

MODULE 3

Heat Treatment, Ferrous and Non-Ferrous Alloys

Every material has its own set of properties, i.e., strength, ductility, toughness, heat resistance, corrosion resistance etc. **Heat treating** is a group of industrial and metalworking processes used to alter the physical, and sometimes chemical, properties of a material. The most common application is metallurgical. Heat treatments are also used in the manufacture of many other materials, such as glass. Heat treatment involves the use of heating or chilling, normally to extreme temperatures, to achieve a desired result such as hardening or softening of a material. Heat treatment techniques include annealing, case hardening, precipitation strengthening, tempering and quenching. It is noteworthy that while the term *heat treatment* applies only to processes where the heating and cooling are done for the specific purpose of altering properties intentionally, heating and cooling often occur incidentally during other manufacturing processes such as hot forming or welding.

PURPOSE OF HEAT TREATMENT

The purpose of heat treatment is to achieve one or more of the following objective.

- a) To improve mechanical properties such as tensile strength, impact resistance, ductility, etc., in metals.
- b) To increase resistance of the metal to wear, heat and corrosion.
- c) To increase the toughness or resistance to Fracture, of the metal.
- d) To improve machinability.
- e) To produce hard surface and tough interior portions.
- f) To refine the grain structure after hot working a metal.
- g) To remove strain hardening of a cold worked metal, and to improve its ductility.
- h) To relieve the internal stresses set up during cold working, casting, welding, and other related processes.
- i) To improve magnetic and electrical power.

Types of Treatment Processes

There are many ways in which metals are heat treated. From the syllabus point of view, the following heat treatment processes only have been discussed in the present chapter.

- a) **Annealing** Full annealing process annealing stress-relief annealing spheroidizing
- b) **Normalizing**
- c) Hardening
- d) Tempering
- e) Austempering
- f) Martempering
- g) Surface hardening
- h) Case hardening or Carburizing Solid or Pack carburizing.
liquid Carburizing. Gas carburizing., cyaniding , Nitriding.
Induction hardening.
- v) Age or Precipitation hardening.

ANNEALING

Annealing is a heat treatment process, in which the metal is heated to a high temperature, holding (soaking) it there for a considerable time, and then allowing it to cool to room temperature at a predetermined rate. Heated the metal to high temperature allow diffusion process to occur fast. Also the holding time at the high temperature is long enough to allow desired phase transformation to occur. The metal is then cooled slowly to room temperature to avoid the distortion (warping) of the metal piece, or even cracking, caused by stresses induced by differential contraction due to inhomogeneities.

Purpose of Annealing

The purpose of annealing is to achieve one or more of the following objectives:

- To relieve internal stresses induced by some primary processes, say rolling, forging, uneven cooling etc.

- To remove coarseness of grains.
- Soften the metal, so as to improve machinability, formability, and sometimes to control magnetic properties

Types of Annealing

- Full annealing
- Process annealing or sub-critical annealing
- Spheroidizing annealing

Full Annealing Purpose

To relieve internal stresses, improve ductility and grain refinement.

Process

The process consists of heating the metal (steel) above the upper critical temperature (in the austenitic zone), holding it there for a considerable time, so that it becomes completely austenitic, and then allowing it to cool slowly in the furnace. Slow cooling associated with full annealing enables the austenite to decompose to form:

- A *pearlite+ferrite* structure in case of hypo-eutectoid steels. A *pearlite+cementite* structure in hyper eutectoid steels.

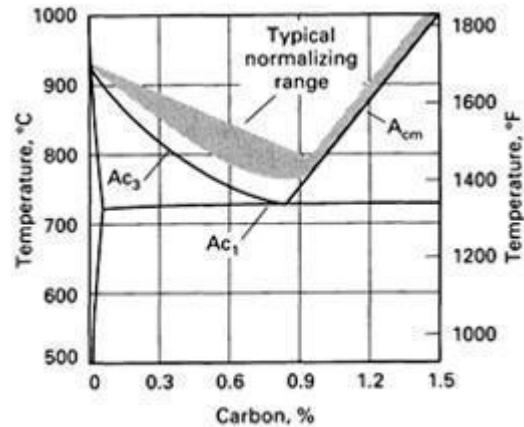
The phase re-crystallizes completely in this process, and the structure is refined. The metal gets softened with improved mechanical properties.

Temperature range

Below fig shows the temperature region on the Iron-carbon phase diagram for full annealing process.

For hypo-eutectoid steels (<0.83% C), the metal is heated to about 50-90°C above upper critical temp (A₃ line in diagrams), i.e., to the austenitic phase.

For hyper-eutectoid steels (>0.83% C), the metal is heated to about 50-90°C above the lower critical temp (A₁ line), i.e., above eutectoid temperature.



Holding or Soaking Time

Holding time depends on thickness or diameter of the component to be treated.

Application

Full annealing is used for low and medium carbon steels that will be machined, or will experienced extensive plastic deformation during formation operation.

Disadvantage

Process is time consuming due to slow cooling rates in the furnace.

Process Annealing or Sub-critical Annealing

Deforming a metal that has been strengthened by cold working process requires a lot of energy. Process annealing is used to revert the effort of cold work,i.e., to softened and increased the ductility of a previous strain or work hardened metal permitting further deformation.

Purpose

To soften and increase the ductility of a previously strain hardened metal.

Process

The process consists of heating the metal in the range of 550-650°C,which just below the lower critical temp on the Fe-C diagram for steel. The metal is held on this temp for a certain duration and then cool slowly usually in air in order to soften the metal for further cold working, as in the case of wire drawing operation. this process leads to recrystallization prior to process annealing, the grain may have been deformed by cold working process afterward having a new grain structure with no deformation the effort of this treatment is to give a reduction in hardness and increase in ductility.

Temperature Range

Heating Temperature ranges from 550-650°C, which just below the lower critical temperature of steel on the iron-carbon diagram.below fig shows it.

Application

Process annealing is often used during cold water process with low C steel (<0.3%), where the material has to be made more ductile and stresses have to be relieved for the deformation process to continue. **Stress Relief**

Annealing

Stress relief annealing is used to eliminate or minimize the internal residual stresses arising from the following.

- Plastic deformation during machining and grinding.
- Non-uniform cooling of a metal that was processed or fabricated at an elevated temperature such as in welding or casting.
- Phase transformation that is induced upon cooling, where in the parent product phase have different densities.

If the stresses are not removed (relieve), distortion or warpage of the metal may take place. Stress relief annealing allows the residual stress to relax.

Purpose

To remove (relieve) internal residual stress.

Process

The process of heating the metal much below the lower critical temperature, held there long enough to attain a uniform temperature, and finally cooled to the room temp in contact of air. Annealing temperature is relatively low, so that the effect resulting from cold working and other heat treatment are not affected. The internal stresses are relieved to major extent without loss in strength and hardness of metal.

Spheroidizing Annealing

When sub-critical or process annealing is applied to steels having carbon concentration greater than 0.3%, the effect of heating is to cause the cementite to assume globular or spherical shapes—hence the name is spheroidizing annealing.

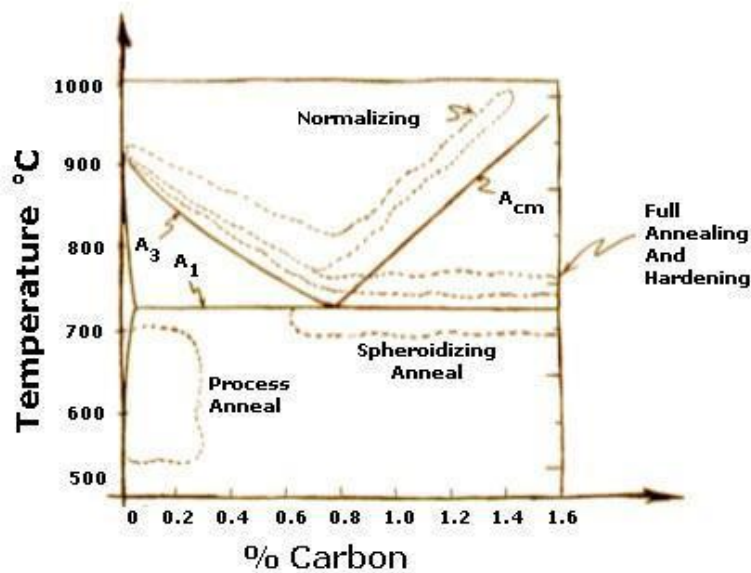
Purpose

To improve machinability, and facilitate a subsequent cold working operation.

Process

The metal is heated to about 30°C below the lower critical temperature (A₁), held there for several hours to allow the cementite to change from lamellar form, and then allowed to cool slowly in the furnace as shown below. The result is Spheroidite structure is desirable when minimum hardness, maximum ductility and maximum machinability are required. Spheroidizing is extensively employed for high carbon steels (>0.3%C) to transform the

lamellar pearlite-cementite structure into spheroidal type. The process is costlier and time consuming.



HEAT TREATMENT PROCESS

NORMALIZING or AIR QUENCHING

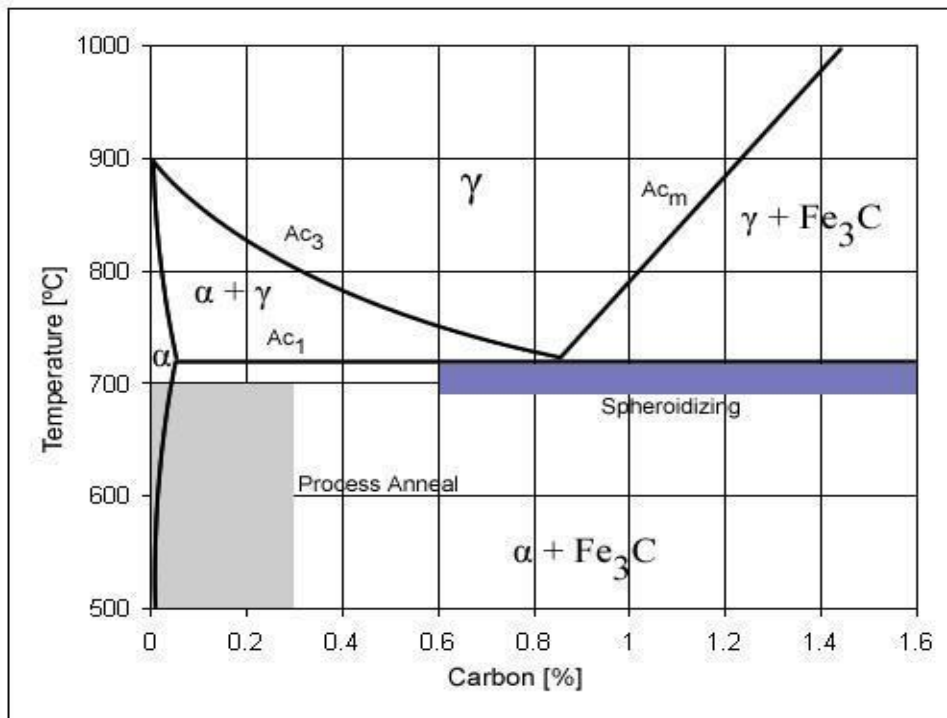
Normalizing or Air quenching is a heat treatment process, in which the metal is heated to about 50 degree c above the upper critical temperature, holding it there for a certain duration, and then allowing it to cool in the surrounding air to room temperature.

Purpose

- To refine the grain structure
- To produce a more uniform and desirable grain size distribution that result in a harder and stronger steel
- To improve machinability and

To obtain a relatively good ductility without reducing the hardness and stress

Figure shows the normalizing temperature region on the iron carbon phase diagram.



Process

The metal is heated to about 50c above the upper critical temperature(A3 and Ac_m line),held there for certain direction, and then allowed to cool in the surrounding air to room temperature. Normalizing process is similar to full annealing, but has a faster rate of cooling. The result of such a treatment is a ferrite and pearlite microstructure for hypo-eutectoid steel, pearlite structure and cementite structure for hyper-eutectoid steel,and only pearlite structure for eutectoid steels.

Application

Normalizing is usually performed on rolled and cast steels, an components subjected to high stesses, and on high carbon steels.

NORMALIZING v/s ANNEALING

Table below gives a brief comparison between normalizing and annealing process.

S.NO.	NORMALIZING	ANNEALING
1.	Normalizing can be applied above the critical temperatures for both hypoeutectoid and hyper-eutectoid steels.	Annealing is applied above the upper critical temperature for hypo-eutectoid steel and slightly above or below the lower critical temperature for hypereutectoid steel.
2.	Faster cooling rate.	Relatively slow.
3.	Hardness and strength obtained is slightly greater than those occurred with annealing.	Relatively low.
4.	Finer grain size.	Comparatively less finer.
5.	Normalized parts are soft and easily machinable.	Comparatively lesser soft.
6.	As the carbon content increases, the ductility of the normalized high carbon steel drop to 1-2% level.	As the carbon content increases, annealing maintains the percentage elongation by around 20%.

HARDENING AND QUENCH HARDENING

Hardening is a heat treatment process carried out in order to increase the hardness of steel. Steels can be heat treated to high hardness and strength levels. This is required because structural components subjected to high operating stresses need the high strength of an hardened structure. Similarly, tools such as dies, knives, cutting tools and forming devices need a hardened structure to resist wear and deformation. The hardening of steel requires the formation of martensite, because martensite has the strongest microstructure than pearlite and austenite.

Process

Hardening involves heating steel with a suitable carbon percentage to temperatures about 30-50°C above the upper critical temperature, so as to produce an austenite structure. It is held at this temperature for a duration of about 15-30mins per 25mm of cross-section of steel specimen, and then cooled rapidly in a suitable medium say water, brine, oil, etc. This rapid cooling result in the transformation of austenite to martensite that is responsible for increasing the hardness of steel.

To achieve a full conversion of austenite into hard martensite cooling needed to be fast enough to avoid partial conversion of austenite into pearlite or bainite. Refer iron carbon diagram shown in

fig 5.27. However during the quenching treatment it impossible to cool the steel specimen at a uniform rate throughout. In other words the surface layer at martensite, and the inner core pearlite+martensite. Hence the full martensite conversion is not achieved. Thus the martensite content and hence the hardness will drip from a high value at the surface to a lower value in the interior regions of the specimens. Production of uniform martensitic structure throughout the cross-section of the specimen depends on three factors.

Composition of The Alloy

In steels the maximum increase in hardness by quenching is obtained if the content carbon content between 0.35-0.6%. increase in carbon content results a decrease in ductility and also has other effects on the material properties.

Quenching Medium

Cooling is faster in water, then oil and slow in air. First cooling is usually accompanied by large thermal gradients and as a result induces residual stresses, brings the danger of warping of the hardened part and formation of cracks.

Size and Shape of the Specimen

Cooling rate depends upon extraction of heat of the surface of the specimen. Thus the greater is the ration of surface area to volume deeper the hardening effect spheres cools slowest, irregular shaped objects fastest.

Hardenability

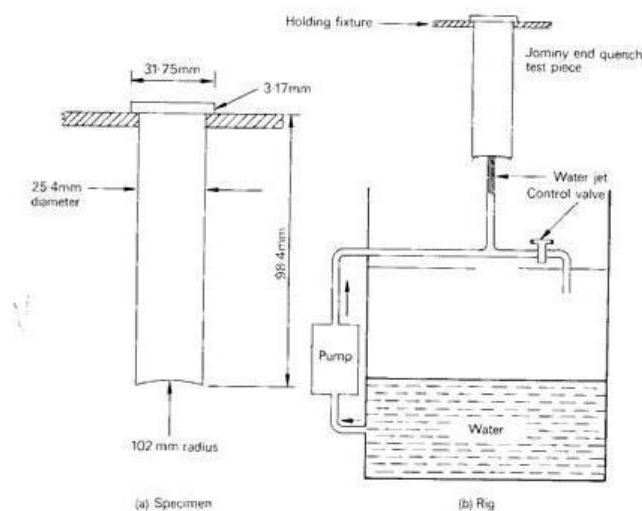
The term hardenability is used as a measure of the depth of martensitic hardened introduced into steel by quenching. In other word, it is the ability of the metal to be hardened by forming martensite. The term hardening should not be confused to hardness, which is defined as the resistance to indentation; rather harden ability is a qualatitive measure of the rate at which hardness decreases with distance from the

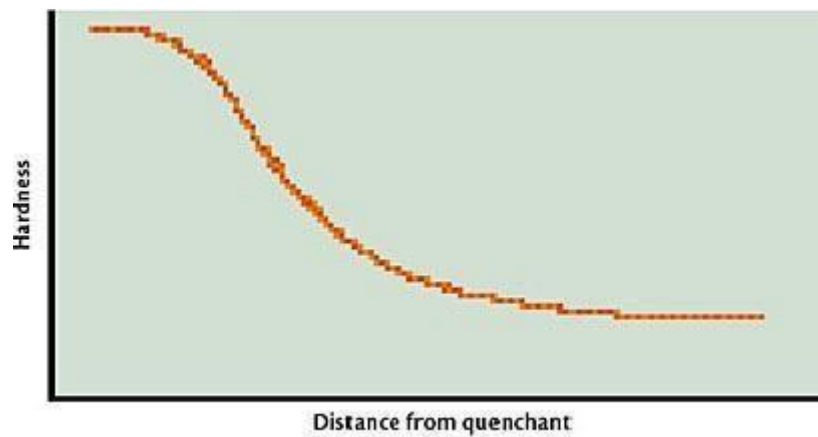
surface of the specimen due to decreased martensitic content. A metal with high hardenability implies the ability of a metal to produce a high martensitic content throughout the volume of specimen.

THE JOMINY END-QUENCH TEST

Hardenability is measured by jominy end-quench test under std. Condition using standard cylindrical specimen, standard austenizing condition and standard quenching condition, refer below fig.

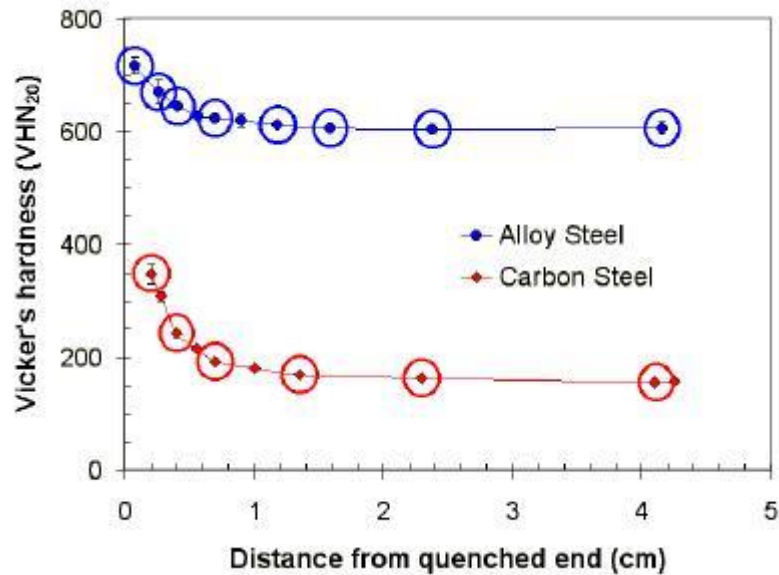
A standard specimen of 25.4 mm in diameter (1 inch) and 100 mm long is heated in a furnace to the austenizing temperature (above A3 line) for a prescribed time. The specimen is strictly removed from the furnace and then mounted in a fixture as shown below. The lower end of the specimen is quenched by a jet of water at a specific flow rate and temperature (24°C) as shown in fig. This results in a different rate of cooling along the entire length of the test specimen. After the specimen has cooled to room temperature, shallow flats of 0.4 mm deep are ground along the length of the specimen, and Rockwell hardness measurements are made at suitable length intervals. The hardenability curve is plotted with hardness as a function of position from the quench end of the specimen. Refer fig below.





The significant point about the Jominy test result is not that they give hardness at different distances along the test specimen, but they give the hardness at different cooling rates. Each distance along the test corresponds to the different rate of cooling. The fastest rate of cooling occurs at the lower end of the specimen where the jet of water impinges first. Hence the lower end exhibits maximum hardness, as is clear in the hardenability curve in below. Since hardness is proportional to the amount of martensite formed, it also means that 100% martensite is formed at the lower end of the test specimen.

It is also clear from the hardenability curve that the hardness increases with distance from the quench end, indicating a decrease in cooling rate. With a diminishing cooling rate, more time is allowed for carbon diffusion and the formation of a greater proportion of the softer pearlite, which may be mixed with martensite and bainite.



To illustrate the use of jominy test result in the selection of steels, consider the hardenability curve for two diff steels shown in the fig above.

It can be concluded from the graph that, the alloy steel is said to be had better hardenability than the plain carbon steel. This implies that, the alloy steel can retain large hardness values for relatively long distance (in the specimen) when compared to plain carbon steel.

TEMPERING

Steels subjected to hardening treatment possess martensitic microstructure, which is the strongest structure than pearlite and austenite. Although martensite is a very strong phase, it is normally very brittle. Even slight impact may cause fracture, of the hardened metal. Hence it is necessary to modify the properties, and this done by means of tempering process.

Tempering is a heat treatment process that reduces the brittleness of steel without significantly lowering its hardness and strength. The tempering forms an essential operation that has to be performed after hardening.

Purpose

- to reduce brittleness of hardened steel(ductility increases).
- To improve toughness of steel
- To relieve internal stresses,and
- Increase percentage elongation at high temperature.

Process

Tempering is done immediately after quench hardening.when the steel cools to about 40°C.The process involves reheating permits partial transformation of martensite,and relieving of internal(residual) stresses. With increasing tempering temperature,transformation of martensite occurs at a high rate. Based on the reheating temperature range of hardened steel,tempering may be classified as follows:

a) Low temperature tempering

carried out in temperature range from 150-250°C

Toughness and ductility increases without significant loss in hardness structure still contains hard martensite Internal stresses are reduced

Applied to cutting tools made from carbon steels and low alloy steels,and case hardened components.

b) Medium Temperature Tempering

carried out in temperature range from 350-450°C

Hardness and strength of steel decreases,while ductility/percentage elongation increases.

Heating in medium temperature ranges causes the transformation of martensite into a less brittle structure,i.e.,a fine pearlite structure termed as troostite. Applied to components such as coil springs,laminated springs,beams,axles,hammers,chisels,etc.

c) High Temperature Tempering

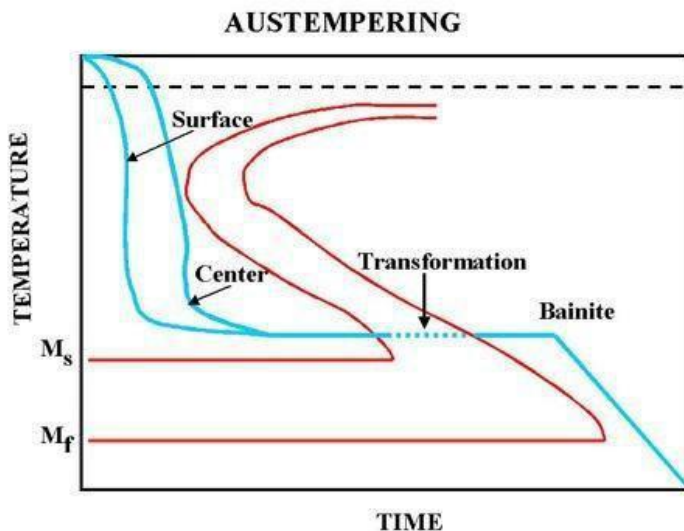
carried out in the temperature range from – 500-650°C. Develops a coarse spheroidal structure known as sorbite.

Eliminates internal stresses completely Imparts high ductility with adequate hardness.

applied to components such as connecting rods,shafts,gear,etc.

6.15 AUSTEMPERING

In the austempering process the end product is 100% bainite. The process involves a heating a steel specimen to austenite state,i.e., above the upper critical temperature(A3 line),followed by cooling rapidly in a salt bath held in the bainite range,i.e.,usually between 205-425°C. the specimen is left in the bath until the austenite is completely transformed to bainite. The specimen is then allowed to cool in the air to room temperature. It is important to note that,the initial rapid cooling(quenching) must be at rate greater than or equal to the critical cooling rate,so that no pearlite is formed.the final cooling rate for the bainite structure can be at any rate as no further changes takes place .below fig shows the above sequence of events on a TTT diagram.



Bainite structure have strengths slightly lower than martensitic structure, but

have better ductility and impact toughness. Since the steel does not suffer a severe quenching treatment, it is less likely to crack and distort. However, austempering suffers from a major drawback. In austempering, the steel specimen is caused to go directly from austenite to bainite. This means that the section must be cooled fast enough to avoid the formation of pearlite. Thin sections can be cooled faster than bulky sections. For this reason, austempering is limited to sections less than ½ inches thick which can be increased by use of alloy steels.

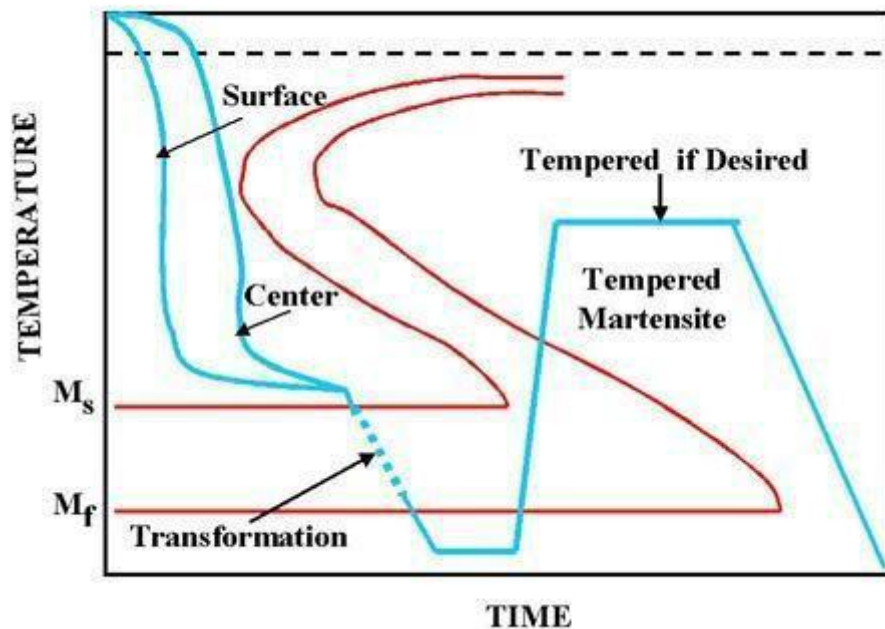
6.16 MARTEMPERING

During the quenching treatment, it is impossible to cool the specimen at a uniform rate throughout. The surface of the steel specimen will cool more rapidly than the interior regions, hence the surface layers are martensitic, while the inner core is pearlite + martensite. Also, rapid cooling ends in distortion and warping, residual stresses and crack formation in the component. These effects are overcome by the martempering process.

Martempering or marquenching is a hardening treatment, which permits the transformation of austenite to martensite to take place at the same time throughout the structure of the steel component with minimum distortion and residual stresses.

Martempering minimizes cracking and distortion, and also reduces the thermal shock of the quenching process. However, hardness and ductility are almost similar to those obtained by direct quenching to the martensite state followed by tempering. Martempering is followed by a tempering process in order to increase the ductility of the steel specimen. Figure below shows the sequence of the martempering process followed by tempering on the TTT diagram.

MARTEMPERING



SURFACE HARDENING

Material used in certain industrial applications like cams, gears, axles, etc requires a hard wear resistant surface called case, and a relatively soft, tough and shock resistant inside, called the core. Surface hardening or surface heat treatment is a process that includes a wide variety of techniques to obtain a very hard surface on the component to wear resist along with a tough interior to resist the impact that occurs during the operation. There are two distinctly different approaches to the various methods for surface hardening. Table below shows the engineering methods for surface hardening of steel.

The first group of surface hardening methods (layer additive) involves an intentional build-up or addition of a new layer, while the second group (substrate treatment) involves surface or subsurface modification without any intentional build-up or increase in part dimensions. The second group method is further divided into *diffusion method* and *selective*

hardening method.

Sl No.	Group 1 : Layer additions	Group 2: Substrate treatment
1.	Hardfacing Fusion hardfacing thermal spray process	Method 1- Diffusion methods Carburizing nitriding carbonitriding nitrocarburizing Titanium-carbon diffusion
2.	Coatings plating Electrochemical , chemical vapour deposition, Physical vapour deposition, ion mixing.	Method 2- selective hardening method Flame Hardening Induction Hardening Laser Hardening Ion implantation Selective carburizing and nitriding.

Diffusion Methods (Case Hardening Methods)

Diffusion method modify the chemical composition of the surface by diffusing interstitial elements like carbon or nitrogen into the surface of steel components. Diffusion method allow effective hardening of surface of the steel components. The various techniques classified under this category include:

- a) Carburizing
pack carburizing gas carburizing liquid carburizing
- b) Cyaniding
- c) Nitriding

Carbonitriding etc.

Selective Hardening Method

Selective hardening methods involve localized hardening or transformation hardening from heating and quenching. However, a few selective hardening methods like selective nitriding or ion implantation and ion beam mixing are

based solely on compositional modification. the various techniques classified under this category include:

- a) Flame Hardening
- b) Induction Hardening
- c) Laser Hardening
- d) Selective carburizing and nitriding, etc.

CARBURIZING

Carburizing is a method of introducing (adding) carbon to the surface of low-carbon steels in order to produce a hard case (surface), while the inner core remains soft and ductile. Components such as gears, cams, cam shafts, pins, pistons, etc., are hardened by this method. Carburizing increases the carbon content of the steel surface by the process of absorption and diffusion. Hardening is accomplished when the high carbon surface layer is quenched to form martensite structure. A high carbon martensite case with good wear and fatigue resistance is superimposed on a low carbon steel case. The inner core remains soft and ductile.

Carburizing process is usually carried out on low carbon steels containing less than about 0.2% C. The process increases the carbon content to about 0.7-0.8% in the surface layers (to a certain depth). The surface carbon is however limited to about 0.9%, because too high a carbon content can result in retained austenite and bainite martensite.

Characteristics

a) Depth of Hardening

There is no limit to the depth of hardening with carburizing techniques, but it is not common to depths in excess of 0.050 inch.

b) Carburizing time and temperature

The time from carburizing ranges from 4-10 hours depending on the type of component being hardened. The temperature ranges from 900-950°C i.e., above the upper critical temperature.

Method

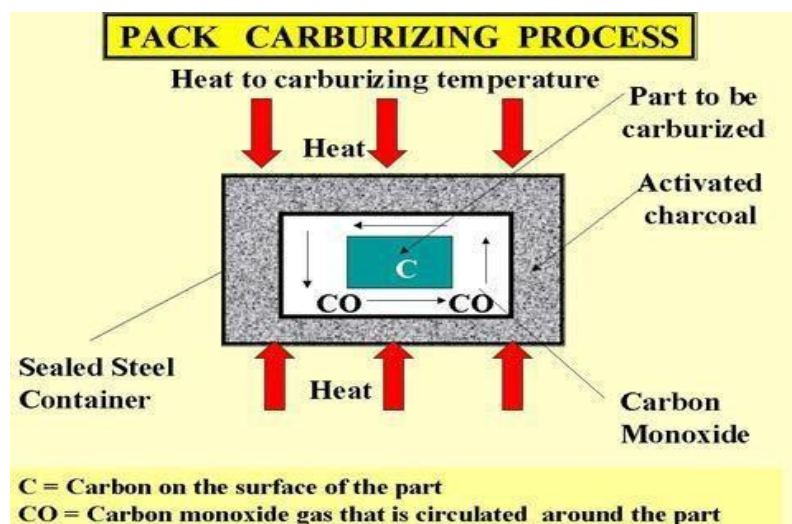
There are three general methods of carburizing based on the carburizing medium or atmosphere. These include:

- Pack carburizing , employing solid carburizing medium
- Gas carburizing, employing suitable hydro-carbon gases.
- Liquid carburizing, employing fused baths of carburizing salts.

Pack Carburizing

In this process, the steel specimen to be carburized is packed in a sealed metal container in such a way that it is completely surrounded by granules of charcoal. Refer below diagram. The charcoal is treated with an activating chemical such as barium carbonate, which energizes or accelerates the carburizing process.

In operation ,the steel specimen is heated to about 900-950°C, which is above the upper critical temperature. It is held at this temperature for a certain period depending on the depth of the case desired. The oxygen present in the container reacts with the carbon content present in the charcoal to produce CO. This carbon-rich atmosphere in contact with the hot steel results in carbon diffusing into the surface layers of the steel component.



Gas Carurizing

In this process , the component to be carburized is heated to about 900°C (above upper critical temperature) for a duration of about 3-4 hours in a furnace in an atmosphere of

carbon-rich gas like methane, ethane, propane, or natural gas. The hydro carbons in the carburizing gas decompose at high temperature, and the carbon diffuses into the surface

austenite layers. The depth of hardened case depends on the rate of the gas flow. Gas carburizing is the most widely used method of carburizing.

Liquid Carburizing

Liquid carburizing is the modification of cyaniding heat treatment process. The process is employed primary for relatively shallow cases(0.1-0.25m), Which can be produce at a cost lower than that done by pack or gas carburizing. The process is carried out in baths containing 20-50% sodium cyanide(NaCN), together with upto 40% sodium carbonate,and varying amount of sodium and barium chloride.the reaction takes place during the process is given below:



The carbon from the molting salt diffuses into the steel specimen.in addition, there is also diffusion into the specimen. Both the carbon or nitrogen can result in microstructure that can be hardened by further cooling the steel specimen. Cycle time for liquid carburizing is much shorter (1-4 hrs) than that for gas and pack carburizing processes. Safe disposal of salt (poissionous elements) is a major disadvantage of the process.

CYANIDING

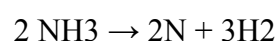
Cyaniding involves diffusion of both carbon and nitrogen into the surface of the steel specimen. The steel specimen to be case hardened is immersed in a molten bath of NaCN maintained between 800-870°C for a period of 30 mins-3 hrs depending on the depth of the case required. The carbon and nitrogen from molten bath diffuses into the component of to from hardened carbide-nitride case. The component is then quenched in oil or water to obtain a hard surface. A case depth of 0.1-1mm may be produced by this process.

Cyaniding increases the fatigue limit of steel. It requires short duration to complete the diffusion process. However health and safety hazard process by the poisonous cyanide forms a major disadvantage of the process.

NITRIDING

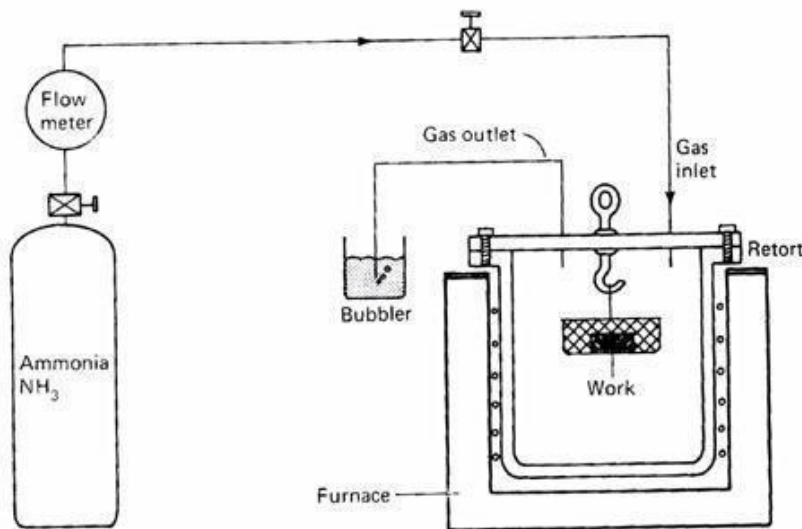
Nitriding involves diffusion of nitrogen into the surface of certain types of steels containing aluminium, chromium, molybdenum, tungsten and vanadium. The process produce a hard case without quenching or any further heat treatment.However , prior to nitriding, stell must be hardened and tempered to the properties required at the core. Fig below shows the arrangement for nitriding process.

In this process, the steel specimen is heated in an atmosphere of ammonia gas, the temperature being in the order of 500-580°C. At this temperature ammonia dissociate into nitrogen and hydrogen as given in the equation below.



Nitrogen diffuses into steel specimen, while hydrogen is exhausted. The time taken from the nitrogen to react with the elements on the surface of the steel specimen is often as much as 100 hrs. The depth to which the nitrides are formed in the steel specimen depends on the temperature and the time allowed for the reaction. Even with some long times, the depth of hardening is unlikely to exceed about 0.7mm. After the treatment the component is allowed to cool slowly in the NH_3 atmosphere.

The advantage of this process is that, hardening is achieved without the oil, water, or air quench. Also, hardening in the presence of nitrogen atmosphere prevents scaling and distortion of the specimen(components).



CARBONITRIDING

Carbonitriding involves diffusion of both carbon(C) and nitrogen into the surface of the steel specimen. The process is carried out in a gaseous atmosphere furnace using a carburizing gas such as methane and propane mixed with several percent of ammonia. Methane and propane serve as a source of carbon, while ammonia serves as a source of nitrogen. Quenching is done in a gas medium which is not as severe as water quench. As a result, there is less distortion in the heat treated specimen.

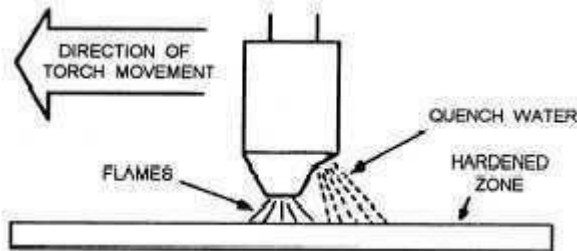
Carbonitriding is carried out at temperature ranging from 850-900°C for a few hours depending on the case depth desired.

FLAME HARDENING

Flame hardening is a process of selective hardening, which involves heating the surface of a steel specimen with an oxyacetylene flame to the austenite range, and then immediately quenching the surface with cold water. Fig below shows the principle of flame hardening. Heating transforms the structure of the surface to austenite, and quenching changes this austenite to martensite. Hence only the surface becomes hard, while the core remains soft and tough. The depth of hardening depends on the heat supplied per unit surface area per unit time. Thus

the faster the flame is moved over the surface, the lesser the depth of hardening achieved. There are three general methods of flame hardening:

- **Spot flame Hardening** : In this method, the oxyacetylene flame(heating torch) is directed to the spot that needs to be heated and hardened.
- **Spin flame hardening** : The workpiece is rotated while in contact with the flame.
- **Progressive flame hardening** : The flame and the quenching medium is directed across the surface of the steel specimen.



INDUCTION HARDENING

Induction hardening is a process of selective hardening used to produce a hard and wear resistant surface with a soft core in steel components.

The process involves placing a steel specimen in an inductor coil that comprises several turns of copper tube. The copper tube acts as a primary coil of the transformer and is water cooled. When a high frequency current of about 1000-10000 cycles/sec is passed through the inductor coil, it sets up a magnetic field. This magnetic field induced high frequency eddy currents and hysteresis currents in the steel specimen. The resistance offered by the steel specimen to the flow of current through it results in rapid heating of the surface layer of the specimen. The temperature produced is in the range of about 700-800°C, which causes the surface layer to transform to martensite. Thus, only the surface of the specimen gets hardened, while the interior core remains soft.

The depth of heating produced by the method, and hence the depth of hardening is related to the frequency of the AC used. The higher the frequency is, the lesser the hardened depth. The major advantage of this process is its speed and ability to confine heating on small parts. However, the cost and maintenance is higher. Also, low carbon steel (<0.4%C) cannot be hardened by this process.

AGE HARDENING or PRECIPITATION HARDENING

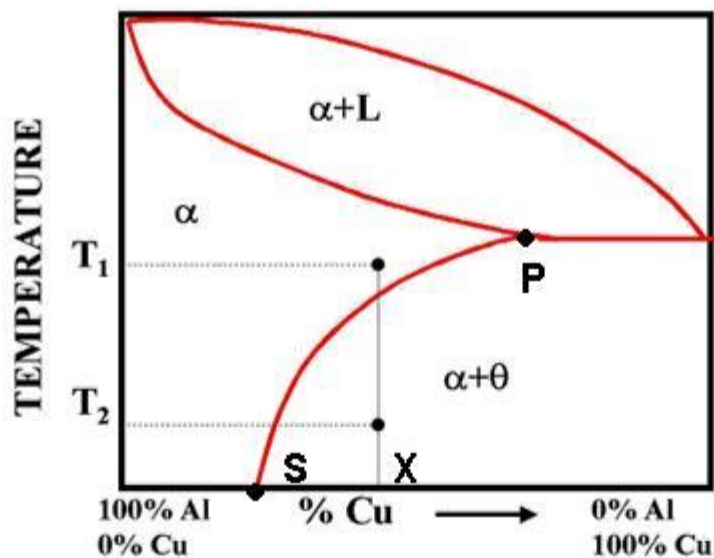
Certain metals and alloys show increase in their hardness after allowing sufficient time at room temperature, or after heating to a slightly higher temperature. This kind of hardening is called age hardening, since the strength develops with time, or as the alloy ages. Age hardening is also known as precipitation hardening, because the strengthening of an alloy results from the precipitation of a fine dispersed second phase from a supersaturated solid solution with the passage of time. The alloys that are hardened by this process include: aluminium-copper, copper-beryllium, copper-tin, and magnesium-aluminium; a few ferrous alloys are also hardened by this process. Of all the different combinations of alloying elements, the mechanism of hardening has perhaps been studied most extensively for the aluminium-copper alloys.

Ages Hardening of Aluminum-Copper(Al-Cu) Alloys

Fig below shows a portion of the phase diagram for an Al-Cu alloy of composition 96% Al 4% Cu. On the right of the phase diagram is shown the resulting microstructure at each step in the hardening process.

Age hardening or Precipitation hardening consists of three steps :

- Solution treatment
- Quenching, and
- Aging.



a) Solution treatment solution treatment involves heating the certain temperature that causes the alloying atoms to dissolve into the section. This results in a homogeneous solid solution of single phase.

In case of Al-Cu alloy, when the aluminium alloy with 4% Cu is heated to about 550°C and held at that temperature for a while, diffusion will occur and a homogeneous solid solution of α -rich in aluminium will form. Refer point no 1 on the phase diagram.

b) Quenching

Quenching is the second step in precipitation hardening, which rapidly cools the homogeneous solid solution and freezes the solution. In more technical terms, quenching cools the material so fast that the atoms of the alloying elements do not have time to diffuse out of solution. i.e., precipitation will not occur. The solution becomes supersaturated.

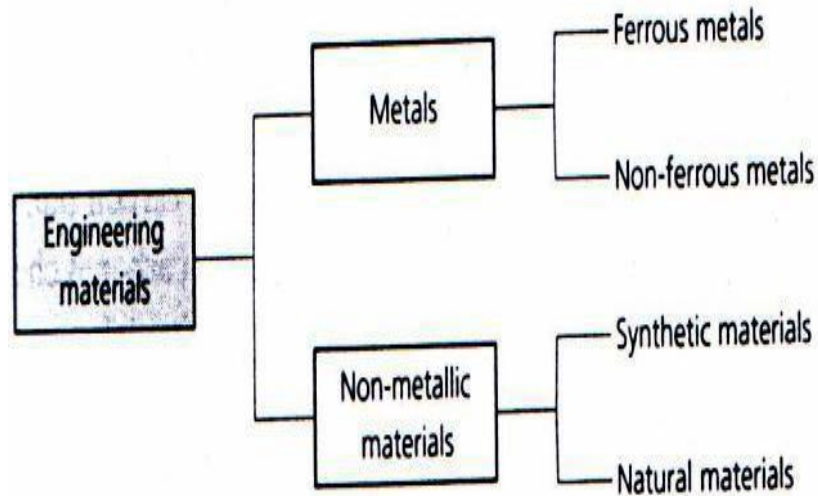
c) Aging

Aging is the process where the solute particles diffuse out of the solution, and into clusters that distort and strengthen the material. This occurs over a prolonged time.

In case of Al-Cu alloy is heated to a temperature of about 165°C (point 3 on the phase diagram) and held at this temperature for about 10 hours. A fine precipitate of CuAl_2 comes out of α -phase with the passage of time. The resulting precipitate tends to be very fine particles dispersed throughout the solid. Such a fine precipitate gives a much stronger and harder alloy.

Engineering materials

Almost every substance known to man has found its way into the engineering workshop at some time or other. The most convenient way to study the properties and uses of engineering materials is to classify them into 'families' as shown in figure below



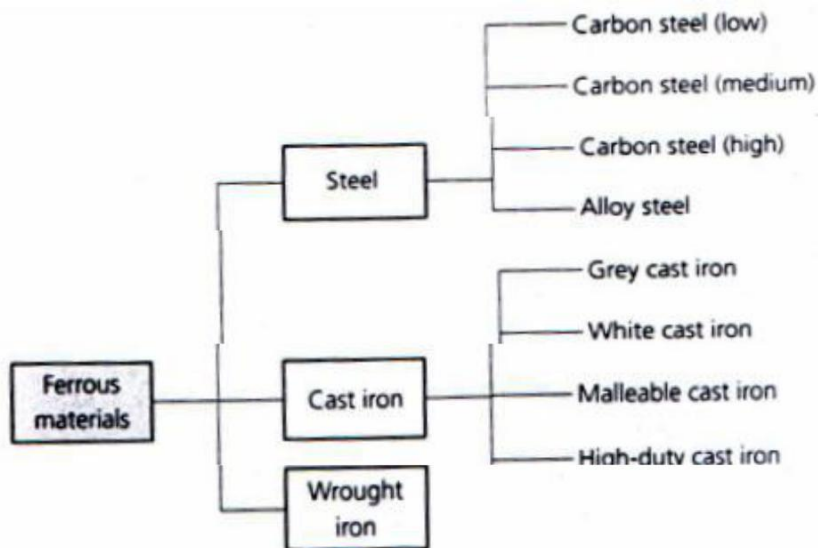
Metals: Ferrous metals

These are metals and alloys containing a high proportion of the element iron.

They are the strongest materials available and are used for applications where high strength is required at relatively low cost and where weight is not of primary importance.

As an example of ferrous metals such as : bridge building, the structure of large buildings, railway lines, locomotives and rolling stock and the bodies and highly stressed engine parts of road vehicles.

The ferrous metals themselves can also be classified into 'families', and these are shown in figure



Non – ferrous metals

These materials refer to the remaining metals known to mankind.

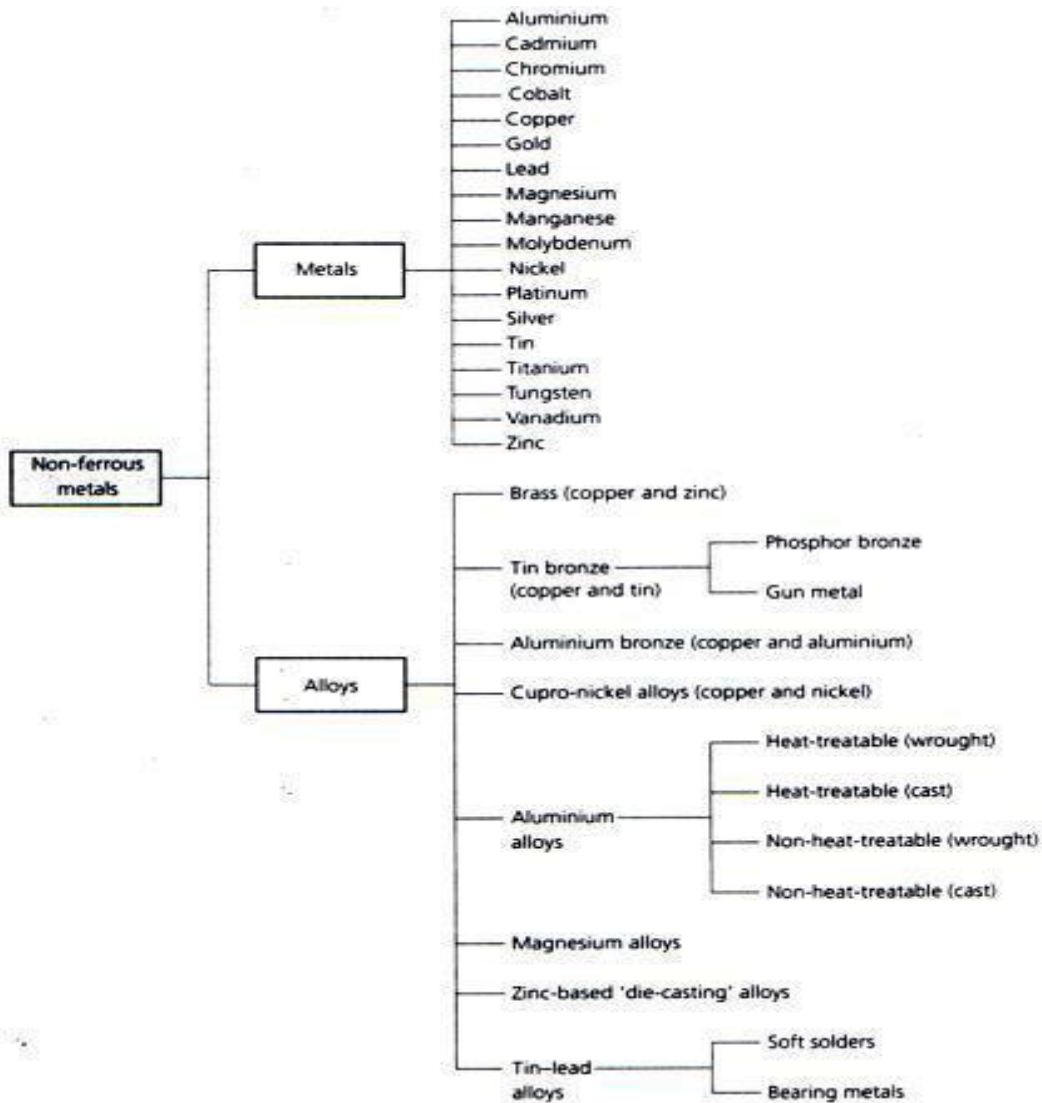
The pure metals are rarely used as structural materials as they lack mechanical strength.

They are used where their special properties such as corrosion resistance, electrical conductivity and thermal conductivity are required. Copper and aluminum are used as electrical conductors

and, together with sheet zinc and sheet lead, are use as roofing materials.

They are mainly used with other metals to improve their strength.

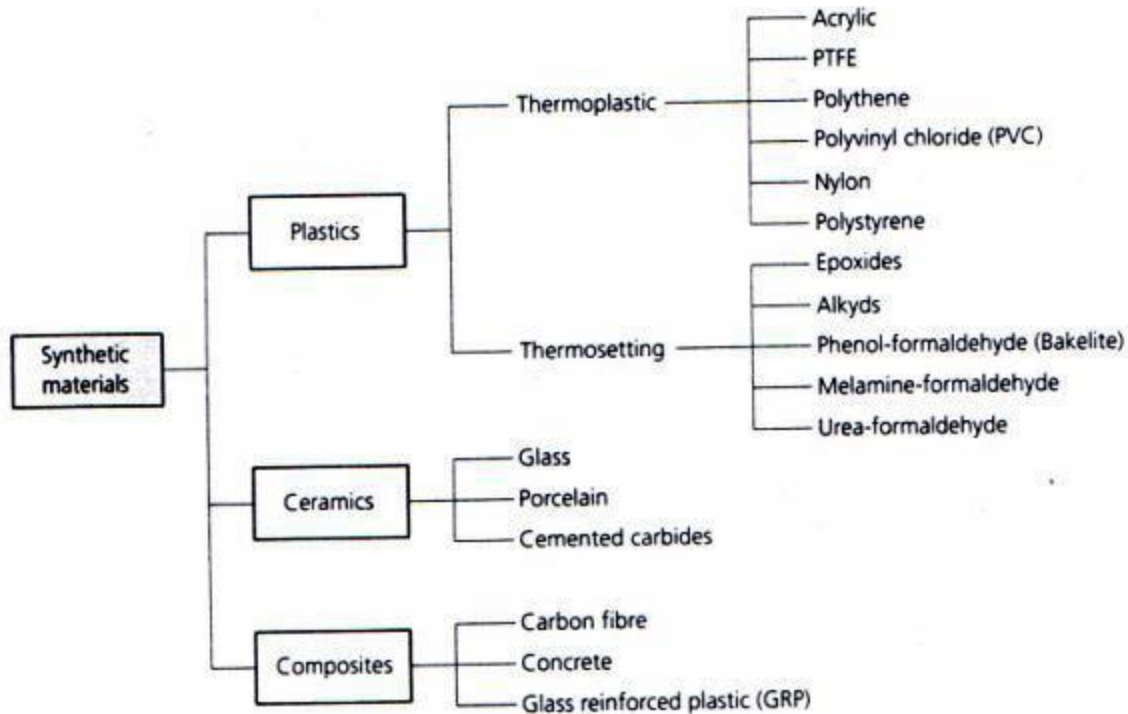
Some widely used non-ferrous metals and alloys are classified **as shown in figure**



Non – metallic materials

Non – metallic (synthetic materials)

These are non – metallic materials that do not exist in nature, although they are manufactured from natural substances such as oil, coal and clay. Some typical examples are classified as shown in figure



They combine good corrosion resistance with ease of manufacture by moulding to shape and relatively low cost.

Synthetic adhesives are also being used for the joining of metallic components even in highly stressed applications.

2.2 Non – metallic (Natural materials)

Such materials are so diverse that only a few can be listed here to give a basic introduction to some typical applications.

Wood: This is naturally occurring fibrous composite material used for the manufacture of casting patterns.

Rubber :This is used for hydraulic and compressed air hoses and oil seals. Naturally occurring latex is too soft for most engineering uses but it is used widely for vehicle tyres when it is compounded with carbon black.

Glass : This is a hardwearing, abrasion-resistant material with excellent weathering properties.

It is used for electrical insulators, laboratory equipment, optical components in measuring instruments etc and, in the form of fibers, is used to reinforce plastics. It is made by melting

together the naturally occurring materials : silica (sand), limestone (calcium carbonate) and soda (sodium carbonate

Emery : This is a widely used abrasive and is a naturally occurring aluminum oxide.

Nowadays it is produced synthetically to maintain uniform quality and performance.

Ceramic: These are produced by baking naturally occurring clays at high temperatures after moulding to shape. They are used for high – voltage insulators and high – temperature – resistant cutting tool tips.

Diamonds: These can be used for cutting tools for operation at high speeds for metal finishing where surface finish is greater importance. For example, internal combustion engine pistons and bearings. They are also used for dressing grinding wheels. Oils : Used as bearing lubricants, cutting fluids and fuels.

Silicon : This is used as an alloying element and also for the manufacture of semiconductor devices.