ME3392
ENGINEERING MATERIALS AND METALLURGY

UNIT II

HEAT TREATMENT

VEERAPANDIAN.K
AP/MECH

HEAT TREATMENT PROCESS

Its a operation or combination of operations involving **heating** and **cooling** of metal / alloy in solid steels to obtain desired conditions (Relieve stress) and properties (like Machinability, ductility etc.).

Heat Treatment Processes

Softening Processes -

Annealing

Normalizing

Hardening Processes -

Hardening

Tempering

Surface Hardening Process -

TYPES OF HEAT TREATMENT PROCESS

- ANNEALING
  - FULL ANNEALING
  - STRESS RELIEF ANNEALING
  - SPHEROIDIZING
- NORMALIZING
- HARDENING AND TEMPERING
  - CONVENTIONAL HARDENING AND TEMPERING
  - AUSTEMPERING
  - MARTEMPERING
- CASE HARDENING
  - CARBURIZING
CYANIDING
NITRIDING
CARBONITRIDING
  - FLAME HARDENING
  - INDUCTION HARDENING
  - ELECTRON BEAM HARDENING
  - LASER BEAM HARDENING

QUENCHING

- It's the **Process of rapid cooling** metal by dipping into a quenching bath.
- The heated steel become much **harder** and **stronger** by a rapid cooling

Quenching mediums

- air
- water
- oil
- brine

Stages of Quenching

- Stage 1: Vapour-Jacket Stage

- Stage 2: Vapour-Transport Cooling Stage

- Stage 3: Liquid Cooling Stage

HEAT TREATMENT OF STEEL

The object of heat treatment is to make the steel suitable for some specific application.

The shape of the grains can be altered by heating the steel to a temperature above that of recrystallization and the duration of heating and the rate of cooling.

Treatments that Produce Equilibrium Condition

- Steel is heated to a temperature up to 500°C, small residual stresses will be relieved to a small extent to cause only a slight reduction in hardness and strength.

- The mechanical properties of steel depend upon the carbon content, the heat treatment temperature, the holding time and the cooling rate.

ANNEALING

Annealing is a process of heating the steel slightly above the critical temperature of steel (723 ° C) and allowing it to cool down very slowly.

PHYSICAL PROPERTIES

- Softness improved
- Strength improved
- Ductility improved
- Internal Stresses relieved

FULL ANNEALING

- Heating the steel to a temperature at or near the critical point, **holding** there for a time period and then allowing it to cool slowly in the **furnace itself.**

The main objects of full annealing are:

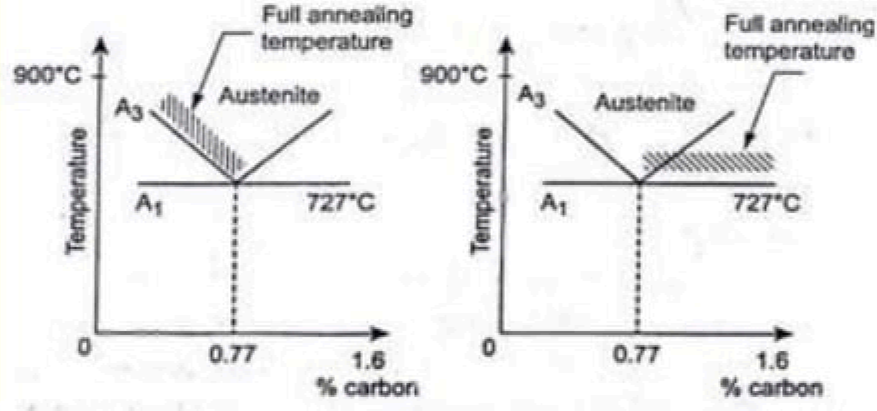
(i) To soften the metal,

(ii) To refine its crystalline structure, and

(iii) To relieve the stresses.

Material: Hot Worked sheets, forgings, and castings made from medium and high carbon steels need full annealing.

FULL ANNEALING



In full annealing, **hypoeutectoid steels (less than 0.77% C) are heated to 30 to 60°C above the upper critical point**

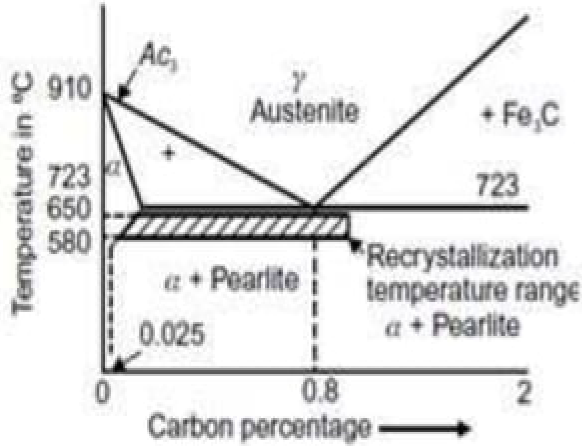
i.e., A_3 line (i.e., **between 723°C and 910°C**), as shown in Fig.. This is to convert the structure to homogeneous single-phase austenite of uniform composition and temperature, held at this temperature for a period of time, and then slowly cooled to room temperature,

Glass Annealing

- It is a **controlled process of slowly cooling** glass to relieve these internal stresses.
- First, the glass is heated to its annealing point; the temperature at which the residual stresses in a glass are reduced over a matter of minutes. It is then slowly cooled to room temperature.

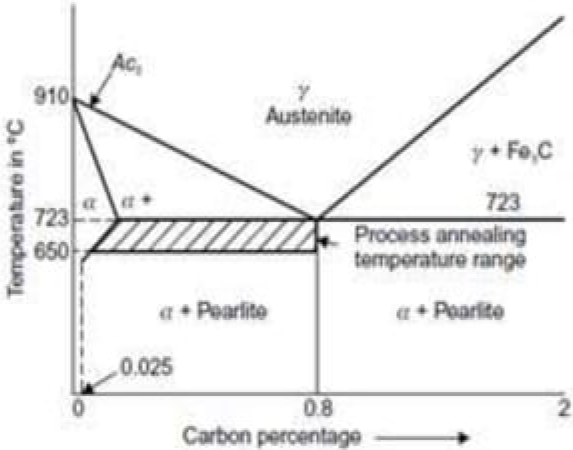
Stress Relief Annealing

Large castings or welded structures tend to possess internal stresses caused mainly during their manufacture and uneven cooling.



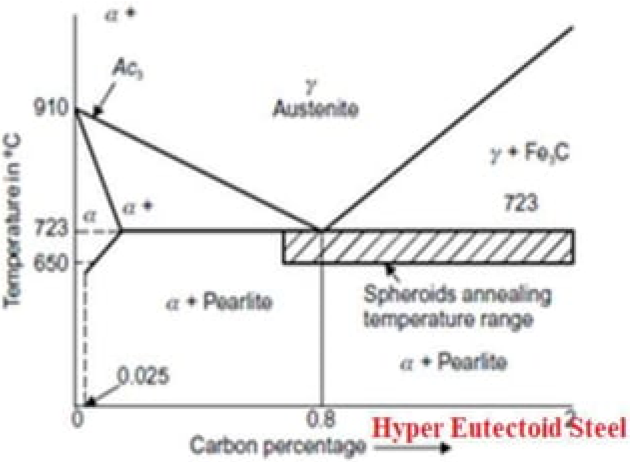
Process Annealing

- It is usually carried out to **remove the effects of cold working and to soften the steel**.
- Process of annealing consists of heating steel uniformly to a temperature of 650°C–723°C and holding at that temperature for sufficient time, followed by slow cooling.



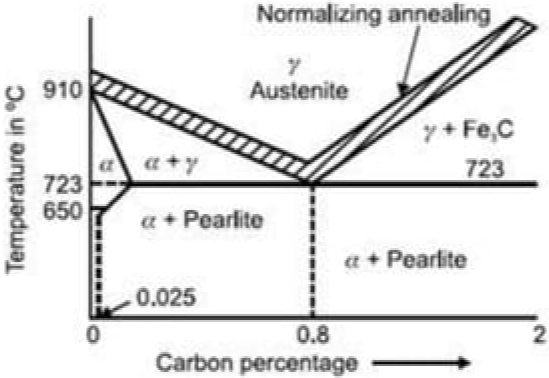
Spheroidal Annealing

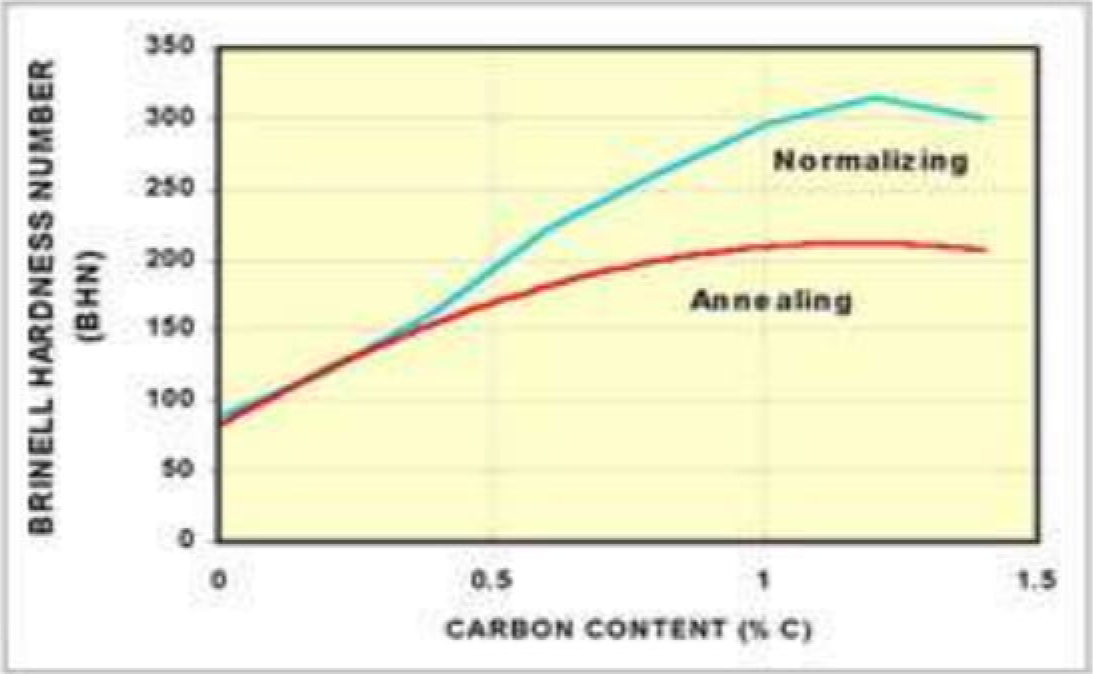
- Hypereutectoid steels consist of pearlite and cementite. The cementite forms a brittle network around the pearlite. This presents difficulty in machining the hypereutectoid steels. To improve the machinability of the annealed hypereutectoid steel spheroidize annealing is applied.



Normalizing

- To achieve **high hardness** and **strength.**
- Metal is heated above Upper critical temperature.
- At that temperature, the structure is converted into Austenite and removed from the furnace then it is cooled under natural convection at controlled room temperature.
- This results in a grain structure of fine Pearlite with excess of Ferrite or Cementite.





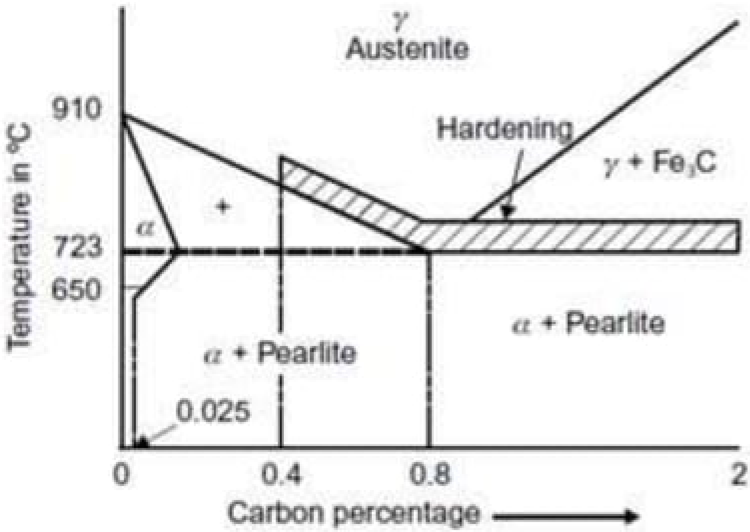
BRINELL HARDNESS NUMBER (BHN)
350
300
250
200
150
100
50
0
Normalizing
Annealing
0
0.5
1
1.5
CARBON CONTENT (% C)

Treatments that Produce Non equilibrium Condition
(Austenite to Martensite)

- Certain applications demand **high hardness** values so that the components may be successfully used for heavy-duty purposes. High hardness values can be obtained by a process known as **hardening process**.
- Steel is heated to produce austenite structure held at that temperature and then quenched in water. The high hardness developed by this process is due to the **transformation of austenite** at considerable low temperature known as **martensite** and this metal is known as non equilibrium condition.
- The properties produced by this method depends on the carbon content of the steel, temperature, holding time and quenching media.

Hardening of Steels

- Its a process of heating the steel above or below the critical temperature for a particular period and then allow to cool by oil or water rapidly



TEMPERING

- In the hardening process we obtained martensite structure . In this structure, the material having **brittle property** and also it has **internal stresses**.
- For minimizing the harness and removing the internal stresses **we heat the metal near to upper critical temp once again and let it for some time then cool by air**

ISOTHERMAL AND CONTINUOUS COOLING TRANSFORMATION DIAGRAMS

- Austenite undergoes transformation depending upon **temperature** and **time**.
- The relationship between structure and rate of cooling (time taken to decompose) can be studied for given steel with the help of a set of isothermal austenite transformation curves, which are popularly known as Time–Temperature–Transformation diagram or **TTT diagram**.
- In this diagram, the temperature - in vertical axis and time - in the horizontal axis. This curve is also known as S curve, C curve or isothermal curve.

WHY – TTT & CCT DIAGRAMS ?

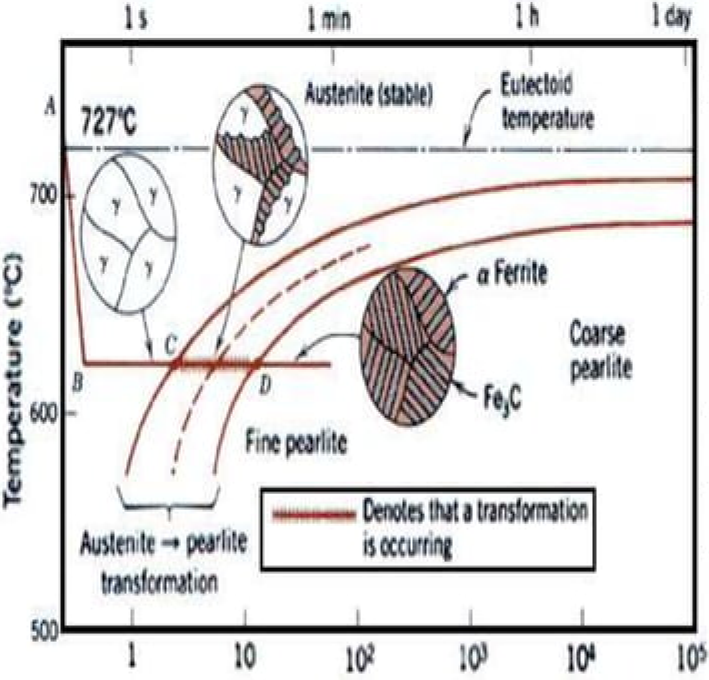
- The phases martensite and bainite are non-equilibrium phase that do not appear in fe-fe3 c (iron-iron carbon) phase diagram

- also strengthening treatment like hardening and tempering are non-equilibrium process.

- in order to show the influence of varying cooling rates, that is time, on the transformation of austenite other types of diagrams are necessary.

- The time temperature transformation or **TTT** diagram and the continuous cooling transformation or **CCT** diagram are used to explain the things in the cooling operation

TTT DIAGRAM



- The time-temperature transformation curves correspond to the start and finish of transformations which extend into the range of temperatures where austenite transforms to pearlite.

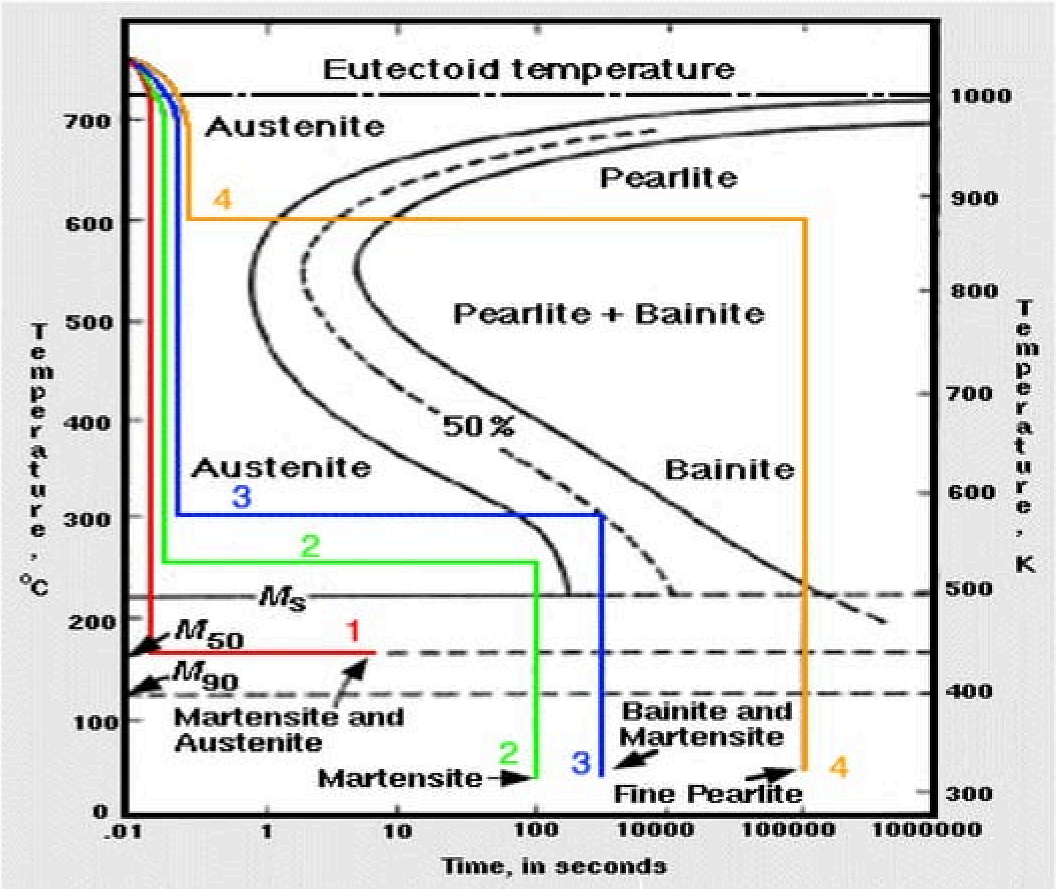
Above 550 C, austenite transforms completely to pearlite.

Below 550 C, both pearlite and bainite are formed and below 450 C, only bainite is formed.

The horizontal line C-D that runs between the two curves marks the beginning and end of isothermal transformations.

The dashed line that runs parallel to the solid line curves represents the time to transform half the austenite to pearlite.

TIME TEMPERATURE PATH ON ISOTHERMAL TRANSFORMATION DIAGRAM



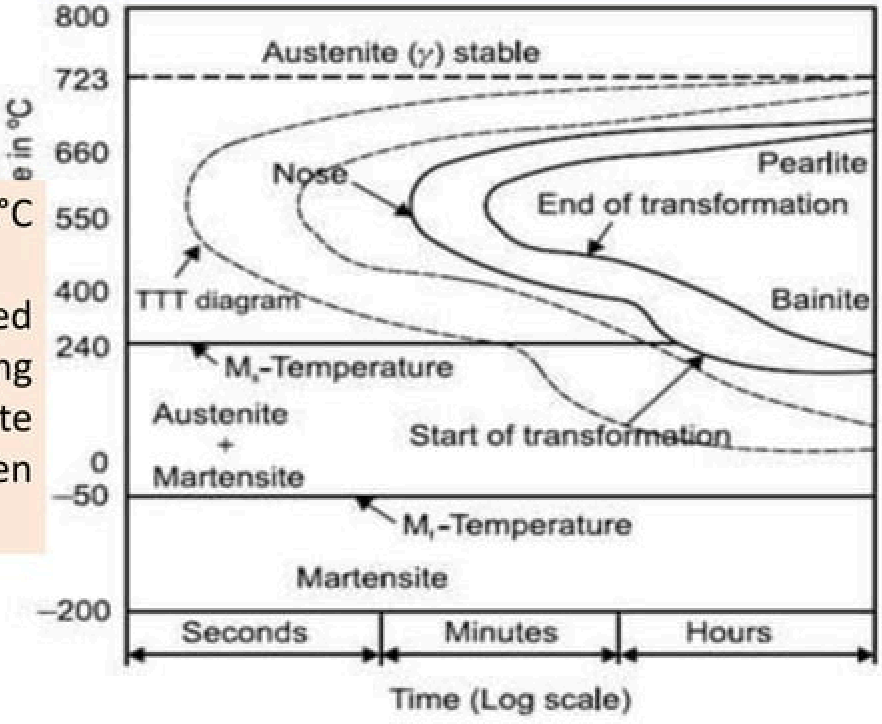
CCT CURVE

- A **continuous cooling transformation** (**CCT**) Curve is often used when heat treating steel.

- These diagrams are often more useful than time-temperature-transformation diagrams because it is more convenient to cool materials at a certain rate than to cool quickly and hold at a certain temperature.

CONTINUOUS COOLING TRANSFORMATION (CCT) CURVE for Eutectoid Steel

From 723°C temperature, specimens are cooled at a constant cooling rate of some definite temperature and then quenched in water



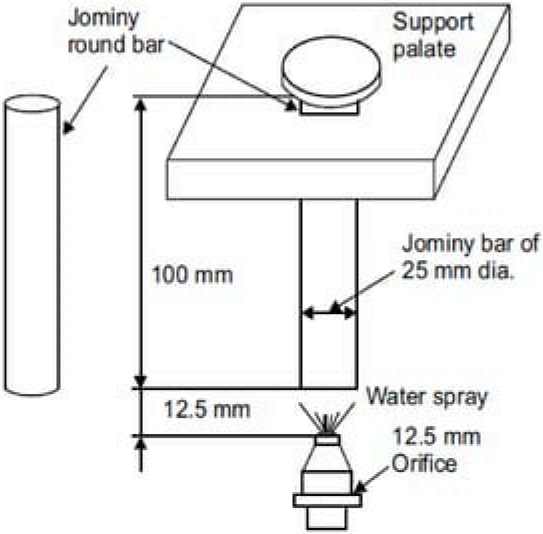
CRITICAL COOLING RATE

- The critical cooling rate is most important in hardening. In order to obtain a **100% martensitic** structure on hardening, the cooling must be much **higher than the critical cooling rate**.

HARDENABILITY (for getting required Hardness)

This property of steels of acquiring hardness throughout the section by means of heat treatment is known as hardenability

Jominy End-Quench Tests



This test used to determine the hardenability of steel.

INTERRUPTED QUENCHING
(modified Quenching)

- The rapid cooling of molten metal gives more problems like
  - induced stresses
  - distortions (warping)
  - crack formation in steel

In order to overcome the disadvantages a modified quenching is to be followed called interrupted quenching

Two forms of modified Quenching are

MARTEMPERING

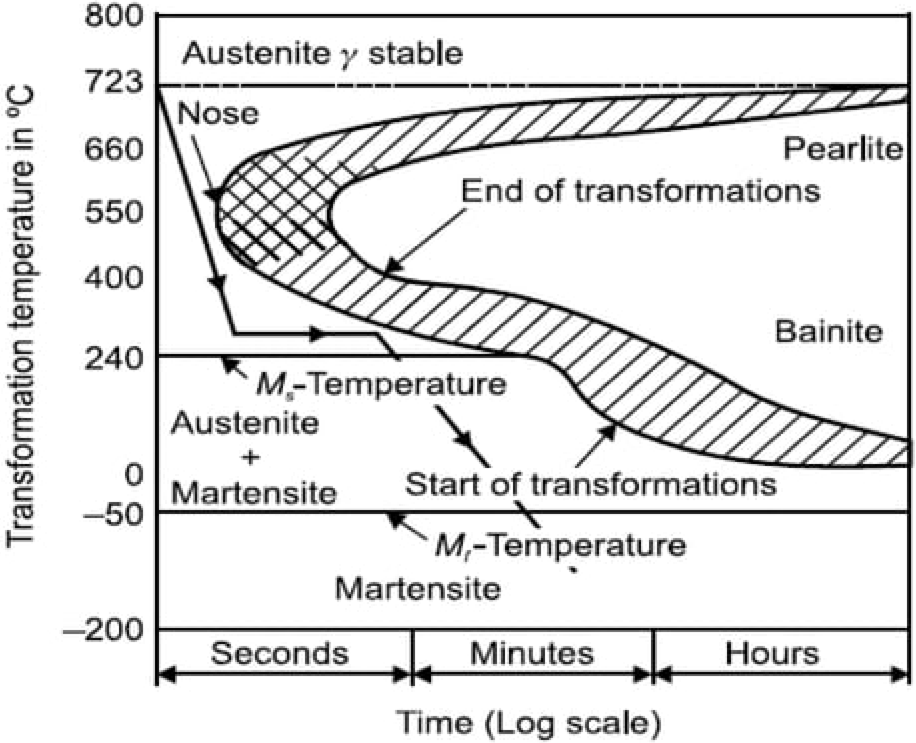
AUSTEMPERING

MARTEMPERING (Mar-quenching)

It's a interrupted cooling procedure for a steel to reduce the stresses, distortions and cracking of steels that may develop during rapid quenching

Martempering process

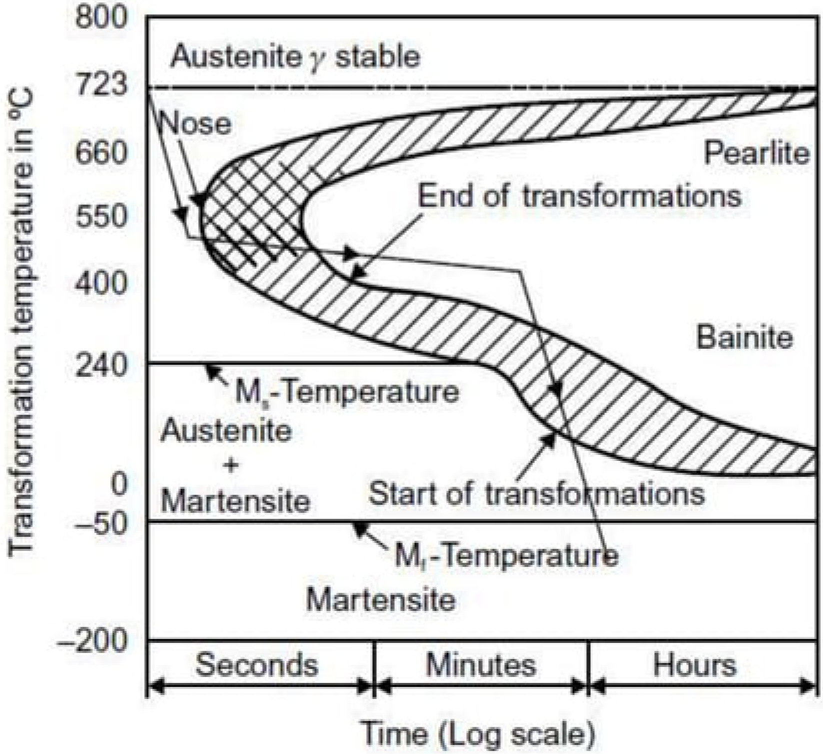
for eutectoid steel



AUSTEMPERING

- It’s a isothermal transformation of steel at a temp below that of pearlite formation and above that of martensite transformation

AUSTEMPERING



CASE HARDENING

OR

SURFACE HEAT TREATMENT

PURPOSE OF CASE HARDENING

- to make **wear resistant** outer surface
- to obtain an inner surface which can **with stand shock** load
- to **improve the corrosion** resistance
- to **improve the thermal** resistance
- to **improve the life** of the material, and reduce cost material.

METHODS OF CASE HARDENING

- **CARBURISING**
- **CYANIDING**
- **CARBO NITRIDING**
- **NITRIDING**
- **INDUCTION HARDENING**
- **FLAME HARDENING**

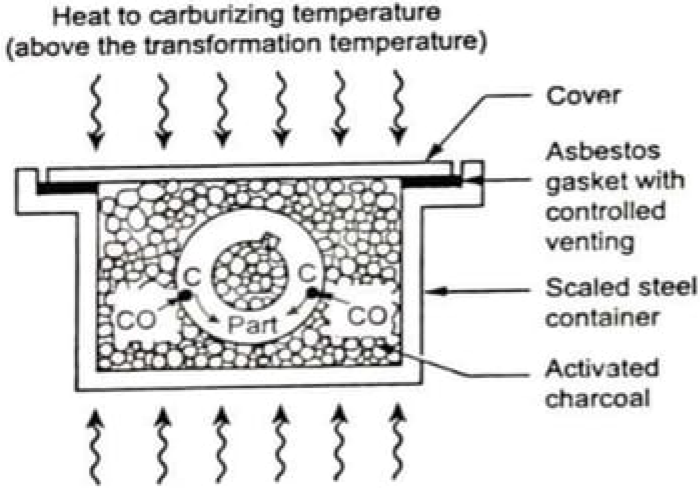
CARBURISING

- it’s a process of **adding carbon** on the outer surface of the **low carbon material.**

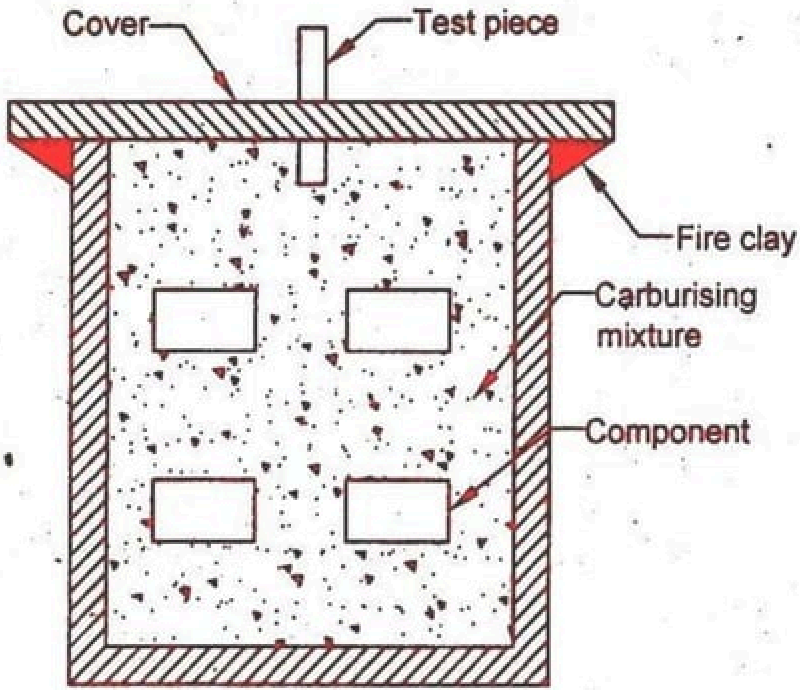
METHODS

1. **PACK CARBURISING**
2. **LIQUID CARBURISING**
3. **GAS CARBURISING**

PACK CARBURISING



Pack carburizing



PACK CARBURISING

- In this the work piece is kept in a box.
- The box containing carburising mixture which consist of charcoal, coke and barium carbonate.
- The box is closed and sealed as air tight with fire clay.
- Now the box is placed in a furnace and heated upto 900 to 950 degree celcius.
- Depend on the hardness level required the workpiece placed inside the furnace for sufficient time in the process.
- During this CO (Carbon monoxide) released and it react with iron on the work piece surface and forms a hard iron carbide
- **2CO + 3 Fe -------- Fe_3C + CO_2**
- **Then the work piece are cooled along with the Box.**

LIQUID CARBURISING

Here the work pieces are immersed in a **liquid salt bath** kept at a temperature of about **900`c.**

The salt bath contains up to **20% sodium cyanide, sodium carbonate and barium chloride** are also added

The work pieces are immersed in the salt bath from 5 minutes to 1 hour according to the required depth of hardened surface.

In this process the work pieces absorb large amount of carbon and a small amount of nitrogen

carbon monoxide is released due to the reaction of sodium cyanide with oxygen. this reacts with iron on the work piece surface and forms iron carbide.

$$2NaCN + 2O_2 \rightarrow Na_2CO_3 + 2N + CO$$

$$2CO + Fe \rightarrow Fe_3C + CO_2$$

Advantages:

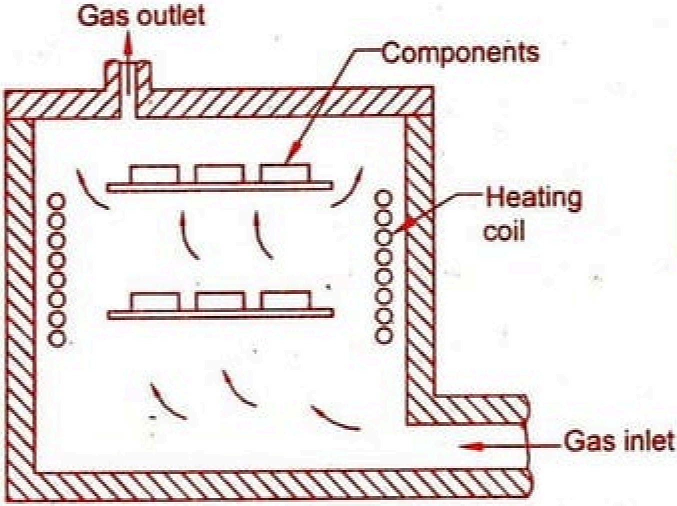
1. It is suitable for **mass production.**
2. Hardening can be done **up to 7mm** depth
3. **Uniform case depth** can be obtained
4. It is a **fast process**
5. **No Oxidation** takes place
6. It is suitable for work pieces of **various shapes and sizes**.

Dis - Advantages:

1. It is costly process
2. Cyanide used in this various shapes.
3. Explosion may occurs if the work pieces not properly dried before immersing in sodium cyanide solution
4. It is necessary to wash the work pieces thoroughly after carburizing.

GAS CARBURISING

- Here the work piece is **kept in an air tight furnace** and heated to a temp of **925 ^{0}C** .
- Gases containing **high carbon such as methane or butane is mixed with air** and passed inside the furnace.
- The work piece kept in the same temperature for 3 – 4 hrs. according to the req. depth of case to be hardened.
- CO (carbon monoxide) released from the process and it react with the iron on the work piece surface and forms IRON CARBIDE



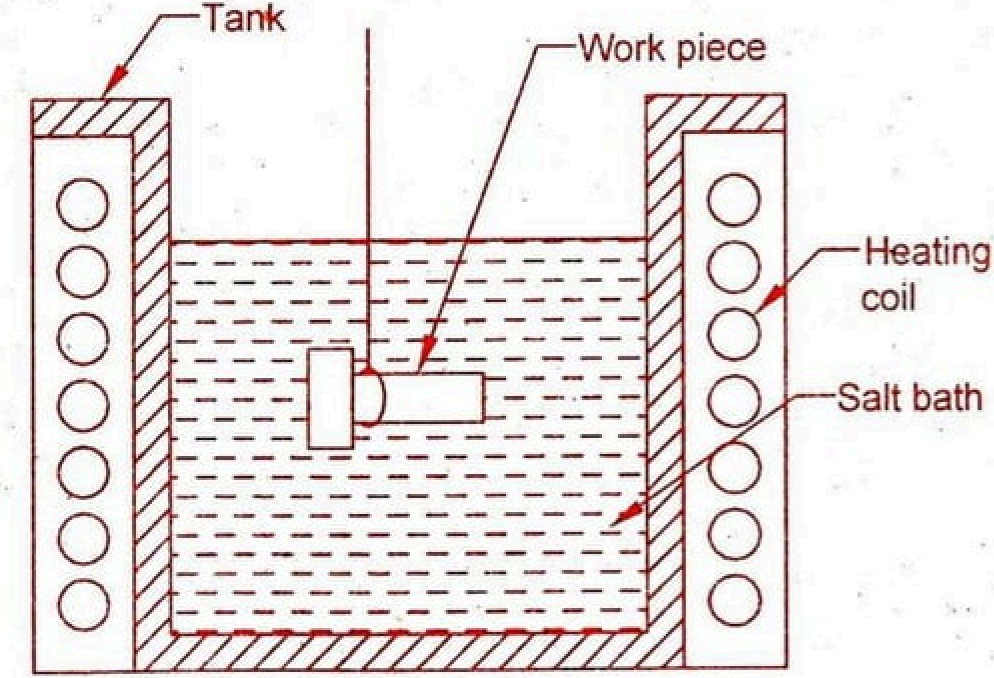
Gas carburizing

APPLICATION

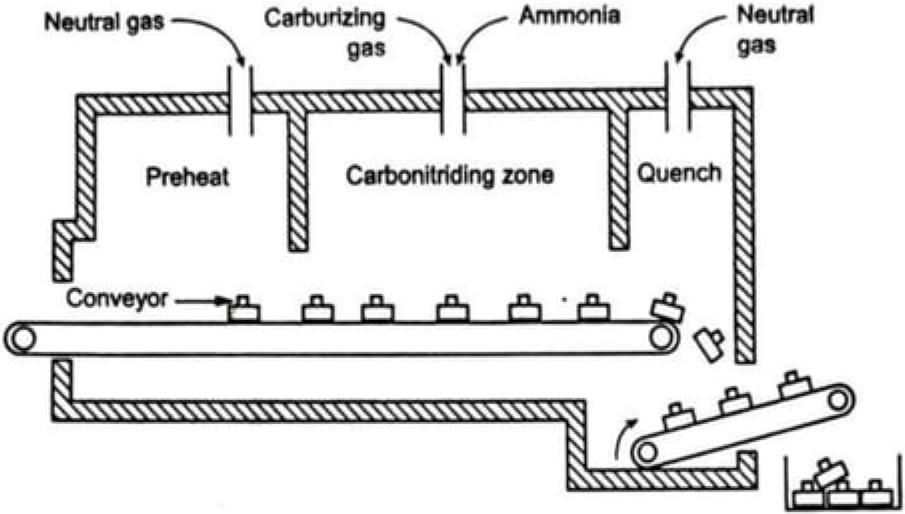
- surface hardening of small and medium sized components such as gear wheels and automobile parts

CYANIDING

- Its a process of hardening the surface of low carbon and alloy steels by **adding carbon** and **nitrogen**.



CARBONITRIDING

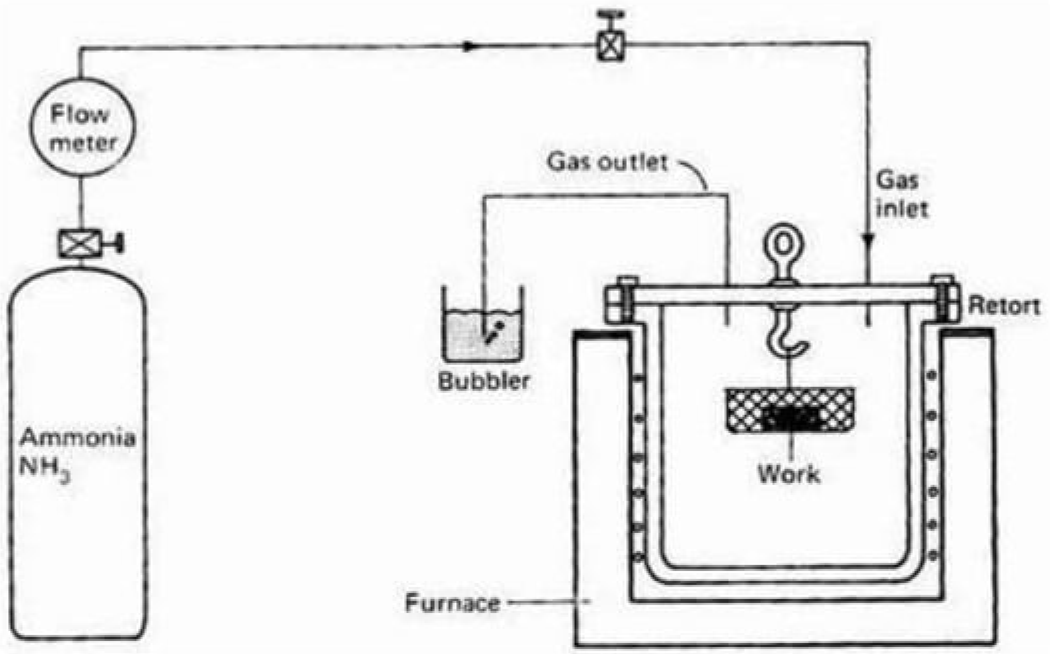


Application

- Suitable for plain carbon steels such as small gears , bolts , nuts, pins etc.

- **ADVANTAGES**
- Cheapest process
- Fast process
- Suitable for mass production
- Less distortion occurs

NITRIDING


Flow meter
Gas outlet
Gas inlet
Retort
Bubbler
Ammonia NH3
Work
Furnace

Application

- Small gears
- Bearings
- Valve seats
- Air craft parts
- Guide ways

are hardened

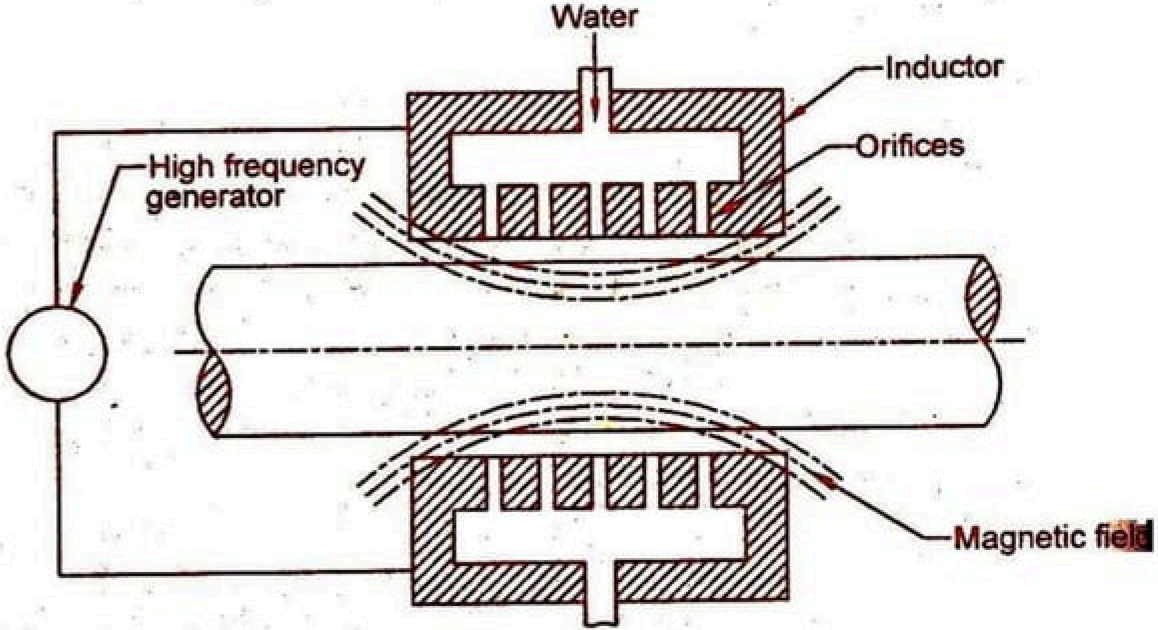
Advantages

- Possible to obtain the hardness up to 70 Rc
- Wear and corrosion resistance increased.
- Good fatigue resistance obtained.
- No distortion will be occurred
- Complicated shape components also hardened.

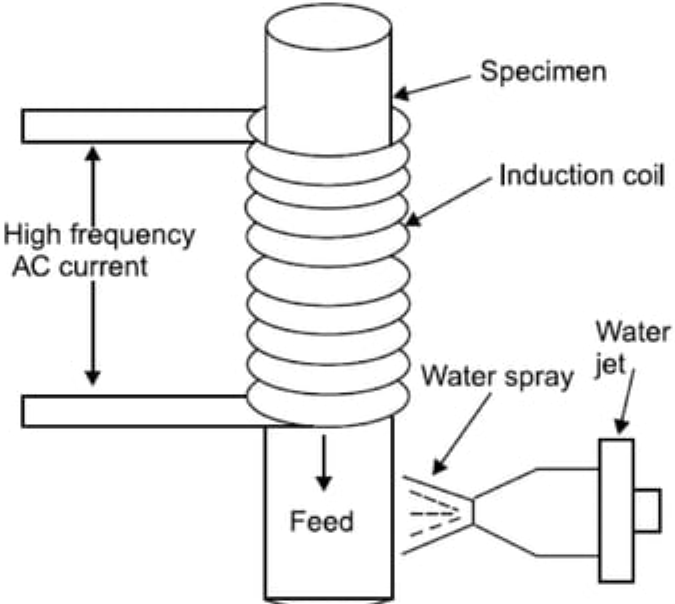
Dis-advantages

- More time consuming process
- Costly process
- Not suitable for plain carbon steels

INDUCTION HARDENING



INDUCTION HARDENING



Application

- Suitable for medium carbon steels.

- Piston rod
- Cam shaft
- Cylinder liners
- Bearings
- gears

hardened by this process

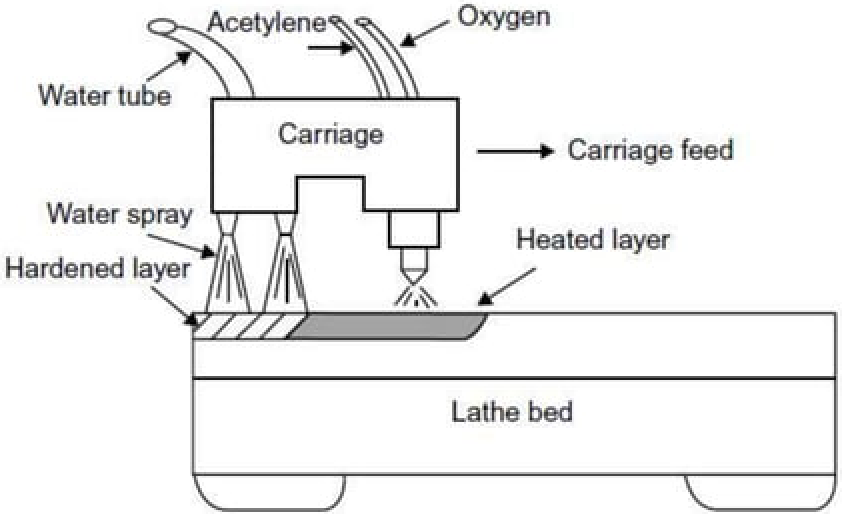
Advantages

- Fast process
- Suitable for mass production
- Possible to obtain case with high quality
- Depth hardening can be easily controlled

Disadvantages

- **Costly process**
- **Low carbon steels cannot be hardened**
- **Difficult to harden complicated shapes**

FLAME HARDENING



Application

- **Machine guide ways**
- **Gears**
- **Shafts**
- **Mill rolls**
- **Piston pins**
- **Cams**

are hardened by this process

ADVANTAGES

- Simple and economical process
- Easy to carry the entire set up to usage area
- Suitable for hardening large size machine parts
- Distortion and scale formation is less