Ballyhaunis Community School

Engineering

Leaving Certificate Engineering Textbook

Metallurgy

Materials Science

Polymers

Welding

Iron Carbon Diagrams

Machining

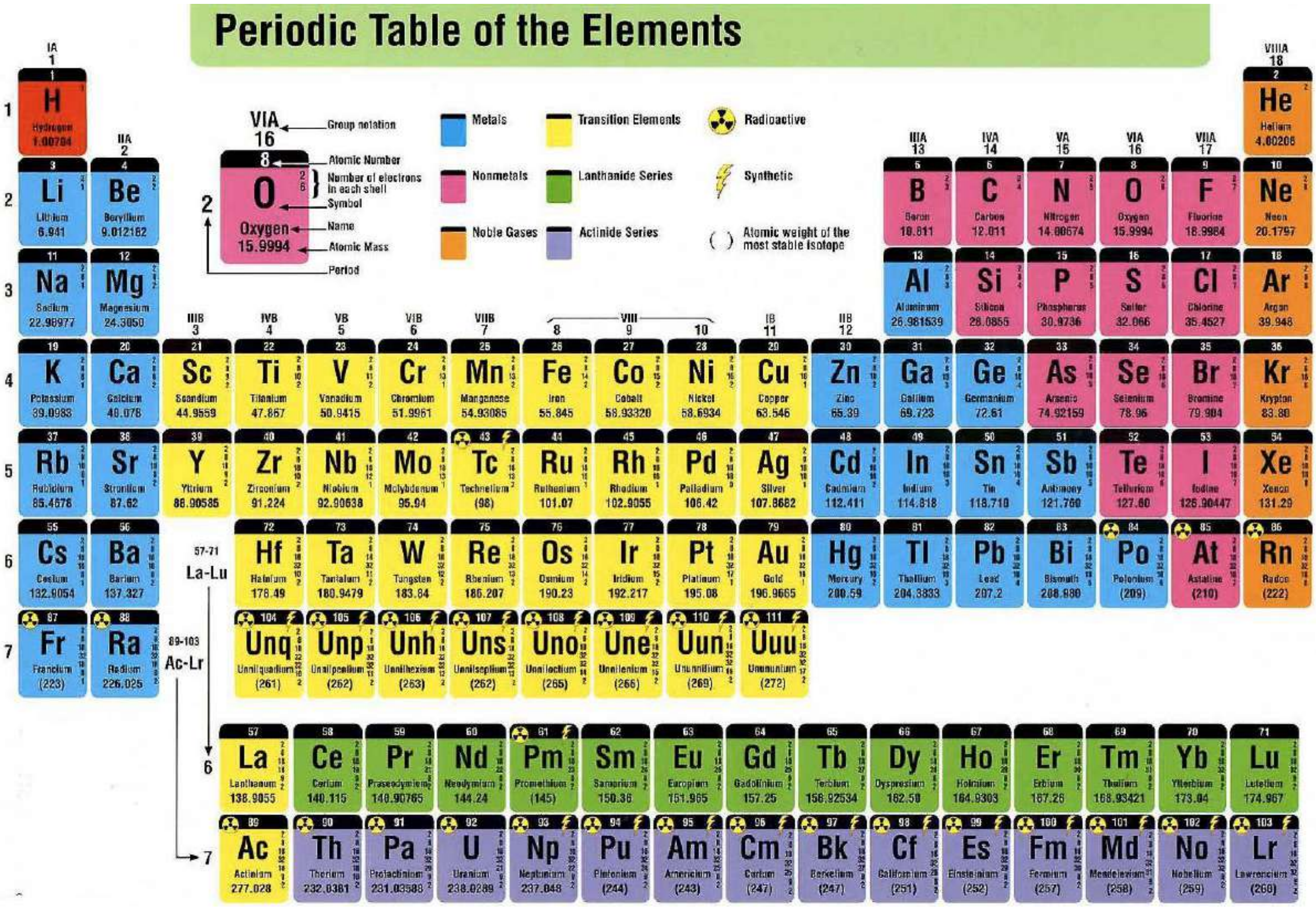
Metallurgy

Where Metals Come From

Contents

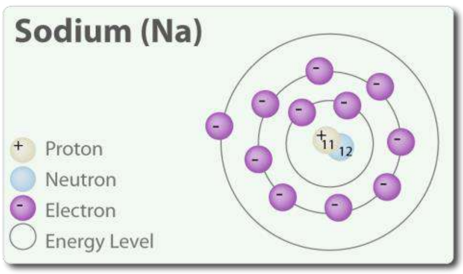
The Periodic Table of Elements

Everything that exists today is made up of a variety of different elements. Sometimes these elements are mixed together as is seen in alloy metals or something as simple as the air that we breathe. The periodic table of elements outlines all the elements that we have discovered so far in our world. Many of these elements are metals which are vital to the progression of engineering in modern times. Some of these include; iron, aluminium, chromium, nickel and cobalt. These materials provide a variety of properties that are suited to different tasks whether it be the iron in shipbuilding or tungsten in a light-bulb filament. We can only begin to understand metals when we understand their construction at the smallest possible level.



The Atom

The atom is the smallest thing that any element can be broken down into. It is made up of what we call a nucleus surrounded by electrons. The nucleus contains positively charged *protons* and *neutrons.* Orbiting these are negatively charged particles which we know as electrons. Atoms follow a few simple rules which effect how they behave and combine with other atoms, these are;

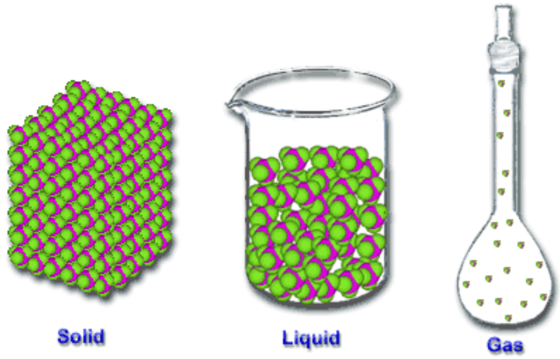


1. All atoms are neutral when their quantity of electrons matches the quantity of protons. If electrons are lost the atom will become overall positively charged due to the loss of negative particles. Likewise if electrons are gained the atom will have an overall negative charge.

2. All atoms desire to have 2 electrons in their first shell and eight electrons in their second, third, fourth and subsequent shells. Atoms also desire to fill their outer shells.

States of Matter

For materials to exist they rely on millions of atoms to bond together with each other. Where atoms are very closely packed solids are created (eg. Steel, timber, plastic). If atoms are able to roll over each other with ease, liquids are produced (eg. water). Where atoms are attracted to each other but not strictly bound together a gas is created.



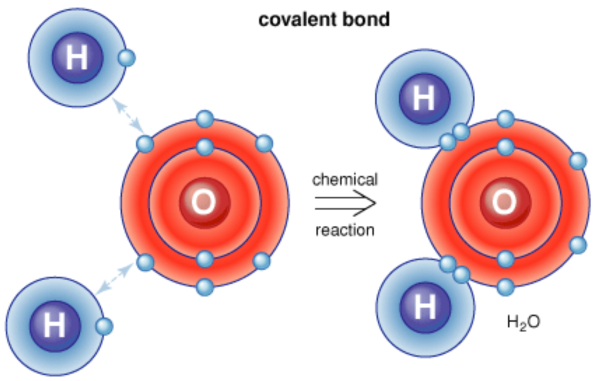
Atomic Bonding

There are three different ways in which atoms bond to create a material. They are;

- Covalent bonding
- Ionic Bonding
- Metallic Bonding

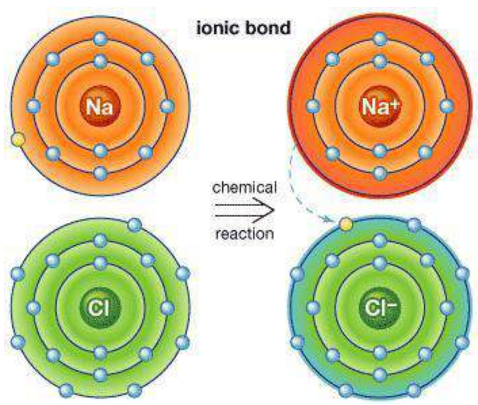
Covalent Bonding

Covalent bonding occurs where two or more atoms will share electrons on their outer shell to satisfy the requirement to fill their outer shell. One example is the molecule of water (H_2O). Two hydrogen atoms and one oxygen atom make up this molecule. Hydrogen has 1 electron on its outer shell but as discussed above desires to have 2. Oxygen has 6 electrons on its outer shell but again desires to fill this to 8. By sharing their outer electrons both oxygen and hydrogen fill their outer shells and in the process create what is called a covalent bond which is also known as primary bonding. This type of bonding is very strong and difficult to break down.



Ionic Bonding

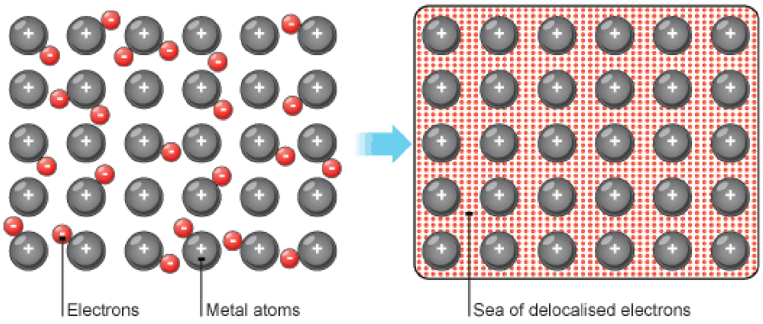
Ionic bonding is a weaker type of bond which occurs where ions are created. An ion is a charged atom, it can be negatively or positively charged. All atoms start out neutral as they have a balance of protons and electrons. If an atom loses one or more electrons it becomes positively charged. The converse is also true with negatively charged atoms being created where atoms gain electrons. Table salt (sodium Chloride, NaCl) is an example of an ionic bond. Sodium starts off with one electron in its outer shell and so requires 7 more electrons to fill its outer shell. Chlorine starts with 7 electrons in its outer shell and requires 1 more electron to satisfy its outer shell. It is easier for sodium



to give up its outer electron than find 7 more. As a result sodium is now positively charged whilst chlorine becomes negatively changed by gaining the given up electron. The positively and negatively charged ions now have a natural electrostatic attraction to each other. The bond created is a secondary bond, where it occurs in plastics it can be broken down with the addition of heat.

Metallic Bonding

Metallic bonding as the name suggests is common with metals. Looking at the periodic table of elements it is clear that all the metals tend to generally have a large number of electrons and therefore more outer shells than most atoms. When an atoms electron is far away from its nucleus, that force of attraction between the electron and nucleus is quite weak and the electron may break free from its atom. When this occurs a cloud/sea of free floating electron is created with positively charged (due to the loss of electrons) atoms suspended within. This type of bond gives metals their ability to conduct as conductivity is defined as the flow of heat or electricity (using the flow of electrons)



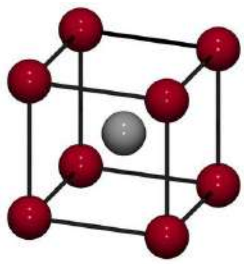
Crystal Structures

A crystal is anything that exists in a solid state where the materials atoms take up a *crystalline* organised and patterned layout. Metals have crystalline structures which can sometimes change which the application of heat. Three or the many structures include

- Body Centred Cubic BCC
- Face Centred Cubic FCC
- Close Packed Hexagonal CPH

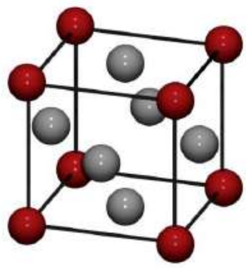
Body Centred Cubic BCC

This arrangement of atoms is based on an imaginary cube. It consists of 9 atoms in total where the atoms are located at each of the 8 corners of the cubic structure and one additional atom at the centre or *body* of the structure. This structure is repeated millions of times over to creating a solid material. BCC is regarded as a loose packed structure and can be found in steel known as ferrite

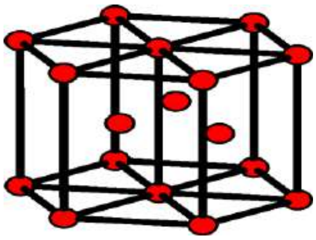


Face Centred Cubic FCC

Here the atomic arrangement although still based on a cube is more closely packed. Again there is an atom located at each corner of the cubic structure with an additional atom located on the centre of each face of the imaginary cube. There are a total of 14 atoms in this structure. It is found in steel at elevated temperatures which is known as austenite.



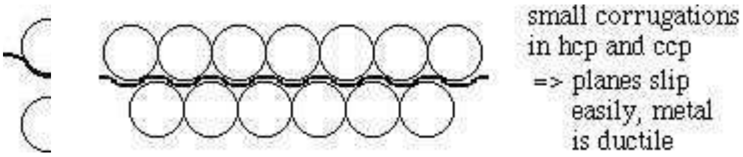
Hexagonal Close Packed HCP



The Close Packed Hexagonal structure is based on an imaginary hexagonal prism. 7 atoms are located on the end of each face of the prism with 3 more atoms separating each of the end faces. The structure has a total of 17 atoms in its structure. It is a very close packed structure and can be found in brass.

Slip in Metals

The term *Slip* in metals refers to a situation where layers or rows of atoms within the atomic structure of the material are able to slip or slide over each other. Where slip is allowed to occur it yields a ductile material (ie. A material that can easily be stretched without breaking). As FCC and HCP have a tightly packed structure slip can occur easily. In contrast to this BCC which is loose packed does not enable slip to occur very easily

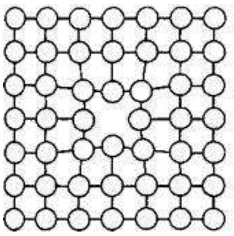


Metal Defects

Although Metals desire to have 100% perfect crystal lattice structures this is impossible and all materials will contain defects either at a single point or along a line or row of atoms. These flaws in most cases are acceptable and can be accommodated for but if the flaw is more severe it may lead to a crack forming on the surface of the material or worse still, from within the material where it can't be seen. Cracks have a tendency to grow and eventually lead to a component breaking.

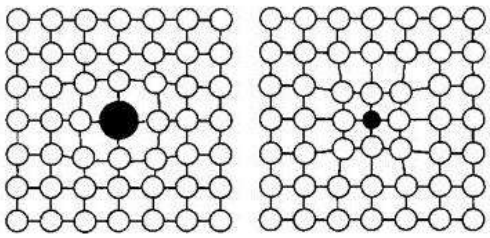
Point Defects

Vacancy



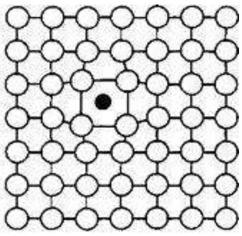
A vacancy defect occurs where there is one or more atoms missing from the crystal lattice structure. A void is created and the material may distort inwards easily due to the defect.

Substitution Defect



Here a rogue atom or atoms which are different elements to that of the parent material have somehow entered the lattice structure. This contamination may compromise the materials properties by placing stress on the material where the rogue atom is larger than that of the parent material or creating softness where the rogue atom is smaller than that of the parent material.

Interstitial Defect

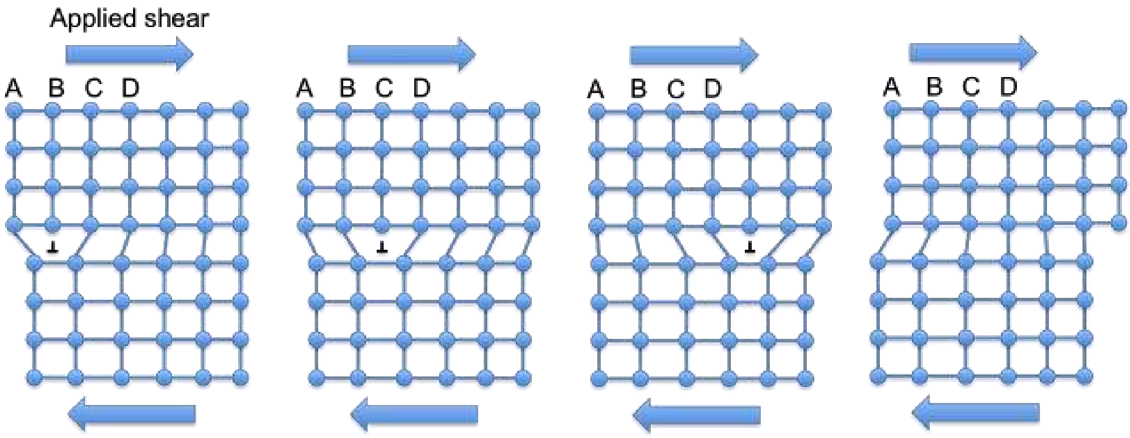


An *interstice* is a Latin word for free space. As the name suggests this defect occurs where a rogue atom finds its way into the lattice structure of a material. It is normally undesirable as it places stress on the material and can make it harder or more brittle than originally intended.

Line Defect

Dislocation

A dislocation is a line defect. With people, a dislocated shoulder is an injury in which your upper arm bone pops out of the cup-shaped socket that's part of your shoulder blade. With materials a dislocation is similar in principle, a flaw where there is an incomplete row of atoms (a dislocation). This flaw starts inside the material but due to a shear pressure acting on the material the flaw will spread through the material until it reaches the surface where a crack usually forms and will probably lead to the eventual failure of the component

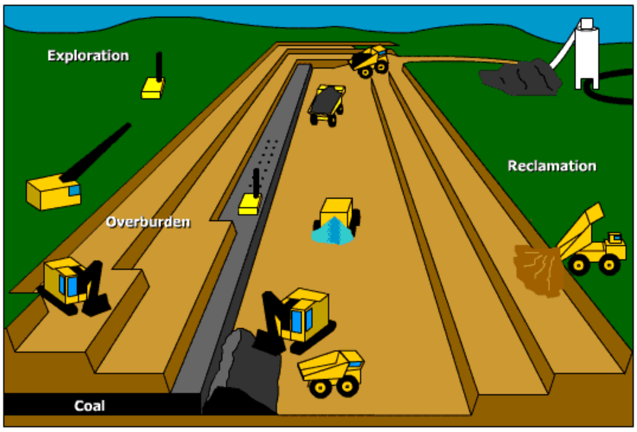


Metal Ore Extraction

To get a piece of timber you cut a tree down and chop it up into sections, and that is it. Metals are more difficult to obtain. All metals are found in ores which are basically a mix of rock and clay with the metal hidden within. These ores can be difficult to locate and also to extract as they are contained below ground and even under lakes or sea beds. There are several ever evolving methods of ore extraction available.

Open Cast Mining

The most basic form of mining is used where a metal ore is found close to the surface. Heavy plant is used to remove the topsoil and overburden which is concealing the ore. The ore is then excavated and transported for further refinement. The process is very cost effective as the ore is easy to find and remove. It has the disadvantage that entire landscapes can be permanently destroyed.



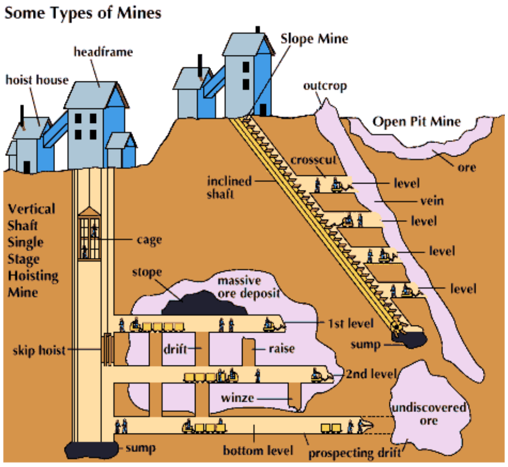
Open Pit Mining

Open pit miming is found where an ore is located than exists close to the surface but also continues deep below ground. Over a period of years the ore is gradually removed with the aid of heavy plant and explosives. This is a very effective type of mining but again has very bad environmental effects on the local landscape.

Figure 1 worlds deepest pit The 570 m (1870 ft) deep Fimiston Open Pit (or Super Pit), a gold mine off the Goldfields Highway, Western Australia

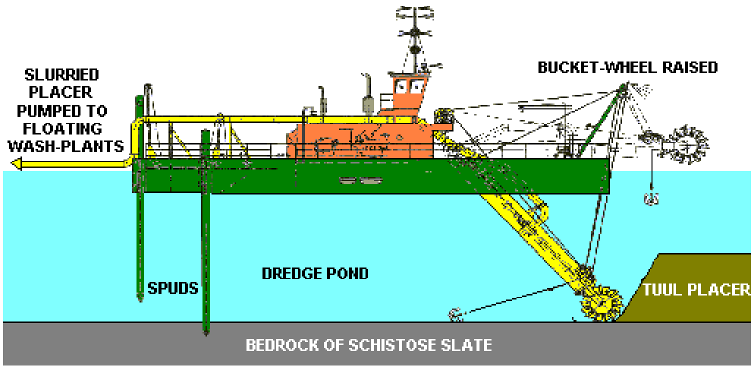
Underground Mining

Not the most cost effective method of mining but if a valuable ore is located deep below the surface underground mining may be utilised. Here a mine shaft is constructed and from here a series or tunnels can be made to remove the ore. The visible effect to the landscape is not as negative as open pit or open cast mining. Safety for the operating personnel has always been a concern due to collapses and gas pockets but this is improving with technological advances in engineering.



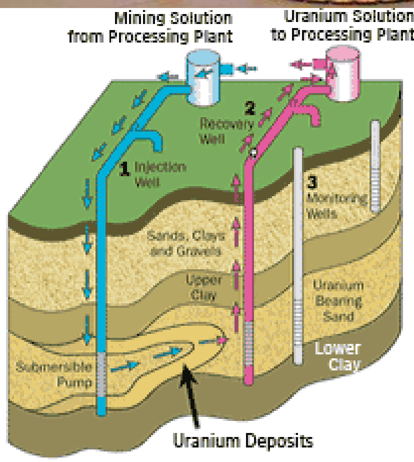
Dredging

Not all ores are to be found are on land. Sometimes rives can flush valuable metal ores from the mountains all the way to lakes or seas. Dredging boats can be used to scoop up a river or sea bed and filter out any valuable ores before returning the unwanted waste. The ore can then be transported to land for further refinement. Dredging usually has a negative impact on aquatic life by silting up the water make it impossible for plant and fish life.



Solution Mining

Solution mining is used with ores that are soluble in water and are located deep underground. A mining plant on the surface drills two bore holes to a pocket of the ore deposit. Water is pumped down one of the bores. The ore dissolves in this water creating a solution which is then forced up to the surface through the second bore hole. The solution is then further refined at the surface. It can be used for uranium or even something as simple as rock salt.

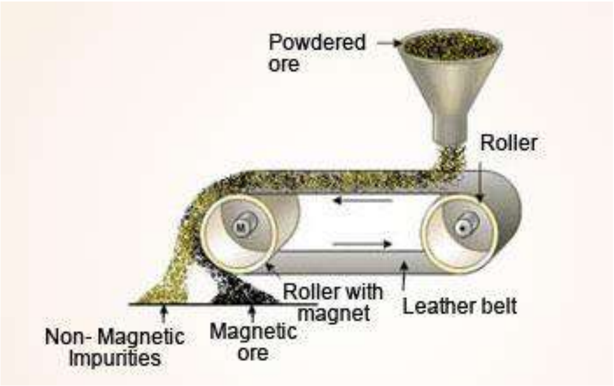


Metal Ore Concentration

Following the extraction of ores from the ground or underwater they are still just ores and not pure metal until further refinement occurs. A variety of processes are used to reduce and remove the large quantities of waste material (mainly clay and rock) from the ore. Magnetism, water, and heat are some of the things utilised to help in the ore concentration process

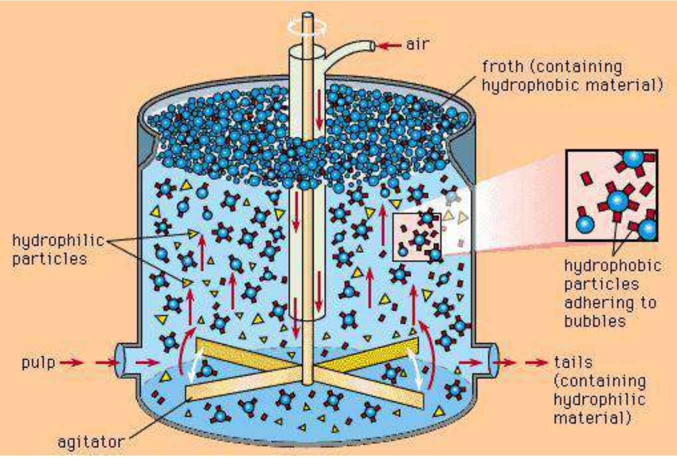
Magnetic Separation

Magnetic separation is a type of ore concentration that is suited to refining iron ore after mining. Following mining the ore will contain a lot of non-iron including clay and rock. To reduce transportation costs it is desirable to remove as much weight as possible. In the process the mined ore is crushed and sent along a conveyor belt. A magnetised roller at the end of the conveyor belt attracts the iron particles to the right whilst the non magnetised waste (rock and clay) falls into a different container to the left.



Floatation Separation

Flotation separation is a form of hydrometallurgy. Here the ore is placed in a large container with water and a chemical to assist the process. An agitator breaks up and mixes the ore. Air is pumped into the water and creates bubbles. These bubbles rise to the top and because of the chemical the metal particles of the ore attach themselves to the bubbles. A metal rich froth is created at the top of the tank where it can be collected by skimming it off. It is suitable for the recovery of copper and lead from their ores



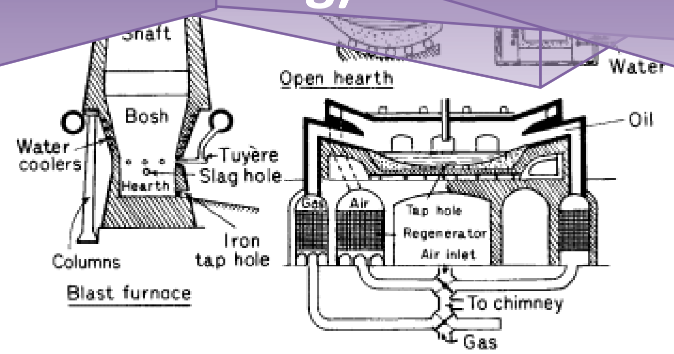
Materials Testing

Understanding Materials

Non Destructive Testing (NDT)

Mechanical Testing (Destructive Testing)

full array of
blast furnace, basic oxyg ace
and open hearth furnace



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Understanding Materials

Material Properties

In order to understand what causes a material to strong or weak we must have an in-depth knowledge of material properties. Properties determine how materials behave under certain conditions. They include

Hardness

'The ability of a material to resist scratching or indentation'

Hardness is very important for materials where wear and tear is an important consideration. The gearbox of a car is made of many meshing gears. If these gears are not made of hard materials they will wear away very easily. Hardness also implies that a material is quite brittle and for this reason some materials can be sometimes too hard as they may splinter or even shatter like glass.

Figure 2 Diamond - Incredibly Hard

Toughness

'The ability of a material to resist impact'

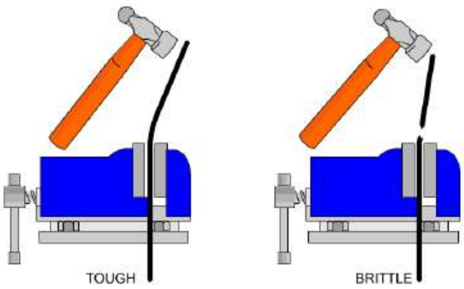


Figure 3 A Simple Toughness Test

Almost all engineering components will take impacts of different degrees. The suspension bars under a car or the frame of a bicycle take impacts every time they travel down a rough road. If the material used in these components is no *tough* it may fail and break. Tough materials are usually softer than hard materials and there can be a trade of between hardness and toughness at times

Ductility

'The ability of a material to be stretched or drawn into wire'

Most metals are ductile but some more so than others. Copper and aluminium can stretch quite well before they break whilst something like cast iron being more brittle is not as ductile. Material may break in two ways; suddenly where they show brittle fracture (they snap) or sometime they stretch a little be the material gives way and this is called ductile fracture. Ductility is also closely related to another property, Malleability – the ability to hammer a material to shape without it breaking.

Figure 4 Deformation Without Fracture

Elasticity

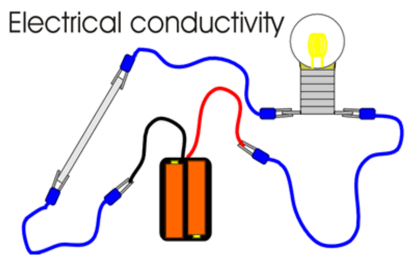
'The ability of a material to return to its original shape after deformation'

Figure 5 Elasticity - The Ability To Return To Shape

Elastic bands are obviously good examples of a material showing elasticity, but all materials show some degree of elasticity, even glass. A steel beam may be allowed to flex when under a load or force but will be expected to automatically spring back or return to its original shape when the force has been removed. Every material also has what is known as an *elastic limit*. This is the point beyond which there is no return. If the elastic limit is exceeded the component is either permanently deformed or breaks.

Conductivity

‘The ability of a material to allow heat or electricity to flow’



Conductivity is extremely important when dealing with electricity. Gold is one of the best conductors available but cost prohibits its use. For this reason copper is used as it is more affordable. Sometimes the property of conductivity is not desired. If a material is not a conductor it may be termed an insulator. Polymers tend to be good insulators. The casings of many electrical goods (hand drills, jigsaws, steam irons etc.) are usually made from insulating polymers in order to prevent electrical shock if a fault is present in the item.

Tensile Strength

‘The ability of a material to resist a tensile load’

This is the maximum tensile force (see below for definition) that can be applied to a material before it will fail and fracture. It is measured kN/mm^2. This is the force that is applied per mm^2 for the cross section of the material. Common steels tend to have a reasonably high tensile strength with softer materials like copper and aluminium having lower value tensile strengths

Figure 6 Cable Under Tension

Fatigue Resistance

‘The ability of a material to resist failure due to repeated loading over a period of time’

A material may resist fracture if a small force is applied. However, if this force is removed and then applied again and again over a long period of time the material may shows signs of a small crack which will grow and eventually lead to fracture. Think of the material failing because it is fatigued or ‘tired’ due to pressure or force acting upon it over time.

Creep Resistance

‘The ability of a material to resist failure due to a fixed load over a period of time’

As with fatigue failure time is a major consideration with creep failure. The difference is the nature of the force. Whilst fatigue is caused by a repeated on/off force or load creep occurs where a constant steady load acts on the material over a long period of time. Consider a steel cable that supports a heavy load over a long time. The cable may eventually begin to stretch becoming thinner and as result weaker. This will eventually lead to fracture.

Glass Transition Temperature

‘The temperature where a material changes from being brittle and glasslike to being soft and flexible’

All materials will display some level of flexibility and ductility at room temperature. We know that if we raise the temperature most materials will become softer and even more flexible. The opposite also applies if we drop the temperature of the working environment for a material. At lower temperatures all materials will reach a point where they will lose their soft and ductile properties and become much more brittle. This is known as the glass transition temperature of the material. The temperature varies for different materials. It is an important consideration in engineering design if a material is to be used in a cold environment like arctic exploration or aeronautics.

Nature of Forces

All materials that fail will do so because of a specific force acting on them. Forces will differ firstly in terms of magnitude (how strong the load is) but also in nature (how the force acts). The nature of forces will affect different materials in different ways where some materials will easily resist one type of force but if the nature of the force changes the material can easily fail. The ultimate material would be able to resist all the forces below, but this is impossible and as in all engineering the challenge is to find the best possible compromise.

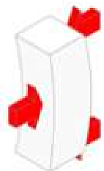
Tension (Tensile Force)

Tension occurs where two opposing forces act to create a pulling effect. Metals tend to have a reasonably good resistance to tensile force. Steel for example can be used to make load bearing cables that may be used on cranes for lifting heavy loads. Materials like concrete however are very poor in tension and tend to fracture (break) easily even under minor tensile loads.

Compression (Compressive Force)

Compression occurs where two opposing forces act to create a squeezing effect. Although poor in tension, concrete is one of the best materials available when put under a compressive load. Load bearing walls of buildings are a simple sign of concretes abilities under compressive loads.

Bending Force

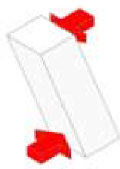


Bending forces are more complex than both tension and compressive forces yet under closer examination actually incorporate both of the above. In a bending force one side of the material is effectively being squeezed (compression) whilst the opposite side is being stretched. Bending forces can easily been recognised in bridges. The difficulty with bridge construction always lay in material selection. Modern construction of bridges often uses reinforced concrete. Reinforced concrete is an amalgamation of traditional concrete combined with steel rods or mesh running through its core. The concrete manages the tensile loads whilst the steel manages the tensile loads.

Torsion (Twisting Force)

A torsion force may be defined as two twisting forces that act in different directions on the same piece of material. This force is of particular concern on the area of automobile engineering where drive shafts can be used to transfer rotary power from a car's engine to its wheels. If there is resistance for example the engine is driving the car up a hill but the car naturally wants to roll back down the hill a twisting force is applied to the drive shaft of the car

Shear Force



Shear forces occur where two opposing forces act on different. The effect of shear can be a sudden failure through the component concerned. To further understand shear consider a shears or scissors. A scissors works where one blade is pressing the paper down and the other blade is pressing the paper up. If enough force is applied the paper shears (or cuts as its otherwise known. In engineering bolts or shafts may shear due to excessive force acting on them

Non Destructive Testing (NDT)

Non Destructive testing is used for locating both surface and internal flaws in engineered components. Flaws may include cracks, voids or inclusions that may lead to premature fracture of a component. This has implications for safety. The aeronautical industry is heavily reliant on NDT. Components may be required to have a long service life and for this reason routine inspections are carried out to ensure the safety of a component. Unsafe items may then be replaced before a component in turn preventing potential accidents due to component failure.

Visual Inspection

Visual inspections are the simplest and most important types of non destructive tests used. There are two main categories.

Macroscopic Inspection

Macroscopic testing uses the power of the human eye with little or no magnification. It is primarily used in the area of quality control in manufacturing industries. The QC process will identify faults or manufacturing defects such as missing fasteners (nuts, bolts, rivets) or poor workmanship. The simple process is important to prevent faulty goods going to market.

Microscopic Inspection

Where a detailed examination of a material is required a microscope with high magnification may be used. This enables the engineer to locate tiny surface cracks or flaws that may be invisible to the human eye without magnification. This can be effective for small components but very time consuming on larger items.

Liquid Penetrant Test

This test is used to highlight surface cracks on components that are difficult to identify using the naked eye. The process is widely used in aircraft maintenance repair and overhaul. Figure 1 below shows the process of the liquid penetrant test. The material being tested must first be cleaned so it is free of oil, grease and dirt particles. A liquid dye is sprayed over the material. This liquid will penetrate into surface cracks on the component. The excess liquid is lightly wiped away. Another spray called a developer is sprayed over the component. The developer draws the colour dye from the crack and helps to show greater contrast in colour between the penetrant dye and the component. If flaws are identified it may be decided to repair, replace or leave the component in service. An alternative to the test shown is to use an ultra violet sensitive liquid penetrant. This will show up brightly in a darkened room using an ultraviolet lamp (blacklight)

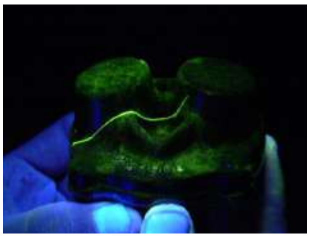


Figure 7 UV Liquid Penetrant Test

Figure 8 Liquid Penetrant Testing Procedure

Magnetic Particle Test

The magnetic particle test utilises the principle that a magnetised component will create a magnetic field. This magnetic field will always have a clear and identifiable pattern. In Fig.2 an electromagnet is used to magnetise the steel test component. Iron filings/dust is then sprayed or sprinkled over the test piece. These filings will arrange themselves in a pattern due to the presence of the magnetic field. If there is a crack on the surface or even inside the material (but close to the surface) this will interrupt the pattern of the magnetic field. Any interruption in the magnetic field pattern is easily identified by a cluster or small lump of iron filings gathering at the area of the flaw. This test can be used in testing engine blocks, piston heads and crankshafts in the automotive industry.

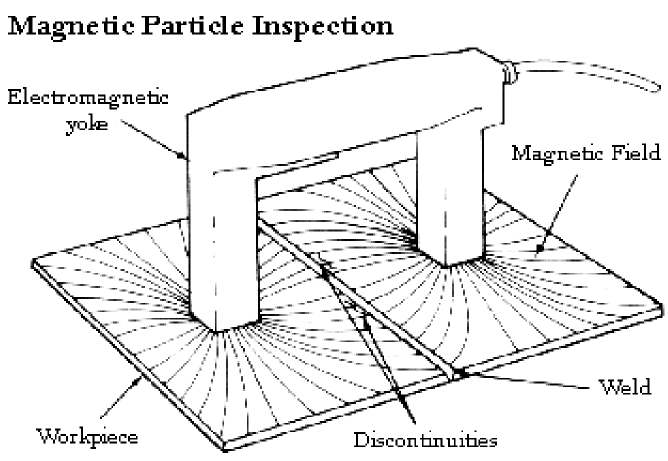


Figure 9 Principle of Magnetic Particle Testing

Eddy Current Test

Eddy current testing also uses the principle of magnetism but unlike the magnetic particle test it is suitable for testing non-ferrous (non iron based, eg. Aluminium, copper, zinc) components. The test equipment consists of an iron rod with a copper coil wrapped around it. An electrical current travels through the coil and this turns the iron rod into an electromagnet. A magnetic field is created around the rod as a result. An oscilloscope is used to measure the strength of the magnetic field. If the iron rod is passed over the test component the invisible magnetic field will penetrate through the component. The density of the component will lead to some resistance of the magnetic field. The oscilloscope is able to measure this resistance. A certain amount of resistance is expected but if there is a flaw inside the material it will

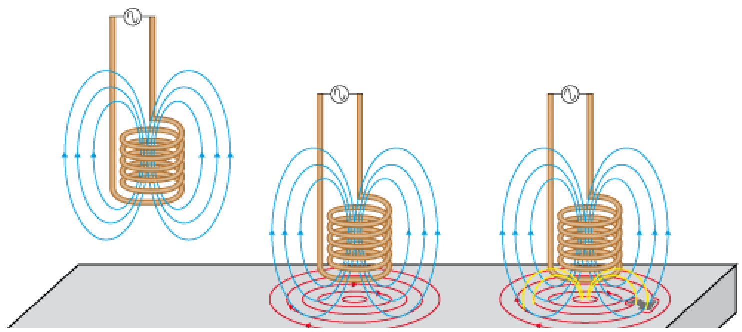


Figure 12 Principle of Eddy Current Testing

Figure 11 Eddy Current Testing Welded Joint

lead to a fluctuation which can be seen on the oscilloscope.

Ultrasonic Test

Ultrasonic testing utilises the principle of sound reflection and echo. When sound is emitted it will travel and when it meets a surface it will reflect, this is how an echo occurs. Not all sound can be heard by humans, consider dog whistles which use high frequency sound waves. In ultrasonic testing an inaudible high frequency sound wave is emitted from a transducer in the form of a pulse. The sound will travel through the thickness of the material and reflect back to the transducer. A display unit will show how long it took the sound to travel. If there is a flaw inside the material the sound will be unable to travel through the entire thickness of the material and reflect back early. This will show up on the display monitor as a shorter wave journey thus identifying a fault. Results are sometimes difficult to interpret and for this reason skilled operators are required.

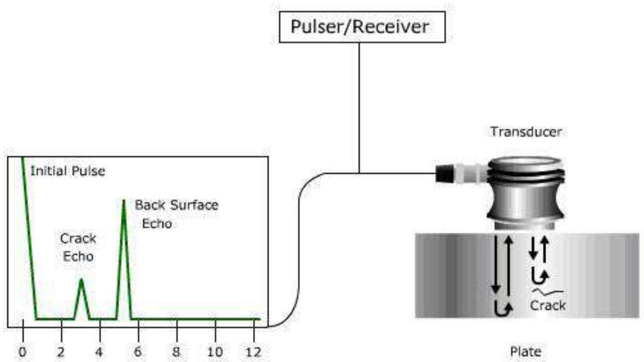


Figure 13 Ultrasonic Testing Equipment

Figure 14 Ultrasonic Testing can be used to inspect joints in railway lines

Radiography Test

Radiography or X-ray testing is used to identify internal flaws in various components. A radiation source, created by the rapid movement of electrons in a focused direction, is used to penetrate through the test component. An internal image is created on a photographic sensitive piece of film that is placed under the component. The dark areas identify where the path of the x-rays went unhindered with the brighter areas showing where a dense material resisted the x-rays. Any flaws in the material are easily identified by a tone change on the film. Radiography testing is very effective but extremely expensive to put in place. It also carries a radiation risk to its operators.

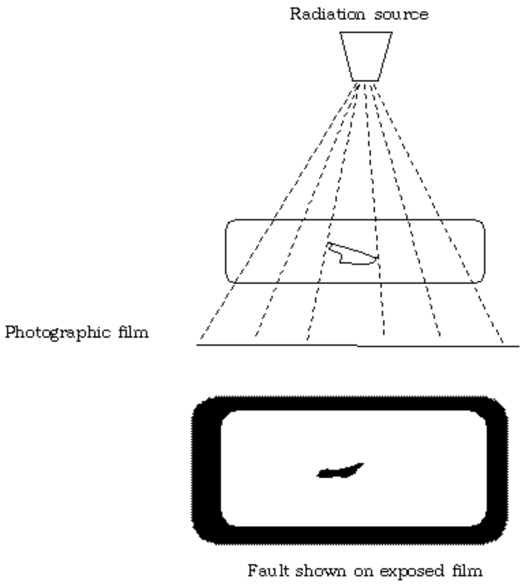


Figure 16 Principle of X-ray testing

Mechanical Testing (Destructive Testing)

Figure 15 X-ray testing is widely used in the aeronautical industry

Mechanical testing is used to investigate materials properties and find its ultimate breaking point in various situations. This is done by applying various loads and taking readings until the point of the materials destruction. Engineers need to be sure about the loads and stresses that a material can take so that the correct material is chosen for a particular application. It has implications for safety as well as finance. Over engineering can be costly whilst not using a material that can withstand an intended load can lead to catastrophic component failure. One area of particular importance is the aeronautical industry. Here weight is a major issue and engineers are always developing new materials that can save weight, this leads to better performance and a saving on fuel costs. However engineers must understand the limits that these materials can take. Aiding this is *Factor of Safety*. If a component is designed to withstand a certain load it may be made even stronger than required. If it is made twice as strong as intended this would be a factor of 2, ten times stronger would be 10 and so on.

Impact Testing

Impact testing is used to determine the toughness of a material, ‘The ability of a material to resist impact’. The principle of the test involves clamping a pre-sized test piece of material in a vice. A pendulum with a blunt striker at its end is raised to a predetermined height. The pendulum is released. The striker fractures/breaks the test piece and continues to travel. If the material was tough the striker will have used most of its energy and will not travel through far past the test piece but if the material is not tough the striker will still hold a lot of momentum and travel through high past the test piece. The swing of the pendulum past the test piece is measured and this determines the toughness of the material. Other properties like brittleness and ductility can be observed from the test depending on how the test piece breaks. Does it snap suddenly or bend before fracture?

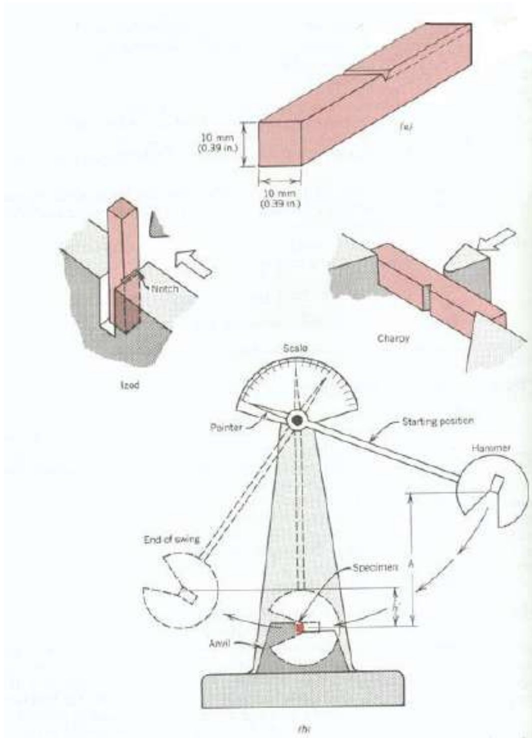


Figure 17 Impact Testing Principles

Two slightly different types of test exist. The *Izod Test* holds the test piece vertically in a vice whilst the *Charpy Test* supports the test piece horizontally between two supports. Both tests do essentially the same thing just in a different way.

Figure 18 Ductile Fracture (top) Brittle Fracture (centre) Initial Specimen (bottom)

Hardness Testing

As suggested by the name this test will investigate the hardness value of a material, ‘The ability of a material to resist scratching or indentation’. A hardness testing machine is used. A small piece of test material called a widget is placed on the machine table. An activating lever forces a pointed or spherical indenter into the material at a pre set force. An indent is left on the surface of the material. The basic principle of the test involves measuring the size of the indent and comparing this to a set of special log tables. A large indent is found on soft materials with a small indent indicating that the material is quite hard. The indenter must always be made from an extremely hard material to ensure test result accuracy two main varieties of the test are used today;

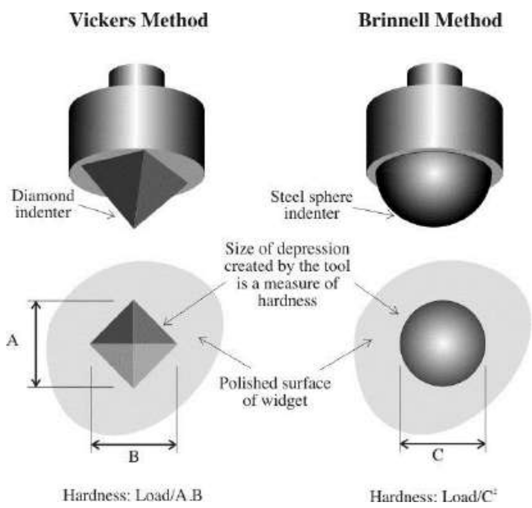


Figure 19 Principles of Vickers and Brinell Hardness Tests

Vickers Testing uses a square based pyramid shaped indenter. The indent left here is square in shape. The length of the diagonals on the indent is measured and an average is calculated. From this a VHN is calculated (Vickers Hardness Number).

Brinell Testing uses a ball shaped indenter. The indent is circular. The diameter of the indent is measured. From this a BHN is calculated (Brinell Hardness Number)

Fatigue Testing

Due to Fatigue, 'The ability of a material to resist failure due to repeated loading over a period of time', being so common and sometimes unpredictable engineering will often attempt to simulate in a laboratory the forces and repeated loads that a material will undergo over a long period of time. Testing can be quite basic and easy to carry out. At a basic level it involves supporting a test piece in a vice and repeatedly bending it forward and back at a set load whilst counting how many movements it takes for the component to fracture. Engineers will alter the test to suit the expected usage of their own components.

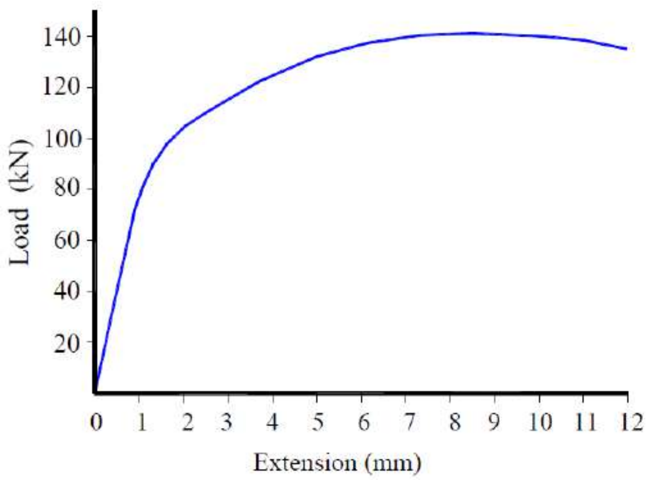
Tensile Testing

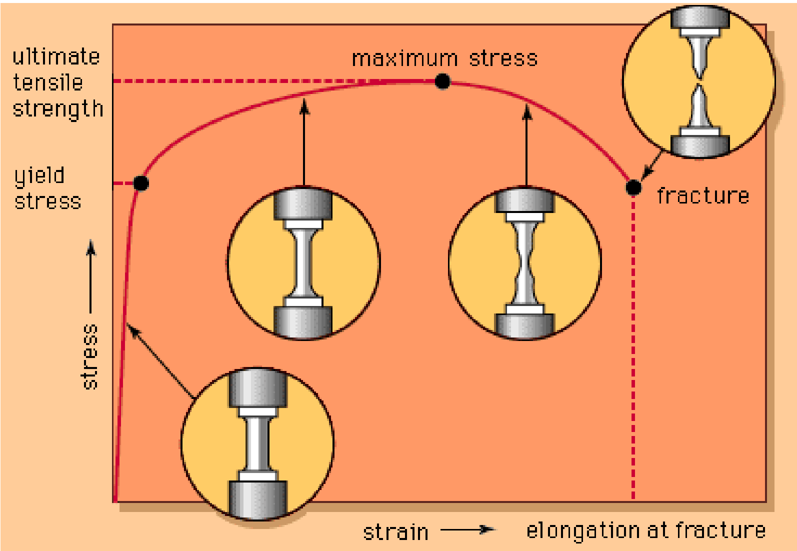
This is probably the most important of the non-destructive tests. The main outcome of a tensile test is to determine the UTS (Ultimate Tensile Strength) for a material. This is the maximum tensile force that a material can withstand before it fractures. By analysing the results of this test many more properties can be observed including, ductility, brittleness, malleability, toughness, hardness and elasticity.

Tensile testing is widely carried out on both metals and polymers. A tensile testing machine is used. A test piece of material is prepared; this is usually flat for polymers or cylindrical bars for metals. The test specimen is clamped within the test machine where it is put under a tensile load. As the load increases the test piece will become gradually longer until it will eventually break. During the course of the test the force (kN) is measured against the extension (mm). A graph is constructed to show these results. Understanding these graphs is important for materials scientists so as to better understand the materials that they will select for a variety of applications


Figure 20 Tensile Test Specimen

Initially a load extension graph is produced. This graph relates to the specific piece of material that has been tested. As test components can vary in size (diameter and length) it is desirable to create more standardised graphs that will relate to the material type as opposed to a specific test piece. In this case a Stress-Strain graph is produced; they are produced by converting the data achieved from a load extension graph. Material Stress is calculated by taking the force used and dividing by the cross sectional area of the component. Stress is measured in units of kN/mm^2. Strain is calculated by taking extension and dividing it by the original length. Strain has no units as it is a ratio or comparison of the materials extension to its original length





A tensile test is initiated when the test piece is put under a tensile load. This piece will begin to stretch and for a limited duration of the test this extension may be described as *elastic deformation*. This means that if the force is removed the material will be able to spring back to its original length. This doesn't last forever though and different materials display different levels of elasticity. A yield point occurs where the straight section of the graph finishes. From here to the highest point on the graph the material continues to extend uniformly (ie. it get thinner as it gets longer) and the region shows *plastic deformation*. Here the deformation is permanent; even if the force is removed the material will not return to its original length. The top of the graph shows the ultimate tensile strength or maximum stress that the material can take. After the maximum stress has been reached to material will neck. *Necking* is where the material thins at a single area or weak spot as it continues to be stretched. This significantly and quickly weakens the material and ultimately leads to fracture of the test piece. Ductile materials will tend to display *cup and cone* fracture due to their ductility whilst harder materials will display brittle fracture.

Figure 22 'Cup and Cone' Fracture

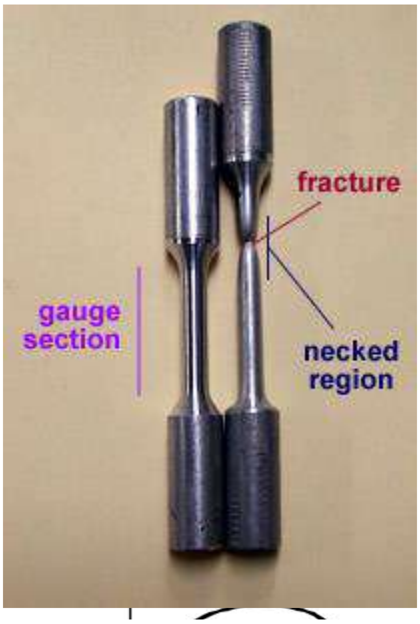
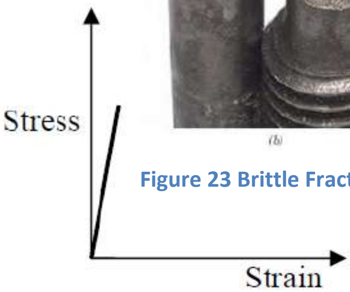
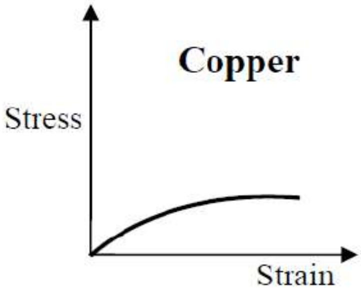


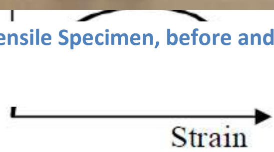
Figure 21 Tensile Specimen, before and after

Material properties related to tensile tests

Figure 23 Brittle Fracture







The diagram above shows three tensile tests on a variety of materials. From these results it can be deduced that Brass is a hard and brittle material as displays very little extension even when put under a heavy load. Copper may be described as being soft and ductile as it extends very easily without breaking even when the load is low. Mild steel is a tough yet ductile material. A reasonably high load is required to stretch the material and it readily extends with the force without breaking until it has extended considerably.

Young's Modulus of Elasticity

Tensile testing also enables materials scientists to investigate the stiffness of a material. Some materials for good or for bad may be more or less flexible than another material. Something like the front wing of an F1 car will require a stiff and rigid material that is not prone to flex as this will aid the cars down-force. High skyscrapers often require materials that allow for the building to flex in situations of high wind or even earthquakes. A measure of a materials stiffness is known as *Young's modulus of elasticity.* It's measured in units of kN/mm^2. Young's modulus is always calculated within the elastic region of a stress strain graph. Young's modulus =Stress/Strain. It may also be calculated by finding the slope on a stress-strain or load-extension graph.

Figure 25 The front wing must be rigid

Figure 24 Skyscrapers require a degree of flexibility

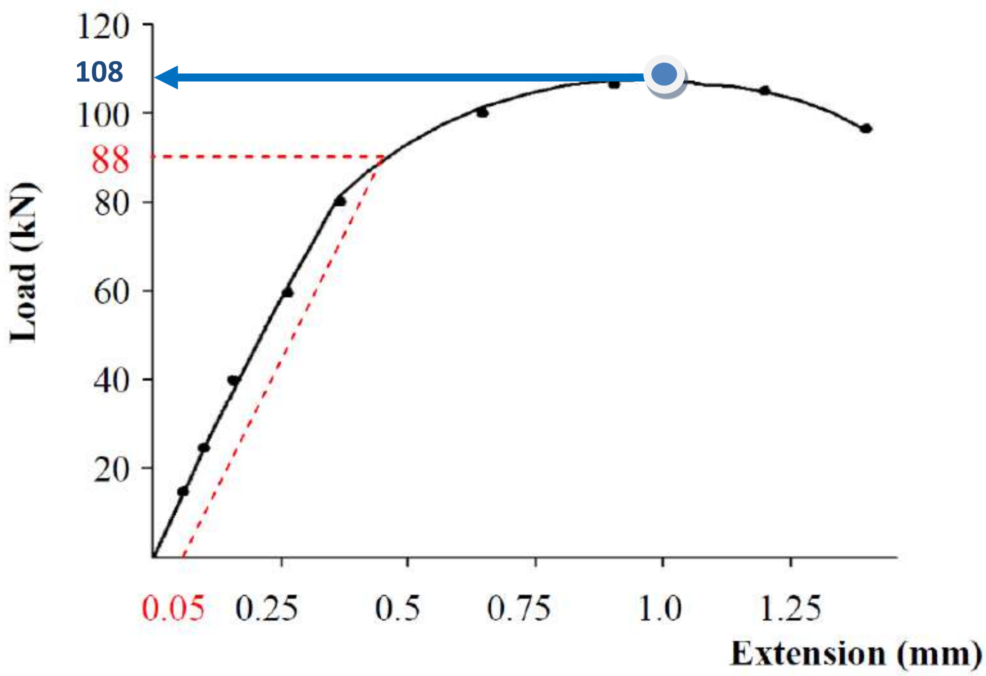
Constructing a Load-Extension Graph

The results shown below were obtained from a tensile test on a non-ferrous alloy with a 10 mm diameter and 50 mm gauge length. Plot the load-extension diagram and determine:

(i) The ultimate tensile strength (UTS)

(ii) The 0.1% proof stress.

Load (kN)	15	25	40	60	80	100	107	108	105	96
Extension (mm)	0.06	0.10	0.16	0.26	0.38	0.65	0.90	1.00	1.20	1.40



(i) **U.T.S.** **= Max.Load (from graph)/C.S.A (Cross sectional Area of the diameter 10 test piece)**
$= 108 / \pi \times 5^2$
= 1.38kN/mm2

(ii) **0.1% proof stress** **=Proof Load/CSA**

Proof Load = 0.1% of 50mm(gauge length)
= 50x.001
= 0.05mm
= Proof load (draw from .05mm on graph parallel to straight line)
= 88kN (from graph)

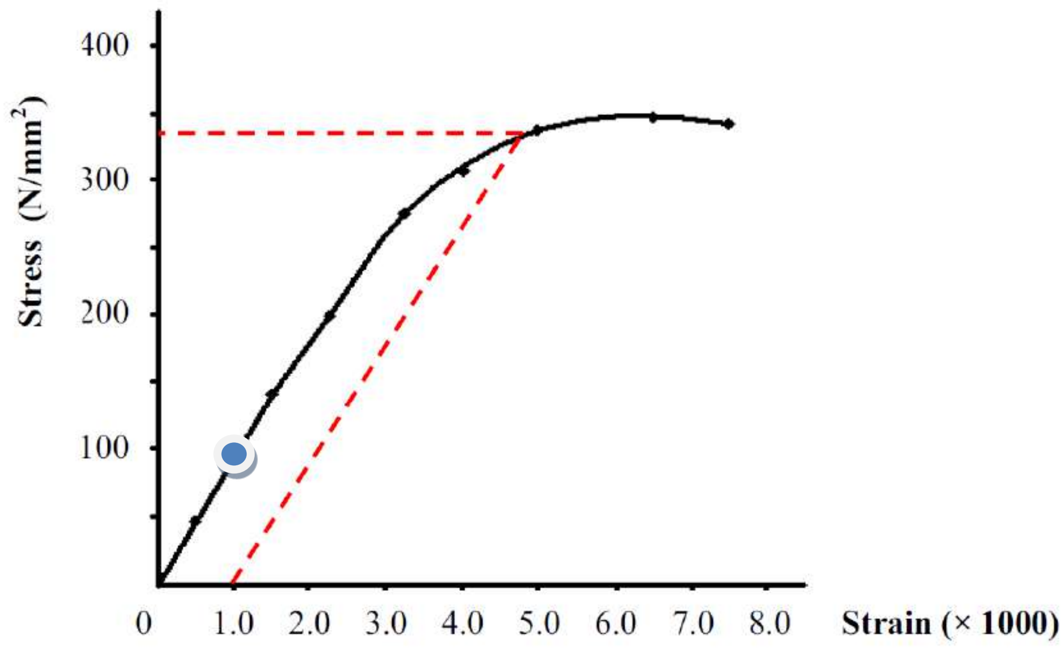
0.1% proof stress = Proof Load/CSA
= 88/ π x 5^2
= **1.12kN/mm2**

Constructing a Stress-Strain Graph

The results shown below were obtained from a tensile test on a non-ferrous alloy. Plot the Stress-Strain diagram for the alloy and determine:

(i) Young's modulus of elasticity
(ii) The 0.1% proof stress.

Stress (N/mm^2)	45	90	135	200	275	308	335	345	340
Extension (x1000)	0.50	1.00	1.50	2.25	3.25	4.00	5.00	6.50	7.50



(i) Young's Modulus = Stress/strain (Any point from straight section of graph)
= 90 / 1
= **90kN/mm2**

(ii) 0.1% proof stress =line drawn from 1 on strain axis
=332 N/ mm2 (from graph)

Polymers

Materials Science of Polymers

Manufacturing with Polymers

Contents

Polymer Materials Science

Introduction

The familiar word plastic means 'capable of being re-shaped or re-moulded'. Not all plastics however are capable of this. For this reason Engineers and materials scientists tend not to refer to these materials as Polymers. *Poly* is a Greek word meaning many whilst a *mer* means molecule (molecules are clusters of atoms). Polymers are therefore many molecules connected to each other. These molecules are usually inter-connected along long chains in a scattered and random manner.

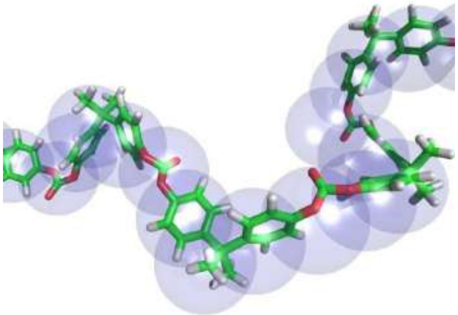


Figure 26 Microscopic view of molecules joining to create a polymer

Polymers have been in existence for a relatively short period of time, less than 200 years, but have become incredibly important and we now rely heavily on a lot of these new materials and the unique properties they bring. Popular materials like timber are produced from trees with metals originating from ores in the ground whilst modern polymers are produced from by-products of the gas and oil refining industry.

Figure 27 Samples of polymers that we use every day

Categories of Polymers

1. **Natural Polymers**
2. **Thermoplastic Polymers (Thermoplastics)**
3. **Thermosetting Polymers (Thermosets)**
4. **Elastomers**

Natural Polymers

Natural polymers have always existed and although there has been much advancement over the last century in synthetic (man-made) polymers, it was only through investigating the properties of natural polymers that modern synthetics were developed. Some examples of natural polymers include;

Natural rubber

Natural Rubber is cultivated by cutting into the bark of the rubber tree to release its sap like material. Latex is the name given to the sap from the rubber tree. Rubber trees only grow in hot climates like. Thailand and Indonesia have an ideal climate for these plantations. Elastic bands can be made from natural rubber. Rubber may be further refined and modified to improve its properties, this will be discussed later.

Shellac

A simple material collected from a specific species of beetle called the *lac bug*. The polymer is hard brittle and leaves a high gloss shine on products. It may be used as a French polish for furniture.

Amber

Amber is quite simply fossilised tree resin that has become hardened over the period of being fossilised. Amber has been used over centuries in jewellery making due to its attractive translucent colour. Because amber starts life in a softened state fossilised insects may be found in the amber which may add to its appeal.

Figure 30 Shellac Producing Beetle (lac bug)

F

Thailand

Figure 29 Amber has an attractive appeal

Thermoplastic Polymers (Thermoplastics)

Thermoplastics are modern synthetic polymers that have been developed over the past century. They include popular materials like acrylic (Perspex), polythene (used for plastic bags) and polypropylene (used for plastic chairs). They are produced by a process called *Addition Polymerisation.* Figure 32 shows the polymerisation process for polyethylene (plastic bag material). This process begins with a single mer (molecule) of ethylene, C_2H_4. A double bond exists within the molecule between the two carbon atoms preventing the mer joining with other mers. A free radical (catalyst), a chemical additive, is introduced. This has the effect of breaking the double bond between the carbon atoms. The mer then bonds to another mer and the breaking down of the double bond is relayed onto the end of the chain. The process rapidly repeats itself creating long slender chains of molecules. These chains commence and terminate at various random locations within the material creating what is called an amorphous structure (a random, scattered and disorganised arrangement).

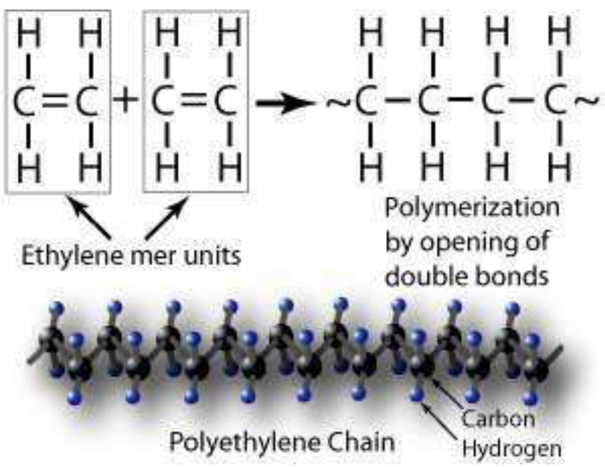


Figure 32 Addition Polymerisation Process

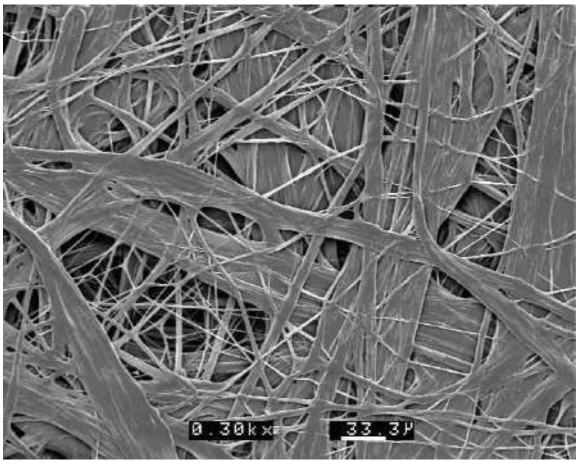


Figure 31 Amorphous Structure of Polyethylene

Within the structure the mers along the chains are bonded covalently. This form of primary bonding is very strong and extremely difficult to break down. Between the different chains or across overlapping chains a weaker type of bonding is found known as secondary bonding or sometimes called *Van Der Wall's Forces,* named after the Dutch scientist who discovered them. These bonds unlike the primary bonds can easily be broken down by heat and reform upon cooling. This principle explains why thermoplastic polymers become flexible when heated and rigid when cooled.

Thermoplastics can be further engineered to improve their properties by the following processes;

Co-Polymers

Mixing and combining different types of molecular chains can improve the material by making it harder, softer, more rigid or flexible depending on what is required. This is similar to making alloys (mixing metals). The newly engineered materials will possess new and unique properties as determined by the required material use.

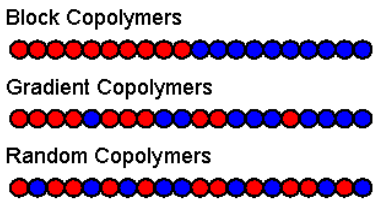
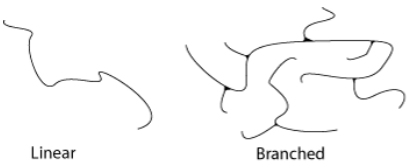


Figure 33 Co-Polymers are similar to alloys

Branching



A linear molecular chain in an amorphous structure will produce a reasonably flexible material. Where a more rigid or firm material is required a catalyst/chemical may be added during polymerisation causing branches to form from each molecular chain. This creates a much firmer material as the different branches mesh together.

Figure 34 Linear and Branched chains

Crystalline Regions

Thermoplastics by their nature have an amorphous structure. These polymers may be modified to include crystalline regions. Crystalline means organised or patterned, this is in contrast to amorphous, random or scattered. Crystalline regions within the structure will give the material more tensile strength in the direction of the aligned chains.

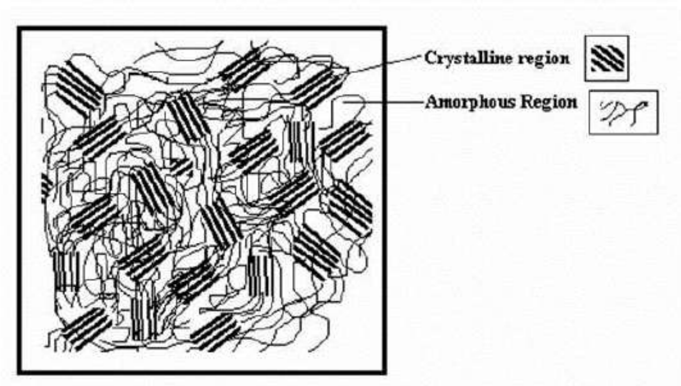


Figure 35 Combining amorphous with crystalline

Thermosetting Polymers (Thermosets)

Thermosets like thermoplastics are fully synthetic. Some common examples of thermosets are Bakelite and epoxy. Thermosets are produced be the process of condensation polymerisation. The name is derived from the process by-product, water or condensation. Unlike the process of addition polymerisation where a single mer is repeatedly joined to identical mers all thermosets will commence with two distinctly different molecules. Figure 37 shows the production of Bakelite (phenol-Formaldehyde), a hard brittle plastic first developed in the early 20th century. The process begins when two molecules of phenol and one molecule of formaldehyde are mixed together. An irreversible chemical reaction takes place. No long chains of polymer are created but a complex crosslinked or networked structure is the result. There is much more primary bonding with even the secondary bonds being replaced by primary bonding crosslinks between adjacent molecules. As no secondary bonding exists thermosets cannot be reheated or remoulded. Their final shape is set during the curing that takes place in the initial moulding process. Thermosets tend to be quite rigid and brittle in comparison to the more flexible (plastic) thermoplastics.

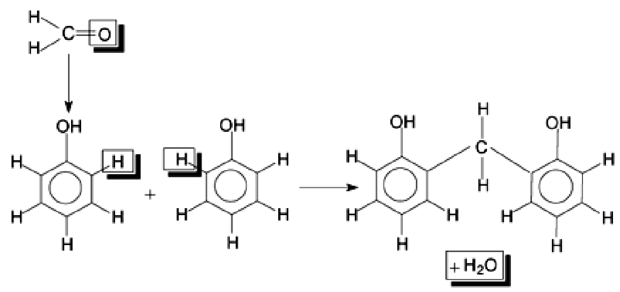


Figure 37 Phenol+Formaldehyde+Formaldehyde=Phenolformaldehyde (Bakelite)+Water (by product)

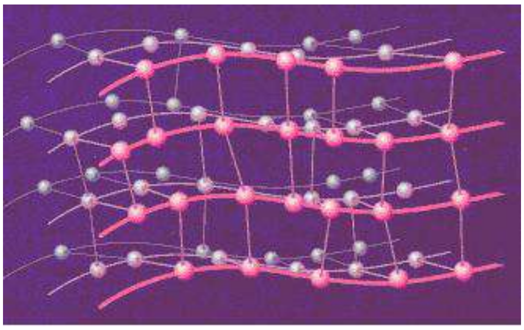


Figure 36 Thermosets have a highly crosslinked structure with all primary bonding

Elastomers

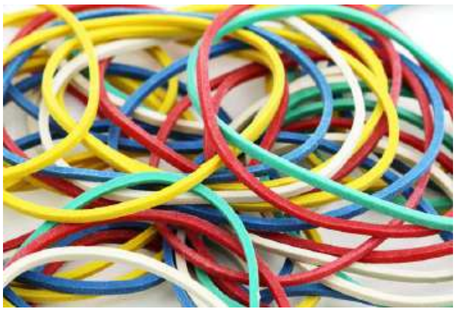


Figure 38 Elastomers always return to shape

Elastomers are a small category of polymers. As they name suggests they include polymers that are highly flexible or elastic. These polymers can be excessively distorted out of shape but will always return to their original form. Although rubber is a natural polymer it may also be thought of as an elastomer. The internal structure is similar to a crossover between a thermoplastic and thermoset. The structure is amorphous with a small amount of crosslinking between elastic chains.

Additives to Polymers

Central to the evolution of polymers is the ability to manipulate these versatile materials to change what they can do and how they look and even how much they cost. The following are added to polymers to change or improve the final product.

Colour Pigments

Quite simply this is a dye put into the manufacturing process to control the colour of the finished product. It is extremely common in the production of acrylic (Perspex).

Fillers

Fillers are non-plastic products that can be added to a polymer for different reasons. Sawdust may be added to increase bulk or volume and bring down the cost where a polymer may be expensive. Glass-Fibre may be used as an ingredient in order to improve the strength properties of a material. This leads into the area of composite materials which has started to boom in recent years. Think of Carbon fibre technology in F1 racing.

Figure 39 F1 cars use a lot of carbon fibre

Plasticisers

Certain additives to polymers will improve the flexibility of the product. A simple example would be the lid of a lunch box which needs to be flexible to aid opening and closing of the product. The word plasticiser comes from the word plastic which again means ‘capable of being moulded’ or being flexible

Stabilisers and antioxidants

Whilst polymers may seem superior to wood as they do not rot or steel as they do not rust, polymers have their own problems. UV or Sunlight can be very harmful to polymers causing them to degrade crack and break. Think of white kitchen goods like a food processor that started out bright white but turns a yellow colour after years sitting on a kitchen counter and may show cracks or become brittle. Stabilisers and antioxidants are chemical additives which attempt to slow down the material degradation process

Flame Retardants

Figure 40 Foam seats on aircraft were once problematic in fire

All polymers have carbon as their main building blocks as does gas, coal, diesel, petrol, and turf all of which are highly flammable meaning that so too are polymers. Certain chemicals added to polymers will inhibit the flammability if a plastic product. This is particularly important as we use more and more plastic items every day. Shoes, jumpers, coats even plastic foam seating used in airlines or some of mix of carpets used in homes.

Lubricants

Polymers are meted to allow them to be shaped usually by pressing them into a mould. When melted polymers tend to be a lot more viscous (thick) than something like water which can be a challenge when moulding the polymer. Lubricants improve the *mouldability* of the polymer.

Vulcanised Rubber

In 1844 after a few years of experimentation with natural rubber *Charles Goodyear* discovered that adding sulphur to natural rubber and allowing it to cure by heating gave a dramatic new material which was far superior to natural rubber. The sulphur had the effect of promoting crosslinking within the material's structure converting rubber from a flimsy elastomer to a true thermoset yet maintaining flexibility. The tough new material was used to make things like wellingtons and coats. John Dunlop later used the new material to develop pneumatic tyres (air filled tyres).

Figure 41 Natural Rubber+Sulphur=Vulcanised Rubber

Disposal of Polymers

The reliance of plastics in everyday day life for simple disposable, throw-away items has lead to issues of concern in the disposal of these materials. As they do not degrade simply like wood and can't easily be re-melted like metals, new and creative means of disposal may need to be explored. There are currently several ways of disposing plastics.

Landfill
Plastics may sometimes be sent to landfill but cause a major problem as they take much longer to degrade when compared to more traditional materials. Many plastics will remain in-tact hundreds and of years after initial disposal

Incineration
A lot of traditional waste in other European countries is burned and used to aid in power production. Burning plastics however causes the release of toxic fumes which can be extremely harmful if not monitored and managed properly.

Recycle
Recycling plastics is more preferable to landfill and incineration. Recycling can be problematic as not all polymers can be remoulded and others that can have a limit the number of times this can happen. Where this is the case sometimes shredding is used creating new modern materials like mats and filler materials used in applications like insulation.

Reduce/Reuse
Reducing/Reusing plastic items is the most environmentally friendly way of dealing with the issue of disposal. Instead of sending away polymers for processing consumers are becoming more conscious of the problems posed and are increasingly finding other uses for plastics. People can now purchase a lot of refill items and more items cut down on packaging by using concentrates. In Ireland the plastic bag levy has had a positive impact in the reduction of waste polythene.

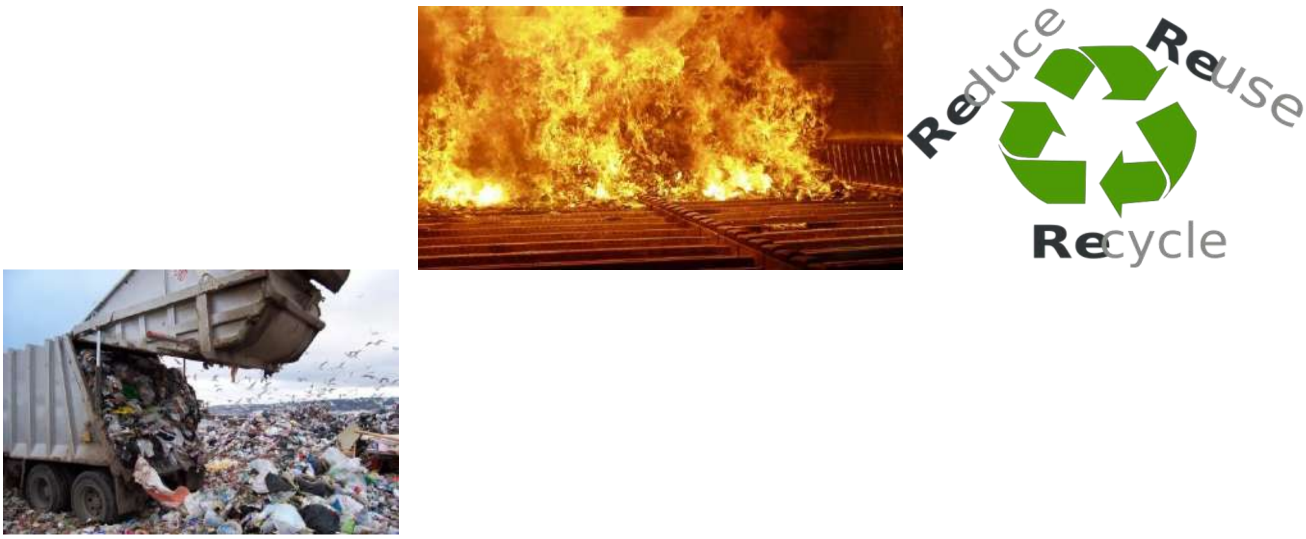


Figure 42 Methods used in the disposal of Plastics

Common Polymers used in Engineering

Figure 43 Common Polymers in use today

Natural Polymers	Thermoplastics	Thermosets	Elastomers
Shellac **Hard shiny polymer from beetle dung.** **Eg. furniture polish**	***Polyethylene PE*** *LDPE,HDPE* Flexible and tough Low density-plastic bags High Density-lunch box	***Bakelite(Phenol-Formaldehyde)*** Hard brittle plastic Eg. Frying pan handles, some plugs and light switches	***Natural Rubber*** Soft and flexible produced from rubber tree sap Eg. Elastic bands
Natural Rubber **Soft and flexible produced from rubber tree sap** **Eg. Elastic bands**	***Polypropylene PP*** Tough, Hard wearing Eg. Blue rope, Chairs	***Vulcanised Rubber*** Natural Rubber+Sulpher promotes more crosslinking. Very tough, wear resistant. Eg. Car Tyres	***Silicone*** **S**oft, flexible and waterproof. Can be used as a sealant Eg, Bathroom sealant
Amber ***Hard and translucent fossilised material e.g. Jewellery***	***Polytetraflourethylene PTFE (Teflon)*** Heat resistant, Non stick Eg. non-stick frying pans surface	***Polyester*** *May also be a thermoplastic.Hardwearing, tough* *Eg. Plastic gears, brush bristles*	
	Polymethylmetacrylate PMMA (Acrylic/Perspex) Versatile, corrosion resistant, tough,inexpensive Eg. Shop Signs	***Epoxy*** Hard and brittle Used in adhesives/glue where a resin and hardener are mixed	
	Polyvinvlchloride PVC Versatile, inexpensive, easily worked, tough Eg. Window frames, plumbing, cable trunking		
	Polystyrene PS Tough, flexible, versatile. Foaming agent may be added Eg, packaging, foam cups, insulation		

Manufacturing with Plastics

Looking around you will see how widely plastics are used. A massive variety of shapes and forms are possible. To achieve this we a variety of manufacturing processes. These include;

1. **Calendering**
2. **Compression Moulding**
3. **Transfer Moulding**
4. **Blow moulding**
5. **Vacuum Forming**
6. **Extrusion Moulding**
7. **Injection Moulding**

Calendering

Calendering is used in the production of large flat thermoplastic sheets or rubber mats. A billet of heated softened polymer (sometimes granulated polymer is used instead) is fed through a series of heated rollers. The rollers flatten the polymer making it gradually thinner as it passes through the manufacturing process. The flattened sheet is either stored on a roll or fed onto a conveyor belt where it can be cut to length.

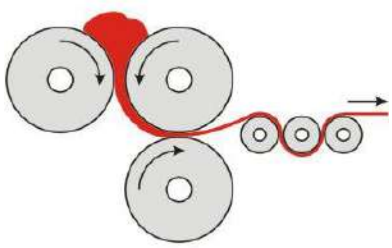


Figure 44 Calendaring is used to make flat sheets and rubber mats

Compression Moulding

Compression moulding is widely used in the moulding of rubber products and as part of the car tyre manufacturing process. The process is mostly suited to Thermosets. A measured quantity of polymer billet, the charge, is placed inside an open heated mould. The process is simple where the mould is forced close, usually with the aid of hydraulics, whilst the polymer fills the mould cavity. The mould remains closed whilst the polymer is allowed to cure. The mould then opens and ejector pins or manual labour may be used to help in the removal of the product

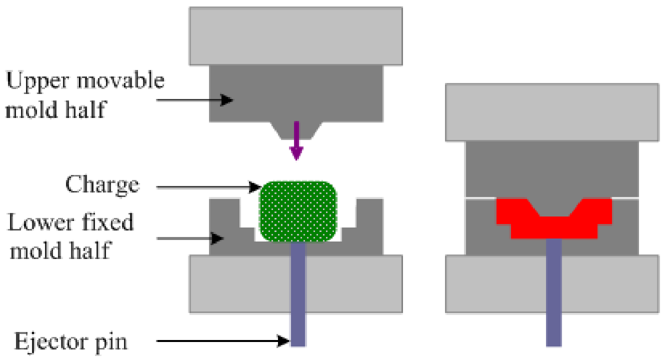


Figure 45 Car Tyres and other rubber products are manufactured using compression moulding

Transfer Moulding

Transfer moulding is increasingly being replaced by injection moulding (see further down). It is mostly used with thermosets where complex shapes are required. It is similar to the compression moulding process but has the advantage that it is not vital to measure the charge of polymer billet, the system allows for excess polymer. Polymer is placed in the transfer port. A plunger is then used to force the polymer into the closed mould through the narrow opening at the sprue. The polymer is allowed to set. The mould is then opened and the product can then be removed. Transfer moulding can be used to aid the manufacture bushings and bearing units that comprise of plastics with a metal core. The metal core or base can be placed inside the mould cavity before the polymer is injected.

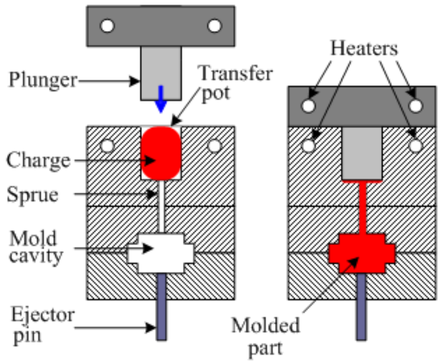


Figure 46 Transfer moulding is used for hard plastics

Blow Moulding

Blow moulding is exclusively uses thermoplastics. The process is used to make containers that can usually hold liquids like soft drinks, milk cartons and household detergents. A split mould is open and a parison is introduced. A parison is a heated hollow tube of thermoplastic polymer. The split mould closes around the parison, pinching the top closed in the process. Air is blown into the parison from the open end (if a parison is not used a *preform* is used, as in the video clip). The plastic expands like a balloon to meet the mould walls where it cools and hardens. The mould opens and the product is removed.

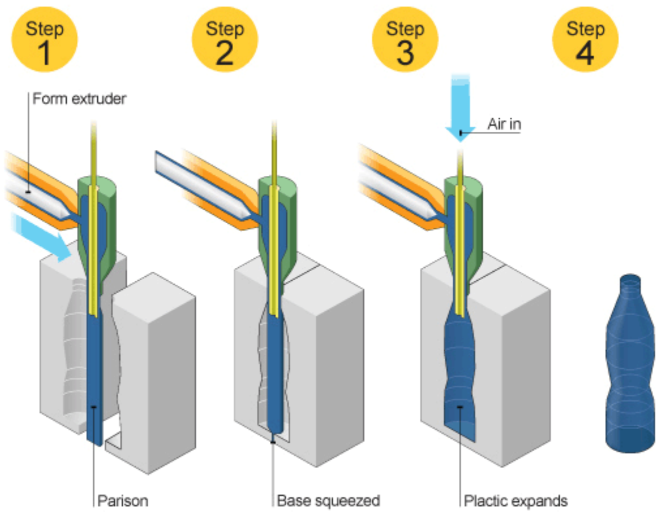


Figure 47 Blow moulding is used to make plastic bottles

Vacuum Forming

Vacuum forming is used where large flat sheets of thermoplastic need to be formed into complex shapes. It can be used in the manufacture of bathtubs, Jacuzzi tubs, model making and moulded shop signs. A flat sheet of thermoplastic is pre-heated to may it pliable. The sheet is placed over a mould and sealed at the edges with a clamp. The mould is drilled with a series of small holes to allow air to be sucked out from underneath. A vacuum pump is turned on and the air remaining between the polymer sheet and the mould is removed leaving a vacuum (nothingness). Atmospheric pressure (the weight of air) forces the plastic firmly against the mould. The clamp is released and the plastic is carefully pulled from the mould. Talc or other powders are sometimes used to prevent the plastic sticking to the mould.

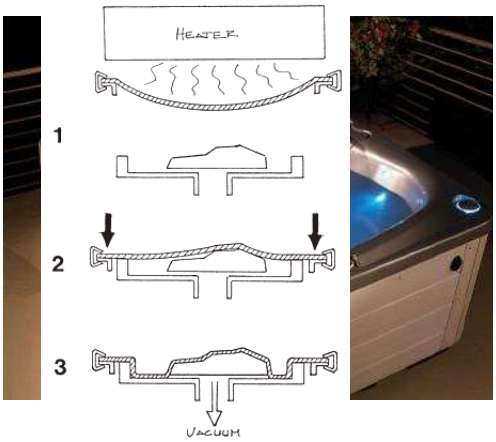


Figure 48 Vacuum Forming can be used when moulding intricate forms

Extrusion Moulding

Extrusion moulding is used in the manufacture of polymers of continuous length with uniform cross section i.e. round, square, and hex bars, window frames and garden hose. It is most suitable for thermoplastics. The polymer is fed from the hopper into the barrel. Here the screw mixes the pellets of polymer ad forces them along the length of the barrel. Heaters attached to the barrel, along with the friction created by the action of the help to melt the polymer. The *Melt* is then pushed, under pressure from the screw, through the die at the end of the machine. The die used determines the shape of the product produced. Extrusion is a continuous operations process with the product being cut to required lengths as it cools after exiting the die.

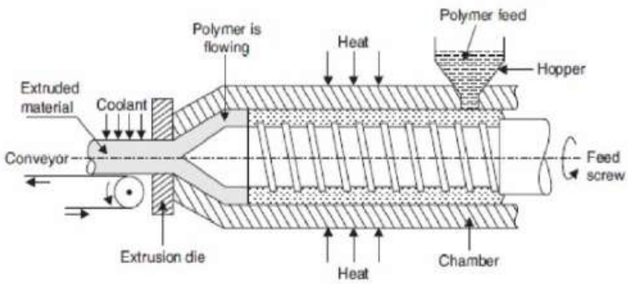


Figure 49 Extrusion moulding process with sample products right

Injection Moulding

Injection moulding is the most widely used plastics manufacturing process today. It is most suited to thermoplastics but more advanced systems can use a double barrel system to cater for thermosets. Most items we come across every day has probably been injection moulded. Pens, rulers, phone covers, keyboards, lunch boxes are a tiny example of the machines products. The process is similar to extrusion with the main difference being the removal of the extrusion die in favour of a cavity mould to aid in the production of finite (fixed shape) product. Polymer pellets are fed at the hopper into the barrel. The screw mixes the polymer and with the aid of heaters that are attached to the barrel the polymer is melted. The mould must be in the closed position before the entire screw is pushed forward inside the barrel by a hydraulic ram. This injects a fixed quantity of polymer into the mould. The screw is retracted whilst the mould remains closed for a few seconds to allow the product to set. The mould is opened and ejector pins help to remove the product. The process is highly automated and is merely supervised by manual labour.

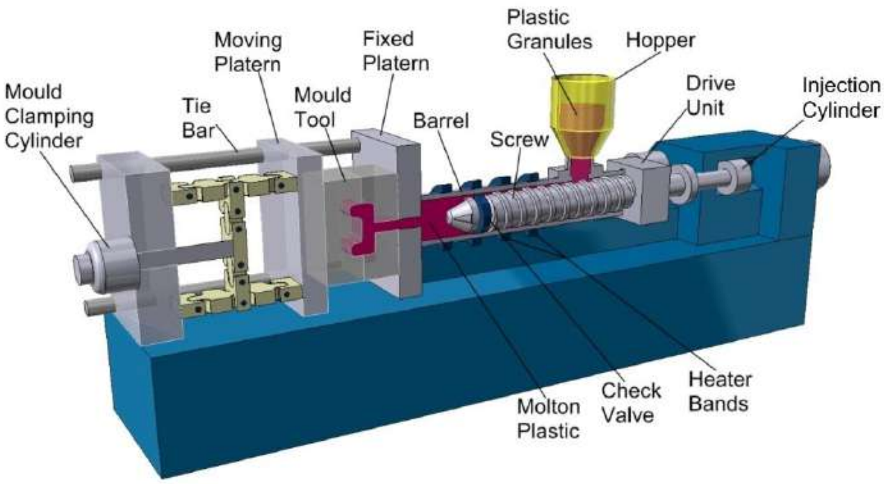


Figure 50 Injection moulding is used in the manufacture of countless plastic products. Chairs, toys, pens, rulers, keyboards ......

Welding

Fusion Joining of Metals

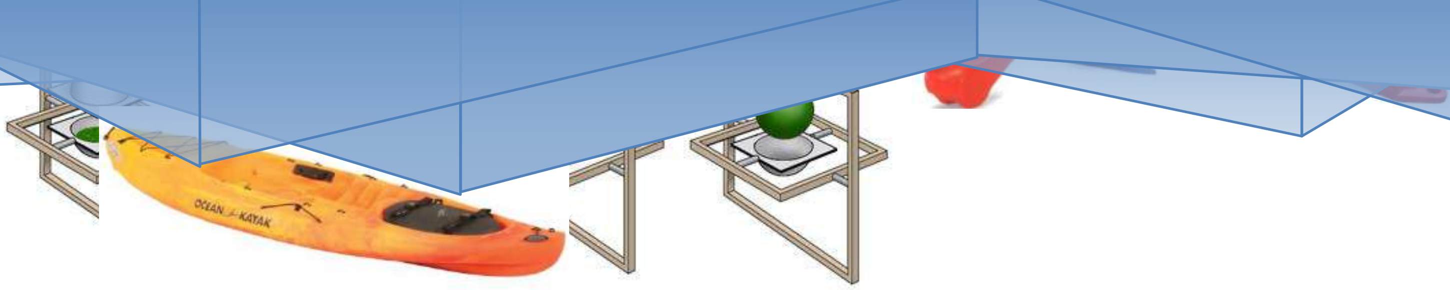


Figure 51 Rotational moulding is used to produce hollow shell-like plastic products

Contents

Introduction

Welding is a permanent metal joining process. Unlike mechanical joining processes (nuts, bolts, screws) which can easily be undone the welding process is not reversible. Welding is a fusion joining process where both parent metals are melted, usually along with filler metal too, these metals then fuse together creating one new component which cannot be parted without a cutting action. The main requirement for any welding process is a suitable heat source which may come in the form of a flame, electric arc or electrical resistance

Categories of Welding

5. Gas Welding
6. Electric Arc Welding
7. Electric Resistance Welding

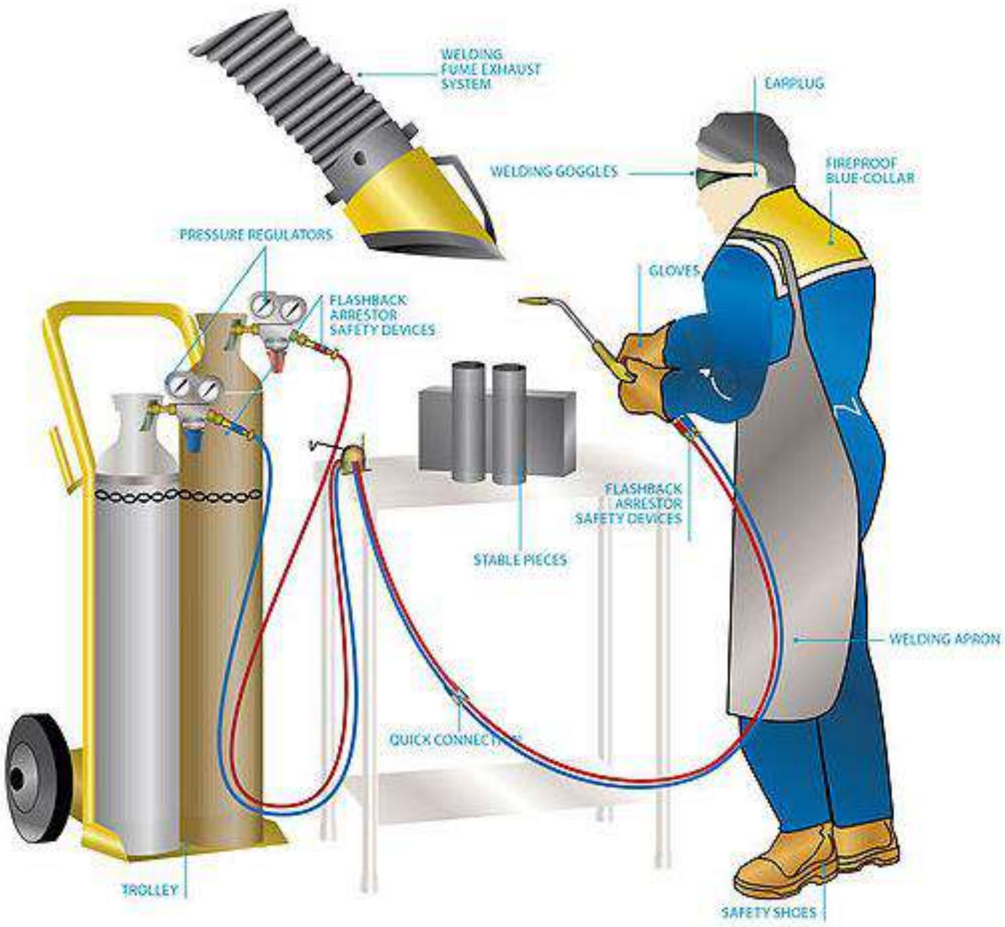
Gas Welding

There are a few types of welding available using gas power. Butane and propane can be used alone for low heat applications but the most common type of gas welding is oxy –acetylene welding.

Oxy-Acetylene Welding

Overview

Gas welding involves the use of a flammable gas being mixed with air or better still pure oxygen. The gas mixture is ignited at the welding torch where a flame is created. This flame must be sufficient to give enough heat to melt the parent metal component. Oxy-Acetylene welding is the most widely used gas welding process used around the world today.



Equipment

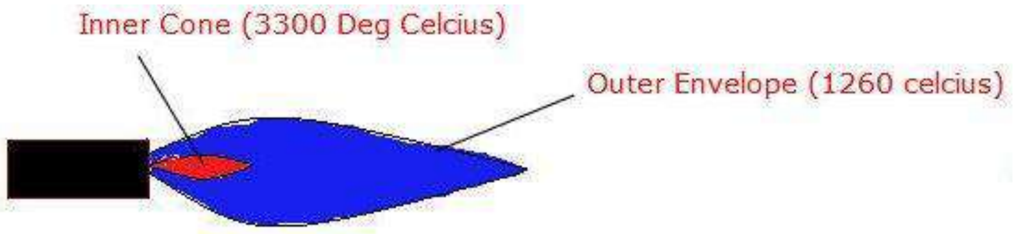
- Oxygen gas bottle
- Acetylene gas bottle
- Hoses
- Torch
- Regulators
- Flash back arrestors
- Filler rod

Process

Acetylene and Oxygen, controlled by the pressure regulators (these are like taps) travel from the gas bottles through the hoses to the welding torch where the operator can further adjust the gas mixture to give a flame suitable for the particular type of welding. The work components are heated to allow the metal to melt at the joining area. A filler rod (the same material as the parent metal) is usually used to aid the joining of the two metals. Different types of work will require different flame types;

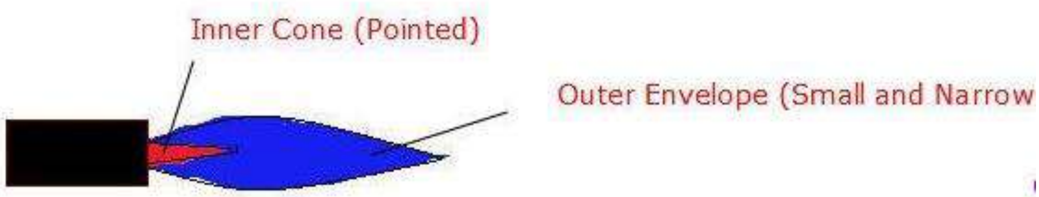
Neutral Flame

Used for general welding of mild steel. This flame is an efficient balance of oxygen and acetylene. It is recognised by its blue colour and well defined inner cone. The hottest part of the flame is at the tip of the inner cone.



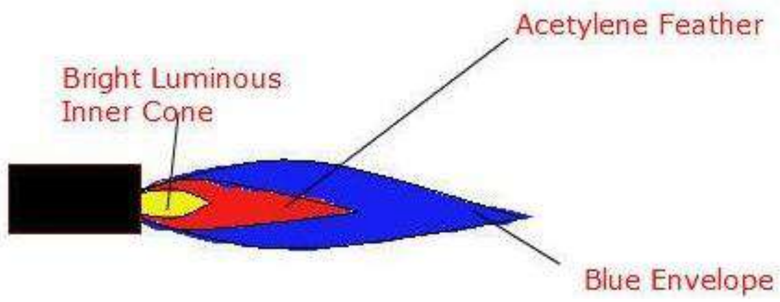
Oxidising Flame

Used for specialised welding of copper, bronze and brass. This flame created where there is a deliberate excess supply of oxygen. It is recognised by its blue to bright white colour, its pointed shape and sometimes a hissing sound.



Carburising Flame

Used for specialised welding of Aluminium or Stainless steel. This flame created where there is a deliberate excess supply of acetylene. It is recognised by its dirty orange colour in the form of what is known as an acetylene feather



Safety Aspects

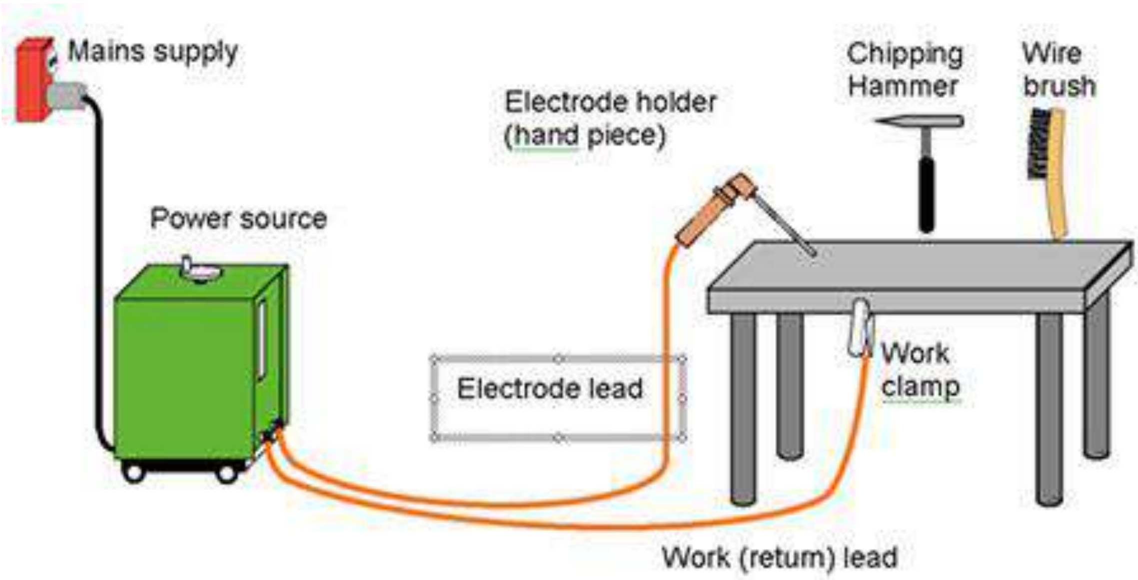
- Colour Coding for equipment hoses/regulators (Oxygen Blue, Acetylene Red)
- Flash Back Arrestors (Valve that prevents flame travelling back through hoses to the gas bottle)
- PPE (Personal Protective Equipment, Boots, Apron, Welding Goggles)
- Well ventilated Area
- Dissolved Acetylene (Acetylene is very volatile by itself so acetone liquid is stored in the gas bottle. The acetone absorbs the acetylene making it much less volatile)
- Screwthreads (Regulators and arrestors have srewthreads. Right hand threads are used for oxygen attachments and left hand threads for acetylene attachments. This prevents accidentally mixing up the welding equipment components)

DISSOLVED ACETYLENE : If acetylene is compressed into a cylinder, it would explode under high pressure. Acetylene cylinders are packed with a porous material that is filled with acetone, this can absorb 25 times its own volume of acetylene.

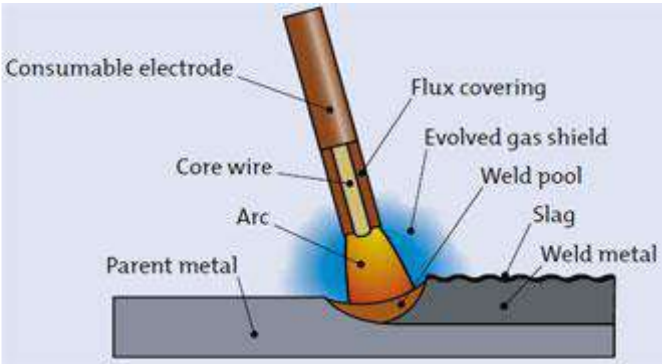
Electric Arc Welding

Electric arc welding utilises the principle of electricity being able to jump over a small gap. When this happens a spark occurs which produces enough heat to melt steel. We call this an electric arc. There are several types of electric arc welding ranging from manual to fully automatic.

Manual Metal Arc M.M.A



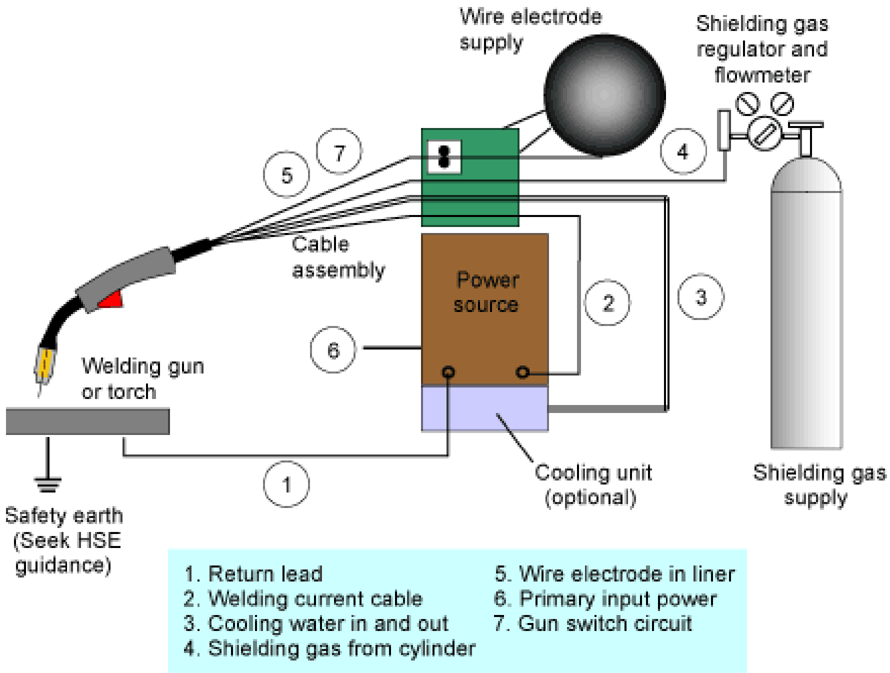
Manual Metal Arc welding is the most basic and common type of electric arc welding. Electric power is provided by a transformer which is connected to a mains electrical power outlet. The transformer reduces the standard 240V to a safer working voltage of approximately 80-100V. An electrode lead allows current to travel to the welding electrode. The electrode is quite simply a metal rod with a chemical powder coating called flux. An electric arc is created between the tip of the electrode and the workpiece. The heat caused by this arc is sufficient to melt the work material and the electrode. As the electrode is *consumed* the flux coating vaporises and creates a protective gas shield around the weld pool. This shield is required to prevent atmospheric contamination and porosity (air bubbles) inside the weld. This gas shield eventually solidifies again and creates a coating over the weld called *slag.* The slag has the advantage of allowing the weld to cool slowly and prevent it becoming brittle. The slag must be chipped away afterwards though using a chipping hammer. The operator moves the electrode in the direction where the weld is required. The ground clamp and return lead are required to complete the electrical circuit without which there would be no electric current flow. The process is a skilled manual operation that is very suitable for the welding of mild steel plate. Applications can include forge and garage work.



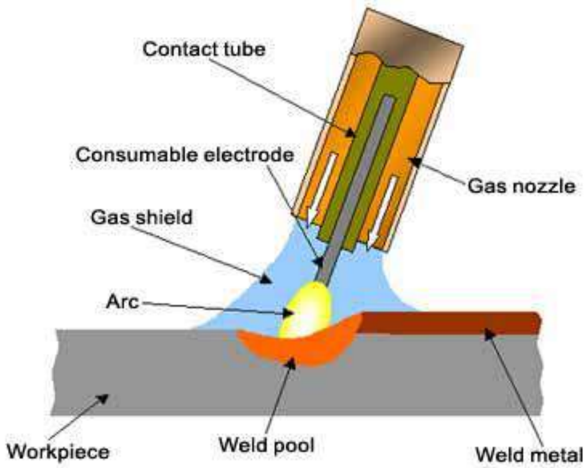
Safety features that minimise MMA welding electrical hazards:

MMA welding machines are protected from electrical surges.
Welding stations need to be free from dampness.
Cables and electrode holders are covered with plastic insulators.
Welding machines are earthed.
Power supplied can be adjusted to an appropriate level

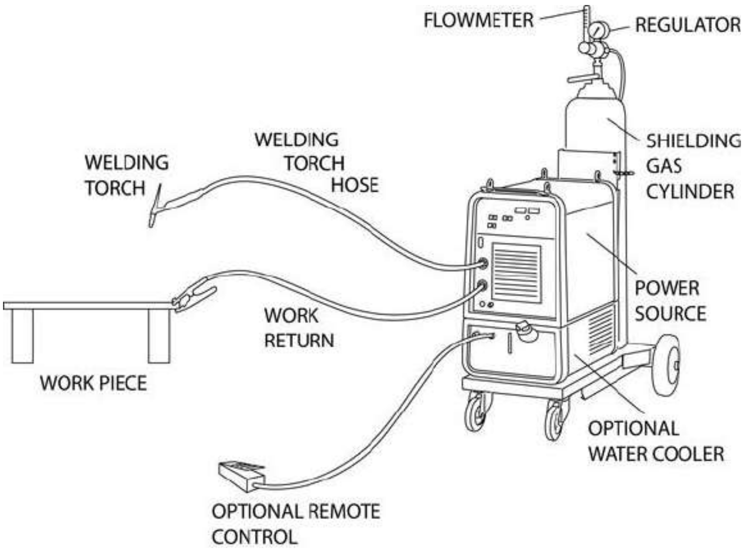
Metal Inerth Gas welding M.I.G



Metal Inerth Gas welding can be described as a semi-automatic welding process. The basic principle of welding using an electric arc is similar to that of MMA. Here we start with a direct current (DC) power supply as this makes welding easier. As in MMA the welding rod is consumed but to make the process quicker and easier this rod is on a round reel where a motor and trigger on the gun control its feed to the weld pool. The welding electrode has no flux coating. The weld pool is protected from atmospheric contamination by a gas shield which is provided through the welding gun from a gas bottle, usually CO_2 or Aragon as these are non reactive gases. The process is ideal for working on mild steel and has the advantage that it can be used for lighter applications like car panel assembly where MMA would tend to burn holes in the lighter gauge materials.



Tungsten Inerth Gas welding T.I.G

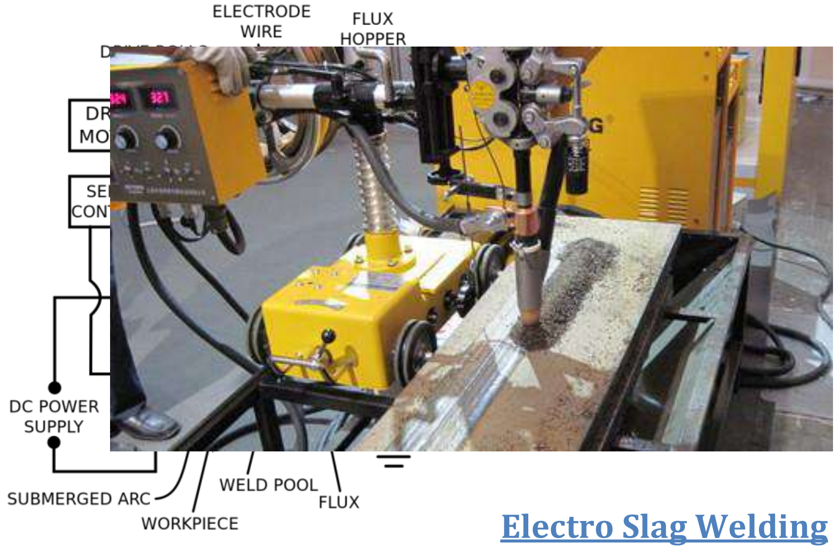


Tungsten Inerth gas welding is a specialised type of welding that is used for metal with hard outer oxide layers like Aluminium and Stainless Steel. These metals are normally incredibly difficult to weld as their oxide layers prevent full penetration of the weld pool between the parent metals being welded. Here an Alternating Current (AC) is used as this has a peeling and breaking effect on the oxide layer thus allowing the weld pool to form fully. The electrode used in this process is made from tungsten which has a very high resistance to heat and is therefore not consumed. A filler rod which is normally an off-cut of the metal being welded is used. As in MIG a gas bottle provides for a shield that protects the weld pool from atmospheric contamination. This is a very skilled and timely process. It is used for welding of Aluminium bicycle frames and car exhaust tailpipes.

Aluminium oxidises very quickly when heated. This tenacious oxide layer is overcome with the use of an inert gas, such as argon, and the cathodic action of the arc on the work-piece. Aluminium can be welded successfully in this way by TIG welding.

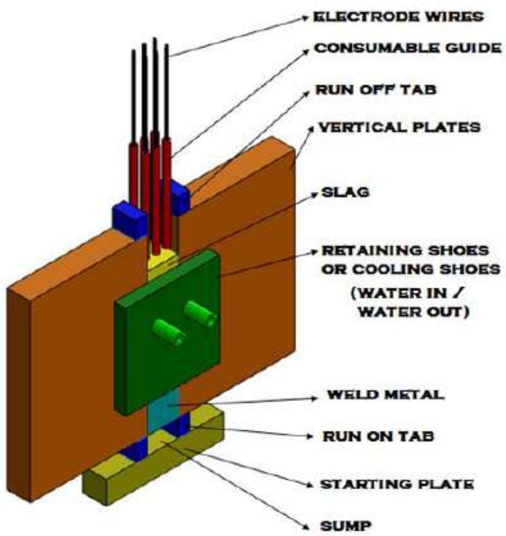
Submerged Arc Welding S.A.W

Submerged arc welding is a fully automated process. It is similar in nature to MIG welding but the operator is replaced using an automatically driven trolley. The electric arc is created at the tip of the electrode wire which is automatically fed from a spool. Granulated flux (grains of flux) is fed to the weld area from a hopper where it *submerges* the weld pool. The entire welding unit is usually mounted on a trolley which is motor driven along the length of the work being welded. SAW is widely used in water boiler tank construction as well as the manufacture of structural steel beams.



Electro Slag Welding

Electro Slag welding is a fully automated welding process. This is used for heavy duty welding of thick steel plate. It is similar to MIG welding with the main difference being that the weld pool is enclosed to prevent spill off and multiple electrodes are used due to the heavy nature of the plates being joined. Te plates being welded are deliberately separated and a cavity area is created using copper shoes to the sides and a starting plate at the bottom. This cavity is then basically filled with molten steel. Multiple consumable electrodes, running through guide tubes, provide the filler for the weld whilst also producing enough heat to melt some of the parent metals, this allows for full fusion welding. To assist the welding process and prevent atmospheric contamination a molten slag pool is created, this pool effectively floats on top of the molten steel and rises up as the weld is being created. The copper shoes (sometimes water-cooled to prevent melting) enclose the entire weld keeping the finished joint neat. The welding process is used in the ship building industry. It is limited however in that it can only be carried out in a vertical direction.



Resistance Welding

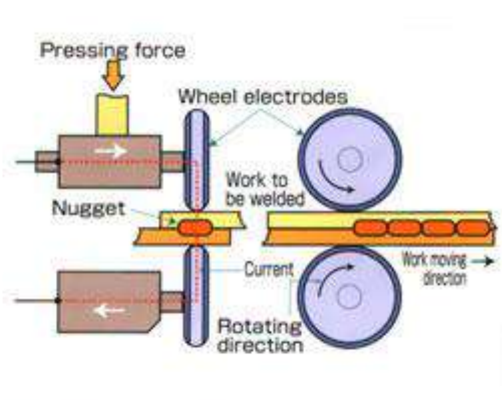
This is not to be confused with electric arc welding. Resistance welding is based on the principle where there is a build up of heat where resistance to the flow of electricity is encountered. The two main types widely used are spot and seam welding

Resistance Spot Welding

With spot welding a power supply is connected to two copper electrodes. Two pieces of light gauge steel are pressed together by the electrodes. The power is engaged, usually by a foot switch. Electricity is conducted easily through the copper electrodes but resistance to current is met by the steel pieces. There is a build up of heat at this location (spot) which is sufficient to melt both pieces of the parent metal and they fuse together due to the *spot weld.* The process is incredibly simple and has no requirement for flux, arcs or filler materials/rods. Spot welding be used in the automotive industry for joining steel body panels and light brackets.

Resistance Seam Welding

Very similar in nature to spot welding, seam welding is used to produce continuous welds or *seams.* Here the normal straight electrodes found in spot welding are replaced by copper wheel electrodes. The weld is still created in the same manner but the machine is set to give out pulsing (on/off/on/off...) current. This creates a series of overlapping spot welds which eventually yields what appears as one continuous seam. The process can be used in the production of steel tins, cans or drums for holding everything and anything from biscuits to olive oil.

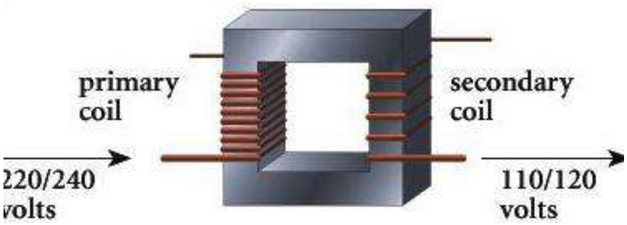


Power Control

All the welding units discussed above require an electrical power source. Mains electricity which is commonly supplied as 230 Volts, Alternating Current. This voltage is dangerous to work with for most welding applications and also has the disadvantage that due to the high voltage the current is low. Higher current is required when welding, especially as the materials being joined become thicker. To solve the problem we use step down transformers and/or rectifiers to supply a more suitable type of electricity.

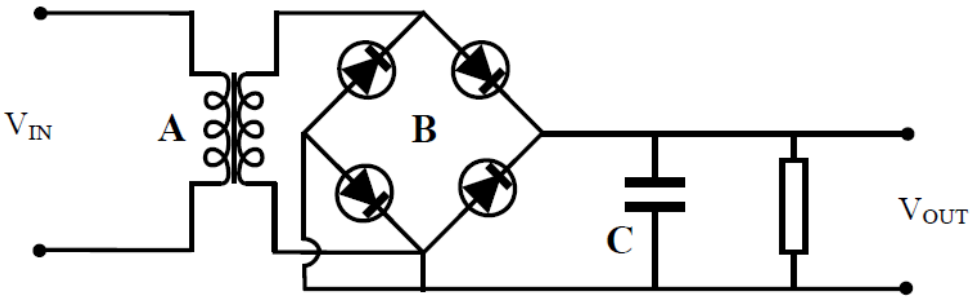
Transformers

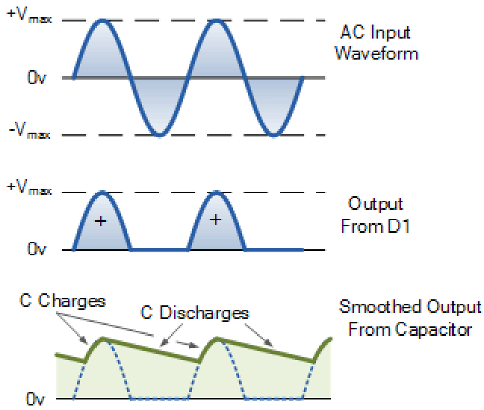
A simple transformer consists of two coils of insulated wire wrapped around an iron core. 230V AC flows through the primary coil and this creates a magnetic field around that coil. The secondary coil works in reverse. The magnetic field from the primary coil induces an electric current in the secondary coil. If the number of windings in the secondary coil are less than that in the primary coil the transformer can be described as step down (lower voltage and higher current)



DC Rectifier

Following on from the transformer it is sometimes also required to have a supply of Direct Current (DC) for some applications like MIG welding. In this case we use a full wave rectifier. The rectifier consists of three main areas. The first step (A in Diagram) involves using a step down transformer to reduce the high AC voltage and increase the current. The next step (B in Diagram) uses diodes (an electronic component that only allows electricity to flow in one direction). The diodes are wired in a ring. This eliminates the negative part of the AC cycle and creates DC. This DC however is not suitable for use as it is not very steady. It fluctuates with peaks and troughs. The capacitor (C in Diagram) is used in the final step to store electrical charge during the peaks and release the charge during the troughs. This gives a steady reliable supply of Direct Current





Iron Carbon Diagrams

Understanding Steel

Contents

What is Steel

Steel is the most important and widely used metal in the modern world of engineering. It is an alloy which is created by combining iron with carbon. At a simple level iron is a very soft and ductile material whilst carbon is an extremely hard and brittle material. By combining these contrast properties a variety of new steel based materials can be created. Sometimes a soft ductile steel is required for something like a car door panel, add a little more carbon and a tougher material is created which may be used for something like a railway track, yet more carbon will give a hard steel which can be used for tools like a scriber and more carbon again will create very hard cast irons for things like bench vices. The amount of carbon required for this is quite small, usually no more than 3%. To give even more variety to this versatile material engineers have developed heat treatments than can drastically change the materials properties to make it harder, softer or tougher. Understanding the properties of steel requires understanding the material at an atomic and crystal level.

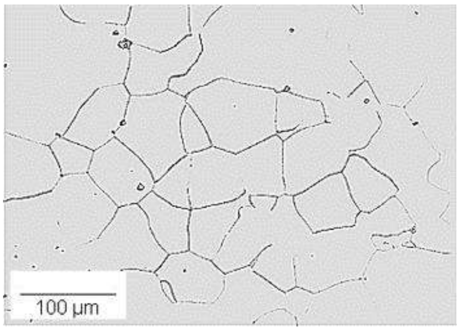



Understanding the Iron Carbon Diagram

Parts of the iron carbon diagram

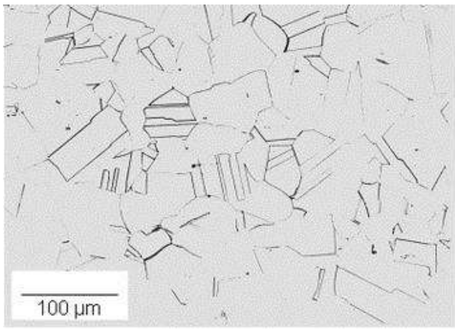
The Iron-Carbon diagram (coming later) has many areas and at first seems very confusing. Whilst molten liquid is simply molten liquid and nothing else, solid steel may exist in many forms and combinations depending on the composition of carbon in the alloy. Looking more closely though there are in reality only four things that can be found (ferrite, austenite, cementite and pearlite). Understanding the properties of each of these is the key to understanding the seemingly complex Graph.

Ferrite



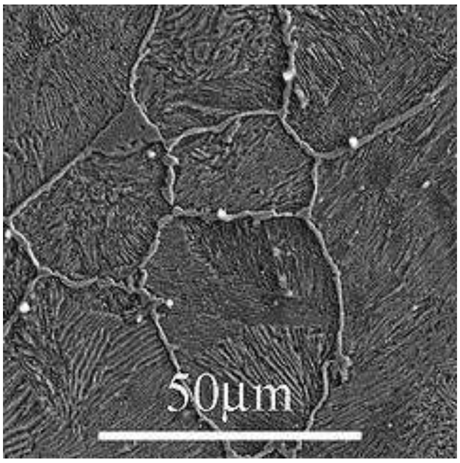
Ferrite can be thought of as an *iron-rich* material with carbon dissolved within the grain structure. Think of a cup of tea with a spoon of sugar stirred in, the sugar will dissolve within the tea leaving a new solution where the sugar cannot be distinguished from the tea. Of course there is a limit to how much carbon the ferrite can hold (as there is to how may spoons of sugar could be dissolved in the tea). When this limit is reached a new material of pearlite is formed (see below). Ferrite has a BCC (Body Centred Cubic) structure and occurs below temperatures of 910°C. Due to the small concentration of carbon ferrite is a soft and ductile material by itself.

Austenite



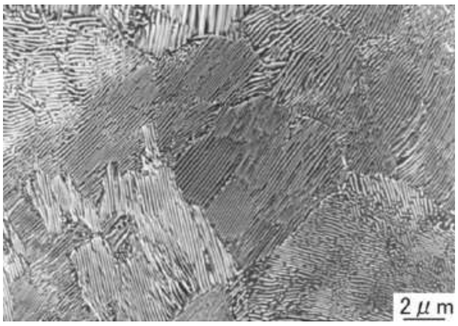
Austenite is incredibly similar to ferrite. Again it is an iron rich material with carbon dissolved within the grains. The difference lies in the lattice structure at an atomic level. Austenite has a FCC (Face Centred Cubic) structure. Austenite only occurs at elevated temperatures 910°C+. Due to the elevated temperature Austenite can hold more carbon within its grain structure but is still a relatively soft and ductile material.

Cementite

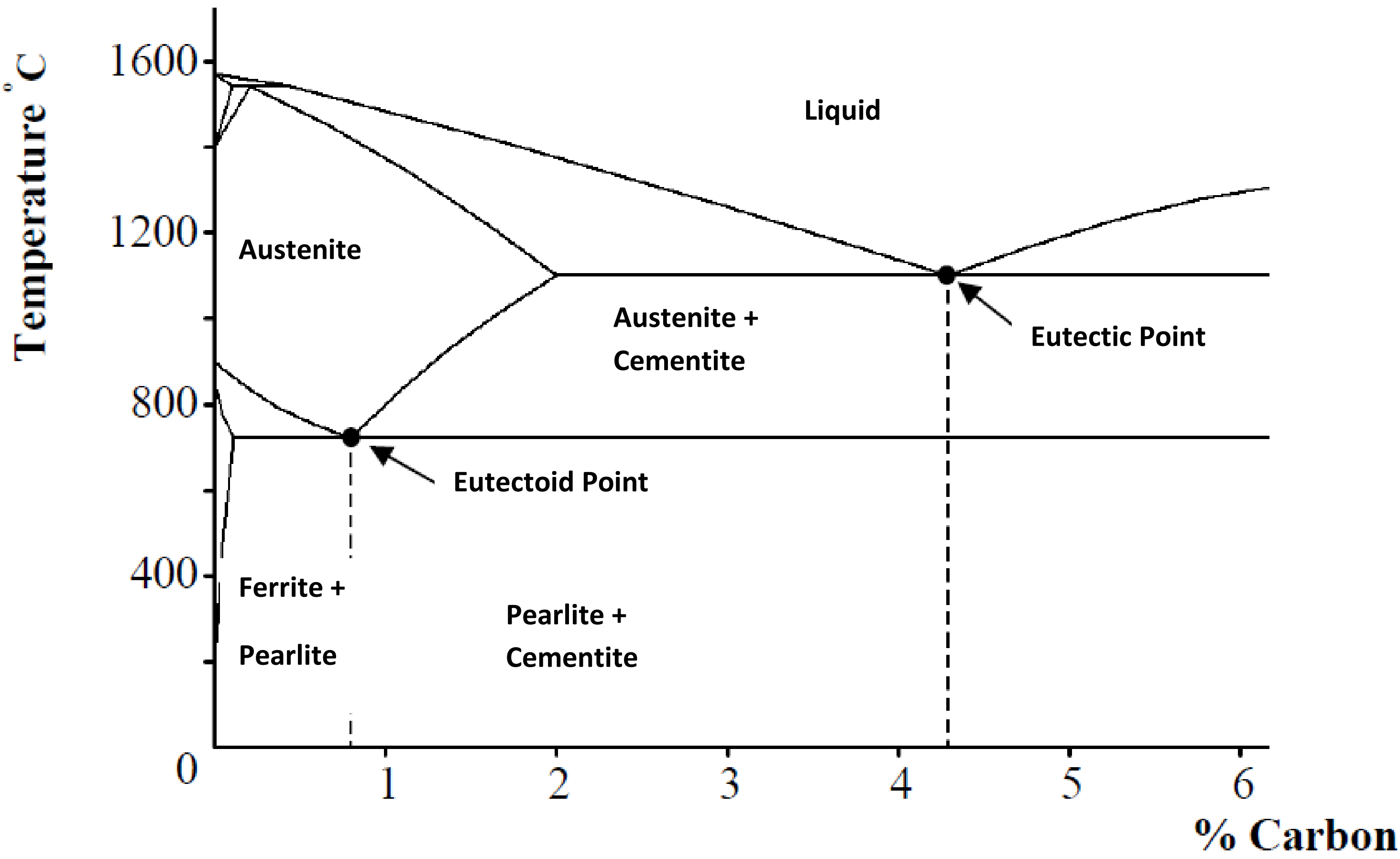


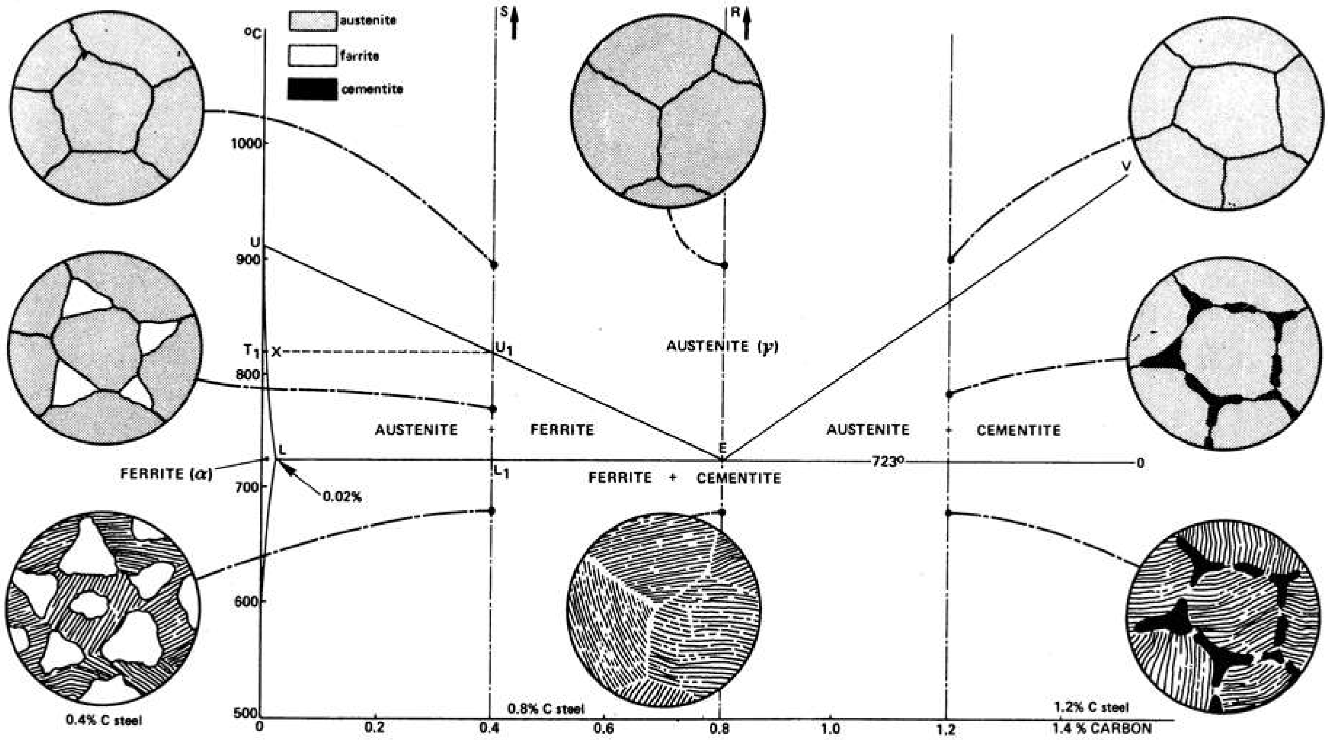
Whilst Ferrite and Austenite are both iron rich, Cementite is the exact opposite. Cementite can thought of as *carbon-rich* with Iron dissolved within its grain structure. Consider a droplet of tea being put on a sugar cube. The sugar cube will absorb the tea into its structure; cementite is doing a similar thing only with carbon and iron. Due to the high concentration of carbon, cementite is an incredibly hard and brittle material. By itself it is of little to no use in any engineering application as it is too hard and brittle.

Pearlite



Pearlite is a strange phenomenon that occurs to some steels as they cool. It is a mixture of layers of ferrite and cementite within the material granular structure; this can be clearly seen in the micrograph. Here the soft/ductile properties of ferrite are mixed with the hard/brittle properties of cementite. This yields a material with properties of significant toughness.


Temperature °C
1600
1200
800
400
0
Liquid
Austenite
Austenite +
Cementite
Eutectic Point
Eutectoid Point
Ferrite +
Pearlite
Pearlite +
Cementite
1
2
3
4
5
6
% Carbon



Heat Treatments

Picture shows heat treating at 980C

Following an understanding of Iron Carbon diagram, Materials Scientists have become capable of manipulating the properties of steel to suit a variety of applications. This is done by controlling the heating and cooling rates of steel components to soften, toughen or harden the material. These treatments include include;

- Annealing
- Normalising
- Stress Relieving
- Hardening
- Tempering

Annealing

Annealing is used to make a material softer. The simple process involves heating the component in an oven to approximately 2/3 of its melting temperature where the material is allowed to *soak* (spreading the heat evenly through the component). The oven is then turned off and the component is left inside to cool extremely slowly. During the process *Recrystalisation* occurs. Recrystalisation is the formation of a new grain structure. The new grains start off quite small and due to the extremely slow cooling rate they have time to blend into each other and grow. A large unstressed grain structure is the result. This gives a soft ductile material which is easy to work with especially if the material requires further cold working (bending, hammering, twisting, stretching etc.) .

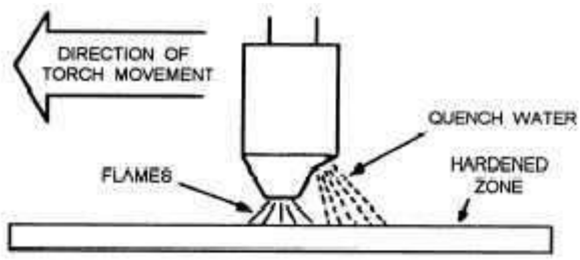
Normalising

This is used to create a tough material (or a *normal* material – not too soft, not too hard). The process of normalising is very similar to that of annealing. Again the material is heated to approximately 2/3 of its melting point and allowed to soak. However the material is then removed from the oven to allow it to cool at a slightly quicker rate than that for annealing. Again, recrystalisation occurs but the grains do not grow large due the shorter cooling time. The result is a tough material with a small grain structure.

Stress Relieving

Sometimes known as half annealing, stress relieving is used to remove internal stresses from a material that has been caused by cold working. The material is heated to a relatively low temperature (approx.300-400°C) and allowed to soak. Upon cooling there is no recrystalisation. Instead the stressed grains are merely reshaped and the material becomes more relaxed where the potential for crack formation has been reduced.

Hardening



Quench Method

It's the addition of carbon to iron that gives a degree of hardness to steel. Heating up steel to a very high temperature and cooling it rapidly in something like water can strangely further harden the steel. For this to work there MUST already be a significant degree of carbon already present. The process works by heating the material until austenite is formed (see previous Iron-Carbon Diagram). The material is not allowed to cool slowly. A quench media of water, oil or brine (salty water-like in a tin of tuna!) is used to rapidly cool the material. Due to the rapid cooling the carbon does not have time to come out of the austenite solution. The result is an austenite grain structure with a strange graphite needle structure seen within. This material is incredibly hard, so much so that it is too brittle for most engineering applications. To remove some of the martensite the material may be tempered (see below)

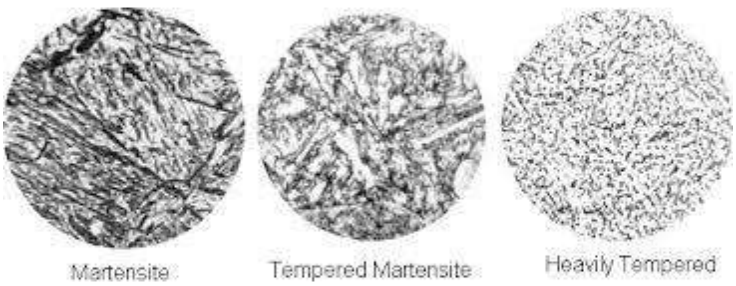
Case Hardening Method

Where steel needs to be hardened but the carbon content is quite low, less than 2%, it may be case hardened. Here more carbon is introduced to the skin of the material where heat helps the steel to absorb some of the carbon into its outer surfaces. The result is a material with a tough inner core where the carbon content is low and a hard outer surface where the carbon content is high (ideal for a gear inside a machine gearbox – hard wearing and tough at the same time). There are alternative methods of case hardening;

1. Pack Method. Graphite powder is packed around the component which is then placed in an oven where it is heated to allow the component to absorb some of the carbon.
2. Salt Bath Method. A liquid solution rich is carbon is mixed and heated with the component placed in the solution.
3. Carburising Method. An Oxy Acetylene torch is used to create a carburising flame (a dirty carbon rich flame). This heats and blackens the component with what is effectively carbon rich soot. Some of this carbon is absorbed into the outer surface of the material.

As with the quench method of hardening it is sometimes required that some of the brittleness associated with hardening is removed by tempering (see next)

Tempering

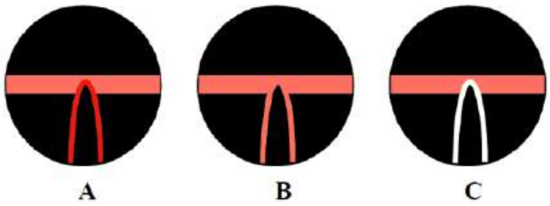


Tempered steel is similar in definition to that of tempered glass, a hard material yet still tough enough to withstand a reasonable degree of impact. Tempering is carried out following a hardening process. Here the material is heated up to a relatively low temperature (approx.300-400°C) and is then allowed to cool slowly. Some of the martensite that has formed earlier is able to transform to ferrite or pearlite. Screwdriver tips are typically hardened but must then also be tempered to give a hard and tough tip that will neither break nor bend.

Pyrometers

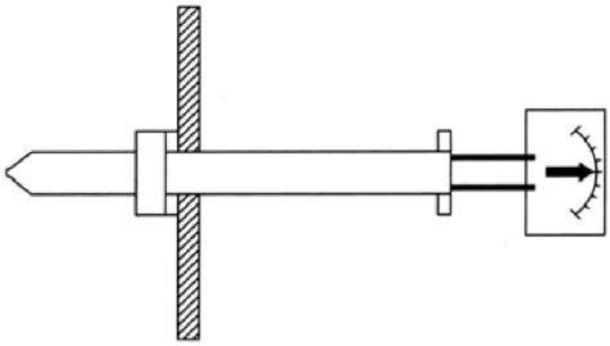
Optical Pyrometer

This device is used to measure the temperature inside a furnace. It is based on the principle of light intensity where the hotter an object becomes the brighter the light it will give off. The furnace contains a window through which to user can see in. A hand held device is used which contains a small bulb. The operator adjusts the brightness of the bulb in the handheld device by increasing or decreasing the electric current via a potentiometer (variable resistor similar to the volume control on a stereo) until the brightness of the bulb matches the brightness of the furnace light. When this happens the user should only be able to see one level of brightness (ie. The filament of the bulb will appear to strangely vanish). The electric current used to light the bulb then relates to the temperature of the furnace, ie. More current mean a hotter furnace. In the diagram the correct furnace temperature can be read at 'B' as the intensity of the curved bulb filament matches that of the light coming through the slit of the furnace window. In 'A' the bulb is set too bright whilst in 'C' the bulb is set too dim to give accurate readings.



Thermocouple Pyrometer

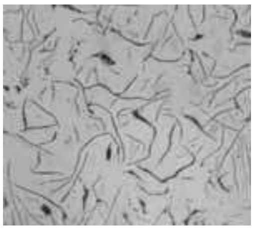
This device is also used to measure furnace temperature. It is based n the principle of conductivity of electrons. A heat resistant probe is places inside the furnace. As the probe becomes gets hot heat is conducted through two wires. Conductivity is the flow of electrons so there is also a tiny electrical current flowing at the same time. As two dissimilar wires are used it will create a voltage (the current will flow through one wire easier than the other)



Cast irons

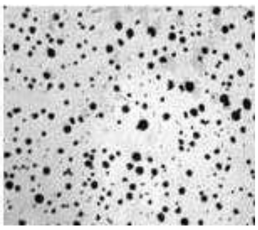
Cast irons occur above at least 1% carbon content. Like all steels they still contain carbon but this carbon is not in full solution with the iron and causes the formation of a much harder and more brittle material when compared with even high carbon steel. There are two main types of cast irons.

Grey Cast Iron



This is formed when slow cooling of the metal occurs. The carbon is formed in the material as graphite flakes. It is very easily moulded and flows well when molten. It is quite weak when put under a tensile load but has good vibration dampening properties. The material is widely used for vices as well as machine frames of pillar drills and lathes.

White Cast Iron



These irons occur due to quicker cooling where there not sufficient time for graphite flakes to occur. Instead the carbon is present as cementite. This material is very hard and brittle making it very difficult to machine (cut, drill, turn). White cast iron is mostly found on the surface of materials where they have been cooled quicker than inside the materials core.

Alloy Steels

Stainless Steel

Stainless steel does not readily corrode, rust or stain with water as ordinary steel does. Unprotected carbon steel rusts readily when exposed to air and moisture. This iron oxide film (the rust) is active and accelerates corrosion by forming more iron oxide; and, because of the greater volume of the iron oxide, this tends to flake and fall away. Stainless steels contain chromium to form a film of chromium oxide, which prevents further surface corrosion by blocking oxygen diffusion to the steel surface and blocks corrosion from spreading into the metal's internal structure. '18/8' or '18/10' are the most commonly used stainless steel and contains 18% chromium and 8% nickel. This steel is often used in stainless steel cutlery and kitchenware due to its hygienic qualities.

High Speed Steel

High-speed steel (HSS) is used in tool bits and cutting tools like power-saw blades and drill bits. It is superior to the older high-carbon steel in that it can withstand higher temperatures without losing its hardness. This property allows HSS to cut faster than high carbon steel, hence the name *high-speed steel*. High speed steels will vary in their composition but often include chromium, tungsten, and cobalt.

Tool Steel

Tool steel refers to a variety of carbon and alloy steels that are particularly well-suited to be made into machine and pressing tools eg. Pressing car door panels. Their suitability comes from their distinctive hardness, resistance to abrasion and deformation. Their composition usually includes chromium, tungsten and manganese.

Machining

Material Cutting Processes

Contents

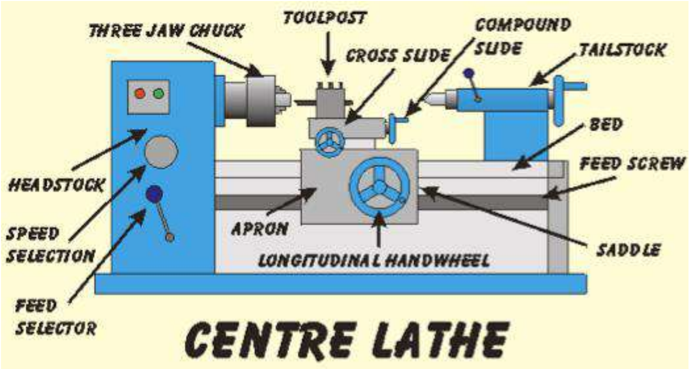
Introduction

Categories of Machining

8. Turning (lathework)
9. Milling
10. Grinding

Turning

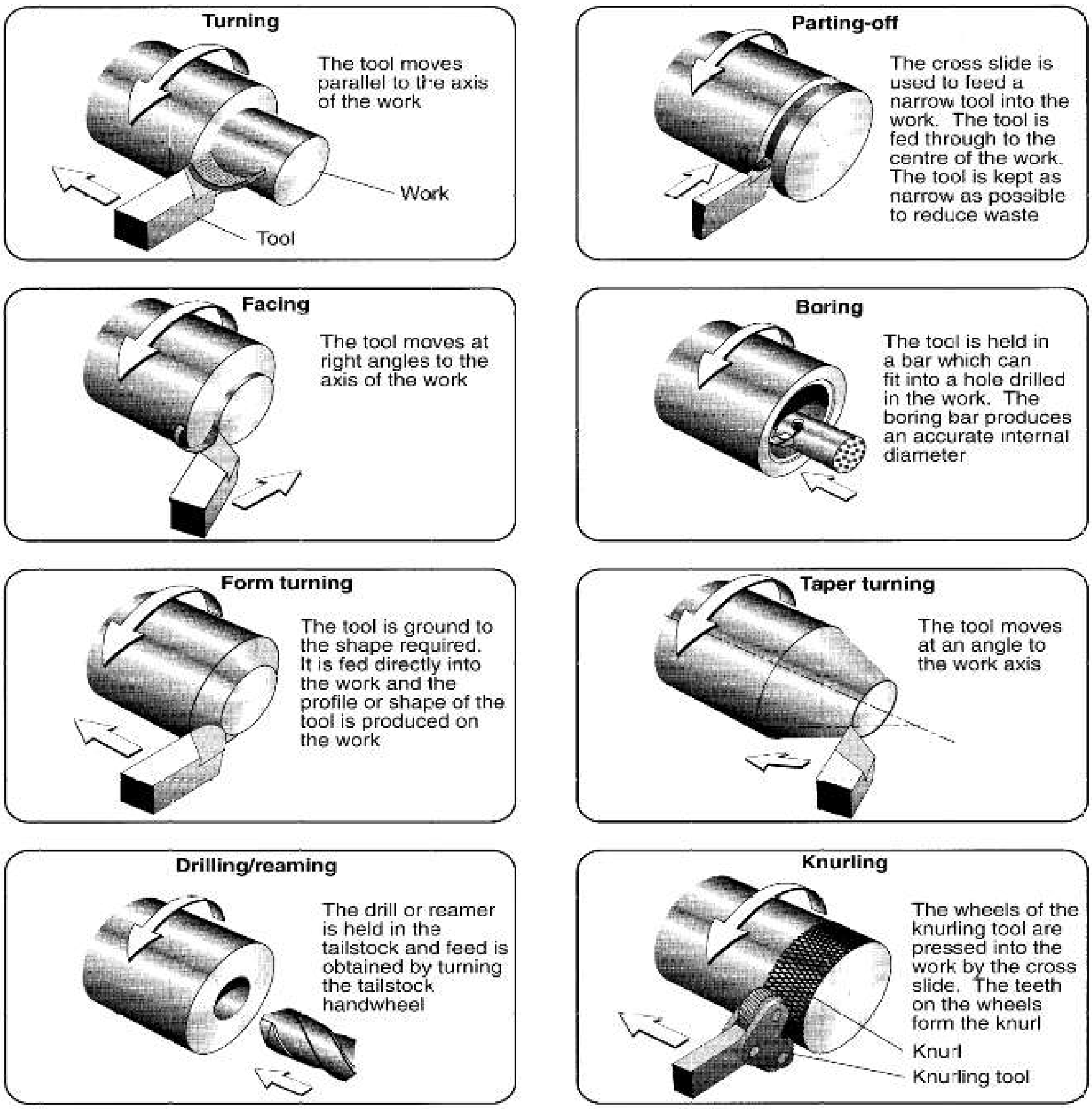
Overview of Turning



In Engineering the Centrelathe is used for shaping cylindrical materials by. This process is known as turning. Turning involves securing a workpiece in a horizontally mounted vice where it is rotated by the machine spindle. A cutting tool is then moved along and across the workpiece until the desired component form is achieved. The main parts of the Lathe include;

- **Headstock:** **Used to house the gearbox and machine spindle**
- **Chuck:** **Holds the workpiece**
- **Saddle:** **Supports the movement of the cutting tool along the length of the lathe**
- **Bed:** **Allows the saddle to slide along the lathe**
- **Cross Slide:** **Enables movement of the cutting tool across the workpiece**
- **Compound Slide:** **This pivots the cutting tool to allow for tapers to be turned**
- **Tailstock:** **Used to support longer bars and enables drilling on the lathe**
- **Toolpost:** **Can support a variety of cutting tools used to machine.**

Turning Operations



The main Turning operations include;

Parallel Turning: The saddle is used to move the cutting tool parallel to the axis of the machine. Used to turn down the diameter of a component.

Facing Off: The cross slide is used to move the cutting tool across the workpiece leaving a smooth face to the end of the bar.

Form Cutting: Using a shaped cutting tool to cut a specific design into a component.

Drilling/Centre drilling: The tailstock is fitted with a drill chuck to enable drilling on the lathe.

Parting Off/Undercutting: A parting off tool is used to cut off a component or to create a slot by undercutting Internal Boring: A boring bar fitted with a cutting tool is used to cut holes or bores internally into a component.

Taper Turning: The top slide is rotated to allow for tapers or points to be shaped on a component.

Knurling: A knurling tool is used to press a grooved grip onto the surface of a component.

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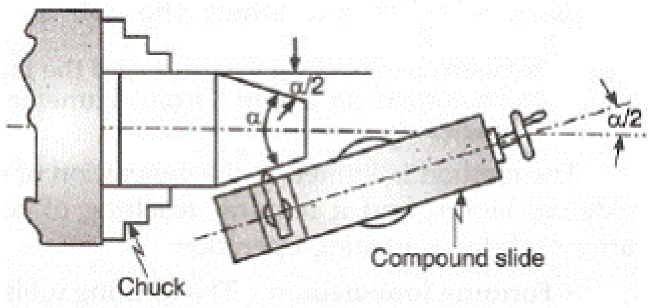
Screwcutting/Threading: External threads can be cut using a special tool and setting automatic feed rates on the lathe

Taper Turning

There are three methods used to turn tapers and points on the lathe

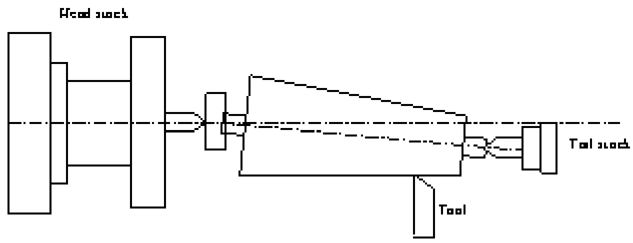
Turning the compound slide

This is used to turn points or short tapers. The compound slide securing bolts must firstly be loosened to enable the slide to rotate. The required adjustment can be read on the machine in degrees. If a point angle of 60° is required the top slide must be set to 30°.



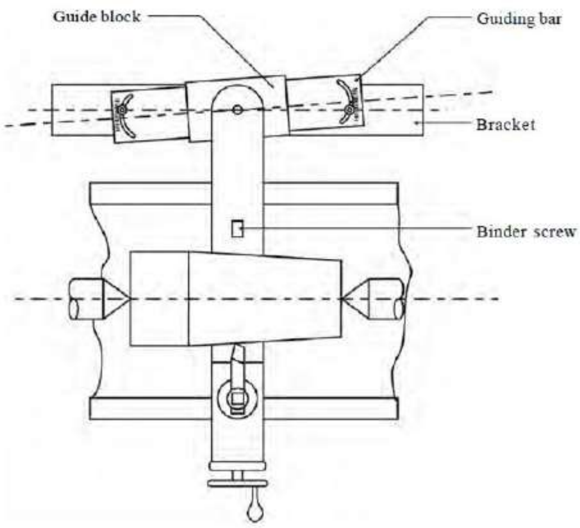
Offsetting the Tailstock

This method is used for turning longer tapers that cannot be machined by rotating the compound slide. The tailstock, which is normally on the same axis as that of the machine, must be adjusted so that it runs off centre. The degree of displacement along with the length of the component being machined will determine the angle of taper. The cutting tool is used as normal as it is the component that has been adjusted rather than the cutting tool. The work is secured between two centres. Knowledge of trigonometry is required to accurately setup the offset distance in order to produce the correct angle of taper.



Taper Turning Attachment Bar

This is an alternative method used to turn longer tapers. Here a guide bar is attached behind the bed of the lathe. The bar is attached to the leadscrew of the cross slide and set at the required taper angle. As the saddle is moved along the component the attachment bar effectively moves the cutting tool in or out across the component. This causes the simultaneous movement of the cutting tool on two axes of the machine, which is required to cut the taper



Work Holding

There are a variety Chucks, supports and steadies that may be used when turning depending on the nature of the component being machined. These include;

Self Centring Chucks

The standard component chuck found on the lathe is a three jaw self centring chuck. This is ideal for standard work of cylindrical components where concentric turning is required. As the chuck is opened or closed all jaws will move simultaneously guaranteeing that the work is held on centre. Solid bars may be held externally by the jaws whilst pipes or tubes may be supported internally by spreading the vice jaws open. Six jaw self centring chucks are also available for larger components.

Four Jaw Independent Chuck

This chuck is used for eccentric turning or turning material like square bars. Unlike the standard self centring chuck each of the jaws must be individually adjusted. This is ideal for eccentric turning in the production cams and camshafts that may be used in engines. A dial gauge may be used to determine how far off centre the component is to be placed in the chuck. The chuck may also support square profile lengths of material where sections of the bar can be eventually turned cylindrical.

Collet Chucks

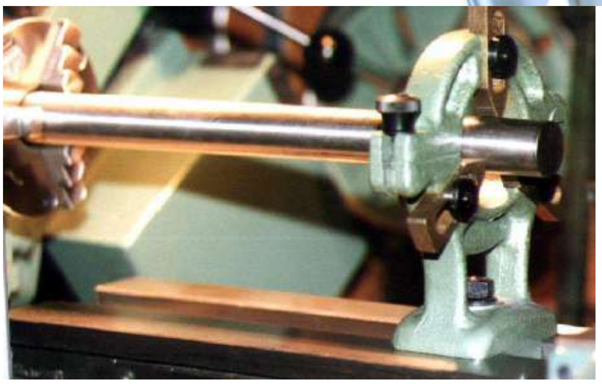
These are found in use on both the centrelathe (for holding the work piece) and the milling machine (for holding milling cutters). They are used as a means of securely holding work in conjunction with quick release mechanisms. One disadvantage may be that a different size collet is required as the diameter of the work or cutter changes. For this reason they are not great for workshops with varying diameters of work or cutting tools but collets are ideal for the mass production engineering applications as may be found in the automotive industry.

Revolving Centre

This is used to support longer materials in the lathe. The revolving centre sits in the tailstock and supports the one end of the work whilst the chuck at the tailstock supports the other end. This leaves the work secured at both ends thus removing vibration from the machining process.

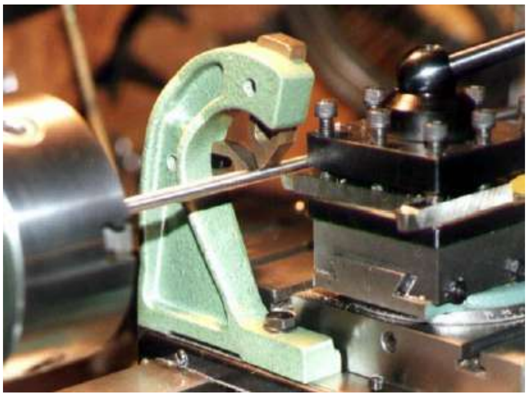
Fixed Steady

An alternative means of supporting longer material is using the fixed steady. This tool is securely fastened to the slideways of the lathe. It supports the work at the opposite end of the machine bed to that of the chuck. The tailstock can be removed to accommodate the fixed steady. Three adjustable fingers support the rotating bar. Grease may be used to help reduce friction between the finger and the rotating bar.



Travelling Steady

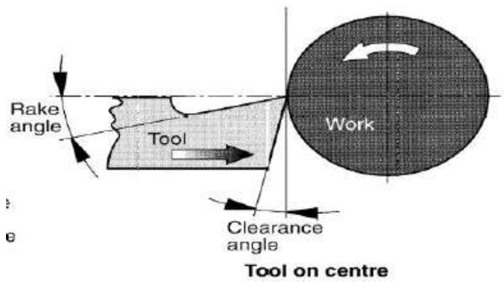
Where extra support is required behind the cutting tool a travelling steady may be used. This support may be required on longer material where the cutting tool may have an undesirable bending effect on the work. The tool is secured to the cross slide and so travels with and supports the work piece behind the cutting tool.



Tool Height

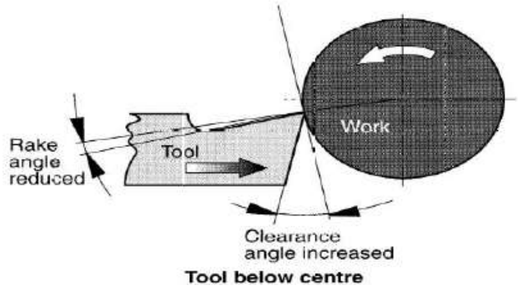
Tool On Centre

Cutting tool height is extremely important when turning. The tool should always be on centre where the tip of the cutting tools can align to the centre of the workpiece. Any deviance affects the tools ability to cut. The rake angle determines the sharpness of the cutting tool. Too small and the tool is blunt but too large and although sharp the tool will be weak. The clearance ensures that only the cutting edge is in contact with the workpiece. This reduces friction and thus tool wear. Here the cutting is at its most efficient.



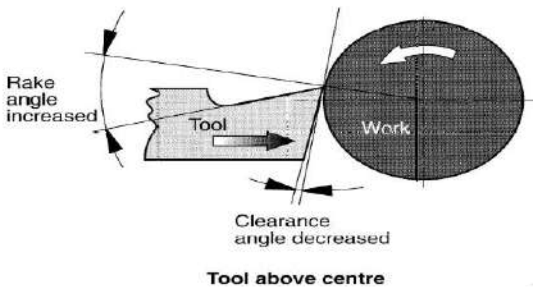
Tool Below Centre

Here the tool is sitting too low. As a result the rake angle has been reduced. This leaves the cutting less sharp. The clearance angle has been increased beyond what is required which makes the tip of the tool weaker and prone to breaking more easily. Facing off is now impossible and a dimple will be left on the face of the bar.



Tool Above Centre

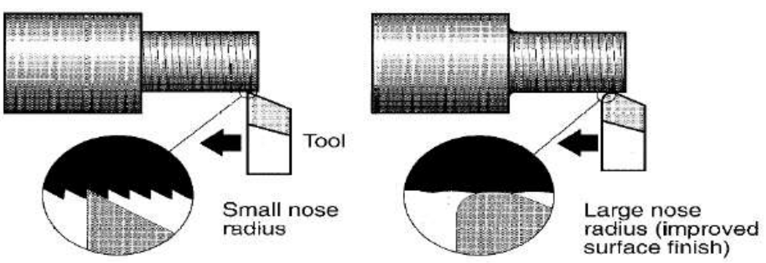
Here the tool is sitting too high. As a result the rake angle has increased. This leaves the toll a lot sharper but that does not matter as the tip is no longer in proper contact with the workpiece. The clearance has been reduced and if raised higher will be totally eliminated. This type of setup leads to massive friction causing a build up of heat and then tool wear. It is hard on the cutting tool the workpiece and the lathe itself. This machining must be avoided



Surface Finish

With all turning operations there are several ways to help improve surface finish. These include

- ***Tool Nose Radius***



A sharp pointed tool may seem desirable but will not leave a high quality finish. In order to smoothen the sharp fluctuations all properly designed tools will have a slight nose radius to them.

- ***Cutting Fluids***

  Although not used in schools cutting fluids are vital in any engineering production facility. They have several purposes during machining. Firstly they keep the cutting tool cool; this prevents wear to the cutting tool caused by heat due to the friction of cutting. They lubricate and aid the cutting action. Cutting fluids also wash away the swarf which causes difficulty if it builds up around the cutting tool.

- ***Spindle Speed***

  The spindle of the lathe is found in the headstock. It is rotated by the machine motor via the gearbox. The chuck is attached to the spindle. Spindle speed is measured in RPM's (Revolutions Per Minute). When seeking an excellent surface finish a high spindle speed should be used. Restrictions to this however will include oversized work or particularly harder materials.

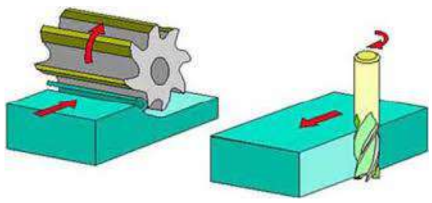
- ***Feed Rate***

Feed rate refers to the speed that the cutting tool is moved along or across the workpiece. This is controlled by the operator. A slower feed will always leave a much better finish but will take longer to produce a component. In machining processes terms like *Roughing Cycle* and *Finishing Cycle* are used. A roughing cycle will be carried out for the majority of machining using a high feed rate and thus saving time. A finishing cycle uses a lower feed rate but is only used on the final passing cut along or across the workpiece.

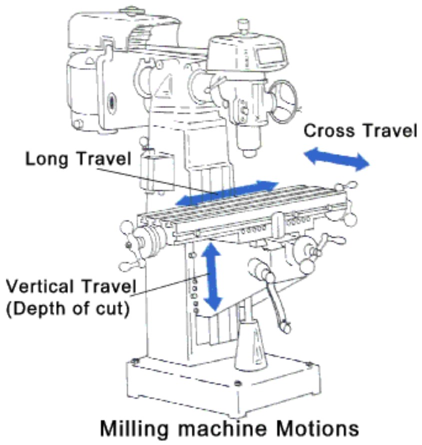
Milling

Overview of Milling

Milling is a machining process used for the shaping of metal and plastic engineering components. It is used widely in the tool making and automotive industries. The milling process used a multi-edged cutting tool that rotates in a fixed position (this may be vertically, horizontally and sometimes at an angle.



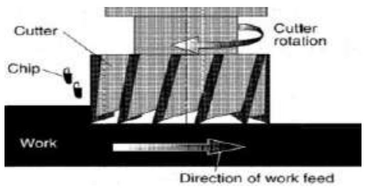
The workpiece is secured to a machine table where it can be fed into the cutting tool. The movement may be on the X, Y, and Z axes. There are two main types of milling machine commonly found.



Milling machine Motions

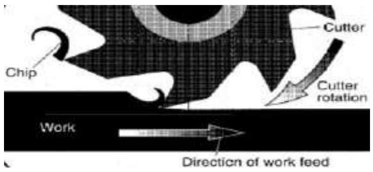
- ***Vertical Milling Machines***

  With this category of machine a cutting tool is mounted in a vertically positioned chuck. The work is fixed to the machine table, usually with the aid of a machine vice. The table is able to move on all three axes allowing for easy movement of the workpiece. Within this category of machines also exist *Turret Milling Machines.* These are basically the similar to vertical milling machines but they have the ability to rotate and pivot the machine head to different angles which is useful for milling angles. The main type of milling carried out on the vertical milling machine is known as face milling.



- ***Horizontal Milling Machines***

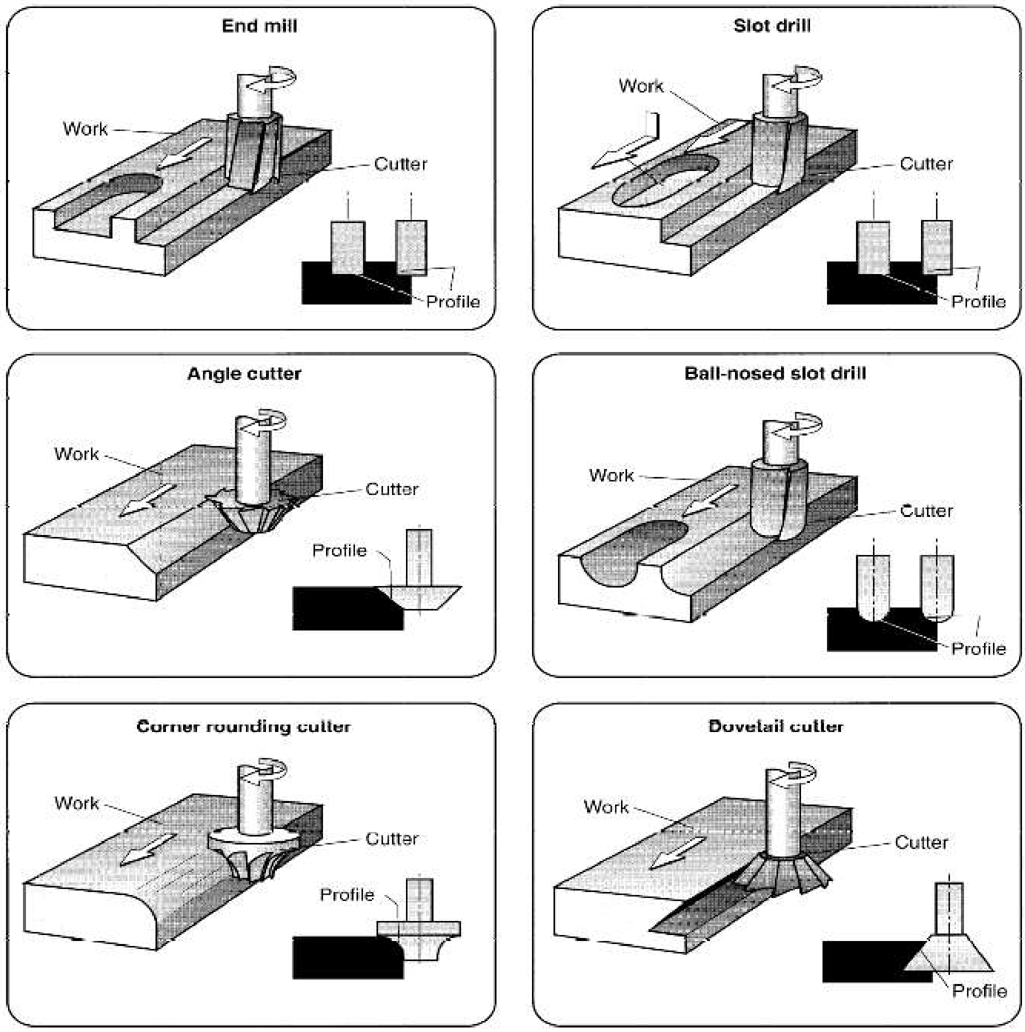
These machines are approximately similar in size to the vertical milling machine. The machine table operates on the same principle as that of the vertical milling machine and can move on all three axes. The cutting tool is hollow and mounted on what is called a horizontally mounted arbour (basically a round steel bar). The main type of milling carried out on the horizontal milling machine is known as peripheral or slab milling.



Types of Milling Cutters

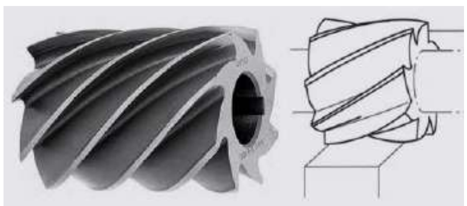
Chuck-mounted cutters are found on the Vertical Milling Machine and amongst others include;

End Mills:	Used for general milling on top and side surfaces. These cutters have 4,6,8 or more cutting edges. They may also be used to make slots but only open ended slots.
Slot Drills:	Used for milling of internal slots. These cutters have only two cutting edges and will not cut as efficiently as an end mill because of this.
Angle Cutters:	Used to create chamfers along edges.
Ball-nosed Slot Drill:	Used for cutting channels into material. Works similar to the standard slot drill.
Corner-rounding Cutter:	Used to mill fillets along edges.
Dovetail Cutter:	Used for the machining of dovetails. Machined dovetails can be found on the lathe topslide.

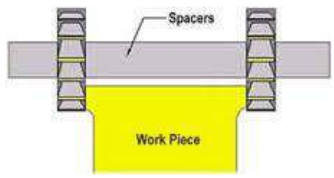


Arbour-mounted cutters are found on the horizontal milling machine and include;

Cylindrical Cutters (Slab Mills): These are the most standard cutter found on the horizontal milling machine. They are used to machine large flat surfaces (slabs)



Side and Face Cutters: These cutters have teeth on the periphery and side face. They are used to machine steps. They may be combined with other cutters to machine several faces at the same time. This is then called gang milling ie. A gang of cutters on a single arbour. A spacer may also be used where milling on the sides is required. When this is done it is called straddle milling.



Slitting Saws: These look like miniature circular saw blades. They may be from 1 mm to 5 mm in thickness. They are used for the making of deep narrow slots into components.

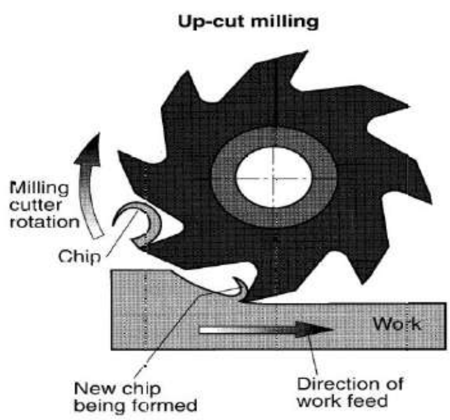
Angle Cutters: These are used for the milling of chamfers along the edges of components.

Form Cutters: These are usually custom bespoke (special 1 off designs) cutters that may take any form that is required. They tend to be specialised for specific jobs and are not commonly available due to their unique forms.

Upcut v Downcut Milling

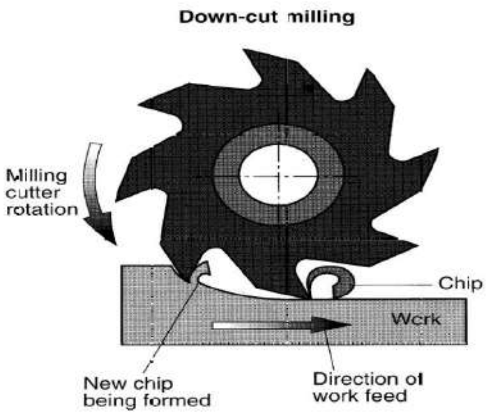
Upcut Milling (conventional Milling)

This is the most normally carried out type of machining. The movement of the cutter is against that of the workpiece movement. Due to this the cutting action is smooth and places little stress on the machine. The chip starts small and gains is thickness before being finally cut away. One disadvantage of this type of machining is the lifting effect that occurs on the work. For this reason very secure clamping must be in place



Downcut Milling (Climb Milling)

With this type of milling the cutting tool moves with the work. This is not the normal type of machining due to increased vibration of the machine. The vibration is caused by the cutting action which is not smooth due to the chip starting off large and the cut then reducing. Downcut milling does have the advantage of requiring less clamping force as the cutter tends to push the work into the machine.



Work Holding

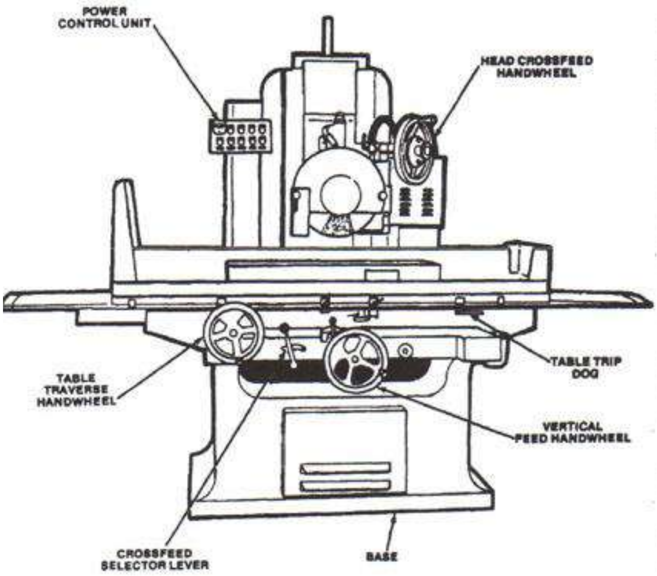
Dividing Head

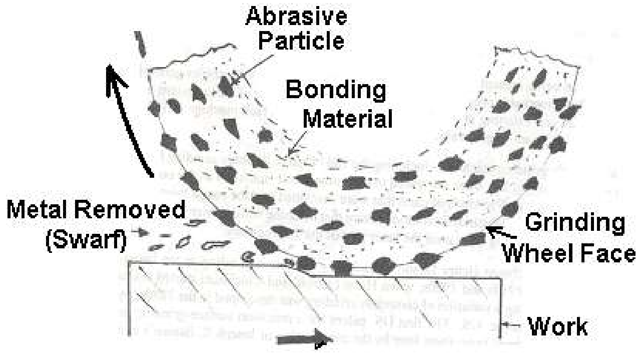
The dividing head is used for holding cylindrical shaped material on the milling machine table. It is equipped with an internal worm and wheel that enables the operator to rotate the work through a precise angle. This is useful when milling flat surfaces on a cylindrical bar or milling spur gear teeth on a blank disc of material. The chuck of the dividing head may also be rotated into a horizontal position. When this is done the device may also be known as a turntable.

Precision Grinding

Precision grinding is used a machining finishing process. Whilst turning and milling remove large quantities of material over a short period of time, precision grinding will only remove tiny fractions of material but leaves an extremely smooth and accurate finish. Unlike most cutting tools that cut at a single point or along and edge, all grinding takes place over the surface of a grinding wheel.

A grinding wheel is made up of an abrasive material that is bonded together (this is similar to sandpaper). This wheel rotates at high velocity, usually 2000-5000RPM. The workpiece is secured to a machine table. As on the milling machine the workpiece is moved into the cutter which rotates in a fixed position. A reciprocating table motion is used to enable the work to pass under the grinding wheel a number of times leading to the desired finish and accuracy.

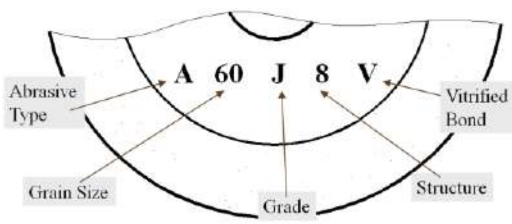




Grinding Wheel Classification

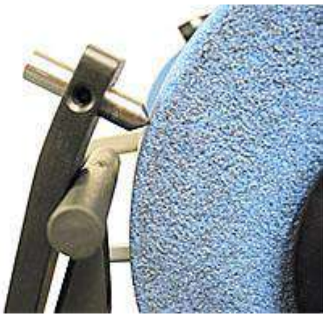
Grinding wheels are made from two essential things. A ceramic abrasive (similar to that found in emery paper) and a bond (this is basically the glue in the system). Grinding wheels are then classified by six elements;

1. The size of the grinding wheel
2. The abrasive type
3. The abrasive grain size
4. The grade (amount of bond used)
5. The structure (open or closed)
6. The Bond Type



Abrasive	Grain Size	Grade	Structure	Bond Type
A Aluminium Oxide	**8-24** Coarse	F-J Soft	0-2 Dense	B Resonoid
C Silicon Carbide	30-60 Medium	K-O Medium	3-8 Normal	E Shellac
D Diamond	80-180 Fine	P-T Hard	9-12 Open	R Rubber
CBN Cubic Boron Nitride	220-600 Very Fine			S Silicate

Grinding Wheel Dressing



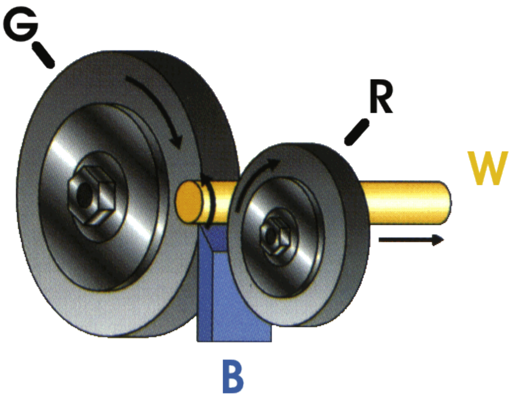
Wheel dressing is carried out to clean or renew the gutting surface of a grinding wheel. A diamond tipped tool is secured to the machine table. With the grinding wheel rotating the tool is moved across the cutting surface of the wheel. The tool removes worn abrasive; this is when a wheel becomes *glazed*. It also solves the problem of *Loading* where clogged swarf sits on the surface of the wheel. After dressing a new cutting surface is exposed.

Wheel Balancing

Wheel balancing is carried out to remove vibration from an improperly weighted grinding wheel. This is similar to balancing wheels on a car where imbalanced wheels lead to vibrations travelling up through the steering column to the driver. The process is carried out by setting the grinding wheel on an arbour and placing this on a stand containing knife edge wheels (the knife edge wheels help reduce friction). The wheel is then spun several times whilst small weights on the face of the wheel are repositioned until the grinding wheel spins freely and easily without vibration. This is very important because as the speed increases any vibration present would increase leading to damage to the machine, grinding wheel and workpiece

Centreless Grinding

Centreless grinding is used to obtain a high quality finish to cylindrical bar or tubes. The work sits on a vertical rest. A control wheel roller moving at a low RPM maintains rotation of the work. The grinding wheel then machines the surface of the bar. This process may also be used for tapered bars like morse tapers found on larger drill bits.



Work Holding

Magnetic Chuck

Although the magnetic chuck is usually more associated with precision grinding it can be used with certain milling operations also. The chuck is basically a large strong permanent magnet. It has an activating lever which moves two plates that will align the poles of a series of magnets. When these poles are aligned the magnetic grip of the chuck is very strong. When machining is complete the permanent magnet is deactivated and the component is simply lifted off the chuck. This workholding device has the advantage that it is quick and simple to use, it can hold a variety of awkwardly shaped materials, and there are no intruding vice jaws which can obstruct any cutting tools. The only disadvantage is that the vice is only suitable to materials that can be magnetised. It is only suitable for ferrous (iron) based materials.