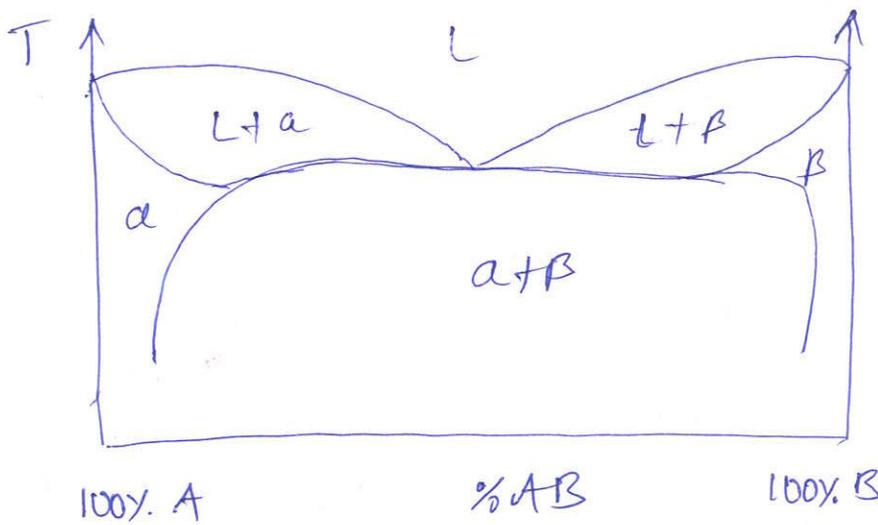


Iron - Carbon Equilibrium Diagram:-

Solid solution:-

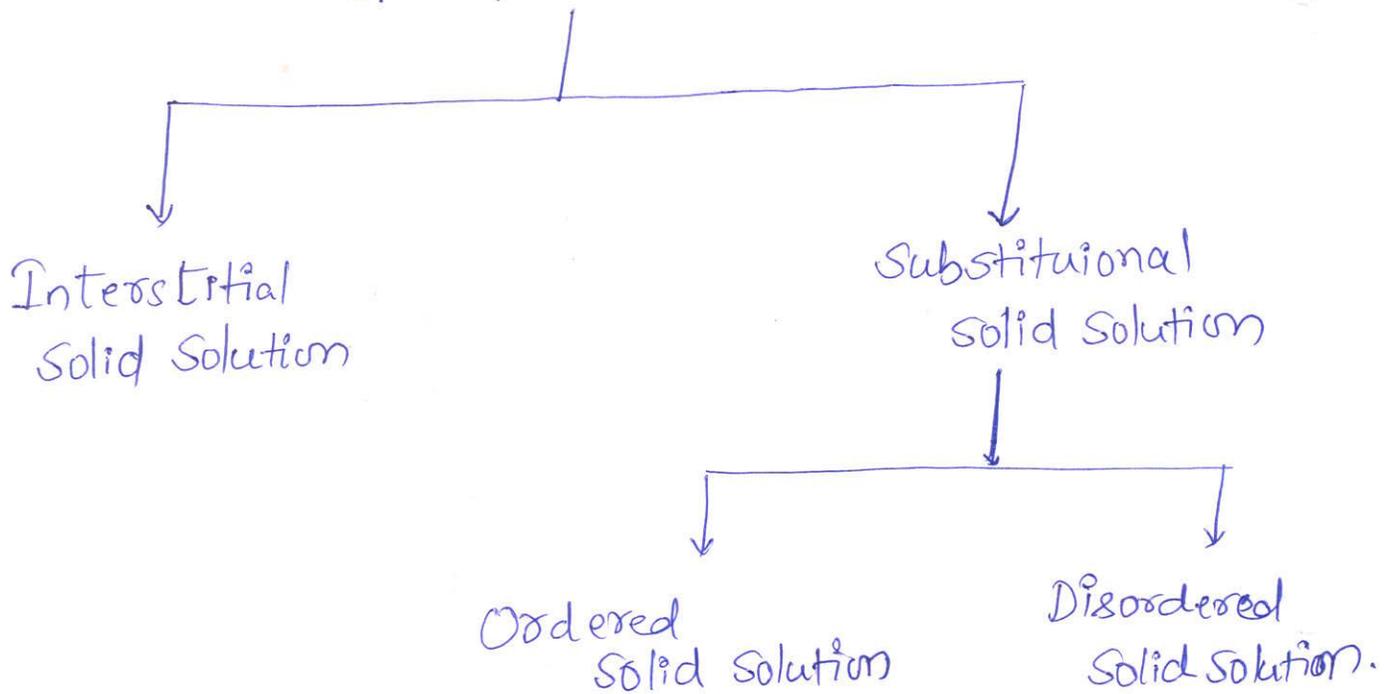
- solid solution is a solid mixture containing one or more minor components (solute) uniformly distributed within the crystal lattice (matrix) of the matrix of the major component (solvent).
- such a mixture is considered a solution rather than a compound when the crystal structure of the solvent remains unchanged by addition of the solutes and when the mixture remains in a single homogeneous phase.
Ex:- Fe = solvent



this binary phase diagram shows two solid solutions.

- solid solution formation usually causes increase of electrical resistance and mechanical strength and decrease of plasticity of the alloy

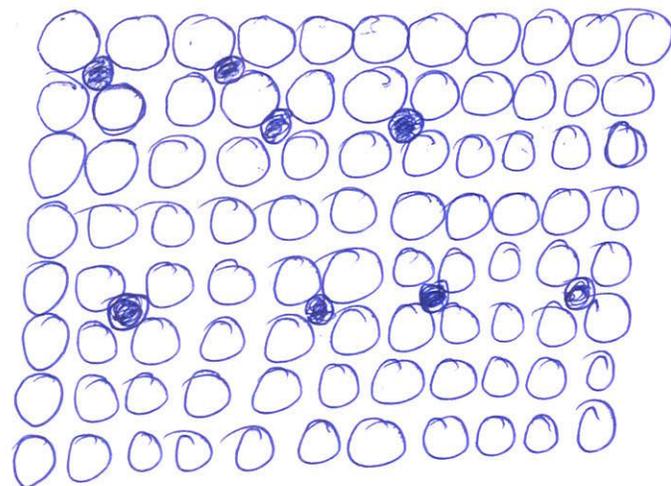
Types of Solid Solution



Interstitial Solid Solution :-

- solute atoms are much smaller than solvent atom.
- ↳ size of the solute is less than 40% that of solvent) so they occupy interstitial position in solvent lattice.
- Carbon, nitrogen, hydrogen, oxygen, lithium, sodium and boron are the elements which commonly form interstitial solid solution. Steel :- C atoms solute in Fe

Note :- atoms of size is denoted by $\rightarrow 1 \text{ \AA} = 10^{-8} \text{ cm} = 10^{-10} \text{ m}$



○ → Solvent Atoms
 ○ → Solute Atoms.

EX :- Fe + C

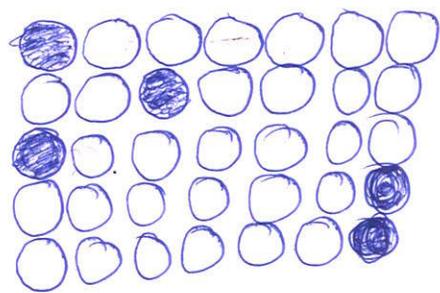
unit-1, pg-2/53

↓ size big ↓ size small

substitutional Solid Solution

(2)

- solute atoms sizes are roughly similar to solvent atoms.
- Due to similar size solute atoms occupy vacant site in solvent atoms.
- Cu and Zn, Cu and Ni, are the example of substitutional solid solution.



○ → solvent atoms

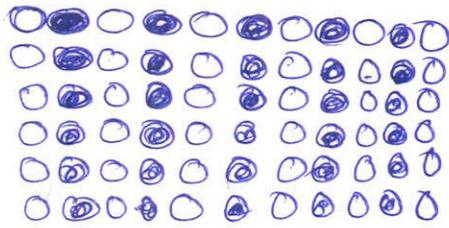
○ → solute atoms

Ex :- Cu - Ni

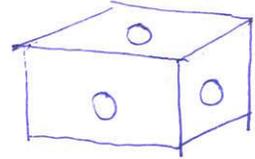
Ordered Substitutional Solid Solutions:-

- if the atoms of the solute occupy certain preferred sites in the lattice of the solvent, an ordered solid solution is formed.
- It may occur only at certain fixed ratios of the solute and solvent atoms
- In Cu - Au system, Cu atoms occupying the face-centred sites and Au atoms occupying the corner sites of the FCC unit cell.

unit-1, Pg-3/53



 → Solvent Atoms
 → solute Atoms.



Disordered Substitutional Solid Solution :-

→ if the atoms of the solute are present randomly in the Lattice of the solute, it is known as disordered solid solution.

→ most of the solid solution are disordered solid solutions.



 ⇒ solvent atoms

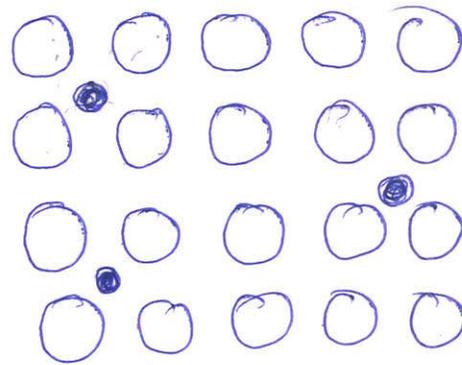
 ⇒ solute atoms

Ex : Brass

Application of solid solution.

(3) ②

→ Why is steel so strong



o → C

○ → Fe

→ Smaller Carbon atoms fill some of the small spaces available between the iron atoms and form Interstitial solid solution.

→ Usually materials deform by the movement of dislocations. The carbon interstitials make steel stronger by fully or partially blocking the movement of dislocations.

Phase Diagrams

Phase Diagrams :-

Phase or equilibrium diagrams are diagrams which indicate the phase existing in the system at any temperature, pressure and composition.

Why study phase diagrams :-

→ Used to find out the amount of phases existing in a given alloy with their composition at any temperature.

unit-1, pg-5/53

→ From the amount of phases it is possible to estimate the approximate properties of the alloy

→ Useful in design and control of heat treatment procedures.

* Terms :-

⇒ System :- A phase is a physically separable.

A. System is that part of the universe which is under consideration.

Phase :- A. Phase is physically separable part of the system with distinct physical and chemical properties.

(In a system consisting of ice and water in a glass jar, ice cubes are one phase. The water is a second phase, and the humid air over the water is a third phase. The glass of the jar is another separate phase.)

⇒ Variable :- A particular phase exists under various conditions of temperature, pressure and concentration.

These parameters are called as the variables of the phase.

Component :- The elements present in the system are called as components.

for ex:- Ice, water or steam all contain H_2O (4) ⊕
so the number of components is 2, i.e. H and O

Gibb's Phase Rule:-

→ The Gibb's phase rule states that under equilibrium conditions the following relation must be satisfied.

$$P + F = C + 2$$

Where,

P = number of phases existing in a system under consideration.

F = degree of freedom i.e. the number of variables such as temperature, pressure or composition (concentration) that can be changed independently without changing the number of phases existing in the system

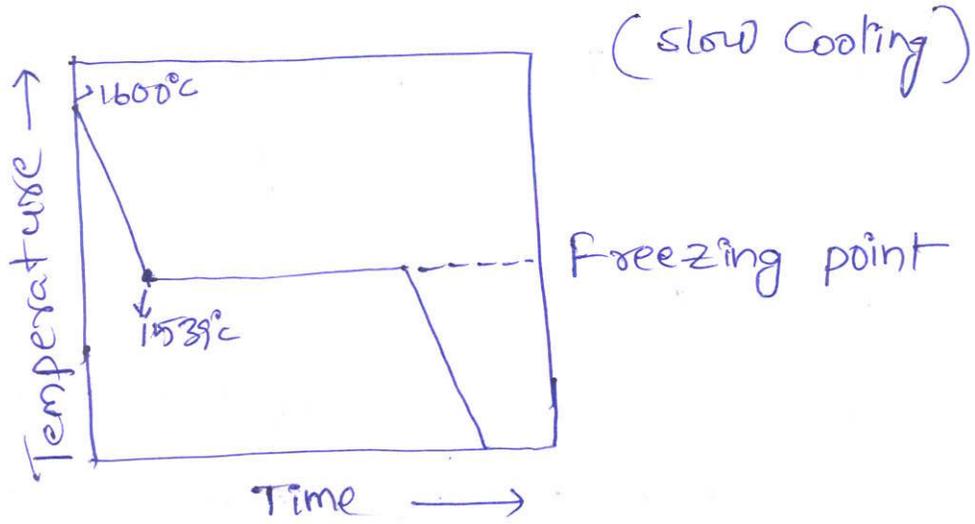
C = Number of components (i.e. elements) in the system.

2 = Represents any two variables out of the above three i.e.

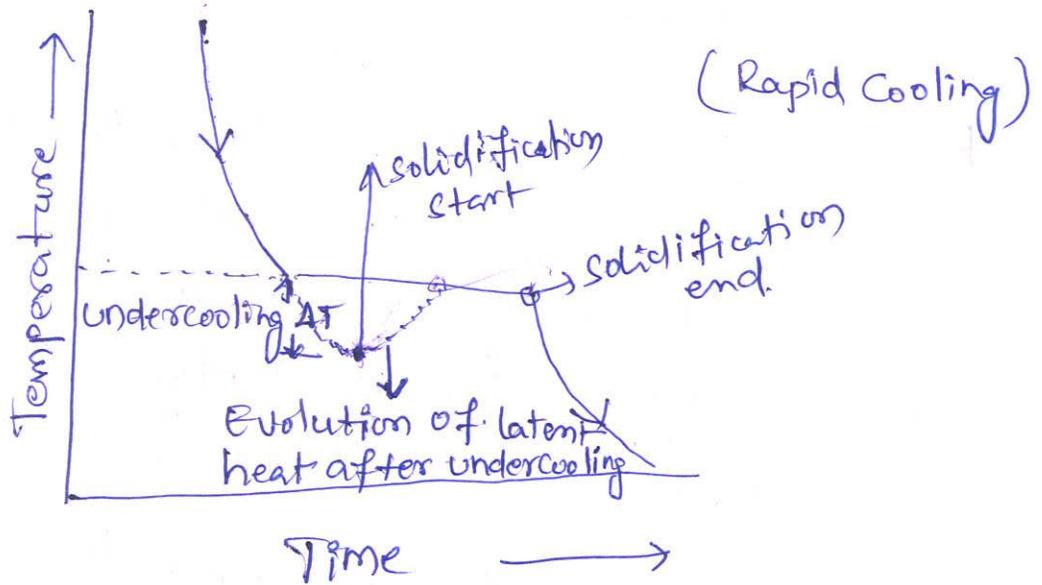
Cooling Curve for the solidification of a pure metal:

→ Under equilibrium conditions, all metals exhibit a definite melting or freezing point.

→ If a cooling curve is plotted for a pure metal. It will show a horizontal line at the melting or freezing temperature



Cooling curve for a pure Metal showing possible undercooling.

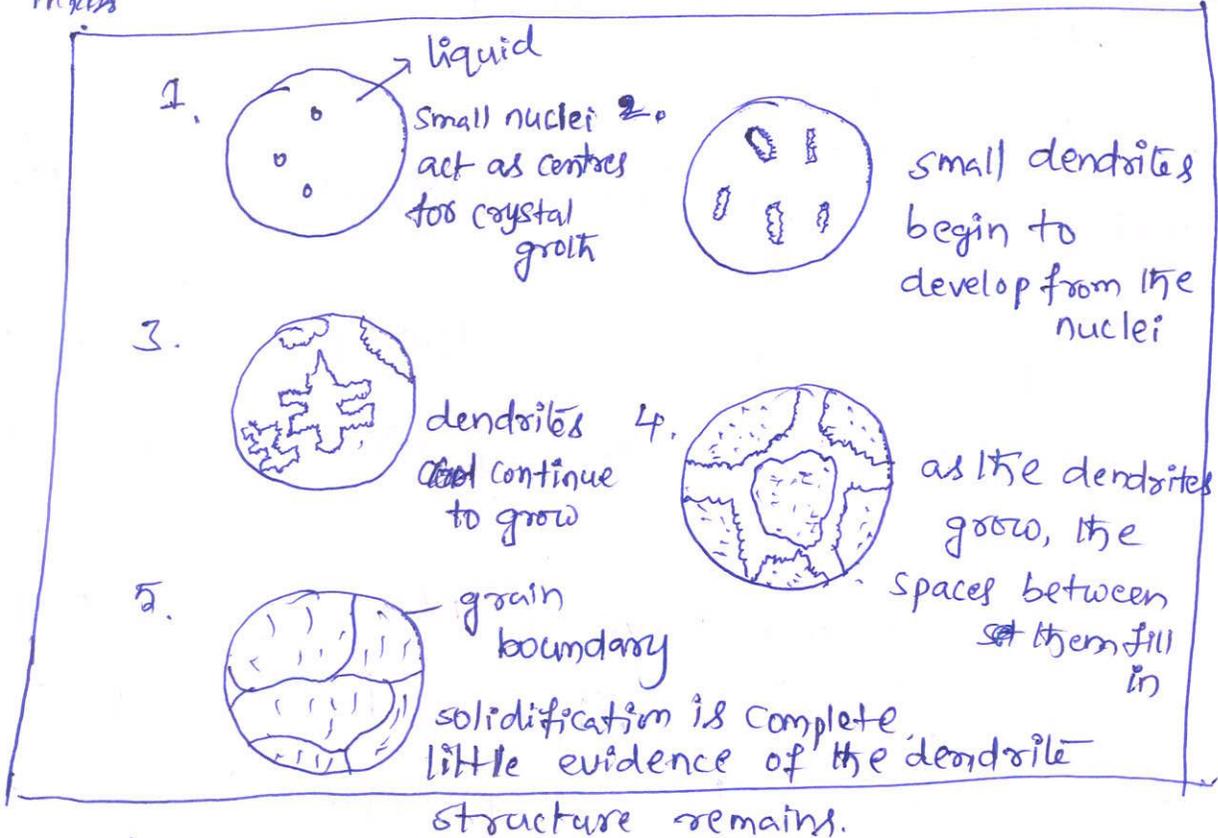


①
②
③
④

Nuclei

large grains → ductile
small grain → brittle

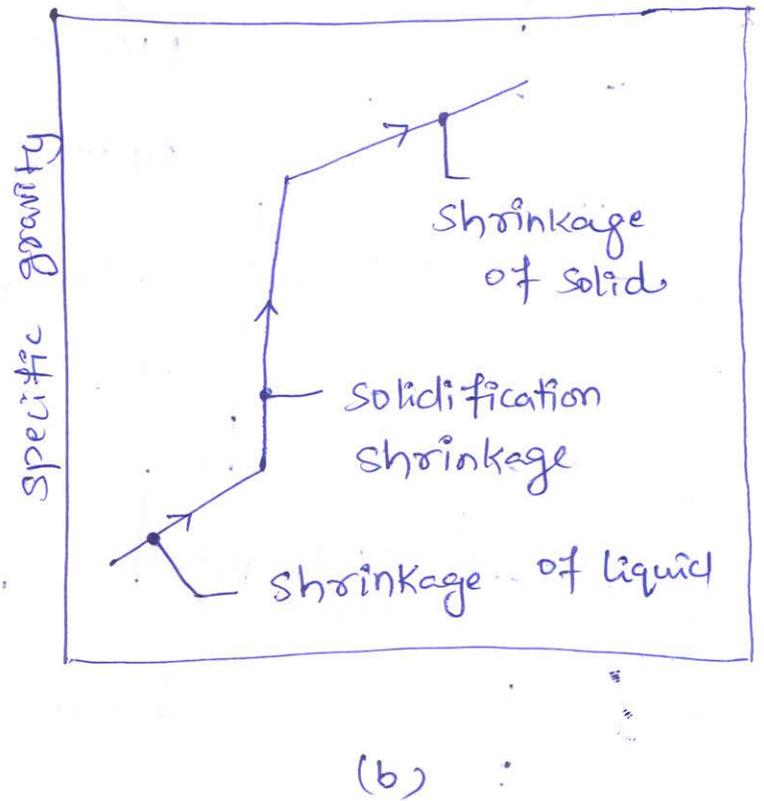
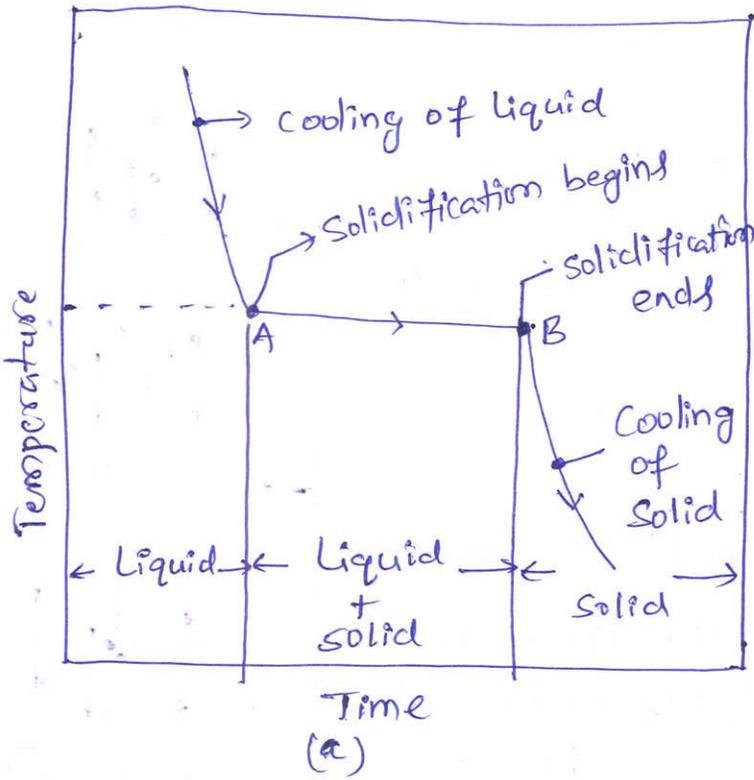
→ stages



→ Fast cooling → Small grains → brittle, hard
→ Slow cooling → Large grains → ductile, improve.

SOLIDIFICATION OF PURE METALS

5

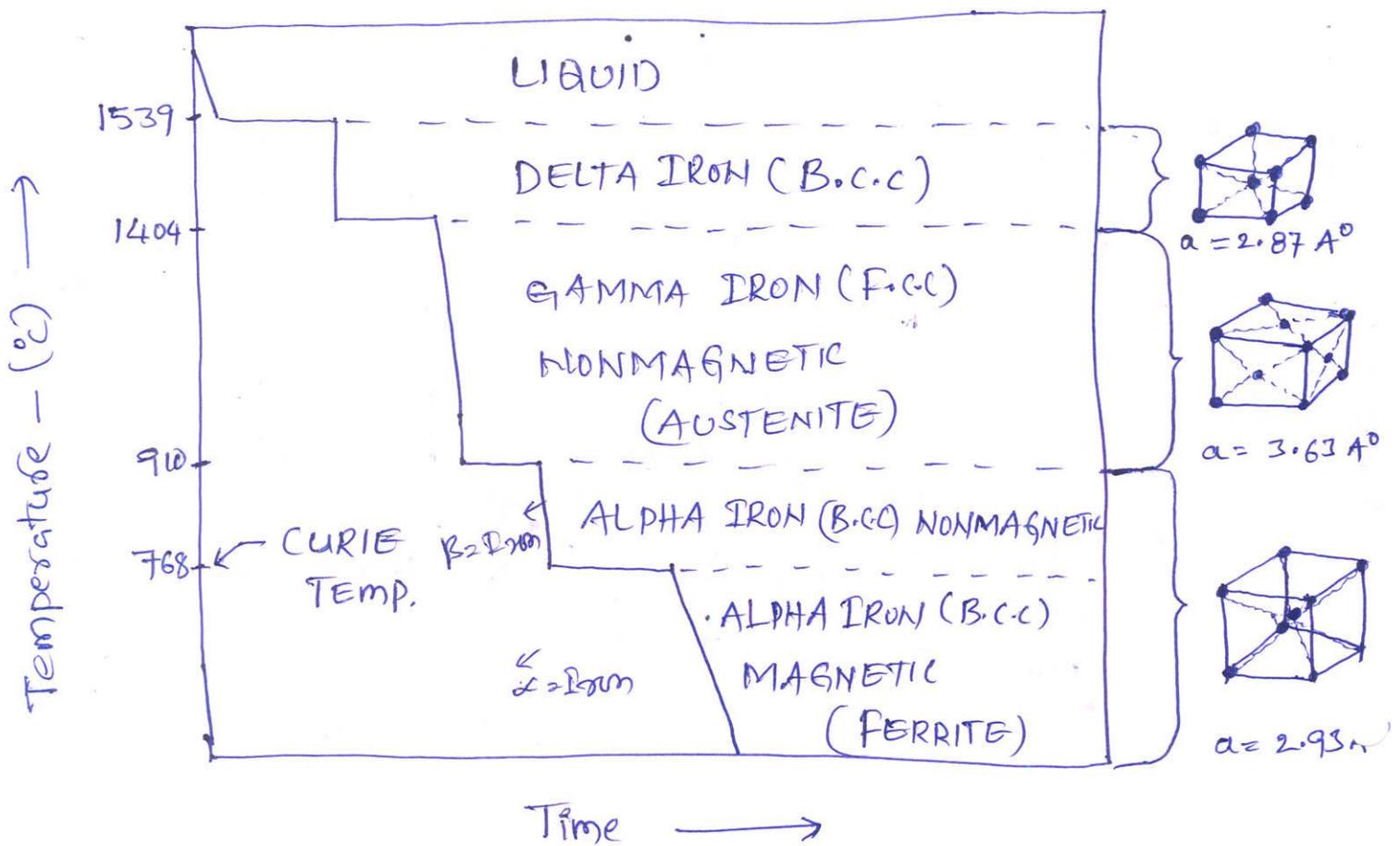


Mechanism of Solidification of Metals

→ The solidification of metals occur by nucleation and growth transformation,

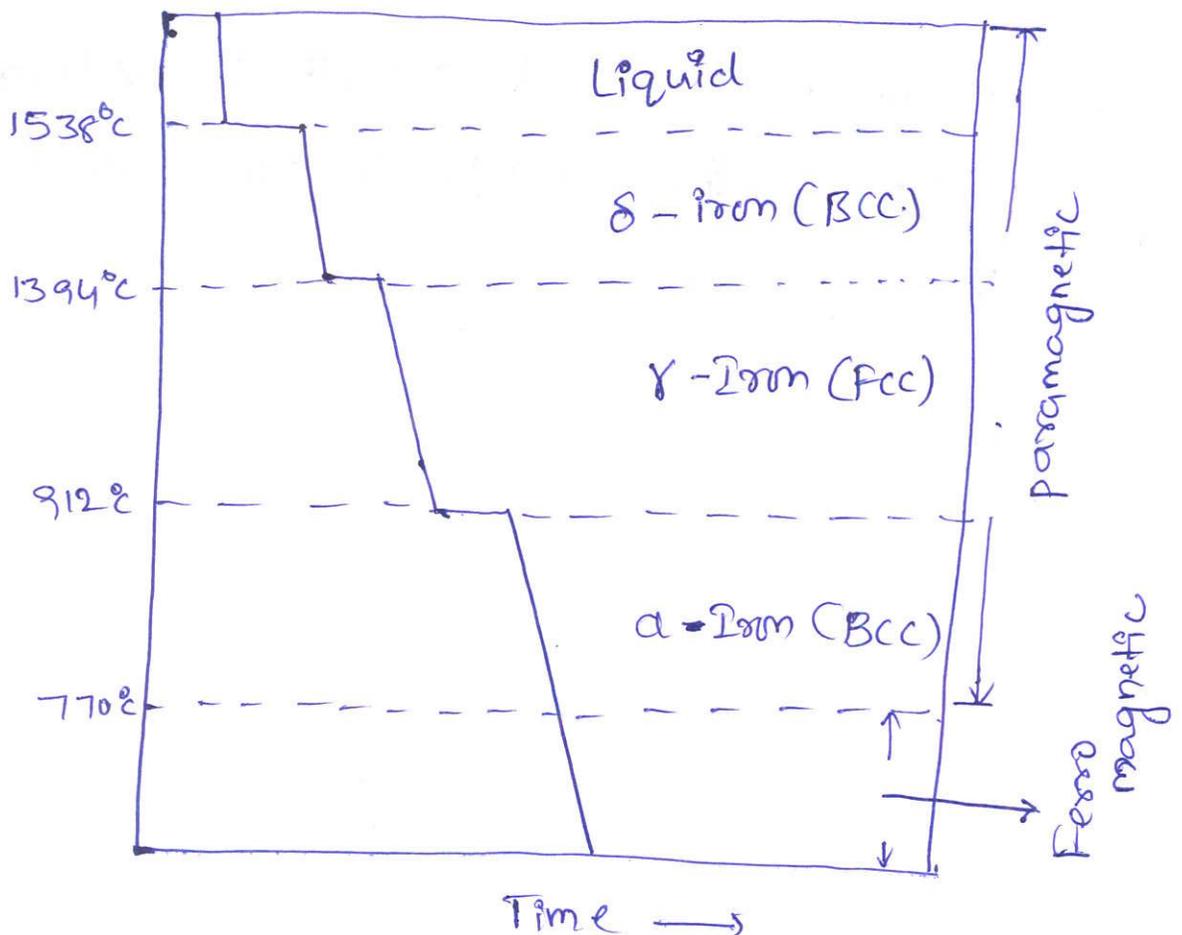
→ In nucleation and growth transformation, the nuclei of the solid phase are formed and then they grow.

Allotropy of pure Iron



Allotropes of Iron:-

If the change in structure is reversible, then the polymorphic change is known as allotropy.



IRON ALLOTROPY

6

- Iron is relatively soft and ductile metal.
- Iron is allotropic metal which means that it exist in more than one type of lattice structure (BCC/FCC) depending upon temperature.
- In normal room temperature state Iron is BCC in lattice arrangement where as at (908 deg.C) it changes to FCC and then 1403 deg.C back to BCC again and vice versa.
- About 770 deg.C the room temperature magnetic properties of iron disappears and it becomes non magnetic called Curie point

BCC - 1535° - 1400°

FCC - 910° - 1400°

→ 910° - 1400° - ∞ Iron - FCC

→ 1535 - 1400° - BCC

→ (770° - below) → Magnetic

* Definition *

Ferrite:- is an interstitial solid solution of Carbon in alpha iron. Ferrite ~~dissolve~~ dissolves considerably less Carbon than austenite, with maximum amount being 0.025% C at 723°C. Ferrite is nearly pure Iron

* Cementite :- Fe_3C is a compound of iron and carbon referred to as iron carbide.
Cementite contains 6.67% C and 93.3% Fe. Cementite ~~contains~~ is so hard it can be machined only by grinding.

* Pearlite :- is a lamellar aggregate of ferrite and cementite formed from the eutectoid decomposition of austenite during slow cooling. pearlite has the microstructural appearance of fingerprints
Note :- (Ferrite + cementite combination)

* Austenite ^(γ -Fe) is an interstitial solid solution of carbon in gamma iron. The solid solubility of carbon in austenite is a maximum of 2.08% at 1148°C and decreases to 0.8% at 723°C. (~~1148~~)

Definition :-

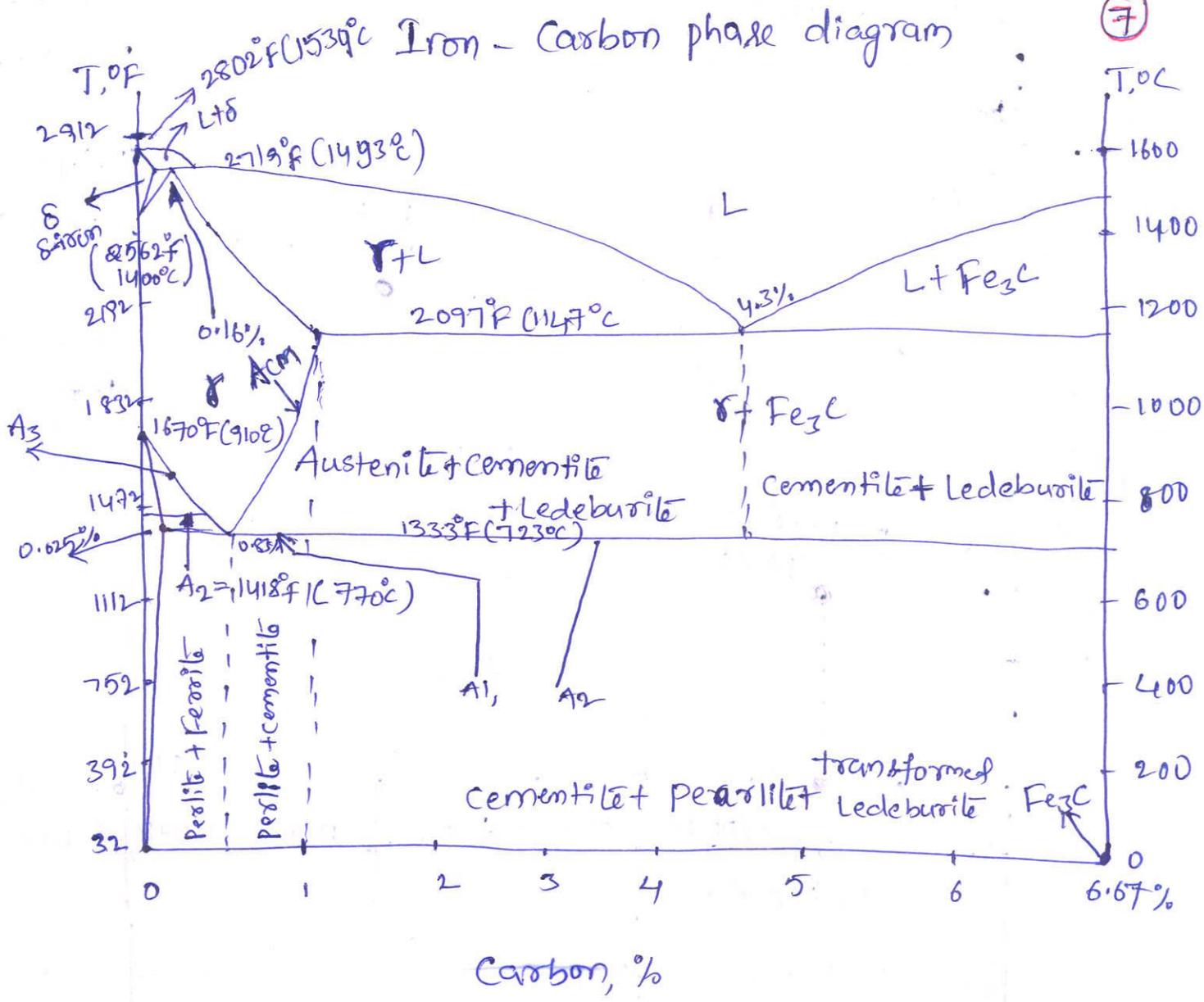
* Upper critical temperature (point) A_3 is the temperature below which ferrite starts to form as a result of ejection from austenite in the hypoeutectoid alloy.

* Upper critical temperature (point) A_{cm} is

The temperature, below which cementite starts to form as a result of ejection from austenite in the hypereutectoid alloy.

* Lower critical temperature (point) A_1 is

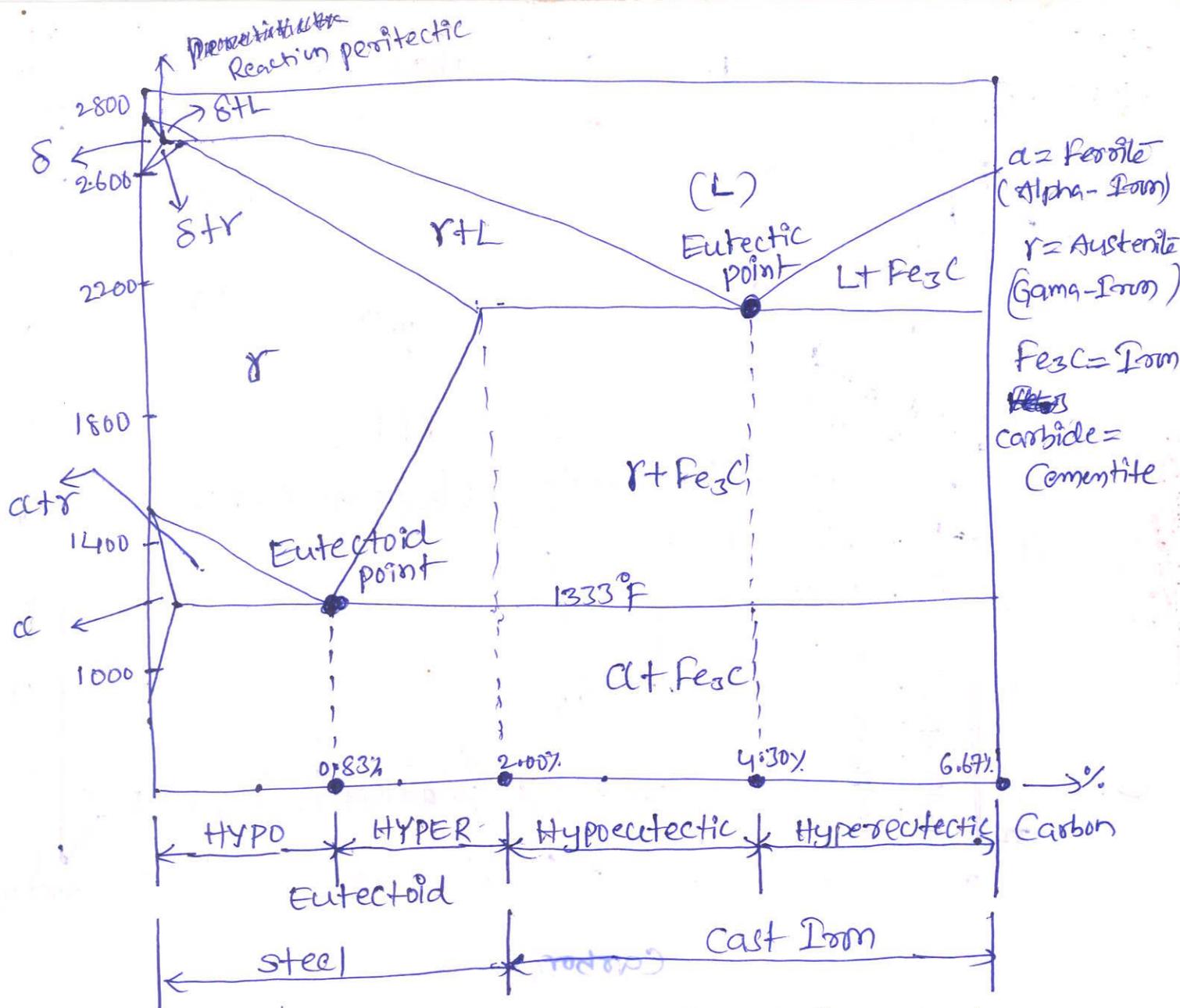
The temperature of the austenite-to-pearlite eutectoid transformation. Below this temperature austenite does not exist.



phases in Iron-Carbon phase Diagram

- 1) → Ferrite :- Solid Solution of Carbon in BCC iron
- 2) → Austenite :- Solid Solution of Carbon in FCC iron
- 3) → δ-Iron :- Solid Solution of Carbon in BCC iron
- 4) → Cementite (Fe₃C) :- Intermetallic compound of iron and carbon with a fixed carbon content of 6.67% by wt.
- 5) → Pearlite :- it is a two phased lamellar (or layered) structure composed of alternating layers of ferrite and cementite.

[Note → Carbon % increases → Metallic strength hardness increases
 Carbon % decreases → ductile property is improve
 more brittle is Fe₃C former]

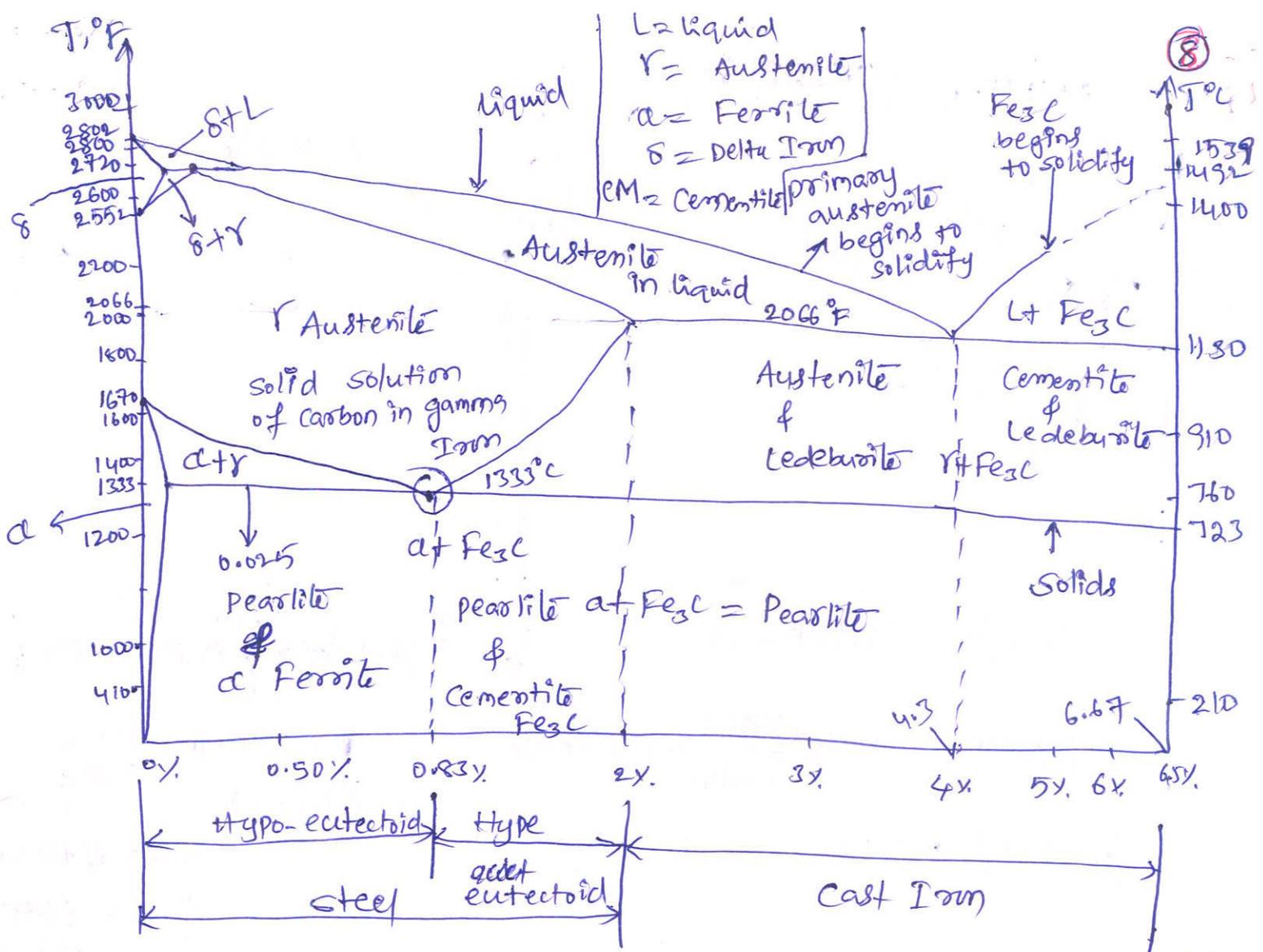


The Iron-Carbon system exhibits three important transformations / reactions as described below:

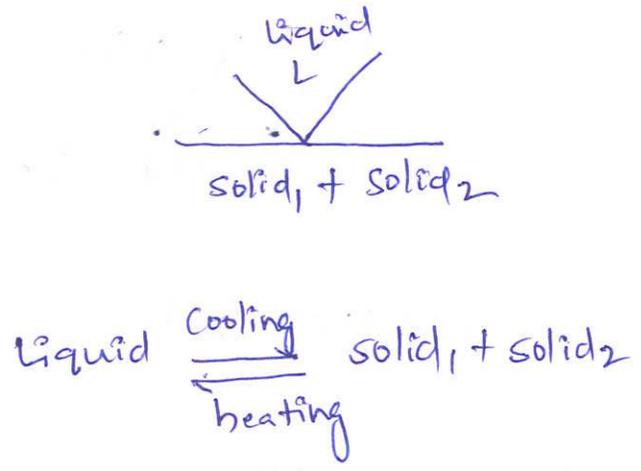
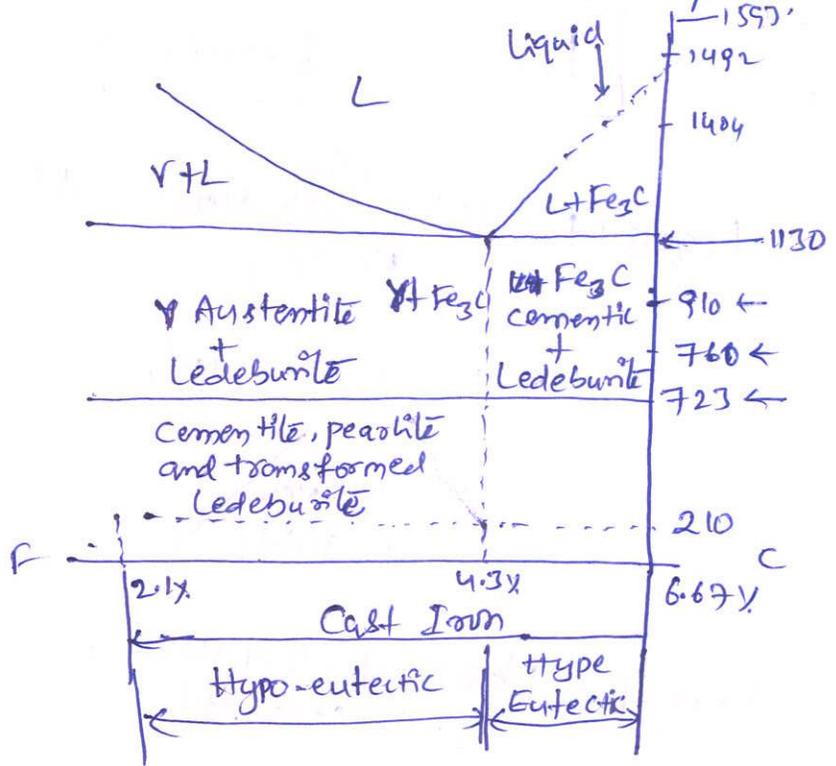
Eutectoid Reaction: 723°C
 $\text{Solid}_1 \leftrightarrow \text{Solid}_2 + \text{Solid}_3$
 Austenite \leftrightarrow Ferrite + Cementite

Eutectic Reaction: 1130°C
 $\text{Liquid} \leftrightarrow \text{Solid}_1 + \text{Solid}_2$
 $\text{Liquid} \leftrightarrow \text{Austenite} + \text{Cementite}$

Peritectic Reaction: 1492°C
 $\text{Solid}_1 + \text{Liquid} \leftrightarrow \text{Solid}_2$
 $\delta\text{-Iron} + \text{Liquid} \leftrightarrow \text{Austenite}$

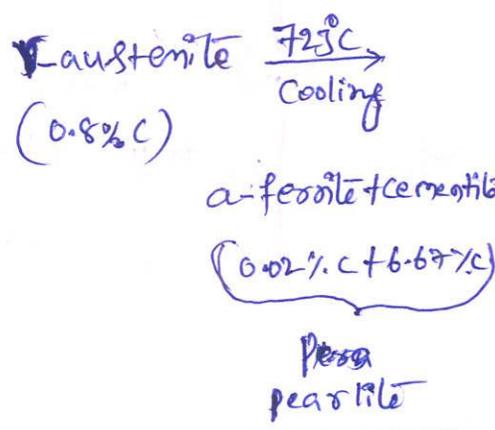
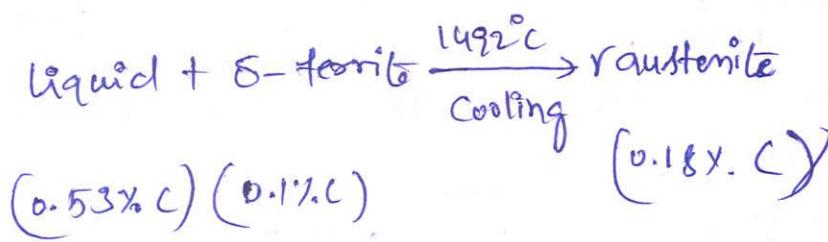
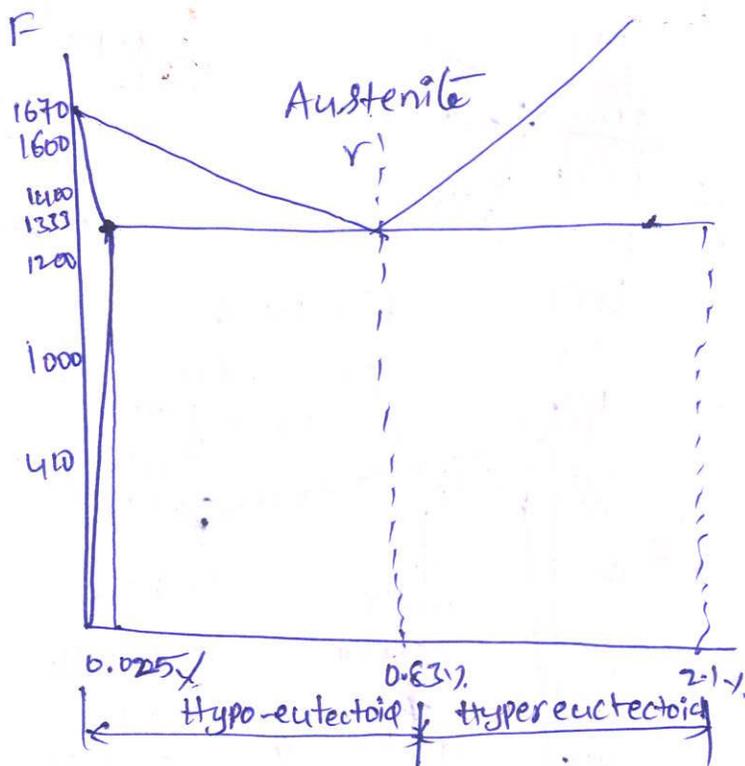
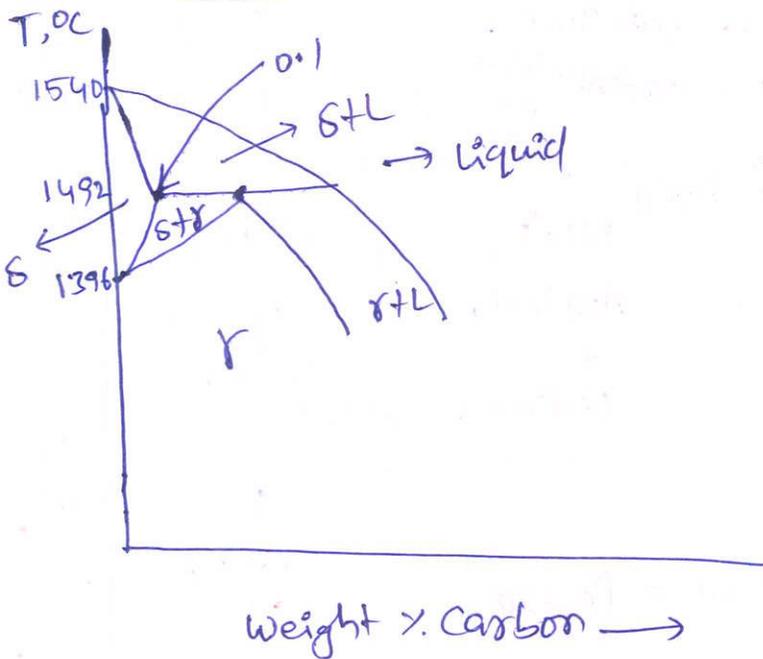


Eutectic Reaction in Iron Carbon Diagram



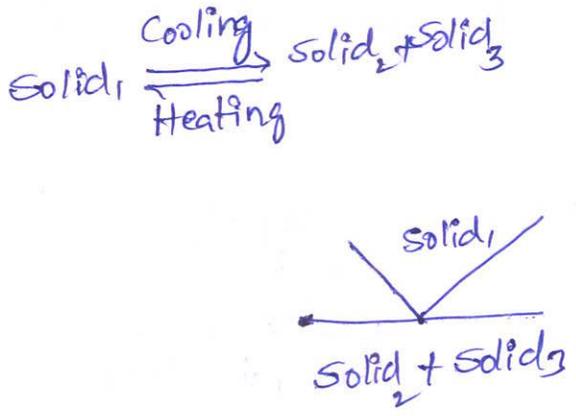
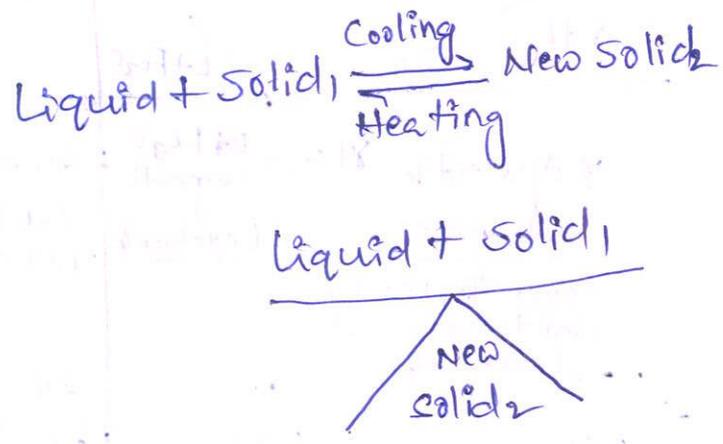
Liquid $\xrightarrow{\text{Cooling}}$ 4.3% Carbon
 Austenite + Cementite
 Ledeburite (Eutectic mixture)
 2066°F

Peritectic Reaction



Peritectic Reaction

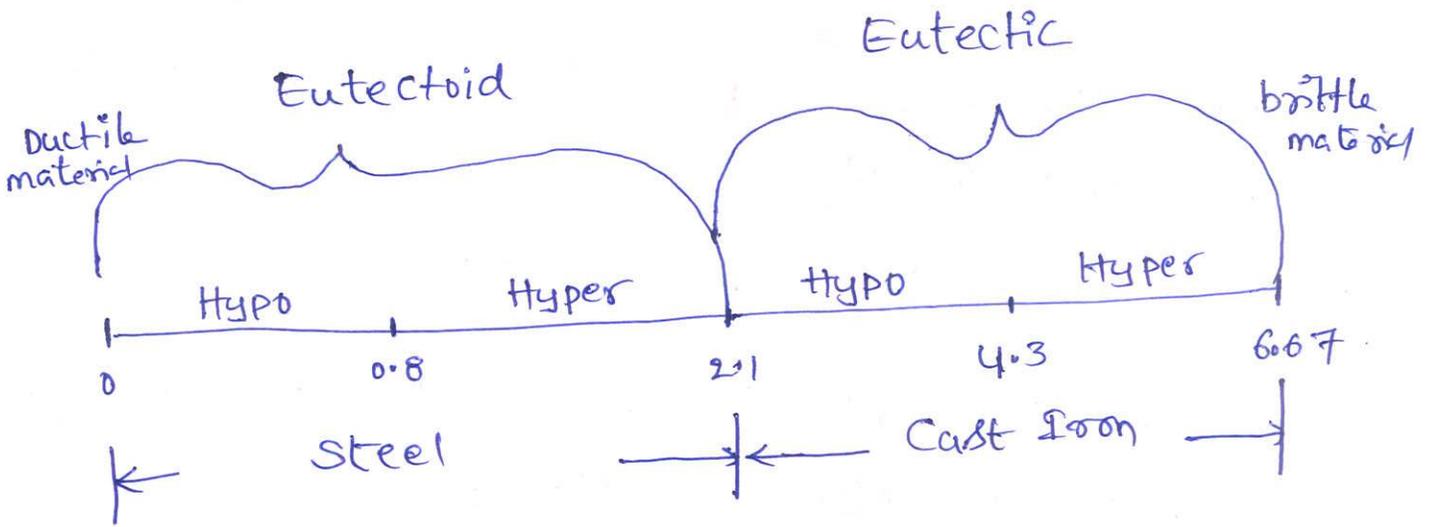
Eutectoid Reaction



Principal Phases of Steel and their Characteristics

Phase	Crystal structure	Characteristics
Ferrite	BCC	soft, ductile, Magnetic
Austenite (γ -Iron)	FCC	soft, moderate strength, non-magnetic
cementite	Compound of Iron & Carbon Fe ₃ C	Hard & brittle

Carbon line



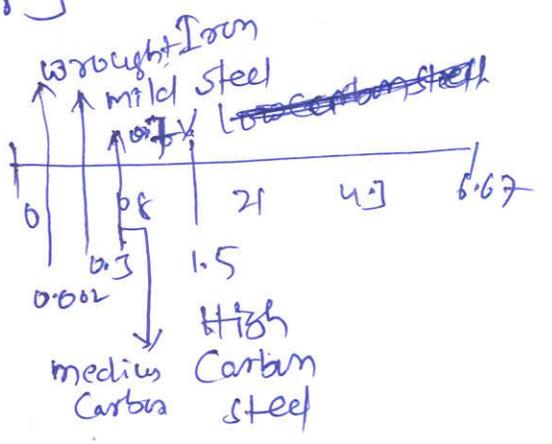
Steel - 2.1% → Eutectoid

Cast Iron - 4.3% → Eutectic

0% - 0.8% ^{b/w} ~~between~~ - Hypo } Steel
 0.8% - 2% ^{b/w} ~~between~~ - Hyper }

2.1% - 4.3% ^{b/w} - Hypo } Cast Iron.
 4.3% - 6.67% ^{b/w} - Hyper }

Carbon (0.002% ~~Carbon~~) → wrought Iron
 Carbon 0.3% mild steel (low Carbon)
 Carbon 0.7% ^{Medium Carbon Steel} ~~low Carbon steel~~
 Carbon 1.5% high Carbon steel



The Iron-Iron Carbide Diagram.

the diagram show three horizontal lines, which indicate isothermal ~~area~~ reaction (on cooling/heating)

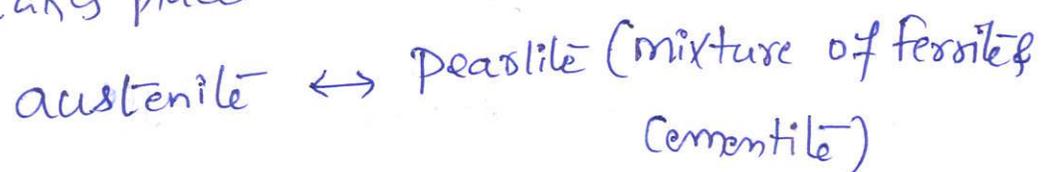
→ first horizontal line is at 1490°C , where peritectic reaction takes place.



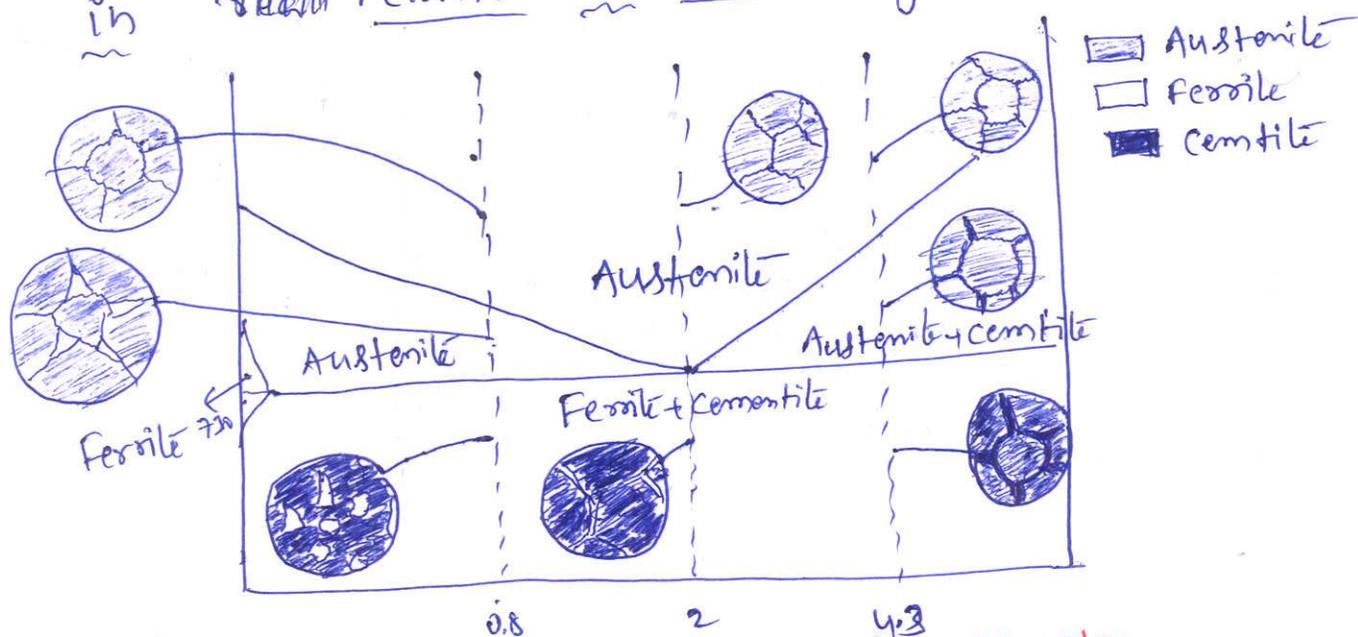
→ second horizontal line is at 1130°C , where eutectic reaction take place:



→ Third horizontal line is at 723°C , where eutectoid reaction takes place



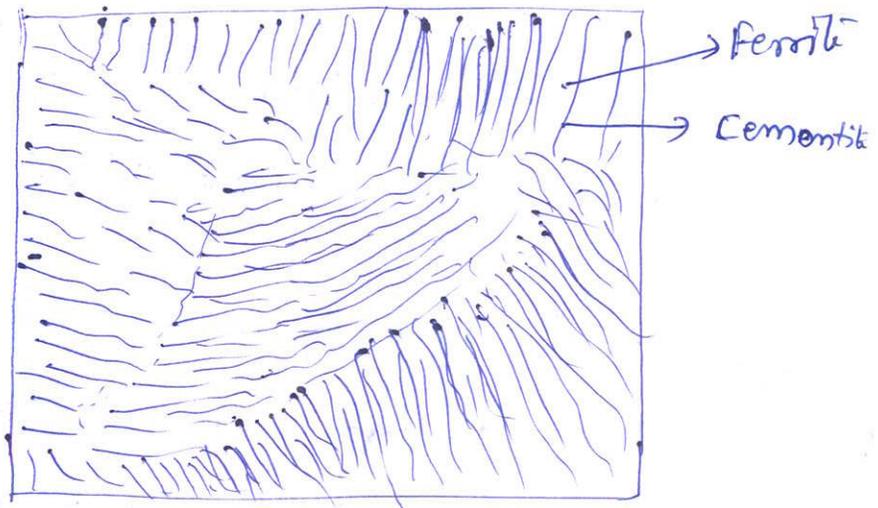
The Austenite to ferrite / cementite transformation
in relation to Fe-C diagram:-



Pearlitic structure:-

10

- The net reaction at the eutectoid is the formation of pearlitic structure.
- Since the chemical separation occurs entirely within crystalline solids the resultant structure is a fine mixture of ferrite^(white) and cementite (dark).
- pearlite is the eutectoid mixture containing 0.80% C and is formed at 723°C on very slow cooling.



Ledeburite:-

- Ledeburite is the eutectic mixture of austenite and cementite.
- it contains 4.3% percent C and is formed at 1130°C.

Ferrite :- Ferrite is known as a solid solution

→ it is an interstitial solid solution of a small amount of Carbon dissolved in a (BCC) iron.

- stable form of Iron below 912 deg.C
- the maximum solubility is 0.025% C at 723°C
- and it dissolves only 0.008% C at room temperature.

→ it is the softest structure that appears on the diagram.

Austenite :-

- Austenite is an interstitial solid solution of carbon dissolved in γ (F.C.C) iron.
- Maximum solubility is 2.0% C. at 1130°C
- High formability, most of heat treatments begin with this single phase
- it is normally not stable at room temperature. But, under certain conditions it is possible to obtain austenite at room temperature.

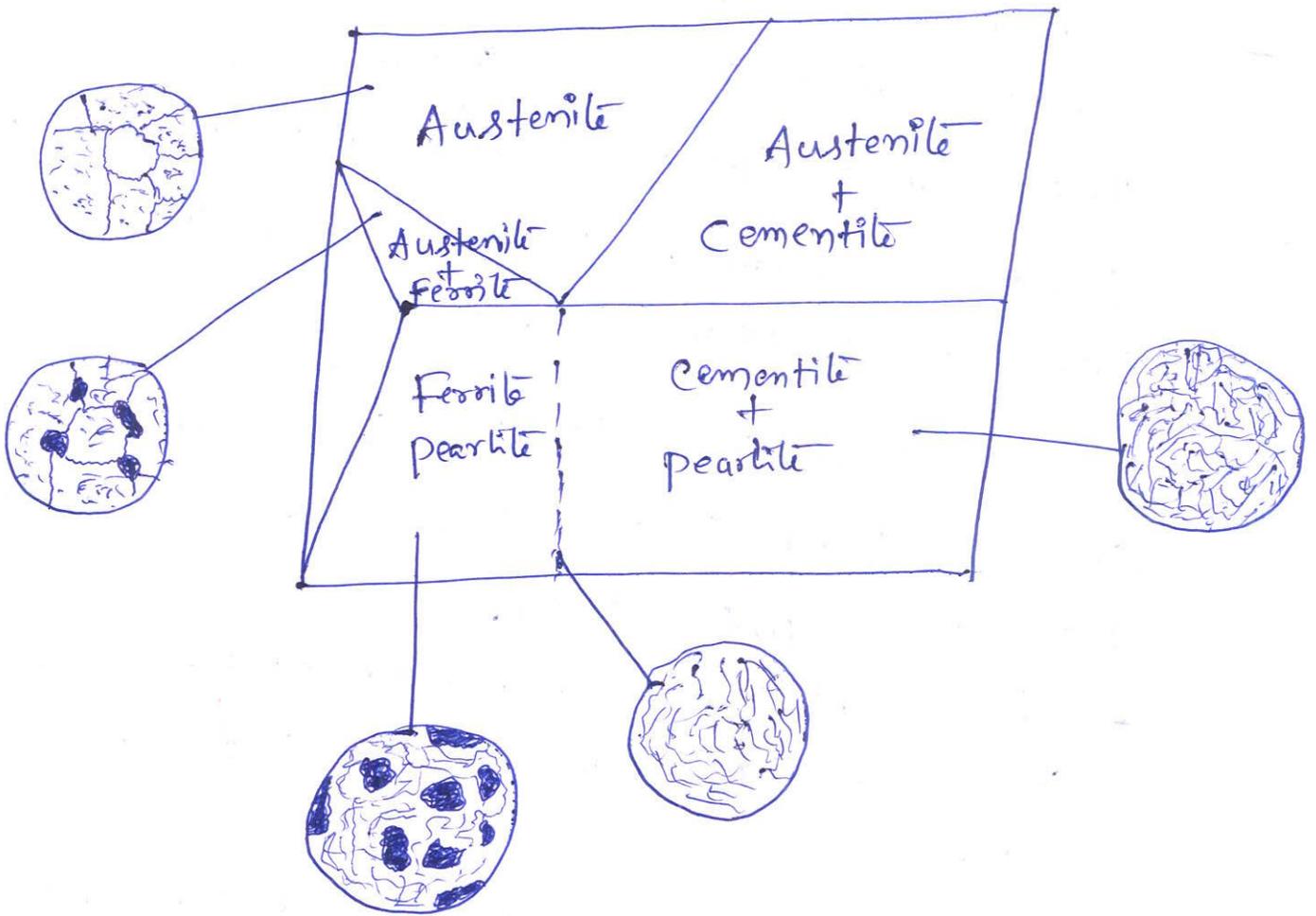
Cementite :-

- Cementite or iron Carbide, is very hard, brittle intermetallic compound of iron & carbon, as Fe_3C , contain 6.67% C
- It is the hardest structure. that appears on the diagram, exact melting point unknown
- Its crystal structure is orthorhombic
- it has
 - ⇒ low tensile strength (approx. 5,000 psi) but
 - ⇒ high compressive strength.

Martensite :-

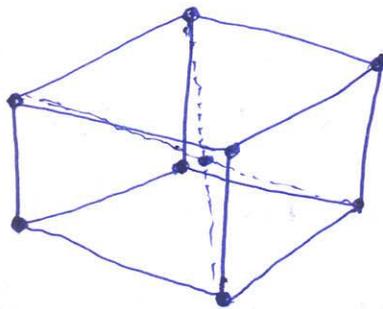
- Martensite a Super-saturated solid solution of Carbon in ferrite
- it is formed when steel is cooled so rapidly that the change from Austenite to pearlite is suppressed
- the interstitial carbon atoms distort the BCC ferrite into a BC-tetragonal structure (BCT); responsible for the hardness of quenched steel.

Variation in Microstructure in Steels :-



Structure of Solids :-

- (1) Body centred cubic (B.C.C) space lattice.
In a unit cell of body centred cubic space lattice there are nine atoms.



(a) Body Centred Cubic (B.C.C) Space Lattice

- The eight atoms are located at the corners of the cube and one atom at its centre.
- This type of lattice is found in alpha (α) Iron, tungsten, chromium, manganese, molybdenum, tantalum, vanadium etc.

- (2) Face centred cubic (F.C.C) space lattice is a unit cell of face centred cubic space lattice there are fourteen atoms.
- The eight atoms are located at the corner of the cube and six atoms at the centres of six faces.
- This type of lattice is found in gamma (γ) Iron, aluminium, copper, lead, silver, nickel, gold, platinum, calcium etc.

(3) close packed hexagonal (C.P.H) space lattice. (12) (17)

In a unit cell of close packed hexagonal space lattice

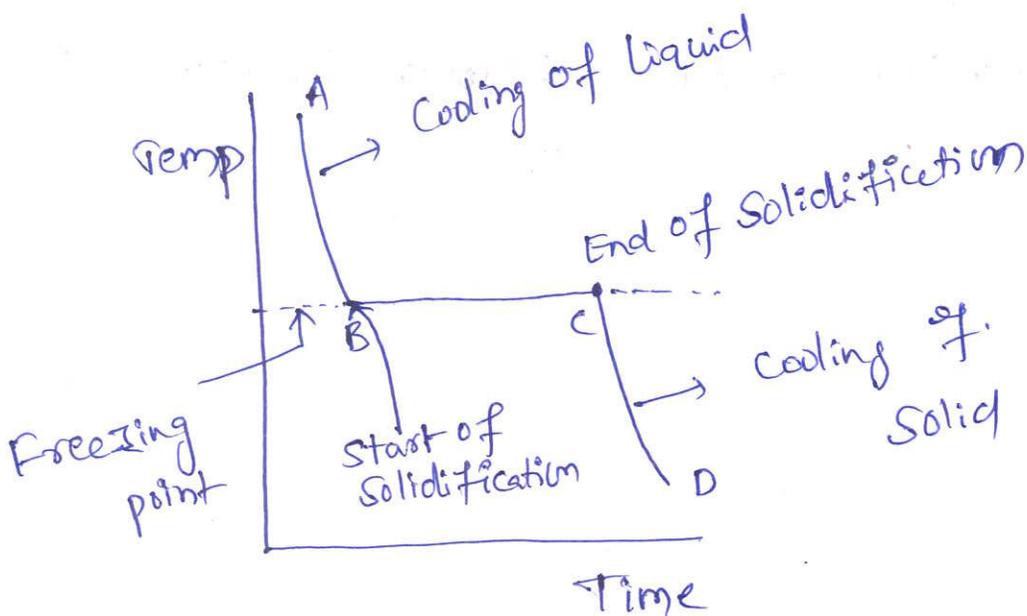
there are seventeen atoms.

→ The twelve atoms are located at the twelve corners of the hexagonal prism, one atom at the centre of each of the two hexagonal faces and three atoms are symmetrically arranged in the body of the cell.

→ This type of lattice is found in zinc, magnesium, cobalt, cadmium, antimony, bismuth, beryllium, titanium etc.

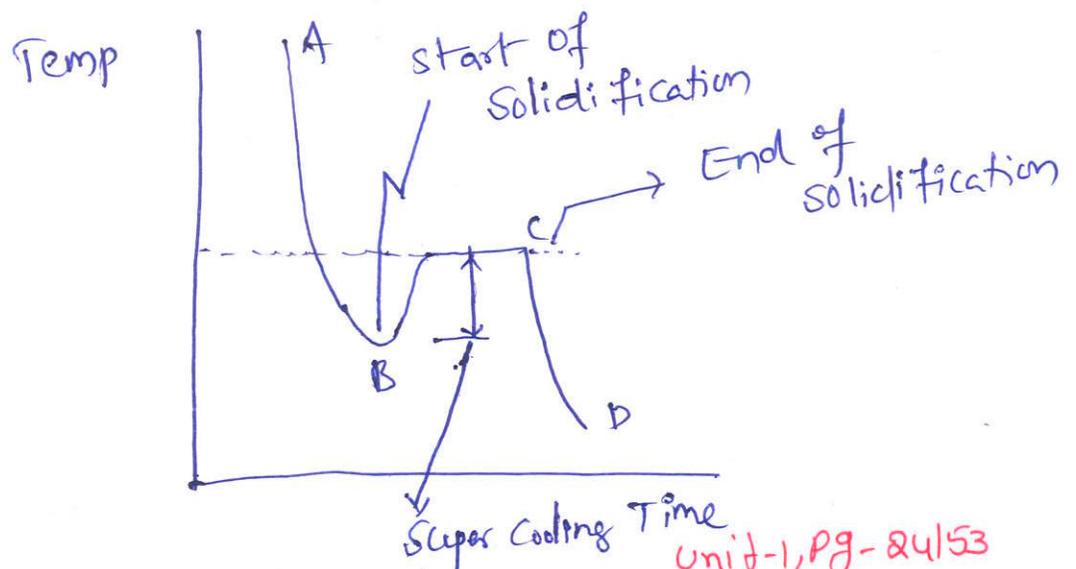
Cooling Curves of pure metals:- (slow cooling)

- Cooling Curve shows the temperature at which phase changes.
- liquid to solid or solid to liquid
- occurs in an alloy system, consists of following the temperature as a function of time.



A → B = Cooling of liquid

Cooling Curves of pure Metals with Super Cooling.



Engineering Materials

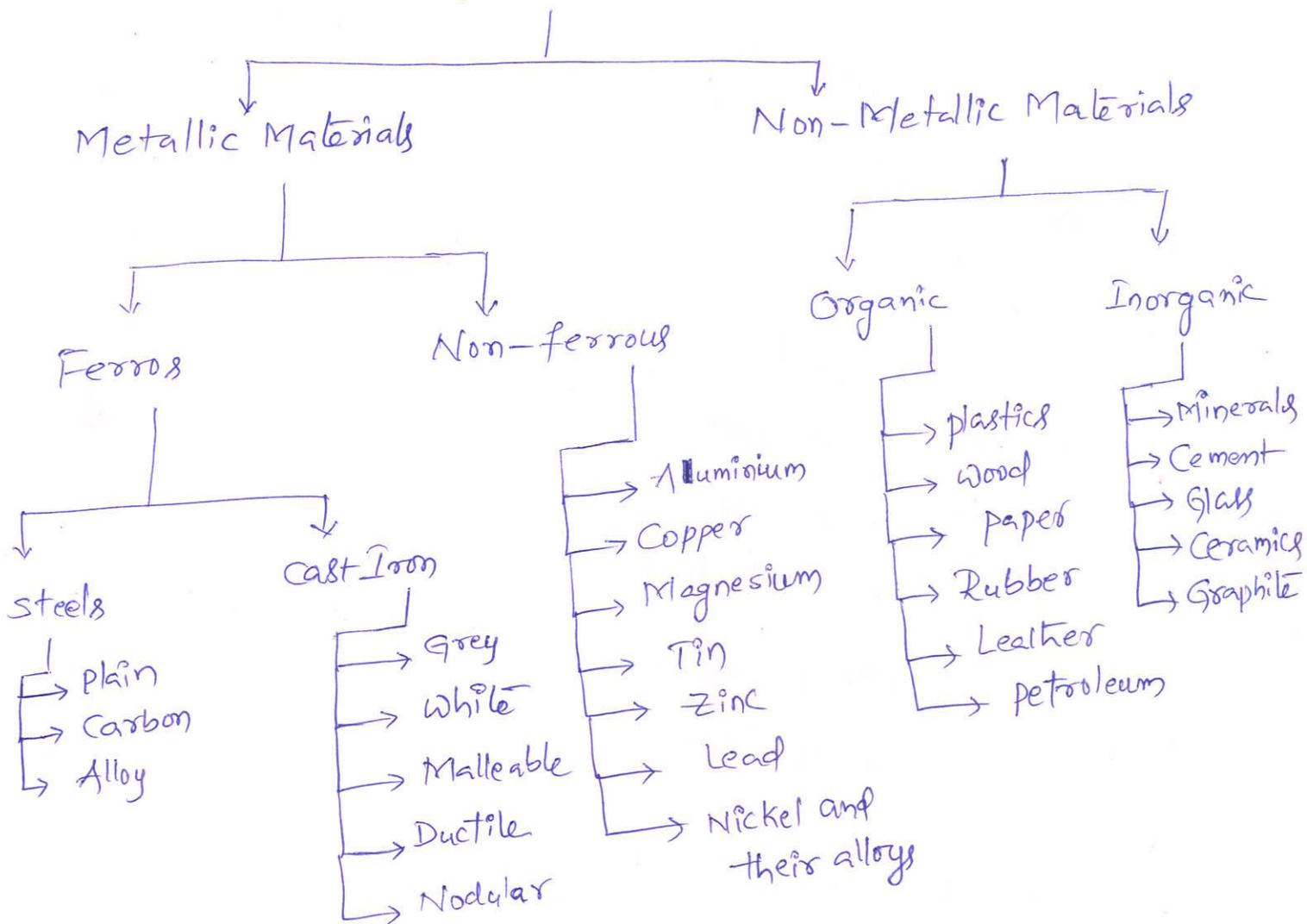
13



Introduction:-

Engineering Materials used to Manufacture of articles or products, dictates which Manufacturing process or processes are to be used to provide it the desired shape.

Engineering Materials.



Ferrous Metals:-

Ferrous Metals are Iron base Metals which include all variety of pig iron, cast iron wrought iron and steels.

Types of Iron Ore

S.NO	Iron ore	Color	Iron %
1	Haematite (Fe_3O_4)	Red	70%
2.	Magnetite (Fe_3O_3)	Black	72%
3.	Limonite	Brown	62-65%
4	Siderite	Brown	48%

Main Types of Iron :-

1. Pig Iron.

2. Cast Iron.

(A) White cast iron

(B) Gray cast iron

(C) Malleable cast iron

(D) Ductile cast iron

(E) Meehanite cast iron

(F) Alloy cast iron.

3. wrought iron

4. Steel

(A) plain Carbon steels

(1) Deep Carbon steels

(2) Low Carbon steels

(3) Medium Carbon steels

(4) High Carbon steels.

(B) Alloy steel. $\left\{ \begin{array}{l} \rightarrow (1) \text{ high speed steel} \\ \rightarrow (2) \text{ stainless steel.} \end{array} \right.$

Unit-1, Pg-26/53

Pig Iron:-

→ Pig iron was originated in the early days by reduction of iron ores in blast furnace and when the total output of the blast furnace was sand cast into pigs which is a mass of iron roughly resembling a reclining pig.

→ Pig iron acts as the raw material for production of all kinds of cast iron and steel products.

→ The charge in the blast furnace for manufacturing pig iron is.

(a) Ore - Consisting of iron oxide or carbonate associated with earth impurities

(b) Coke - A fuel.

(c) limestone - A flux.

In addition to iron, pig iron contains various other constituents in varying form of impurity such as carbon, silicon, sulphur, manganese and phosphorus etc.

It has the following approximate composition which is given as under.

- Carbon - 4 to 4.5%
- Silicon - 0.4 to 2.0%
- Manganese - 0.2 to 1.5%
- Phosphorus - 0.1 to 2.0%
- Sulphur - 0.4 to 1.0%
- Iron - Remainder

1. Grey pig iron (Grade 1, 2, and 3)

Grey pig iron contains about 3% carbon in free form. This is a soft type of pig iron.

2. White pig iron (Grade 4)

White pig iron is hard and strong. It contains almost all of the carbon in the combined form.

Cast Iron :-

Cast iron is basically an alloy of iron and carbon, and is obtained by re-melting pig iron with coke.

Structural Steel Introduction:-

- steel structure is a metal structure which is made of structural steel. Components connect with each other to carry loads and provide full rigidity.
- Because of the high strength grade of steel, this structure is reliable ~~off steel~~ and requires less raw materials than other types of structure like ~~concrete~~ concrete structure and timber structure.
- In modern construction, steel structures is used for almost every type of structure including heavy type ~~off structures~~ industrial building, high-rise building, equipment support system, infrastructure, bridge, tower, airport, Terminal, heavy industrial plant, pipe rack.

Main structural types: -

- Frame structures :- Beams and columns
- Grids structures :- Latticed structure or dome
- Prestressed structures
- Truss structures :- Bar or truss members
- Arch structures
- Arch bridge
- Beam bridge
- Cable-stayed bridge
- Suspension bridge
- Truss bridge: Truss members.

some commonly used HSLA steel grades and

Applications ASTM A517 Grade F

- Yield strength : 760 Mpa
- Tensile strength :- 860 Mpa
- High strength and toughness

Applications:-

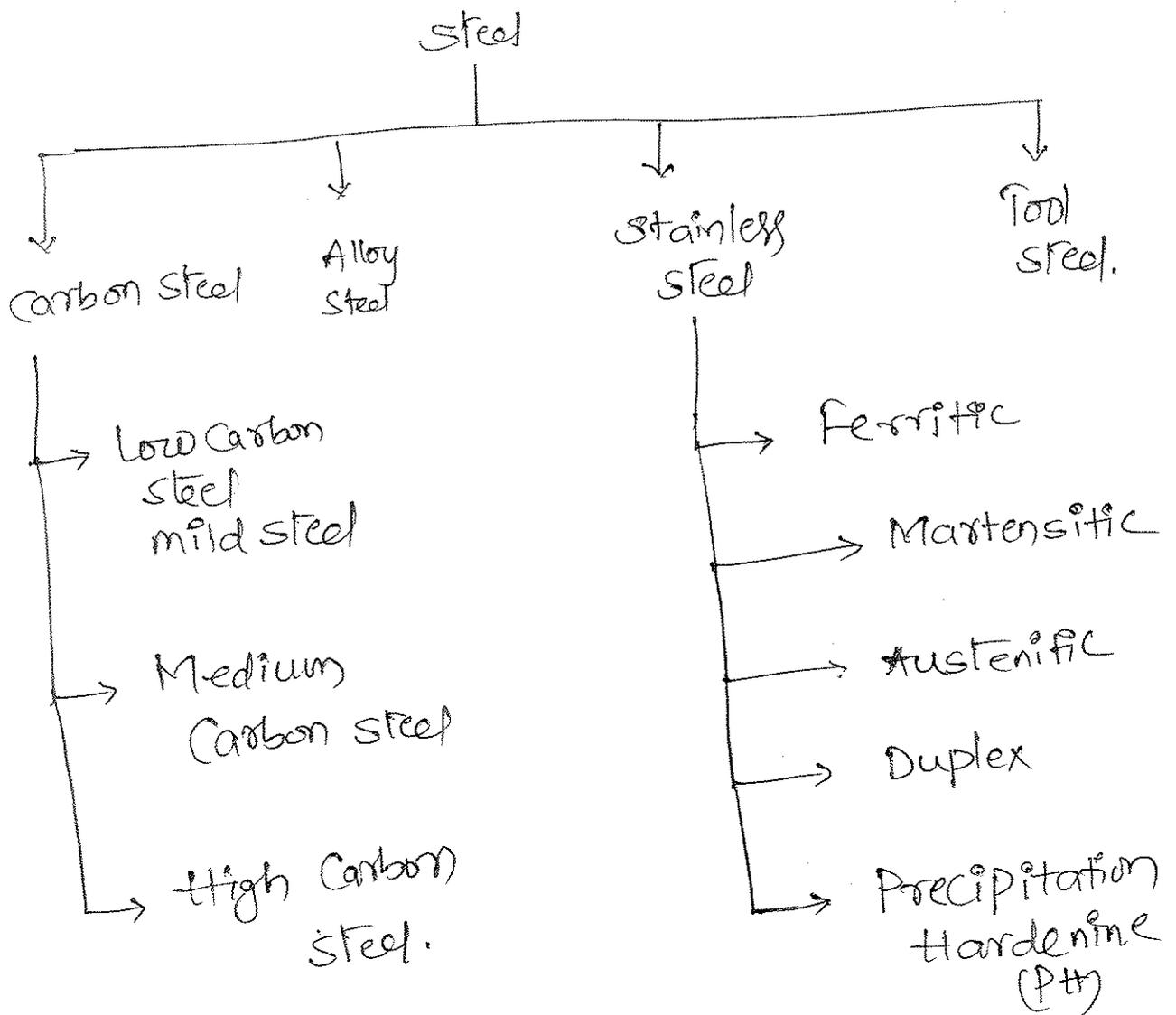
- Bridge construction
- Building construction.

General Applications:-

- Oil and gas pipelines.
- Heavy-duty highway and off-road vehicles
- Aerospace Applications
- Construction and farm machinery.
- Industrial equipment, storage tanks
- Mine and railroad cars.
- passenger car components
- Bridges
- power transmission towers
- Building beams and panels.

Classification of steel

(4)



High strength Low Alloy steels :- (HSLA)

→ The HSLA steel is sheet or plate form have low Carbon content of 0.05 to 0.25% in order to produce adequate formability and weldability

→ And they have Manganese content up to 2.0%

→ small quantities of Chromium, nickel, molybdenum, copper, nitrogen, vanadium, niobium, titanium, are used in various combinations for improving properties.

High Strength Low Alloy (HSLA)

17

- HSLA attains a yield strength of 290-550 MPa. and tensile strength of 415-700 MPa.
- Microstructure of HSLA consists of ultra fine ferrite and pearlite. This fine microstructure is mainly responsible for such high strength and toughness.

Major factor responsible for increased strength in HSLA are

Fine ferrite grain size:-

fine grain size of ferrite in HSLA is achieved by control of austenite grain size by hot rolling and by solid second phase precipitates. These fine solid precipitates (with high melting point-temperature) hinder the growth of austenite by pinning the grain boundary during heating at high temperature and refine the grain size.

Precipitation hardening:-

Precipitation hardening also called as age hardening is a heat treatment technique used to increase the yield strength of materials.

→ Formability :- ~~As a~~ byproduct of the high work hardening

(8)

Solid Solution Strengthening :-

When solute atoms are added into solvent, local stress fields are formed that interact with the dislocation, prevent the motion of dislocations and causes an increase in the strength of the material, this mechanism of strengthening is called as solid solution strengthening.

High strength Low Alloy :- (HSLA)

→ High - strength low alloy (HSLA) steel;

microalloyed steel, are designed to provide better mechanical properties than conventional carbon steels.

→ the HSLA steel in sheet or plate form have low carbon content (0.05 - 0.25%) in order to produce adequate formability and weldability.

They have manganese content from 1.5 - 2.0%

along with 0.1% of chromium, nickel, molybdenum vanadium, niobium, titanium, and zirconium

are used in various combinations to obtain a fine grain size upto 5 μ m

High strength low-alloy steels provide specific desirable combinations of properties such as :-

- ⇒ High strength
- ⇒ Toughness
- ⇒ Wear resistance
- ⇒ Weldability.
- ⇒ ~~Atmos~~ Atmospheric corrosion resistance

Chemical Composition (mass%) and Mechanical properties of the steels.

Types of steel	C	Si	Mn	Ti	Yield Strength MPa	Tensile Strength MPa	Elongation (%)
A. Mild steel.	0.05	0.01	0.24	-	241	384	43
B. Solid solution hardened steel	0.08	0.62	1.46	-	370	487	30
C. DP steel.	0.05	0.89	1.25	-	432	618	27
D. precipitation hardened steel	0.09	0.01	0.80	0.07	539	636	22
E. TRIP steel	0.15	1.48	0.99	-	510	644	37

Reducing Residual stresses

→ There are three major approaches to residual stress relieving:-

- * Thermal And Mechanical
- * shot peening
- * vibratory stress Relief

HSLA

→ Large applications

→ High yield, good weldability and acceptable corrosion resistance.

→ Resist to form martensite in weld zone

Dual-phase steel.

→ Quench from temp. above A_1 but below A_3 to form SF

→ strength comparable to HSLA while improve formability with no loss of weldability

→ Automotive structure and body application

Dual phase Steels

General Characteristics:-

- The idea of producing dual phase steel grades originated in 1970s.
- Efforts have been made to produce lightweight vehicles without losing structural integrity and crash resistance.
- The reduction of weight is order to limit fuel consumption and gas emissions.
- Dual phase (DP) steel are low-carbon low alloy materials with 20-30 vol % hard phase (martensite or bainite) in a ductile ferrite matrix.
- Soft ferritic network provides good ductility; while, hard particles play the load bearing role.
- This microstructure, in fact, shows some kind of metallic composite.

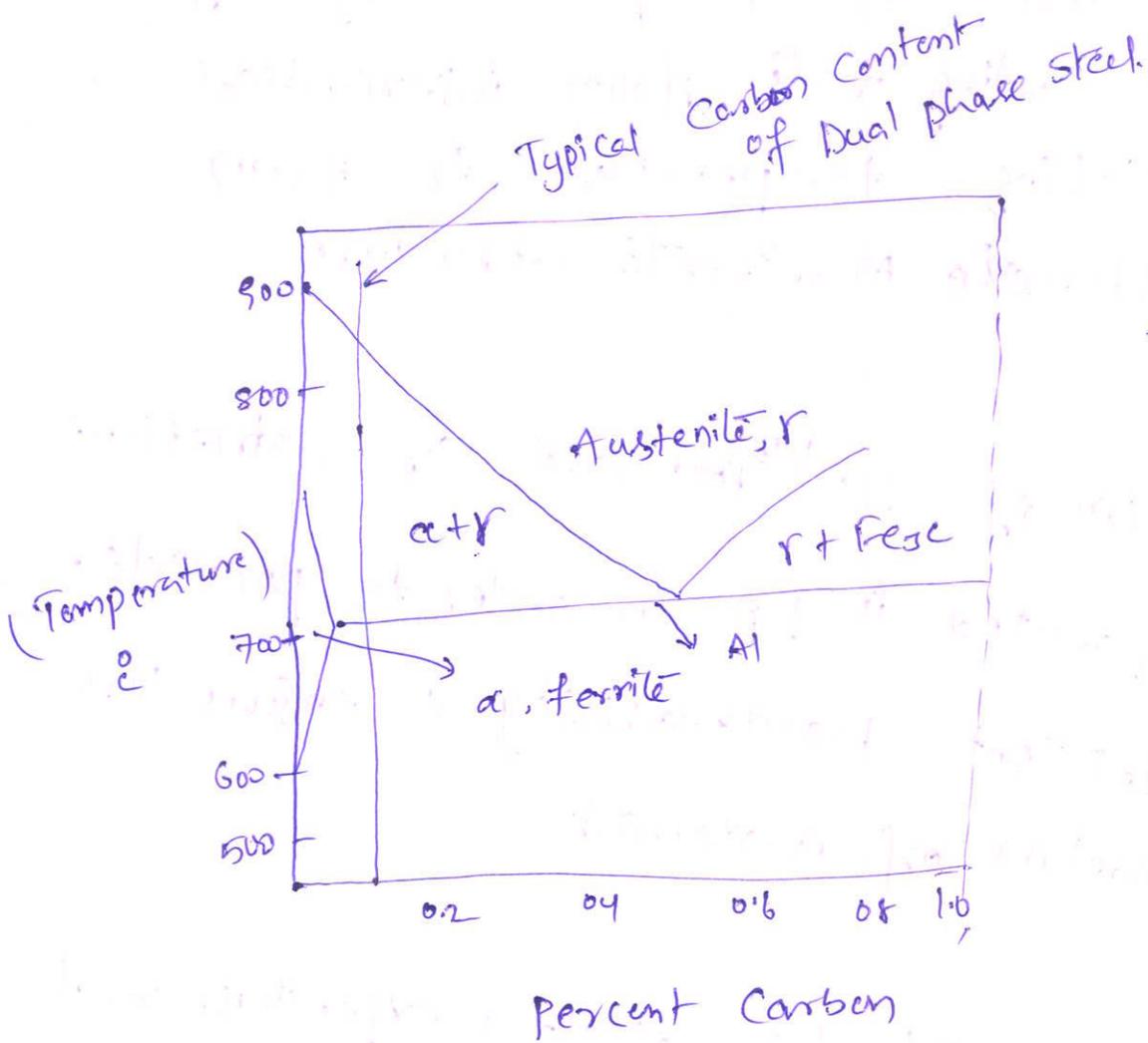
Dual phase steels:

20

→ Microstructure

- ⇒ 75-85 vol % ferrite
- ⇒ Remainder mixture of ~~Mart~~ Martensite, Lower bainite, Retained austenite
- ⇒ Usually consists of more than 2 phase

→ Essentially just a low carbon steel thermomechanically processed for better formability than ferrite-pearlite steels of similar tensile strength



γ = Austenite

α = ferrite

δ = Delta-iron

cm = cementite

Dual phase steel (DP)

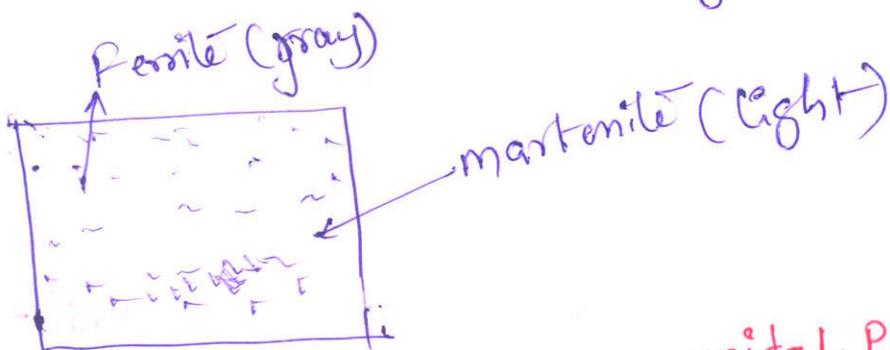
→ After 1970, major interest was generated in USA in low alloy steel that were heat treated to form a mixed microstructures of ferrite and martensite.

• "Dual phase steel"

→ DP steel can be produced in hot-rolled and cold-rolled product by apply rapid cooling rate from isothermal annealing temperature to form ~~martensite~~ martensite structure.

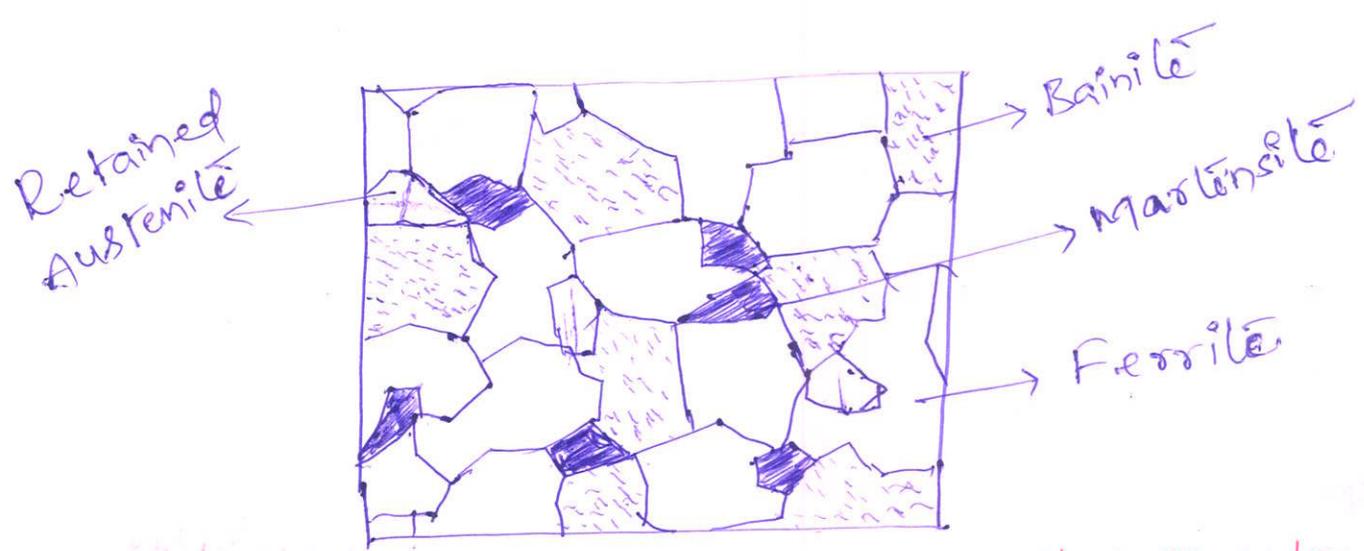
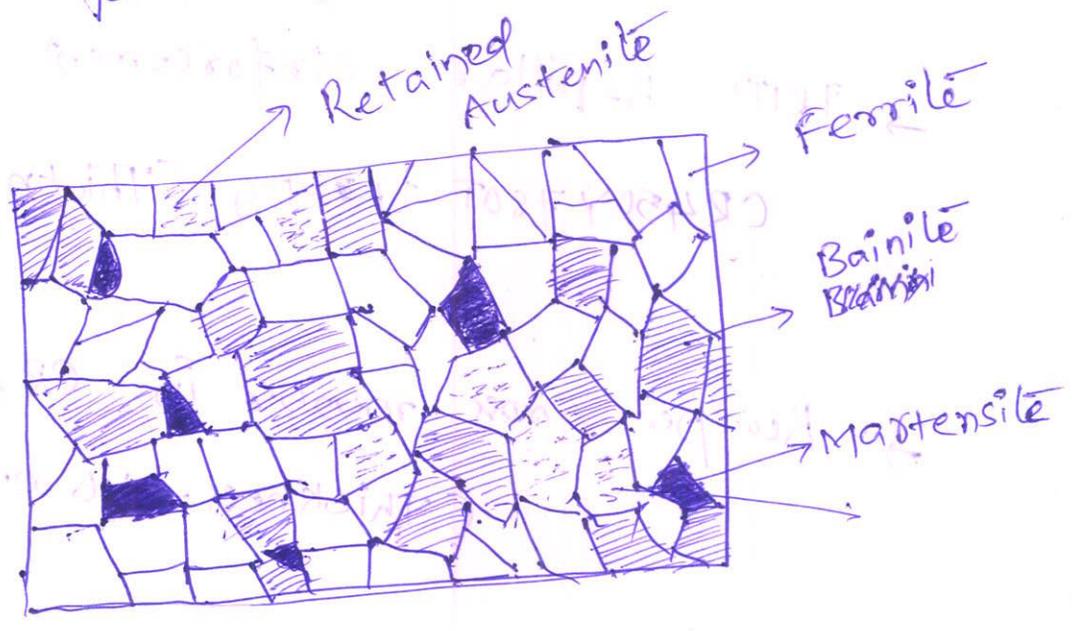
→ Addition of Si, Mn and Cr sometime incorporated in DP in order to provide sufficient hardenability to ensure the formation of martensite.

→ Trend of DP steel → expensive and large scale usage



TRIP Introduction :- TRIP (Transformation-induced plasticity steel)

- TRIP-aided steel are new generation of low-alloy steel.
- Enhanced combination of strength and ductility.
- Triple phase micro structure - Ferrite, bainite and retained austenite.
- Greater elongation.
- High strain hardening capacity.
- Good formability and drawability.



Application:-

- As a result of their high energy absorption capacity and fatigue strength,
- TRIP steels are particularly well suited for automotive structural and safety parts

Such as

- ⇒ Cross members
- ⇒ Longitudinal beams
- ⇒ B-pillar reinforcement
- ⇒ Sills and bumper reinforcements

→ TRIP B-pillar reinforcement is

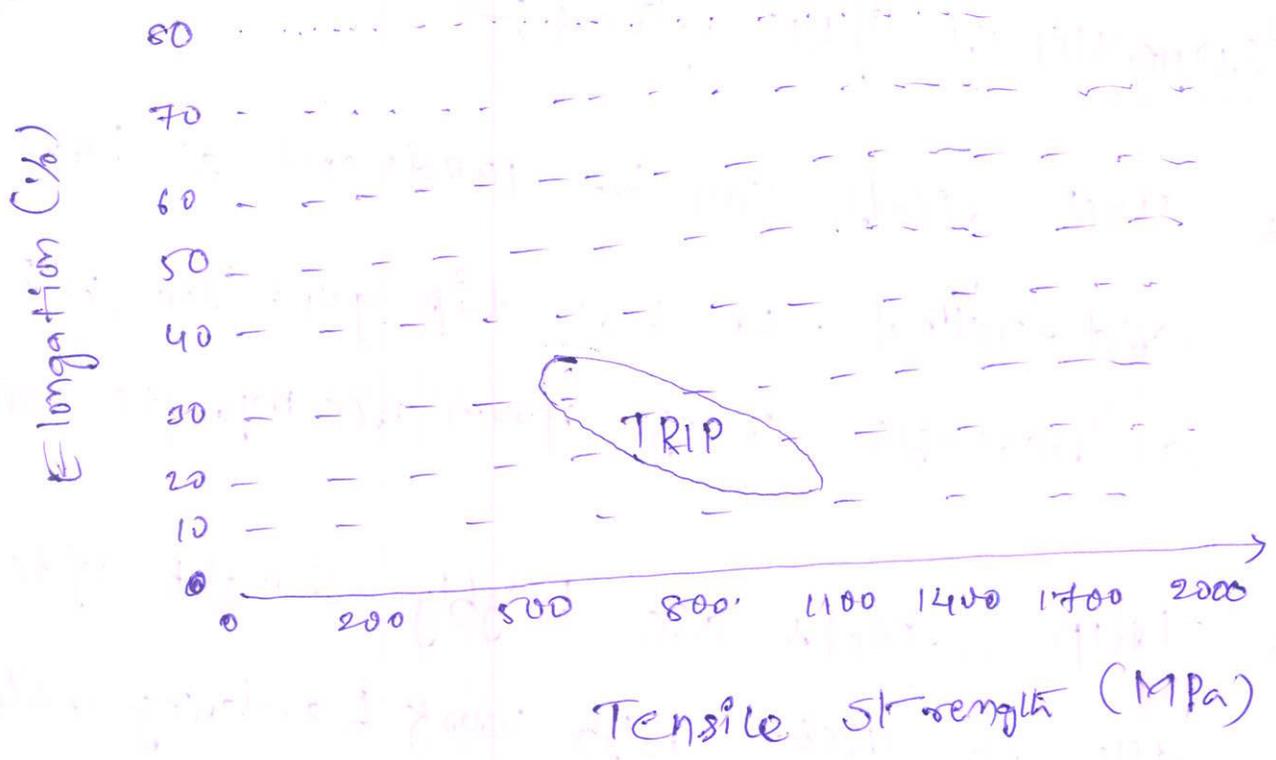
CR450Y780T-TR-EG (Thickness: 1.2 mm)

→ Bumper cross member is CR450Y780T-TR-EG
(Thickness: 1.6 mm)

Properties of TRIP steels:-

22

- TRIP steels can be produced as hot-rolled, cold-rolled, or hot dip galvanized, with a strength range from 500 MPa to 800 MPa.
- TRIP steels are highly sought after due to their high work hardening rate which is created by the hard second phases that are dispersed in the soft ferrite during deformation.
- Despite the fact that initial work hardening rate of the material is lesser than that of, say, dual phase steels, TRIP steels sustain their hardening rate at much higher strain level, where DP steels work hardening rate would deteriorate.
- As a result of the high work hardening rates, TRIP steels also have substantial stretch forming properties.



→ The high strain hardening capacity and mechanical strength make these steels an excellent metal for automotive parts that require a high energy absorption capacity.

→ TRIP steels also have a strong work hardening following deformation.

TRIP Steels Properties:-

→ Work hardening:-

When compared to other advanced high strength steel, TRIP steels exhibit and retain a higher work hardening rate at higher levels of strain.

Maringing Steel

23

Introduction :-

- Maraging Steels are low-carbon $< 0.02\%$ iron-nickel steel that possess an excellent combination of strength and toughness superior to carbon hardened steels.
- very high nickel, cobalt, and molybdenum contents and very low carbon contents.
- strength due to the formation of iron-nickel martensite and then formation of ~~iron-nickel~~ iron-nickel intermetallic compounds as precipitate phase during ~~aging~~ aging.
- Hence the name maraging steel. — martensite ~~forming~~ aging.

Maringing Steels :-

- than it would be had the steel been allowed to cool at a natural rate
- Maraging 350 is an alloy that has become an integral ~~material~~ material in the airplane and aerospace industries.

→ Due to its strength and its ability to withstand excess conditions including frequent and sudden changes in speed and temperature,

→ Mangaging 350 is used in the production of socket motor cases

Martensitic Steel:-

24

13

Martensitic steel are ultra high strength steel alloys a special class of low-carbon steel, that exhibit superior strength and toughness compared to most other steel, yet have a similar ductility.

→ Martensitic is a term derived from Martensite and ageing, referring to the process by which the steel is strengthened.

→ Martensitic steel are widely used in the aerospace industry as well as parts for tools and weapons.

Composition and grades of Martensitic Steel.

→ Martensitic steel grades are named according to their nominal yield strength in thousands of pounds per square inch.

→ the Martensitic steel available commercially are designed to provide specific yield strengths that range from 1030 to 2040 MPa (150 to 350 ksi)

Some Martensitic steels achieve yield strengths up to 3540 MPa

Unit-1, pg-46/53

Different Maraging steel grades and their Composition

Grade	Composition (%)				
	Ni	Mo	Co	Ti	Al
18Ni 200	18	3.3	8.5	0.2	0.1
18Ni 250	18	5.0	8.5	0.4	0.1
18Ni 300	18	5.0	9.0	0.7	0.1
18Ni 350	18	4.2	12.5	1.6	0.1
18Ni cast	17	4.6	10.0	0.3	0.1
12-5-1(80)	12	3.0	-	0.2	0.1

Variations of Maraging steel grades developed

include :-

- stainless grades
- Additional cast grades
- Additional strength levels
- Cobalt-free and low-cobalt grades
- special grades for heavy sections
- Grades with superior magnetic characteristics

properties of Maraging steel:

25

14

- High yield strength and ultimate tensile strength
- High toughness
- High ductility
- High impact strength
- High fatigue strength
- Workability
- High resistance to crack propagation
- Weldability
- Heat treatment features
- Low coefficient of thermal expansion

Different Application areas of Maraging steel:

production tools

- Aluminium and zinc dies
- Casting and forging dies
- Carbide die holder
- Containers
- Gears for machine tools
- Index plates
- pistons
- Springs

Aerospace and aircraft part

- Anchor rails
- hooks
- Rocket motor cases
- universal fixtures

Unit-1, Pg-48/53

Mechanical properties of different 18Ni Maraging Steel grades

Grade	Tensile Strength Mpa	yield Strength Mpa	Elongation 2 in or 50mm (%)
18Ni(200)	1500	1400	10
18Ni(250)	1800	1700	8
18Ni(300)	2050	2000	7
18Ni(350)	2450	2400	6
18Ni(450)	1750	1650	8
200/250 300	1895	1825	11.5

High Speed Steel.

(26)

Introduction to High Speed Steel: - (HSS)

- High speed steel is a highly alloyed tool steel. Capable of maintaining ~~heat~~ hardness even at elevated temperature.
- High-speed tool steel are so named primarily because of their ability to machine materials at high cutting speed.
- High speed steel has unusually high resistance to softening at temperature up to 600°C . It is called red hardness.
- They are complex iron-base alloys of carbon, chromium, vanadium, molybdenum, or tungsten or combination thereof, and in some cases substantial amounts of cobalt.
- The carbon and alloy contents are balanced at levels to give high attainable

→ hardening response, high

→ high wear resistance.

→ high resistance to the softening effect of heat

→ and good toughness, for effective ~~use~~ ^{use} in industrial cutting operation.

→ Especially suited to applications involving complicated tool shapes:

→ drill

→ Taps

→ milling cutter

→ broaches.

Classification of HSS:-

→ The AISI established a classification system for the high-speed tool steel.

→ That system consists of a T for those steels that have tungsten as one of their primary alloying elements and an M. or those steels that have molybdenum additions as one of their primary alloying elements.

High Speed Steel:-

27

Typical alloying ingredients:-

- 1) Carbon
- 2) Tungsten or molybdenum
- 3) Vanadium
- 4) Chromium
- 5) Cobalt in some grade

Influenced of alloying elements on the steel properties

1) Carbon:- forms carbides, increases wear resistance is responsible for the basic matrix hardness

2) Tungsten or

2) Tungsten and/or Molybdenum

Improved red hardness, retention of hardness and high temperature strength of the matrix, form special carbides of great hardness.

3) Vanadium:- forms special carbides of

supreme hardness, increase high temperature wear resistance.

Two basic types of HSS :-

1) Tungsten type designate (T-grades)

2) Molybdenum type, designated. M-grades

→ In addition, there is a number that follows either the M or the T,

→ thus. these are high speed steel.

designated M7, M2, M41, T1, T15 and so on.

few common grade of HSS:

Type	C	W	MO	Cr	V	CO
T-1	0.70	18		4	1	5
T-4	0.75	18		4	1	5
T-6	0.80	20		4	2	12
M-2	0.8	6	5	4	2	
M-4	1.30	6	5	4	4	
M-15	1.55	6	3	5	5	5
M-42	1.05	1.5	9.5	4	1.1	8