# UNIT – II

# HEAT TREATMENT

**2.1** ***What is meant by heat treatment process? Give its purpose.***

Heat treatment is the process of heating metal below its molten stage, and then cooling the metal in a controlled way to select desired mechanical properties.

**PURPOSES (OR) OBJECTIVES OF HEAT TREATMENT:**

- To harden and strengthen metals.
- To relieve internal stresses.
- To improve machinability.
- To improve ductility and toughness.
- To increase wear and corrosion resistance of metals.
- To improve electrical and magnetic properties.
- To refine grain size.

***(Mention the types of heat treatment processes.)***

**2.2 TYPES OF HEAT TREATMENT PROCESSES**

1. **Annealing processes.**
   - Full annealing
   - Stress – Relief annealing
   - Recrystallization annealing
   - Spheroidise annealing
2. **Normalizing**
3. **Hardening**
4. **Tempering**
5. **Austempering**
6. **Martempering**
7. **Case hardening**
   - Carburizing
   - Nitriding
   - Cyaniding
   - Carbon nitriding
   - Flame hardening
   - Induction hardening

***(Explain the various types of annealing?)***

1. **ANNEALING**

   It involves heating to a predetermined temperature, holding at that temperature and then cooling at a very slow rate.

Annealing is classified as,

a. Full annealing
b. Stress relief annealing
c. Recrystallization annealing
d. Spheroidising annealing

**a. Full annealing**

- Full annealing consists of heating steel to above the upper critical temperature, and slow cooling, usually in the furnace.
- This method is suitable for high carbon steels.
- This consists of holding the steel at a selected temperature above the upper critical temperature for sufficient time to allow transformation to pearlite before cooling the steel.
- It requires long time and therefore an expensive method.

**Purpose**

- refines grains, removes strains
- Improves machinability, formability, electrical and magnetic properties.

**b. Stress relief annealing**

- an after-treatment procedure to reduce inner stress within the castings through annealing and slow cooling-down, thereby reducing the risk of dimensional changes during manufacturing or final use of the component.
- It relieves stresses produced by casting, quenching, machining, cold working, welding etc.
- It applies equally well to ferrous and non – ferrous metals.

**c. Recrystallization Annealing:**

- It is carried out by heating the steel to a temperature below the critical temperature (600 – 700$^{o}$C) and slow cooling.
- The recrystallization annealing temperature is not fixed.
- This treatment is used in sheet and wire industries.
- It is used to reduce the distortions of the crystal lattice produced by cold working.

**d. Spheroidising Annealing:**

- Heating the steel to a temperature above the critical point and holding at that temperature followed by slow cooling (25 to 30$^{o}$C per hour) to 600$^{o}$C within the furnace.

**Purpose**

- improves machinability of high carbon steels.
- Prevents cracking of steel during cold forming operations.
- Better strength and ductility can be obtained.

**2. Normalizing**

Steel is heated to about 40 – 50$^{o}$C above the upper critical temperature held at that temperature for a sufficient period of time and then cooled in still air to room temperature.

**Purpose of normalizing**

- to refine the grain structure
- obtain a homogenous structure
- decrease - residual stress
- improves-machinability.

***(What is quenching?)***

**3. Hardening or (Quenching)**

- Hardening treatment consists of heating the steel to hardening temperature, holding at that temperature for a particular time followed by rapid cooling in water, oil or brine solution.

- Hypo eutectoid steels are heated to about 30- 50oc above the upper critical temperature.
- Hyper eutectoid steels are heated to about 30-50oc above the lower critical temperature.

**Purpose of hardening**

- Tensile strength and yield strength are improved.
- The wear resistance and cutting ability of steel are increased.

***(What is tempering? Explain the types of tempering.)***

**4. Tempering**

- It is a heat treatment followed after hardening and involves heating the hardened steel to some temperature below the lower critical temperature soaking at this temperature for sufficient time followed by slow cooling in air.

**Purpose of tempering**

- To relieve the residual stresses and improve ductility and toughness of the hardened steel.

**Types of tempering based on heating temperature**

**a. Low temperature tempering (1-2 Hours at a Temperature up to 250°C)**

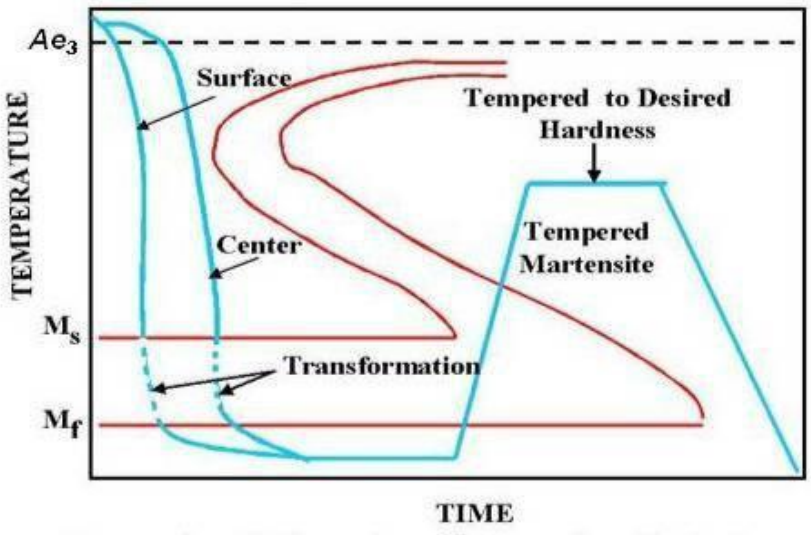
- This treatment is given normally to tools of plain carbon and low alloy steels, to develop high cutting-ability, wear and abrasion resistance with some toughness.
- Reduces the brittleness of steel and increases the toughness.

**b. Medium temperature tempering:(350 C to 500°C)**

- Increase of ductility and toughness.
- Decrease in hardness and strength.

**c. High temperature tempering(500-650°C)**

- This treated steel has better tensile yield and impact strength and is free from internal stresses.
- This structure is very soft and tough.

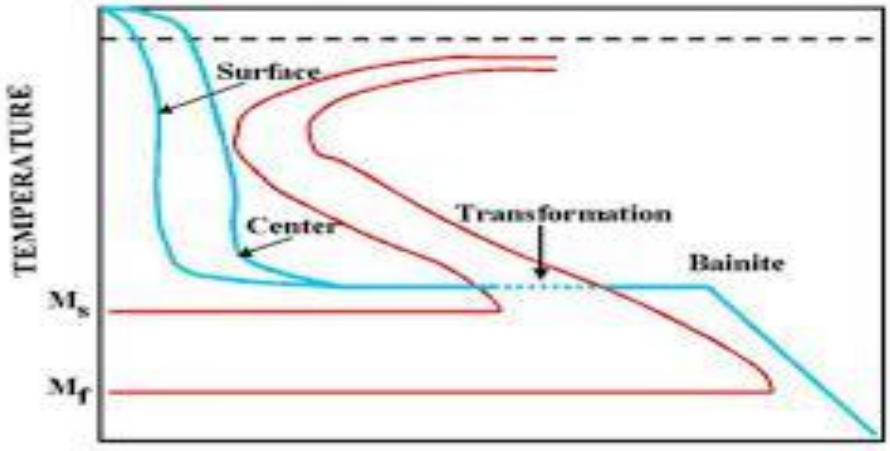



***(Explain aus tempering.)***

**5. Aus tempering**

- heat treatment process used to obtain a bainite structure.
- Heating the steel to proper austenitising temperature (725- 1370 ºC). Quenching in a salt bath having temperature from 250oc to 300oc.

- Held at this temperature for a long time as is needed for the transformation of austenite.
- Since the quenching bath temperature is higher than the Ms temperature, the austenite is transformed in to bainite.




**Purpose of austempering**

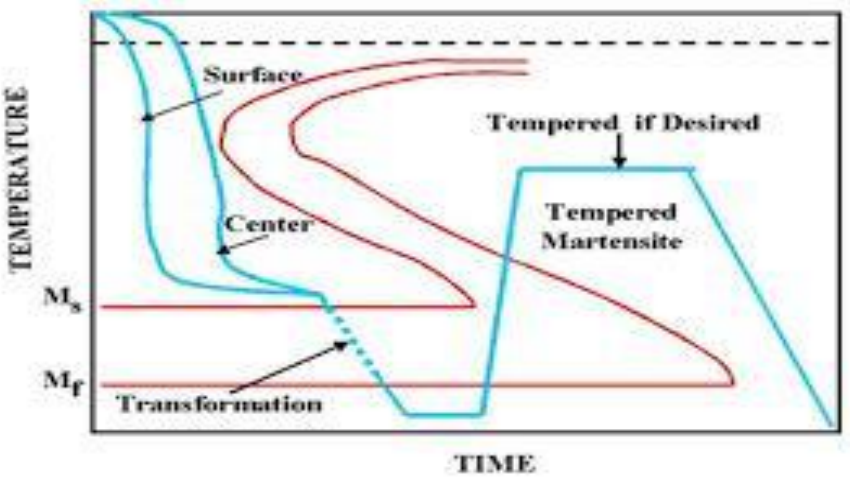
- has high hardness and ductility.
- Residual stress - reduced.
- less of hardening, cracks and wastage.
- Very thick sections cannot be heat treated.
- Long time is needed for the isothermal transformation of austenite to bainite.

***(Explain martempering.)***

**6. Martempering**

- Steel is heated to above the critical range to completely become Austenite. Temperature at 180 – 250oc maintained above Ms. Quenching in a liquid medium. Cooling in air to room temperature.
- Steel has less tendency to crack, distort and develop residual stresses during heat treatment.

- Large sections cannot be treated by martempering because the time required to obtain uniform temperature is too long.
- more suitable for high carbon steels and alloy steels.




***(Explain the various methods of surface hardening or case hardening)***

**7. Case Hardening: (Surface Hardening)**

- Hardening by diffusion of elements like carbon, Nitrogen in to the surface of a non-hardenable steel.
- These elements alter the composition of the surface by forming compounds (carbides, Nitrides) which are inherently hard.
- This produces a potentially hard surface skin.

**The various processes are:**

a) Carburizing
b) Nitriding
c) Carbon nitriding
d) Cyaniding

***(Explain the process of carburizing with its types.)***

**a) Carburizing**

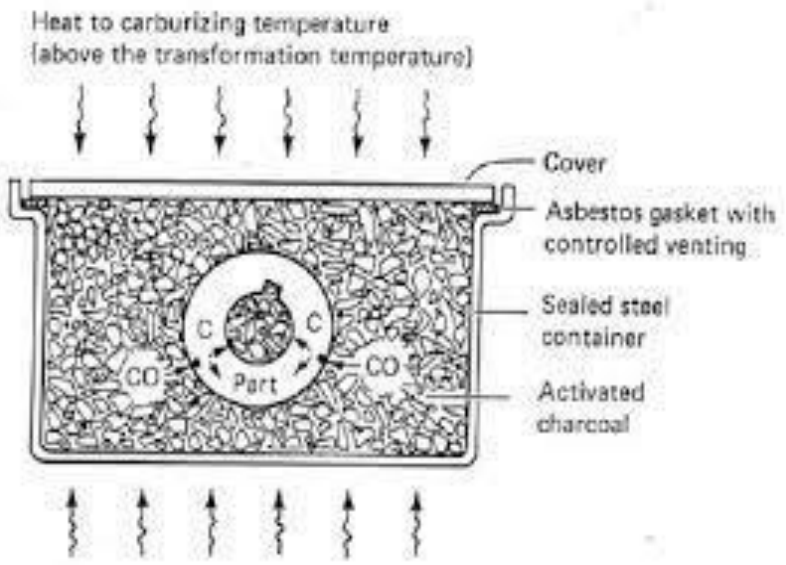
It is a method of diffusing carbon into the surface layer of low carbon steels in order to produce a hard surface. The depth of surface is 0.5 to 2mm. Temperature ranges from 900- 930$^{o}$C.

**Methods of carburizing**

i). Pack carburizing (Solid)
ii). Liquid carburizing
iii). Gas carburizing

**i). Pack carburizing**

- Pack carburizing is otherwise known as solid carburizing. The machined components of low carbon steel which are to be heat treated are packed with 70% charcoal and 30% barium carbonate.
- The components are packed in a steel box. The boxes are then place in a furnace and heated to a temperature of 900- 950oc for 6 to 8 hours.
- After heating, the box is cooled to the room temperature along with the components.




The following reactions takes place in this process.

**$BaCO_3 \rightarrow BaO + CO_2$ (Formation of carbon dioxide)**

**$CO_2 + C \rightarrow 2CO$ (Dissociation of CO2)**

**$2CO + 3Fe \rightarrow Fe_3C + CO_2$ (Enrichment of steel)**

**Advantages**

- This method is more efficient.
- It is the cheapest method.
- It is suitable for large parts.

**Disadvantages**

- It is not suitable for thin cases.
- It does not provide close control on tolerances.
- More time is required.

**ii). Liquid carburizing**

- It is carried out in molten baths, containing 20 to 50% sodium cyanide, 40% sodium carbonate and varying amounts of sodium or barium chloride.
- The mixture is melted and the bath temperature is maintained between 815oc and 900oc. The components are in molten bath for a period of 5 minutes to 1 hour.

**The following reactions are,**

**$BaCl_2 + 2NaCN \rightarrow Ba(CN)_2 + 2NaCl$**

**$Ba(CN)_2 + Fe \rightarrow FeC + Ba(CN)_2$**

**Advantages:**

- Uniform heat transfer.
- Less time is required.
- Rapid rate of penetration.
- Uniform case depth and carbon content.
- Low distortion.

**Disadvantages:**

- Cyanide salts are highly poisonous.
- Parts should be thoroughly washed after treatment to prevent rusting.

**iii) Gas carburizing:**

- The components are heated to a temperature of about 900oc for 3-4 hours and steel is heated in contact with hydro carbons like methane, ethane with carrier gases like $N_2$, $H_2$ and CO.

The following reactions takes place

$$3Fe + CO + H_2 \rightarrow Fe_3C + H_2O$$
$$3Fe + 2CO \rightarrow Fe_3C + CO_2$$

**Advantages:**

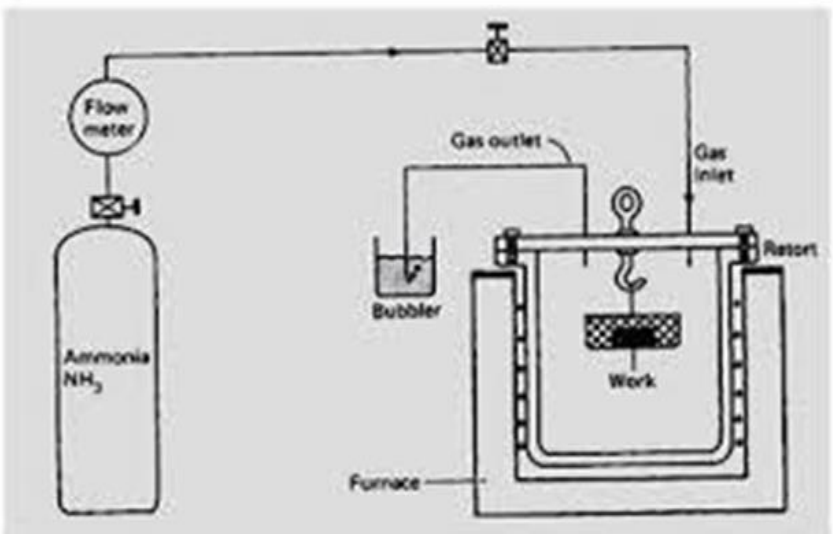
- It is suitable for mass production.
- Less time is required for the operation.
- Close control on tolerance can be obtained.

**Disadvantage:**

- Highly skilled labours are required.
- Labour cost is also less.

**b. Nitriding**

- It is process of coating steel surface with nitrogen. Ammonia gas ($NH_3$) is coated on the surface of steel at temperature ranging from 480$^o$c to 650$^o$C.
- The components are placed in furnace which is then filled with ammonia solution. Then the temperature is raised from 480$^o$ to 650$^o$C and from 0.2 to 0.4 mm deep.
- Nitriding is usually applied to medium carbon steels and alloy steels containing A1, Cr, Mo.



**Advantages :**

- ✓ High surface hardness.
- ✓ Increases the wear resistance of steel.
- ✓ Corrosion resistant.
- ✓ Good Fatigue resistance.
- ✓ No machining is required.
- ✓ No quenching is obtained.
- ✓ Hardening defects are avoided.

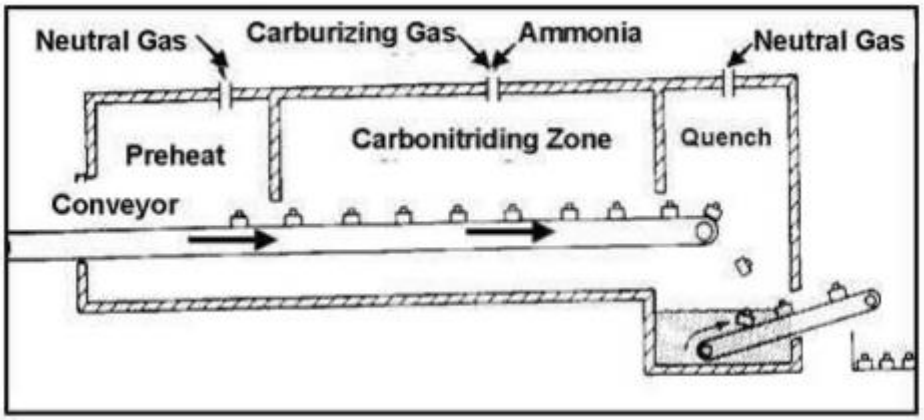
**Disadvantages:**

- ✓ It requires more time.
- ✓ Cost of ammonia is high.
- ✓ Long cycle time.
- ✓ Technical control is required.
- ✓ It is hard and brittle.

**c. Carbon Nitriding:**

Carbon nitriding is **a heat treatment process by which carbon and nitrogen (via ammonia gas) permeate the surface layer of steel components**.

- ➢ The gas mixture consists of a carburising gas which is a mixture of methane (5%) ammonia (15%) and remaining neutral gas.
- ➢ The hardness obtained in steel is RCE65. The case depth obtained in nearly 0.5mm.




**Advantages:**

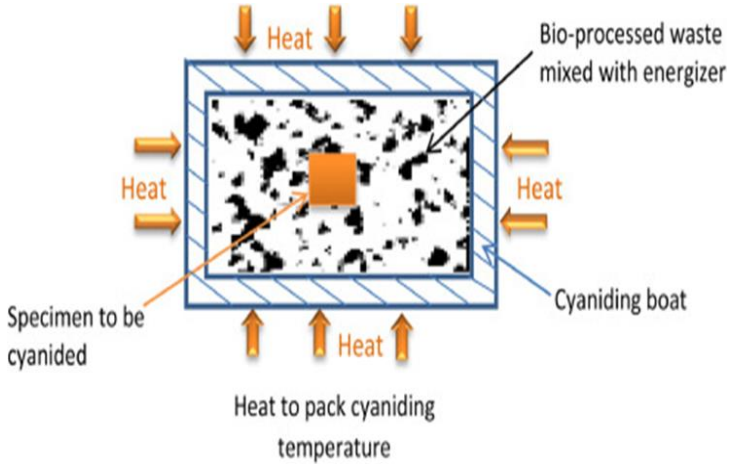
- ➢ Low heat treating temperatures are required.
- ➢ Less quench is needed.
- ➢ Reduced the distortion.
- ➢ Better wear resistance and surface harden ability.
- ➢ The process involves temperatures of around 850°C followed by quenching in oil or gas solutions.

**Applications:**

- It is used bolts, nuts, gears etc.

**d. Cyaniding:**

- It is process in which both carbon and nitrogen are coated to the surface layer of steel. Its depth ranges from 0.1 to 0.2 mm.
- The components are immersed in a liquid bath of 30% NaCN, 40% Na2CO3 and 30% NaCl at 800ºC to 850ºC.
- Then a measured amount of air is passed through the molten bath.
- The mixture is then held at this temperature for a period of 30 minutes to 3 hours.
- Then the cyanide compounds decompose and easily release the carbon and nitrogen atoms.




The reaction taking place is,

$$2NaCN + CO2 \rightarrow Na2CO3 + CO + 2N$$

$$3Fe + 2CO \rightarrow Fe3C + CO2$$

$$Fe + N \rightarrow FeN$$

**Advantages:**

- This process increases the surface hardness.
- This also increases wear resistance and fatigue limit.

**Applications:**

- It is suitable for small parts such as gears, pistons, pins small shafts etc.

## 2.3 SELECTIVE HARDENING

Hardening by phase transformation through rapid heating and cooling of the surface of a hardenable steel is called selective hardening. This method do not alter the composition of the steel.