

Heat Treatment (Binary)

Technology

DATE 4/05/21

- 1.) Introduction
- 2.) P-T phase diagrams, limitations
- 3.) TTT diagrams, limitations
- 4.) CCT diagrams
- 5.) [Mechanism of Pearlite - Austenite transformation
Kinetics of " " "]
- 6.) [Mechanism of Austenite - Pearlite transformation
Kinetics of " " "]
- 7.) [Mechanism of Austenite - Bainite transformation
Kinetics of " " "]
- 8.) [Mechanism of Austenite - Martensite transformation
Kinetics of " " "]

Introduction:

Structure - property relationship

Equilibrium phase diagram



Phases present in equilibrium with each other
Properties

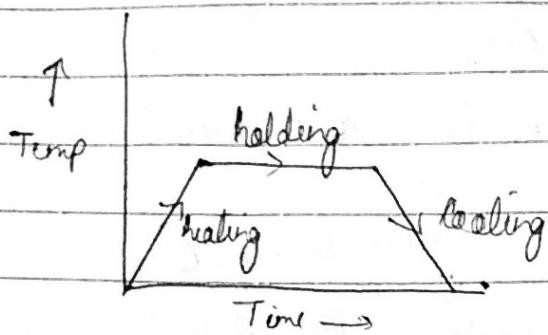


- ⇒ Type of phases present
- ⇒ fraction of phase present

Morphology

- ⇒ size
- ⇒ shape
- ⇒ Distribution

Heat Treatment process



heat treatment is the process of heating the specimen to a specified temperature, holding it to a specified time and then cooling it to a specified rate to the room temperature. cooling rate is very very critical as the final properties depends on the cooling rate.

Purpose of heat treatment

- To relieve internal stresses
- To increase toughness
- To increase ductility
- To increase tensile strength
- To increase hardness
- To improve magnetic properties
- To improve ~~thermal~~ properties electrical conductivity
- To refine grain size

Heat Treatment Variables:-

(i) Heating rate

Size and shape of specimen

small size - can be fast

large size - slow

shape - normal

- complex → variable thickness sections
→ sharp bends

(ii) Holding temperature

- by chemical composition of steel

(S.C.)

- if complex are present

24

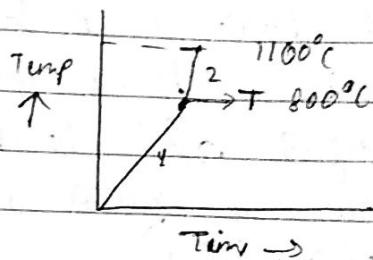
~~other than Fe₃C~~

1

higher holding temperature

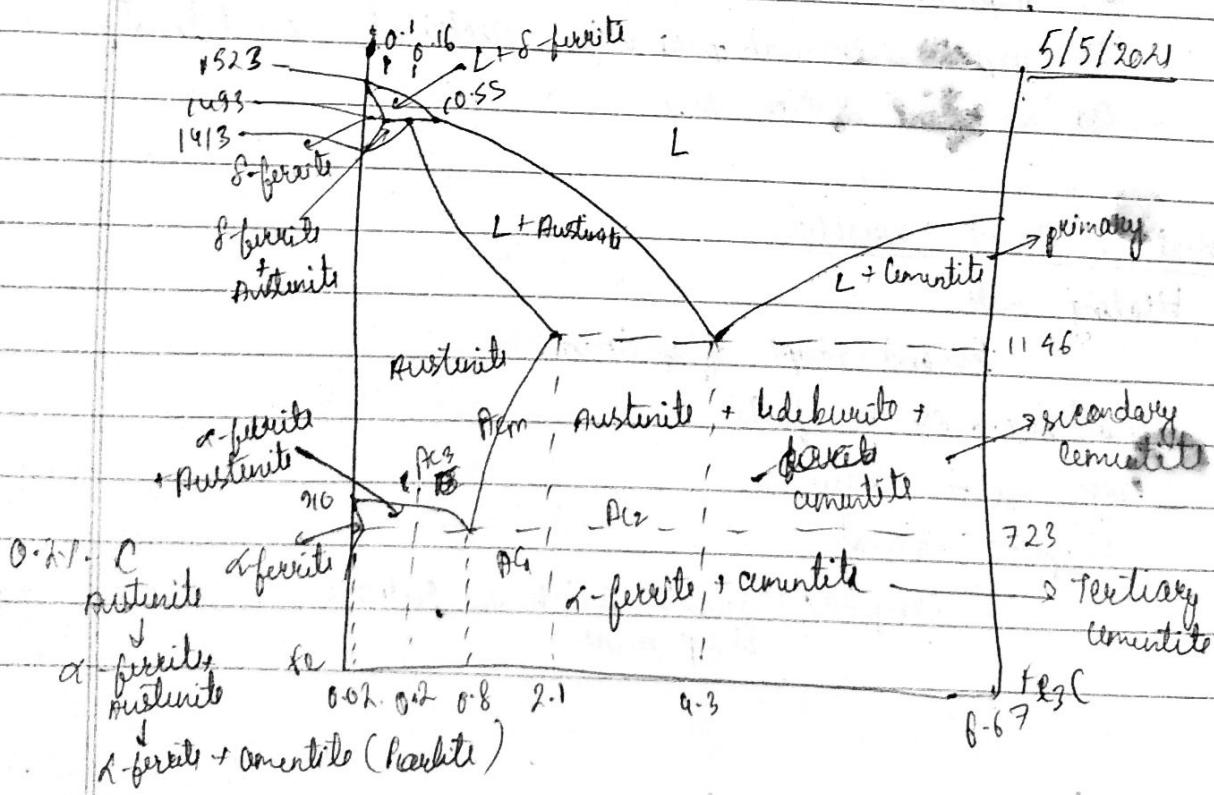
(iii) holding time

- size of specimen
- small size - less time
- large size - more time



(iv) Leaching rate

Very
 air cooling even
 very slowly → Animating
 relatively faster, normalizing
 handwriting

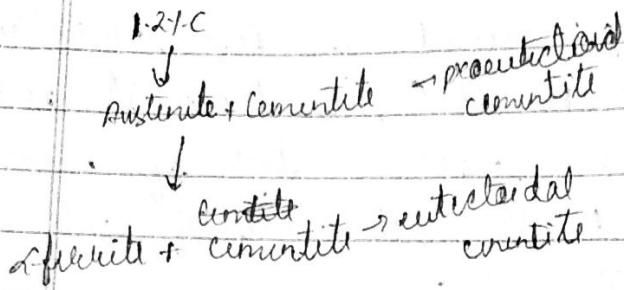


- ⇒ Carbon is also always present as Fe_3C , hence we never draw the diagram as Fe-C, we draw it as Fe- Fe_3C .
- ⇒ why we know 6.67 is the max^m content of carbon in iron; Max^m solubility of carbon in iron is 2.1 at 1146°C

$$\frac{12}{(56 \times 3 + 12)} \times 100 = 6.67\%$$

- ⇒ Ferrite → saturated solid solⁿ of iron or carbon in α -iron, similarly austenite is solid saturated solid solⁿ of iron into α -iron
- ⇒ why is cementite called an intermetallic compound → because cementite does not follow a valency ~~exp~~
rule but has a fixed proportion.
- ⇒ Cementite called as cementite because it is very hard as cement.
- ⇒ Leidenite is an eutectic mixture of austenite and cementite, its structure is not lamellar. (broken lamellae or irregular)
- ⇒ Fe_3C is metastable and it decomposes upon higher temp., hence its does not specific.
- ⇒ why β -iron is not represented.
- ⇒ AC → during α phase trans. temp remains constant and hence it is arrested (cused - A) →
- A_R → during cooling
- A_c → during heating $A_{\gamma} \rightarrow \alpha$ transformation
- Chaufage → heating
refridgeration → cooling

1.21.C



→ Difference between alloy and a solid solution \rightarrow metallic bonding \rightarrow a solid solⁿ is always a single homogeneous phase, but not in case of alloys may or may not be a single phase.

→ Phase diag. shows only the equil^m phases, hence we need TTT diagrams for more details
 like Bainite also phase diagrams requires infinite cooling time,
 and martensite also.

6/05/2021

* Temperature, Time, Transformation (TTT) stage diagram

Large no. of samples (same composition)
 each sample is heated in Austenitic range, holding for some time period depending upon size of sample, then quickly cooled followed by holding at different temperatures below A_1 , A_2 , A_3 till the transformation from austenite to pearlite is complete.
 diff in temp of transformation - very small.

fraction of
isothermal transformation
from austenite to
pearlite

$$t_2 < t_1$$

$$T_2 < T_1$$

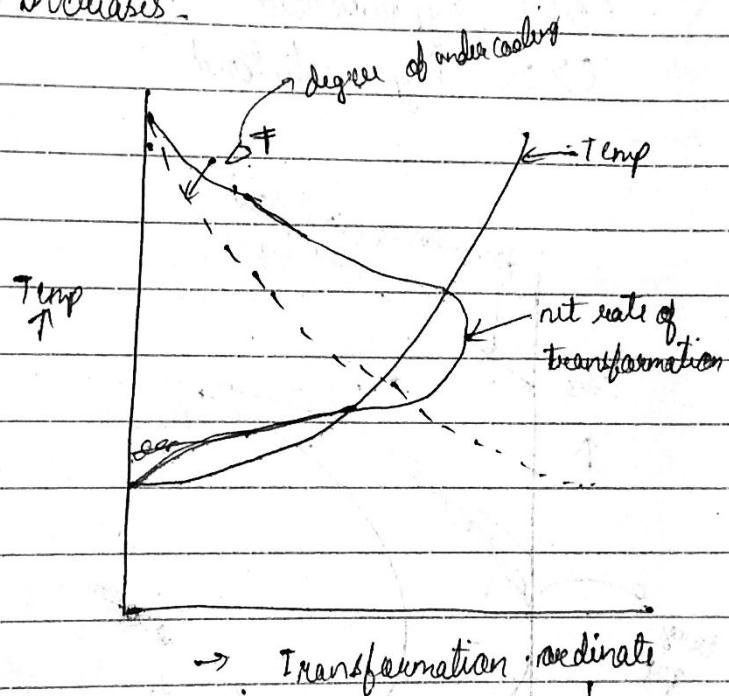
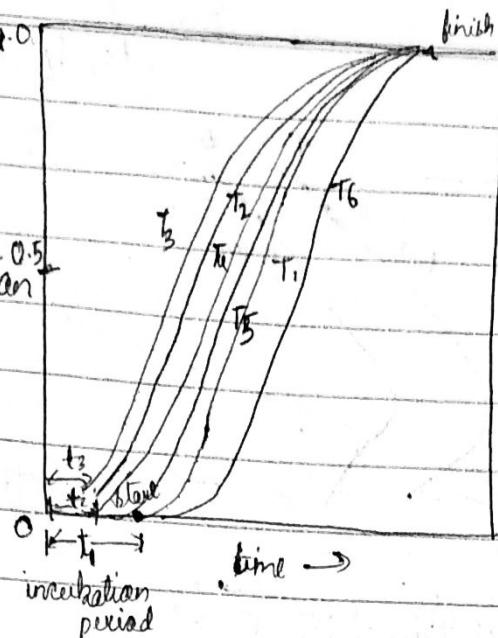
$$T_3 < T_2$$

with further decreasing in temperature the incubation period is increasing, hence first it decreases and then it increases.

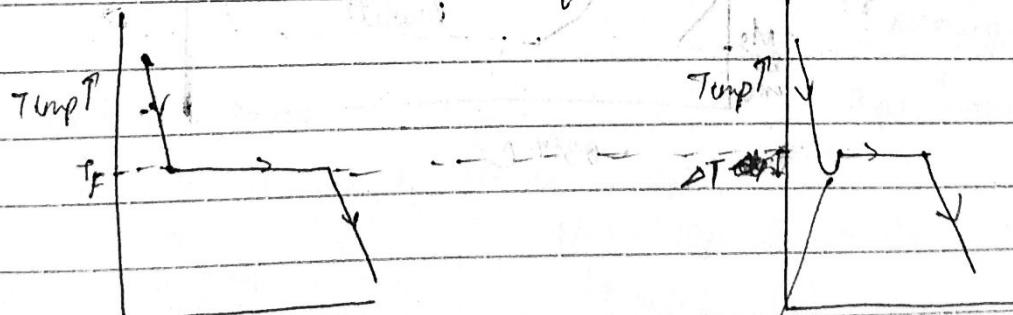
$$T_4 < T_3$$

$$T_5 < T_4$$

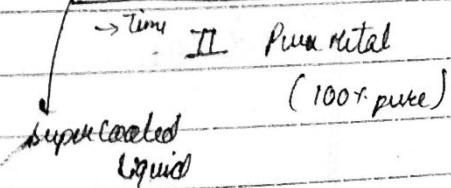
$$T_6 < T_5$$



→ Transformation coordinate



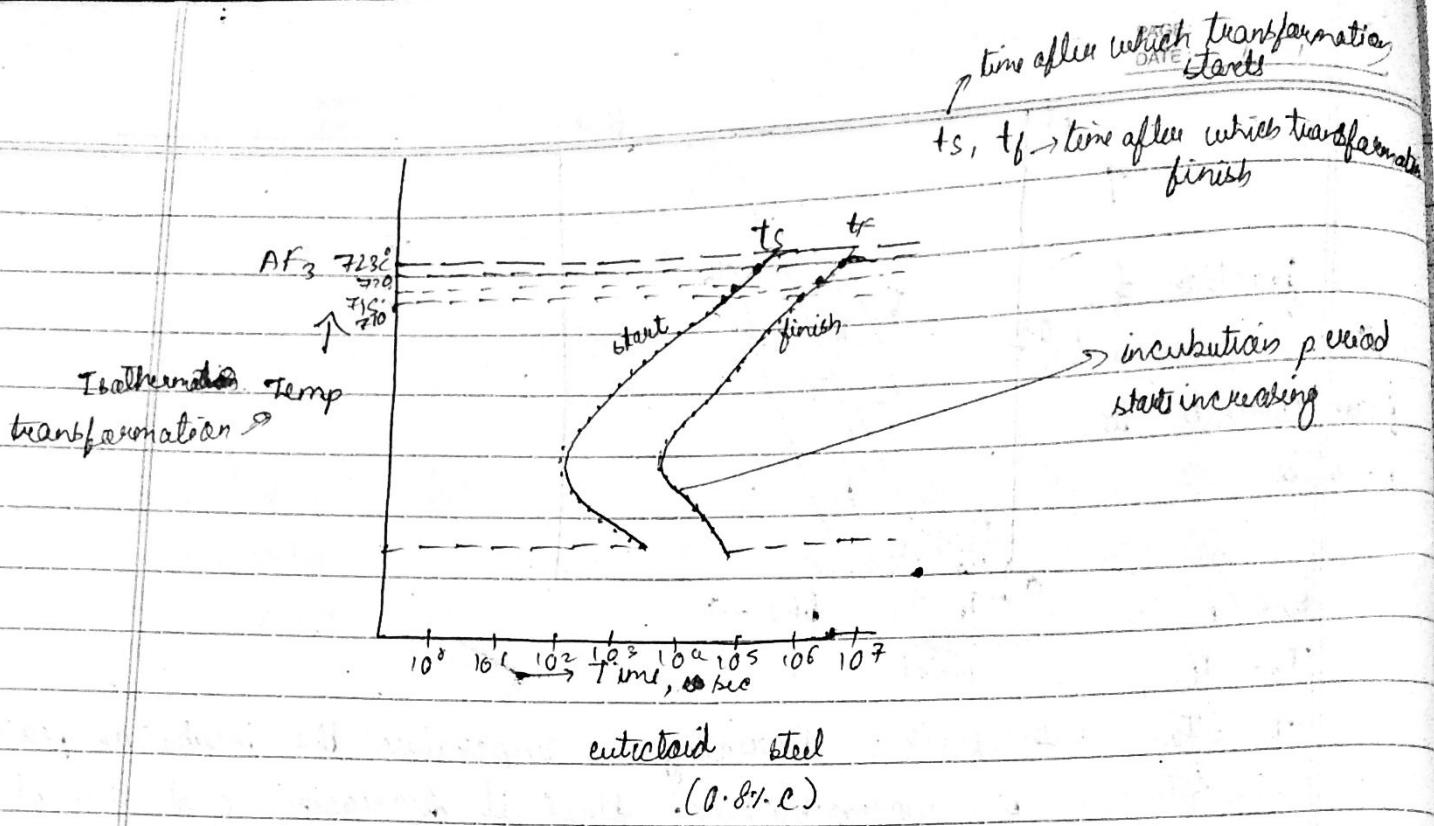
commercially
pure metal (some impurities present)



supercooled
liquid

Pure metal

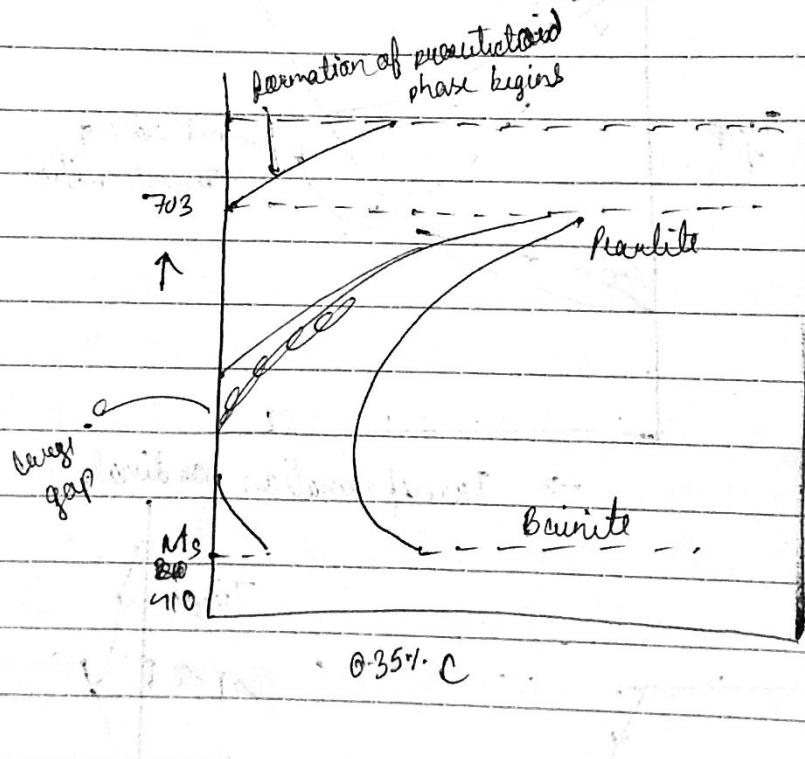
(100% pure)



$C < 0.8$ hypoeutectoid

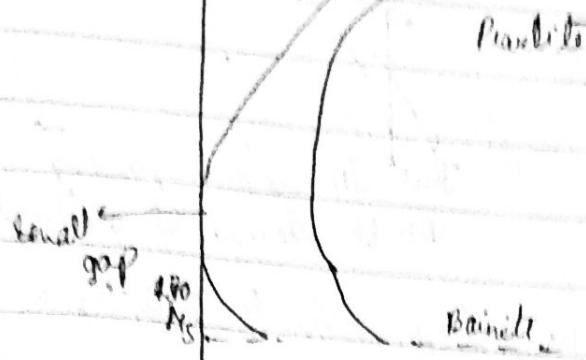
$C > 0.8$ hyper eutectoid

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$\approx Ms$ in case

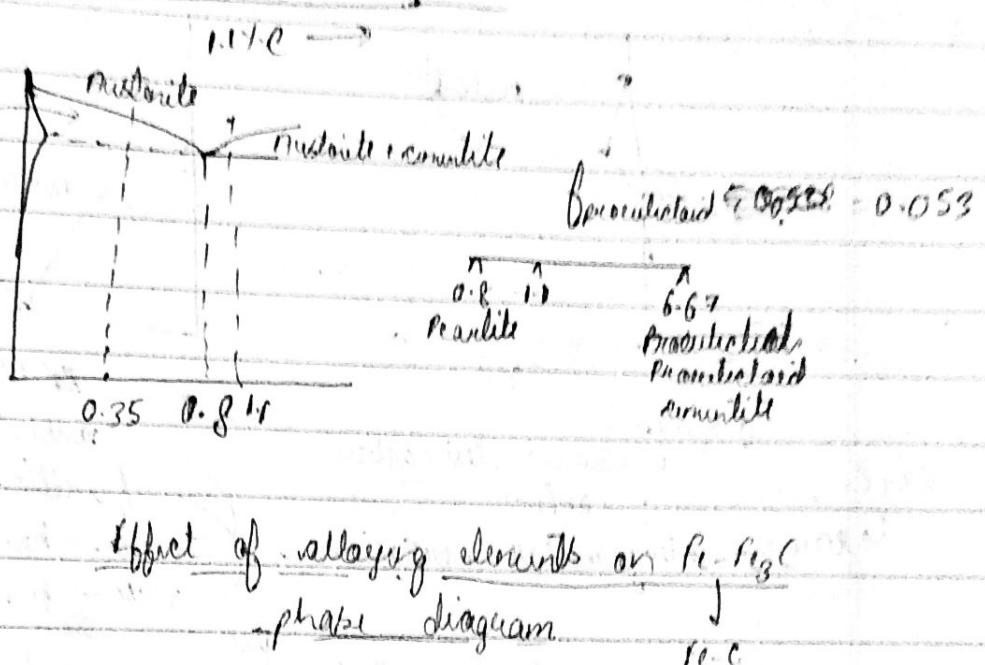
Ferrite-Cementite-Legends



$$0.8 - 0.85 \approx 0.6$$

$$0.8 - 0.023$$

α -ferrite
Austenite
 $0.023 \quad 0.35 \quad 0.8$
Ferrite-Cementite Pearlite
 α -ferrite



Effect of alloying elements on Fe-C phase diagram

I Ferrite stabilizers

Cu, Si

II Austenite stabilizers

Ni, Mg, Al, Cu

C
Si
Mn
P
S

Alloying elements

Carbide formers

W, Cr, Mo, V [Fe, W, Cr, Mo, V], & C

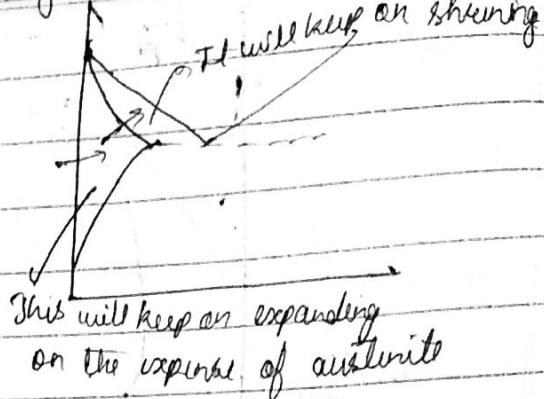
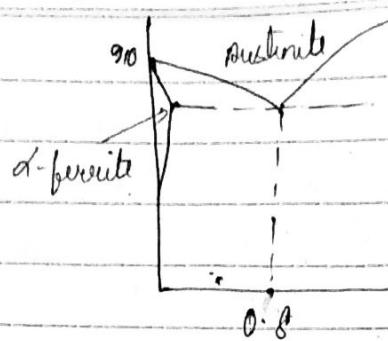
✓
tungsten

those increasingly added

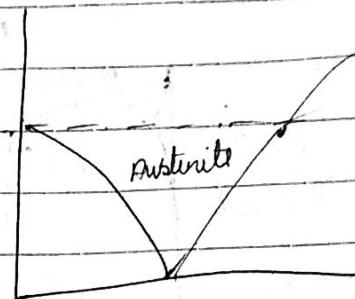
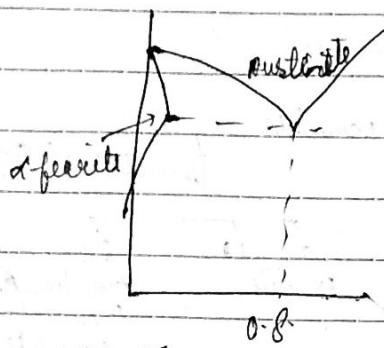
HSS \rightarrow High Strength Steel

\hookrightarrow contains Red hardness (it does not soften even if its red)

after adding ferrile stabilizer



after adding austenite stabilizer

 Cr_3C_2 0.03-0.05
to stainless steel carbon
content

leads to intergranular corrosion

0.1
CMartensitic stainless steel $\xrightarrow{\text{use}}$ surgical toolsaustenitic stainless steel
ferritic stainless steeluse \rightarrow home utensils
use \rightarrow turbine blades

+ 18/8 composition

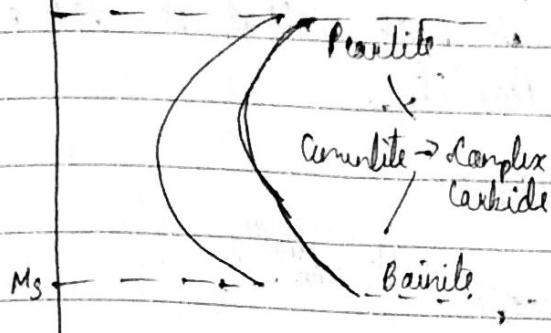
18-Cr-8-Ni

316L
 $\xrightarrow{\text{C-0.03-0.05}}$

316

Effect of Alloying Elements

low alloy steels



elements are present, then \xrightarrow{I} If carbides forming alloying elements are present, then in place of cementite it will be complex carbide

\xrightarrow{II} Special case of low low alloy steel

high alloy steels

Ms
below C

III

Ms

\hookrightarrow is above room temperature

IV

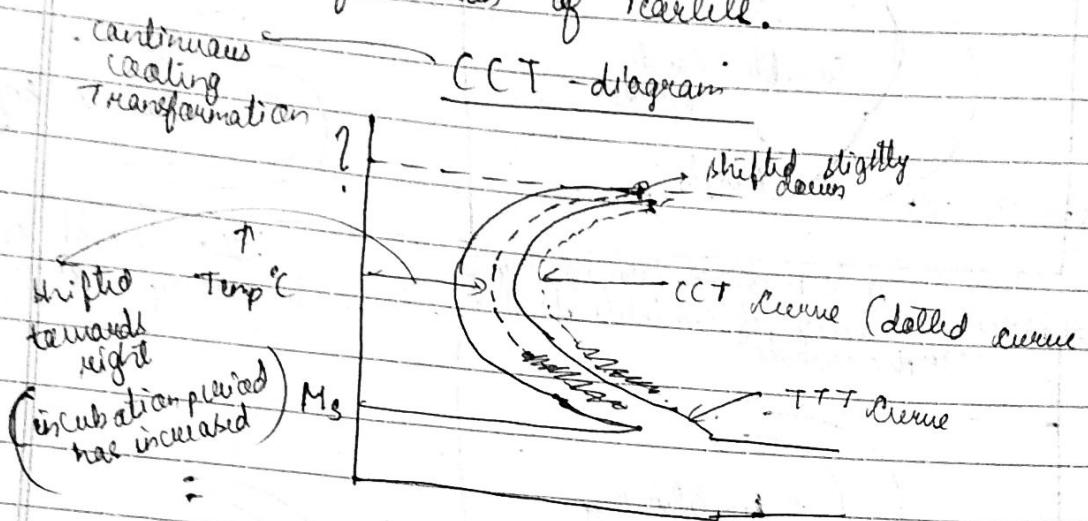
In this case there are two minima corresponding to austenite, there are two distinct bays \Rightarrow pearlitic bay and Bainitic bay are distinct, it is a very special case of low alloy steels.

\Rightarrow III and IV are cases of high alloy steels, there is only pearlitic or bainitic bay but not both.

\Rightarrow Why is no Bainite Bay in III?

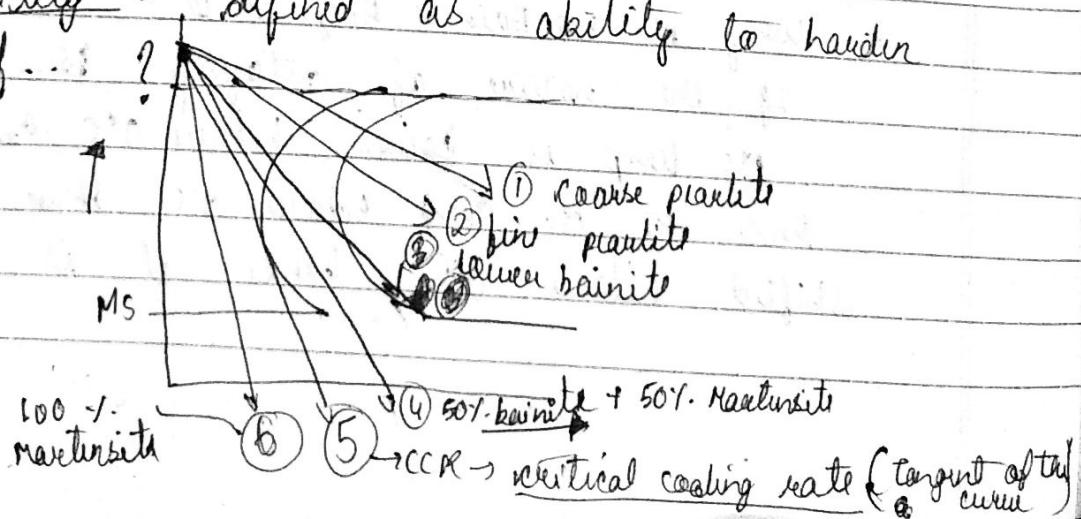
If the nature of alloying elements such that Ms temp is lower below 0°C , hence the bainite has shifted below 0°C hence it is not visible.

" in IV only Bainitic bay is present, the nature of alloying elements is such, that it does not favour formation of Pearlite.



Why CCT diagram? TTT diag. were based on the fact that all transformation takes place at constant temperature. But in real practice very few heat treatment process (like isothermal annealing) occur at const temp, ~~but~~ in most of the cases we have continuous cooling of the transformation specimen.
 Solid line \rightarrow TTT diag
 Dashed line \rightarrow CCT curve
 \Rightarrow difference \rightarrow
 $\Delta T \rightarrow$ increases
 degree of undercooling
 $t \rightarrow$ increases
 incubation period

Hardenability \rightarrow defined as ability to harden itself.



⇒ To get 100% martensite we need to apply a severe quench, if we quench it with brine then it will crack or warp the specimen, which is not good.

remedy:- It is only possible, if we can shift the cooling curve towards right. This shift can be brought about by the addition of alloying elements.

How to increase the hardenability of the steel?

factors affecting hardenability

(i) C content

~~↑~~ C ↑ → hardness increases

but is not practical → brittleness will increase

(ii) grain size: Coarse grain required (small gb area)
nucleation of a pearlite takes place at austenite grain boundaries

→ pearlite formation is favored by large grain boundary area

→ fine grains have large grain boundary area

→ hence, coarse grains will reduce the possibility of formation of pearlite.

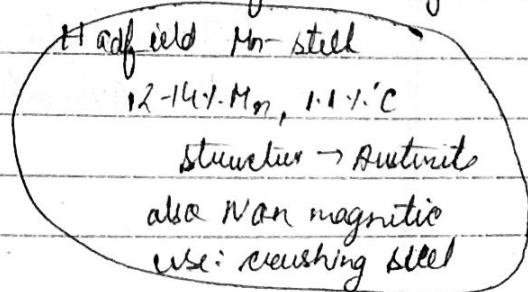
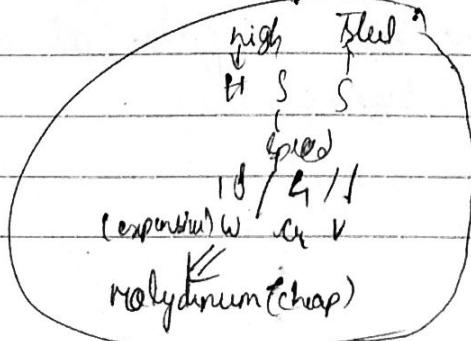
Cracks with coarse grain: prefer ball-pitch →

• Specimen strength decreases.

(iii) Addition of alloying elements

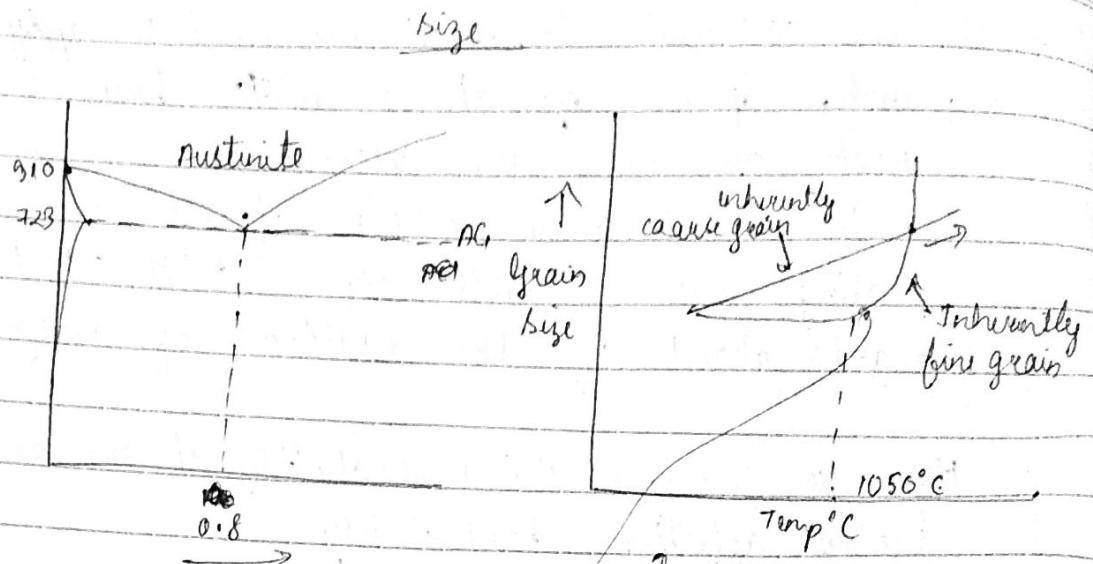
⇒ Mn, Mo → increases the hardenability
Molybdenum

⇒ Co ↓ → decreases the hardenability (the only element)



Austenitic grain size

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→ Transformation should occur at 723°C , i.e. Ar_1 temperature
→ Pearlite \rightarrow Austenite

→ Then size of the austenite grains is called original austenite grain size.

→ Natural transformation thus place slightly above 723°C

→ In ~~real~~ actual situations, pearlite \rightarrow Austenite transformation takes place slightly above Ar_1 .

→ why slightly above PC ?

- To ensure complete transformation
- To ensure pure homogeneity of austenite

% of carbon is uniform throughout

→ "Actual Austenitic grain size"

→ aka. Austenitic grain size

→ plot of grain size vs temperature

→ This is due to presence of carbides, oxides and nitrides at the grain boundaries.

→ refractory compounds (mp is very high)

Nitrogen = group 5A

→ forms a very stable compound with group 3 elements, Al, B, etc.

→ They dissolve in austenitic matrix, and grain growth is rapid, hence larger grain growth rate is faster at after 1050°C .

Steel (based upon austenitic grain size)

Inherently

Coarse grain steel

Inherently

Fine grain steel

Importance (of austenitic grain size) :-

1.)

$$\sigma_y = \sigma_0 + K_y d^{-1/2}$$

\hookrightarrow Hall - Petch equation

σ_y = Yield strength

σ_0 = Frictional stress

K_y \rightarrow Extent of dislocation pileup

d \rightarrow Austenitic grain size

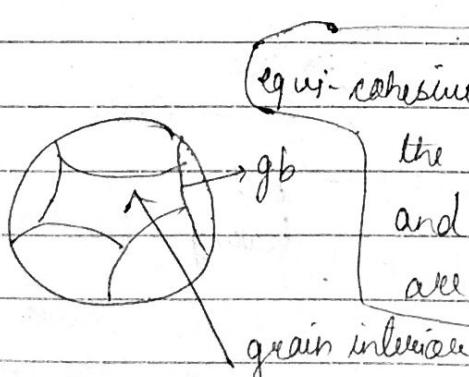
Conclusion: with decrease in grain size the yield strength increases.

2.) Influence Impact transition Temperature

aka ductile to brittle transition temperature

as grain size increases, impact transition temperature also increases, and it \rightarrow brittle mechanism.

3.) Creep strength \rightarrow (high temperature)



equi-cohesive temperature \rightarrow at this temperature

the strength of the grain boundary and strength of grain interior both are equal.

above equi-cohesive temperature, thus grain size increase, creep strength will also increase, but with decrease in grain size creep strength increases below equi-cohesive grain size

4) Fatigue strength → when load reversal takes place
strength under cyclic loading (ability to withstand cyclic loading)
fine grain size → higher fatigue strength

5) Hardenability →
grain size increases → hardenability increases

21/05/2021

Determination of Austenitic grain size

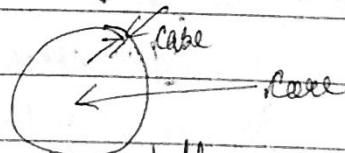
For revealing austenitic grains

metallurgical method

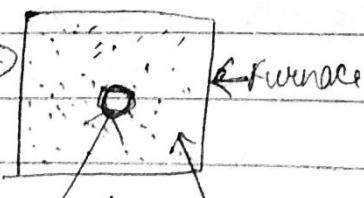
change of composition takes place

No change in composition

I Case carburizing
II Oxidation



The specimen heated to a temp of 910°C in absence of air for 6 to 8 hours



Below up to a small depth we called it case, and the particles not suitable for blast furnace inside is called core.

be hard to reduce abrasion
also the core should be tough.

Then it is allowed to cool in the furnace itself.

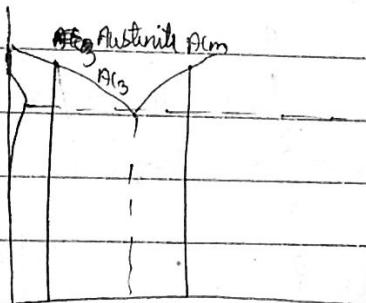


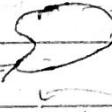
austenite grain ~~as the carbon will diffuse into~~
 after cooling there will be a network of carbon
 on the surface, which is the austenitic grain boundary.

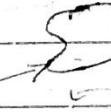
II Oxidation: In this case we heat the sample in the furnace at a high temp and directly cool to remove temperature

oxidation  An oxide layer will form on the surface.

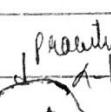
After polishing and etching, the oxide will form a network all around the grain boundary. hence we can measure the austenitic grain boundary.

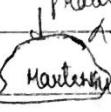


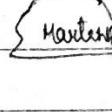
 α_1 α_2 α_3 Thinner
 hypoeutectoid eutectoid steel
 steel \rightarrow (as it is cooled just below A_G)
 precipitated α -ferrite starts precipitating out

 Austenite grain

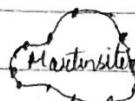
There will be a network precipitated α -ferrite

 \downarrow After quenching

 It will form martensite, hence

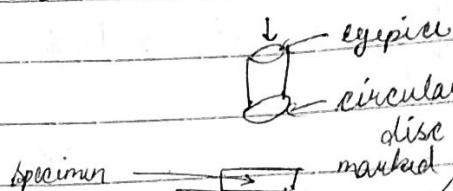
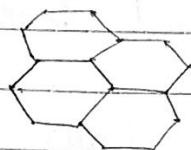
 the amount of precipitated α -ferrite will be same
 and after polishing and etching, and the
 austenitic network can be revealed.

In case of eutectoid steel (at 0.8% C), there is no pre-existing phase



expert heat treat with ~~some~~ special heat treatment, he can develop small needles of ~~cementite~~ all along the grain boundary of austenite.

I By comparing with standard ASTM charts



Average of

different sizes are present in every chart

$$n = 2^{N-1}$$

according to this

n = no. of grains (per sq.inch) ASTM E 112-63 ASTM references
at 100x magnification or IS 4748 - 1968

N = Austenite grain size No.

Grain size No. (N)

n

1

1

⇒ If $N \leq 3$

Coarse grain

2

2

3

4

4

8

⇒ If $N \approx 6$

relatively fine

5

16

6

32

⇒ If $N > 8$

ultra fine

7

64

8

128

ASTM Standard E112-1985:-

$$C_1 = -2.9542 + 1.4927 \ln n_a$$

ASTM has now modified the formula for grain size number.

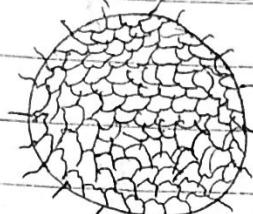
So $G_4 = \text{Grain size no.}$

$n_a = \text{no. of grains / sq. mm} @ \frac{1}{X} \text{, no magnification}$

13/05/21

I Jeffries Planimetric Method

For equiaxed grains



Area of cross-section

5000 mm^2

$$n_a = \frac{n_i + n_o}{2}$$

grains inside
grains outside
these intersected by circumference

$m = \text{magnification should be such that at least 50 grains are inside x-section}$

$$n_a = 2n \left(\frac{m}{100} \right)^2$$

$$G_4 = -2.9542 + 1.9427 \ln n_a$$

$\hookrightarrow \text{no. of grains per mm}^2 \text{ at } 1X \text{ magnification}$

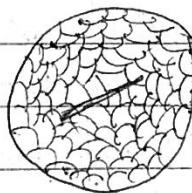
equiaxed \rightarrow same ^{shape} size and orientation

II Heyn's Intercept Method

Intercept Method

\hookrightarrow not for equiaxed grains but for ultra fine grains e.g.: High speed steel

$$N = 10 - 12$$



"length of intercept = 0.005"

$@ X1000 \text{ magnification}$, inch

chosen so that

\Rightarrow magnification is 0.5 mm^2 of actual sample is covered

\Rightarrow point ends = $\frac{1}{2}$ \Rightarrow 10 readings are taken, then the average full intercepts = $\frac{1}{2}$ value is taken

$$\Rightarrow \text{No. of grains per inch} @ X1000 = \frac{I}{0.005} = 200 I$$

$I \rightarrow$ mean intercept length

$$\Rightarrow \text{No. of grains per sq. inch} @ X100 = \frac{(200 I)^2}{100} = 4(I)^2$$

$$n = 2^{N-1}$$

$$\therefore n = (2I)^2 = 2^{N-1}$$

Taking log \ln

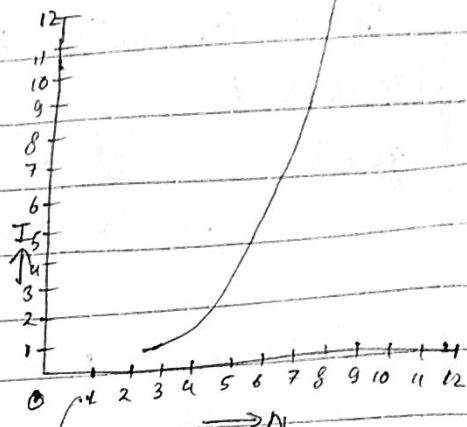
$$(N-1) \log 2 = 2 \log 2 + \log I$$

$$(N-1) \ln 2 = 2 \ln 2 + 2 \ln I$$

$$N-1 = \frac{2 \ln 2}{\ln 2} + \frac{2 \ln I}{\ln 2}$$

$$N-1 = 2 + \frac{2 \ln I}{\ln 2}$$

$$N = \frac{2 \ln I + 8}{\ln 2}$$



ASTM grain size No.
from 'I', we can easily
find out N

IV Shukhov's Fracture Test Method :-

Austenite (grain size)

In this case large no. of samples are taken and they are heated to austenitic phase and it is then quenched, the quenched sample is then broken and the broken sample is observed, the grain size of the fractured surface is measured and arbitrarily they are given nos. as 1 — 10
(coarsest) (finest)

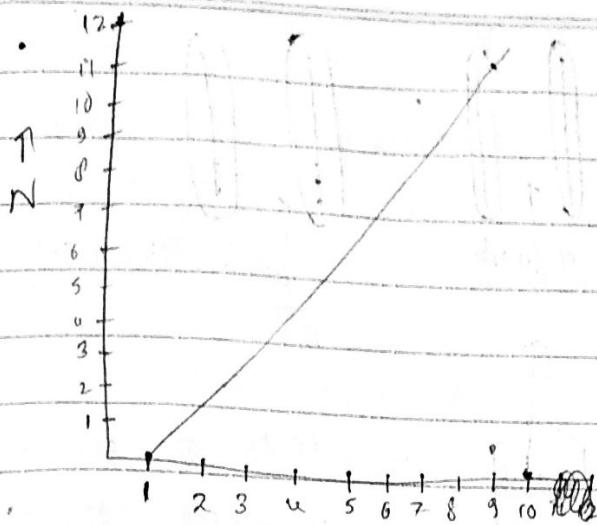
↓ Quenched for hardening

↓ Fractured

Fractured surface (grain size)

These 1-10 are called Shukhov fracture numbers.

Then a plot is drawn,



With the help of this plot, we can find the exact austenite grain size

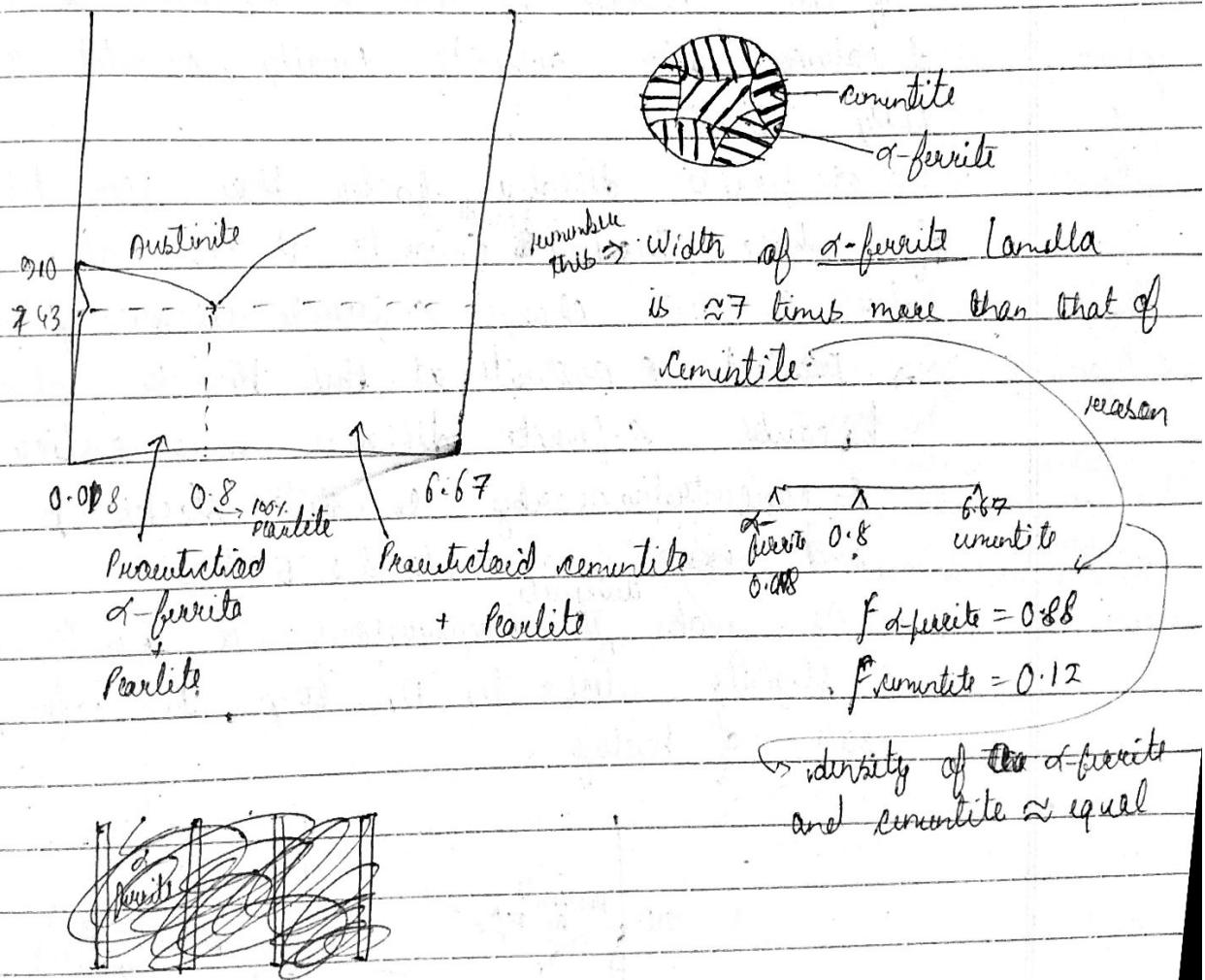
→ Bhupinder's fracture

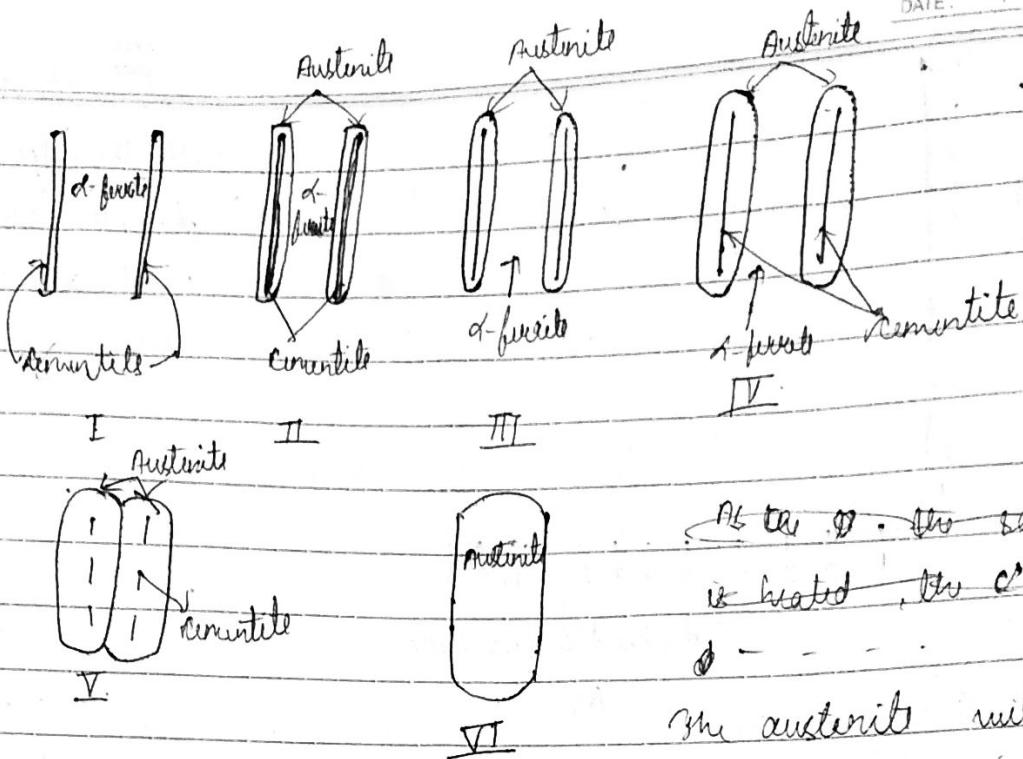
No.

here, $N \rightarrow$ ASTA grain size

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Mechanism of Pearlite \rightarrow Austenite Transformation



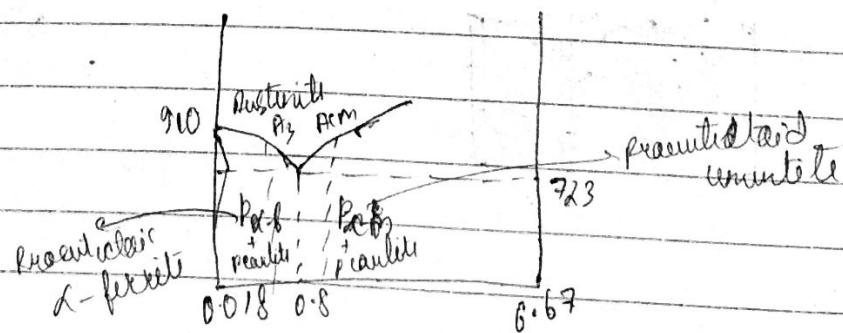


As the sample is heated, the C will

In austenite will nucleate at the interface of α -ferrite and cementite.

After some time, α -ferrite is going into matrix of the austenite, as well as cementite is also dissolving into austenite. Finally, cementite has fully dissolved.

- α -ferrite dissolves faster than cementite because of phase transformation of α -iron to γ -iron at 0.8°C , due to this change α -ferrite dissolves faster,
- ~~Factored~~ Austenite at this temp is not homogeneous because α -ferrite dissolves much earlier, so C concentration nearby cementite sticks is more and near α -lambdas is low.
- To make it homogeneous it has to be heated slightly above the 'A₁' temp. This is for practical rate of heating.

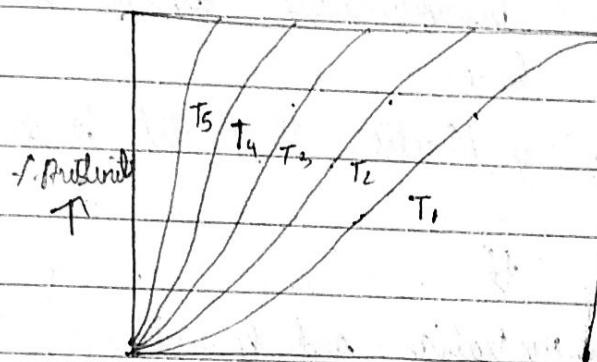


- As the austenite keeps on growing, it keeps on displacing δ -ferrite and finally at A_3 temperature we will get austenite and which is not homogeneous.
- In the case of upper eutectoid, we get austenite at Acm .
- The temp of $Acm > A_3$ Acm is much more higher compared to A_3 .

17/05/21 (And Birod I)

Kinetics of Pearlite to Austenite transformation.

$$T_5 > T_4 > T_3 > T_2 > T_1 > A_1$$



Time \rightarrow

Fig: 1

Step I - take large no. of samples (small size)

Step II - Dip the sample in constant temp bath

Step III - Take out the samples after specific intervals and quench it

(\hookrightarrow materials found / austenite formed will depend upon how much s. austenite was formed before quenching

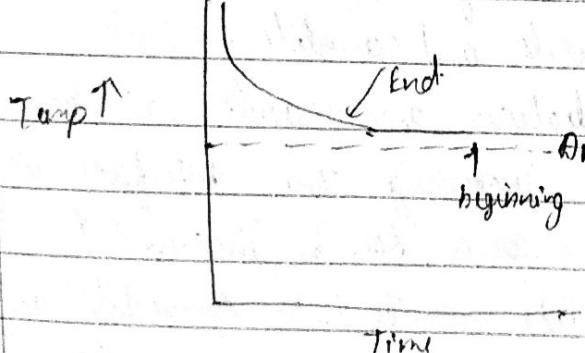


Fig: 2

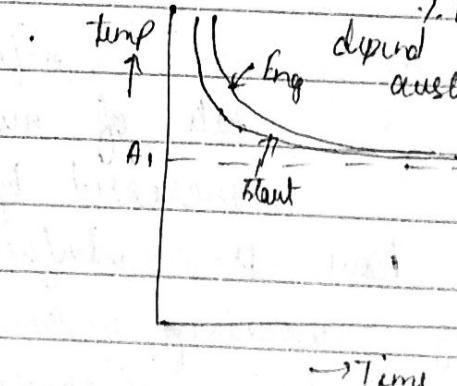


Fig: 3

Conclusions :-

- 1.) Transformation is completed in a short period at higher transformation temperatures.
- 2.) For faster heating rates, transformation starts at higher temperatures and for slower heating rates, transformation starts at lower temperatures.
- 3.) For any given practical rate of heating, the transformation takes place over a range of temperature ^{actual} and not a particular temperature.
- 4.) For the formation of austenite at a constant temperature, the rate of heating should be very, very slow, and in that case α , the curves of fig: 3 will merge with temperature A_1 .

By now we have established that rate or kinetics of pearlite transformation depends on transformation temp and time.

\star other factors affecting kinetics of pearlite to austenite transformation:-

V

Mechanism \rightarrow nucleation and growth

Austenite nucleates

at interface of

α -ferrite and cementite

rate of nucleation and growth can be

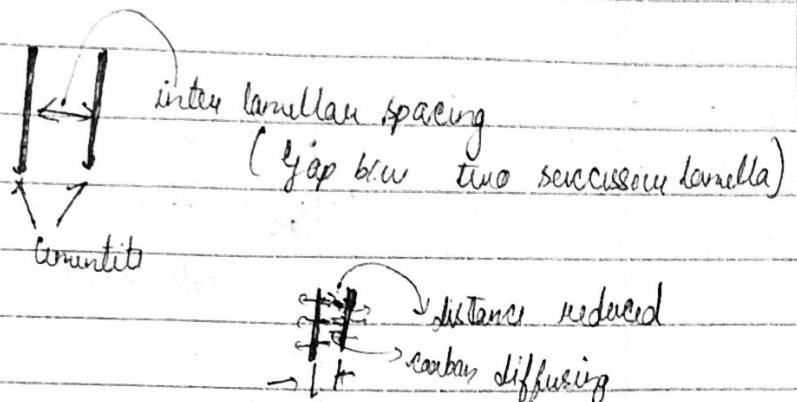
increased by increasing the interface area

\Rightarrow how the interface area can be increased?

- I By increasing cementite content :- cementite content can be increased by increasing %C; that is why ~~transformation~~ transformation of Fe to austenite is faster in case of high carbon steel, increase in cementite content causes increase in interface

area.

- II) By increasing interlamellar spacing
i.e. distance between two successive lamella



- * in which case interlamellar spacing will be more and interlamellar spacing (listens to radius) will be less?
 - interlamellar spacing will be more in case of coarse pearlite
 - " " " less " " fine pearlite
 - In case of fine pearlite transformation to austenite will be faster
 - " " " coarse " " " " " slower
- * Pearlite may also occur as (other than lamellar pearlite)
 - granular pearlite / in both cases interface area is small
 - globular pearlite / therefore transform
 - Pearlite → austenite, slower.

what ever was discussed till now, is for plain C-steel.

- In case of alloy steel suppose carbide forming elements are present, complex carbides will be formed.
- Complex carbides do not dissolve easily in austenite matrix for this much higher transformation temperature is required.

18/05/2021

(Batch 2 2nd)

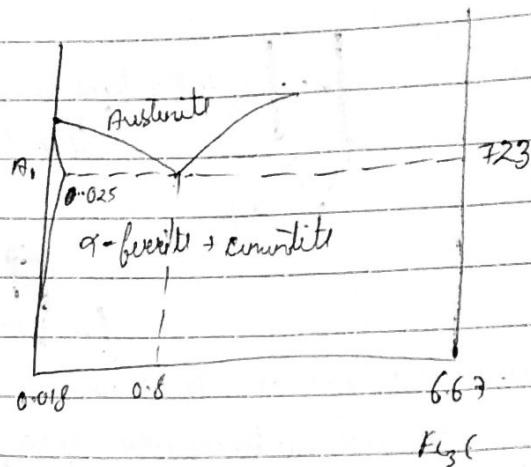
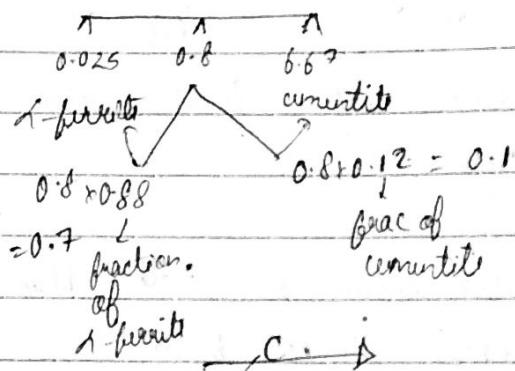
Austenite \rightarrow Pearlite (Mechanisms)

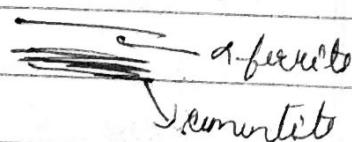
Fig C

Just below 723°C



There will be diffusion of carbon from α-ferrite to cementite. below

~~very~~ solid state diffusion is taking place
below $\approx 723^\circ\text{C}$, hence it is not fast



→ very slow cooling
→ possible by annealing
(furnace cooling)

→ Normalizing can also
be used

of ferrite + cementite



which nucleates first at austenite grain boundary

whichever nucleates first is called first \rightarrow also called

\curvearrowleft active nucleus \rightarrow provided it is present in the final microstructure

\rightarrow Also must have some lattice orientation relationship with the parent phase

\curvearrowleft austenite

② Mehl's hypothesis: It states that cementite is the active nucleus (i.e. it nucleates first on the austenite gb)

Pastulates:-

(i) orientation relation between pearlitic ferrite and parent austenite is different from that of proeutectoid and parent austenite. Therefore, ferrite cannot be active nucleus nucleus.

(ii) Formation of pearlite is affected by the presence of undissolved cementite particles whereas the presence of ferrite does not exhibit any such effect.

(iii) Proeutectoid cementite as well as pearlitic cementite flakes are in general parallel to high indexed plane of austenite.

II

Smith hypothesis

Pastulates:-

① Pearlitic ferrite as well as pearlitic cementite can have any relationship with the parent austenite except for those which allow the formation

incoherent \rightarrow not matching
parent phase
atoms to ^{TE} alter the parent
phase and
make it a new phase

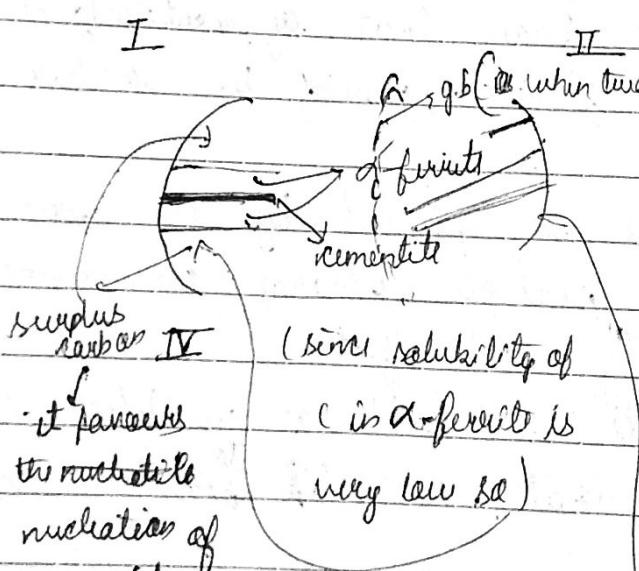
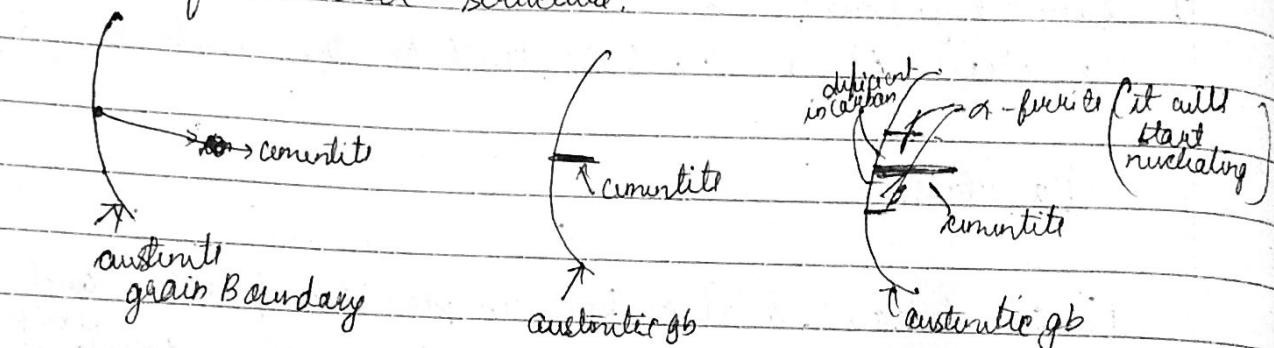
of interfaces which are partially coherent with the parent austenite.

(ii) Both cementite and ferrite can be active nucleus and subsequently, formation of pearlite can be initiated by either of the two.

(iii) In general, α -ferrite will nucleate first in case of hypoeutectoid steel and cementite will nucleate first in case of hypereutectoid steel.

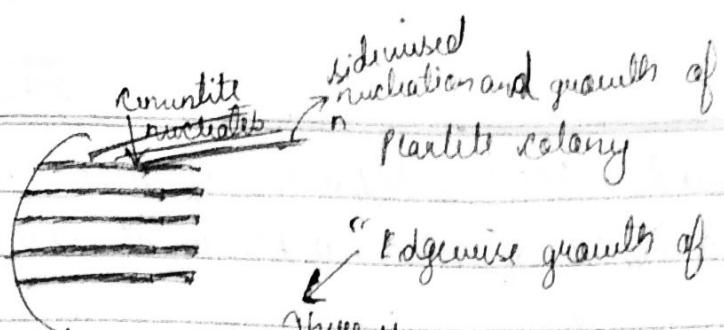
III

Hill and Mehl's hypothesis:- This explains the formation of lamellar structure.



it prevents
the nucleation
of cementite once
again

shape of pearlite colony
looks spherical because alpha-ferrite
and cementite both grow at the
same rate.

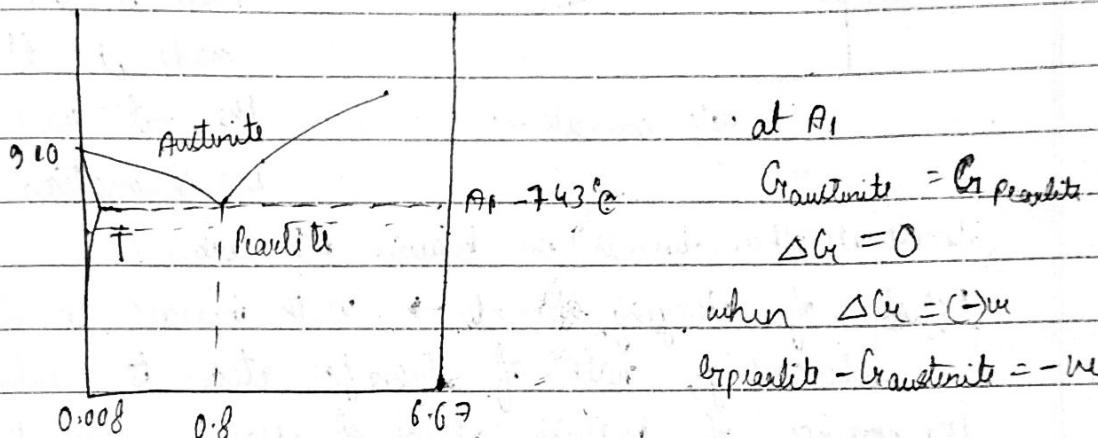


There is
also a
possibility of

(Bunod 3)

21/05/2021

Kinetics of Austenite \rightarrow Pearlite transformation



Transformation to Pearlite depends upon degree of Undercooling

$$= A_1 - T$$

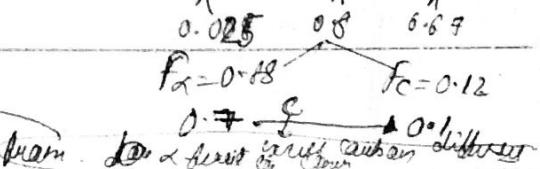
it is the temp at which transformation is taking place

① rate of transformation to Pearlite depends upon degree of undercooling.

② lower the temperature of transformation, rate of transformation will be faster.

Pearlite is a mechanical mixture of α -ferrite + cementite

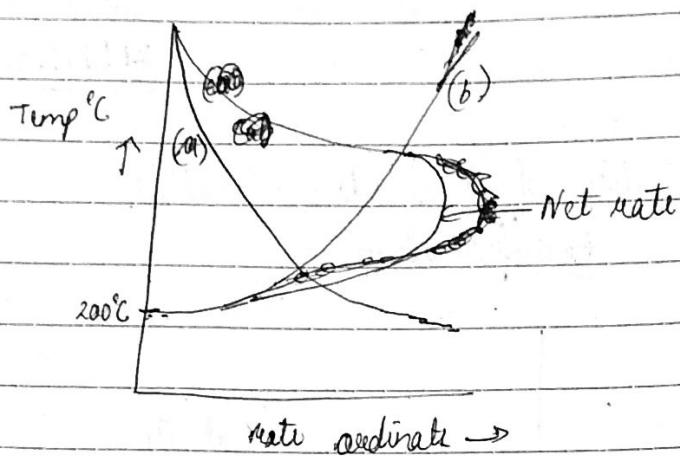
excess carbon diffuses
from α -ferrite to cementite



PAGE: / /
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\Rightarrow At around 200°C diffusion of carbon is negligible.
(as rate of diffusion of carbon is slower at low temp.)

(b) At lower temperatures rate of diffusion of carbon will be slower and at 200°C it is almost negligible.



Since both (a) and (b) are ~~possess~~ opposing factors, hence net rate is the compromise made, i.e. it is the net rate of transformation.

(almost all other elements are heavier than carbon)

Effect of alloying elements \rightarrow With increase in degree of undercooling, rate of transformation to pearlite in the presence of heavier atoms of alloying elements, transformation to pearlite will be faster, because these atoms are heavier compared to carbon.

Interlamellar spacing \rightarrow it is the distance of separation between two consecutive phases.

Interlamellar spacing depends upon transformation temperature provided other parameters are same.

Interlamellar spacing will be small if transformation temperature is lower, i.e. undercooling is larger.

Since, smaller interlamellae for stronger steels interlamellar spacing should be small, then lower transformation temperatures are desired.

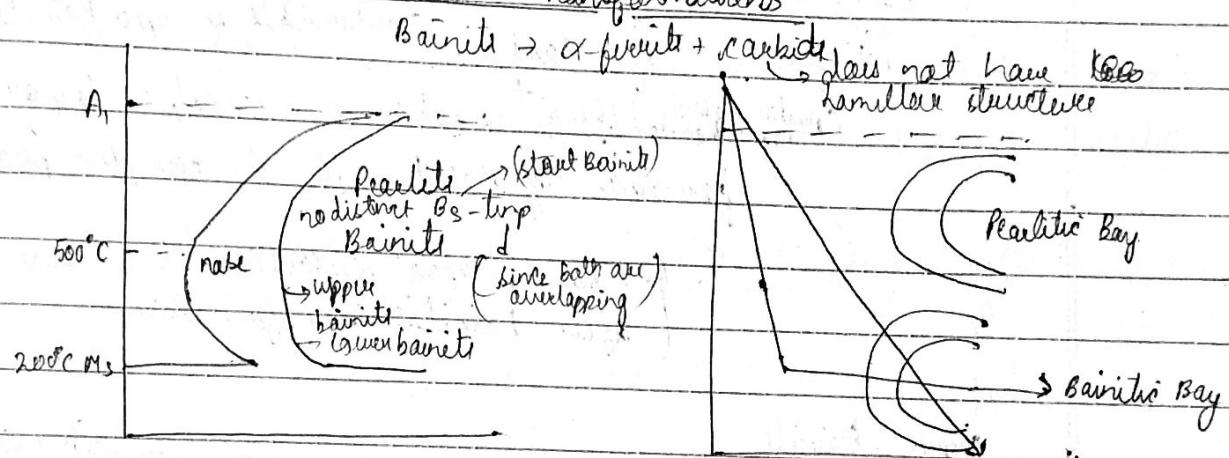
In the case of alloy steels, transformation temperature is always higher, that means in the case of alloy steels, interlamellar spacing is large. interlamellar spacing is insensitive to structure.

Interlamellar spacing does not depend upon the austenitic grain size and also the homogeneity of austenite.

↳ (1 of carbon uniform throughout)
(Bainit ↴)

24/05/2021

Bainitic Transformations:



I 0.8% C Steel

II Special alloy steel

Pearlite and bainite regions overlap.

Bainite can not be obtained by continuous cooling.

Bainite can be obtained by continuous as well as isothermal transformation.

Microstructure of Bainite is acicular (needle-like).

Upper bainite → has both structures (short & elongated) thin - step

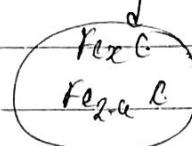
Mechanism of Transformation

500°C / 'C diffusion may take place

200°C / ↓ ratio of diffusion of 'C'
will be slower

Rate of diffusion of 'Fe' or other metallic atoms is negligible or nil.

alloy steel - C carbide



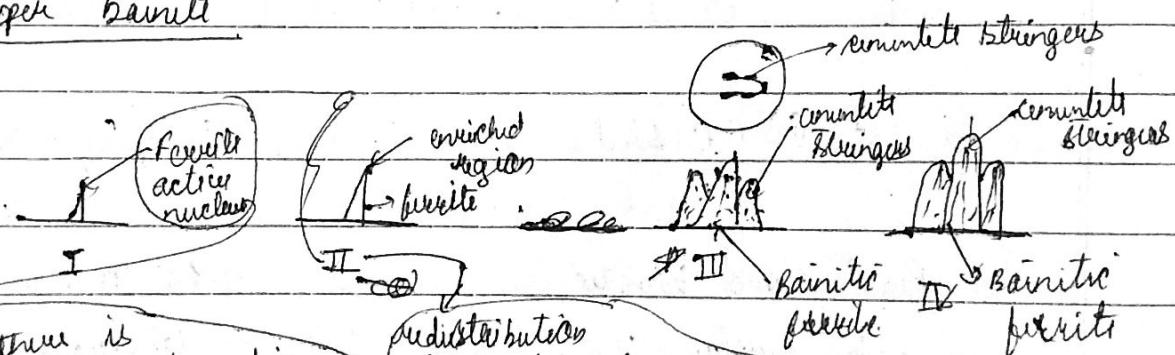
→ initial Bainite (or)

⇒ Diffusion of carbon predominant in upper Bainite
(predominant in lower bainite) shear + mechanism is also important

Formation of Bainite is a complex process.

Because surface distortions have been observed after bainite transformation

Upper Bainite



because there is lattice orientation relationship between ferrite and parent austenite

redistribution of carbon takes place in austenite

high C austenite as well as low C austenite

For the case of Bainite the carbide is very finely distributed, we can observe structure of bainite only at very high magnification as compared to pearlite.

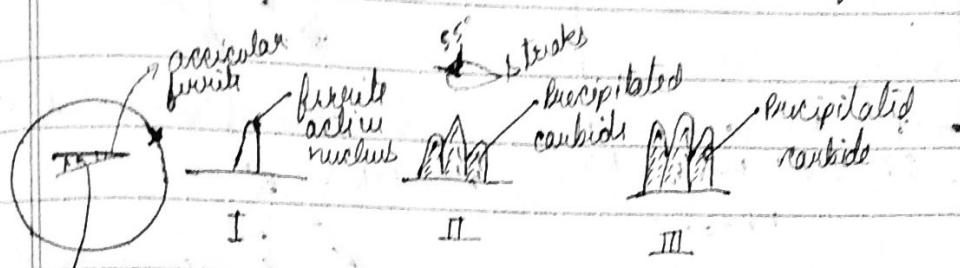
also
pearlite
is the
transformed
state

⇒ cementite stringers are 11 to
Bainitic ferrite

This results in the
set up of stresses

III \rightarrow Cementite precipitates out of α carbon atom enriched regions in the form of fibers.

- In the case of upper bainite, the rate controlling step is diffusion of carbon away from high carbon austenite towards form cementite
- Lower Bainite:



precipitate I \rightarrow ferrite is active nucleus because it has lattice orientation relationship with β bainite ferrite and parent austenite.

II redistribution of carbon was taking place in order to form two austenitic regions, here we have only low carbon martensite.

Low carbon austenite \rightarrow transforms to supersaturated (ϵ) ferrite

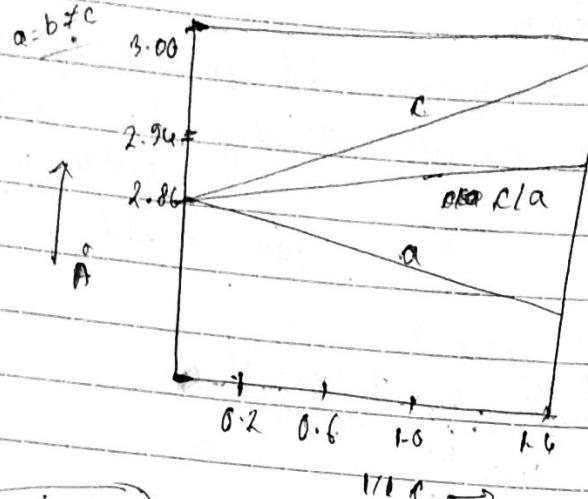
ϵ will precipitate out in form of carbide.

\Rightarrow the precipitated carbide in steels is at an angle of 55° with bainitic ferrite

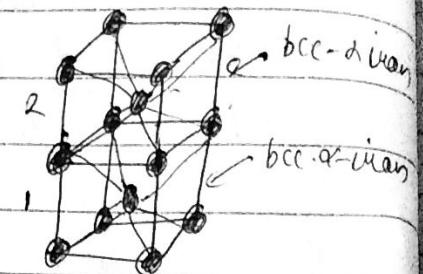
\Rightarrow In the case of alloy steels, precipitation of ϵ -carbids is less than η carbids.

\Rightarrow ϵ carbide cannot precipitate out from austenite

Binaid 5

Martensitic transformation

$$BCT \frac{c}{a} = 1.5 \rightarrow \text{ideal value}$$



radius of sphere which will

$$r = 0.414R$$



common to both
unit cells

octahedral void

1 of c in d-iron
same as γ-iron

comp.
is
same

γ-iron
(FCC)

quenched (cooled very fast)

Martensite

d-iron
(BCC)

d-iron will be supersaturated with 'C'

- Known as Martensite (BCT)

BCT → Body centred tetragonal

$$a = b/c$$

$$\alpha = \beta = \gamma = 90^\circ$$

The 'C' atoms will occupy position in
the interstitial void

Mechanism of Martensitic transformation :-

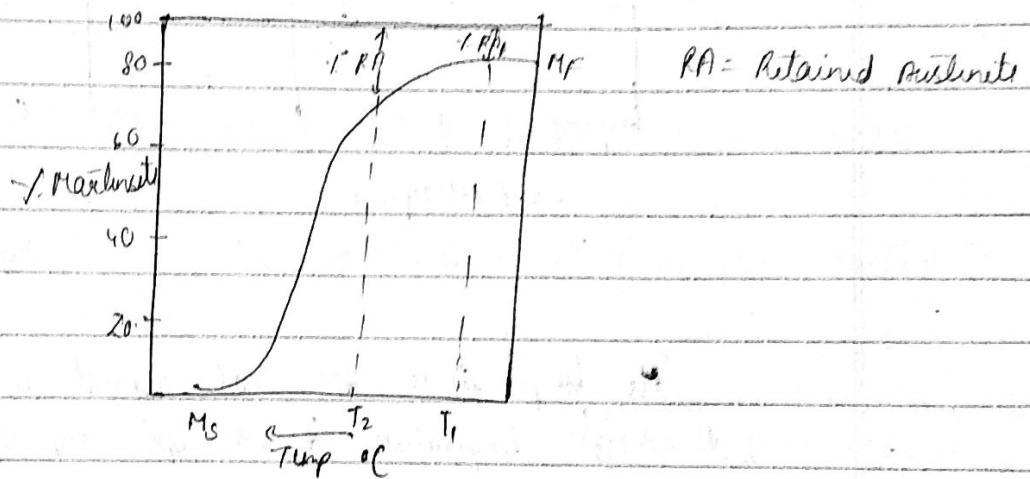
Ques. Q. 1. The transfo

Martensite is a diffusionless transformation unlike pearlite and bainite transformation. It is a displacive transformation that takes place by cooperative movement of a large no. of neighbouring atoms. Each atom moves over a distance which is less than 1 interatomic distance. In this process, the atoms maintain

the neighbourhood undisturbed. A large driving force is required for the transformation to take place. Thus, the magnitude of the driving force is the change in free energy accompanying the transformation. Hence, the magnitude of driving force increases by lowering the transformation temperature.

Although the displacement of individual atoms is less than 1 interatomic distance, the total displacement increases as one moves away from the interface boundary. Such buildup of displacement finally results in a macroscopic slip. The slip can be observed as a wavy structure on the surface of martensite.

Kinetics of Martensitic Transformation



The transformation to martensite starts at \approx a temp M_s , and then it proceeds along a range of Temperature. Amount of Martensite formed depends upon the transformation temperature. Amount of retained austenite depends upon nucleation of new plates of martensite and not due to growth of martensite plates. If a temperature M_f on transformation is complete, however there is no complete transformation from austenite to martensite, this leftover fraction of iron is known as retained austenite.

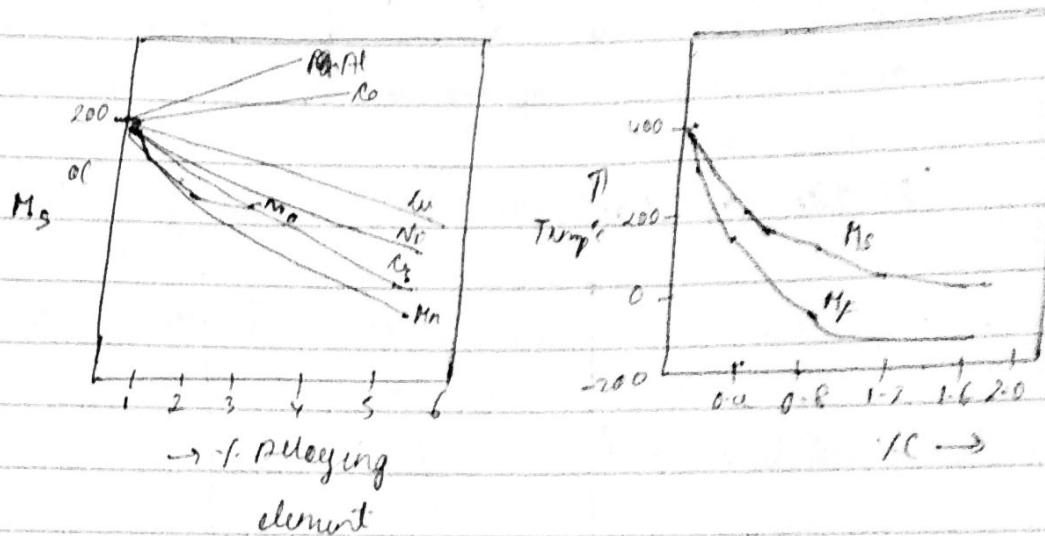
Retained austenite is not a thermodynamically stable phase.

The transformation to martensite begins in fraction of microsecond and completes in fraction of millisecond. This means rate of martensite transformation is independent of transformation temperature.

M_s and M_f temperatures

$$M_s^{\circ C} = 561 - 674(\text{Sec})$$

$$M_s^{\circ C} = 561 - 0.74(1\text{C}) - 33(1\text{Mn}) - 13(1\text{Ni}) \\ - 17(1\text{Cu}) - 21(1\text{Mo})$$



' M_s ' temperature does not depend upon cooling rate but ' M_f ' temperature depends upon the chemical composition of steel and also the austenitizing temperature.

' M_f ' temperature

Except Al, and Co, all other alloying elements all have lower M_f temp and with increase in M_f temp all have lower M_s , but cooling rate does not have effect on M_f .

Austenitizing time :- If austenitizing temp is high, more and more carbides will dissolve, as a result, as a result carbon content will increase with inc in C content M_s is lower.

If austenizing temp is high, grain coarsening will take place. Cause austenitic grain size raises M_s temperature.

M_s will be raised or lowered depending upon which of the two factors predominates that temp.

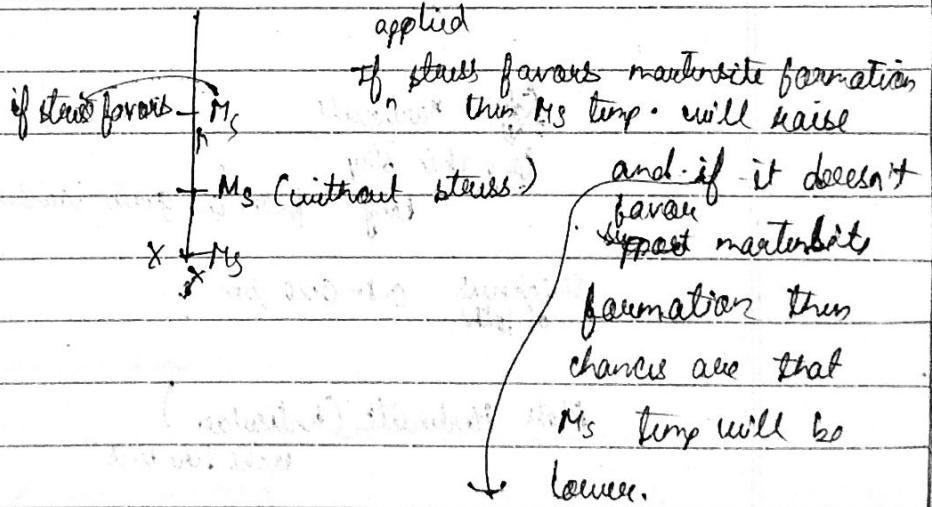
- ⇒ M_f temp is lowered with increase in C content
- ⇒ M_f is also lowered if cooling rate is very very slow.
- So rate of transformation around M_f temp is very very slow, that is why in TTT diagrams, M_f temp is not mentioned.

28/09/21

(Birendra)

Effect of applied stress on Martensite transformations

Applied stress \rightarrow has great effect on Martensite transformation



But it does not happen because due to presence of habit plane, M_s is not lowered.

Plane stress is in which certain phenomena like twinning takes place

due to applied stress, Ms is within area
of plastic deformation
(as plastic deformation
takes place)

Athermal Martensite:

Ms

T_1 martensite will form : This type of martensite is
 T_2 martensite will form again called athermal martensite
after cooling the martensite and holding it at that
temperature. This has been observed in all 'c' steel.

Isothermal Martensite:

Ms

 T (held)

This has been
observed in low 'c' Fe-alloy

high alloy steel

Fibre Martensite long this strip

long from one grain boundary to other grain boundary

thickness
of fibre $0.1 - 0.20 \mu\text{m}$

Plate Martensite (Articular) looks like lines

length - across grain boundary

Hardness of Martensite:-

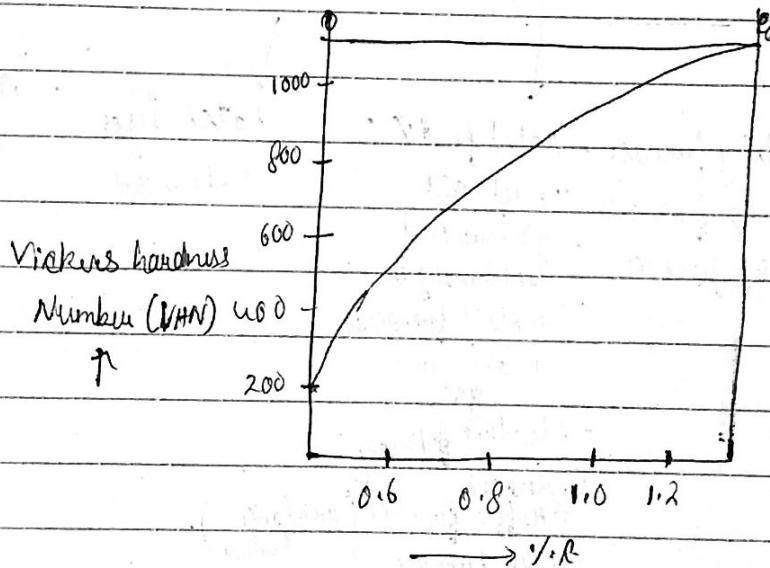
Reasons behind hardness of martensite:-

- 1.) If carbon content increases hardness increases.
- 2.) Due to impurity strain or due to within α -iron lattice.

The strain in α -iron is due to supersaturation of α -iron by carbon atoms, due to excess C-atoms. These atoms occupy position in the octahedral voids, the structure changes to BCT and C/a gets larger.

- 3) Plastic deformation of parent austenite surrounding the martensite plate.

⇒ Maxm hardness of martensite steel in rockwell C scale $\rightarrow 65$



* If 'C' content is high

⇒ If V.R. increases, then M_s and α_f temp is lowered.

⇒ If M_s temp is lowered, % of retained austenite increases and retained austenite is not a desired phase, because it is a softer phase and also not stable phase.

⇒ In case of low 'C' steel, % of martensite formed is not high.

Practically low C
content : (0.15 to 0.25)

Practically
medium C steel
0.3 - 0.65

Practically high C
steel
0.65 - 1.25

PAGE:
DATE:

- Be both high and low C steel are not suitable to form very hard martensite.
- Hence medium % Carbon steel is required to maximise martensite hardness.
- To have 100% martensite to maxm hardness there should be certain minimum value of carbon in steel as

1/06/2021

Batch 7

Heat Treatment Furnaces

and Atmospheres

Use	Source of heat	Type of operations (mark)	Atmosphere
Annealing furnace	Solid fuel X	- Batch type	- open air
Hardenning furnace	Fuel oil	- Continuous	- controlled atmosphere
Tempering furnace	- Gaseous fuel - Natural gas - Blast furnace gas + coke oven gas	-	-
	- Electric	-	-
	- Ruffle furnace (resistance heating)	-	-
	- Pit furnace	-	-
	- Bagie furnace	-	-

Wires / rods

- 1.) Constantan - Cu - 40% Ni - upto 900°C.
- 2.) Nichrome-I - Ni - 20% Cr - 1100°C.
- 3.) Nichrome-II - Ni - 24% Fe - 16% Cr - 950°C
- 4.) Alunel - Ni - 3% Mn, 2% Al, 1% Cr - 1200°C
- 5.) Chromel - Ni - 10% Cr - 1200°C

→ These two wires in thermal couple

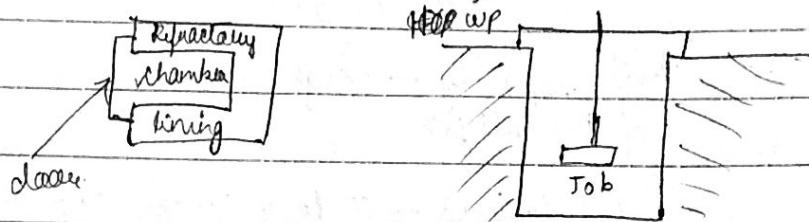
and as heating element

PAGE

DATE

6)	Kanthal	Fe - 25% Cu, 5% Al, 3% Cr	1400
7)	Tungsten		2400
8)	Molybdenum		1800
9)	Platinum		1500
10)	Pt - 10% Rh		1700
11)	graphite		2000
	platinum		

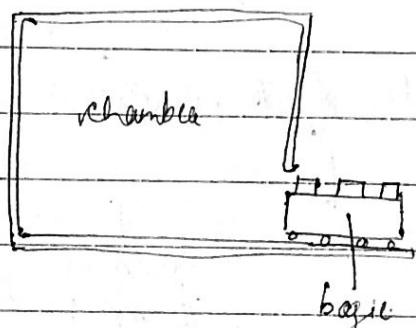
warming platform



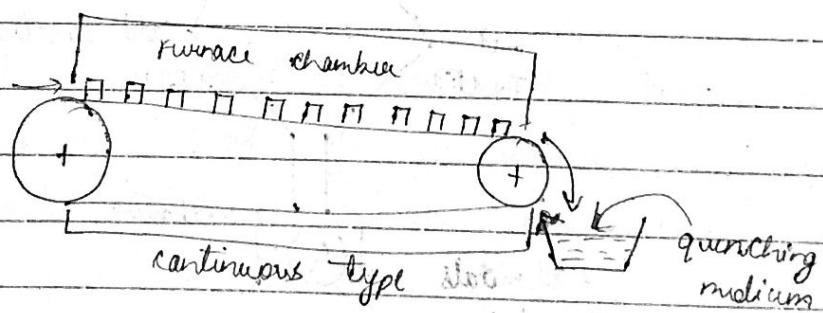
More examples
of Batch
type

I Muffle furnace.

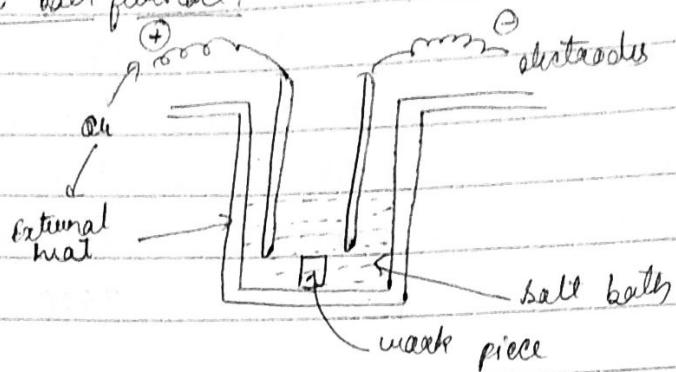
II Pit furnace



III Bagie furnace



salt bath furnace:



chlorides, carbonates, Nitrates, Cyanides
(150 - 1300 °C)

heat capacity - high
of the salt bath

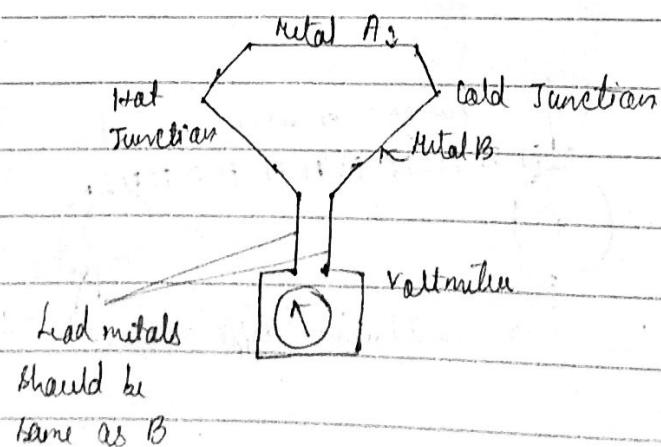
Efficiency - 7 times more than that of muffle

4/06/2021

Measurement of Temperature

Thermometers
upto 500°C
Pyrometric
if temp > 500°C

Thermocouples



Due to difference in temperatures and an emf will produced, and this emf is directly proportional to the difference between the temperature

of hot junction and cold junction.

Thermocouple

Base alloy
of two metals
dissimilarities in metals

are made of esp with
low cast alloy

Noble alloys

The thermocouple made of from
noble metals

ex: platinum ~~100~~ Rhodium 10

There are ~~some~~ conditions for dissimilar wires to form a thermocouple
Requirement of thermocouple metal materials :-

- 1) The metals should be homogeneous
- 2) The material should be resistant to oxidation and corrosion
- 3) The thermal conduct conductivity of the material should be high.
- 4) The formability of the metals should be good so that any shape can be given.
- 5) Melting point of the materials should be higher than the working temperature.
- 6) The ~~emf~~ should increase with increase in Temperature difference.
- 7) There should be linear relationship between ~~emf~~ and temperature.
- 8) The induced ~~emf~~ should be sufficiently large.
- 9) The induced ~~emf~~ should be reproducible.
- 10) The material should not be very expensive.

The chemical composition of some alloys used as Thermocouple wires :-

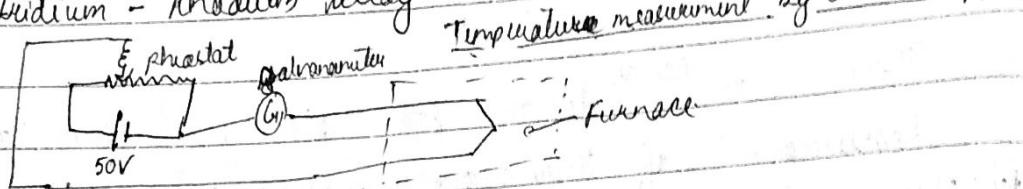
- 1) Constantan
- 2) Chromel
- 3) Alumel
- a) Platinum-Rhodium-alloy

DATE / /

for even higher temperatures following thermocouples can be used.

- 1) Tungsten - Molybdenum
- 2) Tungsten - Rhodium
- 3) Tungsten - 26.1% Rhodium
- 4) Molybdenum - Rhodium
- 5) Tungsten - Iridium
- 6) Iridium - Rhodium alloy

with the help of these thermocouples we can measure temp upto 2300°C



Calibration → We put in hot junction inside a molten metal, the m.p. of that metal should be known, list of metal which are used for calibration:

Al - 660°C

Sb - 630.5°C (Antimony)

Bi - 271.3°C (Bismuth)

Co - 1480°C (Cobalt)

Cu - 1083°C (Copper)

Au - 1063°C (Gold)

Pb - 327.4°C (Lead)

Ni - 1453°C (Nickel)

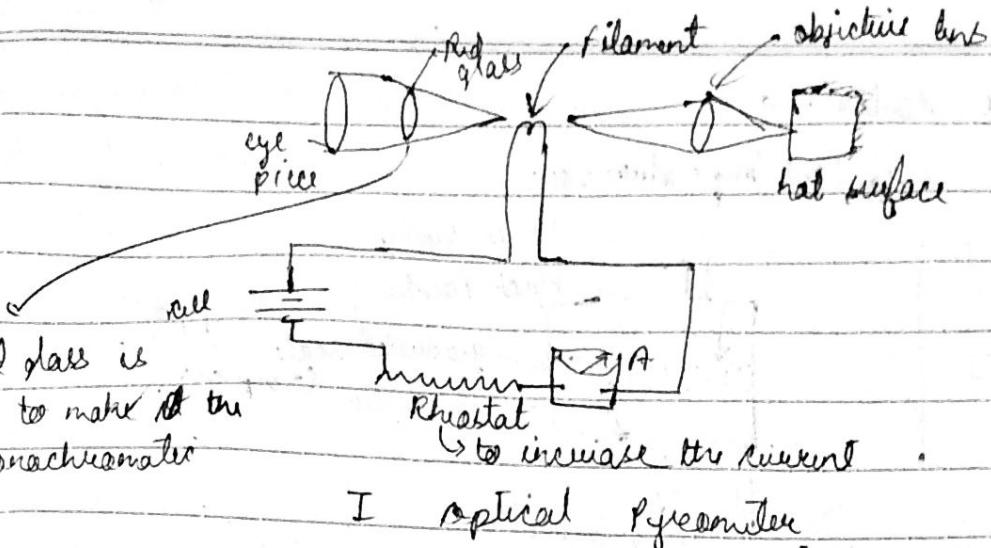
Pt - 1773.5°C (Platinum).

Rh - Rhodium (Rh) - 1966°C .

Pg - 960.5°C (Silver).

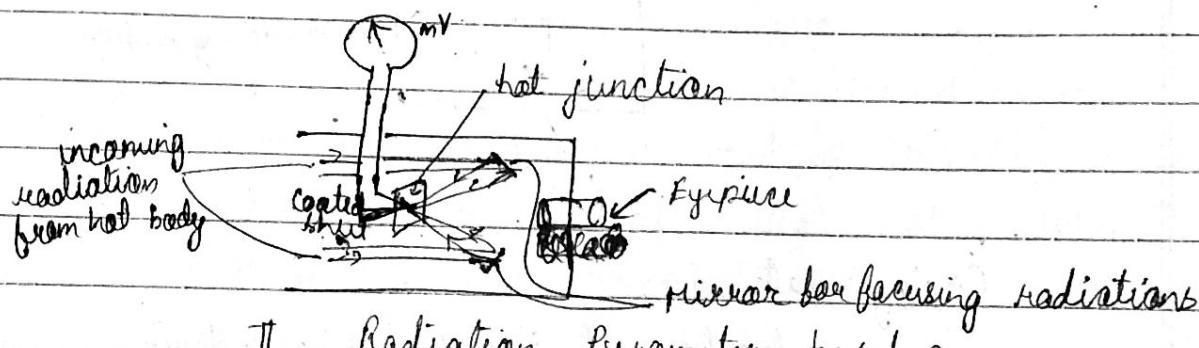
Sn - 231.9°C (tin)

Based on this conclusion, the emf is written next to the temperature.



These are called indirect method, because the device is not directly in contact with the hot body.

In the beginning the filament is dark as it is not hot, as the temp increases, the moment the radius between the glass and body, the filament will disappear, the disappearance of the filament indicates, indicates the temperature of the hot surface.

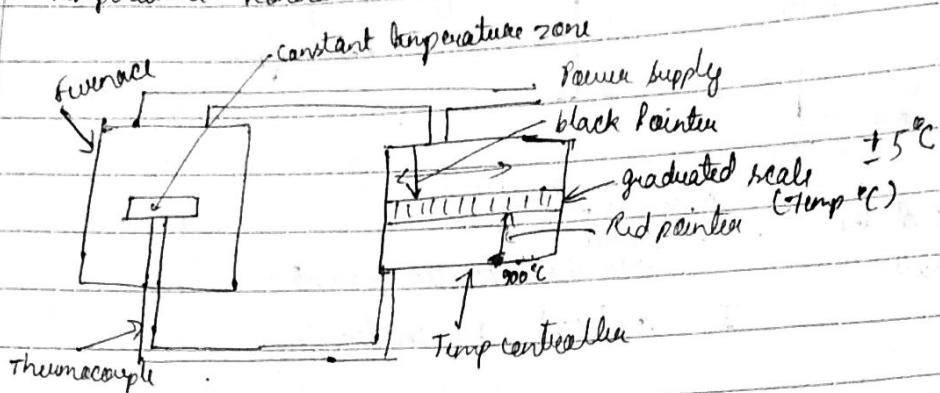


II Radiation Pyrometer based on Stephen-Boltzmann law

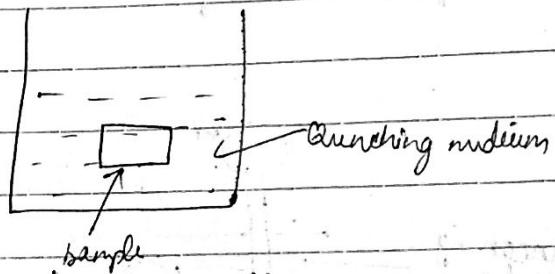
Energy of radiation $\propto T^4$

$$T = \text{temp}$$

The radiations coming from the hot body are reflected by the mirror to the coated shell which is connected to a millivoltmeter, which gives us the temperature of the hot body.

Temperature control \rightarrow 

III. Temperature controller

11/06/2021Quenchants (Quenching medium \rightarrow)Cooling rate

- characteristics of the quenching medium
- chemical composition of steel / non-ferrous alloy
- Design of sample
- surface condition of the sample

 \Rightarrow characteristics of the Quenching medium

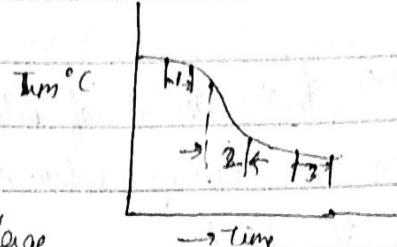
- (a) Temperature of quenching medium
- (b) Latent heat of vaporization of quenching medium
- (c) Specific heat of quenching medium
- (d) Viscosity of quenching medium.

(e) Agitation of quenching medium

(f) Thermal conductivity of quenching medium

Stages of cooling

Stage-1
aka vapour blanket stage



* Vapour film (poor conduction of heat, so rate of cooling will be slow)

Hence in stage 1: rate of cooling will be low as vapour is not a good conductor of heat

Stage-2

aka liquid boiling stage

bubbles of liquid go away → vapour film disappears

liquid (direct contact with hot surface)

Temperature of sample > boiling point of Quenching medium

→ gives the appearance of boiling, that is why this stage is known as liquid boiling stage.

→ cooling rate is fastest in this state as quenching medium is in direct contact with the sample.

Stage-3

aka liquid cooling stage

→ Temp < boiling point of the quenching medium of same

? See cooling will take place

→ hence slowed cooling rate

Characteristics of Quenching medium

① Temperature of Quenching

Water \rightarrow $20-40^\circ\text{C}$ \rightarrow cooling rate will be faster
Mineral oils \rightarrow $40^\circ\text{C} - 150^\circ\text{C}$ \rightarrow cooling rate will be slower

Chances of development of internal stresses is very high,
so causing internal cracks and warping of
the sample.

Predominantly manganese and molybdenum increase the
hardenability.

② Latent heat of vaporization:

Lower \rightarrow It will add stage-I (vapour film), rate of
cooling will be slower

Higher \rightarrow There will be less of quenchant
 \rightarrow Hazards

It will keep on absorbing heat when liquid changes to
vapour, temperature remaining constant.

Higher \rightarrow \checkmark with the absorption of heat, temp of
quenching medium will not increase

③ Specific heat of quenching medium: heat required to increase the temp of 1 kg by 1°C .

Low \rightarrow Temp of Q. M. increases \rightarrow cooling
rate will be slower

\rightarrow suitable for small production

High \rightarrow suitable for mass production

④ Thermal conductivity of quenching medium

It should be good \rightarrow heat transfer will be proper from hot surface of sample to quenching medium will take place.

(5) Viscosity \rightarrow for good heat transfer or faster cooling rate
 \rightarrow Viscosity should be low

(6) Agitation of quenching medium
 \rightarrow good agitation is required

* Different Quenchants:

I Water \rightarrow available for free
 \rightarrow good cooling rate
(20-40°C) \rightarrow no pollution

Limitations:

\rightarrow vapour film (unless agitated vapour film cannot be prevented)

II Aqueous solution:

NaCl / in water
CaCl₂

Brine: Cooling rate faster than normal

\rightarrow NaCl will crystallize water

Vapour film

true NaCl crystals will start jumping and these will break the water vapour film (known as shot peening technically)

Limitation: Its corrosive action on the VAT (surface on which O/H is kept) and equipments itself is the main problem.

III Mineral oils

Lower viscosity is preferred - 40°C

Lat quenching oil - medium viscosity

Hargenching oil - high viscosity

$\rightarrow 150^{\circ}\text{C}$. Can be kept at 150°C .

IV Salt baths

100% NaNO_3 , 50% $\text{NaNO}_3 + 50\%$ KNO_3

Smaller salt bath

→ very effective heat transfer

→ uniform heat transfer

→ No danger of oxidation, carbonization or decarburization.

V

Air

→ Available for free

→ in hardenable steel ~~specimen~~

→ as a g.m. is used when the specimen is of air hardenable type.

VI

Gases - (Not air)

$\text{H}_2, \text{He}, \text{N}_2, \text{Ar}$

Decreasing order of cooling efficiency

handing
is dangerous

costly

pace efficiency

only Ar can be used as quenching medium.

VII

Synthetic Quenching Mediums

* 1.) Oxyalkaline glycol based

2.) Polyalkaline glycol based

3.) Polycyclic pyridinone based

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A range three 2nd one (Polyalkylene glycol is more common).
Advantages These three compounds are water soluble, when the sample is dipped, instead of water vapour film, a glycol film is formed.
⇒ The glycol film has got good thermal conductivity
⇒ After some time off, as the top comes down, glycol is dissolved in water, the cooling takes place by Stalge-2 (where cooling rate is fastest).

14/06/2021

Heat Treatment properties →

4.) Stress relieving → (a.k.a. Residual stresses)

Internal stresses are generated during

- Solidification of metals and alloys
- Mechanical working of metals and alloys
(rolling, forging, extrusion, ...)
- Machining
- shot peening
- — —

Stress - corrosion cracking:

External stress is applied in a corrosive medium, thus the corrosion will be very fast.

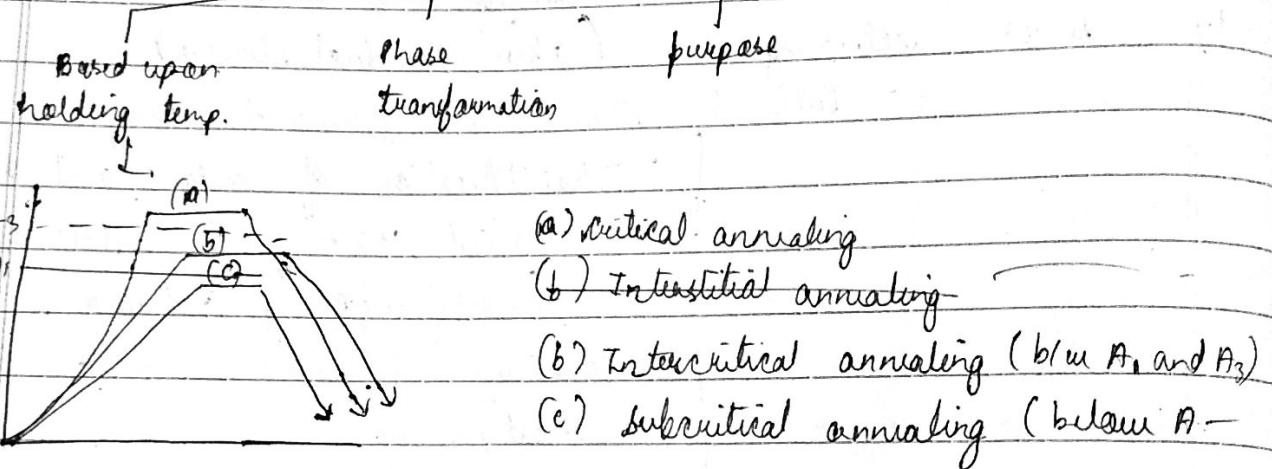
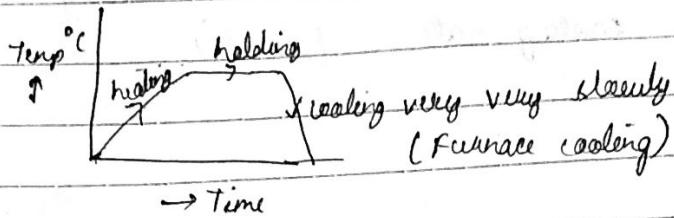
Even if external stresses are missing, this internal stresses will cause stress corrosion.

- If internal stresses are present then it may cause
 - ⇒ Warping
 - ⇒ dimensional instability
 - ⇒ Fatigue strength may be reduced

Process of stress relieving involves heating the element ^{PAGE} until below α
 $\sim 600^\circ\text{C}$, hold ~~for~~ for a specific period, cooled slowly and uniformly

↑
Heating the specimen

2) Annealing



In case of stress relieving no microstructural change takes place.

Phase transformation

(i) 1st order of annealing

(ii) 2nd order of annealing

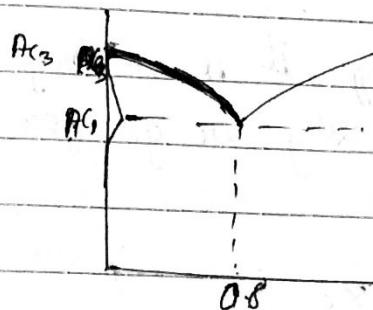
In this case the main emphasis is the desired properties we want at the end (end properties) irrespective of the fact that what kind of phase transformation is taking, therefore there is no constraint on the range of temperature on the 1st order of annealing, hence in this case tiny

* it is not fixed, so it can be a range of temp. (Temp is a range)
 We are concerned what kind of phase transformations are taking place. In this case temperature is an important factor, since annealing (temp is fixed)

Purpose:-

- Full annealing
- Isothermal annealing
- Partial annealing
- Diffusion annealing
- Recrystallization annealing
- Process annealing
- Spheroidizing annealing

Full Annealing:



in case of hypoeutectoid and eutectoid steel

25-30°C above Ac_3 ↘ 25-30°C above Ac_1 ,
steel and then
 cooled slowly
 (furnace cooling)

Purpose:

- (i) stress relieving
- (ii) improve ductility
- (iii) sustain toughness
- (iv) enhances machinability
- (v) improves chemical homogeneity
- (vi) refines grain size
- (vii) removes dissolved gases

⇒ why is full annealing of hyper austenitic is not done?

⇒ why we do not go higher than 30°C ? \rightarrow to avoid grain coarsening at which is not allowed.

at this temp grain coarsening takes place \rightarrow we have to go above 30°C

for eg:- at 121°C to convert it to fully austenite and there will be a continuous network of cementite around coarse grain, \rightarrow is the final microstructure. And both are undesirable constituents as they degrade the mechanical properties.

Isothermal Annealing

⇒ this is also not done for hyper austenitic steel (Reasons already mentioned)

⇒ In the case of full annealing, it is a very time consuming process, that is why we go for isothermal annealing.

$\nearrow \text{A}_{\text{C}3} + 25-30^{\circ}\text{C}$, $\text{P}_{\text{G}} + 25-30^{\circ}\text{C}$
 hypo case austenitic case
 I cooled below
 A_1 and is held
 at temp $800-700^{\circ}\text{C}$

till transformation
 to pearlite is complete

another furnace
 is maintained at this
 temp (just
 transfer the specimen)

once transformation is
 complete, then it is

cooled in air

Advantages:-

→ Time (same microstructure is obtained in less time)

Limitation

→ This process is suitable ^{only} for small size specimens not for large castings (will take large time to homogenize)

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Diffusion Annealing →

To remove chemical inhomogeneity

To remove non-uniformity in structure

Applications in heat treatment of Ingots, heavy castings of plain carbon steel or high alloy steel

1000-1200°C, 10-20 hrs

Slowly
→
→

→
→
→

all this makes
it very costly

- Segregation has been removed

- Structure has been refined

→ grain coarsening will be there → 2nd heat treatment is needed

→ there will be scaling (oxidation) → Re-We need controlled (protective) atmosphere

→ high temp are involved

→ cooling is very slow, it's a lengthy procedure

* for Hypo, eutectoid

low go goa

full annealing

hyper → we go far
normalizing or partial
annealing

Partial annealing →

fall in the critical annealing category

if temp is between A_1 and A_3 } in case of hyper
temp is between A_1 and A_{cm}

This type of annealing is suitable for high carbon steel.

In case of full annealing we are getting a perlite surrounded by continuous network of eutectic.

~~Very high temperature~~ In case of partial annealing the structure will be fine perlite + cementite & does not form a continuous network.

Recrystallization annealing

→ may be an intermediate process or a final process.

application:

- Manufacture of wires, shells, tubes

Annealing temperature (not fixed in this case) because

→ It depends upon amount of prior deformation

→ It also depends upon chemical composition because this generates compactivity stress

→ It also depends upon holding time

which acts as a site nucleus for the nucleation of strain free grains.

Recrystallization Annealing temperature can be lesser if holding time is increased.

Preferred Preferred

→ higher temperature, less holding period

Process annealing:-

→ Intermediate process (not a final process)

Annealing temp. is slightly below recrystallization

temp.

In this process, recrystallization may or may not take place.
process annealing is also carried out
after cold working

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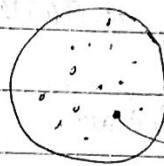
Methods

It differs from recrystallization annealing as its temp is
→ cheaper than recrystallization annealing

* Spheroidizing annealing : - (not applied to low steel)

- In the case of hypo and eutectoid, cementite in lamellar shape changes to globular shape or spheroids.
- In the case of hyper-eutectoid, free cementite will change to globular cementite off or spheroids.

What happens if the shape is changed from lamellar to globular?



spheroids of cementite in a matrix of ferrite

What is change in property if lamellar change to globular?

→ This is done to increase the machinability and is employed in case of medium and low high carbon steel.

(i) Heating to just below A_1 and keeping it for long period.

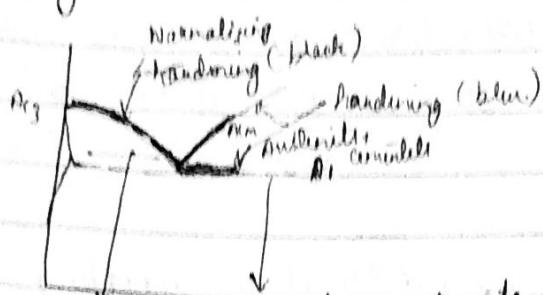
till all cementite has transformed into spheroids.

(ii) heating just above A_1 and then cooling just below A_1 .

Repeating this cycle for many times till the transformation is achieved.

(iii) heating just above A_1 and then cooling it just below A_1 and holding it at this temperature for prolonged period till transformation is complete.

D) Normalizing -



Martensite (fine) $\xrightarrow{\text{Quench}}$ martensite + cementite, also a hard constituent
 e.g. ferrite $\xrightarrow{\text{Slow phase}}$ bainite phase (not desirable)

Purpose of Normalizing:

- 1.) Improve mechanical properties
- 2.) Refine grain size
- 3.) Improve machinability

Normalizing involves heating to temp: $N_{23} \rightarrow 40-50^{\circ}\text{C} \rightarrow$ hyper eutectoid
 $N_{26} \rightarrow 40-50^{\circ}\text{C} \rightarrow$ eutectoid
 $N_{cm} \rightarrow 40-50^{\circ}\text{C} \rightarrow$ hyper eutectoid

Advantages of high holding temperature

\Rightarrow Better homogeneity of austenite
 (if uniform)

cooled in still air, agitated air

air hardenable steels } fine grain perlite - more strength as compared to annealing
 T \downarrow } better dispersion of ferrite and cementite in perlite
 cooling rate should be slow than } improved mechanical properties

air cooling

Diffusion normalizing \rightarrow chemical homogeneity

\downarrow it needs second heat treatment

Normalizing
 \downarrow

refining of grain size

* Annealing treatment not suitable for hypoeutectoid steel, low C steel

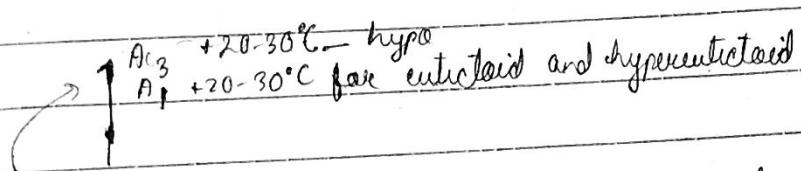
↓
Normalizing
Strength and hardness
both increases

↓
machinability of low C
steel improves

⇒ Coarse pearlite surrounded by continuous network of cementite
in case of annealing if we go above A_{cm} (not desirable)



Not happens in case of normalizing above A_{cm} ,
as here it is cooled at a faster rate so
there is no ~~chance~~ chance for the formation
of continuous network of cementite, hence
in high C steel we get better properties.



⇒ In the case of hardening we are not going above A_{cm} , only
above A_3 and A_1 .

→ and then it is quenched

⇒ If the cooling rate is faster than the critical, ~~rate~~ ^{cooling} → we get

Martensite (hardness is 65 $\rightarrow R_c$ (Rockwell C scale))

(fine pearlite $\rightarrow 40-45$)

(coarse pearlite $\rightarrow 25-30$)

⇒ Martensite is not an equimolar stage, there are lot of internal stresses, plus this martensite needs to convert to ~~more~~ a more stable martensite (as some dimensional change takes place), hence we do tempering. Hardening is always followed by Tempering.

q → concept type questions