material in a continuous section, for example making plastic drain pipes or metal tubes. Typical polymer materials include polythene, PVC and nylon, whereas aluminium alloys , copper and steels are used as they are ductile.

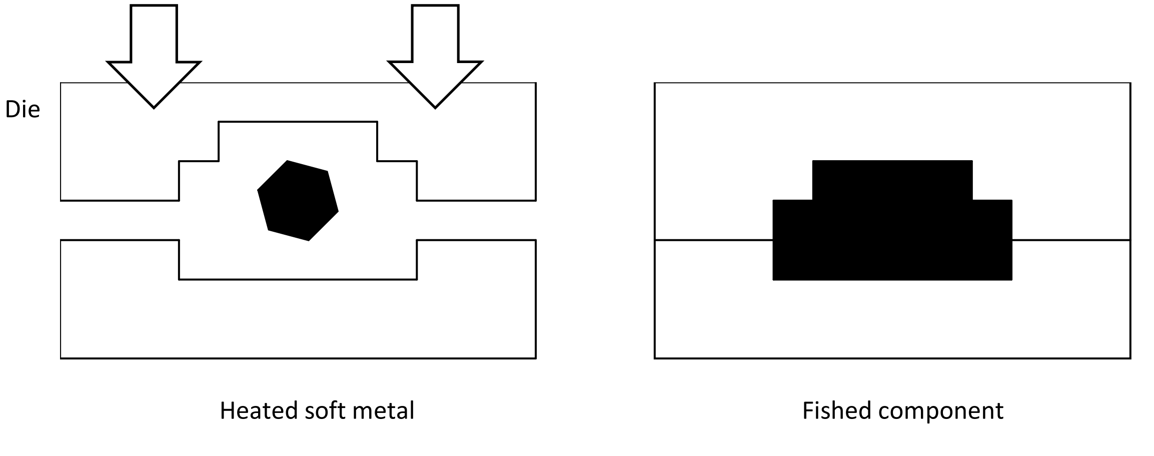
1) The material to be extruded is fed into the rotating screw and is heated at the same time.
2) The molten material is forced through a die in a continuous stream to create long tube or sectional extrusions.
3) The extrusions are passed through a cooling chamber and then cut to the required length.



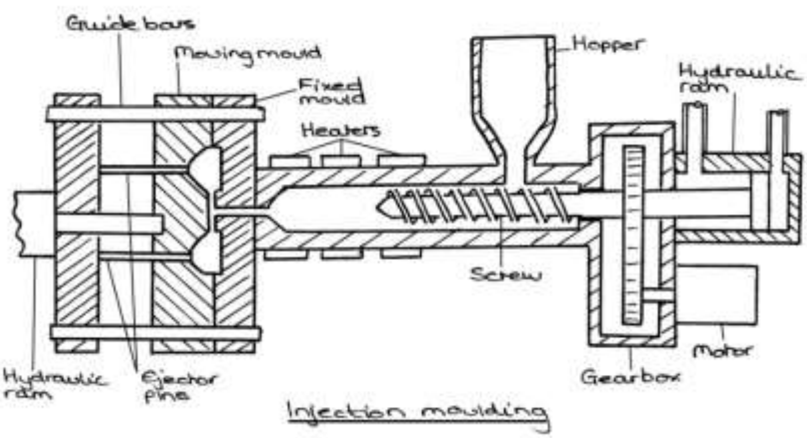

Plastic extrusion

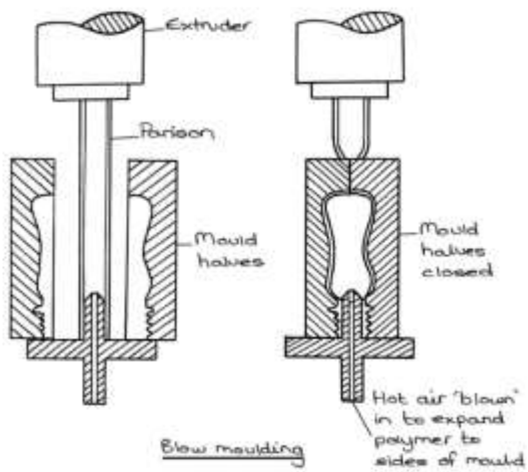
**Drop Forging**

Forging has been done for hundreds of years by blacksmiths. To produce large quantities of metal products, however, drop forging is used. This involves a piece of white hot metal being placed between two dies. A very large force is applied in a single blow by a mechanical hammer. This process improves the strength of the metal which cannot be achieved through casting or machining. Components are used in agriculture, transportation, defence, mining and other industries.



| Injection Moulding | Blow Moulding |
| --- | --- |
| Injection moulding is used to manufacture products such as electrical casings, storage containers and bottle tops. Typical materials include polythene, polystyrene and polypropylene.<br><br>1) Plastic powder or granules are fed from the hopper into a hollow steel barrel.<br>2) The heaters melt the plastic as the screw moves it along towards the mould.<br>3) Once enough melted plastic has collected, the hydraulic system forces the plastic into the mould.<br>4) Pressure is maintained on the mould, until it has cooled enough to open. | Blow moulding is most often used to produce drinks bottles from materials like low density polyethylene, high density polyethylene, polyethylene terephthalate and polypropylene.<br><br>1) Heated plastic is injected into the moulding through a process very similar to injection moulding.<br>2) The split mould closes and air is blown in, forcing the plastic to the sides of the mould.<br>3) The mould is cooled and then opened to remove the product. |

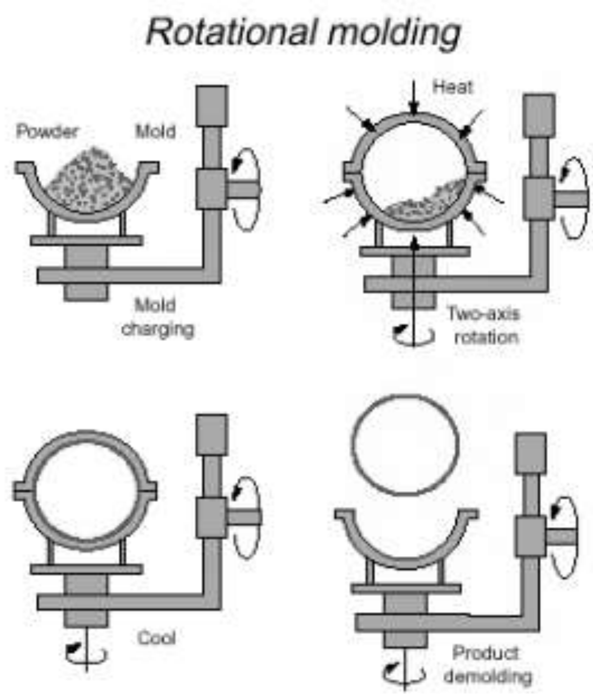



**Rotational Moulding**
This process can be used as an alternative to injection moulding or blow moulding if making an enclosed object, e.g. a ball or plastic wheel.

A rotational moulding machine has arms fixed at the same point. Moulds are attached to each arm and rotated continuously with heated thermoplastic powder inside. The mouldings are made from polythene, which can have fire retardant and vandal resistant qualities.

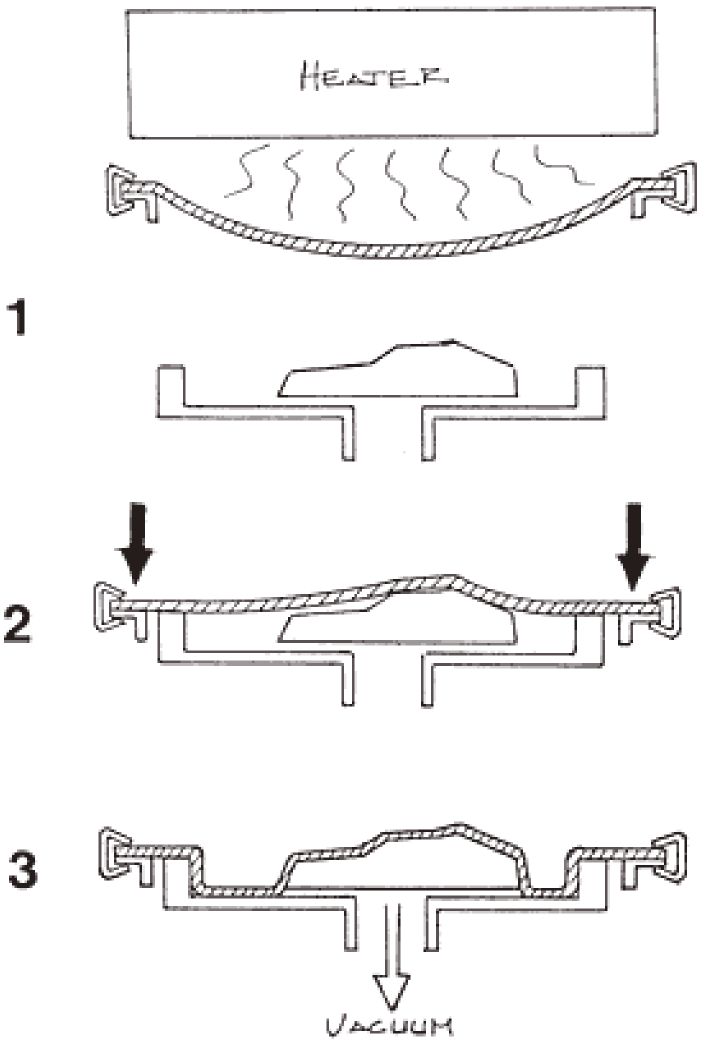
1) The mould splits apart and the plastic is poured in.
2) Heat is applied while the mould is rotated. The plastic is thrown outwards to the inner surface of the mould.
3) On cooling the mould is opened up and the product is ejected.



**Vacuum Forming**

This process is commonly used to make packaging from thermoplastic sheets that can measure up to 1.8m x 1.5m. The most popular material is high-impact polystyrene, which is cheap and is easy to form. Heated plastic is sucked onto the shape of the former required. A former can be a wooden mould around which the softened plastic will be held by the vacuum until it has cooled.

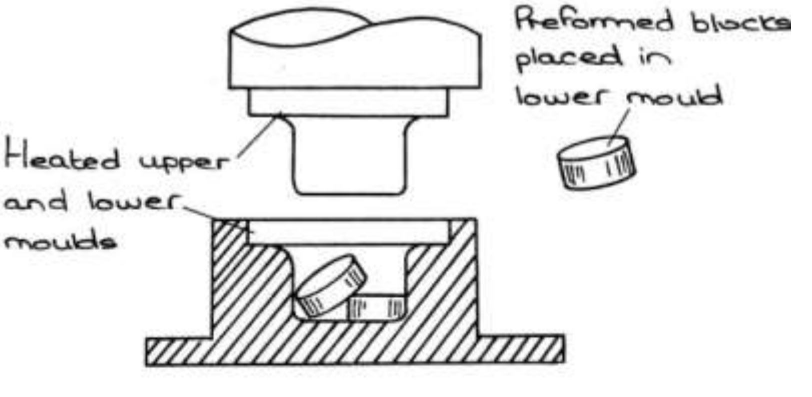
1) The mould is placed on the plattern and the plastic is clamped in position. The plattern is dropped and heat is applied to the plastic.
2) Once the material has softened the heat is removed and the mould is brought up into the material, which drapes over the mould.
3) Air is removed to form a vacuum causing the material to form a rigid impression of the mould.
4) The vacuum pump is switched off, the material is unclamped and the mould is released. The formed material is then cut to the required shape.




**Compression Moulding**

Thermosetting plastics are moulded using compression moulding. Once formed, they cant be reformed. Phenol, urea and melamine formaldehyde are plastics that are moulded in this way.

A large force is used to squash a cube of polymer into a heated mould. The cube of polymer is in the form of a powder, known as a slug.




Compression moulding

**Computer Aided Design**
The use of computer software to produce designs for products is called Computer Aided Design (CAD). The designs can be 2D drawings or 3D models, which can be virtually tested prior to development.

The main advantages of CAD include:
- CAD is extremely accurate, often more accurate than drawing designs by hand.
- It is easier to modify or revise an existing design.
- Storage space is reduced as the files are electronic.
- Files can be shared around the world very quickly, or imported into presentations.
- 3D models can be rotated and viewed from different angles.
- Designs can be simulated to see how well they function. This will allow potential problems to spotted early in the design process.
- Designs can be exported to CAM equipment for manufacture.

The main disadvantages of CAD include:
- Some CAD packages are expensive to buy, so there can be a high initial setup cost.
- There needs to be access to appropriate ICT hardware to run the software. Thus usually needs to be a computer with a very good specification, which can be expensive.
- Some designers may not be familiar with how to use CAD software, so time and money must be spent training them. In addition they must also regularly update their skills.

**CAD Designer**

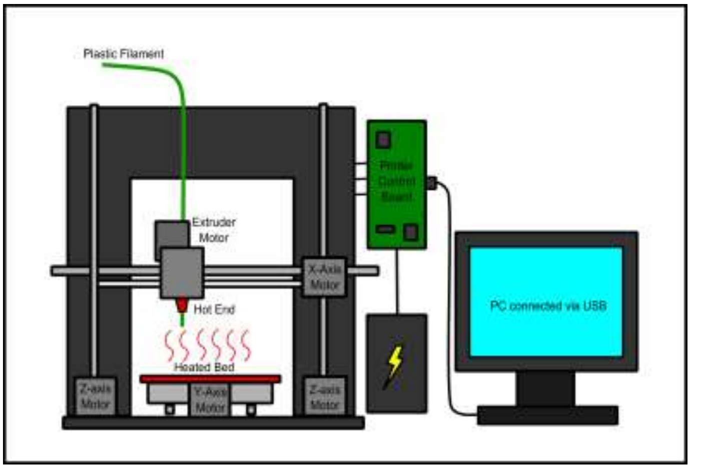
**Solid Modelling**

**Computer Aided Manufacturing**
The use of computer software to control machine tools to manufacture products is called Computer Aided Manufacturing (CAM). Examples of CAM equipment include laser cutters, vinyl cutters and 3D printers.

The main advantages of CAM include:
- Complex shapes can be produced much more easily than when manufacturing by hand.
- There is consistency of manufacture as every product produced is exactly the same.
- It enables high levels of precision and accuracy.
- There is greater efficiency as machines can run 24 hours a day, 7 days a week.
- It increases the speed of manufacture, especially when producing products in large volumes.

The main disadvantages of CAM include:
- As with CAD initial setup costs can be high. CAM machines are usually very expensive, although their cost is reducing with time.
- Operators must be trained to use the equipment, which adds time and cost.
- For one-off products, CAM can actually be slower than if the product was produced by hand.

**3D Printing**
3D printing is a process that replicates a CAD drawing by slicing the CAD model into thin layers using specialist software, allowing intricate items to be made.




This has tended to be a very expensive process, however *Additive 3D Printers* have made the process more affordable. They build models by extruding very thin layers of heated polymer, usually ABS or PLA onto a heated bed fusing each layer together until the model is complete. They are used to produce a small number of identical parts for use in projects or to model designs for testing.

**Laser Cutting**
Laser cutters use high-powered lasers to cut a wide range of materials including acrylic, paper, wood and metal. Laser cutting acrylic is an ideal process as it finishes the edge as it cuts the material from a sheet.

Laser engraving is often used on acrylic and laser engraving laminates for signage or to enhance the text or an image on the surface of the material. This process is more accurate than engraving by hand, however, the equipment cost of laser engraving can be expensive.

**Vinyl Cutting**
Vinyl stickers can be cut using a CNC plotter cutter directly from a CAD file allowing colour and text to be added to the surface of a polymer. A sticker requiring different colours is made up by repeating the process on different coloured vinyl and overlaying each layer to form the image or text. Vinyl stickers are commonly used to create signage as well as creating advertising wrap designs on buses and cars. Care need sot be taken when positioning stickers and they may peel off in some circumstances.

Laser engraved acrylic

Vinyl cut graphic

**Measuring**

When measuring component parts in the workshop we use millimetres as they are more accurate than centimetres. Most components will be measured using a steel rule, however, you may need to use a ***Vernier Calliper*** or a ***Micrometre*** for some components. These measuring tools use hundredths of a millimetre and are very accurate.

***Remember!***

| | | | |
|---|---|---|---|
| 1mm | = | 0.1cm | To convert mm to cm ÷ 10 |
| 10mm | = | 1cm | To convert cm to mm x 10 |
| 50mm | = | 5cm | |
| 57mm | = | 5.7cm | |
| 100mm | = | 10cm | |

**Mathematical Techniques**

**Mean**

The mean is the most common measure of average. To calculate the mean add the numbers together and divide the total by the amount of numbers:

**Mean = sum of numbers ÷ amount of numbers**

**Median**

If you place a set of numbers in order, the median number is the one in the middle.

**Mode**

The mode is the value of the number that occurs most often.

**Example**

The following set of data shows the number of parts made by nine engineering students in a week.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 8 | 4 | 4 | 6 | 3 | 7 | 3 | 2 | 8 |

The mean is 45 ÷ 9 = 5.

You work this out by (the total number of parts) ÷ (the total number of students).

**Use of formulae: Ohm's law**

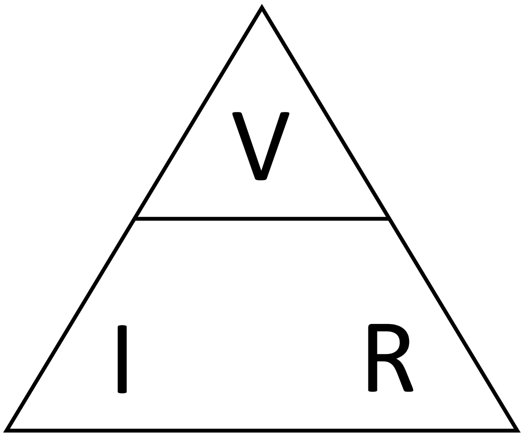
Ohm's law is used to describe the relationship between Voltage (V), Current (I) and Resistance (R).
If you know any of two of these values it is possible to calculate the third. Ohm's law can be arranged in the following three ways depending on what you want to calculate.

$$V = I \times R$$
$$I = V / R$$
$$R = V / I$$

Note: V = Voltage in Volts, I = Current in Amps, R = Resistance in Ohm's

**The Ohm's law triangle**

A very useful tool that can be used when doing one of the above calculations is the Ohm's law triangle shown below. The triangle is used by covering the item which you wish to calculate. The two items that are not covered will then be left in the arrangement required to calculate the covered item.
For example if you want to calculate R you would cover that item. The two remaining items are arranged as V/I. This is the formula to calculate R.




**Complete the calculations below using the examples above:**

| Voltage | | | |
|---|---|---|---|
| Question 1 | I = 5 Amps | R = 1 Ohm | |
| Question 2 | I = 3 Amps | R = 4 Ohm | |
| Question 3 | I = 2 Amps | R = 3 Ohm | |

| Current | | | |
|---|---|---|---|
| Question 4 | V = 5 Volts | R = 1 Ohm | |
| Question 5 | V = 12 Volts | R = 4 Ohm | |
| Question 6 | V = 24 Volts | R = 12 Ohm | |

| Resistance | | | |
|---|---|---|---|
| Question 7 | V = 5 Volts | I = 5 Amps | |
| Question 8 | V = 3 Volts | I = 6 Amps | |
| Question 9 | V = 50 Volts | I = 10 Amps | |

**Use of formulae: Efficiency**

The definition of efficiency is the ratio of the useful work performed by a machine or in a process to the total energy expended or heat taken in. For example, "the boiler has an efficiency of 45 per cent." Engineers at BMW would use this to work out how efficient their vehicles can be by using different engines and materials.

$$\text{Efficiency} = \frac{\text{Useful energy}}{\text{Total energy in}}$$

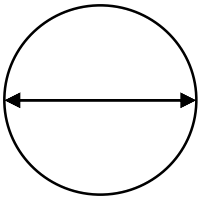
**For example**, a street lamp uses **100 joules** of **electrical energy**.
**75 joules** of this are wasted as **heat energy** and only **25 joules** are converted into **light** (the useful energy).

**Efficiency = 25/100 = 0.25 or 25% efficient**

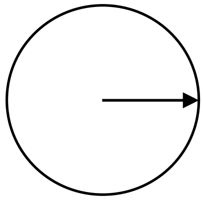
**Complete the calculations below using the efficiency cards provided:**

| Appliance | Energy in | Waste energy | Useful energy | Efficiency |
|---|---|---|---|---|
| Street lamp | 100 J | 75 J | 25 J | 25J/100J = 0.25 |
| | Electrical | Heat | Light | 25% Efficient |
| iPhone | | | | |
| | Electrical | Heat | Light | |
| Lamp | | | | |
| | Electrical | Heat | Light | |
| Torch | | | | |
| | Electrical | Heat | Light | |
| Microwave | | | | |
| | Electrical | Heat | Light | |
| Matches | | | | |
| | Electrical | Heat | Light | |

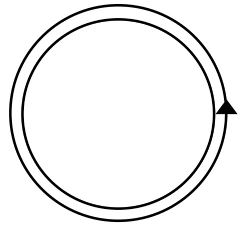
**Areas and volumes of geometrical shapes**



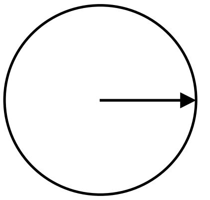
Diameter
Ø or D



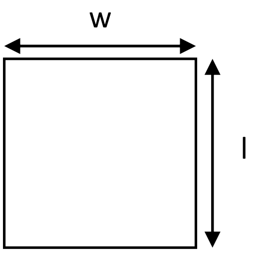
Radius
R



Circumference
C=2πr

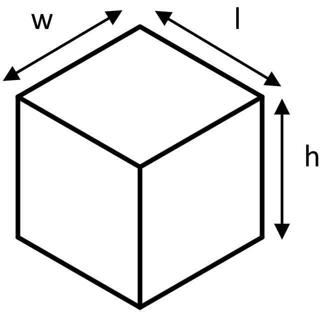


Area
$\pi r^2$

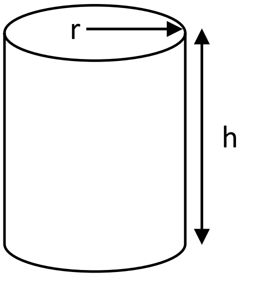



Area
length x width

$\boldsymbol{\pi = 3.142}$




Volume
length x width x height

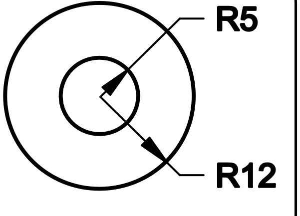



Volume
$\pi r^2$h

| 1 Use $A = \pi r^2$to find the areas of circles with these radii. | | | | |
|---|---|---|---|---|
| 14cm | 35mm | 2.6m | 62mm | 28cm |
| | | | | |

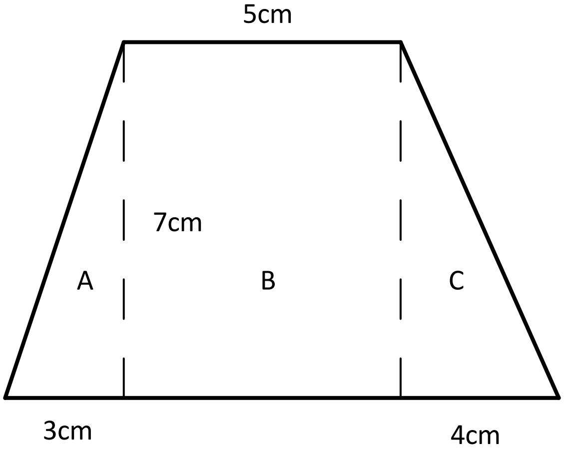
2 A metal washer has the dimensions shown in the diagram.

Calculate the area of the washer.



**Area of complex shapes**

Remember!
Area of a rectangle = length x width (A = l x w)
Area of triangle = ½ x base x height (A = ½ x b x h)



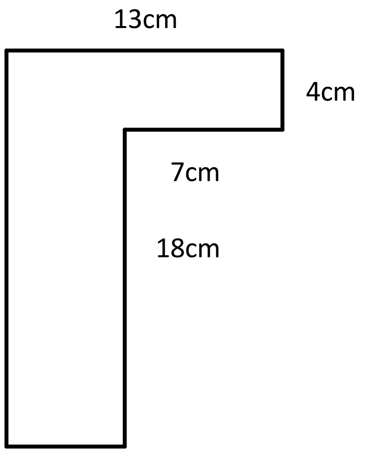

**Example**
Work out the area of the rectangle and each of the triangles separately and then add them together to find the area of the whole shape.

Area of shape = area of triangle A + area of rectangle B + area of triangle C

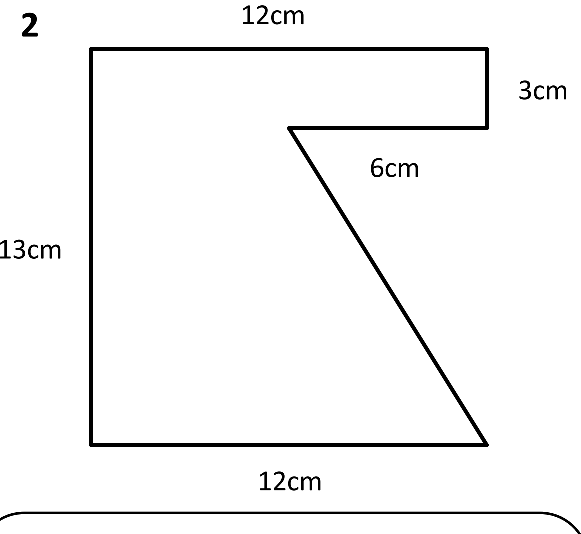
3x7/2 + 5x7 + 4x7/2
10.5 + 35 + 14
= 59.5cm²

Find the area of each of these profiles that must be cut from a piece of sheet steel.

**1**




**2**



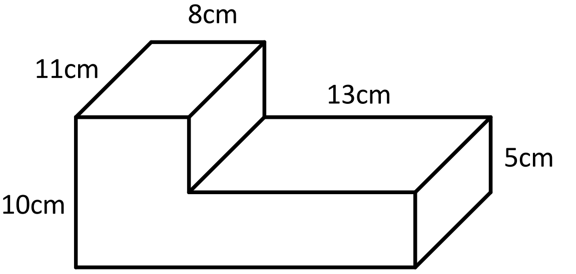
**Volume of complex shapes**

Working out the volume of cuboid shapes is shown opposite.

It is possible to find the volume of shapes made from cuboids by breaking them down into smaller parts.

**Example**

Find the volume of this shape




**Solution**

This shape can be broken into two cuboids **A** and **B**.

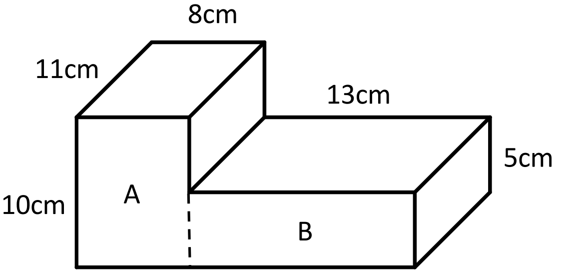
Work out the volumes of these two cuboids and add them together to find the volume of the whole shape.

Volume of shape = volume of **A** + volume of **B**

8 x 11 x 10 + 13x 11 x 5

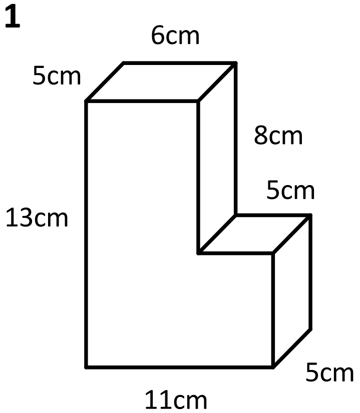
880 + 715

**1595cm³**

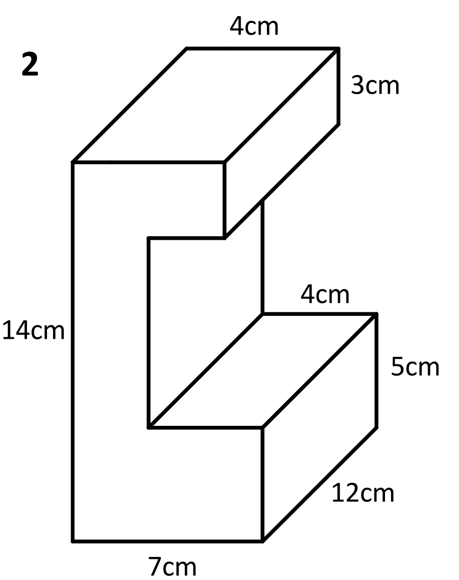



Find the volume of concrete required for each of these components.

**1**

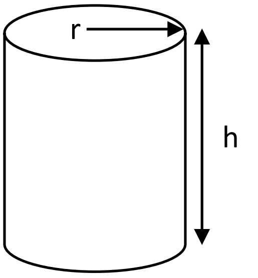



**2**



**Volume of a cylinder**

**To work out the volume of any cylinder you multiply the area of the circle by the length or height.**




Volume
$\pi r^2$h

**Example**

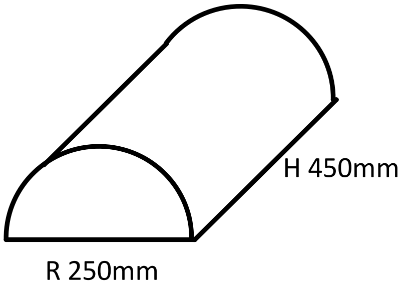
Find the volume of a cylinder with radius 13cm and height 50cm.

**Solution**

Volume $\pi r^2$h
3.142 x $13^2$ x 50
26 549.9
**26 550cm³**

| Use Volume $\pi r^2$h to work out the volumes of the following cylinders. | | | | |
|---|---|---|---|---|
| Radius 8cm<br>Height 35cm | Radius 14cm<br>Height 42cm | Radius 25mm<br>Height 6mm | Radius 3m<br>Height 25m | Radius 5.8m<br>Height 3.5m |
| | | | | |

1. Find the volume of concrete required for the capping stone below.




2. Find the volume of aluminium required to cast the component below.