6th semester

[4/5/21] - HTT

(1) Introduction -

- Structure-Property Relationship
- Equilibrium phase diagram - tells us phases present in equilibrium with each other.

- Properties depends upon types of phases present, fraction of phases present, size (grain size), shape (grain shape), distribution of a particular phase.

size
~~dph~~ shape } Morphology
Distribution

~~The properties~~

Heat-Treatment - why? - to basically modify / improve the mechanical, electrical, magnetic properties of a steel.

Heat Treatment - process

Notes : ↳ (next page)

↓

heating the specimen to a desired temp, holding at ~~of~~ a specific temp. for a ~~parti~~ specified period of time and then cooling at a specified rate.

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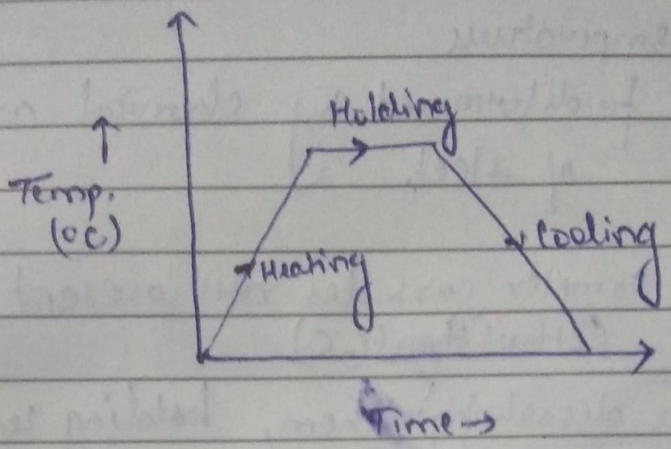


## Purpose of Heat Treatment :-

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

## Heat Treatment variables -

(i) → Heating Rate (depends upon size & shape of specimen)

- for small size → heating rate can be fast
- for large size → heating rate should be slow. (so that the temp. at surface & core can be uniform)

Note: there is not much distance b/w surface & core and the small distance can be looked after at holding temp.

heating rate.

(ii) → Shape - normal (uniform thickness, round bends)
- complex (if variable thickness, sharp bends)

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(iii) → Holding temperature is determined by chemical composition of steel.

but if complex carbides are present, (other than $Fe_3C$)

then for dissolving them, holding temp. should be higher.

(iv) Holding time – depends upon size of specimen

for smaller size, less holding time

for larger size, more holding time is required.

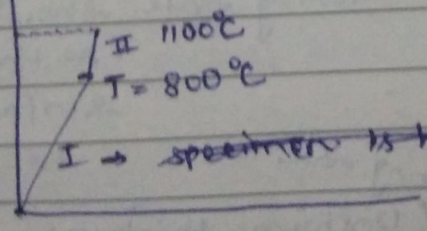
But here, there is a problem –

- there is danger of surface oxidation
- there is danger of grain portioning

Solution we have to adopt 2 stage heating.

In the 1st furnace, the specimen should be ~~heating~~ heated to a temp. where there is negligible surface oxidation.

Then In 2nd furnace which is already maintained at a higher temp., to faster the rate of heating & uniform temp. can be obtained.




Notes :

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(v) → Cooling Rate -

~~If~~

Cooling Rates

Equilibrium CR → very slowly → keep the ~~for~~ specimen inside the furnace & switch off the furnace.

ANNEALING

→ Relative faster CR (Air cooling) → keep ~~sp~~ out of furnace

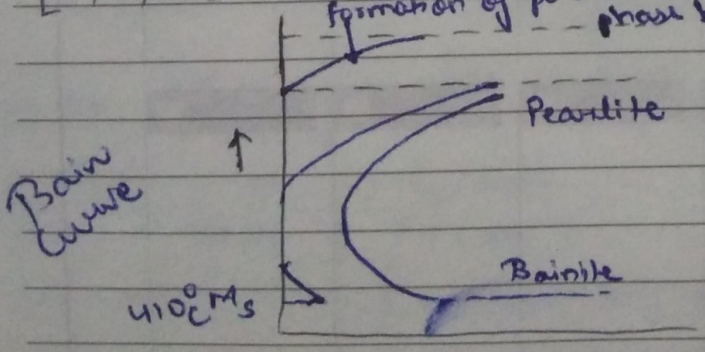
NORMALISING

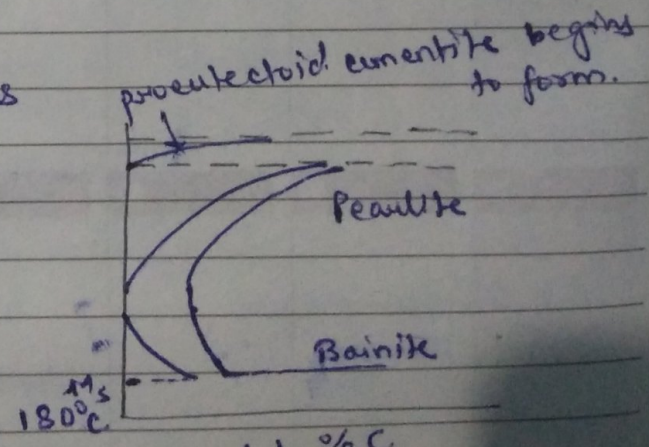
→ Quenching CR is rapid (Hardening)

(water, brine)

~~[5/5/21] → HTT~~

[7/5/21] → HTT



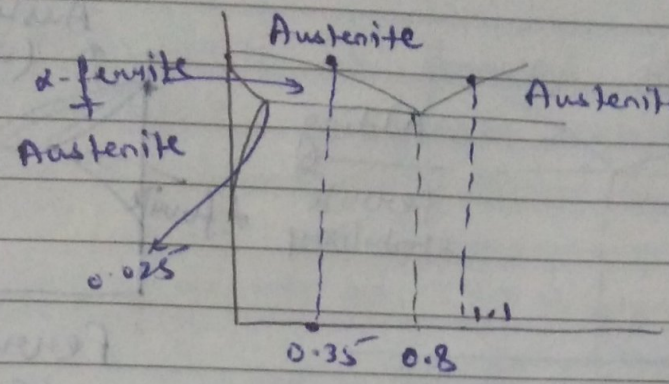

Notes :

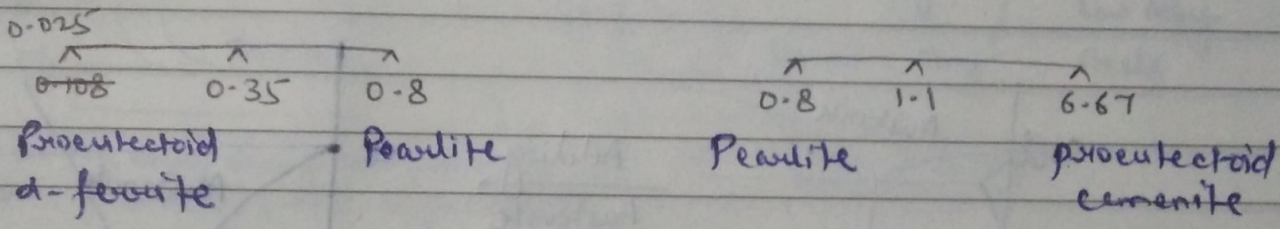
60% proeutectoid α-ferrite + 40% austenite

TTT diagram for Hypoeutectoid steel

TTT diagram for Hypereutectoid Steel

5% proeutectoid cementite + 95% Austenite




$M_s = 210$

| % C low | % C high |
|---|---|
| $M_s$ goes high | $M_s$ goes lower |

0.8% C

## Effect of alloying elements on Fe-$Fe_3C$ phase diagram

C, Si, Mn, P, S — present in steel

Not-Alloying Elements.

Those elements which are being added knowingly

Alloying elements

- Ferrite Stabilizers: Cr, Si (BCC)
- Austenite Stabilizers: Ni, Mn, Al, Cu (FCC)
- Carbide formers → Red Hardness property: W, V, Mo, Cr
  - [Fe, W, Cr, Mo, V] C — Complex Carbide
  - Formation of high carbon steels like HSS

Notes:

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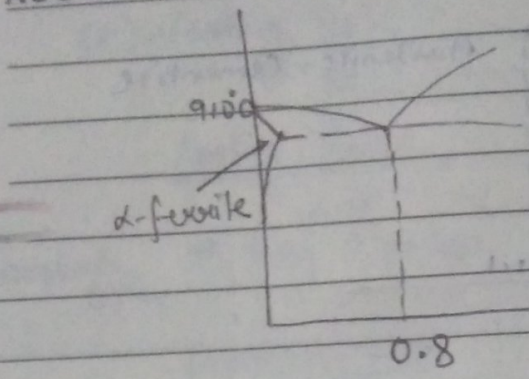
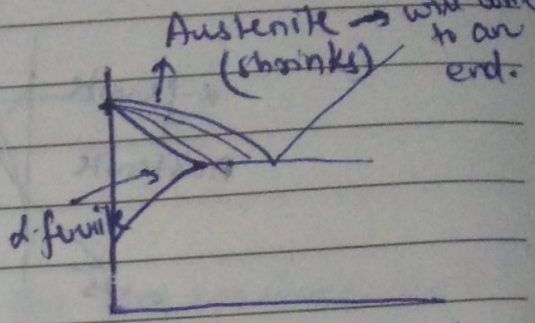
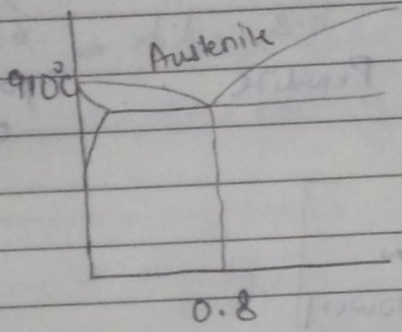


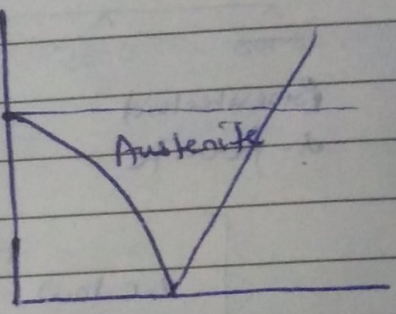

Adding ferrite stabilizer




Ferritic Stainless S
($Fe_2O_3$) → Steam Turbine blades.




Adding Austenite Stabilizer




18/8 Cr Ni

Austenitic Stainless Steel
($Cr_2O_3$ or $Al_2O_3$)
↓
Home Utensils

| Chrome plate S.S | Austenitic S.S |
|---|---|
| can corrode | Cannot-corrode |

(0.1% C) → Martensitic S.S — in surgical tools. (should be hard)

Notes: Carbon in S.S ← 0.03 – 0.05 (very very low) Utensils

$Cr_3C_2$ → intergranular corrosion. (∴ Carbon should be low)
(opposite of HSS)

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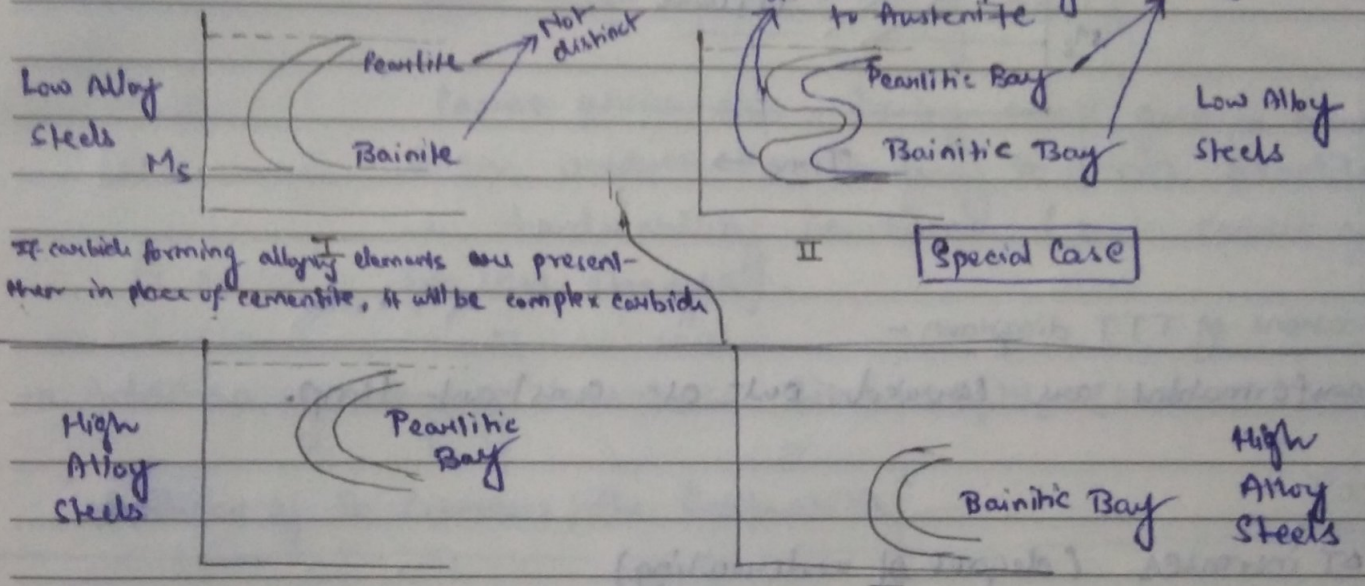
Generally, Austenite is formed above 910° but, if we add austenite stabilizers, then austenite can form at room temp.

Effect of Alloying elements on TTT diagrams




Here, the nature of alloying elements in High Alloy Steels is such that- $M_s$ temp. is below 0°C (sub-zero temp.), so bainite is shifted below 0°C, due to which it is not visible in this TTT diagram.

Here, the nature of alloying elements in High Alloy Steels is such that it does not favour the formation of Pearlite Bay and $M_s$ temp. is above room temp, so only bainitic bay is visible in this TTT diagram.

Notes :

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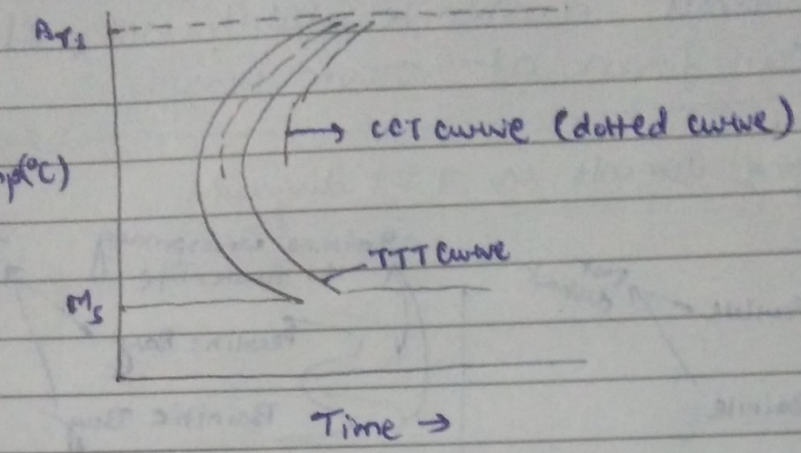
## CCT diagram




Limitations of TTT diagram -

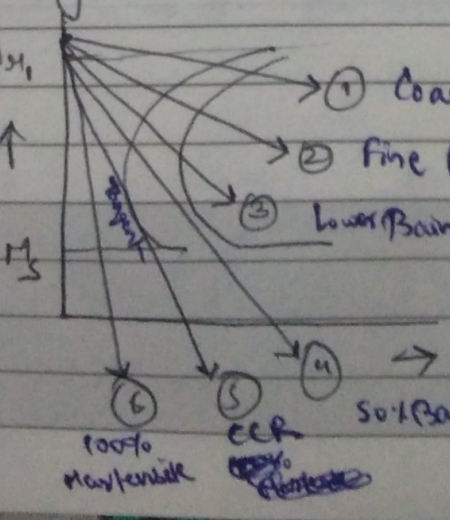
Transformations are carried out at constant temp.

For CCT

ΔT increases (degree of undercooling)
't' incubation period increases.

Isothermal cooling is applicable in very few cases. On the contrary continuous cooling is generally more pratical. Therefore, CCT diagram is more relevant than TTT diagram.

Hardenability — ability to harden itself




Notes :

218-147 = 32nd week

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Factors affecting ~~Inventing~~ Hardenability -

→ Carbon content

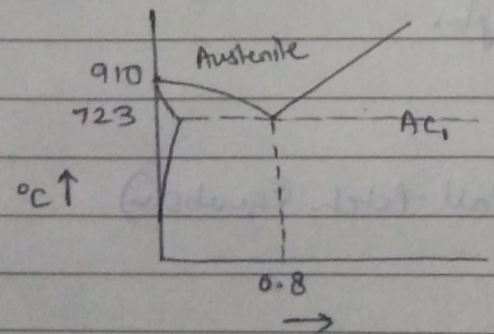
→ Grain size (Nucleation of pearlite takes place at Austenite grain boundaries, so pearlite formation is ~~favoured~~ by large grain boundary area, so fine grains ~~have~~ large grain boundary area)

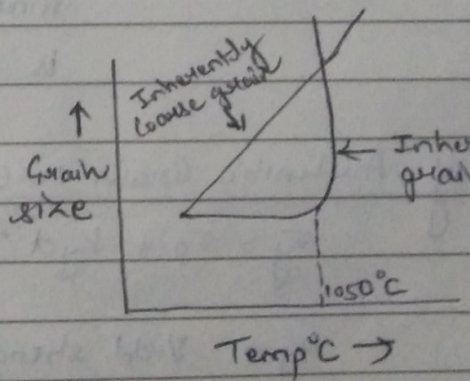
Coarse grain size, having small grain boundary area, reduces the tendency to form pearlite so, hardenability increases. (but coarse grain has less strength).

→ Addition of alloying elements - like Mn, Mo (increases hardenability)

" Addition of Co decreases the hardenability"

Austenitic Grain size




Heating very slowly, Pearlite → Austenite transformation takes place at 723°C.

But,

Notes: In real situations, Pearlite - Austenite transformation takes place slightly above $Ac_1$

? Above $Ac_1$ → To ensure complete transformation.
→ To ensure homogenity of austenite.

(Actual) Austenitic Grain Size is formed.

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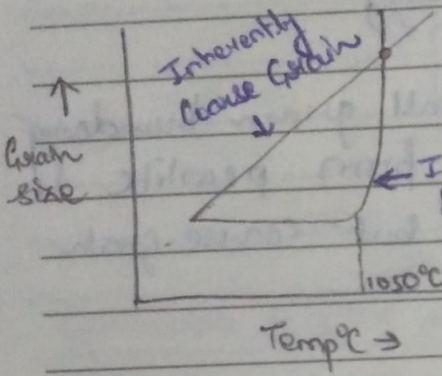
Based upon the austenitic grain size,

Steel

- Inherently Coarse Grain Steel
- Inherently fine grain steel




Why there is no coarsening in inherently fine grain steel till 1050°C?

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

But,

after 1050°C, these refractory compounds dissolve in austenite matrix, and so now grain growth is very high.

Importance of Austenitic Grain size

(1) $\sigma_y = \sigma_0 + k_y d^{-1/2}$ (Hall-Petch Equation)

$\sigma_y$ → Yield strength

$\sigma_0$ → frictional stress

$k_y$ → extent of dislocation pile up

$d$ → Austenitic grain size

Notes:

$$\left[\sigma_y \propto \frac{1}{\sqrt{d}}\right]$$

(3) Impact- transition temperature or
Ductile to brittle transition temperature.

Grain Size ↑ Impact-transition temp. ↑

(5) Creep strength (High temp. strength)

Above equi-cohesive temp., then grain size ↑
so, Creep strength ↑

Below equi-cohesive temp., Grain size ↓
Creep strength ↑

(4) Fatigue Strength (Ability to withstand ~~Strength under~~ cyclic loading)

Fine Grain Size, Fatigue strength ↑

(5) Hardenability

Grain size ↑ Hardenability ↑

Determination of Austenitic Grain Size

Metallography (Metallographic Method)
for revealing austenitic grains

Notes :

↓ Change of Composition takes place

↓ No change in composition

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By change of composition –

I Case Carburizing

II Oxidation

By No change in composition –

## Determination of Austenitic Grain Size

I By comparing with standard ASTM charts. (For equiaxed grains)

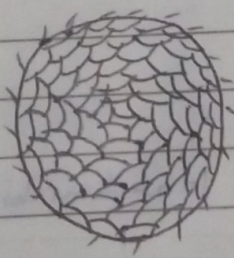
$$G = -2.9542 + 1.4427 \ln n_a$$

where, $G$ = grain size no.

$n_a$ = no of grains / sq mm @ 1X

II Jefferies Planimetric Method

For equiaxed grains



Area of cross-section = 5000mm²

m = magnification should be such that at least 50 grains are inside X-section

$$n = n_i + \frac{n_c}{2}$$

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

Notes: $G = -2.9542 + 1.4427 \ln n_a$

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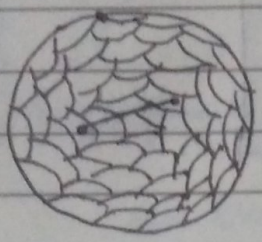
## III Heyn's ~~Incept~~ Intercept Method –

Not for equiaxed grains but ultrafine grains.

eg: High Speed Steel

N 10 – 12



Length of intercept = 0.005"

@ × 1000

m = magnification should be such that atleast $0.5\ mm^2$ of actual sample is covered.

10 readings are taken, then the average value is taken.

point ends = 1/2

Full intercept = 1

No. of grains per inch

@ × 1000

$$= \frac{I}{0.005} \rightarrow \text{Mean intercept length}$$

$$= 200I$$

No, No. of grains per sq. inch @ × 100 $= \left(\frac{200I}{100}\right)^2$

(n)

$$n = (2I)^2$$

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

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

Notes :

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

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

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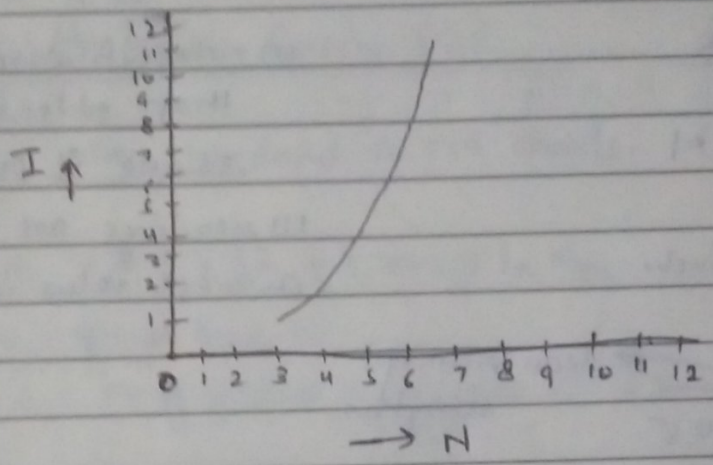
$$\Rightarrow N - 1 = 2 + \frac{2 \ln I}{\ln 2}$$

$$\Rightarrow \boxed{N = \frac{2 \ln I}{\ln 2} + 3}$$




## IV Shepherd's Fracture Test Method

Austenite (grain size)

↓ Quenched for hardening

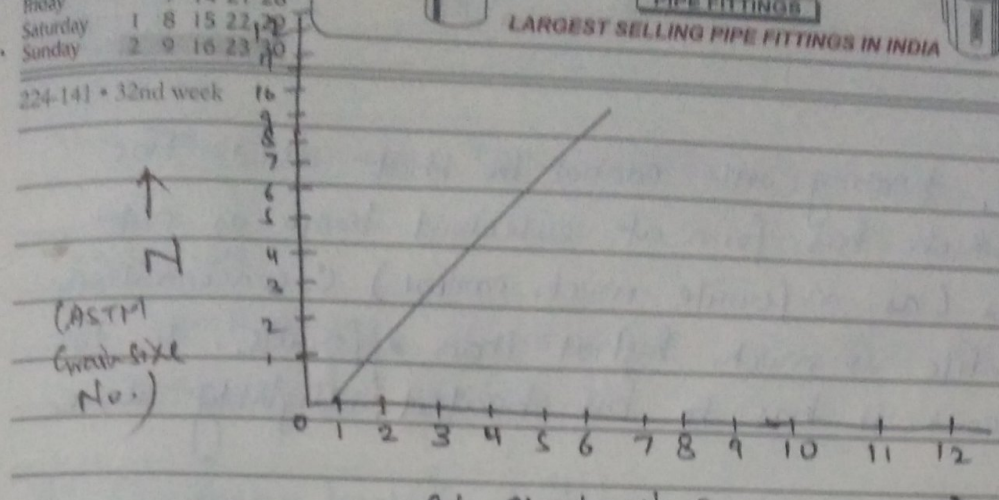
↓ Fractured

↓ Fractured Surface (Grain size) → Shepherd's fracture No.

1 — 10

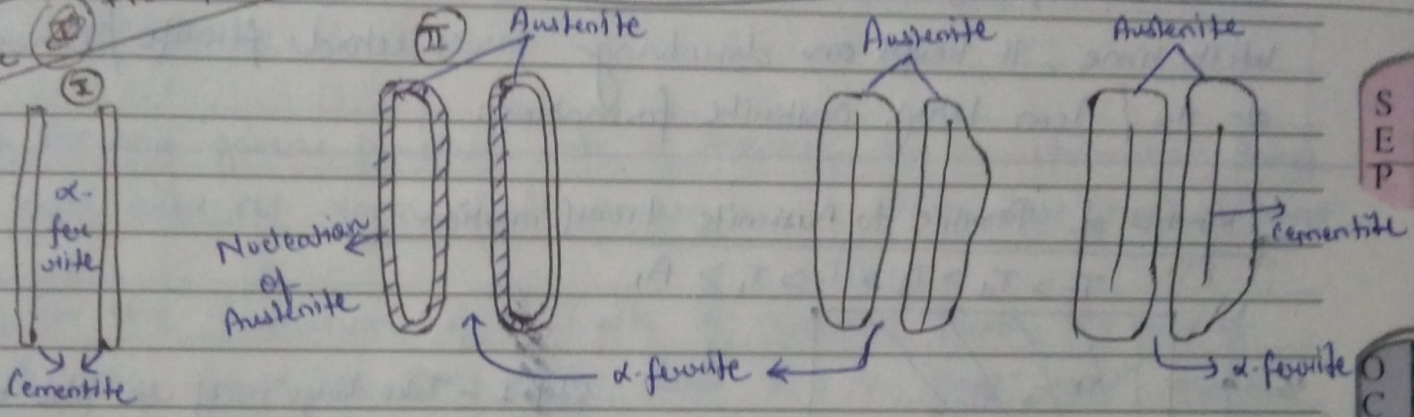
Coarsest grain — finest grain

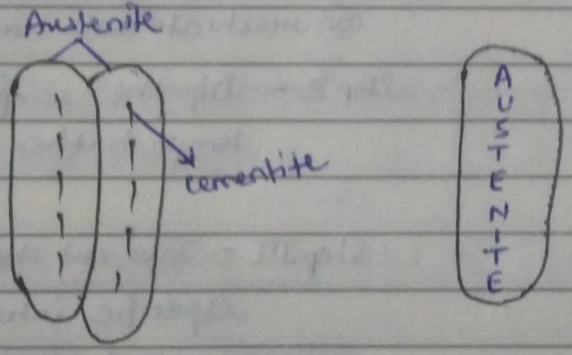
Notes :




## Mechanism of transformation

Pearlite – Austenite




At room temp, ~~very slowly~~, the C diffuses out of cementite so, the adjacent region of cementite, the austenite nucleate at the interface of α-ferrite and cementite.

in this case, as temp. is higher, cementite dissolve much faster than proeutectoid ferrite.

Notes: After α-ferrite dissolve fastly and cementite also dissolve slowly, and they start disappearing and then they disappear eventually. There is a phase transformation α iron – γ iron, due to this change α-ferrite dissolve faster.

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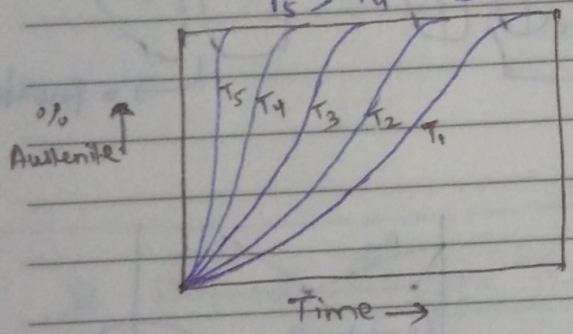
In practice, heating rate cannot be that slow. The austenite which has form at eutectoid temp. is not homogeneous (as $\alpha$-ferrite much earlier) C concentration near cementite is much higher than $\alpha$-ferrite. So, to make it homogeneous, it has to be heated slightly above the $A_1$ temp.

When heated, austenite nucleate.
With time, it keeps on dissolving proeutectoid ferrite / cementite at $A_3$ / Acm temp. austenite formation.

Kinetics of Pearlite to Austenite transformation

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

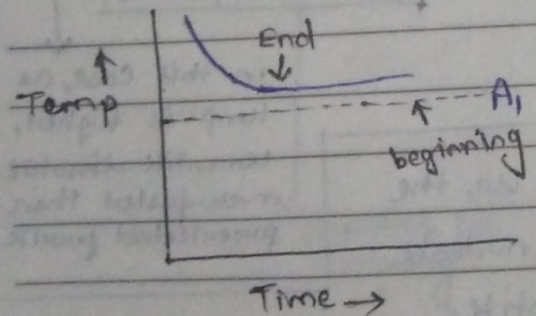



(Fig 1)

Step I – Take large no. of samples of ~~(size)~~ small size, so that we can reach at auste. temp. in small time.

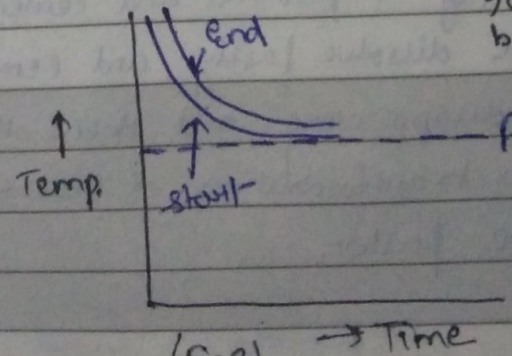
Step II – Dip the samples in constant temp. bath

Step III – Take out the samples after specific intervals and quench it
↓↓
(Martensite)
% Martensite formed will depend upon how much % austenite was formed before quenching.




(Fig 2)

Notes :




(Fig 3)

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The transformation begin slightly upper $A_1$.

Conclusions –

1) Transformation is completed in a short period at higher transformation temperature.

2) For faster heating rates, transformation starts at higher temp. and for slower heating rates, transformation starts at lower temperature.

3) For any given practical rate of heating, the transformation takes place over a range of temp. and not a particular / constant temp.

4) For the formation of austenite at constant temp., the rate of heating should be very very slow and in that case, the two curves in figure 3 will merge with $A_1$.

Rate of pearlite to austenite transformation depends upon transformation temperature and time.

Other factors affecting kinetics of pearlite to austenite –

Austenite → Pearlite

Mechanism → Nucleation & Growth

at interface of $\alpha$-ferrite and cementite.

Notes :

Rate of nucleation and growth can be increased by increasing the interface area.

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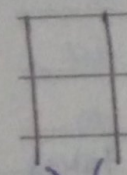
How the interface area can be increased?

→ by increasing cementite content by increasing the carbon content.
That is why, formation of austenite is faster in case of high carbon steel.

→ by decreasing interlamellar spacing ie, (distance b/w 2 successive lamella)




If we all reduce the distance, the length of the path carbon needs to travel during diffusion has reduced. Transformation of austenite, takes place by diffusion of carbon so, nucleation & growth is faster.
Interlamellar spacing is more in case of coarse pearlite. In case of fine pearlite, transformation will be faster.

Pearlite may also occur as -
→ granular pearlite } in both cases, interface area small
→ globular pearlite } so, austenite transformation will slower.

These all is for plain carbon steel.
but 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.

Notes :

## Mechanism of Austenite → Pearlite transformation

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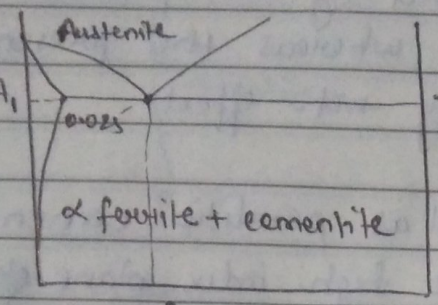
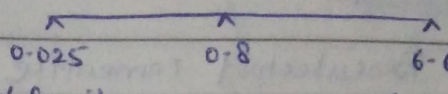



Just below 723°C,




α-ferrite
$0.8 \times 0.88$
$\simeq 0.7\%C$

Cementite
$0.8 \times 0.12$
$\simeq 0.1$

→

Max solubility of C in α-ferrite is 0.025, so there will be diffusion of carbon from α-ferrite to cementite. But it is a slow process.

For diffusion to be complete, rate of cooling should be very slow. This is possible by annealing or normalizing.

By Annealing → coarse pearlite
By Normalizing → fine pearlite

α-ferrite + cementite

which nucleates first at austenite grain boundary

Active nucleus – which nucleates first provided it is present in the final microstructure.

– it must have some lattice orientation relationship with the parent phase.

Mehl's hypothesis –

[In support of Cementite ~~as the~~ being active nucleus]

Notes: Postulates →

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

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(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 are in general parallel to the high index plane of austenite.

Smith Hypothesis – favours α-ferrite as the active nucleus.

(i) Pearlitic ferrite as well as pearlitic cementite can have any orientation relationship with the parent austenite except for those which allow the formation of interfaces which are partially coherent with the parent austenite.

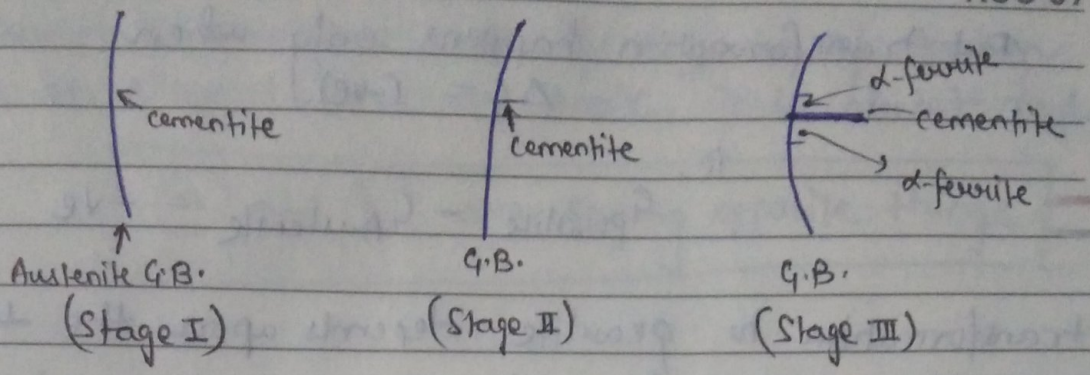
Atom to atom matching between precipitated phase and parent phase → coherent.

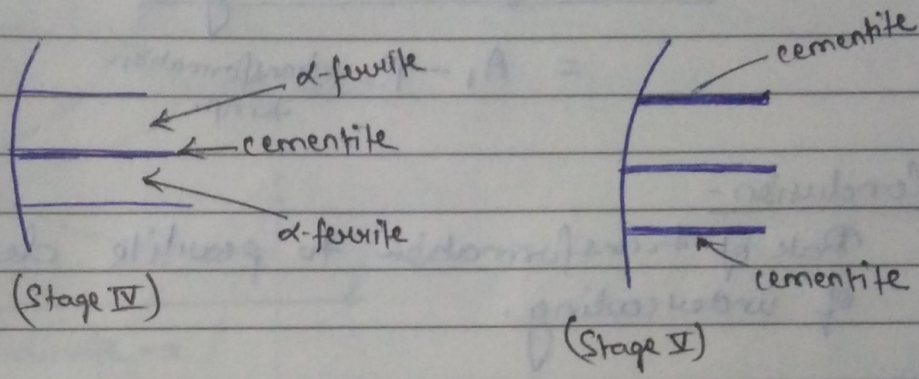
(ii) Both cementite & ferrite can be active nucleus and consequently formation of pearlite can be initiated by either of the two.

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

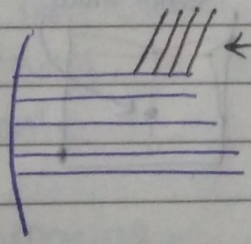
Hull and Mehl's hypothesis – This explains the formation of lamellar structure of pearlite.

Notes :




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



← Sidewise growth of pearlite colony.
Also possibility of edgewise growth of pearlite colony.

## Kinetics of Austenite → Pearlite transformation

At $A_1$ (723°C), $G_{Austenite} = G_{Pearlite}$

Notes: $\Delta G = 0$

Ideally, the transformation should start at $A_1$, in case of very slow cooling.

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But transformation happens only when $\Delta G$ = (-ve)

ie. $G_{pearlite} - G_{Austenite} = -ve$

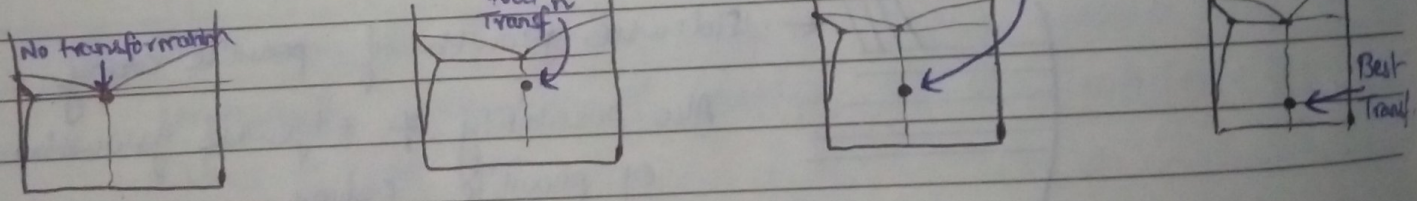
so, transformation to pearlite depends upon the ~~temp difference~~ degree of undercooling

$= A_1 - T$ → transformation temp.

Conclusion -

Rate of transformation to pearlite depends upon degree of undercooling.

(a) Lower the temp. of transformation, rate of transformation will be faster.




Just below $A_1$ →

| | α-ferrite | | cementite |
|---|---|---|---|
| | 0.025 | 0.8 | 6.67 |
| | 0.88 | | 0.12 |
| | ie. | | ie. |
| | 0.7 | Carbon diffusion → | 0.1 |

Notes :

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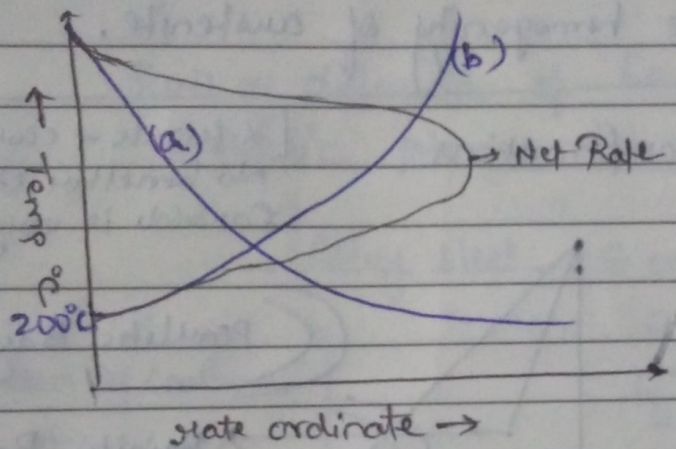
(b) At lower temperatures, rate of diffusion of carbon will be slower and at 200°C, it is almost negligible.

(a) and (b) are saying opposite things.




Effect of Alloying elements-

With increase in degree of undercooling, rate of transformation to pearlite decreases, in the presence of heavier atoms of alloying elements.

Interlamellar spacing-

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

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

Notes:

Since, for stronger steels, interlamellar spacing should be small lower transformation temp. are desired.

Saturday
Sunday 1 8 15 22 29

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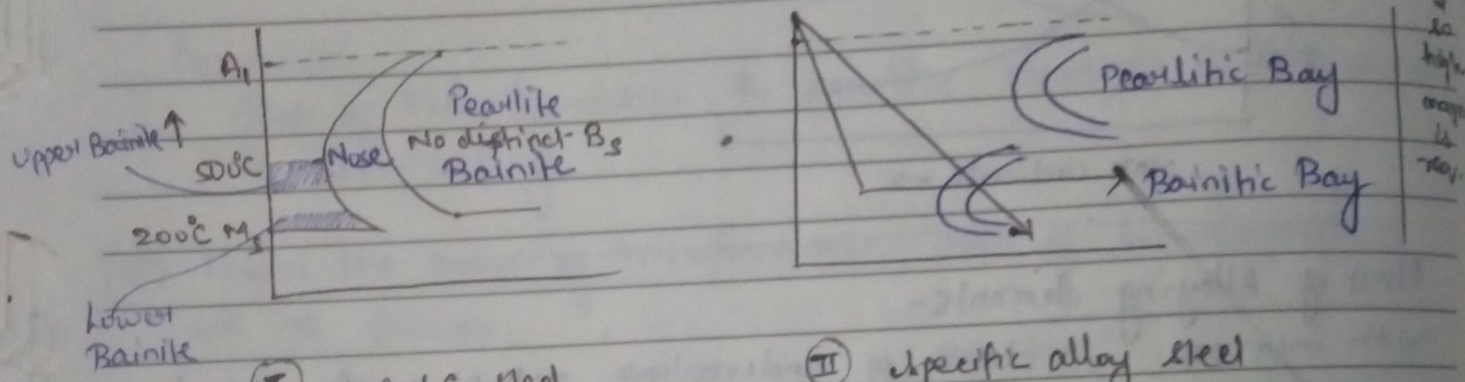
In case of alloy steels, transformation temp. is always higher ~~so~~ that means in the case of alloy steels, the interlamellar spacing is larger.

→ Interlamellar spacing is insensitive to structure.
→ Interlamellar spacing does not depend upon the austenitic grain size and also the homogenity of austenite.

## Bainitic Transformations

[α-ferrite + carbide
No lamellar structure
Carbide is very fine]




(I) 0.8 % C steel

Pearlitic & Bainitic region overlap.
Bainite cannot be obtained by continuous cooling.

(II) Specific alloy steel

Bainite can be obtained by continuous as well as isothermal transformations

Upper Bainite – Lath structure (Elongated strip) – feathery structure
↳ adjacent to pearlite → so similar properties like pearlite
Lower Bainite – Acicular structure (more like needle)
Notes: ↳ adjacent to Martensite → so similar properties like martensite

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# Mechanism of Transformation

500°C
200°C

'C' diffusion may take place

↓ Rate of diffusion of 'C' will be slower

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

Alloy steel – $\epsilon$ carbide

$Fe_xC$

$Fe_{2.4}C$

[diffusion of carbon + Shear Mechanism]

Complex process.

Predominant

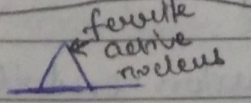
In upper bainite region, 'C' diffusion

In lower bainite region, Shear Mechanism

Rate controlling step

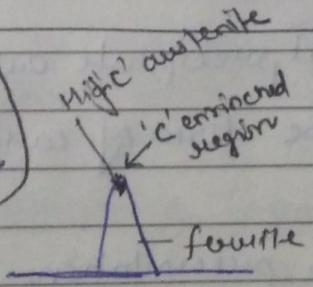
diffusion of 'C' away from High 'C' austenite & form cementite

Upper Bainite




I

ferrite is the active nucleus coz There is lattic orientation relationship b/w Notes: ferrite & parent austenite.

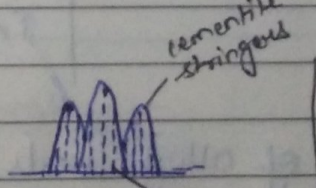



II

Due to high temp., redistribution of 'C' takes place in austenite.

* High 'C' austenite
* low 'C' austenite

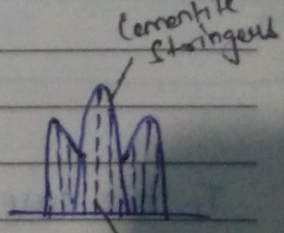
This results in the setup of stress




III

Cementite is precipitated out from High 'C' austenite in the form of ~~Cem~~ stringers.

Low C austenite transforms into ferrite by shear mechanism.




IV

Enlarged form

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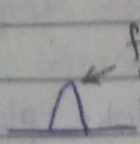
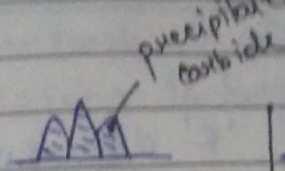
## Lower Bainite




I

Ferrite is the active nucleus because there is lattice orientation relationship b/w ferrite & parent austenite.




II

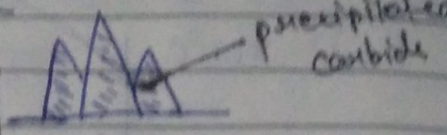
Due to quite low transf$^{n}$ temp., there is no redistribution of 'C' taking place. So, only low 'C' austenite is present

low C austenite

↓

transforms to supersaturated ('with C') ferrite

'C' will precipitate out in the form of carbide




III

Enlarged form

In the case of alloy steels, ~~for~~ precipitation of epsilon carbide has been observed and epsilon carbide cannot precipitate out from austenite. So, carbide is precipitated out from supersaturated ferrite and not from austenite, in case of lower bainite.

Notes :

236-129 • 34th week

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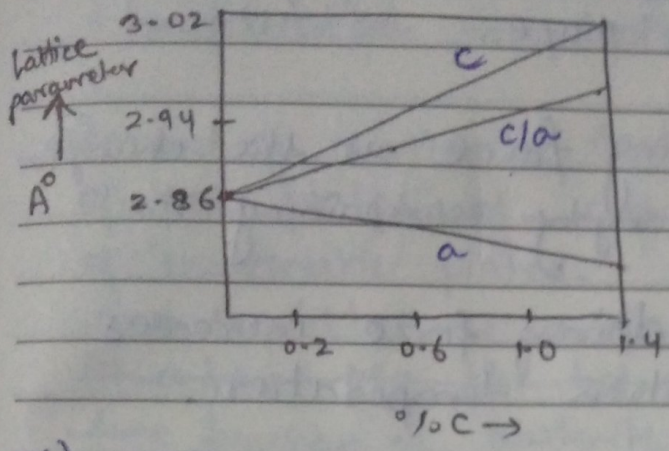
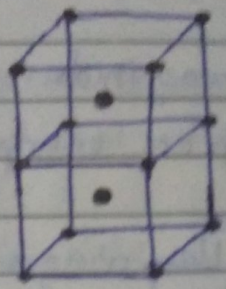
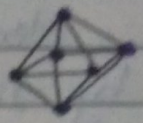
## Martensitic Transformation





(FCC) γ-iron | Comp is same | Austenite (saturated solid solution of 'C' in γ-iron)

↓ quenched

(BCC) α-iron | Martensite (supersaturated solid solution of 'C' in α-iron)

α-iron will be supersaturated with 'C', which is known as Martensite.

Octahedral Radius = 0.414R
Tetrahedral Radius = 0.225R

Martensite – BCT ($a=b\neq c$, $\alpha=\beta=\gamma=90°$), 'C' atoms will occupy position in interstitial void.

### Mechanism of Martensitic Transformation:-

Martensite is a diffusionless transformation, unlike pearlitic & bainitic transformation.

It is a displacable transformation that takes place by co-operative 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 their neighbourhood undisturb.

Notes:

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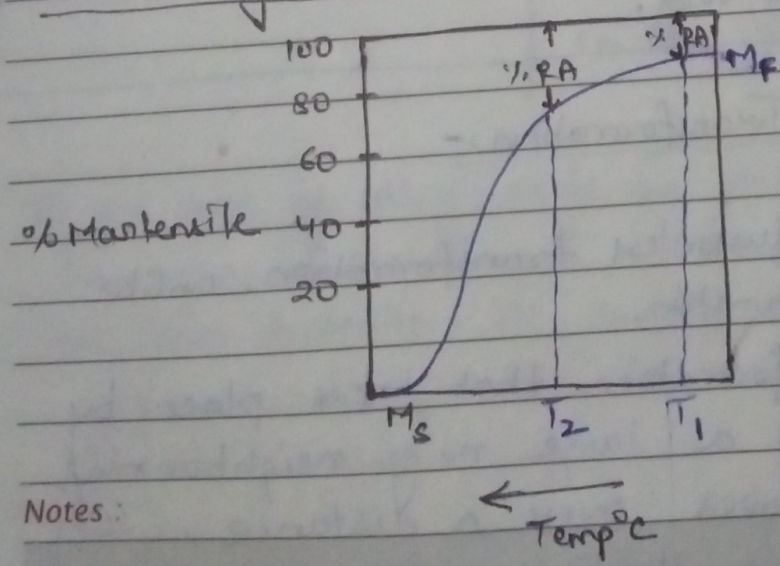
A large driving force is required for the transformation to take place.

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 atom is less than 1 interatomic distance, the total displacement increases as one moves away from the interface boundary. Such buildup of displacement finally result in a macroscopic slip. The slip can be observe as a relief structure on the surface of martensite.

Kinetics of Martensitic transformation-




RA: Retained Austenite

Notes :

The transf Martensitic transformation starts from $M_s$ and transformation of martensitic proceeding at the range of temperature

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Amount of martensite formed depends upon the transformation temperature.

Amount of martensite transform depends upon nucleation of new plates of martensite and not due to growth of martensitic plates.

At a temp $M_F$, the transformation is complete.

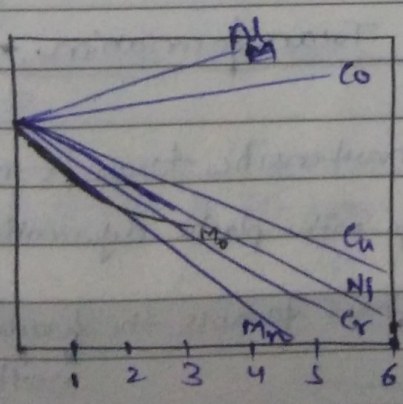
~~At a temp $M_F$, the transformation is complete.~~

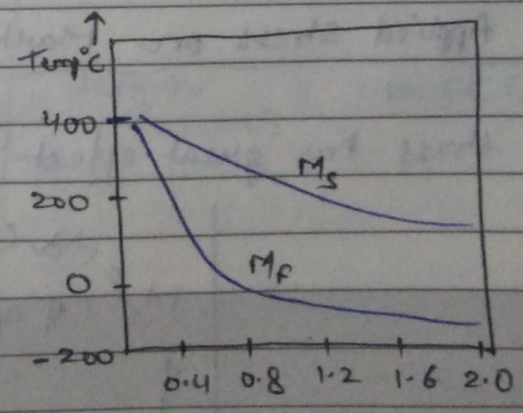
Some fraction of austenite is not transform to martensite, it is called retained austenite.

The transformation to martensite begins in fraction of microseconds and completes in fraction of milliseconds. This means rate of martensitic transformation is independent of transformation temperature.

## $M_s$ & $M_f$ temperatures :-

$$M_s\ ^{\circ}C = 561 - 474\,(\%C) - 33\,(\%Mn) - 17\,(\%Ni) - 17\,(\%Cr) - 21\,(\%Mo)$$




Notes :

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- $M_s$ temperature doesn't depend upon cooling rate but depends upon the chemical composition of steel and austenitizing temperature.
- With increase in 'C' content, $M_s$ & $M_f$ temp. decrease and Al & Co increases $M_s$ temp.

Austenitizing temperature

If austenitizing temp. is high, more and more carbides will dissolve; as a result, 'C' content will increase, thereby $M_s$ is lowered.

If austenitizing temp. is high, grain coarsening will take place. Coarse austenitic grain size rises $M_s$ temperature

$M_s$ is lower or high, depends on which of the 2 factors dominate.

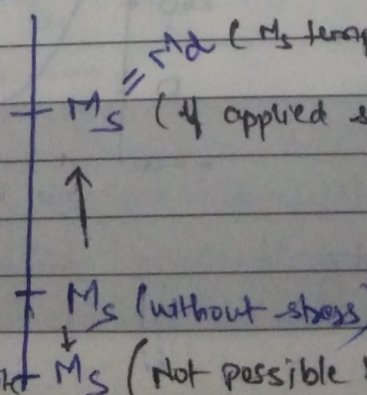
$M_f$ temp is lowered with increase in 'C' content.
$M_f$ temp. is also lowered if cooling rate is very very slow.

ie,
Rate of transformation around $M_f$ temp. is very very slow that is why in TTT diagrams, $M_f$ temp. is not mentioned.

## Effect of Applied stress on Martensitic Transformation -

→ Applied stress has great effect on martensitic transformation.

Notes :



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## Athermal Martensite

Observed in all 'C' steel

cooling below $M_s$ temp. and holding at $T_1$ temp. and again started cooling.

$M_s$

$T_1$ (martensite will form)

$T_2$ (Martensite will form again)

## Isothermal Martensite

Observed in low 'C' Fe-alloy and in high alloy steels.

cooling below $M_s$ temp. and then holding at T temp.

$M_s$

T (hold)

Depending upon the appearance, we have Lath Martensite and Plate Martensite (Lenticular looks like lens)

**Lath Martensite**

↓

(long thin strip)

↓

from one GB to other GB

Thickness : 0.10 – 0.20 μm

**Plate Martensite**

length : across GB (same)

Notes :

Plane, $M_s$ is not lowered.)

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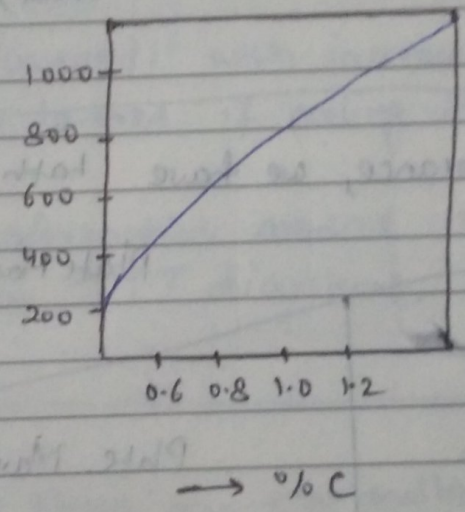
## Hardness of Martensite

Reasons behind hardness of martensite –

1) % Carbon content – If 'C' content ↑, hardness ↑

2) Due to presence of strength in within α-Fe lattice. The strain in α-Fe is due to supersaturation of α-Fe by carbon atoms.

3) Plastic deformation of parent austenite surrounding the martensitic plate.




~~If $M_s$ temp ↓, % RA increases~~

Medium carbon steels offers the highest degree of hardness.

Notes:

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# Heat Treatment - furnaces & atmospheres

## furnaces (Classification)

| Use | Source of Heat | Types of operations (work) | Atmosphere |
|---|---|---|---|
| • Annealing furnace | • Solid fuel ✗ | • Batch type | • open air atmosphere |
| • Hardening furnace | • Liquid fuel (fuel oil) | • Continuous type | • controlled atmosphere |
| • Tempering furnace | • Gaseous fuel (Natural Gas, BF Gas, Coke oven Gas) | | |
| | • Electrical furnaces (Muffle furnace, Pit furnace, Bogie furnace) (Resistance Heating) | | |

## Wires / Rods

| | | |
|---|---|---|
| • Constantan | Cu-40% Ni | upto 900°C |
| • Nichrome-I | Ni 20% Cr | upto 1100°C |
| • Nichrome-II | Ni-24% Fe-16% Cr | upto 950°C |
| • Alomel | Ni-3% Mn, 2% Al, 1% Si | upto 1200°C |
| • Chromel | Ni-10% Cr | upto 1200°C |

Notes :

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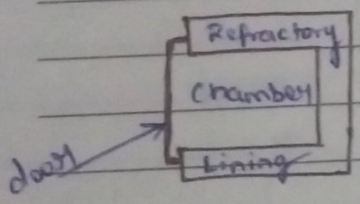
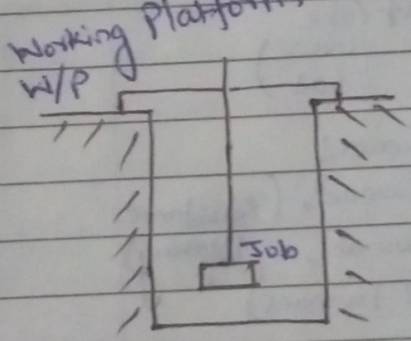
- Kanthal — Fe-25% Cr, 5% Al, 3% Co — upto 1400°C
- Tungsten — upto 2400°C
- Molybdenum — upto 1800°C
- Platinum — upto 1500°C
- Pt- 10% Rh — upto 1700°C
- Graphite — upto 2000°C

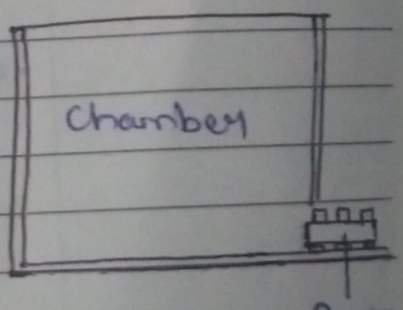
Types of furnaces




I Muffle furnace




II Pit furnace




III Bogie furnace

Batch Type

Notes :

01 SEP'07
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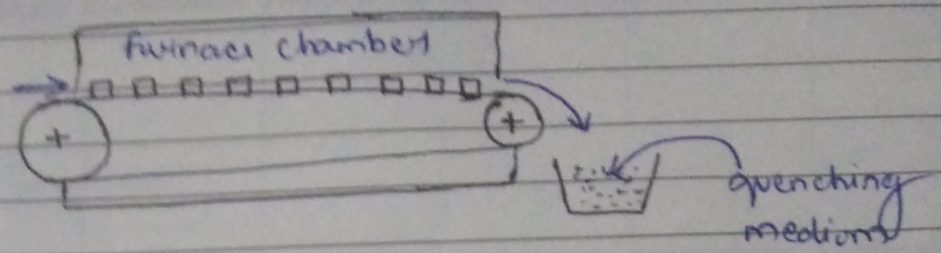
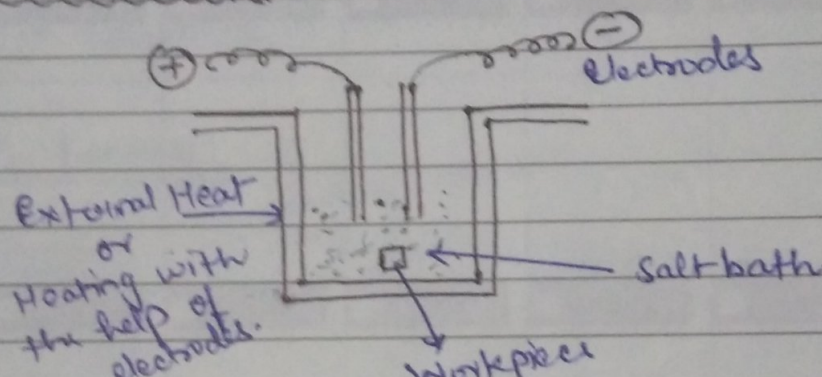



Continuous Type.
(for hardening purposes)

## Salt Bath furnace




Salts
Chlorides, carbonates, Nitrates, Cyanides (150-1300°C)

Heat capacity of salt baths is quite high, so its effectiveness of heating is almost 7 times more than that of muffle furnace.

## Measurement of Temperature

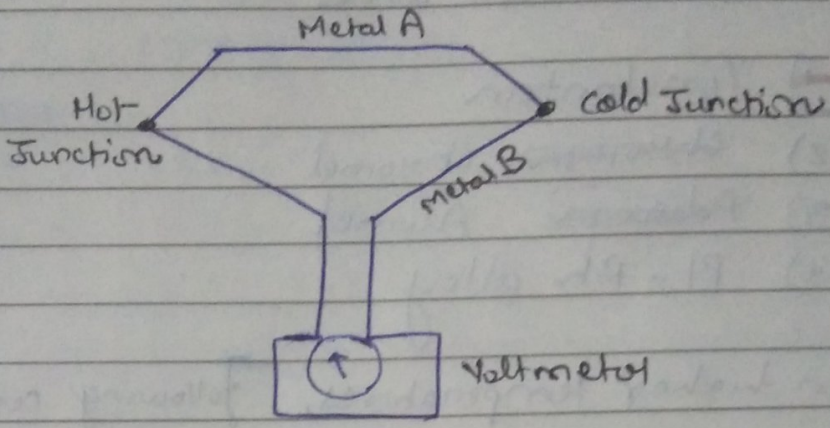
Notes:

- Thermometry (upto 500°C)
- Pyrometer (if temp. > 500°C)

SEP'07 02 Sun

Pyrometer

(1) Thermocouples –




Classification of Thermocouples

- Base Alloys (Low cost Alloys)
- Noble Alloys

Requirement of Thermocouple materials –

1) The metal should be homogeneous.
2) The material should be resistant to oxidation and corrosion.
3) The thermal 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 temp.
6) The EMF should increase with increase in temp. difference.
7) There should be linear relationship b/w EMF & temperature.
8) The induced EMF should be sufficiently large.
9) The induced EMF should be reproducible.
10) The material should not be very expensive.

Notes :

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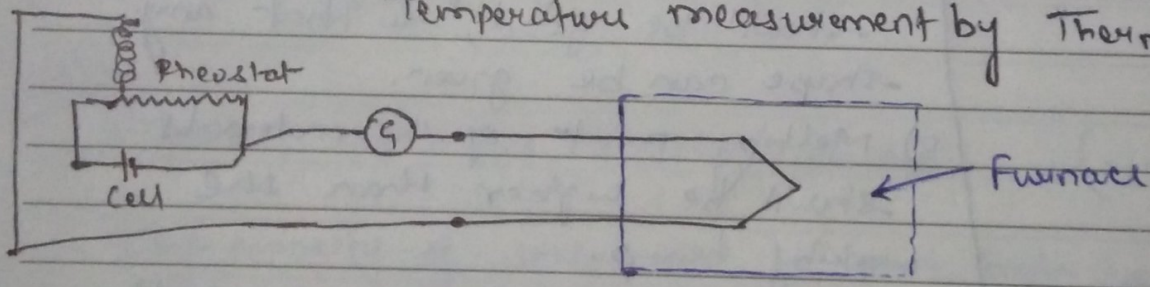
Chemical composition of some alloys used as thermocouple wires —

1) Constantan
2) ~~Chromel~~ Chromel
3) ~~Alumel~~ Alumel
4) Pt - Rh alloy

For even higher temperatures, following compositions can be used —

1) Tungsten - Molybdenum
2) Tungsten - Rhenium
3) Tungsten - 26% Rhenium
4) Mo - Rhenium
5) Tungsten - ~~Iridium~~ Iridium
6) Ir - Ir Rh alloy

Temperature measurement by Thermocouples




Caliberation —

List of metals which are used for caliberation are —

Notes :

Al - 660°C (mp)
Sb - 630.5°C (mp)
Bi - 271.3°C
Co - 1480°C
Cu - 1083°C
Au - 1063°C



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Tue

Pb - 327.4 °C

Ni - 1453 °C

Pt - 1773.5 °C

~~Rh~~

Rh - 1966 °C

Ag - 960.5 °C

Sn - 231.9 °C