UNIT-III (BME-402)

MATERIALS SCIENCE

ALLOTROPIC FORMS OF IRON

At atmospheric temperature iron has three allotropic forms of crystal at different temperature.

Alpha Iron : It occurs from normal temperature to 910^{o}C and has bcc structure.

Gamma Iron : It occurs from 910^{o}C to 1400^{o}C and has fcc centred lattice structure. Iron looses its magnetic properties when heated to 770^{o}C.

Delta iron : This occurs from 1400^o to 1539^{o}C (molten state) and has body centred lattice. Its properties can be improved by addition of Co, Ni, C. At very high temperature fourth form exist called Epsilon iron € i.e. hexaferrum.

These phases of iron at atmospheric pressure are important because of the difference in solubility of carbon, forming different types of steel.

Q. What do you mean by heat treatment. Why heat treatment is done (Purpose of heat treatment of steels). Classify various types of heat treatment processes.

Ans. : Definition :

Properties of metals and alloys may be changed by changing their microstructure. This may be done by heating and cooling the metals. Thus *heat treatment* is the process of obtaining the desired properties by changing the microstructure of metals. These microstructures are obtained by heating and cooling the metals in its solid state under controlled conditions.

Heat treatment process may be carried out by –

(i) heating the metal, to a predetermined (required) temperature in solid state

(ii) soaking (holding) the metal at that temperature for a required time so that whole of the metal attain the required temperature,

(iii) Cooling the metal at a required rate to obtain the desired microstructure and hence the desired properties.

Classification: Various heat treatment processes may be classified (or enumerated) as follows :

(1) Hardening

(2) Tempering

(3) Annealing

(4) Normalizing

(5) Surface Hardening

- (a) Carburizing
  - (i) Solid/pack carburizing
  - (ii) Liquid Carburising
  - (iii) Gas Carburising
- (b) Cyniding
- (c) Nitriding
- (d) Flame hardening
- (e) Induction hardening

Purpose of Heat Treatment :

Heat treatment process serve one or more of the following purposes:

(i) Improve mechanical properties such as hardness, strength, toughness and ductility.

(ii) Improve machinability.

(iii) Improve resistance to corrosion, wear, abrasion & heat.

(iv) Improve /modify electrical and magnetic properties.

(v) Relieve internal stresses produced during cold working.

(vi) Prepare the metal for further operations.

(vii) Refine grain size

(viii) Change chemical composition of the surface

(ix) Remove gases.

(x) Remove cracks and distortions.

(xi) Produce hard surface and tough core.

Q.2 : What are different micro constituents (microstructures) of steel? Enumerate thern and explain briefly the different microstructures and micro constituents of steel.

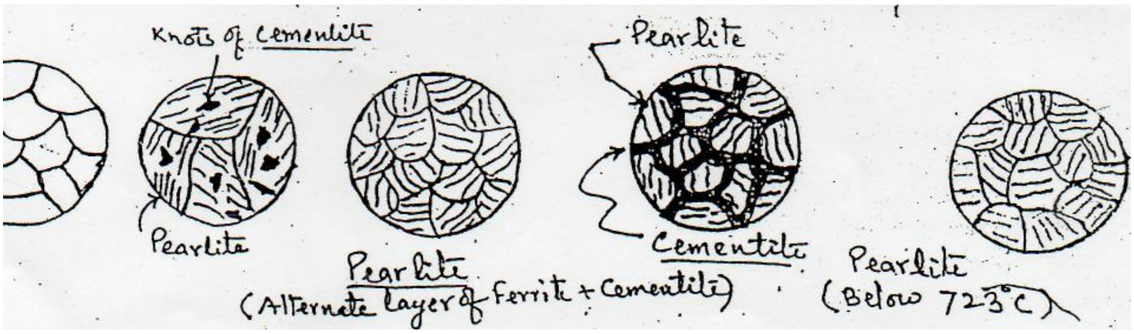
Ans.: Various Microconstituents/microstructures are given below.

(i) Ferrite (ii) Pearlite (iii) Martensite, (iv) Cementite, (v) Austenite

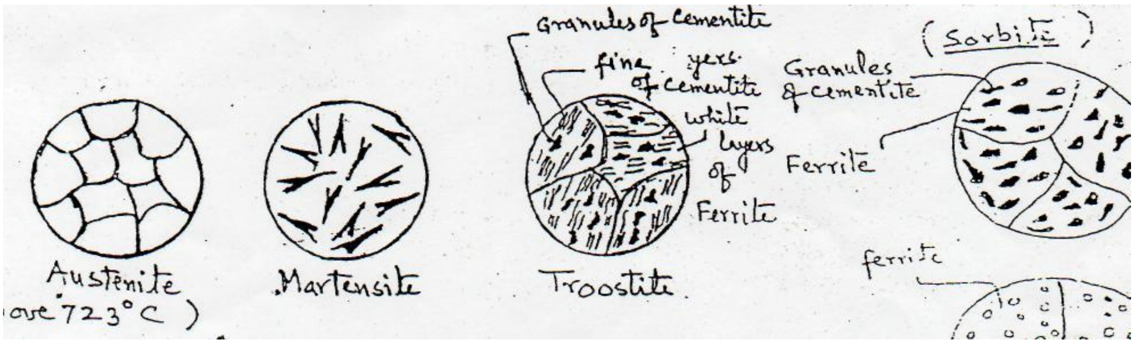
(vi) Troostite, (vii) Sorbite, (viii) Allotropic Forms (ix) Spheroidite.

(i) <u>Ferrite:</u> Ferrite crystals are made of solid solution of carbon iii alpha-iron. Solubility of carbon in ferrite is 0.025 at 723° C. Ferrite is present in low carbon steels and soft cast iron. It does not harden when cooled rapidly. It is very soft, ductile and highly magnetic.

(ii) <u>Cementite:</u> Cementite is formed when iron and carbon combine chemically to form iron carbide (Fe_3C). It has no ductility. Cementite increases generally with increase in Carbon percentage. Its presence in iron and steel decreases the ductility and tensile strength but increases the hardness and cutting ability. It contains 6.67 percent carbon. Cementite occurs either in the form of a network or in globular form or in massive form depending upon heat treatment process.



(iii) <u>Pearlite:</u> It is a mixture of 87.5% Ferrite and 12.5% cementite. It comprises of alternating plates or layers of ferrite and cementite. It has a lustrous pearly appearance. That is why it is known as pearlite. Soft steels are composed of ferrite and pearlite. Steels having 0.83% carbon are composed of 100% pearlite. Hard steels are made of pearlite and cementite.



(iv) <u>Austenite:</u> It is a solid solution of iron carbide (Fe_3C) in gama-iron. It is non magnetic. It occurs above 723°C. It is soft and ductile than ferrite. Upon cooling below 723°C it is completely transformed into (1). ferrite +pcarlite for steels having less than 0.83% carbon (2) pearlite for utectoide steel steels having exactly 0.83% carbon (3) pearlite +cementite for steels having more than 0.83% carbon.

(v) Martensite: Martensite is a mass of needle like structure. It is obtained when austenite is cooled rapidly from higher critical temperature. Formation of martensite starts by the decomposition of austenite below 320°C. It is the main constituent of hardened steel. It is extremely hard, brittle and magnetic.

(vi) Troostite: It is a very fine pearlite. Like pearlite it also has alternate layers of ferrite and cementite. It is stronger than pearlite. It is softer and less brittle than martensite and harder than "Sorbite".

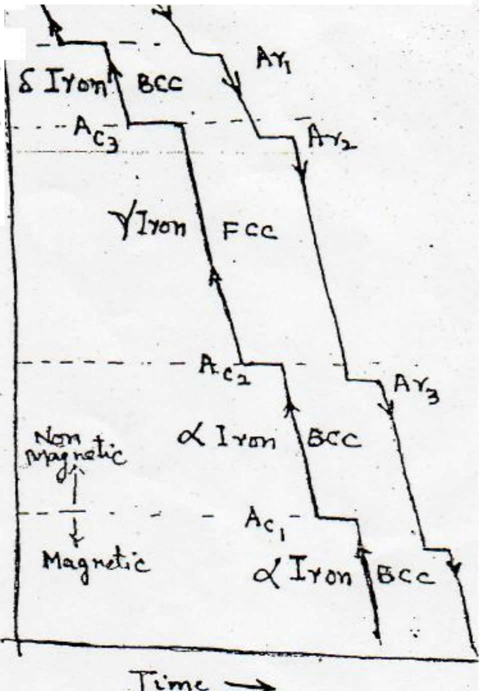
It is obtained (1) When austenite is cooled at a slow rate than required for martensite (i.e. cooled in oil). 2. when martensite is tempered between 250 to 450° C.

(vii) Sorbite: Depending upon the chemical .mnipositioji, size of the job and degree of hardening, the sorbite, begins to form when tempered above 400°C and upto 680°C. Layers of cementite contract to form granules as shown in figure.

Sorbite is less ductite than pearlite but its tensile strength is higher. It is softer and less hard than “troostite” but more ductile than troostite. Sorbite may also be obtained when austenite is cooled at a rate faster than required for pearlite and cooled at a rate slower than than required or “troostite”.

(vii) Spheroidite: To soften air hardened stels and carry out machining operations, the steels are heated just below the lower critical temperature (i.e between 680° C and lower critical temp 723° C) cementite is converted into small rounded speroids.. Granules of comentite are converted into gladoules of cementite, which is softer than "Sorbite".

<u>Allotropic Forms of Iron</u>: Iron and steel also possesses allotropy. Its various allotropic form are: alpha-iron, gamma-iron and S iron



1. Alpha Iron: It has been structure and occurs in two forms.

(i) **Ferromagretite alpha-iron:** It is magnetic from room temperature to 768^{o}C. It has bcc structure and strong.

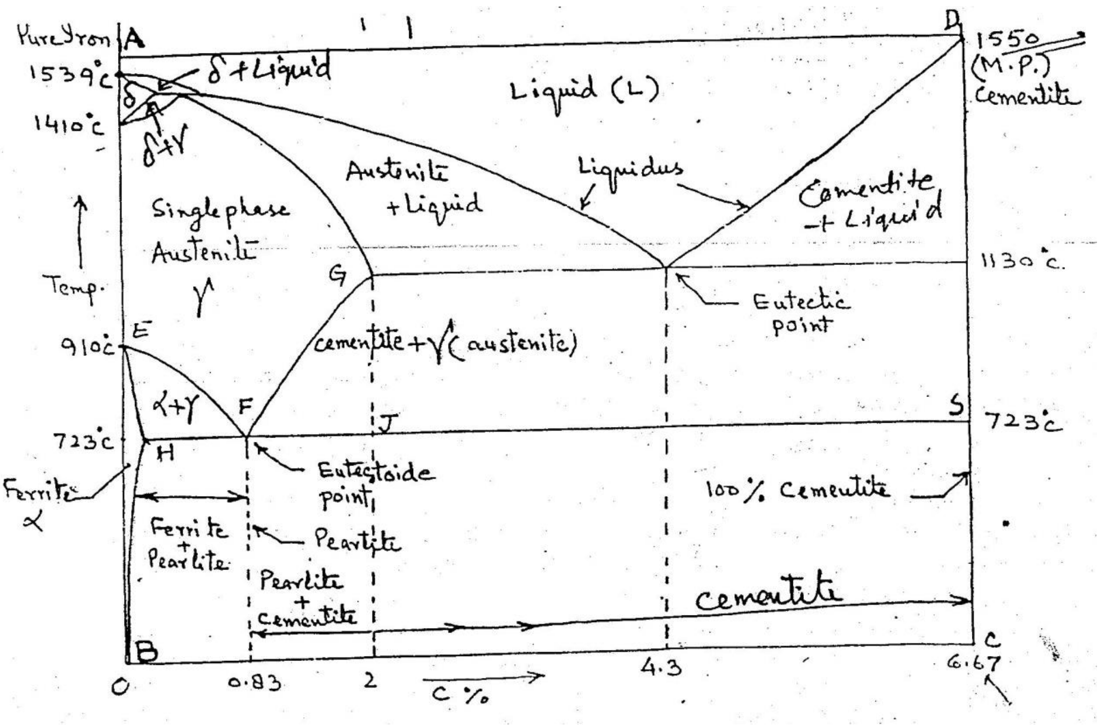
(ii) **Para magnetic alpha-Iron :** It also has bcc structure. It is magnetic and found between 768 to 910^{o}C.

2. Gamma Iron : (Iron) or Austenite: It is found between 910 and 1410^{o}C and fcc structure. It is non-magnetic in nature. It is very ductile and soft. It is known as austenite.

3. Delt Iron (S-Iron): This form is stable between 1410^{o}C and 1539^{o}C and has a bcc crystal lattice.

IRON CARBON PHASE (EQUILIBRIUM) DIAGRAM

Iron carbon equilibrium diagram indicate the relationship among percentage of carbon, temperature and phase changes or constituent micro structures of steel. The effects of heat .treatments and subsequent properties of steel may be well understood by lower left half of the iron carbon phase diagram as shown in figure below:



Iron-carbon phase diagram in the figure above show iron-carbon binary system. Commercially –

- Pure-iron contains upto 0.008% carbon
- Steel contains upto 2.11% carbon
- Cast Iron contains upto 4.5% carbon
- Pig iron contains upto 6.67% carbon

The diagram may be extended to 100% carbon (pure graphite) But the range of 6.67% carbon is important for Engineering Application because at 6.67% it contains 100% cementite.

Explanation/description of diagram :

α-Iron Ferrite;

γ-Iron-Austenite;

Line EFG - Upper Critical temperatures. Line.

Line HFS - Lower critical temp line

Line AB - Pure Iron – Ferrite

Line CD-Pure Cementite

Point A - Melting point of pure iron - 153 °C

Point D- Melting point of cementite - 1550 °C

Point H- Maximum solubility of carbon in ferrite - 0.025% carbon

Point F - corresponds to 0.83% carbon
- called eutectoid point
- Minimum temp at which austenite is obtained

Hypo-Eutectoid Steels – These steels contain less than 0.83% carbon. Constituents of these steels are – Ferrite + Pearlite

When cooled slowly Austenite

$$\xrightarrow[\text{At upper critical temp HF}]{\text{Decomposes to}} (\alpha+\gamma) \xrightarrow[\text{At lower critical temp. HF}]{\text{Converted to}} (\alpha + \text{Pearlite})$$

Hyper-Eutectoid Steels : These steels contain more than 0.83% carbon Constituents of these, steels are - pearlite + cementite

When cooled slowly:

$$\xrightarrow[\text{At upper critical temp FJ}]{\text{Austenite converted to}} (\gamma+\text{Cementite}) \xrightarrow[\text{At lower critical temp. FJ}]{\text{Converted to}} (\text{Pearlite+ cementite})$$

Eutectoide Steels : They contain 0.83% carbon**.** When cooled slowly, Austenite directly converted to pearlite It has a pearly lustre arid made of Pearlite = (Ferrite 87% + cementite 13%).

Constructing the Iron carbon Phase Diagram: Method of Construction is described below:

(i) Heating and cooling curves are made for a number of steel specimens havin different carbon percentages,

(ii) Then various critical point temperatures (temp of change of phase) are plotted on a graph, taking carbon content on X-axis and critical temperatures on y- axis.

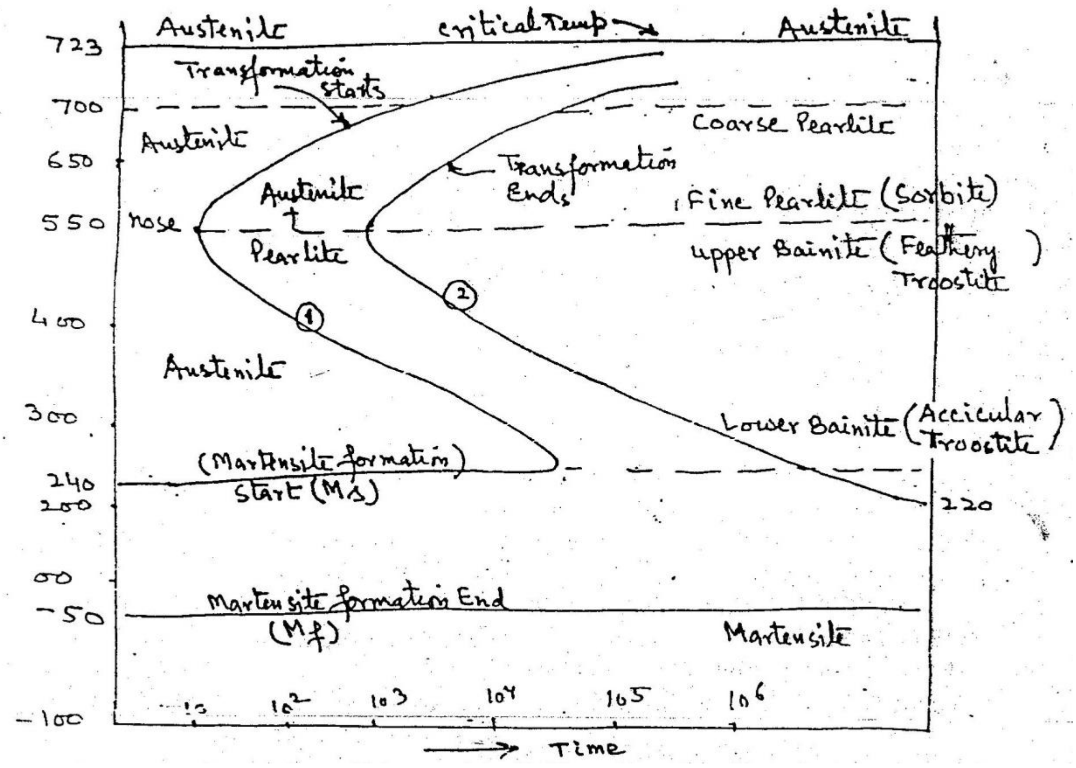
TIME TEMPERATURE TRANSFORMATION DIAGRAM (TTT DIAGRAM):

Main Features:

- TTT Diagram is also known as S-curve, C-curve or Bain's curve.
- Iron carbon diagram shows the changes in microstructure under equilibrium conditions only. It does not show the effect of different cooling rates.
- Whereas TTT diagram indicates the transformation of austenite into various structures at different cooling rates.
- TTT diagram or S-curve is most useful in presenting an over all picture of the transformation behaviour of austenite to get desired structure and time of soaking during heat treatment.

Construction of TTT Diagram :

- TTT diagram for eutectoid steels (with 0.83% carbon) is shown in figure below.
- By plotting starting and end points of transformations or decomposition of austenite, two different curves are obtained. Transformation of austenite takes place between these two curves 1 & 2.
- The log scale of time is used to condense the results plotted into a small space. Because heat treatment process may take a few seconds to several hours.
- The important products of austenite transformation at different cooling rates are labeled on the diagram.



Transformation Behaviour of Austenite: (Effect of cooling Rates)

- Above the line AC_1 or lower critical temp 723°C austenite is stable.
- Line AB passing through the Nose of curve (1) shows the critical cooling curve. It indicates the fall in temp in OB time
- The rate of cooling, slow or fast, decides the transformation process
- In the diagram lines AG, AD, AE, AF and AG represent very slow to very high cooling rates. Effect of cooling rates are given below:-

(i) At a very slow cooling rate (AG) austenite has enough time to decompose into coarse pearlite. It is obtained near 700°C.

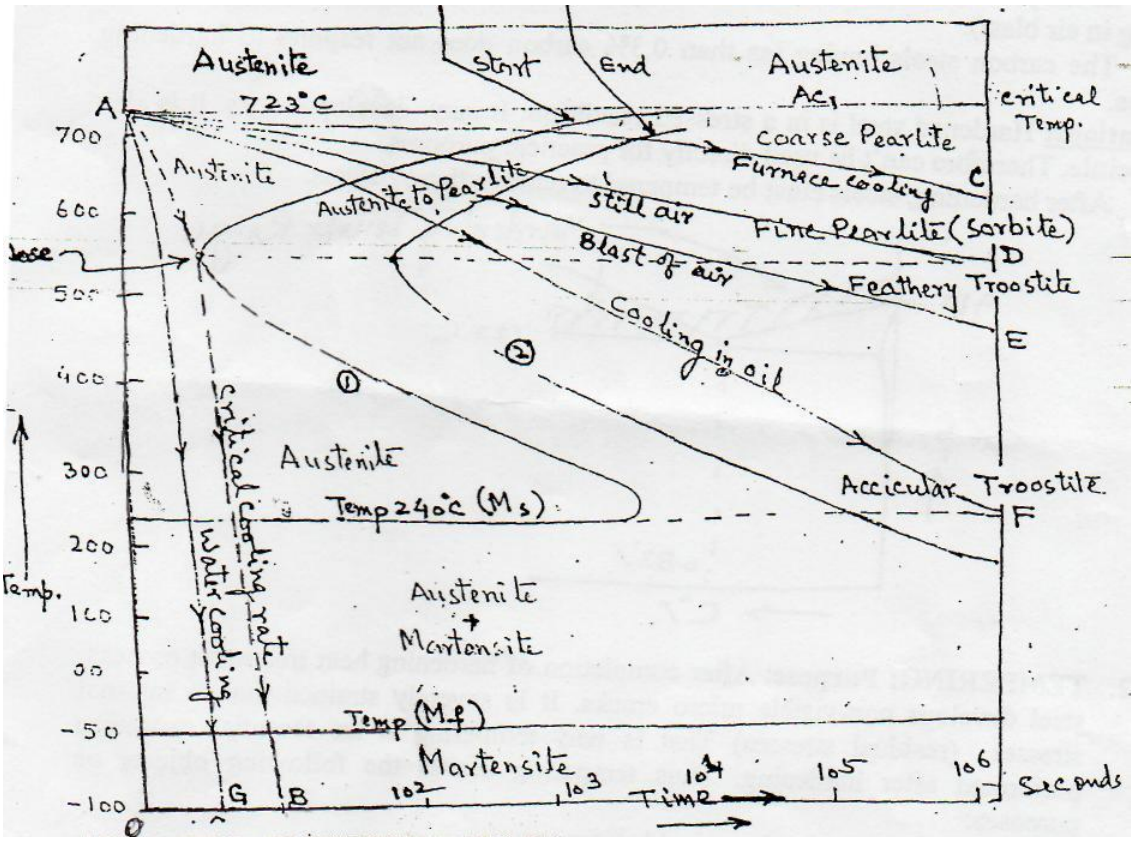
(ii) At some higher rate (shown by line AD) austenite is converted to sorbite. It is obtained between 550-650°C.

(iii) At further higher rate (AE) Troostite having feathery grains is obtained. It is obtained between 500-550 C. It is known as upper bainite.

(iv) At still higher cooling rate (shown by line 'AF') needle like troostite having fine grains is obtained. It is obtained between temperatures 220.C- 500C

(v) When austenite is cooled at extremely high rates (i.e. AG) austenite is transformed into martensite.

(vi) Formation of martensite begins at 240°C and end at -50°C.



HEAT TREATMENT PROCSSES :

1. **Hardening:** Process: The operation of hardening is carried out in three stages:

(i) Heating the work to a temperature critical temp. Hypoeutectoid steels (less than 0.8% carbon) are heated about 30°-50°C above upper critical temperature and Hyper-eutectoid steels (more than 0.83% carbon) are heated above lower critical temp.

(ii) Holding or soaking the steel at this temperature for a considerable time so that structure may change to austenite.

(iii) Quenching or cooling at a faster rate in a suitable medium. Water, oil or salt bath may be used as quenching media.

Cooling at a rate higher than critical cooling rate enable the austenite to change into martensite.

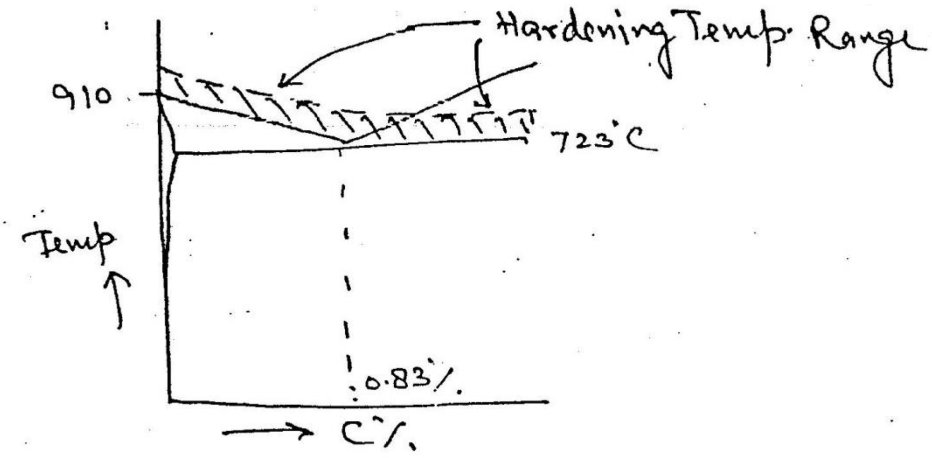
Purpose: Purpose of hardening is to (i) develop high hardeness to enable it to cut other metals, (ii) enable it to cut other metals, (iii) to resist wear and abrasion.

Applications: This process is applied all tools and machine parts used for heavy duty work. Hardening may be applied on parts made of medium carbon steels, high carbon steels and alloys steels.

In alloy steels, the martensite structure may be obtained by slow cooling rate (i.e. cooling in air blast).

The carbon steels having less than 0.3% carbon does not respond to hardening process.

Limitations: Hardened steel is in a stressed condition: It may develop cracks. It is also very brittle. Therefore can't be used directly for practical purposes. After hardening, steels must be tempered to, remove these defects.



2. TEMPERING : Purpose : After completion of hardening heat treatment process, steel develops non-visible micro cracks. It is severely strained due to' internal stresses (residual stresses). That is why tempering is an essential operation performed after hardening. Thus tempering serves the following objects or purposes:

(i) It reduces hardness and brittleness ' . '

(ii) Intereases ductility, toughness and shock resistance

(iii) Stabilize the structure of metal

(iv) Relieve internal stresses produced during hardening

(v) Eliminate microcracks developed during quenching/

Limitations: Besides above desired properties tempering may result in

(i) reduction of hardness

(ii) reduction of impact strength and tensile strength

Process: Tempering process requires or consists of

(i) reheating the hardened steel to a certain temperature below lower critical temperature followed by:

(ii) holding or soaking it at this temperature for a considerable time

(iii) Cooling at a slow rate

Types of tempering processes: Based upon reheating temp range the tempering process may be divided into three types as shown, in the diagram below:

(i) **Low Temperature Tempering:** It is done in the temp range of 150ºC to 250°C. The purpose of this process is to reduce internal stress and to increase ductility without appreciable loss in hardness.

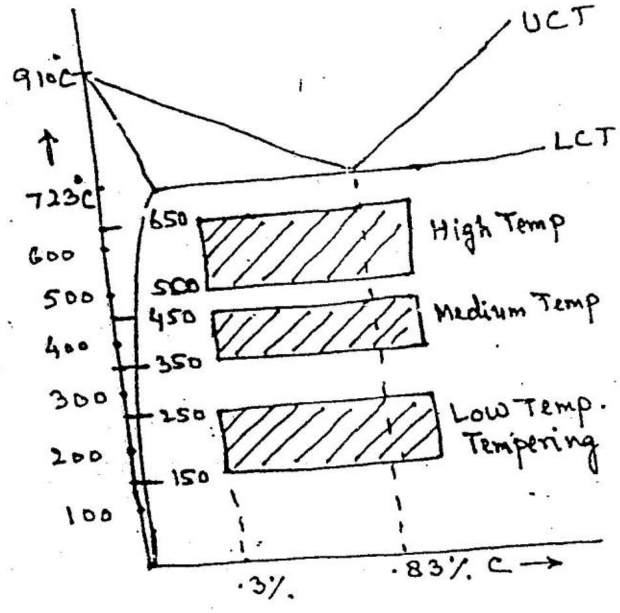
Applied - for tempering of carbon steel and low alloy cutting tools and measuring tools.

(ii) **Medium Temperature Tempering:-** It is done in the temp, range of 350°C to 450°C. At this temp martensite is completely converted to troostite. Ductility and toughness of steel is increased. But some hardners and strength are reduced.

Applied :- for tempering articles subjected to impact load: Chisels, hamers, laminated springs and helical springs etc. :

(iii) **High Temp, tempering;-** In this process-the hardened steel is reheated between 500 C and 650 C Martensite is completely transformed into sorbite, It eliminates the internal stresses completely.

Applied - for tempering machine parts subjected to high stresses e.g. shafts, gears, cranks shaft etc.



(Tempering Temp Range)

SOME METHODS OF HARDENING COMBINED WITH TEMPERING

AUSTEMPERING: Austempering process consist of

(i) heating the steels to the hardening temp.

(ii) holding it there for some time.

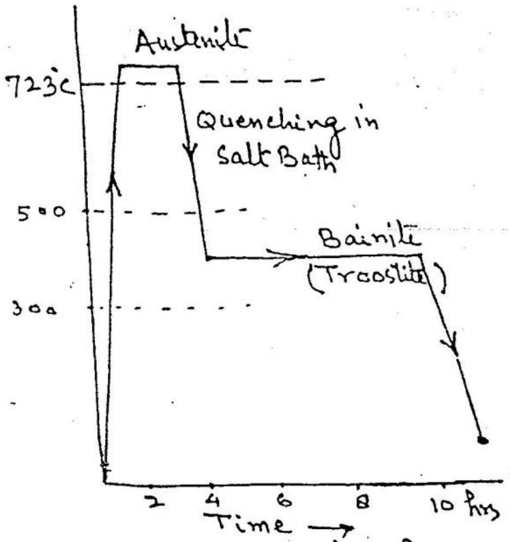
(iii) quenching in salt bath down to a temperature between 300-500°C, so that austenitc is completely converted into lower Bainite (or acicular Troostite).

(iv) It is then allowed cool in any medium to room temp.

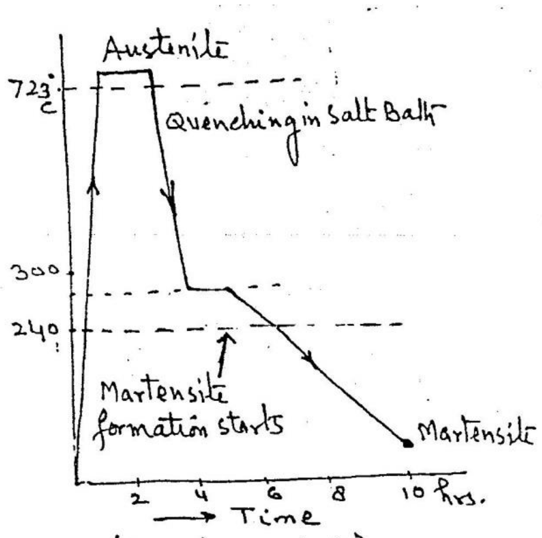
Characteristics: This process is based on the transformation of austenite to acicular troostite at constant temp.

- The steel after austempering has almost same hardness of as that of martensite
- But it is tough and more ductile than other tempered steels
- Cracks are eliminated
- Distortion are also eliminated

The process is applied for aircraft engine parts



(Austempering)



(Martempering)

MARTEMPERING: This is a hardening method, known as Martemporing or stepped quenching.

The process consists of— (i) heating the steel to the hardening temp range (austenite range), (ii) held at this temp for some time (iii) quenching in salt bath having the temp below 300°C (iv) holding it at the above temp so that steel attains uniform temp throughout the mass, (v) cooling in air to room temp. During this cooling period austenite is converted into martensite and some oustenite

Advantages (i) Less distortions and wrapping because the transformation of austenite to martensite occur simultaneously throughout the mass of object (ii) Less volume changes (iii) Lesser chances of cracks & internal stresses

Applications: It is applied in hardening thin articles of carbon steels and considerably thicker parts of alloy steels