ESO205P: Nature of Properties of Materials
01-07-2021

MODULE 3: MICROSTRUCTURE EVOLUTION (PART-2)

Presented By:

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MICROSTRUCTURE ANALYSIS OF STEELS

Aim: To study the decomposition of austenite as a function of cooling rate.

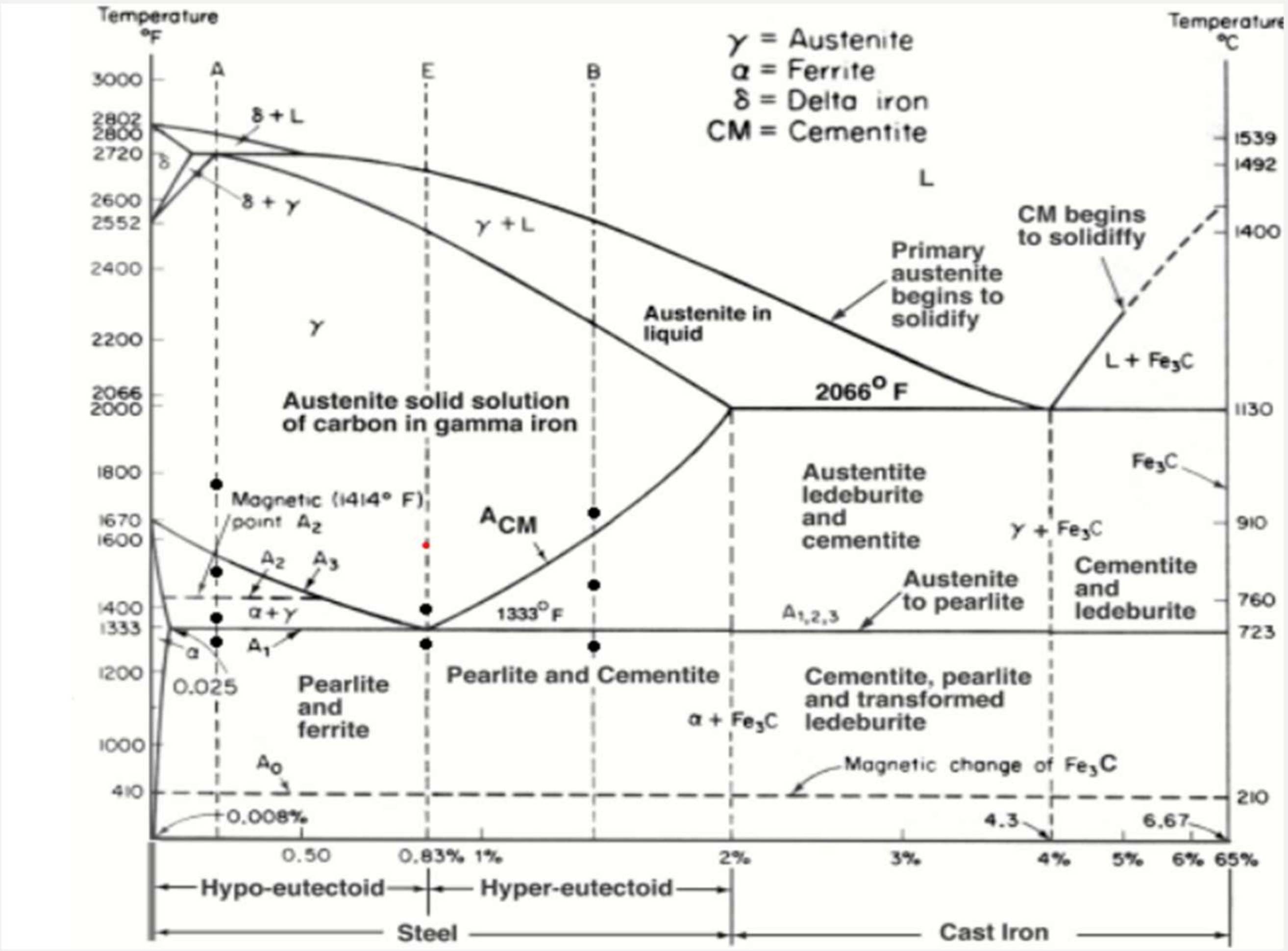
Heat Treatment

- Heating and cooling cycle are performed on metals.
- Increases the strength of metals.
- Changes the mechanical properties.

Iron Carbon Diagram (Fe-C Diagram)

- Indicates the phase changes that occurs during the heating and cooling.
- Indicates the nature and amount of the structural components that exists at any temperature.

Fe-C diagram



Adapted from —Metals Handbook, ASM

Important Reactions

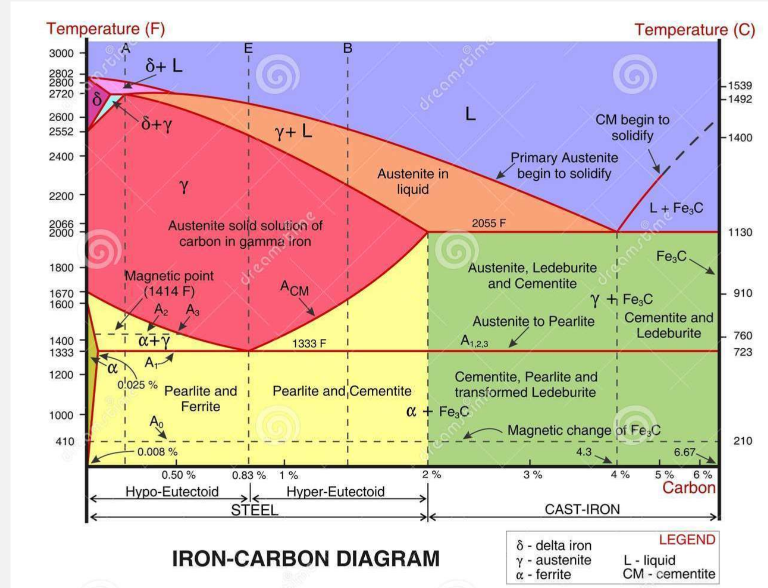
- Peritectic
- Eutectic
- Eutectoid

Equilibrium structure

- Austenite
- Ferrite
- Cementite
- Pearlite

Ferrite

- Solid solution in solvent α-Iron
- BCC form of iron
- Solute is principally carbon with other minor amounts
- Solubility up to 0.025%
- Softest constituent of steel
- Very ductile



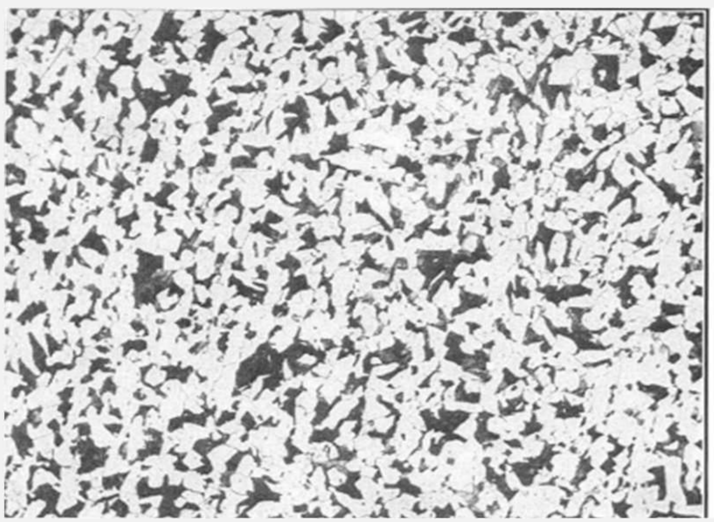


Fig: Microstructure showing ferrite and pearlite.

Austenite

- Carbon dissolved in ϒ phase.
- FCC structure
- Soft and ductile phase
- Max solubility is 2.11% at 2066 F
- Can only exist at elevated temperature in plain c-steel
- In some highly alloyed steel

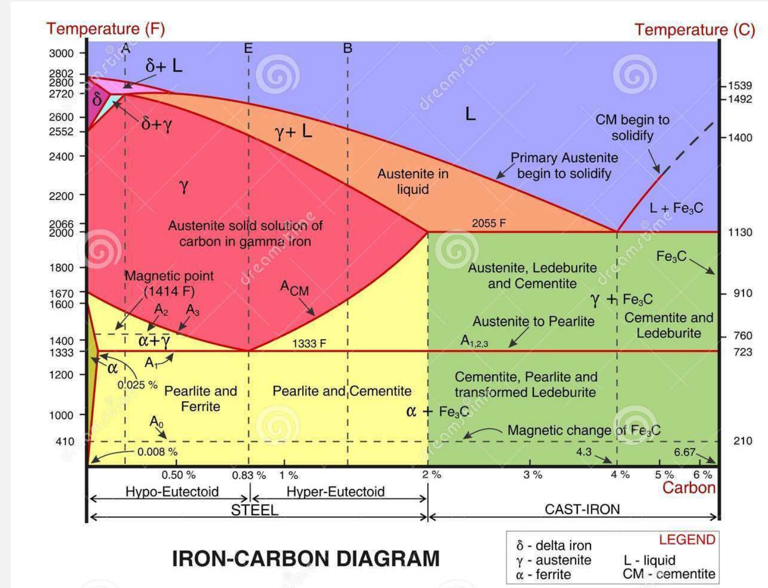


Fig: Microscopical appearance of austenite. Photograph is of 18%Cr-8% Ni stainless steel in which the austenite is stable at room temperature. Chromic acid etched. X 100

Cementite

- Hardest constituent of steel
- Extremely brittle
- Carbon content around 6.67%
- Can never be sole constituent of steel
- Always accompanied by other lower carbon constituents like ferrite or pearlite.

Pearlite

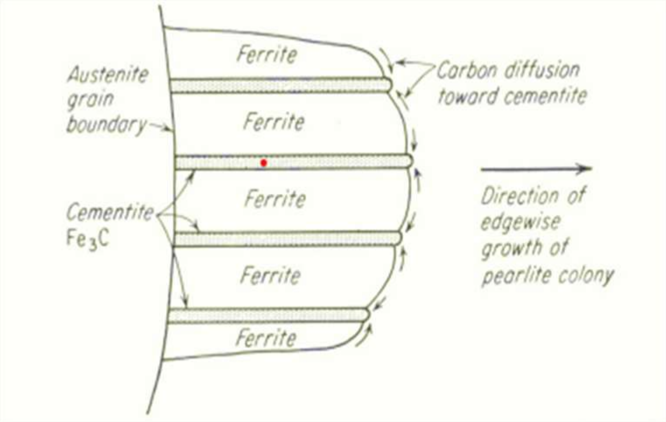


Fig: lamellar structure of ferrite and cementite

- Lamellar structure of alternate plates of cementite and ferrite
- Mechanical properties intermediate between these two
- Softer and more ductile than cementite
- Harder and stronger than ferrite

Quenching of steel

- Rapidly cooled
- Insufficient time for allowed atomic movements at elevated temperature
- New type of reaction occurs
- Changes to new structure called bainite or martensite
- Combination of these two are common

Fine Pearlite

- lamellar pearlitic structure
- individual plates of ferrite and cementite are much thinner
- stronger and harder than coarser pearlite formed by slow cooling

Quenching of steel

Martensite

- When the quenching rate is sufficiently rapid
- Hard and strong, but also is brittle
- Supersaturated solution of carbon in ferrite
- mechanism of formation of martensite is entirely different than for the other structures present in steel
- Individual martensite plates are lenticular in shape, and are generally quite small

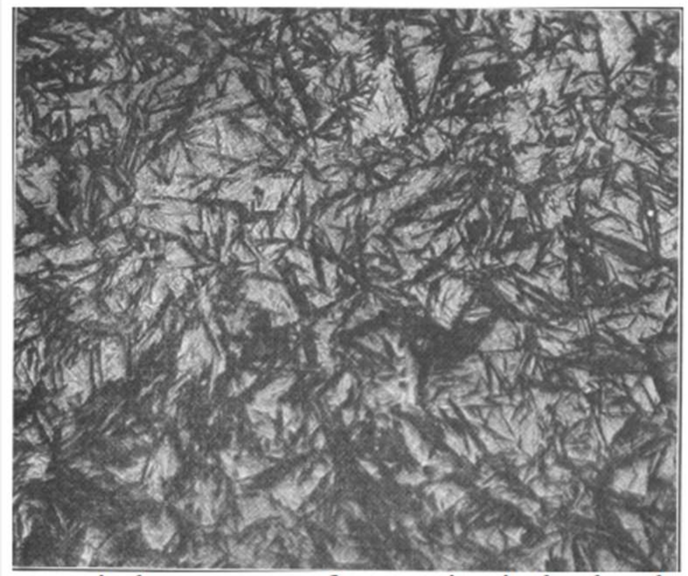


Fig: Typical microscopical appearance of martensite in hardened steel .1.3 % carbon Etched with 2% Nital X500

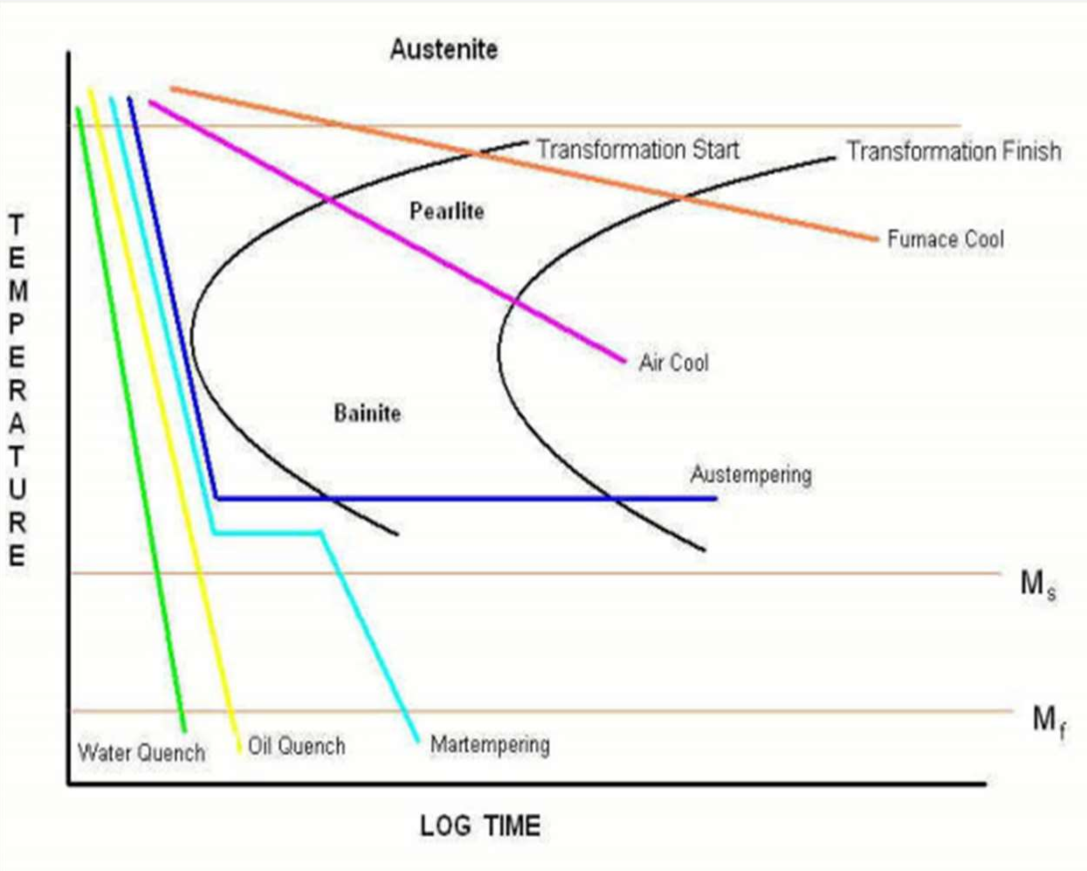
Quenching of steel

Bainite

- Between the temperature range where pearlite forms and that where martensite forms
- appearance of bainite varies considerably with transformation range
- Bainite in plain carbon steels is usually formed by constant temperature transformation of austenite

Fig: Microstructure of Bainite

Time and Temperature in the Transformation of Austenite



- Non equilibrium transformation can best be described with time-temperature-transformation curves, and the continuous-cooling curves which are modified TTT curves

- TTT curves indicate the time required for austenite to transform at any constant temperature

Fig: TTT curves

RECOVERY, RECRYSTALLIZATION AND GRAIN GROWTH GRAIN SIZE MEASUREMENT BY QUANTITATIVE METALLOGRAPHY

Aim: To report microstructural changes in a cold worked single phase alloy during its annealing and grain size determination of recrystallized alloy by quantitative metallography.

Annealing :

Heating of a cold worked structure at given temperature at a given period of time.

Phenomena that occurs during annealing are:

- Recovery
- Recrystallization
- Grain Growth or Coalescence

Recovery:

- First effect of reheating of cold worked metal is reduction of internal stress
- Recovery in cold worked structure occurs when material is held at relatively low temperature for a given time interval
- Change in the number and distribution of point defects, dislocations present
- Structural changes occurs
- Small changes in hardness are usually observed during later stages of recovery

Recrystallization :

- Continual formation of new unstrained grains and their growth until all the strained metal is replaced by unstrained material
- Entails the complete formation of new and unstrained metal grains
- Evident as it mark effects on mechanical properties.
- Ductility is simultaneously restored
- Microscopical appearance of cold worked metal is changed

- **Recrystallisation temperature-** temperature at which the recrystallisation is complete

- **Recrystallisation temperature range-** range of temperature between the first appearance of a new grain and the complete recrystallisation

Recrystallization :

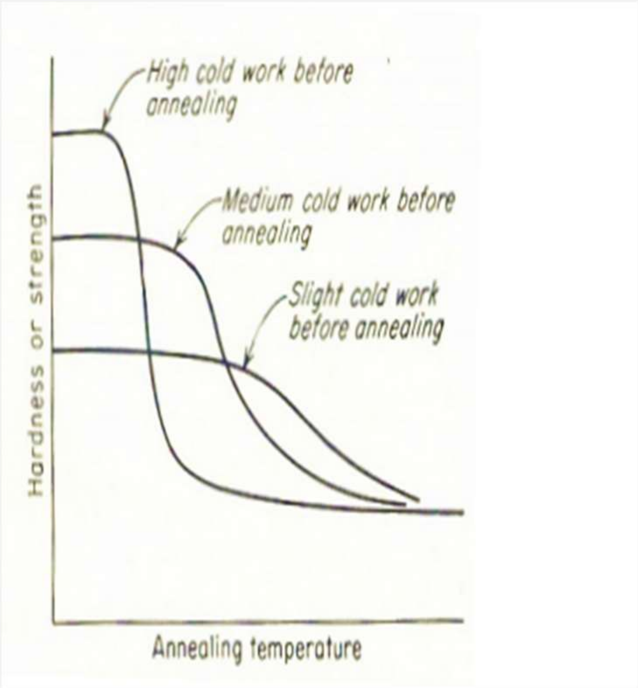


Fig: Effect of prior cold work on recrystallization temperature

Grain Growth or Coalescence :

- Growth of some of the recrystallized grains at the expenses of other grains occur.
- Results in larger average grain size and smaller total number of grains.
- Control of grain growth is an important feature.

The cold worked anneal cycle :

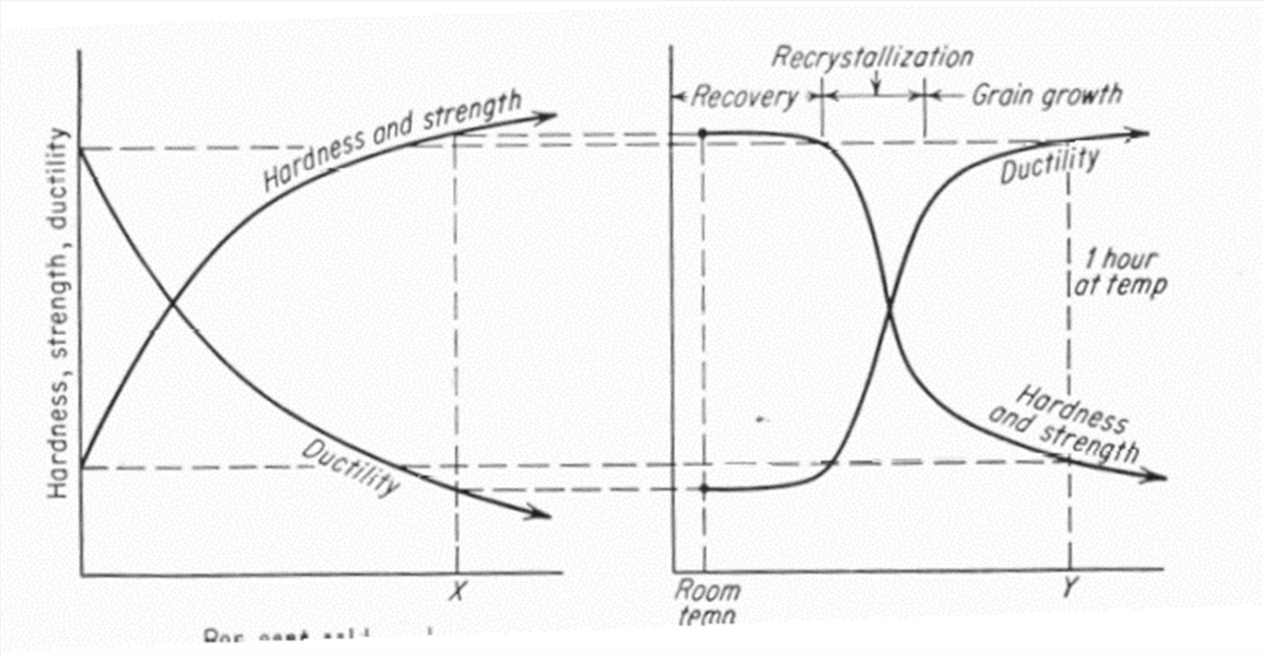


Fig: Cold worked anneal cycle.

The cold worked anneal cycle :

- The occurrence of grain growth can be expressed in the following relationship:

$$D_t - D_0 = Kt^n$$

Where, D_t = Average grain diameter after the annealing time of t,
D_o = Initial grain diameter before grain growth starts,
K and n are constants.

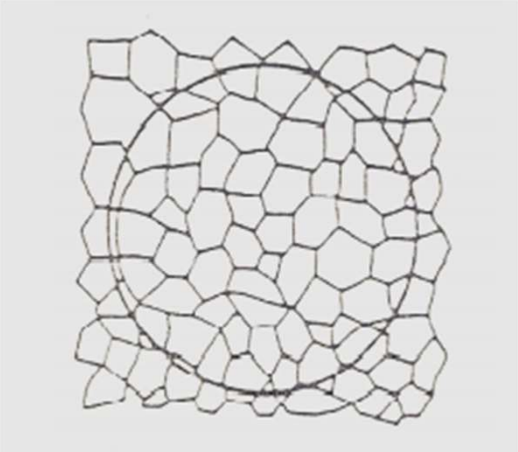
- Usually, a value of n is estimated to be 1/2.

Grain size measurement by quantitative metallography :

- Quantitative estimate of the average grain size of a single phase equiaxed grain structure is done by Jeffery's Planimetric method.

$$n_{eq} = \left(\frac{1}{2}\right) n_c + n_i$$

Where, the n_{eq} is the number of equivalent whole grain within the circle , the grains cut by the circumference are n_c and grains completely within the circle n_i.



- According to ASTM,

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

where,

N = ASTM grain size index number

n is the number of grains per square inch at l00x

Equipment :

- Metallurgical microscope
- A calibrated eyepiece
- Six polished and etched specimens of a single-phase material of cold rolled and annealed samples.

Procedure:

- Observe the microstructures of Sample No.1-6. Note the difference in the shape of grains in each cold rolled and recrystallized sample.
- Note the absence of any recrystallization activity in Sample No.2 and formation of a few recrystallized grains Sample No.4.
- Observe the difference in the grain structure of Sample Nos.5 and 6.
- Calculate the ASTM grain size for sample 6.

Thankyou.