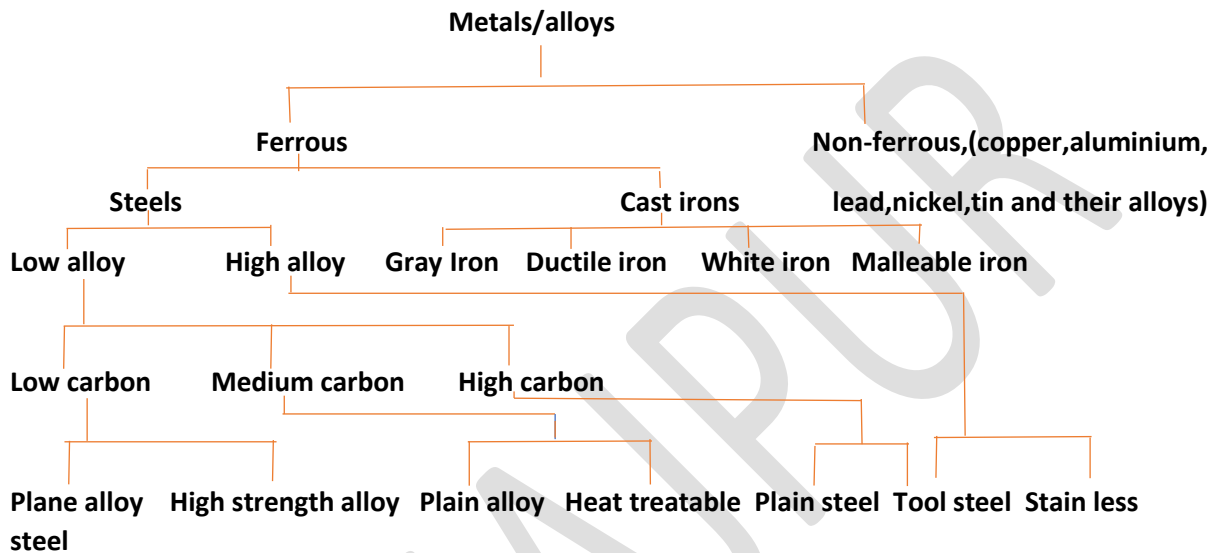


## 2.0 FERROUS MATERIALS AND ALLOYS

### 1.1 Material classification in to ferrous and non ferrous category and alloys

### 5.2 CLASSIFICATION



### STEELS

Steel is an alloy of iron and carbon.

#### Plane carbon steel

(i) A plane carbon steel is an alloy of iron and carbon and it is malleable.

(ii) Carbon steels are different from cast iron as regards the percentage of carbon.

(iii) Carbon steels contain from 0.10 to 1.5% carbon whereas (cast) iron possesses from 1.8 to 4.2% carbon.

(iv) Carbon steels can be classified as Low carbon steel (or Mild steel), Medium carbon steel and High carbon steel.

#### MILD STEEL

Mild steels or low carbon steels may be classified as follows:

i) Dead mild steel — C 0.05 to 0.15%.

- (i) Dead mild steel is used for making steel wire, sheets, rivets, screws, pipe, nail and chain. It has a tensile strength of  $390 \text{ N/mm}^2$  and a hardness of about 115 BHN.
- (ii) Mild steel containing 0.15 to 0.20 % of carbon. It has a tensile strength of  $420 \text{ N/mm}^2$  and hardness 125 BHN.

It is used for making camshafts, sheets and strips for fan blades, welded tubing, forgings, drag lines etc.

(iii) Mild steel containing 0.20 to 0.30% carbon has a tensile strength of  $555 \text{ N/mm}^2$  and a hardness of 140 BHN.

It is used for making valves, gears, crankshafts, connecting rods, railway axles, fish plates, small forgings etc.

### MEDIUM CARBON STEELS

Medium carbon steels contain carbon from 0.30 to 0.70%.

**Steels** containing 0.35 to 0.45% carbon have a tensile strength of about  $750 \text{ N/mm}^2$ . They are used for making:

Connecting rods                      Key stock                      Shift and brake levers  
 Spring clips Aides                  Wires and rods                  Gear shafts                  Small and medium forgings, etc.

**Steels** containing 0.45 to 0.55% carbon have a tensile strength of about  $1000 \text{ N/mm}$  and are used for making parts those are to be subjected to shock and heavy reversals of stress such as

Railway coach axles                  Crank pins on heavy machines                  Crankshafts  
 Axles    Spline shafts etc.

**Steels** containing 0.6 to 0.7% carbon have a tensile strength of  $1230 \text{ N/mm}^2$  and a hardness of 400-450 BHN. Such steels are used for making

Drop forging dies                  Set screws                          Die blocks                          Clutch discs  
 Valve springs                          Self tapping screws                  Plate punches                  Cushion rings  
 Thrust washers etc.

### HIGH CARBON STEELS

High carbon steels contain carbon from 0.7 to 1.5%.

Steels containing 0.7 to 0.8% carbon have a tensile strength of about  $1400 \text{ N/mm}^2$  and a hardness of 450-500 BHN.

These steels are used for making :

Cold chisels                          Wrenches                          Jaws for vises                          Shear blades  
 Hacksaws                          Pneumatic drill bits                          Wheels for railway service  
 Wire for structural work and Automatic clutch discs etc.

**Steels** containing 0.8 to 0.9% carbon have tensile strength of about  $660 \text{ N/mm}^2$  and a hardness of 500 to 600 BHN. Such steels are used for making:

Punches and dies	Rock drills	Railway rails
Circular saws	Machine chisels	Music wires
Clutch discs	Leaf springs etc.	

**Steels** containing 0.90 to 1.00% carbon (high carbon tool steels) have a tensile strength of 580 N/mm<sup>2</sup> and a hardness of 550–600 BHN. Such steels are used for making:

Punches and dies	Springs (Leaf and coil)	Pins
Shear blades	Keys	Seed discs

**Steels** containing 1.0 to 1.1% carbon are used for making:

Railway Springs	Mandrels
Machine tools	Taps etc,

**Steels** containing 1.1 to 1.2% carbon are used for making:

Taps	Twist drills	Thread metals dies	Knives, etc.
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**Steels** containing 1.2 to 1.3% carbon are used for making:

Files	Reamers	Metal cutting tools etc.
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**Steels** containing 1.3 to 1.5% carbon are used for making;

Wire drawing dies	Paper knives	Metal cutting saws
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Tools for turning chilled iron, etc.

## ALLOY STEELS

### Introduction

Steel is considered to be alloy steel when the maximum of the range given for the content of alloying elements exceeds one or more of the following limits: Mn 1.65% Si 0.60% Cu 0.60%

or in which a definite range or a definite maximum quantity of any of the following elements is specified or required within the recognized field of constructional alloy steels: Al, B, Cr, upto 3.99%, Co, Mo, Ni, Ti, W, V, or any other alloying element added to obtain a desired alloying effect.

Given below is the composition of a typical alloy steel

C 0.2-0.4%	Mn 0.3-1.0%
Si 0.3-0.6%	Ni 0.4-0.7%
Cr 0.4-0.6%	Mo 0.15-0.3%

Fe Balance

Alloying elements alter the properties of steel (which is an alloy of iron and carbon) and put it into a slightly different class from ordinary carbon steel.

## Advantages and Disadvantages of Alloy Steel

The important advantages and disadvantages in the choice of alloy steel from the general point of view in relation to plain carbon steel are listed in the following tabulation:

### Advantages

That May be Attained

1. Greater hardenability.
2. Less distortion and cracking.
3. Greater stress relief at given hardness.
4. Less grain growth
5. Higher elastic ratio and endurance strength
6. Greater high temperature strength.
7. Better machinability at high hardness.
8. Greater ductility at high strength.

### Disadvantages

That May be Encountered

1. Cost.
2. Special handling
3. Tendency toward austenite retention.
4. Temper brittleness in certain grades.

### Purpose of alloying

The purposes of alloying steels are:

1. Strengthening of the ferrite,
2. Improved corrosion resistance,
3. Better hardenability,
4. Grain size control,
5. Greater strength,
6. Improved machinability,
7. Improved high or low temperature stability,
8. Improved ductility,
9. Improved toughness,
10. Better wear resistance,
11. Improved cutting ability.,
12. Improved case hardening properties etc.

### Effect of alloying elements

**Carbon:** Carbon content in steel affects

Hardness

Tensile strength

Machinability and Melting point

**Nickel: Nickel**

- Increases toughness and resistance to impact.
- Lessens distortion in quenching
- Lowers the critical temperatures of steel and widens the range of successful heat treatment.
- Strengthens steels
- Doesn't unite with carbon.

**Chromium: Chromium**

Joins with carbon to form chromium carbide, thus adds to depth hardenability with unproved resistance to abrasion and wear.

**Silicon: Silicon**

- Improves oxidation resistance
- Strengthens low alloy steels
- Acts as a deoxidizer.

**Titanium: Titanium**

- Prevents localized depletion of chromium in stainless steels during long heating
- Prevents formation of austenite in high chromium steels
- Reduces martensitic hardness and hardenability in medium chromium steels.

**Molybdenum: Molybdenum**

- Promotes hardenability of steel.
- Makes steel fine grained Makes steel unusually tough at various hardness levels.
- Counteracts tendency towards temper brittleness.
- Raises tensile and creep strength at high temperatures.
- Enhances corrosion resistance in stainless steels.
- Forms abrasion resisting particles.

**Vanadium: Vanadium**

- Promotes fine grains in steel
- Increases hardenability (when dissolved)
- Imparts strength and toughness to heat-treated steel.
- Causes marked secondary hardening.

**Tungsten: Tungsten**

- Increases hardness (and also red-hardness)
- Promotes fine grain Resists heat
- Promotes strength at elevated temperatures.

**Manganese: Manganese**

- Contributes markedly to strength and hardness (but to a lesser degree than carbon)
- Counteracts brittleness from sulphur

- Lowers both ductility and weldability if it is present in high percentage with high carbon content in steel.

**Copper:** Copper (0.2 to 0.5%) added to steel

- Increases resistance to atmospheric corrosion
- Acts as a strengthening agent.

**Boron:** Boron

- Increases hardenability or depth to which steel will harden when quenched.

**Aluminium:** Aluminium

- Acts as a deoxidizer.
- Produces fine austenitic grain size.
- If present in an amount of about 1%, it helps promoting nitriding.

**Cobalt:** Cobalt

- Contributes to red-hardness by hardening ferrite.
- Improves mechanical properties such as tensile strengths, fatigue strength and hardness
- Is a mild stabilizer of carbides and
- Refines the graphite and pearlite
- Improves heat resistance
- Retards the transformation of austenite and thus increases hardenability freedom from cracking and distortion.

**Vanadium:** Vanadium (0.15 to 0.5%)

- Is a powerful carbide former
- Stabilizes cementite and improves the structure of the chill.

### **PROMINENT ALLOY STEELS**

Some of the popular alloy steels are:

- (a) Silicon steel
- (b) Silicon-Manganese steel
- (c) Nickel steel
- (d) Chrome-Nickel steel
- (e) Chrome-Vanadium steel
- (f) Molybdenum steel
- (g) Chrome-Molybdenum steel
- (h) Chrome steel
- (i) Manganese steel
- (j) Tungsten steel
- (k) Vanadium steel

(l) Cobalt steel.

#### **(a) Silicon Steel**

Silicon steel contains C 0.10%, Mn 0.60% and Si 1.00%.

Silicon imparts strength and fatigue resistance and improves electrical properties of steel.

Many bridges have been built of what is called Silicon Structural Steel, This is stronger than carbon steel of equal ductility.

#### **(b) Silicon-Manganese Steel**

Silicon-manganese steels contain C 0.40-0.55%, Si 0.04–1.8%, Mn 0.9-1.0%.

Such steels are used for springs in the hardened and tempered condition (55 Si 2 Mn 90 steel), and for making punches and chisels.

#### **(b) Nickel Steel**

Nickel steel contains

C 0.35% Ni 3.5%

Addition of nickel to structural steel results in an increase of strength, without a proportionality great decrease of ductility.

Nickel steels are used for storage cylinders for liquefied gases and for other low temperature applications.

Other uses of nickel steels are for heavy forgings, turbine blades, highly stressed screws, bolts and nuts (40 Ni 3 steel).

#### **(d) Chrome-Nickel Steel**

Chrome-nickel steel contains.

C 0.35% Ni 1.25% Cr 0.60%

Chrome-nickel steel will have, after heat treatment, almost the same strength and ductility as 3.5% Nickel steel which has also been heat-treated, but it will not cost as much.

Chrome-nickel steels combine the effect of nickel (in increasing the toughness and ductility) and chromium (in improving hardenability and wear resistance).

#### **(e) Chrome-Vanadium Steel**

Chrome-vanadium steel contains

C 0.26% Cr 0.92% V 0.20%

Chromium and vanadium are added to low alloy steel to increase its hardenability and to impart a grain structure that is finer than that of the standard chromium low-alloy steels.

Chrome-vanadium steel is used for malting axles and shafts of automobiles, aeroplanes and locomotives.

### **(f) Molybdenum Steel**

Molybdenum steel contains

C 0.35% Mo 0.76%

Molybdenum steel, when heat-treated, produces a structural steel which has increased elastic limit without correspondingly decreased ductility. Molybdenum improves hot hardness and strength of steel. Molybdenum steels are less temper brittleness.

Molybdenum steels are used for making

Aircraft landing gear, Coil and leaf springs, Fuselage, pressure vessels and Transmission gear, etc.

### **(g) Chrome-Molybdenum Steel**

Chrome-molybdenum steel contains C 0.35% Cr 1.06%

Chrome-molybdenum steel has not as good a combination of strength and as nickel, chrome-nickel and chrome-vanadium steels, but it is quite easy to roll and draw into tubes, to fabricate, and to weld, so that it is very popular for airplane structural parts.

### **(h) Chrome Steel**

Chrome steel contains

Mo 0.36% Cr 0.57%

- Chromium intensifies the effect of rapid cooling on steel. Therefore chromium is used only in steels which are to be heat-treated.
- Chromium forms carbides and thus gives high hardness and good wear resistance. In addition, chromium increases tensile strength and corrosion resistance of low alloy steels.

% of Cr in steel 8% uses in Electrical purposes

15% Cr in steel uses in Springs, ball and roller bearings.

### **(i) Manganese Steel**

Manganese low alloy steels are characterized by:

Mn 1.6-1.9% C. 0.18-0.48%

Si 0.2-0.35% S and P < 0.040 % each.

Manganese increases hardness and tensile strength. A secondary effect is an increased resistance to abrasion. The steel also withstands the shock test excellently.

Manganese steels are used for making

Power shovel buckets

Grinding and crushing machinery

Railway tracks, etc.



### (j) Tungsten Steel

Tungsten low alloy steels are tool steels containing approximately 2% tungsten, 1.70% chromium and 0.50% carbon. This is hard tough tool steel that is commonly used for making cutting tools.

Tungsten forms carbides and prevents softening of the alloy at high temperatures.

The tungsten steel may contain upto 15% tungsten. Tungsten steel is used for making high speed cutting tools and permanent magnets.

### (k) Vanadium Steel

Vanadium is one of the most powerful scavengers that can be added to liquid steel for the special purpose of removing oxygen, Vanadium has the effect of increasing the strength and hardness of the metal. It produces a very small grain size.

Except for castings, vanadium is seldom used as the sole alloying element in steel. It is used together with chromium and other elements when high strength and anti-fatigue properties are essential, as in springs, gears, shafts and heavy forgings.

### Cobalt Steel

Cobalt tool steels are used where high frictional heats are developed. Cobalt imparts additional red hardness to steel and cutting ability of tool is maintained at elevated temperatures.

### Alloy steels (IS: 7598-1974)

Low and medium alloy steels (alloying elements not exceeding 10%).

1st symbol	100 times the average % of C.
2nd, 4th, 6th symbols etc.	Elements
3rd, 5th, 7th symbols etc --	% of elements, multiplied by factors as follows:

Element	Multiplying factor
Co, Ni, Mn, Si and W	4
Al, Be, V, Pb, Cu, Mb, Ti, Ta, Zr and Mo	10
P, S, N	100

Last element Special characteristics.

N.B. (i) Figures after multiplying shall be rounded off to the nearest integer .

(ii) Symbol Mn for manganese shall be included in case Mn content is > 1%

(iii) The chemical symbols of elements present and their figures shall be order of decreasing content.

For Example:

(i) 40 Ni 8 Cr 8 V 2 implies hot rolled steel with 0.4% C, 2% Cr, 2% Ni and 0.2% V.

(ii) 25 Cr 4 Mo 2 G

implies steel with guaranteed (G) hardenability and 0.25% C, 1% Cr, and 0.25% Mo (rounded off as Mo 2). > 10%)

**High alloy steels** (total alloying elements > 10%)

Example :

X 10 Cr18 Ni9 S3

X – High alloy steel

10 – 0.10% C

Cr18 – 18%Cr

Ni9 – 9%Ni

S3 – Pickled condition.

## TOOL STEELS

### Introduction

Tool and Die steels may be defined as special steels which have been developed to form, cut or otherwise change the shape of a material into a finished or semifinished product.

### Properties of Tool Steels

- (i) Slight change of form during hardening.
- (ii) Little risk of cracking during hardening.
- (iii) Good toughness
- (iv) Good wear resistance
- (v) Very good machinability
- (vi) A definite cooling rate during hardening
- (vii) A definite hardening temperature
- (viii) A good degree of through hardening
- (ix) Resistance to decarburization softening on heating (red)
- (x) Resistance to hardness).

### Classification

The joint Industry Conference (JIC), U.S.A. has classified tool steels as follows:

Symbol	Meaning
T	W-High speed steel
M	Mo-High speed steel
D	High C, high Cr steel
A	Air hardening steel
O	Oil hardening steel
W	Water hardening steel
H	Hot work steel

S

Shock resisting steel.

As an example W 8 means water hardening steel with 0.8% C.

### Composition of Tool Steels (%)

#### 1. W-High speed steels (T)

T <sub>1</sub>	→	C 0.7,	Cr 4,	V1,	W 18	
T <sub>4</sub>	→	C 0.75,	Cr 4,	V1,	W 18	Co 5
T <sub>6</sub>	→	C 0.8,	Cr 4.5,	V 1.5	W 20,	Co 12

#### 2. Mo-High speed steels (M)

M <sub>1</sub>	→	C 0.8,	Cr 4,	V1,	W 1.5,	Mo 8
M <sub>6</sub>	→	C 0.8,	Cr 4,	V 1.5,	W 4,	Mo 5

#### 3. High C, high Cr steels (D)

D <sub>2</sub>	→	C 1.5,	Cr 12,	Mo 1		
D <sub>5</sub>	→	C 1.5,	Cr 12,	Mo 1 ,	Co 3	
D <sub>7</sub>	→	C 2.35,	Cr 12,	Mo 1 ,	V 4	

#### 4. Air hardening steels (A)

A <sub>2</sub>	→	C1,	Cr 5,	Mo 1		
A <sub>7</sub>	→	C 2.25,	Cr 5.25,	V 4.75,	W 1,	Mo 1
A <sub>9</sub>	→	C 0.5,	Cr 5,	Ni 1.5,	V1,	Mo 1.4

#### 5. Oil hardening steels (O)

O <sub>1</sub>	→	C 0.9,	Mn 1,	Cr 0.5 ,	W 0.5	
O <sub>6</sub>	→	C 1.45,	Si 1	Mo 0.25		

#### 6. Water hardening steels (W)

W <sub>2</sub>	→	C 0.6/1.4,	V 0.25			
W <sub>5</sub>	→	C 1.1,	Cr 0.5			

#### 7. Hot work steel (H)

H <sub>10</sub>	→	C 0.4,	Cr 3.25,	V 0.4,	Mo 2.5	
H <sub>12</sub>	→	C 0.35,	Cr 5,	V 0.4 ,	W 1.5 ,	Mo 1.5

#### 8. Shock resisting steel (S)

S <sub>1</sub>	→	C 0.5,	Cr 1.5,	W 2.5		
S <sub>2</sub>	→	C 0.5,	Si 1 ,	Mo 0.5		
S <sub>5</sub>	→	C 0.55,	Mn 0.8,	Si 2,	Mo 0.4	

S<sub>7</sub> → C 0.5 Cr 3.25 Mo 1.4

### Heat-treatment of Tool Steels

- Tool steels should be heated slowly to the desired heat-treatment temperature. Tool steel should be kept at proper temperature for sufficient time so that the whole of the tool section gets heated uniformly.
- Overheating of tool steel should be avoided.
- Protective furnace atmosphere or any other method should be employed to avoid scaling or decarburization of tool steel during heating.
- Carbon and low alloy tool steels may be quenched in water or brine and high alloy tool steels in oil, air or molten salts.
- Tool steel may be quenched in a liquid bath of salt or lead held between 480 and 650°C and then cooled in air to about 65°C, (Interrupted Quenching).
- Tool steels should be tempered immediately after quenching and before they cool to room temperature. This reduces cracking.

### STAINLESS STEELS

#### Concept

When 11.5% or more chromium is added to iron, a fine film of chromium oxide forms spontaneously on the surfaces exposed to air. The film acts as a barrier to retard further oxidation, rust or corrosion. As this steel cannot be stained easily, it is called stainless steel.

All stainless steels can be grouped into three metallurgical classes, i.e., (a) Austenitic (b) Ferritic (c) Martensitic

based on their microstructures. Each of the classes has different welding requirements.

#### Austenitic stainless steels

- (i) They possess austenitic structure at room temperature.
- (ii) They possess the highest corrosion resistance of all the stainless steels.
- (iii) They possess greatest strength and scale resistance at high temperatures.
- (iv) They retain ductility at temperatures approaching absolute zero.
- (v) They are non-magnetic so that they can be easily identified with a magnet.
- (vi) They have the following composition:

C 0.03 to 0.25%

Mn 2 to 10%

Si 1 to 2%

Cr 16 to 26%

Ni 3.5 to 22%\*

P and S Normal

Mo and Ti in some cases,

(vii) They may find uses in:

- Aircraft industry (engine parts)
- Chemical processing (heat exchangers)
- Food processing (kettles, tanks)

- Household items (cooking utensils)
- Dairy industry (milk cans)
- Transportation industry (Trailers and railways ,cars etc)

### **Ferritic stainless steels**

- (i) They possess a microstructure which is primarily ferritic.
- (ii) Ferritic stainless steels have a low carbon-to-chromium ratio. This eliminates the effects of thermal transformation and prevents hardening by heat treatment.
- (iii) These steels are magnetic and have good ductility.
- (iv) Such steels do not work harden to any appreciable degree.
- (v) Ferritic steels are more corrosion resistant than martensitic steels.
- (vi) Ferritic steels develop their maximum softness, ductility and corrosion resistance in the annealed condition.
- (vii) Ferritic stainless steels have the following chemical composition  
C 0.08 to 0.20% , Si 1% , Mn 1 to 1.5% , Cr 11 to 27%
- (viii) Ferritic stainless steels have the following uses:
  - Lining for petroleum industry.
  - Heating elements for furnaces.
  - Interior decorative work.
  - Screws and fittings.
  - Oil burner parts.

### **Martensitic stainless steels**

- (i) Martensitic stainless steels are identified by their martensitic microstructure in the hardened condition.
- (ii) Because of the higher carbonic - to - chromium ratio, martensitic stainless steels are the only types hardenable by heat treatment.
- (iii) These steels are magnetic in all conditions and possess the best thermal conductivity of the stainless types.
- (iv) Hardness, ductility and ability to hold an edge are characteristics of martensitic steels.
- (v) Martensitic stainless steels can be cold worked without difficulty, especially with low carbon content, can be machined satisfactorily, have good toughness, show good corrosion resistance to weather and to some chemicals and are easily hot worked.
- (vi) Martensitic stainless steels have the following composition:  
C 0.15 to 1.2% , Si 1% , Mn 1% and Cr 11.5 to 18 % .
- (vii) A few typical uses of martensitic stainless steels are as follows:
  - Pumps and valve parts.
  - Rules and tapes.
  - Turbine buckets.
  - Surgical instruments etc.

# IRON – CARBON SYSTEM

## CONCEPT OF PHASE DIAGRAM AND COOLING CURVE

### SYSTEMS, PHASES AND STRUCTURAL CONSTITUENTS

A system is a substance (or group of substances) so isolated from its surroundings that it is unaffected by these and is subjected to changes in overall composition, temperature, pressure or total volume only to the extent allowed by the investigator.

A system may be composed of gases, liquids, solids or any combination of them and may involve metals and non-metals, either separately or in any combination.

**A system is classified according to the number of components that constitute the system.**

A Component is a unit of the composition variable of the system.

A system having one component is called a Unary system and the systems having two, three and four components are known as Binary, Ternary and Quaternary systems, respectively.

### 2. Phases

In an alloy system, the components may combine (within a certain temperature range) to form two homogeneous coexisting portions, each portion having different composition and properties. For example, a liquid (portion) may exist in equilibrium with a solid solution (portion). These homogeneous, physically distinct portions of the system are called Phases

### 3. Structural Constituent

The phases in alloy are not necessarily uniformly distributed throughout the structure. There are certain ways in which these phases may be associated to form the structure.

The association of phases in a recognizably distinct fashion may be referred to as a structural constituent of the alloy.

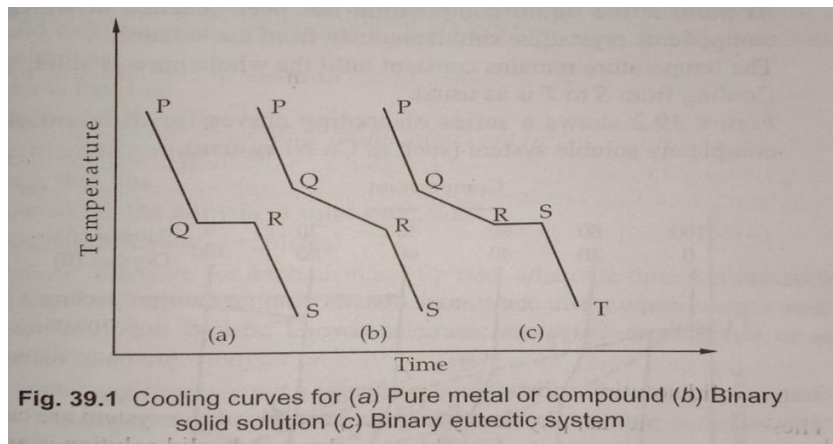
A eutectic is a structural constituent of the alloy.

$\text{CuAl}_2$ ,  $\text{FeAl}_3$  and  $\text{MnAl}_3$  are constituents in aluminium alloys. Pearlite, Martensite and Sorbite are microconstituents in steel.

## COOLING CURVES

### Introduction

A method, to determine the temperatures at which phase changes (liquid solid) occur in an alloy system, consists of following the temperature as a function of time as different alloys in the system are very slowly cooled.



## Types

### (a) Cooling curve of pure metal or compound

Liquid metal cools from P to Q. First crystals begin to form at point Q. From Q to R, the melt liberates latent heat of fusion in such amounts that the temperature from Q to R remains constant, until the whole mass has entirely solidified (at point R). Between Q and R, the mass is partly liquid and partly solid.

On further cooling from R to S, the solid metal cools and tends to reach room temperature.

The slopes of PQ and RS lines depend upon the specific heats of liquid and solid metals respectively.

### (b) Cooling curve of a binary solid solution

Curve portion PQ is similar no matter it is for a pure metal or for a binary system consisting of two metals forming a solid solution.

However, in a binary system, during freezing (i.e., QR) period, the temperature does not remain constant, rather it drops along line QR till the whole mass is solid at point R.

The dropping trend of QR indicates that the alloy does not solidify at constant temperature, rather, it possesses a freezing range\* which is due to the changes in the composition of the solid and liquid phases which naturally result in variable freezing (or melting) points.

The solid cools along RS to attain the room temperature.

### (c) Cooling curve of a binary eutectic system

In this system, the two components are completely soluble in the liquid state but entirely insoluble in the solid state.

Liquid cools along PQ until temperature Q is reached. At Q, one component that is in excess will crystallize and the temperature will drop along QR.

At point R the liquid composition has been reached at which the two components crystallize simultaneously from the solution.

The temperature remains constant until the whole mass is solid.

Cooling from S to T is as usual.

## PHASE DIAGRAM

- A great deal of information concerning the phase changes in many alloy systems has been accumulated and the best method of recording the data is in the form of Phase Diagram, which is also termed as Equilibrium diagram or Constitutional diagram.
- An equilibrium diagram shows the limits of composition and temperature within which the various constituents or phases of an alloy are stable. Changes of structure and the composition of the constituents in equilibrium at a fixed temperature can be ascertained from an equilibrium diagram.
- If in a phase diagram, for each change of phase, adequate time is allowed for the change to complete so that phase change takes place under equilibrium conditions, the phase diagram will be known as phase equilibrium diagram or simply equilibrium diagram.
- Liquidus is that line
  - (a) Above which the alloy is in liquid state.
  - (b) Where solidification starts.
- Solidus is that line
  - (a) Below which the alloy is in solid state, and
  - (b) Where solidification completes.

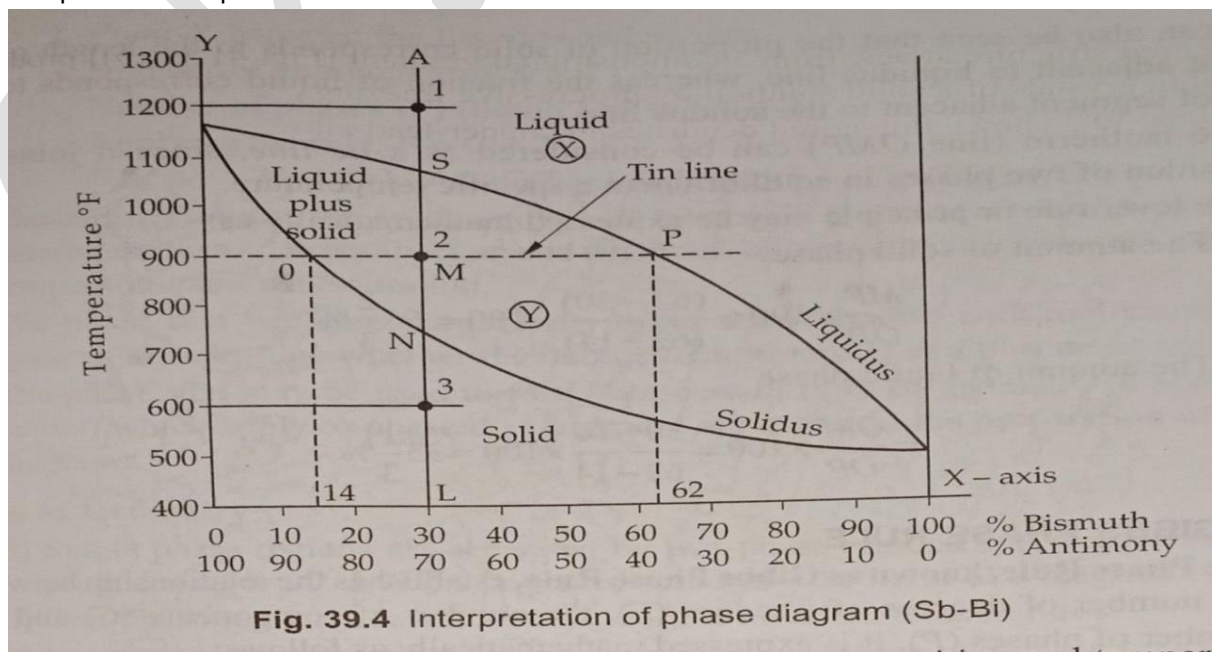
## INTERPRETATION OF PHASE DIAGRAMS

The following three useful conclusions are the rules necessary for interpreting phase diagrams:

1. The phases that are present.
2. The chemical composition of each phase.
3. The Lever Rule (the amount of each phase).

### Rule-1: Prediction of Phases

- From a phase diagram, specific information can be obtained only if a temperature and a composition are specified.





- For example, the state of the alloy of composition 30% Bismuth can be determined only with reference to a certain temperature. Thus when this alloy is at 1200°F, point 1 is located and when it is at 900°F and 600°F, points 2 and 3 are located respectively.
- The next step is to determine the phase or phases present at points number 1,2, and 3.
- Point 1: With 30% Bi-70% Sb alloy at 1200°F, only one phase, i.e., the liquid solution is present.
- Point 2: With the same alloy, but at 900°F, two phases are present, i.e., liquid solution and solid solution.
- Point 3: With the same alloy, but at 600°F, only one phase, i.e., the solid solution is present.

### Rule-2: Phase Composition

- To find out the composition of phases which are stable at a given temperature (say 900°F), draw a horizontal (isothermal) line, OP at the given temperature.
- The projections (upon the X-axis) of the intersections (i.e., O and P) of the isothermal line with the solidus and liquidus respectively, give the compositions of the solid and liquid, which co-exist in equilibrium at that temperature. For example: Liquid phase (point P) has the composition roughly 62% Bismuth.
- Solid phase (point O) has the composition roughly 14% Bismuth. (Remainder being Antimony).

### Rule-3: LEVER ARM PRINCIPLE

- Besides indicating the number of phases and phase composition, the phase diagram also tells the proportion of co-existing phases at any given temperature.
- To determine the relative amount of two phases, erect an ordinate at a point (say 30% Bi) on the composition scale which gives the total or overall composition of the alloy.  
The intersection of this composition vertical (AL) and a given isothermal line OP (i.e., point M) is the fulcrum of a simple lever system and OM and MP are two lever arms, The relative lengths of the lever arms multiplied by the amounts of the phase present must balance.
- This is called the **lever rule** because the amount of a given phase multiplied by its lever arm is equal to the amount of the other phase multiplied by its (i.e., other) lever arm.
- It can also be seen that the proportion of solid corresponds to the length of the segment adjacent to liquidus line, whereas the fraction of liquid corresponds to the length of segment adjacent to the solidus line.
- The isotherm (line OMP) can be considered as a tie line, since it joins the composition of two phases in equilibrium at a specific temperature. The lever rule or principle may be expressed mathematically as:

1. The amount of solid phase

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

2. The amount of liquid phase

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

### GIBBS PHASE RULE

- The Phase Rule, known as Gibbs Phase Rule, establishes the relationship between the number of degrees of freedom (F), the number of components (C) and the number of phases (P). It is expressed mathematically as follows:

$$P + F = C + 2 \dots(i)$$

where, P is the number of phases (e.g., solid, liquid etc.)

F is the number of degrees of freedom or the number of physical variables (pressure, temperature and concentration) that can be independently changed without altering the equilibrium, i.e., without causing disappearance of a phase or the formation of a new phase in the system, and, C is the number of components in the system; for example, Pb and Sn are the components of Pb-Sn equilibrium diagram.

In metallurgical systems where pressure is regarded as remaining fixed at one atmosphere, the pressure variable is often omitted and equation.

$$\text{simplifies to: } P + F = C + 1 \dots(ii)$$

$$\text{or } F = C + 1 - P \dots(iii)$$

Since the degrees of freedom F cannot be less than zero

$$C + 1 - P \geq 0, \text{ or } P \leq C + 1 \dots(iv)$$

Which means the number of phases (P) in a system cannot exceed the number of components plus one.

Therefore in a Binary system having value of C = 2, not more than (2 + 1) = 3 phases may be in equilibrium.

Considering points X and Y in Fig. 39.4, it is required to determine the number of degrees of freedom using the phase rule.

1. Point X, in the region above the liquidus Number of components (C) = 2, Since it is a binary system of Bi and Sb, Number of phases (P) (liquid) = 1

$$\text{Applying the rule, } F = C + 2 - P = 2 + 2 - 1$$

$$= 3 \text{ degrees of freedom.}$$

2. Point-Y, between the liquidus and solidus Number of components (C) = 2 Number of phases (P) (liquid and solid) = 2

$$\text{Applying the rule, } F = C + 2 - P = 2 + 2 - 2$$

$$= 2 \text{ degrees of freedom.}$$

The phase rule applies to dynamic and reversible processes, where a system is heterogeneous and in equilibrium and where the only external variables are pressure, temperature and concentration.

The phase rule becomes particularly useful when dealing with multicomponent systems to determine whether the microstructures are in equilibrium or not. The phase rule may be used to

formulate certain rules of geometry (a few listed below) which apply to phase diagrams and are useful in the preparation of phase diagrams.

### Rules of Geometry

- (i) Single phase regions are separated by two-phase regions and vice-versa. This produces a 1-2-1-2-1- 2.....sequence across the isotherm of a diagram.
- (ii) One-phase regions come in contact only at invariant temperatures.
- (iii) Invariant temperatures involve the termination of three two-phase regions.
- (iv) Solubility lines extrapolate into two-phase regions, etc.

### CLASSIFICATION OF EQUILIBRIUM DIAGRAMS

An equilibrium diagram has been defined as a plot of the composition of phases as a function of temperature in any alloy system under equilibrium conditions. Equilibrium diagrams may be classified according to the relation of the components in the liquid and solid states as follows:

### IRON-CARBON DIAGRAM

- **An equilibrium, phase or constitutional diagram** is a graphical representation of the effects of temperature and composition upon the phases present in an alloy.
- An equilibrium diagram is constructed by plotting temperature along the y-axis and percentage of carbon of the alloy along x-axis. This diagram shows ranges of temperature and compositions within which the various phase changes are stable and also the boundaries at which the phase changes occur.
- Iron- carbon equilibrium diagram indicates the phase changes that occur during heating and cooling and the nature and amount of the structural components that exist at any temperatures. Besides, it establishes a correlation between the microstructure and properties of steel and cast irons and provides a basis for the understanding of the principles of heat treatment.
- An iron carbon equilibrium diagram forms a basis differentiating among iron (0.008% C or less), hypoeutectoid steels (0.008 to 0.8% C), hypereutectoid steels (0.8 to 2.1 %C), hypoeutectic cast irons (2 to 4.3 % C) and hypereutectic cast irons above 4.3 % C.
- The iron carbon equilibrium diagram has a peritectic (point J), a eutectic (point C) and a eutectoid invariant reaction (point S).
- Peritectic reaction equation may be written as  
**Delta ( $\delta$ ) + Liquid (cooling/heating) Austenite**  
The horizontal line at 1493°C shows the peritectic reaction.
- The eutectic reaction takes place at 1150°C and its equation may be written as  
**Liquid cooling/heating Austenite +cementite (ledeburite)**  
Eutectic point is at 4.3 % carbon. Eutectic mixture is not usually seen in the microstructure, because austenite is not stable at room temperature and must undergo another reaction during cooling.
- The eutectoid reaction is represented by the horizontal line of 725°C and point S marks the eutectoid point. The eutectoid equation may be written as  
**Solid cooling/heating Ferrite + cementite (pearlite)**

**Transformation which occurs in the structure of steel contains** 0.4 %, 0.83% and 1.2 % carbon respectively when heated to a temp. high enough to make them austenitic and then allowed to cool slowly have been explained below.

- (i) Steel containing 0.4% carbon is a hypoeutectoid steel and is completely austenite above A<sub>3</sub>, i.e., upper critical temperature line. As it is cooled below A<sub>3</sub>, line the iron begins to change from F.C.C. to B.C.C. As a result, small crystals of body centered cubic (B.C.C.) iron begin to separate out from the austenite (F.C.C.). The B.C.C. crystals retain a small amount of carbon (less than 0.03%) and are referred as crystals of ferrite.
  - As the cooling proceeds, ferrite crystals grow in size at expense of austenite. By the time the steel has reached A<sub>1</sub> line, i.e., 725°C (called lower critical temperature) it is composed of approximately half ferrite and half austenite. At this stage the austenite contains 0.83% carbon and since austenite can hold no more than 0.83% carbon in solid solution at 725°C thus as the temperature drops further, carbon begins to precipitate as cementite.
  - This cementite and still separating ferrite form alternate layers until all the remaining austenite is consumed. The lamellae structure, i.e., eutectoid of ferrite and cementite contains 0.83% carbon and is known as Pearlite. All hypoeutectoid steels when cooled from austenite state will transform into ferrite pearlite in the same way as explained above.
- (ii) Consider the transformation of an eutectoid steel will remain austenite up to the point S. The transformation will begin and end at the same temperature, i.e., 725°C. Since eutectoid steel contains 0.83% carbon initially, it follows that the final transformed structure will be completely pearlite .
- (iii) Consider the transformation of a hypereutectoid steel (say containing 1.2% carbon)
  - As the temperature drops and steel crosses A<sub>cm</sub> (i.e., upper critical temperature) line at point d and moves towards e, the excess carbon above the amount required to saturate austenite (i.e., 0.83%) is precipitated as cementite primarily along the grain boundaries .
  - Thus, above 725°C, i.e., lower critical temperature line, the structure consists of austenite and cementite.
  - As the temperature drops below 725°C, the austenite has become less rich in carbon (because of cementite precipitation), it contains only 0.83% carbon and it transforms to pearlite as it does so in the cases of hypoeutectoid and eutectoid steels explained earlier.
  - The structure of a hypereutectoid steel at room temperature consists of cementite and pearlite.
  - In normal foundry practice, the rate of cooling is slightly faster and as a result more cementite plates are nucleated and individual lamellae of pearlite become thinner and the structure is called fine pearlite.
  - If castings are cooled at still faster rate to prevent transformation of austenite above (approximately) 315°C, martensite forms on further continuous cooling. Martensite is a hard, strong and brittle constituent. It is a super-saturated solution of carbon in ferrite and the presence of excess carbon distorts the normally cubic ferrite to a body-centered tetragonal structure which is produced by a shear mechanism and is strained.

**Transformations which take place in the structure of a cast iron containing 3% carbon is explained as under:**

**Case (a):** Cast iron containing 3% carbon is when cooled under rapid rate as a thin section of a sand casting, from a temperature of about 1400°C, it begins to solidify with the formation of grains of austenite. Austenite continues to solidify until the cast iron reaches the temperature of 1150°C. At

this stage the alloy consists of 50% austenite and 50% liquid of eutectic composition (austenite and cementite, i.e., ledeburite).

- As the alloy cools below solidus, i.e., 1150°C, ledeburite (a form of eutectic consisting of spheres of austenite embedded in cementite) freezes and cementite precipitates from austenite because of the decreasing solubility of carbon in the austenite. This occurs between 1150 and 725°C.
- Cooling of the alloy below 725°C\* involves the transformation of remaining austenite of eutectoid composition (i.e., 0.83% C) to pearlite as explained earlier for steels.
- Thus, the structure of alloy at room temperature consists of cementite, pearlite and transformed ledeburite.
- Cast iron of any composition between 2.0 to 4.3% carbon will solidify in exactly the same way as has been described above.
- **Case (b):** If the above very cast iron is cooled at a slow rate, as usual, austenite will first form from the melt (i.e., liquid) but eutectic freezing being slow, products of eutectic reaction will be austenite and graphite. This is between 1150 and 725°C. As cooling continues, austenite gets depleted in carbon content and graphite flakes grow. At 725°C, remaining austenite transforms to pearlite and the structure of the alloy at room temperature. It is pearlitic gray cast iron.

**The different microscopic constituents of iron and steel which commonly occur are:**

**1. Ferrite 2. Cementite 3. Pearlite 4. Martensite 5. Austenite, 6. Troostite and 7. Sorbite.**

#### **(a) Austenite**

- Austenite is the solid solution of carbon and/or other alloying elements (e.g., Mn, Ni, etc.) in gamma iron.
- Carbon is in interstitial solid solution whereas Mn, Ni, Cr, etc., are in substitutional solid solution with iron.
- Austenite can dissolve maximum 2% carbon at 1150°C.
- Austenite has:
  - \* Tensile strength 10500 kg/cm<sup>2</sup>.
  - \* Elongation 10% in 50 mm.
  - \* Hardness Rockwell C 40 (Approx).
- Austenite is normally not stable at room temperature. Under certain conditions, however, it is possible to obtain austenite at room temperature (as in austenite stainless steels).
- Austenite is non-magnetic and soft.

#### **(b) Ferrite**

- Ferrite is B.C.C. iron phase with very limited solubility for carbon. The maximum solubility is 0.025% carbon at 725°C, 0.1% at 1493°C and it dissolves only 0.008% carbon at room temperature.
- Ferrite is the softest structure that appears on the Fe-C equilibrium diagram. Ferrite has:
  - Tensile strength 2800 kg/cm<sup>2</sup> (Approx.)
  - Elongation 40% in 50 mm.
  - Hardness less than Rockwell C O or Rockwell B 90.

### (c) Cementite

- Cementite or iron carbide, chemical formula  $\text{Fe}_3\text{C}$ , contains 6.67% carbon by weight. It is a typical hard and brittle interstitial compound of low tensile strength (approx.  $350 \text{ kg/cm}^2$ ) but high compressive strength.
- Cementite is the hardest structure that appears on the iron-carbon equilibrium diagram. Its crystal structure is orthorhombic.

### (d) Ledeburite

Ledeburite is the eutectic mixture of austenite and cementite. It contains 4.3% carbon. It is formed at about  $1130^\circ\text{C}$ .

### (e) Pearlite

- The pearlite microconstituent consists of alternate lamellae of ferrite and cementite. Pearlite is the product of austenite decomposition by an eutectoid reaction. Thus, pearlite is an eutectoid mixture containing about 0.8% carbon and is formed at  $725^\circ\text{C}$ .
- Pearlite is the white ferrite background or matrix which makes up most of the eutectoid mixture contains thin plates of cementite (black).
- Pearlite has
  - Elongation 20% in 50 mm.
  - Hardness Rockwell C 20.

### (f) Bainite

- Bainite is the constituent produced in a steel when austenite transforms at a temperature below that at which pearlite is produced and above that at which martensite is formed.
- Bainite is produced by austempering.
- Thus bainite is a decomposition product of austenite, consisting of an aggregate of ferrite and carbide.
- Bainite is an isothermal transformation product and cannot be produced by continuous cooling.

### (g) Martensite

- Martensite is a metastable phase of steel, formed by transformation of austenite below the Martensite temperature ( $640^\circ\text{C}$ ).
- Martensite is an interstitial supersaturated solid solution of carbon in  $\alpha$ -iron and has a body-centered-tetragonal lattice.
- Martensite is considered to be highly stressed  $\alpha$ -iron which is supersaturated with carbon.
- Martensite forms as a result of shear-type transformation with virtually no diffusion. Martensite, normally, is a product of quenching.
- Martensite possesses an acicular or needle-like structure.

### (h) Troostite

- Troostite (Nodular) is a mixture of radial lamellae of ferrite and cementite and therefore differs from pearlite only in the degree of fineness and carbon content which is the same as that in the austenite from which it is formed

- In steel heat treatment, the troostite, i.e., the microstructure, consisting of ferrite and finely divided cementite is produced on tempering martensite below approximately 450°C.
- The constituent also known as troostite pearlite is produced by the decomposition of austenite when cooled at a rate slower than that which will yield a martensitic structure and faster than that which will produce a sorbitic structure.

#### (i) Sorbite

- Sorbite is the microstructure consisting of ferrite and finely divided cementite, produced on tempering martensite above approximately 450°C.
- The constituent also known as Sorbitic Pearlite, is produced by the decomposition of austenite when cooled at a rate slower than that which will yield a troostitic structure and faster than that which will produce a pearlitic structure.

#### Difference between Pearlite, Sorbite and Troostite.

- Pearlite, sorbite and troostite are all ferrite-cementite mixtures having a lamellar structure and distinguishable from each other in eutectoid steel only by their degrees of dispersion.
- The lower the decomposition temperature (higher degree of super cooling), the more dispersed the ferrite-cementite mixture will be.
- Pearlite is obtained at low degrees of supercooling. Sorbite, a finer mixture, is obtained at higher degrees of supercooling.
- At subcritical temperatures in the region of 500 to 550°C, troostite, an even more dispersed mixture, is obtained. Under an optical microscope, troostite is observed as a dark mass because the ferrite and cementite particles cannot be resolved. Thus, unlike pearlite, troostite is difficult to differentiate. However, structure of troostite is sufficiently clearly revealed under an electron microscope.

### Imperfections in Metal Crystals

#### INTRODUCTION

- A crystal is a solid composed of atoms, ions or molecules arranged in a pattern which is repetitive in three dimensions.
- In an ideal crystal, the atomic arrangement is perfectly regular and continuous throughout. An ideal crystal is perfect.
- But, real crystals as in cast or welded objects are never perfect; lattice distortion and various imperfections, irregularities or defects are generally present in them. Because of these defects, there is always a discrepancy between the computed and real yield stresses.
- Not only the yield stress, many more other physical and mechanical properties of engineering metals and alloys are profoundly affected by the imperfections in the crystals.

#### CLASSIFICATION OF CRYSTAL IMPERFECTIONS (OR DEFECTS) –

All defects and imperfections in crystals can be conveniently classed under three main divisions, namely:

##### 1. Point Defects

(a) Vacancies

- (c) Impurities
- (b) Interstitialcies
- (d) Electronic defects

**2. Line Defects**

- (a) Edge dislocation
- (b) Screw dislocation

**3. Planar, Surface, Interfacial or Grain boundaries Defects**

- (b) Tilt boundaries
- (a) Grain boundaries
- (c) Twin boundaries

**4. Volume defects such as cracks or stacking faults.**

**POINT DEFECTS**

- In a crystal lattice, point defect is one which is completely local in its effect, e.g., a vacant lattice site.
- The introduction of point defect into a crystal increases its internal energy as compared to that of the perfect crystal.
- The number of defects at equilibrium at a certain temperature can be determined from equation (i).

$$n_d = Ne^{-E_d/kt}$$

where,  $n$ , is the number of defects.

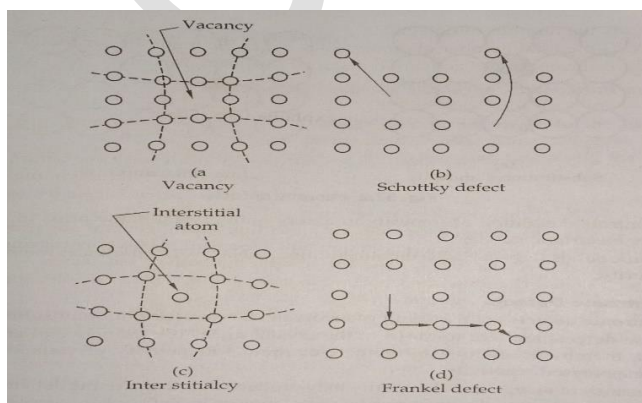
$N$  is the total number of atomic sites per cubic metre or per mole.

$E_d$  is the energy of activation necessary to form the defect.

$k$  is the Boltzmann constant,

and  $T$  is the absolute temperature.

The possible point defects have been explained as under:





### (a) Vacancies

- A vacancy or vacant site implies an unoccupied atom position within a crystal lattice. In other words, vacancies are simply empty atom sites.
- It may be shown by thermodynamic reasoning that lattice vacancies are a stable feature of metals at all temperatures above absolute zero.
- Vacancies may occur as a result of imperfect packing during the original crystallization or they may arise from thermal vibrations of atoms at elevated temperatures, because as thermal energy is increased there is a higher probability that individual atoms will jump out of their position of lowest energy.
- The atoms surrounding a vacancy tend to be closer together, thereby distorting the lattice planes .
- Vacancies may be single, or two or more of them may condense into a di-vacancy or tri-vacancy.

**Schottky defect** is closely related to vacancies and is formed when an atom or an ion is removed from a normal lattice site and replaced in an average position on the surface of the crystal. In other words, when vacancies are created by movements of atoms from positions inside the crystal to positions on the surface of the crystal, a Schottky defect is said to have been formed.

### (b) Interstitialcies

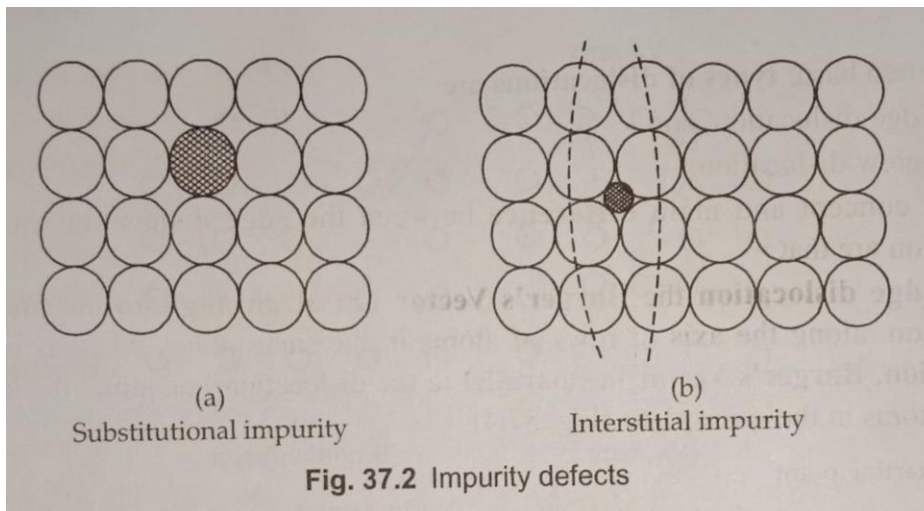
- An interstitial defect arises when an atom occupies a definite position in the lattice that is not normally occupied in the perfect crystal.
- In interstitialcies, atoms occupy positions between the atoms of the ideal crystal.
- The interstitial (atom) may be either a normal atom of the crystal or a foreign atom.
- The interstitial atom may be lodged within a crystal structure, particularly if the atomic packing factor\* is low.
- Interstitialcy produces atomic distortion because interstitial atom tends to push the surrounding atoms farther apart, unless the interstitial atom is smaller than the rest of the atoms in the crystal.

The term interstitialcy serves to emphasize the concept that when the defect migrates through the crystal, it probably does so by a sequence of jumps , rather than by the migration of a single atom from one interstitial position to another

- Frankel defect closely related to interstitialcies. An ion displaced from the lattice into an interstitial site is called a Frankel defect.

### (C) Impurities

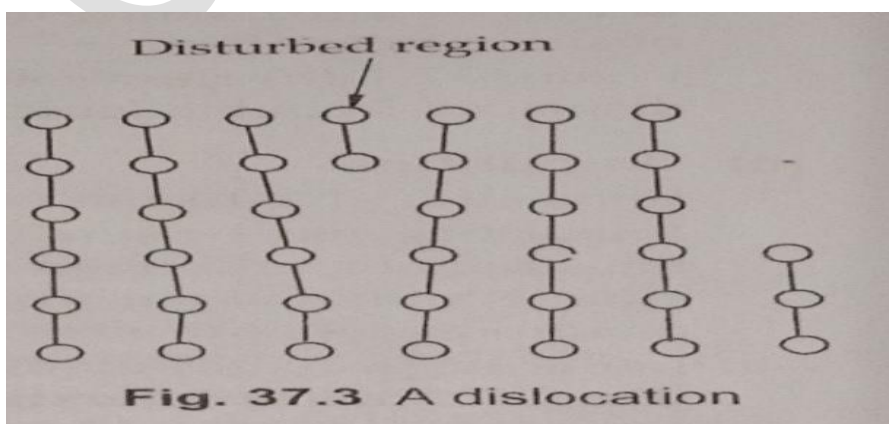
- Impurities give rise to compositional defects.
- Impurities may be small particles (such as slag inclusions in metals) embedded in the structure, or foreign (metal) atoms in the lattice. Foreign atoms generally have atomic radii and electronic structures differing from those of the host atoms and therefore, act as centres of distortion.



- Impurity (foreign) atoms are introduced into crystal structure as substitutional or interstitial atoms, i.e., foreign atoms either occupy lattice sites from which the regular atoms are missing or they occupy positions between the atoms of the ideal crystal. Impurities may considerably distort the lattice.
- Impurity defects occur in metallic, covalent and ionic solids and play a very important role in many solid-state processes such as diffusion, phase transformation and electrical and thermal conductivity.
- A controlled addition of impurity to a very poor crystal is the basis of producing many electronic devices.

#### LINE DEFECTS

- The most important two-dimensional or line defect is the Dislocation.
- A dislocation may be defined as a disturbed region between two substantially perfect parts of a crystal.
- Dislocation is a (line) defect in a crystal structure whereby a part-plane of atoms is displaced from its symmetrically stable position in the array. It is surrounded within the structure by an extensive elastic strain field and its associated stresses.
- The dislocation is responsible for the phenomenon of slip, by which most metals deform plastically. One may conclude that dislocation is the region of localized lattice disturbance separating the slipped and unslipped regions of a crystal.



Dislocations are intimately connected with slip and with many other mechanical phenomena such as strain hardening, the yield point, creep, fatigue and brittle fracture.

The two basic types of dislocations are:

1. Edge dislocation, and
2. Screw dislocation.

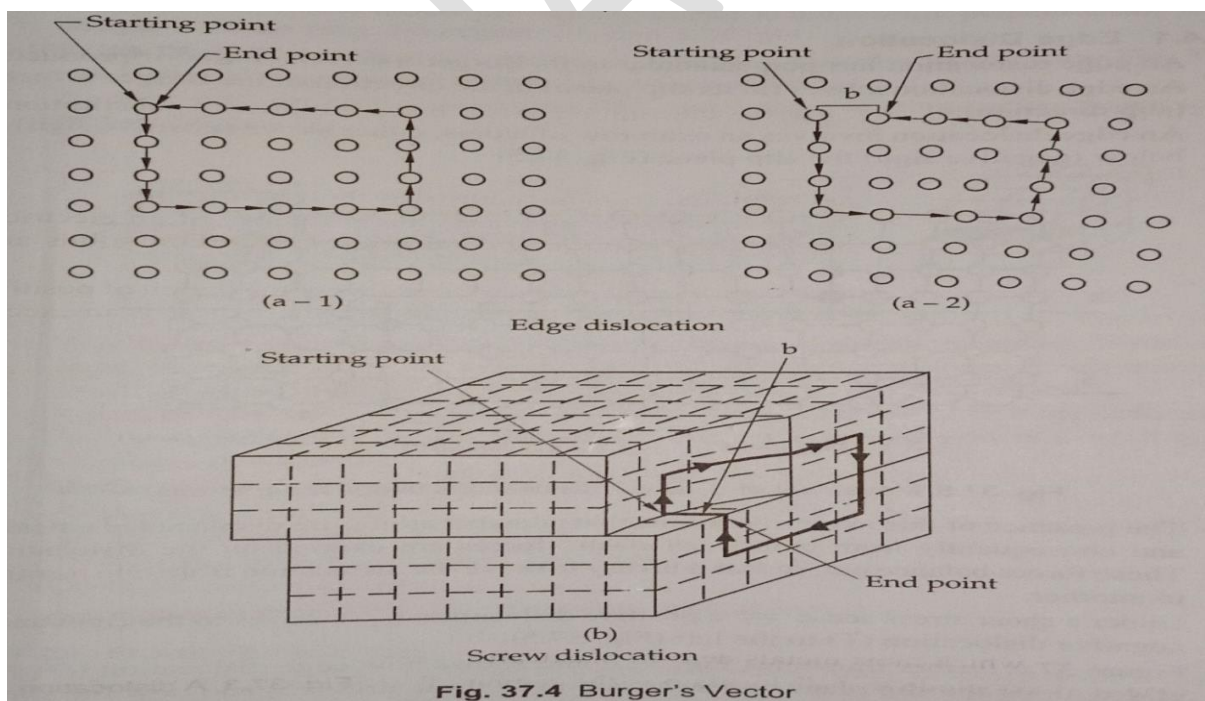
The concept and main difference between the edge dislocation and screw dislocation are that:

In edge dislocation the Burger's Vector lies at an angle to the line of the dislocation, along the axis of rows of atoms in the same plane, whereas in screw dislocation, Burger's Vector lies parallel to the dislocation line along the axis of a line of atoms in the same plane .

Burger's Vector marks the magnitude and direction of the strain component of dislocation.

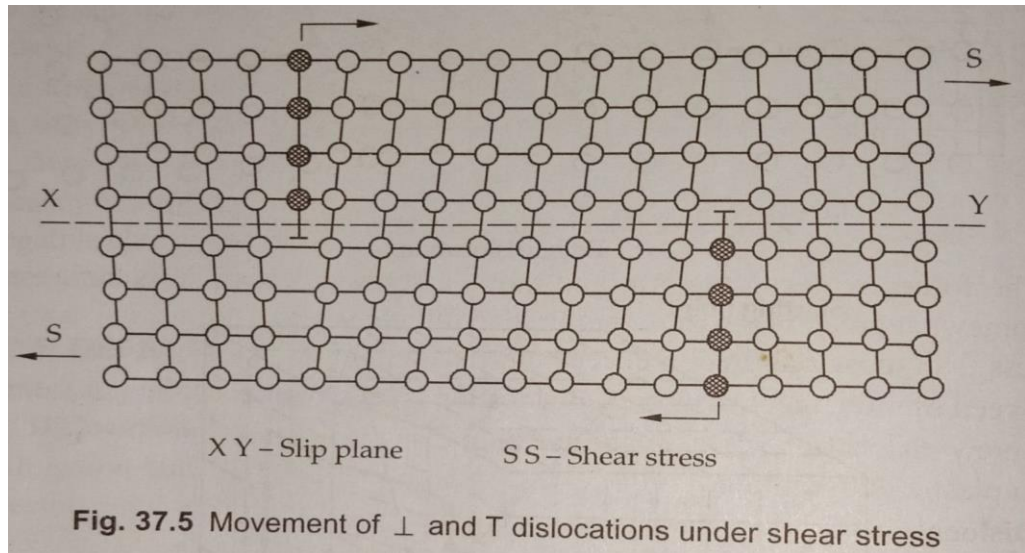
- Burger's Vector,  $b$ , which is actually the Burger's vector of the dislocation can completely describe the dislocation if the orientation of the dislocation line is known. Fig (a-1) and (a-2) show a method of determining the Burger's Vector, which is explained as follows:
  - (i) Choose arbitrarily a positive direction for the dislocation.
  - (ii) In Fig. (a-1), a counter clockwise circuit of atom-to-atom steps in a perfect crystal closes, but when the same step-by-step circuit is made around a dislocation in an imperfect crystal [Fig. (a-2)] the end point does not coincide with the starting point

Therefore, the vector  $b$  connecting the end point with the starting point is the Burger's Vector of the dislocation.



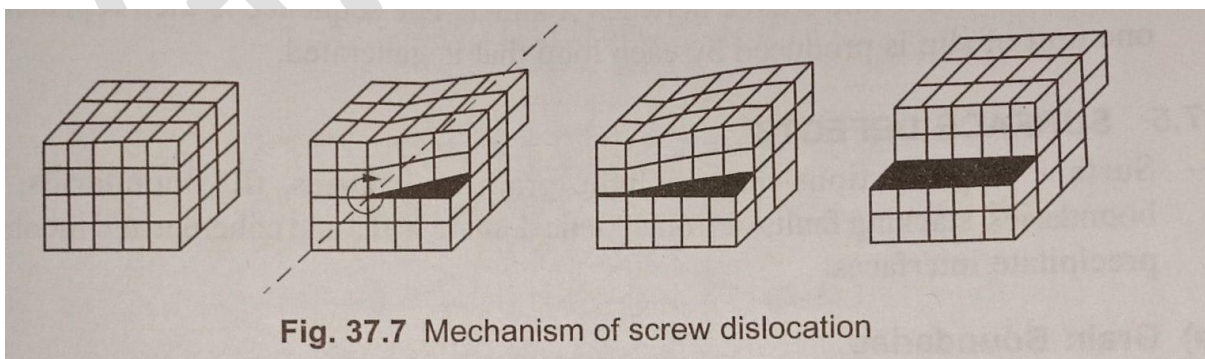
## Edge Dislocation

- An edge dislocation lies perpendicular to its Burger's vector, [Fig. (a-2)]. An edge dislocation moves (in its slip plane) in the direction of the Burger's vector (slip direction).
- An edge dislocation involves an extra row of atoms, either above (positive sign) or below (negative sign) the slip plane.
- The presence of this extra row means that adjacent atoms are displaced elastically, and consequently from both sides elastic forces are exerted on the dislocation. These forces balance out, so that it is easy to move the dislocation from one position to another
- Under a shear stress sense a positive dislocation ( $\perp$ ) moves to the right and a negative dislocation ( $\top$ ) to the left .



- Figure shows how edge dislocation (D) gets glided along the slip plane under the action of shear stress (S) and how the slip is caused by the movement of an edge dislocation.
- As the dislocation glides out of the crystal completely, it produces a slip step of one atom width at the edge of the crystal. The edge dislocation is particularly useful in explaining slip in plastic flow during mechanical working.

### Screw Dislocation



- A screw dislocation lies parallel to its Burger's vector .

- A screw dislocation moves (in the slip plane) in a direction perpendicular to the Burger's vector (slip direction).
- In the screw dislocation, the distortion follows a helical or screw path and both right hand and left-hand senses are possible.
  - A screw dislocation is a continuous helicoidal plane of atoms rather than a series of parallel planes.
- The forces required to form and move a screw dislocation, although probably somewhat greater than those required to initiate an edge dislocation, are markedly less than those required to exceed the elastic limit of a perfect crystal. Speed of movement of a screw dislocation is less than that of an edge dislocation. Screw dislocation is especially useful in explaining crystal growth as well as slip in plastic deformation.

Dislocations arise in crystals as a result of

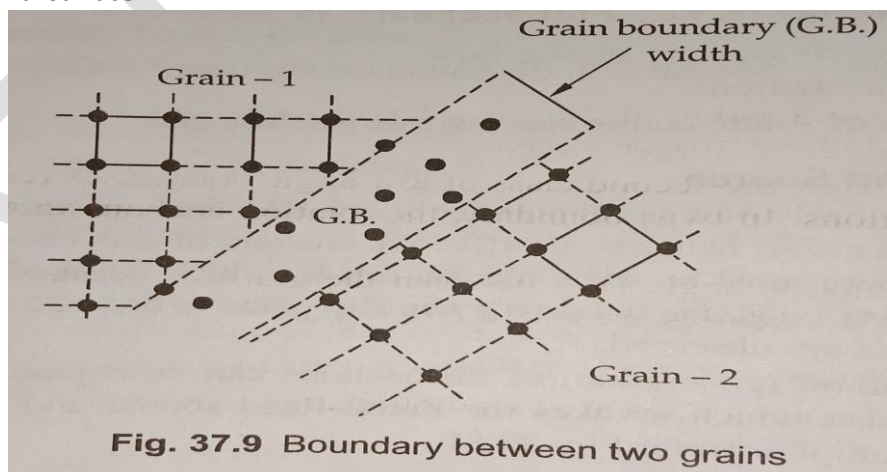
- (i) Growth accidents.
- (ii) Thermal stresses
- (iii) External stresses causing plastic flow.
- (iv) Phase transformations.
- (v) Segregation of solute atoms causing mismatches, etc.

### **SURFACE DEFECTS**

Surface imperfections may include, grain boundaries, tilt boundaries, twin boundaries, stacking faults, ferromagnetic domain walls and coherent and incoherent precipitate interfaces.

#### **(a) Grain Boundaries**

- Grain boundaries are those planar imperfections in polycrystalline materials that separate crystals (grains) of different orientation.
- A grain boundary is formed when two growing grain surfaces meet.
- A grain boundary is either a perfect plane of grain contact or a layer of atoms crystallographically distinct from either grain or a transition region and it is a three dimensional surface.



**Fig. 37.9** Boundary between two grains

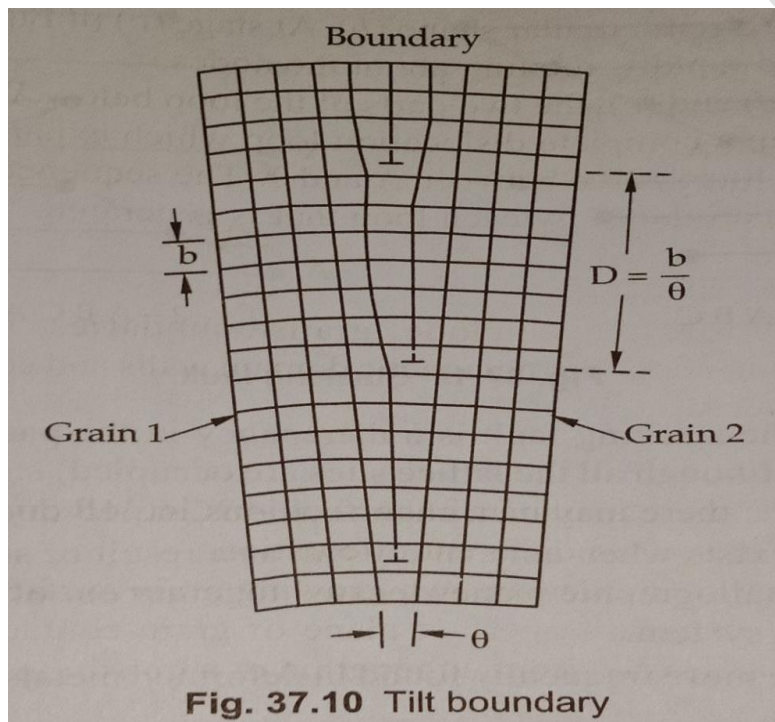
- In grain boundaries the atomic packing is imperfect. At the grain boundary between two adjacent grains there is a transition zone which is not aligned with either grain.



- Most atoms at the boundaries are located in highly strained and distorted positions and their free energy is higher than that of the atoms in the regular, undisturbed part of the crystal lattice.
- Whereas a grain boundary thickness of a few atoms has been confirmed by the field ion micrography, boundaries between grains in commercial metals are often wider, because impurities commonly concentrate at the grain boundaries during solidification.

### (b) Tilt Boundaries

Tilt boundary is another surface imperfection, and it may be regarded as an array of edge dislocations ( $\perp$ ).



- Actually tilt boundary is a class of low angle boundaries.
- By rotation of an axis in the boundary it is possible to bring the axis of two bordering grains into coincidence, i.e., a tilt boundary, in which case

$\tan\theta = \frac{b}{D}$  or  $\theta = \frac{b}{D}$  (because in tilt boundary, the degree of misorientation of the grain boundary or angle of tilt, i.e., is less than  $10^\circ$ ).  $D$  is the dislocation spacing and  $b$  is the length of Burger's vector.

Twist Boundaries, the second-class screw dislocations. In twist boundary, the rotation is about an axis normal to the boundary.

If the misorientation angle ( $\theta$ ), between the grains is greater than  $10^\circ$ - $15^\circ$ , the boundaries are called High-angle boundaries.

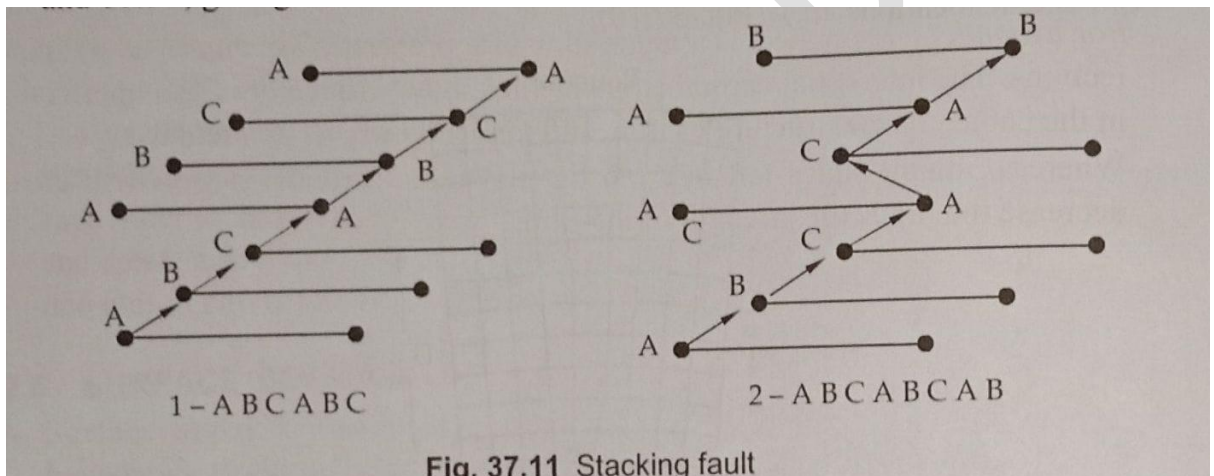
### (c) Twin Boundaries

- Other surface imperfections are twin boundaries.

- A twin boundary separates two parts of crystal having the same orientation and they look like mirror image of each other.

### VOLUME DEFECTS

- Volume defects such as cracks or stacking faults may arise where there is only small dissimilarity (electrostatically) between the stacking sequences of close packed planes in f.c.c. and h.c.p. metals, e.g., ABCABC and ABABAB. It is possible for one atom layer to be out of sequence relative to the atoms of the layers above and below, giving a mistake (defect) e.g., ABCACAB .



- In other words, the stacking fault is a discrepancy in the packing sequence of the layers of atoms (although all the lattice sites are occupied) e.g., instead of a regular sequence ABCABC there may be a change as ABCACAB due to the stacking fault. A stacking fault exists when a metal crystal, as a result of slip or other cause, has two adjacent crystallographic planes located together out of the normal geometric pattern within the system.
- Stacking faults are more frequently found in deformed metals than annealed metals.

### Effect of imperfections on metal properties

- The role of imperfections in the behaviour of engineering materials is vital.
- The imperfections account for
  - (i) Flow and fracture characteristics.
  - (ii) Crystal growth.
  - (iii) Electrical properties including semi-conducting behaviour.
  - (iv) Diffusion mechanisms.
  - (v) Creep characteristics of real metals and alloys.
  - (vi) Annealing and precipitation.
  - (vii) Oxidation and corrosion.
  - (viii) Yield strength, fracture strength, plasticity, thermal conductivity dielectric strength, etc.
    - The study of imperfections has a twofold purpose, namely.
      - (a) A better understanding of them and how they affect metal properties.

(b) Exploration of possibilities of minimizing or eliminating these defects.

For example, metal whiskers of diameter of about 10<sup>-4</sup> cm, exhibit essentially theoretical strengths; they are thought to be free of dislocations. In defect free metal crystals, one would commonly experience tensile strengths of the order of magnitude of millions of kg/cm<sup>2</sup>.

- However, it should be noted that imperfections do not always affect the properties of materials adversely. On the contrary, there are many situations in which a judicious control of types and amounts of imperfections can bring about specific characteristics desired in a material.
- For example, carbon steel is a material whose properties are improved by imperfections. The interstitial carbon atoms, which may be thought of as imperfections in the cubic crystal structure of iron, add tremendously to its strength. Whereas, minute holes left in a plastic film by a sintering process will greatly decrease the dielectric strength of the film.

## HEAT TREATMENT

### PURPOSE OF HEAT TREATMENT

One or the other heat treatment process is carried out in order to

- (i) Cause relief of internal stresses developed during cold working, welding, casting, forging etc.
- (ii) Harden and strengthen metals
- (iii) Improve machinability.
- (iv) Change grain size.
- (v) Soften metals for further (cold) working as in wire drawing or cold rolling.
- (vi) Improve ductility and toughness.
- (vii) Increase heat, wear and corrosion resistance of materials.
- (viii) Improve electrical and magnetic properties.
- (ix) Homogenise the structure, to improve coring or segregation.
- (x) Spheroidize tiny particles, such as those of Fe<sub>3</sub>C in steel, by diffusion.

### CLASSIFICATION OF HEAT-TREATMENT PROCESSES

Various heat treatment processes can be classified as

#### 1. Annealing

- (a) Stress relief annealing.
- (b) Process annealing.
- (c) Spheroidising.
- (d) Full annealing.

#### 2. Normalising

#### 3. Hardening (by quenching)

#### 4. Tempering.

- (a) Martempering.



- (c) Austempering.
- 5. Surface hardening
  - (a) Case hardening
  - (b) Nitriding
  - (c) Cyaniding
  - (d) Flame hardening
  - (e) Induction hardening.
  - (f) Carburizing

### **1. annealing**

Annealing is defined as a softening process consisting to heating the steel to a temperature at or near the critical point, holding there for a proper time and then allowing it to cool slowly in the furnace itself. The temperature required for annealing varies with different steels. Low carbon steels are heated to a temperature slightly above the upper critical temperature. High carbon steels more than 0.9% carbon are heated to a temperature within the critical range. High carbon tool steel and air hardening nickel chromium molybdenum steels are heated to a temperature below their critical point. Hypo-eutectoid steel is heated 20°C above the upper critical temperature, while hypereutectoid steel is heated to 20°C above the lower critical temperature.

#### **Objects of Annealing:**

- (i) To soften the metal.
- (ii) To improve machinability
- (iii) To improve mechanical properties, like ductility.
- (iv) To refine grain size.
- (v) To relieve internal stresses.
- (vi) To remove gases.
- (vii) To produce a definite micro-structure. a
- (viii) To minimise segregation of the essential constituents of the steel.
- (ix) To modify electrical and magnetic properties.
- (x) To prepare steel for subsequent heat treatment.

#### **CONCEPT**

When applied to ferrous alloys, the term annealing ,generally implies full annealing.

Any process of annealing will usually reduce stresses, but if the treatment is applied for the sole purpose of such relief, it should be designed stress relieving.

- (a) **Stress relieving**

- This annealing process relieves stresses produced by casting, quenching, machining, cold working, welding, etc.
- This process applies equally well to ferrous and non-ferrous metals
- Thermal stress relieving requires heating the casting to a temperature at which relaxation of the elastic stress is brought about by plastic deformation corresponding to the elastic strain.
- 

## 2. Normalizing

Normalizing or air quenching consists in heating steel to about 40-50°C above its upper critical temperature (i.e., A<sub>1</sub> and A<sub>cm</sub> line) and, if necessary, holding it at that temperature for a short time and then cooling in still air at room temperature.

- Normalizing differs from full annealing in that the rate of cooling is more rapid and there is no extended soaking period.
- The type of structure obtained by normalizing will depend largely on the thickness of cross section as this will affect the rate of cooling. Thin sections will give a much finer grain than thick sections.
  - Normalizing produces microstructures consisting of ferrite (white network) and pearlite (dark areas) for hypoeutectoid (i.e., up to about 0.8% C) steels. For eutectoid steels, the microstructure is only pearlite and it is pearlite and cementite for hypereutectoid steels.

### Normalizing (Purpose)

- \* Produces a uniform structure.
- \* Refines the grain size of steel, which may have been unduly coarsened at the forging or rolling temperature.
- \* May achieve the required strength and ductility in a steel that is too soft and ductile for machining
- \* Reduces internal stresses.
- \* Improves structures in welds.
- \* Produces a harder and stronger steel than full annealing.
  - \* Eliminates the carbide network at the grain boundaries of hypereutectoid steels.
- \* In general, improves engineering properties of steels.

## 3. Hardening

Hardening is defined as the heat-treating process in which the steel is heated to a temperature within or above its critical range, held at this temperature for a considerable

time to ensure through penetration the temperature inside the component and then allowed to cool by quenching in water, oil or brine solution. If the carbon content of the steel is known, the proper temperature to which the steel should be heated may be obtained by the iron-carbon equilibrium diagram. The hypo-eutectoid steel is heated to 20°C above the upper critical temperature, while the hyper eutectoid steel is heated to 20°C above the lower critical temperature.

### **Purpose of hardening**

1. Carbon content
2. Quenching rate
3. Work size

Hardness obtained from the hardening process depends upon following factors also :

1. Homogeneity of austenite
2. Grain size
3. Heating rate and time.
4. Surface condition
5. Rate of cooling.

### **(iv) Tempering:**

The hardened steel is brittle and unsuitable for most uses. The hardness and brittleness may be reduced by tempering or drawing. According to American society of testing material, the tempering is defined as the process of reheating the hardened steel to some temperature below the critical range, followed by any rate of cooling. Such a reheating permits the trapped martensite to transform and relieve the internal stresses. The tempering temperature is determined by the specification of steel and the final hardness and toughness desired.

Tempering is an essential operation after hardening to modify the properties of the hardened steel for the purpose of increasing its usefulness.

### **Objects of Tempering:**

- (i) To reduce hardness, brittleness and tensile strength.
- (ii) To increase ductility and toughness.
- (iii) To relieve internal stresses.
- (iv) To equalize the hardness in a piece, as far as possible.

### **Process of tempering**

Tempering may be classified into following types:

#### **1. Low Temperature Tempering**

- This treatment is carried out in the temperature range from 150 to 250°C. - Internal stresses are reduced.
- Toughness and ductility get increased without any appreciable loss in hardness.
- The structure still contains martensite.
- Low temperature tempering is applied to cutting tools of carbon steels and low alloy steels and to the components that are surface hardened and carburized.

## **2. Medium Temperature Tempering**

- Medium temperature tempering is carried out in the temperature range from 350°C to 450°C.
- This treatment develops troostite structure.
- With this treatment, hardness and strength of steels decrease, while % of elongation and ductility increase.
- Medium temperature tempering imparts to steels the highest (attainable) elastic limit with sufficient toughness.
- Medium temperature tempering is applied to objects such as coil springs, laminated springs, hammers, chisels, etc.

## **3. High Temperature Tempering**

- High temperature tempering is carried out in the temperature range from 500°C to 650°C.

High temperature tempering:

- Eliminates internal stresses completely.
- Develops a sorbite structure,
- Imparts high ductility in conjunction with adequate hardness, and
- Is used for components such as
  - (i) Connecting rods
  - (ii) Shafts
  - (ii) Gears, etc.

## **MARTEMPERING**

In Martempering, steel is

- (i) heated to above the critical range to make it all austenite ; is then
- (ii) quenched into a salt bath maintained at a temperature above the Ms and is held at this temperature long enough until the temperature is uniform across the section of the workpiece (i.e., from surface to core) without transformation of the austenite; and
- (iii) subsequently cooling the workpiece in air through the martensite range

- The result is the formation of martensite with a minimum of stresses, distortion and Cracking.
- The steel thus obtained may be further tempered in order to increase ductility.
- Large sections cannot be heat treated by martempering because the time required to obtain temperature uniformity (of work-piece surface and its core) exceeds the start of transformation of austenite into bainite.

- Actually, in practice, in order to utilize benefits of martempering, alloying elements are added to steel. Otherwise the critical cooling rate is too fast and the benefits of the martensite hardness cannot be realized in parts that are large or even medium in size.

### **AUSTEMPERING**

- Austempering is not a hardening treatment.
  - Austempering is another type of interrupted quenching, that forms Bainite (and not martensite).
  - In structure and properties, however, the bainite thus formed closely resembles tempered martensite.
  - In general, steels treated thus are tougher and more ductile than steels of tempered martensite having equal hardness and tensile strength.
  - However, a major limitation is that size is restricted to relatively thin sections so that the entire piece can quickly attain the temperature of quenching bath.
  - For steels of high hardenability, larger sections can be used. An additional disadvantage is the relatively long time required for the isothermal transformation of austenite to bainite.
  - Austempering consists in
    - (i) heating the steel above the critical range to make it all austenite; is then (ii) quenched at a critical cooling rate into a salt bath or lead bath held in the bainite range (usually between 205°C and 425°C);
    - (iii) the steel piece remains in the bath until the austenite is completely transformed to bainite and then it is
    - (iv) allowed to cool to room temperature, the rate being immaterial. .
- Tempering is rarely needed after austempering

### **Advantages of Austempering**

1. Greater ductility and toughness (impact strength) along with high hardness.
2. Less distortion.
3. Less danger of quenching cracks because the quench is not very drastic.

## **SURFACE HARDENING**

### **INTRODUCTION**

Numerous industrial applications such as cams, gears, etc., require a hard wear resistant surface called the case and a relatively soft, tough and shock resistant inside, called the core.

No plain carbon steel can possess both these requirements at the same time; because a low carbon steel, containing about 0.1% carbon, will be tough, whilst a high carbon steel of 0.9% or more carbon will possess adequate hardness when suitably heat treated.

However, both these requirements may be met by employing a low carbon steel with suitable core properties and then adding (or penetrating) Carbon, Nitrogen or both to the surface of the steel part in order to provide a hardened case (or layer) of a definite depth. These treatments are known as Case Hardening. The processes used to create hardened cases are:

1. Carburizing

2. Nitriding.
3. Cyaniding.
4. Carbonitriding.

An other method to obtain tough core and hard case in a steel part is to take medium carbon steel in the normalized condition and then introduce local hardness at the surface by some hardening processes such as.

5. Flame hardening.
6. Induction hardening.

Surface treatments involve applying coatings to the surface of metals/alloys in order to

- (i) Improve corrosion, heat or wear resistance,
- (ii) Rebuild worn or undersized parts,
- (iii) Serve as an ornamental finish,
- (iv) Lengthen the useful life of a part manufactured from a low cost material having surface characteristics unsuited for a given installation.

## **CARBURIZING**

### **Definition**

A Carburizing is a method of introducing, carbon into solid iron-base alloys such as low carbon steels in order to produce a hard case (surface). Carburizing is also called cementation.

Carburizing increases the carbon content of the steel surface by a process of absorption and diffusion.

### **Process**

Low carbon steel (about 0.20% carbon or lower) is heated at 870 to 925°C in contact with gaseous, solid or liquid carbon containing substances for several hours. The high carbon steel surface (thus obtained) is hardened by quenching from above the A<sub>1</sub> temperature.

### **Characteristics**

- \* Case depth is about 0.05 inch (1.27 mm).
- \* Hardness after heat treatment is Re 65.
- \* Carburizing causes negligible change in dimensions.
- \* Distortion may occur during heat treatment.

Typical Uses: In the case hardening of

- \* Gears
- \* Camshafts
- \*Bearings

### **Methods**

There are three general methods of Carburizing, depending upon the form of the Carburizing medium, namely:

- (a) Pack Carburizing employing solid Carburizing medium.
- (b) Gas Carburizing employing suitable hydro-carbon gases
- (c) Liquid Carburizing employing fused baths of Carburizing salts.

The choice of a particular method out of the three listed above depends upon:

- (i) The characteristics of the case which are desired,
- (ii) The equipment available,
- (iii) The quantity of parts which is to be handled.

## **PACK CARBURIZING**

### **Introduction**

Pack carburizing involves packing the components into cast iron or steel boxes along with the carburizing material so that a space of approximately 50 mm exists between the components.

Carburizing medium consists essentially of wood, or bone charcoal or charred leather, together with an energiser (a mixture of sodium carbonate and barium carbonate which may account for up to 40% of the total composition).

After the components and the carburizing medium have been packed in the boxes the lids are luted on to them and the boxes are then slowly heated to the carburizing temperature, between 900 and 950°C, and then kept at that temperature up to five hours depending upon the depth of case desired. When carburizing is complete, the parts are quenched or cooled slowly in the boxes, depending upon the nature of the subsequent heat treatment to be applied

## **GAS CARBURIZING**

In this carburization process components are heated at about 900°C for three or four hours in an atmosphere containing gases which will deposit carbon atoms at the surface of the components.

The most commonly used atmosphere for gas carburizing consists of approximately

20% of CO

40 % Hydrogen and

40 % Nitrogen

This endothermic atmosphere is applied both as a source of carbon from CO and as a carrier gas to dilute hydrocarbon gas such as methane which is used both a source of carbon and control surface chemical reaction.

By suitable adjustment of time, temperature and gas composition, the case depth can be varied .

The depth of case vary from 0.25 mm on articles for light work, 0.5 to 1 mm for automobile work, and 0.37 mm for roller bearings and ball races wgrer compressive stresses are high.

### **ADVANTAGES OF GAS CARBURIZING**

- Pack carburization cannot be accurately controlled with regard to case depth and it requires considerable labour in the packing, loading, and unpacking of boxes. Gas carburizing eliminates these handicaps and in addition eliminates pack material, which results in more favourable heat treatment economies.
- Labour costs are lower than in pack carburizing.
- Heating is more rapid and uniform than in pack carburizing.
- The carbon potential can be closely controlled.
- Less time is required than pack carburizing, since there is no need to pack and handle boxes containing workpieces to be treated.

For the same reason, the floor space required is less.

- Gas carburizing provides cleaner surroundings, closer quality control and greater flexibility of operation in comparison with pack carburizing.
- Gas carburizing may be feasibly mechanised.

### **Disadvantages of Gas Carburizing**

1. As compared to pack carburizing, higher skilled personnel are required to maintain the necessary controls.

### **LIQUID CARBURIZING**

#### **Principles**

Carburizing in liquid baths is of comparatively recent origin and is an outgrowth of the older process of cyaniding.

- Liquid carburizing is employed principally for relatively shallow cases (0.10-0.25 mm) which can be produced at lower cost by this process than with pack or gas carburizing

Liquid carburizing is carried out in baths containing 20 to 50% Sodium Cyanide, together with up to 40% Sodium carbonate and varying amounts of Sodium or Barium Chloride.

This cyanide-rich mixture is heated to a temperature of 870-950°C and the workpieces contained in wire baskets are immersed into the liquid bath for periods varying from about 5 minutes to one hour, depending upon the depth of case required.

Thus in liquid carburizing, like cyaniding (or carbonitriding) both C and N are added to the steel surface.

Cyanide cases are seldom to a depth greater than 0.25 mm; liquid carburizing permits cases as deep as 6.25 mm.

#### **Advantages of liquid carburizing**

Liquid carburizing offers advantages of

- \* Rapid heat transfer



- \* Low distortion
- \* Negligible surface oxidation or decarburization
- \* Rapid absorption of carbon and nitrogen
- \* Uniform case depth and carbon content
- \* Reduced time for steel to reach the carburizing temperature.
- \* Flexibility to handle a wide range of parts of varied design and varied case depths.

### **Disadvantages of liquid carburizing**

- \* Cyanide salts are highly poisonous when taken internally (even as fumes) or when in contact with open wounds.
- \* Molten cyanide explodes on contact with water, so all work should be dried carefully before it is placed in the liquid bath.
- \* Parts need thorough washing after treatment to prevent rusting.

### **Applications**

Gas carburizing is particularly suitable for mass production of thin cases in small and medium size parts.

### **NITRIDING**

#### **Definition and Introduction**

Nitriding accompanies the introduction of nitrogen into the surface of certain types of steels (e.g., containing Al and Cr) by heating it and holding it at a suitable temperature in contact with partially dissociated ammonia or other suitable medium. This process produces a hard case without quenching or any further heat treatment.

Process Characteristics Case depth is about 0.381 mm. Extreme hardness (Vickers 1100), - Growth of 0.025-0.050 mm occurs during nitriding. Case has improved corrosion resistance.

#### **Typical Uses**

- \* Valve seats for tris
- \* Guides
- \* Gears OT
- \* Gauges body
- \* Bushings
- \* Moulds for plasters
- \* Aircraft engine parts
- \* Aero crankshafts, air screw shafts
- \* Crank pins and journals
- \* Ball races
- \* Aero engine cylinders

## **Nitriding process**

Before being nitrided, the components are heat treated to produce properties in the core. The normal sequence of operations are:

- (i) Oil quenching from between 850 and 900°C followed by tempering at between 600 and 700°C. the required
- (ii) Rough machining followed by a stabilizing anneal at 550°C for five remove internal stresses.
- iii) Finish machining, followed by nitriding.

Nitriding: The components are placed in a heat-resistant metal container which then filled with ammonia whilst cold. When it is completely purged, it is sealed, placed in a furnace and raised to a temperature of approximately 500°C. ammonia dissociates.

$\text{NH}_3 = 3\text{H} + \text{N}$ , and N is absorbed in the surface layer of steel.

Parts are maintained at 500°C for between 40 to 100 hours\* depending upon the depth of case required; after which the parts are allowed to cool in the container.

## **Advantages of Nitriding**

1. Very high surface hardness of the order of 1150 VPN may be obtained.
2. Since nitrided parts are not quenched, this minimizes distortion or cracking.
3. Good corrosion and wear resistance.
4. Good fatigue resistance.
5. Whereas in a carburized part, hardness begins to fall at about 200°C, a nitrided part retains hardness up to 500°C.
6. No machining is required after nitriding.
7. Some complex parts which are not carburized satisfactorily, can be nitrided without difficulty.
8. The process is economical when large number of parts are to be treated.

## **Disadvantages of Nitriding**

1. Long cycle times (40 to 100 hours).
2. The brittle case.
3. Only special alloy steels (containing Al, Cr and V) can be satisfactorily treated.
4. High cost of the nitriding process.
5. Technical control required.
6. If a nitrided component is accidentally overheated, the surface hardness will be lost completely and the component must be nitrided again.

**Effects of Heat Treatment on Properties of Steel are :**

- (i) To produce hard surface on a ductile interior.
- (ii) To improve machinability.
- (iii) To refine grain size.
- (iv) To relieve internal stress.
- (iv) To increase resistance to wear, heat and corrosion.
- (v) To improve magnetic and electrical properties.
- (vi) To improve mechanical properties, like tensile strength, hardness, ductility, shock resistance, etc.

#### **. Hardenability of Steel :**

• Whereas hardness is a measure of resistance to plastic deformation (by indentation), hardenability is the ease with which hardness may be attained in the depth direction of an object.

Hardenability may also be remembered as the ability of a steel to become uniformly hard or to harden in depth direction.

In a ferrous alloy, hardenability is the property that determines the depth and distribution of hardness induced by quenching.

Hardenability plays an important role in successful hardening.

In the absence of adequate hardenability of steel (as in low carbon steels) even the most drastic quench is incapable of producing martensite in a steel bar of a given size.

It should be remembered that hardenability is not an indication of the hardness of a steel, rather hardenability is an index of the depth to which martensite can be formed in a given steel as the result of quenching

Hardenability value for a given steel is the diameter in inches of a cylindrical bar that will form 50% martensite at the centre during an ideal quench. (An ideal quench is one that instantly cools the surface of a hot bar to room temperature).

: Hardenability is a property of steel heat of steel has a definite hardenability.

#### **Factors affecting hardenability :**

Factors affecting hardenability of a given steel are

- (i) In general the composition of the steel and method of manufacture.
- (ii) The quenching media and the method of quenching
- (iii) Section of the steel.
- (iv) The main composition of the austenite before quenching, including the nature and amount of alloying elements.

All alloying elements except Co, tend to increase the hardenability, and the degree of hardening produced varies from the strong elements (Mn and Mo) to some of the weaker elements (Vanadium).

As compared to carbon steels, alloy steels harden to a considerably larger depth due to the high stability of the supercooled austenite and the corresponding lower critical cooling rate.

(v) The size of austenite grains before quenching. The larger the austenite grain size prior to quenching, the greater the degree of hardenability..

(vi) The homogeneity of the austenite before quenching (the degree of uniformity of dispersion of carbon and carbide and of alloying elements in the austenite).

(vii) The presence of undissolved carbides and nonmetallic inclusions before quenching. The presence of undissolved carbides or nonmetallic inclusions tend to reduce hardenability.

G.P. JALPUR

## 6.0

## Non-ferrous alloys

### Aluminum alloys:

#### Properties of Aluminum:

- It is a light metal, with a density about one-third that of steel.
- Good conductor of heat and electricity.
- High resistance to corrosion.
- Very ductile.
- Non-magnetic.
- It forms high strength alloy with: Cu, Cr, Ni, Fe, Zn, Mo, Si etc.

#### Properties of Aluminum alloy:

- Very strong.
- Malleable and ductile.
- High toughness
- It can be cast, rolled, forged and weld etc.

#### Use of aluminum

- In transportation industry- Hardware, doors, Window frames, tanks, Parts of automobile.
- Conductors and heat exchangers.
- In Food industries- Storage containers, refrigerators, food preparation equipments.
- Cryogenic applications.

#### Types of aluminum alloys

##### 1. Duralumin

Cu: 3.5 – 4.5 %, Mn: 0.4 – 0.7 %, Mg: 0.4 – 0.7 %, Fe or Si: < 0.7 % and Al balanced.

#### Properties:

- High machinability.
- High tensile strength (as high as steel)
- Excellent casting and forging properties.

**Uses:**

- Air craft and automobile parts.
- Bars, Sheets, Tubes , Rivets.
- Light structure.

**Y- Alloy****Composition:**

Cu: 3.5 – 4.5 %, Mn: 1.2 – 1.7 %, Ni: 1.8 – 2.3 % Si and Fe: 0.6 % Al balance

**Uses**

- For casting purpose.
- Air craft engine parts.
- Better strength than Duralumin at high temperature.
- cylinder heads, pistons, cylinder heads, crank cases of internal combustion engines, pump rods etc.

**Cu and it's alloys****Properties of copper**

- Excellent resistance to corrosion.
- It is non- magnetic.
- Ductile and malleable.
- Moderate hardness and strength.
- High thermal and electrical conductivity.
- Resistance to fatigue and abrasion.
- It can be welded and soldered.
- Good machinability.

**Use of Copper.**

- Electrical parts.
- Heat exchangers.
- Screw.
- Household utensils.

## Copper-Aluminum (Aluminum Bronze)

### Composition:

Cu	Al	Fe	Sn	Mn
89	7	3.5	0.35	-
91	6-8	1.5-3.5	-	1(max)

### Properties:

- Good strength.
- High corrosion resistance.
- Good heat resistance.
- Good cold working properties.

### Uses:

- Bearing
- Valve seats
- Gears.
- Propellers.
- Slide valves.
- Cams.
- Imitation jewellery.
- Pump parts.

## COPPER-TIN (BRONZE) ALLOYS

### Composition

Cu : 75 - 95 %. Sn: 5 – 25 %

### Properties

- Resistance to certain type of corrosion.
- Is reasonable hard.
- More hardness.

### Uses:

- Used in marine condensers
- Used as condenser tubes.

## **Phosphor Bronze**

When bronze contains phosphor, it is called phosphor bronze.

The most important copper tin alloys are those which have been deoxidized with phosphorus during the refining process and hence are known as phosphorus bronze.

### ➤ **Standard phosphor bronze for bearing applications**

#### **Composition**

Cu : 90 % , Sn : 10 % and P : 0.5 % (minimum)

### ➤ **Phosphor bronze for gears**

#### **Composition**

Cu : 88 % , Sn : 12 % , Zn : 0.3 % (max), Pb : 0.5 (max) and P : 0.15 % (min)

### ➤ **Leaded phosphor bronze**

#### **Composition**

Cu: 87% , Sn : 7.5%, Zn : 2%(max) , Pb : 3.5 % , P : 0.3%(min) and Ni : 1% (max)

## **Properties**

- High strength and toughness.
- Resistance to corrosion.
- Good load bearing capacity.
- Low co-efficient of friction.

## **Uses**

- Bearing applications.
- Pump parts
- Linings.
- Springs.
- Diaphragms.
- Gears.
- Clutch discs.
- Bellows etc.

## **Babbitt metal**

#### **Composition**

Sn : 88 % , Sb : 8% and Cu : 4%



## **Brasses**

Brasses contain zinc as the principle alloying element. Brasses are subdivided into three groups; (i) Cu-Zn alloys,

(ii) Cu-Pb-Zn alloys or leaded brasses, and

(iii) Cu-Zn-Sn alloys or tin brasses.

Brass has high resistance to corrosion and is easily machinable.

It also acts as good bearing material.

Zinc in the brass increases ductility along with strength.

Brass possesses greater strength than copper, however, it has a Lower thermal and electrical conductivity.

### **Various types of brasses are discussed below:**

**1. Cartridge brass** normally contains 70% Cu and 30% Zn. In the fully annealed condition it has a tensile strength of over 300 N/mm<sup>2</sup>.

Greater % elongation and tensile strength make this brass satisfactory for cold deformation in presses and by spinning or other means, and have led to its almost universal adoption for cartridge and shell cases, as well as for countless cupped articles like the caps of electric lamp bulbs, door furniture etc.

Cartridge brass work hardens when deformed in the cold, and must be annealed if many successive operations are to be performed. An annealing temperature of about 600°C is satisfactory in most cases.

### **2. Admiralty brass**

Admiralty brass contains Cu 71%, Zn 28%, and Sn 1%.

The small amount of tin added to brass improves its resistance to certain types of corrosion.

Admiralty brass, though, it has been to a greater extent superseded by better materials for the exacting conditions of marine condensers, it is still widely used for the tubes and other parts of condensers cooled by fresh water and for many other purposes. For such applications, the modern alloy contains about 0.04% Arsenic, which improves resistance to a penetrative form of corrosion known as dezincification.

2. **Aluminium brass** contains 76% Cu, 22% Zn and 2% Al;

a little arsenic is added to inhibit dezincification.

In contact with sea water, a protective film builds up on the surface of this alloy in the early stages of corrosion and prevents further attack. Moreover,

if the film is damaged, by the abrasive action of sand particles, for instance, it is self-healing.

#### **4. Muntz metal or yellow metal**

60% of copper and 40% of zinc and it essentially a hot working material.

##### **uses**

Ship sheathing

Perforated metal

Valve stems Condenser tubes

Architectural work etc.

#### **5. Naval brass**

##### **Composition**

Cu : 60 %, Zn : 39.25 % and Sn : 0.75 %

##### **Properties**

High resistance to corrosion

##### **Uses**

- Propeller shafts.
- Valve stems.
- Pump impellers.

#### **Lead and its alloys**

##### **Properties of Lead**

1. It has a low melting point of 327°C .
2. It is very resistant to corrosion, against most acids, but not against aqua regia (HCl-HNO<sub>3</sub> mixture).
3. It is poisonous.

4. Its strength, hardness and elasticity are low.
5. It has low resistance to deformation but high formability, cold forming is preferred.
6. Lead can be easily soldered, welded and cast. It can be spread over other metal surfaces.

**In addition lead has:**

7. Heavy weight
8. High density
9. Softness
10. Malleability
11. Lubricating properties
12. High coefficient of expansion
13. Low electrical conductivity

**Uses and applications of lead**

1. Manufacture of storage batteries.
2. As an alloying element to improve the machinability of bronzes, brasses and free machining steels.
3. Tank linings for corrosion protection.
4. Pipe and drainage fittings.
5. Bearing metals.
6. Lead compounds in paints.
7. Lead sheathing of electric cable.
8. Low melting solders.
9. Terne plate (lead-tin coated steel), etc.
10. Radiation protection (from x-rays).

## NICKEL AND ITS ALLOYS

With suitable modifications in temperatures, tools, pressures, rates etc., wrought nickel is amenable to most of the fabrication processes used for mild steel. It can be forged, rolled, bent, extruded, sheared, punched, spun, deep drawn, machined, ground, polished and buffed.

### Properties

1. is a hard lustrous white metal.
2. possesses good corrosion and oxidation resistance.
3. has high tensile strength and can be easily formed hot or cold.
4. can take up high polish
5. can be fabricated using processes similar for mild steel.
6. is ferromagnetic at ordinary and low temperatures but becomes paramagnetic at elevated temperatures.

### Uses

- (i) For corrosion protection of iron and steel parts and Zn-base die castings used in the automotive field.
- (ii) In the chemical, soap, caustic and allied industries for the construction of evaporators, tanks, jacketed kettles, heating coils, tubular condensers and many other processing equipments.
- (iii) As an alloying element in both ferrous and non-ferrous alloys. Nickel is a strong austenite stabilizer and with chromium is used to form the important AISI 300 series of non-magnetic austenitic stainless steels.
- (iv) As a coating for parts subjected to corrosion and wear. Therefore, the second important use of nickel is in electroplating.
- (v) In the incandescent lamp and radio industries. .
- (vi) In electronic (vacuum electronic tubes) and low-current electrical applications
- (viii) As anodes in low-power tubes and in photocells.
- (ix) As thermocouple material.

## **Lead alloy**

### **Bearing hard lead**

#### **Composition**

Sb : 10.5 – 13 %, Cu : 0.3- 1.5 %, Ni :0.3 %,As : 0- 1.5 % and rest is lead.

#### **Uses**

Can be easily soldered to steel for lining bearings.

**Pb (Sb)** Sb : 0.2 – 0.3 % and rest is Lead.

#### **Uses**

Used in drain pipes.

### **Nickel alloys**

#### **Various nickel alloys are:**

- (a) Nickel-Iron alloys (Invar, Elinvar)
- (b) Nickel-Copper alloys (Monel, Constantan)
- (c) Nickel-Copper-Zinc alloys
- (d) Nickel-Chromium alloys
- (e) Nickel-Molybdenum alloys
- (f) Super alloys

#### **(a) Nickel-Iron alloys**

##### **INVAR**

Invar is the Trademark for an iron-nickel alloy containing 40–50% nickel

#### **Properties**

an extremely low coefficient of thermal expansion.

Good corrosion resistance

#### **Uses**

Invar is used for making precision instruments, measuring tapes, weights etc.

## **Elinvar**

The addition of 12% chromium, with invar, produces an alloy (Elinvar)

### **Properties**

With an invariable modulus of elasticity over a considerable temperature range.

low coefficient of expansion.

Good corrosion and oxidation resistance.

### **(b) Nickel-Copper alloys**

The major nickel-based alloy with copper is Monel

#### **Composition**

66% Ni, 31.5% Cu, 1.35% Fe, 0.90% Mn, plus residuals.

#### **Properties**

- Monel has a brighter appearance than nickel,
- is stronger and tougher than mild steel,
- has excellent resistance to atmospheric and sea-water corrosion and generally is more resistant than nickel to acid,
- less resistant to alkalies and equally resistant to salts.

#### **Uses**

- Monel is used in architectural and marine applications because of good corrosion resistance
- Used in important and in specialized equipment used by the food, pharmaceutical, paper, oil and chemical industries.

(iii) Constantan, another alloy of nickel and copper

#### **composition**

45% Ni and 55%Cu.

#### **Properties:**

- Highest electrical resistivity,
- Lowest temperature coefficient of resistance.

- Highest thermal emf against platinum.

### **Uses**

- Electrical resistors
- Thermocouples
- Wheatstone bridges, etc.

### **(c) Ni-Cu-Zn alloys (Nickel-Silver)**

Nickel-copper-zinc alloys though known as nickel-silver, do not contain silver, and in actuality they are brasses with sufficient nickel added to give a silvery white colour,

### **Properties**

- improved corrosion resistance
- high strength.

### **Uses**

- low cost substitutes for silver in tableware and jewellery.
- usually with a silver or gold electroplate on the surface.
- Nickel silvers are also construction materials for many musical.
- drafting and scientific instruments.
- used for marine and architectural applications.

### **(d) Nickel-Chromium alloys**

#### **Inconel**

#### **Composition**

Ni : 80%, Cr : 14%, Fe : 6%

#### **Properties**

- High Corrosion resistance.
- Good heat resistance.

#### **Uses**

- Used as high temperature spring
- in furnace chamber.

- Air craft exhaust.
- Milk industries.

## **ZINC AND ZINC BASE ALLOYS**

Zinc is a blue to gray metallic element.

Zinc has following characteristics:

- (i) Relatively low melting point, 419.5°C (die-casting),
- (ii) Good resistance to atmospheric corrosion,
- (iii) Solubility in copper (brass),
- (iv) Inherent ductility and malleability,
- (v) Thermal conductivity.

### **Uses**

- (i) Stampings
- (ii) Die castings
- (iii) Anodes for electro-galvanizing.
- (iv) Coating on steel.
- (v) Shells for dry batteries.
- (vi) Making different alloys.



## **CHAPTER 7**

### **BEARING MATERIAL**

The material which are used for moving parts such as shafts and spindles of a machine or mechanism.

#### **General properties of bearing material**

- (i) Possess low coefficient of friction .
- (ii) Provide hard ,wear resistance surface with a tough core.
- (iii) Have high compressive strength
- (iv) Have high fatigue strength
- (v) Be able to bear shocks and vibrations.
- (vi) Possess high thermal conductivity to dissipate heat generated due to friction between the bearing and the rotating shaft.
- (vii) Possess adequate plasticity under bearing load.
- (viii) Possess adequate strength at high temperature.
- (ix) Be such that it can be easily fabricated.
- (x) Possess resistance to corrosion.
- (xi) Be such that it does not cause excessive wear of the shaft rotating in it, i.e., bearing material should be softer than the shaft material.
- (xii) Possess anti -seizure characteristics.
- (xiii) Maintain a continuous film of oil between shaft and bearing in order to avoid metal to metal contact.

- (xiv) Possess ability to embed in itself any dirt, etc., present in lubricating oil.
- (xv) Should be cheap and easily available.

## **CLASSIFICATION OF BEARING MATERIAL**

TYPES OF BEARING MATERIALS They are:

- (i) Lead or tin-based alloys. (ii) Cadmium-based alloys.
- (iii) Aluminum based alloys. (iv) Silver-based alloys.
- (v) Copper-based alloys. (vi) Sintered bearing materials,
- (vii) Non-metallic bearing materials.

### **(1) Lead based bearing material (Babbitt metals)**

They may be divided as

- (a) The high tin alloys with more than 80% tin and little or no lead.
- (b) The high lead alloys with about 80% lead and 1–12% tin.
- (c) The alloys with intermediate percentages of tin and lead.

In addition to lead and tin, these bearing alloys contain antimony and copper also .

### **Typical compositions of**

A lead based alloy

Pb 75% , Sb 15% , Sn 10%

### **Properties of lead base bearing material**

- Lead base alloys are softer and brittle than the tin base alloys.
- Lead base alloys are cheaper than tin base alloys.
- Solidus temperature of Lead base alloys - Approx. 240°C.
- Good ability to embed dirt Good conformability to journal Good corrosion resistance
- Very good seizure resistance, etc.
- White metals are tin base or lead base bearing alloys and are usually referred to as babbitts.

### **USES**

- Whereas tin base alloys find applications in high speed engines, steam turbines, lead base alloys are used in rail road freight cars.
- Lead base alloys are suitable for light and medium loads, whereas tin base alloys are preferred for higher loads and speeds.

## (ii) Cadmium-based alloys

### Chemical composition:

	I	II	III	IV
Cd	98%	98%	98.5%	94.75%
Ni	2%	-	-	3%
Ag	-	1%	1%	-
Cu	-	1%	0.5%	1.5%
Zn	-	-	-	0.75%

### Properties

- Low coefficient of friction.
- High fatigue strength.
- High load carrying capacity.
- Low wear.
- Good seizure resistance.
- Fair ability to embed dirt,
- Poor corrosion resistance.
- Having high compressive strength.

### USES

These are used in automobile and aircraft industries .

## (iii) Tin base bearing metal

### Composition

A tin based alloy has a typical composition Sn=88% , Sb = 8% ,Cu = 4%

### Properties :

- (i) have a low co-efficient of friction.
- (ii) Solidus temperature of tin base alloys are approximately 222<sup>0</sup>c.
- (iii) Good ability to embed dirt.
- (iv) Good conformability to journal.
- (v) Good corrosion resistance
- (vi) Low wear.
- (vii) High load carrying capacity.
- (viii) Good seizure resistance.
- (ix) Excellent antifriction properties.

### **Uses**

Tin base alloys find applications in high load and speed engines, steam turbines, rail road frieght cars, locomotive slide valves etc.

### **(iv) COPPER BASE BEARING METAL**

The term bronze covers a large number of copper alloys with varying percentages of Sn, Zn and Pb.

Bronze is one of the oldest known bearing materials.

### **Composition**

Cu = 80% Sn = 10% and Pb = 10%

And Cu = 85% Sn = 15%

### **Properties :**

- (i) Has easily worked.
- (ii) Has good corrosion resistance.
- (iii)Has reasonable hard.
- (iv) Good wearing quality.
- (v) High melting point.
- (vi) High thermal conductivity.
- (vii) Ability to withstand continuous bearing pressure and impact.

## USES

- It is used in the machine and engine industry for bearing bushes made from thin – walled drawn tubes.
- It is used for making bearings required to resist heavier pressures such as in railways.

## CHAPTER 8

### SPRING MATERIALS

#### INTRODUCTION

Springs store mechanical energy. Therefore, the spring material remains under high internal stresses.

The choice of material for springs depends upon the operating conditions, e.g., most heavily loaded springs are made up of steel piano wire, springs which have to withstand corrosion are fabricated out of stainless steel, phosphor bronze, etc.

#### TYPES

- (i) Iron-based spring materials.
- (ii) Copper-based spring materials.
- (iii) Nickel-based spring materials.
- (iv) Special spring materials.

#### **(1) Iron-based spring materials**

Steel is usually the best choice as spring material, unless the spring is for high temperature or a corrosive environment; or must be non-magnetic, etc.

A good spring steel possesses high

- (a) Modulus of elasticity
- (b) Elastic limit
- (c) Fatigue strength
- (d) Notch toughness
- (e) Creep strength.

Steel is used for making

- (a) Helical springs (b) Plate springs
- (c) Leaf springs (d) Torsional springs
- (e) Cone springs, etc.

Spring steels in strip form are usually hardened and tempered.

Iron based spring materials are :

### **(a) Steel piano wire**

#### **Chemical composition:**

C 0.7 to 1.0% Mn 0.3 to 0.6% Fe Remainder

#### **Uses:**

Small sized helical springs.

### **(b) Hard-drawn spring wire**

#### **Chemical composition:**

C - 0.5 to 0.75% , Mn - 0.6 to 1.2% , Fe - Remainder

#### **Uses:**

Where the stresses are low or where a high degree of uniformity is not essential or where fatigue loading is not involved.

### **(c) Oil hardened spring steel**

#### **Chemical composition**

C 0.55 to 0.75% , Mn 0.3 to 0.9% Fe Remainder.

#### **Uses:**

Weighing machines and Cars.

### **(d) Cr-V spring steels**

#### **Chemical composition:**

C 0.5% , Mn 0.8 to 1.1% , Cr 0.2 to 0.9% , V 0.07 to 0.12% and Fe Remainder.

**Uses:**

Engines, Automotive valves and Railway carriages.

**(e) Stainless steel****Chemical composition:**

Cr 18% , Ni 8% C 0.1 to 0.2% and Fe Remainder

**Uses:**

Valve springs in flow-meters.

Other applications requiring a high resistance to corrosion.

**(ii) Copper-based spring materials****Properties**

They possess

- High electrical conductivity,
- Good resistance to corrosion, and
- Lack of magnetic properties.

Such materials can be classed as

(a) One which can be hardened only by cold deformation, and

(b) Others, which can be hardened also by heat treatment.

Materials coming in the second group can be formed into springs while is in the soft or half-hard condition and then required spring properties developed by heat-treatment.

Various copper based spring materials are:

**(a) Phosphor bronze**

Chemical composition: Cu 92% , Sn 8%

**Uses:**

High quality springs for switches, relays, contacts, etc.

## **(b) Brass**

### **Chemical composition:**

Cu 67 %, Zn 33%

### **Uses:**

Switches and contacts (springs).

## **(c) Nickel silver –**

### **Chemical composition:**

Cu 56% ,Ni 18%, Zn 25%.

### **Uses:**

Same as brass, but for better quality springs.

## **(d) Beryllium copper**

### **Chemical composition:**

Cu 98%, Be 2%

### **Uses:**

Brushes, relays, switches, etc., with relatively good resistance to wear, good conductivity and good resistance to corrosion.

## **CHAPTER 9**

## **POLYMERS**

Polymer are those which soften on the application of heat with or without pressure, but they require cooling to set them to shape.

### **Properties**

- (i) They are relatively low in cost.
- (ii) Do not absorb moisture.
- (iii) Flexible over wide temperature range.
- (iv) Chemically resistant.
- (v) Dielectric losses and dielectric constant are low.



- (vi) High resistivity and dielectric strength.
- (vii) They are wax like in appearance, translucent, odourless and one of the lightest plastics.

### **Application**

- (i) Moisture proofing
- (ii) Coating ice-cube trays.
- (iii) Fan and blower casing (gas filled polythene).
- (iv) Packaging .
- (v) High voltage (upon 30KV) applications.
- (vi) Coaxial cables.
- (vii) Lining for lagoons to avoid seepage of polluted water into the underground.
- (viii) Pipes and tanks for water storage.
- (ix) As insulation in submarine cables and radar lines.

### **Thermoplastic Materials**

- (i) They are usually granular materials.
- (ii) They are comparatively softer and less strong form in which they are either liquid or partially thermoplastic solids.
- (iii) They can fill the complicated mould quite easily.
- (iv) They are linear polymers without cross-linking and branching
- (v) The scrap of these plastics can be recycled

### **Thermosetting Materials**

- (i) They are usually supplied as Monomeric or partially polymerized form in which they are either liquid or partially thermoplastic solids.
- (ii) They are more stronger and harder than thermo plastic resins.
- (iii) It is difficult to fill an intricate mould with such plastics.
- (iv) They have three dimensional network of primary covalent bonds with cross- linking between chains.
- (v) They cannot be recycled

again and thus they are economical.

vi) Objects made by thermoplastic resins cannot be used at comparatively higher temperatures as they will tend to soften

Under heat.

(vii) They can be repeatedly (softened by heat and hardened by cooling).

**Uses:** Toys, combs, toilet, goods, photographic films, insulating tapes, hoses, electric insulation etc.

vi) Objects made by thermosetting resins can be used at comparatively higher temperature without damage.

(vii) Once hardened and set they do not soften with the application of heat.

**Uses :** Telephone receives electric plugs, radio and TV cabinets, camera bodies, automobile switch panels etc. parts, circuit breaker

## Elastomers (Rubber)

An Elastomer is a polymeric material that may experience large and reversible elastic deformations.

It is commonly referred as rubber.

### Characteristics of Elastomers

- They are essentially non-crystalline in structure.
- They are non-conductors of electricity and are relatively low heat conductors.
- They are high in resistance to chemical and corrosive environments.
- They have relatively low softening temperatures.

### Properties of elastomers

#### (a) Resilience and Hysteresis

Resilience is a measure of an elastomer's capacity to store energy and is defined as the ratio of energy output to energy input expressed as a percentage.

Because of input energy is always lost through internal friction, resilience value always must be less than 1. This loss of energy in the form of frictional heat is known as hysteresis.

#### (b) Hardness

It is one of the most widely used properties in the specification of rubber. It is measured through Shore durometer test. On the durometer scale , which runs from 0 to 100 , higher the number harder the material. As hardness increases elongation decreases.

**(c) Tensile strength**

Since elastomers are only infrequently used for loading in tension, tensile strength is not directly used for application data and it serves as an overall performance indicator. Values less than 1000 psi usually mean that most other mechanical properties are poor, and values more than 2000 psi generally have good mechanical properties.

**(d) Compression Set**

This characteristic refers to the percentage of deflection or distortion remaining in an elastomer after load (compressive) is removed.

**(e) Tear resistance**

Elastomers have low tear strength. If tear strength is extremely low, small cut can cause catastrophic failure.

**(f) Abrasion resistance**

Because many elastomer applications involve friction and wear, abrasion resistance is usually an important consideration. Abrasion resistance increases as increases hardness.

**(g) Deterioration Resistance**

All elastomers undergo changes in properties with time because of oxidation. This deterioration, which is referred to as aging, is affected by many different environmental factors such as sunlight, heat.

**(h) Oil resistance**

This is an important criteria in the selection of elastomers because many of their applications involve an environment of hydrocarbon fluids such as oil and gasoline. Resistance to oils is based on how much the elastomer swells in the presence of oil.

## **CHAPTER 10. COMPOSITES AND CERAMICS**

### **COMPOSITE MATERIAL**

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

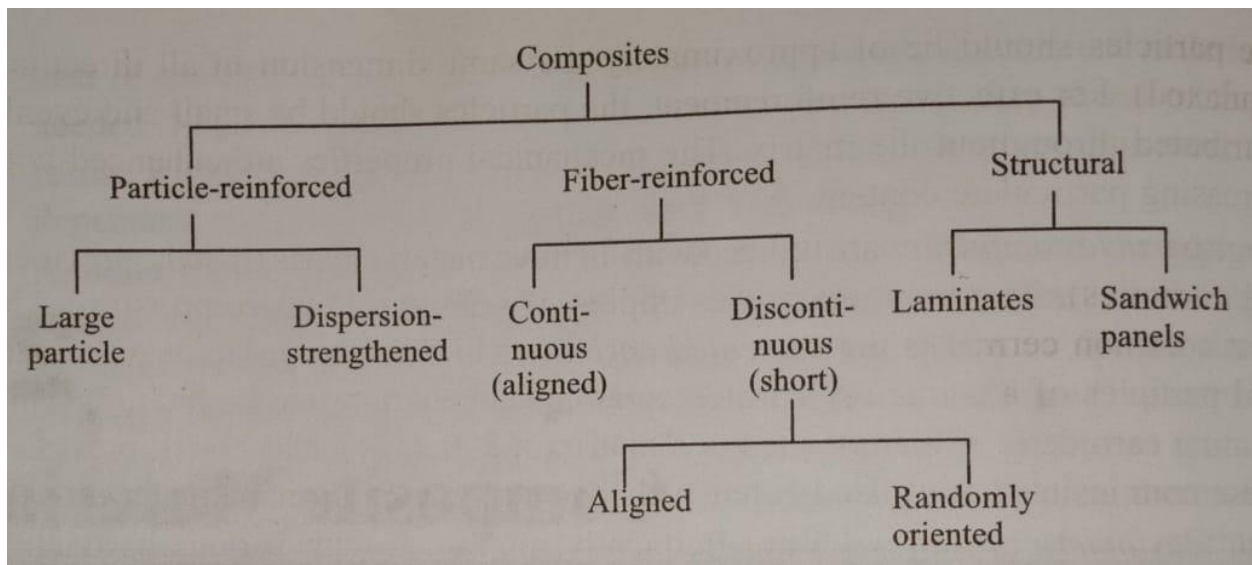
The most common example of a composite material is the fiberglass-reinforced plastic commonly used in household goods and in many industrial applications.

Metals, ceramics, glasses polymers and cement can be combined in composite materials to produce unique characteristics such as stiffness, toughness, and high temperature strength.

Many composite materials are composed of just two phases; one is termed the matrix, which is continuous and surround the other phase, often called the dispersed phase.

## CLASSIFICATION OF COMPOSITE MATERIAL

### Particle-reinforced composites



### Particle-reinforced composites

The dispersed phase for particle

### PARTICLE-REINFORCED COMPOSITES

The dispersed phase for particle-reinforced composites is equiaxed (i.e., particle dimensions are approximately the same in all directions). Large particle and dispersion-strengthened composites are the two sub-classifications of particle-reinforced composites. The distinction between these is based upon reinforcement or strengthening mechanism.

#### (A) Large-particle composites

The term large is used to indicate that particle-matrix interactions cannot be treated on the atomic or molecular level. For most of these composites, the particulate phase is harder and stiffer than the matrix. These reinforcing particles tend to restrain movement of the matrix phase in the vicinity of each particle. The degree of reinforcement or improvement of mechanical behaviour depends on strong bonding at the matrix-particle interface. Some polymeric materials to which fillers have been added are really large-particle composites. A large-particle composite is concrete, being composed of cement (the matrix) and sand and gravel (the particulates).

The particles should be of approximately the same dimension in all directions (equiaxed). For effective reinforcement, the particles should be small and evenly distributed throughout the matrix. The mechanical properties are enhanced with increasing particulate content.

Large particle composites are utilized with all three material types (metals, polymers and ceramics). The cermets are examples of ceramic-metal composites. The most common cermet is the cemented carbide, which is composed of extremely hard particles of a refractory carbide ceramic such as tungsten carbide (WC) or titanium carbide (TiC), embedded in a matrix of a metal such as cobalt or nickel. These composites are utilized extensively as cutting tools for hardened steels.

### **(B) Dispersion-strengthened Composites**

Metals and metal alloys may be strengthened and hardened by the uniform dispersion of several volume per cent of fine particles of a very hard and inert material. The dispersed phase may be metallic or non-metallic; oxide material are often used. Again, the strengthening mechanism involves interactions between the particles and dislocations within the matrix, as with precipitation hardening. The dispersion strengthening effect is not as pronounced as with precipitation hardening; however, the strengthening is retained at elevated temperatures and for extended time periods because the dispersed particles are chosen to be unreactive with the matrix phase. The high-temperature strength of nickel alloys may be enhanced significantly by the addition of about 3 vol % of thoria ( $\text{ThO}_2$ ) as finely dispersed particles; this material is known as thoria-dispersed (or TD) nickel. The same effect is produced in the aluminium-aluminium oxide system. A very thin and adherent alumina coating is caused to form on the surface of extremely small (0.1 to 0.2  $\mu\text{m}$  thick) flakes of aluminium, which are dispersed within an aluminium metal matrix; this material is termed sintered aluminium powder (SAP).

### **FIBER REINFORCED COMPOSITES**

Technologically, the most important composites are those in which the dispersed phase is in the form of a fiber. Design goals of fiber-reinforced composites often include high-strength and/or stiffness on a weight basis. Those characteristics are expressed in terms of specific

strength and specific modulus parameters, which correspond, respectively, to the ratios of tensile strength to specific gravity and modulus of elasticity to specific gravity. Fiber-reinforced composites with exceptionally high specific strengths and moduli have been produced that utilize low-density fiber and matrix materials.

The arrangement or orientation of the fibers relative to one another, the fiber concentration and the distribution all have a significant influence on the strength and other properties of fiber-reinforced composites.

The properties of a composite having its fibers aligned are highly anisotropic, that is, dependent on the direction in which they are measured. For continuous fiber reinforcement the strain in the matrix and the strain in the fiber under load are initially the same. At low stresses, both fiber and matrix deform elastically but, with increasing stress, the matrix may deform plastically while the fiber still will be elastic.

Tensile failure at 90° to the fiber direction occurs at very low stresses. This appears to be the effect of stress concentrations at the fiber-resin interfaces. To counteract this, so called cross-ply laminates are made having alternate orientations of fiber rotated by 90°

By way of summary, then, aligned fibrous composites are inherently anisotropic in that the maximum strength and reinforcement are achieved along the alignment (longitudinal) direction. In the transverse direction, fiber reinforcement is virtually non-existent; fracture usually occurs at relatively low tensile stresses. For other stress orientations, composite strength lies between these extremes.

Most practical composites that are being developed for engineering applications contain discontinuous fibers. Since fibers do not span the whole length of the specimen, the bond between the matrix and the fiber is broken at the fiber's end, which are carrying less stress than the middle part of the fiber. The stress in a discontinuous fiber varies along its length. The strength of the composite with discontinuous fibers is always lower than that prepared with continuous fibers. Even though reinforcement efficiency is lower for discontinuous than for continuous fibers, discontinuous and aligned fiber composites are becoming increasingly more important in the commercial market.

### **The fiber phase**

**Fiber:** Any polymer, metal or ceramic that has been drawn into a long and thin filament.

An important characteristic of most materials is that a small diameter fiber is much stronger than the bulk material.

The probability of the presence of a critical surface flaw that can lead to fracture diminishes with decreasing specimen volume, and this feature is used to advantage in the fiber-reinforced composites. Also, the materials used for reinforcing fibers have high tensile strengths.

On the basis of diameter and character, fibers are grouped into three different classifications: (i) whiskers, (ii) fibers and (iii) wires.

**Whiskers** are very thin single crystals that have extremely large length-to-diameter ratios. As a consequence of their small size, they have a high degree of crystalline perfection and are virtually flaw free, which accounts for their exceptionally high strengths; they are the strongest known materials. Whisker materials include graphite, silicon carbide, silicon nitride and aluminium oxide.

Materials that are classified as **fibers** are either polycrystalline or amorphous and fibrous materials have small diameters; fibrous materials are generally either polymers or ceramics (e.g., the polymer aramids, glass, carbon, boron, aluminium oxide and silicon carbide).

Fine **wires** have relatively large diameters, typical materials include steel, molybdenum and tungsten. Wires are utilized as a radial steel reinforcement in automobile tires, in filament-wound rocket casings and in wire wound high pressure hoses.

## **The matrix phase**

### **Functions:**

(i) The matrix phase binds the fibers together and acts as the medium by which an externally applied stress is transmitted and distributed to the fibers; only a very small proportion of an applied load is sustained by the matrix phase. The matrix material should be ductile. In addition, the elastic modulus of the fiber should be much higher than that of the matrix.

(ii) The matrix protects the individual fibers from surface damage as a result of mechanical abrasion or chemical reactions with the environment.

(iii) The matrix separates the fibers and by virtue of its relative softness and plasticity, prevents the propagation of brittle cracks from fiber to fiber, which could result in catastrophic failure.

It is essential that adhesive bonding forces between fiber and matrix be high. Adequate bonding is essential to maximize the stress transmittance from the weak matrix to the strong fibers.

In general, only metals (such as aluminium and copper) and commercial thermoplastic and thermosetting polymers are used as matrix materials (because some ductility is desirable).

## **Classification and uses of ceramics.**

Classification of Ceramics:

Ceramics may be classified as -

(i) Ceramics can be natural or manufactured

### **(a) Natural ceramics:**

Natural ceramics are silica ( $\text{SiO}_2$ ), silicates and clay minerals. Natural ceramics also called "traditional ceramics" while manufactured ceramics are called as "High-tech ceramics" or "fine ceramics".

### **(b) Manufactured Ceramics:**

Such ceramics include, Sic,  $\text{Al}_2\text{O}_3$ , silicon nitride and many varieties of oxides, carbides, nitrides, borides and more complex ceramics. Some of the naturally occurring ceramics are also, manufactured which results in their enhanced properties as compared to natural ceramics. For example, magnesia ( $\text{MgO}$ ) also occurs in nature, but for industrial use, it is made from the carbonate or hydroxide.

### **(ii) Functional Classification:**

It indicates particular industries and industrial applications of the ceramics as given below :

(a) Abrasives: Alumina; Carborundum

(b) Pure oxide ceramics:  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{SiO}_2$ .

(c) Fired-clay products: Bricks, Tiles, Porcelaine etc.

(d) Inorganic glasses: Window glass, lead glass etc.

(e) Cementing materials: Port land cement, lime etc.

(f) Rocks: Granites, sand stones etc..

(g) Minerals: Calcite, Quartz etc.

(h) Refractories: Silica bricks, Magnesite etc.



### **(iii) Structural Classification:**

It indicates the structural criteria as given below:

(a) **Crystalline ceramics:** Single phase like MgO or multiphase from the MgO to  $Al_2O_3$  binary system.

(b) **Non-crystalline ceramics:** Natural and synthetic inorganic glasses e.g. window glass.

(c) **Glass-bonded ceramics:** Fired clay products crystalline phase are held in glassy matrix.

(d) **Cement-bonded ceramics:** Crystalline or crystalline and non-crystalline phases.

### **USES OF CERAMICS**

(i) **Clay products:** Clay body ceramics include whitewares and stoneware are largely used as tile, sanitary ware, low and high voltage insulators and high frequency applications. It is used, in chemical industry as crucibles, jars and component of chemical reactors. Heat resistant application includes pyrometer tube, burner tips, and radiant heater supports.

(ii) **Refractories:** It is used in the construction or lining of furnaces, boilers, flues, regenerators, convertors, crucibles, dryers, pyrometer tubes and in many others.

(iii) **Cutting tool material:** It is used as cutting tool materials are carbides, nitrides and oxides and cermet's.

(iv) **Abrasives:** It is used to wear away a softer material. Abrasives are used for operations. Such as scratching, grinding, cutting, rubbing and polishing

(v) **Electrical and magnetic applications:** Ceramics find wide applications in electrical and electronic industries as insulators, semi-conductors, dielectrics, ferroelectrics, piezoelectric crystals.

(vii) **Optical applications:** Ceramics are notably useful as a pigment because it is exceptionally durable. It is completely oxidized and not subject to chemical attack and variation. Yttralox is useful in optical applications, because it is as transparent as window glass and can resist very high temperature.

vii) **Phosphorescence:** Ceramic phosphors emit light of a characteristic wave - length when excited or pumped by some appropriate energy source. Light tubes, VDT's and colour T.V rely on this phenomenon. The most widely used laser is ruby (an  $Al_2O_3$  crystal doped with Cr ions). They are being used for machining, welding and cutting etc.

