

# UNIT 21: MATERIALS ENGINEERING

Unit code: F/601/1626

QCF level: 4

Credit value: 15

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## LEARNING OUTCOME 2

### TUTORIAL 2

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

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  - Chemical vapour deposition (CVD)
  - Thermo-reactive diffusion (TD or TRD)

## 1. INTRODUCTION

This tutorial continues the work covered in the previous one. It covers the methods of obtaining suitable properties in metals and polymers.

The properties of most materials can be changed to suits the requirements of the user. Some reasons for doing this is are:

- To make it harder or softer
- To make it more or less brittle
- To make it more or less tough
- To make it stronger
- To make it more or less ductile
- To change the melting or softening temperature
- To make it suitable for coating
- To make it more or less permeable or porous
- To make it more suitable for moulding/casting
- To make it more weldable
- To make it more machinable

You can no doubt find many more reasons. The treatment may involve heat treatment, mechanical working, treating with chemicals and exposure to radiation and so on. The following describes much of this but obviously it is a vast subject and you will need to look elsewhere for more specific or detailed information. There are some basic assessment exercises included but knowledge is best tested by the use of assignments.

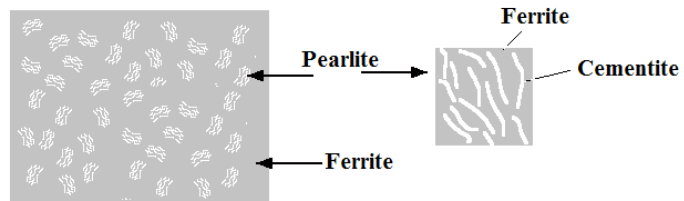
## 2. HEAT TREATMENT

### CARBON STEELS

You should already be familiar with the various structures of iron and carbide but here is a brief revision.

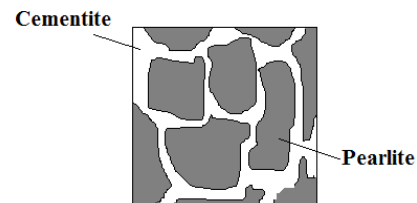
#### STRUCTURE

Carbon and iron form complex crystals on solidification. Crystals of **IRON CARBIDE**,  $\text{Fe}_3\text{C}$ , (also called **CEMENTITE**) forms up to a maximum of 13% of the weight. This is embedded in pure iron (Ferrite) to form a microstructure called **PEARLITE**. At the same time crystals of pure iron form producing the structure shown.



STRUCTURE OF LOW/MEDIUM CARBON % STEEL

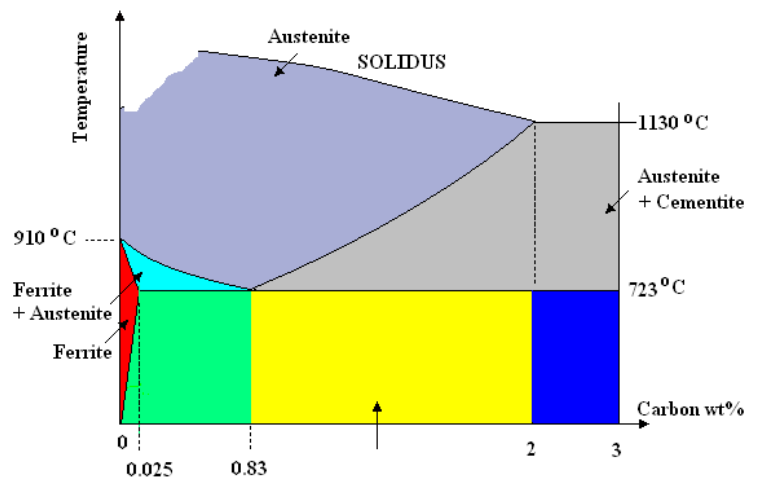
If the carbon is increased beyond 0.83% all the ferrite around the pearlite is used up forming pearlite and the structure becomes pearlite surrounded by cementite as shown.



STRUCTURE OF HIGH CARBON STEEL %

#### AUSTENITE and MARTENSITE

In this tutorial both may be thought of as different forms of steel. When heated above the critical temperature, all the carbon diffuses into the iron to produce a uniform structure called Austenite. This has a crystalline structure of Faced Centre Cubic (FCC). When this is quenched the structure changes into Martensite with a crystal structure that is Body Centred Tetragonal (BCT). Martensite is not shown on the phase diagram because it is not a stable phase and is not produced by cooling slowly. Martensite is easily converted into Austenite by heating it. Heating allows the carbon to diffuse out of the crystal lattice and cementite/ferrite crystals form.



You should have studied the thermal equilibrium diagram for iron and carbon and be familiar with the diagram. Basically the diagram shows what kind of transformations take place in the steel at different temperatures and carbon content. Temperatures on the equilibrium diagram are often referred to by the following definitions of the critical points where changes occur.

**Ac1**- The temperature at which, during heating, austenite starts to form

**Ac3**- The temperature at which, during heating, transformation of the ferrite into austenite ends

**Ar3**- The temperature at which, during cooling, transformation of the austenite into ferrite starts

**Ar1**- The temperature at which, during cooling, transformation of the austenite into ferrite + cementite ends

**Ms**- The temperature at which, during cooling, transformation of the austenite into martensite starts

**Mf** - The temperature at which, during cooling, transformation of the austenite into martensite ends

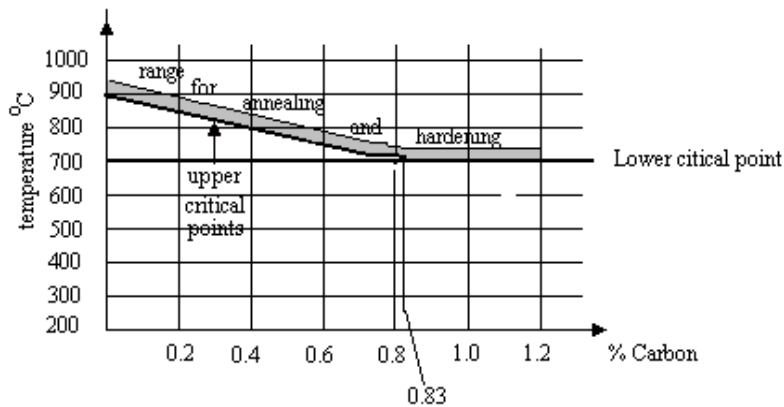
Carbon steel is broadly classified according to the % of carbon as follows.

NAME	CARBON %	TYPICAL APPLICATION
Dead mild	0.1 – 0.15	pressed steel body panels
Mild steel	0.15 – 0.3	steel rods and bars
Medium carbon steel	0.5 – 0.7	forgings
High carbon steels	0.7 – 1.4	springs, drills, chisels
Cast iron	2.3 – 2.4	engine blocks

### HEAT TREATMENT of CARBON STEELS

Heat treatment gives the steel specific properties. A series of one or more thermal cycles are carried out on the steel. During a cycle the steel is usually heated to a given temperature, held at this temperature for a certain time and then left to cool to room temperature in various ways according to the effects required. The various cycles are selected according to the hardness, toughness, microstructure and workability properties required. Before describing the individual heat treatments, consideration must be given to the critical points of steel as these must be known if the various cycles are to be carried out precisely.

Steels containing carbon can have their properties (hardness, strength, toughness etc) changed by heat treatment. Basically if it is heated up to red hot and then cooled very rapidly the steel becomes harder. Dead mild steel is not much affected by this but a medium or high carbon steel is.



When the steel is heated up to 700°C the carbon starts to dissolve into the ferrite to form a uniform structure called **AUSTENITE**. Austenite has a face-centred cubic crystal of ferrite and carbon. As the temperature increases, the process continues until at some higher temperature the structure is all austenite. The temperatures at which this process starts and ends are called the lower and higher critical points. The upper critical point changes with % C as shown on the diagram. Notice that above 0.83% C the upper and lower points are the same. If the steel is cooled slowly, the reverse process occurs and cementite and pearlite forms. The following are all forms of heat treatment.

### HARDENING

If steel just hotter than the upper critical point is plunged into oil or water (quenching) the steel cools very quickly. Instead of pearlite forming, a structure known as **MARTENSITE** is formed. This is a very hard substance and the resulting steel is hard. The degree of hardness depends on how fast it is cooled and water quenching is quicker than oil quenching. The graph shows the critical temperature plotted against % C. For example 0.3 % carbon steel should be heated to a temperature between 880 and 910°C.

TABLE OF HARDNESS OF QUENCHED STEELS

Carbon %	0.1	0.3	0.5	0.7	0.9	1.2
Brinell Hardness	150	450	650	700	680	690

## ANNEALING

The purpose of annealing is to soften hard steel. The steel is heated slowly to the upper critical point and held at this temperature for a time. It is then allowed to cool slowly. This process removes any stresses trapped in the material due to quenching, machining or mechanical working (such as rolling it).

TABLE OF ANNEALING TEMPERATURES RANGES FOR CARBON STEELS

Carbon %	0.12	0.12/0.25	0.3/0.5	0.5/0.9	0.9/1.3
Temperature °C	875/925	840/970	815/840	780/810	760/780

## NORMALISING

This is similar to annealing. When the steel has been kept hot for a long time (e.g. for forging), the crystals become very large. When a cold steel has been mechanically worked, say by cold drawing it into a bar, the crystals are elongated in one direction. Normalising returns the crystal structure to normal and it is carried out by cooling the steel in air.

## TEMPERING

The crystalline structure of Martensite is Body Centred Tetragonal (BCT). Martensite is easily converted into Austenite (a Face Centred Cubic crystal FCC) by heating. It is easier to quench steel and produce an abundance of Martensite and then produce the required hardness by heating to temperatures below the lower critical point. This allows some of the Martensite to change into Pearlite. This softens the steel but also makes it tougher.

TABLE OF TYPICAL TEMPERING TEMPERATURES

Component	Turning Tools	Drills Milling	Punches Twist Drill	Cold Chisels	Springs
Temperature °C	230	240	260	280	300

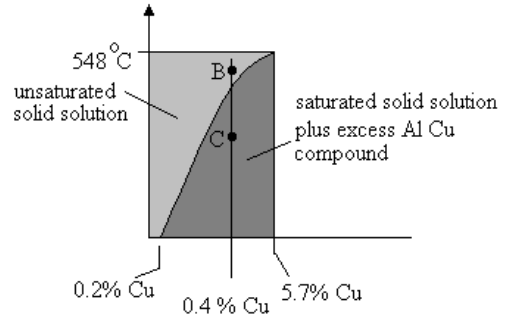
## HEAT TREATMENT OF OTHER METALS

Some metals such as aluminium alloys are classed as heat treatable or non heat treatable. The heat treatment methods for other metals and alloys are numerous and would need a vast amount of study to cover them all. One important method worth studying is solution heat treatment and aging.

### SOLUTION HEAT TREATMENT AND AGING

This is a process in which an alloy is heated to a suitable temperature and held at that temperature until one element has dissolved as much as possible into the other (solid solution). It is then cooled rapidly to hold that constituent in solution. Most solution heat treatments soften or anneal

Consider the case of an aluminium-copper alloy. Part of the thermal equilibrium diagram is shown. This shows that in going from 0 to 548°C the amount of copper that can be dissolved in aluminium increases from 0.2% to 5.7%. The light grey section contains an unsaturated solid solution. The dark grey portion contains the maximum dissolved copper possible (saturated solution) and any more copper than these forms the compound  $\text{CuAl}_2$ .



Consider the alloy known as Duralumin widely used in making skins for aircraft and containers. This alloy contains 4% copper. Suppose the molten solution cools down very slowly. First it will pass through the unsaturated portion and will eventually end up as a saturated solution with excess copper.



At room temperature the structure will be as shown left with a background of solid saturated solution with 0.2% Cu and the rest are particles of compound containing the other 3.8% of the copper. The compound is a hard and brittle substance so duralumin in this form is brittle.



Suppose we now heat up the alloy to point C. The compound gradually dissolves into the solid solution (diffusion of atoms) as shown. At point B, just below the melting temperature, all the copper is dissolved into the solid solution with no compound at all. The alloy has to be kept at this temperature long enough for the transformation to be complete. If the alloy is now quenched in water for rapid cooling, the copper is trapped in the solid solution and the solid solution is supersaturated. The quenched structure is stronger and more ductile. This is an example of **SOLUTION TREATMENT**.

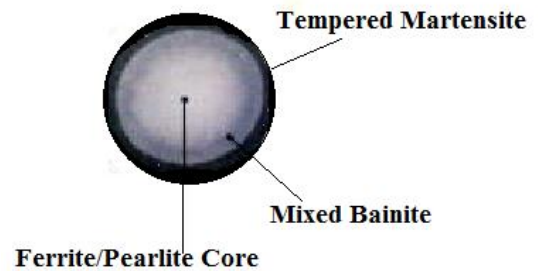
If the quenched duralumin is left at room temperature for a few days, the structure partially reverts to the equilibrium condition and the strength and hardness increases and the ductility reduces. This is called **AGE HARDENING**. This process may be accelerated by heating the alloy to 160°C and this is called **PRECIPITATION HARDENING**.

### 3. THERMO-MECHANICAL PROCESSING

This is also called **thermo-mechanical treatment (TMT)**. It is a process of obtaining suitable properties (mostly for steel) by a combination of work hardening and heat treatment done together during processing. The hot steel is usually rolled and quenched as it emerges and this produces a harder surface but a softer core. Typically a bar being made this way has the surface compressed. Intermediate layers have a deformed crystal structure and these become tempered by the heat from the core.

For example steel reinforcing bar for concrete structures is made as follows. A steel billet is heated to around 1100°C and then progressively reduced by rolling to the final size and shape. After the last rolling stand it is quenched. This converts the surface layer to martensite and causes it to shrink. The shrinking compresses the core. The core has a structure of austenite and remains hot. Strict control of the quenching produces the required mechanical properties. As the core cools the surface heats up and tempering occurs. An intermediate layer between the centre and surface will have a structure of bainite. Slow cooling in the final process tempers the core to ferrite and pearlite.

The final result is a strong and tough bar with a tempered martensite in the surface layer of the bar, an intermediate layer of martensite and bainite, and a refined, tough and ductile ferrite and pearlite core. The bars do not need to be further cold worked to produce work hardening.



This web link provides a good tutorial on the subject.

<http://www.slideshare.net/ansarrizvi/thermo-mechanical-treatment>

The following describes some of the controlled processes used in TMT for steel.

1. Rolling down from the normalising temperature, yet fully austenitic (above the  $A_{r3}$  temperature) followed by a rapid cool of approximately 10°C/sec. This produces a refined grain size and increases the strength by suppressing the formation of ferrite and pearlite in favour of a strong tough bainite.
2. Rolling above or below the  $A_{r3}$  in the austenite ferrite mixed region. This produces austenite grain refinement and the recrystallised grains are flattened and nucleation of fine ferrite is encouraged by the deformation. At a temperature above the  $A_{r1}$ , the controlled rolling is interrupted, and followed by rapid cooling to room temperature or an intermediate temperature.
3. Rolling is a preliminary process, followed by cooling and reheating to just above the  $A_{r3}$  temperature and then rapid cooling to well below the  $A_{r1}$  temperature. This develops the finest equiaxial austenite grain size before the cooling begins.

By appropriate choice of deformation temperature and strain rate, the strength of the steel can be increased. The strength of a TMCP steel is higher than for normalised steel of the same composition. Thus a TMCP steel has a leaner composition (lower alloy content) than a conventional normalised steel of the same strength.

The lean composition of TMCP steels can be beneficial with respect to weldability.

## **SELF ASSESSMENT EXERCISE No. 1**

1. In relation to carbon steel do the following.
  - (a) Describe the method of carburising.
  - (b) What process would you use to harden gear teeth and machine tool slideways?
  - (c) Describe the process of full annealing.
  - (d) Why can't wrought iron be heat treated or hardened?
  - (e) Look up and list alloys that can be solution treated.
2. Find out by research and explain how Thermo-Mechanical rolling has influenced the manufacture of large steel pipelines. What are the improvements made to the steel structure that has made it suitable for natural gas pipe lines in hostile environments?
4. Find out by research and explain how and why aluminium alloy rivets are made soft in preparation for use. If they are not used immediately they are often refrigerated at 0°C. Why is this? Here is a useful source:

<http://avstop.com/ac/apgeneral/rivets.html>



## 5. MODIFYING POLYMERS

### POLYMERS

Polymers may be moulded or machined depending upon their mechanical and thermal properties and this was covered in the previous tutorial. A copolymer is a polymer made from more than one mono-polymer and (covered in tutorial 3 of outcome 1).

### ADDITIVES and MODIFIERS

The final properties of a product may also be enhanced by using additives in the polymer. These are very numerous and impossible to describe in detail here so you will need to search for more if required.

This web link gives a comprehensive list

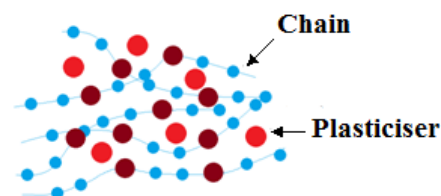
<http://www.specialchem4polymers.com/tc/index.aspx>

The properties of polymers can be changed in a number of ways. This can involve using additives to change the crystallinity, the chain length of the molecules, cross linking the molecules or plasticising (opposite of cross linking).

Increasing the length of the molecules is similar to increasing the crystallinity and both of these affect the mechanical and thermal properties of the polymer.

### PLASTICISERS

These are also called **dispersants** and are added to improve the flow of the polymer during moulding and extrusion. It reduces the glass transition temperature thus making the polymer softer. The substance gets between the chains of molecules and keeps them apart. One of the main polymers to benefit is polyvinyl chloride as it makes PVC more flexible and durable. One of the main plasticizers is called **phthalate**. Plasticisers are also important in rubber making.

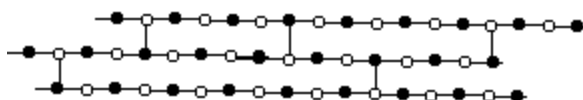


Some plasticisers are giving concern as a health risk. Among the phthalate-based plasticizers the ortho-phthalates have been restricted in the European Union, and more recently in North America. Alternates to phthalates are being developed.

### CROSS LINKING

The amount of the polymer that forms crystals is called its crystallinity. The higher the crystallinity of the polymer, the stronger and stiffer the material becomes and the melting point gets higher. The melting point of the polymer is basically the melting point of the crystals. When the polymer is heated the crystals will melt, the material will become very soft and can flow slowly like a thick liquid. In this state the polymer can fill a mould and be cast into a shape. When the polymer cools down, new crystals can form between the chains and the new shape is fixed.

You may recall that a **thermoplastic** may be re-melted over and over but a **thermosetting** plastic can only be melted once. Thermosetting polymers are not suitable for re-melting. They set into a hard state by initiating a chemical reaction either by heating them or mixing them with a catalyst (often this is initiated by exposure to Ultra Violet light). This process is called **curing** and it makes the molecules **cross-link** forming a more rigid structure. Reheating will not soften the polymer.



Crosslink polymers such as acrylates, polyethers, polyurethanes, and polyesters have better:

Tear resistance  
Tear propagation

Elongation at the break  
Abrasion resistance

Examples of thermosetting polymers are

1. Melamine resin - used in furniture.
2. Bakelite - used for saucepan handles and electric light fittings.
3. Epoxy resins - used in many types of glue.

## SILICON

You may well have come across products like silicon adhesives, sealants and rubber. You may have used sprays that make a surface repel water. All these contain silicon (Si) in some form of a compound.

**SILICON RUBBER** - Silicon rubbers are inorganic synthetic elastomers made from a cross linked silicon-based polymer reinforced with filler.

### Silicon rubbers are widely used in:

- Automotive gaskets, diaphragms and valves, boots, O-rings, hoses, cables, and connectors
- High-voltage insulators, insulator coatings, and cable accessories for electrical power transmission
- Keypads and photocopier rollers
- Aids for food preparation and delivery including bake ware
- Infant care including baby bottle nipples and pacifiers
- General seals and gasket preparation
- Tubing and profiles
- Calendared goods
- Fabric coating
- Air, fluid and material delivery devices, including tubing and conveyors
- Protective equipment and masks
- Sporting goods and toys
- Three-dimensional extruded profiles
- Mould making and prototyping

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### Advantages of Silicone Rubbers

- Long service life in adverse environments
- Minimally affected by weather extremes such as rain, snow, humidity, ozone or damaging ultraviolet (UV) rays
- Flexible and resilient across a wide temperature range
- Excellent electrical insulating qualities that do not change significantly under severe environmental stress
- Enhanced comfort and feel of consumer goods
- Excellent sealing performance
- Inertness, which makes them ideal for many food-contact options
- A wide hardness range from 10 to 80 Shore A
- A wide range of colour choices from transparent to brightly coloured
- Excellent resistance to a wide range of fluids and chemicals
- Noise and vibration control
- Water repellent
- Wide range of high consistency silicone rubber (HCR) and liquid silicone rubber (LSR) materials as well as standard silicone rubber compounds, silicone rubber bases or additives to meet your specific processing and performance needs

**SILANES** - is the name of the substance with chemical formula  $\text{SiH}_4$  and it is a toxic, extremely flammable substance. Other compounds of silicon are also called silanes and they are widely used as additives in polymers. This important range of additives is used to create cross links and hence curing and hardening of the product.

**Silanes are used in:**

- Automotive
- Energy Transmission
- Coatings
- Construction
- Paints and Inks
- Green Tire
- Plastic and Rubber
- Pigment Treatments
- Mineral Filler and Sealants and Adhesives
- Fibreglass and Composites

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**Silanes can be used as:**

- Coupling agents to bind organic polymers to mineral or siliceous fillers, resulting in improved mixing, bonding and strength
- Cross linking agents to improve a polymer's resistance to tears and abrasion
- Adhesion promoters
- Hydrophobing (water-proofing) and dispersing agents
- Water scavengers to capture excess moisture/prevent premature curing
- Polypropylene catalyst "donor"

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**Advantages of Silanes**

- Mechanical strength
- Electrical properties
- Moisture resistance in polymers
- Water repellent
- Adhesion
- Compatibility
- Dispersion of pigments, minerals and fillers
- Polymer yield

Silanes are used to change the surface properties of a material. This is why it is so useful in making various kinds of coatings adhere to difficult surfaces. It also helps the bonding of glass and carbon fibre to the resin matrix. They are also used in the production of microchips by affecting the surface of the polycrystalline silicon wafers. Ink and paint are examples of products that benefit from silane monomer additives. In particular it is used to promote adhesion between elastomers and difficult surfaces such as resinous coatings and metals. Other applications include:

- Abrasion resistance
- Pigment and filler dispersion
- UV resistance
- Water and chemical resistance
- Abrasion resistance
- Composite strength
- Rheology control
- Rolling resistance in tires
- Toughness
- Wet electrical properties

**WATER REPELLENTS AND SURFACE PROTECTION**

Silanes are used in surface layers to repel water and stains. There is a wide range of silanes, siloxanes, and emulsions that solve surface coating problems in construction. They are used to make surfaces resist the absorption of water and oil.

**SELF ASSESSMENT EXERCISE No. 2**

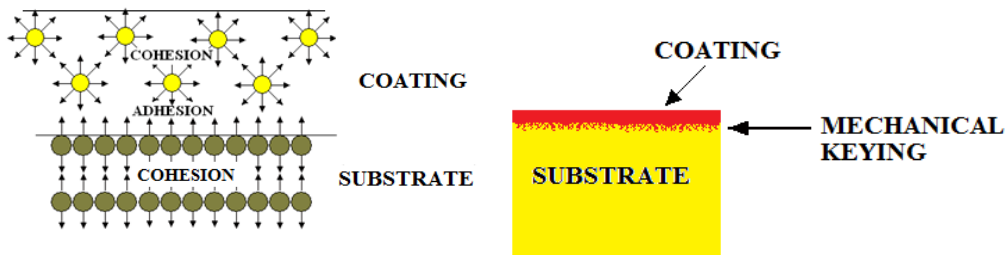
1. Find out the general purpose of an "O" ring seal as used in Hydraulics or other applications. If such a seal is to be used on the piston rod of a hydraulic cylinder in very cold temperatures, what would be the mechanical properties and the chemical properties required from the material? Suggest suitable materials.  
If the cylinder had to work in very hot temperatures, what would be the mechanical properties and the chemical properties required from the material? Suggest suitable materials.
2. By researching explain why Silanes have found a use in dental treatment?

## SURFACE TREATMENTS

Surfaces of objects are coated with various substances to obtain the required property. This might be to make the surface:

- sticky
- non stick
- slippery
- decorative
- resistant to various forms of corrosion
- repel water or other liquids
- stick to liquids
- hard and resistant to wear
- resistant to cracking
- suitable for specialised purposes like silicon wafers and semiconductor circuitry

The coating may be very thin (e.g. in semiconductors) or thick (e.g. galvanised steel). The coating material must bond to the surface (this is the substrate). The way the coating attaches and affects the surface is important. Some stick to the surface through molecular adhesion. Others depend on mechanical keying and absorption into the substrate. Others react chemically with the surface through chemical cohesion between the two substances. In other cases the chemical compound formed, such as an oxide film, is itself the coating. In chemical adhesion two materials may form a compound. If the atoms swap or share electrons we have ionic or covalent bonding. In reality the coating may be a combination of these.



Traditional methods of protecting and enhancing metallic surfaces are:

**Galvanising** - is a method of coating steel parts with zinc either by hot dipping (dipping in molten zinc) or electro depositing methods. This makes the part highly resistant to corrosion and gives it a silvery finish. It is widely used on things like fencing wire, nails and general outdoor items.



**Sheradising** – is a form of galvanising called vapour galvanising. The objects (usually small engineering components) are put in air tight containers with zinc powder at temperatures below the melting point of zinc. Zinc diffuses into the substrate by vaporising and reacting with the iron.

**Calorising** - is a method of imparting resistance to oxidation to an iron or steel surface by heating in aluminium powder at 800° to 1000°C. The process creates a rich layer of alumina (a ceramic) which significantly increases the surface hardness of the component (600-650 BHN) and gives it greatly improved wear resistance. The intermetallic layer seals the base metal improving resistance to oxidation, sulfidation, and carburisation and hydrogen permeation.

**Chromising** - is used for steel components that work at high temperature such as valves for internal combustion engines and forging tools. The substrate must be carbon steel (typically 0.6%C) and after treatment the surface has a chromium content of 13 to 30%. Iron chromate granules (FeCr) are heated in an atmosphere of hydrogen and hydrogen chloride (H<sub>2</sub>+HCl) at about 850°C. The chemical reaction inserts chromium into the substrate surface.

**Chromating** - is the process of covering a surface with an oxide layer that chemically reacts to form metal chromates. Chromating is often used to prepare steel, aluminium, and magnesium surfaces. The process is based on dipping the component in chromic acid. Chromate conversion coatings are common on everyday items such as hardware and tools and usually have a distinctive yellow colour.

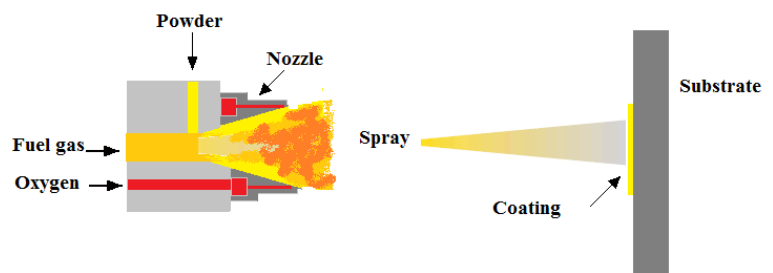


**Phosphating** - is the process of coating a metal surface (usually steel) with phosphates. Phosphate improves the corrosion, wear-resistance and lubricity of a steel surface. It also provides a foundation for other coatings principally paint. The parts are dipped in or sprayed with iron, zinc or manganese phosphate salts dissolved in a solution of phosphoric acid. A reaction takes place causing the iron phosphate, zinc phosphate or manganese phosphate to precipitate onto the surface.



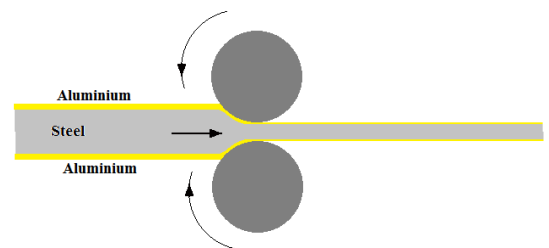
**Metal Spraying** – is also called thermal spraying. The process involves coating things like machine parts, tools, and structural steel with metal usually to protect it from corrosion. The most typical coating materials are zinc, aluminium, alloys, ceramics, plastics and composites. Cobalt or nickel with a little amount of chromium, and manganese chrome help create a harder surface on soft materials to resist wear and tear.

Powder or wire is heated to a molten or semi-molten state and blasted as tiny particles onto the substrate. Thick coats are obtained by repeated spraying. The process involves melting the coating by means of an arc or flame. The particles are then sprayed at high velocity on the surface to be coated using compressed air to propel it. The common processes used are called flame, arc, and plasma. One advantage of this method is that coatings of thickness 20 µm to several mm can be quickly sprayed over large surfaces, something that cannot be done with other methods.



This is a useful link for more information. <http://www.amphardchrome.co.uk/metal-spraying.php>

**Cladding** – is a way of coating sheet materials with another by rolling them together in layers so that they become bonded. The main example is cladding steel with aluminium by rolling them until a steel sheet with an aluminium coating is obtained. The two materials basically weld together. The name is also used for many other covering processes.



**Anodising** – is a process of coating metal surfaces with anodic oxide. The surface is decorative, durable and corrosion-resistant. The metal (typically aluminium) is immersed in a bath of electrolyte and a current passed through the circuit. The component forms the anode of the circuit. Oxygen ions are released from the electrolyte to combine with the aluminium atoms at the surface to make the oxide film. The film does not chip or peel like paint. The oxide is porous and suitable for painting but generally it is harder than aluminium but has low to moderate wear resistance that can be improved with increasing thickness or by applying suitable sealing substances. Other nonferrous metals, such as magnesium and titanium, also can be anodised.



Anodised carabinas

**Electroplating** – is similar to anodising but the component is the cathode. The surface is coated with another metal usually for decorative purposes (e.g. silver) or for protection from corrosion, abrasion etc. (e.g. chrome plating). The object is immersed in a salt solution of the metal that will be used to plate the object. The electric current creates positive metallic ions of the salt which are attracted to the part being plated where it reverts to metal on contact.

## **PLASTIC AND PAINT COATING**

This is used to cover the surfaces of many parts with polymer and there are many methods and materials used. Here are a few.

**Dipping** - the metal components are dipped into thermoplastic powders in a fluidised bed. Components are pretreated, usually degreased and shotblasted, heated up to between 250 and 400°C depending upon the coating required, then dipped into the Fluid Bed of plastic. The Powder particles melt onto the metalwork forming a smooth continuous coating.



**Chain**

### **Advantages**

- Thicker coatings (0.3mm up to 1.00mm)
- Smooth continuous coating
- Very long service life
- Extreme corrosion resistance
- Excellent chemical resistance
- Good Edge (metal) coverage
- Excellent UV and weather resistance
- Non-toxic coatings.

### **Typical components**

- Medical Furniture
- Transmission and Gearbox components
- Stacking Chairs
- Domestic and commercial wirework
- Wheelchair parts
- Automotive Springs, Brackets & Pressings.
- Stadia Seating
- Outdoor Street and Park Furniture
- Litter Bins
- Automotive aftermarket accessories

**Electrostatic** - the powder is sprayed onto the parts usually as they move along a track. The powder is attracted to the parts by electrostatically charging them and grounding the components. The coated parts then move through an oven typically at 180°C for about 10 minutes in the case of thermosetting polymers to melt them and cure them to produce an attractive finish. Pre-treatment chemistry assures adhesion and a uniform. Typical polymers used are Epoxies, Polyesters and Urethanes. Metal surfaces coated are typically Steel, Aluminium, Zinc, Brass and Copper. If thermoplastic coatings are used the process powder is melted and no curing takes place.

Typical components

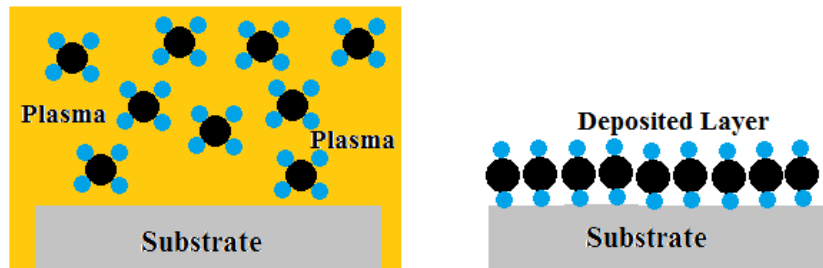
- Rainwater Gutters and down pipes
- Roof rack components
- Outdoor Wirework
- Garden Equipment
- Industrial Roof Insulation Supports
- Display equipment
- Hand railing
- Security Posts
- Barriers



**Pipe Clip**



**Plasma** - is neither solid, liquid or gas and it is usually obtained by heating a substance to a high temperature. It contains positive ions, electrons, neutral gas atoms or molecules, UV light and also excited gas atoms and molecules. By choosing the gas mixture, power and pressure it can be precisely made to produce the required result. Plasma treatments are performed in an evacuated enclosure, or chamber. The air is pumped out and a gas is allowed to flow in at low pressure before energy in the form of electrical power is applied. It's important to note that these types of plasmas are actually at low temperature, meaning that heat sensitive materials can be processed quite readily. For example they can be made to cover a surface so that they are either hydrophobic (repels water) or hydrophilic (attaches to liquids). The process creates a very thin layer on the substrate in just a few minutes that does not affect the look or feel of the material. It is a permanent coating that bonds to the substrate on an atomic scale. The monomers are introduced with the plasma feed gas. Plasmas create the right conditions at the surface of the material for the monomers to combine and bond.



This link shows a video of plastic plasma spraying

[http://www.plasmatreat.co.uk/plasma-treatment/plasma-pretreatment/plasma-coating\\_nano\\_coating.html](http://www.plasmatreat.co.uk/plasma-treatment/plasma-pretreatment/plasma-coating_nano_coating.html)

Plasma coating is suitable for

- general plastics and rubber
- performance textiles
- filtration media
- metals, glass, ceramics and composites
- medical plastics
- consumer electronics plastics
- automotive components
- aerospace components
- Improvement of barrier characteristics of plastics for packaging using plasma polymer nanocoating
- Making the surface better for painting with long-term stability and resulting high flexibility in manufacturing
- PT Release coatings, for injection molding tools, allow a high number of process cycles without the components having to be stressed with release agents that contain silicone.
- PT Bond coatings assure long-term adhesion in the adhesive joint.
- Because of their good barrier effect, corrosion protection coatings offer extremely high corrosion protection with long term resistance to corrosive electrolytes – especially for aluminum alloys.

### Paint coating

Painting is such a vast subject that it cannot be dealt with satisfactorily in a tutorial. The reasons for painting are the same as for plastic coating. The materials used depend on the substrate and properties required. Application may be by brush, spray or electrostatic. Paint can have many types of finish and to make the coating durable paint must bond to the substrate.

## CERAMIC COATING

Long established uses of ceramic coatings include glass enamel where glass powder in a paste is coated onto a surface and then heated until it melts and fuses. Silk screen printing followed by heating is used to print patterns and labels on glass ware in a similar process.

Products such as cutting tools and components subject to wear and abrasion are surface treated to improve the wear resistance, friction and hardness thereby increasing the life span. Materials treated include High Speed Steels, carbides (cermets), and a wide variety of tool steels. There are many methods of doing this and the following is a brief description of some. Silicon chips are also a ceramic so some of this applies to their manufacture.

### **Physical vapour deposition (PVD)**

This describes a range of processes for depositing metallic films on surfaces. All of them occur in vacuum of 10 mbar or less. The substrate to be coated is bombarded with energetic positively charged ions. Gases such as nitrogen, acetylene or oxygen may be introduced into the vacuum chamber during metal deposition to create various surface compositions. The result is a very strong bond between the coating and the tooling substrate and tailored physical, structural and tribological (friction and wear) properties of the film. The coating of the surface may be done with a cathodic arc or electron beam sources.

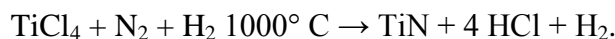
### **Chemical vapour deposition (CVD)**

This process is carried out in an atmosphere at high temperatures (typically 1050°C) in a CVD reactor. During this process, thin-film coatings are formed as the result of reactions between various gaseous phases and the heated surface of substrates within the CVD reactor. As different gases are transported through the reactor, distinct coating layers are formed on the tooling substrate. The process gives very accurate pure layers and is widely used in producing the different layers in a microchip.

### **Titanium Nitride (TiN)**

This is an extremely hard ceramic material often used as a coating on titanium alloys, steel, carbide, and aluminium components to improve the substrate's surface properties. Also known as Tinite it is applied as a thin coating (typically less than 5 µm) to harden and protect cutting and sliding surfaces, for decorative purposes (due to its gold appearance), and as a non-toxic exterior for medical implants. An example is shown.

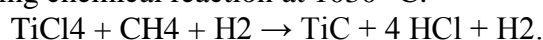
During the CVD process TiN is formed as a result of the following chemical reaction at 1000°C



Look at this link to see more examples <http://www.yellowjersey.org/tin.html>

### **Titanium carbide (TiC)**

**This** is an extremely hard refractory ceramic material, similar to tungsten carbide (around 9 to 9.5 on the Moh scale). It is commercially used in tool bits and has the appearance of a black powder. It is formed as the result of the following chemical reaction at 1030° C.



The final product of these reactions is a hard, wear-resistant coating that exhibits a chemical and metallurgical bond to the substrate.



## **Thermo-reactive diffusion (TD or TRD)**

This is a high temperature coating process for producing metal carbides (typically vanadium carbide) on the surface of a carbon-containing substrate. The process has several stages consisting of a pre-heat cycle, a coating segment, ultra-sonic cleaning, heat-treating, and post-coating polishing. The coating is performed in a molten bath of solute (typically Borax), a metal source, and a reducing agent. Carbide-forming compounds in the bath react with carbon in the substrate and produce metal carbides on the substrate surface. TD coatings exhibit a diffusion type bond, thereby providing superb adhesion between the metal carbide layer and the substrate. This produces excellent resistance to the types of wear and galling often seen in many metal-forming processes.

## **Mechanical Processes**

An example of this is peening. This is a process of hammering a surface to spread it and shape it. Another example is shot peening (also called shot blasting). This is a process of bombarding the surface with particles to remove contaminants such as scale in preparation for another treatment. The process also deforms the surface putting it into compression. It can be used to curve a thin plate (a method used in making aircraft wings). It also improves the fatigue strength because it closes up micro cracks and removes scratches. Polishing by other methods also removes fine surface cracks and improves the fatigue life of the component. The picture shows a gear being treated to make it more resistant to fatigue.



### SELF ASSESSMENT EXERCISE No. 3

1. Using any source of information describe in full the process of chromating aluminium. Name three parts that will benefit from this process and explain the reasons why they benefit.
2. Using any source of information describe in full the process of phosphating. Name three parts that will benefit from this process and explain the reasons why they benefit.
3. Describe in detail the process of chromium plating metal components. Describe 3 components that are coated this way and explain the benefits of the process. How is the thickness of the coating controlled?
4. Find out what kind of polymer is designated FFKM and list the mechanical and chemical properties it has. What are the processes used on it to give it its properties.

“O” ring seals made from FFKM were the cause of the space shuttle Challenger’s disaster. Which property of the seal was the cause of this?

Find out what surface treatment is suitable for “O” ring seals to make them:

- Have less friction
- Easier to install

5. Find out the basic processes used in the manufacture of silicon micro chips. After the silicon wafer is made, a layer of silicon dioxide is deposited on the surface. Explain the process and how it is done. What further layers are deposited to make the circuitry complete? Describe the changes created in the substrates as a result of each process.
6. Some cheaper drill bits made of alloy steel are coated in titanium nitride. Why is this? Explain how the process is conducted and how the titanium molecules bond to the steel.