

**HEAT TREATMENT OF STEELS:**

Heat treatment may be defined as an operation or combination of operations involving heating and cooling of metals and alloys in solid state to obtain desirable conditions or properties.

Or

Heat treatment can be defined as heating and cooling operation applied to metals and alloys in solid state so as to obtain desired properties.

**PURPOSE OF HEAT TREATMENT:**

1. Relieving internal stress developing during cold working, welding, casting and forging.
2. To improve ductility and toughness.
3. Grain refinement.
4. Improve machinability.
5. Inc. hardness or tensile strength and achieving changes in chemical composition of metals surfaces as in case of case hardening.
6. Improve electric and magnetic properties.
7. Inc. heat, wear and corrosion resistance of materials.

**Heat treatment process variables/stages..**

1. Temp. Up to which the metal/alloy is heated.
2. The length of time. The metal/alloy is held at that temp. i.e. holding time.
3. Rate of cooling: the atmosphere surrounding the metal alloy when it is heated.

**Classification of heat treatment of stress:****1. Annealing:**

- Stress relief annealing
- Process annealing
- Spherodizing annealing
- Full annealing.

2. Normalizing
3. Hardening
4. Tempering
5. Austempering
6. Martempering
7. Case hardening or surface hardening

### **ANNEALING:**

This consists of heating the steel to a certain predetermined temp. Holding it at that temp. for sufficient time to allow the necessary changes to occur and then cooling slowly at a predetermined rate.

### **PURPOSE OF ANNEALING:**

1. To relieve internal stress induced by previous treatment/operational such as rolling, casting, forging etc.
2. To improve machinability.
3. To soften the stress.
4. To refine and homogenize structure.
5. To induce stable structure.
6. To improve mechanical, physical, electrical, and magnetic properties.

### **STRESS RELIEF ANNEALING:**

Stress relieving annealing relieves the internal stress induced by cold working, casting, welding etc.

In this process the cold working steel is heated to a temp. Between 500<sup>0</sup>c to 550<sup>0</sup>c usually below its recrystallization temp. (0.3 to 0.4 mp) heated to this temp. In air. Due to this the internal stress are relieved without changes in microstructure. If the stress are not relieved they might later cause warpage or even failure of the part.

Stress relief annealing is suited for ferrous and non ferrous metals.

### **PROCESS ANNEALING:**

This is used in sheet and wire drawing industries to remove the effects of cold work this heat treatment is applied after cold work to soften the steel by reccrystalization and to permit further cold work.

In this process the cold working steel is heated above its reccrystalization temp.  $600^{\circ}\text{C}$  i.e. below the lower critical temperature line  $A_1$ .

### **SPHEROID ZING ANNEALING:**

The hyper eutectoid steel is consisting of pearlite and cementite network will have poor machinability. Because the cutting tool can't penetrate through the hard and brittle cementite plates.

Spheroidize annealing produces spheroidal or globular form of cementite from plates of cementite .so that the machinablity will be the improved.

### **Methods of follow produce spherodized structure:**

- a) Heating steel and its proloned holding at a temp. just below the lower critical temp  $A_1$ .
- b) Heating and cooling alternatively between temp. that are just above and just below the lower critical temp. line  $A_1$ .
- c) Heating to a temp. above lower critical temp. kine  $A_1$  and then either then cooling very slowly in the furnace or holding at a atemp. Just below the lower critical temp.

### **FULL ANNEALING:**

The purpose of full annealing is

- a) To refine grains
- b) To induce softness
- c) To improve machinablity
- d) To improve electrical and magnetic properties.

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In this process hypo eutectoid steels are heated above A3 and hyper eutectoid steels are heated above A1 by 30 °C to 50 °C held at this temp. For a definite period (2.5-3 min per 1mm thickness) and then cool slowly in the furnace itself. Depending on the composition, hyper eutectoid steels are always annealed from above A1 temp. And not from above ACM temp. because

- a) If annealed from above ACM temp. Brittleness is induced.
- b) Above ACM temp grain coarsing of austenite occurs.

### **NORMALIZING:**

Normalizing or air quenching consist of in heating stress to above 40 °c to 50 °C above its upper critical temp. (A3, ACM lines), and if necessary holding it at that temp. for short time and then cooling it still air temp.

Normalizing differs from full annealing is that the rate of cooling is more rapid and there is no extended soaking period.

### **PURPOSE OF NORMALIZING:**

1. Produces uniform structures
2. Refine the grain size of steel
3. Reduces internal stress
4. Improves structural in weld
5. Produces harder and stronger steel than full annealing

### **HARDENING:**

It is the heat of steels which inc. its hardness by quenching.

### **PURPOSE OF HARDENING:**

1. To inc. the hardness of steels and tool steel.
2. To improve the wear resistance of steels.
3. To improve magnetic properties

Note: plain carbon steels are quenched hardened by water and alloy steels are quenched / hardened by oil

0.3 – 0.5 % C steels are hardened by hardening operation in this process the hypo eutectoid steels are heated above the lower critical temp. by 30-50 °C held at that temp. Sufficient time and then quenched (rapidly cooled) in water or oil or brine solution. Due to this the austenite changes instantaneously into martensite.

Martensite is the super saturated solid sol. of carbon in the  $\alpha$ -iron, which is very hard and brittle and this imparts high hardness to steels after hardening treatment.

### **TYPES OF QUENCHING MEDIUM:**

Some of the industrial quenching media in order of decreasing severity.

- I. 5 – 10 % caustic soda – very drastic quenching
- II. 5 – 20 % NaCl
- III. Cold water
- IV. Tap water.
- V. Mineral oil
- VI. Animal oils
- VII. Vegetable oil
- VIII. Air-least drastic quenching

### **TEMPERING :**

Hardening of steel by quenching produces a micro structure consisting of martensite and retained austenite. The martensite formed during quenching is highly brittle and stressed.

The hardened steel is not used in this condition because cracking and distortion occurs. And also retained austenite is an unstable phase and the dimensions of the object may be changed with time.

Hardening is always followed by tempering.

### **Definition:**

Tempering consist of heated the hardened components below the lower critical temperature. Hold at that temperature for sufficient period and then cooling to room temperature usually in air (water, oil)

### **CLASSIFICATION OF TEMPERING:**

- i. Low temperature tempering
- ii. Medium temperature tempering
- iii. High temperature tempering

#### **I: LOW TEMPERATURE TEMPERING:**

1. This treatment is carried out in the temperature range  $150^{\circ}\text{c}$ - $250^{\circ}$
2. internal stress are relieved
3. the structure still contains martensite
4. L.TT is applied to cutting tools of carbon steels and low alloy steels.

#### **2.MEDIUM TEMPERATURE TEMPERING:**

1. It is carried out from the range  $350^{\circ}$ - $450^{\circ}\text{c}$
2. This treatment develops troosite structures
3. Is applied to objects such as coil springs, laminate springs hammer chisels.

#### **iii. HIGH TEMPERATURE TEMPERING :**

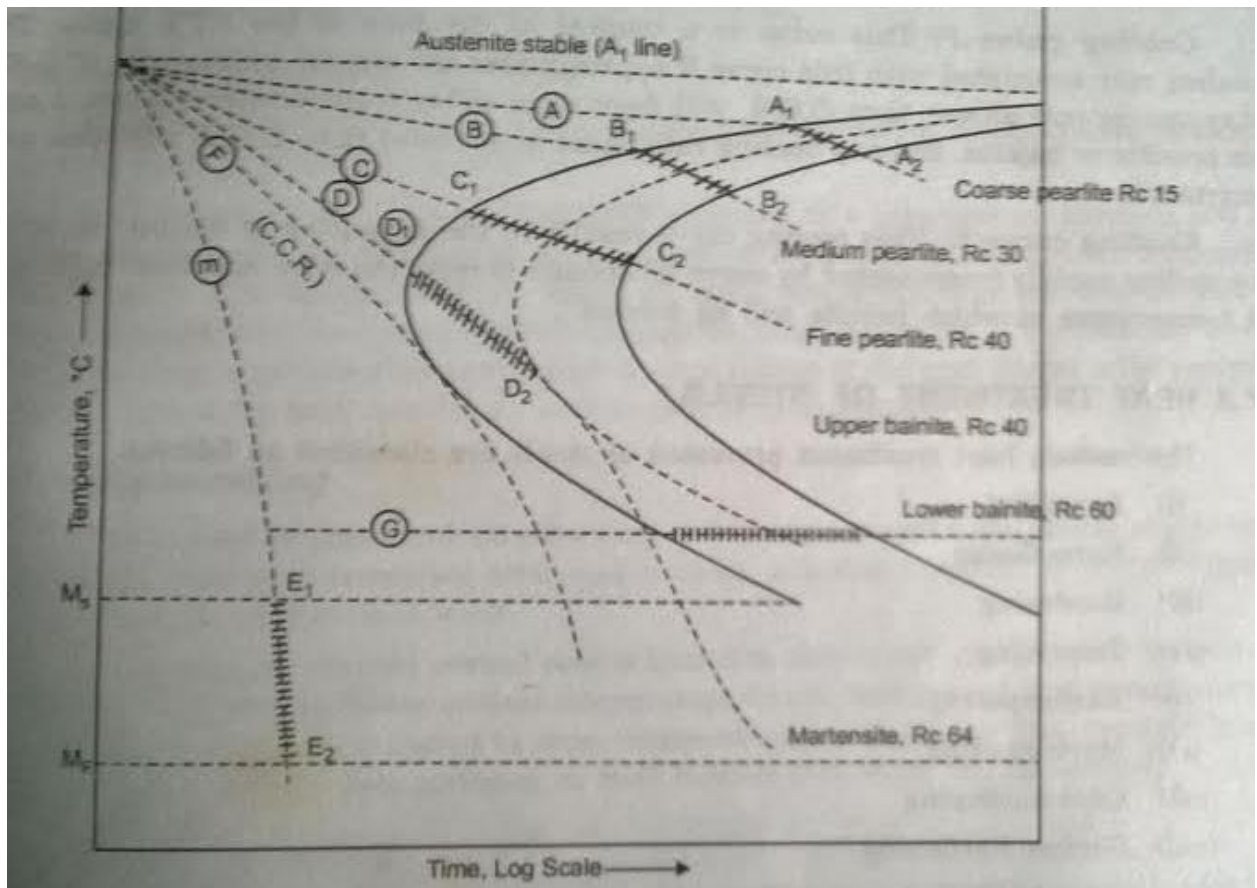
1. It is carried out in the temperature range  $550^{\circ}$ - $650^{\circ}\text{c}$
2. It eliminates stress completely
3. It develops sorbite structures
4. Used for components such as connecting rods, shafts

#### **AUS TEMPERING:**

Austempering is the cooling of austenite steel with a rate more than critical cooling rate in molten salt bath held at temperature between the nose of the TTT diagram and MS temperature that is in the bainite region the component held at that temperature for a sufficient period of time till the entire structure in the component completely transformed to bainite. It then

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cooled in air at any desired rate to room temperature at the end of aus tempering a bainite structure obtained further heat treatment by tempering is not necessary



### ADVANTAGES OF AUSTEMPEARING:

1. The final structure and properties are similar to the tempered martensite obtained during tempering without cooling curves going through the martensite region.
2. There is no formation of retained austenite in this structure and there is more dimensional stability of the component

### DIS ADVANTAGES OF AUSTEMPEARING:

1. The hardness obtained is not as high as the obtained through martensite transformation as in hardness
2. This soaking time for the transformations place is more hence this is a more expensive process.

**MARTEMPEARING:**

Martempering is a hardening process. Mar tempering involves heating steel to above the austenizing temperature and then quenching in to the salt bath maintain at a temperature above Ms point (250<sup>0</sup>c).the steel is held in the bath till the temperature throughout the section.

**ADVANTAGES OF MARTEMPEARING:**

1. There is less distortion and warping since in the formation of martensite the same time throughout cross section.
2. Possibility of quench cracks is less.

**SURFACE HARDENING (OR) CASE HARDENING:**

Hard and wear resistance surface is called case (or) surface,soft,tough and shock resistance inside the material is called core.

Eg:cams,gears.

**METHODES FOR CASE HARDENING:**

**METHODS THE COMPONENT IS HEATED**

1. Carbonizing
2. Nitriding
3. Cyaniding
4. Carbonitriding

**METHODS ONLY THE SURFACE OF THE COMPONENT IS HEATED**

6. Flame hardening.
7. Induction hardening.

**CARBORISING:**

It is a method of introducing carbon in to a solid iron base alloys such as low carbon steels in order to produce hard case.



**CHARACTERISTICS:**

1. Case depth is about 0.05 inch
2. Hardness after heat treatment RC65
3. Carburizing causes negligible changes in dimensions
4. Distortion occurs during heat treatment

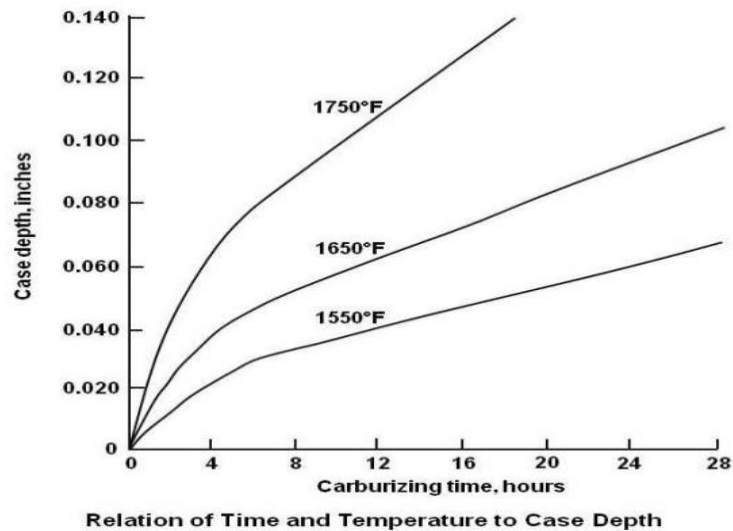
**USES:** Gears, camshafts.....etc

**TYPES OF CARBURIZING:** Three types:

- i. Pack carburising(solid)
- ii. Liquid carburising
- iii. Gas carburising

i. **Pack carburizing(solid):**

The box is steel box of cast iron.distance between pieces 500mm.energized material is 40% of  $\text{Na}_2\text{CO}_3 + \text{BaCO}_3$ .



Holding time – 5 hours

Temperature –  $900^{\circ}\text{C} - 950^{\circ}\text{C}$

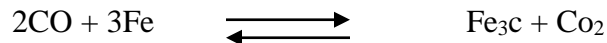
**The carburising process involves the following stages**

i) Formation of “CO” in the containing carburising material when heated b/w 900 – 950<sup>0</sup>c

ii) Dissociation of “CO” with the evaluation of atomic carbon



iii) End richment of steel surface layers with carbon



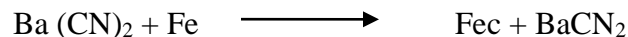
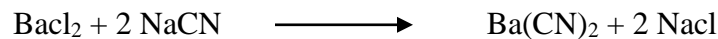
iv) Diffusion of carbon absorbed by the steel surface, deep in the metal. The rate of diffusion of carbon in austenite at a given temp is depend up on the diffusion coefficient and the carbon concentration. At high temp the diffusion is more

v) It is desired to prevent any area of component from being carburised that area.

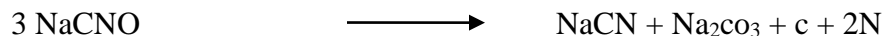
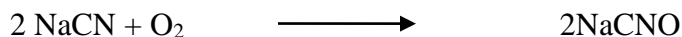
a) May be electroplated with “cu” to a thickness of 0.075 to 0.1 mm because is in soluble in copper at a carburising temp

**LIQUID CARBURISING:**

It is a carried out in molten salt bath containing 20-50% NaCN, together with up to 40% Na<sub>2</sub>CO<sub>3</sub> and varying amounts of sodium (or) barium chloride. This cyanide mixture is heated to a temp of about 870-950<sup>0</sup>c and work piece contained in wire baskets are immersed in the liquid salt bath for periods varying from 5min to 1 hour depending upon the case depth required. The reaction occupied in cynide bath is



In this process “N” is also diffuse through the oxidization of sodium cyanide.



**Cyanide:-**

In cyaniding case is higher in N and lower in C and in liquid carburising the C is more and less N.

- Cyanide cases are seldom (or) rarely to a depth of greater than 0.25 mm, liquid carburising permits cases as deep 0.25 mm.

**Advantages:-**

- Rapid heat transfer
- Low distortion
- Negligible surface oxidization
- Rapid absorption of carbon & nitrogen
- Uniform case depth, and carbon content
- Reduce time to reach the carburising temp

**Dis advantages:-**

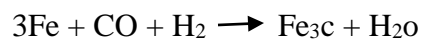
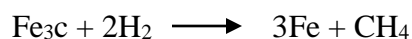
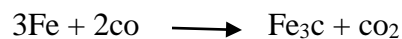
- Cyanide salts are highly poisonous when taken internally (or) when contact with open wounds.
- Parts need through washing after treatment to prevent rusting.

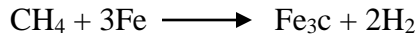
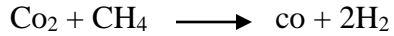
**Gas carburising:-**

**Definition:-** In carburising the components are heated at about 900<sup>0</sup>c for 3 (or) 4 hours in an atmosphere containing gases which will deposit 'C' atoms at the surface of the components.

Carrier gas consist of a mixture of 20% CO, 40% N<sub>2</sub>, and 40% H<sub>2</sub>

**During carburising the following reactions will occur:**





- Gas carburising can be applied in mass production
- The depth of case may vary from 0.25 mm on articles for light work.
- 0.5-1 for Automobile work.
- 0.37 mm for roller bearings and ball races where compression stresses are high

**Advantages:-**

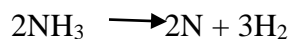
- 1) Labor costs are lower than pack carburising
- 2) Floor space required is less
- 3) Less time is required
- 4) Heating is more rapid

**Dis advantages:-**

- 1) As compared to pack carburising higher skilled persons are required to maintain necessary controlled.

**Nitriding:-** It is the process of producing the hardest case (or) surface layer on medium – carbon steel only. It consists of heating the steel in a chamber with ammonia gas circulating at a temp range 500 to 600<sup>0</sup>c. Work piece should not be overheated, as the hardness vanishes on over-heating. No quenching medium is required

The chemical reaction is



**Applications:** air craft engine parts, gears, clutches, valve parts, Inspection gauges etc.

**Advantages:**

1. Good corrosion and wear resistance
2. Good fatigue resistance
3. No machining is required after nit riding

4. The process is economical

**Dis advantages:**

1. Long cycle time
2. High cost of nitriding process
3. Technical control required

**Process characteristics:**

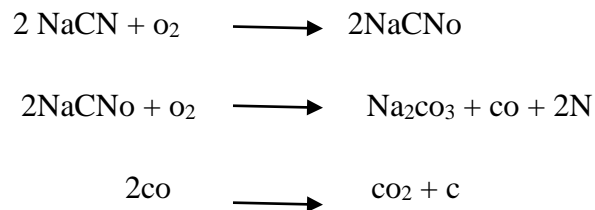
1. Case depth is about 0.381 mm
2. Extreme hardness (1150VHN)

**Cyaniding:**

In cyaniding 'C' and 'N' are introduced in to the surface of the steels by heating it to a suitable temp and holding it contact with molten cynite to form a thin skin or case. Which is sub sequent quenching hardened.

In this process the components are immersed in a liquid bath of 30% NaCN, 40% Na<sub>2</sub>CO<sub>3</sub>, 30% NaCl maintained at a temp of 800<sup>0</sup>c-850<sup>0</sup>c for a period of 30 minutes – 3 hours.

NaCN reacts with O<sub>2</sub> of air and is oxidised. The basic reaction in the bath is



**Characteristics of the process:**

1. Case depth is about 0.25 mm
2. Hardness is about Rc 65
3. Distortion may occur during heat treatment

**Uses:** screws, nuts, bolts, small gears, plain carbon steels.

### **Carbonitriding:**

Carbonitriding is carried out by heating the components in the temp range 800-870<sup>0</sup>c for about 3-4 hours in a gaseous mixture consisting of carburising gases and ammonia. A typical gases mixture contains about 15% NH<sub>3</sub>, 5% CH<sub>4</sub>, 80% carrier gas.

“Carbonitriding” is a modification of gas carburising process

### **Process characteristics:**

1. Case depth is about 0.5 mm
2. Hardness after heat treatment RC 65
3. Negligible dimensional change
4. Distortion is less

**Uses:** Gears, bolts, nuts.

**Flame hardening:** In this process heat is applied to the surface of the workpiece by means of an oxy-acetylene flame. Temperature of the flame is 750 – 950<sup>0</sup>c.

**Uses:** Large parts like, lathe beds, and large gears, cams, piston pins, shafts etc.

**Induction hardening:** This method is similar to flame hardening in principle.

Induction hardening is applied mainly to “medium carbon steels”. In this process, heating is accomplished through the use of primary inductor coils placed around the surface to be hardened as a high frequency A.C of about 2000 to 500000 cps passes through the inductor coils.

### **Advantages:**

1. fast operation
2. No manual handling of hot parts.

**Uses:** Long lead screws, tractor links, camshafts, crank shafts, and pump shafts.

### Hardenability

Hardness is a measure of resistance to plastic deformation (by indentation)

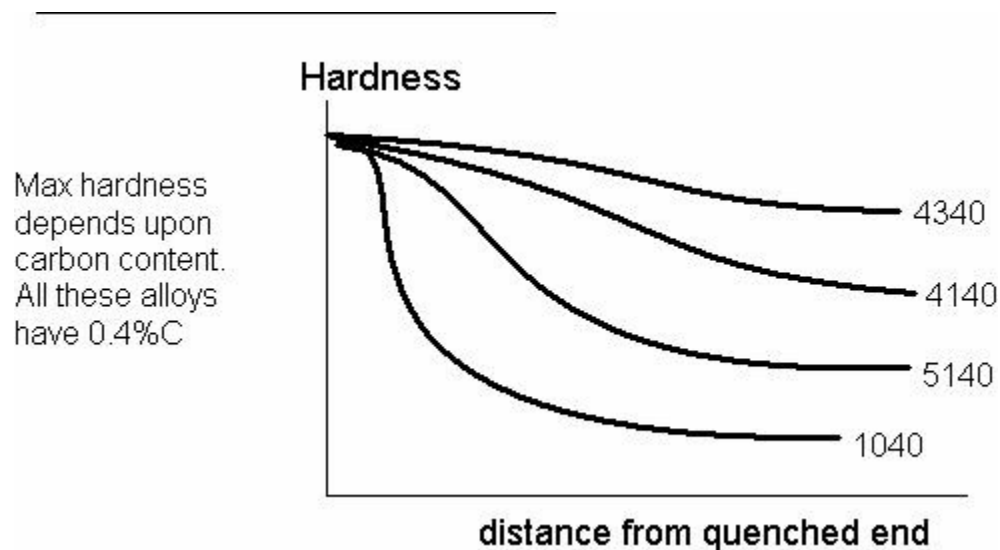
Hardenability is in which the hardness may be attained in the depth direction of the object.

(Or)

Hardenability is the ability of steel to become uniformly hard (or) to harden in depth direction.

### Factors effecting harden ability:

Jomminy test:



1. The composition of steel and method of manufacturing
2. The quenching media and method of quenching
3. Section of steel
4. All alloying elements excepts 'CO' tends to increase hardenability.
5. As compared to carbon steels alloy steels hardened to considerable large due to high stability & corresponding

**Methods to determine Hardenability:**

1. Grossmann method
- 2. Jominy test (end quench hardenability test):**
  1. A 25 mm diameter by 100 mm long bar is properly Austenitised as quench on the end of standardized way
  2. Heat is removed substantially from the quenched end surface and is thus withdrawn at different rate along the bar.

**Age Hardening:**

1. The strengthening of alloy resulting from the precipitation of finely dispersed second phase from a super saturated solid solution. The finely dispersed second phase dispersed precipitates with age i.e with the passage of time.
2. Certain alloys such as Al-4.5% Cu, Al-6%Zn etc. Shows increase in hardness with age (time) at room temp. After heating to slightly higher. This type of hardening is known as age hardening (or) precipitation hardening.

**Requirements for age hardening:**

1. The primary requirement of age hardening is that the solubility decreases with decreasing temp; so that a super saturated solid solution may be obtained.
2. With time the ppt that separates out from the matrix should be coherent.  
Ex: in Al-4.5 % Cu. The second phase with time is  $\text{CuAl}_2$

**Age hardening procedure:**

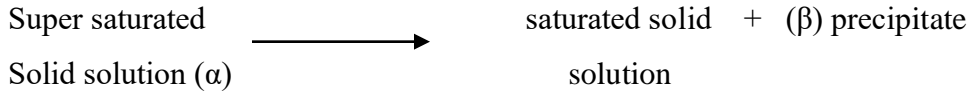
It requires the following procedure.

- i) **Heating:** The alloys first solutionised by heating it in to a single phase region.
- ii) **Quenching:** after solutionising the alloys rapidly quenched in to the two phase region. The rapidity of quench prevents the formation of equilibrium precipitate and thus produces a super saturated solid solution. The quenching media is usually water.
- iii) **Aging:** On aging at or above room temp, fine scale transition structure as small as  $100^{\circ}\text{A}$  units form.



**Age hardening mechanism:**

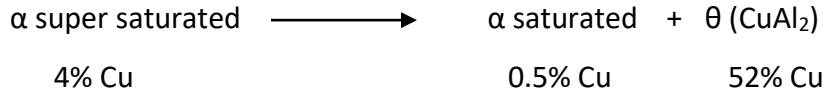
1. The essential requirement for precipitation to occur in solid solution is the decreasing solubility of solute with decreasing temp.
2. This results in a super saturated solid solution being unstable, tends to decompose according to the relation.



There are two distinct coherent phases  $\alpha$  and  $\beta$ ,

A limited no. Of solute atoms will provide a greatest interference to dislocation moments.

The alloy exist as a single ' $\alpha$ ' solid solution at a temp of 548°C when it is cooled to room temp it exist as a mixture of  $\alpha + \theta$ , where ' $\alpha$ ' is a solid solution of Al with a very small percentage of (Cu 0.52) and  $\theta$  is an intermetallic composed (CuAl<sub>2</sub>) that has 52% Cu under slow cooling from 548°C To room temp the following transformation occurs.



**Natural aging:**

Precipitation with time at room temp is called "natural aging"

**Artificial aging:-** Precipitation at high temp is called "Artificial Aging"

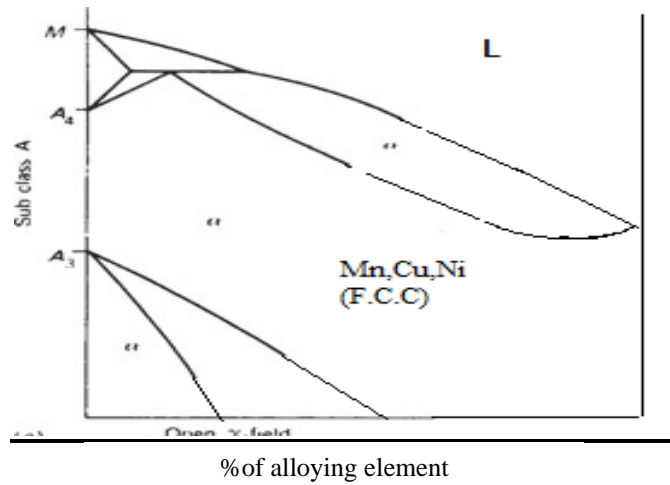
**EFFECT OF ALLOYING ELEMENTS ON Fe-Fe<sub>3</sub>C:**

**1. Austenite Stabilizer:**

Mn, Cu, Ni are Austenite stabilizer elements. These elements are having FCC structure.

These elements raise the ' $A_u$ ' temperature and lower the ' $A_3$ ' temperature, as a result of which they temperature range in which austenite exist as a stable element is increased. By

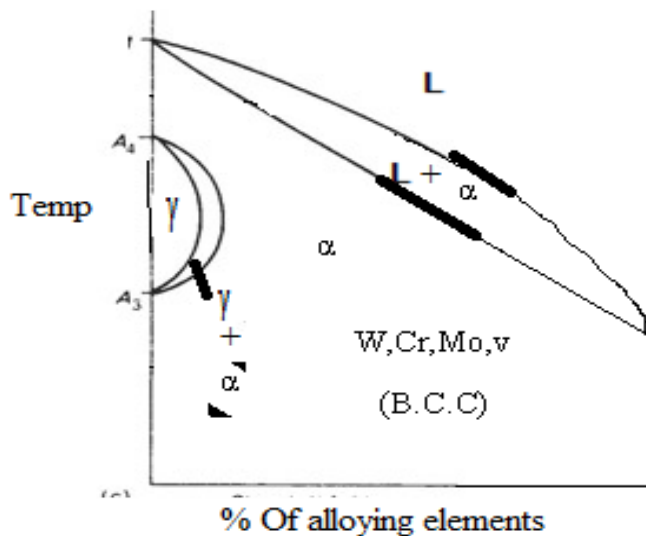
adding more alloying elements that stabilize and the stable austenite can be obtained even at room temp



**2.Ferrite stabilizer:**

W, Cr, MO, V are the ferrite stabilizer elements. These elements are having BCC structure

These elements lower  $A_4$  temperature raises  $A_3$  increases there by increasing the range of stability of Ferrite. At certain composition the lines  $A_4$  and  $A_3$  merge to form a closed loop  $\gamma$  and above this ferrite exist from room temperature to the melting point and the austenite phase does not exist steels obtained by stabilizing Ferrite are called Ferrite steels.



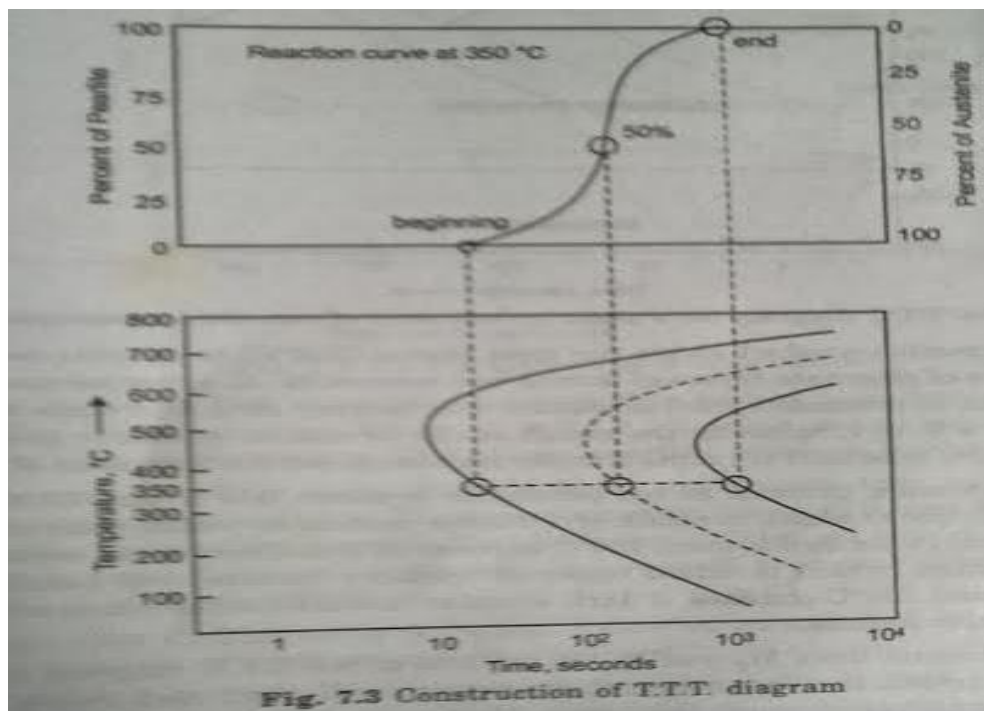
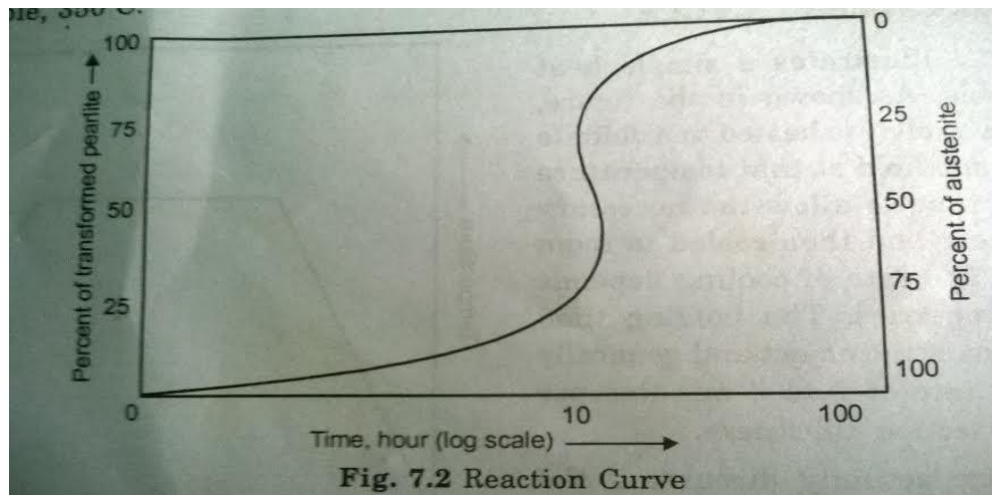
## HEAT TREATMENT OF ALLOYS

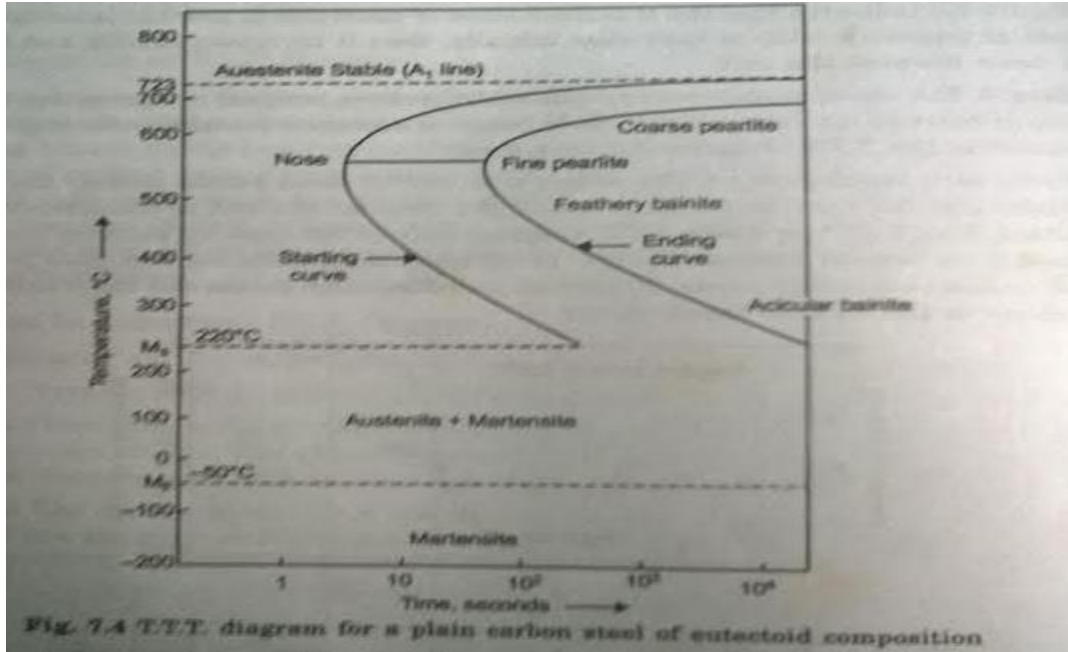
### TTT DIAGRAM (TIME- TEMPERATURE- TRANSFORMATION)

(TIME- TEMPERATURE- TRANSFORMATION)

(OR)

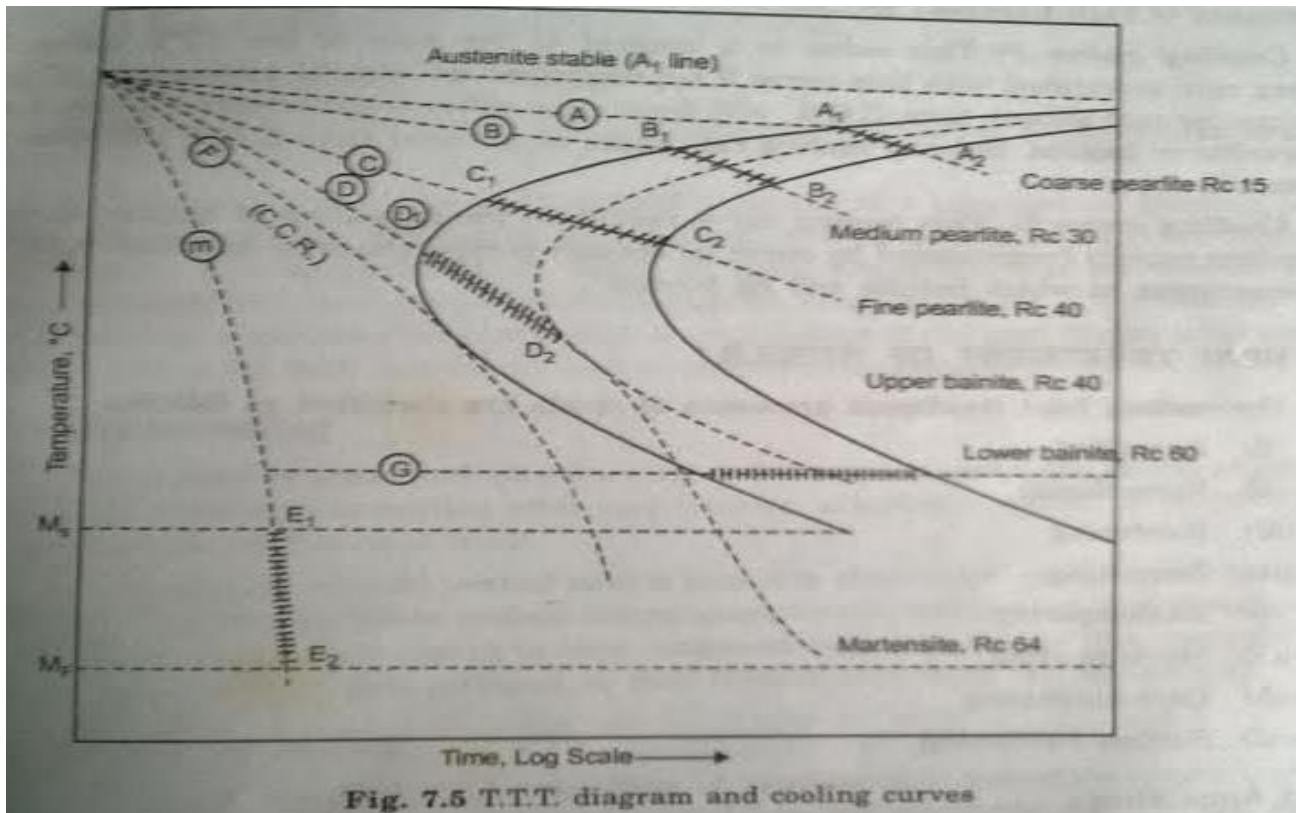
c- Curve (OR) s- Curve (OR) BAILS CURVE (OR) ISOTHERMAL FORMATION CURVE





**T-T-T DIAGRAM AND COOLIND CURVES: (CCT)**

(CCR- critical cooling rate)



## HEAT TREATMENT OF ALLOYS

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A<sub>1</sub> – A<sub>2</sub> → Annealing → slow  
B<sub>1</sub> – B<sub>2</sub> → Normalizing → faster compare to annealing  
C<sub>1</sub> – C<sub>2</sub> → oil quenching → slow  
D<sub>1</sub> – D<sub>2</sub> → Fine pearlite  
E<sub>1</sub> – E<sub>2</sub> → martensite → faster  
F → CCR → Faster → M → slower → P & B  
G → Bainite rapidly

**Cooling curve A:** It is an Annealing process it is cooled very slowly. Transformation product is coarse pearlite with low hardness (RC15). The transformation starts at A<sub>1</sub> and ends at A<sub>2</sub>.

**Cooling curve B:** This curve shows faster cooling rate than curve A. This is normalizing operation. The transformation starts at B<sub>1</sub> and ends at B<sub>2</sub> and the resulting product is medium pearlite (RC30)

**Cooling curve C:** this curve is slow oil quenching and the resulting products consist of mixture of medium and fine pearlite.

**Cooling curve D:**

This curve is an intermediate cooling rate and at point 'D' the austenite will start transforming in to pearlite up to point D<sub>2</sub> and then when M<sub>s</sub> is crossed the remaining will instantaneously transformed to martensite. Hence the final microstructure consists of martensite and pearlite.

**Cooling curve E:** This curve is a drastic quenching it is cooled rapid enough to avoid transformation of in the nose region.

**Cooling curve F:** This curve is a tangent to the nose of the TTT curve. the cooling rate associated with this curve approximate the critical cooling rate, it form bainite and martensite.

**Cooling curve G:** This cooling curve results in the formation bainitic structure by cooling rapidly enough to miss the nose and then holding at a temperature at which bainite will be formed.