

Department of
Mechanical Engineering

LAB MANUAL
ENGINEERING MATERIALS & METALLURGY

B.Tech–3rd Semester



KCT College OF ENGG AND TECH. VILLAGE
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List of experiments

1. Study of different engineering materials and their mechanical properties.
2. To study the microstructures of the following materials:
 - I) Hypo Eutectoid & Hyper-Eutectoid steels
 - II) Hypo eutectic & Hypereutectic Cast Iron
 - III) Grey & White Cast Iron
 - IV) Non-Fe metals i.e. Al, Mg, Cu, Sn & alloys
3. To Study about annealing of steel, effect of annealing temperatures and time on hardness.
4. To study about microstructure and hardness of steel at different rates of cooling.
5. To study hardening of steel, effect of quenching medium and agitation of the medium on hardness.
6. To study effects of carbon percentage on the hardness of steel.
7. Harden ability by Jominy End Quench test
8. To study about normalizing and tempering of steel components.
9. To study case hardening processes i.e. carburizing, cyaniding & nitriding.
10. To study TTT diagrams.

LAB IN-CHARGE

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OBJECTIVE: Study of different engineering materials and their mechanical properties.

THEORY: The engineering materials may be classified as follows:

1. Metals (e.g., iron, aluminum, copper, zinc, lead etc.)
2. Non-Metals (e.g., leather, rubber, plastics, asbestos, carbon etc.)

Metals may be further subdivided as:

- i) Ferrous metals (e.g., cast iron, wrought iron and steel) and alloys (e.g., silicon steel, high speed steel, spring steel etc.)
- ii) Non ferrous metals (e.g., copper, aluminium, zinc, lead etc.) and alloys (brass, bronze, duralumin etc.)

Metals: The metals falling under iron group, i.e. all types of iron and steel are called ferrous metals, whilst others are specified as non-ferrous.

Non-metals: The commonly adopted non-metals are leather, rubber asbestos and plastics.

Leather is used for belt drives and as packing or as washers. It is very flexible and withstands considerable wear under suitable conditions.

Rubber is used as packing, belt drive and as an electric insulator. It has a high bulk modulus and must have lateral freedom if used as a packing ring.

Asbestos is used for lagging round steam pipes and steam boilers.

Plastics is a term applied to a large class of mouldable organic compounds. They are used for bushing, steering wheels, tubes for oil and water, automobile tyres etc. Plastics are divided roughly in two classes, called thermoplastic and thermosetting plastics. Thermoplastics become soft and pliable when heated to moderate temperature and then hardened when cooled. They will soften every time when heat is applied and reworked as often as desired. Thermosetting plastics soften the first time they are heated, hardened when cooled and cannot be softened by reheating. Plastics can be moulded, cast, folded into sheets and extended.

Engineering materials may also be classified as follows:

1. **Metals and Alloys:** Metals are polycrystalline bodies consisting of a great number of fine crystals differently oriented with respect to one another. Depending upon the mode of crystallization, these crystals may be of various irregular shapes, and, in contrast to crystals of regular shape, are called crystallites or grains of the metal. Metals in the solid state and to some extent, in the liquid state possess high thermal and electrical conductivity, and a positive temperature coefficient of electrical resistivity. The general resistance of pure metals increases with the temperature. Many metals display superconductivity; at temperature near absolute zero, their electrical resistance drops abruptly to extremely low values.

Pure metals are of low strength and in many cases, do not possess the required physiochemical and technological properties for some definite purpose. Consequently they are seldom used in engineering. The over-whelming majority of metals used are alloys.

Alloys are produced by melting or sintering two or metals and a non-metal, together. Alloys possess typical properties inherent in the metallic state, the substance that make up the alloy are called its components. An alloy can consist of two or more components.

Examples of metals and alloys: iron, copper, aluminium, steels, brasses, bronze, invar, superalloys etc.

2. **Ceramic Materials:** These materials are non-metallic solids made of inorganic compounds such as oxides, carbides, nitrides, borides and silicides. They are fabricated by first shaping the powder with ore without the application of pressure into a compact which is subsequently subjected to a high temperature treatment, called sintering. Traditional ceramics were made from crude naturally occurring mixtures of materials having inconsistent purity. These have been used essentially in the manufacture of pottery, porcelain, cement and silicate glasses. New ceramics possess exceptional electrical, magnetic, chemical, structural and thermal properties. Such ceramics are now extensively used in electronic control devices, computers, nuclear engineering and aerospace fields.

Examples of ceramics: MgO, CdS, ZnO, SiC, $B_4T_1O_2$, silica, sodalime, glass, concrete, etc.

3. **Organic Materials:** these materials are derived directly from carbon. They usually consist of carbon chemically combined with hydrogen, oxygen or other non-metallic substances. In many instances their structures are fairly complex. Common organic materials are Plastics and Synthetic Rubbers. These are termed 'polymers' as they are formed by polymerization reaction in which relatively simple molecules are chemically combined into massive long-chain molecules or "three-dimensional" structures.

Examples of Organic Materials: Plastics: PVC, PTFE, polythene; Fibers: terylene, nylon, cotton; Natural and synthetic rubbers, leather etc.

Examples of Composite materials are as:

- | | |
|-----------------------------------|-------------------------------------------|
| 1. Metals and alloys and ceramics | 2. Metals and alloys and organic polymers |
| (i) Steel reinforced concrete | (i) Vinyl-coated steel |
| (ii) Dispersion hardened alloys | (ii) Whisker-reinforced plastics |
| 3. Ceramics and organic polymers | |
| (i) Fibre-reinforced plastics | |
| (ii) Carbon-reinforced rubber | |

Mechanical Properties of Metals:

1. Strength. The strength of a metal is its ability to withstand various forces to which it is subjected. It is usually defined as tensile strength, compressive strength, proof stress, shear strength, etc. Strength of materials is a general expression for the measure for the measure of capacity of resistance possessed by solids of various kinds to any cause tending to produce in them a permanent and disabling change of form or positive fracture.

2. Elasticity. A material is said to be perfectly elastic if the whole of the stress produced by a load disappears completely on the removal of the load. The modulus of elasticity, Young's modulus (E) is the proportionally constant between stress and strain for elastic materials. It is the indicative of stiffness, small values of E indicate flexible materials and large value of E reflect stiffness and rigidity. In metal cutting, modulus of elasticity of the cutting tools and tool holder affect their rigidity.

3. Plasticity. It is the property that enables the formation of permanent deformation in a material. It is the reverse of elasticity; a plastic material will retain exactly the shape it takes under load, even after the load is removed. Gold and lead are highly plastic materials. Plasticity is used in stamping images on coins and ornamental work.

4. Ductility. It is the ability of a metal to withstand elongation or bending. Due to this property, wires are made by drawing out through a hole. The material shows a considerable amount of plasticity during the ductile extension.

5. Malleability. It is the property by virtue of which, a material may be hammered or rolled into thin sheets without rupture. This property generally increases with the increase of temperature.

6. Toughness. Toughness or Tenacity is the strength with which a metal opposes rupture. It is due to attraction which the molecules have for each other; giving them power to resist tearing apart. It is expressed as energy absorbed (Nm) per unit volume of material participating in absorption (m^3) or Nm/m^3 .

7. Brittleness. Lack of ductility is called brittleness. When a body breaks easily on being subjected to shocks, it is said to be brittle.

8. Hardness. It is usually defined as resistance of material to penetration. Hard materials resist scratches or being worn out by friction with another body. the converse of hardness is known as softness.

9. Fatigue. When subjected to fluctuating loads, materials tend to develop a characteristic behaviour which his different from the materials under steady loads. Fatigue is the phenomenon that leads to fracture under such conditions. Fracture takes place under repeated or fluctuating stresses whose maximum value is less than the tensile strength of the

material. Fatigue fracture is progressive, beginning as minute cracks that grow under the action of the fluctuating stress. Fatigue starts at the point of highest stress.

10. Creep. It is the slow plastic deformation of metals under constant stress or under prolonged loading usually at high temperature. It can take place and lead to fracture at static stresses much smaller than those which will break the specimen by loading it quickly. Creep is specially taken care of while designing I.C. engines, boilers and turbines. It mainly depends upon metal, service temperature to be encountered and the stress involved. The creep is measured during various time intervals and results are plotted to get a creep curve.

RESULT: The study of engineering materials and mechanical properties was successfully carried out.

OBJECTIVE: To study the microstructures of the following materials:

11. Hypo Eutectoid & Hyper-Eutectoid steels
12. Hypo eutectic & Hypereutectic Cast Iron
13. Grey & White Cast Iron
14. Non-Fe metals i.e. Al, Mg, Cu, Sn & alloys

APPARATUS: Sample specimens, emery papers, polishing wheel, etchant, metallurgical microscope.

THEORY:-

1. **HYPOEUTECTOID STEEL:-** Consider the slow cooling of Fe-0.4% C steel under equilibrium conditions from say 1600 Degree C to room temperature. At temperature the solidification begins with the formation of solid δ -Ferrite. Steels containing carbon below 0.77% is called hypo eutectoid steels.
2. **EUTECTOID STEEL (0.77% C) :-** Eutectoid steel, when cooled from say 1600°C, starts solidifying at temperature *J* with the formation directly of solid austenite from liquid. Solidification is completed at point *K*, when the alloy has grains only of austenite of carbon 0.77%. Further cooling of this alloy to point *U* or eutectoid temperature takes place without any change. This alloy then at 727°C undergoes eutectoid reaction to give 100% pearlite. Thus, eutectoid steel shows 100% pearlite in microstructure.
3. **HYPER-EUTECTOID STEELS: -** Hyper-eutectoid steels contain carbon between 0.77% to 2.11 %. Consider cooling of say 1.2% carbon steel from molten state, say from 1500°C. Solidification begins at a temperature *d* with the formation of solid austenite. With continued cooling, solid austenite continues to form until temperature *e* is reached at which solidification is completed. At this temperature, solid steel is composed entirely of grains of austenite of composition 1.2% carbon. This phase persists with continued further cooling until a temperature corresponding to *w* is reached, which is the A_{cm} temperature of the steel, and cementite begins to form. Cementite continues to form as a network along grain boundaries of austenite with the decreasing temperature, Fig. 8.18 until the eutectoid temperature is reached. This amount of austenite (of 0.77%C) undergoes eutectoid reaction to produce pearlite (of same amount). Thus, a 1.2% C steel has 7.29% of proeutectoid cementite and 92.71% pearlite.

Microstructural examination can provide quantitative information about the grain size of specimens, grain shapes, amount of interfacial area per unit volume, dimensions of constituent phases, amount of distribution of the phases and effect of heat treatment on mechanical properties.

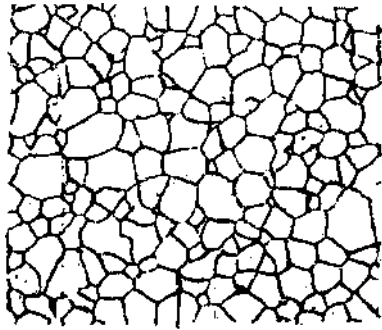
Microstructural examination in other words is also called Metallography, which is a specialized discipline in the science of materials technology. Several necessary steps in doing metallography of materials include:

1. Selection of sample or specimen
2. Polishing it to make it flat and mirror smooth
3. Etching to create relief on the surface to be observed
4. Observing the structures on microscope
5. Sketching or photographing the structures

PROCEDURE: A sample specimen is prepared observing following procedure:

1. **Selection of Specimen:**-A specimen is so selected that it represents, as far as possible, the whole section or the entire piece. Only a small piece can be used and only a plane or flat section can be observed.
2. **Cutting the Specimen:** - Having selected a particular area in whole mass, specimen is cut. Hacksaw or power hacksaw may be taken into application. The edges of specimen are beveled or chamfered slightly to prevent tearing of polishing cloth / emery paper.
3. **Preparing specimen surface:** - Primarily, application of a fairly coarse file or grinding is done to achieve a flat surface. Then, using emery papers of progressively finer grades, grinding of the specimen is done.
4. **Polishing:**-The cloth covered polishing wheels and fine abrasive slurry is used to produce a final mirror-finish. The wheel is first washed off the old abrasive and then some fine abrasive is applied on wet cloth.
5. **Etching:** - There are specific etchants suitable for various purposes and metals. To etch a specimen, it is first ensured to be clean and dry. Then a small amount of etchant is taken into a white porcelain evaporating dish. Then, etchant is dropped over the surface with help of small clean cotton. The surface should be kept completely covered with etchant liquid. Etching turns the shiny mirror appearance into a slightly cloudy mirror one. Then, etchant is removed with flowing tap water and quickly the specimen is blown dry. Then, using the metallurgical microscope, the microstructure of the specimen is observed.

RESULTS: Various microstructures show the following characteristics:



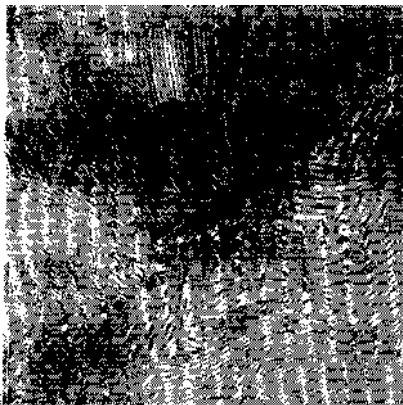
(1) Microstructure of ferrite



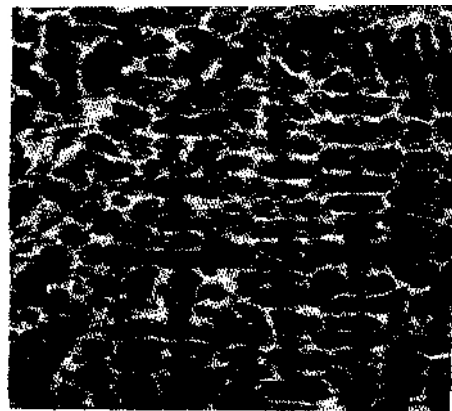
(2) Microstructure of 0.35% C Steel



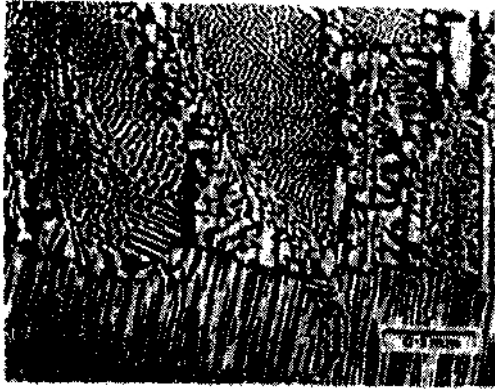
(3) Microstructure of 0.45% C Steel



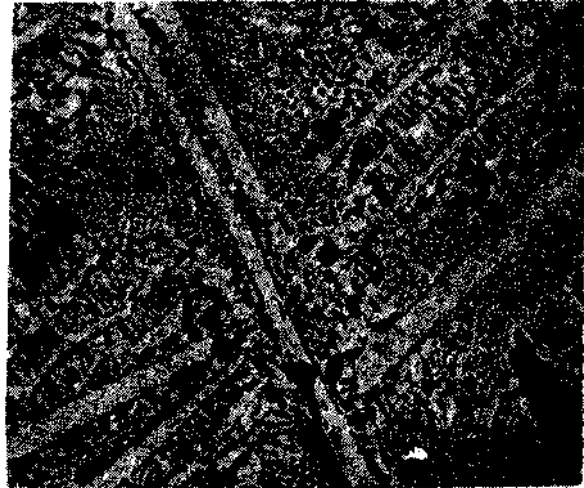
(4) Microstructure of 0.77% C Steel



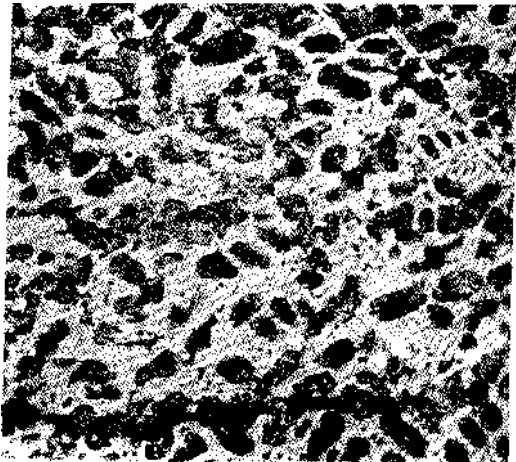
(5) Hypoeutectoid white cast iron



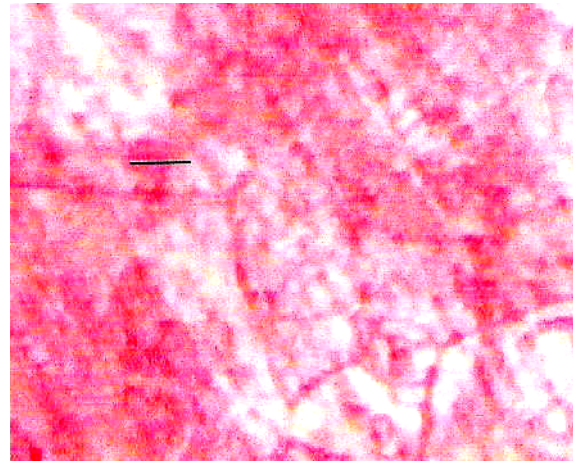
(6) Eutectic White Cast Iron



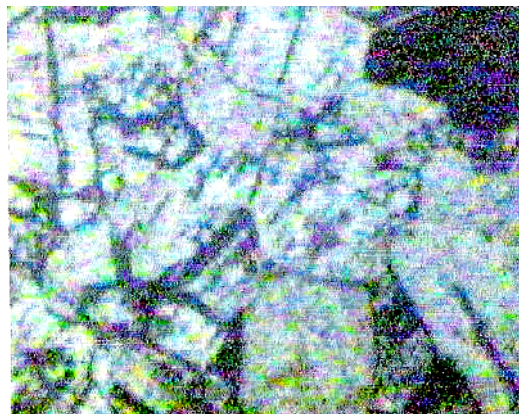
(7) Structure of hypereutectic white cast iron



(8) hyper eutectic white cast iron



(9) Magnesium Alloy



(10) Nickel alloy

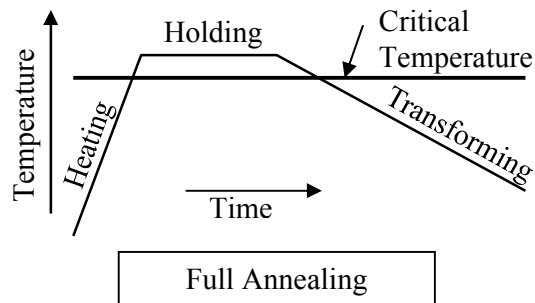
OBJECTIVE: To Study about annealing of steel, effect of annealing temperatures and time on hardness.

THEORY: Annealing, in general, refers to heating the material to a predetermined temperature, soaking at this temperature, and then cooling it slowly, normally in a furnace by switching it off. The aims of annealing the steel could be varying, and that is why, there are a number of types of annealing heat treatments. The main aims of annealing and as a consequence the derived names of the type of annealing are:

1. Improvement in mechanical properties of the cast or hot worked steels by refining the grain size—*Full annealing*
2. Homogenisation of segregated castings, and ingots of steels and alloy steels — *Homogenising annealing*
3. Restore ductility of cold worked steels —*Recrystallisation annealing*
4. Improve the machinability and cold formability particularly of high carbon steels and alloy steels —*Spheroidisation annealing*
5. Relieve the internal stresses of cast, hot worked, or welded structures —*Stress-relieving annealing.*

The important aspect of full annealing as well as the normalising is to let austenite transform to pearlite on cooling (and not to bainite, or martensite). In the pearlitic range of transformation as the transformation temperature decreases below A_1 , the pearlite becomes finer and finer resulting in increased strength and hardness of the steel

FULL ANNEALING :-



Full annealing, or annealing (without any adjective) consists of heating the steel to a temperature above its upper critical temperature, soaking there for sufficient time to obtain homogeneous austenite and then, left to cool in the furnace (normally at rate of 50 to 30°C/h) by switching it off, or as a cheaper practice to submerge in a good heat

insulating material like ash, lime, etc. The austenitising temperature, for full annealing, is a function of carbon content of the steel and is generalised as:

For hypoeutectoid steels and eutectoid steel

$$= A_{c3} + (20 - 40^{\circ}\text{C}) \text{ (to obtain single phase austenite)}$$

For hypereutectoid steels

$$= A_{c1} + (20 - 40^{\circ}\text{C}) \text{ (to obtain austenite + cementite)}$$

Heating at these temperatures results in fine grains of austenite for hypoeutectoid steel, which on slow furnace cooling through $A1$ results in coarse grains of ferrite and pearlite.

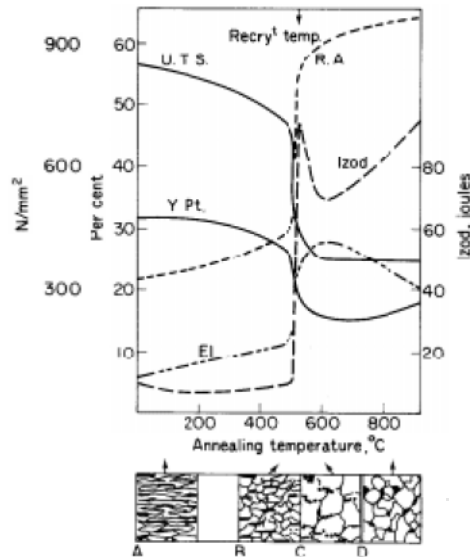


Figure 1. Effect of annealing cold-worked mild steel

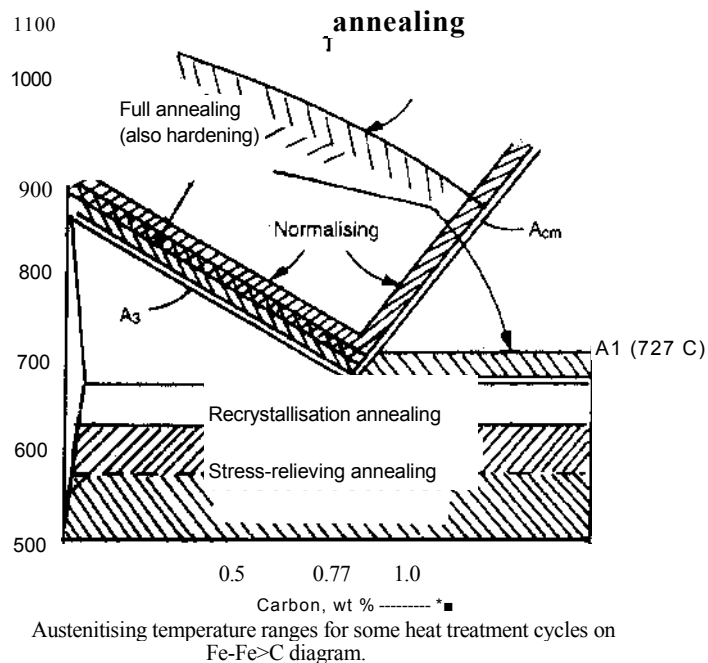


Figure 2. Effect of annealing at 650°C on worked steel. Ferrite recrystallised. Pearlite remains elongated (x600)

Three important point of full annealing are:-

1. **Proper austenizing temperature** :- To get fine grains.

2. **Soaking time:** Minimum of 1 hour for sections up to 25 mm and increased at 30 minutes for each additional 25 mm of thickness to get homogeneous austenite.
3. **Very slow cooling (30-50°C/h) through A_1 :** So that austenite always transforms at A_1 temperature or almost just below it to obtain equiaxed and relatively coarse grained ferrite as well as pearlite with large interlamellar spacing to induce softness and ductility but lowering the hardness and strength in steels. If hypoeutectoid steel is heated at much higher temperature than recommended above, grain growth of grains of austenite are obtained with partly, or completely spheroidised Fe_3C which on slow cooling through A_1 produces fine grains (as compared to original) of pearlite and spheroidised cementite. Had the steel been heated to slightly above A_{cm} temperature to get a single phase homogeneous austenite, grain growth of austenite invariably takes place. Such steel on slow cooling again gets proeutectoid cementite formed at the grain boundaries of austenite as a thicker network and pearlite has coarse grains. Such a cementite network provides easy fracture path and renders the steel brittle during deformation, or in service. Also, it takes time, heat energy, less productivity, more scaling and decarburisation with no advantage. Thus, heating is avoided in such ranges for annealing. The driving force for spheroidisation of cementite is the reduction in austenite-cementite interface area, and thus, the reduction in interfacial energy accompanies the spheroidisation.



Isothermal Annealing: It is a type of full annealing in which, steel is first cooled rapidly to the desired transformation temperature to prevent any structural change above that temperature. Then, the steel is held at selected temperature for the time necessary to complete transformation.

This provides a **more uniform microstructure that could be expected by continuous cooling**. As it is required to drop the temperature rapidly, so it is applicable to small sections and would be suitable for large bars in batch type furnaces.

A modified application of isothermal annealing is possible, however, in which the charge is heated in one furnace and transferred to another, which has been set at a temperature somewhat lower than the desired temperature of transformation in order that the temperature of the charge will drop rapidly to that required. The selection of the temperature of second furnace is governed by the temperature to which the charge is first heated, mass of the charge and the desired transformation temperature. Any undue delays might result in portions of charge being cooled to too low temperature. Continuous furnaces are also applicable to this type of cycle.

Process / Sub-Critical Annealing: This process consists of heating steel to a temperature first under lower critical point and holding at this temperature for proper time (2 – 4 hours) followed by air cooling. It results in **softening of steel** due to particle coagulation of the carbide to form the spheroids or small globules of carbide.

This heat treatment is quite satisfactory for rendering bars more suitable for cold sawing or shearing and is used to great extent for these purposes. Since the temperature to which heated, is somewhat lower than in full annealing, there is less scaling and warping is controllable.

Spheroidisation: This process causes practically all carbides in the steel to agglomerate in the form of small globules or spheroids. There may be wide range of hardness with such a structure for any steel since **the size of the globules has a direct relation to hardness**. Spheroidising may be accomplished by heating to a temperature just below lower critical and holding for sufficient time. A more desired and commonly used method is to heat just above critical temp. and cool very slowly (about 6°C per hour) through critical range or to heat within critical range and cool slowly.

It is used for practically all steels containing over 0.6% carbon, to be machined or cold formed.

RESULT: The phenomenon of different modes of annealing was studied.

OBJECTIVE: To study about microstructure and hardness of steel at different rates of cooling.

APPARATUS: Muffle furnace, water bath, oil bath, and hardness tester.

THEORY: Heat treatment is an operation or combination of operations involving the heating of a solid metal or alloy to definite temperatures, followed by cooling at suitable rates in order to obtain a steel with certain physical and mechanical properties, which are due to changes in the nature, form, size and distribution of the micro constituent. The heat treatment in steels is made possible by the eutectoid reaction occurring in iron-carbon diagram. The heat treatment may be done to accomplish one or more of the purposes like to homogenize, to soften, to relieve stress, to harden, to toughen.

There are three main stages in all heat treatment cycle.

1. Heating the metal or alloy to the predetermined heat treating temperature.
2. Soaking the metal at that temperature until the structure becomes uniform throughout the section.
3. Cooling the metal at some predetermined rate will cause the formation of desirable structures in the metal.

PROCEDURE:-

1. First all the samples are put in the furnace at 900°C for ½ hr.
2. After half hr. the samples are taken out one by one.
3. One sample should be quenched in water.
4. Another samples is immersed to cool in oil.
5. The next sample should be kept in open air to get air cooled.
6. Another sample is kept in the furnace itself to get cooled down to room temperature in the furnace.
7. As each samples gets cooled, its faces are ground and polished to get an even surface.
8. Nextly, hardness is checked and a graph is plotted, if desired.
9. A piece from the hardened end of each sample is cut and prepared for metallographic examination and its microstructure is studied.

PRECAUTIONS:

1. For quenching, the sample should be immediately transferred from the furnace to the water/oil bath.

2. The quenching media should be agitated.
3. The specimen should be well grinded and polished before measuring hardness.
4. Hardness should be checked in cold state.

RESULT: - Microstructure & hardness was studied at different rates of cooling.

OBJECTIVE:- To study hardening of steel, effect of quenching medium and agitation of the medium on hardness.

APPARATUS:- Samples of steel muffle furnace and quenching media.

THEORY:- Hardening is a process in which steel is heated to a temperature above the critical point, held at this temperature and quenched (rapidly cooled) in water, oil or molten salt baths. If a piece of steel is heated above its upper critical temperature and plunged into water to cool, an extremely hard, needle – shaped structure known as martensite is formed. In other words, sudden quenching of steel greatly increases its hardness.

After hardening, steels must be tempered to:-

1. Reduce the brittleness,
2. Relieve the internal stresses, and
3. Obtain pre-determined mechanical properties.

The hardening process is based on very important metallurgical reaction of decomposition of eutectoid. This reaction is dependent upon the following factors:

- a. Adequate carbon content to produce hardening.
- b. Austenite decomposition to produce pearlite, bainite and martensite structures.
- c. Heating rate and time.
- d. Quenching medium
- e. Quenching rate.
- f. Size of the part.
- g. Surface conditions.

In order to increase the cooling rate the parts may be moved around the quenching bath, either by hand, or by passing them through the tank in a basket attached to mechanical conveyer. Large parts may be lowered into the tank by a crane and kept moving while cooling. It is often cheaper and more efficient, however, to circulate the cooling liquid around the hot part. The heating rate and heating time depend on the composition of the steel, its structure, residual stresses, the form and size of the part to be hardened. The more the intricate and large the part being hardened, the slower it should be heated to avoid stresses due to temperature differences between the internal and external layers of the metal, warping, and even cracking. The practically attainable heating rate depends upon the thermal capacity of the furnace, the bulk of the charged parts, their arrangements in the furnace, and other factors. The heating rate is usually reduced, not by reducing the furnace temperature but by preheating the articles. The heating time for carbon tool steels and medium-alloy structural

steels should be from 25 to 30% more than for carbon structural steels. The heating time for high-alloy structural and tool steels should be from 50 to 100% higher.

Hardening Methods: -

1. Annealing
2. Normalising
3. Hardening & Tempering
4. Martempering
5. Austempering
6. Surface-Hardening

Quenching mediums: -

The rapidity with which the heat is absorbed by the quenching bath has a considerable effect on the hardness of the metal. Clear, cold water is very often used, while the addition of salt still increases degree of hardness. Oil, however, gives the best balance between hardness, toughness and distortion for standard steels. Special soluble oils are used in many plants instead of ordinary fist oil, linseed oil or cottonseed oil.

Quenching media	Rate of cooling	Structure produced	Hardness obtained(Rc)
Water	Very fast	Martensite	65
Oil	Fast	Very fine pearlite	35
Air	Medium	Fine pearlite	25
Furnace cool	Very slow	Coarse pearlite	15

LIQUID QUENCHING The two methods used for liquid quenching are called still-bath and flush quenching. Instill-bath quenching, you cool the metal in a tank of liquid. The only movement of the liquid is that caused by the movement of the hot metal, as it is being quenched. For flush quenching, the liquid is sprayed onto the surface and into every cavity of the part at the same time to ensure uniform cooling. Flush quenching is used for parts having recesses or cavities that would not be properly quenched by ordinary methods. That assures a thorough and uniform quench and reduces the possibilities of distortion. Quenching liquids must be maintained at uniform temperatures for satisfactory results. That is particularly true for oil. To keep the liquids at their proper temperature, they are usually circulated through water-cooled.

Water

Water can be used to quench some forms of steel, but does not produce good results with tool or other alloy steels. Water absorbs large quantities of atmospheric gases, and when a hot piece of metal is quenched, these gases have a tendency to form bubbles on the surface of the metal. These bubbles tend to collect in holes or recesses and can cause soft spots that later lead to cracking or warping. The water in the quench tank should be changed daily or more often if required. The quench tank should be large enough to hold the part being treated and should have adequate circulation and temperature control. The temperature of the water should not exceed 65°F. When aluminum alloys and other nonferrous metals require a

liquid quench, you should quench them in clean water. The volume of water in the quench tank should be large enough to prevent a temperature rise of more than 20°F during a single quenching operation. For

Brine

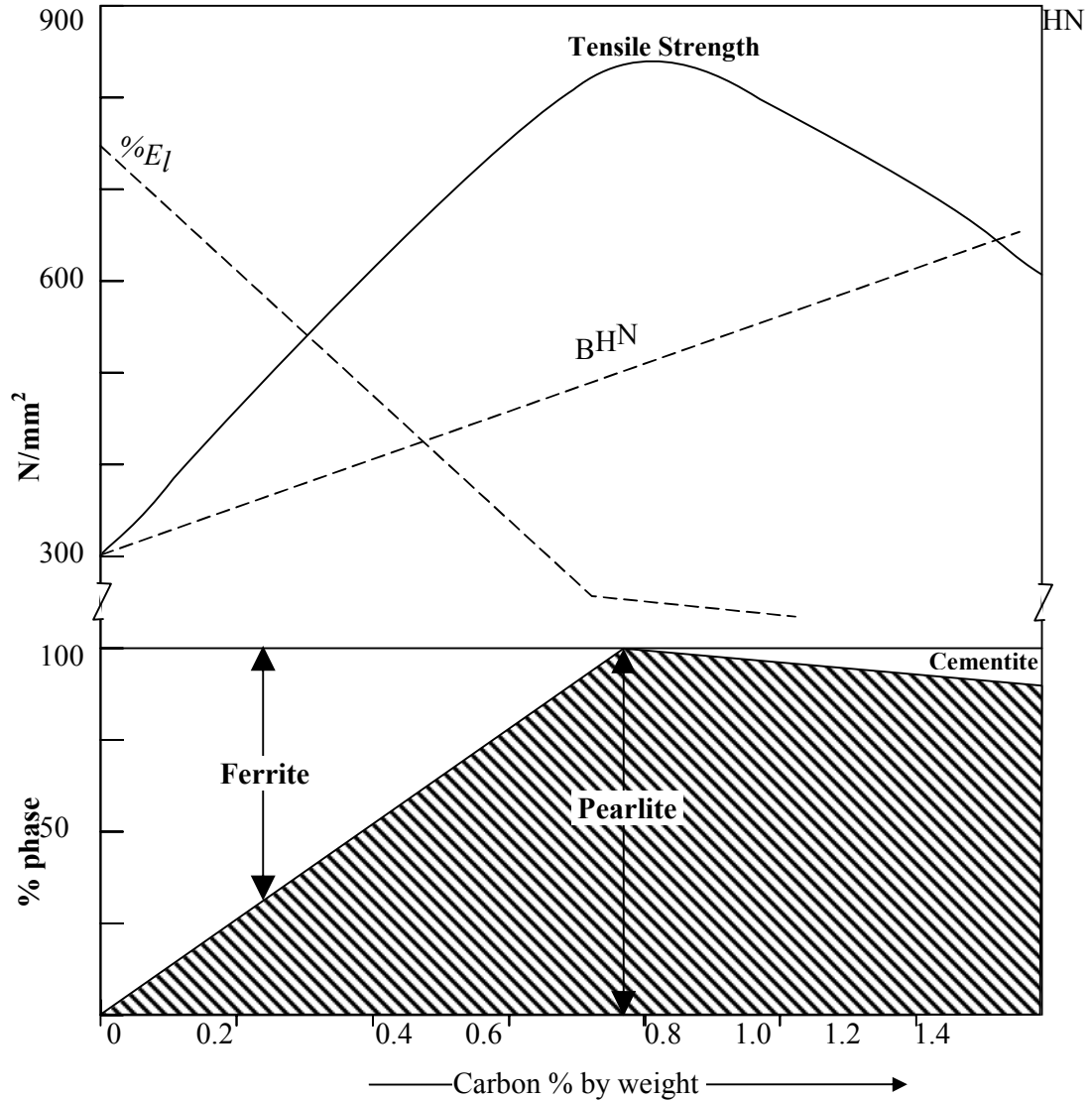
Brine is the result of dissolving common rock salt in water. This mixture reduces the absorption of atmospheric gases that, in turn, reduces the amount of bubbles. As a result, brine wets the metal surface and cools it more rapidly than water. In addition to rapid and uniform cooling, the brine removes a large percentage of any scale that may be present. The brine solution should contain from 7% to 10% salt by weight or three-fourths pound of salt for each gallon of water. The correct temperature range for a brine solution is 65°F to 100°F. Low-alloy and carbon steels can be quenched in brine solutions; however, the rapid cooling rate of brine

RESULT: Hardening phenomena was studied .

OBJECTIVE: To study effects of carbon percentage on the hardness of steel.

APPARATUS: Set of samples, a muffle furnace.

DIAGRAM:



EFFECT OF CARBON ON MECHANICAL PROPERTIES.

THEORY: Of all the alloying elements, carbon exerts the most profound and significant effect on the allotropy of iron as illustrated in Iron-Carbon diagram. The crystal structure of BCC- α -Fe and FCC austenite are modified by adding carbon atoms in the interstices of iron atoms. Carbon addition decreases the freezing temperature of iron to become 1147 Degree C at 4.3% of carbon in cast iron. A lowering of temperature of about 400 Degree C helps to melt and cast the cast irons easily as compared to steels. Carbon is an austenite stabilizer i.e.

as the carbon content increases in iron it increases the range of austenite formation and expands greatly the austenite field and also decreases the fields of ferrites.

The much larger phase field of austenite compared to α -Ferrite reflects the much greater solubility of carbon in γ -iron than in α -Fe. The large difference in solid solubilities of carbon between γ -iron & α -Fe leads normally to the rejection of carbon as cementite at the boundaries of γ -phase. The difference in the solid solubilities of carbon in γ -iron & α -Fe introduces another transformation called the eutectoid transformation in the system. This reaction plays a dominant role in heat treatment of steels. When high carbon alloys after solution treatment in γ -region are rapidly quenched to room temperature, a supersaturated solid solution of carbon in iron is formed called martensite. This is the basis of hardening in steels.

Effect of carbon on mechanical properties of annealed steels

As the carbon content of slowly cooled steels increases, the amount of pearlite increases from 0.0 to 0.77 C from 0-100 Degree C the remaining other phase being ferrite. Pearlite, the mixture of two phases, hard brittle cementite embedded in soft and ductile ferrite makes the steel strong and stronger as its amount increases to 100% mixture. Pearlite can be, in a simple way, compared with the road surfacing mixture of asphalt and pebbles. Road surfaced with either asphalt or pebbles is not strong but the mixture of these two-one of which is soft and other is hard and brittle makes the road strong and lasting.

The cementite plate in pearlite acts as a barrier to the motion of dislocations in ferrite thereby increase the resistance to the deformation and thus, strength but reduce the ductility and toughness. As the carbon content increases, thus the hardness increases with the decrease of %elongation, % Reduction in area and impact of strength. Increase of carbon increases the pearlite content, thus increases the yield strength and tensile strength of hypo eutectoid and eutectoid steels. As the carbon content of the steel becomes 1.0 to 1.2%, proeutectoid cementite, which precipitates at the grain boundaries of austenite, forms a thick network there. Cementite is brittle with no ductility. In tensile testing, under the external stress, high stresses are developed in the network, and thus cementite fails. The fracture nucleates and propagates along the grain boundaries. The tensile strength, yield strength decrease and the ductility becomes very small.

Figure illustrates the effect of increasing carbon on the transition temperature, which too increases. Cementite is the cause of increased transition temperature as the carbon content increases. Cracks easily nucleate at cementite-ferrite interfaces, but propagate in ferrite, a short distance before meeting another cementite plate. But energy is absorbed during

propagation. There is thus, a wide transition temperature range, depending on carbon content. High carbon steels show brittle fracture under impact loading at room temperature because many crack- nuclei can form at pearlitic interfaces.

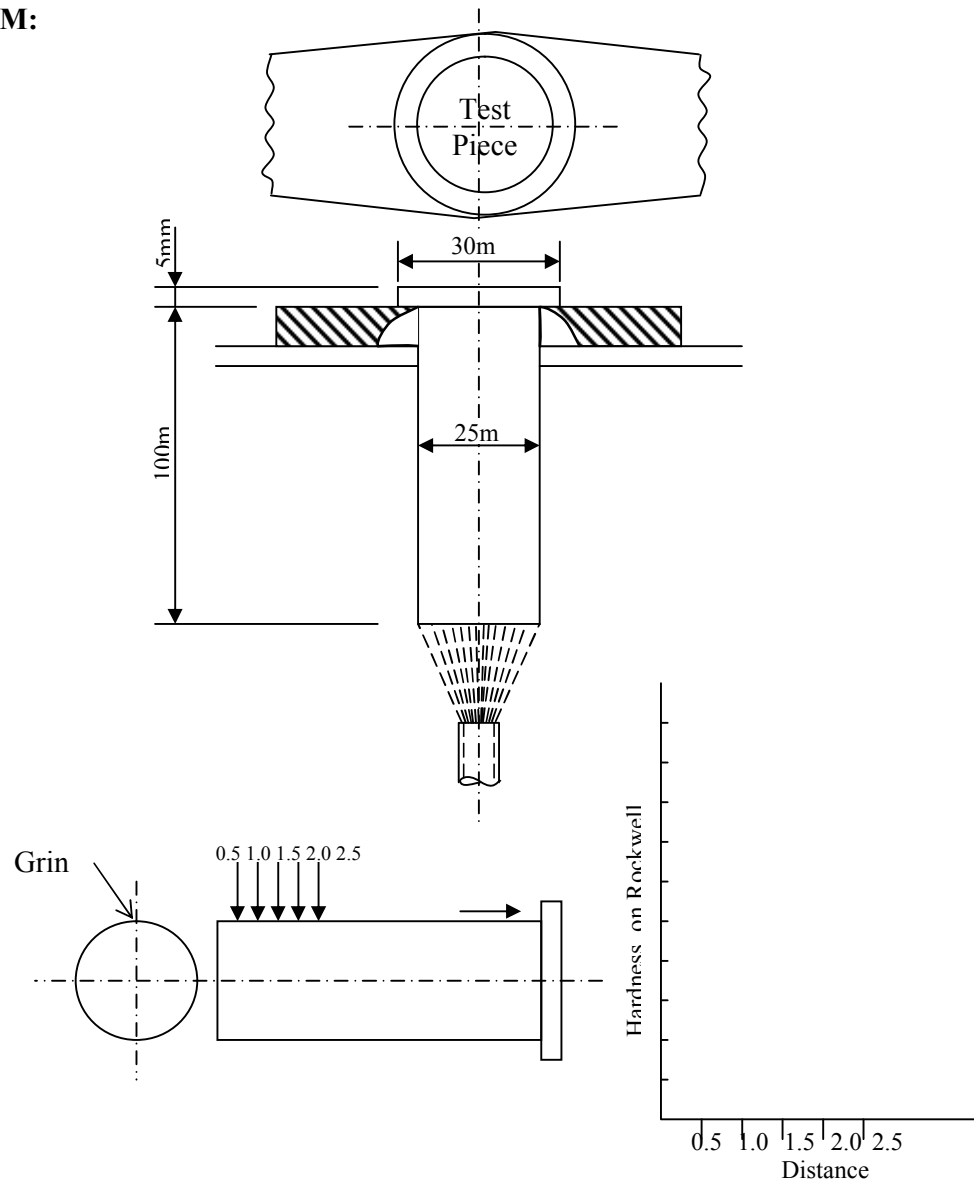
PROCEDURE: Some identified steel samples with different carbon contents are required. Samples are first heated in furnace at 900°C for ½ hour, and then cooled within furnace up to room temperature. Then opposite faces are ground and polished followed by checking the hardness. Then, samples are hardened by keeping at above 900°C for ½ an hour, and then quenching individually. This is followed by checking hardness like earlier (after grinding & polishing). A graph should be plotted.

Precaution should be taken that hardness is measured after sample has cooled to room temperature.

RESULT: The effect of carbon content on the hardness of steel was studied.

AIM: - Harden ability by Jominy End Quench test

DIAGRAM:



THEORY :-

Introduction

This apparatus is useful for determining the harden ability of steels by End Quench test. The test consist of heating a standard test specimen to a given temperature (Austinitising temperature) for a specific period of time (soaking time) followed by a water quenching at one end under specified conditions. The specimen must be as per B.S. 4437 or Indian Standards (IS: 3848: 1966). The quenched specimen is subject to hardness test at various points from quenched end along the length of test piece from

the quenched end.

APPARATUS:-

1. Centrifugal pump with exact flow
2. Bottom sump for water
3. Top pressure head tank
4. Specimen loading chamber
5. Quick releasing valve
6. Outlet for draining the water

PRINCIPLE:- After heating the test specimen (austinitised), it is kept on the specimen holder where it is automatically centered with respect to water jet. The quick action valve starts impinging the water jet on the specimen end instantly. The well defined water jet is achieved by suitably chosen nozzle provided in the apparatus.

PROCEDURE:-

1. Prepare a test specimen as per IS/BS standards, 25 mm diameter and 100 mm length as per drawings. The specimen should have a collar for seating in the apparatus.
2. Austinitise the specimen (according to the austinitising temperature). Soak it for 1 hr and carefully take it out with the help of tongs and gloves. Without delay transfer it into Jominy end quench apparatus and open the tap.
3. Let the cooling continues, when it is cooled sufficiently, grind the specimen on the cylindrical surface along the length from the quenched end as shown.
4. Take hardness in Rockwell 'C' Scale (150 Kg diamond indenter) at every 0.5mm distance. This can be best achieved with the help of a 'V' anvil attachment available with the Rockwell Hardness Tester.

PRECAUTIONS:-

1. The instrument has been designed and manufactured as per I.S. and B.S. Specifications. Therefore do not adjust any part of the equipment.
2. The specifications must be as per IS and BS Specifications
3. Keep the equipment dry when not in use by draining the water through water outlet.

4. Do not use hard water as scales may form nozzles and copper conduits.
5. Use De-ionized water or reasonably soft water.

RESULT :-

Take as many readings (about 20 to 25) and draw a plot.

OBJECTIVE: To study about normalizing and tempering of steel components..

APPARATUS: Sample specimen, Muffle furnace, water bath, oil bath, Hardness tester.

THEORY: Heat Treatment is an operation or combination of operations involving the heating of a solid metal or alloy to definite temperatures, followed by cooling at suitable rates in order to achieve certain physical and mechanical properties, which emerge due to changes in nature, form size and distribution of the micro constituent. The heat treatment in steels is made possible by the eutectoid reaction occurring in iron-carbon diagram.

Heat treatment is generally done to:-

1. Improve machinability.
2. Change or refine grain size
3. Relieve stresses induced during cold or hot working
4. Improve mechanical properties e.g. tensile strength, hardness, ductility, shock resistance.
5. Improve electric and magnetic properties

Various heat treatment processes in use are:

- (a) Hardening
- (b) Annealing
- (c) Normalizing
- (d) Tempering
- (e) Surface Hardening

Normalising: Of other heat treatment operations, this is a simple process of heating the steel approximately 4°C above critical temperature followed by cooling below this range in still air. It is done so as to meet the following objectives:

1. To eliminate coarse grain structure due to forging, rolling and stamping
2. To increase strength of medium carbon steel

3. To improve machinability of low carbon steel
4. To improve the structure of welds
5. To reduce internal stresses
6. To achieve desired results in mechanical and electrical properties

Tempering: The steel hardened by quenching, is considered to be in an unstable condition. The martensitic structures formed by direct quenching of high-carbon steel are hard and strong as well as brittle. They cannot be plastically deformed and have very little toughness, also they are unable to resist impact loads and are extremely sensitive to stress concentrations. Hence hardness and strength is required to be reduced to some extent. This purpose is achieved by tempering.

Tempering is the process of heating quenched, hardened steel to some pre-determined temperature between room temperature and critical temperature of steel for a certain length of time, followed by air cooling. So, this process is carried out to:

1. Increase toughness
2. Decrease strength
3. Stabilize structure
4. Relieve stresses
5. Change volume

PROCEDURE: First, the samples should be checked for hardness. Then, keep them in furnace at 900°C for ½ an hour. Afterwards, one sample is cooled to room temperature in air while other is quench hardened followed by again keeping it in furnace but now at 200-250°C. Then, this sample is also air cooled. As such, one sample is normalized and the other is tempered. Now, the samples are grinded and polished to obtain a flat surface and hardness of both the samples is checked again.

RESULT: The phenomenon of normalising and tempering was observed.

OBJECTIVE: To study case hardening processes i.e. carburizing, cyaniding & nitriding.

THEORY:

- 1) **CARBURISING**:- *It is the process of enrichment of a surface depth of low carbon steel with carbon.* It is then hardened, and is thus, also called *case-hardening*. It develops a combination of high surface hardness as well as high toughness and impact strength of low carbon steel core as required by many engineering parts in service life such as heavy duty gears, ball-bearings, bushings, rock-drill bits, etc. The base steel, the low carbon steel (0.1 to 0.25% C) is readily machinable to easily produce different shapes. It also imparts high toughness and impact strength to the components. The carbon- enriched case has compressive stresses developed in it (presence of extra carbon increases the volume of it) to impart good fatigue strength to the component. The case is hardened to develop high surface hardness and wear resistance

THEORY OF CARBURISING

Carburising is achieved by keeping the low carbon steel, usually having 0.1-0.25% carbon (Table 10.16 gives some compositions of carburising steels) in contact with solid, liquid or gaseous atmosphere of high carbon activity at high temperatures usually between 850°C to 950°C, but commonly between 900° to 925°C, when the steel is austenitic (because the solid solubility of carbon in austenite, 0.77%C at 727°C is much higher than ferrite, 0.02% C at 727°, and it increases with the increase of temperature). Carburising is carried out to obtain surface carbon content of 0.6 to 1.10%. With still higher surface carbon content, the case becomes very brittle due to coarse cementite network formed in it. When low carbon steel at high temperature is in contact with an atmosphere of high carbon activity, carbon is absorbed at the surface. The carbon content at the surface increases till the carbon activity at the surface of steel equals the carbon activity in the atmosphere. If it is higher than the solubility limit of carbon in austenite at the carburising temperature, then the carbon content of the surface can not be increased

beyond this solubility limit, which is approximately given by the A_{cm} line in Fe-Fe₃C diagram for Fe-C alloys.

Thus, the maximum surface carbon content is limited by the carbon potential of the atmosphere, or the solubility limit of carbon in austenite at the carburising temperature, whichever is lower. *Normally the desired surface carbon content is lower than the solubility limit, and commonly the carbon potential of the atmosphere is controlled to achieve the desired surface carbon.*

Carbon potential of the atmosphere is defined as that carbon content which a specimen of a carbon-steel foil acquires when equilibrium conditions have been achieved between the carbon potential of the carburising medium and the carbon content of the foil. Normally, the carbon content of the surface of carburised steel is taken to be equal to the carbon potential of the atmosphere, although presence of carbide forming elements.

MECHANISM OF CARBURISING:-

When a low carbon steel at the austenitising temperature is brought in intimate contact with carburising medium, the carbon in atomic form (gaseous form) is liberated by the chemical reactions, and carburising occurs in two steps:-

First Step: Absorption of carbon occurs (till it becomes equal to that of atmosphere) at the surface of the steel. Maximum carbon content on the steel surface is attained in a shorter time, and is then maintained at it for the rest carburising time.

Second Step: Carbon of the surface diffuses inside the case. The depth of carburisation is dependent on the diffusion of carbon from the surface to the interior.

The depth of carburisation is the distance below the surface to a definite carbon content, or the total depth of carbon penetration. It depends on time and temperature of carburising, the carbon potential of the atmosphere and the composition of the steel.

CARBURIZING

Purpose of Carburization: to provide a hard surface on normally unhardenable steels.

CARBURIZATION PROCESSES

PACK CARB.

GAS CARB.

LIQUID CARB.

Depth of Hardening:

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

Carburizing Time:

4 to 10 hours

Carburizing Temperature:

1750 °F (above the upper critical temperature-Austenite area)

Quenching:

All of the carburizing processes (pack, gas, liquid) require quenching from the carburizing temperature or a lower temperature or reheating and quenching. Parts are then tempered to the desired hardness.

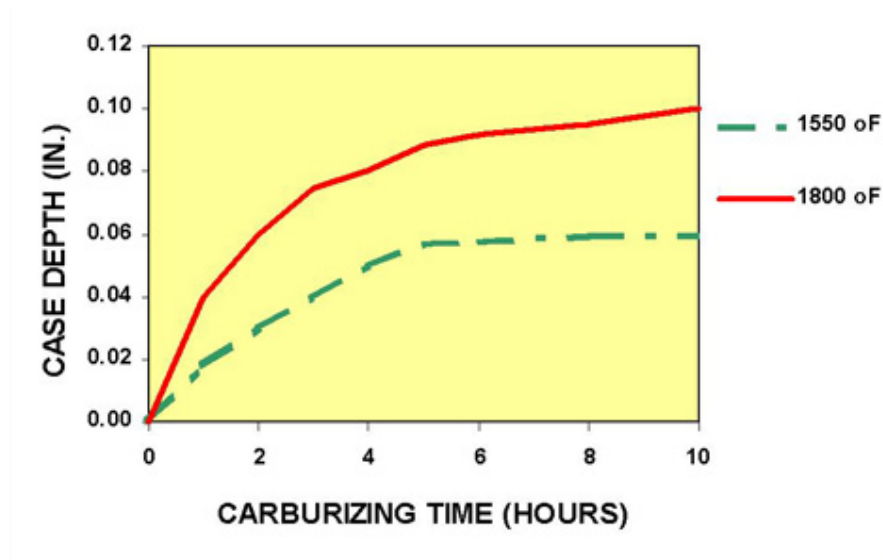
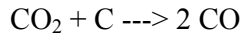


Figure 1. Case depth vs. Carburizing time.

Pack Carburizing:

In this process, the part that is to be carburized is packed in a steel container so that it is completely surrounded by granules of charcoal. The charcoal is treated with an activating chemical such as Barium Carbonate ($BaCO_3$) that promotes the formation of Carbon Dioxide (CO_2). This gas in turn reacts with the excess carbon in the charcoal to produce carbon monoxide CO . Carbon Monoxide reacts with the low-carbon steel surface to form atomic carbon which diffuses into the steel. Carbon Monoxide supplies the carbon gradient that is necessary for diffusion. The carburizing process does not harden the steel. It only increases the carbon content to some predetermined depth below the surface to a sufficient level to allow subsequent quench hardening.

Carbon Monoxide reaction:



Reaction of Cementite to Carbon Monoxide:

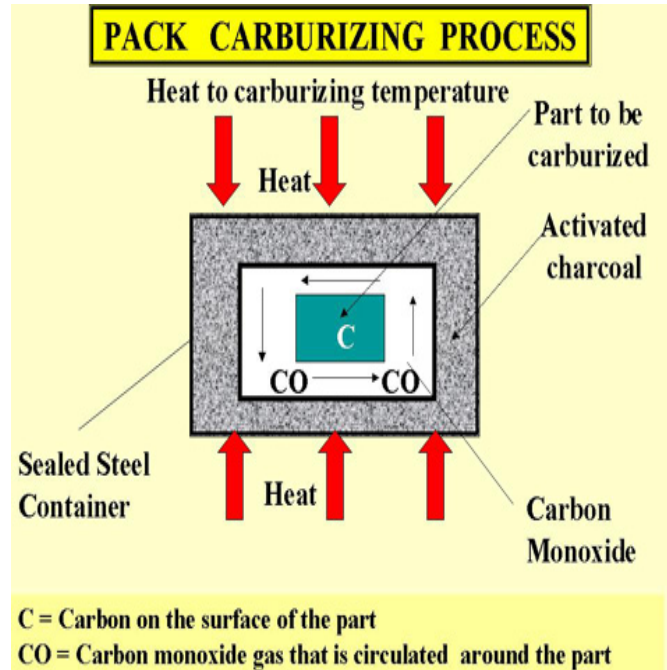
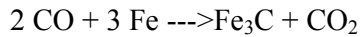


Figure 2. Pack carburizing process

Quenching Process:

It is difficult to quench the part immediately, as the sealed pack has to be opened and the part must be removed from the pack. One technique that is used often is to slow cool the entire pack and subsequently harden and temper the part after it is removed from the sealed pack.

Depth of Hardening:

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

Carburizing Time:

4 to 10 hours

Gas Carburizing:

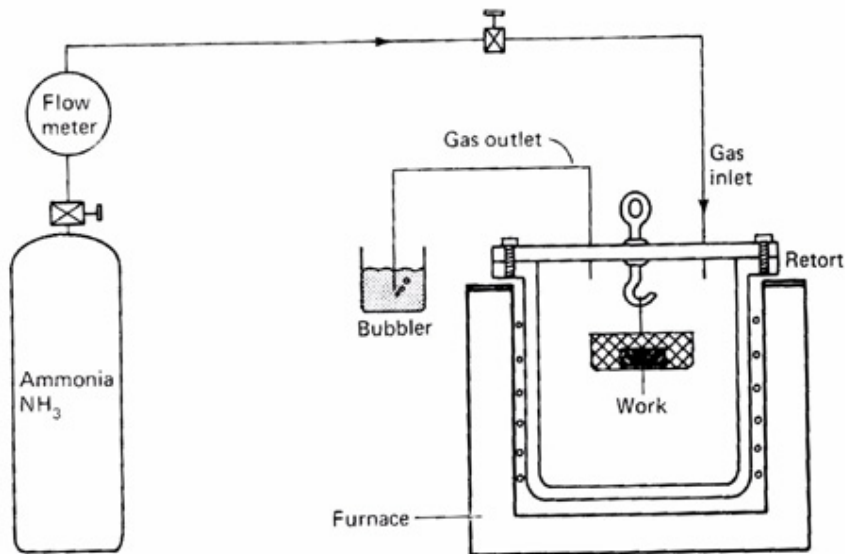
Can be done with any carbonaceous gas, such as methane, ethane, propane, or natural gas. Most carburizing gases are flammable and controls are needed to keep carburizing gas at 1700 °F from contacting air(oxygen). The advantage of this process over pack carburizing is an improved ability to quench from the carburizing temperature. Conveyor hearth furnaces make quenching in a controlled atmosphere possible.

Liquid Carburizing:

Can be performed internally or externally heated molten salt pots. Carburizing salt contains cyanide compounds such as sodium cyanide (NaCN). Cycle times for liquid cyaniding is much shorter (1 to 4 hours) than gas and pack carburizing processes. Disadvantage is the disposal of salt. (environmental problems)and cost (safe disposal is very expensive).

NITRIDING : Nitriding is a Surface Hardening process, in which, nitrogen is introduced to the steel by passing ammonia gas through a muffle furnace, containing the steel to be nitrided. The ammonia is purchased in tanks as a liquid and introduced into the furnace as a gas at slightly greater pressure than the atmospheric one. With the nitriding furnace operating at a temperature of 480°C-540°C, the ammonia gas partially dissociates into nitrogen and hydrogen gas mixture. The dissociation of ammonia is shown by the equation: $2\text{NH}_3 = 2\text{N} + 3\text{H}_2$. The nature of this process to obtain a case hardened product is very different from that of the carburizing one. Carbon doesn't play any part in the nitriding operation but influences machinability of the steel. The temperatures used here are much lower than those used in carburizing and below the critical temperature of the steel. The operation of the nitriding cycle is using controlled so that the dissociation of the ammonia gas is held to approximately 30% but may be varied from 15%-95% depending upon operating conditions.

Simple carbon steels, which are often used for carburizing are not used for nitriding. Steels used in the process are special alloy steels. With the nitriding developing rather thin cases, a high core hardness is required to withstand any high crushing load. High tempering temperatures call for a steel with a higher carbon content to develop this increase in core hardness. In addition to high carbon content, various alloying elements are called for in the steel to bring about an increase in the formation of these nitrides. Chromium, molybdenum, vanadium, and tungsten, all being nitrides formers, are also used in nitriding steels. Nickel in nitriding steels hardens and strengthens the core and toughens the case but with slight loss in its hardness.



The gas mixture leaving the furnace consists of hydrogen, nitrogen and undissociated ammonia, which is soluble in water, is usually discharged into water and disposed off in this manner. The free nitrogen formed by this dissociation is very active, uniting with the iron and other elements in the steel to form nitrides. These nitrides are more or less soluble in the iron and form a solid solution, or, are in a fine state of dispersion, imparting hardness to the surface of the steel. From the surface the nitrides diffuse slowly, and the hardness decreases inwardly until the unaffected core is reached. The depth of penetration depends largely upon the length of time spent at the nitriding temperature. Diffusion of these nitrides is much slower than diffusion of carbon in the carburizing operations so a much longer time is required to develop similar penetration. Generally, the surface hardness is much greater after nitriding than it is after carburizing and hardening. The maximum hardness obtained from a carburized and hardened case runs around 67 Rockwell C whereas it is possible to obtain surface hardness value in excess of 74 Rockwell C by nitriding. The surface hardness of the nitrated case can not be measured by the case, it is using measured by the Rockwell superficial scale such as 15N or 30N scale. The hardness may be estimated from a hardness conversion table. In order to obtain localized nitriding of parts or to stop nitriding on some surface areas, the best method is to use tin as a protecting agent against the nitriding action. Tin, in the form of a paste or paint made from tin powder, or tin oxide mixed with glycerine or shellac, may be applied as a satisfactory stop off method. Although tin melts at a lower temperature than used in nitriding, ample protection is provided by thin layer of tin that is held to the surface by surface tension. Care should be exercised to apply the tin paint or electroplate to a clean surface and to avoid a thick layer of tin which may run or dip into surface where protection is not desired.

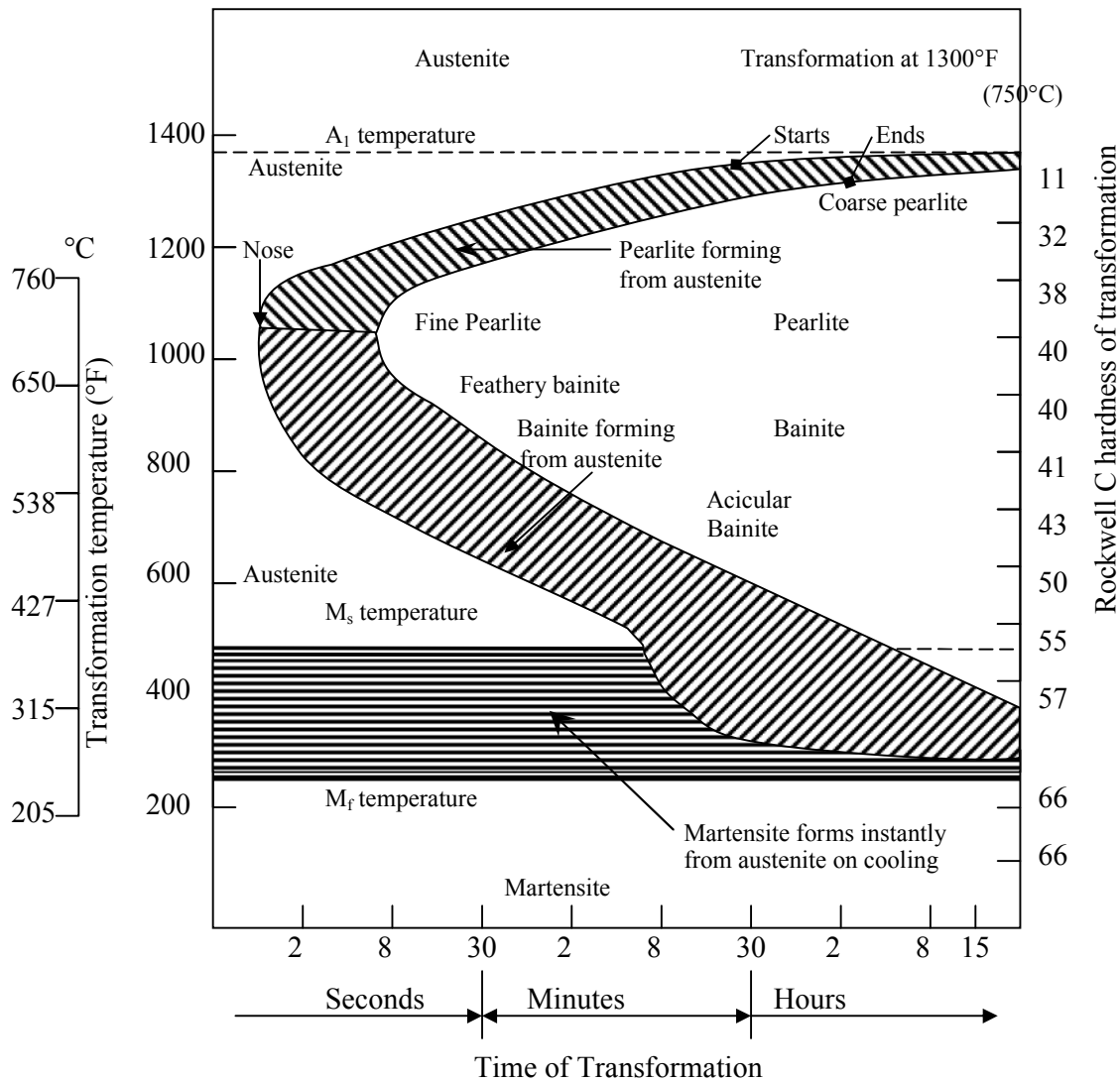
All heat treatments, such as the quench hardening of steel in the nitriding process, are carried out before the nitriding operation. After rough machining operations, the steel is heated to about 950°C, held for the necessary length of time at this temperature in order to have the alloying elements go into solution in the austenite, thereby imparting core strength and toughness after quenching and finish machining, to produce a sorbitic structure which has a rough case and eliminates any brittleness resulting from any free ferrite. This hardening, thus reduces distortion during nitriding. After tempering all oxide film and traces of decarburization are removed. Any decarburization left on the surface of the steel to be nitrided will usually result in failure of the nitrided surfaces by peeling or spalling of. The steel is then nitrided and allowed to cool slowly to room temperature in the nitriding box or chamber. No quenching is required, the steel develops its maximum hardness without necessitating a further quenching operation.

CYANIDING:- Cyaniding is a process of superficial case hardening in which the steel is heated in a molten cyanide salt at about 850°C followed by quenching. Both carbon and nitrogen are absorbed in this process. In carbon nitriding, steel is heated in a gaseous mixture of ammonia and hydrocarbons whereby both carbon and nitrogen are absorbed.

RESULT:- The phenomenon of various surface hardening processes was studied.

OBJECTIVE: To study TTT diagrams.

DIAGRAM:



TTT diagram for the decomposition of austenite in eutectoid carbon steel

THEORY: T (Time) T (Temperature) T (Transformation) diagram is a plot of temperature versus the logarithm of time for a steel alloy of definite composition. It is used to determine when transformations begin and end for an isothermal (constant temperature) heat treatment of a previously austenitized alloy. When austenite is cooled slowly to a temperature below LCT (Lower Critical Temperature), the structure that is formed is Pearlite. As the cooling rate increases, the pearlite transformation temperature gets lower. The microstructure of the material is significantly altered as the cooling rate increases. By heating and cooling a series of samples, the history of the austenite transformation may be recorded. TTT diagram indicates when a specific transformation starts and ends and it also shows what percentage of transformation of austenite at a particular temperature is achieved.

Cooling rates in the order of increasing severity are achieved by quenching from elevated temperatures as follows: furnace cooling, air cooling, oil quenching, liquid salts, water quenching, and brine. If these cooling curves are superimposed on the TTT diagram, the end product structure and the time required to complete the transformation may be found.

In Figure 1 the area on the left of the transformation curve represents the austenite region. Austenite is stable at temperatures above LCT but unstable below LCT. Left curve indicates the start of a transformation and right curve represents the finish of a transformation. The area between the two curves indicates the transformation of austenite to different types of crystal structures. (Austenite to pearlite, austenite to martensite, austenite to bainite transformation.)

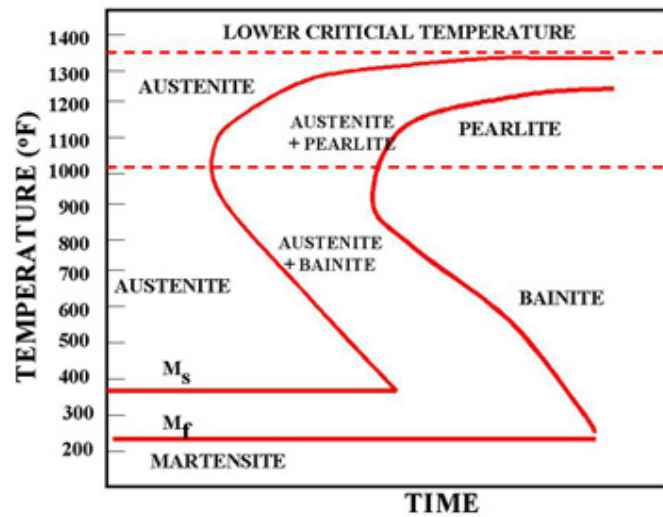


Figure 1. TTT Diagram

Figure 2 represents the upper half of the TTT diagram. As indicated in Figure 2, when austenite is cooled to temperatures below LCT, it transforms to other crystal structures due to its unstable nature. A specific cooling rate may be chosen so that the transformation of austenite can be 50 %, 100 % etc. If the cooling rate is very slow such as annealing process, the cooling curve passes through the entire transformation area and the end product of this the cooling process becomes 100% Pearlite. In other words, when slow cooling is applied, all the Austenite will transform to Pearlite. If the cooling curve passes through the middle of the transformation area, the end product is 50 % Austenite and 50 % Pearlite, which means that at certain cooling rates we can retain part of the Austenite, without transforming it into Pearlite.

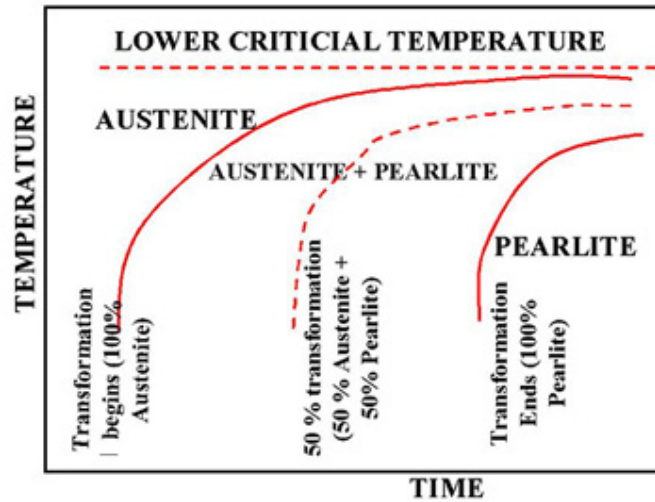


Figure 2. Upper half of TTT Diagram(Austenite-Pearlite Transformation Area)

Figure 3 indicates the types of transformation that can be found at higher cooling rates. If a cooling rate is very high, the cooling curve will remain on the left hand side of the Transformation Start curve. In this case all Austenite will transform to Martensite. If there is no interruption in cooling the end product will be martensite.

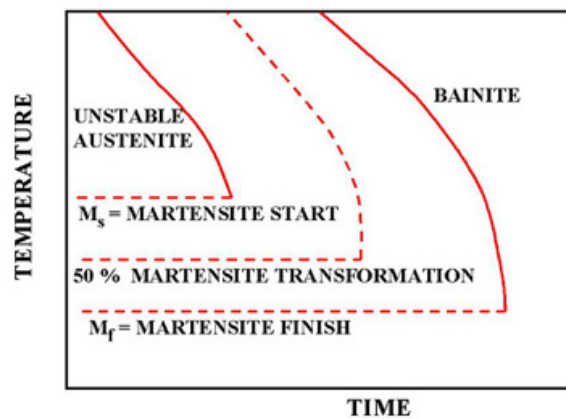


Figure 3. Lower half of TTT Diagram (Austenite-Martensite and Bainite Transformation Areas)

In Figure 4 the cooling rates A and B indicate two rapid cooling processes. In this case curve A will cause a higher distortion and a higher internal stresses than the cooling rate B. The end product of both cooling rates will be martensite. Cooling rate B is also known as the Critical Cooling Rate, which is represented by a cooling curve that is tangent to the nose of the TTT diagram. Critical Cooling Rate is defined as the lowest cooling rate which produces 100% Martensite while minimizing the internal stresses and distortions.

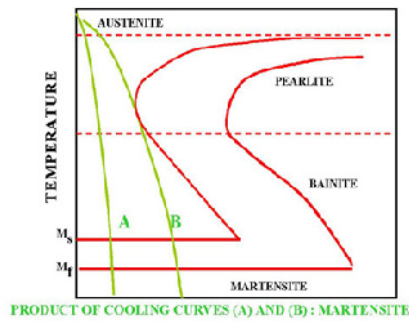


Figure 4. Rapid Quench

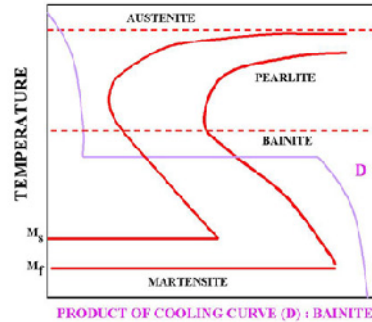


Figure 5. Interrupted Quench

In Figure 5, a rapid quenching process is interrupted (horizontal line represents the interruption) by immersing the material in a molten salt bath and soaking at a constant temperature followed by another cooling process that passes through Bainite region of TTT diagram. The end product is Bainite, which is not as hard as Martensite. As a result of cooling rate D; more dimensional stability, less distortion and less internal stresses are created. In Figure 6 cooling curve C represents a slow cooling process, such as furnace cooling. An example for this type of cooling is annealing process where all the Austenite is allowed to transform to Pearlite as a result of slow cooling.

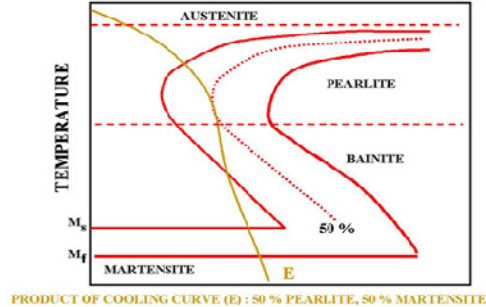
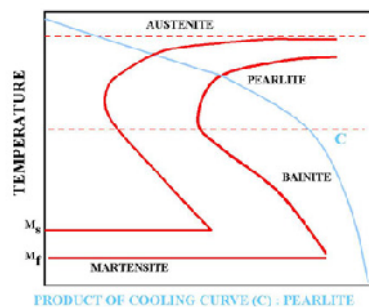


Figure 6. Slow cooling process (Annealing) Figure 7. Cooling rate that permits both pearlite and martensite formation.

Sometimes the cooling curve may pass through the middle of the Austenite-Pearlite transformation zone. In Figure 7, cooling curve E indicates a cooling rate which is not high enough to produce 100% martensite. This can be observed easily by looking at the TTT diagram. Since the cooling curve E is not tangent to the nose of the transformation diagram, austenite is transformed to 50% Pearlite (curve E is tangent to 50% curve). Since curve E leaves the transformation diagram at the Martensite zone, the remaining 50% of the Austenite will be transformed to Martensite.

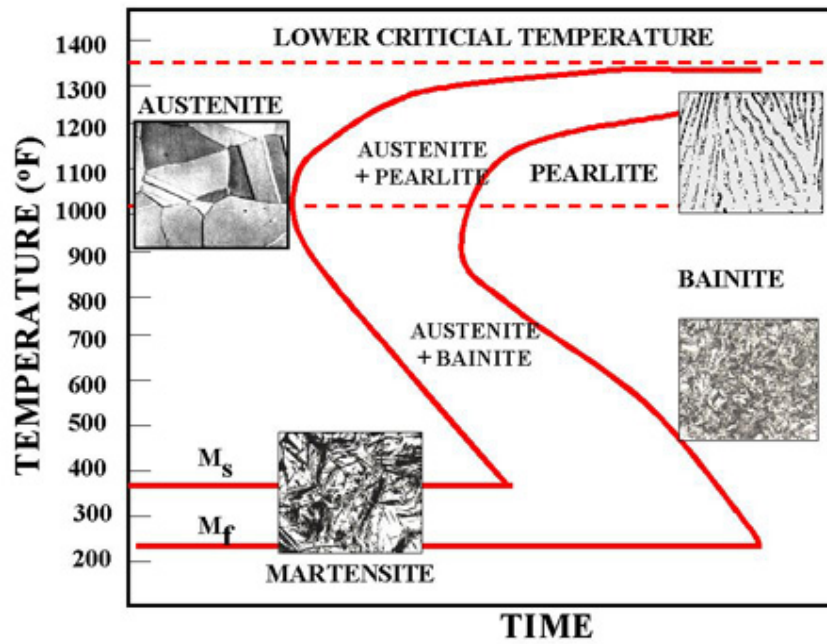


Figure 8. TTT Diagram and microstructures obtained by different types of cooling rates

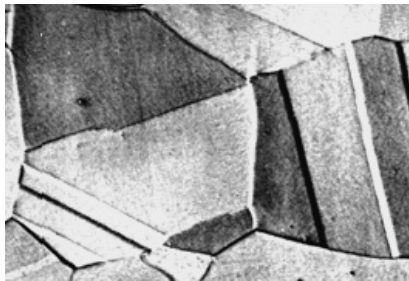


Figure 9. Austenite

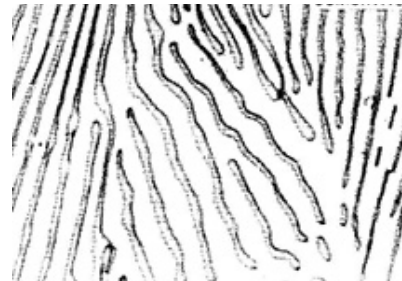


Figure 10. Pearlite



Figure 11. Martensite

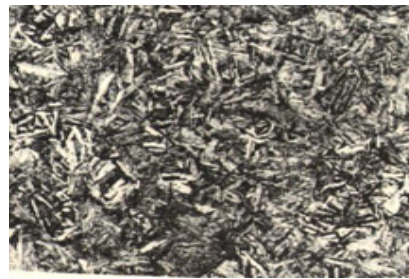


Figure 12. Bainite

RESULT:- TTT diagram was studied

