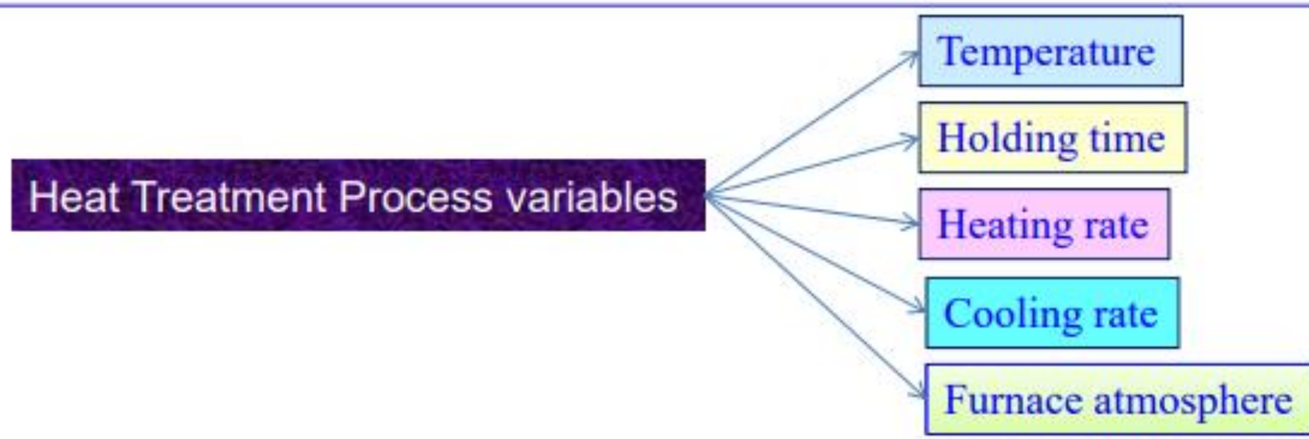
Heat Treatment Processes of Carbon Steel

Heat treatment: the controlled heating and cooling cycles of metals for the primary purpose of altering their properties (strength, ductility, hardness, toughness, machinability.

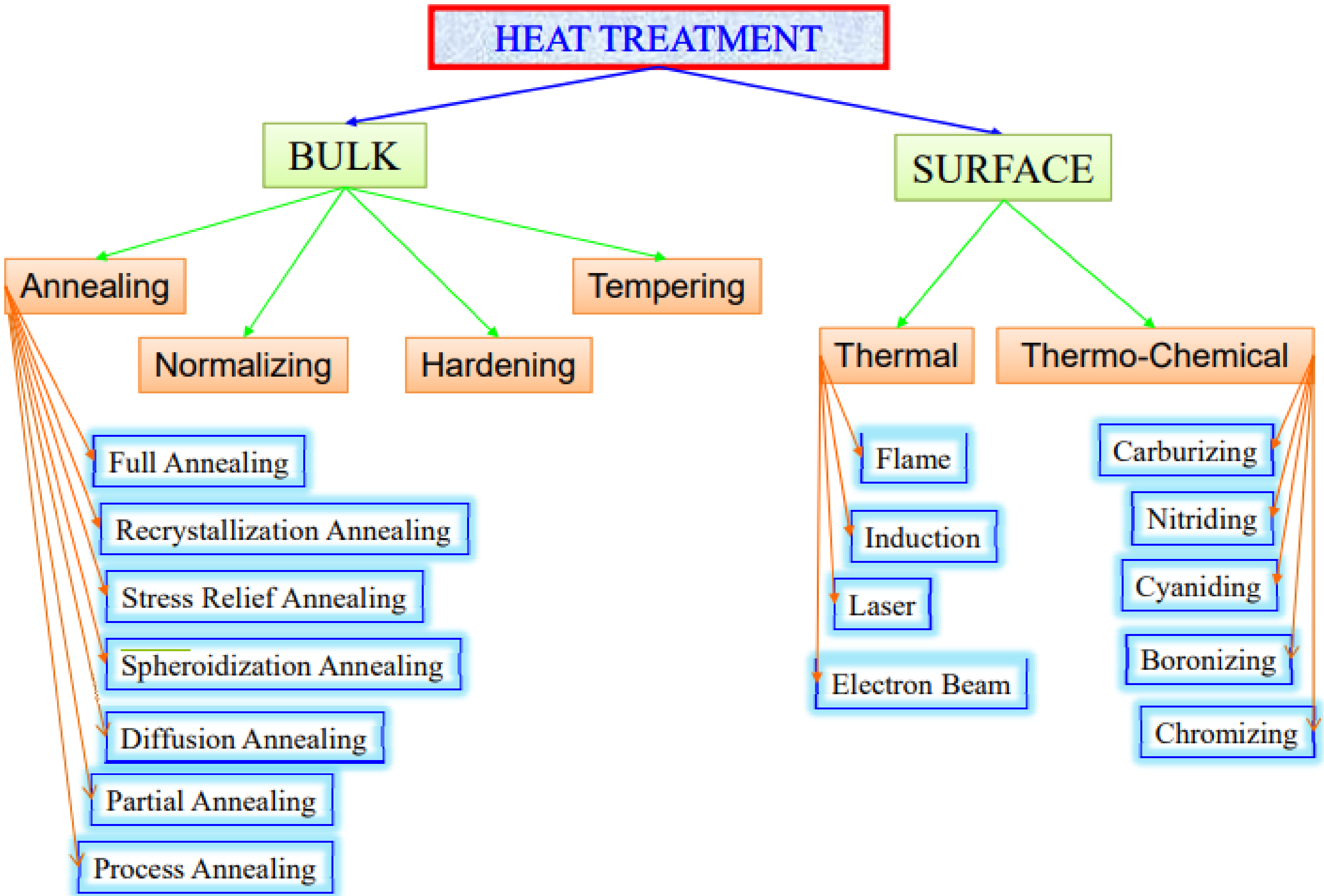
Metallurgy lectures – Prepared by **Dr. Kamal Al-hamdani** **Lec 6**

Objective

- To increase strength, hardness and wear resistance (*bulk hardening, surface hardening*)
- To increase ductility and softness (*Tempering, Recrystallization Annealing*)
- To increase toughness (*Tempering, Recrystallization annealing*)
- To obtain fine grain size (*Recrystallization annealing, Full annealing, Normalizing*)
- To remove internal stresses induced by differential deformation by cold working, non-uniform cooling from high temperature during casting and welding (*Stress relief annealing*)
- To improve machinability (*Full annealing and Normalizing*)
- To improve cutting properties of tool steels (*Hardening and Tempering*)
- To improve surface properties (*surface hardening, high temperature resistance-precipitation hardening, surface treatment*)
- To improve electrical properties (*Recrystallization, Tempering, Age hardening*)
- To improve magnetic properties (*Hardening, Phase transformation*)



Classification



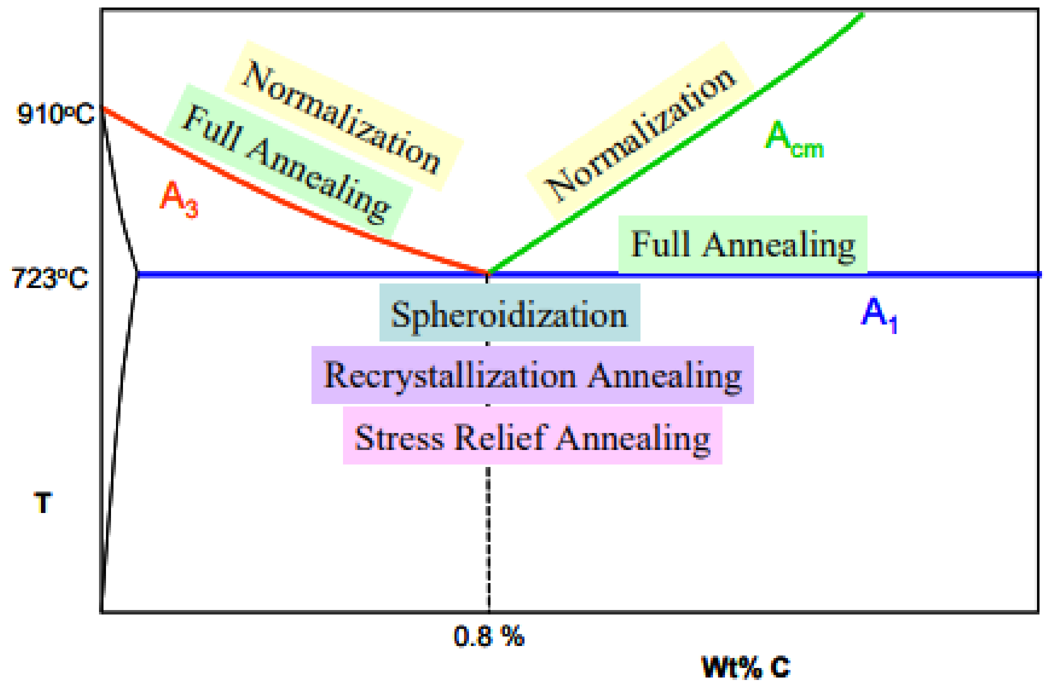
Annealing

Recrystallization Annealing

- The Heat below A_1 → Sufficient time → Recrystallization

  Cold worked grains → New stress free grains

- Used in between processing steps (e.g. Sheet Rolling)



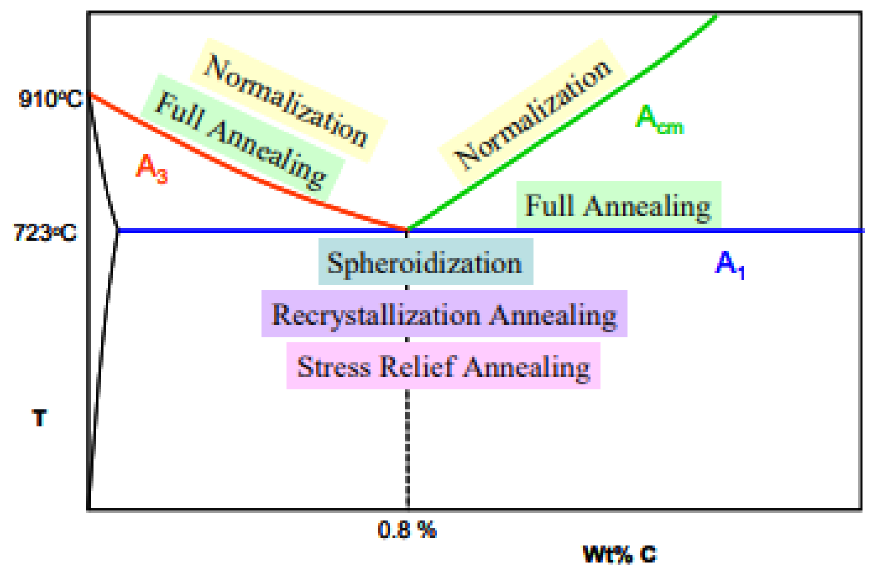
Annealing

Stress Relief Annealing

Residual stresses → Heat below A_1 → Recovery → Annihilation of dislocations, polygonization

Residual stresses arise from:

- → Differential cooling
- → Martensite formation
- → Machining and cold working
- → Welding



Annealing

Spheroidization Annealing

Heat below/above A_1 (Prolonged holding*)
Cementite plates → Cementite spheroids → ↑ Ductility

- *Used in high carbon steel requiring extensive machining prior to final hardening and tempering*
- *Driving force is the reduction in interfacial energy*

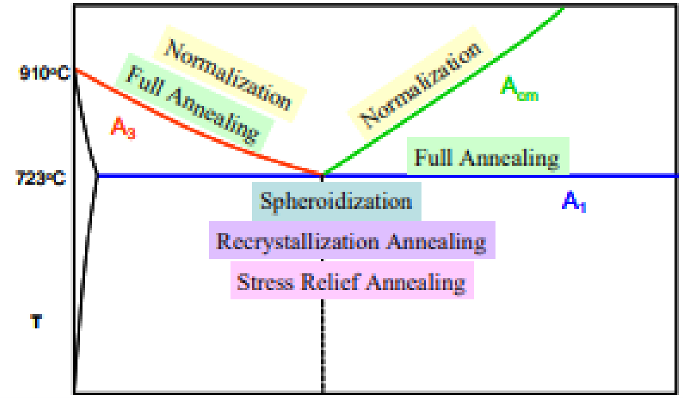
- The spheroidized structure is desirable when minimum hardness, maximum ductility, or(in high-carbon steels) maximum machinability is important.
- Low-carbon steels are seldom spheroidized for machining, because in the spheroidized condition they are excessively soft and "gummy".
- Medium-carbon steels are sometimes spheroidization annealed to obtain maximum ductility.

Normalizing

Heat above A_3 | A_{cm} → Austenization → Air cooling → Fine Pearlite (Higher hardness)

Purposes

- Refine grain structure prior to hardening
- To harden the steel slightly
- To reduce segregation in casting or forgings



- In hypo-eutectoid steels normalizing is done 50°C above the annealing temperature
- In hyper-eutectoid steels normalizing done above A_{cm} → due to faster cooling cementite does not form a continuous film along GB

Annealed Vs Normalized

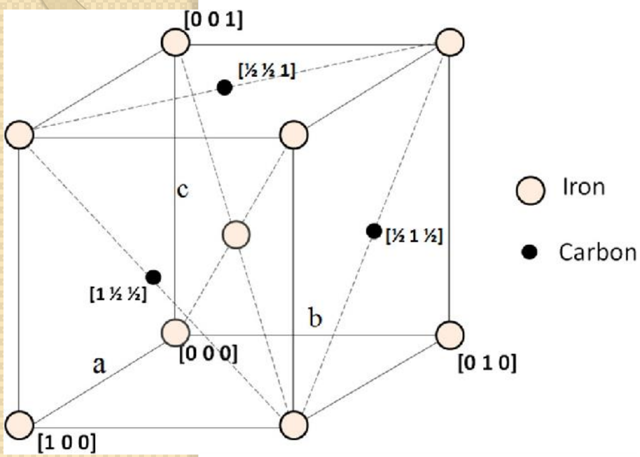
Annealed	Normalized
Less hardness, tensile strength and toughness	Slightly more hardness, tensile strength and toughness
Pearlite is coarse and usually gets resolved by the optical microscope	Pearlite is fine and usually appears unresolved with optical microscope
Grain size distribution is more uniform	Grain size distribution is slightly less uniform
Internal stresses are least	Internal stresses are slightly more

Hardening

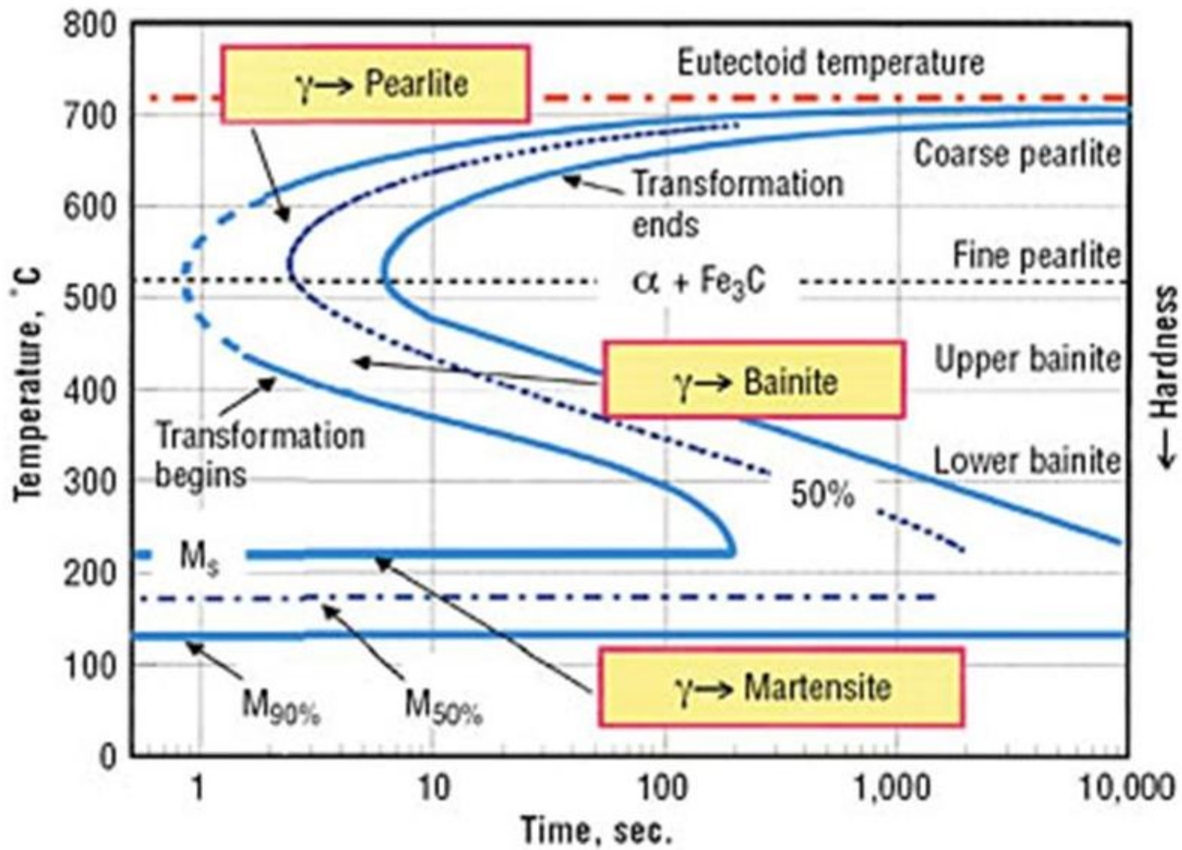
Heat above A_3 | A_{cm} → Austenization → Quench (higher than critical cooling rate)

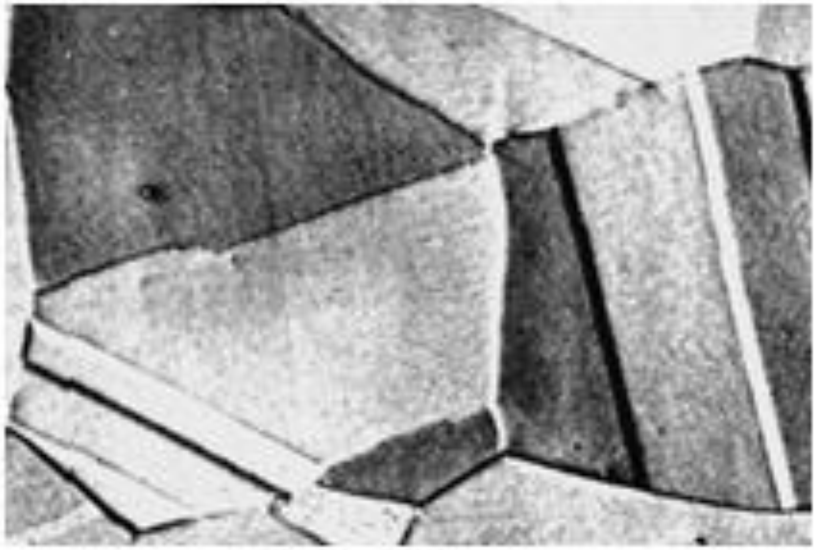
- Certain applications demand high tensile strength and hardness values so that the components may be successfully used for heavy duty purposes. High tensile strength and hardness values can be obtained by a processes known as Hardening.
- hardening process consists of four steps. The first step involves heating the steel to above A_3 temperature for hypoeutectoid steels and above A_1 temperature for hypereutectoid steels by 50^0C.
- The second step involves holding the steel components for sufficient socking time for homogeneous austenization.
- The third step involves cooling of hot steel components at a rate just exceeding the critical cooling rate of the steel to room temperature or below room temperature.
- The final step involves the tempering of the martensite to achieve the desired hardness. Detailed explanation about tempering is given in the subsequent sections. In this hardening process, the austenite transforms to martensite. This martensite structure improves the hardness.
- In the hardening process, which involves quenching and tempering. During quenching outer surface is cooled quicker than the center. In other words the transformation of the austenite is proceeding at different rates. Hence there is a limit to the overall size of the part in this hardening process.

TTT DIAGRAM

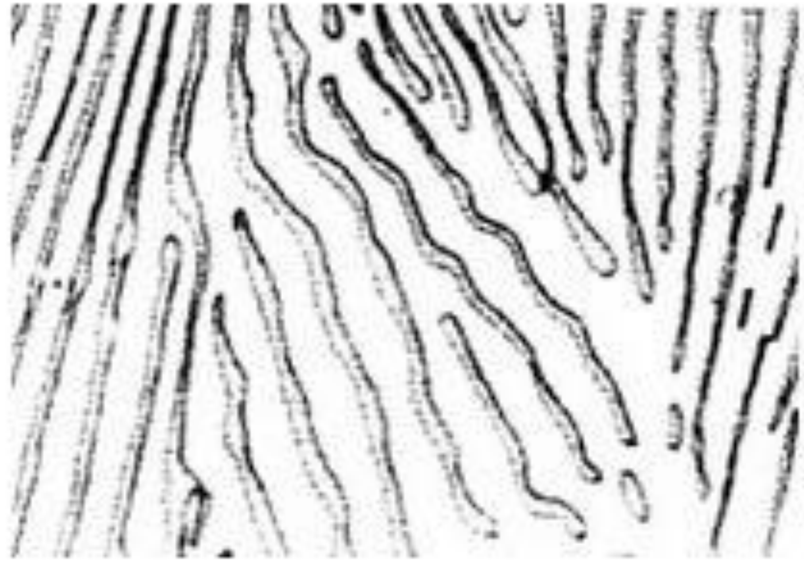


Body centered tetragonal martensite





Austenite



Pearlite

Martensite

Bainite

Martensite:

Is a type of hard crystalline steel that's formed by rapidly cooling (quenching) hot steel; thus, preventing the atoms from diffusing out of the crystalline structures.

Pearlite

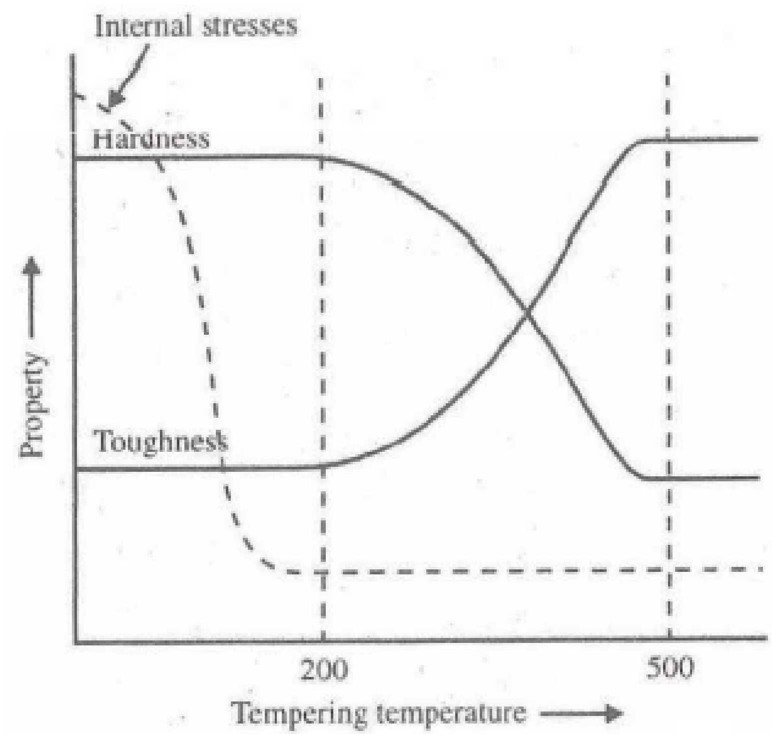
Another type of microstructure, Pearlite is cooled more slowly than its martensite counterpart, making it softer and easier to bend.

Bainite

A third type of steel which falls somewhere between martensite and pearlite. Bainite is a type of steel that's produced by cooling faster than pearlite but slower than martensite. Additionally, bainite has plate-shaped designs in its microstructures, while martensite has long oval-shaped designs.

Tempering

- The hardened steel is not readily suitable for engineering applications. It possesses following three drawbacks.
  - ✓ Martensite obtained after hardening is extremely brittle and will result in failure of engineering components by cracking.
  - ✓ Formation of martensite from austenite by quenching produces high internal stresses in the hardened steel.
  - ✓ Structures obtained after hardening consists of martensite and retained austenite. Both these phases are metastable and will change to stable phases with time which subsequently results in change in dimensions and properties of the steel in service.
- Tempering helps in reduce these problems. Tempering is the process of heating the hardened steel to a temperature maximum up to lower critical temperature (A_1), soaking at this temperature, and then cooling, normally very slowly.



Variation in properties with tempering temperature

Tempering

Objective

- Relieve Internal stresses
- Restore ductility and toughness
- To improve dimensional stability
- To improve magnetic properties

Structure in as Quenched state

- Highly supersaturated martensite
- Retained austenite
- Undissolved carbides
- Rods, or plates of carbide particles produced during 'auto-tempering'
- Segregation of carbon