SPHEROIDISE ANNEALING

The machinability of high carbon tool steels is at its best condition when the structure is composed of grained (or globular) pearlite. All alloy steels, including those of the carbide class, as well as ball bearing steels, should have a structure of globular pearlite in the deliverable state.

The process of producing a structure of globular pearlite is known as *spheroidising* or *spheroidise annealing*. This is performed by heating the steel slightly above the critical point Ac_1 (line GS), (730°C to 770°C) with subsequent holding at this temperature followed by slow cooling in the furnace at the rate of 25°C to 30° C per hour to a temperature of 550°C to 600°C. The subsequent cooling may be conducted in still air at room temperature. This process transforms lamellar pearlite into globular type.

The range of heating temperatures, at which globular pearlite is formed, is very narrow in steels with near-eutectoid compositions. The optimum annealing temperature is 750° C for eutectoid steels and 770°C for hypereutectoid steel (Fig. 6.6). The machinability of hypereutectoid, however, cannot be improved by this process but by full annealing or by normalizing.

HOMOGENISING

Homogenising or *diffusion annealing* is applied to steel ingots (both carbon and alloy steel) and heavy complex casting for eliminating chemical inhomogeneity within the separate crystals by diffusion.

This is carried out at temperatures from 1,100°C to 1,200°C (the optimum temperature is 1,150°C) at which diffusion proceeds quite easily and to some extent, equalizes the composition of steels. After the required heating temperature is achieved, the metal is held for a very short period. Holding is followed by cooling with the furnace for 6 to 8 hours to 800°C to 850°C and then further cooling in air.

Homogenising naturally causes a very rapid growth (for heating to a very high temperature) of austenitic grains. After homogenising, therefore, the steel ingots necessarily undergo an ordinary phases (full) annealing for the fine-grain structure to be formed.

ISOTHERMAL ANNEALING

Isothermal annealing is carried out as for ordinary annealing to form austenite. It is then cooled comparatively rapidly in air or by a blast in a furnace to a temperature of 50°C to 100°C below point Ar_1 line PSK (lower critical) i.e., to 600°C to 700°C. The steel is held isothermally at this temperature (at constant temperature) during a certain period of time to provide for complete decomposition to pearlite and hence the name *isothermal annealing*. This is followed by comparatively rapid cooling.

A homogeneous structure of the metal is obtained and the results of annealing are more stable. The main advantage of isothermal annealing is that it reduces the time required for heat treatment of the steel. This is especially true for alloyed steels which must be cooled very slowly to obtain the required reduction in hardness.

6.7 NORMALIZING

When steel is cold-worked the crystal structure is distored, and the metal may be brittle and unreliable. The internal structure of hot-worked forged part may also be distorted owing to being worked at a very low temperature. It can also be seen that a variable finishing temperature will result in a variable structure for forgings of the same carbon content. Likewise, if a casting is poured at a somewhat indefinite temperature and cools at different rates in different parts, it may be unreliable.

Normalizing is, therefore, used particularly for the following purposes :

1. To eliminate coarse-grained structure.
2. To remove internal stresses that may have been caused by working.
3. To improve the mechanical properties of the steel.

In addition to all these purposes, it may be used to increase the strength of medium carbon steels to a certain extent (in comparison with annealed steels), to improve the machinability of low carbon steels, to improve the structure of welds, etc.

Normalizing is frequently applied as a final heat treatment for items which are to operate at relatively high stresses.

The process of normalizing consists of :

1. Heating the metal to temperatures within the normalizing range in Fig. 6.6 which is shown usually 40°C to 50°C above Ac_3 (line *GS*) and Ac_m (line *GSE* higher-critical).
2. Holding at this temperature for a *short time* (about 15 minutes).
3. Cooling in air.

This produces a homogeneous structure consisting of ferrite and pearlite for hypoeutectoid steel, only pearlite for eutectoid steel and pearlite and cementite for hypereutectoid steels. The normalized structure of alloy steels consists of ferrite and sorbite.

Normalized steels have a higher yield points, tensile strength and impact strength then if they were annealed, but ductility and machinability obtained by normalising will be somewhat lower.

6.8 HARDENING

The operation of hardening is applied to all tools and some important machine parts intended for especially heavy duty service as well as to all machine parts made of alloy steel.

The purposes of hardening with *subsequent tempering* are :

1. To develop high hardness to resist wear and to enable it to cut other metals.
2. To improve strength, elasticity, ductility, and toughness.

The process consists of :

1. Heating the steel to a temperature above critical point.
2. Holding at this temperature for a considerable period.
3. Quenching (rapid changing) in water, oil or molten salt bath.

Hypoeutectoid steels are heated from 30°C to 50°C above points Ac_3 (higher critical) while hypereutectoid steels are heated about the same amount above Ac_1 (lower critical). This is shown in Fig. 6.7. In the first case, ferrite + pearlite, and in the second, perarlite + cementite, are transformed into austenite upon heating. A considerable

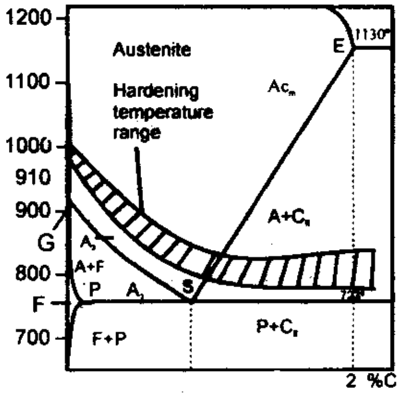

Figure 6.7 Temperature ranges for hardening

part of the cementite is retained.

Rapid cooling should enable the austenite to be supercooled to the martensitic point.

Alloy steels and high speed steels are heated for hardening to about 1,100°C to 1,300°C, and cooled in a current of air. The alloying elements increase the stability of austenite and retard the decomposition of austenite into martensite. This means that with less drastic speed of cooling the same harder (martensite) constituent can be obtained as would be developed in a carbon steel by a faster rate of cooling. The Table 6.1 gives cooling rates in various cooling media and the mechanical properties and structures resulting from such cooling rates applied to eutectoid steels.

TABLE 6.1 COOLING RATES RESULTING STRUCTURES AND MECHANICAL PROPERTIES

Cooling rate	*Structures*	*UTS (MPa)*	*Yield (MPa)*	*Hardness (Rock-well) 'c'*	*% Elongation*	*% Reduction in area*
Water quench	Martensite	1720	–	65	Low	Low
Oil quench	Very fine pearlite	1100	551	35	5	30
Air cool	Fine pearlite	860	275	25	8	22
Furnace cool	Coarse pearlite	525	138	15	12	27

(MPa = 1.02×10^{-1} Kgf/mm^2)

REQUIREMENTS FOR HARDENING

It will probably be advantageous to summarize at this time several of the more important requirements in the hardening of steel. They are given below :

1. Composition, carbon and alloy content.
2. Homogeneity of the austenite.
3. Grain size of the austenite.
4. Heating rate and time.
5. Quenching medium.
6. Quenching rate.
7. The size (mass of the part).
8. Surface condition.

6.9 MARTEMPERING

Martempering or ***interrupted quenching*** is a ***hardening*** operation that produces martensite. It is ***not tempering***. In this method the steel is heated to the hardening temperature and then quenched in a medium, usually in a salt bath, having a temperature, just above that where martensite starts to form (usually from 150°C to 300°C). The article is held until it reaches the temperature of the medium but not long enough to austenite decomposition. It is then cooled further to room temperature in air and sometimes in oil. The austenite is transformed to martensite during the last period of cooling to room temperature. This treatment will provide a structure of martensite and retained austenite in the hardened steel.

Martempering has the following advantages over conventional quenching :

1. Less volume changes occur due to the presence of a large amount of retained austenite.
2. Less warping since the transformations occur almost simultaneously in all parts of the article.
3. Less danger of quenching cracks appearing in the article.

6.10 AUSTEMPERING

In austempering or *isothermal quenching* the steel part is heated to the required hardening temperature and then quenched in a molten salt or lead bath usually at a higher temperature, i.e., from 300°C to 350°C, than that is prescribed for martempering. The steel is held in the bath for as long a time as is needed for isothermal transformation of the austenite, i.e., until transformation to *bainite* (acicular troostite) and *not martensite* is complete.

Although the steel is of the same hardness as that of martensite, it is tougher and more ductile than other quenched and tempered steels. Tempering is rarely needed after austempering.

The foundation for the austempering process is based upon the austenitic transformation at constant temperature and is represented diagrammatically by *TTT*–curves in Fig 6.5.

6.11 HARDENABILITY

Hardenability is that property of a steel which determines the *depth* and *distribution* of hardness obtained by the quenching. It is not an indication of the *hardness*. Hardenability is usually interpreted as the ability to become uniformly hard or to harden in depth. The depth of hardening is usually taken as distance from the surface to the semimartensitic zone, i.e., 50 per cent martensite plus 50 per cent pearlite.

Full hardening of carbon steels is observed in articles of a diameter or thickness up to 25 mm. Alloy steels harden to considerably larger depth due to the high stability of the supercooled austenite and correspondingly lower critical cooling rate. Therefore, alloy steels may be effectively hardened by quenching in oil instead of water.

DETERMINATION OF HARDENABILITY

Several methods are used to determine the hardenability of steels :

1. by the appearance of the fracture,
2. by the distribution of the hardness along the cross-section, and
3. by an end quench test.

The simplest and most reliable of these methods is the *Jominy* or *end quench test*. The standard Jominy specimen consists of a cylindrical rod 100 mm long and 25 mm in diameter. In making a test, the specimen is first heated to a suitable austenitic temperature and held there long enough to a uniform austenitic structure. It is then placed in a jig and a stream of water is allowed to strike one end of the specimen. The experimental arrangement is shown in Fig. 6.8. The advantage of the Jominy test is that in a single specimen one is able to obtain a range of cooling rates varying from a very rapid water quench at one end to slow air quench at the other end. Following the complete transformation of the austenite in the bar, two shallow flat surfaces are ground on opposite sides of the bar and Rockwell

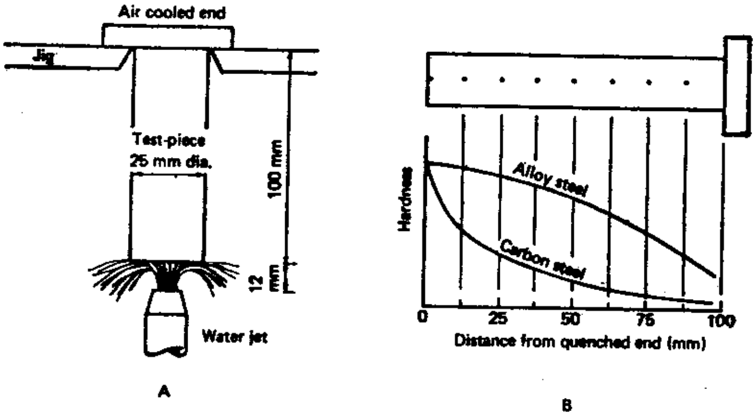

Figure 6.8 Jominy or end-quench test

hardness values are taken at 1.5 mm intervals along the bar. The results of the test are expressed by the hardenability number *lc*, in which *l* is the distance from the quenched end to the point with a semimartensite structure, and *c* is the hardness value. The measured hardness values may also be plotted against the distance to obtain a hardenability curve. A typical example is shown in Fig. 6.8b where it can be seen that the hardness is greatest where the cooling is most rapid–near the quenched end.

After plotting such a curve, a horizontal line may be drawn at the corresponding hardness of the ;semi-martensite zone for the given steel. The intersection of this line with the curve will indicate the length of the hardened zone (distance from the quenched end).

6.12 TEMPERING

When a piece of steel is taken out of the quenching medium, as already stated, it is hard, brittle and will have severe unequally distributed internal stresses besides other unfavourable characteristics. In general, tempering restores ductility and reduces hardness and results in some decrease in hardness. The primary objects of tempering are, therefore, as follows :

1. To stabilize the structure of the metal.
2. To reduce internal stresses produced during previous heating.
3. To reduce some of the hardness produced during hardening and to increase the ductility of the metal.
4. To give the metal right structural condition combined with toughness and shock-resistance.

The tempering treatment requires :

1. Reheating the steel after hardening to temperatures below Ac_1 point (*PSK* line in Fig. 6.6).
2. Holding it for a considerable time.
3. Slow cooling. It is desirable that the temperature of the steel shall be maintained for not less than 4 to 5 minutes for each millimeter of the section.

Exact temperatures at which tempering should be carried out depends upon the purpose for which the article or tool is to be used. According to the heating temperatures, ranges of which are specified in the lower part of Fig. 6.6, tempering is classified into 3 types. They are :

1. *Low temperature tempering* which is done in the temperature from 150°C to 250°C. The purpose of this procedure is to relieve internal stresses and to increase the ductility without appreciably reducing its hardness. Low temperature tempering is applied in the heat treatment of carbon and low alloy steel cutting tools, as well as measuring tools and parts that have been carburised and surface hardened.
2. *Medium-temperature tempering* which involves heating the work to 350°C to 450°C. The structure of steel is altered by this procedure. Martensite is transformed into secondary troostite. The results are a reduction in hardness and strength of the metal and an increase in the elongation and ductility. Medium temperature tempering is mainly applied to the articles and parts which are subjected to impact loads : chisels, hammers, springs, spring plates, etc.
3. *High-temperature tempering* which is done in the range of 500° C to 650° C. At these temperatures sorbite is formed in the steel and the internal stresses are almost completely eliminated. High-temperature tempering imparts high ductility to parts, yet permits them to retain adequate hardness. This is applied to machine parts which are subjected to high stresses and impacts, gear wheels, shafts, connecting rods, etc.

TEMPERING BATHS

Baths using tempering oils may be employed for temperatures up to approximately 230°C. Tempering oils are usually mineral oils. For temperatures above about 230°C, liquid salt baths are preferred. These salt baths usually consist of mixture of nitrates, or nitrates and nitrites. For higher temperatures, chlorides and fluorides are usually employed. Steel parts are often tempered in electrically heated or gas-fired furnaces within which the air is circulated to produce uniform temperature.

TEMPER COLOURS

There is a curious phenomenon associated with low-temperature tempering of carbon tool steels. This is the formation of temper colours on the surface of the steel being treated. These colours are caused by the surface oxidation of the steel with the formation of thin films of iron oxide. Table 6.2 gives tempering colours and corresponding tempering temperature from 220°C to 300°C above which the tempering colours vanish and surface films of oxide become opaque.

In the shop-floor the general practice of quality check includes visual inspection of colour of the work pieces.

TABLE 6.2 APPROXIMATE TEMPERING TEMPERATURE AND TEMPER COLOUR FOR TOOLS

Types of work	*Approx. tempering Temp. in °C*	*Temper colour*
Springs	300	Dark blue
Screw drivers	295	Blue
Cold chisels for wrought iron	290	Violet
Planing cutter for soft wood	285	–
Cold chisels and sets for steel, cold chisels for cast iron, chisels for wood	280	Purple
Gimlets, axes and hot sets	275	–
Surgical instruments, augers and pressing cutters	270	Reddish-brown dappled with purple
Twist drills for wood	265	–
Plane irons, gouges and brace-bits and stone-cutting tools	260	–
Rock drills, screw-cutting dies, boring cutters and reamers	245	–
Shear blades, milling cutters and bone cutting tools	240	Golden yellow
Wood ingraving tools, paper-cutter, planers for iron	235	–
Hammer faces, planers for steel, screwing dies for brass	230	Straw or dark straw
Hacksaws, steel engraving tools, circular saws for steel, light turning and parting tools	225	–
Scrapers and lathe tols for brass	220	Light straw or pale yellow

6.13 CASE HARDENING : CARBURISING

The oldest known method of producing a hard surface on steel is case hardening or carburising. The steel used for this purpose is usually a low-carbon steel of about 0.15 per cent carbon, which does not respond appreciably to heat treatment. In course of the process, the outer layer is converted into a high carbon steel with a carbon content ranging from 0.9 to

1.2 per cent carbon. If it receives proper heat treatment, it will have an extremely hard surface on the outside and a soft ductile core.

This process, in brief, is merely heating iron or steel to red heat, in contact with some carbonaceous materials such as wood, bone, or leather charcoal, with compounds such as carbonates of barium, calcium, or sodium which are termed "energizers". These energizers are added with the materials to increase the concentration of carbon monoxide and thus improve the rate of curburising. Iron, at temperatures close to and above its critical temperature, has an affinity for carbon. The carbon thus enters the metal to form a solid solution with iron and converts the outer surface into a high carbon steel.

On completion of the carburising treatment the composite steel, having a high carbon case and a low carbon core, is heated in different ways depending on the results desired. Since there is some grain growth in the steel during the prolonged carburising treatment, the work should be heated to the critical temperature of the core and then cooled, thus refining the core structure. The steel should then be reheated to a point above the transformation range of the case and quenched to produce a hard, fine structure. The lower heat-treating temperature of the case results from the fact that steels having high amount of carbon are normally austenised for hardening just above the lower critical temperature.

Alloy steels are usually quenched in oil and carbon steels in water. This treatment will produce a hard fine-grained case, while the core of the structure will retain the properties of low carbon steel.

6.14 CYANIDING

It is a process of producing hard surface on low carbon or medium carbon steels by immersing the steel in a molten salt bath containing cyanide maintained at 800°C to 900°C and then quenching the steel in water or oil. The hardness produced by this treatment is due to the presence of compounds of nitrogen as well as of carbon in the surface layer.

A bath containing one-third each of sodium chloride, sodium carbonate and sodium cyanide is used for the cyaniding treatment. Under average conditions, a depth of case of 0.125 mm will be produced in about 15 minutes at 850°C. But special salt compositions are available which enable much thicker cases to be obtained, if required. Cyaniding is used chiefly for cases not exceeding about 0.8 mm in thickness.

One advantage of this process is that the bright finish of machined parts can, if required, be maintained ; a second is that distortion is more easily avoided ; a third is that the change in hardness from the case to the core is more gradual and flaking of the case is eliminated.

6.15 NITRIDING

Nitriding is a process of producing hard surface layer on alloy steels only. Nitriding consists essentially of heating the steel in an atmosphere of ammonia gas at temperature of 500°C to 650°C without further heat treatment. The ammonia is dissociated and the nascent nitrogen combines with elements in the steel to form nitrides. These nitrides give extreme hardness to the surface. A hard surface layer usually from 0.2 to 0.4 mm in depth is produced in 50 hours.

Nitriding is the last operation after shaping and heat treatment process. Thus after forging, the sequence of operations is :
(a) oil hardening at 850°C to 900°C, (b) tempering at 600°C to 650°C, (c) rough machining, (d) stabilising (to remove internal stresses) at 525°C to 550°C, (e) final machining and ultimately, (f) nitriding.

Nitriding is used on many automotive, airplane, and diesel engine wearing parts, as well as on numerous miscellaneous parts such as pump shafts, gauges, drawing dies, gears, clutches, and mandrels. Its use is limited by the expense necessary for the treatment and the comparatively thin case obtained.

6.16 INDUCTION HARDENING

Induction heating has proved satisfactory for many surface hardening operations as required on the bearing areas of crankshafts, camshafts, axleshafts and similar wearing surfaces. It differs from ordinary case-hardening practice in that the analysis of the surface steel is not changed, the hardening being accomplished by an extremely rapid heating and quenching of the wearing surface which has no effect on the interior core. The hardness obtained in induction hardening is the same as that obtained in conventional treatment and depends on the carbon content.

In this process, a high-frequency current of about 2,000 hertz is passed through a copper inductor block which acts as a primary coil of a transformer. The block is placed around but does not touch the surfaces to be hardened. The heating effect is due to the induced eddy current and hysteresis loss in the surface material. The hardening temperature is about 750°C to 760°C for 0.5 per cent carbon steel and 790°C to 800°C for alloy steel. The heated areas are then quenched immediately by sprays of water delivered through numerous small holes in the block. Both automatic and hand control can be employed. A depth of case of approximately 3 mm is obtained in about 5 seconds.

Although the equipment cost is high, it is practiced by the advantages of the process used, which include fast operation, freedom from scaling, clean operation, little tendency for distortion, no manual handling of the hot parts, and low treating cost. Medium carbon steel has proved satisfactory for parts, and the nature of the process has practically eliminated the necessity for using costly alloy steels.

6.17 FLAME HARDENING

The process of hardening steel by heating it with the flame of an oxy-acetylene torch is known as flame hardening which, like the induction-hardening process, is based on rapid heating and quenching of the surface by water. The flame is directed to the desired part without heating the remainder of the work efficiently to affect it. The advantages in favour of its application are as follows :

1. Because it heats quickly, flame heating is convenient when hardness is required only for a limited depth, the remainder retaining its original toughness and ductility.
2. Flame heating makes it possible and practical to harden a part or all of a piece of work that is too large or too inconvenient to place in a furnace.
3. The amount of time required for heating is less with flame heating than with a furnace.

6.18 DIFFUSION COATING

Diffusion coating, or metallic cementation, is the process of impregnating the surface of steel with aluminium, chromium, silicon, boron, beryllium and other elements.

Diffusion coating is accomplished by heating and holding steel parts in direct contact with one of the above elements which may be in the solid, liquid or gaseous state. This process imparts a number of valuable properties to steel, among which are high heat, corrosion and wear resistance. In many cases, steel subjected to diffusion coating may be used as a substitute for a high alloy steel.

6.19 HEAT TREATMENT OF ALUMINIUM

Aluminium is the only nonferrous material of structural importance that can be effectively heat-treated to enhance its mechanical properties. The heat treatment of aluminium involves all the distinct steps as with ferrous materials. The mechanism of this heat treatment that has commercial importance is known as *precipitation hardening*.

PRECIPITATION HARDENING : AGE HARDENING

Precipitation is the decomposition of a solid solution into two phases of different composition–the precipitate, and the solid solution. And precipitation hardening is the process whereby hardening of an alloy is caused by the precipitation of a constituent from a supersaturated solid solution by heating to some elevated temperature. Precipitation hardening is sometimes referred to as *age hardening* which is defined as the spontaneous increase of hardness at room temperature with lapse of time. Both terms are used interchangeably owing to their identical mechanism of hardening.

The phenomenon of precipitation can occur only in those alloys in which there is a decrease in solid solubility with decreasing temperature resulting in a supersaturated solution.

In essence, the situation is depicted in Fig. 6.9, which is characteristic of all alloys which age-hardened and the aluminium copper alloys have been used as a typical example. This diagram shows that aluminium forms a solid solution with copper in which the latter has a maximum solubility of 5.7 per cent at the eutectic temperature (548°C). For an example *duralumin* contains 4 per cent copper and small quantities of other alloying elements at temperature 500°C. At this point, all

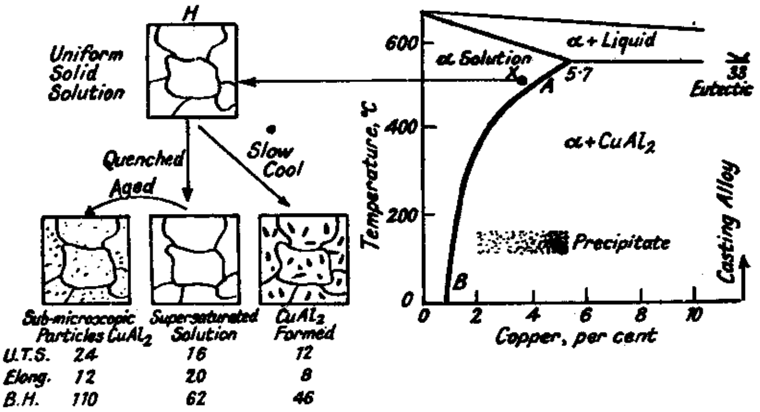

Figure 6.9 A typical age-hardening diagram (aluminium-copper alloys)

the compound is dissolved to form a honogeneous solid solution. The structure is shown at *H* at the left-hand side of the equilibrium diagram. When the alloy is slowly colled from 500°C, the solubility is reduced and the compound is precipitated as relatively coarse particles, visible under the microscope, until at room temperature about 0.5 per cent of copper remains in solution. This is indicated by the falling solubility curve*AB*.

After slow cooling, alloys containing up to 0.5 per cent copper will have a single-phase structure (α-solution of copper in aluminium). If the copper content ranges from 0.5 to 5.0 per cent, a two-phase structure (α+$CuAl_2$) will be obtained.

On rapid cooling (quenching), however, there is not enough time for diffusion to bring about the nucleation and growth of the precipitates and a super-saturated solid solution is retained at room temperature. This condition is unstable and as a function of time, at room temperature and at elevated temperatures up to 200°C the alloy (α+$CuAl_2$) *ages* and tends to reject the excess crystals of $CuAl_2$ and the alloy acquires a single-phase structure, α-solid solution, and the precipitate. This results in an increase in strength and hardness. The maximum hardness is attained before any precipitate is visible under the microscope, although some atomic changes must have occurred.

Other aluminium alloys require precipitation hardening at about 165°C. To prevent the onset of normal age-hardening storage in a refrigerator at temperature down to – 20°C is used. This is especially done where riveting or pressing operations are involved on solution treated alloys.

The above phenomenon shows that the relative amount of the precipitate is determined by the rate of decrease in solubilities of one constituent of the solid solution, the rate of temperature change, and the time. To obtain optimum properties, therefore, control is must for both time and temperature with the proper combination depending on the alloy.

It is generally believed that the first stage in precipitating reaction is the formation of nuclei of the precipitating phase, followed by growth of the nuclei in larger particles. This results in the lattice distortion which is responsible for the hardening of alloys. The actual cause of age-hardening, however, is the obstruction to the motion of dislocation set up by the fine transition precipitate particles and the strains produced by the mismatch of the transition products with the matrix. Controlling the progress of the transformation so as to obtain the maximum obstruction to dislocation motion is the aim of the heat treatment of this alloy.

Similar precipitation phenomena occurs in several other systems such as Al-Ag, Al-Mg, and Cu-Be. In fact, there are some 200 precipitation hardening alloys in commercial use. But it must be remembered that no one pattern appears to be followed by all alloys capable of precipitation hardening, but, rather a number of patterns are possible.

If an alloy is held for a long period of time at the treatment temperature or if the temperature is raised to 250°C and higher, coagulation of the particles, formed at the centres of decomposition, is observed and the intermediate phase becomes stable. This is called *overaging*.

In general, precipitation is accompanied by changes in the physical, chemical and mechanical properties of alloys. Electrical conductivity generally increases (except in Al-Cu alloys), and hardness increases by passing through a maximum and then decreases. Strength also increases with hardness but ductility decreases.

6.20 HEAT-TREATMENT OF CUTTING TOOLS

Cutting tools most commonly used are made of carbon steel and high-speed steel. They are heat treated to develop certain desired qualities in the cutting tools, particularly to have high hardness and high wear-resistance, which are needed to prevent the cutting edges of a tool from becoming blunt by wearing away in service.

The first operation is *forging*, which should be carried out at 850° to 950°C for carbon steel depending upon the carbon content of steel and at 1100° to 1300°C for high speed steel. Forging should never be continued when the tool has cooled to a temperature of about 723°C for carbon steels and about 920°C for high speed steels.

The next operation is *normalizing* or *annealing*. Plain carbon steels are usually normalized, while high-speed steels are annealed. This is essential, and must be carried out in advance of hardening in order to have uniform grain structure and to relieve the strains set up by forging. Tools of carbon steels are heated for normalizing to 760° to 840°C. Heating should be slow upto about 723°C, after which cooling is done freely in air. The first golden rule in heat-treating any high-speed tool is to warm the steel before it is put into either the fire or the furnace, and then to heat it up slowly, thoroughly, and evenly. If this simple hint is observed, there is virtually no risk of spoiling. The reason is that high-speed steel is denser, i.e., about 10 per cent heavier than ordinary steel and its thermal conductivity is lower. High-speed steels are heated for annealing to about 900°C, allowed to cool in still air, reheated to about 800°C, and again cooled in still air. To put the steel into the softest condition it is heated to about 850°C and cooled in the furnace. Powdered charcoal, charred bone, charred leather, slaked lime, sand, fireclay, etc. can be used to pack the closed box in which the steel is annealed, to prevent carburisation. The steel is held at the annealing temperature for not less than 3 to 4 minutes for each 1 mm of section thickness of the longest pieces being treated.

The next step is ***hardening***. General recommendations for hardening temperatures for any given tool steel based on carbon content are as follows : For steels of 0.70 to 0.80 per cent carbon content, 780 to 850°C ; for steels of 0.80 to 0.95 per cent carbon, 765° to 790°C ; for steels of 0.95 to 1.10 per cent carbon, 750° to 775°C ; and for steels of 1.10 per cent and over carbon, 750° to 770°C. They are next quenched by immersing them in a bath of fresh water, but water is not an ideal quenching medium. In order to secure more even cooling and reduce danger of cracking, brine solution with 10 per cent brine or caustic soda solution with 3 to 5 per cent caustic soda may be used. The hardening of high-speed steel requires several steps or separate operations. The first consists in pre-heating the tool to about 800°C in a pre-heating furnace. The steel is held at this temperature for 15 to 20 seconds for each 1 mm of the section thickness of the article to be treated. The second step is to transfer the steel to a furnace where it can be heated rapidly to the hardening range of about 1100°C to 1300°C. In treating tools care should be taken to prevent decarburisation. The tool is held at this temperature for one or two minutes depending upon the bulk, and then removed and cooled in a blast of cold dry air, or quenched in oil.

Hardened steel is then ***tempered***. Tempering is designed, as previously indicated, to remove the excessive brittleness characteristic of a newly hardened tool, without reducing to any appreciable degree of the hardness at the cutting edge. Tempering temperatures for carbon steels usually vary from 150 to 300°C and for high-speed steel from 550 to 650°C, depending upon the type of tool and its use. In heating steels for tempering, either a furnace or some kind of bath such as oil, various salt mixtures or lead may be used.

The heat-treating processes applied to various tools of carbon and high-speed steel are essentially similar to one another. Some differences are caused by the fact that certain tools, e.g., screw taps, screw dies, lathe, planer and shaping tools, are best not hardened throughout, whereas others, e.g., drills, milling cutters, should be hardened throughout.

6.21 HEAT-TREATING FURNACES

Furnaces which are used for heat-treating metals may be classified as : (1) hearth furnaces, and (2) bath furnaces.

Heat-treatment involves, at all events in its main stages, raising the metal to a correct temperature in a furnace fired or heated by various methods. The fuel used may be coke, coal, gas (town, blast-furnace, or natural), fuel oil, or electricity. Gas and oil are in common use for heat-treatment of large workpieces. A gasfired furnace is most suitable for heating upto about 1100°C. In recent years with the availability of cheap electric power, electrically heated furnaces have gained steadily in popularity. The advantages claimed for them are simplicity, economy, precision of temperature control, high thermal efficiency, cleanliness of operations, and saving of space. The close control of scaling and deoxidation of the surfaces of workpiece is also considerably easier in electrically heated furnaces. Electricity is principally used where the temperatures required are not above 1100°C.

Both types of furnaces should include automatic temperature regulators so that a control of temperature can be maintained. Accurate temperature control is a primary requisite for a furnace for the heat treatment of metal, and particularly that of aluminium alloys.

6.22 HEARTH FURNACES

The heating may be by gas, oil or electricity. The *electrically-heated hearth furnaces* are usually similar in general appearance to fuel-fired furnaces. The electric resistance heating elements, which will convey heat directly to the charge by radiation, are supported in the furnace wall by the refractory lining. In low temperature furnaces, the heat is transmitted to the charge by the enforced circulation of electrically heated air.

Hearth furnaces for oil or gas fuels are built with the heating chamber and combustion space arranged in the following ways.

STATIONARY HEARTH FURNACES

This consists of a rectangular structure of steel lined with fire bricks. One end of this structure is provided with a movable door which is also lined with fire bricks. This construction is known as a *box-type* or *batch type* furnace. This may be classified as follows :

Direct fuel-fired furnace. This is very popular in all temperature ranges. The metal is heated in direct contact with the products of combustion from the fuel. This type of construction is more adaptable for annealing steel castings and for heating steel which is to be forged.

Indirect fired furnace. This is extensively used in heat-treating practices upto a temperature of about 1100°C. It has a heating chamber which separates the combustion space from the workpiece. Reduced scaling and contamination from the fuels are the advantages in its use.

Muffle furnace. The muffle, made from suitable refractory, is a permanent part of the furnace and contains all of the work space. In this furnace, the hot gases surround the heating chamber but do not enter it. This is used principally in tool rooms for the heat-treatment of dies and special tools to avoid scaling, decarburisation, and other compositional changes.

Recirculation furnace. This is used for tempering, toughening, and stress-relieving, in the temperature ranges below 723°C. In this furnace the fuel, gas or oil, is burned in a chamber and products of combustion are circulated through the work space by a suitably arranged centrifugal fan and baffling.

MOVABLE-HEARTH FURNACES

There are two principal types of movable hearth furnaces : (1) the car bottom, and (2) the rotary type. These furnaces are strictly specialized and work on a mass production scale.

Car bottom furnace. In the car bottom furnace, excluding the bottom, the furnace is similar in shape to a fixed-hearth furnace. The charging and discharging of a large heat-treating furnace is done most conveniently by mounting the hearth on a car which can be moved from the furnace for loading and unloading.

Rotary-hearth furnace. The rotary-hearth furnace is used for hardening, tempering, and carburising process. The furnace structure is a refractory-lined shell that encloses a rotating hearth. The materials are charged as individual pieces, or as small pieces in trays, through the door. They do not require much floor space, nor do they require boxes made of non-scaling steels.

6.23 BATH FURNACES

Liquid baths are often used for heating steel in the heat-treating processes. They are usually cylindrical and consist of a sheet-steel casing lined with insulating bricks faced with refractory material. This forms the heating chamber in which is suspended a steel pot. The materials which serve as the heating media are usually salt, lead, and oil. Heating may be by gas, oil or electricity. In the case of gas, low-pressure forced-draught fan is coupled with the gas supply and provides a high flame temperature. In the electrically-heated types, there are externally-heated type, and immersed electrode type.

The *externally-heated bath furnaces* are used for quenching and tempering upto about 700°C. The electrical resistance elements are located in the walls of the furnace and heat the outside wall of the metal pot by radiation. A refractory lining is made to withstand the high temperature and prevent rapid loss of heat.

The *immersed electrodes salt bath furnaces are* used for preheating, Carburising and hardening, and the working temperature is between 700° and 1000° C. In this furnace, electrodes, usually two in number, are immersed in the liquid bath, and a low voltage alternating current is passed between them, since direct current tends to electrolytically decompose the liquid salt.

SALT BATH

Salt baths are filled with a salt or mixture of different salts, which melt when heated, and so form a liquid heating medium. The workpiece is inserted into the liquid and the heat of the liquid raises the temperature to the required point. The heating of large number of small parts are done conveniently when they are strung on wires or placed in wire baskets. The salts used must be such that it will not attack the steel, i.e., will not alter its

TABLE 6.3 SALT AND SALT MIXTURES MOST FREQUENTLY USED FOR SALT BATHS

Main purpose of the salt bath	*Salt ans salt mixtures Name of salt*	*Temperatures °C*		
		percent	*melting*	*working*
Saltpetrous bath for tempering springs & articles	Sodium saltpeter	55		
	Potassium saltpeter	45		
	Sodium saltpeter	45	218	230-550
	Potassium saltpeter	55		
	Sodium saltpeter	100	317	325-600
	Potassium saltpeter	100	337	350-600
Salt baths for heating carbon and low-alloy steels to be hardened	Sodium choride	35	620	650-900
	Calcined soda	65	620	650-900
	Sodium chloride	22	654	675-900
	Barium chloride	78		
Salt baths for heating high-speed steels for hardening	Sodium chloride	100	960	1100-1350
Alkaline baths for bright hardening	Caustic soda	100	322	350-700
	Caustic potash	100	360	400-650
	Caustic soda	37	159	180-350
	Caustic potash	63		

composition, will not produce oxidation or decarburisation, corrosion, or erosion ; and it will not attack the point in which it is held.

Common salts are sodium and potassium chlorides, nitrates, and cyanides. They are mixed in various proportions and with other salts to obtain different melting points for services in various ranges from 180° to 1350 °C and for various purposes. Salts and salt mixtures most frequently used for salt baths are given in Table 6.3.

LEAD BATH

In the lead bath, the pot, which is made of cast steel or some heat-resisting alloy, is filled with lead. The lead used in the bath is ordinary commercial pig lead. A covering of charcoal is placed on top of the bath to decrease the oxidation of the lead. Owing to the high specific gravity of molten lead, steel will float in it, and, therefore, must be held below the surface.

With its low melting point, 327°C, it is soon raised to temperature, and can be effectively employed for temperature upto 1,285°C, i.e., for most hardening and tempering operations. Lead bath is particularly favourable for heating in the hardening of files, broaches, reamers, drills, axes, and many other tools. The advantages of the lead bath for heating steel preparatory to hardening or for tempering are : (1) that uniform temperature can be obtained throughout the work ; (2) that the steel will not become oxidized during the heating period ; and (3) that the rate of heating is rapid in the lead bath. The disadvantage with this bath is that the work must be perfectly dry before immersion in the bath, or steam may be formed, leading to dangerous explosions.

OIL BATH

Oils are used only in quenching and tempering steel parts at temperatures upto 260°C. Mineral oil having a high flash point is satisfactory for this purpose and heated in a metal container. The equipment is similar to salt bath furnace.

6.24 FURNACE TEMPERATURES

In all heat-treating practices and in a number of different situations, some equipment are necessary for measuring temperatures.

Mercury boils at 357°C, and thus cannot be used above this temperature. Most of the heat-treatments involve temperatures well above 357°C, so this places a severe limitation on the use of *mercury thermometers*. They may be suitable for heat-treatments which are carried out below this temperature.

A scientific and reliable method of measuring temperatures is by an instrument called pyrometer. Two types of pyrometers in common use are :

1. Thermo-electric pyrometers
2. Optical pyrometers

THERMO-ELECTRIC PYROMETERS

These may be employed at any temperature upto about 1,200°C for those made of "basemetals" and to 1,500°C for "noble-metals".

Base metal couples are made from nickel-chromium wire with nickel-aluminium wire for temperatures upto 1200°C ; nickel chromium with constantan wire upto 800°C. Base-metal couples oxidize more readily than noble-metal couples and they have, therefore, a much shorter life than the other. A noble-metal couple consists of one wire of pure platinum and the other of an alloy of platinum and rhodium. This is used for temperatures upto 1500°C. The wires in the noble-metal couple do not oxidize readily.

The operation of the thermo-electric pyrometers is based on the principle that when two wires of different metals are joined to form a complete electric circuit, and one junction is at a higher temperature than the other, an electric current flows in the circuit. The magnitude of the current depends upon the metal used, and the temperature difference of the junctions.

In the practical application of this principle, an electric meter is connected to two wires which are welded together to form the hot junction. The two wires forming the junction are known as *thermo-couple*. The three essential parts of a thermo-electric pyrometer are the thermo-couple, the

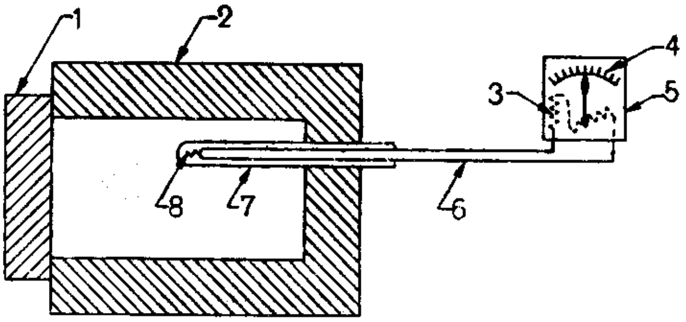

Figure 6.10 Thermo-electric pyrometer

1. Door, 2. Furnace, 3. Resistance, 4. Temperature scale, 5. Galvanometer, 6. Wires, 7. Silica tube, 8. Thermo-couple.

galvanometer, and the wires leading from the thermo-couple to the galvanometer, which is so calibrated that instead of indicating electrical units, it reads in degrees of temperature. Fig. 6.10 gives the installation of a thermo-electric pyrometer.

OPTICAL PYROMETERS

It is sometimes desirable to measure the temperature of a fuel bed or other body which may be at or above a red heat. For this purpose, a thermo-couple is frequently not the best means either because the temperatures are too high or the position is inaccessible. Under such circumstances, optical pyrometers (Fig. 6.11) are used, and these may be employed at any temperatures upto about 4,000°C. This type of instrument is frequently used by the steel smelters to ascertain the temperature of the furnace while melting steel.

It compares the intensity of light being emitted from the furnace with that of some standard source. This instrument may be calibrated so that it reads in degrees of temperature, instead of in units of electric current. In practice, the telescope is sighted on the hot object and focused. The lamp filament will then be seen against the red-hot background. Current is supplied to the filament from a battery through an adjustable resistance and is gradually increased until the tip of the filament just disappears into the background. When *too much* current passes through the lamp filament, it appears as a bright line upon a darker background. This is due to the fact that the excess current will make the filament glow more brightly than the

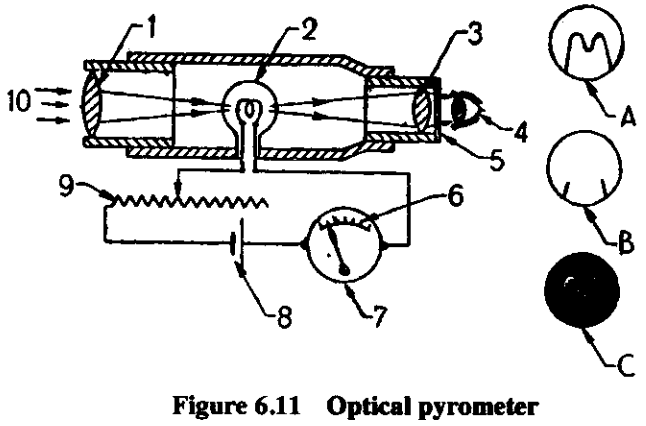

Figure 6.11 Optical pyrometer

1. Lense, 2. Lamp, 3. Eye piece, 4. Eye, 5. Diaphragm, 6. Temperature scale, 7. Ammeter, 8. Battery, 9. Resistance for lamp, 10. Light from furnace, A. Low reading, B. Correct, C High reading.

hot body. With *insufficient* current, it will show as a dark line on a lighter background. When the current is *correctly adjusted*, the tip of the filament will merge into and be indistinguishable from the background. At this moment, the current is read on an ammeter which is calibrated to give temperature readings.

SEGAR CONES

In the case of breakdown of the permanent pyrometer, segar cones are used as a temporary means for determining approximate temperatures. The cones are pyramidal in shape, made from mixtures of kaolin, lime, feldspar, megnesia, quartz and boric acid, each cone melting at a predetermined temperature arranged in steps from 600 to 2000°C. When a furnace temperature is required, several of these cones, within the required temperature range, are put in the furnace and observed. The temperature is judged from which cone collapses, and which remain unaffected by the heat of the furnace. For example, to verify an approximate temperature of 825°C, cones having melting points of 700, 750, 800 and 850°C are put in the furnace and the temperature is ascertained from their condition after sufficient time has elapsed for them to be effected (Fig. 6.12)

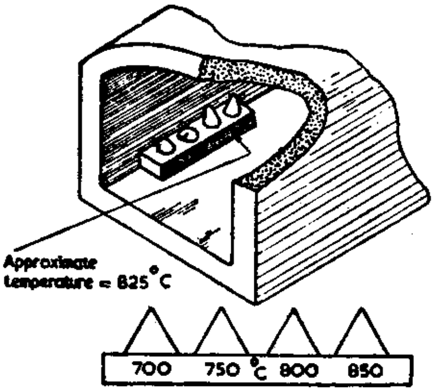

Figure 6.12 Furnace temperature measurement using seger cones

REVIEW QUESTIONS

1. Define the term "heat treatment" and list three main stages of any heat treatment procedure.
2. For what reasons may steel be heat treated ?
3. Give a list of all heat treatment processes.
4. What factors affect the choice of cooling rates for steels ?
5. What is the purpose of annealing and how it is done ?
6. Describe and distinguish normalizing, full annealing, process annealing, homogenising, and spheroidising.
7. State and explain the requirements of hardening State also the factors which affect hardenability and how this is measured.
8. Distinguish between the hardness and hardenability of a steel.

9. Explain the meaning of the term "isothermal heat treatment" and briefly discuss one example of this type of treatment.
10. What is martempering and austempering ? Are they hardening or tempering processes ? Explain your answer with reasons.
11. What is the difference between flame hardening and induction heardening ? State their advantages, limitations ans applications.
12. Briefly explain diffusion coating.
13. Write the procedural steps for heat treatment of cutting tools.
14. Describe in brief the construction and working of any bath furnaces.
15. Briefly describe the operation and applications of thermo-electric pyrometers.
16. Explain briefly the theory of tempering. Why steel is tempered, and how it is done ? What are the effects of tempering on the mechanical properties of steel ?
17. Give reasons why a piston pin should be made from case hardened low carbon steel and not from fully hardened medium carbon steel.
18. State and explain the difference between hardening and case hardening.
19. Briefly explain: (a) cyaniding, (b) carburising, (c) nitriding, (d) induction hardening. State their advantages, disadvantages and limitations.