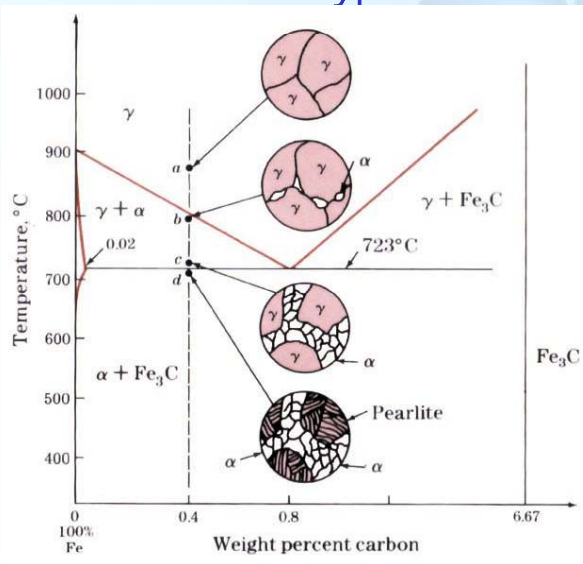
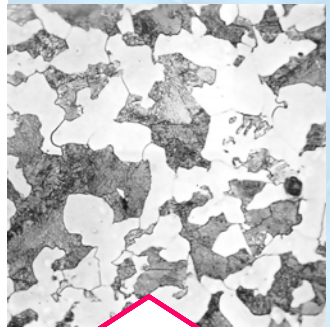
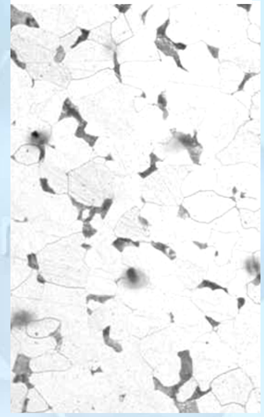
Hypoeutectoid Carbon Steels





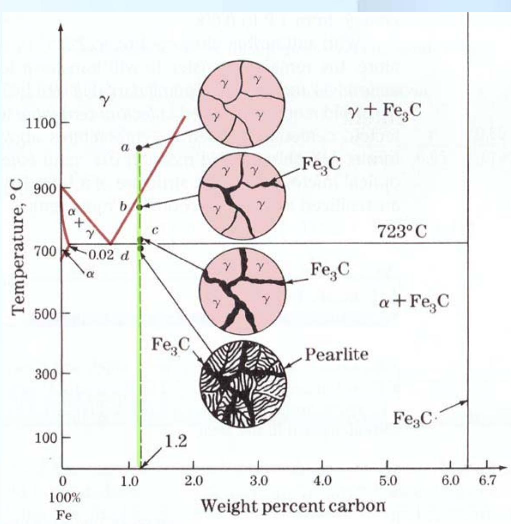
1035 Steel: white regions are pro-eutectoid ferrite grains

Another example: Amount of carbon?

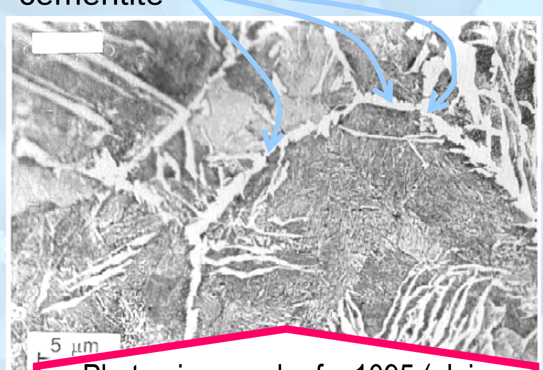


By the end of this lecture you should be able to predict the amount of carbon in a plain-carbon hypoeutectoid steel by just looking at a micrograph

Hypereutectoid Carbon Steels



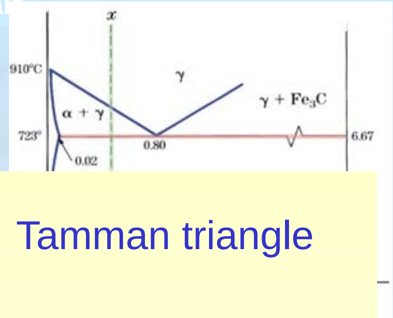
The proeutectoid phase now is cementite



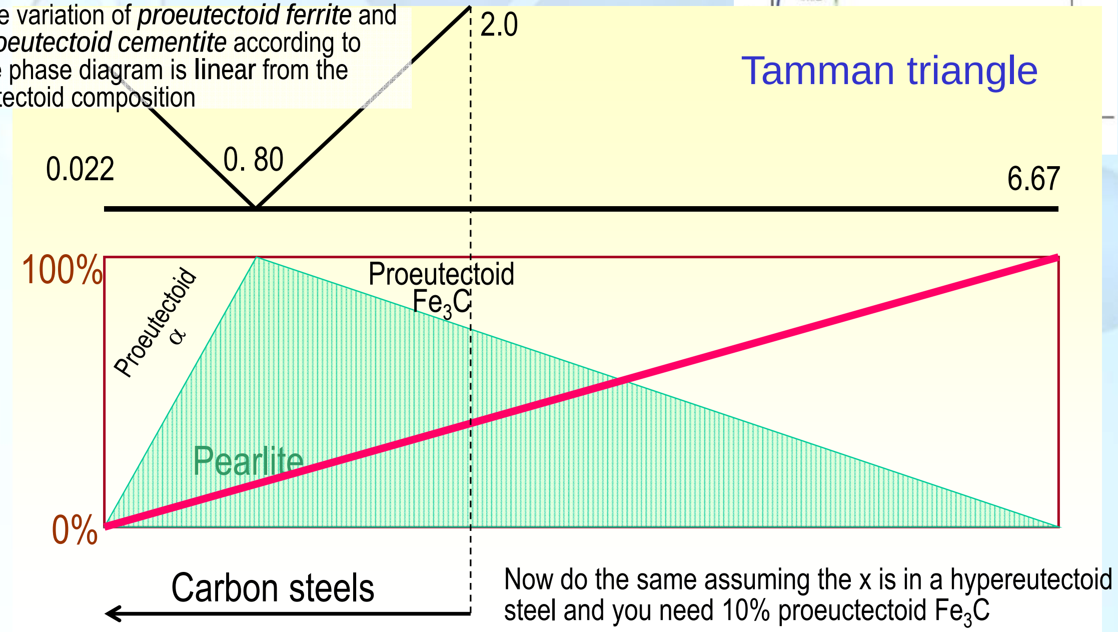
Photomicrograph of a 1095 (plain carbon) steel. Notice the network shape of proeutectoid cementite

Proeutectoid cementite tends to form in the parent austenite grain boundaries. This worsens the brittleness of these steels even more. High carbon steels have limited applications.

Example Problem

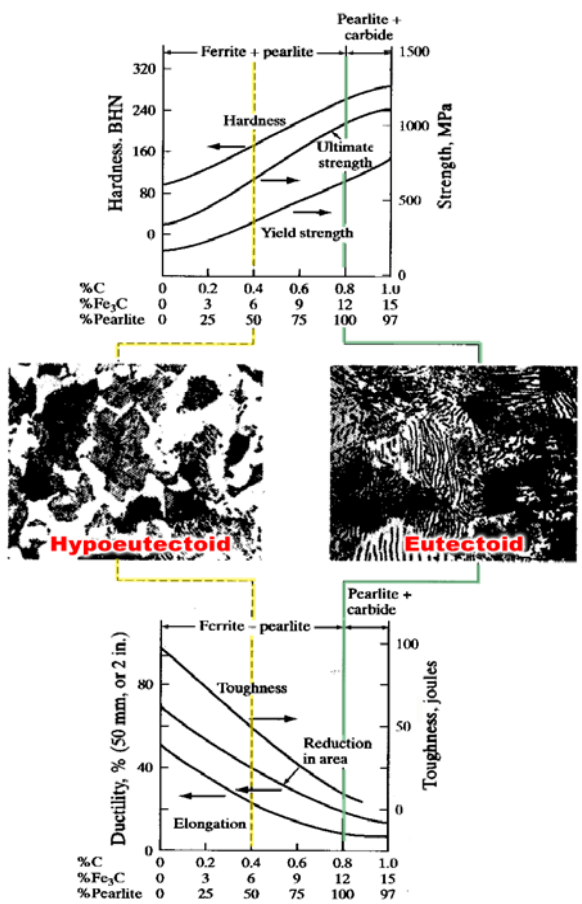


Homework: a) Determine the value x that allows you to obtain 92% of total ferrite. b) Determine the value x that allows you to obtain 30% proeutectoid ferrite



So, why do I care about proportions of ferrite, pearlite, or cementite?

- Because those proportions (or percent) regulate the mechanical properties of the steel.
- You can pick a chemical composition that fits your steel needs (according to your design):
  - UTS
  - Hardness
  - Toughness, etc.



This is a brief (and very limited) classification of solid-solid phase transformations in crystalline engineering materials:

- Diffusion-controlled phase transformations without change of number of phases and their composition:
  - Recrystallization
- Diffusion-controlled phase transformations with change of number of phases and composition
  - Isothermal transformations (eutectic, etc.)
- Difussionless or displacive transformations.
  - Martensitic transformations

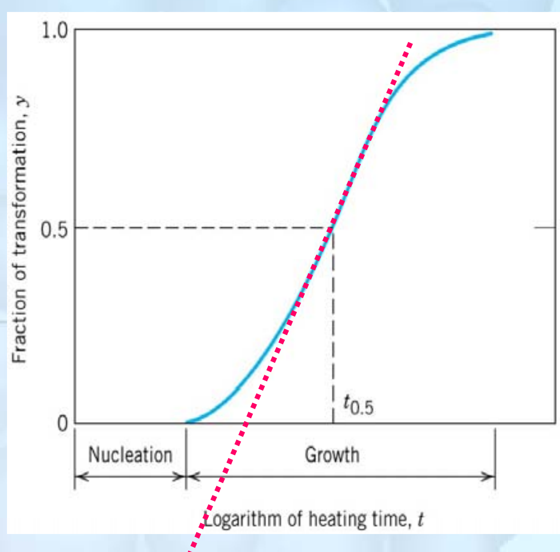
We need to know the kinetics of diffusion-controlled phase transformations:

Remember recrystallization. The fraction of transformed phase follows the Johnson-Mehl-Avrami (JMA) equation:

$$y = 1 - \exp(-k \cdot t^n)$$

The JMA model only describes the phenomenon at <u>one temperature.</u>

The inverse is the transformation time to achieve 50% (or 0.5 in fraction) of the transformation is "the rate of the transformation:"



$$r = t^{-1}_{0.5}$$

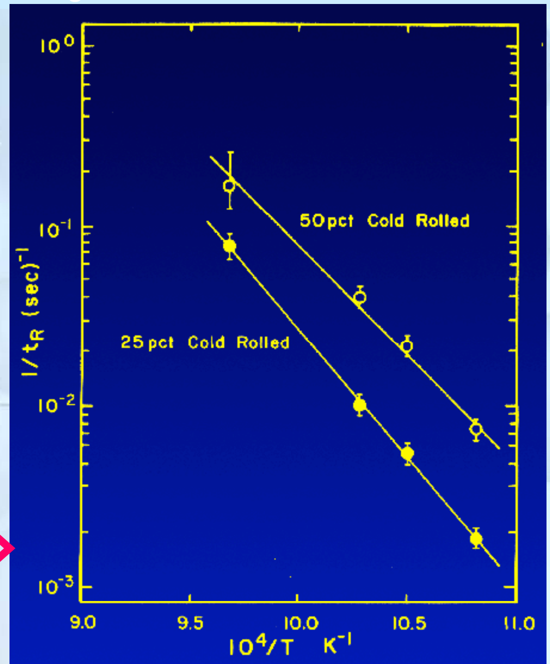
This is the inverse of the maximum slope

The rate of transformation also depends on temperature according to an Arrhenius equation:

$$r = r_o \exp(-Q/RT)$$

again Q is the activation energy for the transformation.

Remember: the recrystallization rate is an example of the application of an Arrhenius equation.

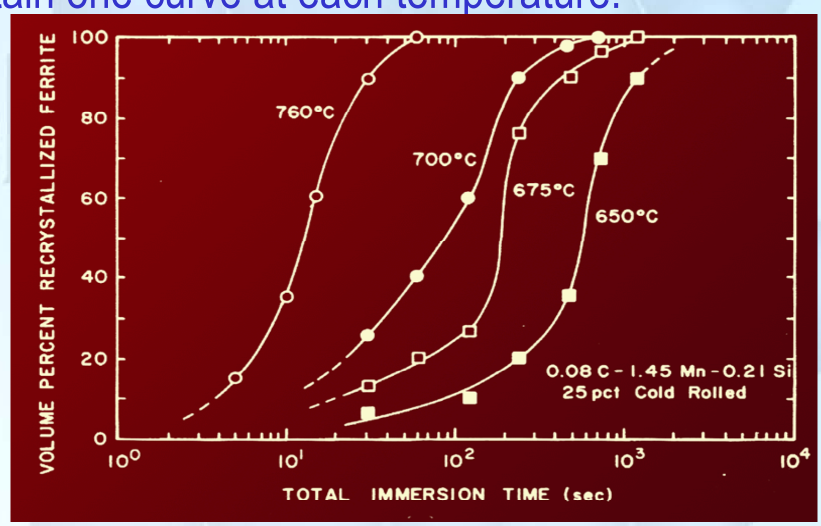


Temperature dependence of the rate of ferrite recrystallization in 0.08C-1.45Mn-0.21Si steel cold-rolled 25 and 50 pct.

Plotting the same data as a function of the amount of phase transformed we obtain one curve at each temperature:

Each curve follows the JMA equation:

$y = 1 - \exp(k \cdot t^n)$



Note that there is a "nucleation time" too: each transformation doesn't start from t = 0. It takes some time for the transformation to start.

Microstructure and Property Changes in Fe-C Alloys

Let's apply those kinetic models to transformation in steels.

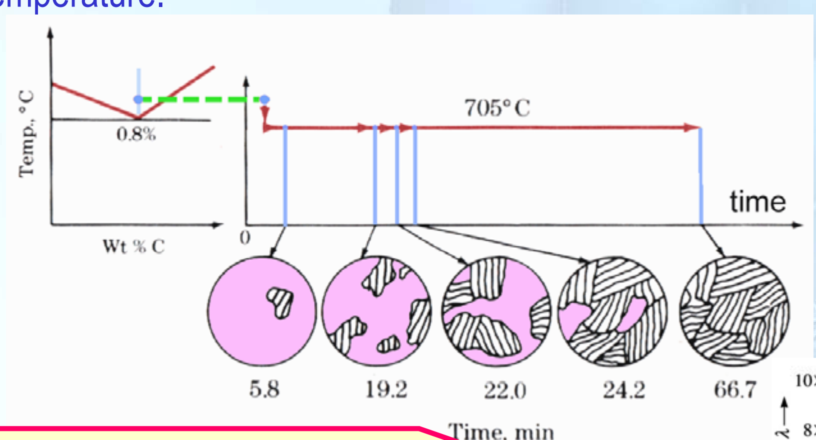
Remember the definition of *heat treatment*:

A controlled heating and cooling cycle or cycles intended to adjust the microstructure and mechanical properties of a material for a specific purpose

Examples: annealings, normalizing, quenching and tempering, etc.

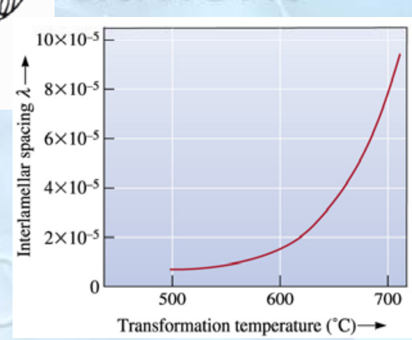
First we'll perform an isothermal annealing in a eutectoid plain carbon steel. Let's assume we austenitize a eutectoid steel and drop the temperature just below the eutectoid temp: T_e (this is the equilibrium temperature for the eutectoid transformation)

First, we will study a eutectoid steel annealed just below the eutectoid temperature.



What if we choose a lower temperature?

Austenite will transform isothermally into pearlite following the JMA model

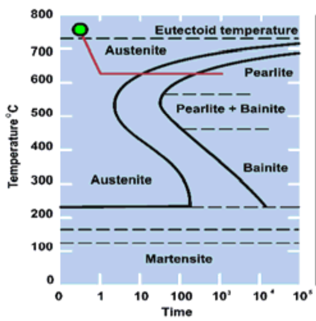


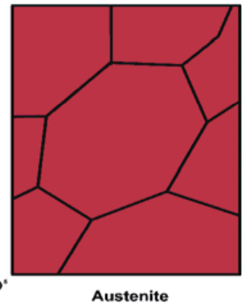
Remember lower temperatures → less diffusivity → *smaller lamellar spacing*

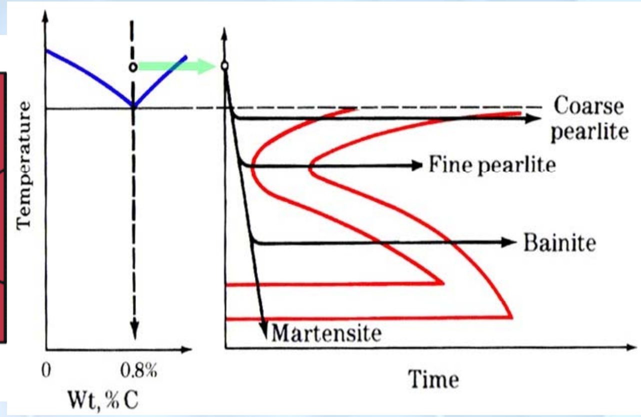
Now let's trace the isothermal decomposition of austenite at lower temperatures

Remember there are two competing factors that shape the initial transformation line:

- Degree of instability
- Diffusivity



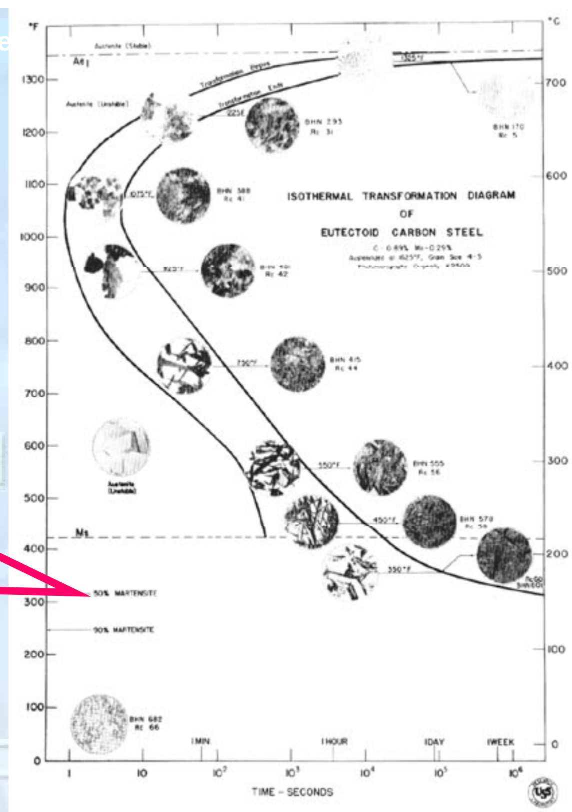




Remember that in all diffusion-driven transformations, the fraction of transformed phase follows the Avrami equation: $y = 1 - e^{-k \cdot t^n}$

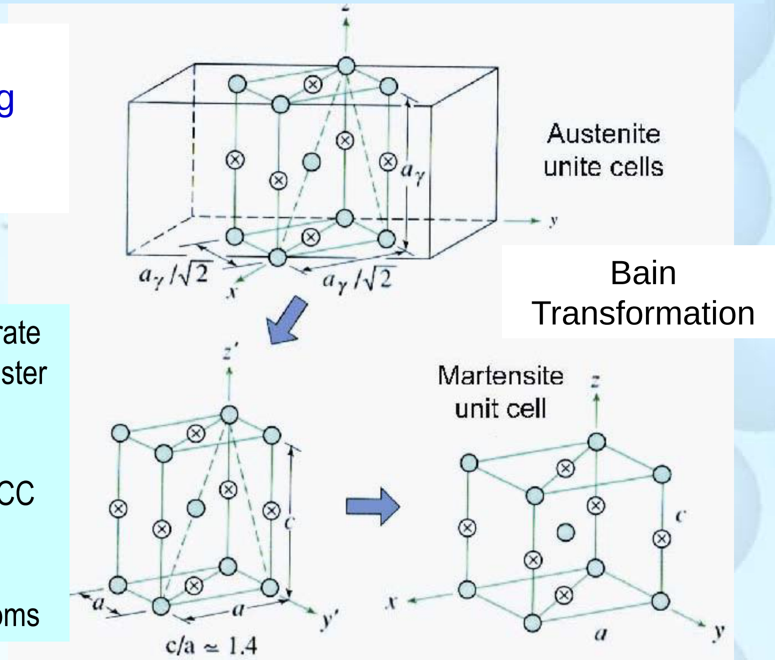
Real TTT Diagram for a Eutectoid Steel

When the temperature of the isothermal bath is too low, carbon diffusion is heavily compromised and another type of transformation takes place.



A new metastable phase shows up: martensite.

It is the result of fast cooling a steel starting from an austenitic microstructure.



As a result of the high cooling rate carbon atoms cannot diffuse faster out of the FCC crystal.

Then they supersaturate the BCC structure and promote the formation of a BCT structure supersaturated with carbon atoms

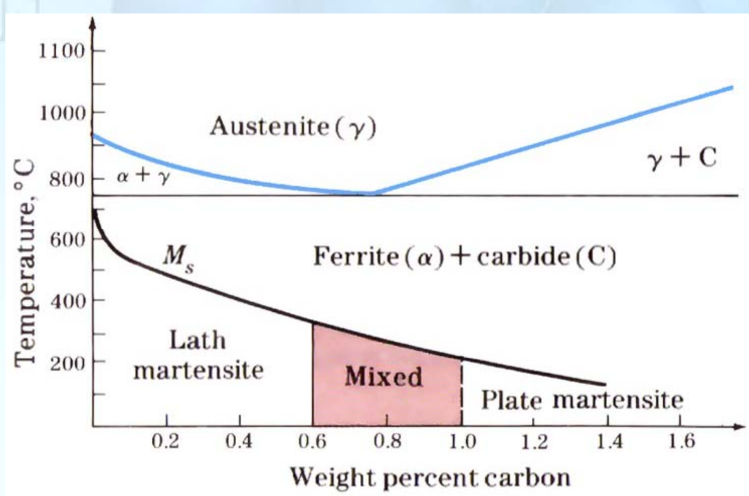
Martensitic Transformations

They are examples of displacive (*diffusionless*) transformations. They are not assisted by diffusion!

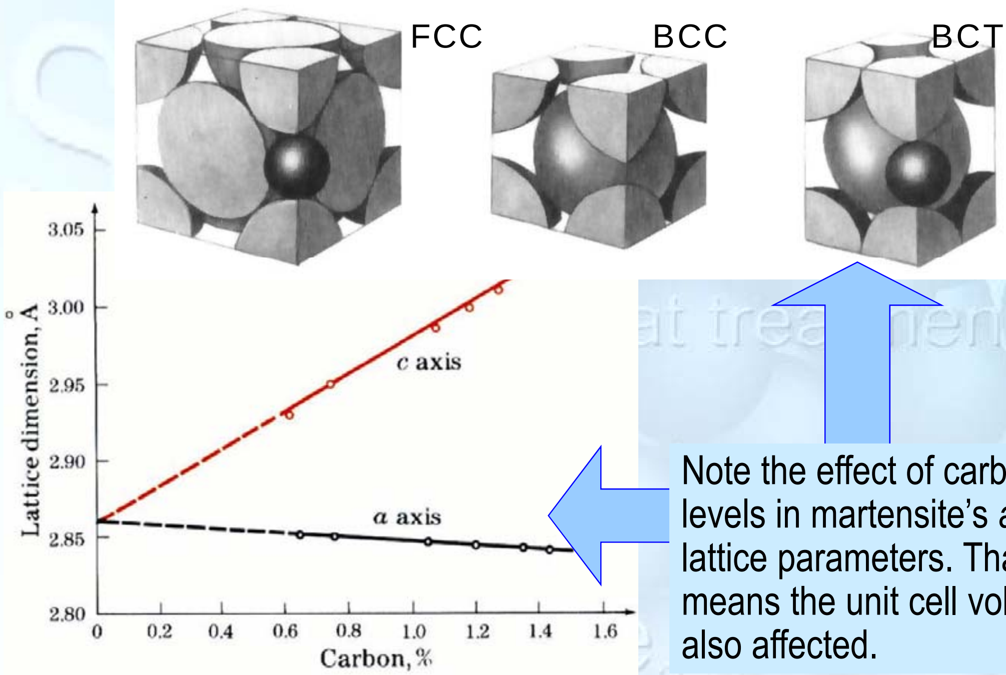
Steel martensite starts to form at a given temperature M_s and finish forming at another temperature M_f.

Types of martensite in plain carbon steels:

- Lath martensite
- Plate martensite



The Role of Carbon in the Shape of Martensite BCT Crystal Structure



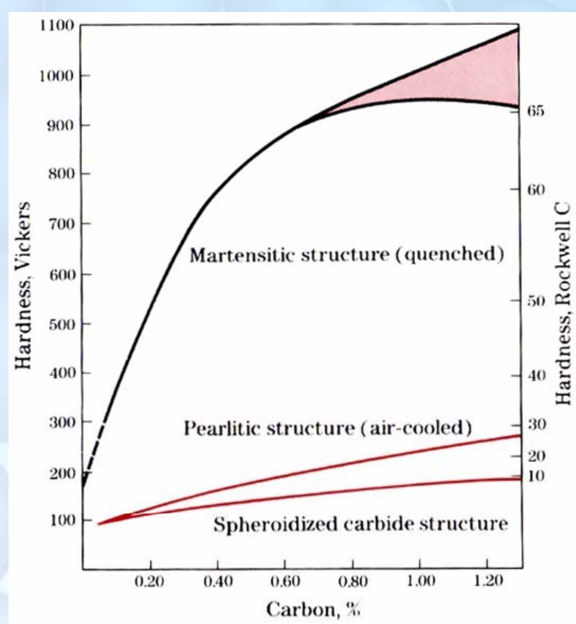
Note the effect of carbon levels in martensite's *a* and *c* lattice parameters. That means the unit cell volume is also affected.

Hardness and Strength of Fe-C Martensite

Martensite mechanical properties strongly depend on the carbon level in the steel.

<u>Strengthening mechanisms:</u>

- High dislocation densities in lath martensite
- High dislocation densities plus solid solution strengthening plus twinning deformations in plate martensite



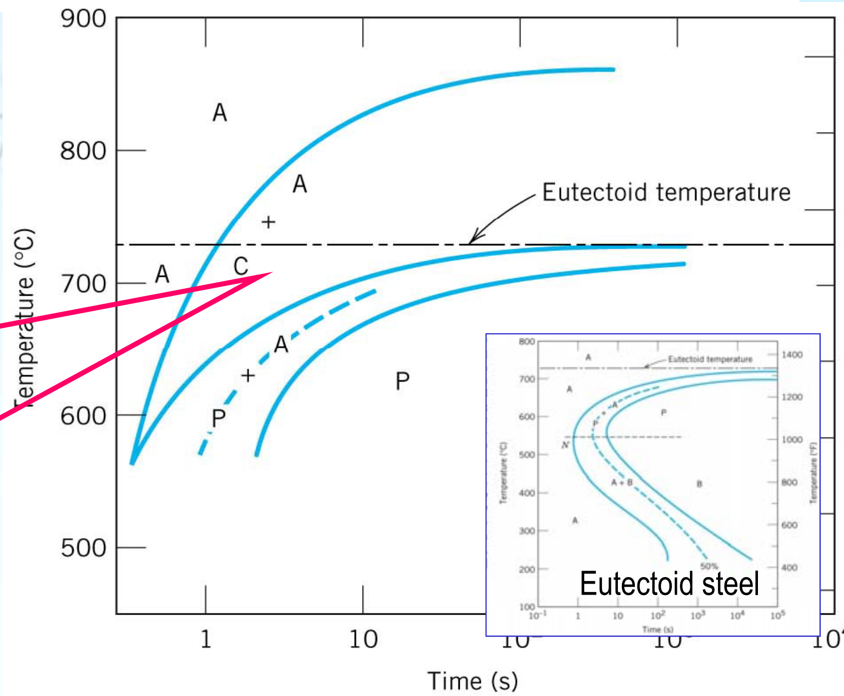
Properties of Individual Microconstituents in Steel

- Pearlite
  - Yield strength 200 - 800 MPa
  - Tensile strength 600 - 1200 MPa
- Bainite
  - Yield strength 800 - 1300 MPa
  - Tensile strength 1300 - 1400 MPa
- Martensite
  - Yield strength 500 - 1800 MPa

Let's go back to the TTT curves but now for a hypereutectoid plain carbon steel with 1.13%C

So, if it's hypereutectic what is the proeutectoid phase?

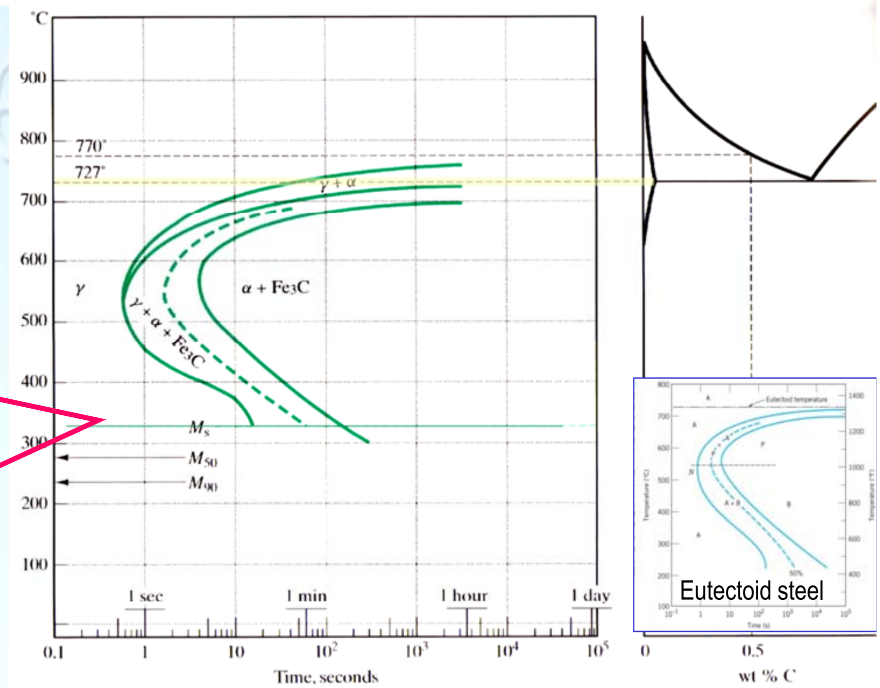
Can you see the difference with the eutectoid TTT curve close to the eutectoid temperature?



Now let's see a TTT curve for a hypoeutectoid plain carbon steel with 0.4%C

What is the proeutectoid phase?

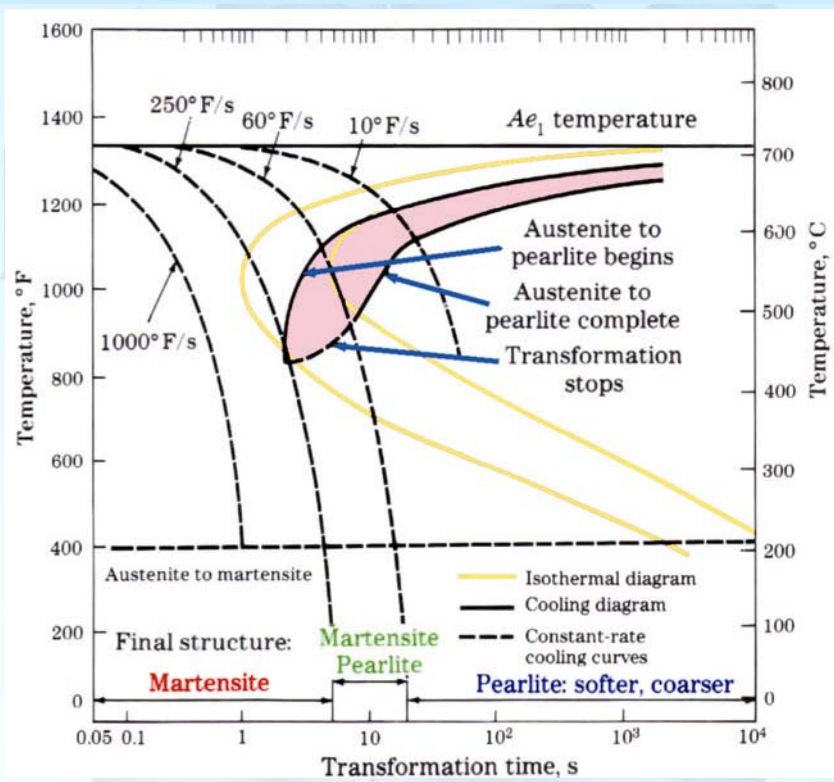
Is it easy to obtain martensite in this steel?



Continuous Cooling Transformation CCT Curve

Eutectoid Steel

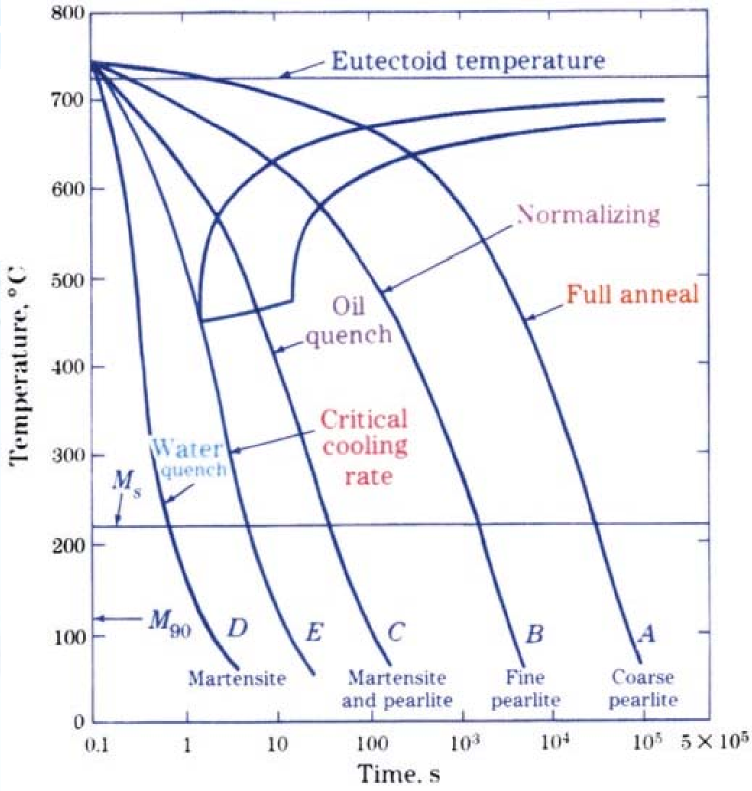
The diagram is produced <u>without</u> interrupted cooling but by tracking the transformation <u>continuously</u> in the cooling media



CCT Curves: Different Cooling Media

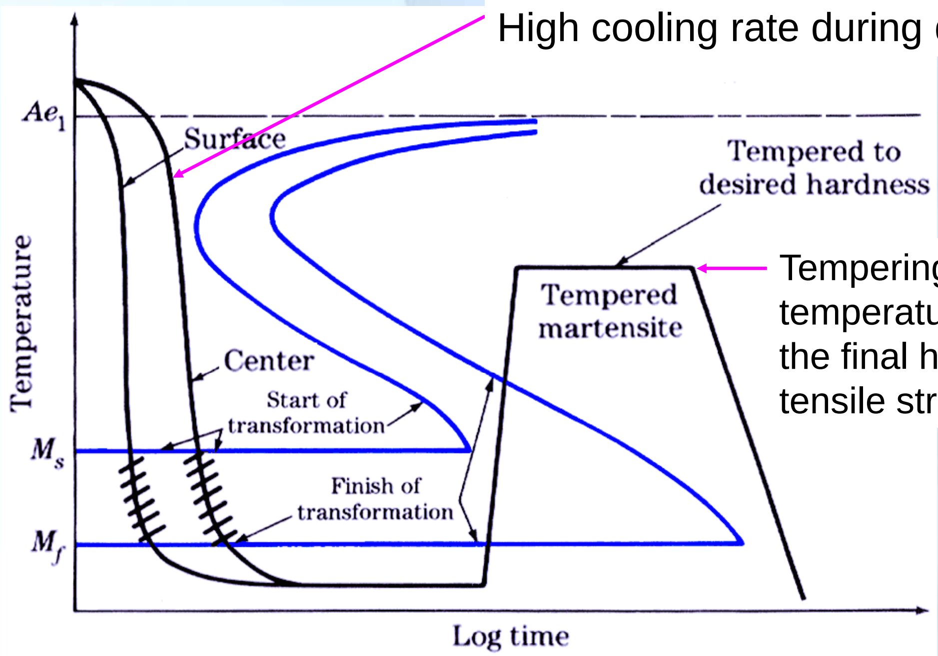
Please, define the critical cooling rate CCR.

Sometimes the hardenability of a steel is measured by the CCR



Quenching and Tempering

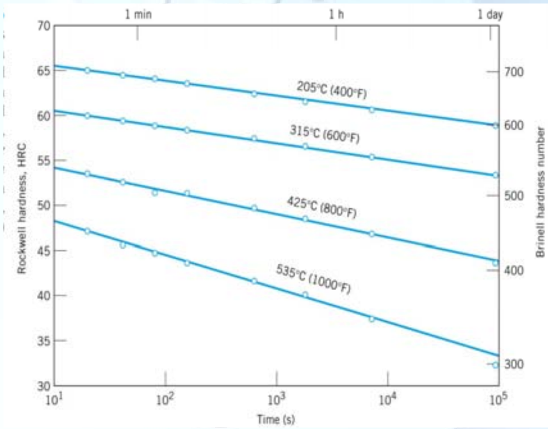
High cooling rate during quenching



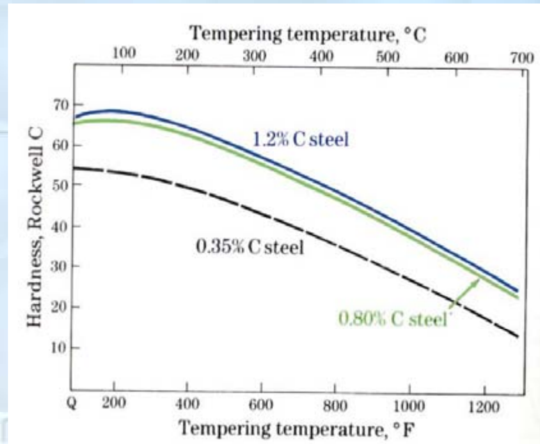
Tempering temperature regulates the final hardness and tensile strength

Effect of Tempering Temperature in Hardness

This image shows the effect of tempering temperatures and times in the final hardness of a eutectoid steel steels



In this plot, look at the effect of carbon in the final hardness of the tempered steels



INGE 4001 - Engineering Materials

Let's summarize what we've learned about phase transformations in plain carbon steels:

By controlling the phase selection process you can control the final mechanical properties of a steel. These are the main reason for the many uses of steel: cheap and versatile

Now, think that you can add many elements to diversify those properties even more.