MSE-226 Engineering Materials

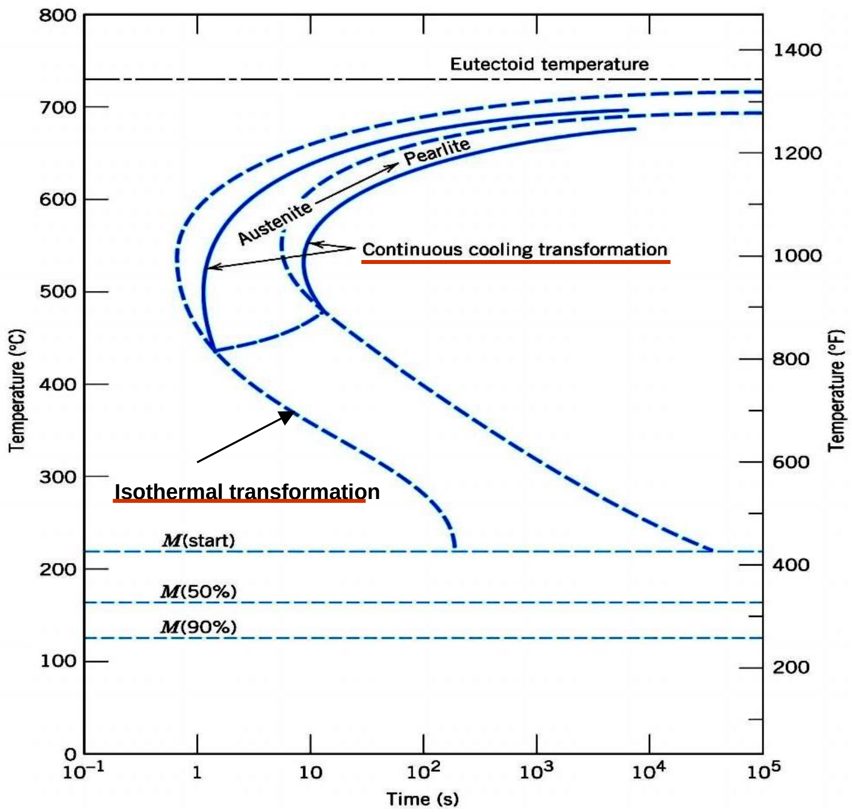
Lecture-4

"THERMAL PROCESSING OF METALS-2"

CONTINUOUS COOLING TRANSFORMATION (CCT) DIAGRAMS:

- In industrial heat-treating operations, in most cases a steel is not isothermally transformed at a temperature above the martensite start temperature but is continuously cooled from austenitic temperature to room temperature.

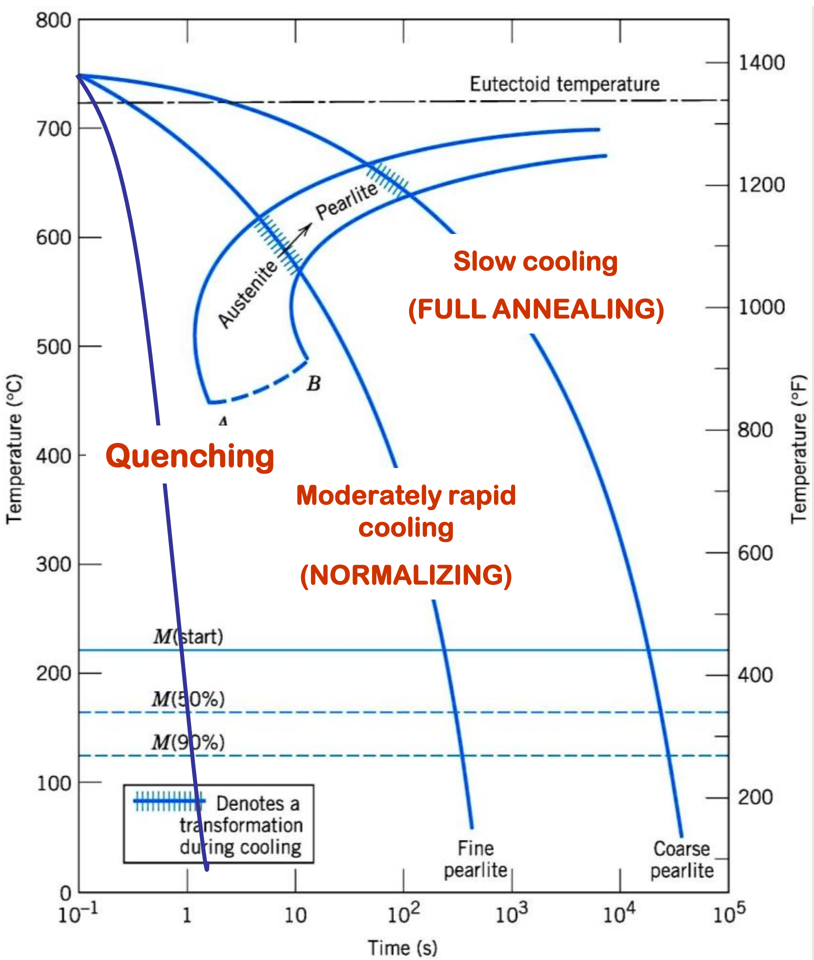
Comparison of IT and CCT diagrams for eutectoid steel

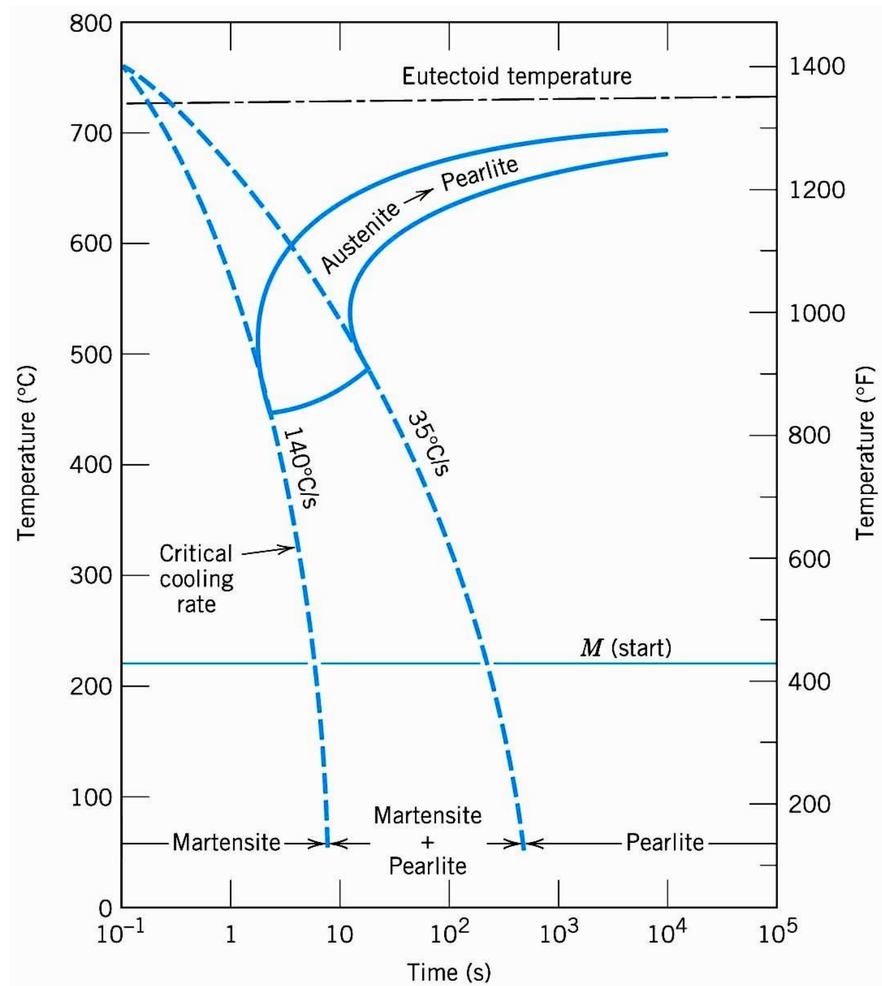


- No bainitic phase region in CCT diagrams of plain carbon steels!!!

CONTINUOUS COOLING TRANSFORMATION (CCT) DIAGRAMS:

- In continuously cooling a plain-carbon steel, the transformation from austenite to pearlite occurs over a range of temperatures rather than at a single isothermal temperature



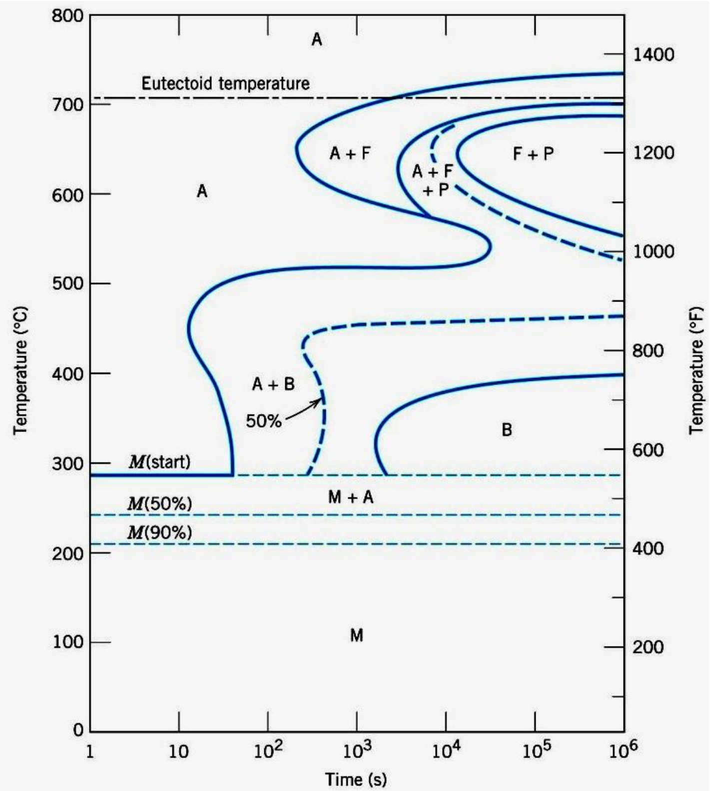


CONTINUOUS COOLING TRANSFORMATION (CCT) DIAGRAMS: EFFECT OF ALLOYING

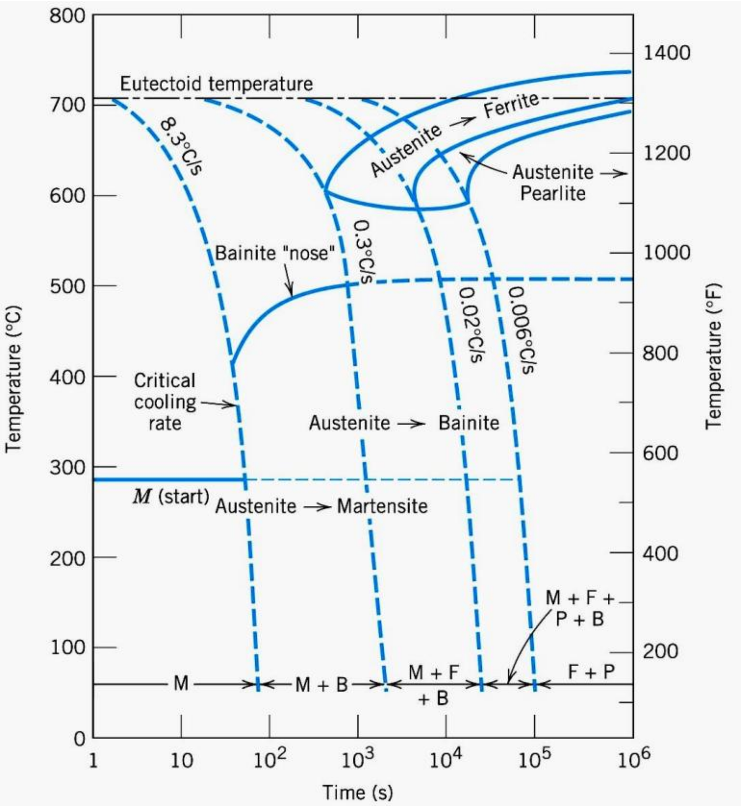
1) Alloying elements shift the austenite-to-pearlite transformation lines to longer times

2) A seperate bainite nose is formed

IT-diagram, 4340 steel



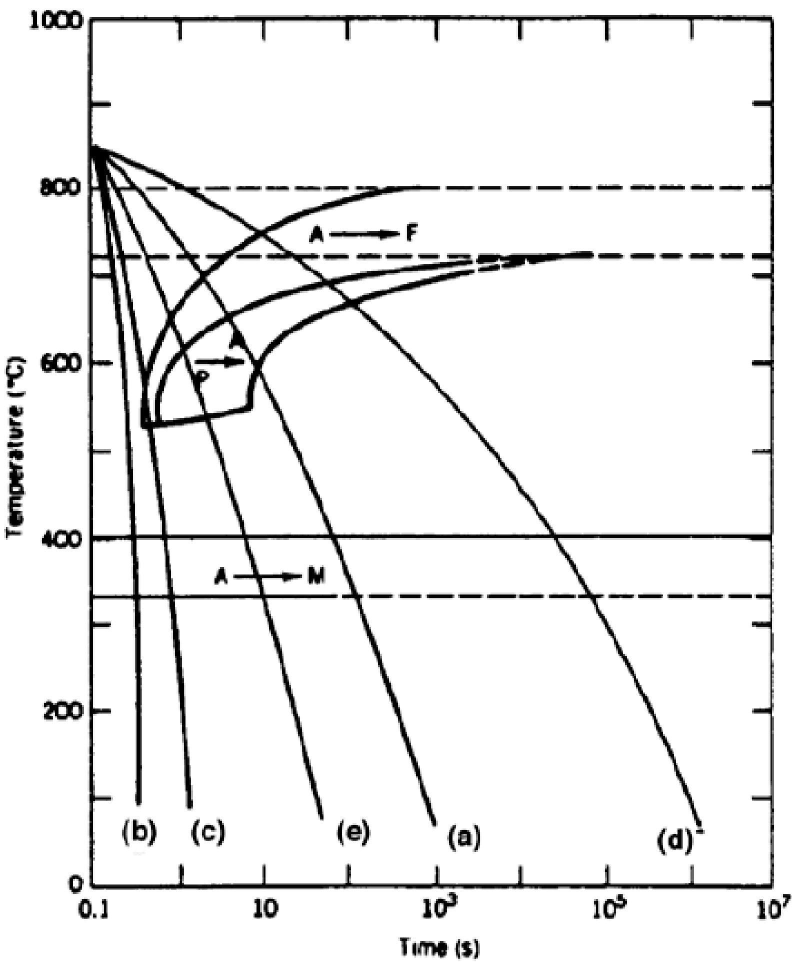
CCT-diagram, 4340 steel (Ni, Cr, Mn, Mo as alloying elements)



Normally, BAINITE will not form (or will form to a small extent) during continuous cooling of plain carbon steels. By alloying, it becomes possible to obtain bainite phase upon continuous cooling

USE of CCT DIAGRAMS : Example

Which microstructures do you observe upon cooling of 0.35 wt.% C iron-carbon alloy after austenitization at 850ºC at different rates shown below?



(a) Proeutectoid ferrite+fine pearlite

(b) Martensite

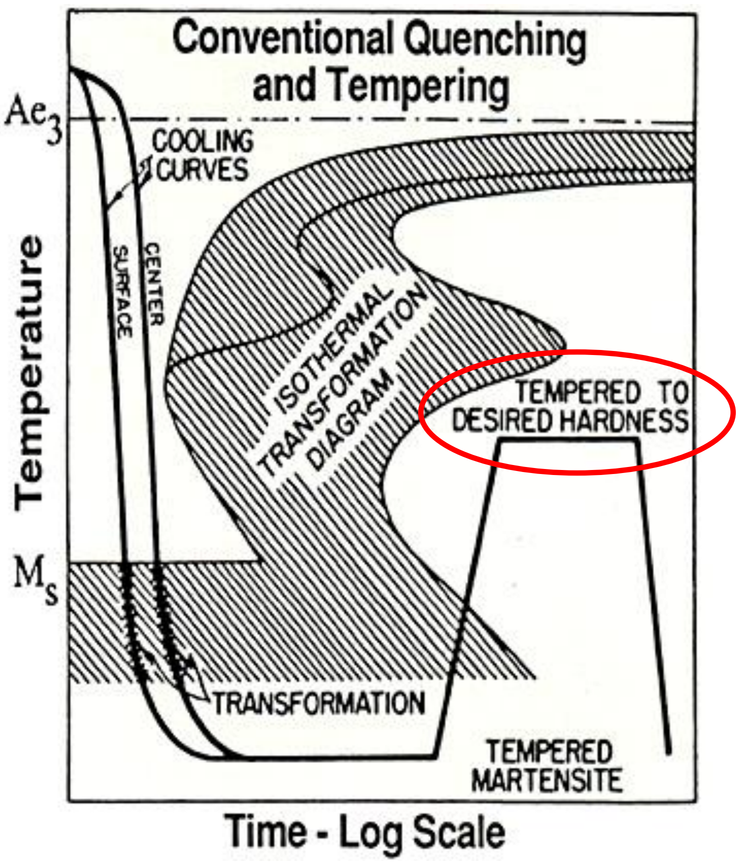
(c) Proeutectoid ferrite + martensite

(d) Proeutectoid ferrite + coarse pearlite

(e) Proeutectoid ferrite + pearlite + martensite

TEMPERING

1) Conventional Quenching and Tempering



- Altough martensite is very hard unfortunately it is very **BRITTLE** for industrial use. In order to toughen the steel and make it more ductile, a heat treatment called **tempering** is applied.

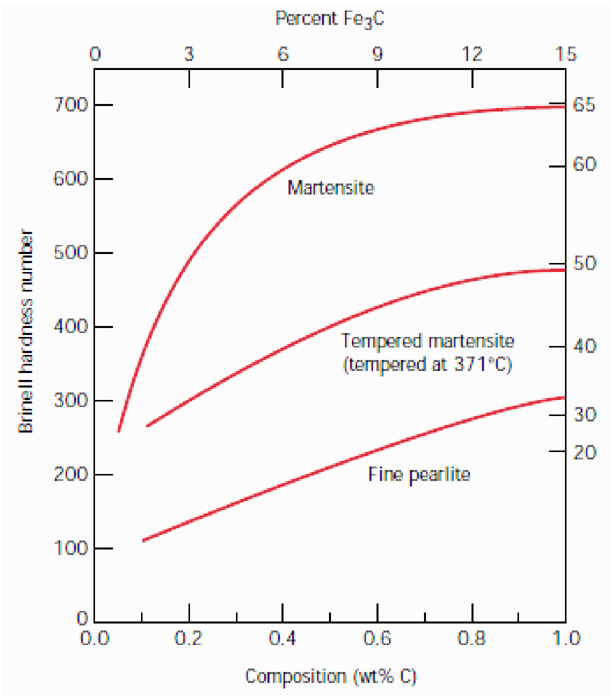
Application of Tempering:

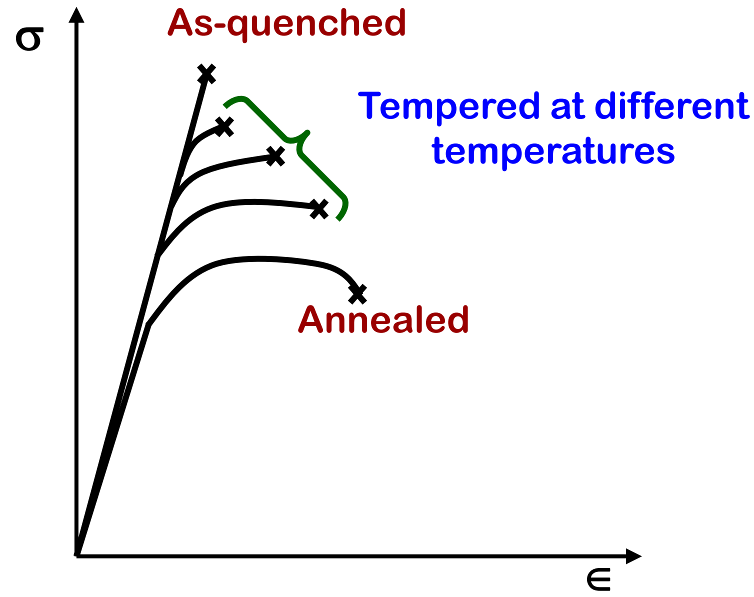
- **Heat the martensitic steel to a temperature below the eutectoid temperature, wait at that temperature and cool the steel at any rate.**

Results of tempering

- Ductility and toughness increases

TEMPERING: The Reason of Hardness Decrease





❑ **<u>The reason of hardness decrease</u>** upon tempering is the diffusion of carbon out of the BCT (c/a ratio decreases), (carbide precipitation)

Martensite (BCT, single phase) ⟶ Tempered Martensite (α+Fe_3C)

❑ The microstructure of tempered martensite consists of small and uniformly dispersed cementite particles within continuous ferrite matrix. The size of the cementite particles influences the mechanical behaviour of tempered martensite.

TEMPERING: Tempering temperature ranges

- By changing tempering parameters (**temperature and time**), size of the cementite particles are controlled.

1) Tempering up to 200°C:

- ε-carbide(hexagonal),$Fe_{2.4}C$, coherent precipitates form
- c/a ratio is still high

2) Tempering above 200°C:

- ε-carbide dissolves and Fe_3C appears
- When steel is tempered between 200-300°C, the shape of the precipitate is rodlike. At higher temperatures (400-700°C) the rodlike carbides coalesce to form sphere-like particles(spheroidite)

Low temperature tempering (T<200°C)

Hardness drop is small; impact toughness is relatively satisfactory

e.g. Automotive gears(case carburized+heat treated)

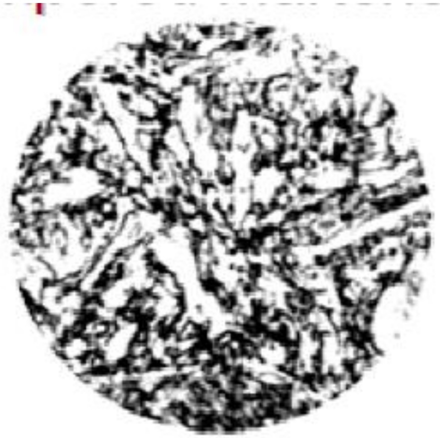
High temperature tempering (400-700°C)

Hardness drop is high; improved impact toughness

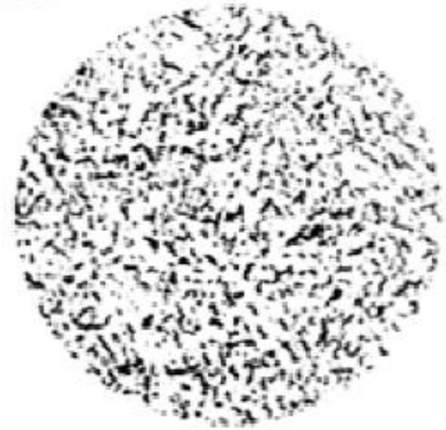
e.g. Gun Barrels and all springs

TEMPERING

Martensite



Tempered Martensite



Heavily Tempered

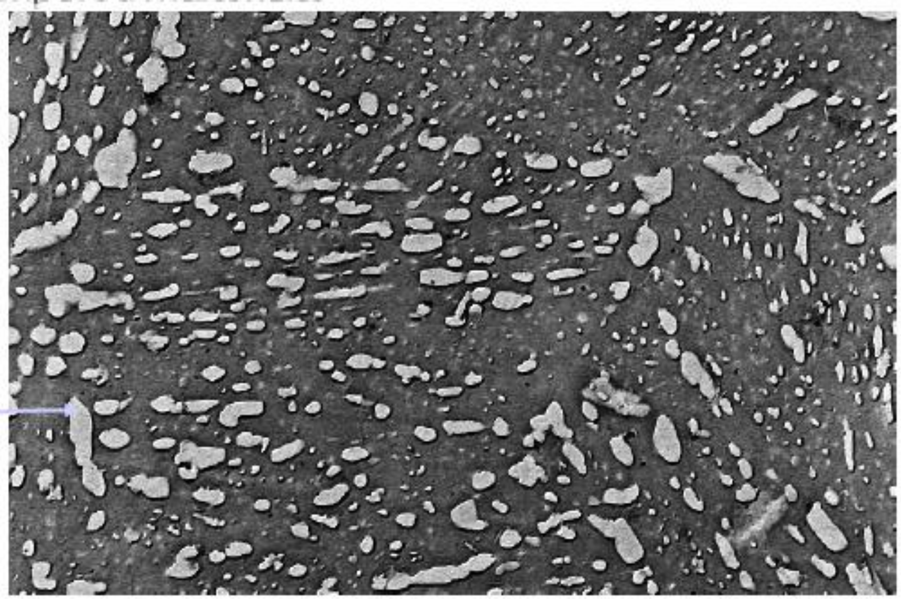
Martensite (BCT)

Tempering

@ 250-650 °C

Tempered Martensite

(α + Fe_3C)

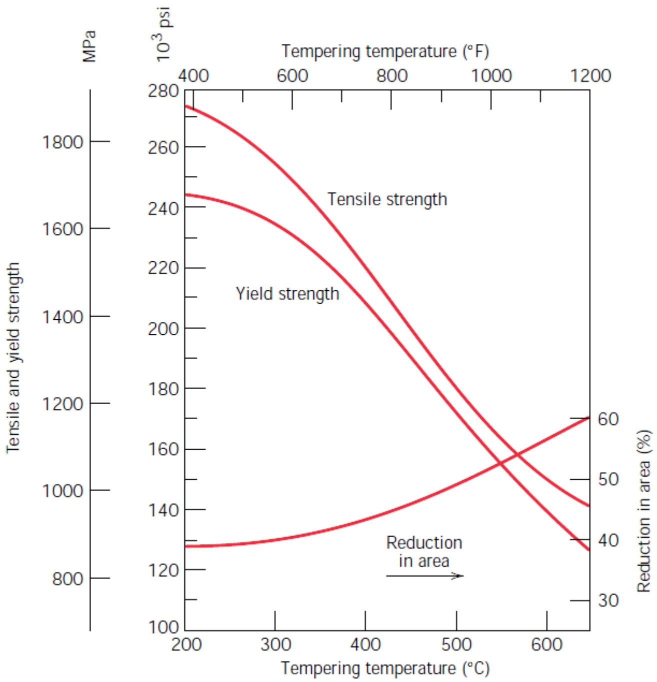


TEMPERING: Effect of temperature and time

1) TEMPERATURE

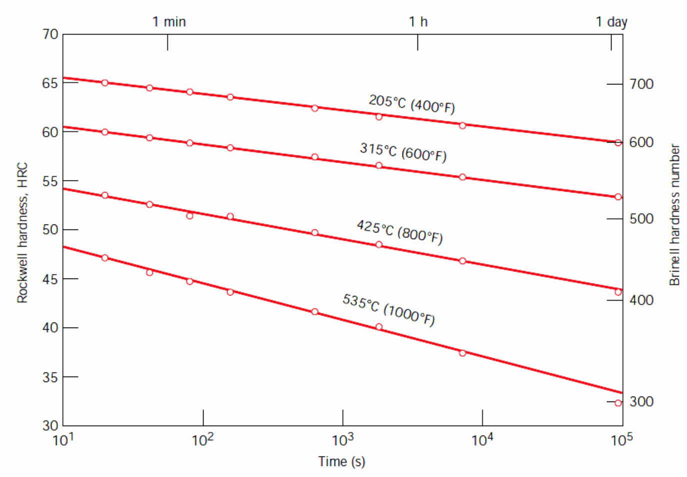
As tempering temperature increases the rate of softening increases due to increasing of the rate of cementite particle growth.

Temperature is a diffusion controlled process so as temperature increases diffusion will be accelerated.



2) TIME

With increasing tempering time hardness decreases….



SPHEROIDIZING HEAT TREATMENT

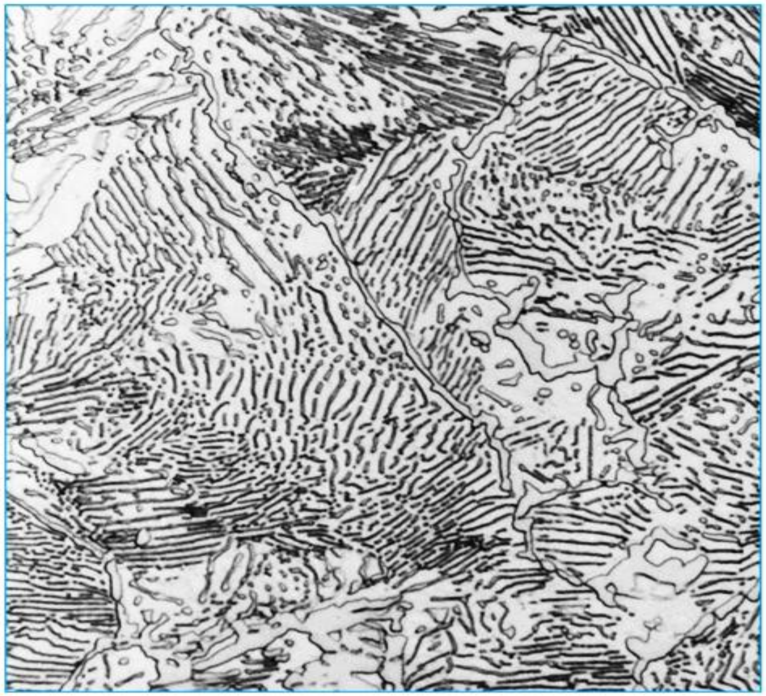
- ❑ A kind of high temperature tempering process for martensitic structures or heating the pearlitic or bainitic steels to high temperatures.

- ❑ Conducted to achieve minimum hardness and maximum ductility

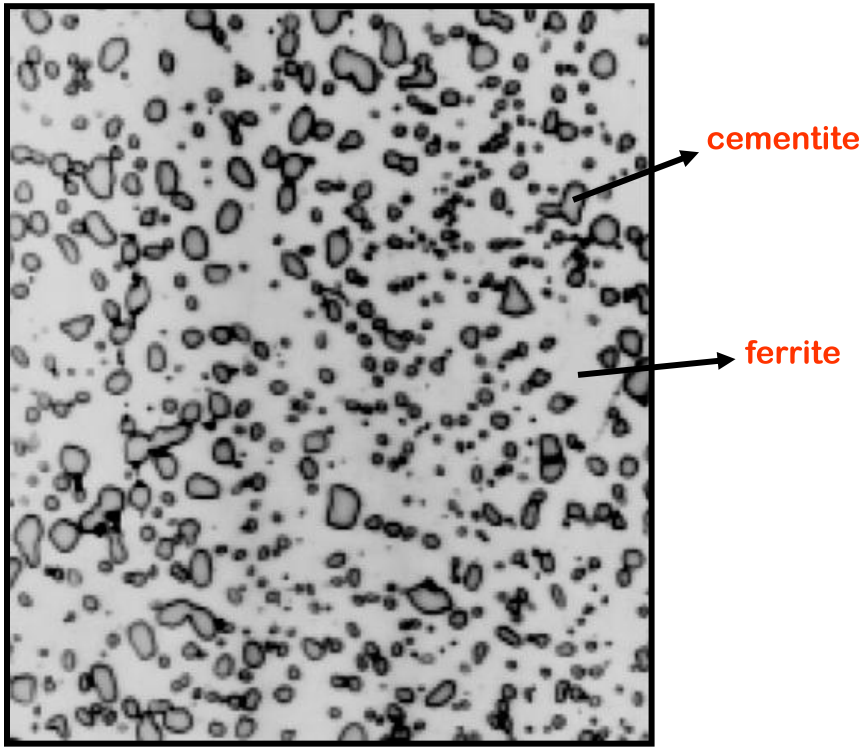
- ❑ **Application:**

Generally **high carbon(hypereutectoid) steels** having, pearlitic, bainitic or martensitic microstructures are heated to high temperatures below eutectoid temperature (700^{o}C) for a sufficiently long period of time(18-24 h).

SPHEROIDIZING HEAT TREATMENT



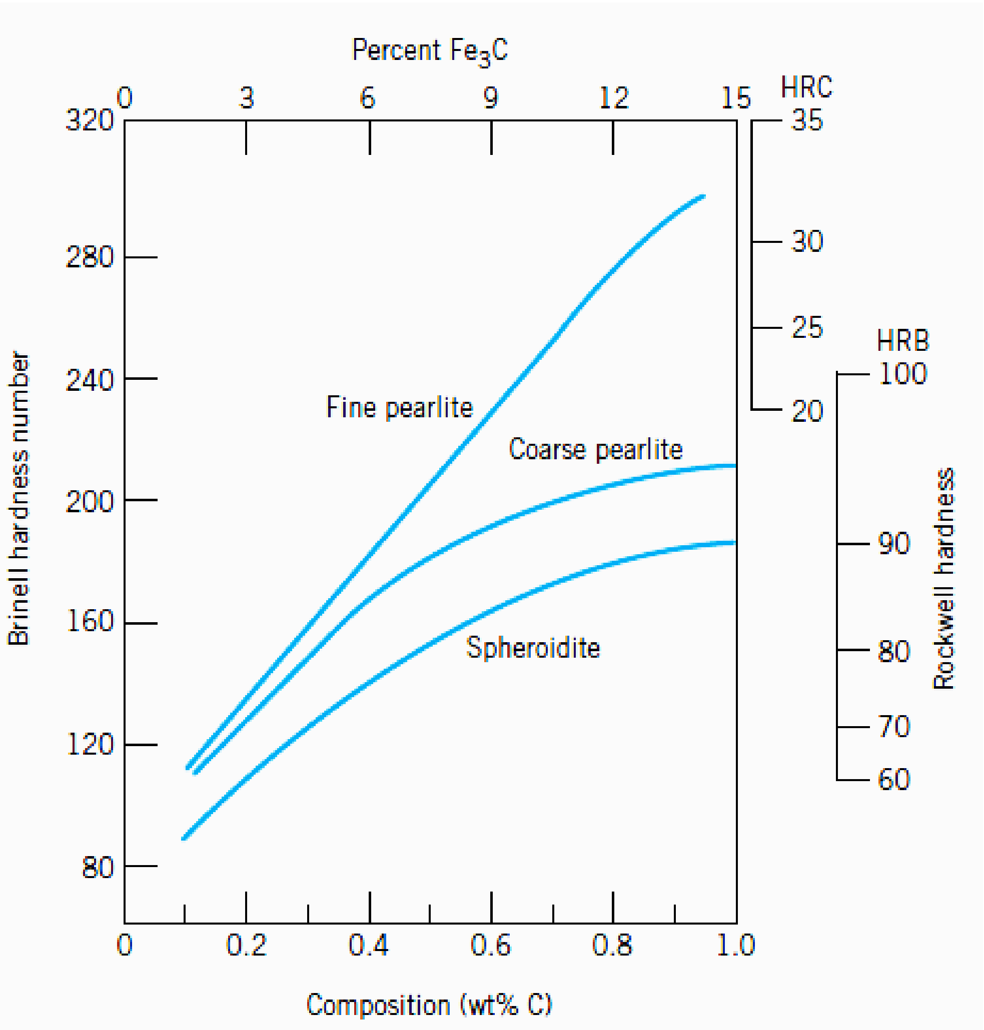
Pearlite, partially transformed to spheroidite

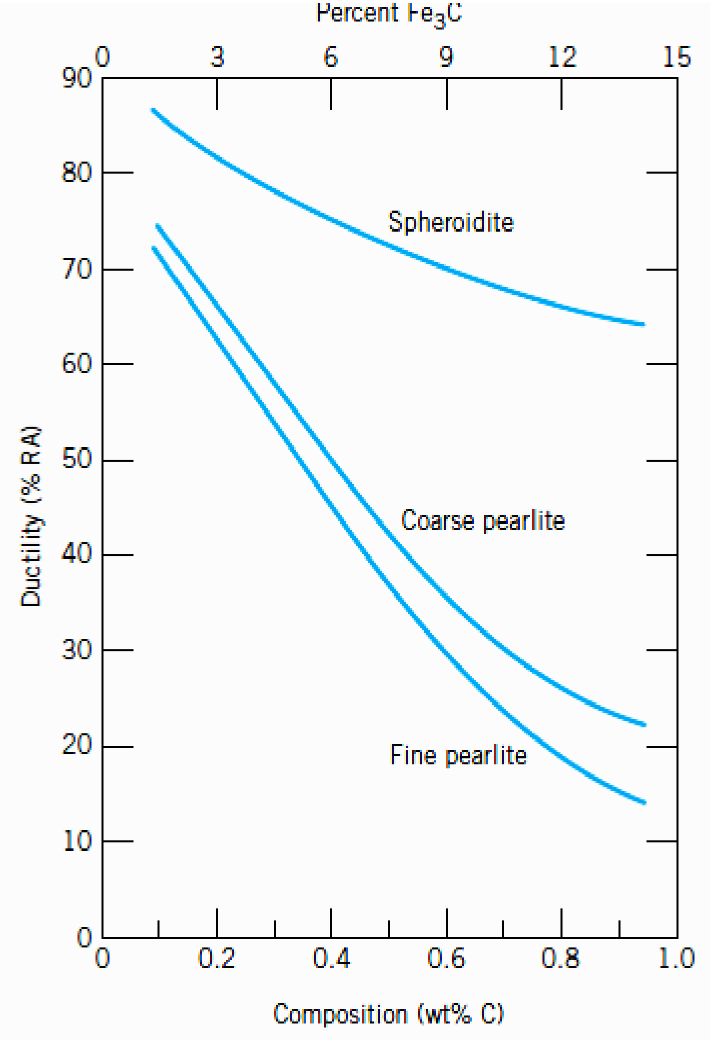


Spheroidite microstructure

- At the end of spheroidizing heat treatment cementite particles become spherical.

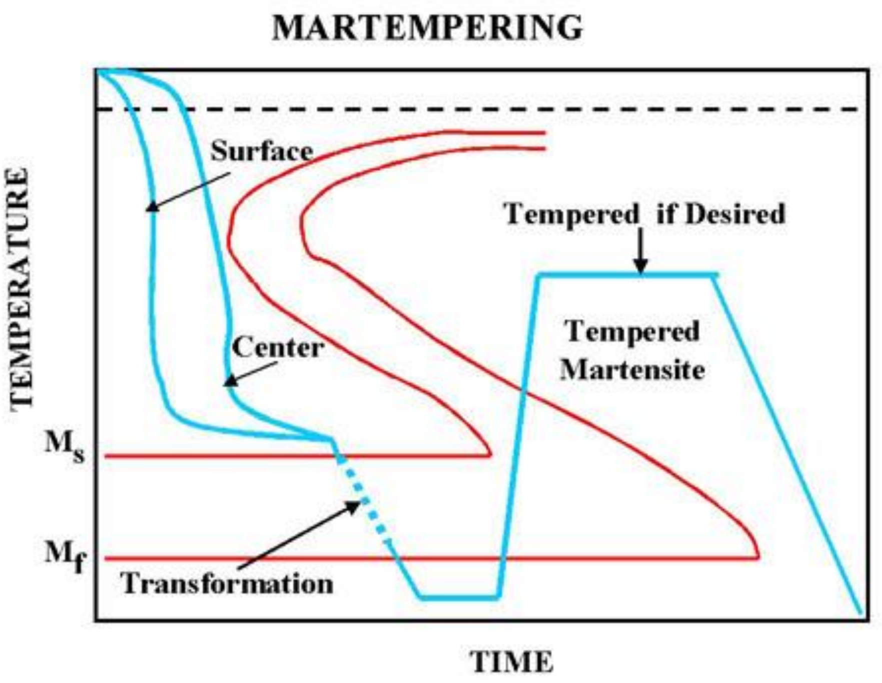
Mechanical Properties of Spheroidite and pearlite





MARTEMPERING (Marquenching)

- It is a modified quenching procedure used for steels to minimize distortion and cracking that may develop during uneven cooling of the heat treated material.



- The effect of quenching is less drastic. Again steel is ~100% martensite. But it is more stress free so that it is more resistant to cracking and distortion.

Disadvantage:

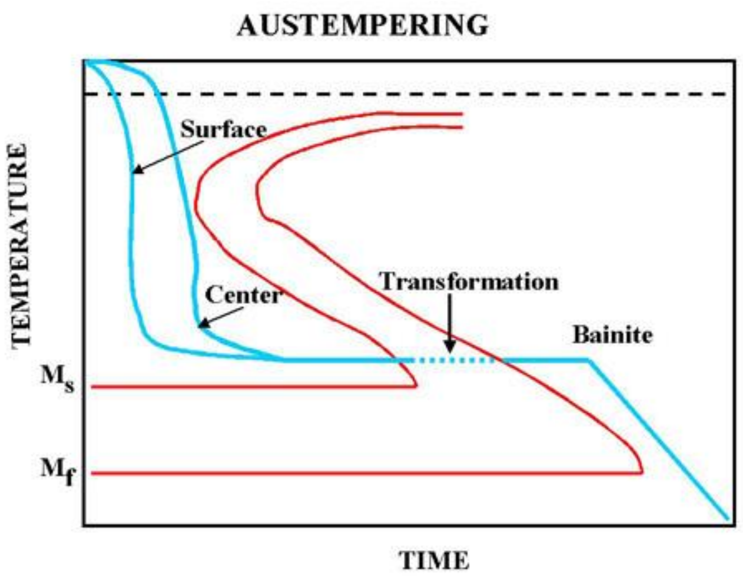
Time consuming and inconvenient

- **Application of Martempering**

Very similar to general quenching and tempering. After austenitization, the steel is quenched in hot oil or molten salt bath at a temp. slightly above M_s.Then, the steel is hold until the temperature is uniform throughout and this isothermal treatment is stopped before the austenite-to-bainite transformation begins. Finally, the part is cooled to room temperature at a moderate rate.

AUSTEMPERING

- It is an <u>isothermal heat treatment that produces a bainite structure</u> in some plain-carbon steels. This process provides an alternative procedure to quenching and tempering for increasing the toughness and ductility of some steels.



- Parts have less internal stress and more resistant to cracking and distortion but not hard and strong.

- Limited to thin and fine parts such as needles and springs

- **Application of Austempering**

The steel is quenched rapidly between 250-320^{o}C. It is soaked here for a long time.. LONG ENOUGH to produce 100% bainite. After 100% transformation, the steel is held at that temperature for a short time and then quenched to room temperature..

More gentle heating than either martempering or general tempering..

ISOTHERMAL QUENCHING AND TEMPERING

- Produces structure having both bainite and martensite. The steel is rapidly quenched until 50% of the austenite transformation is complete. Then it is held at this temperature for a few seconds and then heated to higher temperature to produce bainite from the remaining austenite.. The steel is soaked at this temperature for a period of time to remove internal stresses.

Between martempering and austempering

Microstructure vs. Mechanical Properties

HARDNESS
STRENGTH

- Martensite
- Tempered martensite
- Bainite
- Fine pearlite
- Coarse pearlite
- Spheroidite

DUCTILITY

- Can control the formation of specific phases and microstructure so that desired properties result