UNIT 21: MATERIALS ENGINEERING

Unit code: F/601/1626

QCF level: 4

Credit value: 15

LEARNING OUTCOME 2

TUTORIAL 1

On successful completion of this unit a learner will:

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2 **Understand the relationships between manufacturing processes and material behaviour**

Treatment processes: heat treatments e.g. quench and precipitation hardening processes, complex heat treatments (such as conjoint mechanical/thermal treatments), glass transitions; other treatment processes e.g. coated materials (such as CVD/vacuum coating processes), chip technology: surface treatments/surface engineering, polymer treatments, composites/powder produced materials, matrix/reinforcement relationships, dispersion strengthening

Liquid processing: metal casting and injection moulding/extrusion of polymers; effect of processing on structure and properties e.g. grain structure, porosity

Mechanical processing effect on structure and properties illustrated by a range of processes e.g. mechanical working of metals, powder processing of metals and ceramics, extrusion and forming of polymer sheet, welding use of adhesives; effect of processing on structure and properties e.g. residual stresses, work hardening

Composite and structure: e.g. alloying, co-polymerisation additives, cross-linking. Crystallinity, lattice structure, slip planes and their effect on properties of parent material

CONTENTS

1. INTRODUCTION

This tutorial is mainly about manufacturing methods which you may have already studied (e.g. unit 10 of the National Certificate/Diploma). You should study it either briefly to refresh your knowledge or in depth if you are unfamiliar with the contents. Manufacturing affects the properties of the material and the properties of the material affect the manufacturing process. Most of this aspect is covered in the next tutorial but quite a lot is also contained in this one.

2. PROCESSING OF METALS

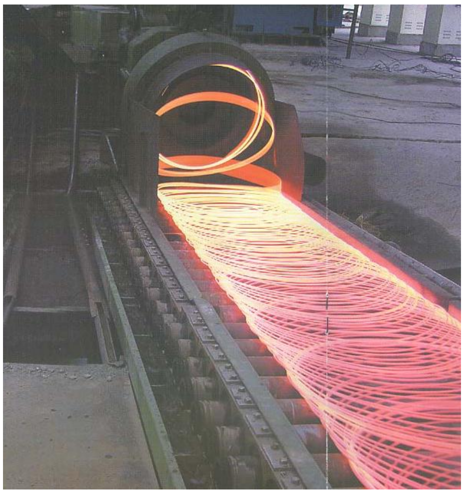
When a metal solidifies grains or crystals are formed. The grains may be small, large or long depending on how quickly the material is cooled and what happened to it subsequently. If the metal is maintained at a substantially higher temperature for a long period of time, the crystals will consume each other and fewer but larger crystals are obtained. This is called ***GRAIN GROWTH***. The grain size and direction can be changed by deforming the metal in the cold or hot state and this affects many mechanical properties such as hardness, strength and ductility. Heat treatment will also affect the grain and hence properties. In general slow cooling allows large crystals to form but rapid cooling promotes small crystals.

MANIPULATIVE PROCESSES
The following describes the various ways of producing metal products by manipulating the shape with plastic deformation.

COLD WORKING - Cold working a metal by rolling, coining, cold forging or drawing leaves the surface clean and bright and accurate dimensions can be produced. If the metal is cold worked, the material within the crystal becomes stressed (internal stresses) and the crystals are deformed. For example cold drawing produces long crystals. In order to get rid of these stresses and produce "normal" size crystals, the metal can be heated up to a temperature where it will re-crystallise. That is, new crystals will form and large ones will reduce in size. Cold working of metals change the properties quite dramatically. For example, cold rolling or drawing of carbon steels makes them stronger and harder. This is a process called *WORK HARDENING*.

HOT WORKING - If the process is carried out at temperatures above the crystallisation temperature the process is called *HOT WORKING*. Most metals (but not all) can be shaped more easily when hot. Hot rolling, forging, extrusion and drawing is easier when done hot than doing it cold. The process produces oxide skin and scale on the material and producing an accurate dimension is not possible.

HOT ROLLING
This is used to produce sheets, bars and sections. If the rollers are cylindrical, sheet metal is produced. The hot slab is forced between rollers and gradually reduced in thickness until a sheet of metal is obtained. This may be cut into lengths (usually the thicker sheets) or coiled into cylinders as shown above (e.g. thin steel sheets for making car panels).



Steel wire is also produced this way. The steel starts as a round billet and passes along a line of rollers. At each stage the reduction speeds up the wire into the next roller. The wire comes of the last roller at very high speeds and is deflected into a circular drum so that it coils up. This product is then used for further drawing into rods or thin wire to be used for things like springs, screws, fencing and so on.
The rollers may be profiled to produce rectangular bars, and various shaped beams such as I sections, U sections, angle sections and T sections.

You can see hot steel rolling on this link.
http://www.youtube.com/watch?v=6xnKmt_gsLs&feature=player_embedded

COLD ROLLING

The process is similar to hot rolling but the metal is cold. The result is that the crystals are elongated in the direction of rolling and the surface is clean and smooth. The surface is harder and the product is stronger but less ductile. Cold working is more difficult that hot working.

FORGING This is usually performed on hot metals but cold forging is done when things like coins are stamped into a shape by squeezing it between two halves of a die.

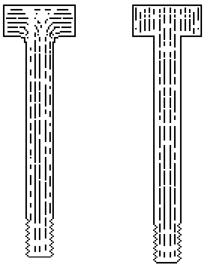
The dies may be a hammer and anvil and the operator must manipulate the position of the billet to produce the rough shape for finishing (for example large gun barrels).

This link has a good video of a forging process

http://www.brooksforgings.co.uk/?gclid=CL335snDiqoCFcRO4QodNHeSxw

DROP FORGING use a heavy weight dropped onto the billet. You can see the process at this link. http://www.brooksforgings.co.uk/drop-forging.asp

Hot working, especially rolling, allows the metal to re-crystallise as it is it is produced. This means that expensive heat treatment after may not be needed. The material produced is tougher and more ductile. Hot working aligns the grains in a particular direction giving it a fibrous property. This may be used to advantage. Forging in particular makes use of aligning the grains to give maximum strength in the required direction. The diagram illustrates how the head of a bolt is formed by forging to change the direction of the grain. The right hand diagram shows the result of machining the head leaving a weakness at the corner.



Engine crankshafts are forged to produce optimal grain flow in a similar manner. These can also be cast. Look at this video. http://www.youtube.com/watch?v=VxmbGBx0Ybg

Other products produced by forging are typically spanners, socket sets, garden tools, golf clubs, pipe line valve parts, pins and screws.

DRAWING

In this process, a metal billet is pulled through a die. The hole in the die has the shape of the finished section. This process is used to produce copper wire, seamless steel or copper tubing and so on.

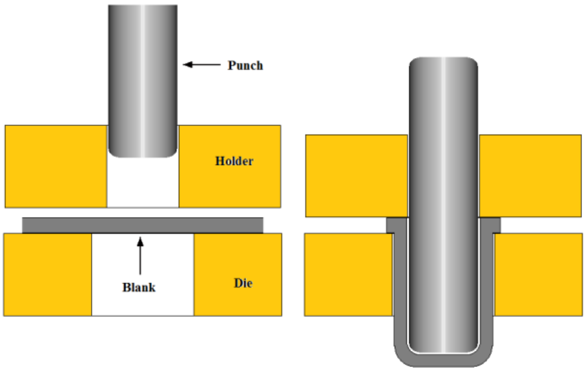
Cold drawing produces work hardening and it may be necessary to anneal the metal at some stage.

Cold drawing used on steel allows precise and complex sections to be produced. After careful pre-treatment and de-scaling, the special profile bars are drawn through a forming die up to three or four times. Special profiles can be produced that offer the same precision achieved by machining but without the waste.

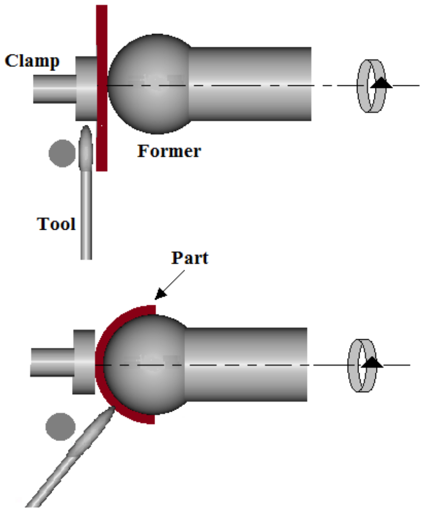
The advantages include:

- Smooth and scale-free surface
- Sharp edges
- Uninterrupted grain orientation
- Increased tensile strength and yield point

Applications include many cold drawn steel shapes such as both carbon and stainless steel fittings, various stainless steel shapes used in aerospace applications, linear motion and machinery applications. The economical advantages of using cold drawn stainless steel profiles are numerous.
This web site explains a lot about the manufacture of copper tubes by cold drawing.
http://www.copper.org/publications/newsletters/innovations/how/howdo_tube.html
This link shows how copper wire is drawn and annealed.
http://www.youtube.com/watch?v=Y2YeENgabmY

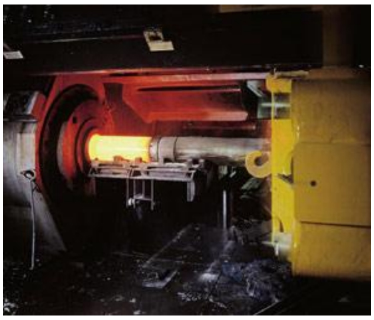


DEEP DRAWING is a term used to describe the process of forcing a sheet material into a cup shape as shown below. The metal is drawn into the die by the punch.
More complicated shapes are made in several stages and using external and internal dies in a process called PRESSING. This link shows a video of such a process.
http://www.youtube.com/watch?v=UClyNf6P_GM&feature=related



SPINNING
In this process the blank is held against the former and the whole assembly is spun. The blank is the forced into the shape of the former by forcing a forming tool against it. This method is used to produce aluminium satellite dishes, cooking pans and so on. The process is not best suited to large volume production.
You can see the process on this link
http://www.youtube.com/watch?v=um-biLfru-c&feature=related
This link shows a related process for making alloy car wheels.
http://www.youtube.com/watch?v=bzFzgtwvWZs

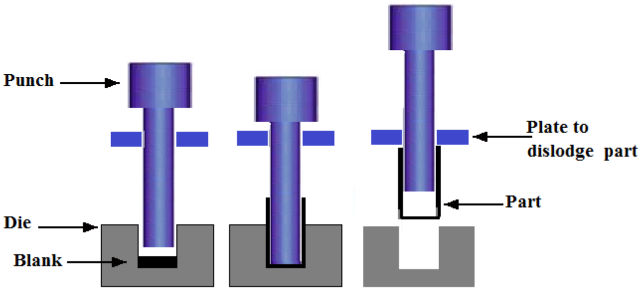
EXTRUSION
Squeezing toothpaste from a tube is an example of extrusion. Under stress, ductile metal will flow and in industry a metal billet is forced through a die from behind by a powerful hydraulic ram. The die has the shape of the section required. This method is used to produce aluminium sections and quite complicated shapes may be produced this way.



Hot Steel may be extruded as shown. The heated billet is pushed through a die into a profile bar. The advantages of extrusion over hot rolling, forging or machining are that it produces complex shapes even using metals which are difficult to form such as stainless steel and small batches can be produced economically.
The video on this link shows a steel tube being extruded over an internal die to make it into a large elbow.
http://www.youtube.com/watch?v=ny9PLxbRM7A
This video shows how aluminium tube is extruded.
http://www.youtube.com/watch?v=QKAg1yMZIpY&feature=related

IMPACT EXTRUSION

This process is similar to deep drawing but the blank is hit so fast with the punch that it flows plastically to mould itself into the shape formed between the die and punch. Materials best suited for this process are aluminium, lead and tin. Drink cans and battery cases are made this way.



You can see a video of the process at this link.
http://www.youtube.com/watch?v=zMhVPId-pRA

If the process is done more slowly, it might be called extrusion as shown on this link. http://www.youtube.com/watch?v=9mQ2ic-kDlk

SELF ASSESSMENT EXERCISE No. 1

1. Which hot metal working process would most likely be used to produce seamless steel pipes of large diameter? Give your reasons.

2. Which process would you choose to make a small number of large circular copper bowls? Give your reasons.

3. Which process would you choose to make large number of aluminium drink cans? Give your reasons.

4. Steel hydraulic tubes must withstand very high internal pressure and must be accurate made with a good smooth surface finish. Which manufacturing process would be best?

5. What are the advantages of using the hot forging method to produce engine crankshafts?

6. Name the process by which large quantities of steel car panels (e.g. doors and wings) are produced and what form the steel has prior to processing?

7. If you had to machine steel bar or rod in a lathe what difference would you expect to find between hot and cold rolled steel?

8. What is the process most likely to be used to produce aluminium sections with accurate dimensions?

9. Cold drawn copper wire is usually annealed after it is made. What is the reason for this?

LIQUID CASTING AND MOULDING

Many materials, especially metals, are suitable for casting by pouring the liquid metal into a mould and allowing it to solidify. The product has the shape of the mould and this may be the shape of a component which will need machining to complete it (for example an engine block) or an ingot for further processing such as rolling or drawing.

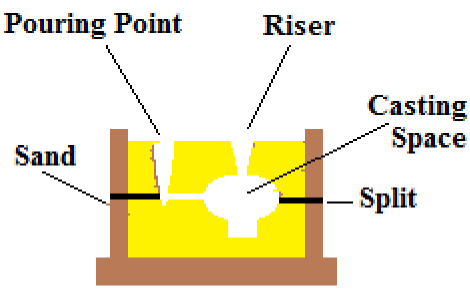
When the metal cools it contracts and the final product is smaller than the mould. This must be taken into account in the design.

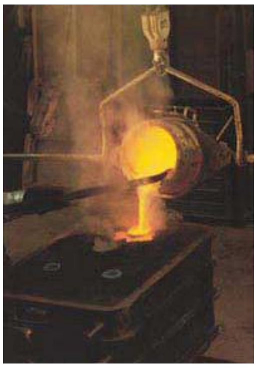
The mould produces rapid cooling at the surface and slower cooling in the core. This produces different grain structure and the casting may be very hard on the outside. Rapid cooling produces fine crystal grains. Here are some cast components.

There are many different ways of casting.

SAND CASTING

Sand casting is commonly used with cast iron, cast steel, aluminium alloy and brass. Heavy components such as an engine block would be cast in a split mould with sand in it. The shape of the component is made in the sand with a wooden blank. Risers allow the gasses produced to escape and provide a head of metal to take up the shrinkage. Without this, the casting would contain holes and defects.





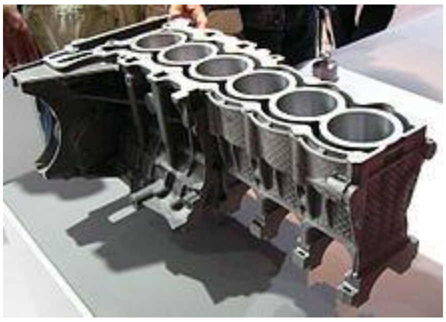
Sand casting is an expensive method and not ideally suited for large quantity production. You can see a video at this link. http://www.youtube.com/watch?v=dlQ54WATvzA

CENTRIFUGAL CASTING

This is similar to die casting. Several moulds are connected to one feed point and the whole assembly is rotated so that the liquid metal is forced into the moulds. This method is especially useful for shapes such as rims or tubes. Gear blanks are often produced this way. You can see the process on this link.
http://www.youtube.com/watch?v=3qKGx_AxHp0

DIE CASTING

Die casting is an efficient, economical process used for high-speed production of dimensionally accurate complex shapes. Little or no machining is required and thousands of identical castings can be produced before the mould wears out. Die castings uses a metal mould. The molten metal may be fed in by gravity as with sand casting or forced in under pressure. If the shape is complex, the pressure injection is the best to ensure all the cavities are filled. Often several moulds are connected to one feed point. The moulds are expensive to produce but this is offset by the higher rate of production achieved. The rapid cooling produces a good surface finish with a pleasing appearance. Good size tolerance is obtained. The best metals are ones with a high degree of fluidity such as zinc, copper, aluminium and magnesium with their alloys are also common.



You can see a video description of die casting at this link
http://www.youtube.com/watch?v=W6VgCaRozq8
You can see a video of real machines in action here.
http://www.youtube.com/watch?v=FEbJFbN4PfA

INVESTMENT CASTING

In this process, wax shapes are first made in a metal mould. The shape is then coated with a ceramic material. The wax is melted leaving a ceramic mould. After the metal is poured, the mould is broken to release the casting. The advantage of this is that metals with a very high melting temperature may be cast (e.g. turbine blades). These metals would destroy ordinary die casting moulds very quickly. Excellent dimensional tolerance is produced. Shown are some components made this way.

You can see the casting process on this link.
http://www.youtube.com/watch?v=BX8w-GUPz1w

POWDER TECHNIQUES

In this process, metal powder is poured into the mould and pressed with a die into the required shape. The powder is heated and pressurised so that the particles fuse. The structure produced is porous because granules do not melt completely but become sintered leaving gaps between them. The end product may a course sinter or a fine sinter. Bronze bearing bushes which retain lubricants in the porous structure are produced this way. Steel components such as shaft couplings are made this way. Very hard materials such as tungsten carbide may be formed into cutting tool tips by this method.

SELF ASSESSMENT EXERCISE No. 2

1. Find out and name three things made by centrifugal casting and three metals that can be cast this way.
2. What are the advantages and disadvantages of using the investment casting process to make things?
3. Find and name 3 things that are made by die casting and state the metals used. What are the advantages of this method?
4. Find and name 2 things made by sand casting with cast iron.

MACHINING

Machining processes are not covered in depth here. Machining processes involve the removal of material from a bar, casting, plate or billet to form the finished shape. This involves turning, milling, drilling, grinding and so on. The advantage of machining is that it produces high dimensional tolerance and surface finish which cannot be obtained by other methods. It involves material wastage and high cost of tooling and setting. Modern machine tools are computer controlled and can carry out many complex operations in the same machine. The cutting tool or the workpiece may be moved relative to each other.
Video of CNC Milling
http://www.youtube.com/watch?v=Wk2VYwCIcZE

GRINDING is conducted to produce accurate dimensions and a good surface finish. A cylindrical grinder rotates the workpiece against the grinding wheel. Surface grinders traverse the grinding wheel over the workpiece to produce a flat surface. The grinding wheel is made of hard ceramic material and there are many types depending on the material to be ground and the surface finish required. Modern CNC grinders move the small grinding head around the component.

Surface Grinder on Left, Cylindrical Grinder on Right

Video of CNC grinding at this link http://www.youtube.com/watch?v=ROKJhTX_VTQ

SELF ASSESSMENT EXERCISE No. 3

1. If a steel component can be made by die casting or by machining it from a billet. Which would be the best to use if only 5 parts are required and which if 5000 parts are required? Explain your reasoning.

2. When a small quantity of components is ordered from a manufacturer who makes them on a CNC machine, they are often allocated a "minimum batch number". What does this mean and why is it used?

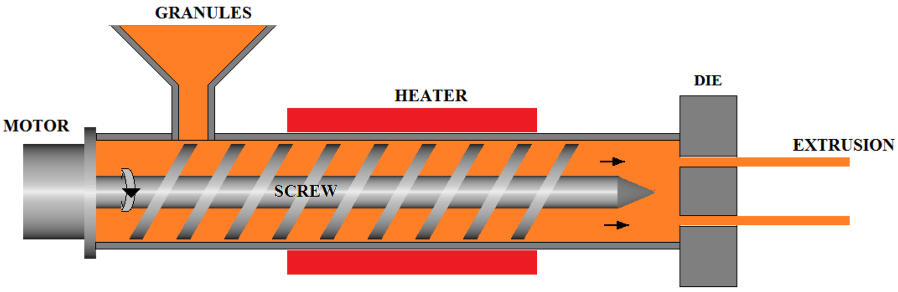
3. Find out and describe the meaning of "honing" in materials removal and explain why it is used.

4. Find out and state three reasons for using cylindrical grinding in the manufacture of components.

3. PROCESSING POLYMERS

Thermoplastics are often melted and extruded in a screw extruder as shown. Care has to be taken to ensure the plastic is at the correct temperature and pressure for the process.

Extrusion is a process of forcing molten plastic through a die to create finished sections and tubes. Commonly a screw extruder is used. The granules are fed into the screw and rotation forces them forward. The heater melts the granules and the molten plastic is continuously extruded out of the end.

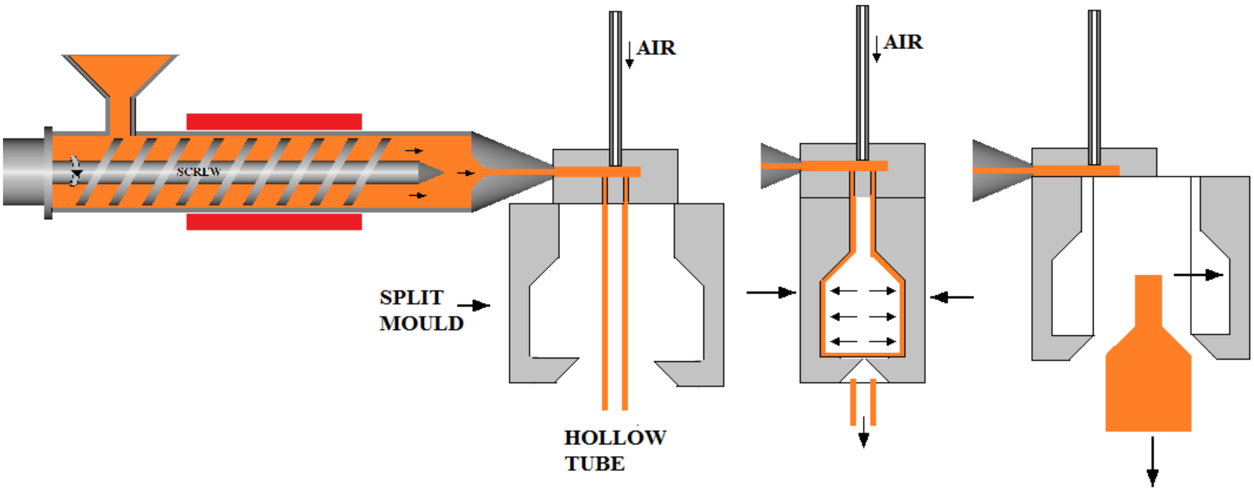


Blow moulding is a process where the molten plastic is inflated against the wall of the mould to form hollow plastic shapes such as bottles, jugs, buckets and tubes. Materials suitable for this are:

- Low Density Polyethylene (LDPE)
- High Density Polyethylene (HDPE)
- Polyethylene Terephtalate (PET)
- Polypropylene (PP)
- Polyvinyl Chloride (PVC)

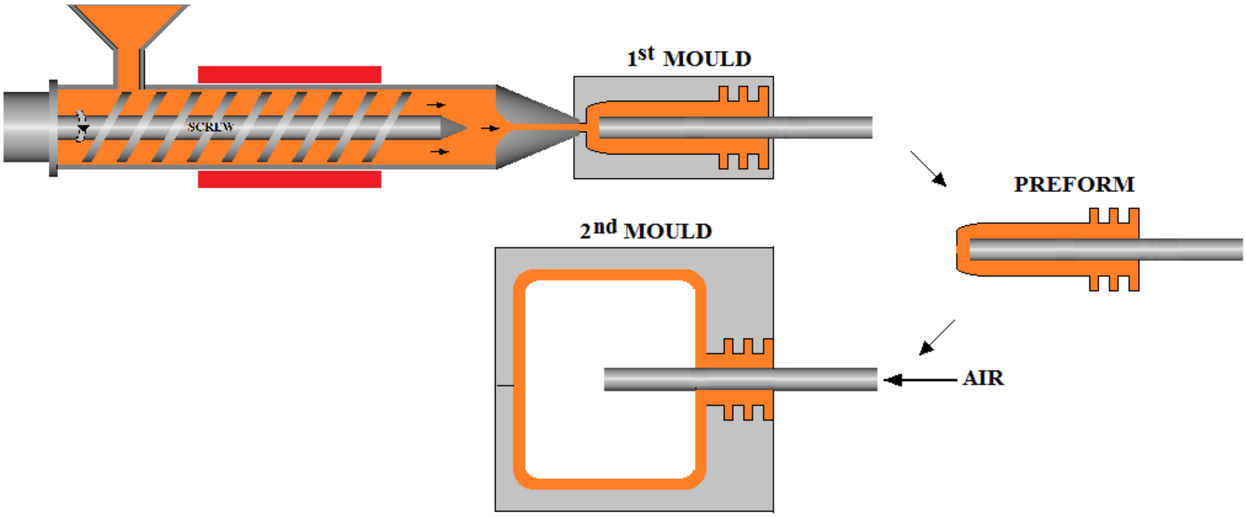
There are several variations on the basic process.

Extrusion blow moulding
The process begins with melting down the plastic and forming a hollow tube. The tube-like piece of plastic is called a preform or parison. The parison is then clamped into a split mould and air is forced into it. The air pressure expands the plastic against the wall of the mould. Once the plastic has cooled and hardened the mould opens up and the part is ejected.



You can see an animated video of the process at this link.
http://www.bpf.co.uk/plastipedia/processes/extrusion_blow_moulding.aspx

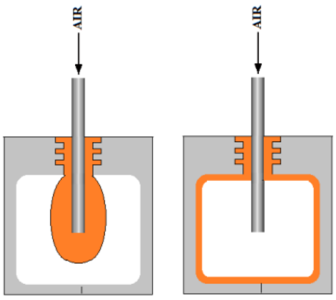
Injection blow moulding is a similar process but precise amounts of plastic are injected into a split mould to create a preform on a pin. The preform on the pin is then indexed to a new mould where it is inflated and allowed to cool. The bottle is then indexed to the next station and ejected. This allows more precise detail in the neck and threaded area. The preforms can be stored and used later with reheating used to soften it. This process is suitable for bottles requiring clarity, and gas barrier properties needed for fizzy drinks.



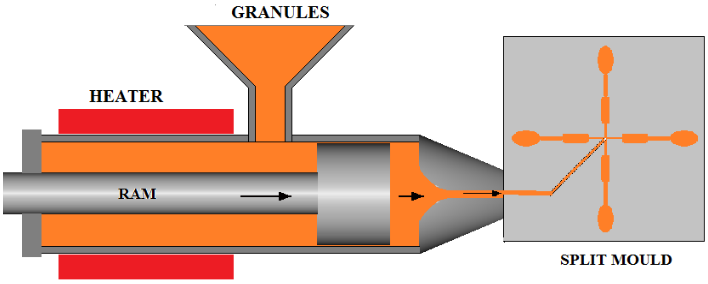
You can see an animation of this process at these links.
http://people.bath.ac.uk/en3hl/blow.html
http://www.bpf.co.uk/plastipedia/processes/injection_stretch_blow_moulding.aspx

Injection Stretch blow moulding
The process is similar to the extrusion blow moulding but the plastic is injected into the mould and expanded in one process.

You can see an animation of this process at this link.
http://www.youtube.com/watch?v=V0FM8Ty8qYg



Injection moulding is used to produce a variety of solid components. The molten plastic is forced into the mould (often with a ram). The mould might create several identical parts at the same time.



Thermosets are moulded into more durable components. The raw material for thermosetting plastics is soft dough like material, liquid or soft uncured sheets called Sheet Moulding Compound (SMC). In order to form in the mould they have to be ***cured***. In many cases this involves heating them to 200^{o}C or above to start an irreversible process to solidify and harden. The curing can be initiated by adding a chemical as in epoxy resin which only cures and sets when the two are mixed. In this form they are often used as adhesives and in particular for reinforced glass fibre products (GRP). Other things can trigger the curing process such as irradiation.

Thermosets are generally stronger than thermosetting plastics. Examples of thermosetting plastics are:

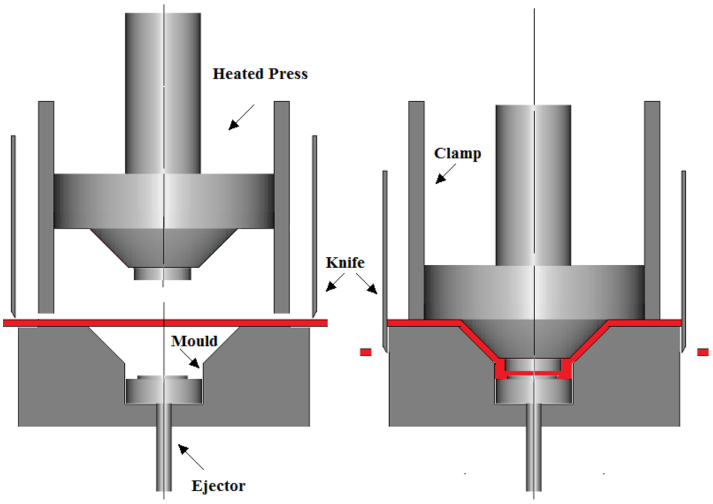
- Polyester fibreglass systems.
- Rubber (natural and Vulcanised).
- Bakelite - used in electrical insulators and plastic ware.
- Duroplast - a light but strong material, similar to Bakelite used for making car parts.
- Urea-formaldehyde foam (used in plywood, particleboard and medium-density fibreboard)
- Melamine resin (used on worktop surfaces and furniture).
- Epoxy Resin – used in GRP structures.
- Polyimides used in printed circuit boards and in body parts of modern airplanes.
- Cyanate Esters or Polycyanurates for electronics applications.

A few of the many products made with thermosets are:

- Wellingtons and rubber boots.
- Tires.
- Milk Crates.
- Bottle caps.
- Figurines.
- Gaming pieces (chess, counters etc.).
- Light Machinery parts (bearings, fan blades, gears etc).
- Car parts (bumpers, fuse oxes, filter cases etc.)
- Electrical parts (plugs, sockets etc.)
- Appliances (electric kettles etc.)
- Worktops.
- Furniture.

Parts are created by much the same method as described for thermoplastics with due care needed in providing the correct catalyst especially temperature and curing. Many parts are created using compression moulding.

Compression moulding is a forming process in which a plastic material is placed directly into a heated metal mould, then is softened by the heat, and forced to conform to the shape of the mould as the mould closes. Materials used for compression moulding are either soft dough or SMC. When the plastic has cured and hardened, it is ejected from the mould.



You can see a video at this link.http://www.youtube.com/watch?v=xOzyaKDbE8s&NR=1

SELF ASSESSMENT EXERCISE No. 4

1. If thermosetting plastic is to be used in an injection mould, why should the mould be heated and not the injector?

2. Look up and list the properties of ABS that makes it suitable for making car bumpers (fenders)?

3. What would be the most likely way to manufacture Nylon Hair Combs? Give your reasons.

4. If similar ropes are made from Polypropylene and Nylon what difference would you expect in their performance.

5. Find out and explain why Polycarbonate is suited to making drinking cups and mugs.

6. Both ABS and Urea Formaldehyde are used to make electric plugs. One is thermosetting and one is a thermoplastic, find out which is which.

   Which one would be used to make a moulded one piece plug and which a two piece plug and why?

   Which is most likely to be used for applications where the plug may be accidentally hit e.g. by moving equipment about)?

4. CERAMICS

Ceramics are non metallic materials such as glass and stone. The properties of ceramics are hardness, high melting point, high electrical resistance, high thermal resistance, high thermal capacity and high resistance to degradation by corrosion and chemicals. There are a wide range of products. Here is a partial list.

- Bottles and glasses.
- Sanitary ware (WCs, Sinks and so on like in the picture).
- Tableware.
- Electrical insulators.
- Cooker hobs.
- Parts for heaters.
- Hair rollers and curlers.
- Parts for electronics.
- Fire bricks and tiles.
- High tech applications such as coating turbine blades and space shuttle tiles.

The raw material for pottery items is clay - a mixture of fine particles and water. To make pottery the clay is formed into the required shape and heated in a furnace until it dries and loses its water content. Then the temperature is raised until the particles fuse without melting. Typically the products are passed through a heated tunnel kiln in which they are preheated, sintered and then cooled slowly to avoid cracking.

The moulded product is called greenware and needs to be converted into a strong durable form. Any trapped water will convert to steam at 100^oC and destroy the ceramic so the kiln is kept below this temperature until all the water has evaporated. In the kiln the following structural changes take place.

The temperature is then raised up to a maximum of 800^oC in order to burn off any impurities in the clay. Hotter than this and the surface starts to fuse and seal the bulk material so any impurities will cause damage. Rapid heating creates stresses leading to cracks. Between 800-900°C sintering begins. This is the stage where clay particles begin to cement themselves together to create a hard material called bisque. Between 1100-1200°C the silicate materials change into glass. Particles melt and form crystals resulting in shrinkage. Cooling must be slow to avoid cracking during the shrinkage.

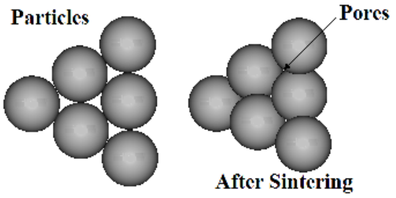
Other ceramics such as glass are produced by melting the minerals (largely silica) and moulding them or shaping them by some other method.

Enamelling is a process of coating objects with glass or other ceramics by fusing a paste on the surface. This gives it protection and can be decorative.

Other ceramic materials for making hard cutting tools are covered below.

SINTERING and POWDER TECHNOLOGY

Many ceramics are produced by a process called sintering. In general this is a process in which powders (and sometimes fibres) of suitable materials are heated and pressed together. The materials do not melt but molecules diffuse from one to the other to bond them. The result is often a porous material which can be useful in making filters. The picture shows the structure of such a material.



The process is also used to produce metallic objects of complex moulded shapes that require no machining to finish them resulting in reduced material wastage. High pressure moulding reduces the porosity and produces components very similar to cast or wrought components. The majority of structural components are based mainly on iron based powder. Iron and copper are easy to compress to form high density material with adequate strength for handling during sintering, but do not produce very high strength sintered parts. For higher strengths, powder with alloys is used but these are harder to press and require a greater pressing force. Materials such as stainless steels with chromium and nickel elements require very high temperatures and long sintering times. The picture shows some examples of components produced this way.

SELF ASSESSMENT EXERCISE No. 5

1. Define a ceramic material.
2. Explain why a sintered material may be porous and give an example of something in which this is useful.
3. What are the properties of ceramics that make them so suitable for bathroom fittings (sinks, toilets, tiles and so on)?
4. What are the properties of ceramics that make them suitable for use as a halogen lamp holder?
5. What are the properties of ceramics that make suitable for use in storage heaters?
6. List 3 advantages of powder technology over machining to manufacture a gear wheel.
7. What are the structural changes that occur in clay when heated up to the sintering temperature?

5. <u>COMPOSITES</u>

A composite material is a combination of two or more materials to obtain the best properties of both. There are broadly two classifications, ***PARTICLE and FIBRE***.

PARTICLE COMPOSITES

This is a material in which particles of one material is fixed in a matrix of another. Some of the simplest examples are materials used for the ***construction industry***. Here are some examples.

Tarmac – a matrix of gravel held in a matrix of tar, ideal for roads.

Mortar and Concrete – sand, gravel and stone bonded into a matrix of cement that sets and forms a light material strong in compression. Since it can be moulded or laid down wet, it is an ideal building material.

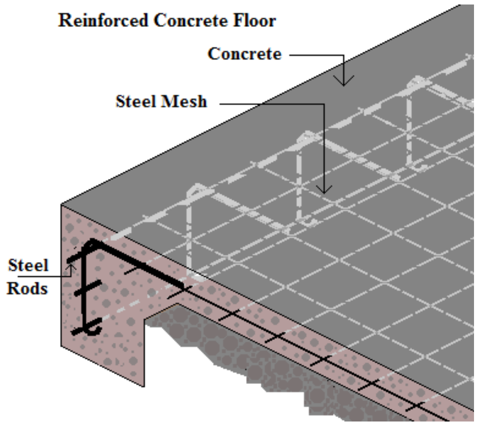
Particle composites are used in engineering to make a range of hard cutting tools. The main product is called ***cermet***.

Cermets – This is a material in which ceramic powder is bonded in a metallic matrix to get the best properties from both such as hardness, high working temperatures and strength. The ceramic materials are often oxides, borides and carbides. The metals are nickel, molybdenum and cobalt. The volume of a typical cermet is about 20% to bond the ceramic particles.

Cermets are used widely in electronics to make resistors and capacitors for high temperature use.

Cermets are also used to make dies and cutting tips for tools used in machining and sawing of hard materials. Particles of very hard ceramic materials are embedded in a metal. They have good resistance to oxidation and keep their hardness at high temperatures. Typically the cermet contains titanium carbide and titanium nitride. For example, tungsten carbide embedded in cobalt make very hard cutting tools and dies. They can be compacted into the required shape and then heated to sinter them. This means the cobalt is hot enough to re-crystallise and form a matrix around the tungsten. The pictures show examples of cutting tools with cermet tips.

FIBRE COMPOSITES



Examples are:

- Reinforced concrete.
- Glass reinforced plastics (GRP)
- Carbon fibres.
- Aramid fibres.
- Natural composites such as wood.

Concrete is very brittle and weak in tension so it is normally only used for support structures (columns and solid floors). By adding steel rods, the structure becomes stronger in tension and withstands some bending. Hence bridges, unsupported floors and other structures where some bending occurs can be made to take the tension. The resulting structure is lighter than steel on its own. Brittle materials fail by cracks spreading through them with little resistance. Adding fibres prevents the crack opening and spreading.

Glass and carbon fibres when made new are very strong and flexible and if they are imbedded in a matrix of plastic (thermosetting) they retain their high tensile strength. The result is a very strong flexible and light structure. Many things are made from these materials such as boat hulls, tennis rackets, fishing poles and racing cycle frames like the one shown.

Many GRP products are made from sheets of chopped fibres laying in random directions. This is formed into the shape required often in a mould and pasted with epoxy resin. All the air must be forced out of the fibres and resin forced in either with rollers, brushes or with a vacuum process. A gel coat is often used to form an outer layer with a smooth coloured finish.
You can see the process on this video link
http://www.youtube.com/watch?v=bwQCzyvVSvs

6. LAMINATES

An important type of composite material is those made up from laminated layers of either the same or different materials glued to each other in layers to obtain an overall structure with the combined properties of each layer. For example one layer may make the material water proof as in laminate flooring. Other examples are snow boards and skis that need to be strong and flexible. Many aircraft parts are made from sheets of laminated material.

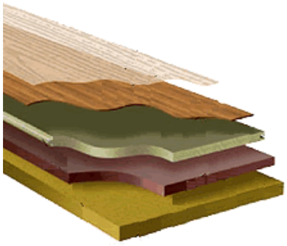
PLYWOOD

Grainy materials like wood have strength in one direction only so if they are layered with the grain at 90^o to each other, equal strength is obtained in both.

TYRES

An ideal tyre must have strength, good grip, not wear and not puncture. For this reason a tyre consists of laminated layers of Rayon, Nylon and Steel in a rubber matrix with cross plies to produce strength in all directions.


Tire


Laminate Flooring


Plywood

It is very important that laminated structures do not come apart between any layers (***de – lamination***) so appropriate bonding materials must be used. This can occur due to stress or environmental conditions such as chemical spills.

SELF ASSESSMENT EXERCISE No. 6

1. Explain how a material that is strong in one direction and weak in another may be formed to be strong in both directions.
2. Find out what materials are used to manufacture snow boards and how they are joined together. Explain the desired properties that are produced as a result of this process.
3. Look up at least 4 main parts of a modern aircraft that are made from composite materials.

7. SMART MATERIALS

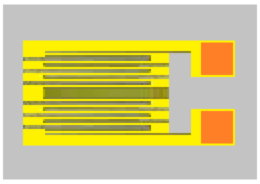
The structures and types of smart materials were described in outcome 1. The syllabus item is "The effects of post-production use". This phrase does not make a lot of sense to the author and has been construed as meaning "post-production uses". Here we will look at some uses for these materials.

PIEZOELECTRIC

The two important affects of this material is that it produces an electric charge when stressed and changes dimensions when an electric charge is applied. This makes it very useful in the electronics industry.

Electronic oscillators/timers - Quartz can be cut into precise crystals and used in electronic oscillators to regulate the frequency. The crystal resonates at the frequency defined by its dimensions and so it can be used to regulate or filter electronic oscillations. A good post production use is in quartz in watches.

Transducers – Many transducers involve making electrical measurements based on some form of mechanical movement or stress. If the thing being measured can be made to stress the piezoelectric material, a charge will be produced that forms the basis of the electrical signal that can be electronically processed to display the thing being measured. Here are some examples.



Strain Gauge – The piezo-resistive material forms the basis of gauges fixed to structures so that any changes in dimensions produce a change in resistance that is electronically processed to indicate the strain. This can be applied to a variety of instruments where the strain is produced by some other affect.

Force Gauge - Force produces strain so the strain gauge is the basis of many weighing systems. The gauge can be incorporated into many systems such as Torque measurement. The picture shows a button load cell.

Pressure Transducer – The pressure deforms a surface with piezoelectric material on it and so the electric charge represents the pressure. A typical sensor is shown.

Accelerometers – Acceleration produces a force which produces strain and hence strain gauges form the basis of instruments to measure acceleration. This forms the basis of many systems ranging from navigation to computer toys.

Vibration monitor – This is fundamentally a microphone that converts vibrations into a proportional electric signal.

Audio Devices – Microphones pick up air vibrations so a piezoelectric material will produce an electric signal representing the sound. When an oscillating electric signal is applied to piezoelectric material, it vibrates so simple loudspeakers and tone generators are made from this material. The picture shows an audio alarm using this principle.

Igniters – When a piezoelectric material is struck the high fast rate of strain produces a large charge of electricity that is sufficient to produce a spark between two electrodes and this is used in devices for igniting gas flames such as that shown.

Actuators and Motors – Piezoelectric materials change dimensions under the control of an electric charge so they can produce small mechanical motion that can produce linear movement or rotational movement. The movement is precise and is ideal for control devices.

ELECTRO-RHEOSTATIC (ER) FLUIDS

ER Fluids change their viscosity in the presence of an electric field. This may be used to change a liquid into a gel or almost solid structure. Here are some applications.

Hydraulic Valves – The change in the fluid is very quick so valves can be made to open and close very quickly at a flick of a switch.

Clutches and Brakes – The plates of the clutch are locked together by applying a charge to the fluid separating them. If one set of plates is fixed, the system is a brake.

Shock Absorbers – Many shock absorbers consist of a piston sliding inside a cylinder full of fluid. The fluid is forced through holes to produce a damping force. Increasing the viscosity of the fluid increases the resistance to motion so the stiffness of the shock absorber can be controlled electrically if the fluid is ER.

Robots – The joints of a robot can be locked by solidifying the fluid in them.

MAGNETO-RHEOSTATIC (MR) FLUIDS

MR fluids change their viscosity in the presence of a magnetic field. The applications are similar to those of ER fluids except that the change is produced by using an electromagnet instead of directly applying the electric charge to the fluid. Dampers and shock absorbers containing MR fluids are used in a variety of things like washing machines to damp out vibrations. Here are additional applications.

Prosthetics – Artificial limbs make use of damping devices (shock absorbers) and MR fluids are better for this than ER fluids.

Body Armour – It may become possible in the near future to make bullet proof clothes containing MR fluid.

Exercise machines - The stiffness or resistance in an exercise machine is sometimes electrically controlled with MR dampers.

SHAPE-MEMORY ALLOYS (SMA)

The structure of SMA was covered in tutorial 1. A SMA can be bent or stretched in the cold state and will keep the shape until heated above the transition temperature and it then returns to its original shape and keeps that shape when cooled again. Some SMA materials behave slightly differently and on cooling retain some of the deformation. One of the most popular memory metals is called Nitinol. It is mainly produced as wire and thin sheets before being turned into products.

You can download a very good tutorial on this material on this web site.
http://www.ccmr.cornell.edu/education/modules/documents/Nitinol.pdf

There is a lot of information about Nitinol manufacture and properties at this link.
http://www.memry.com/nitinol-iq/nitinol-fundamentals

You can see a Video demonstrating Nitinol wire at this link.
http://www.youtube.com/watch?v=Y7jjqXh7bB4

An important property of these alloys is that they are hard and springy above the transition temperature when in the Austenitic form. Below the transition temperature when in the Martensitic form it is soft and easy to bend.

Nitinol is super elastic, biocompatible and resistant to fatigue. Here are some applications:-

Glasses – The alloy has a low transition temperature is makes it ideal for the frames for optical glasses which are almost indestructible except at cold temperatures. The picture demonstrates the super elastic properties at normal temperatures.

Stents - are spring like devices inserted into arteries and veins to stop them narrowing. Nitinol is ideal as it stretches easily and is biocompatible.

Teeth Brace - In dentistry the tooth brace has an archwire that is bent into the shape of the patient's teeth. When the wire warms up in the mouth it tries to change shape and pushes on the teeth to gently force them into a new shape. The transition temperature for this use must be less than the body temperature (typically 27^{o}C).

Thermostats – When used in devices like electric kettles, the change in shape can be made to switch off the power at say 98^{o}C and this is an example of a thermostat. This implies that SMA can be made to have a range of transition temperatures. There are many applications for these devices such as anti-***scalding*** valves can be used in taps (water faucets) and shower heads.

Aircraft - Variable Geometry e.g. to reduce engine noise.

Pipe Couplings - oil line pipes for industrial applications, water pipes and similar types of piping for consumer/commercial applications.

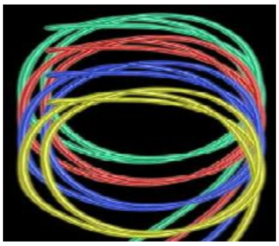
Muscle wire – This is nitinol wire that actually shortens in length when electrically powered. They can lift thousands of times their own weight. The direct linear motion is ideal for robotic use and small motors or solenoid activated devices. You can see a small robot in action with this wire at this link.
http://www.youtube.com/watch?v=k9f-W6Xi_Wo

COLOUR CHANGING MATERIALS

Thermochromic – Some substances change colour with temperature and this property is called Thermochromism. This has many uses such as indicating if a drink is too hot. There are two basic types, ***liquid crystals*** and ***leuco dyes***. Leuco dyes allow wider range of colours to be used, but their response temperatures are more difficult to set with accuracy.

Liquid crystals **–** are the name given to the material used in liquid crystal displays (LCD) but the optical properties are controlled by an electric field. These are widely used in display screens for many electronic devices.

Photochromic – Some materials change colour with light intensity. Glasses that darken in bright sunlight are an example. Usually, they are colourless in a dark place, and when sunlight or ultraviolet radiation is applied the molecular structure of the material changes and it exhibits colour. When the relevant light source is removed the colour disappears. This is used with T shirts to make logos appear. The picture shows colour changing threads.
These materials may be purchased from http://www.mindsetsonline.co.uk



Electroluminescent – These are materials that emit light of various colours when electricity passes through them. The material may be organic or inorganic. A typical EL material is a thin film of zinc sulphide with manganese and gives out a yellow-orange light.

SELF ASSESSMENT EXERCISE No.7

If you have already done this SAE in tutorial outcome 1 tutorial 3 then skip it.

1. Make a list of piezoelectric materials and give one application for each.
2. Make a list of the ER fluids available and give one use for each.
3. Make a list of the MR fluids available and give one use for each.
4. Make a list of the SMA materials available and give one use for each.
5. Define the meaning of thermochromatic, photochromic and electroluminescent.
6. The SMA Nitinol stands for nickel, and tin and the “nol” part stands for something also. Find out what this is.
7. Find out which kind of smart material has the brand named *INDIGLO* and give some uses for it.