UNIT – II

HEAT TREATMENT

Definition:

Heat Treatment is defined as an operation or a combination of operations which involves heating and cooling of a metal or alloy in solid state to obtain desirable properties.

2.1 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.

2.2 ISO – THERMAL TRANSFORMATION DIAGRAM :

ISO - thermal transformation diagram is otherwise known as s-curve , Bain's curve or T.T.T. (Time – Temperature- Transformation) diagram.

Isothermal transformation diagram shows the relation between temperature and time for the transformation of decomposition of austenite when the transformation occurs at constant temperature.

In Iron – iron carbide equilibrium diagram austenite is a meta stable phase which is existing above $727^{0}c$.

It has been observed through iron-iron carbide equilibrium diagram that austenite does not exist at room temperature.

It gets transformed into different phase based on the cooling rate.

Steps to construct isothermal transformation diagram :

Step 1 :

Prepare a large number of relatively small specimens cut from the same bar.

Step 2 :

Place the specimens in a molten salt bath just above the austenite temperature. The specimens are held at this temperature for a long enough time to become completely austenite.

Step 3:

Place the specimens in a furnace or molten salt bath which is held at desired reaction temperature, at 350^0c.

Step 4 :

After a given specimen is Allowed to react isothermally for a certain time, it is cooled (quenched) in cold water.

Step 5 :

After cooling the specimens are checked for hardness and the microscopic examination is carried out.

Step 6 :

The above steps are repeated at different sub critical temperatures until sufficient points are obtained to plot the curve. The Series of reaction curves form the T.T.T curve.

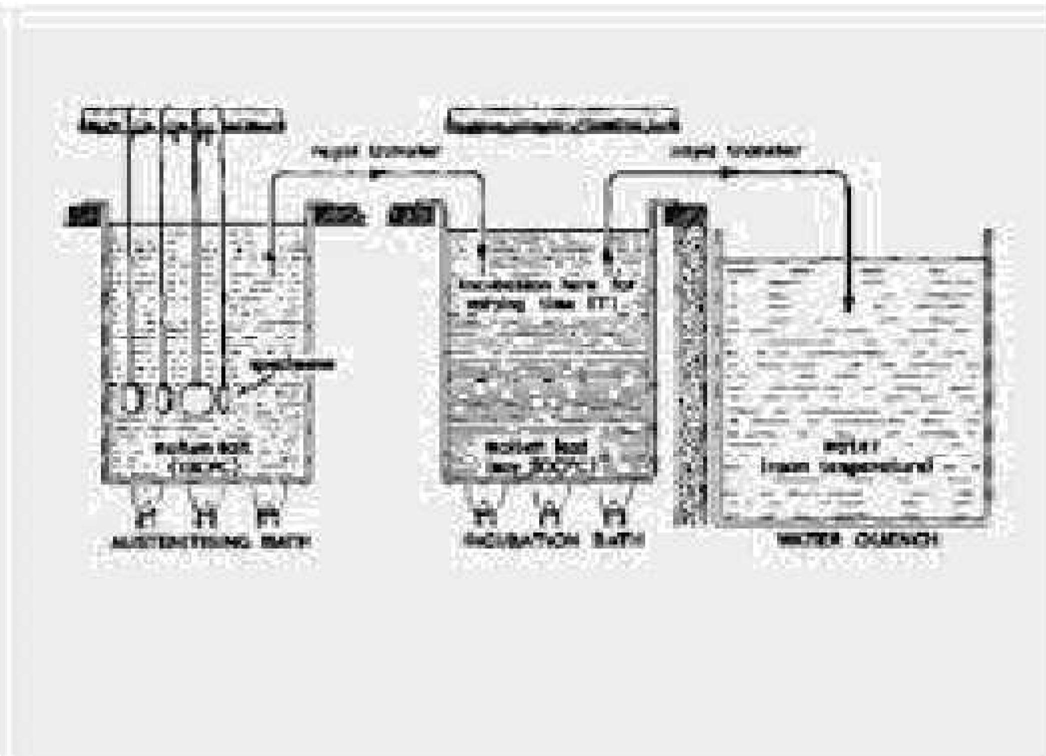


Fig 2.1 Isothermal transformation diagram

2.3 T.T.T DIAGRAM (TIME -TEMPERATURE -TRANSFORMATION):

Austenite transformation under non equilibrium condition is a TTT diagram. This diagram indicates the time necessary for transformation to take place and the structure that is produced when austenite is cooled to any predetermined transformation temperature. TTT diagram for eutectoid steel composition. Temperature 723^{o}c eutectoid steel consists entirely of stable austenite. At high temperature, the reaction products form with increasing time at constant temperature

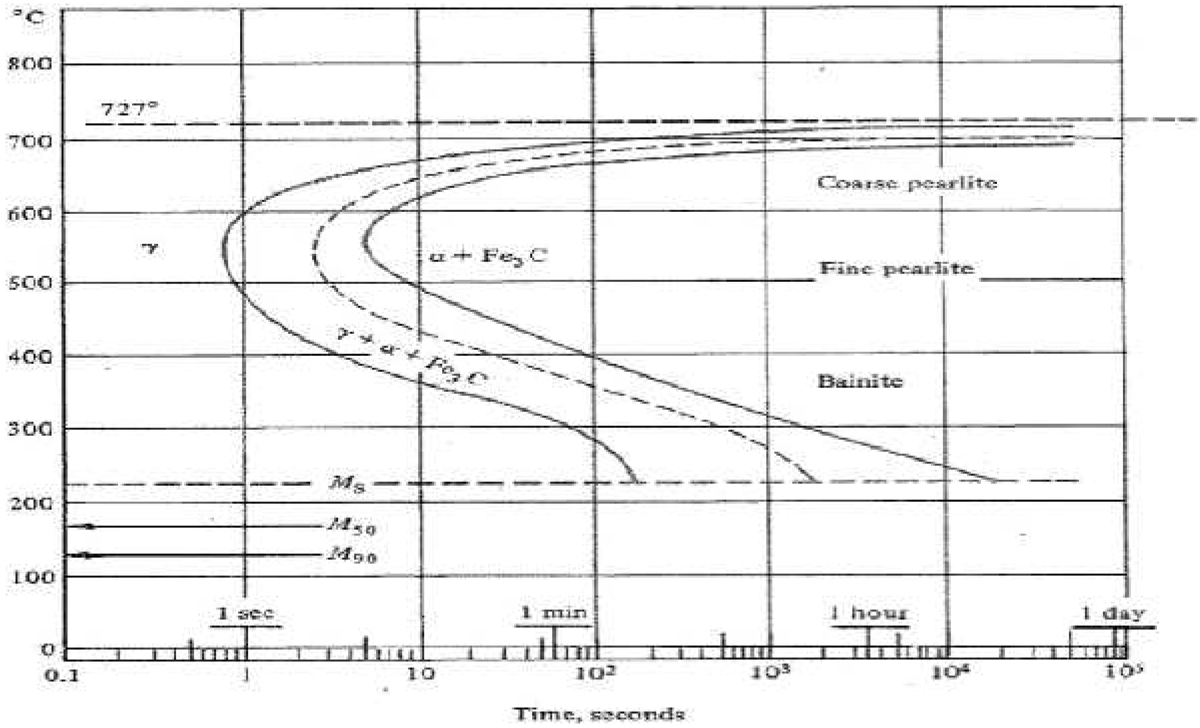


Fig 2.2 TTT Diagram for eutectoid steel

2.4 COOLING CURVES:

Cooling curve a shows a very slow cooling rate and this corresponds to annealing. The transformation product at that temperature is coarse pearlite. Cooling curve B is isothermal annealing the process is carried out by cooling the material above A1 line and holding at that temperature to produce complete transformation. The transformation product is medium pearlite.This cooling curve D is of an intermediate cooling rate and austenite will start to transform to fine pearlite from point line is crossed, the remaining austenite will transform to martensite. Cooling curve the final micro structure at room temperature will be martensite of high hardness. Cooling cure F is a slower than the critical cooling rate will produce softer transformation product like pearlite. Any cooling rate which is faster than the critical cooling rate will produce harder transformation product like martensite. Cooling curve is possible to form pearlite or Martensite by slow cooling.

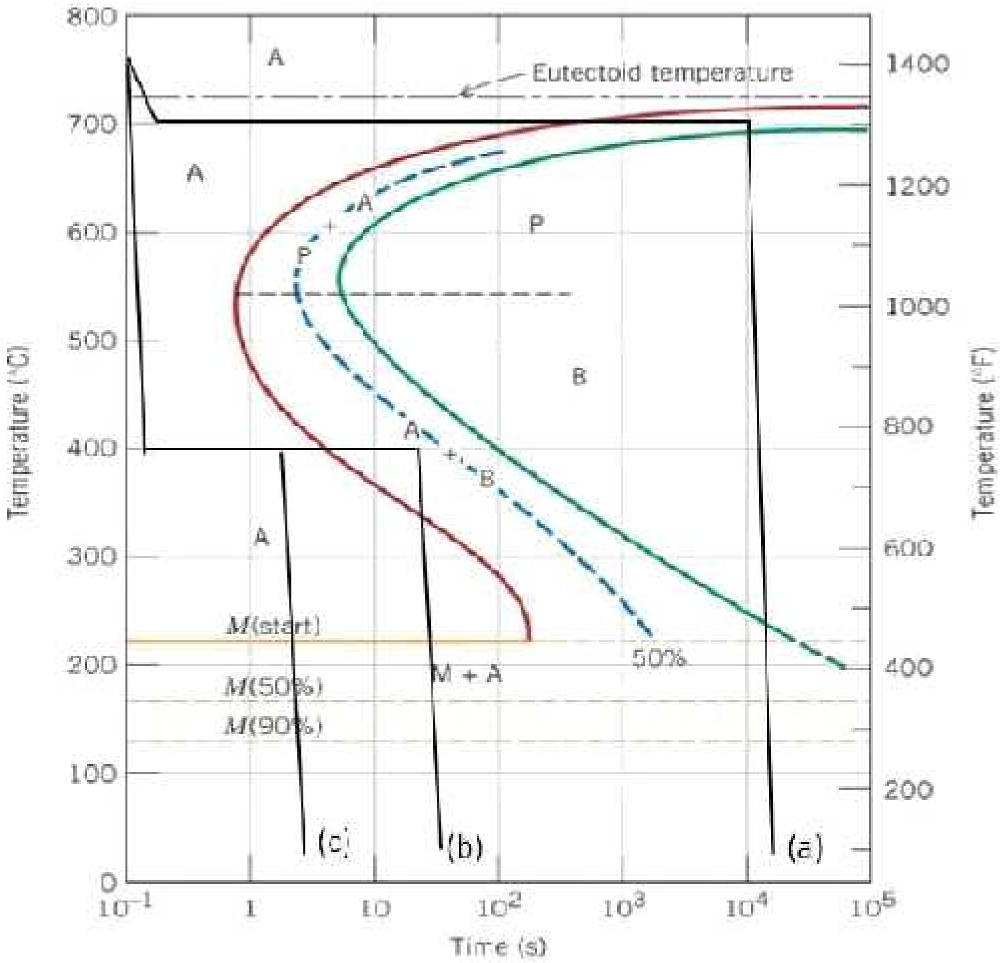


Fig 2.3 cooling curves

2.4.1 CCR (CRITICAL COOLING RATE) :

The minimum cooling rate that will avoid the formation of any of the softer products of transformation is known as critical cooling rate. This is determined by chemical composition and austenite grain size. It is an property of a steel.

2.5 HARDENABILITY :

The term hardenability refers to the ease with which hardness may be attained. That is ,the ease with which a steel will transform to hardened structure on quenching is called hardenability. The hardenability of a steel is define as that property which determines the depth and distribution of hardness induced by quenching from the austenitic condition.

Factors affecting hardenability:

The composition of the steel

The austenitic grain size.

The structure of the steel before quenching

The quenching medium and the method of quenching

Determining hardenability (jominy end quench test):

The most widely adopted method of determining hardenbility is the jominy end –quench test method. The Jominy end-quench test method is universally adopted because:

It is relatively easy to perform.

It is excellent reproducibility.

It gives information useful to a designer as well as manufacturer.

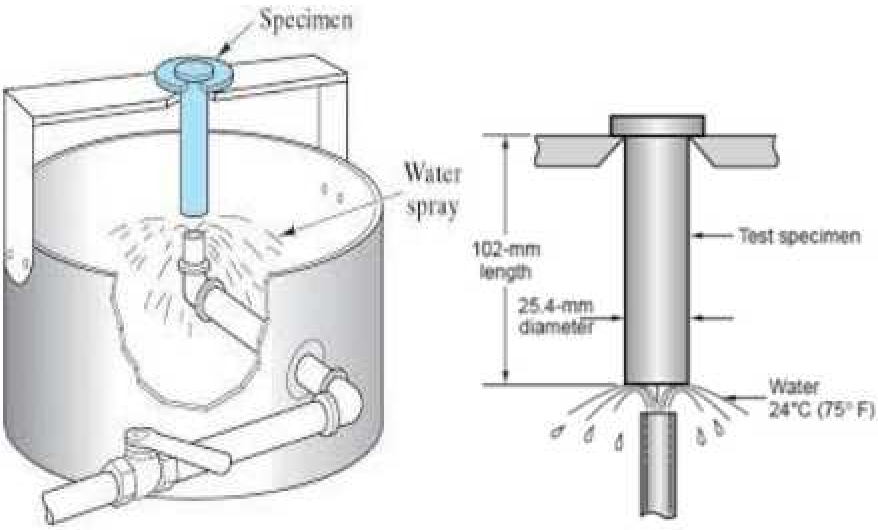


Fig 2.4 Jominy end -quench apparatus

Testing procedure:

In this test, specimen dimensions and test conditions are standard.

Specimen is of cylindrical shape of diameter 25.4mm (1 inch) length of approximately 102mm.(4 inch). It has a machined shoulder at one of its end.

Standard specimen is austenitized at a constant temperature for a fixed amount of time & quickly transferred to quenching jig fixture.

Water is allowed to flow from the bottom end though a pipe of internal dia 12.7mm for about 20 minutes.

The distance between the bottom end of the specimen pipe is maintained as 12.7 mm.(1/2 inch)

The pressure of water jet is adjusted such that the free height of water jet is 64mm (2.5 inch).

At this pressure water forms a complete umbrella over the bottom surface of the specimen.

Temperature of water is required to maintain in between 21 to 27^{0}C.

Cooling rate of the specimen varies from bottom which is subjected to water quenching to the top end is air cooled.

The bottom end is subjected to full hardening when the top end undergoes normalizing cycle.

Thus the specimen is subjected to all possible rates of cooling throughout its length.

This cooling rate is independent of the composites of the specimen.

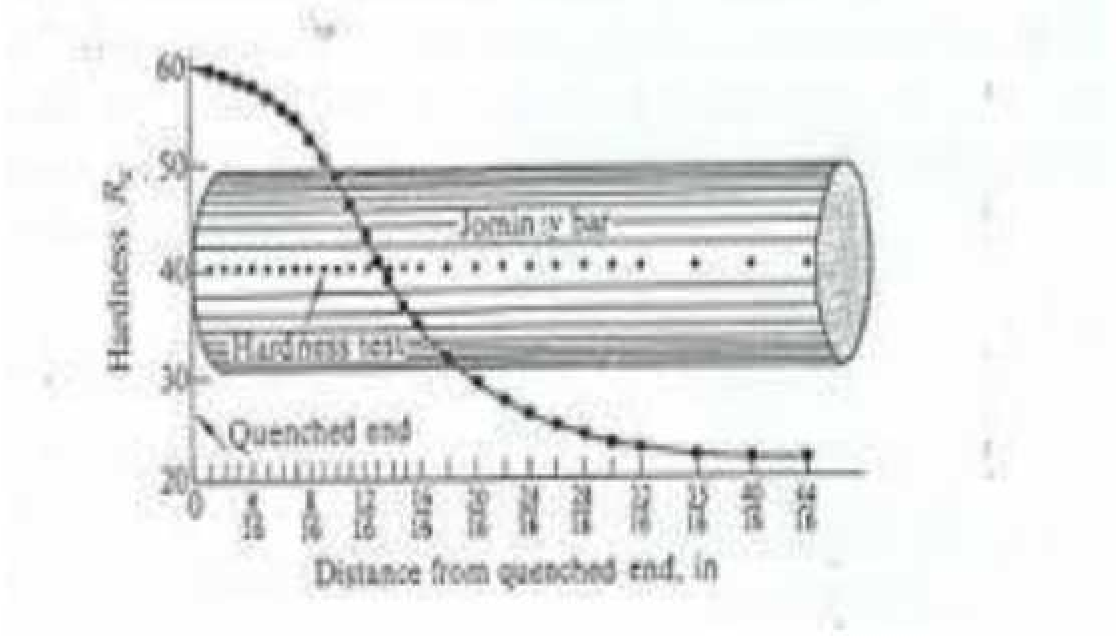


Fig 2.5 Distance from Quench End

2.6 TYPES OF HEAT TREATMENT PROCESSES :

Annealing processes.

Full annealing

Stress Relief annealing

Recrystallisation annealing

Spheroidise annealing

Diffusion annealing

Normalising

Hardening

Tempering

Austempering

Martempering

Case hardening

Carburising

Nitriding

Cyaniding

carbon nitriding

Flame hardening

Induction hardening

2.6.1.ANNEALING :

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

Annealing is classified as :

Full annealing

Stress relief annealing

Recrystallisation annealing

Spheroidising annealing

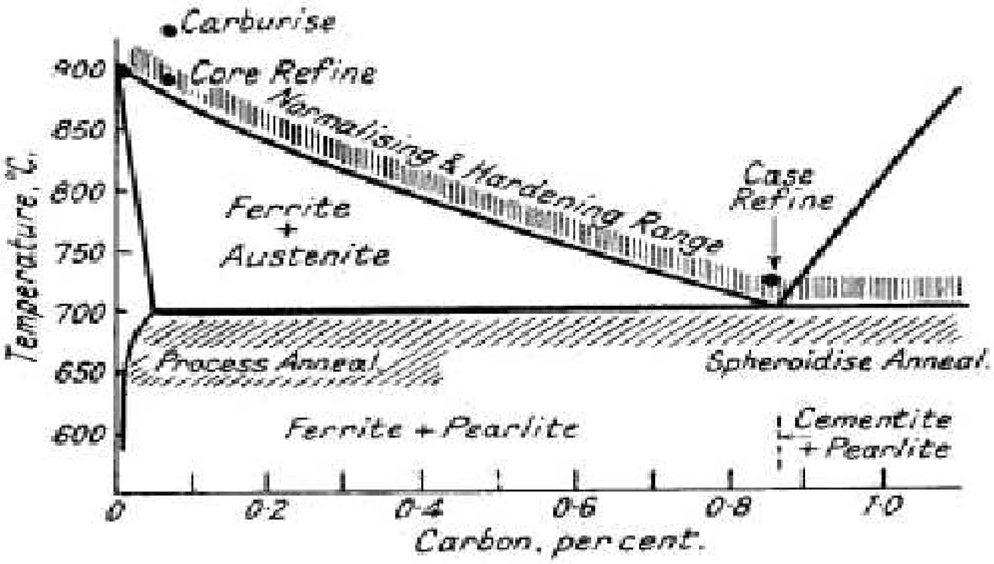


Fig 2.6 Annealing

i) Full Annealing :

It implies annealing a ferrous alloy by austenitic and then cooling slowly through the transformation range. The temperature for hypo eutectoid steels is usually between 723^{0}c and 910^{0}c. The temperature for hyper eutectoid steels is usually between 723^{0}c and 1130^{0}c.

It involves heating steel to proper annealing temperature in the austenitic zone.Cooling very slowly the steel object through the transformation range in the furnance till the object acquires a low temperature. Slow cooling with full annealing enables the austenite to decompose at low degrees of super cooling so as to form degrees of super cooling so as to form

Pearlite + Ferrite structure in hypo eutectoid steels.

Pearlite + cemetite structure in hyper eutectoid steels.

It improves purpose of this treatment is refines grains, Removes strains, Improved mach inability , improves formability and improves electrical and magnetic properties.

ii) Stress relief Annealing :

It relieves stresses produced by casting, quenching machining, cold working, welding etc.

It applies equally well to ferrous and non – ferrous metals.

Thermal stress relieving requires heating relaxation of the elastic stress is brought about by plastic deformation corresponding to the elastic strain.

Stress relieving annealing , steel is heated to a temperature between 500 and 550^{o}c, is the melting point of the cast metal or alloy.

iii) Recrystallisation Annealing :

Cold working of steels increases the hardness and strength but decreases the ductility.

It is carried out by heating the steel to a temperature below the critical temperature 600 700^{o}C and slow cooling.

The recrystallisation annealing temperature is not fixed. It depends on the chemical composition, amount of deformation, holding time and the initial grain size.

This treatment is used in sheet and wire industries.

It is to reduce the distortions of the crystal lattice produced by cold working

iv) Spheroidising Annealing :

It is to improve the machinability of high carbon steels.

Heating the steel to a temperature above the critical point and holding at that temperature followed by slow cooling (25 to 30^{0} c per hour) to 600^{0}c with the furnace.

Cementite affects the properties of the materials.

Prevents cracking of steel during cold forming operations.

Better strength and ductility can be obtained.

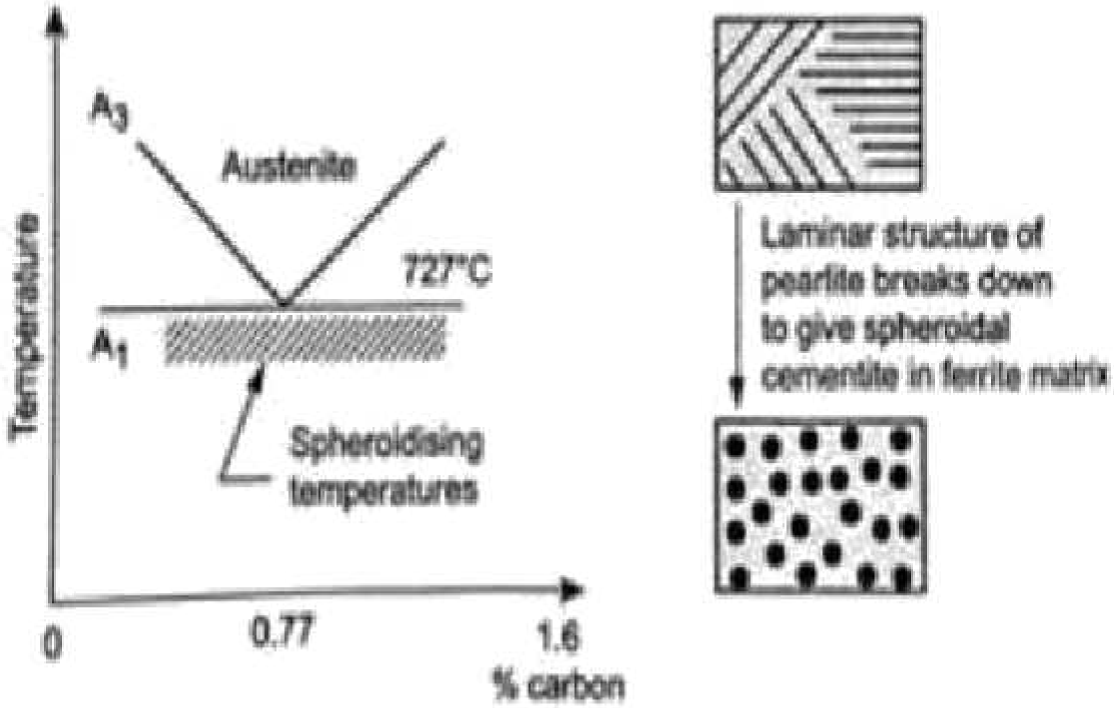


Fig 2.7 Spheroidising annealing

2.6.2 NORMALISING :

The purpose of normalizing is to refine the grain structure, obtain a homogenous structure, decrease the residual stress and improve the machinability.

Steel is heated to about 40 50°c above the upper critical temperature A3 held at that temperature for a sufficient period of time and then cooled in still air to room temperature.

In this process, the homogeneity of austenite increases since the temperature involved is more than that for annealing.

It results in better dispersions of ferrite and cementite in the final structure.

The grain size is finer in the normalized structure than in the annealed one. This results in a slightly higher strength and hardness but lower ductility than full annealing.

Rolled and forged steels possessing coarse grains are subjected to normalizing treatment for grain refinement.

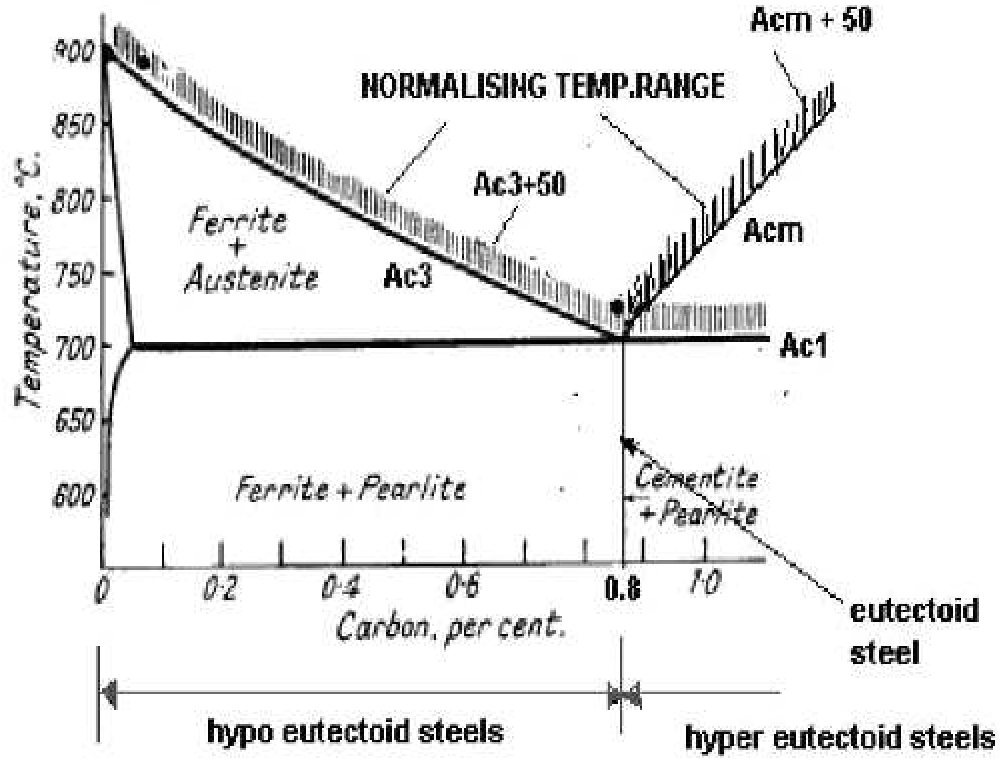


Fig 2.8 Normalising

2.6.3 HARDENING :

It is a heat treatment process which impact high hardness to steel to improve its mechanical strength and to retain its ductility.

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

Hypo eutectoid steels are heated to about 30- 50^{0}c above the upper critical temperature (A3).

Hyper eutectoid steels are heated to about 30-50^{0}c above the lower critical temperature (A1).

Rapid cooling means the cooling rate is just in excess of the critical cooling rate.

Rapid

Austenite (γ iron) ⟶ Martensite

(FCC) cooling (BCC)

Tensile strength and yield strength are improved.

By hardening steel components like, gears, shafts and bearings.

The wear resistance and cutting ability of steel are increased.

Factors Affecting Hardening process.

1.Hardening temperature

2.Holding time

3.Quenching medium

4.Cooling rate

5.Size and shape of steel parts

6.Surface condition.

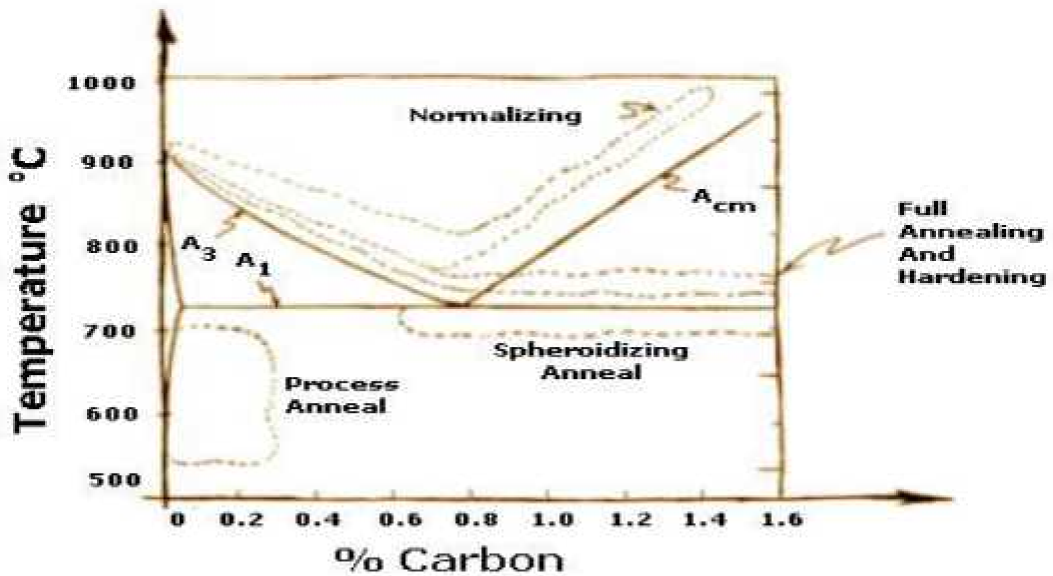


Fig 2.9 Hardening process

2.6.4 TEMPERING:

It is a heat treatment followed after hardening and involves heating the hardened steel to some temperature below the lower critical temperature (A1) soaking at this temperature for sufficient time followed by slow cooling in air.

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

The loss of hardness and wear resistance.

The process consists of heating the steel below the lower critical temperature 150^0c-630^0c followed by cooling in air or at any other desired cooling rate.

As marten site is a super saturated solid solution, if energy is supplied by tempering, it decomposes to a two phase micro structure consisting of BCC alpha ferrite and small particles of carbide.

Depending on the rage of temperature, tempering is classified into following **types.**

Low temperature tempering :

Temperature is heated about 200^0c

- Marten site ⟶ low carbon Martensite + carbide ($Fe_{24}C$)

Reduces the brittleness of steel and increases the toughness.

(ii) Medium temperature tempering :

Temperature is heated about 200 400^{0}c.

Low carbon martensite – Ferrite – carbide – cementite (Fe_3C)

Austenite gets transformed to baintic.

This structure is called frostbite

Increase of ductility and toughness.

Decrease in hardness and strength.

High temperature tempering :

Temperature is heated about 400 – 650^{o}c.

Cementite obtained.

Structure is known as sorbite.

This treated steel has better tensile yield and impact strength and is free from internal stresses.

This structure is very soft and tough.

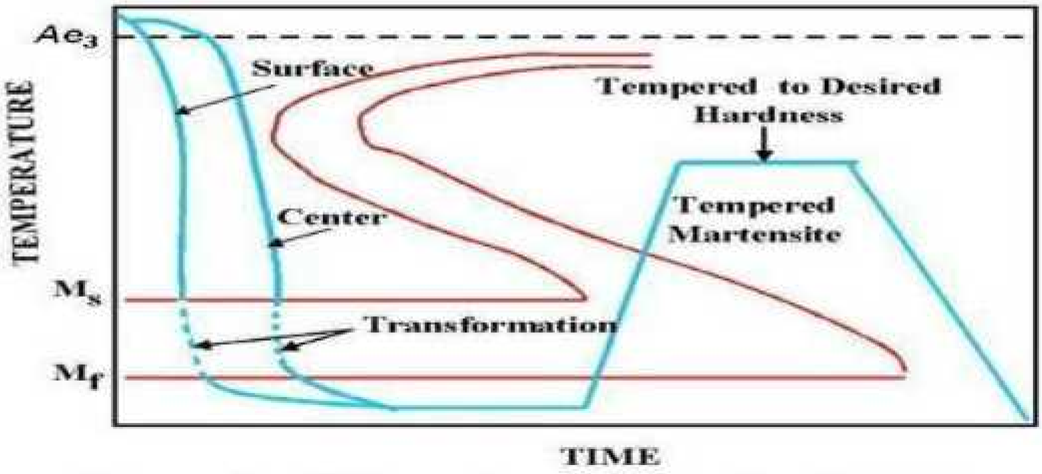


Fig 2.10 Tempering

2.6.5 AUSTEMPERING:

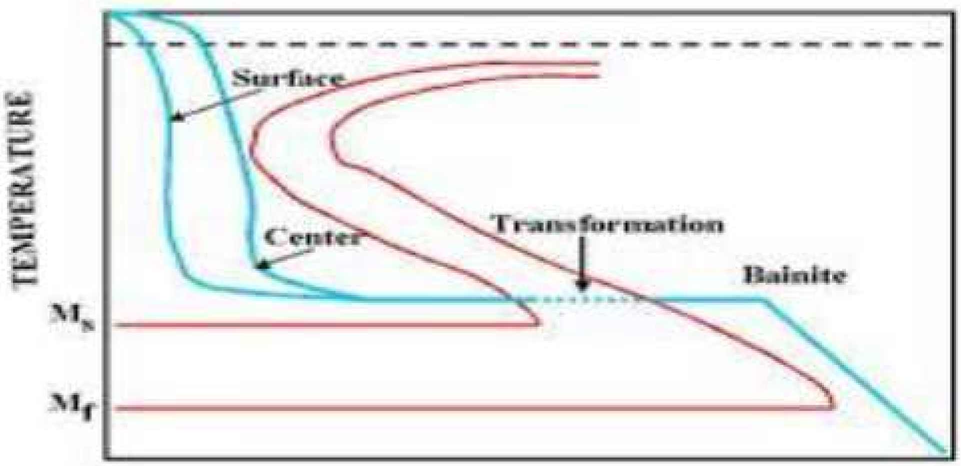


Fig 2.11 Austempering

It is a heat treatment process which is used to obtain a bainite structure.

Heating the steel to proper austenitising temperature.

Quenching in a salt bath having temperature from 250^0c to 300^0c.

Held at this temperature for a long time as is needed for the transformation of qustenite.

Since the quenching bath temperature is higher than the Ms temperature . the austenite is transformaed in to bainite.

It has high hardness and ductility.

Residual is stress in the metal are reduced .

There is less of hardening cracks and wastage.

The size is restricted to him sections.

Very thick sections cannot be heat treated by this method.

In this method is long hours are needed for the isothermal transformation of austenite to bainite.

2.6.6 MARTEMPERING:

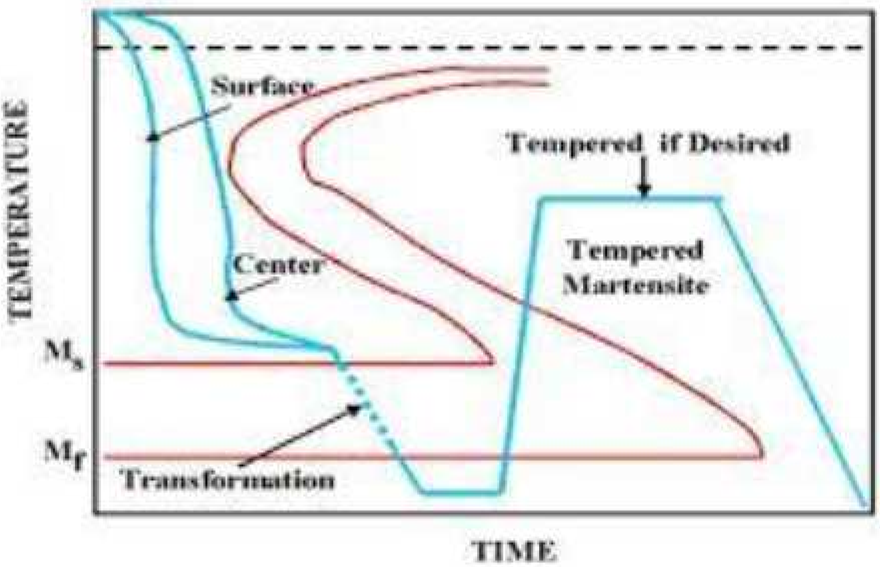


Fig 2.12 Martempering

It have less tendency to crack, distort and develop residual stresses during heat treatment.

Steel is heated to above the critical range to completely become Austenite.

Temperature at 180 – 250^{0}c maintained above Ms

Quenching in a liquid medium.

Cooling in air to room temperature.

Large sections cannot be heat temperature by mar tempering because the time required to obtain uniform temperature .

This process is more suitable for high carbon steels and alloy steels.

2.6.7 CASE HARDENING : (SURFACE HARDENING)

Hardening by diffusion of hardening elements (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 :

Carburising

Nitriding

Carbon nitriding

Cyaniding

2.6.7.1 CARBURISING :

It is a method of 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 range from 900- 930^{0}c.

Method of carburizing :

Pack carburizing (Solid)

Liquid carburizing

Gas Carburising

i) Pack carburizing (or) Solid 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- 950^{o}c for 6 to 8 hours.

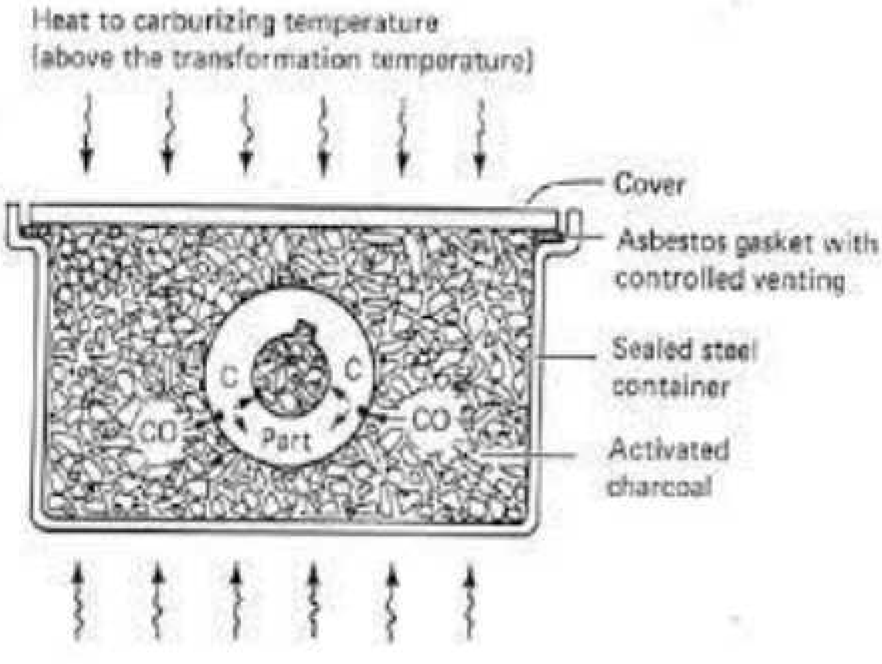


Fig 2.13 Pack carburizing

After heating, the box is cooled to the room temperature along with the components.

The following reactions takes place in this process.

$BaCo3 \rightarrow Bao - Co_2$ (Formation of carbon monoxide)

$CO_2 + C \rightarrow 2CO$ (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.

Time is required.

Gas carburizing:

The components are heated to a temperature of about 900^0c 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.

Floor size are less.

Labour cost is also less.

Disadvantage :

Highly skilled labours are required.

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 815^{0}c and 900^{0}c. The components are in molten bath for a period of 5 minutes to 1 hour.

The Following reactions are

$Bacl_2 + 2NacN \rightarrow Ba(CM2 + 2Nacl$

$Ba (CN)_2 + Fe \rightarrow Fec + Ba (CN)_2$

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 thorough washing after treatment to prevent rusting.

2.6.7.2 NITRIDING:

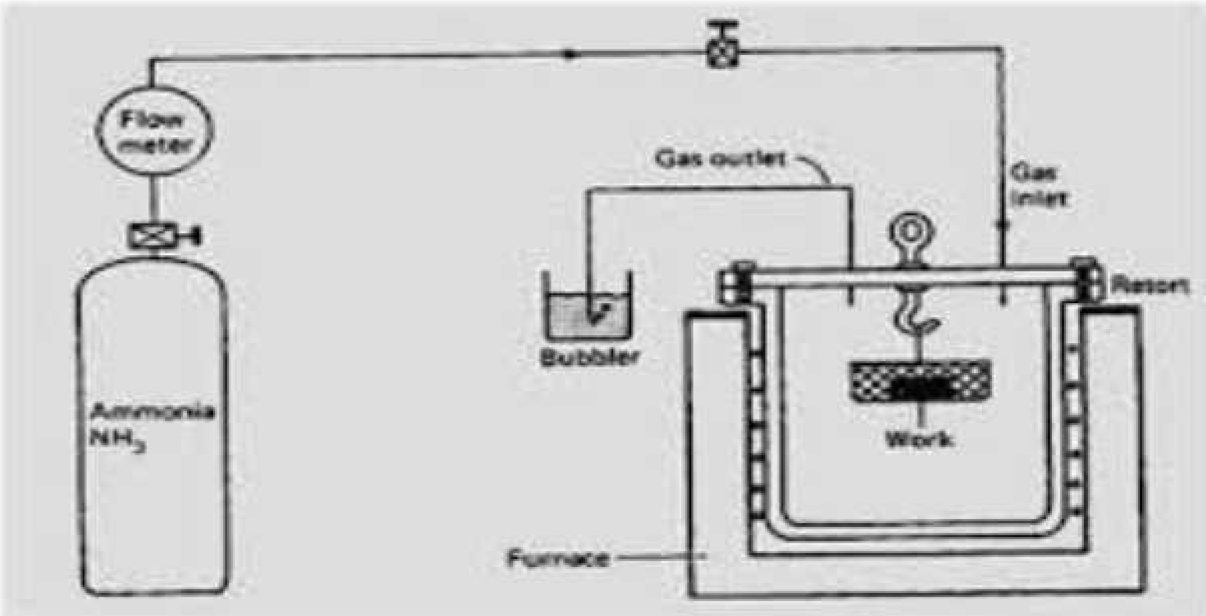


Fig 2.14 Nitriding

It is process of the surface of steel with nitrogen. Ammonia gas (NH3) on the surface of steel at temperature ranging from 480°c to 650°c.

The components should hardened temperature and undergo the complete sequence of machining operations, including grinding.

The components are placed in furnace which is then filled with ammonia solution. Then the temperature is raised from 480° to 650°c and from 0.2 to 0.4 mm deep.

Nitriding is usually applied to medium carbon steels and alloy steels containing A1, Ch, Mo.

Advantages :

High surface hardness.
Increases the wear resistances 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.

2.6.7.3 CYANIDING :

It is process in which both carbon and nitrogen are added to the surface layer of steel. Its depth ranges from 0.1 to 0.2mm.

The components are immersed in a liquid bath of 30% NaCN, 40% Na_2Co_3 and 30% Nacl at 800^0c to 850^0c. 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 decomposes and easily release the carbon and nitrogen atoms.

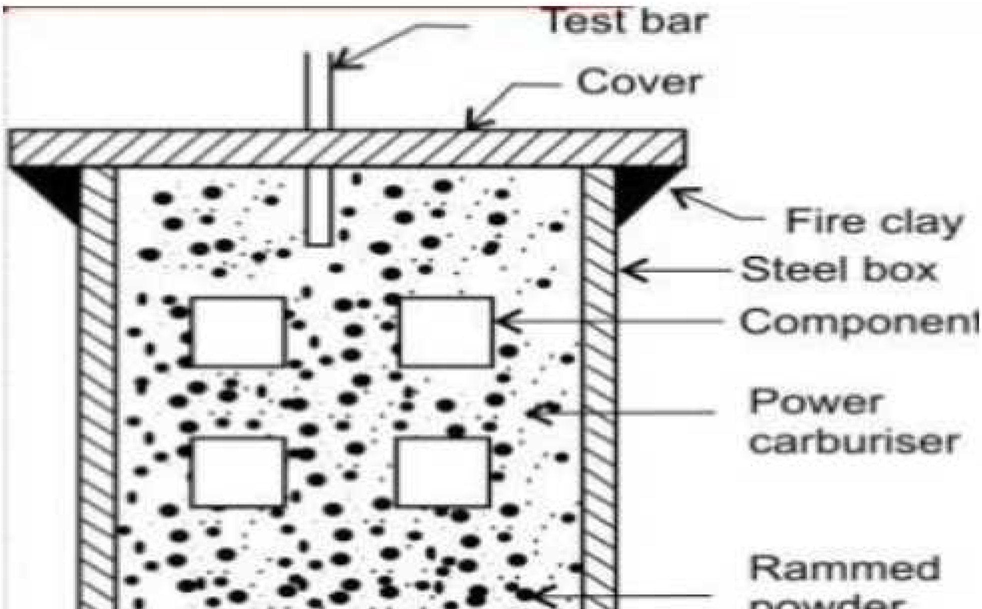


Fig 2.15 Cyaniding

$2NacN + Co_2 \rightarrow Na_2Co_3 + Co + 2N$

$3Fe + 2co \rightarrow Fe_3C + Co_2$

Fe + N →Fe N

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.

2.6.7.4 CARBON NITRIDING:

The Surfaces are enriched with carbon and nitrogen using liquid baths where as in carbon nitriding.

Carbon nitriding is carried out by heating the components in the temperature range from 850^0 to 930^0c in a gas mixture, consisting of natural gas and ammonia.

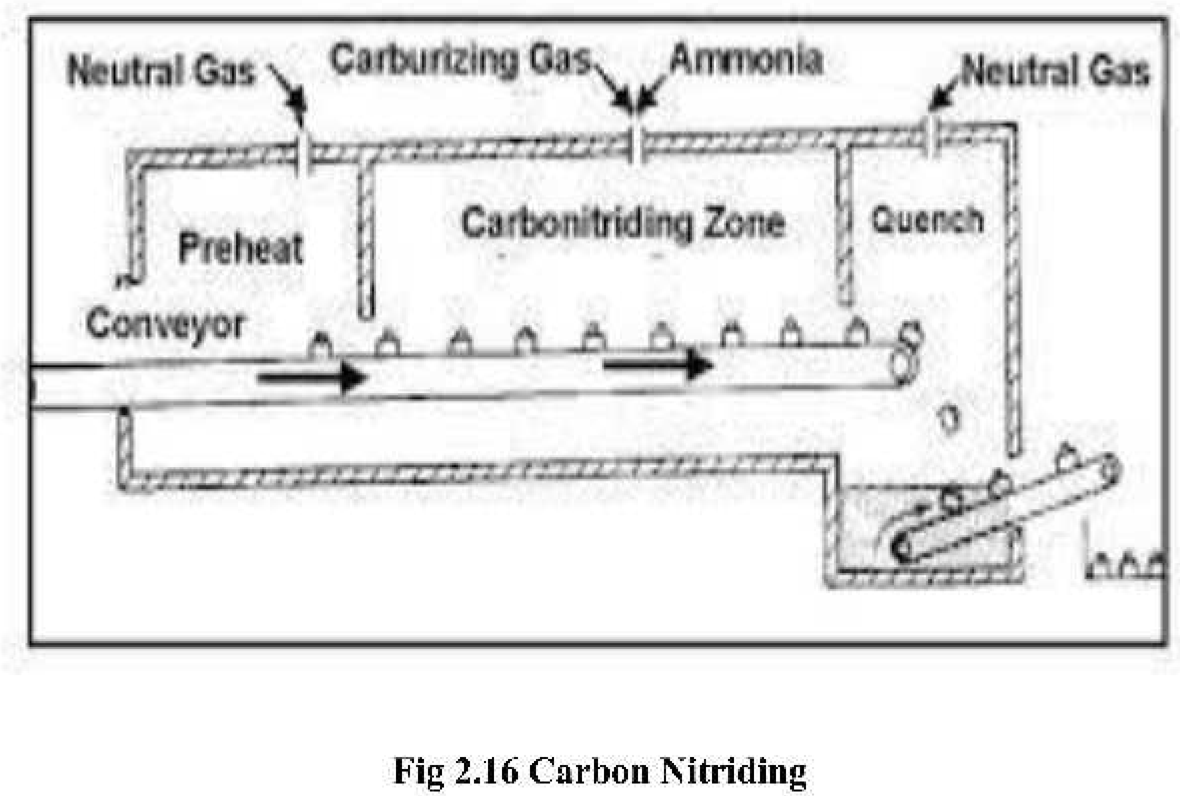


Fig 2.16 Carbon Nitriding

The gas mixture consists of a carburising gas which is a mixture of methane (5%) ammonia (15%) and remaining neutral gas.

The phases present in steel at this temperature are ferrite and austenite.

Nitrogen in the surface layer of steel increases harden ability and permits hardening by oil quench.

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.

Applications :

It is used bolts , nuts, gears etc.

SELECTIVE HARDENING :

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

The Processes are :

Flame hardening

Induction hardening

2.6.8 FLAME HARDENING :

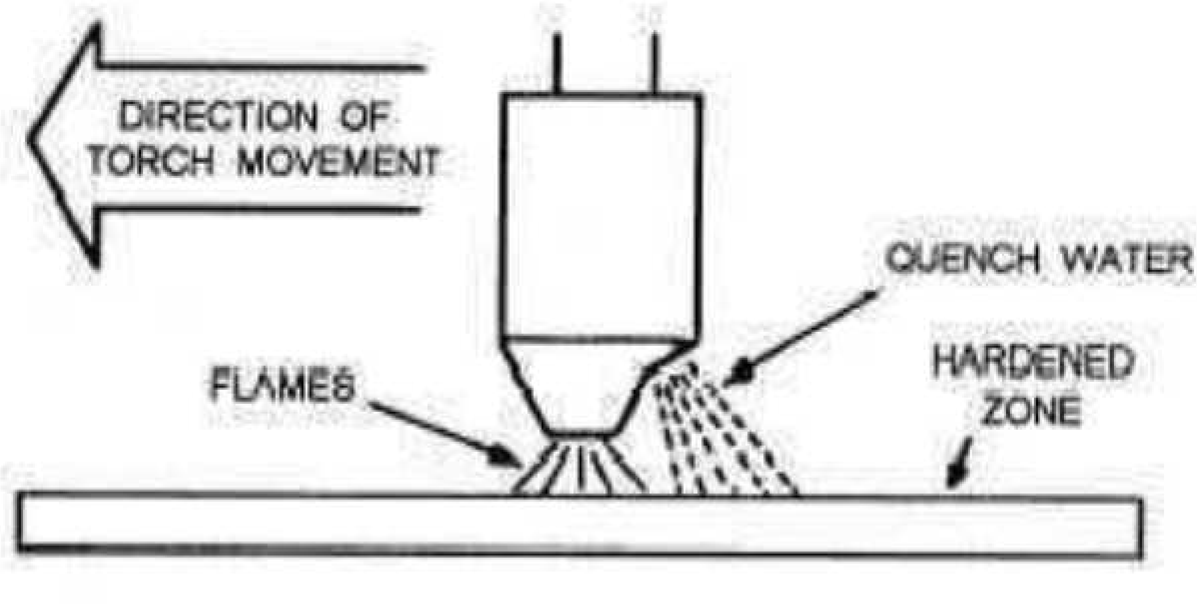


Fig 2.17 Flame Hardening

Flame hardening is the process of selective hardening with a combustible gas flame as the source of heat for austenitizing.

Flame hardening can be performed only on steels with a sufficiently high carbon content-atleast 0.4% C (to allow hardening).

Principle of flame hardening:

The surface to be hardened is heated to a temperature above its upper critical temperature, by means of a travelling oxy-acetylene torch.

Then it is immediately quenched by a jet of water issuing from a supply built into the torch-assembly. Thus the surface hardening results when the austenitized surface is quenched by the water spray that follows the flame.

Suitability:

The flame hardening technique is suitable for the plain carbon steels with carbon contents ranging from 0.40% to 0.95% and low alloy steels.

Advantages:

The process is more efficient and very economical for larger works.

As heating rate is high the surface of work remains clean.

Disadvantages:

very thin sections may get distorted excessively.

overheating may cause cracks.

2.6.9 INDUCTION HARDENING:

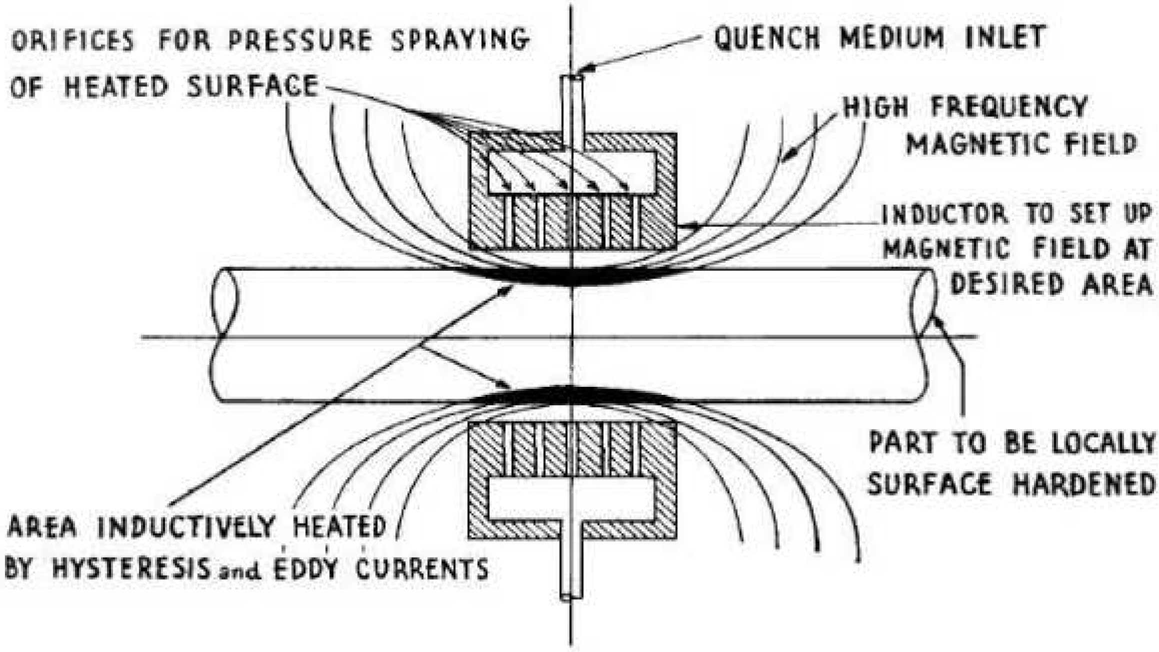


Fig 2.18 Induction Hardening

The heating in this process is done with in a thin layer of metal surface by high frequency induced currents.

A high frequency current is passed through the primary coil. This generate alternate magnetic field. This magnetic field induces eddy currents of the same frequency in the surface layer which heat the surface of the components.

Within a short period of 2 to 5 minutes the temperature of surface layer comes to above the upper critical temperature of the steel.

The component is quenched by water spray usually without removing the inductor coil. Due to fast heating and no holding time, Austenite is transformed in to fine grained Martensite.

Induction hardening is commonly followed by low temperature tempering at 160^0 to 200^0c . Steels with carbon between 0.4 to 0.5%.

Advantages :

Fast heating.
No holding time.
Increase the production rates.
Low alloy steels are also surface hardened.
Easy control the depth of hardening.

Disadvantages :

High equipment cost.
Irregular shapes cannot be used.
High Maintenance cost.

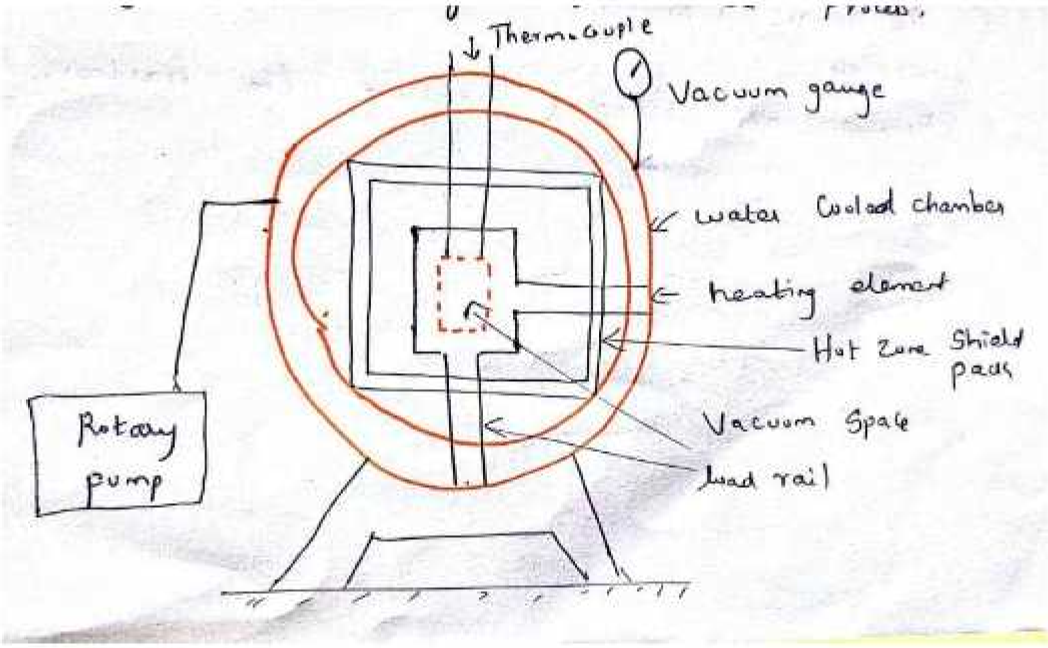
Application :

Cylinder liners, machine tool ways, pump shafts.

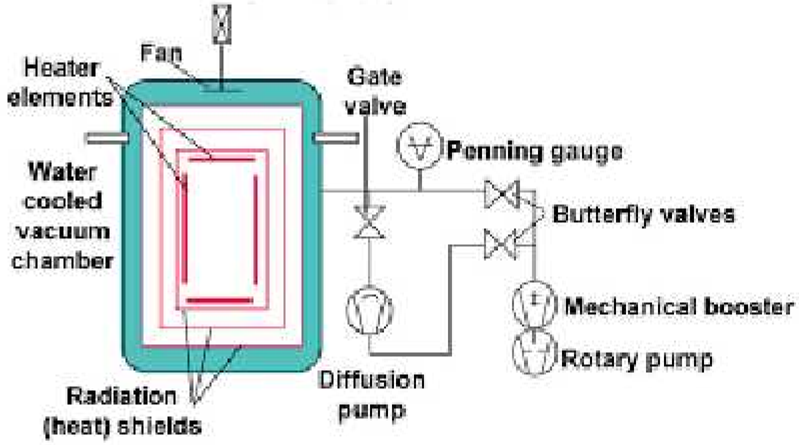
2.6.10 VACUUM AND PLASMA HARDENING:

2.6.10.1 VACUUM HARDENING.

During vacuum hardening, material is heated in the absence of oxygen by convection in the medium of inert gas (N_2) and / or heat radiation in the underpressure. Steel is hardened with a stream of nitrogen, whereby cooling rate can be determined by selecting the excess pressure. Depending on the workpiece shape it is possible also to choose the direction and time of nitrogen blowing. Optimization of time and steel temperature control are carried out during process with the use of pilot thermocouples which can be placed on a workpiece in the heating chamber.



Steel that is heat treated in a vacuum furnace obtains the specified properties of strength and hardness throughout the entire cross-section, without surface decarburization. Austenitic grain is fine and it complies with international standards.



Advantages:

- Modern computer-controlled process regulation which ensures a high level of repeatability,
- Steel is not carborized or decarburised,
- Dimensional changes are minimal,
- Optimal times of process,
- Flexibility,
- Decorative effect (clean and bright surface),
- Environmentally friendly process.

Applications:

- Hot- and cold-work tool steel products,
- Tools for plastics,
- Forging tools,
- Cutting tools,
- Die casting tools,
- Pressing tools,
- Cylinders, pistons, industrial knives,
- High-speed steel products (drills, milling cutters, etc.)

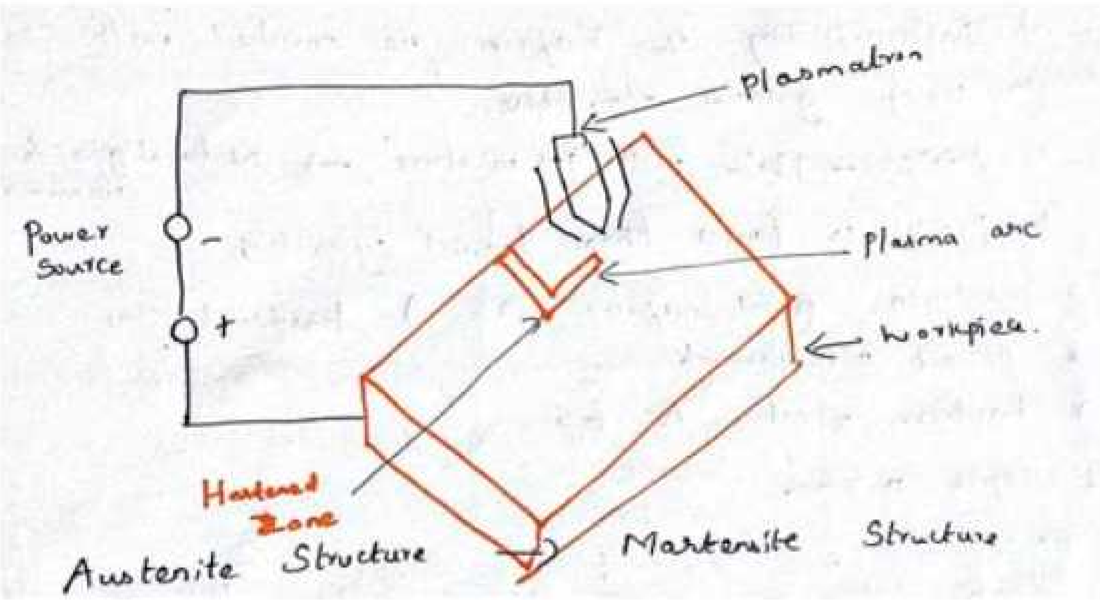
2.6.10.2 PLASMA HARDENING:

Plasma hardening is a surface method, also known as ion hardening or glow discharge hardening. Increase economical, effective and promising technology in heat treatment. During plasma nitriding, in a vacuum at a temperature between 350 °C and 600 °C, in the presence of nitrogen and electric field, a plasma of accelerated atoms develops which collide against steel surface at a very high speed. A hard compound layer of nitrides is formed, followed by a diffusion layer and tough core.

Procedure

- Austenite structure to martensite structure.
- No quenching medium
- Negative terminal connects to tungsten electrode and Positive terminal connect to work piece.

- Maintain 13mm distance between nozzle and work piece. o 30 amps current torch plasma arc is produced.
- After arc is moved over the entire surface of the work piece. o Remove all setup and measure the hardeners values



Advantages:

- High surface hardness, better wear resistance, lower coefficient of friction, increased corrosion resistance,
- A wide range of steels which can be nitrided - low and highalloyed steels (high speed steel, sintered steel, cast iron, stainless steel, ordinary construction steel),
- Less surface roughness in comparison with gas nitriding,
- Anti-corrosion and decorative effect (surface oxidation),
- Automated process with controlled growth of the white compound layer,
- High level of repeatability,
- Partial nitriding is possible through mechanical covering or covering with paste,
- Shorter times and lower temperatures ensuring minimal dimensional changes,
- Environmentally friendly process.

Applications:

- Parts for the automotive industry,
- Heavy-duty parts in mechanical engineering,
- Tools for plastics,
- Hot-work tools,
- Cutting tools, Die casting tools,
- Various machine parts: piston rods, pistons, mandrel, connecting rods, shafts, gears,

UNIT – 2:HEAT TREATMENT

PART: A

1.Define heat treatment process?

Heat treatment process may be defined as an operation or combinationOf operation involving heating and cooling of a metal/alloy in the solid state to obtain desirable properties.

purpose of heat treatment process

To relieve internal stress.
To improve machinability.
To improve hardness of the metal surface.
To increase resistance to wear, heat and corrosion

List any two factors that affect hardenability of steels.

Composition of steel
Critical cooling rate
Presence of alloying element
Presence of complex carbides
Homogeneity of austenite

What is mar tempering?

Mar tempering, also known as mar quenching, is a interrupted cooling procedure used for steels to minimize the stresses, distortion and cracking of steels the may be develop during rapid quenching.

4. What is quenching?

Quenching refers accelerated cooling.The cooling can be accomplished by contact with a quenching medium which may be a gas, liquid or solid.Most of the times, liquid quenching media is widely used to achieve rapid cooling.

What are the different processes of surface hardening? [N/D'15]

DIFFUSION METHOD
Carburizing
Nitriding
Cyaniding
Carbonitriding
THERMAL METHOD
Flame hardening
Induction hardening

What is meant by recrystallisation?

Recrystallisation is a process by which distorted grains of cold-worked metal are replaced by new, strain-free grains during heating above a specific minimum temperature.

7. Differentiate carburizing and nitriding.

Carburizing, or carburization is a heat treatment process in which iron or steel absorbs carbon liberated when the metal is heated in the presence of a carbon bearing material, such as charcoal or carbon monoxide, with the intent of making the metal harder.

Nitriding is a heat treating process that diffuses nitrogen into the surface of a metal to create a case-hardened surface. These processes are most commonly used on low-carbon, low-alloy steels.

What are the types of heat treatment processes?

The important heat treatment processes are

Annealing 2. Normalizing 3.Hardening 4.Tempering 5.Aus tempering 6.Mar tempering Case hardening

What do you mean by the term case hardening?

In many applications, it is desirable that the surfaces of the components should have high hardness, while the core or inside should be soft the treatments given to the steel to achieve this is called case hardening.

List any two factors that affect hardenability of steels.

Grain Size and Chemical Composition

What is austempering? [A/M'15]

Austempering is a type of interrupted quenching that forms bainite structure.

It is an isothermal heat treatment process used to reduce quenching distortion and to make a tough and strong steel.

Differentiate Annealing and normalizing [A/M'15]

Annealing	normalising
Cooling is established in the furnace	Cooling is done in still air
Provides coarse grain structure	Provides fine grain structure
Temperature is lower than normalising temperature	Temperature is higher than annealing temperature
Process is costly	Process is economical

PART: B

1. Explain the short notes on Annealing

Various heat treatment processes for steels are classified as follows

Annealing (ii) normalizing (iii) hardening (iv) tempering

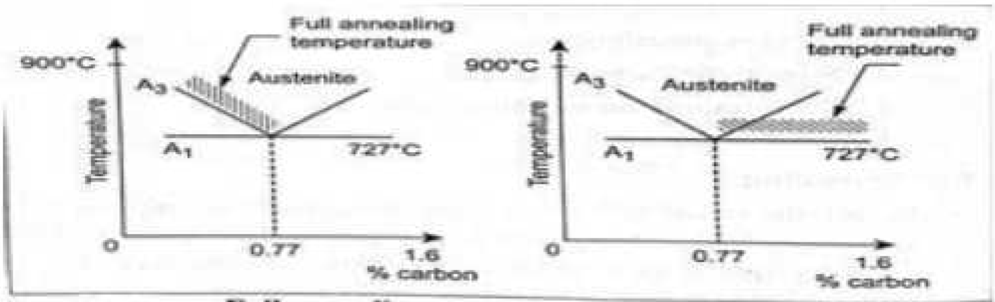
Annealing :

Process of heating a metal which has a distorted to structure to sufficient high temperature remove all distortion subsequent cooling that microstructure metal is free from any strain and distortion at room temperature.

Full annealing, spheroidising annealing, stress relief annealing, recrystallisation annealing

FULL ANNEALING:

Purpose: it is used to improve ductility, remove internal stress, enhance magnetic and electrical and refine grain structure properties.



Full annealing temperatures for hypo eutectoid steel

. Full annealing temperatures for hyper eutectoid steel

Method : 1. heating the steel to austenitic region
Followed by slow cooling
Steel is heated above the upper critical temp for hypo eutectoid steels.
4.Above the lower critical temp for eutectoid

Steel is heated lower critical pearlite changes to fines austenite crystal.
As temp varied courses ferrite dissolved and disappears at upper critical temp. ○ Subsequent furnace cooling ferrite and pearlite for hypoeutectoid steel.

- Pearlite for eutectoid steel.
- Properties based on size of pearlite and ferrite and their relation
- Small size better distribution of ferrite and pearlite
- Rate of cooling affect the size of ferrite and pearlite grains
- Slow cooling large rounded ferrite crystal formed and evenly distributed.
- Higher rate of cooling small ferrite crystals is produced with fine pearlite in the centre.

Application:- This treatment improves the machinability of medium carbon steels. **Limitations:-**This process is not employed for hypoeutectoid steel.

SPHEROIDISING ANNEALING:

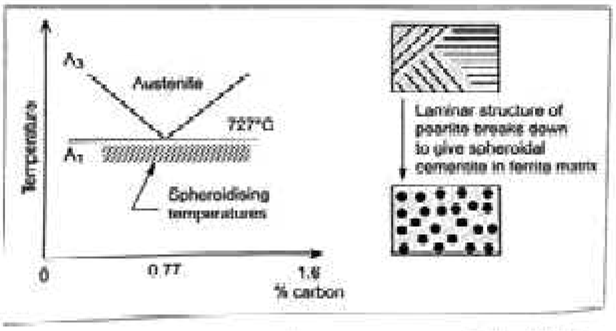
Purpose: Improve machinability and ductility of high carbon steel and air hardening alloy steels.

<u>Various methods are available</u> to produce spheroidising structure.

First method: Heating the steel just below lower critical temperature holding at that temperature for a prolonged.

Second method: Heating and cooling steel alternately just above and below the lower critical temperature.

Third method: Heating a steel to a temperature above the lower followed by slow cooling to temp below lower at that temp holding critical temp for a long time.



Spheroidising annealing temperatures *Spheroidising*

Structural change:

No phase change takes place.

Lamellar and free cementite coalesces into tiny spheroids due to surface tension effect.

Final structure consists of spheroids of carbide in a matrix of ferrite.

Write short notes stress relief annealing, recrystallisation annealing

STRESS RELIEF ANNEALING:

Purpose:

Residual stresses are induced during like solidification of castings, forming ,, machining, welding, grinding and phase transformation.

- Steel with residual stress fail stress corrosion cracking under corrosion environment.

These stresses entrance war page and dimensional instability in steels. ○

To eliminate or reduce steel is subjected to stress relief annealing.

Steel heated uniformly below the lower critical temp and held at sufficient period of time followed by uniform cooling.

Magnitude of stress relieved depend on temp and holding time.

- Structural change:
- Steel is heated below lower critical temp.
- Only residual stress relieved.
- No microstructure changes.

Recrystallisation annealing:

Cold working of steel increase the hardness and decreases ductility. ○ Grains are deformed and residual stresses are induced.

- Necessary to soften the material to improve ductility for further cold working.
- Annealing process is employed for this is refused to as recrystallisation.

<u>Method:</u>

Heating the steel above recrystallisation temp holding at that temp particular time period followed by cooling. Recrystallisation temp is not fixed it depends on chemical composition, amount of deformation m holding time and the internal grain size.

- Layer the degree of deformation or longer the holding time lowers the recrystallistiaon temp.

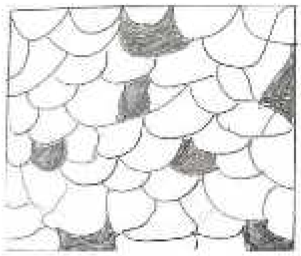
Structural change:

After this treatment property changes by cold working are removed.

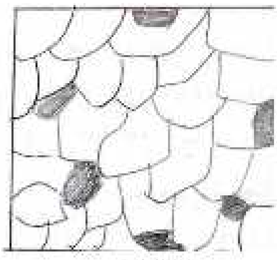
- Ductility increase hardness and strength decrease.

Structural change:

After this treatment property change by cold working are removed.



Before



After

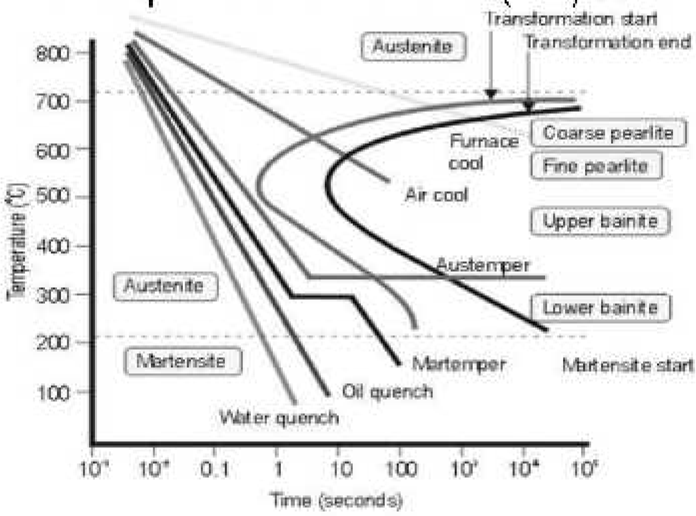
Application: manufacturing steel wires, sheets or strips.

3. Discuss the method of constructing isothermal diagrams. {APRIL/MAY 2011}

Time-Temperature-Transformation (TTT)Curve

TTT diagram is a plot of temperature versus the logarithm of time for a steel alloy of definite composition. It is used to determine when transformations begin and end for an isothermal heat treatment of a previously **austenitized** alloy TTT diagram indicates when a specific transformation starts and ends and it also shows what percentage of transformation of austenite at a particular temperature is achieved.

Time-Temperature-Transformation (TTT) Curve



The TTT diagram for AISI 1080 steel (0.79%C, 0.76%Mn) austenitised at 900°C

Isothermal transformation diagrams (also known as time-temperature-transformation diagrams) are plots of temperature versus time (usually on a logarithmic scale). They are generated from percentage transformation-vs logarithm of time measurements, and are useful for understanding the transformations of an alloy steel that is cooled isothermally. An isothermal transformation diagram is only valid for one specific composition of material, and only if the temperature is held constant during the transformation, and strictly with rapid cooling to that temperature. Though usually used to represent transformation kinetics for steels, they also can be used to describe the kinetics of crystallization in ceramic or other materials. Time-temperature-precipitation diagrams and time-temperature-embrittlement diagrams have also been used to represent kinetic changes in steels.

Isothermal transformation (IT)

Diagram or the C-curve is associated with mechanical properties, micro constituents/microstructures, and heat treatments in carbon steels. Diffusional transformations likeaustenite transforming to a cementite and ferrite mixture can be explained using the sigmoidal curve; For example the beginning of pearlitic transformation is represented by the pearlite start (P_s) curve. This transformation is complete at P_f curve. Nucleation requires an incubation time. The rate of nucleation increases and the rate of micro constituent growth decreases as the temperature decreases from the liquidus temperature reaching a maximum at the bay or nose of the curve. Thereafter, the decrease in diffusion rate due to low temperature offsets the effect of increased driving force due to greater difference in free energy. As a result of the transformation, the microconstituents, Pearlite and Bainite, form; Pearlite forms at higher temperatures and bainite at lower.

Austenite is slightly undercooled when quenched below Eutectoid temperature. When given more time, stable microconstituents can form: ferrite and cementite. Coarse pearlite is produced when atoms diffuse rapidly after phases that form pearlite nucleate. This transformation is complete at the pearlite finish time (P_f).

However, greater undercooling by rapid quenching results in formation of martensite or bainite instead of pearlite. This is possible provided the cooling rate is such that the cooling curve intersects the martensite start temperature or the bainite start curve before intersecting the P_s curve. The martensite transformation being a diffusionless shear transformation is represented by a straight line to signify the martensite start temperature.

Explain the procedure of Jominy end quench test.(A/M 2009,2011,2013) Hardenability:

The term hardenability refers to the ease with which hardness may be attained. That is ,the ease with which a steel will transform to hardened structure on quenching is called hardenability. The hardenability of a steel is define as that property which determines the depth and distribution of hardness induced by quenching from the austenitic condition.

Factors affecting hardenability:

The composition of the steel

The austenitic grain size.

The structure of the steel before quenching

The quenching medium and the method of quenching

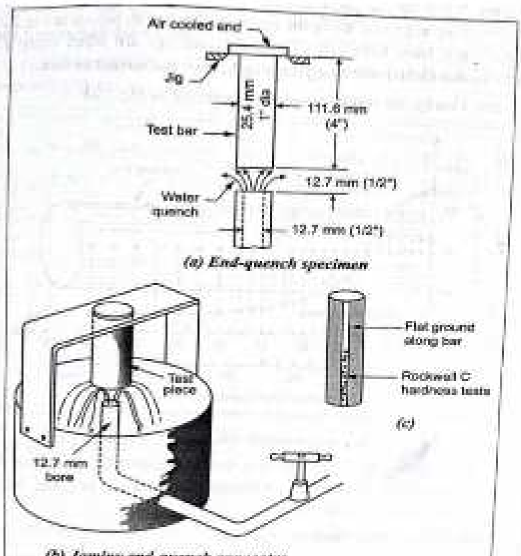
The most widely adopted method of determining hardenbility is the jominy end –quench test method.

The Jominy end-quench test method is universally adopted because:

It is relatively easy to perform

It is excellent reproducibility

It gives information useful to a designer as well as manufacturer.



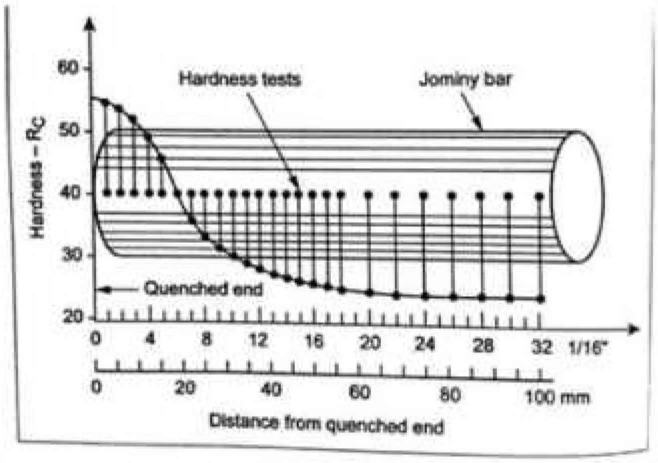
(b) Jominy end-quench apparatus

Testing procedure:

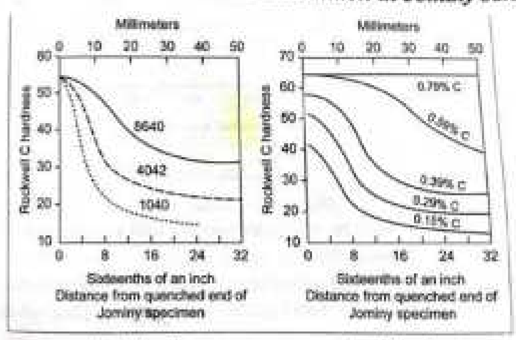
In this test, specimen dimensions and test conditions are standard.

- Specimen is of cylindrical shape of diameter 25.4mm (I inch) length of approximately 102mm.(4 inch). it has a machined shoulder at one of cts end.
- Standard specimen is austenitized at a constant temperature for a fixed amount of time & quickly transferred to quenching jig fixture.
- Water is allowed to flow from the bottom end though a pipe of internal dia 12.7mm for about 20 minutes.

The distance between the bottom end of the specimen pipe is maintained as 12.7 mm.(1/2 inch)
The pressure of water jet is adjusted such that the free height of water jet is 64mm (2.5 inch).
At this pressure water forms a complete umbrella over the bottom surface of the specimen.
Temp of water is required to maintain in between 21 to 27oC.
Cooling rate of the specimen varies from bottom which is subjected to water quenching to the top end is air cooled.
The bottom end is subjected to full hardening when the top end undergoes normalizing cycle.
Thus the specimen is subjected to all possible rates of cooling throughout its length.
This cooling rate is independent of the composites of the specimen.



Typical hardness distribution in Jominy bars



Jominy hardness curves for engineering steels with the same carbon content and varying types and amounts of alloy elements

Jominy hardness curves for engineering steels with identical alloy conditions but variable carbon content

Interrupted quenching:-
Continuous rapid cooling (quenching) at room temp use to form martensite has disadvanteage of setting up severe internal stress warping of the material and crack form in steel less costlies to achieve desired hardness to reduces stress is an interrupted quenching process.

PART-C

1. Explain Case hardening

Classified as carburizing, nitriding, cyaniding, carbonitriding [N/D'15]

CARBURIZING:

Introduce carbon into surface layer of low carbon steels in order to produce a hard surface.

Old and cheapest method

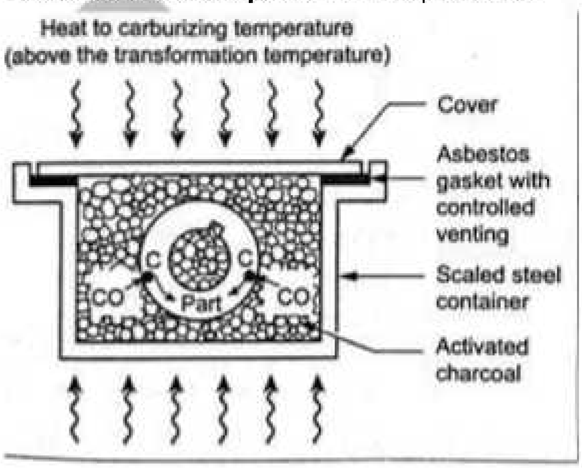
- Depth of case 0.5 to 2mm.
- Temp range 900-930oC.
- Solubility of carbon is more in austenite state than in ferrite state, fully austenite state is required for carburizing.
- Achieved by heating steel above critical temp
- Diffusion of carbon is made by holding the heated steel in contact with carbonaceous material which may be a solid a liquid or a gas.

Pack carburizing
Gas carburizing
Liquid carburizing

(i)Pack carburizing

900-950oC for 6 to 8 hours

- Cooled at room temperature
- Reactions takes place in the process



Pack carburising

$BaCO_3$ → $BaO + CO_2$ (dissociation of CO_2)

$CO_2 + C \longrightarrow 2CO$ (dissociation of CO_2)

$2CO + 3Fe \longrightarrow Fe_3C + CO_2$ (enrichment of steel)

Advantage:

Economic and efficient

Suitable for massive
parts Disadvantages:

- Not suitable for thin carburized cases
- Does not provide close control or tolerance
- Increase time.

(ii)Gas carburizing:

- 900oC for 3 to 4 hours
- Heated in contact with hydrocarbon like methane, ethane or propane with carries gases like N2, H2 &Co.

$3Fe + Co + H_2 \longrightarrow Fe_3C + H_2O$

$3Fe + 2Co \quad Fe_3C + Co_2$

Advantages:

Suitable for mass production
- Decrease Time tor operation
- Low labor cost
- Low floor size.

(iii)Liquid carburizing:

It carried out in molten baths, containing 20 to 50% sodium cyanide, 40% sodium carbonate and varying amounts of sodium or barium chloride.

Mixture is melted with 815C and 900 C in molten bath for 5mins to 1 Hr.

$BaCl_2 + 2NaCn \longrightarrow Ba(Cn)_2 + 2NaCl$

$Ba(Cn)_2 + Fe \longrightarrow FeC + Ba(Cn)_2$

Advantages:

Uniform heat transfer
- Decrease time
- Rapid rate of penetration

Cyanic salts are highly poisonous.

Parts should be thoroughly wasted to avoid rasting

NITRIDING:

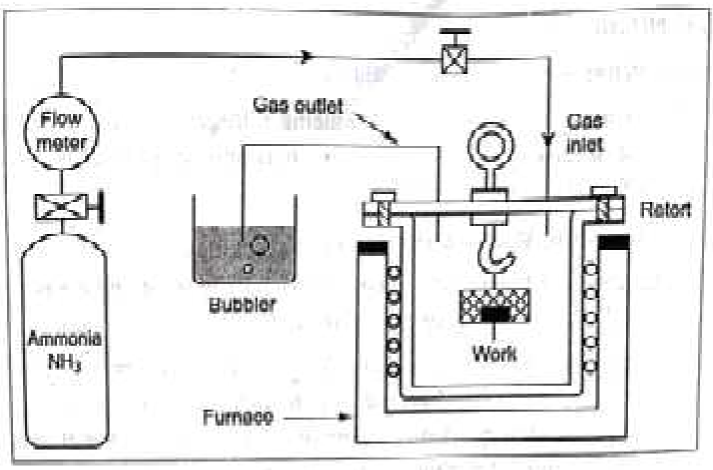
- Process of saturating the surface of steel with nitrogen.
- Ammonia gas on the surface of steel at temp 480oC to 650oC.

Process:

- Before nitriding component s hould be hafdenend , tempered , machining operation like grinding.
- Only finishing grinding or lapping is done after nitriding.
- Nitriding is suitable for medium carbon steels , alloy steels containg Al,Mo,Sb cantimony.

$2NH_3 + 3H_2 \longrightarrow 2N + 3H_2$ (dissociation of ammonia)

After nitriding cooled to 200^oC in a stream of ammonia.



Schematic of a gas nitriding system

Advantages :

Hardest cases of RC70 are obtained. ○ Increase surface hardness

- Increase wear resistance to steel
- Fatigue limit and corrosion resistant.
- No quenching
- Hardening defects are avoided by nitriding.

Increase more time for gas carburizing ○ Two distinct zone

- Outer zone (white layer it should be hard and brittle)
- Inner zone (alloy nitride precipitation
- Ammonia cost is high
- Technical control is required

Aircraft engine parts such as cams, cylinder,valve stems, shafts,piston rods, crankpins & journals,aero crankshafts.

Hardening process 9 surface of steel) is carbon and nitrogen.
Depth is 0.1 to 0.2 mm.
Cyanide components decompose release his cyan group.
Cyan group contains carbon and nitrogen atoms, iron.

$2NaCn + Co_2 \longrightarrow Na_2Co_3 + Co + 2N$

$3Fe + 2Co \longrightarrow Fe_3c + Co_2$

$Fe + N \quad FeN$

Types of cyaniding:

Pack cyaninding

- Liquid cyaniding
- Low temperature cyaniding

Medium temperature cyaniding

○ High temperature cyaniding

Powered mixture consists of charcoal and potassium ferro cyanide. ○ 540 to 560 oC .(1.5 to 3hrs)

○ Used to improve cutting properties of steel

Molten bath in which various cyanide compounds NacN, Ca (cN)2 are dissolved.

Advantages :

Increase surface hardness

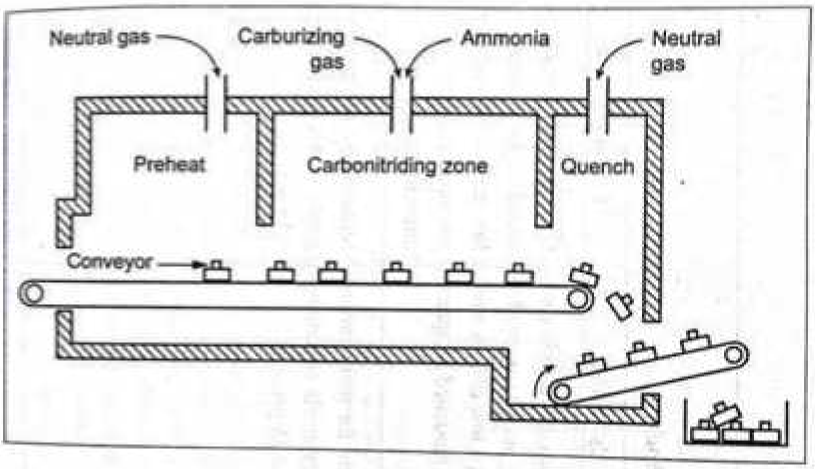
Increase resistance and fatique limit

Application :

- Suitable for gears, Pistons , Pins small shafts etc.

CARBONITRIDING :

- In cyaniding the surfaces are enriched with carbon and nitrogen using liquid baths.
- Carbonitriding the surfaces are enriched with carbon and nitrogen using gaseous atmosphere.
- 850oC – 930oC (with gas mixture natural gas and ammonia) ○ Process is lower than liquid cyaniding
- Nitrogen (steel surface) increase hardenability
- Permit 0:1 quench
- Hardness steel RC 65.
- Depth 0.5mm



Conveyor hearth carbonitriding

2.Explain Vacuum Hardening and plasma Hardening

VACCUM HARDENING:

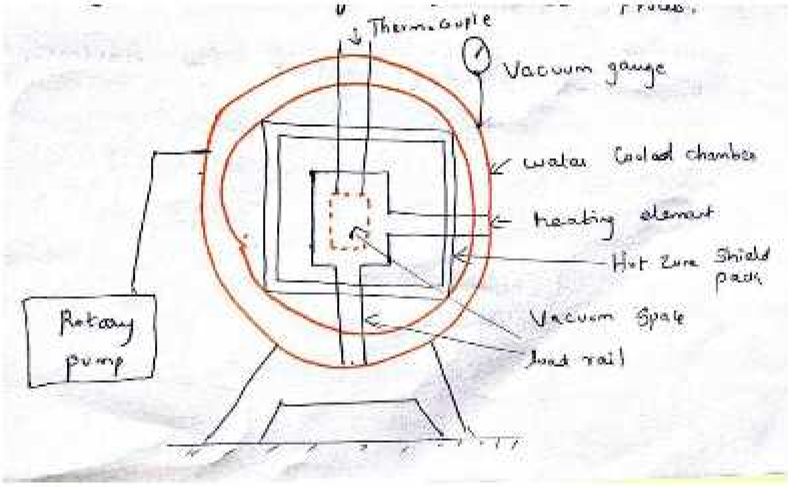
Vacuum hardening heat treatment is carried out vacuum furnaces and it has many advantages.

- No decarburization

No oxidation and hence bright surface

Uniformity in temperature and hence low distortion.

- Temperature guided by defined thermocouple.
- Fully automation of heat treatment process.



PLASMA HARDENING:

It is hardening surface method

Increase economical, effective and promising technology in heat treatment.

- Austenite structure martensite structure.
- No quenching medium
- Negative terminal connect to tungsten electrode.
- Positive terminal work piece.
- Maintain 13mm distance between nozzle and work piece.
- 30 amps current torch plasma arc is produced.
- After arc is moved over the entire surface of the work piece.
- Remove all setup and measure the hardeners values