Metallurgy

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Metallurgy

It is the study of metals and alloy

Metals

- Metal can be defined as any elements that ionized positively in solution.

Periodic table

	1	2	3†		4	5	6	7	8	9	10	11	12‡	13	14	15	16	17	18
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc		22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y		40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	58-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	90-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
					58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
					90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Metals: Alkali, Alkaline earth, Transition, Lanthanide, Actinide, Post-transition

Metalloids

Nonmetals: Reactive, Noble gas

Properties not yet determined

† (a) Whether group 3 is composed of -La-Ac or -Lu-Lr is under review by the IUPAC. (b) The last two members of the group are also known as transition metals.
‡ Some authors treat Zn, Cd and Hg as transition metals.

Periodic Table

- Metals occupy the left side.
- Non-metals occupy the right side.
- Metalloids (semiconductors) are arranged in between, e.g: carbon and silicon.

Properties of metals:

- Metals gain their unique properties from their

  i. Metallic bond.

  ii. Crystalline structure.

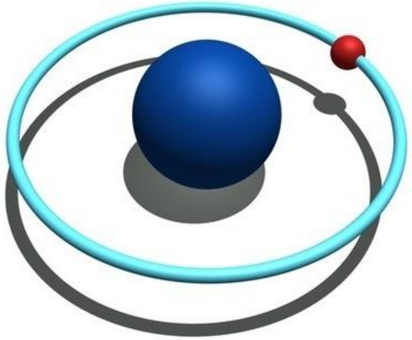
Properties of metals:

1. Ionized positively in solutions.

2. At normal conditions, they are crystalline solids except

   i. Mercury and gallium ➔ liquids.

   ii. Hydrogen➔ gas.



Properties of metals:

3. Opaque ➔ because the free electrons absorb light.
4. Lusters ➔ because the free electrons reflect the light.
5. Good thermal conductors ➔ because free electrons carry heat.
6. Good electrical conductors ➔ because free electrons carry electricity.

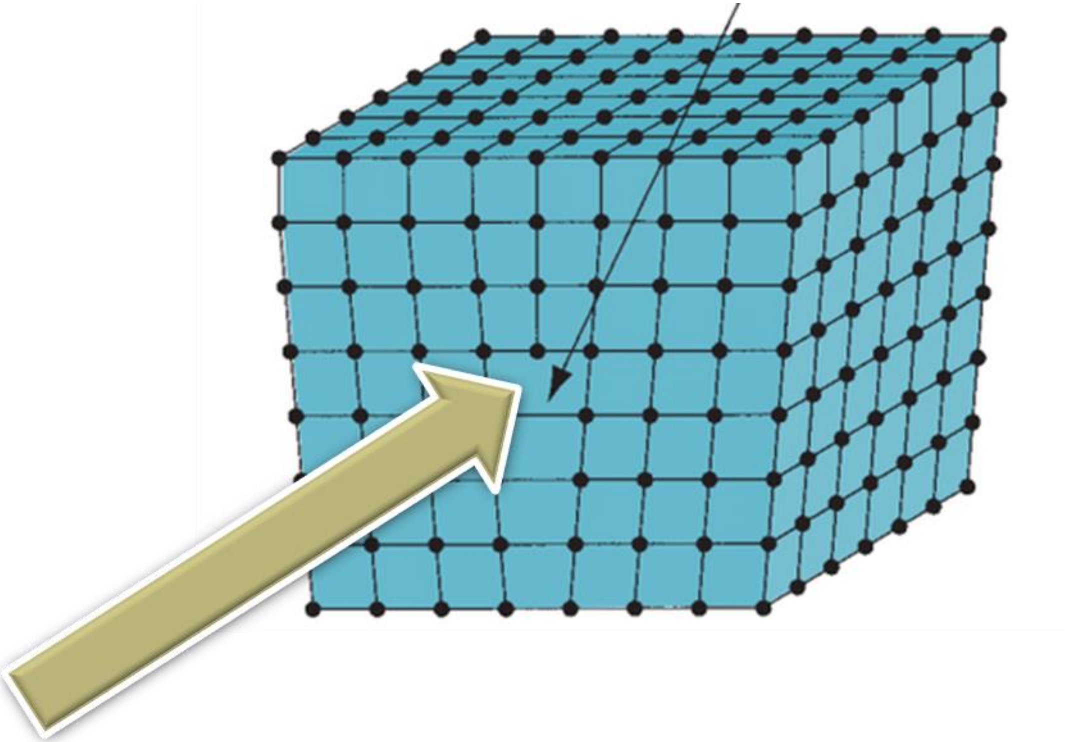
Properties of metals:

7. High mechanical properties → because the metallic bond is a primary bond.

8. High melting and boiling point → because the metallic bond is a primary bond.

Properties of metals:

9. Malleable and ductile ➔ due to presence of crystalline imperfection (dislocations).



Properties of metals:

10. Give metallic ring when striking.

11. Most metals are white in color with different tint except:

    i. Gold ➔ yellow

    ii. Copper ➔ red.

Pure Metals in Dentistry:

1. Titanium in dental implants and framework of fixed partial dentures.
2. Mercury in dental amalgam restoration.



Pure Metals in Dentistry:

3. Silver and copper in electroplated dies.

4. Platinum foil in construction of porcelain crowns.

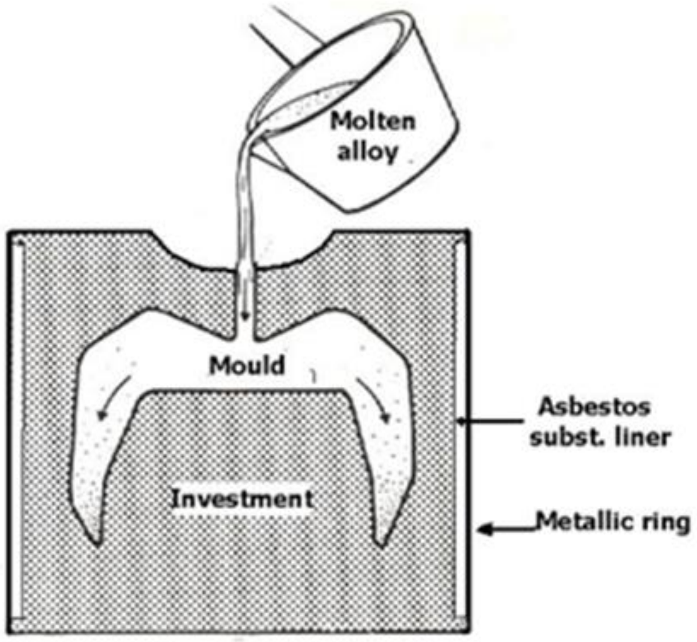
5. Gold foils used as direct restoration (Historical).

Shaping of Metals:

1. Casting
2. Cold working
3. Powder metallurgy (sintering)
4. Electroplating

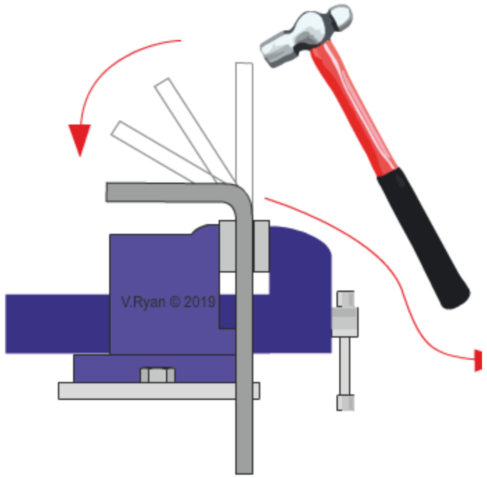
1. Casting

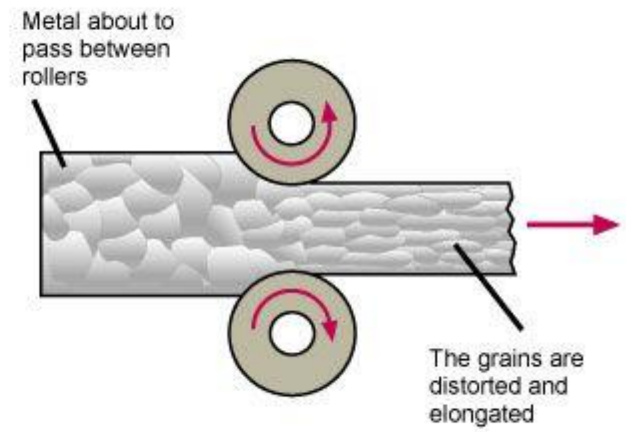
- It is the process of pouring a liquid metal or alloy into a mold with desired shape.
- Heat is applied above the melting point of metal or alloy.



2. Cold Working

- It requires applying stresses above the yield strength of the metal.
- Plastic deformation occurs through slip of metal atoms through line crystalline defects (dislocations).



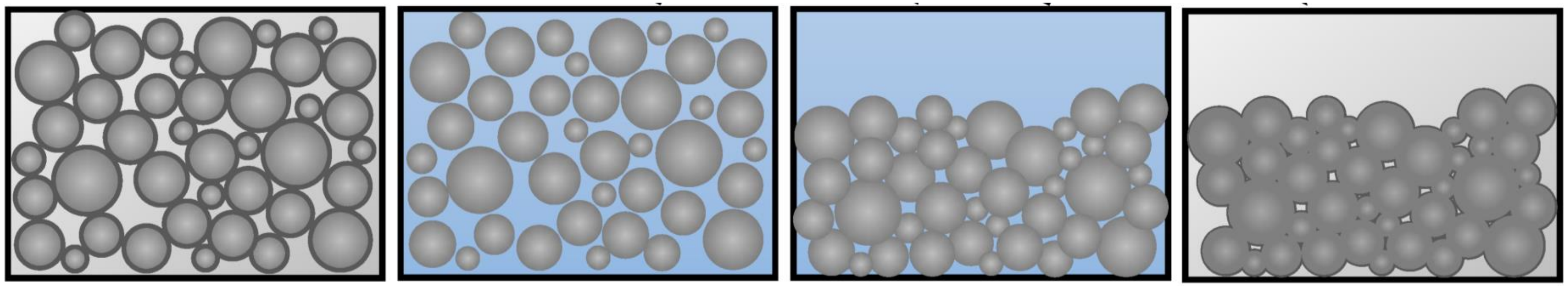


2. Cold Working

- Application of heat below melting temperature facilitates cold working.

3. Powder metallurgy (Sintering):

- It is the process of densification and agglomeration of metal powder.
- It requires application of high temperature (below melting temperature) to allow atomic diffusion.

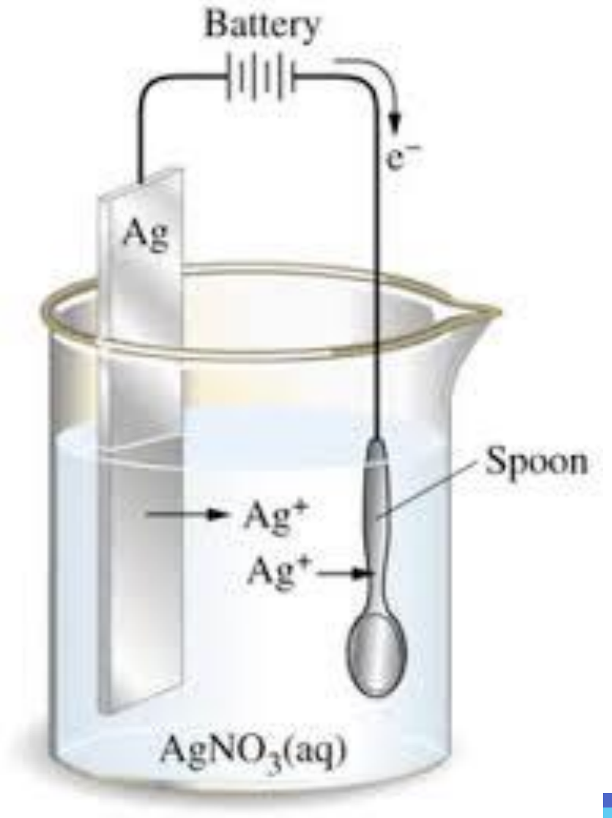


3. Powder metallurgy (Sintering):

- Sintering can be facilitated by application of pressure.
- Sintering is accompanied by shrinkage and elimination of porosities.

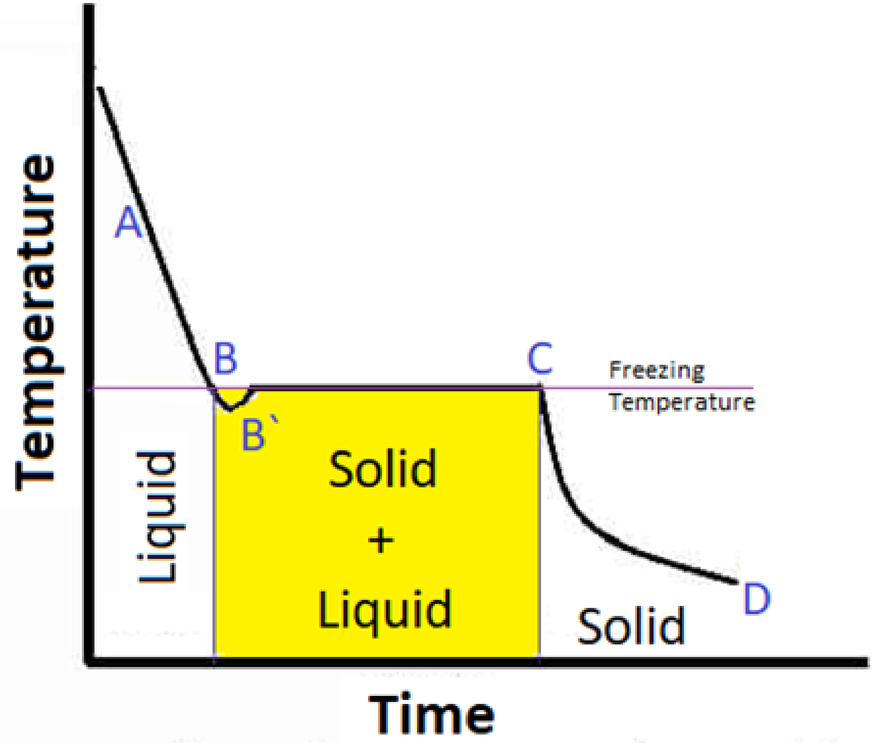
4. Electroplating

- It the process of electrolysis (corrosion in reverse) as in silver and copper electroplated dies.



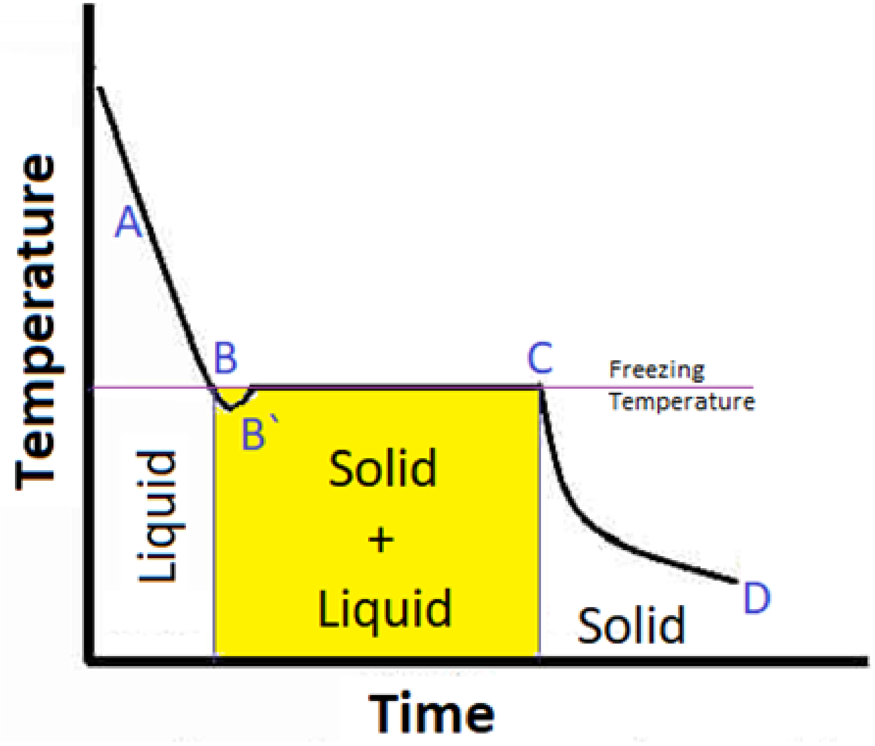
Solidification of Metals:

- In order to understand metal solidification mechanism, a metal is melted then allowed to cool. Temperature during cooling is plotted as a function of time.



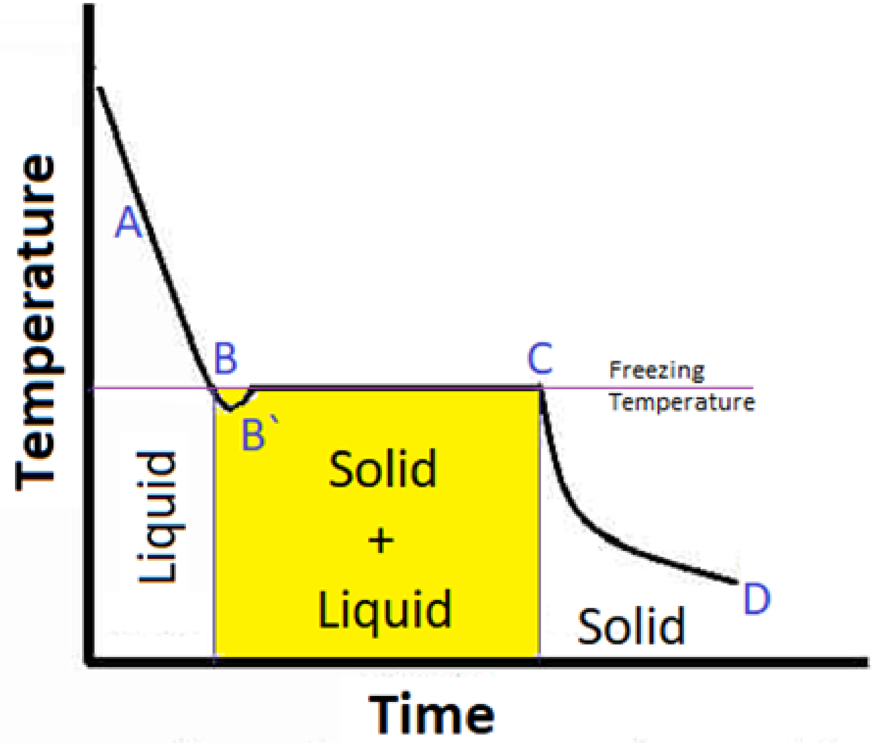
Solidification of Metals:

- The temperature decreased from A to B
- The metal are purely liquid.



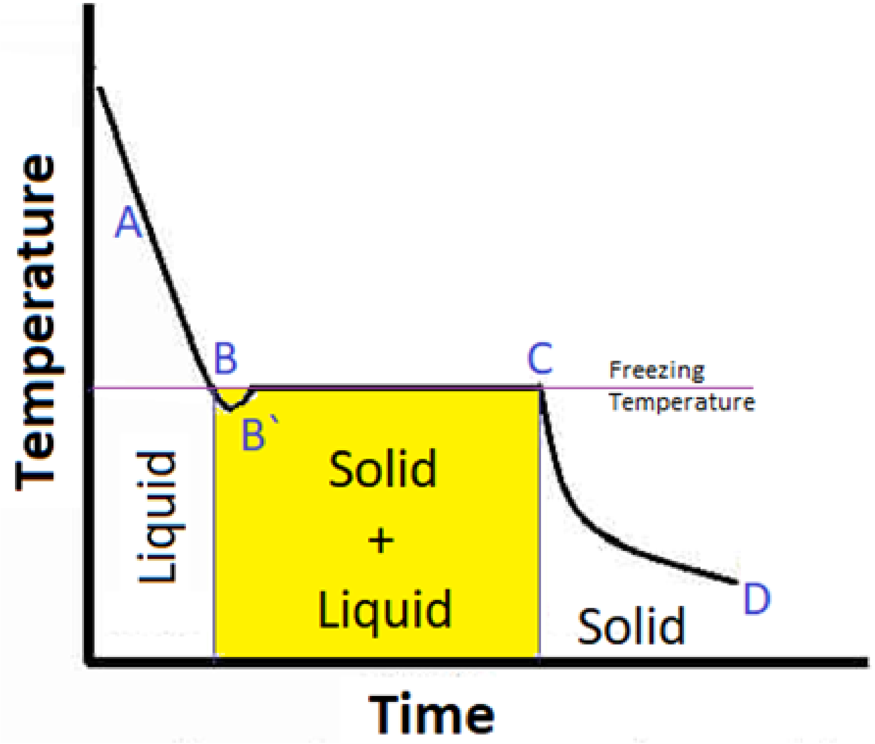
Solidification of Metals:

- The temperature remains constant from B to C (horizontal plateau)
- The metal is liquid and solid.



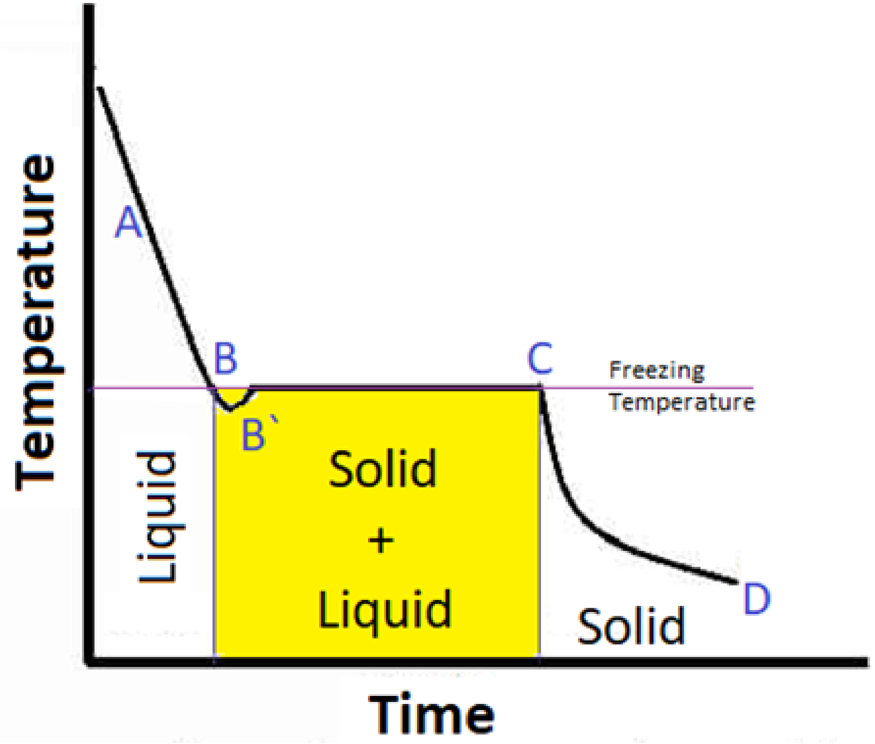
Solidification of Metals:

- The Temperature decreased from C to D (room temperature)
- the metal is purely solid.



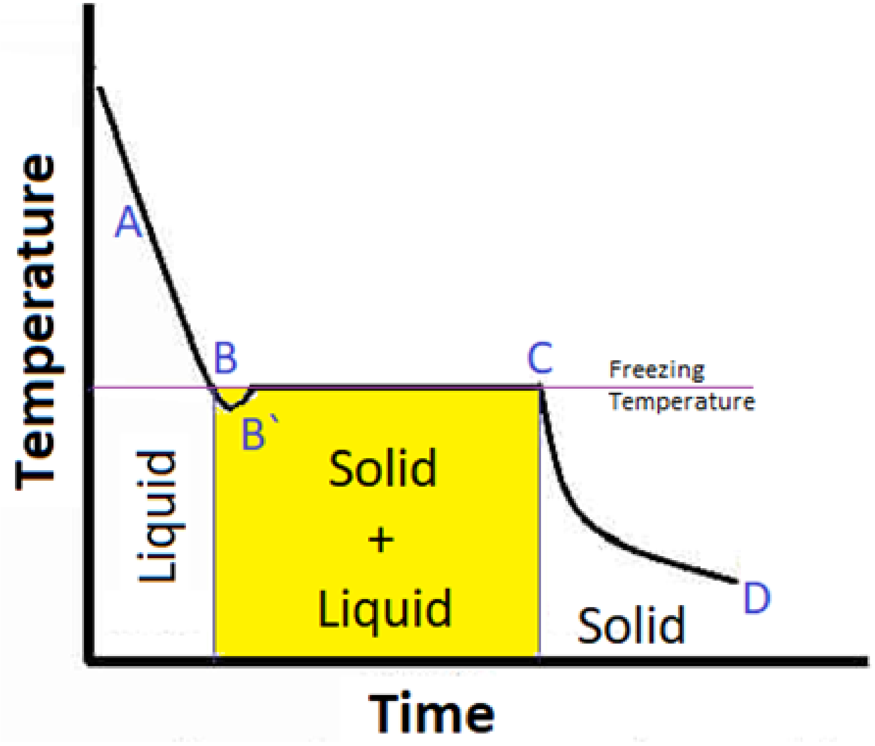
Solidification of Metals:

- The melting and freezing temperature (T_f) is indicated by the horizontal plateau



Solidification of Metals:

- The temperature remains constant at T_f due to the liberation of latent heat of fusion.



Solidification of Metals:

➢ **Heat of fusion:**

The amount of heat required to convert 1 gm of the material from solid to liquid state at the melting temperature.

Solidification of Metals:

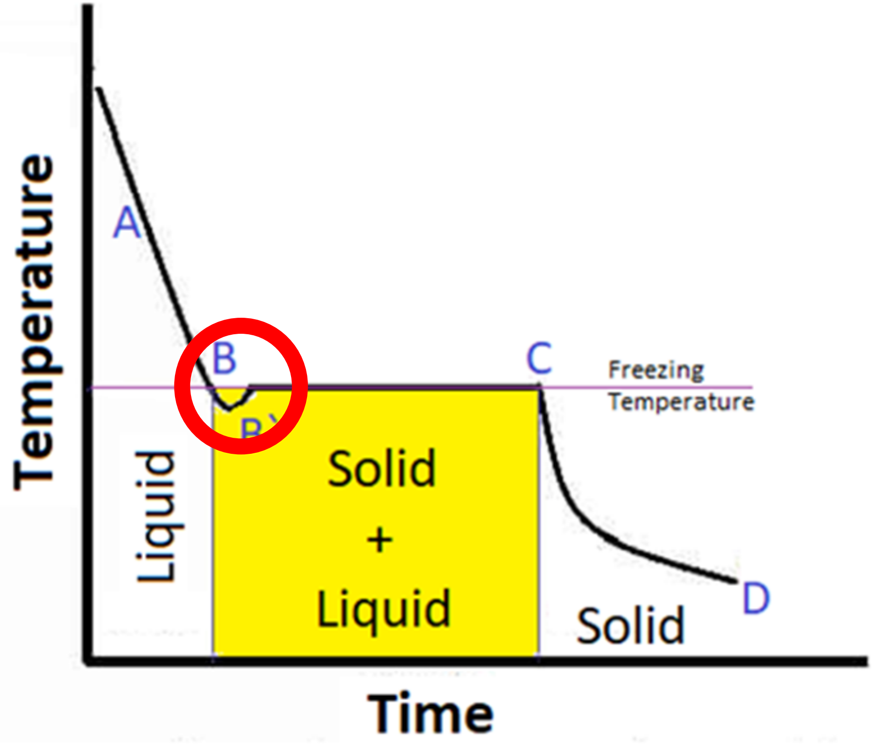
- **Latent Heat of fusion:**

The amount of heat liberated from convert 1 gm of the material from liquid to solid state at the melting temperature

Solidification of Metals:

- **Supercooling:**

Initial cooling to B’ is called supercooling. After the crystallization begins, the temperature is raised to T_f and remains until complete crystallization.



Structure during Solidification:

- Two-steps mechanism theory can explain the solidification of metal in two steps;

  a) Nucleus formation

  b) Crystallization.

Structure during Solidification:

a) **<u>Nucleus formation</u>**

- When the molten metal cooled and reaches its freezing point → some atoms aggregates in the space lattice arrangement to form what is called "embryo".

Structure during Solidification:

a) **Nucleus formation**

- Once the supercooling reached, the formed embryos grow to form centers for solidifications called "nuclei of crystallization"

Structure during Solidification:

a) **<u>Nucleus formation</u>**

- Nucleus originates by:

1. Homogeneous nucleation.
2. Heterogeneous nucleation

Structure during Solidification:

a) **Nucleus formation**

   1. Homogeneous nucleation.

   Nucleus arise from atoms of the metal itself.

Structure during Solidification:

a) Nucleus formation

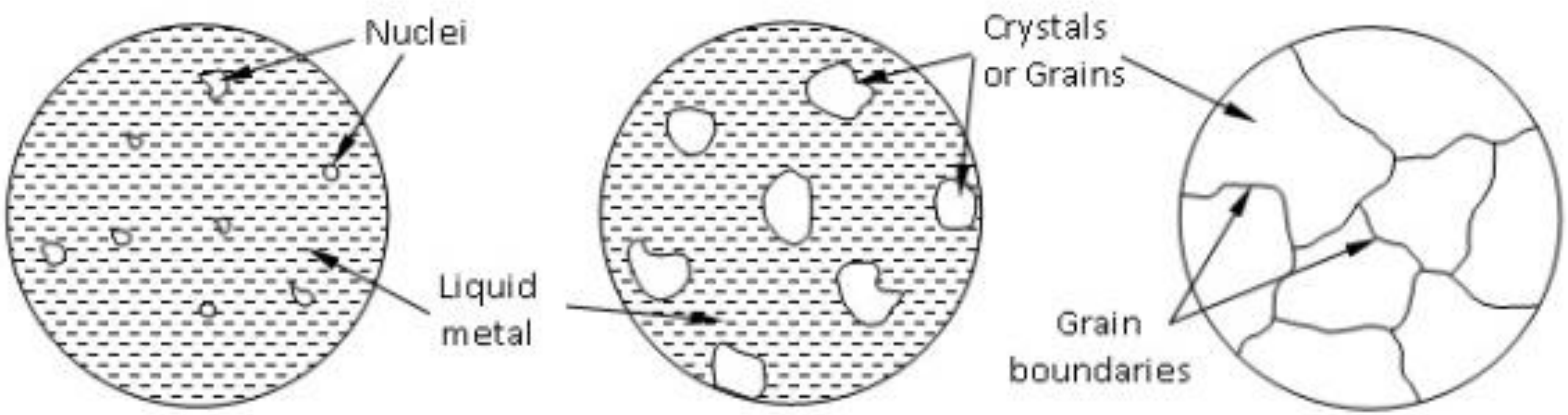
2. Heterogeneous nucleation.

- Nucleus arises from atoms of foreign metal such as: iridium.
- The foreign metal should have higher melting temperature than the original metal. Therefore, it would be solid before the solidification of the original metal starts.

Structure during Solidification:

b) **<u>Crystal Growth (Crystallization):</u>**

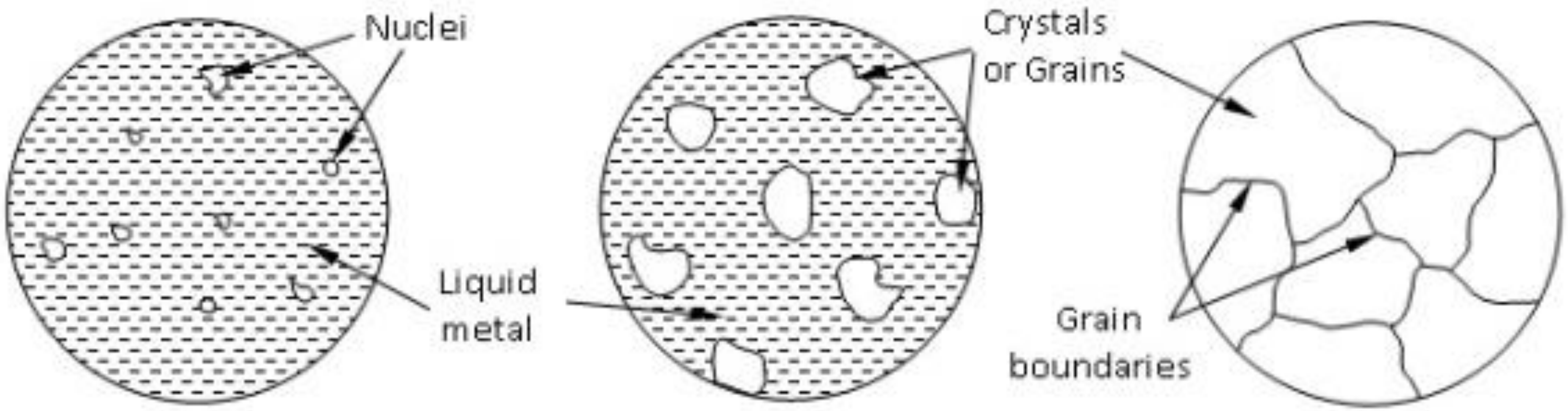
- The molten atoms aggregate around the nuclei in three dimensions (tree like structure or dendrites) to form crystals.



Structure during Solidification:

b) Crystal Growth (Crystallization):

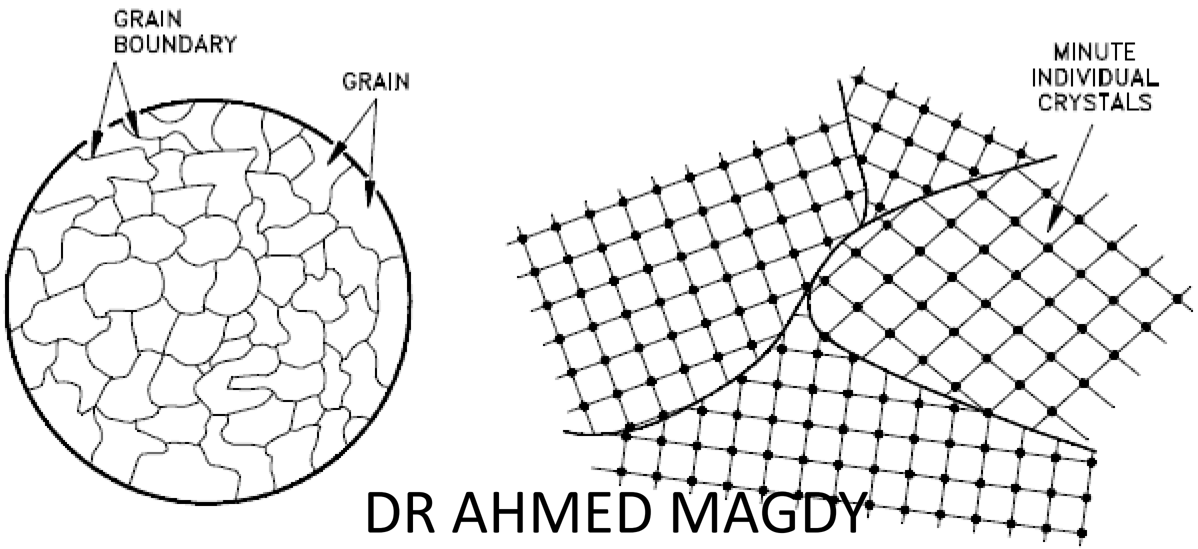
- The crystal growth continues until contact between adjacent crystals occurs.



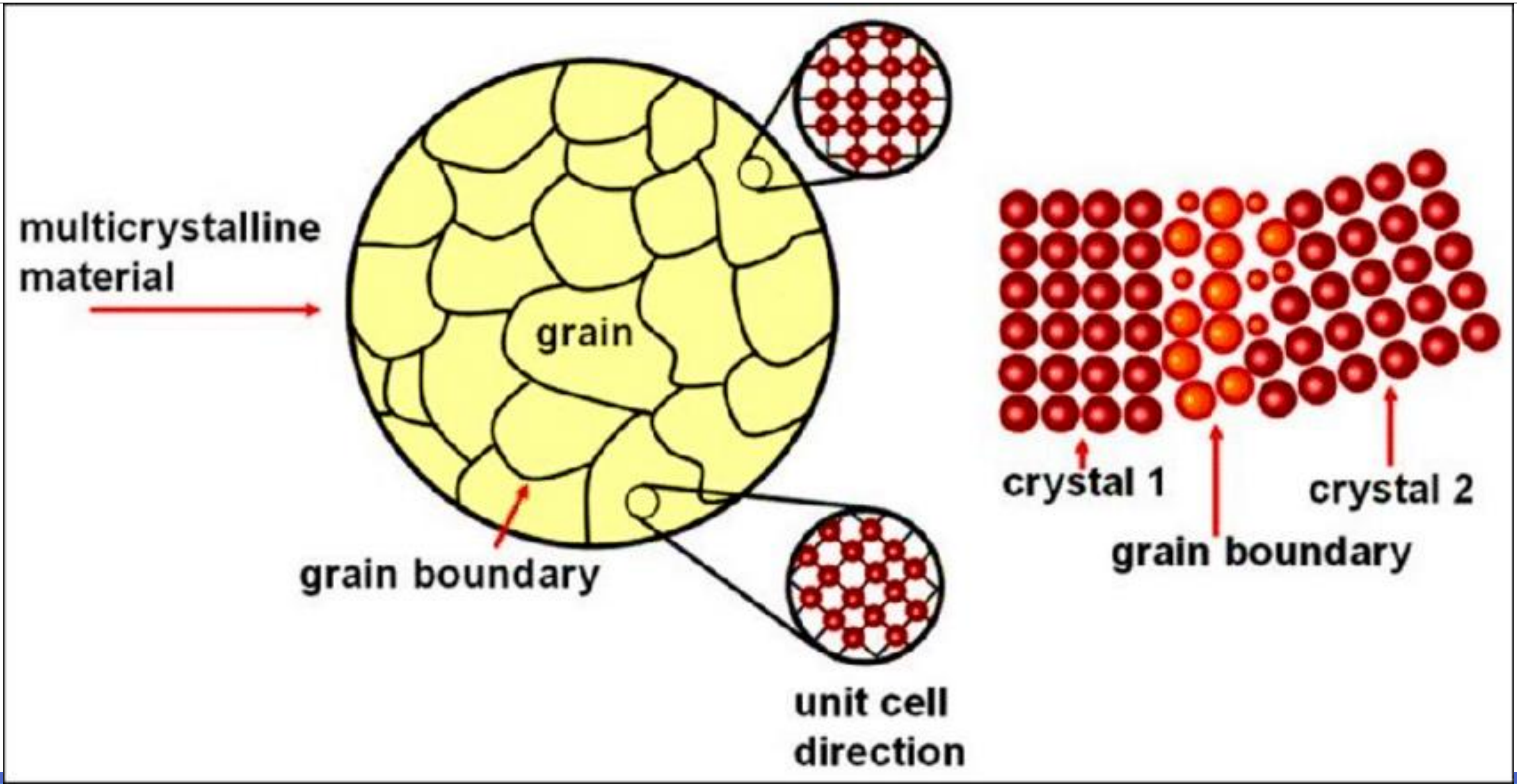
Structure during Solidification:

b) **Crystal Growth (Crystallization):**

- Atoms between two adjacent grains are called grain boundaries.
- Atoms at the grain boundaries are highly stressed atoms.



Structure during Solidification:



Structure during Solidification:

b) **<u>Crystal Growth (Crystallization):</u>**

- In very rare occasions, the molten metal solidifies in a single crystal (whisker).

Factors Controlling Grain Size:

a) Rate of Cooling from liquid state:

b) Nucleating agents (Grain refiners):.

Factors Controlling Grain Size:

a) **Rate of Cooling from liquid state:**

Rapid rate of cooling → more nuclei of crystallization → more grains → smaller grain size → more grain boundaries.

Factors Controlling Grain Size:

b) **Nucleating agents (Grain refiners):**

Nucleating agent is a foreign metal with higher melting point than original metal (heterogeneous nucleation).

Factors Controlling Grain Size:

b) **Nucleating agents (Grain refiners):**

Addition of nucleating agent → more nuclei of crystallization → more grains → smaller grain size → more grain boundaries.

Factors Controlling Grain Size:

b) **Nucleating agents (Grain refiners):**

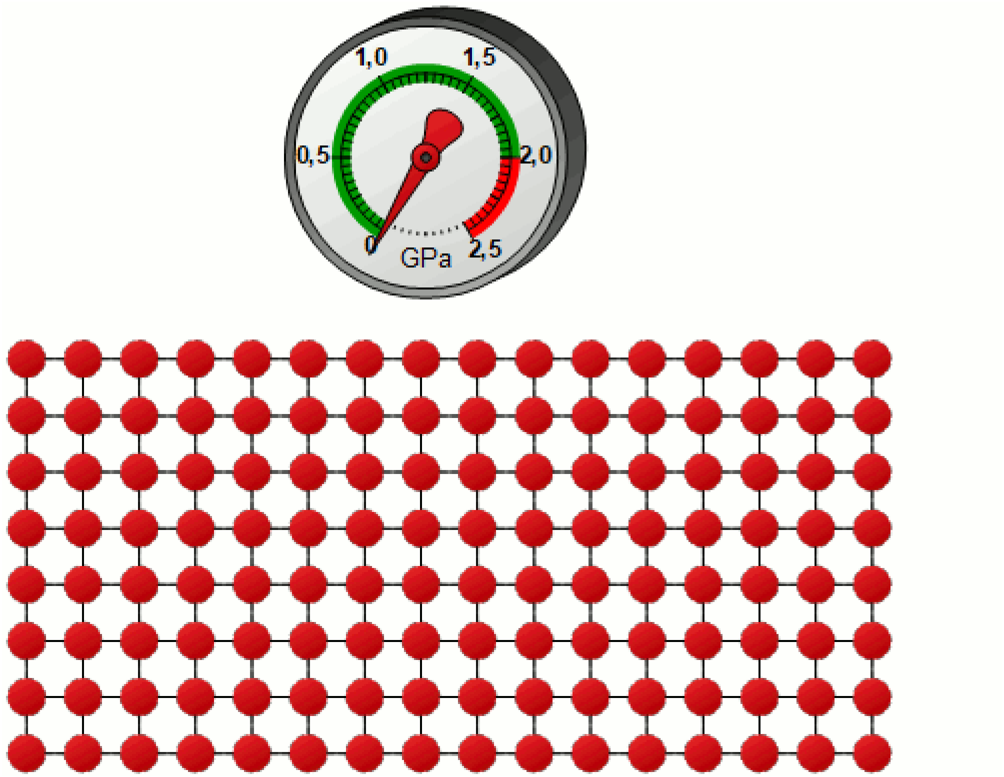
It is called grain refiner as they produce metal with smaller (finer) grain size.

Relation Between Microstructure and Mechanical Properties:

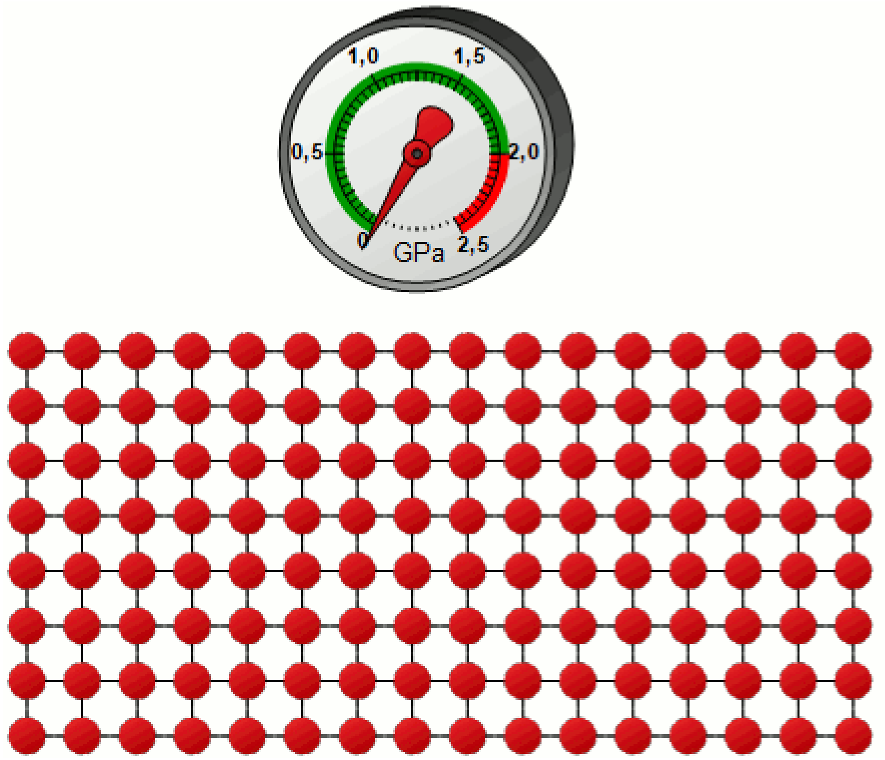
1. **Elastic deformation:**

- It is a temporary deformation, results from stretching of the interatomic bond.
- It depends on chemical composition and not affected by microstructure or heat treatment.

Elastic



Plastic

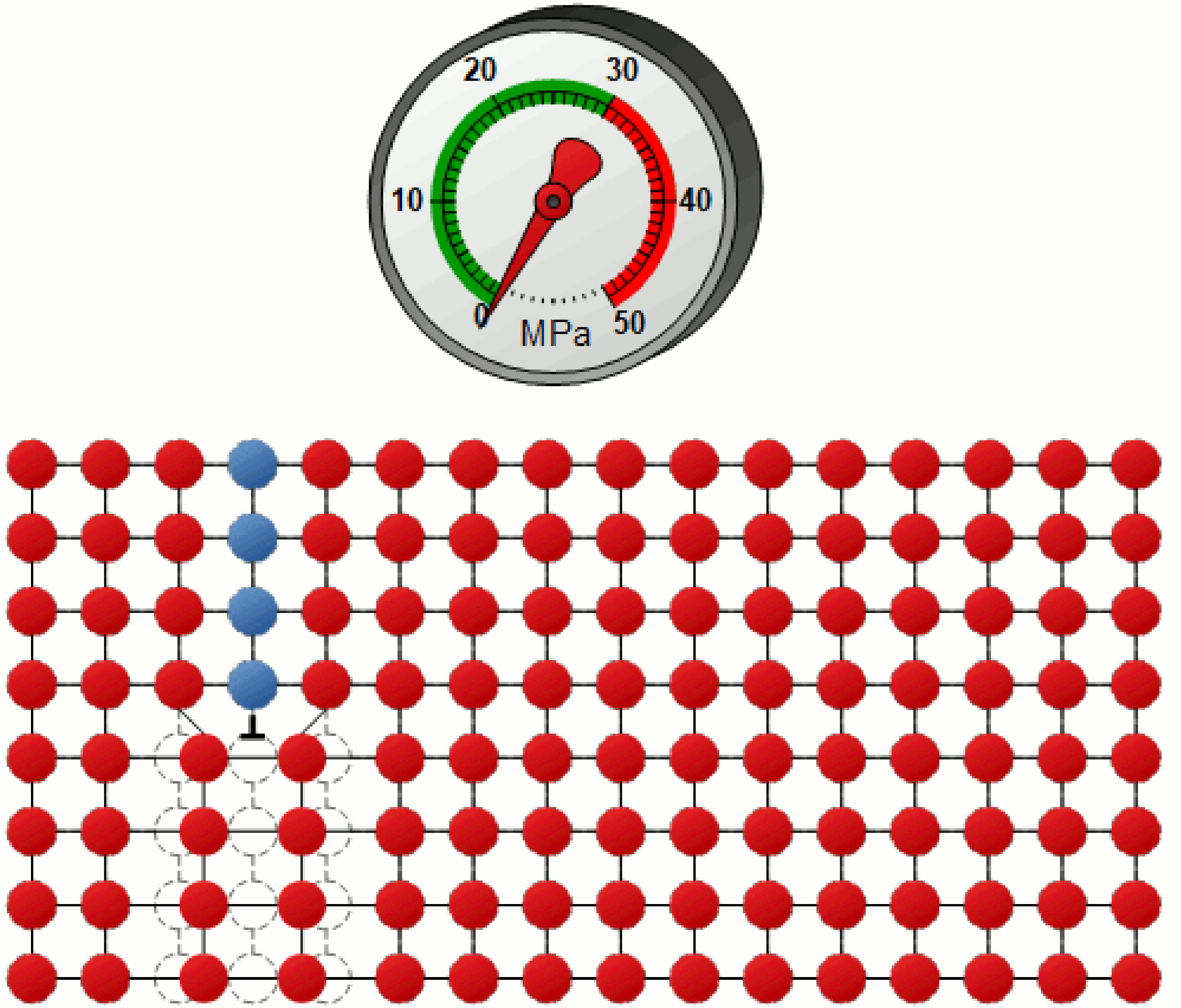


Relation Between Microstructure and Mechanical Properties:

2. **Plastic deformation:**

- It is a permanent deformation.
- It results from slip of atoms over each other.
- Atomic slippage occurs at dislocations (line defect) and the movement (slippage) of atoms is called dislocation movement.

Relation Between Microstructure and Mech



Relation Between Microstructure and Mechanical Properties:

2. **Plastic deformation:**

- Casted metals contain numerous dislocations ➔ atoms slip (movement of dislocation) occurs easily.

i.e: Permanent deformation requires less stress

i.e: Metal characterized by low strength, low hardness and high ductility.

Relation Between Microstructure and Mechanical Properties:

2. **Plastic deformation:**

- If dislocation movement is obstructed ➔ atoms slip become difficult.

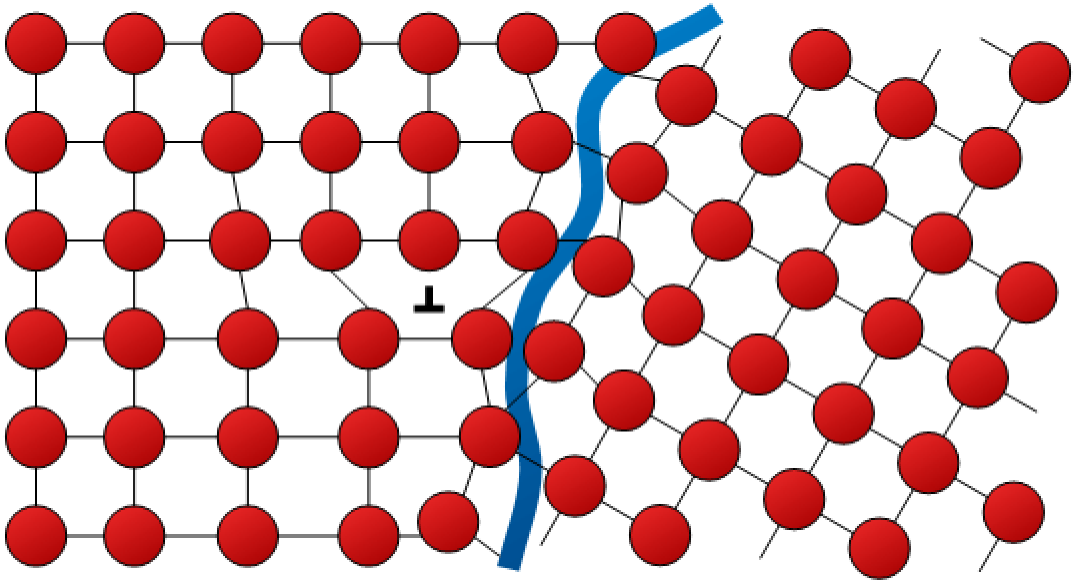
i.e Permanent deformation require more stress.

i.e: Metal characterized by high strength, high hardness and low ductility.

Relation Between Microstructure and Mechanical Properties:

Obstructing dislocation movement occurs by:

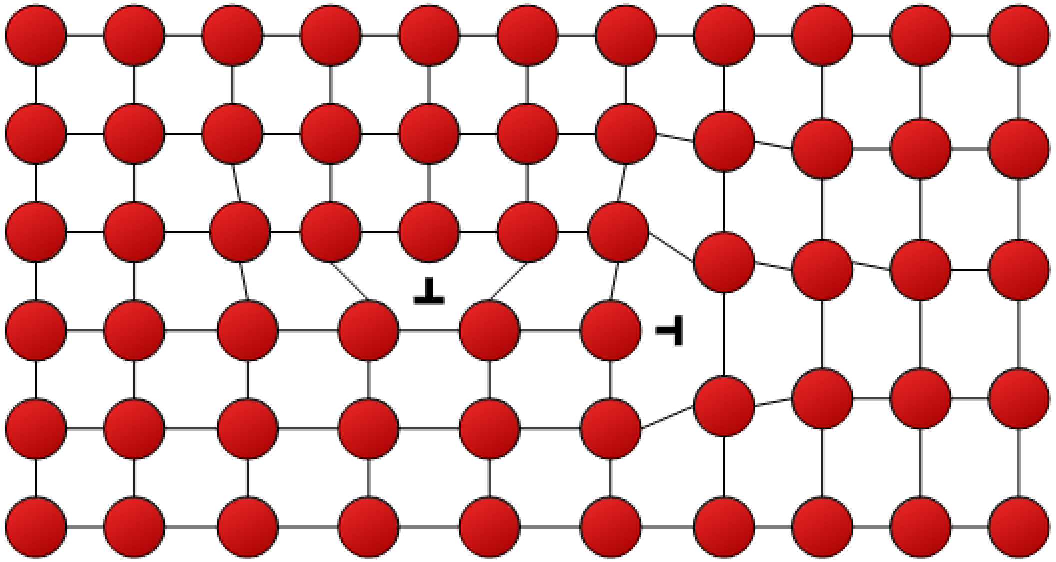
1. Grain boundaries: Therefore, metals with small grains have higher strength and hardness.



Relation Between Microstructure and Mechanical Properties:

Obstructing dislocation movement occurs by:

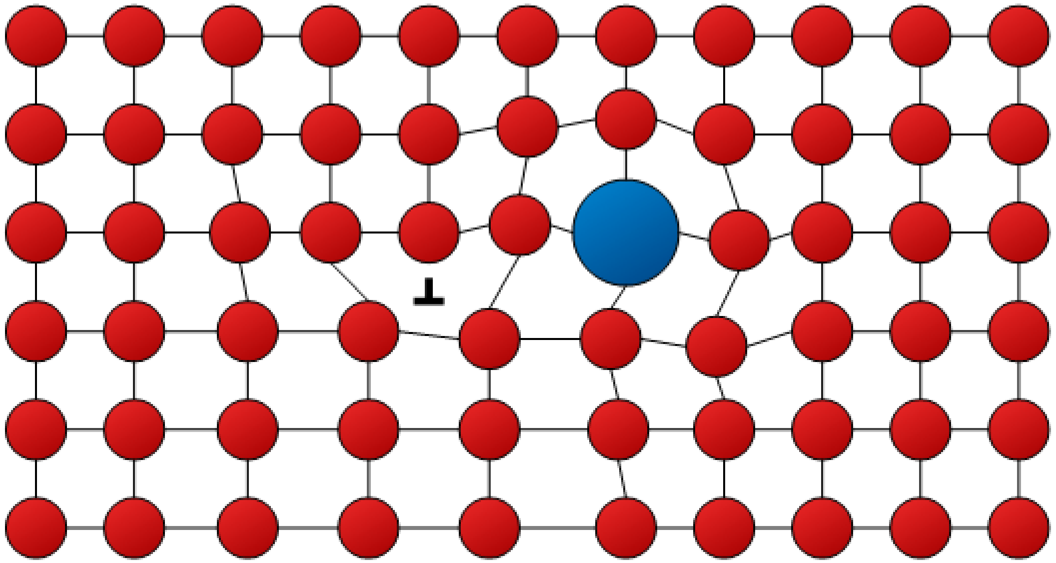
2. Other dislocations.



Relation Between Microstructure and Mechanical Properties:

Obstructing dislocation movement occurs by:

3. Other types of space lattice discontinuity (as impurities).



Wrought Metals:

- They are the metals that subjected to cold working (Stresses above yield strength).

Wrought Metals:

- Cold worked structure characterized by:

1. Fibrous structure.
2. High strength, hardness and proportional limit.
3. Low ductility.
4. Low tarnish and corrosion resistance → cannot be used inside patient mouth.

Heat Treatment Annealing:

- It is a heat treatment process that can reverse the effect of cold working.
- It is done by heating the cold worked structure at temperature below its melting temperature.

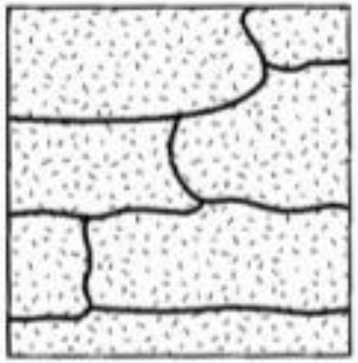
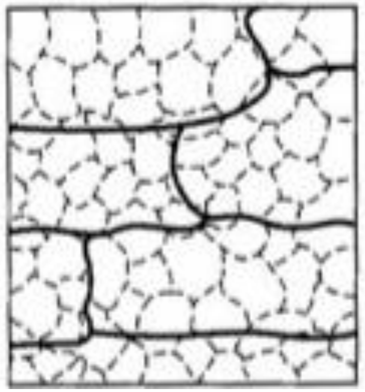
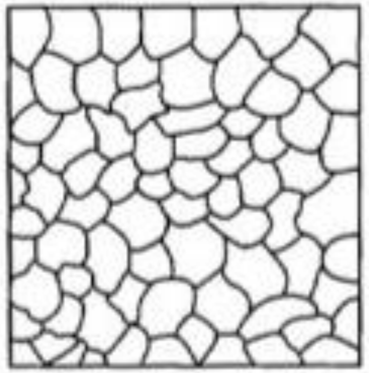
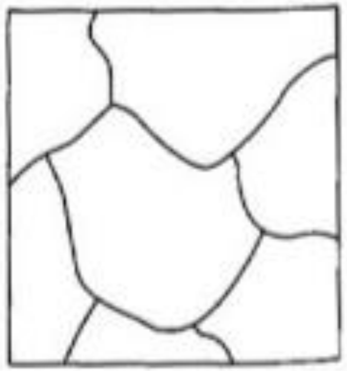
Heat Treatment Annealing:

- It involves three stages according to time of heating:

1. Recovery.
2. Recrystallization.
3. Grain Growth.

Heat Treatment Annealing:

	Cold working	Recovery	Recrystallization	Grain growth
Structure	Fibrous structure	Fibrous structure	Fine cast grains	Coarse grains

Heat Treatment Annealing:

	Cold working	Recovery	Recrystallization	Grain growth
Tensile strength and hardness	Increased	Very little decrease	Decreased (like cast metal)	Slight decrease
Ductility	Decreased	No changes	Increased (like cast metal)	Slight increase

Heat Treatment Annealing:

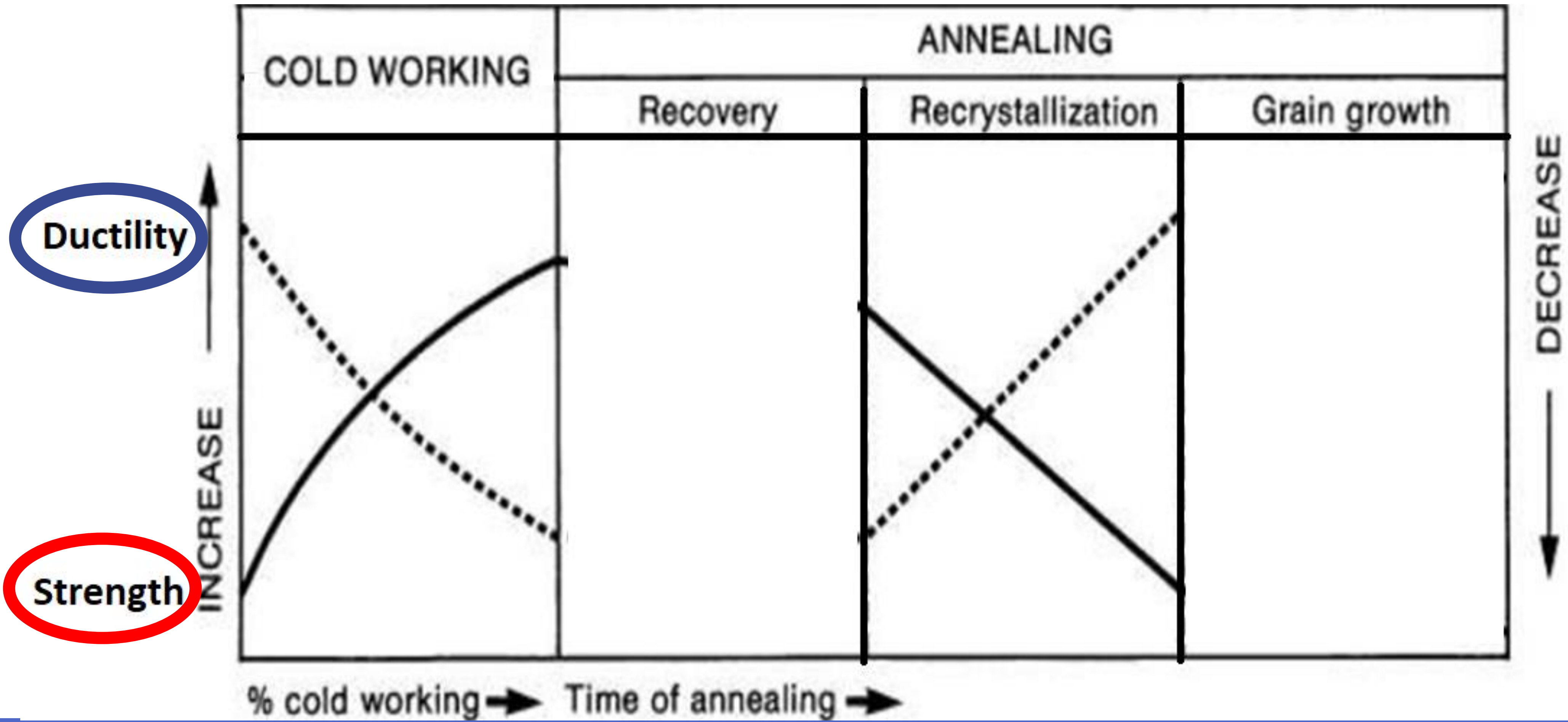
	Cold working	Recovery	Recrystallization	Grain growth
Corrosion resistance	Low	High	High	High
Internal stresses	High	Relieved	Strain free	Strain free

Heat Treatment Annealing:

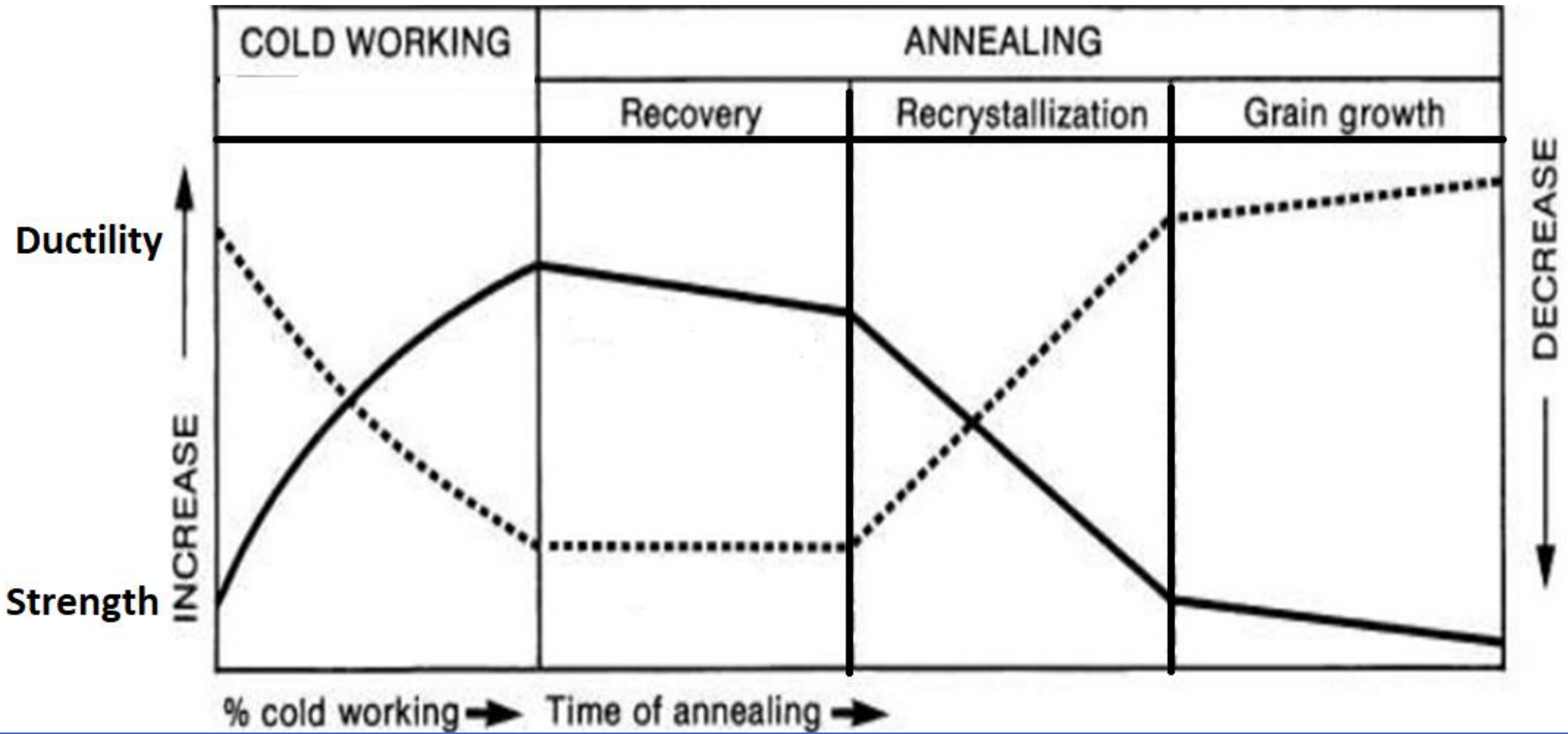
COLD WORKING	ANNEALING		
	Recovery	Recrystallization	Grain growth

% cold working → Time of annealing →

Heat Treatment Annealing:



Heat Treatment Annealing:



Heat Treatment Annealing:

- Any cold worked structure should be subjected to recovery to:
  a) Avoid its corrosion inside oral cavity.
  b) Avoid its fracture or warpage during service (due to high internal stresses).

Heat Treatment Annealing:

- Recrystallization may be done if low strength and high ductility are required.

Alloys

- Alloy is the mixture to two or more metal.
- Alloys are more commonly used in dentistry because of their higher mechanical properties.

Definitions

- **Phase:**

Any physically distinct, homogenous and mechanically separable portion of a system.

Definitions

- **Solution:**

A system in which the molecules of a solute diffuse and intermingle randomly within the atoms of solvent.

Definitions

- **Solvent:**

In the alloy system, the metal with persistent space lattice.

If the two metals have the same space lattice, the solvent will be the metal occupy > 50% of the space lattice.

Definitions

- **Solute:**

The other metal in the alloy system.

Classification of Alloys:

1. **According to use:**

Alloy for inlays, crown and bridges, removable partial dentures and implant.

Classification of Alloys:

2. **<u>According to number of alloying elements:</u>**

Binary alloys contain two metals, ternary alloys contain three metals etc…

Classification of Alloys:

3. **<u>According to major element:</u>**

Gold alloy, silver alloy and etc…

Classification of Alloys:

4. **According to nobility:**

   a) High noble alloy: contains ≥40% gold and ≥60% other noble elements

   b) Nobile alloy: ≥25% noble metals

   c) Predominantly base metal alloys: <25% noble metals.

Classification of Alloys:

5. **<u>According to miscibility of atoms in solid state:</u>**

When two molten metals are mixed, they usually form a solution in the liquid state.

Classification of Alloys:

5. **<u>According to miscibility of atoms in solid state:</u>**

When they are cooled they may be one of three things:

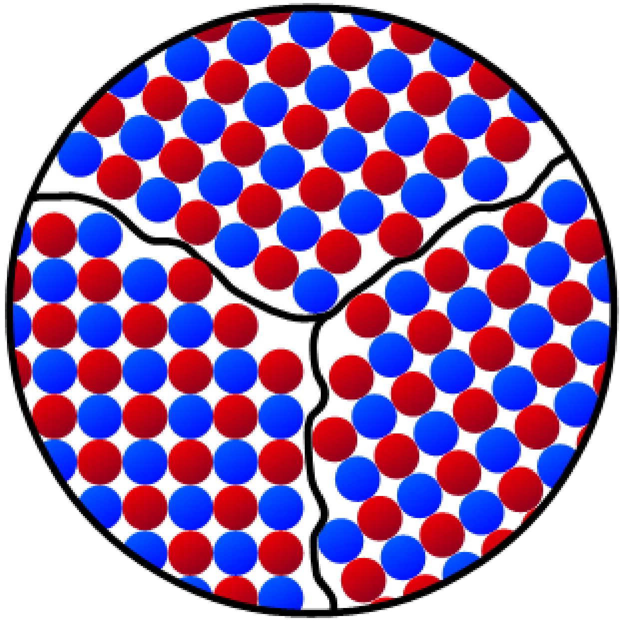
a) Solid solution alloy.

b) Eutectic alloy.

c) Intermetallic compound.

Solid Solution Alloys

- It is an alloy where the parent metals are soluble in both liquid and solid states.
- Most dental alloys are solid solution alloys.



Solid Solution Alloys

- **Types of Solid Solution Alloy:**

  a) Substitutional solid solution alloy.

  b) Interstitial solid solution alloy.

Solid Solution Alloys

a) **Substitutional solid solution alloy:**

The solute atoms substitute some spaces of solvent atoms randomly in the space lattice.

Solid Solution Alloys

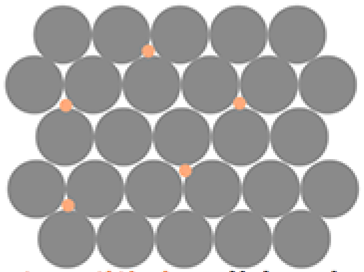
a) **Substitutional solid solution alloy:** Conditions :

1. The two metals should have same space lattice.
2. Have the same valence.
3. The atomic size difference between the two metals is less than 15%.
4. No chemical affinity between the two metals. Otherwise, intermetallic compound will be formed.

Solid Solution Alloys

b) Interstitial solid solution alloy: :

- The solute atoms present in the interstitial spaces between the solvent atoms.
- The solute atoms should be much smaller than the solvent atoms



Interstitial solid soln.

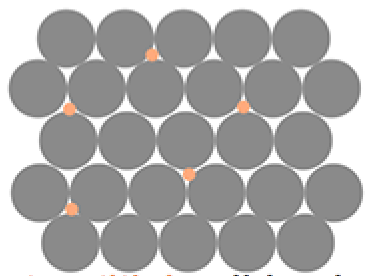
Solid Solution Alloys

b) Interstitial solid solution alloy: :

- Example: Stainless steel (alloy of carbon in iron)

Iron has a FCC space lattice with a relatively large space in the center of the space lattice.

Carbon atom occupy that space


Interstitial solid soln.

Solid Solution Alloys

- **Properties of Solid Solution Alloy**

1. They have melting range.
2. They are homogeneous (Solid is one phase).

Solid Solution Alloys

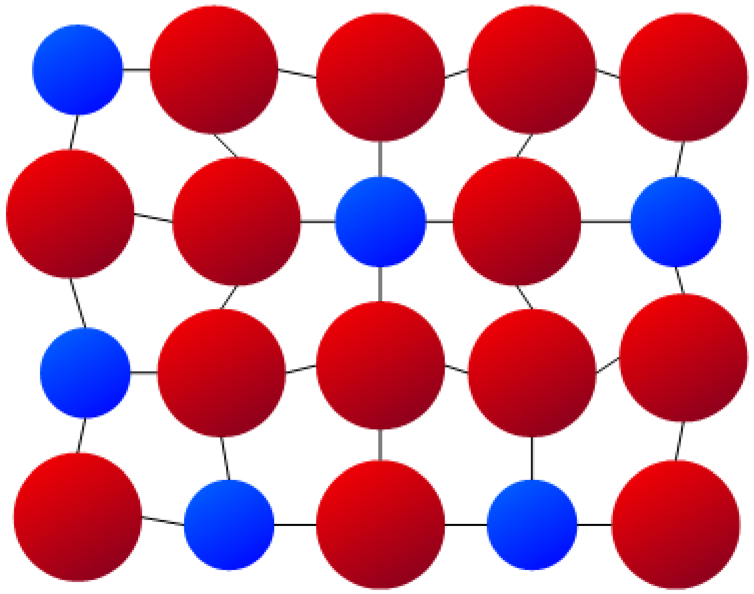
- **Properties of Solid Solution Alloy**

3. They have high tarnish and corrosion resistance.
4. They have higher strength and hardness than parent metals.
5. They have lower ductility than parent metals.

Solid Solution Alloys

- **<u>Properties of Solid Solution Alloy</u>**

Increased strength and hardness and decrease ductility is due to:



Solid Solution Alloys

- **Properties of Solid Solution Alloy**

Increased strength and hardness and decrease ductility is due to:

The solute atoms causes expansion or contraction in the space lattice of the solvent atoms ➔ localized distortion ➔ interfere with dislocation movement.

Eutectic Alloy

- It is an alloy where the parent metals are soluble in liquid state but either partially soluble or completely insoluble in the solid states.
- Eutectic is a Greek word that means (lowest melting).
- The eutectic composition has a lower melting point than the parent metals.

Eutectic Alloy

- **Properties of Eutectic Alloy:**

1. They have melting point.
2. They are heterogeneous.

Eutectic Alloy

- **Properties of Eutectic Alloy:**

3. They have poor tarnish and corrosion resistance.
4. They have higher strength and hardness than patent metals.
5. They are brittle.

Eutectic Alloy

- **Dental Example of Eutectic Alloy:**

Silver-copper eutectic alloy (used in admixed amalgam).

Intermetallic Compound

- The parent metals have chemical affinity towards each other.
- They form a new chemical compound under specific temperatures.
- The atoms of one metal occupy a definite position in the space lattice of the other atom.

Intermetallic Compound

- **Properties of Intermetallic Compound:**

1. They are hard and brittle.
2. They properties differ from the properties of parent metals.

Intermetallic Compound

- **Dental Example of Intermetallic Compound:**

  $Ag3SN$ (γ phase) of dental amalgam alloy

Constitution Diagrams (Equilibrium Phase diagrams)

Importance:

1. It shows phases present at different compositions and temperatures.
2. Determine the chemical composition of each phase.

Constitution Diagrams (Equilibrium Phase diagrams)

Importance:

3. Determine the melting and freezing temperature of each phase.

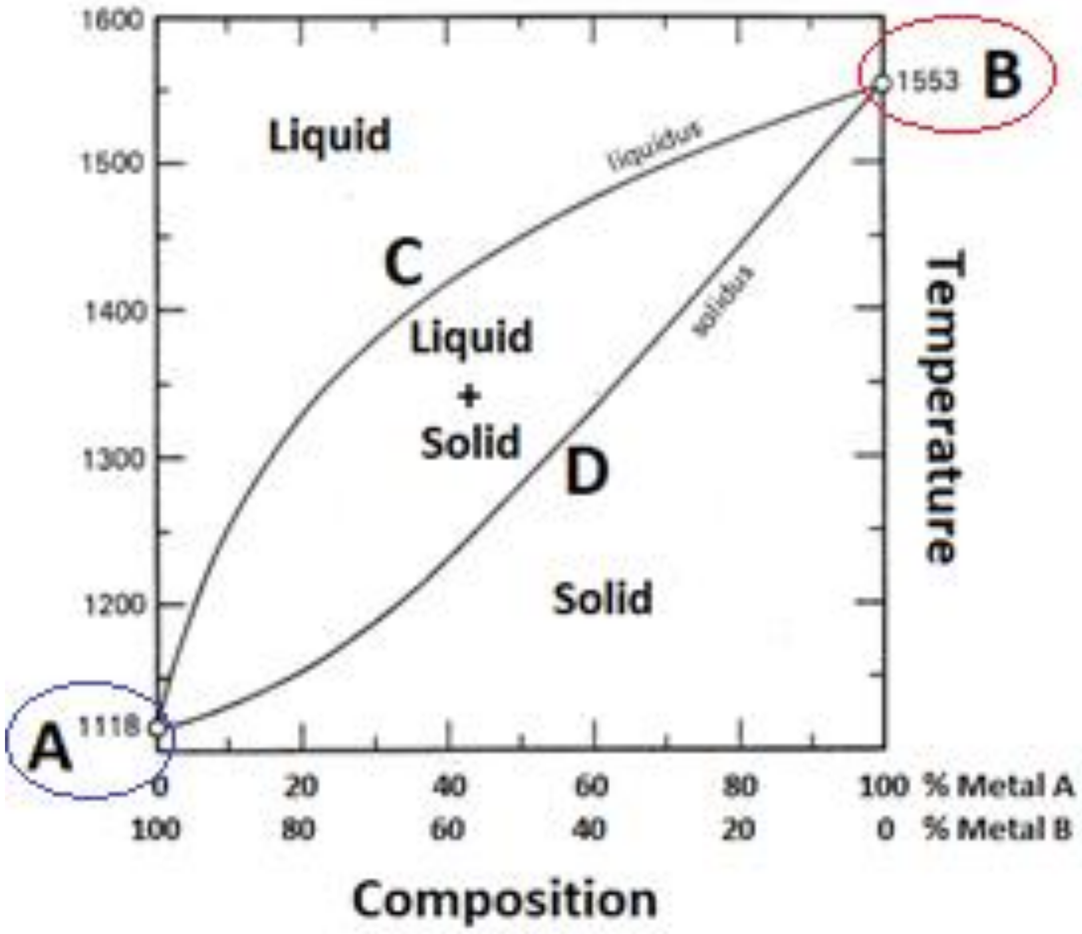
4. Determine the range of solidification of the alloy.

Constitution Diagrams (Equilibrium Phase diagrams)

Description of Solid Solution Phase

Diagram:

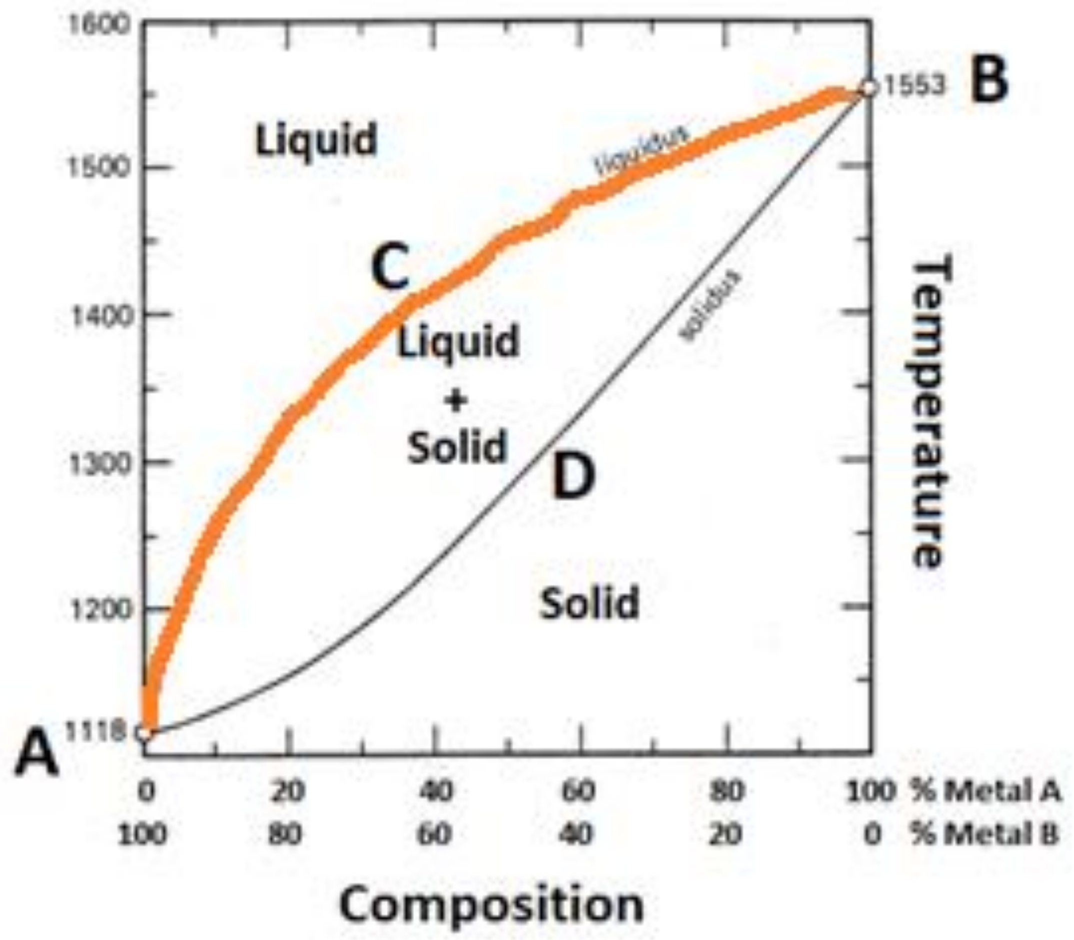
- The melting point of metal A is 1118 ° C.
- The melting point of metal B is 1553 ° C.



Constitution Diagrams (Equilibrium Phase diagrams)

Description of Solid Solution Phase Diagram:

- The line (ACB) is the **liquidus line** ➔ at any alloy composition and temperature above the alloy is liquid.

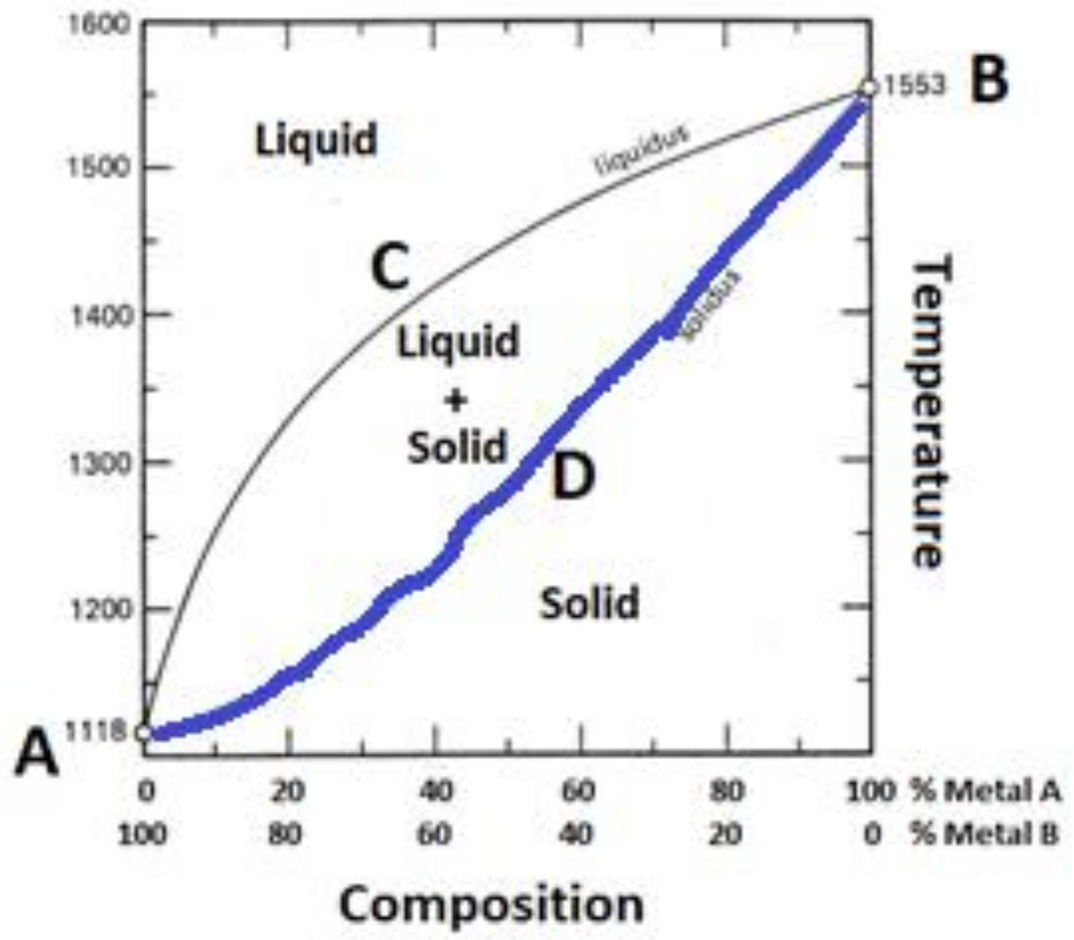


Constitution Diagrams (Equilibrium Phase diagrams)

Description of Solid Solution Phase

Diagram:

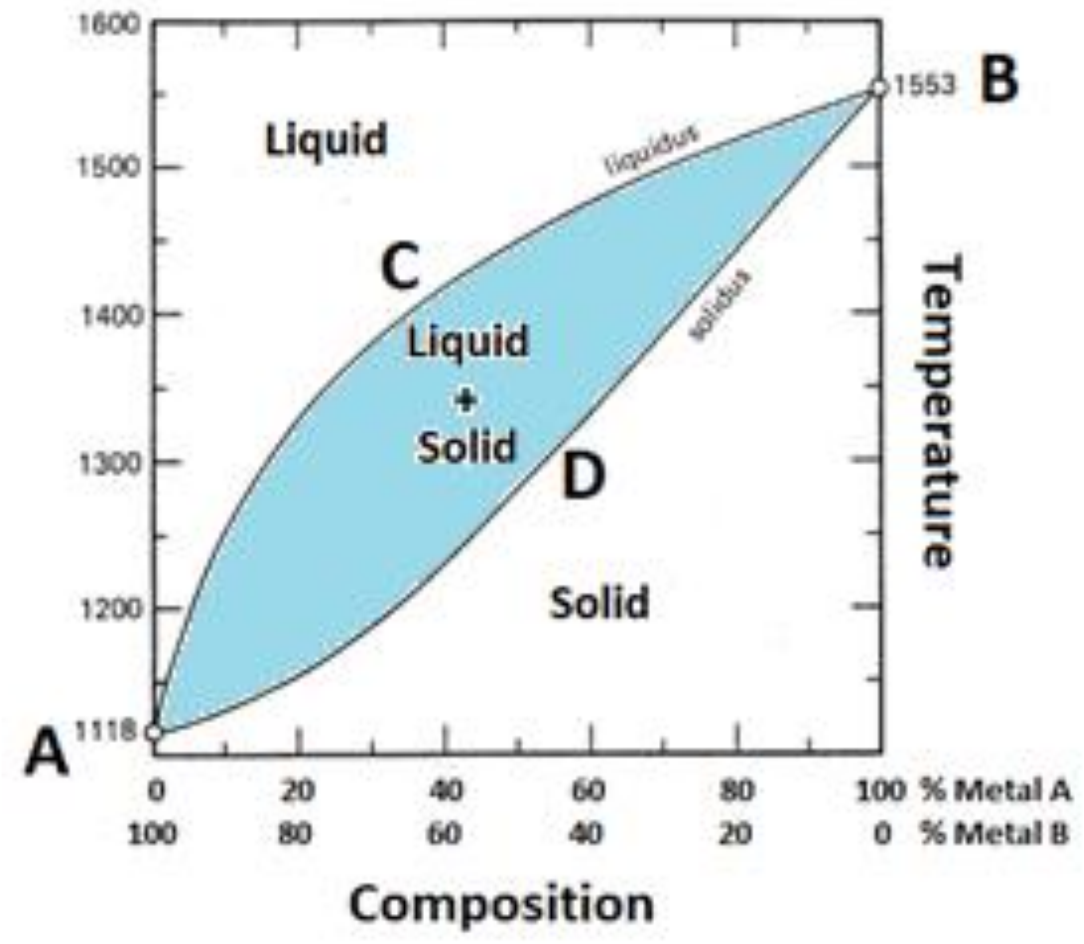
- ➢ The line (ADB) is the **solidus line** ➔ at any alloy composition and temperature below the alloy is solid.



Constitution Diagrams (Equilibrium Phase diagrams)

<u>Description of Solid Solution Phase Diagram:</u>

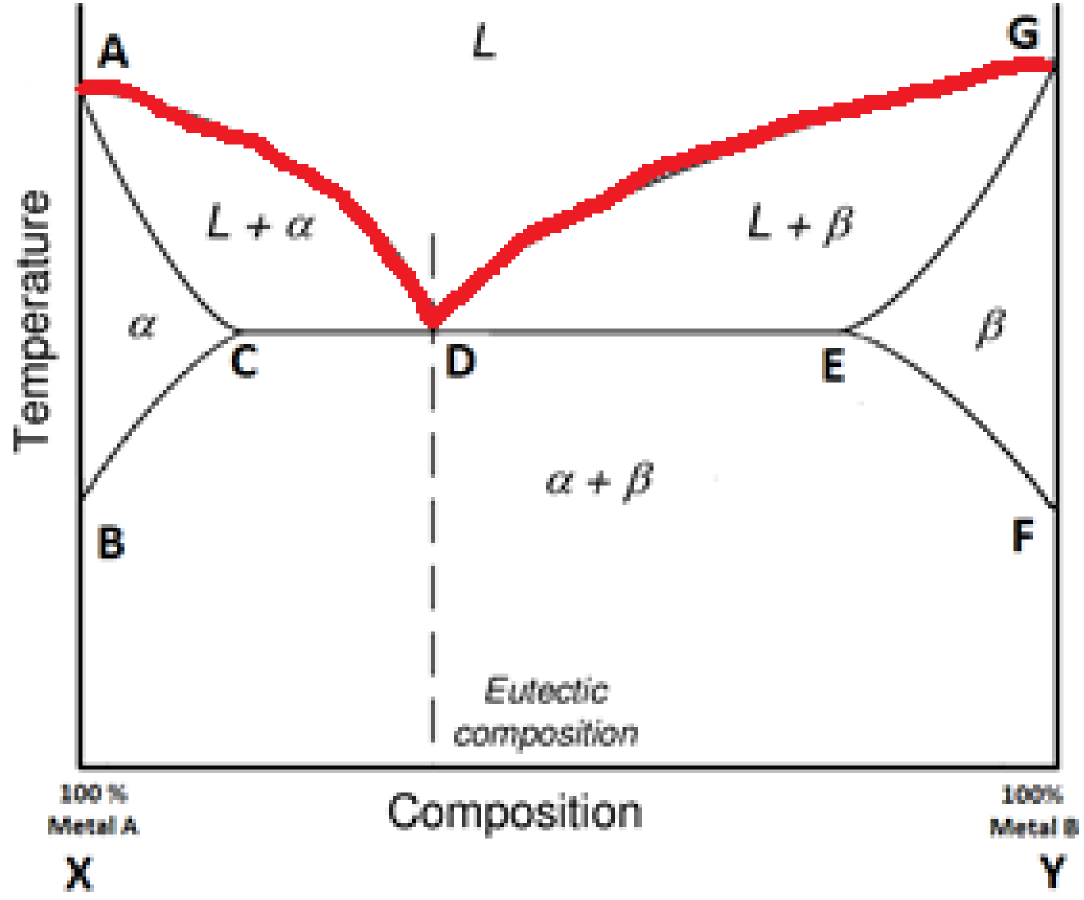
- At any alloy composition and temperature between the two lines the alloy will be solid and liquid



Constitution Diagrams (Equilibrium Phase diagrams)

<u>Description of eutectic Phase Diagram:</u>

- The line (ADG) is the **liquidus line**

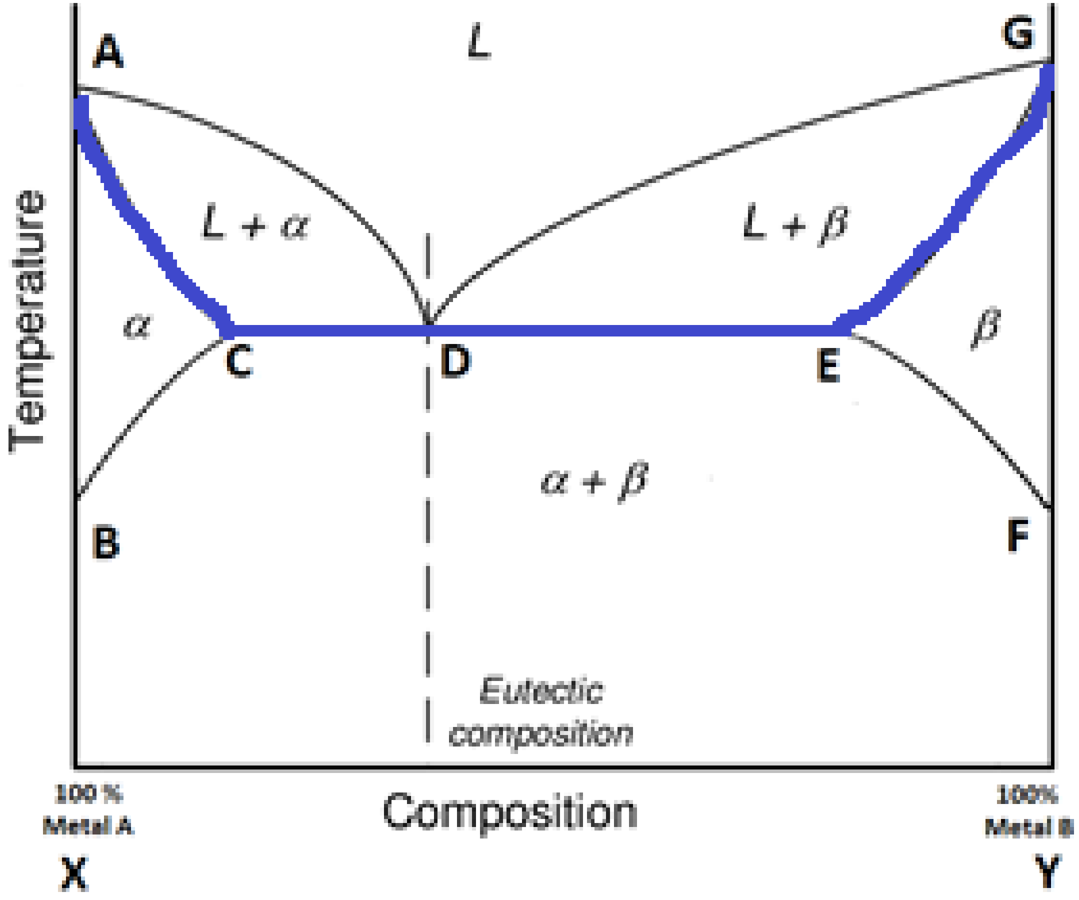


Constitution Diagrams (Equilibrium Phase diagrams)

Description of eutectic Phase

Diagram:

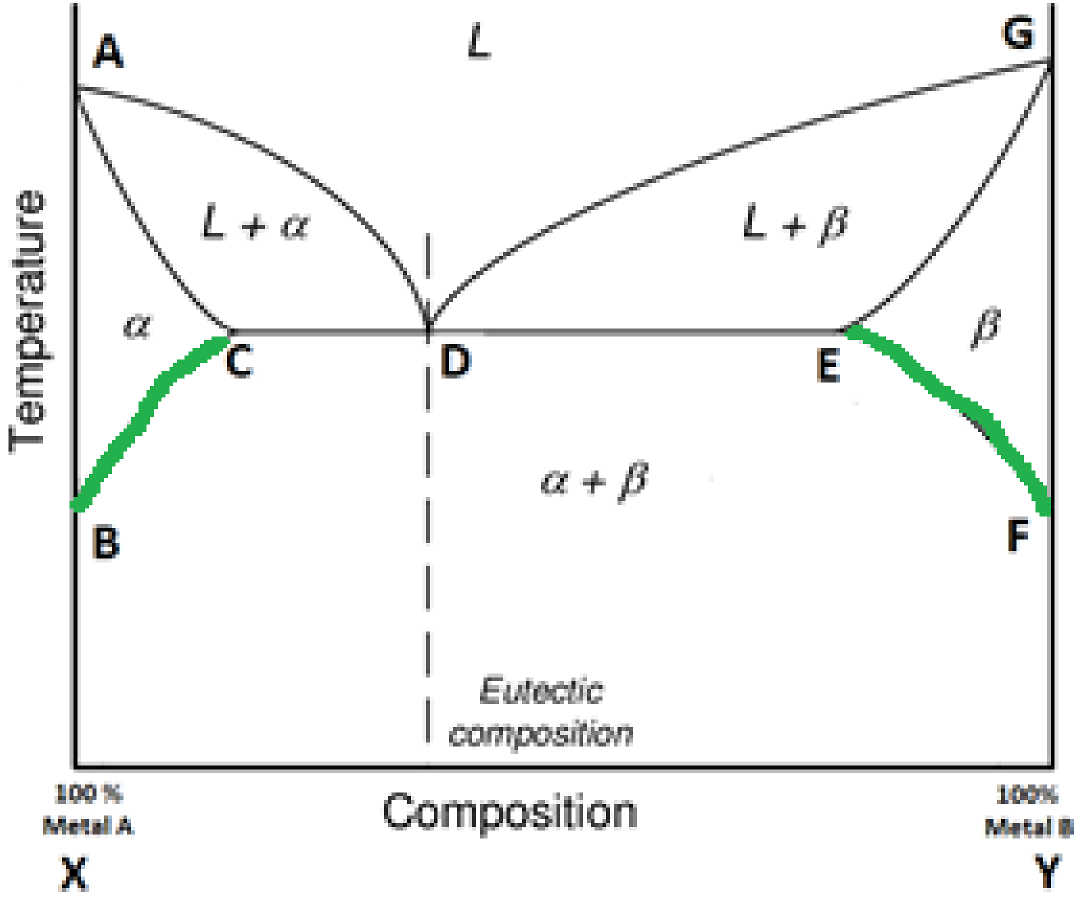
- The line (ACDEG) is the **solidus line**



Constitution Diagrams (Equilibrium Phase diagrams)

Description of eutectic Phase Diagram:

- (BC) and (FE) are **solvus lines** ➔ represent the limit of solubility of both metals in each other.

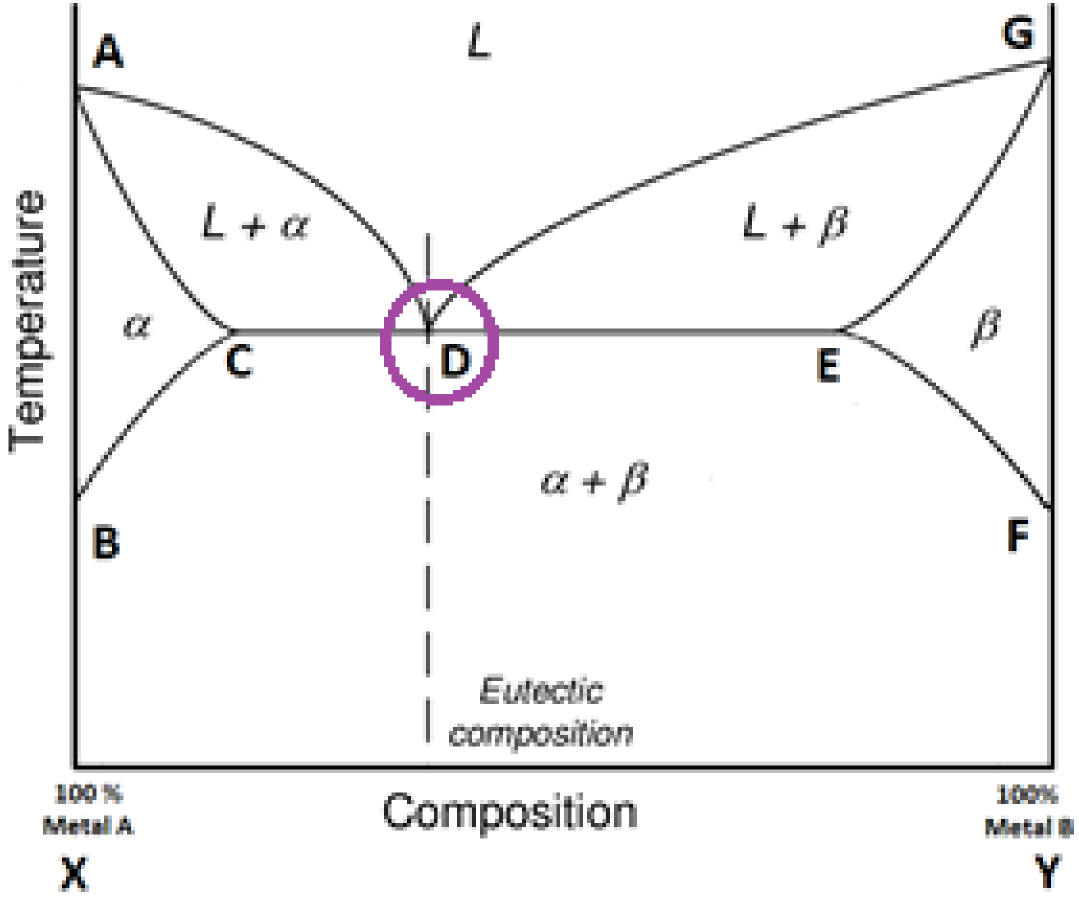


Constitution Diagrams (Equilibrium Phase diagrams)

Description of eutectic Phase

Diagram:

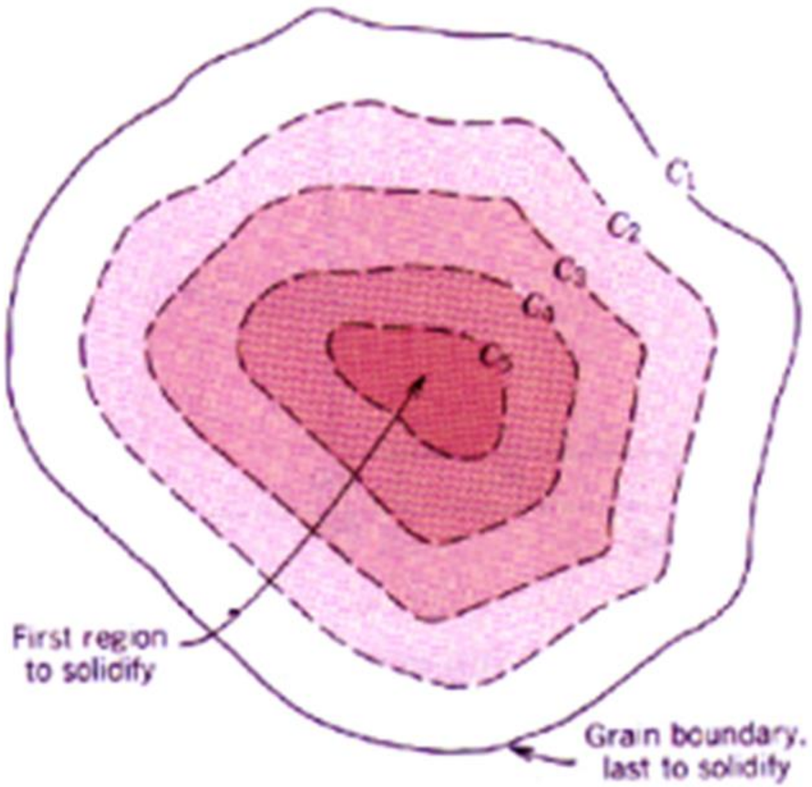
- Point D is called eutectic point or eutectic composition of lowest melting temperature.



Coring

Definition:

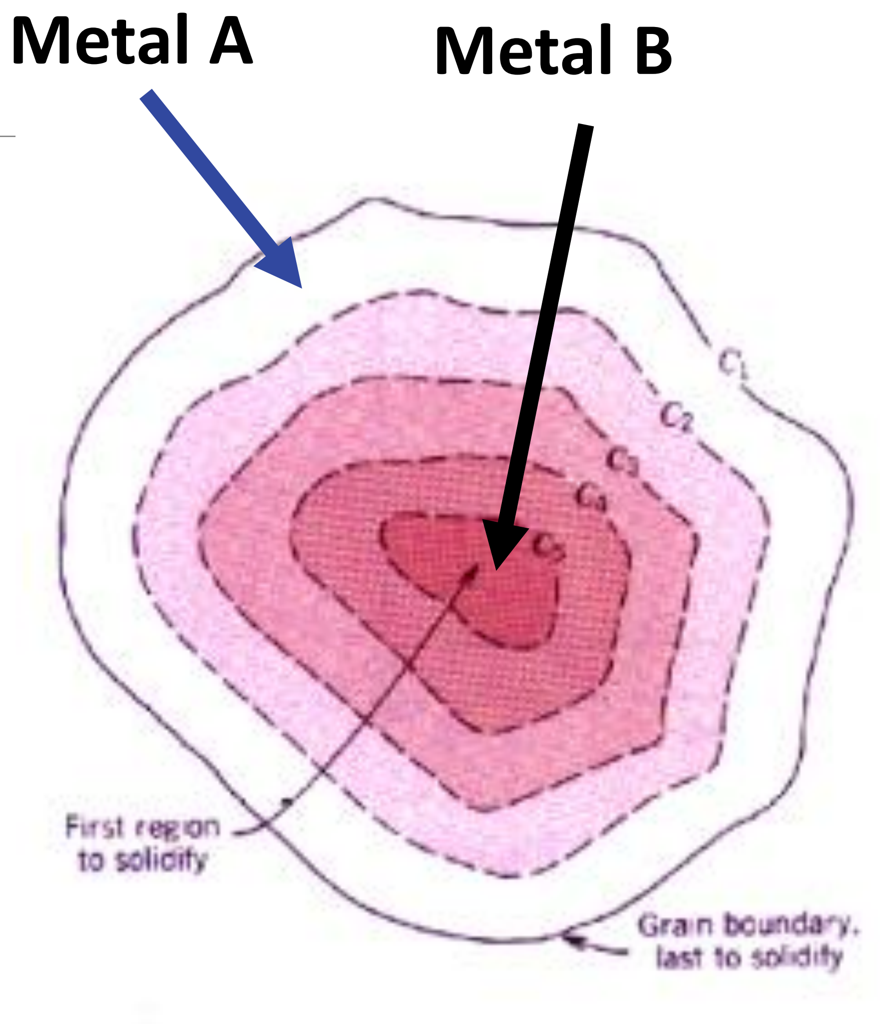
- It is the process of incremental solidification of alloy with changing in composition.



Coring

Discerption:

- The peripheral part of the grain is rich in metal A, while the central part in rich in metal B with gradual increase of metal A from inside to outside the grain.



Coring

Mechanism:

- The first embryo is formed from the metal with highest melting point (metal B).
- As the temperature decreased, the grains increased in size incrementally.

Coring

Mechanism:

- The inner increments are rich in metal B so the liquid will be depleted of it.

Coring

Mechanism:

- When reaching freezing temperature of metal A, the core of each grain is formed and the periphery of grains will be precipitated with more metal A.

Coring

<u>Effect of coring:</u>

1. Increase strength and hardness.
2. Decrease ductility.
3. Decrease tarnish and corrosion resistance.

Coring

Methods to Eliminate Coring

1. Slow cooling.
2. Homogenization Heat Treatment.

Coring

Methods to Eliminate Coring

1. Slow cooling.

- This allows atomic diffusion towards equilibrium between inner and outer increments of each grain.

Coring

Methods to Eliminate Coring

2. Homogenization Heat Treatment.

- It is a heat treatment procedure.
- The cored alloy is heated at a temperature near its solidus temperature.

Coring

Methods to Eliminate Coring

2. Homogenization Heat Treatment.

   - It is like annealing of wrought metals but with higher heat and for longer time.

Coring

Methods to Eliminate Coring

2. Homogenization Heat Treatment.

   - It is characterized by:

     a) There is little or no grain growth.

     b) Increase in ductility.

Thank You

DR AHMED MAGDY