

ENGINEERING MATERIAL NOTE

3RD SEMESTER

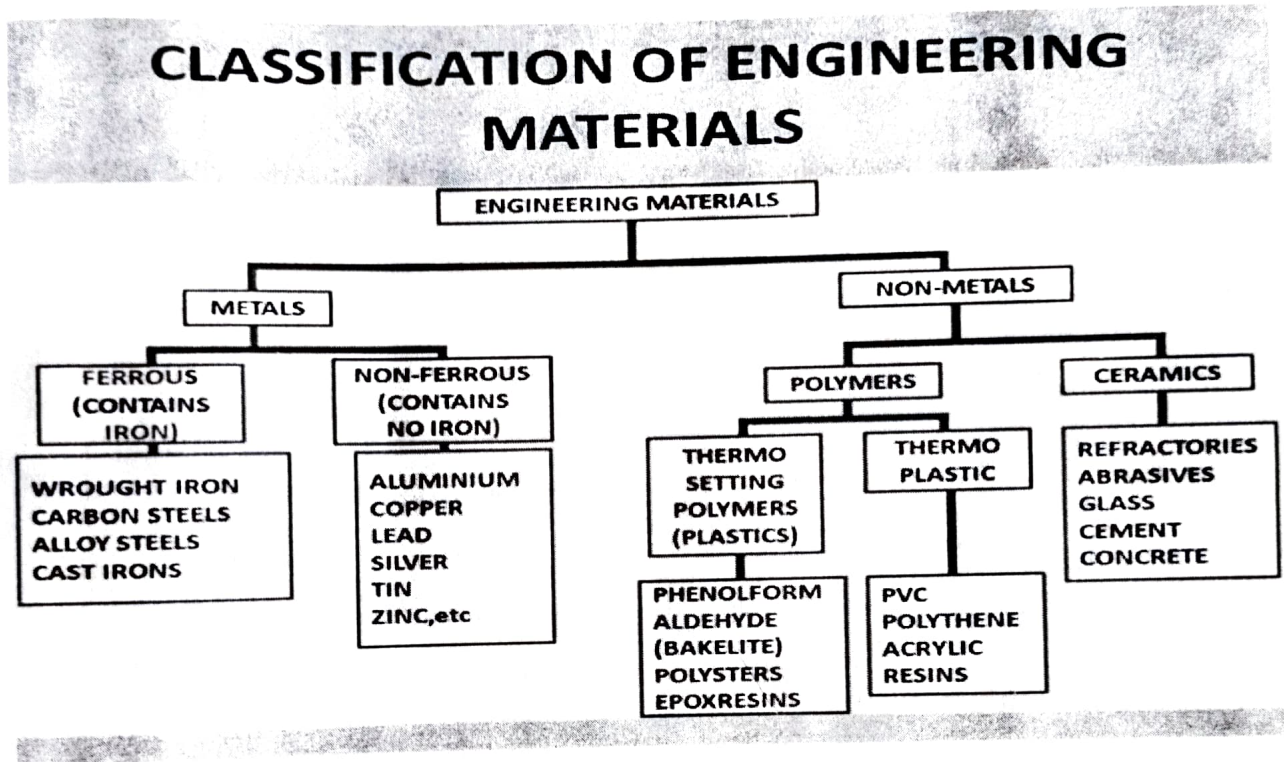
BRANCH: - MECHANICAL ENGG.

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CHAPTER -01:-ENGG. MATERIAL & THEIR PROPERTIES

Engineering material:-

Engineering materials are metals and plastics. Wood is used to make patterns and models. Smart materials and composites such as carbon fiber are also important engineering materials. Plastics - engineering plastics are usually very strong or tough.



Ferrous Metals Examples

All of them have different specifications, resulting in a variety of applications. To give a better overview, we made a ferrous metals list:

Non-Alloy Steels

1. Those elements are sulphur, phosphorus, silicon and manganese.
2. Sulphur and phosphorus can actually have a detrimental effect on the steel's quality but again, not with such low-level content.
3. Although the term "non-alloy steels" doesn't get much mention in a typical engineering company as such, our beloved structural steels like S235, S355 etc belong to this group.
4. Non-alloy steels are classified by their carbon content as low, medium and high carbon steel.
5. Each has their own uses and the characteristics vary.

Low Carbon Steel

1. Low carbon, or mild steels contain 0.05...0.25% of carbon.
2. They are pretty low-cost and very well suited for bending operations.
3. The surface hardness can be increased through carburizing.

4. The low cost and malleability low carbon steels are widely used.
5. Some examples include bolts and nuts, forgings, medium-loaded details etc.
6. Examples of low carbon steels: C10E/1.1121, C15E/1.1141

Medium Carbon Steel

1. Medium carbon steels contain 0.25...0.6% of carbon.
2. The higher carbon content increases their strength and hardness compared to low carbon steels.
3. At the same time, the ductility decreases.
4. The increase of carbon and manganese allows tempering and quenching.
5. Medium carbon steels are mainly used for making different automotive industry components like gears, axles, shafts but also bolts, nuts, screws etc.
6. Steels ranging from 0.4...0.6% are also suitable for everything related to locomotives and rails.
7. Examples of medium carbon steels: C40E/1.1186; C60E/1.1221

High Carbon Steel

1. The carbon content numbers for high carbon steels vary according to different sources.
2. Some have more sub-groups, while other stop with high carbon steels that start with 0.6% carbon content and end around 1%.
3. Another quality of high carbon steels is their tendency to keep a shape.
4. This is why tool steels have a lot of different applications in the field of engineering.
5. As a downside, the weld ability, ductility and impact toughness are all inferior to steels with less carbon.
6. The shape-keeping quality makes them useful as springs.
7. Other use-cases include blades, rail steels, wire rope, wear-resistant plates, all kinds of tools etc.
8. Examples of high carbon steels: C70U/1.1520, C105U/1.1545

Alloy Steels

1. Alloy steels make up another sub-group of ferrous metals. Steel's alloying elements are chrome, nickel, silicon, copper, titanium etc.
2. Each has their own effect on material properties. Of course, they are usually combined, so the end products have a bit of everything.
3. We discuss how the most common elements affect the outcome.

Chromium

1. Chromium is the element responsible for creating stainless steel.
2. Presence of chromium at levels above 11% makes a metal corrosion-resistant.
3. As discussed in the material wear article, the protection takes place through creating an oxidized chromium layer on top of the metal.
4. This means that the base metal does not get into contact with oxygen and the danger of corrosion is greatly diminished.

Manganese

1. Manganese improves ductility, wear resistance and hardenability.
2. The latter is done through quenching where manganese has a significant impact.
3. It diminishes the danger of defect formation during the process by making it more stable.
4. It also eliminates the formation of harmful iron sulfides, increasing strength at high temperatures.

Nickel

1. Its main purpose is to increase ductility and corrosion resistance in combination with other elements, namely chromium.
2. When chromium content is around 18% and nickel at 8%, we get an extremely durable stainless steels.

Silicon

1. Improves strength and provides elasticity in springs.
2. Another significant effect is increasing a metal's magnetic properties.

Titanium

3. Improves strength and corrosion resistance, limits austenite grain size.

Vanadium

1. The formation of vanadium carbides limits the grain size.
2. This has an effect on increasing a material's ductility.
3. It also increases strength, hardness, wear and shock impact resistance.
4. Because of its effectiveness, the amounts must be held low.
5. Otherwise, it can have a negative impact on material properties.

Molybdenum

1. Molybdenum has a large effect on steel alloys at high temperatures.
2. It improves mechanical properties but also resistance to corrosion and acts as an amplifier for the effects of other alloying elements.

Cast iron

1. Cast iron is an alloy of iron and carbon, with carbon content somewhere between 1.5 and 4 percent.
2. There are also other elements present – namely silicon, manganese, sulphur and phosphorus.
3. The properties of cast iron:
 - Great cast ability
 - Relatively cheap
 - High compressive strength
 - Good wear resistance
 - Low melting point

Non-Ferrous Metal

1. Non-ferrous metals do not contain iron.
2. They are softer and therefore more malleable.
3. They have industrial uses as well as aesthetic purposes – precious metals like gold and silver are both non-ferrous.
4. Actually, all pure metal forms, except for pure iron, are non-ferrous.

Non-Ferrous Metals' Properties

1. Non-ferrous metals' advantages make them usable in many applications instead of iron and steel.
2. The properties of non-ferrous metals:
 - High corrosion resistance
 - Easy to fabricate – machinability, casting, welding etc
 - Great thermal conductivity
 - Great electrical conductivity
 - Low density (less mass)
 - Colorful

- Non-magnetic

Non-Ferrous Metals List

1. Again, we are going to provide some information on each metal and its properties. Examples of non-ferrous metals:

Copper

1. Copper is pretty widely spread in the industrial sphere.
2. Add the alloys brass (copper and zinc) and bronze (copper and tin), and you may already see the many uses of copper.
3. If not, we can help you out. For mechanical engineers, slide bearings and bushings may be the most known uses.
4. Still, copper and copper alloy properties allow more applications:
 - High thermal conductivity – heat exchangers, heating vessels and appliances etc
 - High electrical conductivity – used as an electrical conductor in wiring and motors
 - Good corrosion resistance – beautiful but expensive roofing
 - High ductility – makes the material very easily formable and suitable for making statues

Aluminum

1. In engineering terms, a very special and important metal.
2. May not be so useful in everyday application because of the price but its combination of low weight and great machinability make it the go-to metal in yachts, planes and many automotive parts.
3. Aluminum is also the base metal in many alloys.
4. The best known aluminum grades are probably duralumin, Y-alloy and magnesium.
5. Aluminum properties include:
 - Corrosion resistant
 - Good conductor of heat and electricity (but less than copper) – in combination with ductility and malleability replaces copper in some instances
 - High ductility and lightweight
 - Becomes hard after cold working, so needs annealing
 - Very heavy
 - Resistant to corrosion – doesn't react with many chemicals
 - Soft and malleable

Zinc

1. Zinc on its own doesn't mean much to the average person.
2. As an alloying element, on the other hand, it has a wide range of purposes.
3. It is mainly used for galvanizing steel in all kinds of fields.
4. Galvanizing makes a material more durable against corrosion.

Properties of engineering materials

1. Mechanical properties
2. Physical properties
3. Electrical properties
4. Chemical properties
5. Thermal properties
6. Magnetic properties

1. Mechanical properties:-

- Strength
- Stiffness
- Elasticity
- Plasticity
- Malleability
- Ductility
- Toughness
- Weld- ability
- Machinability
- Fatigue
- Hardness
- Brittleness
- Creep
- **Resilience**

2. Physical Properties of Engineering Materials

- Density.
- Specific gravity.
- State Change temperatures.
- Coefficients of thermal expansion.
- Specific Heat.
- Latent heat.
- Fluidity.
- Weld ability.

3. Electrical Properties

- Resistivity
- Conductivity
- Temperature coefficient of Resistance
- Permittivity
- Thermoelectricity

4. Chemical Properties of Engineering Materials

- Chemical composition.
- Atomic bonding.
- Corrosion resistance.
- Acidity or Alkalinity.

5. Thermal properties

1. Specific heat.
2. Thermal conductivity.
3. Thermal expansion.
4. Melting point or heat resistance.
5. Thermal shock.

6. Magnetic properties

- Permeability
- Retentively or Magnetic Hysteresis
- Coercive force
- Reluctance

Performance of Requirements:-

- Design of electrode composites for Li-ion and Na-ion batteries
- Development and characterization of improved biomedical materials
- Corrosion and protection of Al alloys in aging aircraft applications
- Development of new gas, thermal and bio-sensors
- Properties of materials that influence large-scale manufacturing
- Development of co-continuous ceramic composites
- Corrosion susceptibility of emerging Al-Li alloys
- Development of high-temperature coatings for carbon/carbon composites
- Design of protective coatings for refractory metals.
- Fatigue properties of die cast magnesium alloys.

Material Reliability:-

1. The safety and reliability of technical systems is always also a question of corrosion protection.
2. Systems with reliable components play a vital role in accident prevention and occupational safety.
3. Reliable surface protection increases the safety of both people and the environment, preserves the quality of products, and increases the operational reliability of complex technical systems and components.
4. This, for example, in the automotive industry, in construction, as well as fastening technology.
5. The mission's system technology offers maximum corrosion protection and hence maximum safety and reliability of technically demanding applications even under extreme conditions.
6. Since the coating diffuses into the base material, an inseparable intermetallic phase develops between zinc and the base material.
7. Ductility can also be improved through targeted "tempering" during the main process to further optimize the material properties.

CHAPTER-02:-FERROUS MATERIAL& ALLOYS

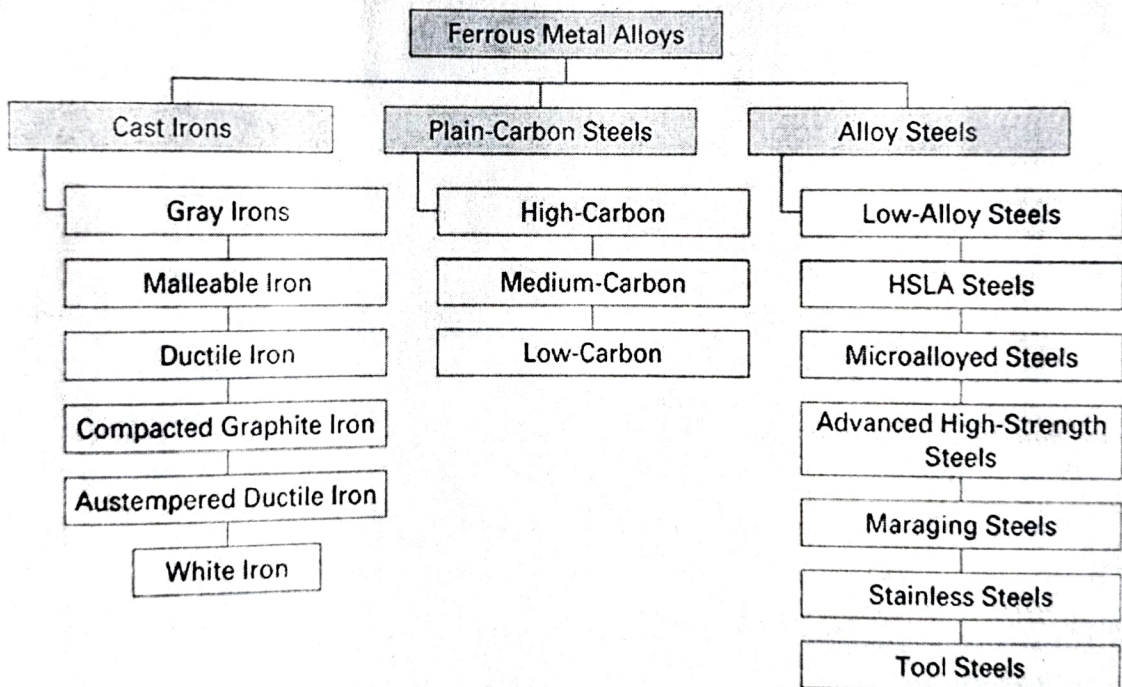
Characteristics of Ferrous Material:-

1. Durable.
2. Great tensile strength.
3. Usually magnetic.
4. Low resistance to corrosion.
5. A silver-like color.
6. Recyclable.
7. Good conductors of electricity.

Application of Ferrous Material:-

1. Ferrous metals are widely used in piping.
2. Although high amounts of carbon causes most of these metals an increased proneness to rust and corrosion.
3. Metals containing wrought iron (lack of sulfur and carbon) and chromium content can resist oxidation and thereby provide protection against corrosion.

Classification of ferrous metal:-



Carbon percentage of steel

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

Low Carbon Steel (Mild Steel):

1. Typically contain 0.04% to 0.30% carbon content.
2. This is one of the largest groups of Carbon Steel. ...
3. Medium Carbon Steel:
4. Typically has a carbon range of 0.31% to 0.60%, and a manganese content ranging from 0.60% to 1.65%.
5. They do, however, have high ductility, making them excellent for machining, welding and low cost.
6. High-strength, low-alloy steels (HSLA) are also often classified as low-carbon steels, however, also contain other elements such as copper, nickel, vanadium and molybdenum. Combined, these comprise up to 10 wt.% of the steel content.
7. High-strength, low-alloy steels, as the name suggests, have higher strengths, which is achieved by heat treatment.
8. They also retain ductility, making them easily formable and machinable.
9. HSLA are more resistant to corrosion than plain low-carbon steels.

Medium-carbon steel

1. Medium-carbon steel has a carbon content of 0.25 – 0.60 wt.% and a manganese content of 0.60 – 1.65 wt.%.
2. The mechanical properties of this steel are improved via heat treatment involving austenitising followed by quenching and tempering, giving them a martensitic microstructure.
3. Heat treatment can only be performed on very thin sections, however, additional alloying elements, such as chromium, molybdenum and nickel, can be added to improve the steels ability to be heat treated and, thus, hardened.
4. Hardened medium-carbon steels have greater strength than low-carbon steel, however, this comes at the expense of ductility and toughness.

High-carbon steel

1. High-carbon steel has a carbon content of 0.60– 1.25 wt.% and a manganese content of 0.30 – 0.90 wt.%.
2. It has the highest hardness and toughness of the carbon steels and the lowest ductility. High-carbon steels are very wear-resistant as a result of the fact that they are almost always hardened and tempered.
3. Tool steels and die steels are types of high-carbon steels, which contain additional alloying elements including chromium, vanadium, molybdenum and tungsten.
4. The addition of these elements results in the very hard wear-resistant steel, which is a result of the formation of carbide compounds such as tungsten carbide (WC).

Alloy steel:-

Alloy steel is often categorized based on the type of alloy and its concentration. These are a few of the most common additions to alloy steel:

- **Aluminum** removes oxygen, sulfur, and phosphorus from steel.
- **Bismuth** improves machinability.
- **Chromium** increases wear resistance, hardness, and toughness.
- **Cobalt** increases stability and encourages the formation of free graphite.
- **Copper** improves hardening and corrosion resistance.
- **Manganese** increases hardenability, ductility, wear resistance, and high-temperature strength.
- **Molybdenum** lowers carbon concentration and adds room-temperature strength.
- **Nickel** improves strength, corrosion resistance, and oxidation resistance.
- **Silicon** increases strength and magnetism.
- **Titanium** improves hardness and strength.
- **Tungsten** improves hardness and strength.
- **Vanadium** increases toughness, strength, corrosion resistance, and shock resistance

High-Alloy Steel

1. High-alloy steels are defined by a high percentage of alloying elements.
2. The most common high-alloy steel is stainless steel, which contains at least 12 percent chromium.
3. Stainless steel is generally split into three basic types: martensitic, ferritic, and austenitic.
4. Martensitic steels contain the least amount of chromium, have a high hardenability, and are typically used for cutlery.
5. Ferritic steels contain 12 to 27 percent chromium and are often used in automobiles and industrial equipment.
6. Austenitic steels contain high levels of nickel, carbon, manganese, or nitrogen and are often used to store corrosive liquids and mining, chemical, or pharmacy equipment.

Low-Alloy Steel

1. Low-alloy steels have a much lower percentage of alloying elements, usually 1 to 5 percent.
2. These steels have very different strengths and uses depending on the chosen alloy.
3. Large diameter flanges manufacturers typically choose alloys for a specific mechanical property.
4. The variety of potential alloys makes low-alloy steel useful for a variety of projects, including seamless rolled ring forging and studding outlet manufacturing.

Stainless Steel

1. We know that steel is an alloy of iron and carbon with a maximum carbon content of 2.1%.
2. Stainless steels are a group of steels that are resistant to corrosion through the addition of alloying elements.
3. The term stainless steel is used to describe a family of about 200 alloys of steel with remarkable heat and corrosion resistance properties.
4. The carbon percentage can range from 0.03% to 1.2%.
5. Its distinguishing characteristic is the high amount of chromium.
6. Stainless steel contains aluminum of 10.5% of chromium that improves its corrosion resistance and strength.
7. The chromium in the alloy creates a passive layer on oxidation when exposed to air.
8. This layer acts as a shield against further corrosion essentially making the alloy rustproof.
9. This mechanism allows for retaining a spotless appearance for long periods under normal working conditions.

Benefits of Stainless Steel

1. Stainless steel has been used with phenomenal success in various industries for over 70 years.
2. More applications are being discovered with every passing year as its advantages become more widely identified.
3. With an increase in demand, production has increased making it more affordable than ever.
4. Besides polished finishes, a whole range of patterned and coloured surfaces are available.
5. This makes finding a suitable option for your needs possible.

Use-Cases

1. Stainless steel is an exceedingly versatile material.
2. It is preferred where the properties of steel and corrosion resistance are required in tandem.
3. Its first use was in cutlery but due to its corrosion resistance properties.
4. Next, it found its way to the chemical industry.
5. Today, we can see stainless steel pretty much everywhere.
6. The use-cases vary from industry to industry.
7. For example, the uses include making minuscule parts for wristwatches.
8. At the same time, large panels with a certain surface finish may cover whole buildings.

Tool steel:-

1. **Tool steel** refers to a variety of carbon steel and alloy steel that are particularly well-suited to be made into tools.
2. Their suitability comes from their distinctive hardness, resistance to abrasion and deformation, and their ability to hold a cutting edge at elevated temperatures.
3. As a result, tool steels are suited for use in the shaping of other materials.
4. With a carbon content between 0.5% and 1.5%, tool steels are manufactured under carefully controlled conditions to produce the required quality.
5. The presence of carbides in their matrix plays the dominant role in the qualities of tool steel.
6. The four major alloying elements that form carbides in tool steel are: tungsten, chromium, vanadium and molybdenum.
7. The rate of dissolution of the different carbides into the austenite form of the iron determines the high-temperature performance of steel (slower is better, making for a heat-resistant steel).

Effect of Tool steel like Cr, Mn, Ni, V, Mo.

1. The elements like chromium (Cr), molybdenum (Mo), vanadium (V), increasing steel hardness and strength.
Examples of steels containing relatively high concentration of carbides: hot work tool steels, high speed steels.

Manganese (Mn) – improves hardenability, ductility and wear resistance.
Mn eliminates formation of harmful iron sulfides, increasing strength at high temperatures.

Nickel (Ni) – increases strength, impact strength and toughness, impart corrosion resistance in combination with other elements.

Chromium (Cr) – improves hardenability, strength and wear resistance, sharply increases corrosion resistance at high concentrations (> 12%).

Tungsten (W) – increases hardness particularly at elevated temperatures due to stable carbides, refines grain size.

Vanadium (V) – increases strength, hardness, creep resistance and impact resistance due to formation of hard vanadium carbides, limits grain size.

Molybdenum (Mo) – increases hardenability and strength particularly at high temperatures and under dynamic conditions.

Silicon (Si) – improves strength, elasticity, acid resistance and promotes large grain sizes, which cause increasing magnetic permeability.

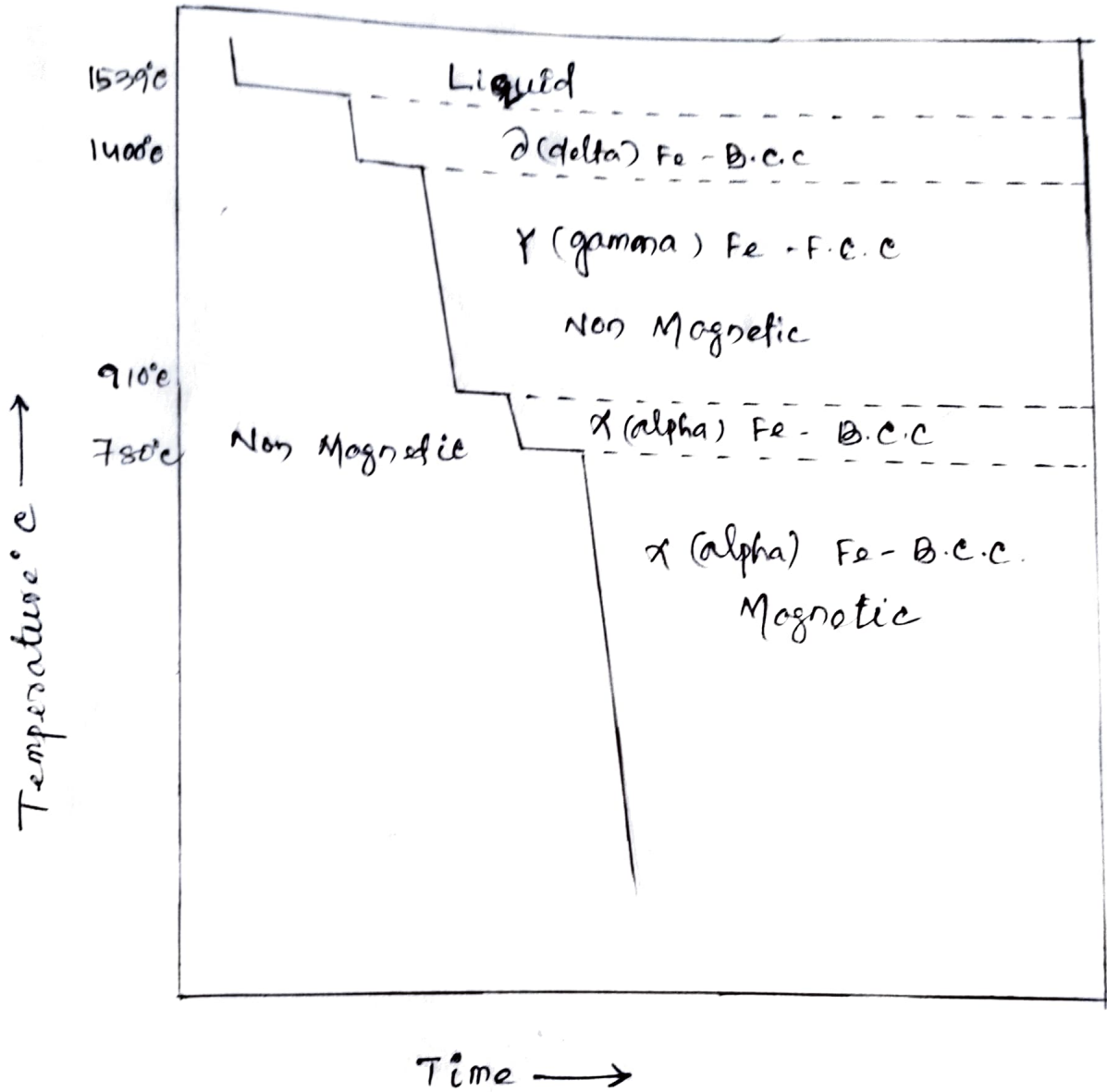
CHAPTER:-03 IRON-CARBON SYSTEM

Concept of Phase diagram:-

A phase diagram in physical chemistry, engineering, mineralogy, and materials science is a type of chart used to show conditions (pressure, temperature, volume, etc.) at which thermodynamically distinct phases (such as solid, liquid or gaseous states) occur and coexist at equilibrium.

Cooling curve:-

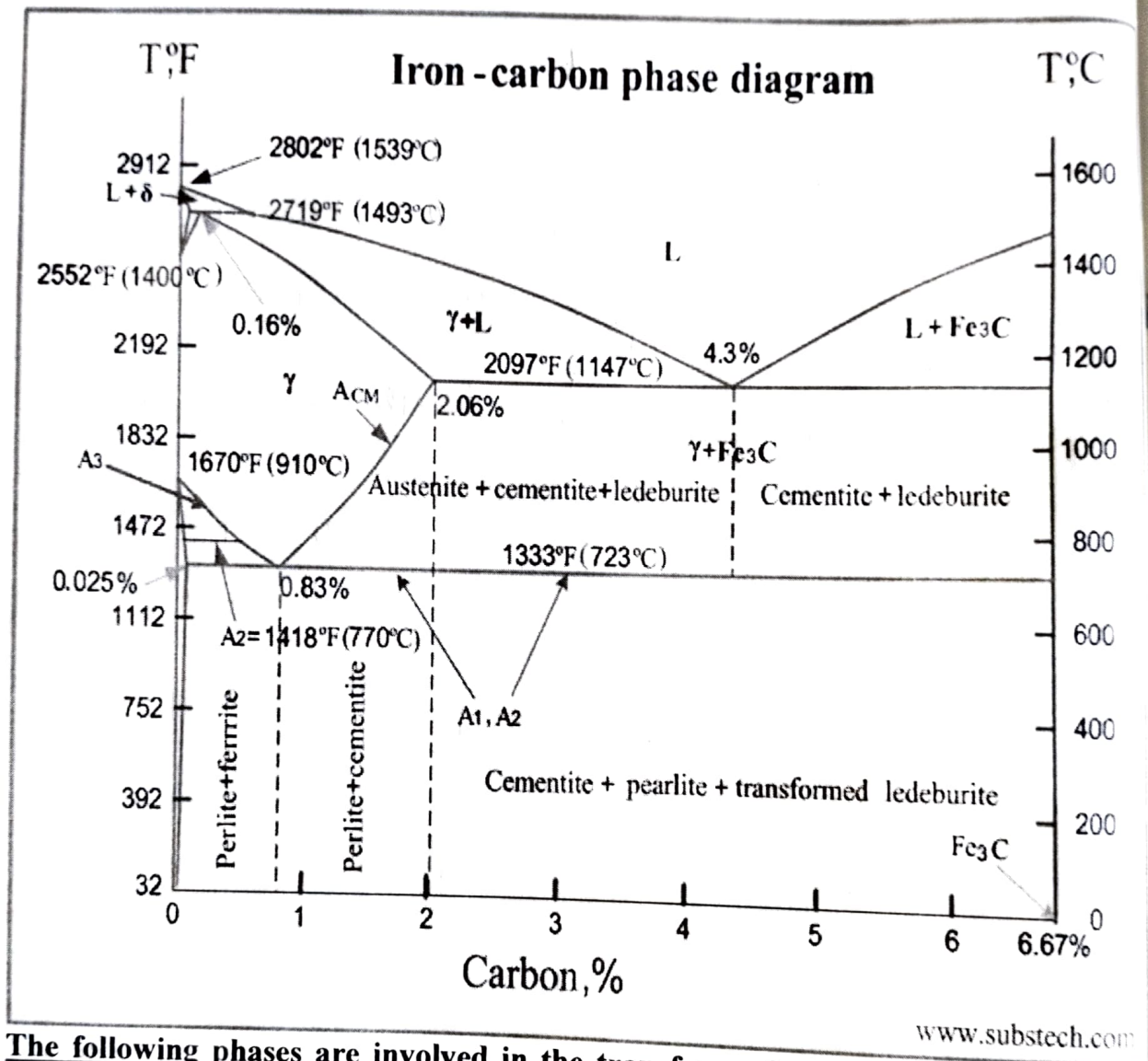
2. A cooling curve is a line graph that represents the change of phase of matter, typically from a gas to a solid or a liquid to a solid.
3. The independent variable (X-axis) is time and the dependent variable (Y-axis) is temperature.
4. The amount of energy required for a phase change is known as latent heat.
5. Cooling curve graphs are useful as they clearly show up a phenomenon of phase changes of matter.
6. To explain this, we shall use water as our example.
7. First we start with a sealed container of steam, particles are moving at a high speed. temperature of which is, say, 150 °C.
8. As we measure the temperature of the rapidly cooling gas, we see that it falls at a rate that is typical of the specific heat capacity of steam; until when it reaches 100 °C, when something odd happens - the temperature stagnates.
9. After an amount of liquid water has collected the temperature continues to drop, again proportional to the specific heat capacity of water (different to that of steam), until again the temperature stagnates, this time at 0 °C.
10. Later, the temperature again resumes falling.
11. The explanation is that different phases of matter are associated with different energy levels.
12. Steam at 100 °C is the same temperature, but contains much more thermal energy than liquid water at 100 °C.
13. The same goes for water and ice at 0 °C.
14. This is because molecules of water are much more free to move around as a gas than as a liquid, and that freedom of movement means there is much more kinetic energy associated with each molecule, and that energy is transferred as the substance shifts phase - explaining why energy seemingly disappears when boiling a kettle.



Cooling Curve of Pure Iron

Iron-carbon phase diagram :-

- **Iron-carbon phase diagram** describes the iron-carbon system of alloys containing up to 6.67% of carbon, discloses the phases compositions and their transformations occurring with the alloys during their cooling or heating.
- Carbon content 6.67% corresponds to the fixed composition of the iron carbide Fe_3C .
- The diagram is presented in the picture:



The following phases are involved in the transformation, occurring with iron-carbon alloys:

- L - Liquid solution of carbon in iron;
- δ -ferrite -- Solid solution of carbon in iron.
- Maximum concentration of carbon in δ -ferrite is 0.09% at 2719 °F (1493°C) – temperature of the paratactic transformation.
- The crystal structure of δ -ferrite is BCC (body centered cubic).

- Austenite – interstitial solid solution of carbon in γ -iron.
- Austenite has FCC (cubic face centered) crystal structure, permitting high solubility of carbon – up to 2.06% at 2097 °F (1147 °C).
- Austenite does not exist below 1333 °F (723°C) and maximum carbon concentration at this temperature is 0.83%.
- α -ferrite – solid solution of carbon in α -iron.
- α -ferrite has BCC crystal structure and low solubility of carbon – up to 0.025% at 1333 °F (723°C).
- α -ferrite exists at room temperature.
- Cementite – iron carbide, intermetallic compound, having fixed composition Fe_3C .
- Cementite is a hard and brittle substance, influencing on the properties of steels and cast irons.
- The following phase transformations occur with iron-carbon alloys:
 - Alloys, containing up to 0.51% of carbon, start solidification with formation of crystals of δ -ferrite.
 - Carbon content in δ -ferrite increases up to 0.09% in course solidification, and at 2719 °F (1493°C) remaining liquid phase and δ -ferrite perform paratactic transformation, resulting in formation of austenite.
 - Alloys, containing carbon more than 0.51%, but less than 2.06%, form primary austenite crystals in the beginning of solidification and when the temperature reaches the curve ACM primary cementite stars to form.
- Iron-carbon alloys, containing up to 2.06% of carbon, are called steels.
- Alloys, containing from 2.06 to 6.67% of carbon, experience eutectic transformation at 2097 °F (1147 °C).
 - The eutectic concentration of carbon is 4.3%.
 - In practice only hypoeutectic alloys are used.
 - These alloys (carbon content from 2.06% to 4.3%) are called cast irons.
 - When temperature of an alloy from this range reaches 2097 °F (1147 °C), it contains primary austenite crystals and some amount of the liquid phase.
 - The latter decomposes by eutectic mechanism to a fine mixture of austenite and cementite, called ledeburite.
 - All iron-carbon alloys (steels and cast irons) experience eutectoid transformation at 1333 °F (723°C). The eutectoid concentration of carbon is 0.83%.

CHAPTER:-04 CRYSTAL IMPERFECTIONS

Crystal

1. A crystalline **material** consists of primarily organized **crystal structure**.
2. A **crystal** is a solid composed of atoms, ions, or molecules arranged in a pattern that is repetitive in three-dimensions.
3. Each **crystal lattice** is defined by a **crystal system**.

Types of lattice structure or crystal structure

Basic of the crystal structure consists of space lattice pattern and basis

Crystal structure = space lattice + basis

Basis may contains one atom per lattice pattern

e.g.

1) **FCC** (Space lattice) + 1 Aluminum atom at each lattice point (basis) = FCC Crystal of Aluminum (Crystal structure)

2) **BCC** + 1 Iron atom at each lattice point (basis) = BCC Crystal of Iron

□ **FCC** = Face Centered Cubic

e.g. Copper, Aluminum, Nickel, Pb, Ag

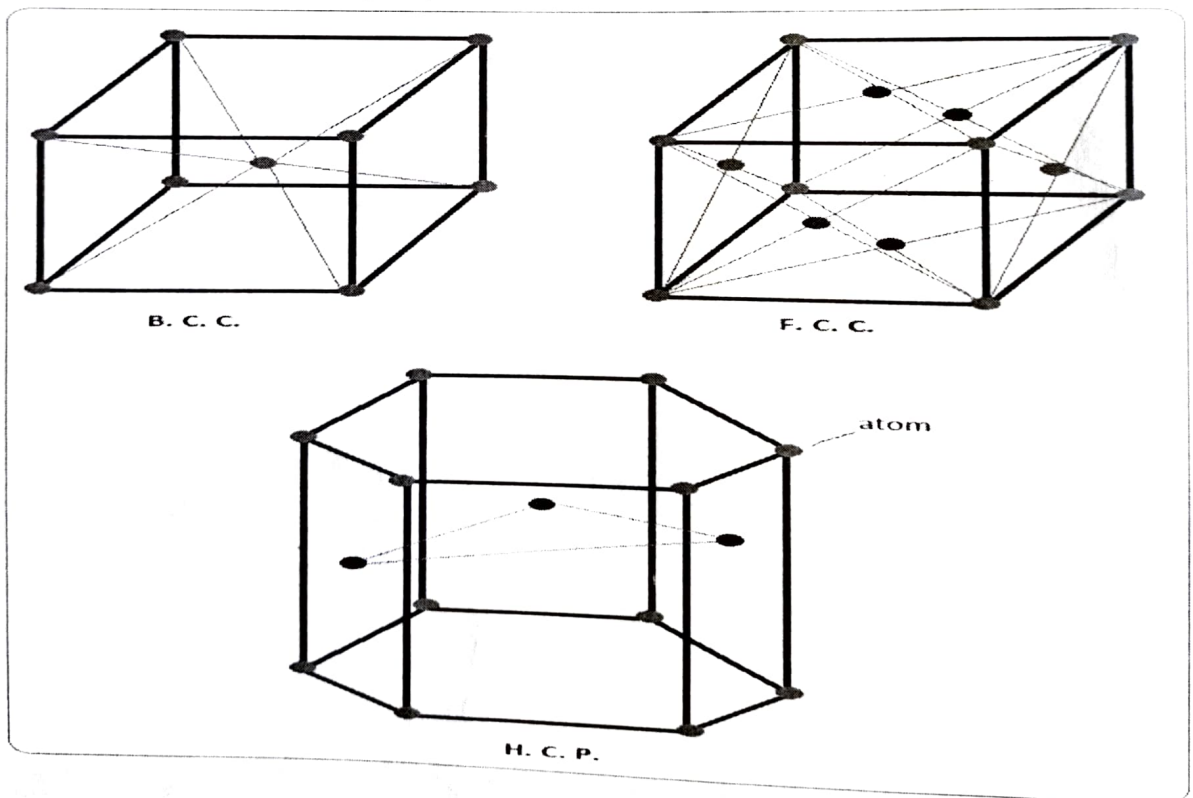
□ **BCC** = Body Centered Cubic

e.g. W, Mo, Cr

□ **HCP** = Hexagonal close pack

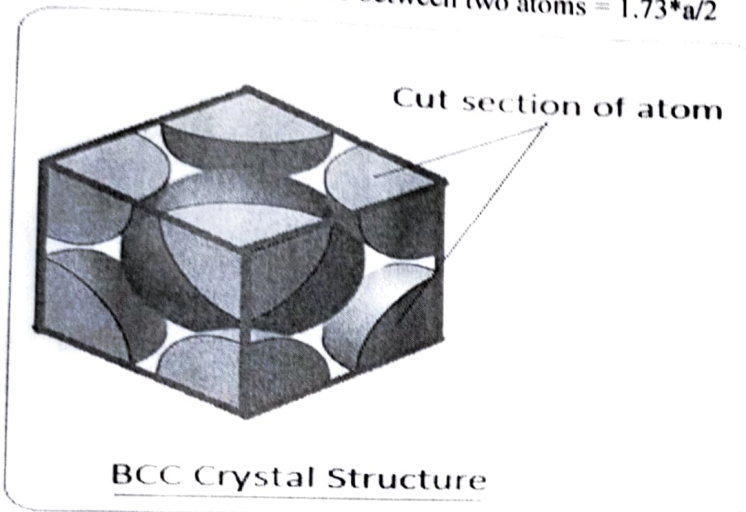
Mg, Zn, Ti, Cd, Zr

Unit Cell: The basic difference between all these pattern lies in the difference between the unit cell which is nothing but the repeatability of each pattern in lattice space.



B.C.C (Body Centered Cubic)

- 1 atom at center of cube and one atom each at all the corners
- No. of atoms per unit cell = $N_c/8 + N_f/2 + N_i/2$ Where N_c = No. of atoms at center, N_f = No. of atoms at face and N_i = No. of atoms inside.
- **Atomic radius** = $1.73 \cdot a/4$, Where a = distance between two adjacent atoms
- Atomic packing radius = 0.68
- V, Mo, Ta, W are having BCC structure at room temperature
- **coordination no** is 8
- The nearest distance between two atoms = $1.73 \cdot a/2$



F.C.C (Face Centered Cubic)

- 1 atom at each corner of cube
- 1 atom at the intersection of the diagonal of each of six faces of the cube
- No. of atoms per unit cell = $N_c/8 + N_f/2 + N_i/2 =$ Four atoms
- Atomic radius = $1.41 \cdot a/4$
- Atomic packing factor = 0.74
- e.g. Cu, Al, Pb, Ni, Co etc
- Coordination number = 12
- Nearest distance between two atoms = $a/1.41$
- No. of atoms per unit cell shows the density packedness
- So, FCC is more density packed than BCC

H.C.P. (Hexagonal Close Pack)

- 1 atom at each corner of hexagon
- 1 atom at each center of hexagon faces
- 1 atom at the center connecting perpendiculars in three rhombuses
- No. of atoms per unit cell = 6
- Atomic radius = $a/2$
- Atomic packing factor = 0.74
- Coordination number = 12
- e.g. Zn, Cd, Mg

Because of allotropes of iron, it got two different lattice structure at different temperatures.

- At **room temperature** crystal structure of Iron is BCC(Body Centered Cubic)
- At **912 °C** the crystal structure changes(Face Centered Cubic) and
- At **1,394 °C** its crystal structure changes to a Body centered cubic (BCC)

Ideal Crystal

- (1) A crystal of perfect structure, with none of the structural defects inevitable in real crystals,
- (2) The ideal crystal is a theoretical model widely used in solid-state theory.

Imperfection

- A perfect crystal, with every atom of the same type in the correct position, does not exist.
- There always exist crystalline defects, which can be point defects occurring at a single lattice point; line defects occurring along a row of atoms; or planar defects occurring over a two-dimensional surface in the crystal.
- There can also be three-dimensional defects such as voids.

Crystalline Defects:

Imperfections or defects:

- Any deviation from the perfect atomic arrangement in a crystal is said to contain imperfections or defects.
- Or a crystalline defect is a lattice irregularity having one or more of its dimensions on the order of an atomic dimension.

There are 4 major categories of crystalline defects:

- 1. Zero dimensional: Point defects occurring at a single lattice point.**
- 2. One dimensional: Linear defects (dislocations) occurring along a row of atoms.**
- 3. Two dimensional: Planar (surface) defects occurring over a two-dimensional surface in the crystal.**
- 4. Three dimensional: Volume (bulk) (void) defects**
 - Defects influence the electrical and mechanical properties of solids; in fact it is the defects that are usually responsible for the existence of useful properties.
 - While it is perhaps intuitive to think of defects as bad things, they are in fact necessary, even crucial, to the behavior of materials:
 - Almost, or perhaps all, technology involving materials depends on the existence of some kind of defects.
 - Adding alloying elements to a metal is one way of introducing a crystal defect.

Thus some important properties of crystals are controlled by as much as by imperfections and by the nature of the host crystals.

- The conductivity of some semiconductors is due to entirely trace amount of chemical impurities.
- Color, luminescence of many crystals arise from impurities and imperfections
- Atomic diffusion may be accelerated enormously by impurities or imperfections
- Mechanical and plastic properties are usually controlled by imperfections.

Crystal Defects Classification:

1. Point defects:

- a. Vacancy
- b. Schottky
- c. Self-interstitial
- d. Frenkel
- e. Colour centers
- f. Polarons
- g. Excitons

2. Line defects

- a. Edge dislocation
- b. Screw dislocation

3. Surface defects

- a. Grain boundaries
- b. Tilt boundaries
- c. Twin boundaries
- d. Stacking faults

4. Volume defects

- a. Inclusions
- b. Voids

Point Defects:

Point defects are where an atom is missing or is in an irregular place in the lattice structure.

Vacancies

1. A perfect crystal with regular arrangement of atoms cannot exist.
2. There are always defects, and the most common defects are point defects.
3. This is especially true at high temperatures when atoms are frequently and randomly change their positions leaving behind empty lattice sites, called vacancies.

Or

1. Vacancies are empty spaces where an atom should be, but is missing.
2. In most cases diffusion (mass transport by atomic motion) - can only occur because of vacancies.

How many vacancies are there?

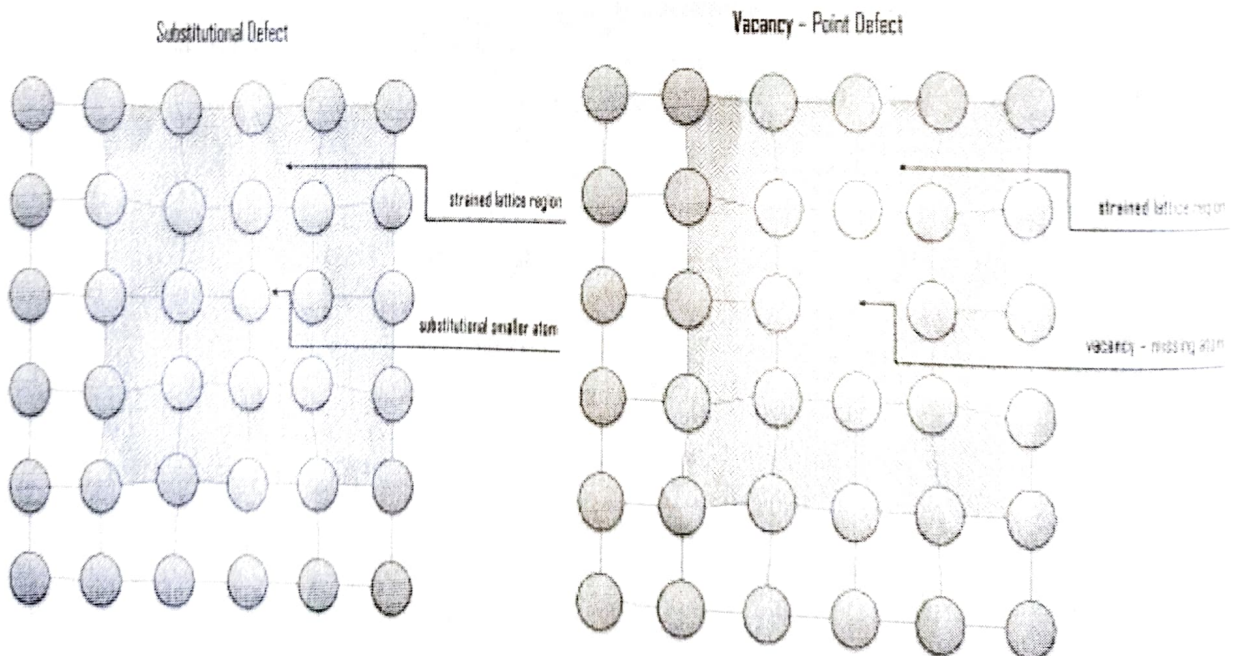
- The higher is the temperature, more often atoms are jumping from one equilibrium position to another and larger number of vacancies can be found in a crystal.
- Actually, the equilibrium number of vacancies, N_V , increases exponentially with the absolute temperature, T , and can be estimated using the equation

(Boltzmann Distribution):

1. $N_v = N \exp(-Q_v/kT)$
2. Where N is the number of regular lattice sites, k is the Boltzmann constant (1.38×10^{-23} J/atom.K), and Q_v is the energy needed to form a vacancy in a perfect crystal.
3. Using this simple equation we can estimate that at room temperature in copper there is one vacancy per 10¹⁵ lattice atoms, whereas at high temperature, just below the melting point (1358 K) there is one vacancy for every 10,000 atoms.
4. These are the lower end estimations, a large numbers of additional vacancies can be introduced in a growth process or as a result of further treatment (plastic deformation, quenching from hightemperature to the ambient one, etc.).

Example:

- Calculate the equilibrium number of vacancies per cubic meter for copper at 1000OC.
- The energy for vacancy formation is 0.9eV/atom; the atomic weight and density (at 1000OC) for copper are 63.5 g/mol and 8.4 g/cm³, respectively.
- A Schottky defect is a type of vacancy in which an atom being free from regular site, migrates through successive steps and eventually settles at the crystal surface. a pair of anion and cation vacancies.



Impurities:

- A pure metal consisting of only one type of atom just isn't possible; impurity or foreign atoms will always be present, and some will exist as crystalline point defects.
- In fact, even with relatively sophisticated techniques, it is difficult to refine metals to purity in excess of 99.9999%.
- At this level, on the order of 10^{22} to 10^{23} impurity atoms will be present in one cubic meter of material.
- Metals which have impurity called alloys.
- Alloying is used in metals to improve mechanical strength and corrosion resistance.
- The addition of impurity atoms to a metal will result in the formation of a solid solution and/or a new second phase, depending on the kinds of impurity, their concentrations, and the temperature of the alloy.
- Several terms relating to impurities and solid solutions deserve mention.
- "Solvent" represents the element or compound that is present in the greatest amount host atoms.
- "Solute" is used to denote an element or compound present in a minor concentration.

Solid Solutions:

- A solid solution forms when, as the solute atoms are added to the host material, the crystal structure is maintained, and no new structures are formed.
- If two liquids, soluble in each other (such as water and alcohol) are combined, a liquid solution is produced as the molecules intermix, and its composition is homogeneous throughout.
- A solid solution is also compositionally homogeneous; the impurity atoms are randomly and uniformly dispersed within the solid.

Impurity point defects are found in solid solutions, of which there are two types:

Substitutional:

There are several features of the solute and solvent atoms that determine the degree to which the former dissolves in the latter, as follows:

1. Atomic size factor.

Appreciable quantities of a solute may be accommodated in this type of solid solution only when the difference in atomic radii between the two atom types is less than about.

Otherwise the solute atoms will create substantial lattice distortions and a new phase will form.

2. Crystal structure.

For appreciable solid solubility the crystal structures for metals of both atom types must be the same.

3. Electronegativity.

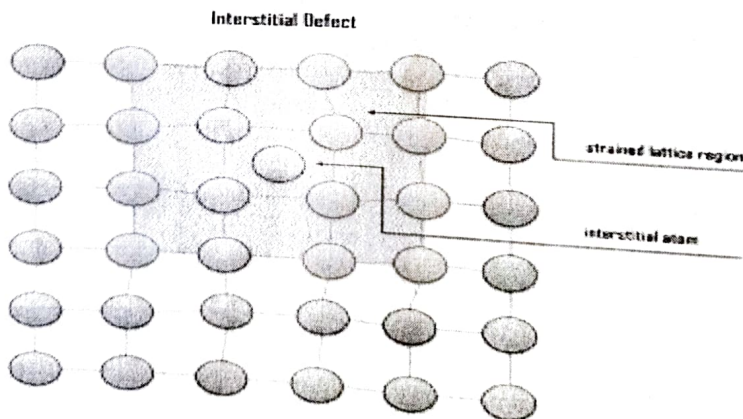
- The more electropositive one element and the more electronegative the other, the greater is the likelihood that they will form an intermetallic compound instead of a substitutional solid solution.

4. Valences.

- Other factors being equal, a metal will have more of a tendency to dissolve another metal of higher valency than one of a lower valency.

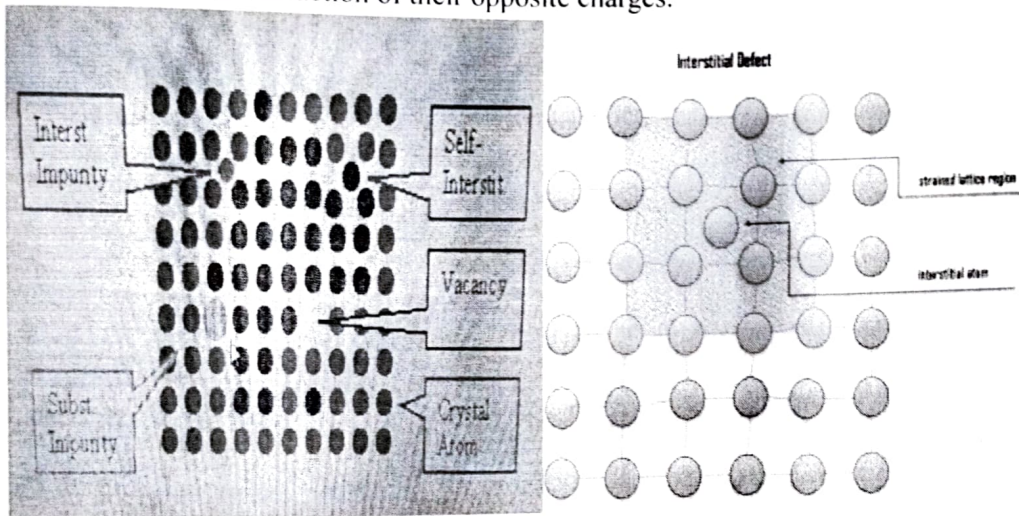
Interstitials –

- Atoms that are squeezed in between regular lattice sites.
- If the interstitial atom is of the same species as the lattice atoms, it is called self-interstitial.
- Foreign, usually smaller atoms (carbon, nitrogen, hydrogen, oxygen) are called interstitial impurities.
- An example of interstitial impurity atoms is the carbon atoms that are added to iron to make steel.
- Carbon atoms, with a radius of 0.071 nm, fit nicely in the open spaces between the larger (0.124 nm) iron atoms.
- They introduce less distortion to the lattice and are more common in real materials and more mobile.
- If the foreign atom replaces or substitutes for a matrix atom, it is called a substitutional impurity.
- A substitutional impurity atom is an atom of a different type than the matrix atoms, which has replaced one of the bulk (matrix) atoms in the lattice.
- Substitutional impurity atoms are usually close in size (within approximately 15%) to the bulk atom.
- An example of substitutional impurity atoms is the zinc atoms in brass. In brass, zinc atoms with a radius of 0.133 nm have replaced some of the copper atoms, which have a radius of 0.128 nm.



Frenkel defect

1. Frenkel defect is a pair of cation (positive ion) vacancy and a cation interstitial.
2. Or it may also be an anion (negative ion) vacancy and anion interstitial.
3. Or the combination of a vacancy and interstitial is called a Frankel defect.
4. However anions are much larger than cations and it is not easy for an anion interstitial to form.
5. In both Frenkel and Schottky defects, the pair of point defects stays near each other because of strong coulombic attraction of their opposite charges.



2- Linear Defects (Dislocations):

1. In linear defects groups of atoms are in irregular positions.
2. Linear defects are commonly called dislocations.
3. Any deviation from perfectly periodic arrangement of atoms along a line is called the line imperfection.
4. A line defect is a lattice distortion created about a line formed by the solidification process, plastic deformation, vacancy condensation or atomic mismatch in solid solutions.
5. The line imperfection acting as boundary between the slipped and un-slipped region, lies in the slip plane and is called a dislocation.
6. Dislocations are generated and move when a stress is applied.
7. The strength and ductility of metals are controlled by dislocations.

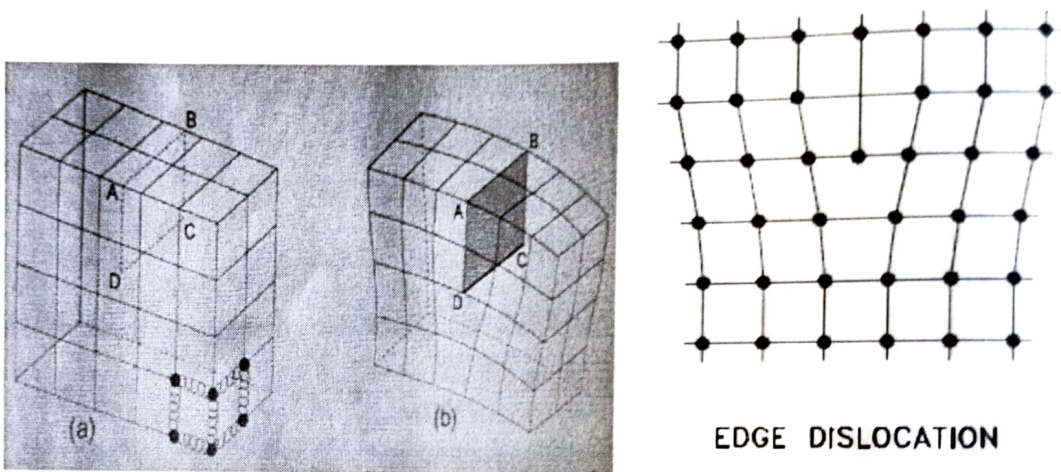
Two extreme types of dislocations are distinguish as

1. Edge dislocations and
2. Screw dislocations.

Edge Dislocations:

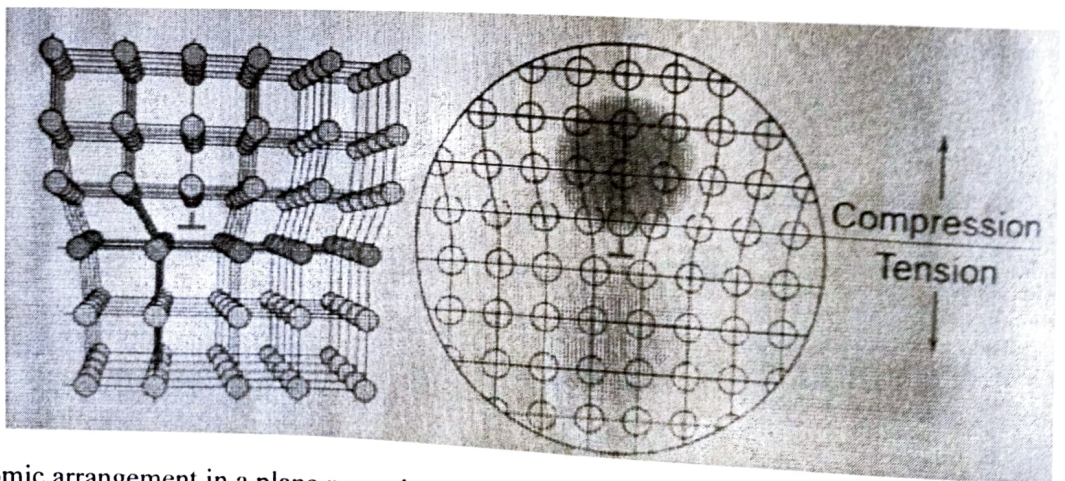
1. The inter-atomic bonds are significantly distorted only in the immediate vicinity of the dislocation line.
2. As shown in the set of images below, the dislocation moves similarly a small amount at a time.
3. The dislocation in the top half of the crystal is slipping one plane at a time as it moves to the right from its position in image (a) to its position in image (b) and finally image (c).
4. In the process of slipping one plane at a time the dislocation propagates across the crystal.
5. Edge dislocation is considered positive when compressive stresses present above the stresses existing below the dislocation line, it is considered as negative edge dislocation, and represented by T.

A schematic view of edge dislocations are shown in figure below.



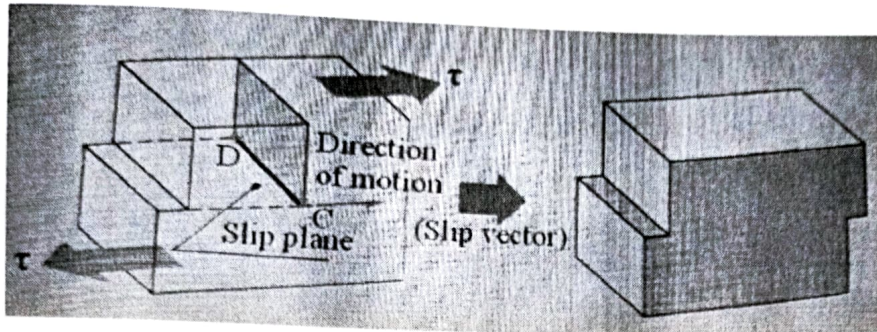
(a) Model of a simple cubic lattice; the atoms are represented by filled circles, and the bonds between atoms by springs.

(b) Positive edge dislocation DC formed by inserting an extra half-plane of atoms in ABCD.

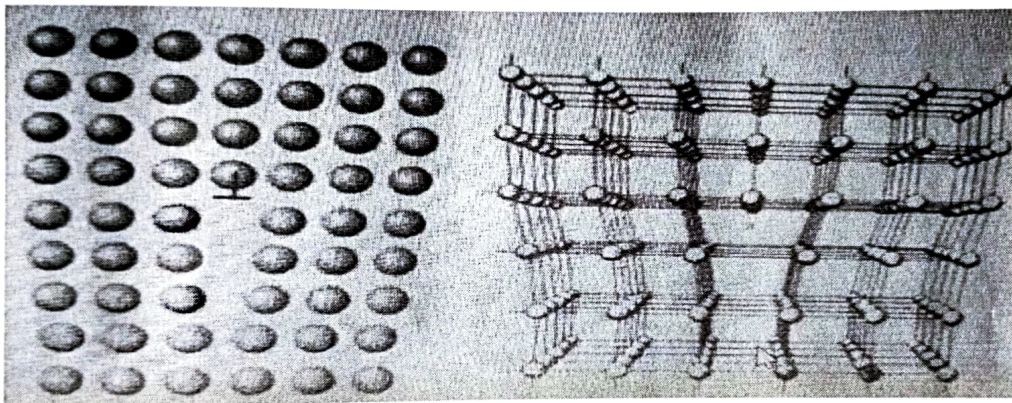


(c) Atomic arrangement in a plane normal to an edge dislocation.

- The atomic arrangement results in compressive stress above the slip plane and a tensile stress below the slip plane.
- An edge dislocation with the extra plane of atoms above the slip plane, is called a positive edge dislocation and if the extra plane of atoms lies below the slip plane, the dislocation is a negative edge dislocation.



(d) Dislocation moves along slip plane in slip direction perpendicular to dislocation line CD. A pure edge dislocation can glide or slip in a direction perpendicular to its length. It may move vertically by a process known as climb, if diffusion of atoms or vacancies can take place.



2- Screw or Burgers dislocation:

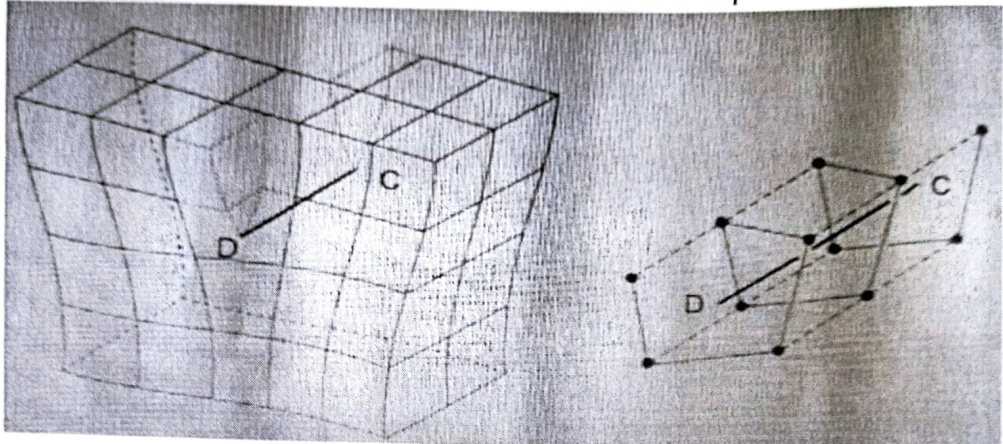
- The screw dislocation is slightly more difficult to visualize.
- The motion of a screw dislocation is also a result of shear stress, but the defect line movement is perpendicular to direction of the stress and the atom displacement, rather than parallel.



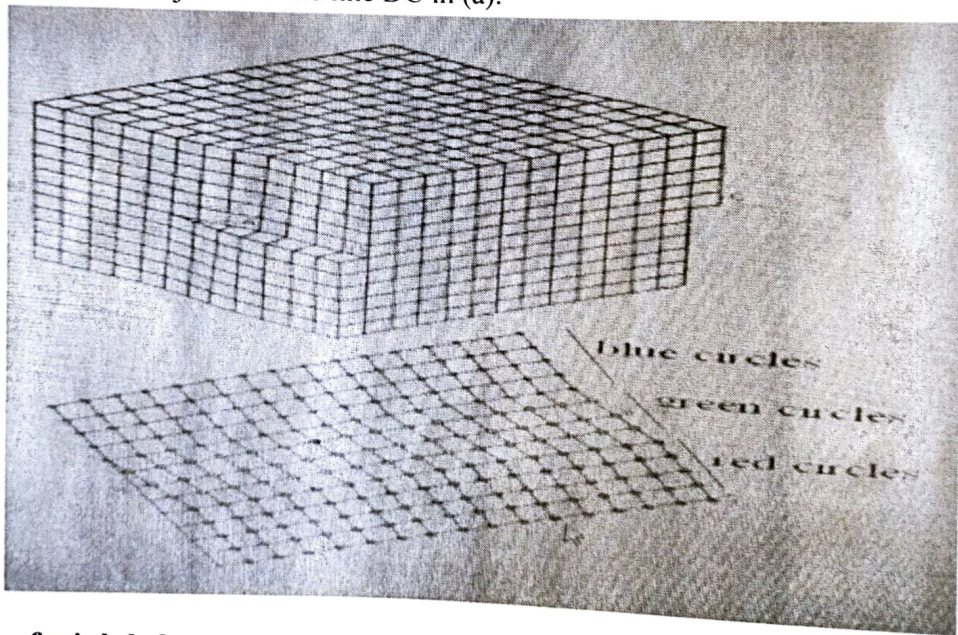
- To visualize a screw dislocation, imagine a block of metal with a shear stress applied across one end so that the metal begins to slip.

Then the bonds are broken.

- As was the case with the edge dislocation, movement in this manner requires a much smaller force than breaking all the bonds across the middle plane simultaneously.
- If the shear force is increased, the atoms will continue to slip.



- (a) left-handed screw dislocation DC formed by displacing the faces ABCD relative to each other in direction AB; The dislocation line is parallel to its slip vector or (Burgers vector)
- (b) spiral of atoms adjacent to the line DC in (a).



3- Interfacial defects

1. Interfacial defects can be defined as boundaries that have two dimensional imperfections in crystalline solids, and have different crystal structures and/or crystallographic orientations on either side of them.

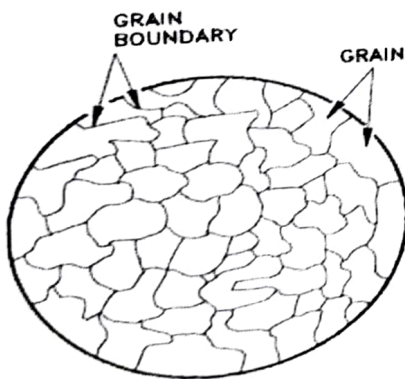
2. They refer to the regions of distortion that lie about a surface having thickness of a few atomic diameters. For example: external surfaces, grain boundaries, twin boundaries, stacking faults, and phase boundaries.
3. These imperfections are not thermodynamically stable, rather they are meta-stable imperfections. They arise from the clustering of line defects into a plane.

External surface:

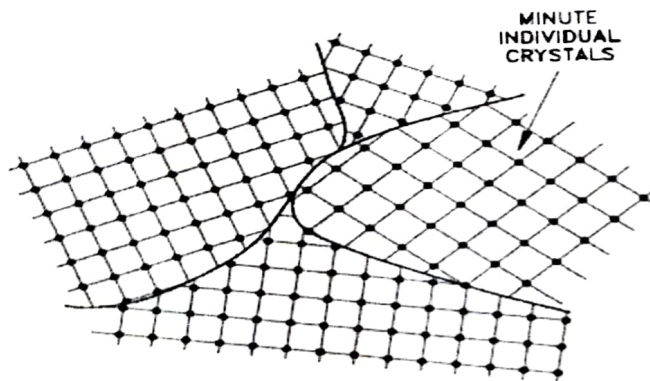
1. The environment of an atom at a surface differs from that of an atom in the bulk; especially the number of neighbors (coordination) at surface is less.
2. Thus the unsaturated bonds of surface atoms give rise to a surface energy.
3. This results in relaxation (the lattice spacing is decreased) or reconstruction (the crystal structure changes).
4. To reduce the energy, materials tend to minimize, if possible, the total surface area.

Grain boundaries:

1. Crystalline solids are, usually, made of number of grains separated by grain boundaries.
2. Grain boundaries are several atoms distances wide, and there is mismatch of orientation of grains on either side of the boundary as shown in figure below.
3. When this misalignment is slight, on the order of few degrees ($< 10^\circ$), it is called low angle grain boundary.
4. These boundaries can be described in terms of aligned dislocation arrays.
5. If the low grain boundary is formed by edge dislocations, it is called tilt boundary, and twist boundary if formed of screw dislocations.
6. Both tilt and twist boundaries are planar surface imperfections in contrast to high angle grain boundaries.
7. For high angle grain boundaries, degree of disorientation is of larger range ($> 15^\circ$). Grain boundaries are chemically more reactive because of grain boundary energy.
8. At ambient temperatures, grain boundaries give strength to a material.



(A)



(B)

Twin boundaries:

1. It is a special type of grain boundary across which there is specific mirror lattice symmetry.
2. Twin boundaries occur in pairs such that the orientation change introduced by one boundary is restored by the other (figure below).
3. The region between the pair of boundaries is called the twinned region.
4. Twins which form during the process of recrystallization are called annealing twins, whereas deformation twins form during plastic deformation.
5. Twinning occurs on a definite crystallographic plane and in a specific direction, both of which depend on the crystal structure.
6. Annealing twins are typically found in metals that have FCC crystal structure (and low stacking fault energy), while mechanical/deformation twins are observed in BCC and HCP metals. Annealing twins are usually broader and with straighter sides than mechanical twins. Twins do not extend beyond a grain boundary.

Volume defects

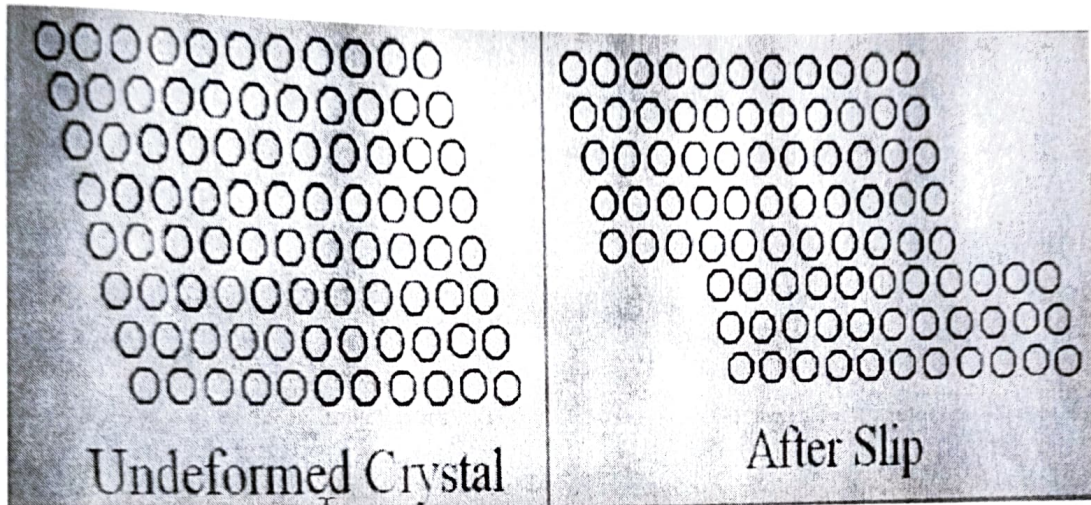
1. Volume defects are Voids, i.e. the absence of a number of atoms to form internal surfaces in the crystal.
2. They have similar properties to microcracks because of the broken bonds at the surface.
3. Microcracks and Voids occur in Amorphous materials.

Effect of Imperfection on Material properties:-

1. Mechanical properties (such as the strength, ductility, toughness, and ductile-brittle transition) depend upon the crystal structure and imperfections.
2. Point defects influence electrical conductivity, mechanical strength, and diffusivity.
3. Lattice, as well as bulk defects, is relevant in material processing involving solidification, deformation, and powder metallurgy.
4. **For example**, rimmed steel sheets are particularly susceptible to strain (within 30 days).
5. This is due to the presence of dissolved carbon and nitrogen in steel.
6. This is eliminated by vacuum degassing and in aluminum killed steels.
7. Similarly, the strength of copper is increased by the addition of nickel owing to the formation of a solid solution.
8. The additional imperfection tends to hinder dislocation motion and consequently the strength increases.
9. Also, hard ceramic particles of alumina (Al_2O_3) are dispersed in a soft, ductile matrix of aluminum.
10. These particles resist the movement of dislocations in the aluminum matrix, and hence increase the strength of aluminum metal.
11. Large grains have lower free energy than small grains.
12. Lowest energy state occurs in a single crystal (without grain boundaries). Whiskers are single crystals, which in some cases are made directly from vapor.
13. Parallel planes of high atomic density and corresponding large interplanar spacing exist in the crystal structure.
14. In FCC (e.g. aluminum, gold, copper), there are 12 possible slip directions, so easily deformed.
15. In HCP (Hexagonal Close Packed), twinning occurs and in FCC (Face Centered Cubic), so slip occurs easily.

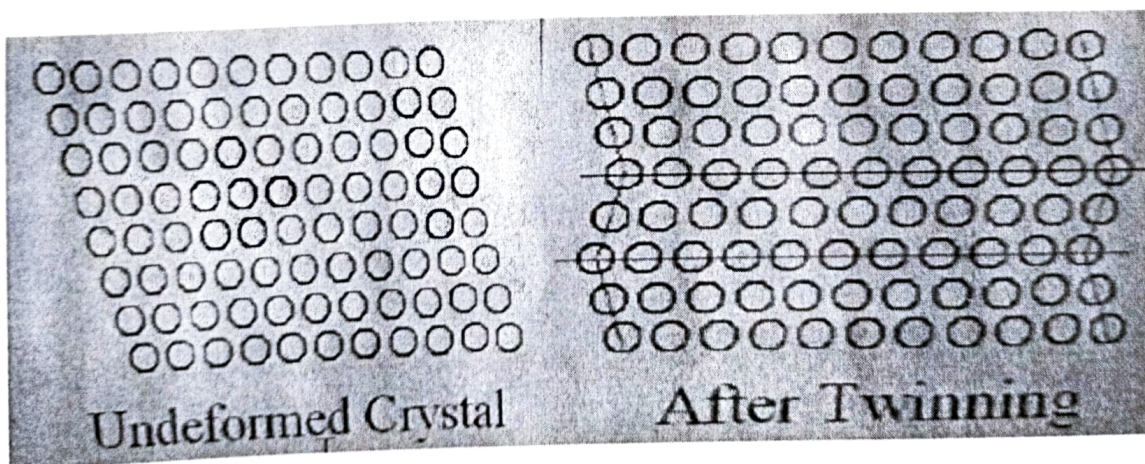
Deformation by Slip

1. Slip is the prominent mechanism of plastic deformation in metals.
2. It involves sliding of blocks of crystal over one other along definite crystallographic planes, called slip planes.
3. It is analogous to a deck of cards when it is pushed from one end.
4. Slip occurs when shear stress applied exceeds a critical value.
5. Mechanisms of plastic deformation in metals
6. During slip each atom usually moves same integral number of atomic distances along the slip plane producing a step, but the orientation of the crystal remains the same.
7. Generally slip plane is the plane of greatest atomic density, and the slip direction is the close packed direction within the slip plane.



Deformation by Twinning :

1. Portion of crystal takes up an orientation that is related to the orientation of the rest of the untwinned lattice in a definite, symmetrical way.
2. The twinned portion of the crystal is a mirror image of the parent crystal.
3. The plane of symmetry is called twinning plane.
4. The important role of twinning in plastic deformation is that it causes changes in plane orientation so that further slip can occur.



Effect of Deformation Material Properties

1. However, the quantitative dependences of the steel microstructure and mechanical properties on strip casting parameters are unknown and require investigation.
2. The strip casting process was simulated using a Glebes 3500 thermo-mechanical simulator.
3. Mechanical properties were measured using microhardness and tensile testing.
4. Microstructures consisting of 40-80% polygonal ferrite with remaining martensite, bainite and very small amount of Widmanstätten ferrite were produced.
5. Deformation to 0.17-0.46 strain at 1050. °C refined the prior austenite grain size via static recrystallization, which led to the acceleration of ferrite formation and the ferrite grain refinement.
6. The yield stress and ultimate tensile strength increased with a decrease in ferrite fraction, while the total elongation decreased.
7. The improvement of mechanical properties via deformation was ascribed to dislocation strengthening and grain boundary strengthening.

CHAPTER:-05 HEAT TREATMENT

1. Heat treatment is the process of heating and cooling metals, using specific predetermined methods to obtain desired properties.
2. Both ferrous as well as non-ferrous metals undergo heat treatment before putting them to use.
3. Over time, a lot of different methods have been developed.
4. Even today, metallurgists are constantly working to improve the outcomes and cost-efficiency of these processes.

Heat Treatment Methods:-

1. There are quite a few heat treatment techniques to choose from.
2. Every one of them brings along certain qualities.

The most common heat treatment methods include:

- Annealing
- Normalizing
- Hardening
- Ageing
- Stress relieving
- Tempering
- Carburization

Annealing

1. In annealing, the metal is heated beyond the upper critical temperature and then cooled at a slow rate.
2. Annealing is carried out to soften the metal. It makes the metal more suitable for cold working and forming.
3. It also enhances the metal's machinability, ductility and toughness.
4. Annealing is also useful in relieving stresses in the part caused due to prior cold working processes.
5. The plastic deformations present are removed during recrystallization when the metal temperature crosses the upper critical temperature.
6. Metals may undergo a plethora of annealing techniques such as recrystallization annealing, full annealing, partial annealing and final annealing.

Normalizing

1. Normalizing is a heat treatment process used for relieving internal stresses caused by processes such as welding, casting, or quenching.
2. In this process, the metal is heated to a temperature that is 40° C above its upper critical temperature.
3. This temperature is higher than the one used for hardening or annealing.
4. After holding it at this temperature for a designated period of time, it is cooled in air.
5. Normalizing creates a uniform grain size and composition throughout the part.
6. Normalized steels are harder and stronger than annealed steel.
7. In fact, in its normalized form, steel is tougher than in any other condition.
8. This is why parts that require impact strength or need to support massive external loads will almost always be normalized.

Hardening

1. The most common heat treatment process of all, hardening is used to increase the hardness of a metal.
2. In some cases, only the surface may be hardened.
3. A work piece is hardened by heating it to the specified temperature, then cooling it rapidly by submerging it into a cooling medium. Oil, brine or water may be used.
4. The resulting part will have increased hardness and strength, but the brittleness increases too simultaneously.
5. Case hardening is a type of hardening process in which only the outer layer of the work piece is hardened.
6. The process used is the same but as a thin outer layer is subjected to the process, the resultant work piece has a hard outer layer but a softer core.
7. This is common for shafts.
8. A hard outer layer protects it from material wear.
9. A hardened surface provides protection from that and the core still has the necessary properties to handle fatigue stresses.

Stress Relieving

1. Stress relieving is especially common for boiler parts, air bottles, accumulators, etc.
2. This method takes the metal to a temperature just below its lower critical border.
3. The cooling process is slow and therefore uniform.
4. This is done to relieve stresses that have built in up in the parts due to earlier processes such as forming, machining, rolling or straightening.

Tempering

1. Tempering is the process of reducing excess hardness, and therefore brittleness, induced during the hardening process.
2. Internal stresses are also relieved.
3. Undergoing this process can make a metal suitable for many applications that need such properties.
4. The higher the temperature used, the softer the final work piece becomes.
5. The rate of cooling does not affect the metal structure during tempering and usually, the metal cools in still air.

Surface Hardening

Nitriding

1. Nitriding is a surface hardening treatment, where nitrogen is added to the surface of steel parts either using a gaseous process where dissociated ammonia as the source or an ion or plasma process where nitrogen ions diffuse into the surface of components.
2. Gas nitriding develops a very hard case in a part at relatively low temperature, without the need for quenching.
3. The process has the advantage of being able to penetrate blind holes, and also allows for the masking of parts to keep areas which may need further machining soft.
4. Also parts of different sizes and shapes may be nitrided in the same cycle, allowing for versatility of the process.
5. Ion nitriding, on the other hand, is a more restrictive process.

6. In general, parts to be nitrided are heat treated to the proper strength level, and final machined.
7. The parts are then exposed to active nitrogen at a carefully controlled temperature, typically in the range of 925°F to 985°F.
8. This temperature is usually below the final tempering temperature of the steel so that nitriding does not affect the base metal mechanical properties.

Carburization

1. In this heat treatment process, the metal is heated in the presence of another material that releases carbon on decomposition.
2. The released carbon is absorbed into the surface of the metal.
3. The carbon content of the surface increases, making it harder than the inner core.
4. Carburizing is a heat treat process that produces a surface which is resistant to wear, while maintaining toughness and strength of the core.
5. This treatment is applied to low carbon steel parts after machining as well as high alloy steel (4320, 8620, 9310, 17CrNiMo6-7) bearings, gears and other components.
6. Parts that require increased wear resistance and fatigue strength are excellent candidates for carburizing.

Effect of Heat Treatment on Properties of Steel

- (i) **Tensile Strength (T.S):** is the load required to fracture unit area of the metal.
- (ii) **Yield Strength (Y.S):** is a measure of the onset of plastic deformation. (0.2% permanent extension).
- (iii) **Percentage Elongation (E.L) in gauge length:** is a measure of the ductility of the material.
- (iv) **Percentage reduction in cross-sectional area (Ra)** measured at the point of fracture is also related to ductility.
- (v) **Very ductile materials are considerably reduced in cross – section** before they break.
- (vi) **Young's Modulus of Elasticity (E):** is the stiffness, rigidity, or springiness of a material. It is the slope of the linear portion of the stress/strain graph for the material.
- (vii) It is also the ratio between the stress applied and the elastic strain it produces.
- (viii) **Toughness (Er):** is the energy absorbed by the material before it fractures. This is the area under the force – extension or stress – strain curve up to rupture point (N.mm).
- (ix) **Brinell Hardness Number (BHN):** indicates the surface hardness of the material.

Hardenability of Steel

1. The hardenability of a metal alloy is the depth to which a material is hardened after putting it through a heat treatment process.
2. It should not be confused with hardness, which is a measure of a sample's resistance to indentation or scratching.
3. It is an important property for welding, since it is inversely proportional to weld ability, that is, the ease of welding a material.
4. When a hot steel work-piece is quenched, the area in contact with the water immediately cools and its temperature equilibrates with the quenching medium.
5. This results in a work-piece that does not have the same crystal structure throughout its entire depth; with a softer core and harder "shell".
6. The softer core is some combination of ferrite and cementite, such as pearlite.
7. The hardenability of ferrous alloys, i.e. steels, is a function of the carbon content and other alloying elements and the grain size of the austenite.
8. The relative importance of the various alloying elements is calculated by finding the equivalent carbon content of the material.
9. The fluid used for quenching the material influences the cooling rate due to varying thermal conductivities and specific heats.
10. Substances like brine and water cool the steel much more quickly than oil or air.
11. If the fluid is agitated cooling occurs even more quickly.
12. The geometry of the part also affects the cooling rate: of two samples of equal volume, the one with higher surface area will cool faster.

CHAPTER:- 06 NON-FERROUS ALLOYS

Aluminum alloys

1. **Aluminum alloys** (or **aluminum alloys**; see spelling differences) are alloys in which aluminum (Al) is the predominant metal.
2. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc.
3. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable.
4. About 85% of aluminum is used for wrought products, for example rolled plate, foils and extrusions.
5. Cast aluminum alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys.
6. The most important cast aluminum alloy system is Al-Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics.

Duralumin

1. It is relatively soft, ductile and easily workable under normal temperature.
2. The alloy can be rolled, forged and extruded into various forms and products.
3. The tensile strength of duralumin is higher than aluminum, although its resistance to corrosion is poor.
4. The electrical and heat conductivity of duralumin is less than that of pure aluminum and more than that of steel.
5. It was initially used in rigid airship frames, and its heat-treatment methods and composition were wartime secret.
6. With the introduction of new monologue construction methods in early 1930s, duralumin was widely used in the aircraft industry.
7. The light weight and high strength of duralumin when compared to steel enabled its application in aircraft construction.
8. However, a special laminated form of duralumin called allay is used in the aircraft industry as it tends to lose strength during welding.

Chemical Composition

The chemical composition of duralumin is outlined in the following table.

Element	Content (%)
Aluminum, Al	95
Copper, Cu	4
Magnesium, Mg	1

Mechanical properties

The mechanical properties of duralumin are displayed in the following table.

Properties	Metric	Imperial
Hardness, Brinell	115-135	115-135
Tensile strength	420-500 MPa	60900-72500 psi
Elongation at break	≤ 22%	≤ 22%
Tensile modulus	73 GPa	10600 ksi
I-zood impact, unnotched	0.08 – 0.22 J/cm	0.150 – 0.412 ft.lb/in

Manufacturing process

1. Duralumin can be easily forged, casted and worked with respect to its low melting point.
2. It is annealed between temperatures ranging from 350 to 380°C (662 to 716°F) and air-cooled.
3. The alloy now becomes plastic and can be readily worked and formed into desired sections.
4. The alloy is then heat treated at 490 to 510°C (914 to 950°F) to enhance its tensile properties.
5. Following this, duralumin is quenched and hardened.

Applications

The following are some of the major applications of duralumin:

- Aircraft frames
- Frames of speedboats and automobiles
- Lightweight guns like the FAMAS type 97
- Surgical and orthopedic work
- Manufacturing components of measuring instruments

Y -alloy

1. Y-Alloy is also called copper-aluminum alloy.
2. The addition of copper to pure aluminum increases its strength and machinability.

Its composition contains following chemical contents.

Copper = 3.5-4.5%

Manganese = 1.2-1.7%

Nickel = 1.8-2.3%

Silicon, magnesium, iron = 0.6%

Aluminum = 92.5%

Properties

1. The addition of copper in aluminum increases its strength and machinability.
2. Y-alloy can be easily cast and hot worked.
3. Like duralumin, this alloy is heat treated and age hardened.
4. The age-hardening process of Y-alloy is carried out at room temperature for about five days.

Applications

1. Y-Alloy is mainly used for cast purposes, but it can also be used for forged components like duralumin.
2. Since Y -alloy has better strength than duralumin at high temperatures, therefore it is much used in aircraft engines for cylinder heads, pistons, cylinder heads, crankcases of internal combustion engines die casting, pump rods etc.

Aluminum-copper alloys :-

1. The aluminum-copper alloys are composed of a solid solution of copper in aluminum which gives an increase in strength, but the bulk of the strength increase is caused by the formation of a precipitate of copper aluminum CuAl_2 .
2. To gain the full benefits of this precipitate it should be present as a finely and evenly distributed submicroscopic precipitate within the grains, achieved by solution treatment followed by a carefully controlled ageing heat treatment.
3. In the annealed condition a coarse precipitate forms along the grain boundaries and in the aged condition the submicroscopic precipitates coarsen.
4. In both cases the strength of the alloy is less than that of the correctly aged condition.
5. The early aluminum-copper alloys contained some 2-4% of copper.
6. Increasing the amount of copper, however, to 6% or more, markedly improved weld ability owing to the large amounts of eutectic available to back-fill hot cracks as they formed.
7. The limit of solid solubility of copper in aluminum is 5.8% at 548 °C; at ambient this copper is present as a saturated solid solution with particles of the hardening phase copper aluminum, CuAl_2 , within the grains as a fine or coarse precipitate or at the grain boundaries.

<u>Property</u>	<u>Copper(Cu-ETP)</u>	<u>Aluminum(1350)</u>
Tensile strength (half-hard)	260-300	85-100
0.2% proof strength (annealed)	50-55	20-30
0.2% proof strength (half-hard)	170-200	60-65
Elastic modulus	116-130	70

Composition

<u>Element</u>	<u>Content (%)</u>
Copper, Cu	79-81
Aluminum, Al	19-21
Iron, Fe	0.30 max
Silicon, Si	0.15 max

Use

1. Copper and aluminum are most frequently used as the electrical conductors in electrical cables due to their low resistance and excellent conductivity.
2. These metals are both ductile and relatively resistant to corrosion, but they also have different properties which make them useful for various applications.

Copper tin alloys

1. Copper tin alloys or tin bronzes are known for their corrosion resistance.
2. Tin bronzes are stronger and more ductile than red and semi red brasses.
3. They have high wear resistance and low friction coefficient against steel.
4. Tin bronzes, with up 15.8% tin, retain the structure of alpha co

Property

<u>Property</u>		<u>Cu</u>	<u>CuSn6</u>
Tensile strength	[N/mm ²]	220-300	470-530
Yield strength at 1% elongation	[N/mm ²]	120-200	380-460
Resistance (IACS)	[%]	101	13
Conductivity	[S*m/mm ²]	58.5	7.5
Resistivity	[Ohm*mm ² /m]	0.0171	0.1333
Thermal coefficient of resistance	[1E-6/K]	3800-4100	600-700
Solder ability	[-]	good	good

Composition

- This is typical gun-metal, most varieties of which, however, contain a deoxidizer, frequently zinc (e.g. Admiralty gun-metal, **copper 88%**, **tin 10%**, zinc 2%).
- The structure of the cast material depends on the rate of cooling, both through the range of solidification and below.

Uses

The tin bronzes are used in bearings, gears, piston rings, valves and fittings.

Babbitt Alloy

1. Babbitt metal is most commonly used as a thin surface layer in a complex, multi-metal structure, but its original use was as a cast-in-place bulk bearing material.
2. Babbitt metal is characterized by its resistance to galling.
3. Babbitt metal is soft and easily damaged, which suggests that it might be unsuitable for a bearing surface.

Uses

Tin based Babbitt's were commonly used as they could stand up to the impact of the connecting rods and crankshaft.

Babbitt bearings were also commonly used in factories, before the invention of low cost electrical motors, to distribute power throughout via a central engine.

Today, Babbitt is more commonly used as a thin layer covering bearings made of replaceable steel so that it still acts as a bearing surface.