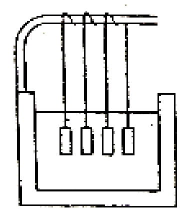
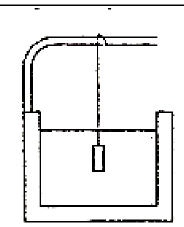
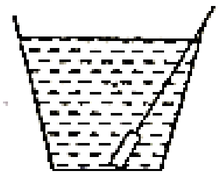
UNIT -2: HEAT TREATMENT

Explain Construction of TTT Diagram

This diagram is also known as Isothermal Transformation diagram. Davenport and Bain were the first to develop the TTT diagram of eutectoid steel. They determined pearlite and bainite portions whereas Cohen later modified and included M_S and M_F temperatures for martensite.

		
Furnace 1: molten salt bath (austenitizing)	Furnace 2: Isothermal heat treatment (at T_1,T_2, ..etc,)	cold water quenching
Figure: Steps in Processing Specimens		

The following steps are usually followed to determine an Isothermal- transformation diagram:

1. Prepare a large number of samples cut from the same bar. The cross section has to be small in order to react quickly to changes in temperature.
2. Place the samples in a furnace 1 or molten salt bath at the proper austenitizing temperature. They must be kept in the furnace I for long enough to become completely austenite.
3. Then samples are removed from furnace I and put in furnace II which is held at constant subcritical temperature (T_1) and each one is kept for different specified period of time say t_1, t_2, t_3, t_4 ,... t_n. after specified times, the samples are removed and quenched in water at room temperature. Each sample is also checked for hardness and studied microscopically. The microstructure of each sample is studied using metallographic techniques. The type of phase (as well as quantity of phases) is determined on each sample.
   The time at which the austenite start transforming to pearlite or bainite or martensite and the time at which the transformation ends should be noted. But below 230 degree centigrade, it appears the transformation is time independent, only function of temperature.
4. The above steps are repeated at different subcritical temperatures (T_2, T_3 etc) until sufficient points are determined to plot the curves on the diagram.
5. Transformation of austenite is plotted against temperature Vs time on a logarithm scale to obtain the TTT diagram. TTT diagram for eutectoid steels is shown in figure below. The shape of diagram looks like S or like C.
   From TTT diagram, it is observed that closer to the austenitizing temperature (Eutectoid temperature) coarse pearlite forms due to low driving force or nucleation rate. At higher under coolings or lower temperatures finer pearlite forms. At the nose of TTT diagram very fine pearlite forms. Upper bainite forms at high temperature close to the nose of TTT diagram while the lower bainite forms at lower temperature but above Ms temperature.

Note: If austenite transforms at higher temperature to a structure which is stable at room temperature, rapid cooling will not change the transformed product. In other words, if pearlite is transformed at 700 degree centigrade, the pearlite will be exactly the same at room temperature no matter how drastically it is quenched, since there is no reason for the pearlite to change.

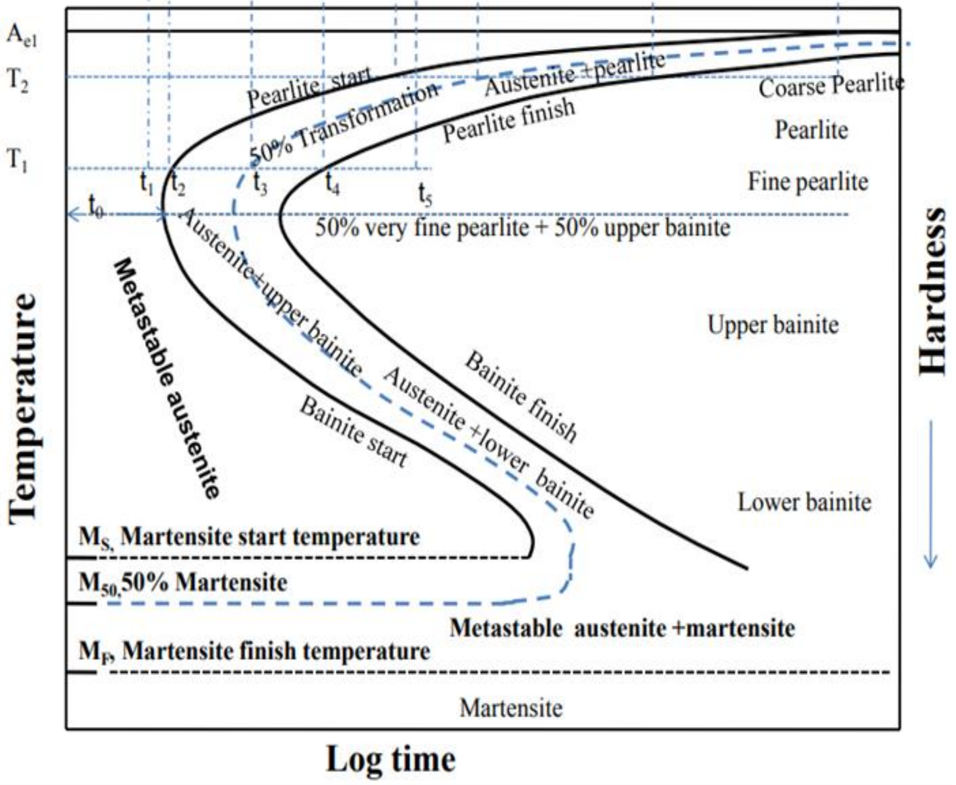


Figure : Time Temperature Transformation diagram

HEAT TREATMENT OF STEELS

Heat treatment is defined as an operation or combination of operations, involving heating, holding and cooling of a metal or an alloy in its solid state with the object of changing the characteristics of the material. All basic heat treating processes for steel involve the transformation or decomposition of austenite.

Objectives:

Heat treatment is generally employed for following purposes

- To improve machinability
- To change or refine grain size
- To relieve the internal stresses of metal induced during cold or hot working.
- To improve mechanical properties
- To increase resistance to wear, heat and corrosion
- To produce a hard surface on a ductile interior

Heat treatments are used to alter the physical and mechanical properties of metal without changing its shape.

Steels can be heat treated to high hardness and strength levels. The reasons for doing this are obvious. Structural components subjected to high operating stress need the high strength of a hardened structure. Similarly, tools such as dies, knives, cutting devices, and forming devices need a hardened structure to resist wear and deformation.

DIFFERENT HEAT TREATMENTS:

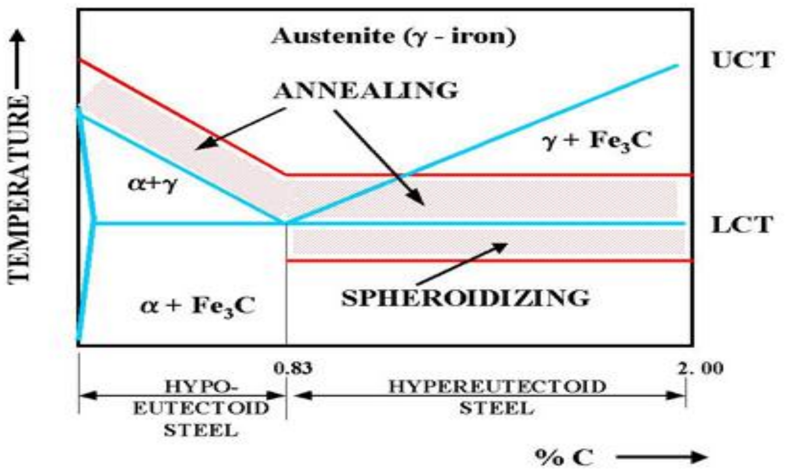
- Annealing
- Normalising
- Hardening
- Tempering
- Surface hardening

ANNEALING:

Annealing is a process of heating the steel slightly above the critical temperature of steel (723 degrees Centigrade), holding it at this temperature for sufficient time and allowing it to cool down very slowly (within the furnace).

The following are some of the advantages of annealing.

- It softens the steel.
- It enhances and improves the machinability of steel.
- It increases the ductility of steel
- It enhances the toughness of steel
- It improves the homogeneity in steel
- The grain size of the steel is refined a lot by annealing



Types of annealing:

1. **Full Annealing** - The process involves heating the steel to 30 to 50 degrees Centigrade above the critical temperature of steel and maintaining the temperature for a specified period of time, then allowing the material to slowly cool down inside the furnace itself without any forced means of cooling.

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

2. **Stress Relief Annealing or subcritical annealing:**

   Large castings or welded structures tend to possess internal stresses caused mainly during their manufacture and uneven cooling. This internal stress causes brittleness at isolated locations in the castings or structures, which can lead to sudden breakage or failure of the material. This process involves heating the casting or structure to about 650 Degree centigrade (1000-1200F). The temperature is maintained constantly for a few hours and allowed to cool down slowly.

3. **Process Annealing:**

   The material is heated up to a temperature just below the lower critical temperature of steel (1000 – 1250F).

   Cold worked steel normally tends to posses increased hardness and decrease ductility making it difficult to work. Process annealing tends to improve these characteristics. This is mainly carried out on cold rolled steel like wire drawn steel, etc. This process is mainly suited for low carbon steel. This heat treatment is used in sheet and wire industries. This is very similar to stress-relief annealing.

4. **Spherodise Annealing:**

   This is a process for high carbon and alloy steel in order to **improve their machinability**. The process tends to improve the internal structure of the steel. This can be done by two methods:

   a. The material is heated just below the lower critical temperature about 700 Degree centigrade and the temperature is maintained for about 8 hours and allowed to cool down slowly.

   b. Heating and cooling the material alternatively between temperatures just above and below the lower critical temperature.

5. **Isothermal Annealing :**

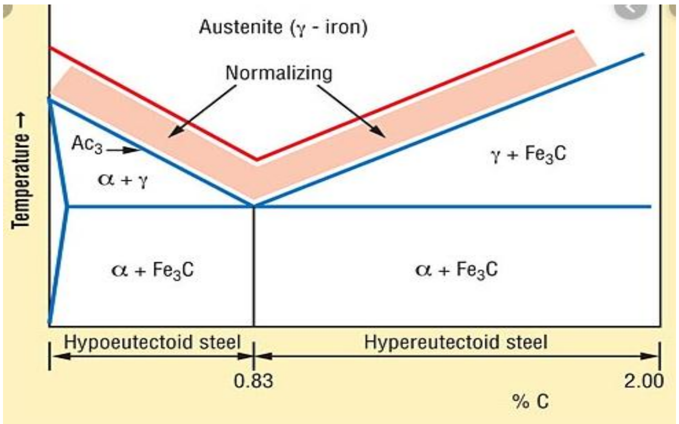
   This is a process where is steel is heated above the upper critical temperature. This causes the structure of the steel to be converted rapidly into austenite structure. The steel is then cooled to a temperature below the lower critical temperature about 600 to 700 Degree Centigrade. This cooling is done using a forced cooling means. The temperature is then maintained constant for a specified amount of time in order to produce a homogenous structure in the material. This is mainly applicable for low carbon and alloy steels to improve their machinability.

NORMALISING:

In this Steels are heated above upper critical temperature, soaked and cooled in air. The cooling rate is faster than annealing giving a smaller grain structure.

Normalizing is accomplished by heating at least 30-50 degree centigrade above the upper critical temperature for hypo eutectoid steels and 30-50 degree centigrade above A_{cm} for hyper eutectoid steels. . After sufficient time has been allowed for the alloy to completely transform to austenite and then cooled in air.

Note : the purpose of normalizing is to produce a harder and stronger steel than full annealing.



Differences between Annealing and Normalising:

Sl. No.	Criterion	Annealing	Normalizing
1	Temperature range	30 – 50 ^{o}C above A_3 for hypoeutectoid Steels and same above A_1 for hypereutectoid steels	30 – 50 ^{o}C above A_3 for hypoeutectoid Steels and same above A_{cm} for hypereutectoid steels
2	Method of cooling	Cooled within the furnace, very slow rate of cooling	Cooled in the air; slow rate of cooling
3	Grains structure obtained	Coarse grains (Pearlite) and usually gets resolved by the optical microscope	Fine grains (Pearlite) and usually appears not resolved by the optical microscope
4	% of proeutectoids formed	More compared to Normalizing steels.	less compared to Annealed steels.
	% of Pearlite formed	Less compared to Normalizing steels.	More compared to Annealed steels.
5	Properties	Annealed steels posses high ductility and less hardness, tensile strength and toughness	Normalized steels posses slightly more hardness, tensile strength and toughness
6	Cost	Takes costly furnace time	Cheaper, components spent less time in furnace
7	Purpose	Main purpose is to relive the internal stress, refine the grain structure and improve the ductility.	Main purpose is same as annealing but in this we get higher strength material than annealing process
8	Grain size distribution	More uniform	Less uniform

HARDENING:

Hardening is a process in which steel heated to a temperature above the critical point, held at this temperature and quenched (rapidly cooled) in water, oil or molten salt bath. Sudden quenching of steel greatly increases its hardness because austenite is transformed into martensite which is hard. The purpose of hardening process is to increase the hardness, wear resitance and cutting ability of the steels.

After hardening steels must be tempered to reduce the brittleness, relieve the internal stresses and obtain pre-determined mechanical properties.

TEMPERING:

Tempering is usually performed after hardening, to reduce some of the excess hardness, and is done by heating the metal to some temperature below the lower critical point for a certain period of time, then allowing it to cool in still air.

Tempering is used to reduce the brittleness of quenched steel. Many products that require hardness and resistance to breakage are quenched and tempered. The higher the temperature in the tempering process, the lower the hardness.

Tempering is a process of heat treating, which is used to increase the toughness of iron-based alloys.

The exact temperature determines the amount of hardness removed, and depends on both the specific composition of the alloy and on the desired properties in the finished product. For instance, very hard tools are often tempered at low temperatures, while springs are tempered to much higher temperatures.

Classification of tempering processes:

Depending on the tempering temperature, the tempering process can be classified as shown below.

- Low temperature tempering (150 – 250^{o}C)
- Medium temperature tempering (350 – 450^{o}C)
- High temperature tempering (500 – 600^{o}C)

Low temperature tempering:

The purpose of low temperature tempering are to relieve internal stresses and to increase ductility without changing the structure. The process is done in the temperature interval from 150 to 250^{o}C. the tempered component cannot carry dynamic loads, for this reason, the cutting tools and parts must be carburized and surface hardened.

Medium temperature tempering:

In this case the hardened steel is heated between 350 – 450^{o}C temperature. The object of heating up to this temperature is to change the martensite structure to troosite. As a result of change in structure, the steels are become more tough and ductile, but the hardness is considerable reduced. This tempering is commonly employed for coils and laminated springs.

High temperature tempering:

High temperature tempering consists of heating the steel to the temperature interval of 500 – 600^{o}C. at this temperature martensite is transformed into sorbit. In this process the internal stresses are completely eliminated and the toughness is improved.

Sorbite steels are more softer and more ductile than troosite steels. Troosite and sorbite are usually known as tempered martensite. This tempering process is applied to gear wheels, axle shafts and connecting rods.

MARTEMPERING:

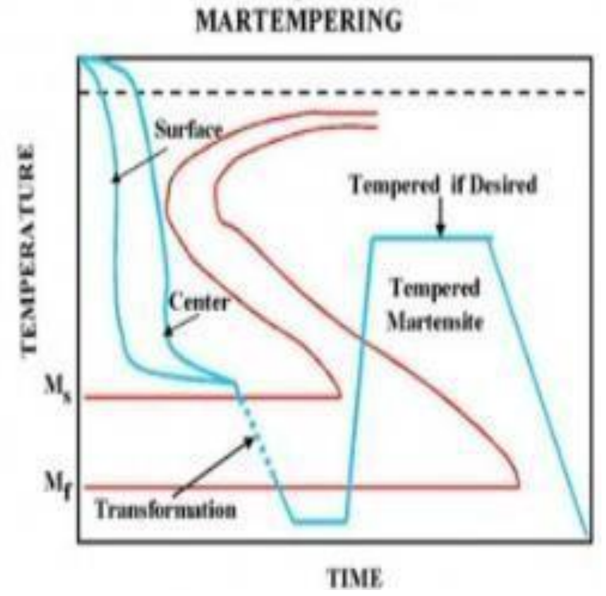
Martempering is also known as **stepped quenching** or **interrupted quenching**. In this process, steel is heated above the upper critical point and then quenched in a salt bath kept at a temperature of 150-300° C. The work piece is held at this temperature above (Ms) until the temperature becomes uniform throughout the cross-section of work piece. After that it is cooled in air or oil to room temperature. The steel is then tempered. Martempering is a heat treatment for steel involving austenitisation followed by step quenching, at a rate fast enough to avoid the formation of ferrite, pearlite or bainite to a temperature slightly above the martensite start (Ms) point.

Martempering Process:

1. Austenize the steel.
2. Quench the steel in a salt bath maintained at a temperature greater than the Ms temperature (usually 30–40 degree C).
3. Hold for sufficient time till we obtain a homogeneous temperature along the centre and the surface of the component.
4. Air cool through the Ms temperature down to the room temperature.
5. Martensite is obtained throughout the cross section of the whole component.

So, in MARTEMPERING,

- ***Austenite*** is transformed to ***MARTENSITE*** (not Bainite / Pearlite).
- ***Holding time should not be large*** or else Austenite may transform to Bainite.
- ***Tempering is done*** after the process .



AUSTEMPERING:

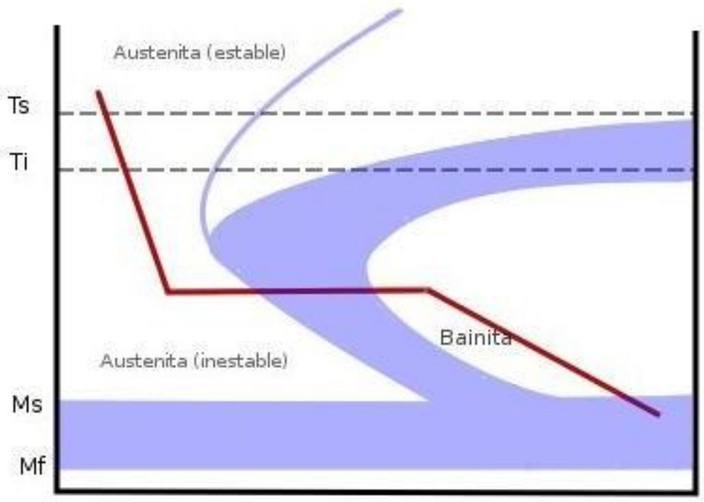
- Austempering heat treatment is given to steel to produce lower bainite in high carbon steel without any distortion or cracking.

Austemepring Process:

- Austenize the steel.
- Quench the steel in a molten salt bath maintained at a temperature greater than the Ms temperature (at 300 - 400 degree C)
- Hold for sufficient time till we obtain a homogeneous temperature along the centre and the surface of the component.
- Lower Bainite is formed .

In AUSTEMPERING,

- ***Austenite*** is transformed to ***LOWER BAINITE*** (not any other phase).
- ***No tempering is done*** after this hardening process.
- ***There is an increase in the holding time*** as there is no tempering required.



SURFACE HARDENING:

Flame hardening :

Flame hardening is a surface- hardening method that involves heating a metal with a high- temperature flame, followed by quenching. It is used on medium carbon, mild or alloy steels or cast iron to produce a hard, wear-resistant surface.

Flame hardening is often used to harden only a portion of an object, by quickly heating it with a very hot flame in a localized area, and then quenching the steel. This turns the heated portion into very hard martensite, but leaves the rest unchanged. Usually, an oxy-gas torch or oxy- acetylene flame is used to provide such high temperatures. Flame hardening uses direct impingement of an oxy-gas flame onto a defined surface area. The result of the hardening process is controlled by four factors:

- Design of the flame head
- Duration of heating
- Target temperature to be reached
- Composition of the metal

being treated Typical flame-

hardening applications include:

- Blades
- Gears
- Rolls
- Cams
- Automotive components

Flame hardening in its simplest form is the heating up of steel to its hardening temperature by a flame and then quenching in water or oil. It is used to produce a hard case on the surface of a wide range of mechanical components.

There are four methods of flame hardening:

- Stationary – in this method both torch or flame and work piece are stationary. It is used when the specified area be heated. Local area is heated by one or more flames followed by water quenching.
- Progressive – heating by flame(s) and quenching are moved over the component surface at a controlled rate. In this method, torch or flame moves over stationary work piece. This method is used for hardening of large parts, such as the ways of a

lathe, but is also adaptable to the treatment of teeth of large gears.

- Spinning – in this method flame or torch is stationary while the work piece rotates. This method is used to harden parts of circular cross section, such as precision gears, pulleys.
- Progressive – Spinning (Combination flame hardening) – in this method, torch or flame moves over a rotating work piece. This method is used to surface- harden long circular parts such as shafts and rolls.

The gas used for the heating process is a mixture of oxygen and acetylene, although occasionally propane is employed. When the surface reaches the austenizing temperature, the part is immediately quenched to produce a locally hardened surface. Typical surface hardness range is 55-60 HRC in medium carbon steels. It is used on parts such as:

- Crane wheels
- Cable sheaves
- Rollers

The benefits of flame- hardening include:

- Increased wear resistance
- Less distortion
- Reduced processing time
- Ability to use low to medium carbon steels
- Reduces cost by hardening only selective areas
- Achieves high hardness for increased life
- Less machining and grinding than other methods

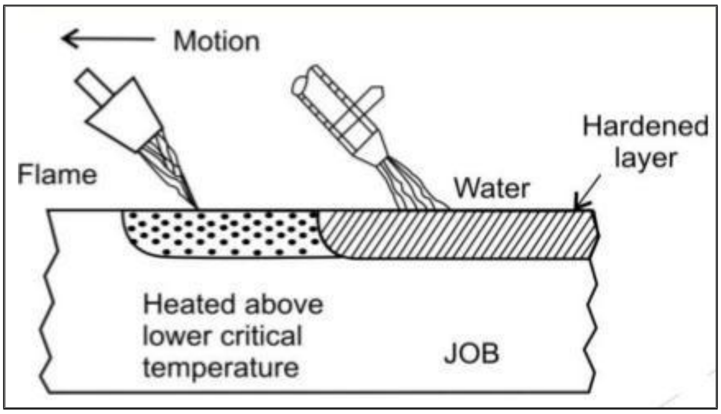


Figure: Flame hardening

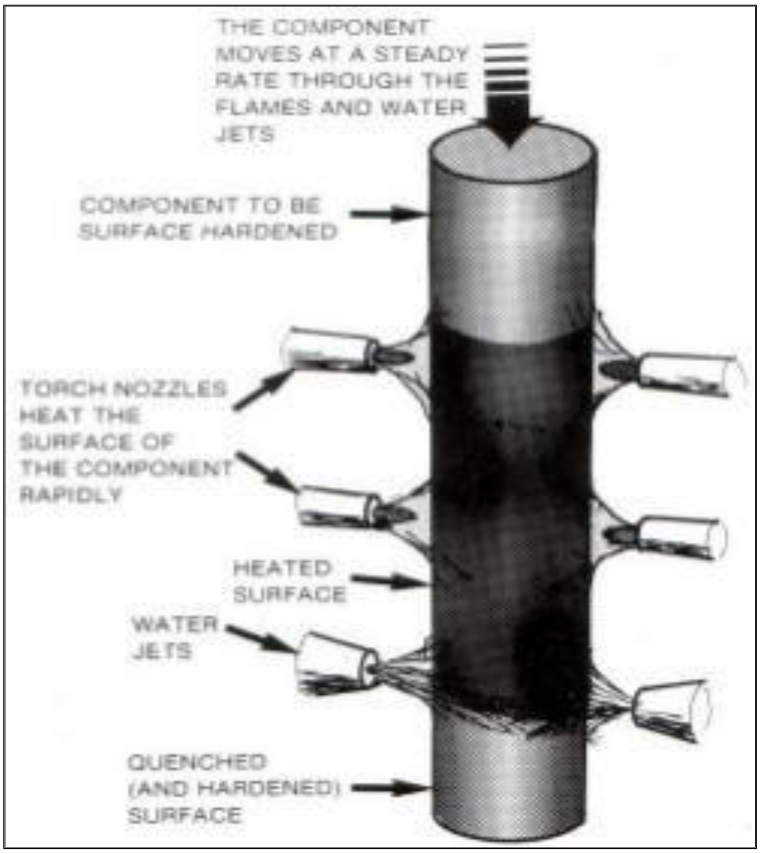


Figure: Flame hardening

Induction hardening:

The procedure for induction hardening is the same as flame hardening. But the high temperature is produced by alternative magnetic field.

Induction hardening is a process used for the surface hardening of steel and other alloy components. The parts to be heat treated is placed inside a water cooled copper coil and then heated above their transformation temperature by applying an alternating current to the coil. The alternating current in the coil induces an alternating magnetic field within the work piece, which if made from steel, caused the outer surface of the part to heat to a temperature above the transformation range. Parts are held at that temperature until the appropriate depth of hardening has been achieved, and then quenched in oil, or another media, depending upon the steel type and hardness desired. The core of the component remains unaffected by the treatment. The hardness of the case can be HRC 37 – 58.

The parts to be heat treated are placed inside a copper coil and then heated above their transformation temperature by applying an alternating current at a specific frequency and power level to the coil. The components are heated by means of an alternating magnetic field to a temperature at or above the transformation range followed by immediate quenching.

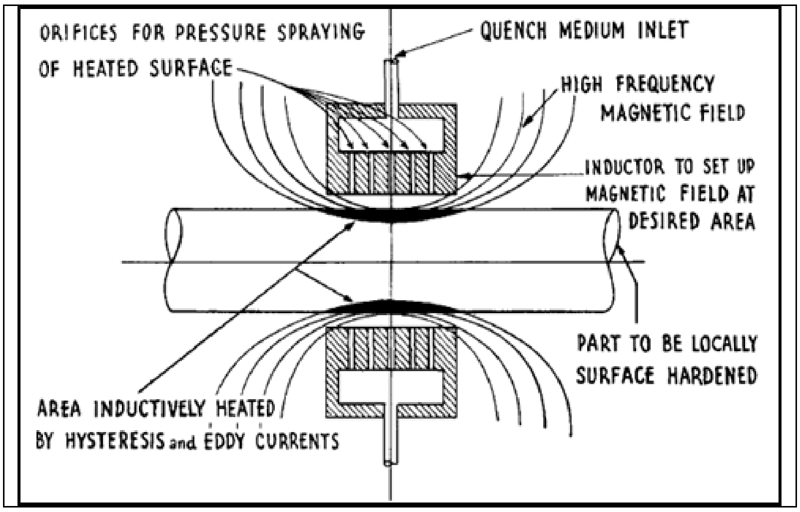


Figure : Induction hardening

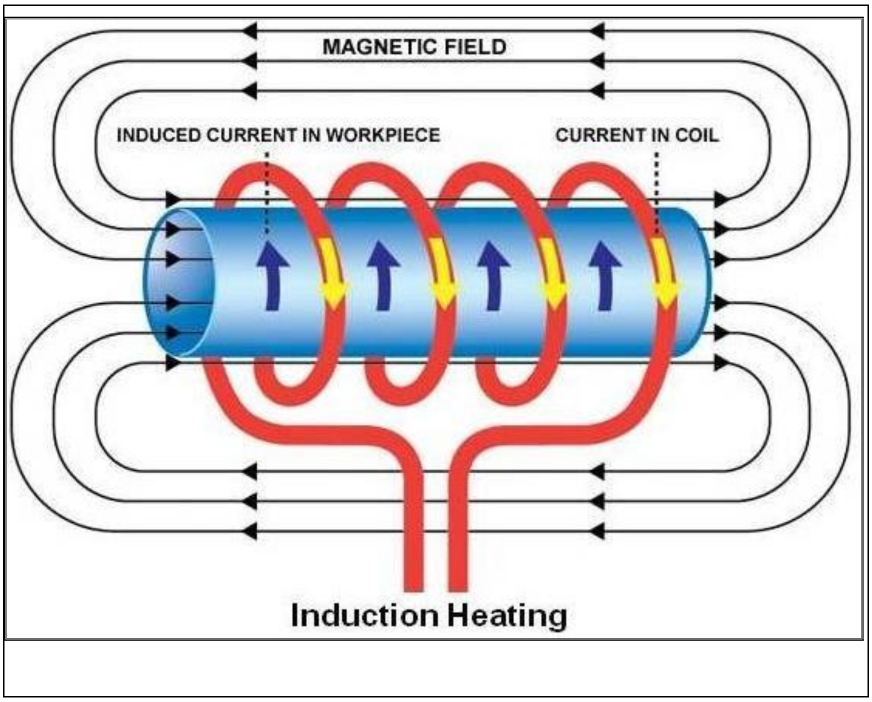


Figure : Induction hardening

Limitations:

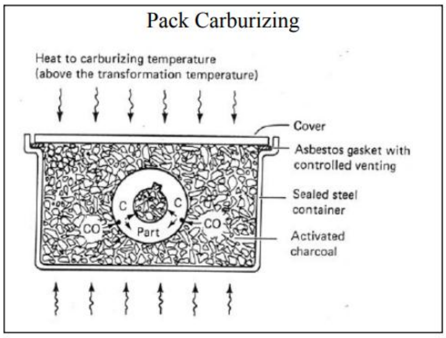
- Applications such as gears and shafts, which have readily-accessible and geometrically- uniform surfaces, are easily treated.
- Components with irregular shapes and surfaces requiring treatment can be difficult to induction harden in view of the restrictions imposed by coil design or limited accessibility. Flame hardening offers a somewhat greater degree of versatility.

Explain different Case hardening methods:

- Case hardening is a technique by which both surface hardness and fatigue life are enhanced for steel alloys
- Case hardening methods improve wear and fatigue resistance
- Different case Hardening methods are (i) carburizing (ii) nitriding (iii) cyaniding and (iv) carbonitriding (v) Nitrocarburizing

Carburizing : is a surface-hardening heat treatment that introduces carbon into the surface of steel. Low carbon steels are exposed into carbon rich environment. By this way carbon is made to deposite on the surface of parts. The carbon can come from a solid, liquid or gaseous source.

- ***Packing carburizing***: in this method parts are packed in charcoal or coke. When it is heated to a carburizing temperature, carbon layer is formed on the surface of the parts.



- ***Gas carburizing*** : in this method, parts are kept in a furnace and furnace is filled with methane or propane gas. When the furnace is heated to a temperature, carbon is deposited on the surface of parts.
- ***Liquid carburizing*** : in this method, parts are placed in a molten salt bath containing sodium cyanide, barium chloride etc.

Nitriding: is a surface-hardening heat treatment that introduces nitrogen into the surface of steel. Nitriding heats the steel part in an atmosphere of ammonia gas.

Cyaniding: Cyaniding is a case-hardening process that is fast and efficient; it is mainly used on low-carbon steels. The part is heated to 871–954 °C (1600–1750 °F) in a bath of sodium cyanide and then is quenched and rinsed, in water or oil, to remove any residual cyanide.

$2NaCN + O_2 \rightarrow 2NaCNO$

$2NaCNO + O_2 \rightarrow Na_2CO_3 + CO + N_2$

$2CO \rightarrow CO_2 + C$

Carbonitriding: Carbonitriding is a surface-hardening heat treatment that introduces carbon and nitrogen into the austenite of steel. This treatment is similar to carburizing in that the austenite composition is changed and high surface hardness is produced by quenching to form martensite. Carbonitriding produces a martensitic case with nitrogen levels less than carbon levels.

Carbonitriding is similar to cyaniding except a gaseous atmosphere of ammonia and hydrocarbons is used instead of sodium cyanide.

Nitrocarburizing: is a surface-hardening process that uses both carbon and nitrogen, but with more nitrogen than carbon.

Vacuum carburizing and plasma carburizing: have found applications because the absence of oxygen in the furnace atmosphere thus eliminates grain-boundary oxidation.