MATERIAL SCIENCE AND ENGINEERING

UNIT 3

HEAR TREATMENT

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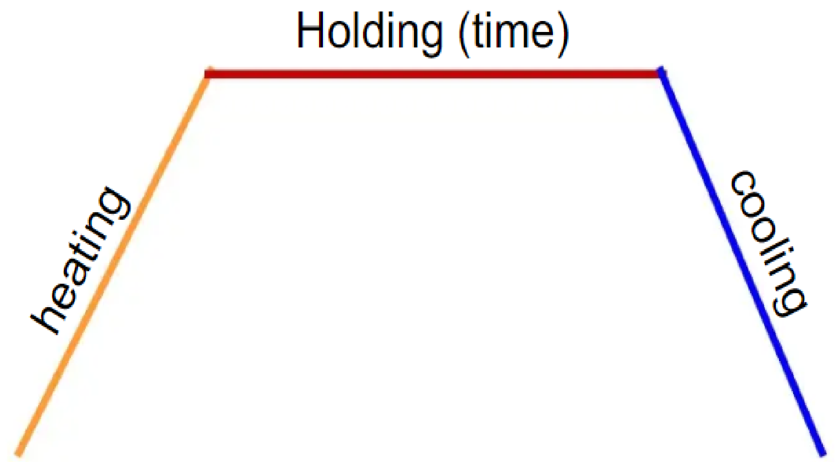
. Heat Treatment

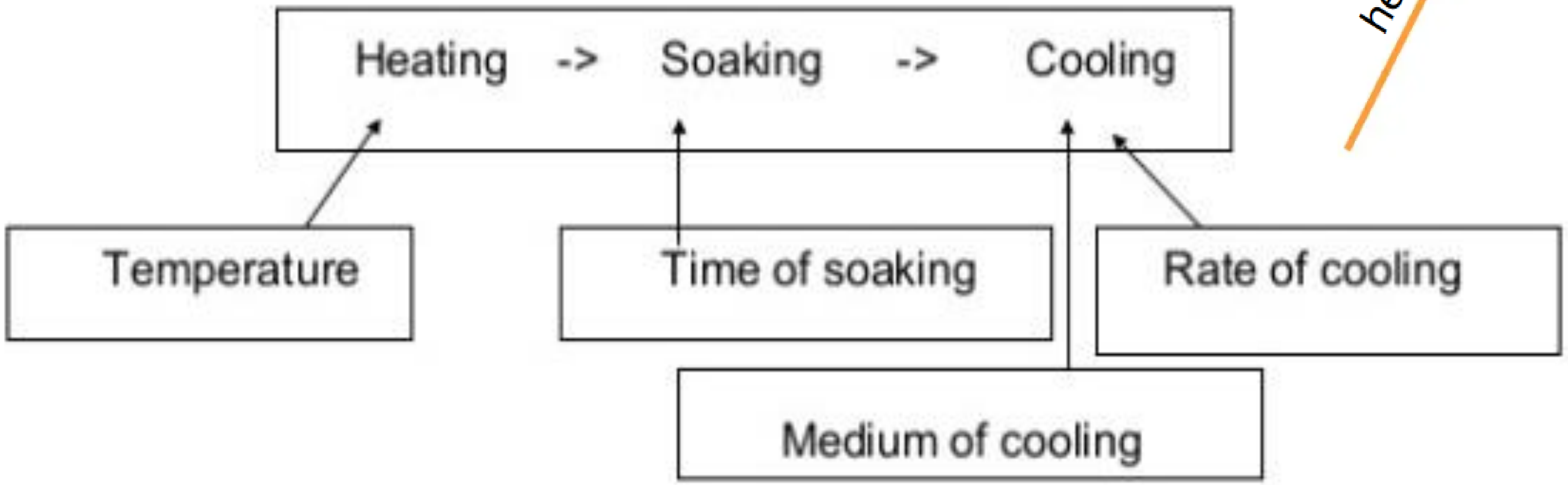
- *Heat Treatment process is a series of operations involving the* ***Heating and Cooling*** *of metals in the solid state.*

- *Its purpose is to change a mechanical property or combination of mechanical properties so that the metal will be more useful, serviceable, and safe for definite purpose.*

- *By heat treating, a metal can be made harder, stronger, and more resistant to impact, heat treatment can also make a metal softer and more ductile.*

Heat Treatment





- Different combinations of the above parameters
- Different compositions of materials and initial phases of materials

Give rise to different heat treatments

Purpose of heat treatment:

- Improvement in ductility
- Relieving internal stresses
- Grain size refinement
- Increase of strength and hardness
- Improvement in machinability and toughness

Factors involved

- Temperature upto which material is heated
- Length of time that the material is held at the elevated temperature
- Rate of cooling
- The surrounding atmosphere under the thermal treatment.

Types of Heat Treatment Processes

- Annealing
- Normalizing
- Quenching or Hardening
- Tempering
- Case Hardening, etc.

Annealing

- A heat treatment in which a material is exposed to an elevated temperature for an extended time period and then slowly cooled
- Purposes:

  - Relieve stresses

  - Increase softness, ductility, and toughness

  - Produce a specific microstructure

Annealing: Annealing

➢ Annealing involves heating the material to a predetermined temperature and hold the material at the temperature and cool the material to the room temperature slowly. The process involves:

1) Heating of the material at the elevated or predetermined temperature
2) Holding the material (Soaking) at the temperature for longer time.
3) Very slowly cooling the material to the room temperature.

- Stages: heating to desired temperature, holding or soaking, then cooling
- Time and temperature dependence;

  - Internal stress

  - Sufficient time for transformation

  - Diffusion

Why Annealing?

- Improve ductility or toughness
- Enhance machineability
- Refrain grain size
- Reduce the gaseous contents in material.
- Relieve internal stresses developed during solidification, machining etc.

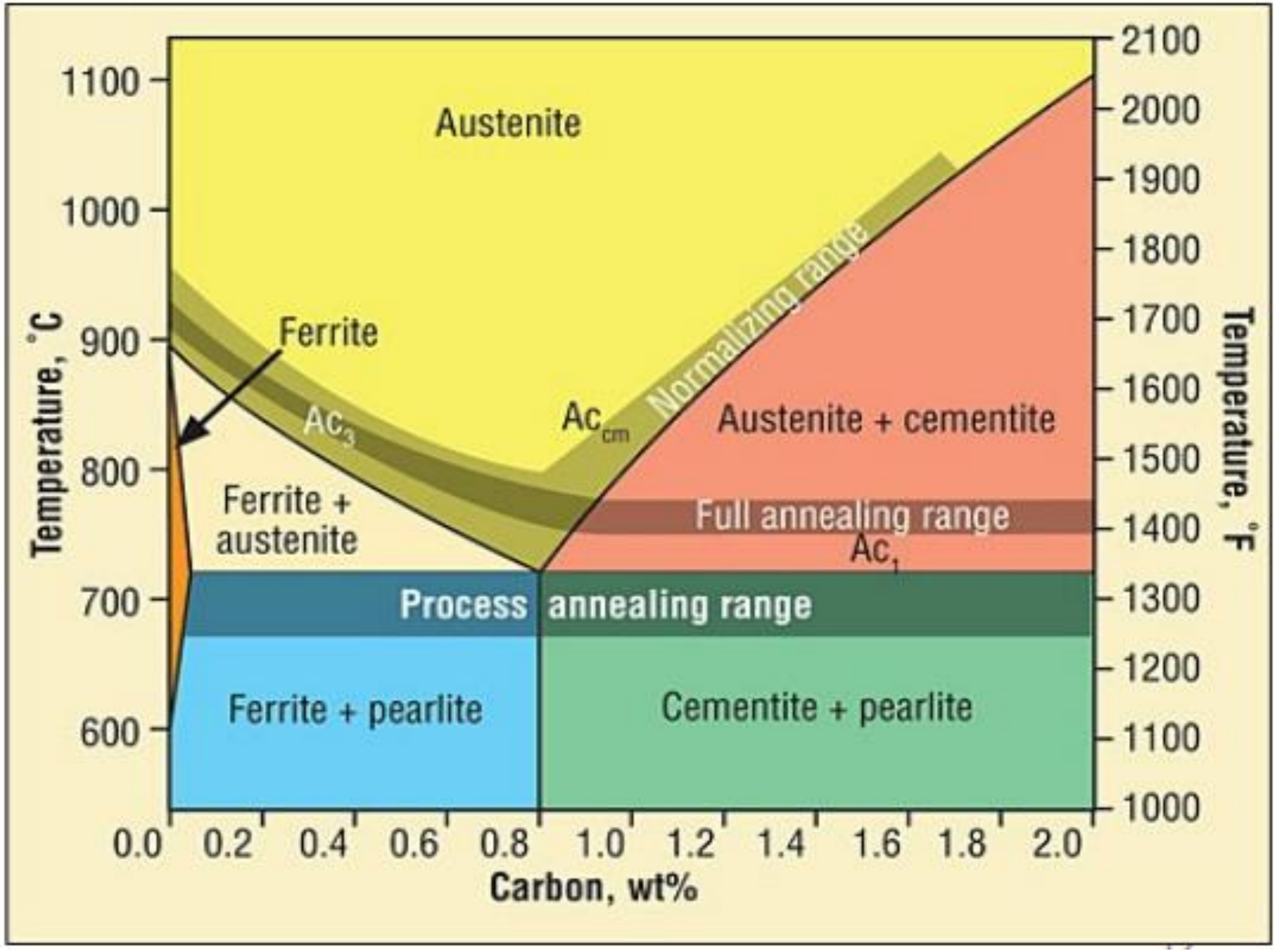
Types of Annealing

- Process annealing
- Stress relief annealing
- Spheroidizing
- Normalization, etc.

Process Annealing

This process is mainly suited for low carbon steel. In this process material is heated up to a temperature just below the lower critical temperature of steel or above its recrystallisation temoerature and then is allowed to cool slowly for sometime.

Cold worked steel normally have increased hardness and decrease ductility making it difficult to work. Process annealing improves this characteristics by making it more ductile and decreasing its hardness. This is mainly carried out on cold rolled steel like wire drawn steel, etc.


Austenite
Ferrite
Ac3
Accm
Normalizing range
Austenite + cementite
Ferrite +
austenite
Full annealing range
Ac1
Process annealing range
Ferrite + pearlite
Cementite + pearlite
Temperature, °C
Temperature, °F
Carbon, wt%
1100
1000
900
800
700
600
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0

Stress Relief Annealing

- As the name suggests, this process is employed to relieve internal stresses. No microstructural changes occur during the process.

- Internal stresses are those stresses which can exist within a body in the absence of external forces. These are also known as residual stresses are locked-in stresses.

- These stresses are developed in operations like:

Solidification of castings, welding, machining, grinding, shot peening, surface hammering, cold working, case hardening, electroplated coatings, precipitation and phase transformation.

- The process of stress relieving consists of heating materials uniformly to a temperature below the lower critical temperature, holding at this temperature for sufficient time, followed by uniform cooling.

- Plain carbon steels and low alloy steels generally temperature is limited to 600 °C. Higher temperature is used for high alloy steels.

- The extent of the stresses relieved depend upon the temperature employed and holding time.

Spheroidizing annealing

Spheroidizing Annealing process is for high carbon and alloy steel in order to improve their machinability.
In spheroidizing annealing, the steel is heated to a temperature below A1 temperature, kept at the temperature for sometime followed by slow cooling. The holding time varies from 15-25 hours.
It is mainly used for eutectoid steel and hypereutectic steel such as carbon tool steel, alloy tool steel, bearing steel etc.

Normalization Annealing

Normalization is a type of annealing process which is carried to enhance the hardness of steel. In this process, the steel is heated above its upper critical temperature.

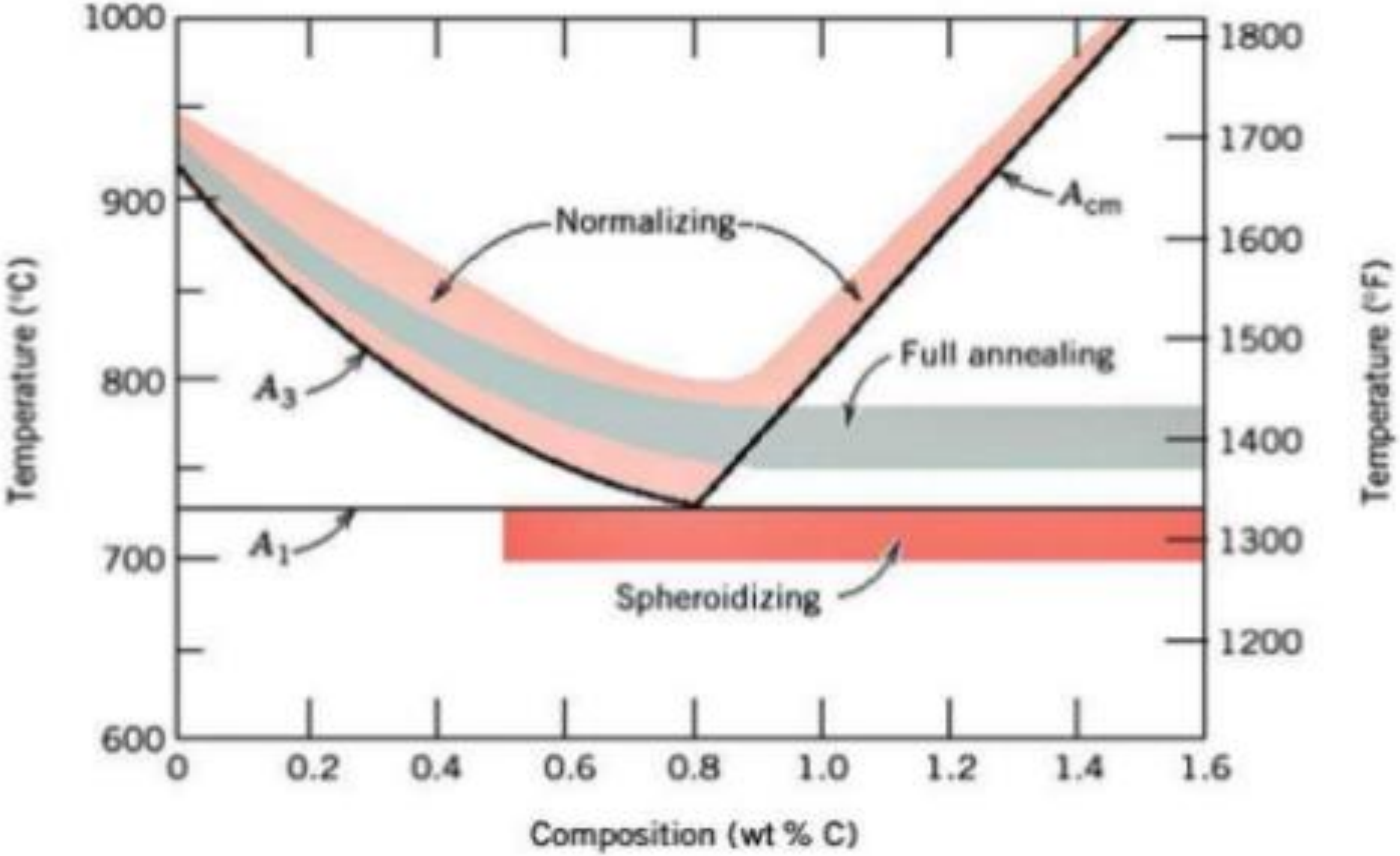
Due to the heating process involved in the normalization, there is the formation of the Austenite structure.

Normalizing

- *It is a type of heat treatment applicable to ferrous metals only.*
- *It differs from annealing in that the metal is heated to a higher temperature and then removed from the furnace for air cooling.*
- *The purpose of normalizing is to remove the internal stresses induced by heat treating, welding, casting, forging, forming, or machining.*

Normalizing

- A heat treatment process consisting of austenitizing at temperatures of **30–80˚C** above the A_{C3} transformation temperature followed by slow cooling (usually in air)
- The aim of which is to obtain a fine-grained, uniformly distributed, **ferrite–pearlite** structure
- Normalizing is applied mainly to unalloyed and low-alloy hypoeutectoid steels
- For hypereutectoid steels the austenitizing temperature is **30–80˚C** above the A_{C1} or A_{Cm}



1000
900
800
700
600
Temperature (°C)
1800
1700
1600
1500
1400
1300
1200
Temperature (°F)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
Composition (wt % C)
Normalizing
Full annealing
Spheroidizing
A_3
A_1
A_{cm}

Quenching:

- Quenching is a process of rapid cooling of materials from high temperature to room temperature or even lower. In steels quenching results in transformation of austenite to martensite (a non-equilibrium constituent).

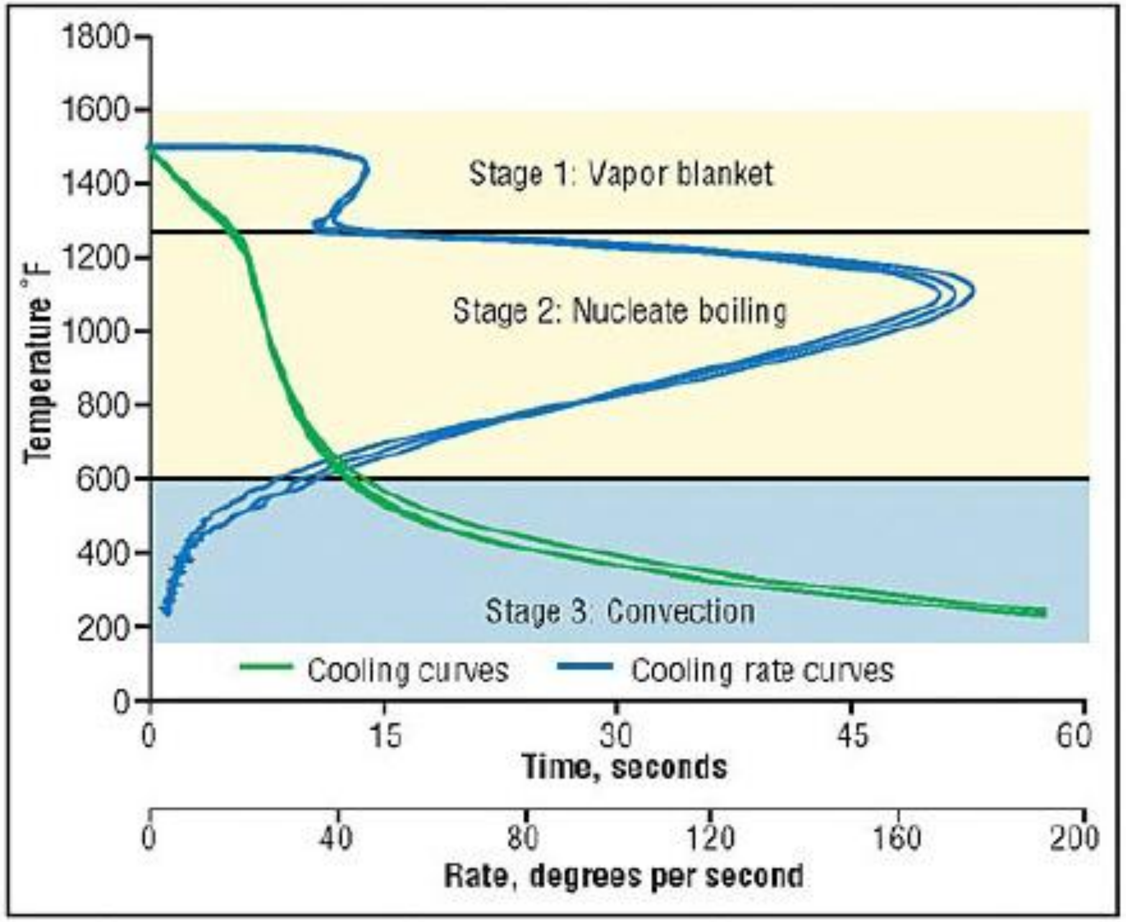
- During cooling, heat must be extracted at a very fast rate from the steel piece. This is possible only when a steel piece is allowed to come in contact with some medium which can absorb heat from the steel piece with in a short period.

- Under ideal conditions, all the heat absorbed by the medium should be rejected to the surroundings immediately.

Quenching:

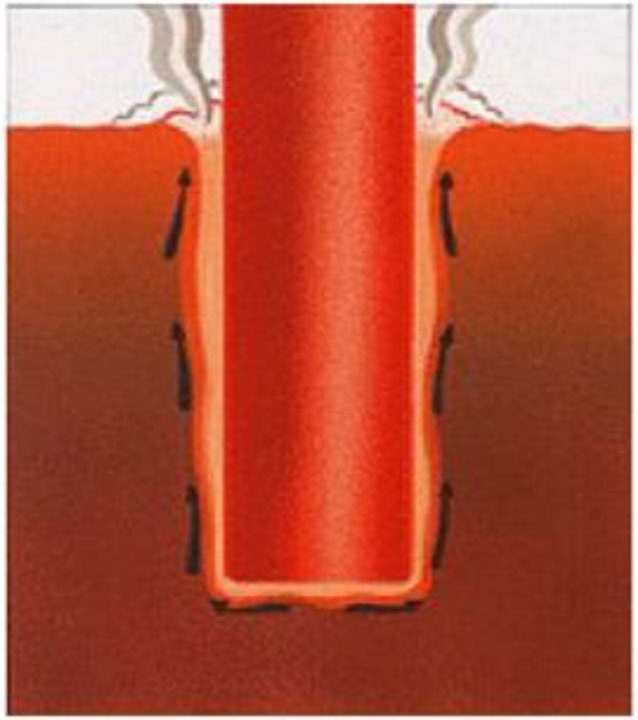
➢ The removal of heat during quenching is complex in the sense that heat is removed in three stages.

1) Vapor Blanket,
2) Nucleate Boiling,
3) Convection.



➢Vapor Blanket (stage 1)

As soon as the work-piece comes into contact with a liquid coolant (quenchant), the surrounding quenchant layer is instantaneously heated up to the boiling point of the quenchant and gets vaporized due to the high temperature of the work- piece.



- This acts as an insulator, preventing the quenching oil from contacting the metal surface. As a consequence, the rate of cooling during this stage is slow.
- At this stage the work piece is cooled only by conduction and radiation through the vapor film.
- Only the surface is cooled considerably prior to the formation of vapor envelop.

➢Nucleate Boiling (stage 2)

This second stage is also called as transport cooling stage or liquid boiling stage. The temperature of the work-piece comes down, through very slowly and the vapor blanket is no longer stable and collapses.

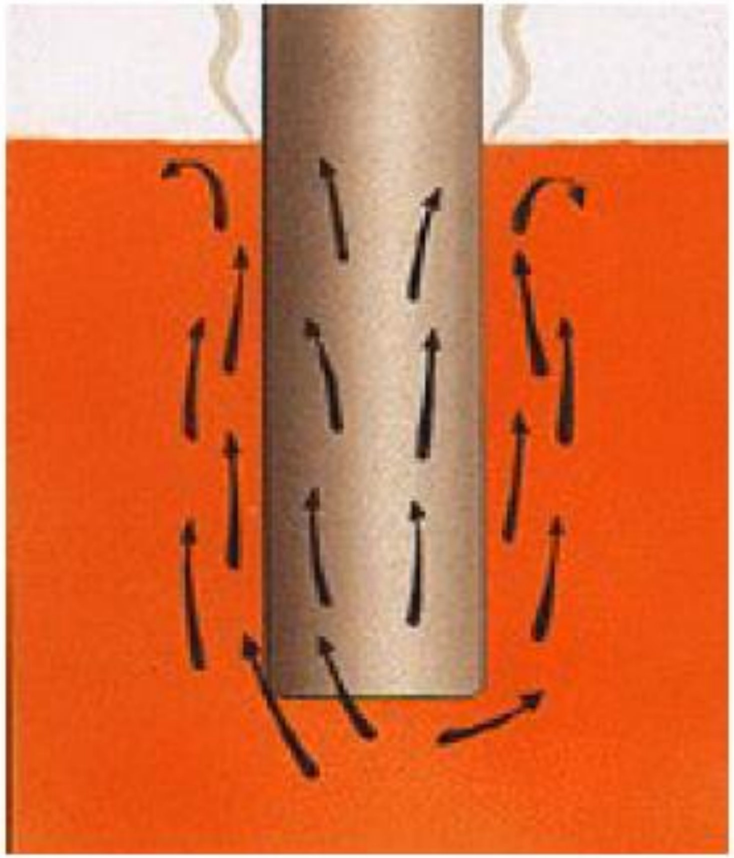
- ➢ Metal surface comes into contact with the liquid/ quenchant. Violent boiling quickly removes heat from the quenched component while forming bubbles and being pushed away, resulting in the cooler fluid coming into contact with the work piece.

- ➢This happens till the temperature of the work piece comes down to the boiling point of the liquid.

- ➢ Maximum cooling rate is achieved during this stage.

➢Convection (stage 3)

The third stage is called as the liquid cooling stage or the convection stage.



- I starts when the temperature of the surface becomes equal to the boiling point of the quenchant.
- Cooling at this stage takes place via conduction and convection processes.
- The rate of cooling is the slowest at this stage.

Effect of quenching medium

- Water has maximum cooling rate amongst all common quenchants except few aqueous solutions.

- It is very cheap and easily disposed off compared to other quenchants.

- Hence water is used for carbon steels, alloy steels and non-ferrous alloys.

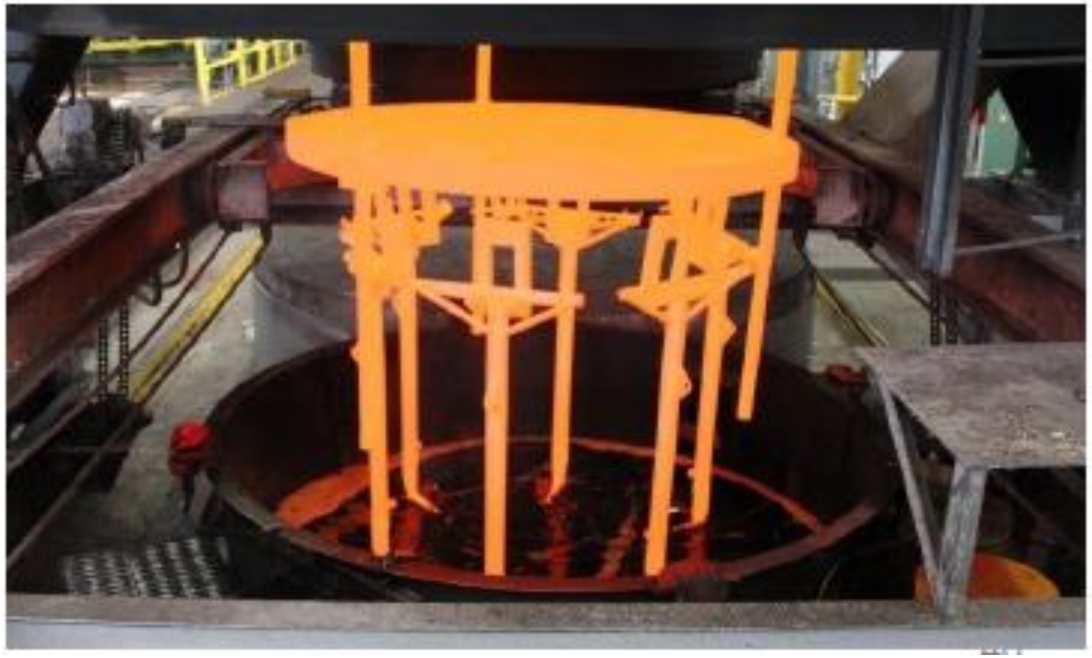
- The layer if scale formed on the surface during heating is also broken by water quenching, thus eliminating an additional process of surface cooling.

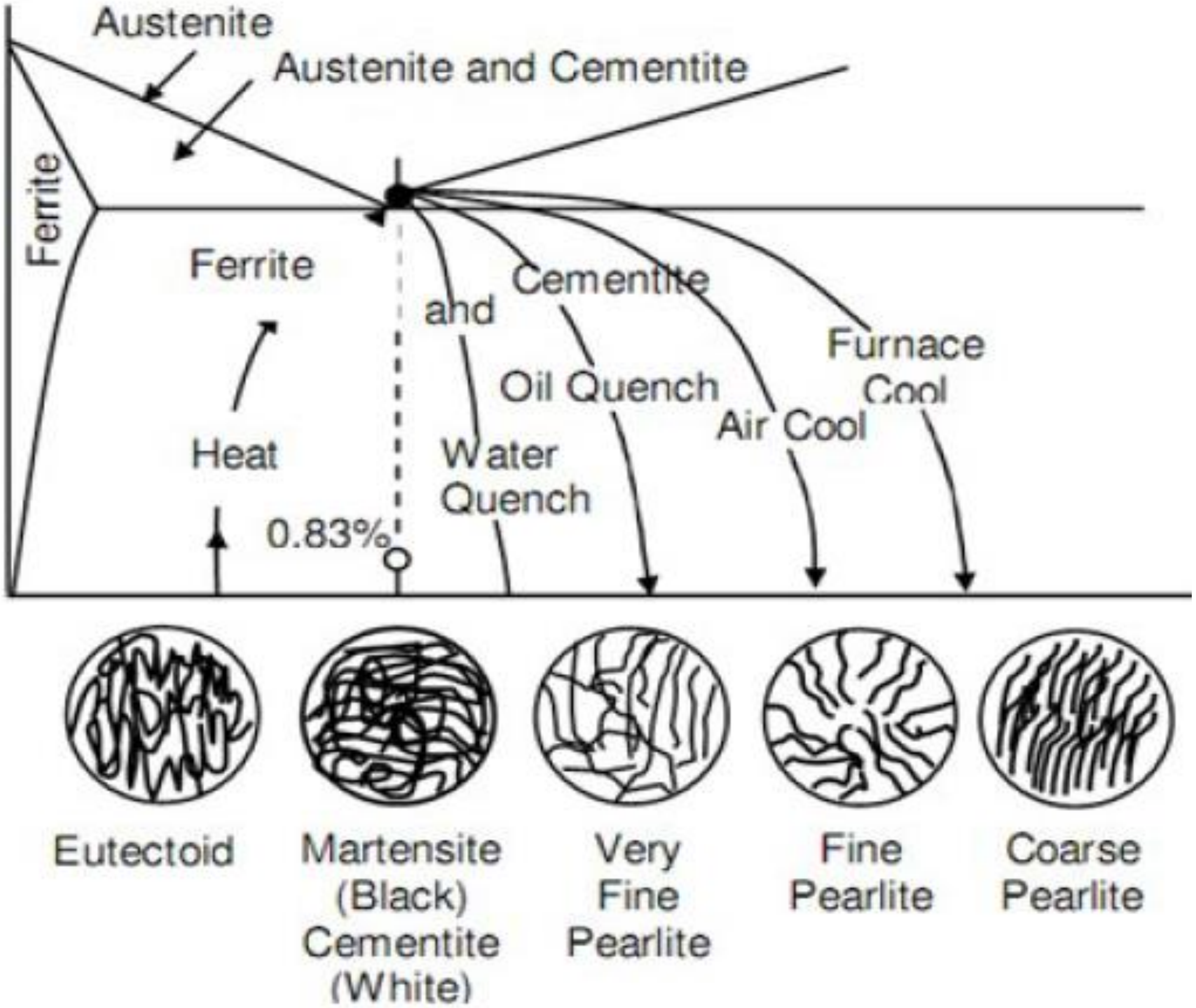
- Most of the Oils used as quenchants are mineral oils. These are in general paraffin based and do not possess any fatty oils.

- Quenching in oil provides slower cooling rates as compared to those achieved by water quenching.

- The slower cooling rate reduces the possibility of hardening defects.

- The temperature difference between core and the case of work piece is less for oil quenching than for water quenching.




Austenite
Austenite and Cementite
Ferrite
Ferrite
and
Cementite
Heat
0.83%
Water
Quench
Oil Quench
Air Cool
Furnace
Cool
Eutectoid
Martensite
(Black)
Cementite
(White)
Very
Fine
Pearlite
Fine
Pearlite
Coarse
Pearlite

Hardening:

- Hardening and Hardness are two very different things. One is a process of heat treatment and other is a extrinsic property of a material.

- Hardening is a heat treatment process in which steel is rapidly cooled from austenitising temperature. As a result of hardening, the hardness and wear resistance of steel are improved.

- Hardening treatment generally consists of heating to hardening temperature, holding at that temperature, followed by rapid cooling such as quenching in oil or water or salt baths.

MATERIAL SCIENCE AND ENGINEERING

UNIT 3

TTT Diagram

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Content of this Presentation

- Incubation Time
- S-curve
- C-curve
- TTT

Usefulness of the Topic

- How to obtain Pearlite, Bainite and Martensite by TTT diagram
- Role of cooling rate on various structures.

Incubation Period

- Upon quenching austenite to approximately 700°C it was observed that for substantial period of time there was no change in the microstructure and it was austenite only. This time period during which nothing happened to the sample is called incubation time.
- when there was decrease in the quenching temperature incubation period also decreases, and at 550°C it was only 1 second. on decreasing the quenching temperature further incubation period started increasing again.

Upon projecting the % decomposition V_S time graph, to temperature vs time graphs 2 'C' curves appears this diagram is called **Time-Temperature-Transformation curve (or) TTT Curve or C-Curve or S-curve or Bains Curve.**

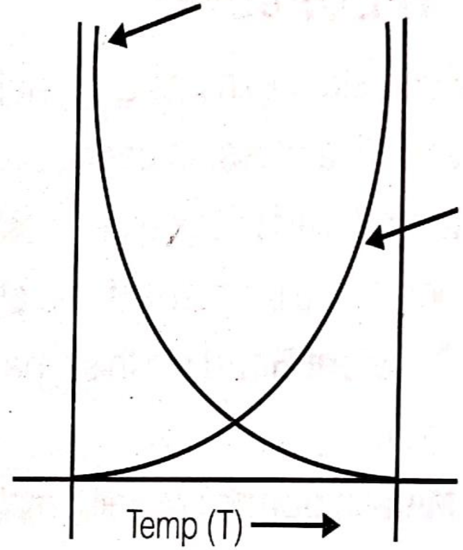


Fig. 2.43 : Driving force and diffusion variation with temperature

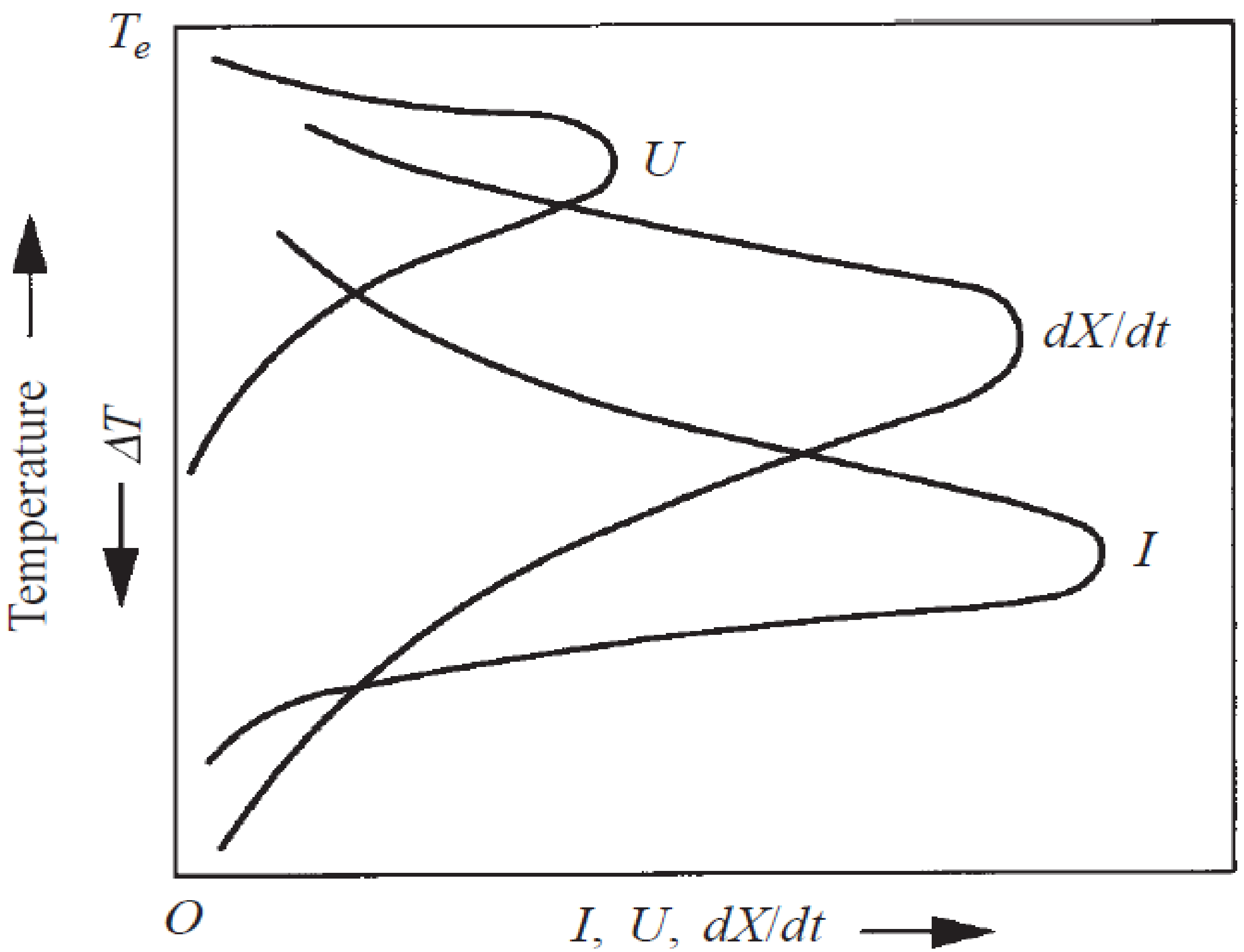
The factors responsible for curve are :

1. **Driving Force :** $\Delta G = G_{final} - G_{initial}$

   If ΔG is +ve, it means the final phase is stable. If its value is zero it means the phase is neutral and it is –ve it means the final phase is unstable. As there is a decrease in temperature the (ΔG) driving force value increases and so incubation period decrease from 725°C to 550°C.

2. **Atomic Mobility (Diffusion) :** It decreases with decrease in temperatures slightly below 725°C, the driving force is very low that is why incubation period is more. Below 550°C although the value of driving force is very high but due to lower temperature, diffusion is very low. This increases the incubation period.

The temperature dependence *of the nucleation rate* ***I****, the growth rate* ***U****, and the transformation rate* ***dX/dt.***

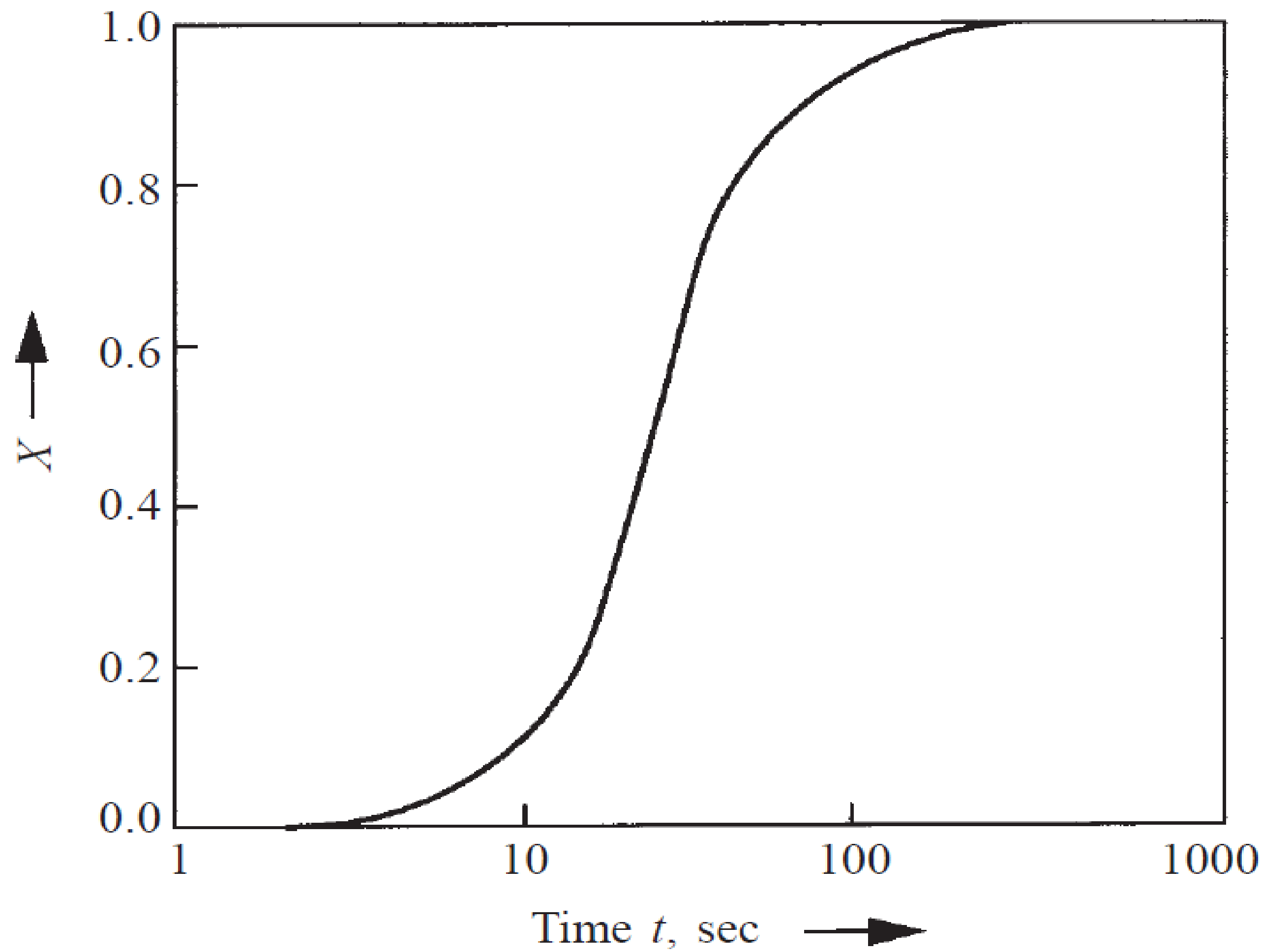


Rate of Transformation

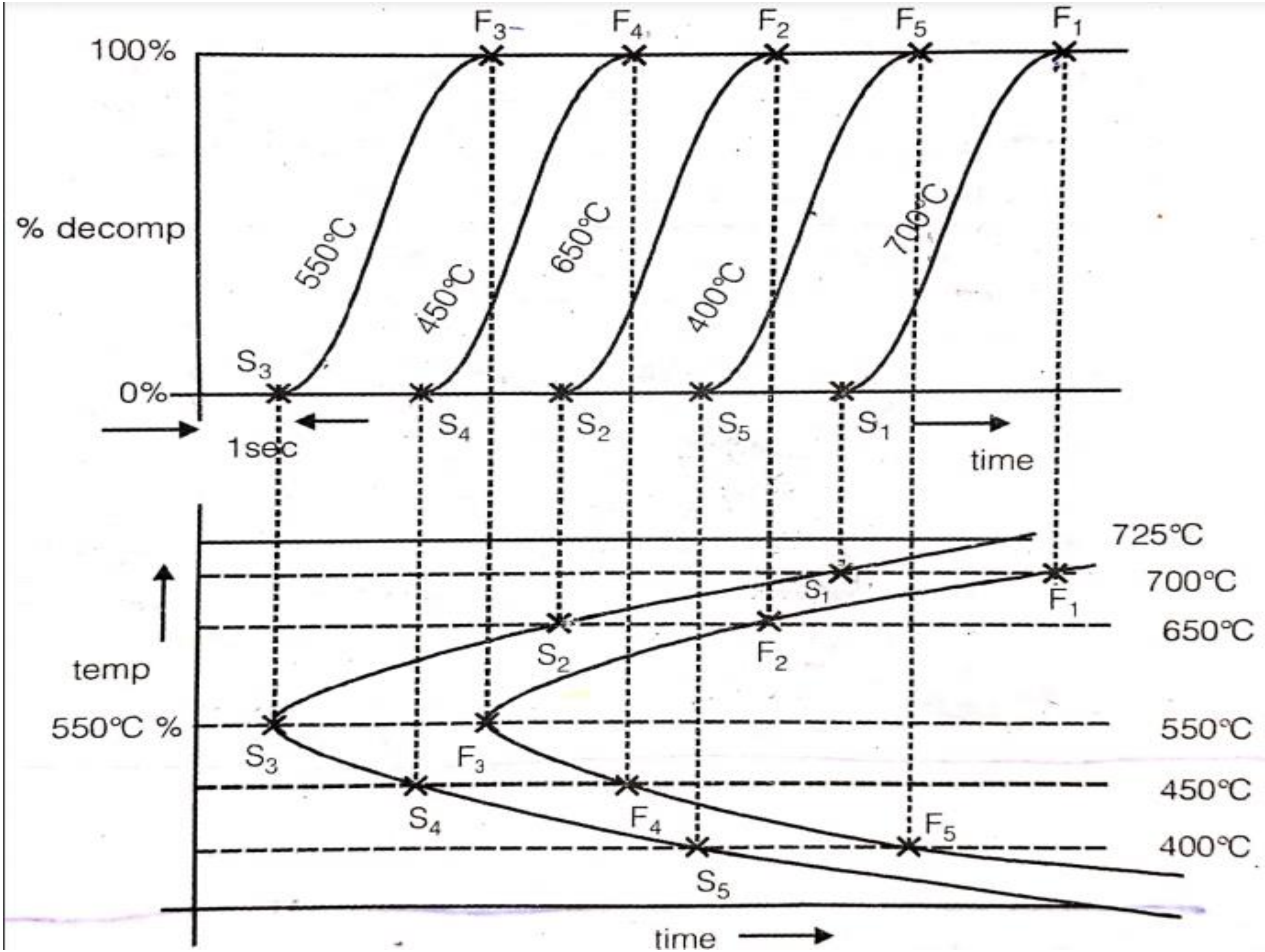
- By convention rate of transformation is taken as the reciprocal of time required for the transformation to proceed halfway completion

$$Rate = 1/t(0.5)$$

The fraction transformed *X is plotted against t*

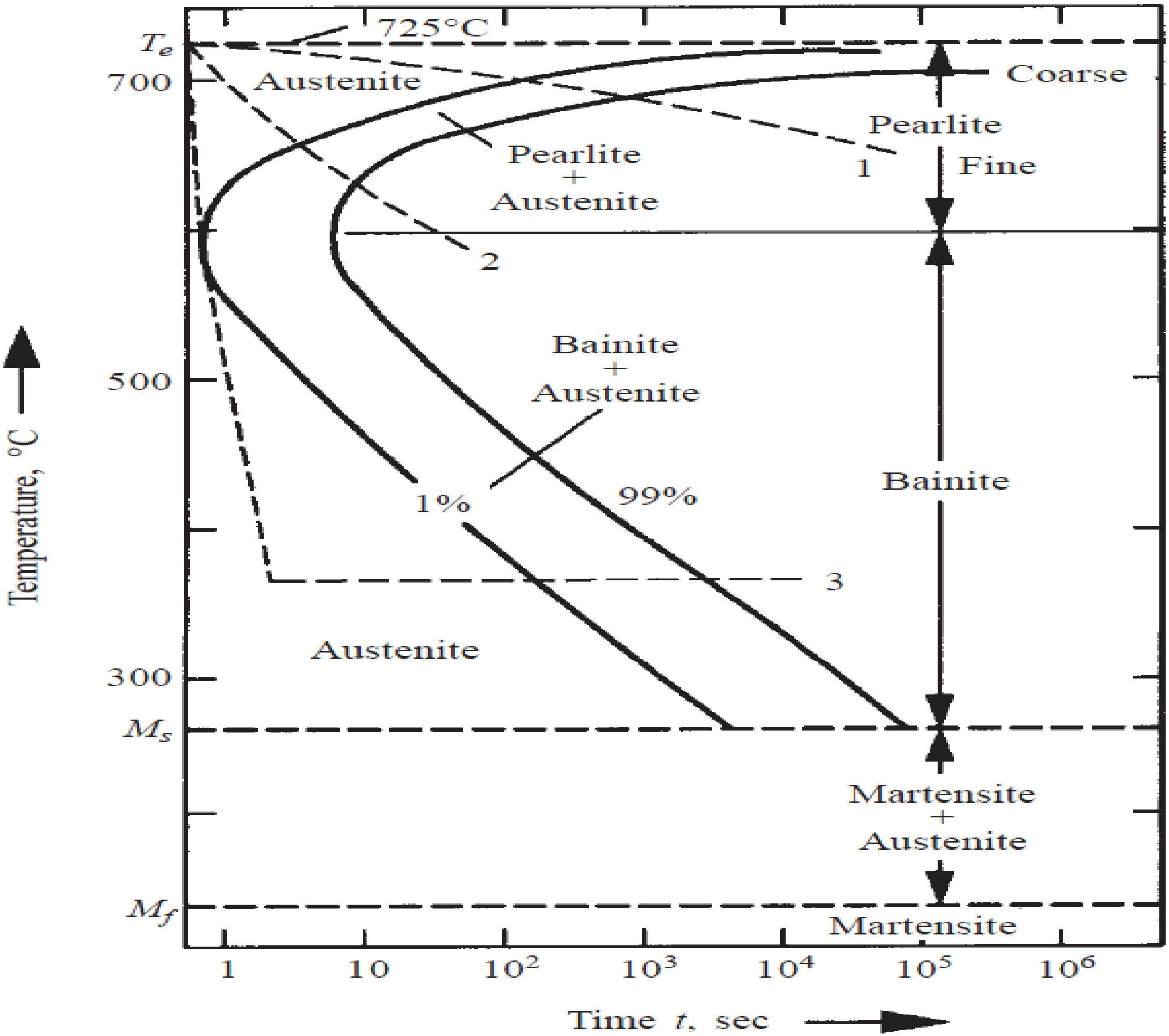


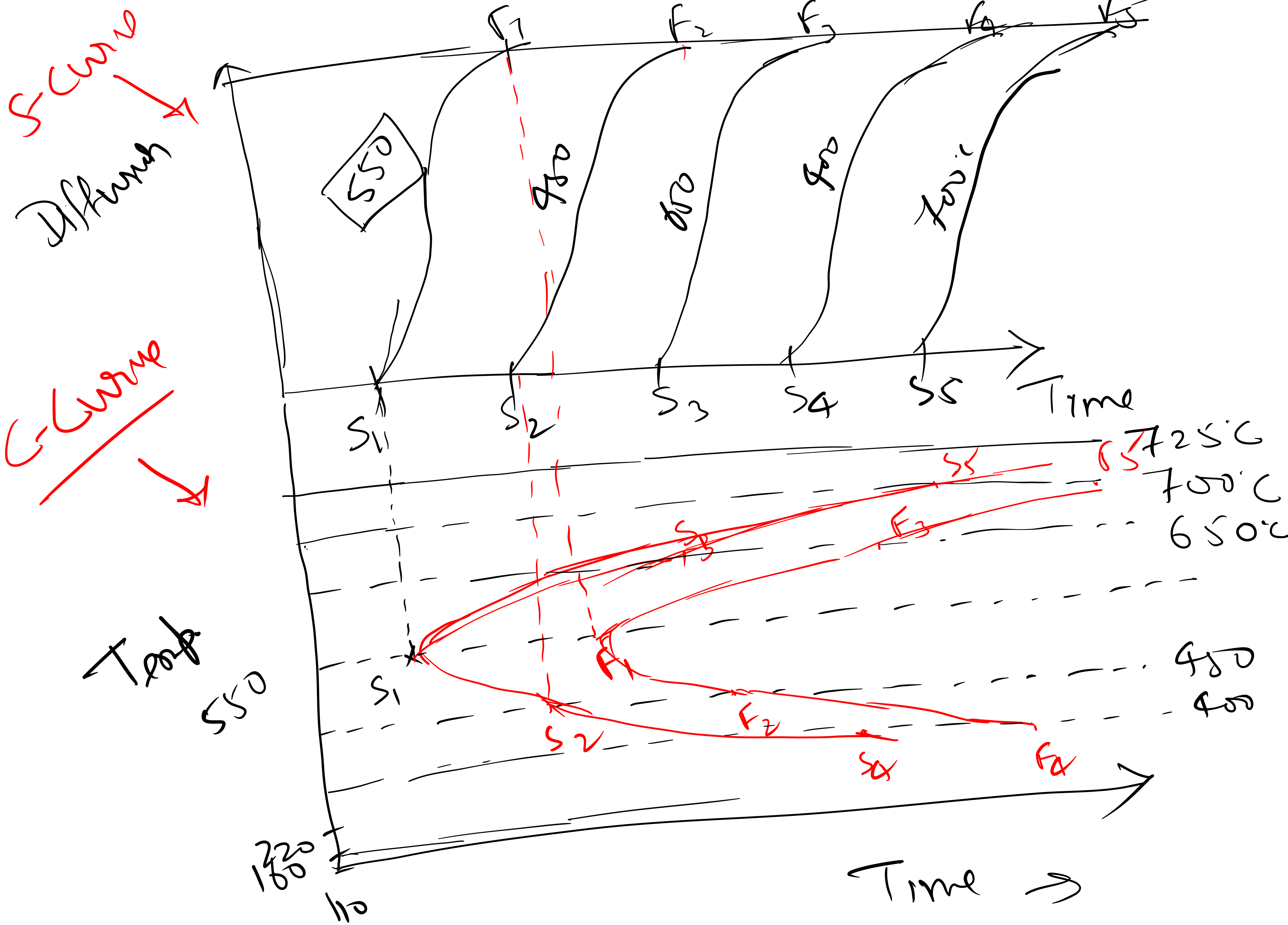
The curve has a **sigmoidal form.**



100%
% decomp
0%
1sec
time
550°C
450°C
650°C
400°C
700°C
S3 S4 S2 S5 S1
F3 F4 F2 F5 F1
temp
550°C %
725°C
700°C
650°C
550°C
450°C
400°C
time

The T-T-T diagram for a eutectoid steel.





S-Curve
Diffusion
550
450
500
600
700°C
F1
F2
F3
F4
F5
S1
S2
S3
S4
S5
Time
C-Curve
725°C
700°C
650°C
450
400
Temp
550
220
180
110
Time

- The slow cooling process produces coarse structure and fast cooling produces fine structure.
- when the cooling rate is such that if just touches the nose of TTT diagram is called ***critical cooling rate***.
- any cooling rate equal to or higher than critical cooling rate carbon will almost freeze on its location.
- Microstructure appeared like colloidal solution of cementite into ferrite or mechanical mixture of ferrite and cementite, this microstructure is called **martensite.**

- Martensite is the hardest and the most brittle phase of iron.
- It’s microstructure is BCT (body cantered tetragonal)
- in pearlite formation carbon diffuses several atomic distances and it is produced purely by process of diffusion but the martensite is a **diffusionl ess process**, in which carbon diffuses only fraction of atomic distances.

MATERIAL SCIENCE AND ENGINEERING

UNIT 3

TEMPERING

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Tempering

- A hardened steel piece, due to martensitic structure, is extremely hard and brittle, due to which it is found unsuitable for most practical purposes. So a subsequent treatment is required to obtain a desired degree of toughness at the cost of some strength and hardness to make it suitable for use.
- This process enables transformation of some martensite into ferrite and cementite. The exact amount of martensite transformed into ferrite plus cementite will depend upon the temperature to which the metal is reheated and the time allowed for the transformation.
- The process involves reheating the hardened steel to a temperature below the lower critical temperature, holding it at that temperature for sufficient time and then cooling it slowly down to the room temperature.

- When the hardened steel is reheated to a temperature between 100^{o}C to 200^{o}C, some of the interstitial carbon is precipitated out from martensite to form a carbide called epsilon carbide. This leads to the restoration of BCC structure in the matrix.
- Further heating to between 200^{o}C 400^{o}C enables the structure to transform to ferrite plus cementite. Further heating to between 400^{o}C and 550^{o}C leads to the nucleation and growth of a new ferrite structure, rendering the metal weaker but more ductile.
- The section thickness of the components being treated also have a decisive effect on the results. Heavy components and thicker sections required longer tempering times then the lighter and thinner ones.
- On the basis of the ranges of temperatures to which the components are reheated for tempering, the tempering procedures are classified in 3 type:

1. Low temperature tempering

- This treatment results in reduction of internal stresses and improvement in toughness and ductility without any appreciable loss in hardness.
- The heating range for this type of tempering is from 150^oC to 250^oC.
- The different colours appearing on the surface of the metal are indicative of the approximate temperature attained by it.
- Carbon tool steels, low alloy tool steels, case carburized and surface hardened parts, measuring tools, etc are tempered by this method.

2. Medium temperature tempering

- This process involves reheating the component to a temperature range between 350^oC to 450^oC, holding at that temperature for sufficient time and then cooling it to room temperature.
- In this process diffusion is low and microstructure is called as troostite.
- This method of tempering is used to increase the toughness of steel but reduces the hardness. It also increases the ductility and decreases the strength.
- It is mainly used for articles where a high yield strength, coupled with toughness, is a major requirement and subjected to impact loading, like ***coils*** and ***springs***, ***hammers, chisels,*** etc.

3. High temperature tempering

- The process involves reheating the hardened steel to a temperature between 500^{o}C to 650 ^{o}C, holding it there for a certain time and then cooling it down to the room temperature.
- This process enables the steel attaining high ductility while retaining enough hardness.
- This provides a micro-structure (***pro alpha+pearlite,*** called as ***Sorbite***)which carries a useful combination of good strength and toughness with complete elimination of internal stresses ***.E.g. Crankshafts, connecting rods*** and ***gears.***


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MATERIAL SCIENCE AND ENGINEERING

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FERROUS MATERIALS

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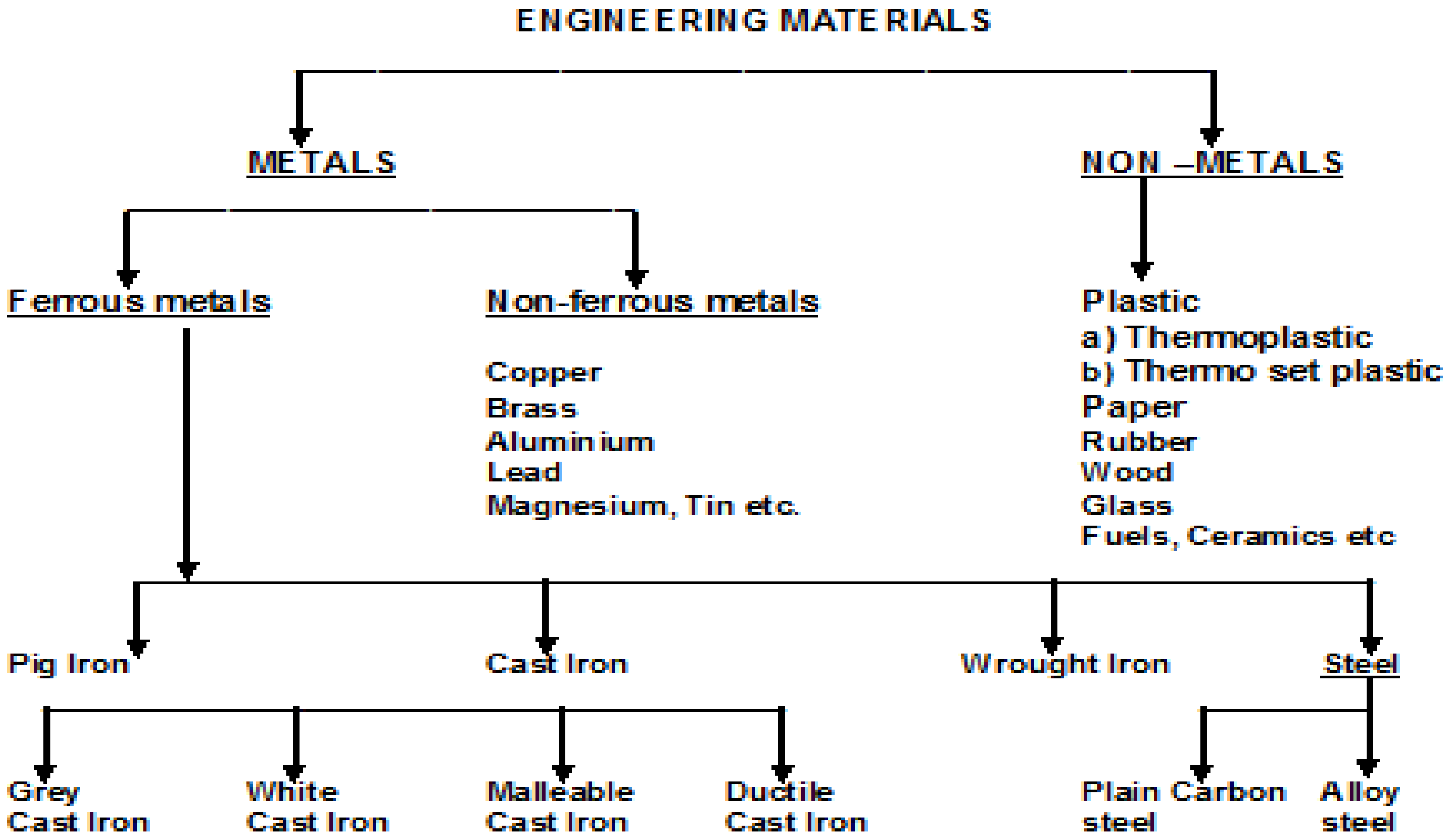
Engineering Materials:

- Materials are an important aspect of engineering design and analysis.
- The product quality has been found to be influenced by the **engineering design, type of materials selected, and the processing technology employed**. Therefore, the importance of materials and their processing techniques cannot be undervalued in today's world. Materials form the stuff of any engineering application or product.
- There is a wide variety of materials available which have shown their potential in **various engineering fields ranging from aerospace to household applications.** The materials are usually selected after considering **their characteristics, specific application areas, advantages and limitations.**
- The challenge for designers is to select an optimal material suitable for the specific design requirements.

Classification of engineering materials:



Classification of engineering materials:

It is the systematic arrangement or division of materials into groups on the basis of some common characteristic.

1. According to General Properties
2. According to Nature of Materials
3. According to Applications

1. According to General Properties:

***(a). Metals* (*e.g.* iron, aluminum, copper, zinc, lead, etc.):**

Iron as the base metal, and range from plain carbon (> 98 % Fe) to
(i). Ferrous: high alloy steel (< 50 % alloying elements),
e.g. cast iron, wrought iron, steel, alloys like high-speed steel, spring steel, etc.
(ii). Non-Ferrous: Rest of the all other metals and their alloys, e.g. copper, aluminum, zinc, lead, alloys like brass, bronze, duralumin, etc.
***(b). Non-Metals* (e.g. leather, rubber, asbestos, plastics, etc.):**

Classification Continued...

2. According to Nature of Materials:

(a). Metals: e.g. Iron & Steel, Alloys &Superalloys, Intermetallic Compounds, etc.

(b). Ceramics: e.g. Structural Ceramics (high-temperature load bearing), Refractories (corrosion-resistant, insulating), Whitewares (porcelains), Glass, Electrical Ceramics (capacitors, insulators, transducers), Chemically Bonded Ceramics (cement & concrete)

(c).Polymers: e.g. Plastics, Liquid Crystals, Adhesives

(d). Electronic Materials: e.g. Silicon, Germanium, Photonic materials (solid-state lasers, LEDs)

(e). Composites: e.g. Particulate composites (small particles embedded in a different material), Laminate composites (golf club shafts, tennis rackets), Fiber reinforced composites (fiberglass)

(f). Biomaterials: e.g. Man-made proteins (artificial bacterium), Biosensors, etc.

(g). Advanced / Smart Materials: e.g. materials in computers (VCRs, CD Players, etc.), spacecrafts, aircrafts, rockets, shape-memory alloys, piezoelectric ceramics, magneto-strictive materials, optical fibres, microelectromechanical (MEMs) devices, electrorheological / magnetorheological fluids, Nanomaterials, etc.

Classification Continued...

3. According to Applications

(a). Electrical Materials: e.g. conductors, insulators, dielectrics, etc.

(b). Electronic Materials: e.g. conductors, semi-conductors, etc.

(c). Magnetic Materials: e.g. ferromagnetic, paramagnetic & diamagnetic materials, etc.

(d). Optical Materials: e.g. glass, quartz, etc.

(e). Bio-Materials: e.g. man-made proteins, artificial bacterium, etc.

Cast Iron:

- It is an alloys of Fe and C (like steel) but contain higher Carbon (typically Carbon is 2.5 to 4%).
- Very brittle, not amenable to deform
- Easy to cast (due to lower melting point) into complicated shapes and cheap.
- With alloying, good foundry practice and heat treatment, properties can be varied over wide range.

Carbon can occur in C.I's as:

combined carbon (Fe_3C) or free carbon (graphite).

- The Shape and distribution of free carbon also important Parameters that influence are:

• Carbon content,

• Alloy and impurity content,

• Cooling rate during and after freezing,

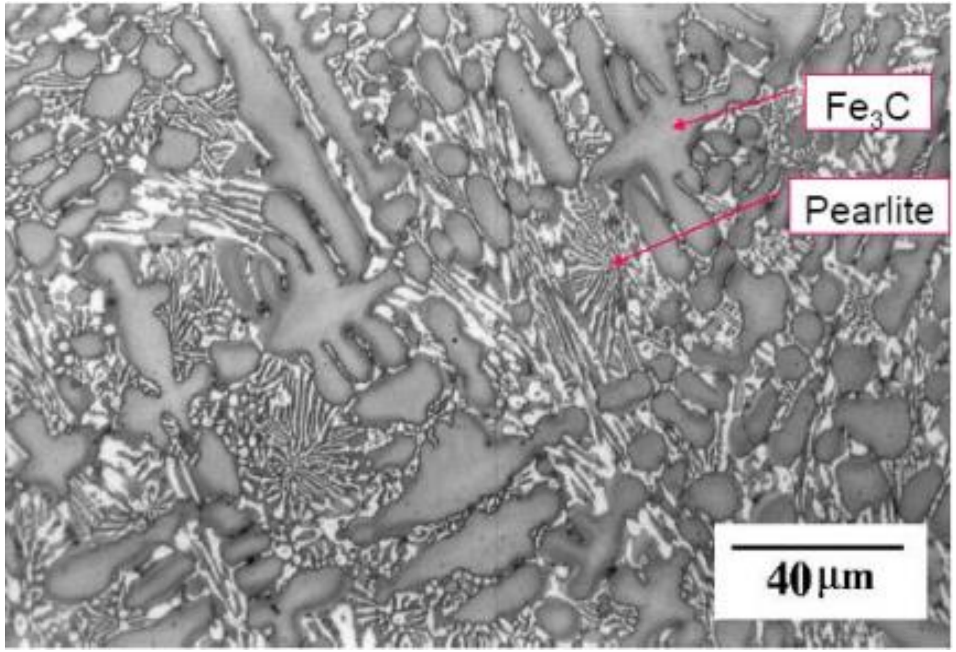
• Heat treatment after casting

Types of Cast Iron:

1. White Cast Iron (combined carbon Fe_3C)
2. Malleable Cast Iron (free carbon as irregular particles)
3. Chilled Cast Iron (white cast iron at the surface and gray cast iron at the interior)
4. Grey Cast Iron (Flake Graphite)
5. Spheroidal Graphite (SG) / Ductile Cast Iron / Nodular Cast Iron (free carbon as spheroids)
6. Alloy Cast Iron

1. White Cast Iron:

- A high cooling rate and a low carbon equivalent favors the formation of white cast iron.
- Hard and brittle
- Excellent wear resistance
- High compressive stress.
- Shows a white crystalline fractured surface.
- Fe_3C + Pearlite.

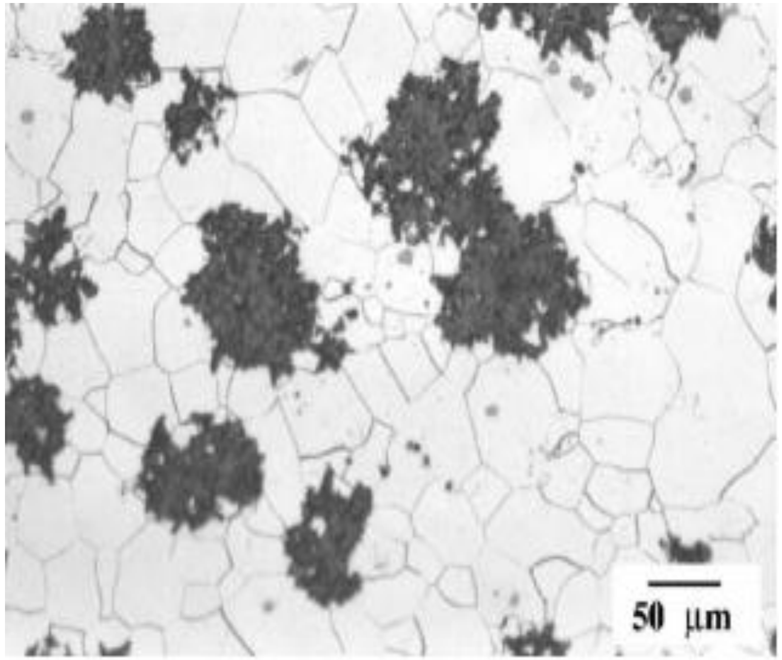


2. Malleable Cast Iron:

- Malleable cast iron is essentially white cast iron which has been modified by heat treatment. It is formed when white cast iron is heated to around 920 deg C and then left to cool very slowly. Graphite separates out much more slowly in this case, so that surface tension has time to form it into spheroidal particles rather than flakes.

- The structure of malleable cast iron consists of **ferrite, pearlite and tempered carbon** as compared to the fracture inducing lamellar structure of gray cast iron.

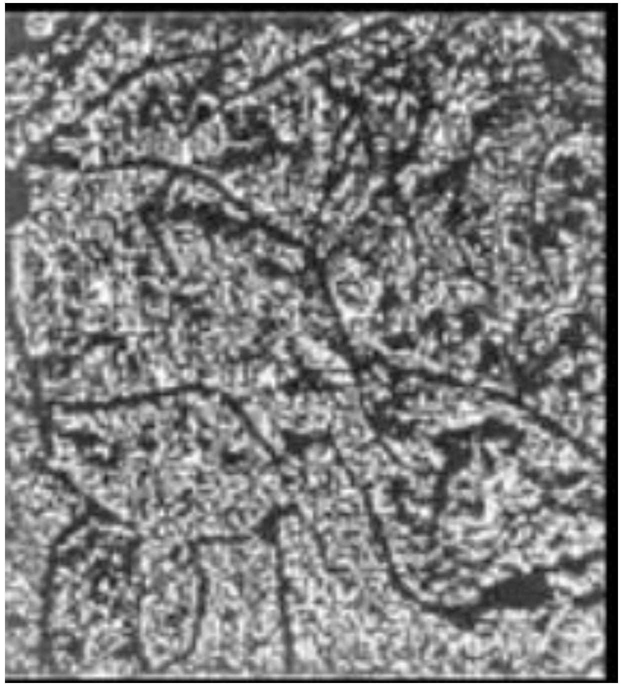
- Malleable cast iron like ductile iron possesses considerable ductility and toughness because of its combination of nodular graphite and low carbon metallic matrix.
- It can be pierced, coined, or cold formed.
- Requiring maximum machinability.
- must retain good impact resistance at low temperatures.
- Wear resistance (martensitic malleable iron only).



3. Gray Cast Iron:

- **Gray iron**, or **grey cast iron**, is a type of **cast iron** that has a graphitic microstructure. It is named after the **gray** color of the fracture it forms, which is due to the presence of graphite.

- A low cooling rate or a high carbon equivalent promotes grey cast iron. The general characteristics of Gray cast iron are:



- Cheap
- Low melting point
- Fluid – easy to cast, especially advantageous into large complex shapes
- Excellent machinability
- Excellent bearing properties
- Excellent damping properties
- Excellent wear resistance (hi C)
- Can be heat treated (surface hardenec
- Can be alloyed etc.

Compressive strength >> tensile strength

4. Chilled Cast Iron:

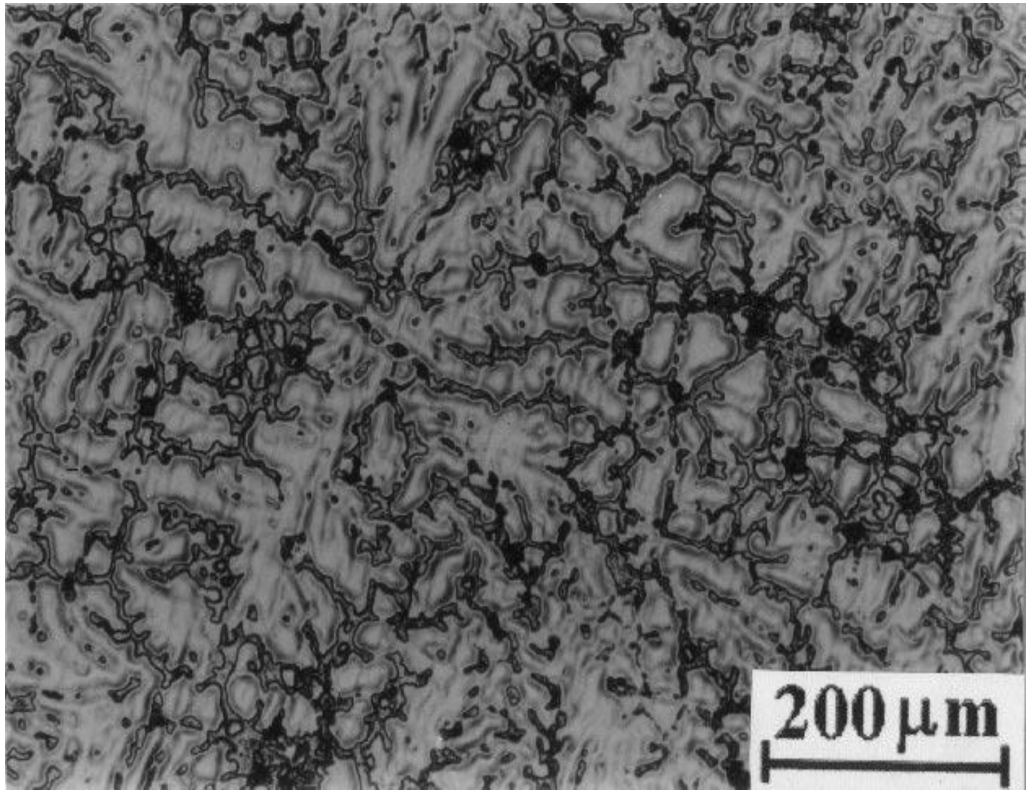
It is obtained by casting against a chiller

• Surface is White C.I. (faster cooling rates)

• Harder / wear resistant surface

• Depth depends on composition (C, Si decrease chill depth) Carbide forming elements like Cr, Mo increase chill depth

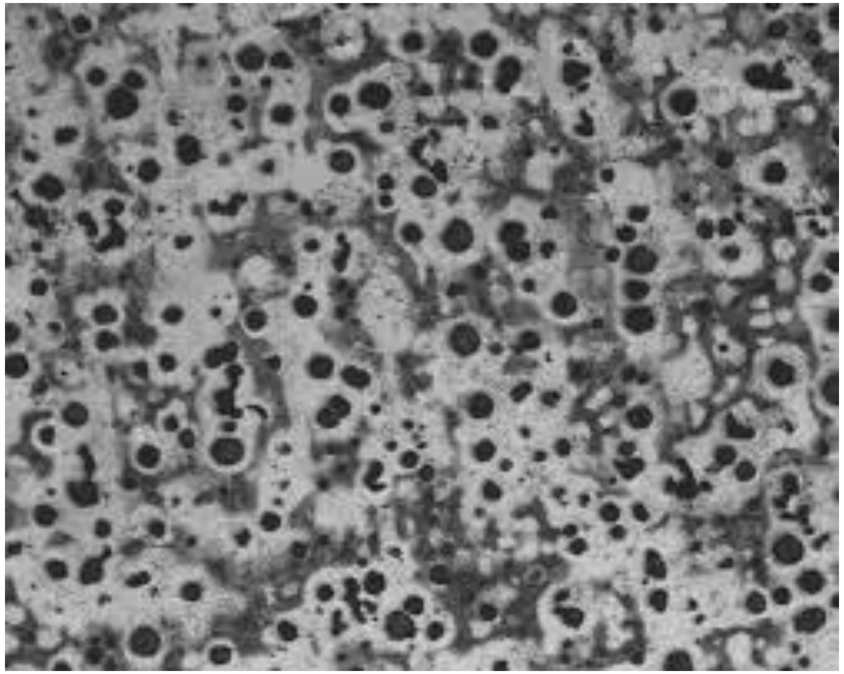
Applications: Railway car wheels, crushing rolls, heavy machinery.



5. Nodular Cast Iron:

- Nodular Cast Iron is an engineering material displaying high ductility, elastic modulus, mechanical strength and corrosion resistance.

- It has low cost and is easy to produce and machine and is thus widely used as a structural material.
- Gray iron composition for C and Si
- Impurity level control important as it will affect nodule formation
- Have nodule instead of flake if we add in 0.05% Mg and/or Ce
- As cast structure: graphite forms as nodules instead of flakes
- Additions of Ce / Mg poisons the easy growth direction and results change in graphite morphology from flakes to spheres which occurs due to isotropic growth.



6. Alloy Cast Iron:

- Alloy cast irons are considered to be those casting alloys based on the iron-carbon-silicon system that contain one or more alloying elements intentionally added to enhance one or more useful properties.
- Alloy cast irons can be classified as:

➢ White cast irons,

➢ Corrosion-resistant cast irons,

➢ Heat-resistant cast irons etc.

Carbon Steel:

- Carbon steel is an iron-carbon alloy, which contains up to 2.1 wt.% carbon. For carbon steels, there is no minimum specified content of other alloying elements, however, they often contain manganese.
- The maximum manganese, silicon and copper content should be less than 1.65 wt.%, 0.6 wt.% and 0.6 wt.%, respectively.
- Carbon steel can be classified into three categories according to its carbon content: low-carbon steel (or mild-carbon steel), medium-carbon steel and high-carbon steel. Their carbon content, microstructure and properties compare as follows:

Types of carbon steel	Carbon content (wt.%)	Microstructure	Properties	Examples
Low-carbon steel	< 0.25	Ferrite, pearlite	Low hardness and cost. High ductility, toughness, machinability and weldability	AISI 304, ASTM A815, AISI 316L
Medium-carbon steel	0.25 – 0.60	Martensite	Low hardenability, medium strength, ductility and toughness	AISI 409, ASTM A29, SCM435
High-carbon steel	0.60 – 1.25	Pearlite	High hardness, strength, low ductility	AISI 440C, EN 10088-3

Alloy Steel:

- **Alloy steel** is a class of steel that, in addition to carbon, is alloyed with other elements, ranging from 1 wt.% to 50 wt.%, which are used to enhance the material's various properties [1].
- These elements commonly include manganese, nickel, chromium, molybdenum, vanadium, silicon, and boron. Less common elements include aluminum, cobalt, copper, cerium, niobium, titanium, tungsten, tin, zinc, lead, and zirconium.

Types of alloy steel

There are multiple subcategories of alloy steel. These include:

- Low-alloy steel (less than 8 wt.% non-iron elements)
- High-strength low alloy (HSLA) steel
- High-alloy steel (more than 8 wt.% non-iron elements)
- Stainless steel
- Micro-alloyed steel
- Advanced high-strength steel (AHSS)
- Tool steel

Properties of alloy steel:

- Alloy steels can contain a wide variety of elements, each of which can enhance various properties of the material, such as mechanical thermal and corrosion resistance.
- Elements added in low quantities of less than around 5 wt.% tend to improve mechanical properties, for example increasing hardenability and strength, whereas larger additions of up to 20 wt.% increase corrosion resistance and stability at high or low temperatures.
- Overall, in comparison to carbon steels, alloy steels can exhibit increased strength, ductility and toughness. The disadvantages, however, are that alloy steels usually have lower machinability, weldability and formability.
- The effects of adding various elements to steel, along with the typical amounts in weight fraction, is summarized in the upcoming table.

Difference between Metals & Non-Metals:

S. No.	Property	Metals	Non- metals
1.	Structure	Crystalline	Amorphic
2.	State	Generally solids at room temp.	Gaseous & solid at ordinary temp
3.	Luster	Metallic luster	No metallic luster (except iodine & graphite
4.	Conductivity	Good conductors of heat & electricity	Bad conductors
5.	Malleability	Malleable	Not malleable
6.	Ductility	Ductile	Not ductile
7.	Hardness	Generally hard	Hardness varies
8.	Density	High	Low
9.	Excitation of valence electron by e.m.f.	Easy	Difficult

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NDIA

MATERIAL SCIENCE AND ENGINEERING

UNIT 3

NON FERROUS MATERIALS

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Properties and applications of non- ferrous metals

Non- ferrous metals:

- Non-ferrous metals are those which do not contain iron as main constituent or base metal.
- Non-ferrous metals have industrial applications because of their case of fabrication (like rolling, forging, casting, welding, and machining), electrical and thermal conductivity, resistance to corrosion, light-weight, etc.
- However, at high temperatures, their strength is lowered, and shrinkage is more than ferrous metals. The principal non-ferrous metals used in engineering applications are Copper, Aluminum, Zinc, Tin, Lead, Cobalt, Nickel, Chromium, Magnesium, and their alloys.
- Following are the special advantages of non-ferrous metals over ferrous metals in some selected areas. In ***Civil Engineering Construction***, Aluminum and some of its alloys offer a very suitable alternative material to steel in some special engineering construction. Thus, wrought aluminum alloys are:

- ➢ Economical,
- ➢ Resistant to Corrosion,
- ➢ Light in weight,

- Compared to steels, they have been used in, i.e., construction of bridges and roofs in situations where not much strength is required. In these situations, they have been found to save 50% of extra weight.
- In ***Engineering Industries***, Copper, zinc, nickel, and chromium in their pure and alloyed forms have been used as materials in situations where:

➢ High tensile strength is required at elevated temperatures.

➢ High ductility and malleability are required.

➢ High resistance to heat is required.

➢ High electrical conductivity is required

1. Aluminum:

- Aluminum is mainly obtained from bauxite ore. The most common *ore* of aluminum is **Bauxite (**Al_2O_3. n H_2O**).** As a metal, aluminum was first discovered in 1825.
- It is highly resistant to corrosion. When exposed to moist air, aluminum forms a thin film of oxide at the top, which is impervious to air/moisture, and thus saves the metal from further corrosion.

Properties of Aluminum.

Following are some important properties of this metal.

1. It is silvery-white metal and shows brilliant luster when fresh.
2. It is an excellent conductor of heat and electricity.
3. It is light in weight with a specific gravity of about 2.7.
4. It is a good reflector of light.
5. It is non-magnetic and has high resistance to corrosion.

1. It is soft, tough, malleable, and ductile.
2. It is very ductile and can be transformed into any shape by rolling, stamping, extruding, forging, drawing, and spinning.
3. Its melting temperature is about 658°C.
4. It has high tensile strength.
5. It can also be cast into any shape by any method of casting, i.e., die casting, chill casting, and sand casting.
6. It is resistant to organic acids, salt solutions, etc.

Uses of Aluminum:

1. It is used in the manufacturing of equipment for chemical and food industries, cooking utensils, cookers, steam-jacketed kettles, etc.

2. Due to its lightweight and high tensile strength, it is used in structural work of airplanes, ships, trains, buses, trucks, etc. And also used for roofing, sheathing, window frames, foils, posts, etc.

3. It is used for manufacturing of electric cables.

Used for manufacturing of reflectors and mirrors.

5. Aluminum powder is used for preparing paints.

6. It is used in iron and steel making as a de-oxidizer.

2. Copper:

- Copper is extracted from copper ores such as copper pyrites, etc. Metallic copper and its various alloys have been used in engineering industries and for many other activities from 100 of years. This is due to some of the useful properties of copper.

Properties of Copper:

Some of the most important properties of copper are as under:

1. It is soft, strong, tough, malleable, and ductile.
2. It is very malleable and ductile so that it can be converted into any desired shape.
3. It has excellent joining properties, i.e., it can be joined by almost all the common methods: welding, soldering, brazing, and riveting.
4. It becomes brittle just before melting.
5. It can be forged, soldered, rolled and drawn into wires.
6. It has good resistance to corrosion.
7. It is a good conductor of both heat and electricity next to silver.
8. It forms excellent alloys.
9. It is reddish-brown in color.
10. Its specific gravity is 8.93.
11. It has a melting point of 1083°C.

Uses of Copper.

1. It is used for making cables and wires for electric applications.

2. It is used for electroplating.

3. Used for manufacturing of utensils and making of copper alloys.

4. It is used for making of munitions and tubes in engineering applications.

Copper Alloys:

Following are the alloys of copper:

•Brasses.

•Bronzes.

3. Lead:

- Lead has been used for centuries in buildings and other engineering industries. Lead is extracted from three chief ore minerals.
  - Galena
  - Cerrussite,
  - Anglesite

Properties of Lead:

The metallic lead has the following properties.

1. It has bluish Grey color.
2. It has typically brilliant luster.
3. It has a high density – 11.35 g/cm^3.
4. It has a low melting point of 327 centigrade.
5. It has a high boiling point of 1744 centigrade.
6. It is very good at resisting corrosion.

Lead Alloys:

- In general, lead doesn’t form many alloys. Its alloying capacity is limited because of its low melting point. Following are the important alloys of lead.
  - Solder
  - Bearing metal

4. Zinc:

Zinc is another non-ferrous metal. It is obtained from zinc ores like zinc blends and calamine. The chief ore mineral of zinc is sulfide called *sphalerite*. Smithsonite, Zincite (ZnO) and Calamine ($ZnCO_3$) are other common zinc minerals.

Zinc Properties:

Following are some important properties of Zinc.

1. It is bluish-white in color and has bright luster.
2. It resists corrosion.
3. It is brittle at normal temperature.
4. It becomes malleable and ductile when heated to a temperature of 100 to 150°C. Hence, at this temperature, it can be rolled into sheets and drawn into wires.
5. It has a melting point of 419 centigrade and boiling point of 907 centigrade.
6. It has a tensile strength of 700-1400 kg/cm^2.
7. Commercial zinc (spelter) is easily attacked by acids.
8. Zinc surface is covered by a dull basic zinc carbonate in moist air.

5. Nickel:

Nickel was first discovered in 1750. It is manufactured from its sulfide ore named *pentlandite* [NiFe(S)]. The ore is first concentrated by froth floatation process, and then roasted and smelted like other non-ferrous metals.

Nickel Properties:

Following are some important properties of nickel.

1. It is the strongest metal in all the non-ferrous metals, having tensile strength ranges from 4200-8400 kg/cm^2.

2. It is highly resistant to many types of corrosion. Thus it car moisture, atmospheric gases, etc.

3. Its modulus of elasticity, thermal and electrical conductivity i

4. It is highly malleable and ductile.

5. Its density is 8.9 g/cm^3.

6. It has a melting point of 1455 centigrade.

6. Magnesium:

Magnesium forms the lightest materials used in structural engineering. It has a set of properties that make it suitable as an engineering material.

Magnesium Properties and uses:

Magnesium is a very useful metal both as a pure metal and in alloys its main properties are as follows:

1. It is very light with a specific gravity of 1.74.

2. It has a melting point of 650 centigrade, which is similar to that of aluminum.

3. It has poor corrosion resistance.

4. It has quite a high thermal conductivity and a high coefficient of thermal expansion.

5. It forms very useful alloys with some metals like aluminum, thorium, zinc, zirconium, and tin, etc.