UNIT-3

Heat Treatment of Steel

↳ Heat treatment is defined as controlled heating & cooling of metals to change their physical & mechanical properties, without changing the product shape.

↳ Various types of heat treatment processes are;

(1) Annealing, (2) Normalising. (3) Hardening

(4) Tempering, (5) Spheroidising.

(1) Annealing :-

↳ It is a type of heat treatment process, where a metal is heated to a suitable temperature, kept at that temperature for sometime and then allowed to cool slowly.

↳ Mostly cooling is done inside the furnace.

↳ Main aim of annealing is to increase the ductility of the metal.

↳ Various types of annealing processes are as follows.

(A) Full Annealing

(B) Process Annealing

(C) Stress-Relief Annealing

~~(D) Iso thermal Annealing~~

(D) Spheroidise Annealing

(A) Full Annealing :-

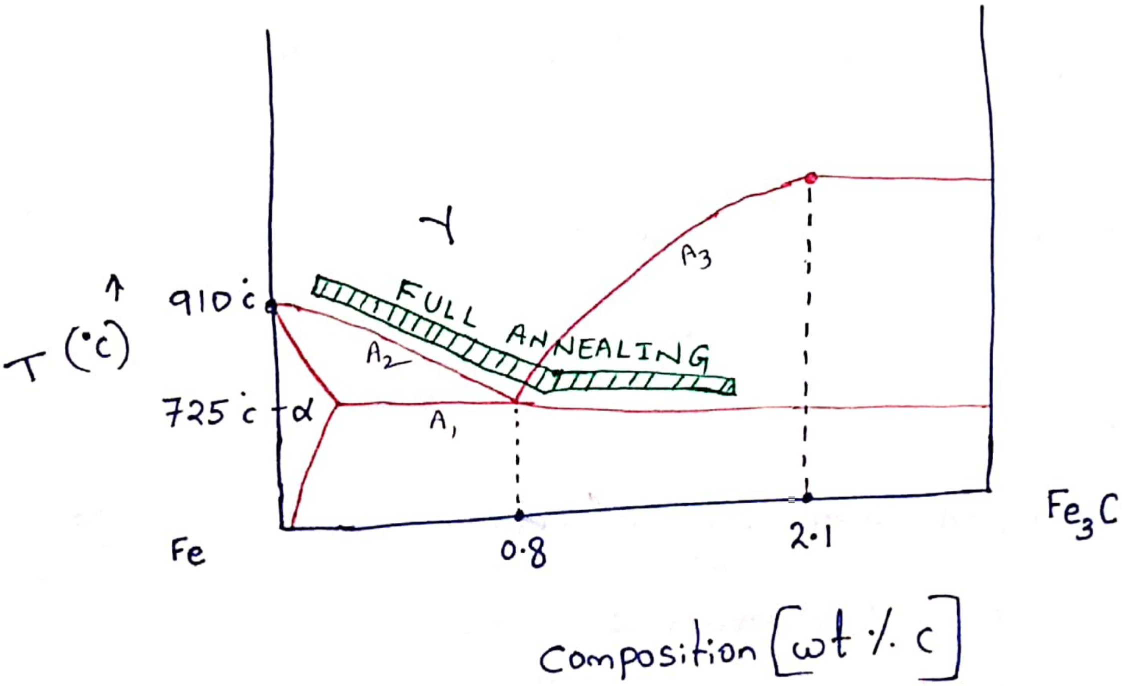
↳ Full annealing consists of heating the steel to austenitic region, holding it at that temperature for considerable time and then slowly cooling it inside the furnace.

↳ Full annealing process contains the following steps.

(i) Heating of the steel above 725°c. (for ex. 800°c)

(ii) Holding the steel at that temperature for a definite time.

(iii) Allowing the steel to get slowly cooled inside the furnace itself.



↳ Full annealing is done;

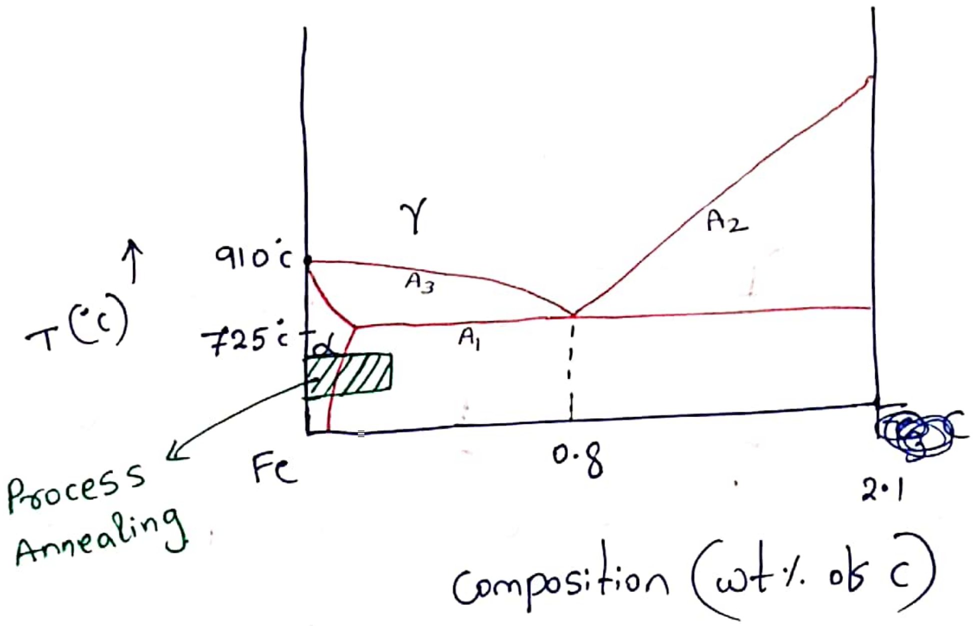
(i) To improve ductility.

(ii) To Remove internal stresses.

(iii) To improve mechanical, electrical & magnetic properties.

(B) Process Annealing :-

- It is also called as sub-critical annealing.
- Process annealing contains the following steps.
  - (i) Heating the steel below critical temperature (900-600°c).
  - (ii) Holding the steel at that temperature for a definite time.
  - (iii) Allowing the steel to get slowly cooled in the air.



(C) Stress-Relief Annealing :-

- It is used to remove internal stresses present in the material.
- Stress Relief annealing contains the following steps.
  - (i) Heating the steel below critical temperature (550°c–650°c)
  - (ii) Holding the steel at that temperature for a definite time. (1-2 hours)
  - (iii) Allowing the steel to get slowly cooled in air.

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① Spheroidise Annealing :-

↳ It is used to improve machinability of the material.

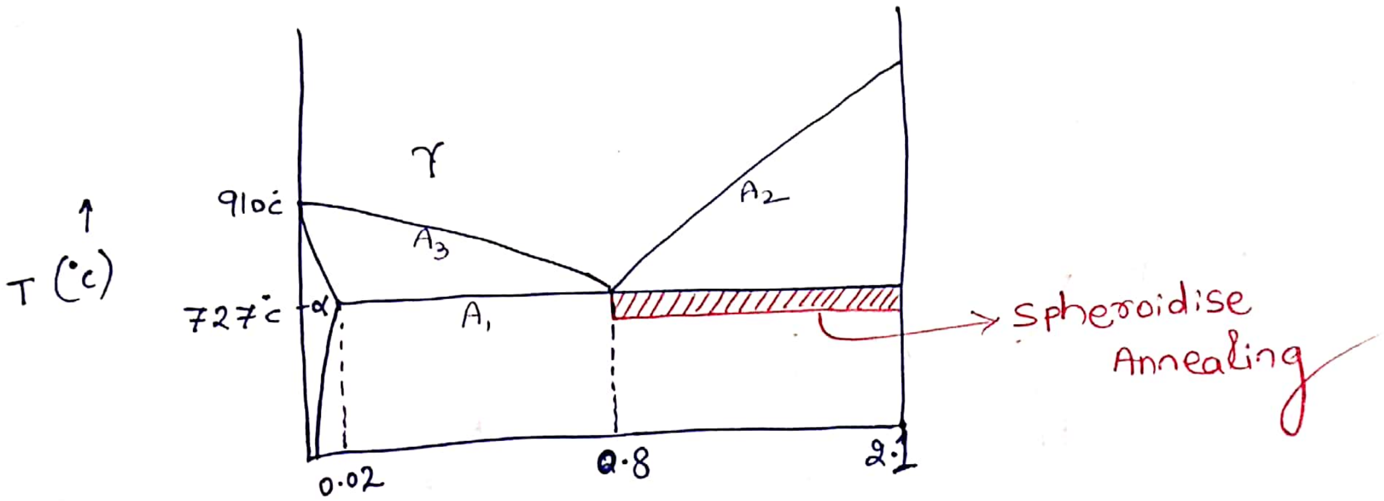
↳ It contains the following steps.

(i) Heating of the steel just below critical temp. (650~720°c).

(ii) Holding the steel at that temperature for a suitable time.

~~(iii) cycling cycled~~

(iii) Cyclic cooling and heating the steel around critical temperature.



↳ Mostly spheroidise annealing is done for more than 0.8% c steel.

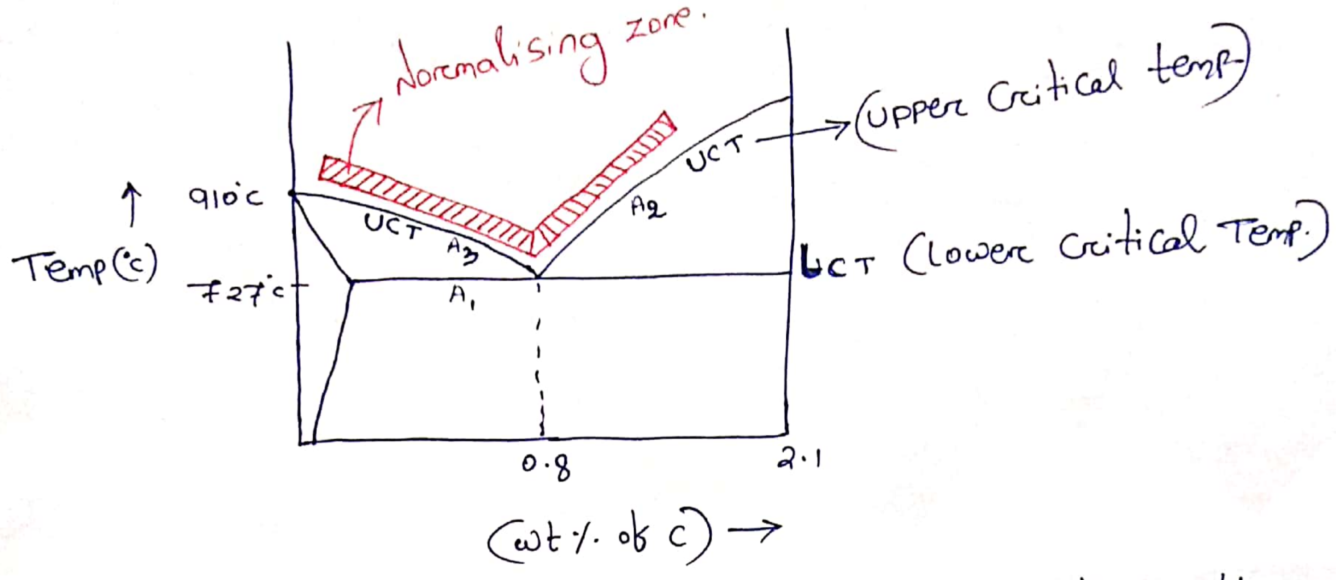
② Normalising :-

↳ Normalising contains the following steps.

(i) Heating the steel 30-50°c above upper critical temperature (UCT).

(ii) Holding the steel at that temperature for a suitable time.

(iii) Allowing the steel to get cooled in still air.



↳ Cooling time taken in Normalising process is lesser than Annealing Process. Hence it is commonly used in industry as it is faster, economical & efficient process.

↳ The main aim of Normalising is to increase the toughness of the material.

Purpose of Normalising :-

(i) To improve machinability. (ductility)

(ii) To remove internal stresses.

(iii) To obtain uniform grain structure.

(3) Hardening :-

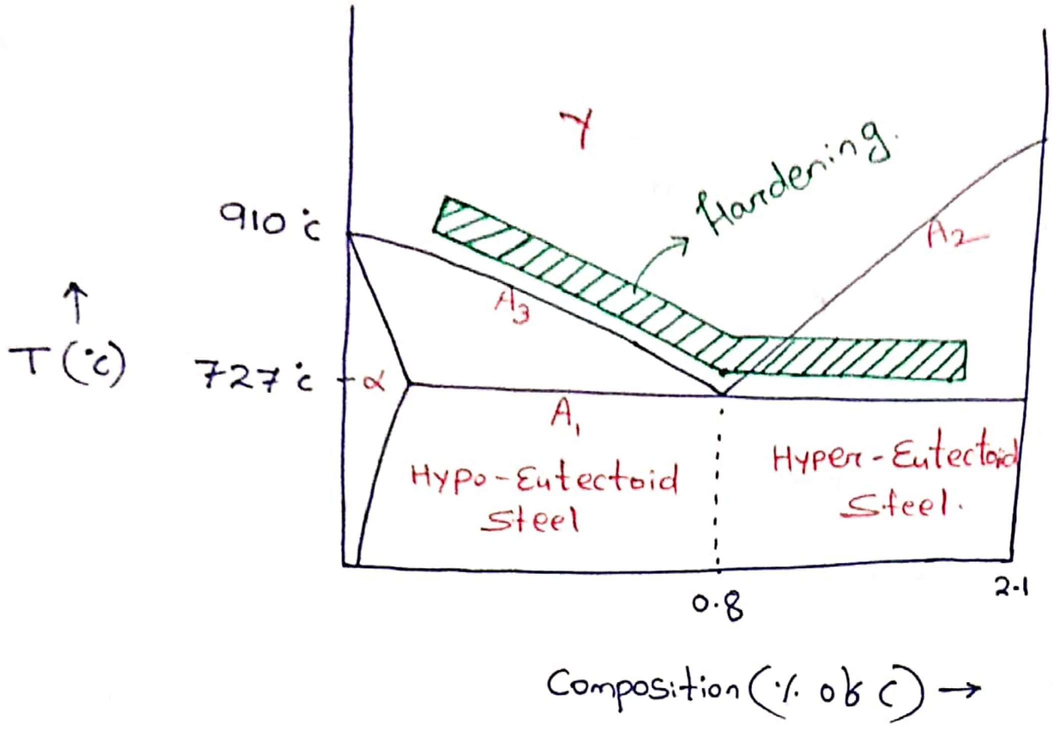
↳ Hardening contains the following steps.

(i) Heating the steel 30 to 50°c above "A_3" temperature line in case of hypo-eutectoid steel and 30 to 50°C above A_1 temperature line in case of hyper-eutectoid steel.

(ii) Holding the steel at that temperature for a suitable time.

(iii) Allowing the steel to get rapidly cool by quenching in water.

↳ Due to rapid cooling, Austenite is directly transformed into Martensite.

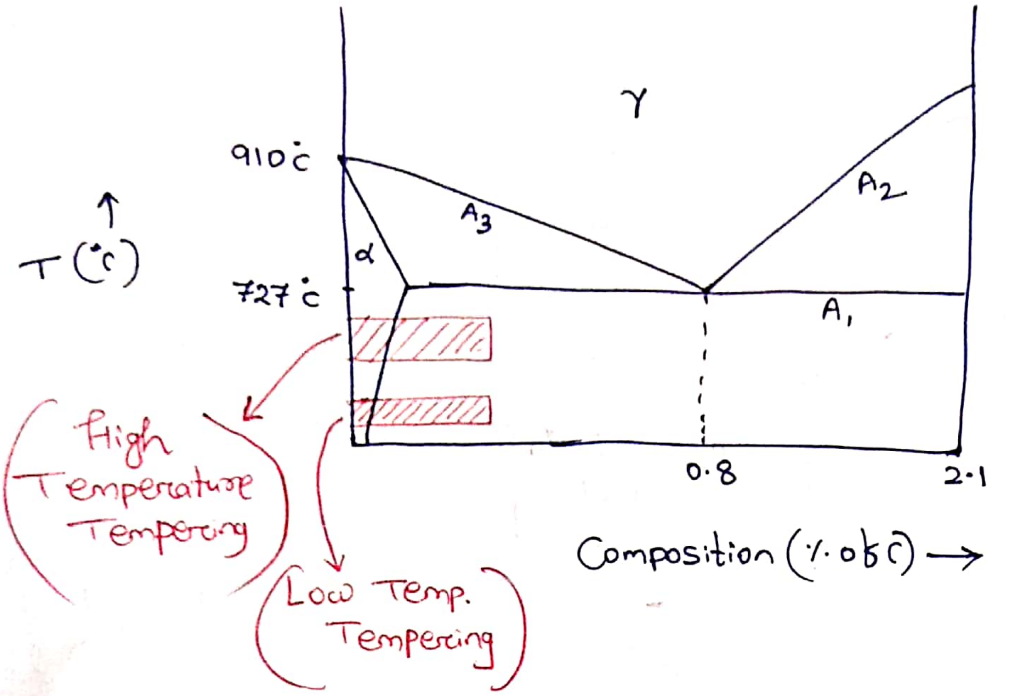


Purpose of hardening :-

- To improve the hardness of steel & wear resistance.
- To improve strength & toughness.
- To improve cutting ability of steel.

(4) Tempering

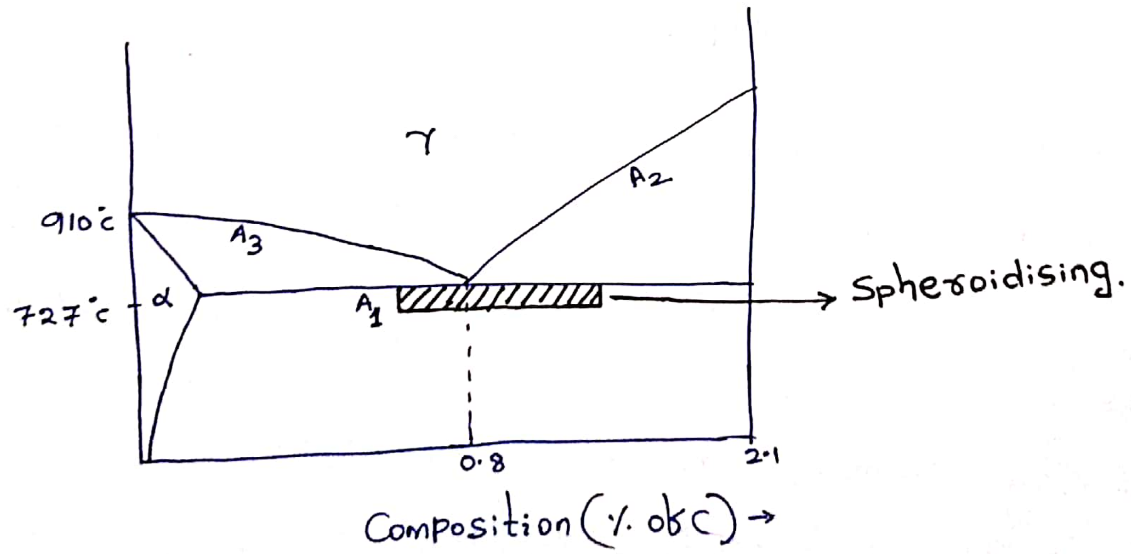
- Tempering is a heat treatment process of heating the hardened steel to a temperature below A_1 line (Lower critical temperature); in order to make it softer and more ductile.
- Tempering contains the following steps.
  - (i) Heating the hardened steel below A_1 line [100-700°C]
  - (ii) Holding the steel at that temperature for a suitable time.
  - (iii) Allowing the steel to get cooled to room temperature in air.



↳ Tempering produces tempered martensite with lower hardness than martensite but better toughness & ductility.

↳ Higher tempering temperature and higher the tempering time, ~~~~ then it leads to lower hardness & better ductility.

⑤ Spheroidising



↳ Spheroidising contains the following steps.

(i) Heating both hypo-eutectoid & hyper-eutectoid steel just below A_1-line (Lower Critical Temperature).

(ii) Holding the steel at that temperature for a suitable time.

(iii) Cyclic cooling & heating the steel around A_1-line.

Isothermal Transformation Diagram [TTT Diagram]

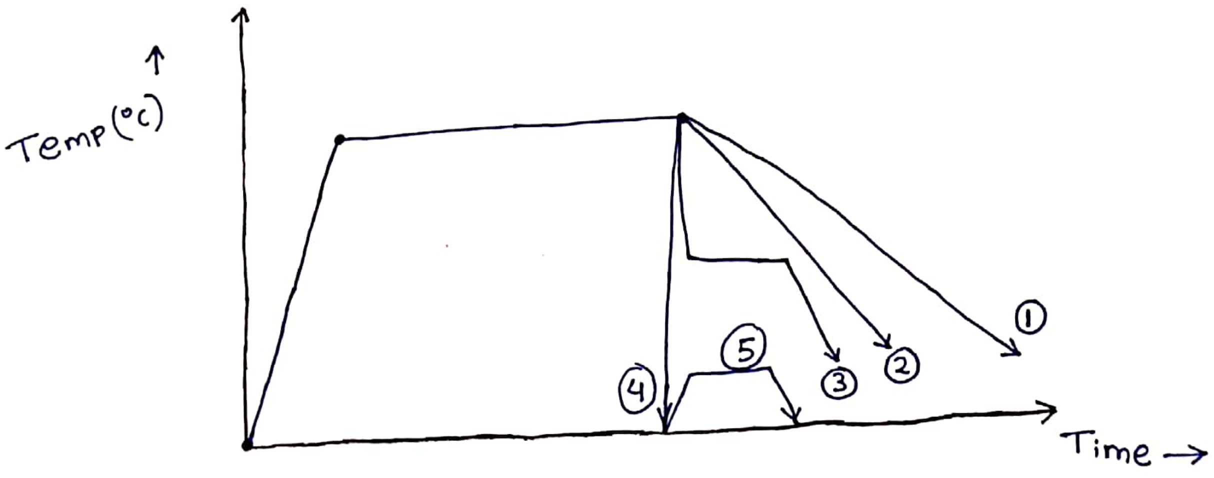
T T T

T → Time
T → Temperature
T → Transformation

↳ The relationship between temperature, time and transformation for a specific composition of steel is represented as Isothermal Transformation Diagram "or" TTT diagram.

↳ It helps to determine specific microstructure in materials after having different cooling rates.

↳ TTT diagram is also called as S-curve / C-curve / Bain's Curve.



① Annealing ⟶ slow cooling (Furnace) ⟶ Coarse Pearlite.

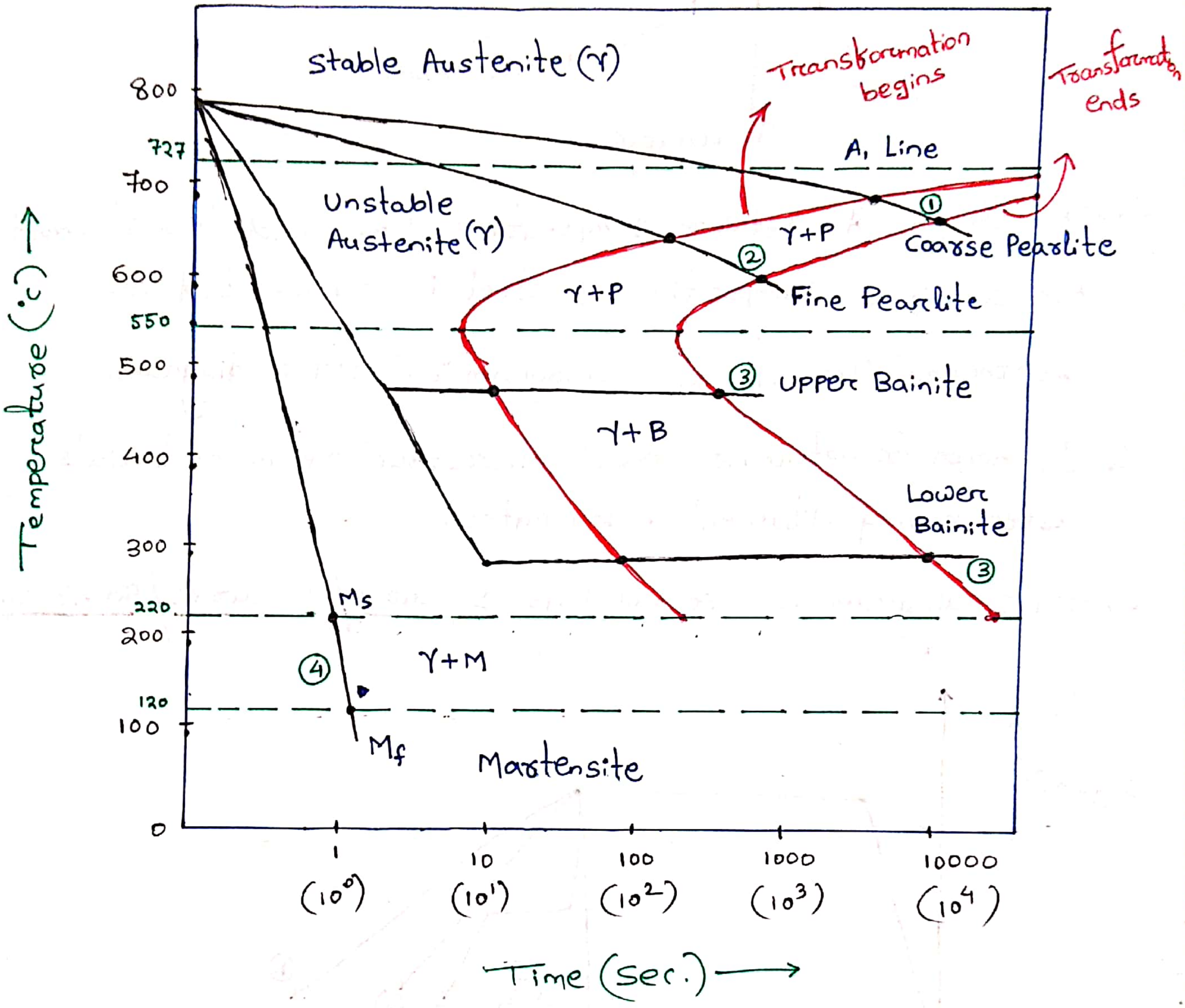
② Normalising ⟶ Faster cooling (Air cooling) ⟶ Fine Pearlite

③ Austempering ⟶ Interupted ⟶ Bainite

④ Quenching (Hardening) ⟶ Very fast cooling (water) ⟶ Martensite

⑤ Tempering ⟶ Heating after Quench ⟶ Tempered Martensite.

TTT Diagram for Eutectoid Steel (0.8% Carbon steel)



↳ TTT diagram deals with conversion of Austenite into Pearlite, Bainite, Martensite.

↳ In TTT diagram, left side "c" curve indicates the starting of austenite transformation and right side "c"- curve indicates the ending of austenite transformation.

↳ The time Period between starting and ending of austenite transformation is called as <u>incubation Period</u>.

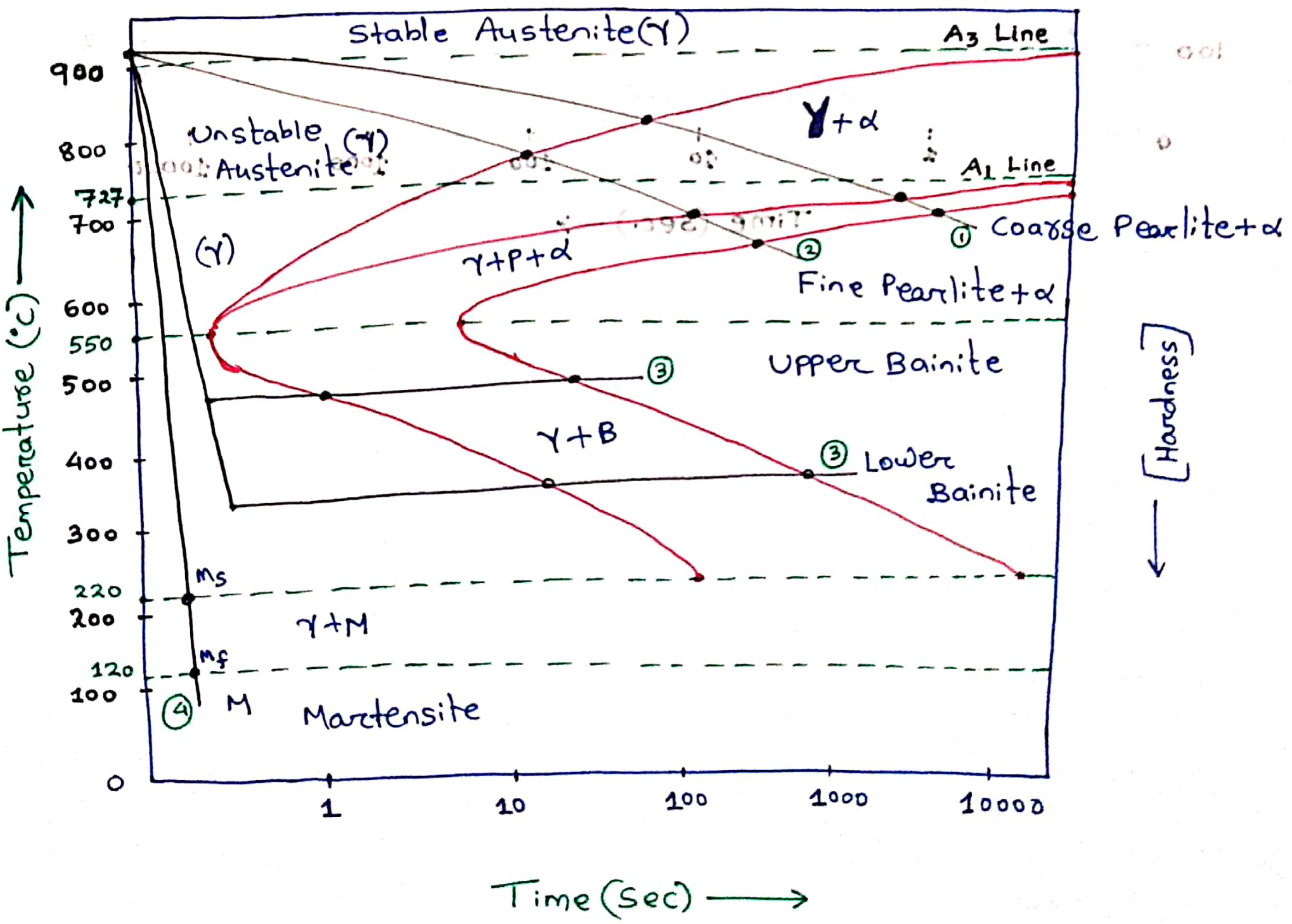
↳ Transformation product between A_1 line (727°c) and nose temperature (550°c) is Pearlite (P).

↳ Transformation product between nose temperature (550°c) and M_s line (220°c) is Bainite (B).

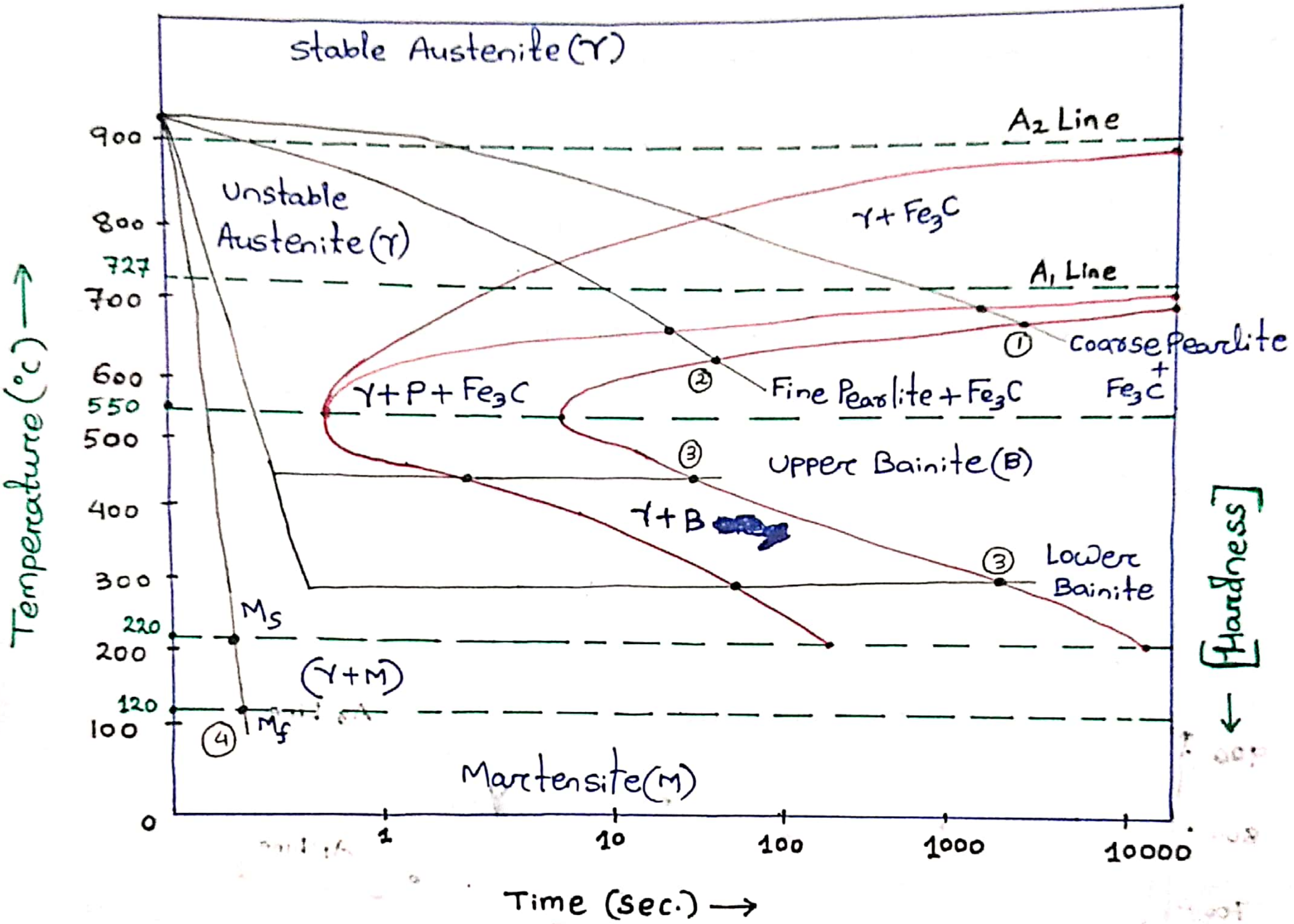
↳ Transformation product below M_f line (120°c) is Martensite.

↳ As the transformation temperature decreases, hardness of the given steel increases. Hence Pearlite is relatively soft, Bainite is medium hard and martensite is very hard.

TTT Diagram for Hypo-eutectoid steel :- [% of C < 0.8]



TTT Diagram for Hyper-eutectoid steel [% of C > 0.8]



Austenite to Bainite Transformation :-

Bainite :-

↳ If the transformation of Austenite takes place below 550°C, then it results in formation of Bainite.

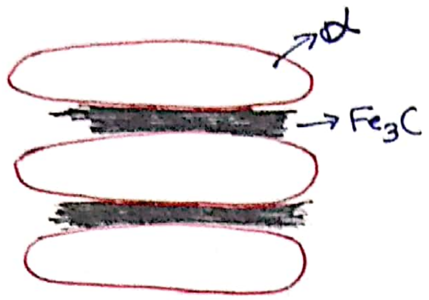
↳ Bainite is a combination of ferrite(α) and Cementite(Fe_3C).

↳ Bainite is classified into 2 types.

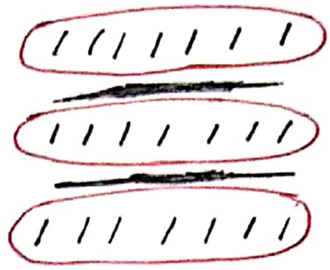
(i) Upper Bainite :- It is formed in the temperature range between 400°C to 550°C.

(ii) Lower Bainite :- It is formed in the temperature range between 250°C to 400°C.

↳ Micro-structure of upper & lower Bainite is drawn below.



Upper Bainite
(High Temperature)



Lower Bainite
(Low Temperature)

Austenite to Martensite Transformation :-

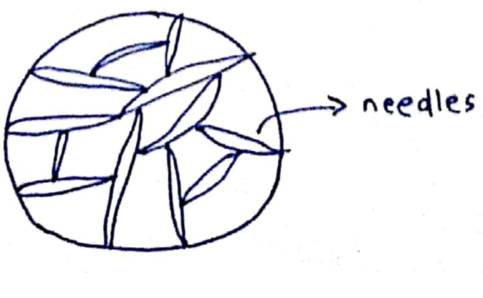
↳ If austenite is cooled at very fast rate, then the resulting micro-structure is called Martensite.

↳ During cooling from austenitic region, austenite starts transforming into martensite at a temperature of about 220°c & it is represented as "M_s" (martensite start) in TTT-diagram.

↳ The temperature at which 99% of austenite is transformed into Martensite is called "M_f" (Martensite finish) in TTT-diagram which is about 120°c.

↳ The transformation of austenite to martensite isn't fully completed and some amount of austenite will exist at temperature below "M_f". This is called as Retained Austenite.

↳ Micro-structure of Martensite appears like a rod/needle shape.



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