Preheating and post heating treatment

Objectives: At the end of this lesson you shall be able to
- **explain the necessity of heat treatment in welding**
- **describe different methods of heat treatment applied in welding**
- **state the purpose of preheating**
- **state the purpose of post heating.**

Different methods of heat treatment

Direct preheating, Indirect preheating, Local preheating

Preheating and its purpose: Preheating means heating a joint to be welded before or during welding to a certain temperature as shown in tables 1 and 2.

Table 1

Preheating of various metals

Metal	Temperature °C
Nickel alloys (wrought)	Warm it below 16°
Nickel alloys (cast)	90° - 200°
Copper and copper alloys	200° maximum
Silicon bronze	90°
Brass low zinc	200° - 260°
Brass high zinc	260° - 370°
Phosphor bronze	150° - 200°

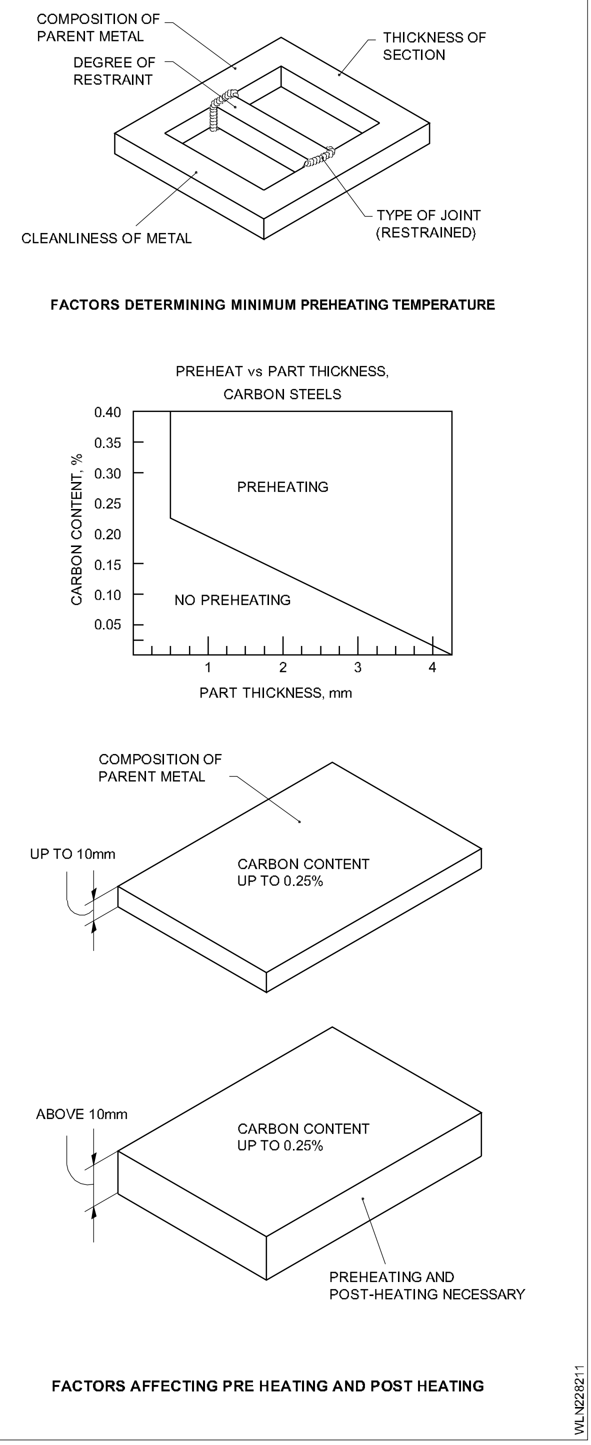
The preheating reduces the rate of cooling after welding. This is necessary to prevent the weld metal from cracking in restrained/rigid joints. Also some of the non-ferrous metals like copper, brass, aluminium, etc. expand more due to heating and ferrous metals like cast iron, medium and high carbon steels require preheating as they are too brittle. These materials are necessarily to be preheated to avoid cracking or distortion. In some cases, it is also necessary to preheat during welding between each layer of deposition.

The minimum preheating temperature for satisfactory welds of different grades of steel, cast iron, non-ferrous metals will depend upon the: (Fig 1)

– type of metal
– composition and properties of the parent metal
– thickness of the plate
– type of joint
– degree of restraint of the joint
– rate of heat input.

Do not allow the temperature to drop below the minimum preheating temperature between each weld run.

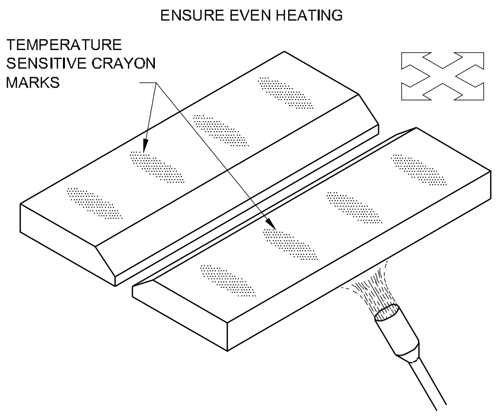
Fig 1



FACTORS AFFECTING PRE HEATING AND POST HEATING

The preheating temperature can be checked by temperature indicating crayons. (Fig 2)

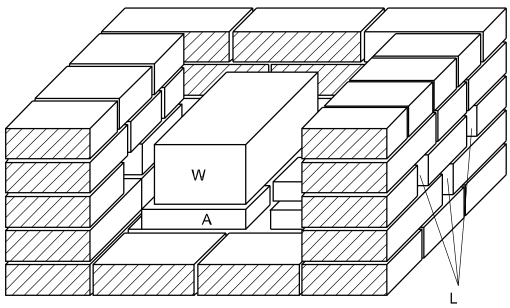
Fig 2



PREHEAT PLATES TO 200°C USING TORCH OR FURNACE AND USE OF CRAYONS

If the job and area to be preheated are large, then it is done in a preheating furnace (Fig 3).

Fig 3

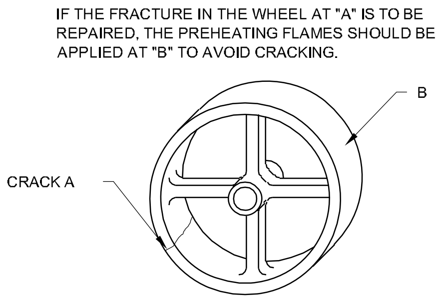


A - SUPPORTING BRICKS, W - WELDED JOB, L - AIR VENTS

TEMPORARY BRICK FURNACE FOR REPAIR WORK

If it is small localised preheating is applied to the joint area only. This is called local preheating. (Fig 4)

Fig 4



TECHNIQUE OF LOCAL PREHEATING

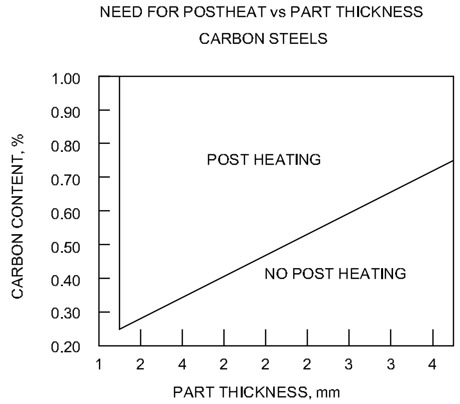
Post heating: Post heating means that the part is heated immediately after welding. The reasons for post heating are to prevent hard and brittle spots from forming in the weldment. It also relieves the residual stresses caused by the welding heat and due to welding of a rigid joint.

The important aspects to be considered while post–heating are:

– the rate of heating
– temperature to which the part is to be post-heated
– holding time in the furnace
– the rate of cooling.

Post heating of carbon steels depends on the thickness of the base metal and its carbon content. (Fig.5)

Fig 5



Post heating retards the rate of cooling of a welded joint.

For plain carbon steels the joint is heated from 100°C to 300° C for general post heating. This treatment will reduce the cracking tendency of carbon steel and cast iron. If they are not post heated, cracks may develop.

Also the welding heat can develop hardness and brittleness in some areas of the joint. In addition the grains of the base metal in the heat affected zone and fusion zone will grow in size which will change the property of the welded joint.

In the case of joints which are not free to expand i.e., restrained joints and in joints in which there is a stress already present before welding, the residual stresses will be more after cooling of the joint. If these residual stresses are not removed after welding, then the joint will fail or distort when they are put into use or the joint is machined or the joint is subjected to dynamic loading.

To avoid the above problems a welded job is usually either normalised or annealed or stress-relieved.

TABLE 2

Preheating temperatures for plain and alloy steels

	Approximate composition (percentage)			Recommended preheating temperature	
	% Carbon			°C	°F
PLAIN CARBON STEELS	C				
Plain carbon	Below 0.20			Up to 95	Up to 200
Plain carbon	0.20 to 0.30			95 to 150	200 to 300
Plain carbon	0.30 to 0.45			150 to 280	300 to 500
Plain carbon	0.45 to 0.80			260 to 425	500 to 800
CARBON MOLYBDENUM STEELS	C	Mo			
Carbon molybdenum	0.10 to 0 .20	0.50		150 to 260	300 to 500
Carbon molybdenum	0.20 to 0.30	0.50		200 to 315	400 to 600
Carbon molybdenum	0.30 to 0.35	0.50		260 to 425	500 to 800
MANGANESE STEELS	C	Mn	Si		
Silicon structural	0.35	0.80	0.25	150 to 260	300 to 500
Medium manganese	0.20 to0 .25	1.0 to 1.75		150 to 260	300 to 500
SAE T 1330	0.30	1.75		200 to 425	400 to 600
SAE T 1340	0.40	1.75		260 to 425	500 to 600
SAE T 1350	0.50	1.75		315 to 480	600 to 900
12% Manganese		1.25	12.0	Usually not required	Usually not required
NICKEL STEELS	C	Ni			
SAE 2015	0.10 to 0.20	0.50		Up to 150	Up to 300
SAE 2115	0.10 to 0.20	1.50		95 to 150	200 to 300
2”% Nickel	0.10 to 0.20	2.50		95 to 200	200 to 400
SAE 2315	0.15	3.50		95 to 260	200 to 500
SAE 2320	0.20	3.50		95 to 260	200 to 500
SAE 2330	0.30	3.50		150 to 315	300 to 600
0SAW 2340	0.40	3.50		200 to 370	400 to 700
LOW CHROME MOLYBDENUM STEELS	C	Cr	Mo	^{0}C	^{0} F
2% Cr. ”% Mo	Up to .15	2.0	0.5	200 to 315	400 to 600
2% Cr. ”% Mo	0.15 to 0.25	2.0	0.5	260 to 425	500 to 800
2% Cr. 1% Mo	Up to 0.15	2.0	1.0	260 to 370	500 to 700
2% Cr. 1% Mo	0.15 to 0.25	2.0	1.0	315 to 425	600 to 800
MEDIUM CHROME MOLYBDENUM STEELS	C	Cr	Mo		
5% Cr. ”% Mo	Up to 0.15	5.0	0.5	260 to 425	500 to 800
5% Cr. ”% Mo	0.15 to 0.25	5.0	0.5	315 to 480	600 to 900
8% Cr. 1% Mo	0.15 Max.	8.0	1.0	315 to 480	600 to 900
PLAIN HIGH CHROMIUM STEELS	C	Cr			
12 to 14% Cr TYPE 410	0.10	13.0		150 to 260	300 to 500
16 to 18% Cr TYPE 430	0.10	17.0		150 to 260	300 to 500
23 to 30% Cr TYPE 446	0.10	26.0		150 to 260	300 to 500

Pre-heat treatment and post weld heat treatment

Objectives: At the end of this lesson you shall be able to
- **explain heat treatment**
- **explain the different methods of heat treatment.**

Heat treatments: Heat treatments are used to obtain certain desired properties. Essentially, heat-treating metals consists of heating and cooling it after it has reached the solid state. There are a number of different methods of heat treatment for various steels in today's industry.

Normalising: Normalising is very similar to annealing except that the steel is held above the critical temperature very briefly and the cooling takes place in air at normal temperature. Normalising will result in refining the grain structure of a metal. It is sometimes used after quenching.

Annealing: Annealing involves heating of metal to a temperature above the critical point and allowing it to cool slowly. The purpose of annealing may be to accomplish one or more of the following.

- To soften the metal, e.g. to improve machinability.
- To relieve internal residual stresses.
- To refine the grains.
- To improve ductility.
- Homogenizing to reduce.

Hardening: Hardening increases the strength of the pieces after they are fabricated. It is accomplished by heating the steel to a temperature above the critical point, and then cooling it rapidly in oil, water or lime. Only medium, high and very high carbon steels can be hardened by this method. The temperature at which the steel must be heated varies with the steel used.

Case hardening: It is the process of hardening the outer surface of steel. It is done by inducing additional carbon into the case of the steel. This is done in a number of different ways all of which require heating to a high temperature and rapid cooling.

Some of the methods employed are:

- to pack the steel part in a sealed metal box which contains some carbonizing material
- to immerse the steel part in a molten cyanide salt bath
- to dip the heated steel part in a container having powdered cyanide
- to heat the steel part and pass carbonizing gas over it
- to employ manual or machine-controlled oxy-acetylene flame process.

Tempering: Tempering (grain refining) is used to relieve some of the brittleness which occurs after a piece of steel has been fully hardened, and to make the steel tough.

It is accomplished by reheating the hardened metal to a specified temperature, depending upon the hardness to be removed, and then quenching.

Quenching: Quenching is the rapid cooling of a metal usually done by immersing it in oil or water. This will cause certain changes in the structure of the metal. For example, carbon steel that is quenched will form a martensite structure.

Stress relieving: Stress relieving is a means of removing the internal stresses which develop during the welding operation.

This process consists of heating the structure to a temperature below the critical range (approximately 590°C) and allowing it to cool slowly. Another method of relieving stresses is peening (hammering). However, peening must be undertaken with considerable care because there is always the danger of weakening the physical strength of the metal.

Stress relieving should be done only if there is a possibility that the structure will crack upon cooling and no other means can be used to eliminate the expansion and contraction forces.

Hardening and tempering

Objectives: At the end of this lesson you shall be able to
- **explain the principle of hardening**
- **describe the effect of carbon content in hardening**
- **explain the process of hardening**
- **explain the tempering of steel**
- **desribe the purpose of tempering**
- **explain the factors on which the mechanical properties of hardened steel depend.**

Introduction: If a piece of steel is heated to a sufficiently high temperature, all the carbon will be dissolved in the solid iron to form the solid solution, austenite of the steel. When it is slowly cooled, the change in the arrangement of the iron atoms will cause a solid solution called ferrite to be produced. The solid solution can only contain up to 0.006% carbon, and so the excess carbon will be forced to leave the solid solution, and produce cementite. This will, with ferrite, form a laminated structure called pearlite.

The principle of hardening: If steel is cooled rapidly (quenched) the excess carbon will not have sufficient time to leave the solid solution with the result that it will be trapped in the iron, and so cause an internal distortion. This internal distortion is the cause for the increase in the hardness of steel with a corresponding reduction in its strength and ductility. This is the basis of the hardening process.

The mechanical properties produced as a result of this treatment will depend upon

- the carbon content of the steel
- the temperature to which it is heated
- the duration of heating
- the temperature of the steel at the start of quenching
- the cooling rate produced by quenching.

The effect of carbon content upon the hardness produced by the process is illustrated in Fig 1.

Fig 1

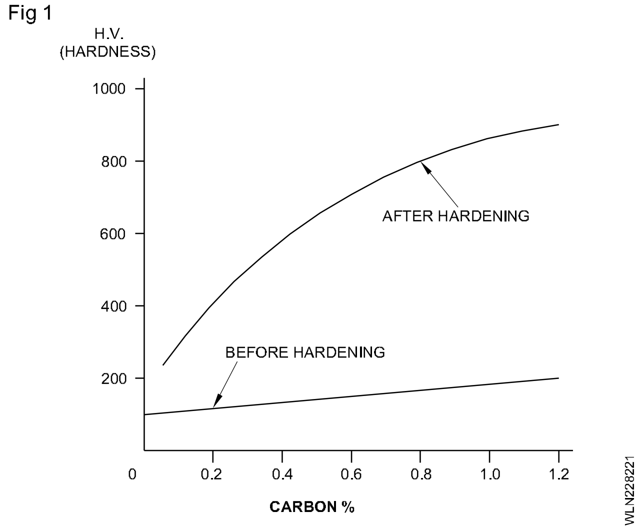
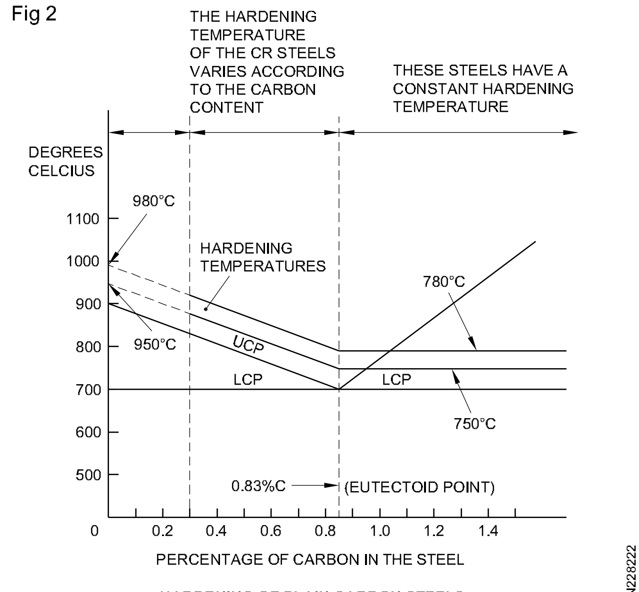


Fig 2 illustrates the temperatures to which steels are heated before quenching.

Fig 2

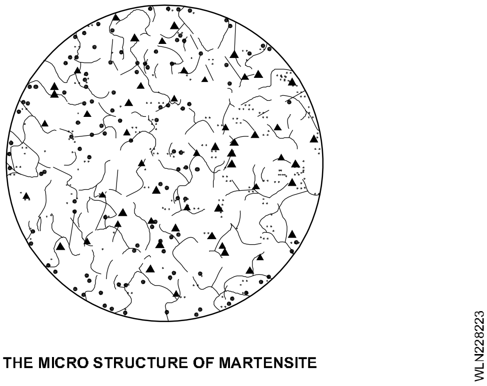


HARDENING OF PLAIN CARBON STEELS

Soaking time: After heating, the steel is held at that temperature for some time. Normally 5 mts are allowed as soaking time for 10 mm thickness of steel.

Cooling: Then the steel is cooled in a suitable quenching medium at a certain minimum rate called the critical cooling rate. The critical cooling rate depends upon the composition of the steel. This cooling transforms all the austenite into a fine, needle-like structure called martensite, the appearance of which is shown in Fig 3.

Fig 3



THE MICRO STRUCTURE OF MARTENSITE

The structure of steel treated this way is very hard and strong, but very brittle.

The quenching medium: The quenching medium controls the rate of cooling.

For rapid quenching a solution of salt or caustic soda in water is used.

For very slow quenching a blast of air is sufficient.

Oil gives an intermediate quenching.

Water and oil are the most common quenching media used.

Air quenching is suitable only for certain special alloy steels.

Tempering: After hardening, steel is usually reheated to a suitable temperature below the lower critical point (heating) to improve its toughness and ductility but it is done at the expense of hardness and strength. It is done in order to make the steel more suitable for service requirements.

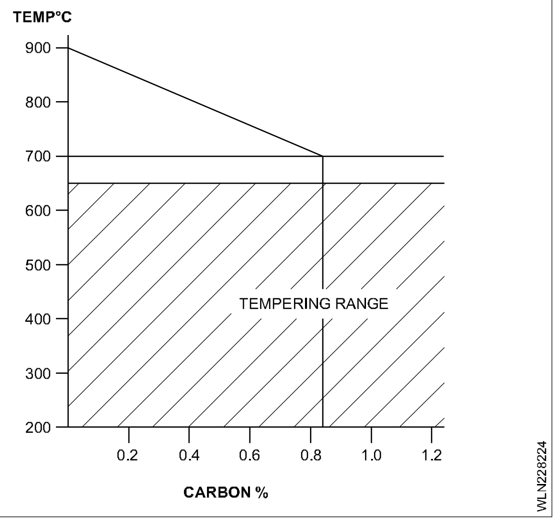
Purpose of tempering the steel: Steel, in its hardened condition, is generally too brittle and too severely strained. In this condition, steel cannot be used, and hence it has to be tempered.

The aims of tempering are:

- to relieve the steel from internal stresses and strains
- to regulate the hardness and toughness
- to reduce the brittleness
- to restore some ductility
- to reduce shock resistance.

Process of tempering: The tempering temperature depends upon the properties required, but it is between 180°C and 650°C. (Fig 4) The duration of heating depends upon the thickness of the material. Tools are usually tempered at a low temperature. The temperature itself is judged by the colour of the oxide film produced upon heating. (Table 1)

Fig 4



This method is not, however, suitable for accurate temperature assessment.

Table 1

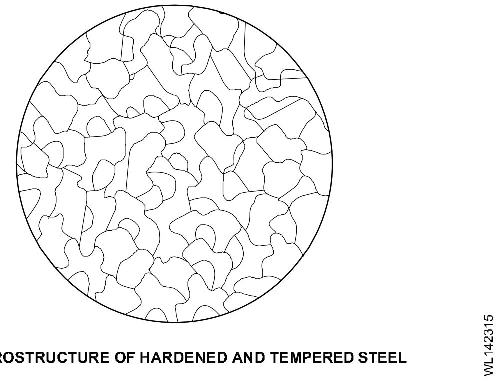
Tempering temperature

Temper colour	Temperature in °C
Pale straw	230
Dark straw	240
Brown	250
Brownish purple	260
Purple	270
Dark purple	280
Blue	300

In a manufacturing plant, when heat-treating is done on a production basis, modern methods are used. Tempering is done in controlled atmosphere furnaces with the temperatures controlled by modern instruments. Under such conditions, it is possible to obtain accurate and uniform results in any number of pieces.

Fig 5 illustrates the appearance of the microstructure of hardened and tempered steel.

Fig 5

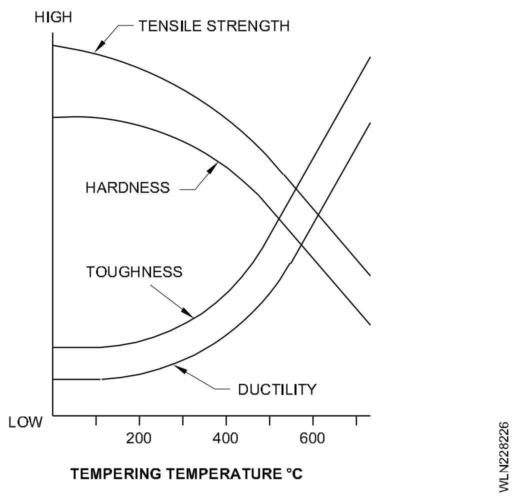


THE MICROSTRUCTURE OF HARDENED AND TEMPERED STEEL

Generally, tempering in the lower temperature range for an increased time provides greater control in securing the desirable mechanical properties. Such heat treatment may not be feasible under all conditions. For precision work, where results justify the method, and for certain combination of mechanical properties, tempering for long periods of time in a lower temperature range provides a reliable method of getting the desired results.

Fig 6 illustrates how the mechanical properties of hardened steel can be modified by tempering.

Fig 6



Heat treatment of steels (Annealing and normalising)

Objectives: At the end of this lesson you shall be able to
- **explain the purpose of heat treatment**
- **explain the purpose of annealing**
- **distinguish between the processes of annealing and normalising.**

The properties of steel depend upon its composition and its structure. The properties of steel and its structure can be changed by heating it to a particular temperature and then, allowing it to cool at a definite rate. The process of heating and cooling for changing the structure of steel, and thus obtaining the required properties is called 'Heat treatment of steel'.

If the steel is heated to a suitable temperature, and then, slowly cooled, the steel will be soft, weak and ductile.

If the steel is heated to a suitable temperature, and then, rapidly cooled (quenched) the steel will be hard and brittle.

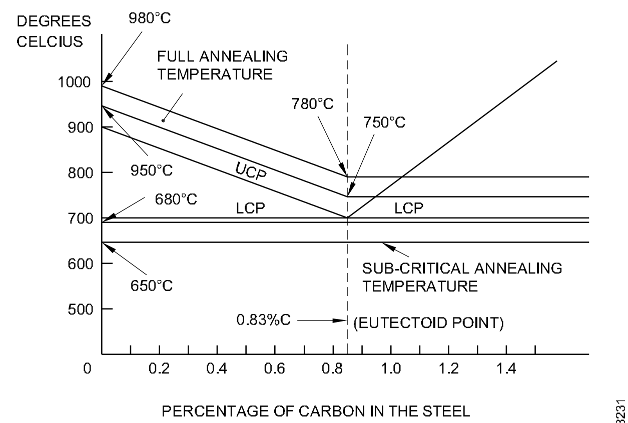
Classification of heat treatments

The treatments that produce equilibrium conditions are annealing and normalising.

Treatments that produce non-equilibrium conditions are hardening and tempering (usually done in conjunction with each other).

Annealing: In this process, steel is heated to a suitable temperature depending upon its carbon content (Fig 1), and is held at that temperature for sufficient time, and then slowly cooled to room temperature.

Fig 1



ANNEALING TEMPERATURES FOR PLAIN CARBON STEELS

WLN228231

The heating, soaking (holding the temperature) and slow cooling cause the grains to become large, and so, produce softness and ductility. For annealing, hypoeutectoid steel is heated to 30° to 50°C above the upper critical temperature, and it is 50°C above the lower critical temperature for hypereutectoid steel. (Fig 1)

Soaking time at this temperature is 5 mts/10 mm of thickness for carbon steel.

The cooling rate for carbon steel is 100 to 150°C/hour.

The cooling is done in the furnace itself by switching off the furnace or the steel is covered either with sand or dry lime and dry ash.

Annealing temperature

Carbon content%	Temperature°C
<0.12	875 to 925
0.12 to 0.25	840 to 970
0.25 to 0.50	815 to 840
0.50 to 0.90	780 to 810
0.90 to 1.3	760 to 780

Purpose of annealing

Annealing is done:

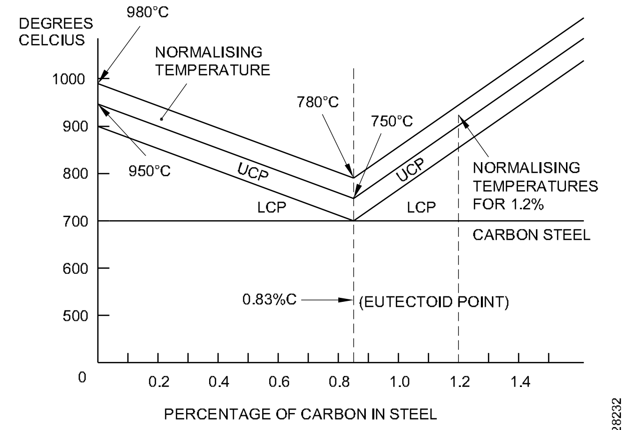
- to obtain softness
- to improve machinability
- to increase ductility
- to relieve internal stresses
- to reduce or eliminate structural inhomogeneity
- to refine grain size
- to prepare the steel for subsequent heat treatment process.

Normalising: Due to continuous hammering or uneven cooling, strains and stresses are formed in the internal structure of steel. These should be removed from forgings or castings; otherwise, they may fail at any time while in use.

Normalising is done to produce a fine grain for uniformity of structure and for improved mechanical properties.

The normalising process: In this process, steel is heated to a suitable temperature depending upon its carbon content, (Fig 2) and held at the same temperature, and then, cooled freely in air.

Fig 2



NORMALISING TEMPERATURES FOR PLAIN CARBON STEELS

WLN228232

Normalising is usually done before machining and before hardening to put the steel in the best condition for these operations.

The steel is heated to a temperature (300 to 400C above the upper-critical temperature) at which all austenite is present even in the case of high carbon steel. This is because this process is the first step towards providing the final properities, and it is necessary to start with austenite to ensure uniformly.

The heated piece for normalising should not be kept at a wet place, in wet air or kept in forced air as they will induce some hardness.

Use of temperature indicating crayons

The temperature of the preheated job can be checked by wax crayons. Marks are made on the cold job pieces by these crayons before preheating and after the job pieces reach the preheating temperature the marks will disappear.

This indicates that the job has been heated to the required preheating temperature. Different wax crayons are available for checking different temperatures. The temperature which is checked by the crayon will be marked on it.