Mechanical treatment of steel:

The purpose of giving mechanical [redacted]

[redacted]

(3) heating medium;

(4) methods employed in heating and cooling a given variety of steel;

(5) quenching mediums;

(6) rate of heating and cooling;

(7) variety or specification of steel; etc.

The heat treatment is generally an expensive proposition. But if it can be planned on a large scale, its cost can be justified.

The principal processes involved in heat treatment of steel are as follows:

(1) Annealing
(2) Case hardening
(3) Cementing
(4) Cyaniding
(5) Hardening
(6) Nitriding
(7) Normalizing
(8) Tempering.

(1) ***Annealing:*** The main object of this process is to make the steel soft so that it can be easily worked upon with a machine. The annealing reduces the tensile strength. But it increases ductility and brings back the steel to the best physical state to resist fracture under sudden stresses. The high carbon and high speed steels must necessarily be annealed before hardening to improve the toughness. The annealing also causes the following effects:

(i) Altering the microstructure in such a way as to make it suitable for hardening.

(ii) Improving machineability and mechanical properties.

(iii) Relieving the internal stresses.

(iv) Removing or minimising segregation of the essential constituents of steel.

(v) Restoring ductility, particularly after the steel has been subjected to the cold working.

Following is the procedure for annealing:

(i) The steel to be annealed is heated to the desired temperature. The temperature depends upon the carbon content of steel and it is about 50°C to 55°C above the critical temperature. Table 10-2 shows the temperature to be kept during annealing for steels with different carbon contents.

TABLE 10-2

ANNEALING TEMPERATURE

No.	Range of annealing temperature	Carbon content of steel
1.	871 to 925	Below 0.12%
2.	843 to 870	0.13 to 0.29%
3.	816 to 842	0.30 to 0.49%
4.	788 to 815	0.50 to 1.00%

(ii) After the desired temperature is achieved, the steel is held at the annealing heat till it is thoroughly heated. The time for which annealing temperature is to be maintained will depend on type of furnace, nature of work, etc. In general, it may be mentioned that this time should be just sufficient for making the carbon dissolved into and diffused through the material.

(iii) The steel is then allowed to cool slowly in the furnace in which it was heated.

(2) ***Case hardening:*** In this treatment, the core of specimen remains tough and ductile and at the same time, the surface becomes hard. Such a result is achieved by increasing the carbon content at the surface. It is also known as a process of chemical heat treatment in which the saturation of the surface having low carbon steel is carried out by diffusion of carbon from the surrounding medium at a high temperature.

The case hardening is important for components like gears, bearing surfaces, etc., which require faces to be tough, shock resistant and capable of carrying high stresses. The steel used for this purpose is generally of low carbon content and does not respond appreciably to the heat treatment. The process of case hardening consists of increasing the carbon content of the case so that it will respond to the hardening and keeping the core soft and ductile.

Following is the procedure of case hardening:

(i) The article to be carburized is held in the carburizing mixture for a definite time and at definite temperature. The time and temperature will depend upon the depth of case required and composition of steel. The usual period is 6 to 8 hours and the usual temperature range is 900°C to 950°C.

(ii) After carburizing, the article is treated in one of the following ways:

(a) It is quenched directly from box at the carburizing temperature.

(b) It is cooled slowly in the carburizing box and then it is reheated and quenched.

(c) It is cooled slowly in the carburizing box and then it is reheated twice and also quenched twice.

The above is the general process of case hardening. The various other useful case hardening processes have been developed such as cyaniding, induction hardening, nitriding, flame hardening, etc. These processes adopt a specially prepared carburizing mixture and specially designed furnace.

Depth of case hardening: Following factors affect the depth of case hardening;

(i) period of treatment,

(ii) quality and nature of carburizing mixture, and

(iii) temperature of furnace.

It is observed that at higher temperature of furnace, the depth of case hardening is more. Further, if period of treatment is about 4 to 6 hours, the depth of case hardening is about 0.50 mm to 1 mm and if period of treatment is increased to about 18 hours or so, the depth may be about 3 mm or so.

Carburizing mixtures: Following are the carburizing mixtures which are commonly used in the process of case hardening:

(i) animal charcoal,

(ii) bone and horn parings,

(iii) cyanides,

(iv) finely cut leather pieces, and

(v) wood charcoal and soda ash, proportion being 95% and 5% respectively.

The last one is more commonly used. The animal charcoal is also sometimes preferred as nitrogen contained in it helps the carbon to unite more rapidly with iron.

Precautions in case hardening: Following precautions are to be taken in the process of case hardening:

(i) If articles are of alloy steels, they should be quenched in oil.

(ii) The quenching should preferably be carried out in water. But for articles with unequal or uneven shapes or thickness, the oil quenching should be adopted.

(iii) The article should be placed in such a way that it can expand freely in all directions.

(iv) The article to be treated should be clean and free from dirt, grease, oil, rust, etc.

(v) The box in which the process is to be carried out should be cemented with fire-clay. It should be seen that air is thoroughly excluded from the box.

(vi) The thickness of carburizing layer should be at least 25 mm all round the article.

(3) ***Cementing:*** In this process or technique, the skin of the steel is saturated with carbon. The process consists in heating of the steel in a carbon rich medium between the temperature of 880°C to 950°C.

(4) ***Cyaniding:*** This process is used to produce hard cases on the surfaces of low or medium carbon steels. It consists in adding carbon and nitrogen to the surface layer of the steel so as to increase its hardness, wear resistance and fatigue limit. The steel is heated in a molten cyanide salt bath maintained at a temperature of 950°C and it is then followed by water or oil quenching.

The commonly used molten salts in this process are sodium chloride, sodium carbonate, sodium cyanide, soda ash and barium chloride. The composition of salt bath will vary according to the temperature of the salt, thickness of the case to be obtained, type of steel to be treated and period of operation. The process grants the case thickness of about 0.075 mm to 1 mm.

The carbon monoxide is formed by the decomposition of sodium cyanate. It evolves atomic carbon which is diffused in the steel. At the same time, the nitrogen is also dissociated from sodium cyanate and it is introduced in the steel.

Following are the *advantages* of cyaniding:

(i) It helps in retaining the bright finish of parts.

(ii) It is most suitable for parts subjected to high loads.

(iii) The cracks and distortions can be minimized by uniform heating maintained by the salt.

Following are the *disadvantages* of cyaniding:

(i) The fumes formed are unhealthy and hence, it requires careful handling of the process.

(ii) The liquid carburizing can produce better surface hardness.

(iii) There is risk of spiltering of poisonous salts.

(5) *Hardening:* The object of this process is just the reverse of that of the annealing process. The steel is to be made hard by this process whereas it is made soft by the annealing process.

The process of hardening is just similar to that of annealing except that there is difference in rate of cooling. In hardening process, the cooling is to be carried out at controlled rate. Such a controlled rate of cooling is known as the *quenching*.

Following are the mediums of quenching, the most common quenching mediums being oil and water:

(i) *Air:* The hot article is allowed to cool down in still air. A mild quench is obtained by this medium. The thin sections such as knife blades are effectively hardened by cooling in air.

(ii) *Molten salts:* The molten salts are usually used as medium of quenching for martempering and austempering. The steeped quenching or hardening by interruption is known as the *martempering*. The quenching at constant temperature or isothermal quenching is known as the *austempering*. The lower the temperature of the salt bath, the higher the cooling rate it provides. The cooling in a salt bath is achieved only by conduction. Hence, the cooling capacity is increased to a great extent by agitation. The thin film of chlorides covering the article grants protection to the article from oxidation.

(iii) *Oil:* The hot article is dropped in oil to cool down. The quenching in oil is quite slow. But it helps in preventing the quenching cracks developed due to rapid expansion of the article. It is more suitable for quenching alloy steels than plain carbon steels. The temperature range for quenching capacity of oil is limited from 20°C to 150°C. The *disadvantages* of oil quenching are as follows:

(a) The cooling rate is comparatively low.

(b) The oil possesses high inflammability.

(c) The tendency of oil is to thicken or become gummy in the course of time.

On account of the danger from cracking, it is usual to air cool smaller sections and oil quench larger sections.

(iv) *Water:* This is the most commonly adopted medium for quenching. The hot article is dropped in water to cool down. It is used for carbon steels and for medium carbon low alloy steels. It tends to form a pronounced vapour blanket or bubble which causes high structural stresses and even quenching cracks.

(6) ***Nitriding:*** The process of saturating the surface layer of steel with nitrogen by heating is known as the *nitriding*. The heating is carried out between the temperature 480°C to 650°C in an atmosphere of ammonia. The thickness of nitriding layer may vary from 0.01 mm to 1.00 mm. The treatment makes the steel hard and increases its resistance to corrosion, wear and fatigue in such media as the atmosphere, water, steam, etc. The nitriding produces a hard case without quenching or any further heat treatment. The ammonia gas dissociates at the nitriding temperature as follows:

$$2NH_3 \rightarrow 2N + 3H_2$$

The atomic nitrogen thus formed diffuses into the iron. The nitriding is usually applied to medium carbon alloy steels which acquire high wear resistance due to this process.

Following are the *advantages* of nitriding:

(i) It generally avoids the machining and finishing of the product.

(ii) It helps in obtaining very high surface hardness.

(iii) It is a better process than carburizing.

(iv) It offers good wear resistance.

(v) It proves to be economical for mass production.

(vi) The distortion and cracks are minimum as quenching is eliminated.

(vii) The nitrided parts retain hardness upto 500°C.

Following are the *disadvantages* of nitriding:

(i) It is not economical unless specialized equipment is available.

(ii) It requires long operation time say about 100 hours for a depth of 0.038 mm.

(iii) The limited alloy steels containing only aluminium, chromium, vanadium and molybdenum can form good nitrides.

(iv) There is oxidation due to prolonged heating time.

(7) ***Normalizing:*** The object of this process is to restore steel structure to normal condition and it is adopted when structure of steel is seriously disturbed for any reason. This process also makes the material reasonably ductile without seriously affecting its strength.

Following is the procedure of normalizing:

(i) The steel is heated to a point 40°C to 50°C above its upper critical temperature.

(ii) It is maintained at that temperature for a short duration.

(iii) It is then allowed to cool down in still air at room temperature. This is also known as the *air quenching*.

With respect to annealing and normalizing, the following points should be noted:

(i) *Duration:* The heat treatment process of normalizing is of short duration due to the increased rate of cooling in air.

(ii) *Heating range:* The normalizing requires a heating range which is about 40°C above that of annealing.

(iii) *Mechanical properties:* The normalizing raises the yield point, ultimate tensile strength and impact strength values of steel. The normalized steels are harder and stronger but less ductile than annealed steels with the same composition. In general, the mechanical properties of the normalized steels are better than the annealed steels.

(8) ***Tempering:*** This process is applied to the steels which are treated with the hardening process. The hardened steel is in a stressed condition and very brittle and cannot be used for practical purposes. The steels after hardening must be tempered to achieve the following *objects* :

(i) to improve ductility, strength and toughness;

(ii) to increase the hardness and wear resistance;

(iii) to obtain predetermined mechanical properties;

(iv) to reduce the brittleness; and

(v) to relieve the internal stresses caused by hardening.

Following is the procedure adopted for tempering:

(i) The article after being quenched in hardening process is reheated to suitable temperature. This temperature should be below the critical temperature.

(ii) The temperature is maintained for a certain period. The duration of period depends on quality of steel required and composition of steels.

(iii) The article is then allowed to cool down in still air.

The tempering procedures are classified in the following *three* categories in accordance with the heating conditions:

(i) *Low-temperature tempering:* The temperature range is 150°C to 200°C and its purpose is to reduce the internal stresses and to increase toughness without any appreciable loss in hardness.

(ii) *Medium-temperature tempering:* This method requires the temperature range of 350°C to 400°C. It is used to toughen the steel at the expense of hardness.

(iii) *High-temperature tempering:* It is carried out with the temperature range of 500°C to 650°C. It almost completely eliminates the internal stresses and provides the most favourable ratio of strength to toughness for structural steels.

Properties of mild steel:

Following are the properties of mild steel:

(1) It can be magnetised permanently.
(2) It can be readily forged and welded.
(3) It cannot be easily hardened and tempered.
(4) It has fibrous structure.
(5) It is malleable and ductile.
(6) It is not easily attacked by salt water.
(7) It is tougher and more elastic than wrought-iron.
(8) It is used for all types of structural work.
(9) It rusts easily and rapidly.
(10) Its melting point is about 1400°C.
(11) Its specific gravity is 7.80.
(12) Its ultimate compressive strength is about 80 to 120 kN per cm^2.
(13) Its ultimate tensile and shear strengths are about 60 to 80 kN per cm^2.

Properties of hard steel:

Following are the properties of hard steel:

(1) It can be easily hardened and tempered.
(2) It can be magnetised permanently.
(3) It cannot be readily forged and welded.
(4) It has granular structure.
(5) It is not easily attacked by salt water.
(6) It is tougher and more elastic than mild steel.
(7) It is used for finest cutlery, edge tools and for parts which are to be subjected to shocks and vibrations.
(8) It rusts easily and rapidly.
(9) Its melting point is about 1300°C.
(10) Its specific gravity is 7.90.
(11) Its ultimate compressive strength is about 140 to 200 kN per cm^2.
(12) Its ultimate shear strength is about 110 kN per cm^2.
(13) Its ultimate tensile strength is about 80 to 110 kN per cm^2.