C. V. Raman Polytechnic, Bhubaneswar

Department of Mechanical Engineering

LECTURES NOTE

Subject- Engineering Materials

3RD SEM MECHANICAL

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Phase diagram

❖ **System, phases and structural constituents**

A **system** is a substance isolated from its surrounding and is subjected to changes in overall composition. It is classified according to number of components that constitute the system. A system having one component is known as unary system, 2 component known as binary system etc.

A **phase** may be defined as any part or portion of chemical system which possesses distinctive physical characteristics, limited by definite bonding surfaces and mechanically separated from its surrounding.

A **structural constituent** may be referred as the association of phases in a recognizable distinct fashion.

❖ **Cooling curves:**

It is a method to determine the temperature at which phase change occurs in an alloy system, consists of following the temperature as a function of time as different alloys in the system are very slowly cooled. The data obtained in this manner form a cooling curve for each alloy.

This method is used

➢ Study the changes occur during the solidification of alloys
➢ Determining transformations corresponding to solidification

(a) Cooling curve for pure metal
   ➢ The liquid metal cools from P to Q. solidification starts at Q
   ➢ From Q to R, the melt liberates its latent heat of fusion in such amount that, the temperature remains constant until the whole mass solidifies.
   ➢ In between Q to R, there exists both liquid and solid phase
   ➢ On further cooling from R to S, the solid metal cools and reach at room temperature

(b) Binary solid solution
   ➢ The liquid metal cools from P to Q. solidification starts at Q
   ➢ During freezing, the temperature does not remain constant, rather it drops along QR line till the whole mass is solid at R. this temperature drop occurs due to changes in the composition of solid and liquid phases.
   ➢ On further cooling from R to S, the solid metal cools and reach at room temperature

(c) Binary eutectic solution

- ➤ In this, the two components are completely soluble in liquid phase but insoluble in solid phase
- ➤ The liquid metal cools from P to Q. solidification starts at Q
- ➤ At Q, the component having excess composition will crystallize and the temperature will drop along QR
- ➤ At R, the liquid composition has been reached where the two components will crystallize simultaneously. This occurs at constant temperature.
- ➤ On further cooling from S to T, the solid metal cools and reach at room temperature
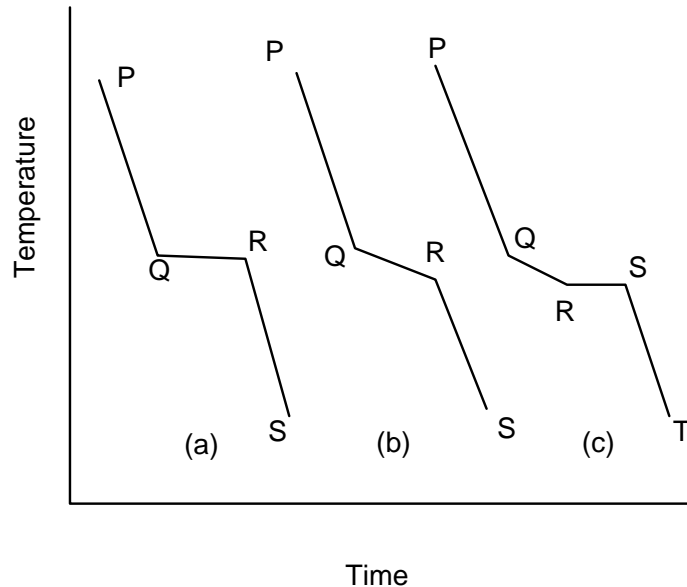
Figure. Cooling curve for (a) pure metal, (b) binary solid solution and (c) binary eutectic system

Phase diagram

- ➤ It is also known as equilibrium diagram and is used in study of alloys.
- ➤ It has temperature in y-axis and composition in X-axis.
- ➤ It shows phases present at different compositions and temperatures under slow cooling (equilibrium) conditions.
- ➤ It indicates equilibrium solid solubility of one element/compound in another.
- ➤ It suggests temperature at which an alloy starts to solidify and the range of solidification.
- ➤ It shows Liquidus line (the line above which the melting of an alloy is complete or at which the solidification starts) and solidus line (the line where the solidification is complete or melting begins)
- ➤ If two metals of a binary solid solution (such as Cu-Ni)system are mixed in different proportions, melted and then cooled, and a cooling curve is constructed for each composition as shown in figure, the resulting diagram obtained by joining points Q1, Q2… and R1,R2…will be the phase diagram.

➢ The phase diagram shows two distinctive phases one is solid solution another is liquid solution. Within these two phases, both solid and liquid phase exists together.
➢ If the phase diagram, for each change of phase, sufficient time is given for the change to complete under equilibrium condition, the phase diagram is known as equilibrium diagram.

Phase diagram is classified as

1. Unary Phase diagram: If a system consists of just one component (e.g.: water), equilibrium of phases exist is depicted by unary phase diagram. The component may exist in different forms, thus variables here are – temperature and pressure
2. Binary Phase diagram: If a system consists of two components, equilibrium of phases exists is depicted by binary phase diagram. For most systems, pressure is constant, thus independently variable parameters are – temperature and composition
3. Ternary phase diagram: It consists of three component system. It deals with three metals.
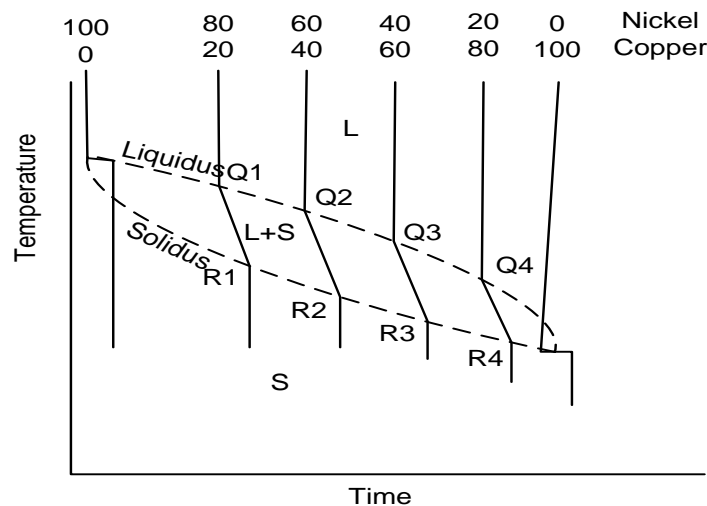

Figure. Phase diagram

❖ Interpretation of phase diagram
  ➢ The phases present
  ➢ Chemical composition of phases
  ➢ The amount of each phase using lever rule

Lever arm principle

• If an alloy consists of more than one phase, the amount of each phase present can be found by applying the lever rule to the phase diagram.

• It is a tool used to determine weight percentages of each phase of a binary equilibrium phase diagram. It is used to determine the percent weight of liquid and solid phases for a given binary composition and temperature that is between the liquidus and solidus.
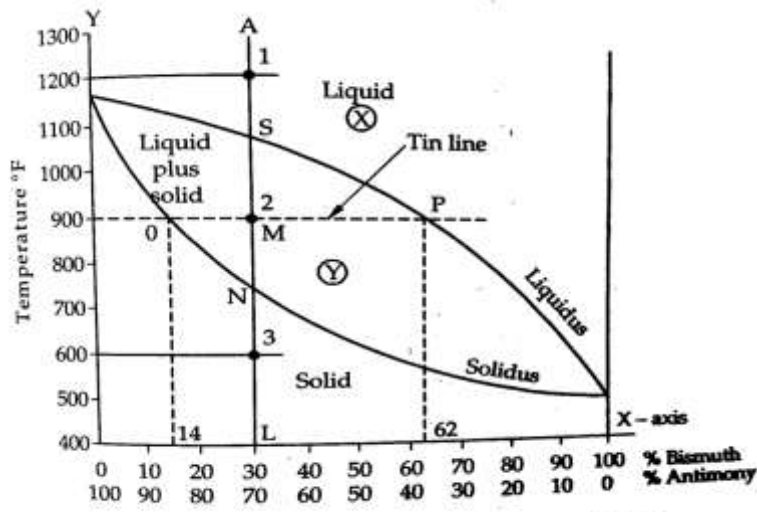
Fig. 39.4 Interpretation of phase diagram (Sb-Bi)

- To determine the relative amount of two phases, extent the ordinate at a point (say 30% Bi) on the composition scale which gives the total or overall composition of the alloys.
- The intersection of this composition vertical (AL) and iso thermal line OP is the fulcrum of a simple lever system. OM and OP are the two lever arms.
- The proportion of solid corresponds to the length of the segment adjacent to liquidus line, where as the fraction liquid corresponds to the solidus line.
- The line OMP is called as tie line. It is an isothermal (constant temperature) line through the alloy's position on the phase diagram when it is in a two phase field, intersecting the two adjacent solubility curves.

Mathematically,
The amount of solid phase

$$\frac{MP}{OP} \times 100 = \frac{62-30}{62-14} \times 100 = 66\frac{2}{3}\%$$

The amount of liquid phase

$$\frac{OM}{OP} \times 100 = \frac{30-14}{62-14} \times 100 = 33\frac{1}{3}\%$$

❖ **GIBBS PHASE RULE**

- It establishes relationship between number of degree of freedom (F), the number of Components (C) and the number of phases (p).
- P+F=C+2

- At Point X

    C=2, P=1

    F=C+2-P =3 degrees of freedom
- At point Y

    C=2, P=2

    F=C+2-P =2 degrees of freedom
- Degrees of freedom refers to the number of independent variables (e.g.: pressure, temperature) that can be varied individually to effect changes in a system
- In practical conditions for metallurgical and materials systems, pressure can be treated as a constant (1 atm.). Thus Condensed Gibbs phase rule is written as:

    P+F=C+1

❖ Iron- An allotrope

   - ➢ Iron is an allotropic metal which means that it exists in more than one type of lattice structure depending upon temperature.
   - ➢ Iron is molten above 1539°c
   - ➢ Upon cooling, it solidifies in δ-Fe of BCC structure
   - ➢ On further cooling at 1400°C, the phase change occurs and the atom rearrange it-self into γ-Fe of FCC structure
   - ➢ The further cooling at 910°C, another phase change occurs from non magnetic FCC structure to BCC structure. α-Fe exists at this temperature
   - ➢ Finally, at 770°C, non- magnetic α-Fe gains its magnetic property without change in its lattice properties.
   - ➢ In room below 770°C temperature, α-Fe exists, which is of BCC structure and magnetic in nature
   - ➢ **Curie point:** 770°C is known as curie point. After heating above this temperature limit, the magnetic property of iron disappears.
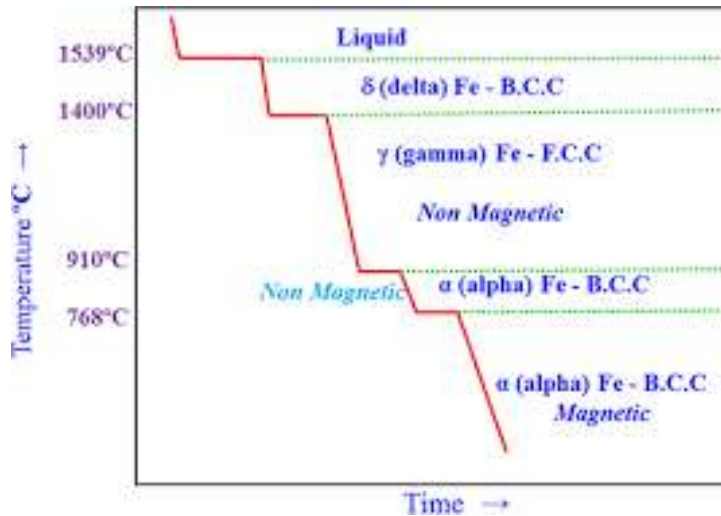
❖ Iron-Carbon Equilibrium diagram

Iron-Carbon equilibrium diagram indicates the phase changes that occur during heating and cooling and the nature and amount of structural components that exists at room temperature.

Key points

0.8% C- eutectoid point (723°C)

4.3%C- eutectic point (1147°C)

0.008- 2.06%C-steel

Reactions:

1. Peritectic reaction (1493°C)

δ + Liquid ⟶ Austenite

2. Eutectic Reaction (1130°C)
   It occurs at 4.3% C composition and at 1130°C where liquid is directly converts into austenite and cementite composition.

Liquid ⟶ Austenite+Cementite (ledeburite)

3. Eutectoid Reaction (723°C)
   It occurs at 0.8% C composition and at 723°C where Austenite is directly converts into ferrite and cementite composition.

Solid ⟶ Ferrite+cementite (Pearlite)

Iron - carbon phase diagram
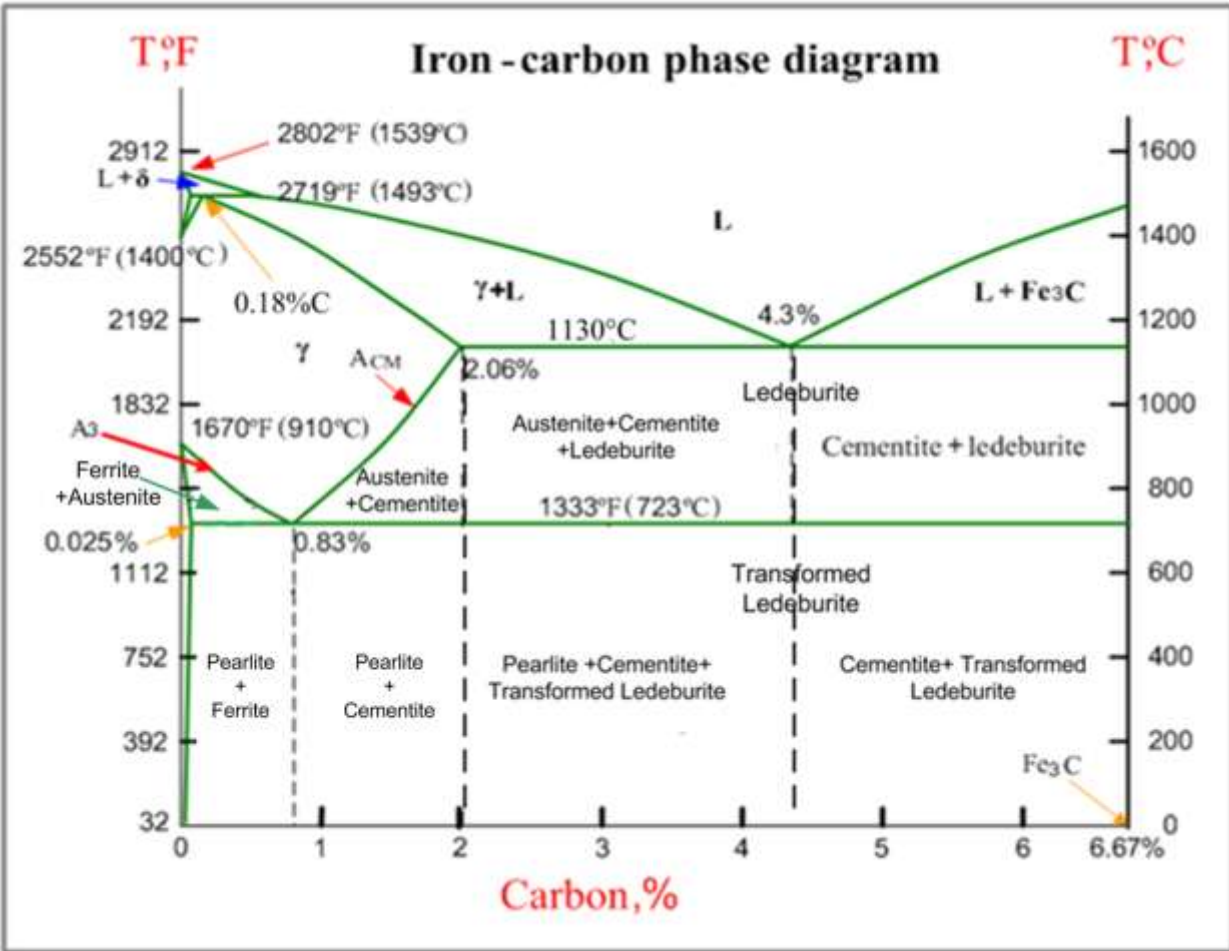
> The composition of Alloy having carbon percentage from 0.008- 2.06% C is considered as steel. From 0.008 to 0.8% C is termed as hypo-eutectoid steel where as hypereutectoid steel carbon composition varies in between 0.8- 2.06%.
> The composition of Alloy having carbon percentage from 2.06% C above is considered as cast iron. From 2.06-4.3% C is termed as hypo-eutectic cast iron where as carbon composition of hypereutectic cast iron is above 4.3%.

Transformation in steel

Case-1 (steel containing 0.4%C-hypo eutectoid steel)

> Completely austenite above A3. Upon cooling ferrite starts to precipitate.
> When the steel touches lower critical temperature (723°C), it contains half ferrite and half austenite.
> Here the austenite can hold up to max 0.8%C. Thus, upon further cooling, carbon is precipitated as cementite.
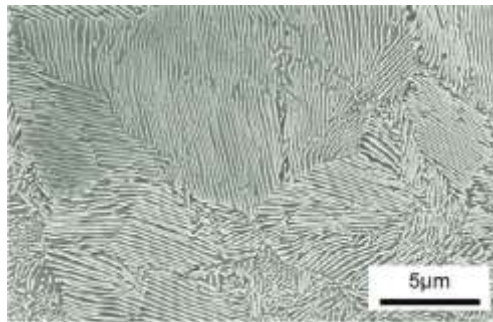
> ➤ The cementite and ferrite form alternate lamellar layers called pearlite. Final structure contains ferrite and pearlite.

Case-2 (steel containing 0.83 %C- eutectoid steel)

> ➤ Remain austenite up to 723°C

> ➤ Since eutectoid steel contains 0.83%C initially, it will transform into pearlite structure upon further cooling

Case-3 (steel containing 1.2%C-hyper eutectoid steel)
> ➤ As the temperature drops and steel crosses the line Acm, excess carbon (above 0.83%) is precipitated as cementite along the grain boundaries.
> ➤ Above lower critical temperature , it consists austenite and cementite.
> ➤ As the temperature drops below 723°C, the austenite becomes less rich in carbon (0.83%C) and precipitated as pearlite
> ➤ Final structure contains cementite and pearlite

Transformation in cast iron

Case-4 (steel containing 3%C-hypo eutectic cast iron)
> ➤ Upon cooling austenite starts to precipitate until it touches 1130°C.
> ➤ At 1130°C, the liquid contains eutectic composition (ledeburite)
> ➤ Upon cooling, ledeburite and cementite precipitates along with some austenite.
> ➤ The further cooling below 723°C, the remaining austenite of 0.83%C precipitate into pearlite

➢ Final structure contains cementite, pearlite and ledeburite

Case-5 (steel containing 4.3%C- eutectic cast iron)

➢ Remain liquid up to 1130°C

➢ Since eutectic cast iron contains 4.3%C initially, it will transform into ledeburite structure upon further cooling

❖ Micro-constituents of iron and carbon

1. Ferrite: Iron that contains very little carbon is called ferrite. It has maximum solubility of 0.3% at 723°C. it is also called as α-Fe. It is the softest structure and possesses the hardness of 80 HRB.
2. Cementite: It is an extremely hard and brittle compound. Cementite increases with increase in carbon percentage in iron. It contains maximum carbon percentage of 6.67%. It has less tensile strength.
3. Austenite: It is a solid solution of carbon and other alloying elements in γ-Fe. It can dissolve up to maximum 2.06% carbon at 1130°C. it is not stable at room temperature and non magnetic in nature. Upon cooling below 723°C, it converts into ferrite which is magnetic in nature and cementite to form pearlite.
4. Ledeburite: It is a eutectic mixture of cementite and austenite. It contains 4.3% carbon and formed at 1130°C.
5. Pearlite: It is a mixture of ferrite and cementite. It contains 0.8% carbon and formed at 723°C. hardness of pearlite structure is 20 HRC. It consists of alternate lamellae of ferrite and cementite in steel.
6. Martensite: It is a hard, brittle, needle like structure formed due to rapid cooling of high carbon steel above critical temperature. it is considered as highly stressed α-Fe, supersaturated with carbon.
7. Bainite: It is produced from austenite at a temperature below at which pearlite is produced, above at which martensite is formed. It is a mixture of ferrite and cementite. Bainite is produced by isothermal transformation below the nose of TTT diagram and cannot be produced by continuous cooling.

➢ TTT Diagram

➢ TTT diagram stands for "time-temperature-transformation" diagram. It is also called isothermal transformation diagram
➢ Davenport and Bain were the first to develop the TTT diagram of eutectoid steel. They determined pearlite and bainite portions whereas Cohen later modified and included MS and MF temperatures for martensite.
➢ It shows the relationship between temperature and time.
➢ The Iron-Carbon equilibrium diagram shows only the phases and the resulting microstructures corresponding to equilibrium conditions.

> The principal source of information on the actual process of austenite decomposition under non equilibrium conditions is the TTT diagram, which relates the transformation of austenite to the time and temperature conditions to which it is subjected.

 Steps to construct TTT diagram

1. Place the sample in molten salt bath, held at the proper austenitizing temperature.
2. When austenitized, the sample is transferred to another salt bath held at temperature below A1. The specimen is allowed to react isothermally. After that it is quenched in iced brine or cold water.
3. The quenching stops the isothermal reaction by changing the remaining austenite into martensite.
4. The data obtained from the series of iso thermal reaction curves for the whole temperature range for a given composition of steel is summarized, TTT diagram is obtained
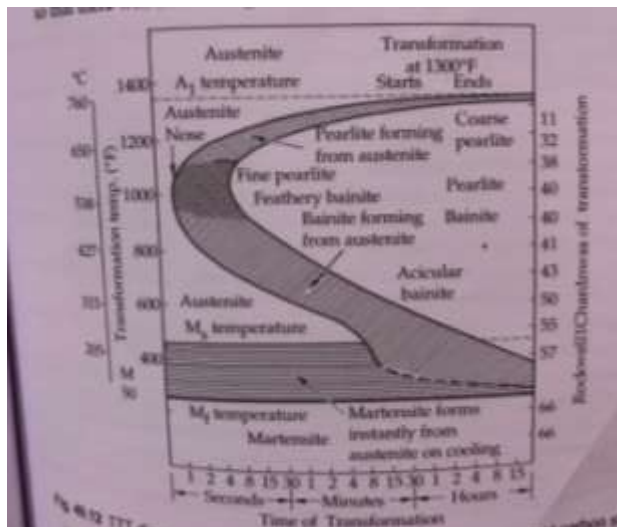
> Transformation temperature between 550-723°C, results in lamellar structure of pearlite. At a temperature just below A1 line, nucleation will be very slow and results in coarse pearlite.
> Between 550-250°C, the slower rate of decomposition of carbon results in Bainite
> Martensite is formed due to rapid cooling to a temperature below Ms line.

❖ **Effect of cooling rate on formation of different reaction product**
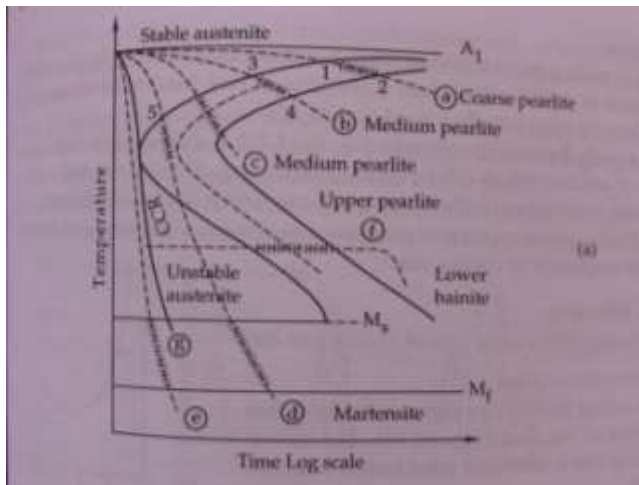
Curve-a: Very slow cooling rate, coarse pearlite will be produced

Curve-b: Transformation will start at 3 with coarse pearlite and end at 4 with medium pearlite.

Curve-c: The microstructure will be a mixture of medium and fine pearlite.

Curve-d: At point 5, the austenite will transform into fine pearlite. As Ms line is crossed, remaining austenite will convert into martensite. So at room temperature both fine pearlite and martensite will exists.

Curve-e: This is obtained due to fast cooling. When the Ms line will be reached, martensite starts precipitating. At Mf, the precipitation completes and the structure contains only martensite.

Curve-ef: Bainite structure obtained by cooling rapidly to miss the nose curve and then holding in the temperature range at which bainite is produced.

Curve-g: This curve is tangent to the nose of TTT curve. The cooling rate associated with this curve is known as critical cooling rate. Any cooling equal or faster than CCR, produces martensite structure. Any cooling slower than CCR results in either bainite or pearlite.

Note:

CCR (critical cooling rate) is the rate of cooling at which all austenite is converted into 100% martensite.

Case Hardening and surface hardening

It is a process that includes a wide variety of techniques which is used to improve the wear resistance of parts without affecting the softer, tough interior of the part. This combination of hard surface and resistance to breakage upon impact is useful in parts such as a cam or ring gear, bearings or shafts, turbine applications, and automotive components that must have a very hard surface to resist wear, along with a tough interior to resist the impact that occurs during operation.

For low carbon steel, this can be done by adding or penetrating carbon, nitrogen or both to the surface of the steel parts in order to provide a hardened case. These treatments are known case hardening.

Types

1. **Carburizing**
   Carburizing is the addition of carbon to the surface of low-carbon steels at temperatures (generally between 850 and 980° C) at which austenite, with its high solubility for carbon is stable in nature. When the carburized steel is heat treated, the case is hardened while the core remains soft and tough. Hardening is accomplished when the high-carbon surface layer is quenched to form martensite so that a high-carbon martensitic case with good wear and fatigue resistance is superimposed on a tough, low-carbon steel core.

   Use: gears, camshafts, bearings

   There are three general methods of carburizing
   a. Pack carburizing
   b. Gas carburizing
   c. Liquid carburizing

- **Pack carburizing**
  Parts are packed in a cast iron or steel boxes along with carburizing material and heated in a furnace to the carburizing temperature between 900-950°C. The sample is kept at that temperature up to 5 hrs depending upon the depth of the case desired. At this temperature CO gas is produced which is a strong reducing agent. The reduction reaction occurs on the surface of the steel releasing carbon, which is then diffused into the surface due to the high temperature. When enough carbon is absorbed inside the part, the parts are quenched or cooled slowly in the boxes depending upon the nature of heat treatment.
  Carburizing medium generally consists of wood, charcoal or charred leather with an energizer (a mixture of sodium carbonate and barium carbonate)
  Mechanism involved following stages
  - Formation of carbon monoxide (CO) when the box is heated above 900°C
  - Dissociation of CO and evolution of atomic carbon
  - Diffusion of carbon into steel surface by forming cementite.

$$2CO \rightleftharpoons CO_2 + C_{atom}$$

$$2CO + 3Fe \rightleftharpoons CO_2 + Fe_3C$$
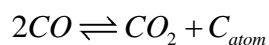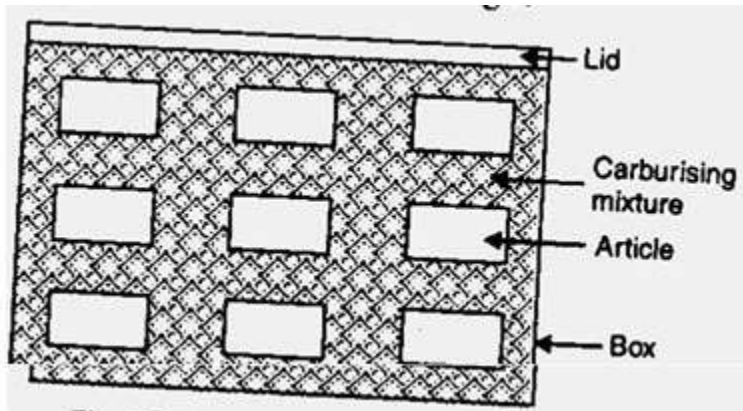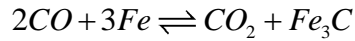
- **Gas Carburizing**

  In gas carburizing, the components are heated up to 900°C in an environment containing gases which will deposit carbon atoms at the surface of the component.
    - ➢ The atmosphere mostly contains CO, hydrogen and nitrogen is known as carrier gas
    - ➢ The carrier gas is prepared by burning town gases. The resulting combustion gases are cooled and passed over silica gel to remove water vapor. CO2 is removed by passing over heated coke or charcoal.
    - ➢ Advantages of Gas Carburizing
      - • It takes less time when compared with pack Carburizing method
      - • Control is more accurate to achieve surface carbon content and case hardness
      - • When compare with pack Carburizing, complicated shape components are carburised by this method

- **Liquid Carburizing**

  Carburizing salt contains cyanide compounds such as sodium cyanide (NaCN). The components are immersed in the liquid bath of NaCN at a temperature of around 870 to 900°C so that the carbon is diffused into the surface of the steel. In this method the time required for carburizing the metal surface of 0.2 to 0.3mm in 35 to 55min. Then the metal is undergone rapid quenching to lock the carbon inside the structure. By this method uniform case hardening is obtained when compared with other methods.

  Advantages of Liquid Carburizing
  - • Uniform case hardening depth is obtained
  - • Components are free from oxidation

  Rapid heat transfer and rapid absorption of carbon

  Disadvantages

  Cyanide salts are poisonous

  Molten cyanide explodes when comes in contact with water

2. **Nitriding**

- In nitriding, the steel piece is heated in a furnace between 500 – 600 °C and at the same time is exposed to ammonia gas (NH3). The heat from the furnace causes the ammonia to decompose into hydrogen (H2) and nitrogen (N2). Nitrogen reacts with elements in the steel to form nitrides in the outer layer of the steel providing high hardness and wear resistance.
- Nitriding times range between 40–100 hours depending on steel composition and depth of hardening desired. Since nitriding does not involve austentizing the steel, it can be carried out at comparatively low temperatures and thus produce less distortion and deformation.
- Principal reasons for nitriding are: To obtain high surface hardness, To increase wear resistance, To improve fatigue life and To improve corrosion resistance
- In this process, nitrogen is diffused into the surface of the steel being treated. The reaction of nitrogen with the steel causes the formation of very hard iron and alloy nitrogen compounds. The resulting nitride case is harder than tool steels or carburized steels. The advantage of this process is that hardness is achieved without the oil, water or air quench.
- **Advantages:**
    - Very high surface hardness
    - Minimized distortion and cracking
    - Good corrosion and wear resistance
    - No machining required after nitriding
    - Process is economical
- **Disadvantages**
    - Long cycle time (40 to 100 hrs)
    - High cost
    - Technical control required
- Use: gears, gauges, aircraft engine parts, crank pins

3. Cyaniding

In cyaniding, Carbon and nitrogen are introduced into the surface of steel by heating it to a suitable temperature and holding it in contact with molten cyanide. Low carbon steel is heated between 800-870°C in a molten sodium cyanide bath for about 30 min to 3 hour depending upon the depth of case required. Quenching in oil or water from this bath hardens the surface of steel.

Use: Screws, nuts and bolts, small gear

4. Carbonitriding

This process involves both the diffusion of C and N into the steel surface. Nitriding is performed in a gas atmosphere furnace using a carburising gas mixed with ammonia (NH3) (source of N). Carbonitriding is performed at temperatures above the upper critical temperature (650-850°C).

Use: gears, bolts, nuts

Composites

Composite materials are produced by combining two dissimilar materials into a new material that may be better suited for a particular application then either of the original materials alone.

Ex. Fibreglass reinforced plastic; used in house hold application and many industrial application

Plastic alone is relatively weak and has low elastic modulus so, it bends and stretches easily. On the other hand, the glass fibres provide greater strength and stiffness to the composite. Its modulus of elasticity is 50 times higher than plastic. Together they form a high strength composite for the application. When the composite is loaded or subjected to tensile stress, maximum load is taken by the glass fibres.

Many composite materials consists of two phases: one is matrix and other is dispersed phase

Advantages

- High specific strength
- High toughness
- High strength at elevated temperature
- Better creep and fatigue resistance
- Lower thermal expansion

Classification of composites

- Particle reinforced
- Fibre reinforced
- Structural composites

1. **Particle reinforced composites**
- The dispersed phases in particle reinforced composites are equiaxed (particle dimensions are almost same in all direction)
- It is subdivided into large particle composites and dispersion strengthened composites
A. **Large particle composites**

- Particle- matrix interaction is treated in macroscopic level.
- The particulate phase is harder and stiffer than the matrix
- The matrix phase transfers some of the applied stress to the particles which bears a fraction of load.
- Ex. Concrete: (cement-matrix, sand and gravel –particulate)
- In large particle composite the particle should be approximately in same dimension in all directions. The particles should be small and evenly distributed for effective reinforcement.
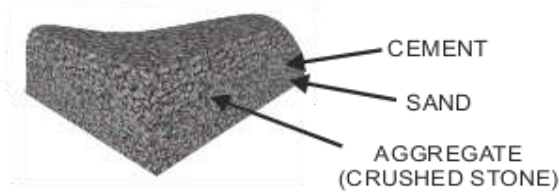
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- Ex. Cermet is a ceramic metal composite. Most common cermet is cemented carbide. It consists of WC or TiC embedded in a matrix of metal such as cobalt or nickel.
- Ex. Vulcanized rubber; it is a material that undergoes a chemical process known as vulcanization. This process involves mixing natural rubber with additives such as sulphur. These are obtained by strengthening with 20-50 nm carbon-black particles. It is used in auto tires.
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B. Dispersion-strengthened composites

- Uniformly dispersed fine, hard particles are used for the reinforcement
- The dispersed phase may be metallic, non metallic; oxide materials are often used.
- They are more stronger than pure metal
- Strengthening of the matrix phase happened at elevated temperature for extended period of time.
- Strengthening depends upon size of the particle and intermolecular spacing
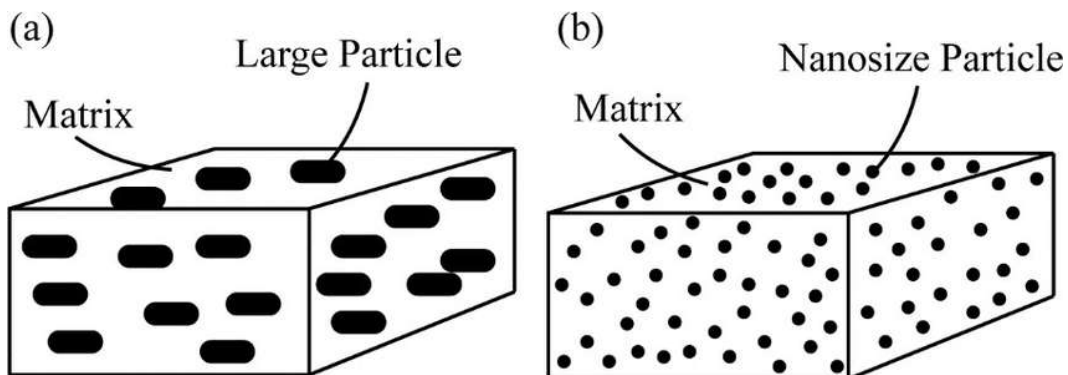- Ex: SAP (sintered aluminium powder): fine Al2O3 particles are dispersed in pure aluminium matrix.

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Figure. (a) **Large particle composites, (b) Dispersion-strengthened composites**

2. **Fibre-reinforced composites**

- The dispersed phase is in the form of fibres
- The arrangement, orientation of fibres with relative to one another, concentration of fibre, all have a significant influence on the properties of the fibre reinforced composite.
- The critical fibre length is necessary for effective strengthening of the composite material
- For continuous fibre reinforcement, the strain in the matrix and the strain in the fibre are initially same. At low stress both fibre and matrix are deform elastically. But, with increasing stress, the matrix may deform plastically while the fibres will be in elastic state.
- Most practical composites used, contains discontinuous fibres. Since the fibre does not span the whole length of the specimen, the bond between the matrix and fibre is broken at the fibre end. The stress in a discontinuous fibre varies along its length.
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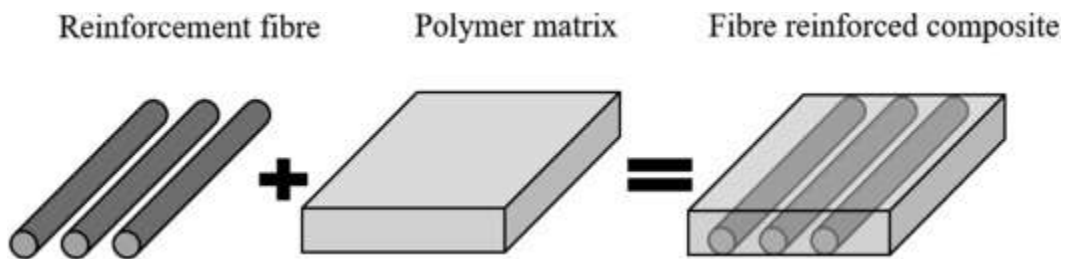
  ❖ The fibre phase
- Any polymer, metal or ceramic that has been drawn into thin filament.
- On the basis of the diameter and character, the fibres are classified into 3 types
- 1. Whiskers, 2. Fibres, 3. Wires
- Whiskers are very thin single crystals which have extremely large length to diameter ratio. They have high strength. But, they are extremely expensively. Whisker material includes graphite, silicon carbide, aluminium oxide etc.
- Fibres are either polycrystalline or amorphous and have small diameter. Fibre materials are generally polymers or ceramics. Ex. Glass, carbon, boron, silicon carbide etc.
- Wires have generally large diameter. The materials include steel, molybdenum and tungsten. It is utilized in automobile tires, wire wound high pressure hoses.

  ❖ The matrix phase
- It binds the fibres together and acts as a medium by which external applied load is distributed to fibres.
- It should be ductile
- It protects the fibres from surface damage
- Elastic modulus of fibres are higher than matrix
- Matrix separates fibres and because of its softness and plasticity, it prevents the propagation of cracks from fibre to fibre
- In general, on metals and thermosetting and thermoplastic polymers are used as matrix

Ex. Fibreglass reinforced composites

- Glass fibre is arranged in a continuous or discontinuous manner in a plastic matrix.

- Composition: SiO_2- 55%, CaO- 16%, Al_2O_3- 15%, B_2O_3- 10% and MgO- 4%
- Glass is popular as a fibre because
  - It is easily drawn into high strength fibres from molten state
  - Easily available
  - Glass is relatively strong and when embedded in a plastic matrix, the composite produced have very high strength
  - Also, it possess chemical inertness
- Among the different plastic materials for use in matrix phase, polyester is most common.
- Fibre glass is moisture proof, heat resistant and fire proof.
- When fibre glass is embedded in a thermosetting resin and subjected to heat and pressure, the resulting product is called as fibre glass reinforced plastics (FRP)
- Used in structural parts of aircraft, used for screens and partitions, small boats, pipes, tubings, tanks, welding helmet etc.


Ex-2. Hybrid composite

- It is obtained by using two or more different types of fibres in a single matrix
- A common combination of fibre and matrix are two types of fibres such as carbon and glass fibre incorporated with polymeric resin.
- Carbon fibres are strong, stiff and provide low density reinforcement. But, they are expensive
- Glass fibres are inexpensive but lack of stiffness.
- The glass carbon hybrid is stronger and tougher and can be produced at low cost than all carbon or all glass reinforced plastics.
- Use: light weight orthopaedic components, sporting goods, air transport structural components etc.
3. Structural composites
- It consists of both homogeneous and composite material. The properties of this composite depends upon the properties of the constituent material and also the geometrical design of the various structural elements.
- Common structural composites are
- 1. Laminar composites
- 2. Sandwich panel

- Laminar composite composed of two dimensional sheets that have a particular high strength direction. The layers are staked and cemented together in such a way that the high strength direction differs in each successive layer

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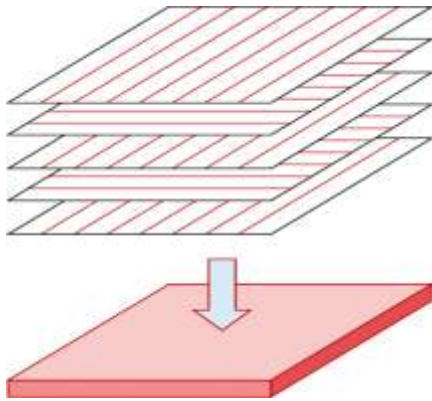
- Sandwich panel: it consists of two strong outer sheets separating by a layer of dense material which has lower stiffness and lower strength. The outer sheets/ face materials include aluminium alloys, fibre reinforced plastics, steel and plywood. The core separates the faces and resists deformations perpendicular to the face plane. Material used for core are foamed polymers, synthetic rubbers, balsa woods etc. One type of popular core consists of honey comb structure. It consists of thin foils that have been formed into interlocking hexagonal cells. The axes remain perpendicular to face plane.
Ex. Used in aircrafts, buildings for making walls, roofs etc.
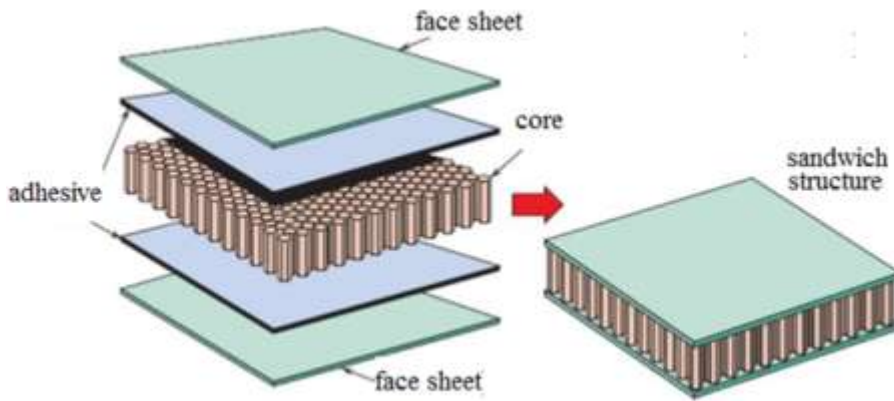
Ceramics

Ceramic materials are defined as those containing phases that are compounds of metallic and non metallic elements. All the early ceramics products were made from clay. It was then dried and fired to develop the permanent structure. Other forming methods used for ceramic materials are injection moulding, sintering and hot pressing. In other cases the formed materials are allowed to harden on the job by the addition of water as in case of cement. Portland cement is also a mixture of powdered materials such as dicalcium silicate, tricalcium silicate and tricalcium aluminate.

Classification

A. Classification of ceramic material
   1. Functional classification
      - Abrasives: Alumina, Carborundum
      - Fire clay product: Bricks, tiles, porcelain etc
      - Inorganic glasses: Window glass, lead glass etc
      - Cementing materials: Portland cement, lime etc.
      - Rocks: granite, sand stone
      - Minerals: Quartz, calcite etc.
      - Refractories: Silica bricks, magnesite etc.
   2. Structural classification
      - Crystalline ceramics: Single phase like MgO or multi phase from the MgO to Al2O3 binary system.
      - Non-crystalline ceramics: Natural and synthetic inorganic glasses
      - Cements: crystalline or non crystalline phases
B. Classification of ceramic product
      - Bricks and tiles
      - Cements and concretes
      - Abrasives
      - Glass
      - Insulators
      - Refractories
      - Electrical porcelain
      - Mineral ores
      - Slags and fluxes
      - Whiteware

Advantages of ceramic material

1. The ceramics are hard, strong and dense
2. They have high resistance to corrosion and wear

3. High compression strength
4. Excellent dielectric properties
5. Good thermal insulator
6. High Creep resistance
7. Easily available

Application

1. The whitewares (older ceramics) are used in sanitary wares, low and high voltage insulators, as pyrometer, burners, in chemical industry- as crucible, jars and components of chemical reactors.
2. Newer ceramics such as borides, carbides, nitrides, silicates, metalloid and intermetallic compounds which have high hardness, heat resistance values are used in
   - Refractories for industrial furnaces
   - Electrical and electronic industries: as insulator, semiconductor, dielectrics, piezoelectric crystal, glass, quartz, mica etc
   - Nuclear application: as fuel element, fuel container, control rod
   - Ceramic metal cutting tool : carbides, nitrides and cermets
3. Advanced ceramics (SiC, ZrO2, TiB2 etc)
   - Internal combustion engine, turbines
   - Electronic packaging
   - Cutting tools
   - Energy conversion, storage and generation

Spring material

It stores mechanical energy.

It sustains under high internal stresses.

An ideal spring material has **high strength properties, a high elastic limit and a low modulus**. Because springs are resilient structures designed to undergo large deflections, spring materials must have properties of extensive elastic range.

Types of spring material

- IRON based
  - Steel is the best choice for spring materials unless it is for high temperature or a corrosive environment
  - It has high modulus of elasticity
  - It has high elastic limit
  - It has high fatigue and creep strength
  - USE: Helical springs, cone spring, torsional spring etc.
    Helical spring

There are several types of iron based spring

a. Steel piano wire
   Composition: C (0.7-1%), Mn- (0.3-0.6%), Fe-rest
   Use: small sized helical spring

b. Cromium-Vanadium Spring steel
   Composition: C(0.5%), Cr- (0.2-0.9%), Mn-(0.8-1.1%), V(0.7-0.12%)
   Vanadium helps in producing cleaner steel because of the deoxidizing action. It has great strength, toughness and resistance to fatigue.
   Use: Engines, Automobiles

c. Stainless steel
   Composition: Cr-(18%), Ni (8%), C- (0.1-0.2%)
   Use: valve springs, high resistance to corrosion

d. Oil hardened steel
   Composition: C(0.55-0.75%), Mn-(0.3-0.9%)
   Use: weighing machines and cars

2. Copper based

➤ High electrical conductivity
➤ Good resistance to corrosion
➤ Lack of magnetic properties
Types

a. Phosphorous bronze
   Composition: Cu (92%), Sn (8%)
   Use: High quality springs for switches, relays

b. Brass
   Composition: Cu (67%), Zn (33%)
   Use: switches and contacts

c. Nickel-silver
   Composition: Cu (56%), Ni (18%), Zn (25%)
   Use: switches

d. Beryllium copper

Composition: Cu (98%), Be (2%)

Use: brushes, switches, relays which has good resistance to wear and good conductivity

3. Nickel based

a. Nickel itself

Composition: 99.5% Ni
Use: magnetic, electrically conductivity springs with good corrosion resistance

b. Monel

Composition: 68% Ni, Cu-27%, Fe and Mn rest
Use: weakly magnetic, corrosion resistant springs for light load
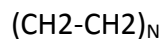
c. Inconel

Composition: 80% Ni, Cr-14%, Fe – 6%
Use: Corrosion and oxidation resistant springs for use at high temperature

Chapter-9

Polymers

A polymer is a macromolecule, made up of many smaller repeating units called monomer. Polymers have high molecular weight in the range of several thousand or even higher.

Ex: ethylene is a monomer, poly (ethylene) is a polymer

$(CH2-CH2)_N$

PET: two monomers forms an ester bond makes polyester

Natural occurring polymers are wood, rubber, cotton, wool, leather, proteins, enzymes etc.

Many of our useful plastics, rubbers and fiber materials are synthetic polymers. These are inexpensive and can replace metal and wood parts with satisfactory properties.

Characteristics

- Low density
- Good corrosion resistance
- Low co efficient of friction
- Good surface finish
- Economical

- Poor tensile strength and temperature resistance
- Low mechanical properties

Some common types of polymers

Thermoplastic Polymers: Thermoplastic polymers are hard at room temperature, but become soft when heated, because on heating individual polymer chains slip from one another. The individual chains of thermoplastic polymer are held together by van der Waals forces. They are strong if the polymer chains are lined up in an ordered, closely packed array. When temperature raised the secondary bonding forces are diminished and increase the molecular motion. Thermoplastic polymers are relatively soft and ductile. It has low melting point. Polyethylene, polystyrene, polypropene and teflon are some examples for thermoplastic polymer.

Thermosetting Polymers: The greater the degree of cross-linking makes the polymer more rigid. Such cross-linked polymers are called thermosetting polymers. Thermosetting polymers are generally stronger than thermoplastic polymers due to strong covalent linkage (cross-linking) between polymer chains not by weak intermolecular van der Waals forces. They are more brittle in nature and their shape is permanent. Once it is hardened they cannot be recycled. These polymers become soft during their first heating and become permanently hard when cooled. They don't soften upon subsequent heating. Bakelite and polyurethanes are examples for thermosetting polymers. If they heated to excessive temperature, the decomposition takes place (EX- bad smell of Bakelite during electric short circuit)

Elastomers: An elastomer is a randomly oriented amorphous polymer, which stretches and then reverts back to its original shape. To avoid slipping of polymer chains it must have some cross-linking. When elastomers are stretched, the random chains stretch out where as the van der Waals forces are not strong enough to maintain them in that arrangement and retains its original shape when the stress is removed. Rubber is an example of an elastomer.

Application of polymers:

1. Coating: to protect surface from corrosion, to improve item appearance, to provide electrical insulation
2. Adhesive: to join the surface of two metals
3. To produce porous plastic material. It is produced by bubbling inert gas when the material is in molten state. These are used in automobiles, thermal insulation and furniture.