heating temperature ranges for normalizing process of both hypo and hyper carbon steel. Fig. 8.8 shows the structure obtained after normalizing of medium carbon steel.

Objectives

1. To soften metals
2. Refine grain structure
3. Improve machinability after forging and rolling
4. improve grain size
5. Improve structure of weld
6. Prepare steel for sub heat treatment

8.9 ANNEALING

It is a softening process in which iron base alloys are heated above the transformation range held there for proper time and then cool slowly (at the of rate of 30 to 150°C per hour) below the transformation range in the furnace itself. Heating is carried out 20°C above upper critical temperature point of steel in case of hypo eutectoid steel and the same degree above the lower critical temperature point in case of type eutectoid steel. Fig 8.7 shows the heating temperature ranges for annealing or softening process of both hypo and hyper carbon steel. Fig. 8.9 shows the structure obtained after annealing of medium carbon steel. The structure of steel on slow cooling changes into ferrite and pearlite for hypo eutectoid steel, pearlite for eutectoid steel and pearlite and cementite for hyper eutectoid steel. The time for holding the article in furnace is ½ to 1 hour. As ferrous metals are heated above the transformation range, austenite structure will be attained at this temperature.

For a particular type of structure specific cooling rate is required to have good annealing properties for free machining. As metal is slowly cooled after heating and holding in and with the furnace and buried in non conducting media such sand, lime or ashes, carbon steels are cooled down at particular rate normally 150-200°C per hour while alloy steel in which austenite is very stable and should be cooled much lower (30°C to 100°C per hour). Very slow cooling is required in annealing to enable austenite to decompose at two degrees of super cooling so as to form a pearlite and ferrite structure in hypo-eutectoid steel, a pearlite structure in eutectoid steel and pearlite and cementite structure in hyper eutectoid steel. In successfully annealed steel, the grains of ferrite are large and regular while pearlite consists of cementite and ferrite. Hypo-eutectoid hot worked steel may under go full annealing to obtain coarse grain structure for free machining. When steel is cold worked the hardness (Brinell hard) considerably increases and ductility decreases slightly. The ductility of steel may be then restored by so called recrystallisation or process annealing.

8.9.1 Objectives of Annealing

The purpose of annealing is to achieve the following

1. Soften the steel.
2. Relieve internal stresses
3. Reduce or eliminate structural in-homogeneity.
4. Refine grain size.
5. Improve machinability.
6. Increase or restore ductility and toughness.

Annealing is of two types

(*a*) Process annealing

(*b*) Full annealing.

In process annealing, ductility is increased with somewhat decrease in internal stresses. In this, metal is heated to temperature some below or close to the lower critical temperature generally it is heated 550°C to 650°C holding at this temperature and it is slowly cooled. This causes completely recrystallisation in steel.

The main purpose of full annealing of steel is to soften it and to refine its grain structure. In this, the hypo-eutectoid steel is heated to a temperature approximately 20° to 30°C above the higher critical temperature and for hypereutectoid steel and tool steel is heated to a temperature 20 to 30°C above the lower critical temperature and this temperature is maintained for a definite time and then slowly cooed very slow1y in the furnace itself.

8.10 SPHEROIDIZATION

It is lowest temperature range of annealing process in which iron base alloys are heated 20 to 40°C below the lower critical temperature, held therefore a considerable period of time e.g. for 2.5 cm diameter piece the time recommended is four-hours. It is then allowed to cool very slowly at room temperature in the furnace itself. Fig 8.7 shows the heating temperature ranges for spheroidizing process of carbon steel. Fig. 8.9 shows the structure obtained after annealing of carbon steel. During this process, the cementite of steel which is in the combined form of carbon becomes globular or spheroidal leaving ferrite in matrix, thus imparting softness to steel. After normalizing of steels, the hardness of the order of 229 BHN and as such machining becomes difficult and hence to improve machining, these are spheroidised first and then machined. This treatment is carried out on steels having 0.6 to 1.4% carbon. The objectives of spheroidising are given as under.

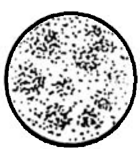


Fig. 8.8 Structure of normalized medium carbon steel

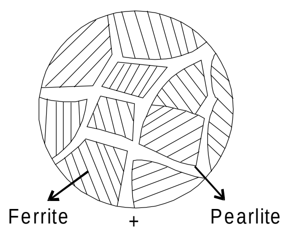


Fig. 8.9 Structure of annealed medium carbon steel

1. To reduce tensile strength
2. To increase ductility
3. To ease machining
4. To impart structure for subsequent hardening process

8.11 COMPARISON BETWEEN ANNEALING AND NORMALISING

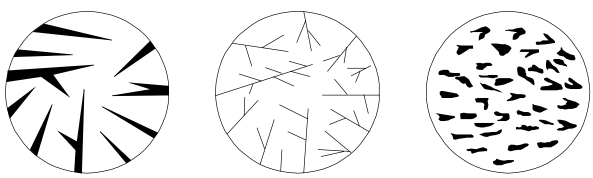
The comparison between annealing and normalizing is given as under in Table 8.1.

Table 8.1 Comparison between Annealing and Normalising

S.No.	Annealing	Normalising
1	In this hypo-eutectoid steel is heated to a temperature approximately 20 to 30°C above temperature the higher critical temperature and for hypereutectoid steel is heated 20 to 30°C above the lower critical temperature.	In this metal is heated 30 to 50°C above higher critical temperature.
2	It gives good results for low and medium carbon steel	It also gives very good results for low and medium carbon steel
3	It gives high ductility	It induces gives higher ultimate strength, yield point and impact strength in ferrous material.
4	It is basically required to soften the metal, to improve machinability, to increase ductility, improve, to refine grain size.	It is basically required to refine grain size, improve structure of weld, to relieve internal stresses.

8.12 HARDENING

Hardening is a hardness inducing kind of heat treatment process in which steel is heated to a temperature above the critical point and held at that temperature for a definite time and then quenched rapidly in water, oil or molten salt bath. It is some time said as rapid quenching also. Steel is hardened by heating 20-30°C above the upper critical point for hypo eutectoid steel and 20-30°C above the lower critical point for hyper eutectoid steel and held at this temperature for some time and then quenched in water or oil or molten salt bath. Fig 8.7 shows the heating temperature ranges for hardening process of both hypo and hyper carbon steel. Fig. 8.10 (a) shows the structure obtained on water quenching on hardening of medium carbon steel. Fig. 8.10 (b) shows the structure obtained on oil quenching on hardening of medium carbon steel. Fig. 8.10 (c) shows the structure obtained on water quenching on hardening of medium carbon steel and followed by tempering.



(a) **(b)** **(c)**

Fig. 8.10 Structure of hardened carbon steel

Metal is heated up to austenite formation and is followed by fast and continuous cooling of austenite to temperature 205° to 315°C or even lower than that. Due to such rapid cooling, austenitic structure changes to new structure known as martensite. It is evident that faster the rate of cooling harder will be the metal due to formation of more martensitic structure. Martensite has a tetragonal crystal structure. Hardness of martensite varies from 500 to 1000 BHN depending upon the carbon content and fineness of the structure. Martensite is a body centered phase produced by entrapping carbon on decomposition of austenite when cooled rapidly. It is the main constituent of hardened steel. It is magnetic and is made of a needle like fibrous mass. It has carbon content up to 2%. It is extremely hard and brittle. The decomposition of austenite below 320°C starts the formation of martensite.

Sudden cooling of tool steel provides thermal stresses due to uneven cooling. It provides unequal specific volume of austenite and its decomposition product. The structural transformations are progressing at different rates in outer layers and central portion of the article. When martensitic transformation takes place in the central portion of the article, due to tension stress produces cracks. The harness depends upon essentially on the cooling rate. The effect of cooling on austenite transformation is given in Fig. 8.11.

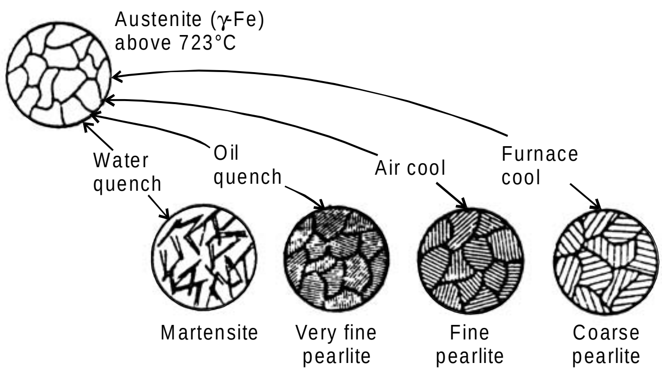


Fig. 8.11 Effects of coooling of austenite transformation

8.13 TTT CURVE

The hardness depends upon the structure of materials. The different structure through transformation can be obtained using different cooling rates. The effects of cooling of austenite (steel above 723°C) transformation are depicted in Fig. 8.11. It can be nicely represented in a temperature, time and transformation (TTT) curve. It is also known as C or S or Bain's curve. Fig 8.12 shows TTT diagram for hypo eutectoid steel.

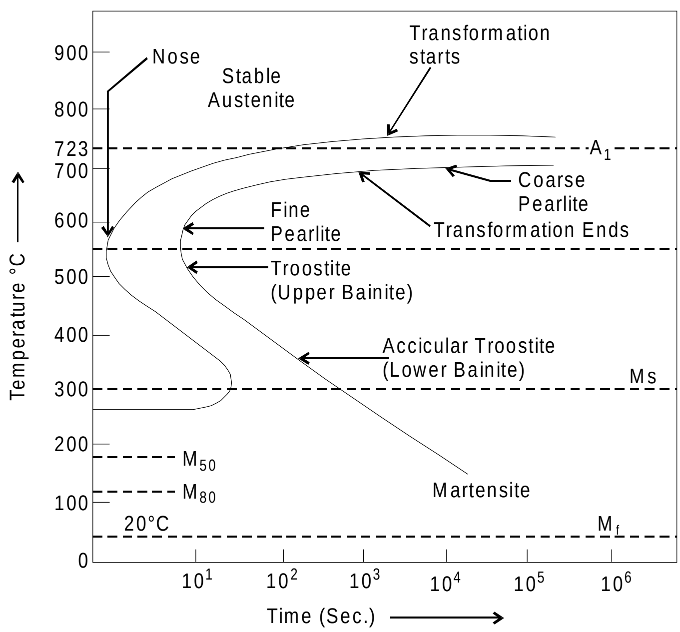


Fig. 8.12 TTT diagram for hypo eutectoid steel

Fig. 8.13 shows a series of cooling curves which result from different rates of cooling when superimposed on TTT curve. These curves reveal the decomposition of stable austenite existing above critical temperature in various forms during cooling depending upon the cooling rate. The transformation of austenite starts during suitable cooling. The minimum cooling rate required to produce martensite in given steel is determined by the position of the nose of the S curve. The cooling rate required to avoid the nose of the S curve is called the critical cool. Any other cooling rate, faster than to that of the nose of S curve will cause complete transformation of austenite to martensite.

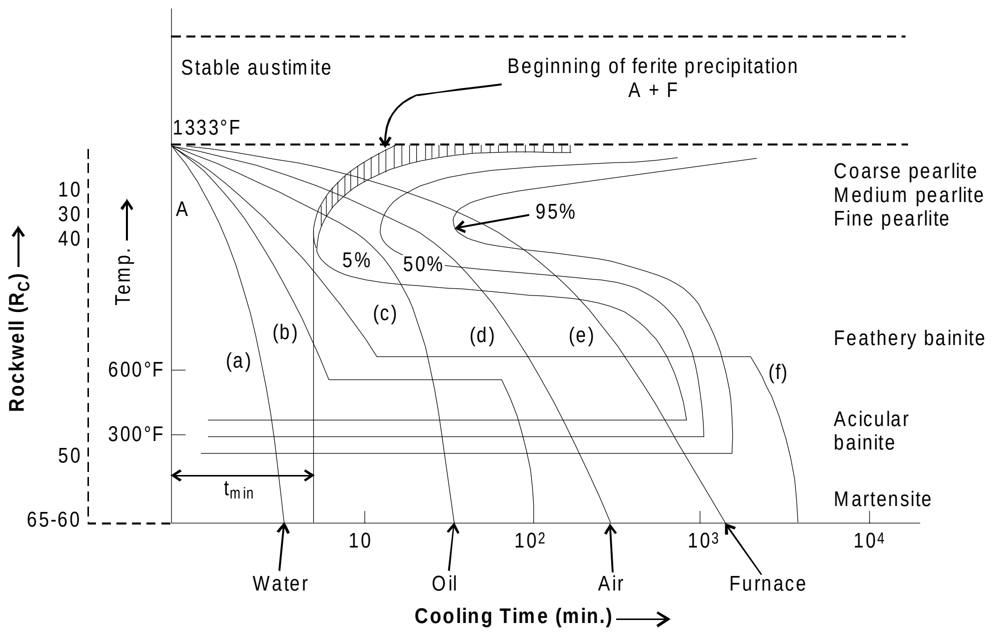


Fig. 8.13 Series of different cooling rates curves in TTT diagram

Assume a cooling rate 'a' achieved in water, this curve does not cut the nose of TTT curve, and the pearlite transformation does not take place. However the resulting structure at room temperature is martensite. Cooling curve 'c' reflects that the cooling rate is slower than water and is in oil still lesser than the critical cooling rate, the curve 'c' will result in the micro structure composed of martensite. Curve 'd' and curve 'e' corresponds to the rate of cooling during normalizing and annealing. The parts of austenite transform to fine and coarse pearlite. The intermediate cooling rate curves 'f' and 'b' higher than critical cooling rate results in the structure between pearlite and martensite known as feathery bannite and acicular (needles) bannite. Intermediate cooling rate is achieved by quenching or dipping the austenite at two hot oil baths maintained at different temperature such as in case of austempering (f curve) and mar tempering (b curve). Those special cooling rate will form coarse and fine bainite structure according the level of temperature of quenching.

Transformation of austenite to pearlite depends upon the temperature, time and transformation curve. It relates the transformation of austenite to the time and temperature conditions to which it is subjected. As metal is heated above the critical point austenite will form in the structure of metal if it is cooled slowly with respect to time. The structure wil1 change to coarse pearlite and cementite placeless in a ferrite matrix due to transformation of temperature and hence nuclei thus formed grow rapidly. Such as coarse laminar pearlite is relatively soft and is not very ductile. After this, if slightly faster cooling than above slow cooling is applied to austenite; coarse bainite structure will be formed.

8.14 TEMPERING

If high carbon steel is quenched for hardening in a bath, it becomes extra hard, extra brittle and has unequal distribution internal stresses and strain and hence unequal harness and toughness in structure. These extra hardness, brittleness and unwanted induced stress and strain in hardened metal reduce the usability the metal. Therefore, these undesired needs must be reduced for by reheating and cooling at constant bath temperature. In tempering, steel after hardening, is reheated to a temperature below the lower critical temperature and then followed by a desired rate of cooling. Reheating the of hardened steel is done above critical temperature when the structure is purely of austenite and then quenching it in a molten salt path having temperature in the range of 150-500°C. This is done to avoid transformation to ferrite and pearlite and is held quenching temperature for a time sufficient to give complete formation to an intermediate structure referred to as bainite then cooled to room temperature. The temperature should not be held less than 4 to 5 minutes for each millimeters of the section. After tempering structure is changed into secondary structure like martensite, troostite, sorbite and spheroidised. Fig. 8.14 shows different tempered states of martensite, troosite, sorbite and spherodite. Depending upon the temperature of reheat, the tempering process is generally classified in to three main categories. Which are discussed as under.

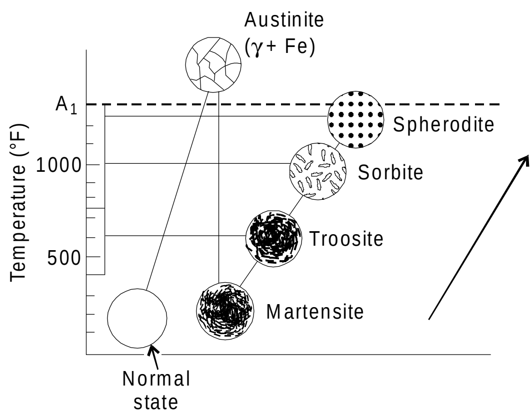


Fig. 8.14 Structures of tempered states of martensite, troosite, sorbite and spherodite

8.14.1 Low Temperature Tempering

Hardened steel parts requiring tempering are heated up to 200°C and then quenched in oil. Tempering is used to retain hard micro-structure of martensite which increases brittleness. Fig 8.15a represents the microstructure of martensite.

8.14.2 Medium Temperature Tempering

Hardened steel parts requiring tempering are heated in the temperature range of 200-350°C. This process gives troosite structure. Troosite structure is another constituent of steel obtained by quenching tempering martensite. It is composed of the cementite phase in a ferrite matrix that cannot be resolved by light microscope. It is less hard and brittle than martensite. It is also produced by cooling the metal slowly until transformation begins and then cooling rapidly to prevent its completion. It has a dark appearance on etching. It is weaker than martensite. Fig 8.15b represents the microstructure of troosite

8.14.3 High Temperature Tempring

Hardened steel parts requiring tempering are heated in the temperature range of 350-550°C. This process gives sorbite structure. Sorbite structure is produced by the, transformation of tempered martensite. It is produced when steel is heated at a fairly rapid rate from the temperature of the solid solution to normal room temperature. It has good strength and is practically pearlite. Its properties are intermediate between those of pearlite and troosite. Parts requiring tempering are heated in the temperature range of 550-750°C. This process gives spheriodite structure. Fig 8.15(c) represents the microstructure of sorbite. However there are other special kinds of tempering also which are discussed as under.

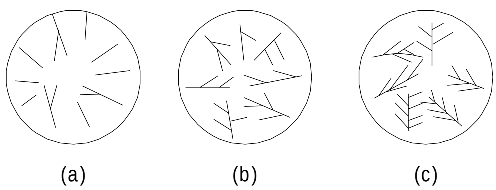


Fig. 8.15 Structures obtained tempering of hardened steel

8.14.4 Aus-Tempering

It is a special type of tempering process in which and steel is heated above the transformation range then suddenly quenched in a molten salt bath at a temperature 200 to 450°C. The piece is held at that temperature until the and outside temperature are equalized. The part is then reheated and cooled at moderate rate. Aus-tempering produces fine bainite structure in steel but with minimum distortion and residual stresses. Fig. 8.16 shows the process of aus-tempering for medium C-steel. Aus-tempering is mainly used tempering for aircraft engine parts.

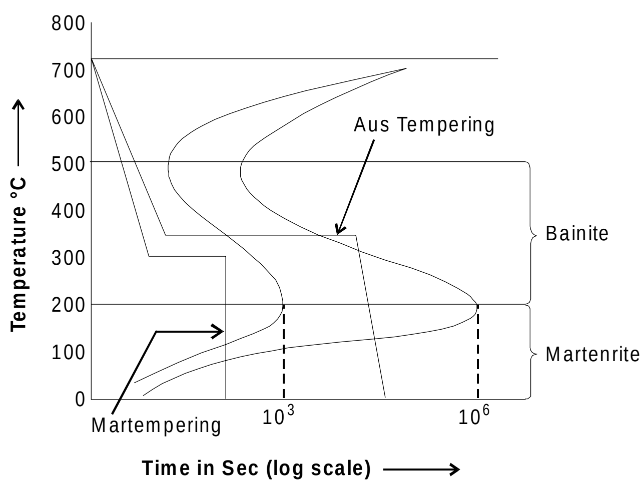


Fig. 8.16 Aus tempering and mar tempering process

Advantages of Aus-Tempering

1. Quenching cracks are avoided.
2. Distortion and warping are avoided.
3. A more uniform microstructure is obtained.
4. Mechanical properties of bainite are superior to conventional hardening microstructure.

Limitations of Aus-Tempering

1. The process is very costly.
2. The process is time consuming.

8.14.5 Mar Tempering

It is a type of tempering process in which and its base alloys are heated above the transformation range then suddenly quenched in a molten salt bath at a temperature 80 to 300°C. The piece is held at that temperature until the and outside temperature are equalized. The part is then reheated and cooled at moderate rate. Mar-tempering produces martensite in steel but with minimum distortion and residual stresses. Fig. 8.16 shows the mar tempering process for medium C-steel and its micro structures of given stages. Cold chisels are hardened at the cutting edge and followed by tempering. Because these processes increase the hardness of chisel and increase the cutting ability.

8.15 CASE HARDENING

Some times special characteristic are required in metal such as hard outer surface and soft, tough and more strength oriented core or inner structure of metal. This can be obtained by casehardening process. It is the process of carburization i.e. saturating the surface layer of steel with carbon or some other substance by which outer case of the object is hardened where as the core remains soft. It is applied to very low carbon steel. It is performed for obtaining hard and wear resistance on surface of metal and higher mechanical properties with higher fatigue, strength and toughness in the core. The following are the case hardening process.

(1) Carburizing
(2) Nitriding.
(3) Cyaniding.
(4) Induction hardening.
(5) Flame hardening

These processes are discussed as under.

8.15.1 Carburizing

Carburizing can be of three types

1. Pack carburizing
2. Liquid carburizing and
3. Gas carburizing

The above carburizing processes are discussed as under.

8.15.1.1 Pack Carburizing

Metals to be carburized such as low carbon steel is placed in cast iron or steel boxes containing a rich material in carbon like charcoal, crushed bones, potassium Ferro-cyanide or charred leather. Such boxes are made of heat resisting steel which are then closed and sealed with clay. Long parts to be carburized are kept vertical in -boxes. The boxes are heated to a temperature 900°C to 950°C according to type of steel for absorbing carbon on the outer surface. The carbon enters the on the metal to form a solid solution with iron and converts the outer surface into high carbon steel. Consequently pack hardened steel pieces have carbon content up to 0.85% in their outer case. After this treatment, the carburized parts are cooled in boxes. Only plane carbon steel is carburized in this process for hardening the outer skin and refining the structure of the core to make it soft and tough. Small gears are case hardened by this process for which they are enclosed in the cast iron or steel box containing a material rich in carbon, such as small piece of charcoal and then heat to a temperature slightly above the critical range. Depth of hardness from 0.8-1.6 mm is attained in three to four hours. The gears are then allowed to cool slowly with-in the box and then removed. The second stage consists of reheating the gears (so obtained) to about 900°C and then quenched in oil so that its structure is refined, brittleness removed and the core becomes soft and tough. The metal is then reheated to about 700°C and quenched in water so that outer surface of gear, which had been rendered soft during the preceding operation, is again hardened.

8.15.1.2 Liquid Carburizing

Liquid carburizing is carried out in a container filled with a molten salt, such as sodium cyanide. This bath is heated by electrical immersion elements or by a gas burner and stirring is done to ensure uniform temperature. This process gives a thin hardened layer up to 0.08 mm thickness. Parts which are to be case-hardened are dipped into liquid bath solution containing calcium cyanide and polymerized hydro-cyanide acid or sodium or potassium cyanide along-with some salt. Bath temperature is kept from 815°C to 900°C. The furnace is usually carbon steel case pot which may be by fired by oil, gas or electrically. If only selected portions of the components are to be carburized, then the remaining portions are covered by copper plating. There are some advantages of the liquid bath carburizing which are given as under.

Advantages

1. Greater depth of penetration possible in this process.
2. Selective carburizing is possible if needed.
3. Uniform heating will occur in this process.
4. Little deformation or distortion of articles occur in this process.
5. Ease of carburizing for a wider range of products.
6. It is time saving process.
7. Parts leave the bath with a clean and bright finish.
8. There is no scale in this process as occur in pack hardening.

8.15.1.3 Gas Carburising

In gas carburizing method, the parts to be gas carburized are surrounded by a hydrocarbon gas in the furnace. The common carburizing gases are methane, ethane, propane, butane and carbon monoxide are used in this process. Carbon containing gas such as carbon monoxide (CO), methane (CH_4), ethane (C_2H_6) or town gas is introduced in the furnace where low carbon steel is placed. The furnace is either gas fired or electrically heated. Average gas carburizing temperature usually varies from 870° to 950°C. Thickness of case hardened portion up to 11 mm can be easily obtained in 6 hours. The carburized parts can heat treated after carburizing. Steel components are quenched in oil after carburizing and then heated again to form fine grain sized austenite and then quenched in water to form martensite in surface layers. This gives maximum toughness of the core and hardness of the surface of product.

8.15.2 Cyaniding

Cyanide may also be used to case harden the steel. It is used to give a very thin but hard outer case. Cyaniding is a case hardening process in which both C and N_2 in form of cyaniding salt are added to surface of low and medium carbon steel. Sodium cyanide or potassium cyanide may be used as the hardening medium. It is a process of superficial case hardening which combines the absorption of carbon and nitrogen to obtain surface hardness. The components to be case hardened are immersed in a bath having fused sodium cyanide salts kept at 800-850°C. The component is then quenched in bath or water. This method is very much effective for increasing the fatigue limit of medium and small sized parts such as gears, spindle, shaft etc. Cyanide hardening has some advantages and disadvantage over carburizing and nitriding method. Cyaniding process gives bright finishing on the product. In it, distortion can be easily avoided and fatigue limit can be increased. Decarburizing can be reduced and time taken to complete the process is less. But the main disadvantage of this process is that it is costly and highly toxic process in comparison to other process of case hardening. There are some common applications of cyaniding process which are given as under.

Application

Cyaniding is generally applied to the low carbon steel parts of automobiles (sleeves, brake cam, speed box gears, drive worm screws, oil pump gears etc), motor cycle parts (gears, shaft, pins etc.) and agriculture machinery.

8.15.3 Nitriding

Nitriding is a special case hardening process of saturating the surface of steel with nitrogen by holding it for prolonged period generally in electric furnace at temperature from 480°C to 650°C in atmosphere of Ammonia gas (NH3). The nitrogen from the ammonia gas enters into on the surface of the steel and forms nitrides and that impart extreme hardness to surface of the metal. Nitriding is a case hardening process in which nitrogen instead of carbon is added to the outer skin of the steel. This process is used for those alloys which are susceptible to the formation a chemical nitrides. The article to be nitride is placed in a container (made of high nickel chromium steel). Container is having inlet and outlet tubes through which ammonia gas is circulated. Ammonia gas is used as the nitrogen producing material. The alloy steel containing Cr, Ni, Al, Mo, V and Nitre-alloy are widely used for this process. Plain carbon steels are seldom nitirided. There are some common applications of this process which are given as under.

Application

Many automobile, diesel engines parts, pumps, shafts, gears, clutches, etc. are treated with the nitriding process. This process is used for the parts which require high wear resistance at elevated temperatures such as automobile and air plane valve's and valve parts, piston pins, crankshafts, cylinder liners etc. It is also used in ball and roller bearing parts die casting dies, wire drawing dies etc.

8.15.4 Flame Hardening

It consists of moving an oxyacetylene flame, over the part where hardening is required. Immediately after this, the heated portion is quenched by means of water spray or air passing over it. Temperature attained by the surface is controlled and the rate of cooling is controlled by selecting a suitable medium. Flame hardening is suitable for large sized articles where only some portions of the surface requiring hardening and hence there is no need to heat the whole article in the furnace. Metal is heated by means of oxy-acetylene flame for a sufficient time unto hardening range and than quenched by spray of water on it. The hardened depth can be easily controlled by adjusting and regulating the heating time, temperature, flame and water spray. The main advantages of the process is that a portion of metal can be hardened by this process, leaving rest surface unaffected by confining the flame at relevant part only where hardening is required. This process is best suited to smal1 numbers of jobs which requiring short heating time. This method is highly suitable for stationary type of larger and bulky jobs.

8.15.5 Induction Hardening

Induction hardening is accomplished by placing the part in a high frequency alternating magnetic field. It differs from surface hardening in the way that hardness of surface is not due to the increase in carbon content but due to rapid heating followed by controlled quenching. In this process, a high frequency current is introduced in the metal surface and its temperature is raised up to hardening range. As this temperature is attained, the current supply is cut off instantaneously water is sprayed on the surface. Heat is generated by the rapid reversals of polarity. The primary current is carried by a water cooled copper tube and is induced into the surface layers of the work piece. Thin walled sections require high frequencies and thicker sections must require low frequencies for adequate penetration of the electrical energy. The heating effect is due to induced eddy currents and hysteresis losses in the surface material. Some portion of the metal part is heated above the hardening temperature and is then quenched to obtain martensite on the metal surface. There are some advantages of this process which are given as under.

Advantages

Induction hardening is comparatively quicker. A minimum distortion or oxidation is encountered because of the short cycle time. The operation is very fast and comparatively large parts can be processed in a minimum time. There are some applications of this process which are given as under.

Application

Induction hardening is widely used for hardening surfaces of crankshafts, cam shafts, gear automobile components, spline shafts, spindles, brake drums etc. It is also used for producing hard surfaces on cam, axles, shafts and gears.

8.15.6 Difference between Flame and Induction Hardening

Flame hardening and induction hardening methods have the same purpose of obtaining hard and wear surface whilst the core remains soft. The main difference between them is in the manner or the mode of heating.

In the induction hardening high frequency current of about 1000 to 10000 cycles per is passed through a copper inductor block which acts as a primary coil of the transformer. Heating by high frequency current is accomplished by the thermal effect of the current induced in the article being heated in this process. This way 750°C to 800°C temperature is obtained in the metal. Now, the heated surface is quenched by the water. In the flame hardening process, the metal surface is heated by means of oxy-acetylene flame. Heating is carried for sufficient time so as to raise the temperature of the portion of the surface of the specimen above the critical temperature. Then surface is cooled rapidly by spray of water.

Flame hardening method is cheaper as initial investment in this process is less in comparison to induction hardening method. However, same equipments can be used for all sizes of specimen in induction hardening process.

In induction hardening, the hardness depth is controlled very accurately by using different frequencies and a method is very clean and quick in comparison of flame hardening method.

Induction hardening method is generally used for crank shaft shafts, gears, pinions and a wide range of automobile and tractor components. Flame hardening method is generally used for local hardening of components such as hardening of gear wheel teeth only**.**

8.16 COMPARISON BETWEEN FULL HARDENING AND CASE HARDENING

The comparison between full hardening and case hardening is under in Table 8.2.

Table 8.2 Comparison between Full Hardening and Case Hardening

S.No.	Full Hardening	Case Hardening
1	It is process carried out on steel parts to resist wear or abrasion and in case of cutting tools to improve their cutting ability.	The main objective of case- hardening of steel parts is to have a hard surface and tough core. The various methods are, carburizing, cyaniding, nitriding, flame hardening and induction hardening.
2	In this process, the structure formed of materials and whole of the part is effected.	In this process, the only outer surface (up to some depth) is saturated by carbon, nitrogen or both. Where core is not affected (remains tough).
3	Its main purpose is to resist wear and increase the cutting ability.	Its main purpose is get outer surface hard where inner core is kept tough. It is used to obtain close tolerances on machine parts, higher fatigue limit and high mechanical properties in core of the metal part.
4	Hardening is always followed by tempering to increase its usefulness.	Case hardening is not always followed by tempering.
5	In hardening the metals are heated above critical temperature and then cooled rapidly.	In case hardening, the metals are heated obut it not necessary to cool them rapidly. always.
6	It is a cheap and fast process.	It is costly and time consuming process.

8.17 HEAT TREATMENT OF TOOL STEEL

First of a1l, the purpose or functional requirements of the tool to be used should be understood clearly. Accordingly the heat-treatment will be carried on the tool to obtain the desired qua1ities in the tool steel to meet the needed objective. For example a cutting tool requires particularly sufficient strength, high hardness and high wear-resistance. Therefore, it is initially shaped by forging operation which should be carried out at temperature 850°- 950°C with the help of hammers. Next normalizing is to be performed on it to relieve the stresses and strains developed during forging and to have a uniform grain structure. Next the tool steel is hardened by heating followed by sudden or rapid cooling depending upon the carbon percentage in tool steel. The various heating ranges of different tool steels are as follows

C% in tool steel	Heating Range
0.7- 0.8%	780-850°C
0.8- 0.95%	765-790°C
0.95-1.10%	750-775°C
Above 1.10 %	740-760°C

The tool steel is heated to this temperature range and kept at that temperature for sufficient time to achieve uniform structure inside the metal. Then it is quenched by immersing it into a bath of fresh water (rapid cooling). For securing more homogenous cooling and reduce danger of cracking, brine solution (10% brine or caustic soda solution) may be used. After hardening, tempering is performed to remove extra hardness and brittleness induced during hardening. This is performed by reheating the hardened tool steel up to 150-300°C once again and same is cooled in oils to reduced internal stresses. Tempering is carried over to tool steel for the purpose of increasing its usefulness and to provide good results in its performance. The important point is to note that drills and milling cutters should be hardened through out. But certain tools like screw taps, screw dies, lathe, planer and shaping tools are not hardened throughout the surface of the cutting tools.

8.18 HEAT TREATMENT OF HIGH SPEED STEEL

First the HSS tool is heated to about 850°C and kept at this temperature for 4 to 5 hours. This is done to dissolve all the carbides or homogenization of WC, VC and Cr_4C_3. After it, tool is heated to 1200°C for 1-4 minutes. The purpose of heating to high temperature is that more the substance is cooled from high temperature to lower temperature difference, the more will be the hardness. Tool is not kept at such temperature for sufficient longer time. After this, it is quenched in salt bath to 650°C and kept at this temperature for 10-20 minutes. Direct quenching to room temperature is dangerous. Then the tool is oil quenched. For increasing the life of HSS tool, surface treatment processes are also done like, liquid cyaniding, gas cyaniding and solid or dry cyaniding.

8.19 QUESTIONS

1. Why are the Time-Temperature-Transformation (TTT) diagrams constructed?
2. How do you classify the different heat treatment processes?
3. What are the objectives of annealing?
4. Explain the various methods of annealing?
5. Explain various hardening methods?

6. Write short notes on :
   (*a*) Normalizing
   (*b*) Tempering
   (*c*) Mar-tempering
   (*d*) Aus-tempering
   (*e*) Case hardening
   (*f*) Flame hardening
7. Discuss tempering process in detail?
8. Discuss various types of surface hardening or case hardening processes?
9. Explain the following case hardening processes:
   (*a*) Cyaniding
   (*b*) Nitriding
   (*c*) Induction Hardening
   (*d*) Types of carburizing
10. Write short notes on :
    (*a*) Sub zero treatment of steels
    (*b*) Age Hardening.
11. Explain various heat treatment defects with causes and remedies.