BMM1523/BHA1113
ENGINEERING MATERIALS

HEAT TREATMENT OF METAL ALLOYS

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Chapter Description

- **Aims**

  Students are expected to have basic understanding on improvement of strength in steel by heat treatment process.

- **Expected Outcomes**
  - Understand the martensite formation
  - Able to use the function of Jominy test
  - Understand the function of annealing process

- **References**

1. William D. Callister and David G. Rethwisch. Materials science and enginnering: An Introduction, 9th Ed. Wiley, 2014.

Heat treatment of Ferrous alloys

- Modification of microstrucre by applying the heating and cooling process. This process will cause phase transformation that effect its mechanical properties.

- Effects of thermal treatment depend on the alloy composition, the rates of heating and cooling during heat treatment, and the initial cold work.

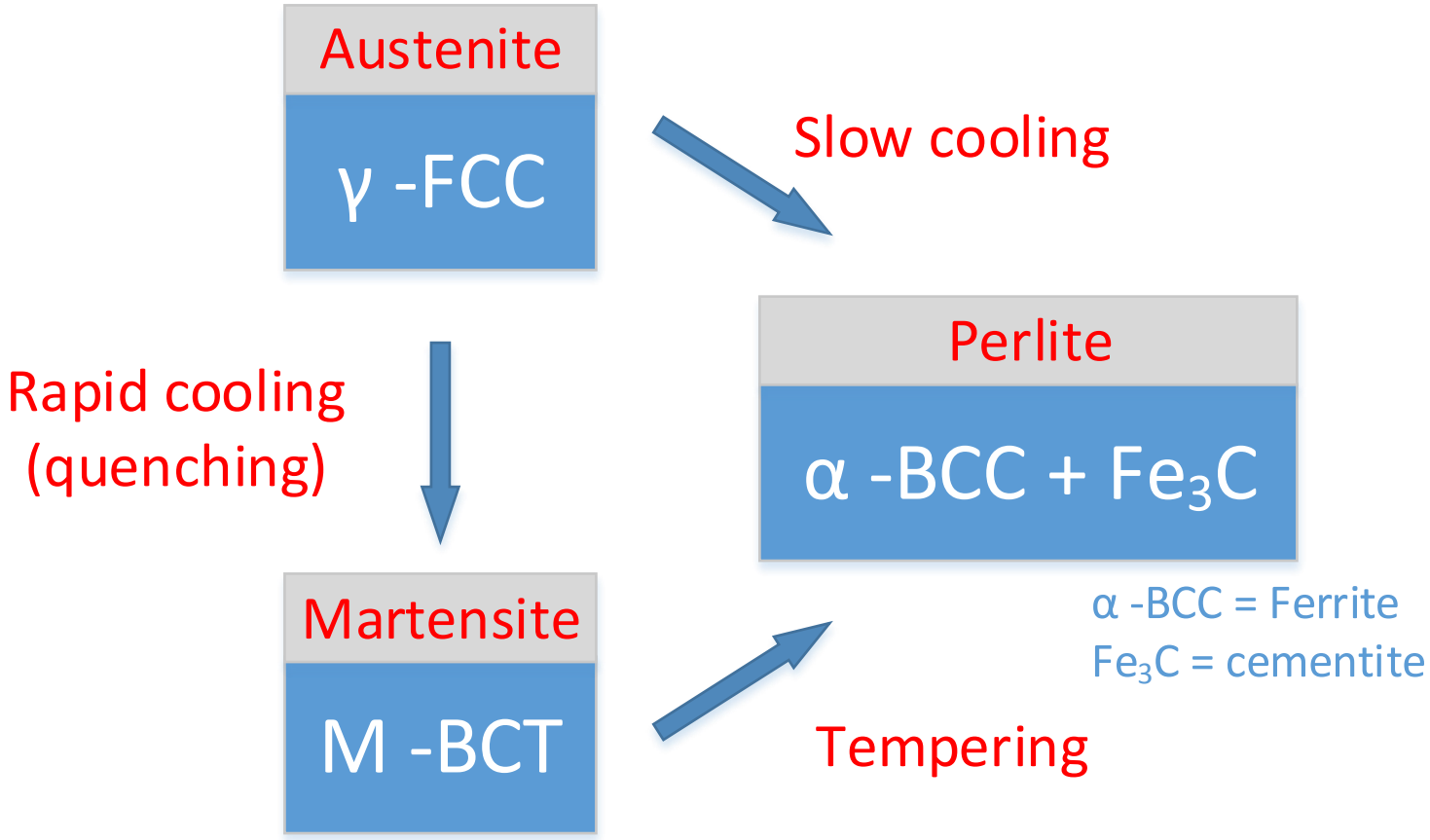
Heat treatment – Concept 1

- To force a metal to do something beyond the normal laws of solubility. Such as, to make one phase dissolve in another when it normally wouldn't.

Heat treatment – Concept 2

- The metal is having a two-phase region at room temperature and a single phase region at a higher temperature.
- Heating the metal alloy to one phase region then cool it fast to retain the high temperature phase at room temperature.
- This will produce phase with the properties different than the dual phase.

Heat Treatment of Steel



Austenite to Pearlite Transformation

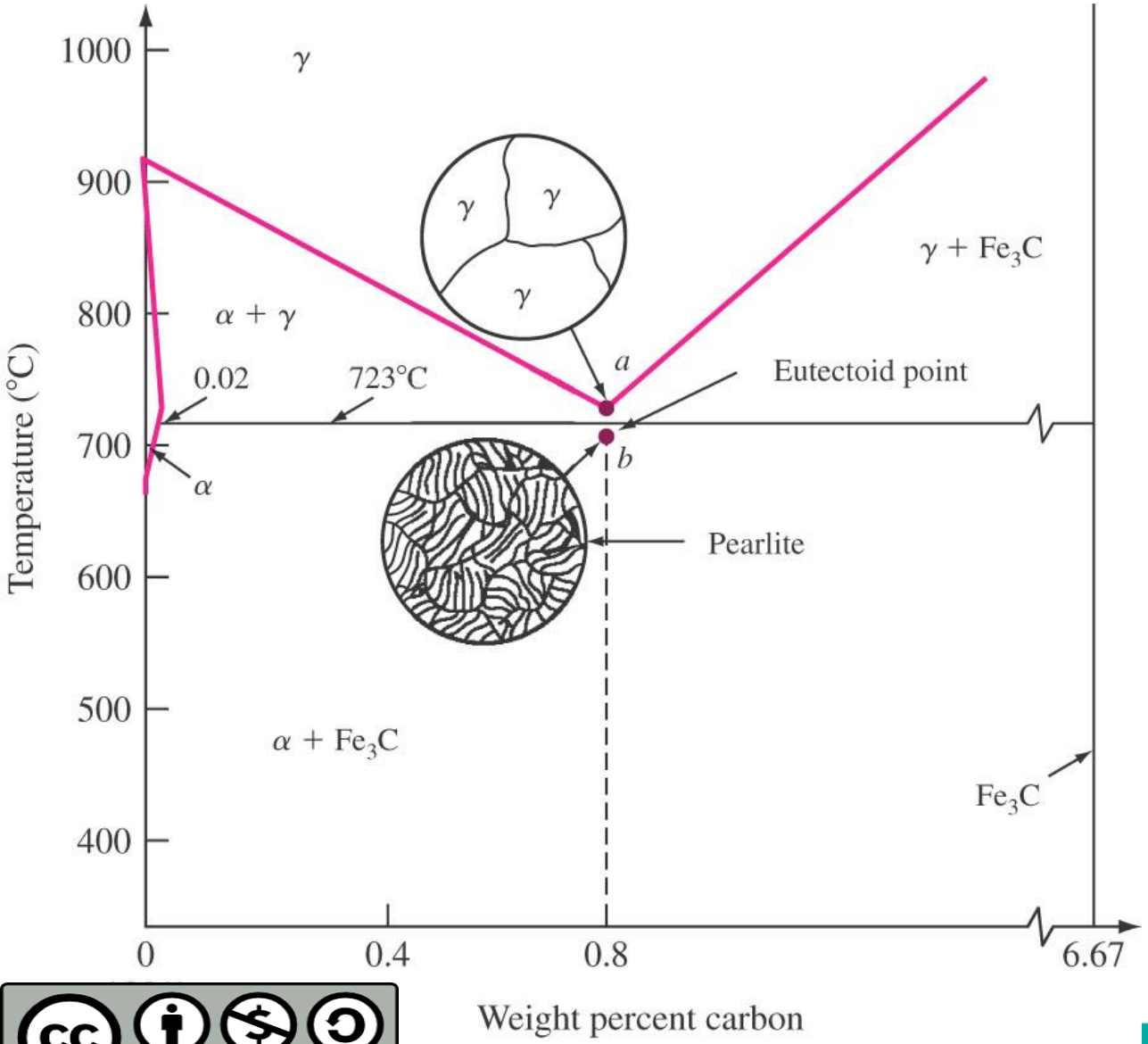
(a) It is based on eutectoid transformation that can be observed in Fe-C phase diagram

$$\gamma \rightarrow \alpha + Fe_3C$$

(b) The steel is slowly cooled (furnace cooling) from austenite temperature to room temperature.

(c) Steel properties: ductile but less strength

Iron–Carbon Alloy Above and Below Eutectoid Temperature



The microstructures of carbon steel at eutectoid composition (0.77% carbon), above and below the eutectoid temperature of 727 °C.

Pearlite properties

(a) Two phase structure of

$$\alpha + Fe_3C$$

(b) α – phase gives ductility properties, meanwhile **Fe3C** more to strength (hardness) properties

(c) More carbon → more Fe_3C → higher strength

Austenite to Martensite Transformation

(a) It is based on diffusionless transformation and **cannot** be observed in Fe-C phase diagram

$$\gamma \rightarrow \mathbf{M}$$

(b) The steel was heated up to austenite phase temperature (above 700°C) so that all pearlite structure transformed into austenite phase. Then rapidly cooled (quenching) to room temperature for martensite formation. Cooling media: air, water, oil, etc.

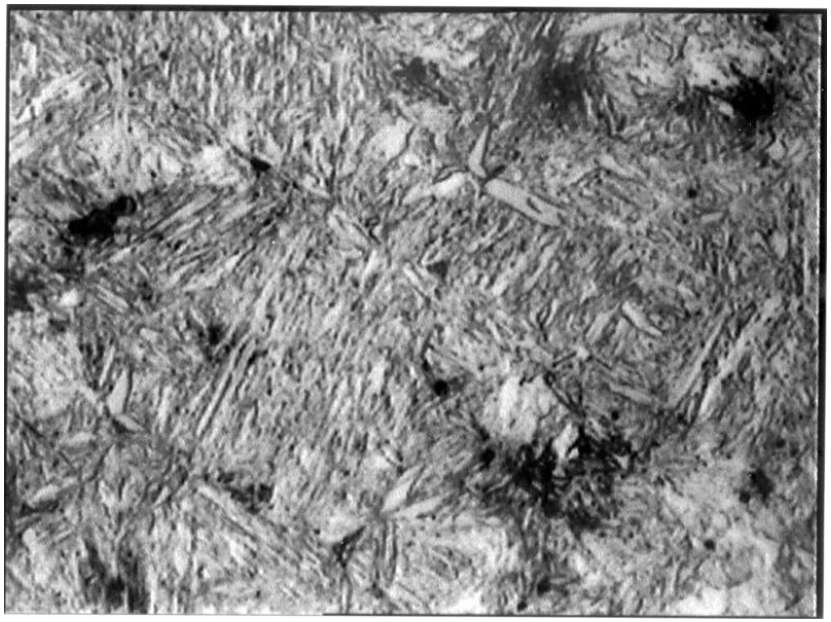
(c) Steel properties: high strength but brittle.

Martensite properties

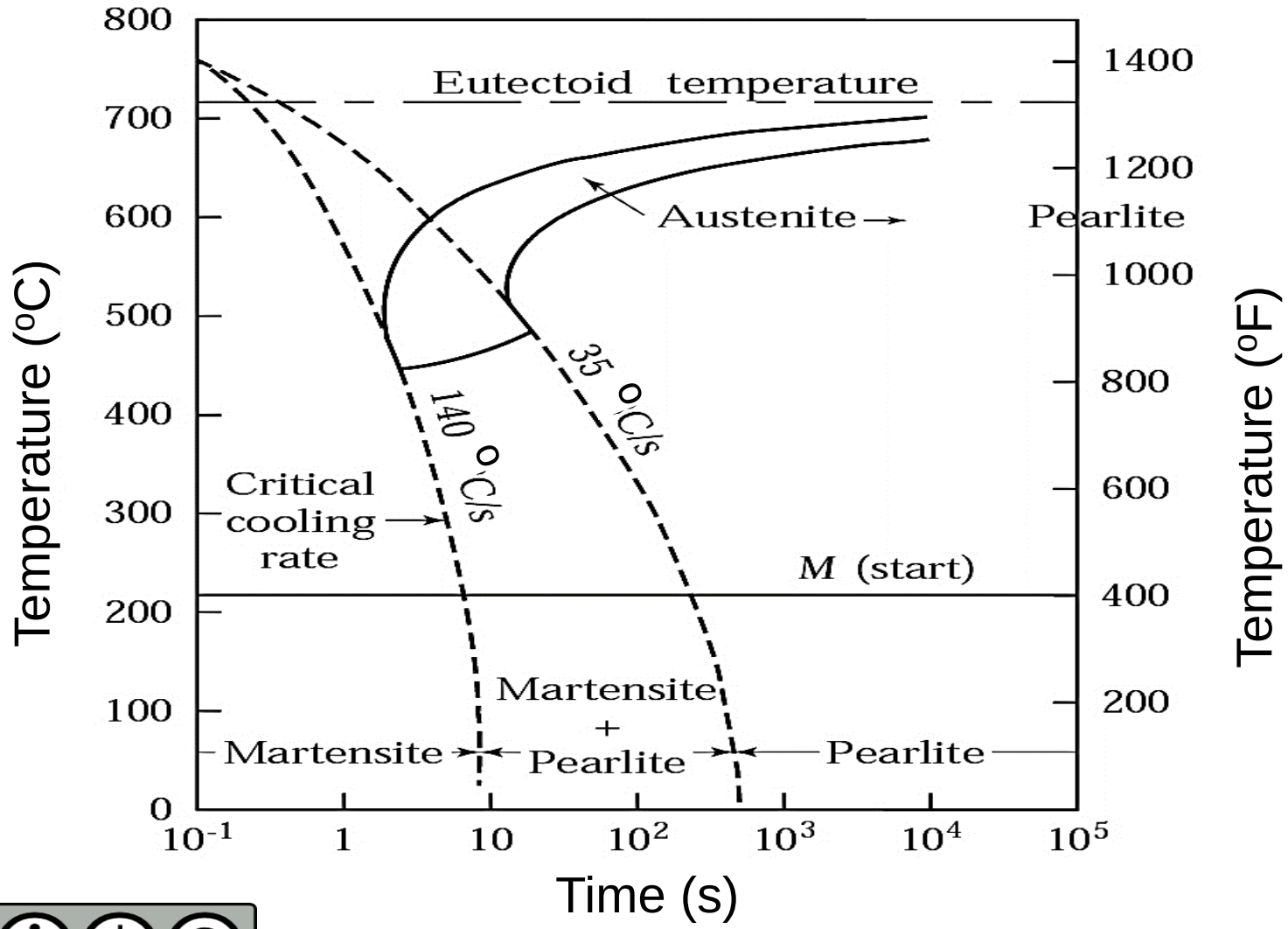
(a) It is an interstitial supersaturated solid solution of carbon with BCT (body-centered tetragonal) structure.

(b) It is formed due to rapid cooling of austenite, so that does not provide enough time for the formation of Fe_3C.

(c) It has a plate-like microstructure



Continuous cooling transformation (CCT) diagram.



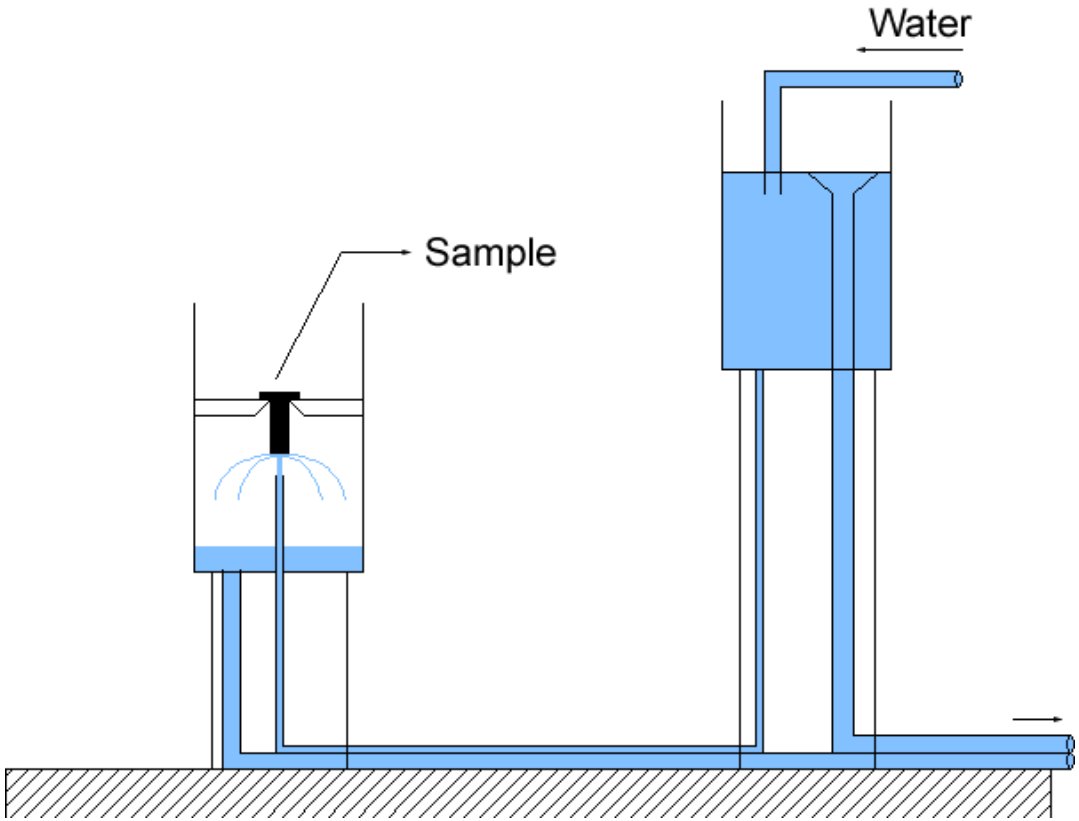
Tempered Martensite

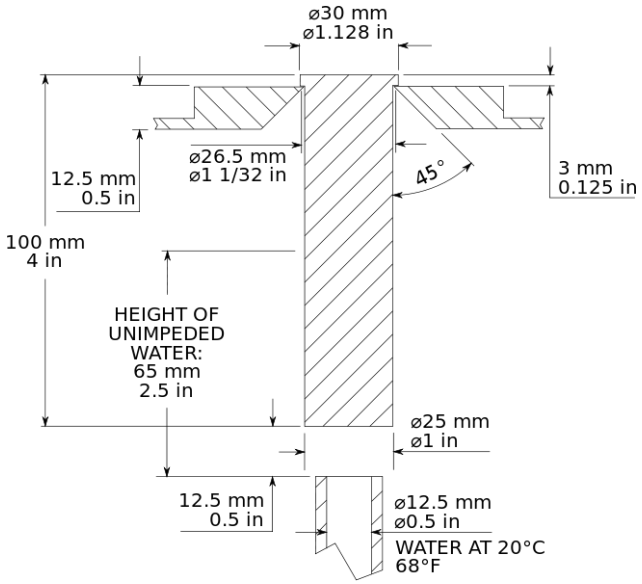
- Tempering of martensite phase is objected to increase toughness and decrease hardness.
- The process is conducted by heating the marteniste at 150^{o}C - 650^{o}C, which will make it decompose into 2 phases structure, consist of α-ferrite and small particles of Fe_3C.
- When the tempering time and temperature increased, the hardness of tempered martensite will decrease due to particles cementite grow bigger

HARDENABILITY

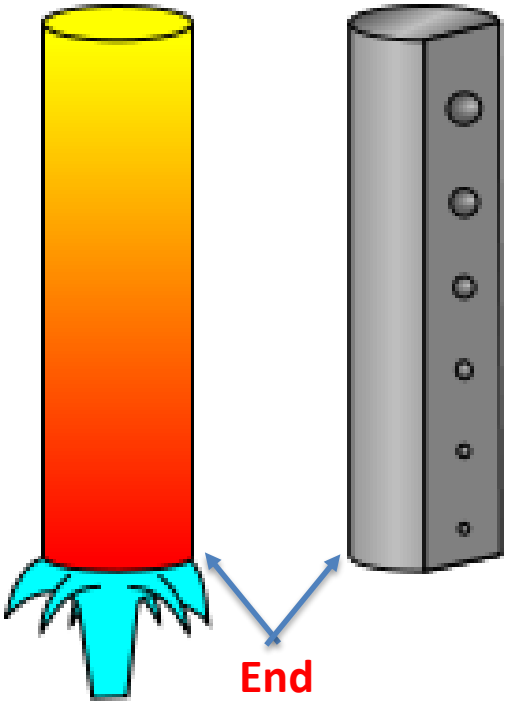
- The capability of ferrous alloy to be harden by heat treatment process
- A measure of hardness that obtained from heating and subsequence rapid cooling process.
- Most commonly Jominy Test
- It depend primarily on composition of steel, grain size of austenite, and cooling rate of heat treatment.

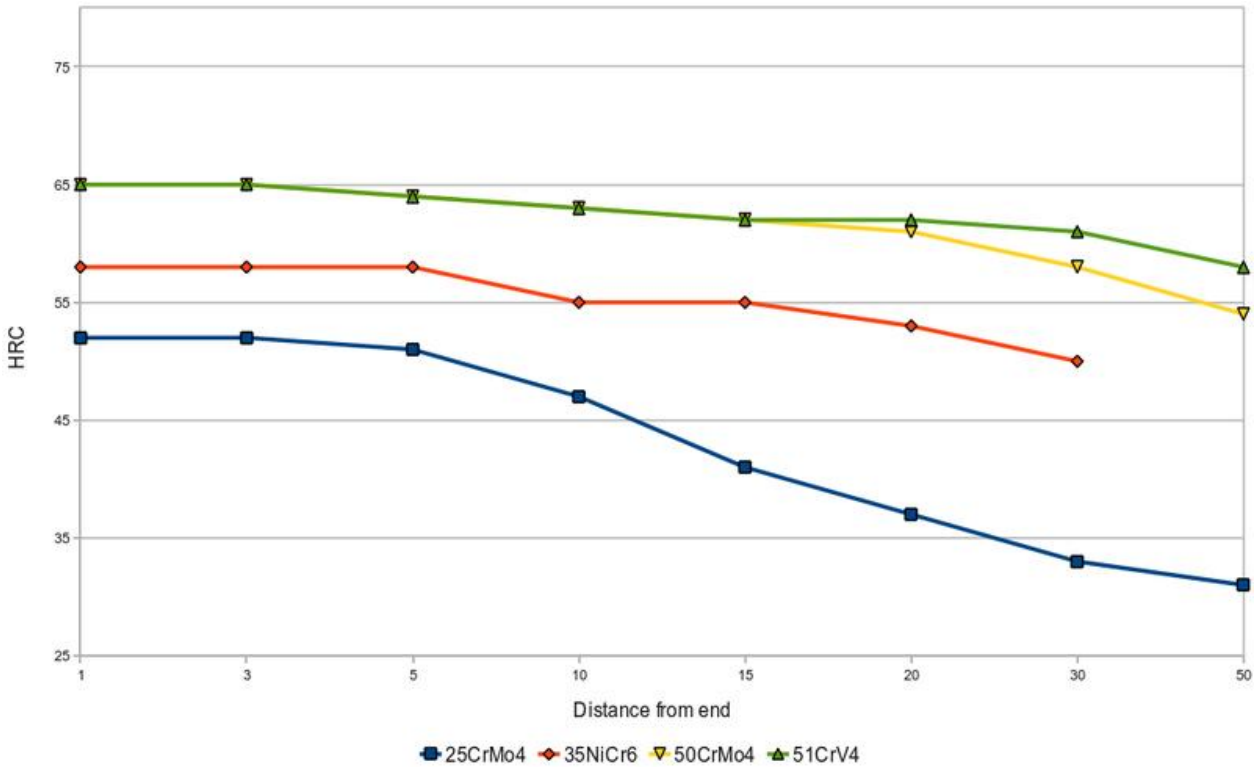
Jominy test





Jominy Test





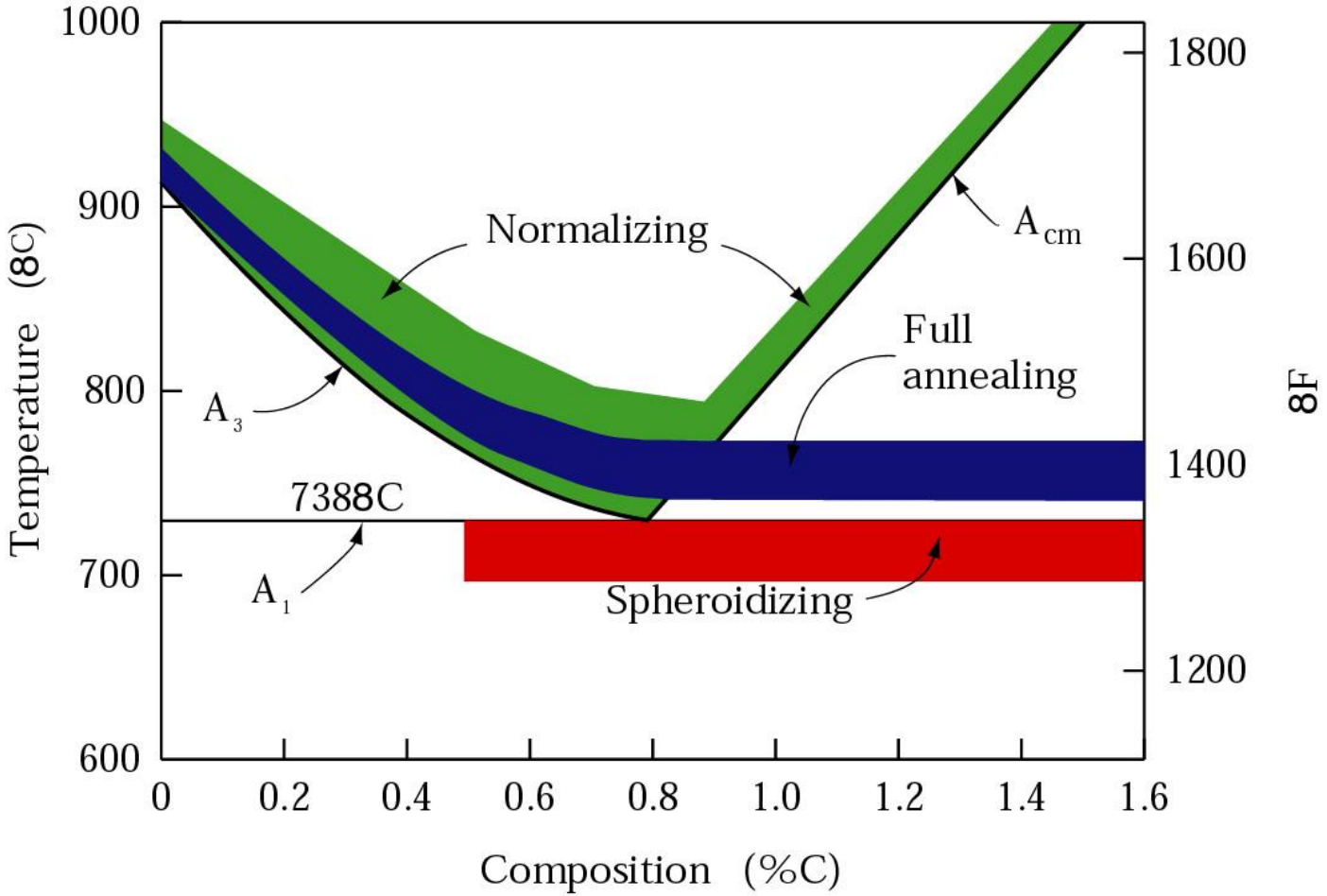
Other heat treatment process

1. Annealing
2. Normalizing
3. Spherodizing

Annealing

- A heat treatment process that objected to restore the mechanical properties of steel after cold-worked: increase ductility, reduce hardness and strength.
- The structural change: removing residual stress and dislocation; formation of new grains with free of stress and dislocation.
- Three process involved;
    i. Heating at temperature above recrystallization temperature.
    ii. Holding at that temperature for a period of time,
    iii. Furnace cooling
- Full annealing term for annealing of ferrous alloys, generally low carbon and medium-carbon steels. Steel heated at A1or A3, and the cooling slowly in a furnace. Obtained coarse pearlite which soft and ductile and has small uniform grains.

Heat-treating temperature ranges for plain-carbon steels, as indicated on the iron-iron carbide phase diagram.



Normalizing

- A heat treatment process (for steel) at temperature above A_3 and A_{cm} (above austenitic region) and then air cooled.
- Purpose of normalizing:

  1. Grain refinement;

  2. Improve steel strength; higher than annealed steel;

  3. Improve composition homogeneity in casting or forging products and also to provide a more uniform structure.

  4. Avoid excessive softness from annealing process

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- ❑Thin Films Technology
- ❑Metals and Alloys.

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