Mat E 272

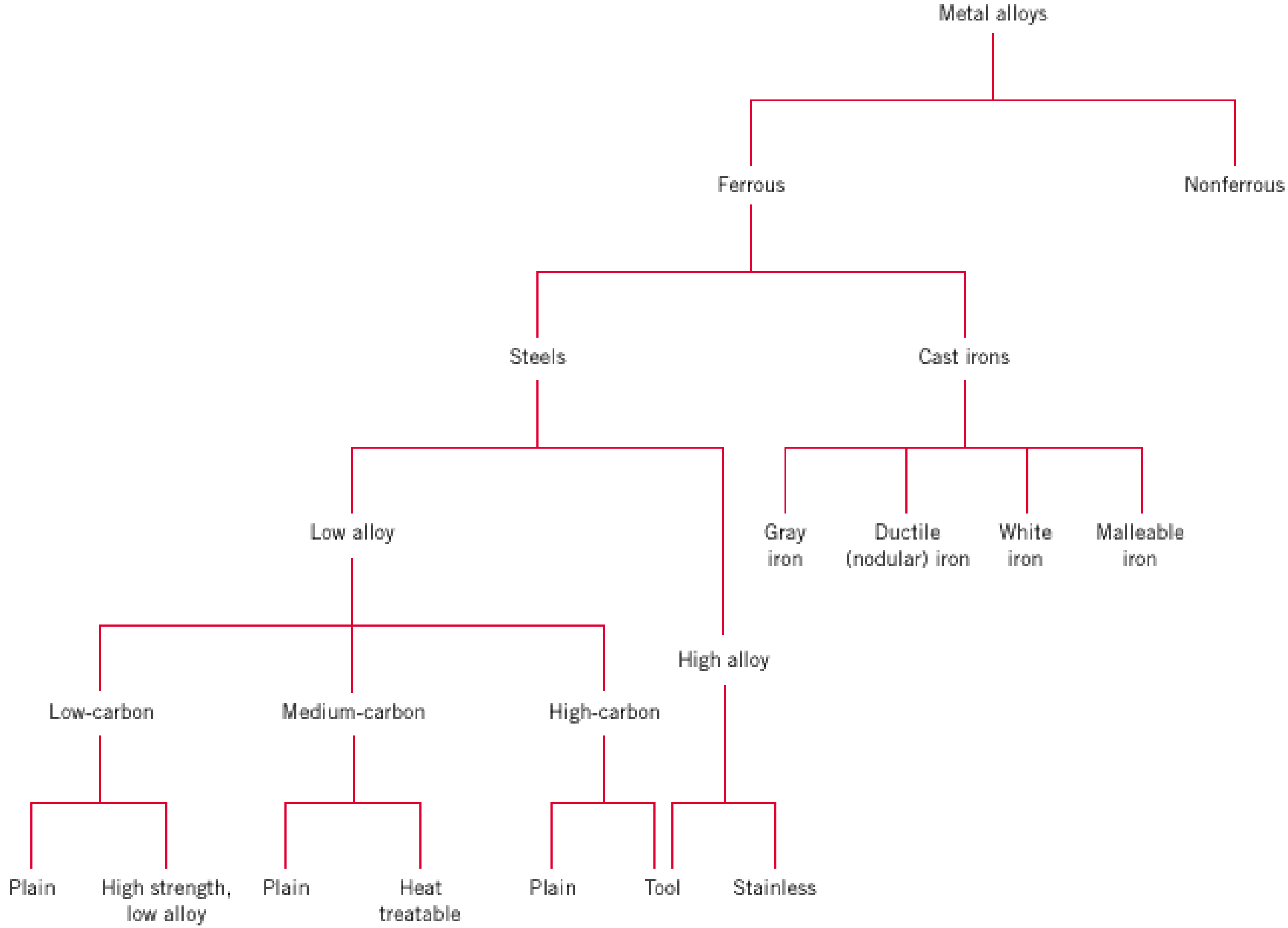
Lecture 18: Steels I

November 6, 2001

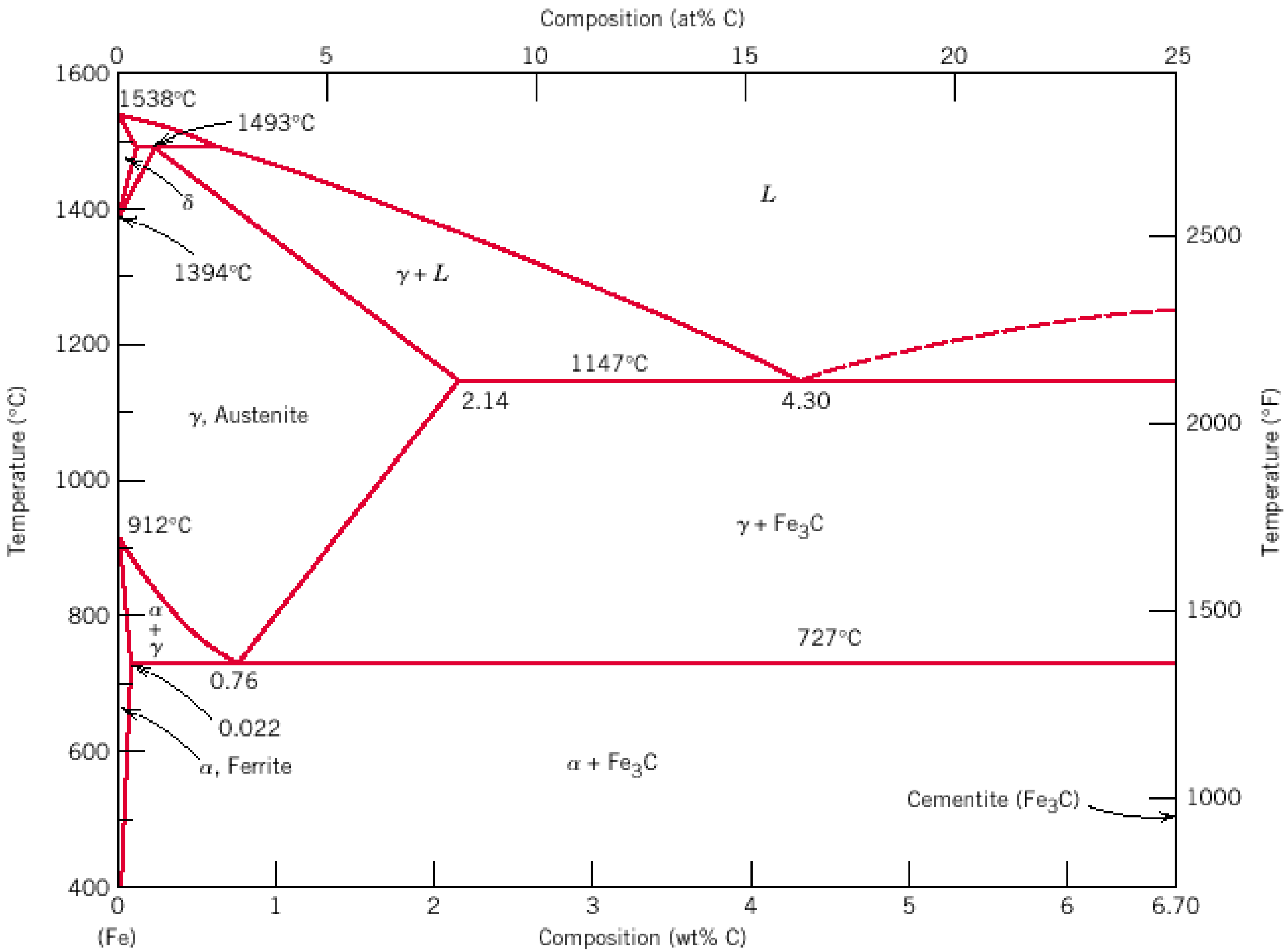
Introduction:

We previously discussed fundamentals of the interpretation of binary phase diagrams, and applied these concepts toward an understanding of the various phases and microstructures possible in iron and steel alloys. By learning how to predict microstructures as a function of composition, thermal history, and cooling rates, we can make judicious selection of materials for various applications. In our previous discussion, we began examining some of the possible microstructures resulting from cooling austenite. It is precisely because of such widely different microstructures that the various grades of steel serve a diverse range of applications. Today we expand our examination of microstructures in steel and also in cast irons.

Alloy classification scheme



Fe-C equilibrium phase diagram



Phase Transformations in Steels - Spheroidite

Pearlite:

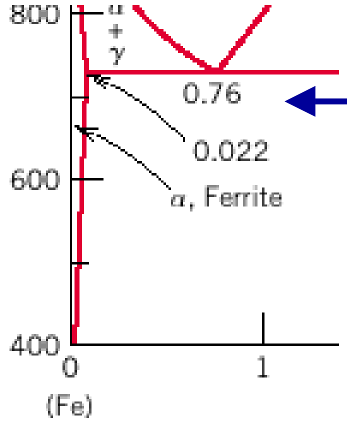
A two-phase eutectoid (lamellar) microstructure resulting from equilibrium cooling transformation of γ to (α + Fe_3C).

Bainite:

Another two-phase microstructure resulting from rapid cooling transformation of γ to (α + Fe_3C).

Spheroidite:

Two-phase microstructure of α + Fe_3C resulting from heat treatment of pearlite or bainite just below the eutectoid temperature (A1). Reduction in Fe_3C - α surface (or interfacial) area causes cementite bands or needles to become spherical.

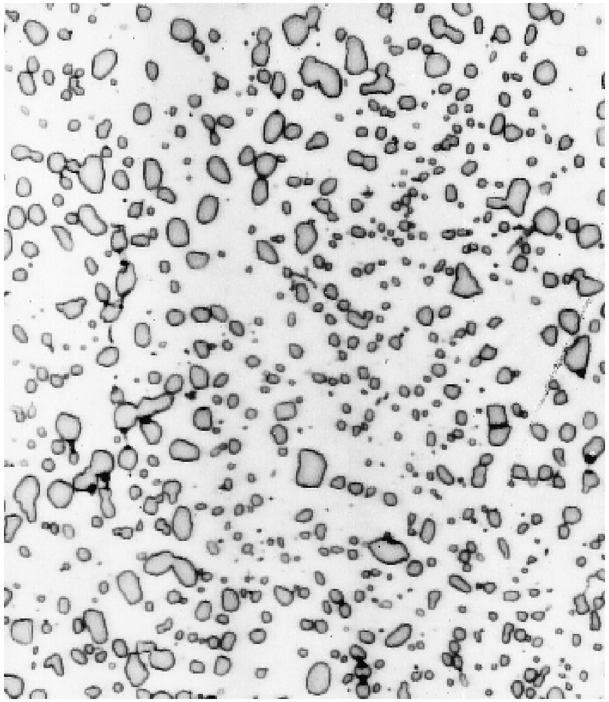


Heat treat just below the eutectoid (A1)

The problem with machining high carbon steels is often the hard barriers to cutting caused by the layers of cementite.

A spheroidizing heat treatment modifies the structure, transforming the elongated bands or needles of cementite into globules.

Machinability can be significantly improved.



Typical Fe-C microstructure following a spheroidizing heat treatment.

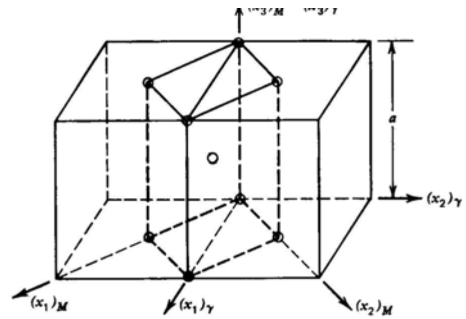
Phase Transformations in Steels - Martensite

Description:

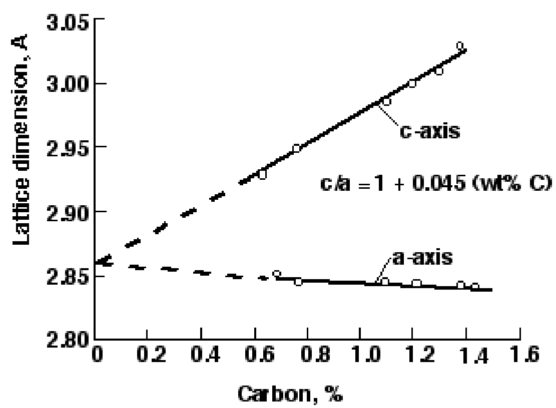
The martensitic transformation is not unique to steels.

It is fundamentally different than other transformations because NO DIFFUSION IS INVOLVED (called “athermal”).

Martensitic transformation occur as a result of rapid quenching via local (cooperative) rearrangement of Fe atoms. This rearrangement of atoms produces a new crystal structure (BCT). Since no diffusion is involved, this transformation takes place very fast.(i.e., at the speed of sound in the material)



Bain correspondence (relating the γ FCC structure to BCT)



Relationship between carbon content and lattice asymmetry in FCC (γ) to BCT.

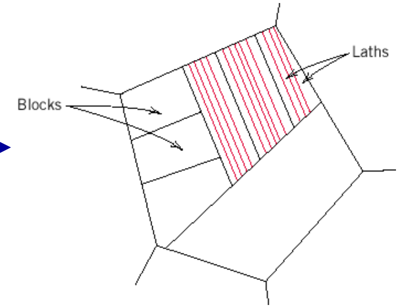
Typical martensitic microstructure (dark grains are BCT-martensite, lighter regions correspond to retained austenite (γ).

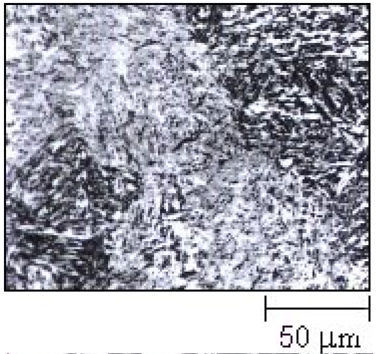
Martensitic transformation

Types of martensite:

I. Lath martensite

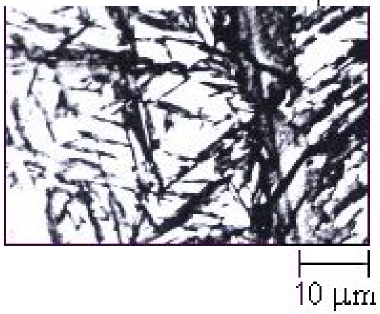
forms in alloys with < 0.6 wt. %C
(low to medium carbon steels)
grows as long, thin plates aligned
parallel to each other





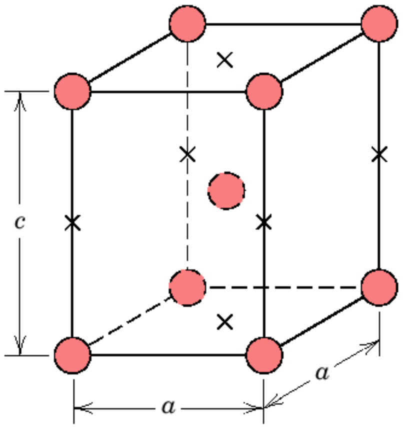
II. Plate martensite

also called “Lenticular”
found in alloys with > 0.6 wt. % C
(medium to high carbon steels)
needle-like or plate morphology



Characteristics:

- Martensite IS a different phase!
- Extremely hard
- Results in dramatic increase in strength & decrease in ductility
- Usually co-exists with retained austenite



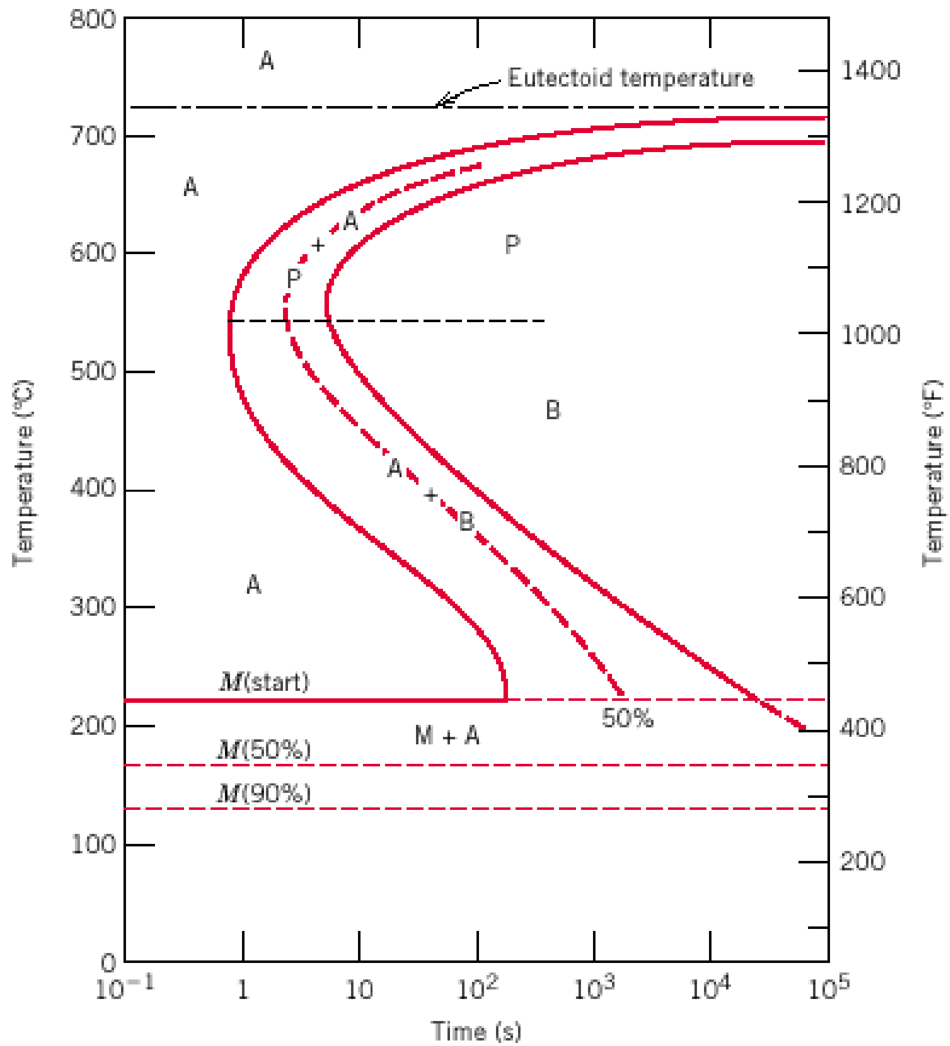
Body-centered Tetragonal (BCT) crystal structure

Complete TTT curves (eutectoid composition)

By including the martensitic transformation, we now have a complete set of isothermal transformation curves for steel of a eutectoid composition.

Note that in order to obtain martensite, you must quench the steel at a sufficiently fast rate so as to avoid the pearlite/bainite "nose" on the diagram

(slower cooling results in nucleation and growth of bainite or pearlite)



Complete TTT curves (other compositions)

Every composition has a unique TTT diagram.

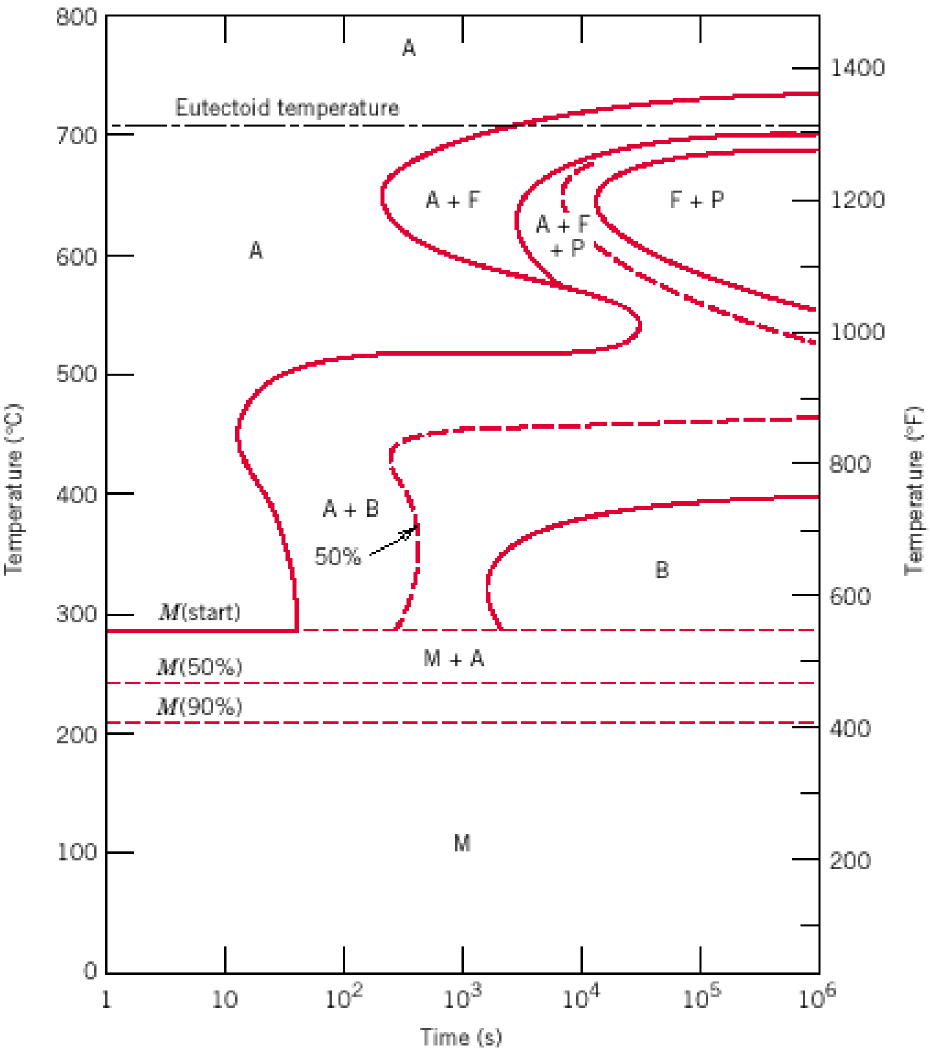
Certain elements are added to steels for the purpose of shifting the TTT nose to longer times (to the right).

This makes it somewhat easier to engineer specific microstructures throughout a massive workpiece (wherein cooling rates can differ significantly from the outside to the center).

This is an isothermal transformation diagram for 4340 alloy steel (contains Ni, Cr, and Mo)

(note the presence of a separate "nose" for the austenite-pearlite and austenite-bainite transformation.

The martensite transformation temperatures are not significantly changed.)



Continuous cooling curves - steels

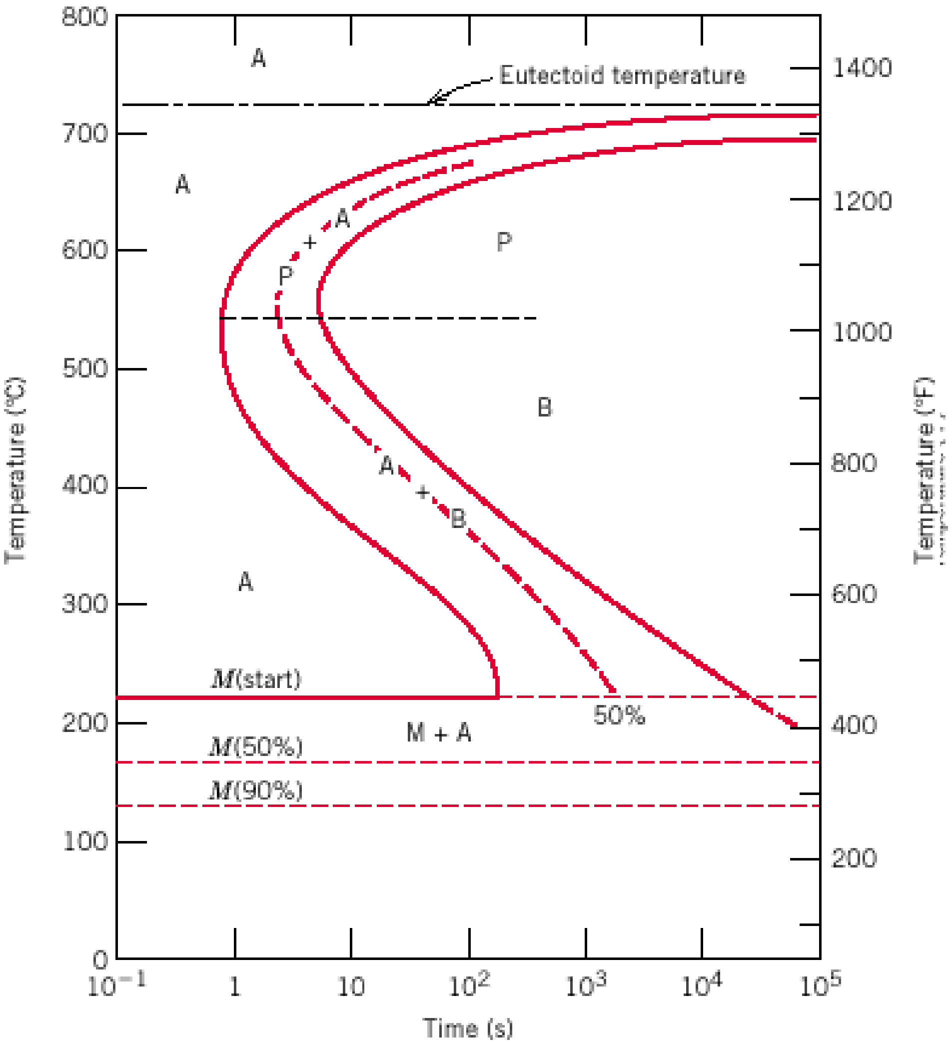
Problem:

The isothermal transformation (TTT) curves represent microstructures resulting from cooling at a <u>constant temperature</u>. In most situations, it is not practical to cool isothermally.

We need to modify the isothermal diagrams to account for uniform cooling.

Solution:

The TTT curves are appropriately modified to account for the effects of cooling with time. In general, this has the effect of shifting the austenite to pearlite transformation curves downward and to the right:



Continuous cooling - steels

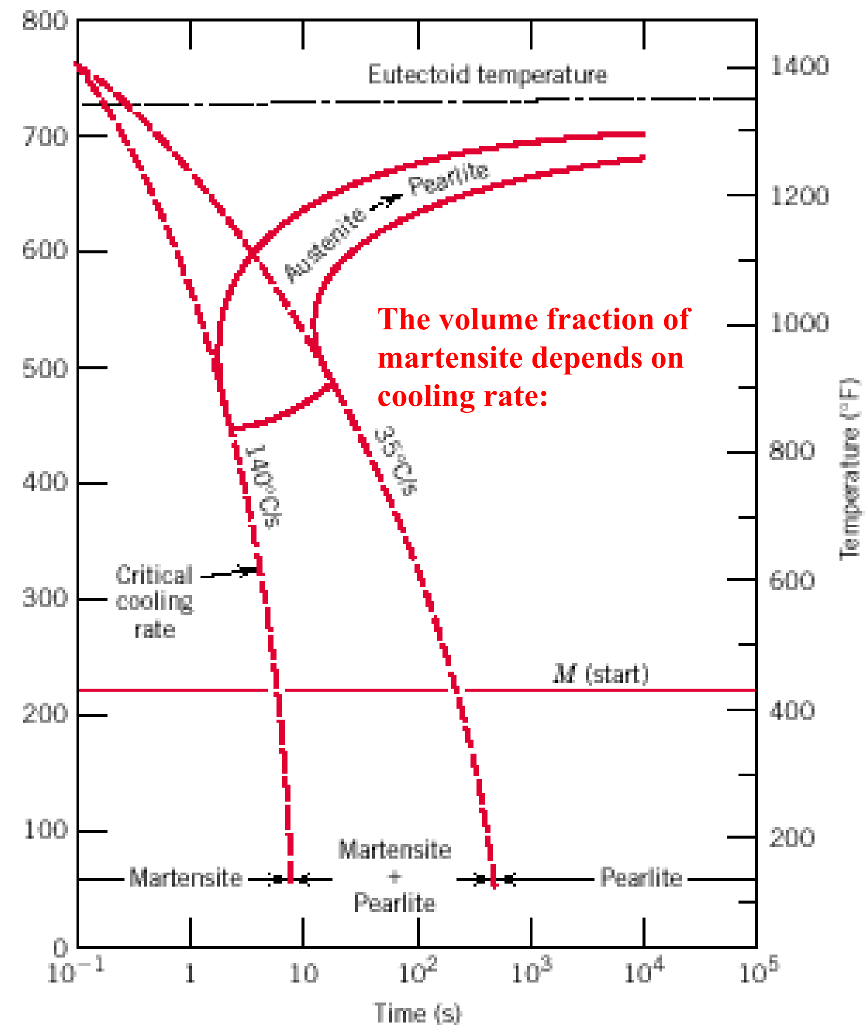
Cooling rates:

It should be clear that different microstructures will result from different cooling rates. For example, we know that rapid cooling gives fine pearlite whereas slow cooling gives coarse pearlite.

How can we represent different cooling rates on the CCT diagram?

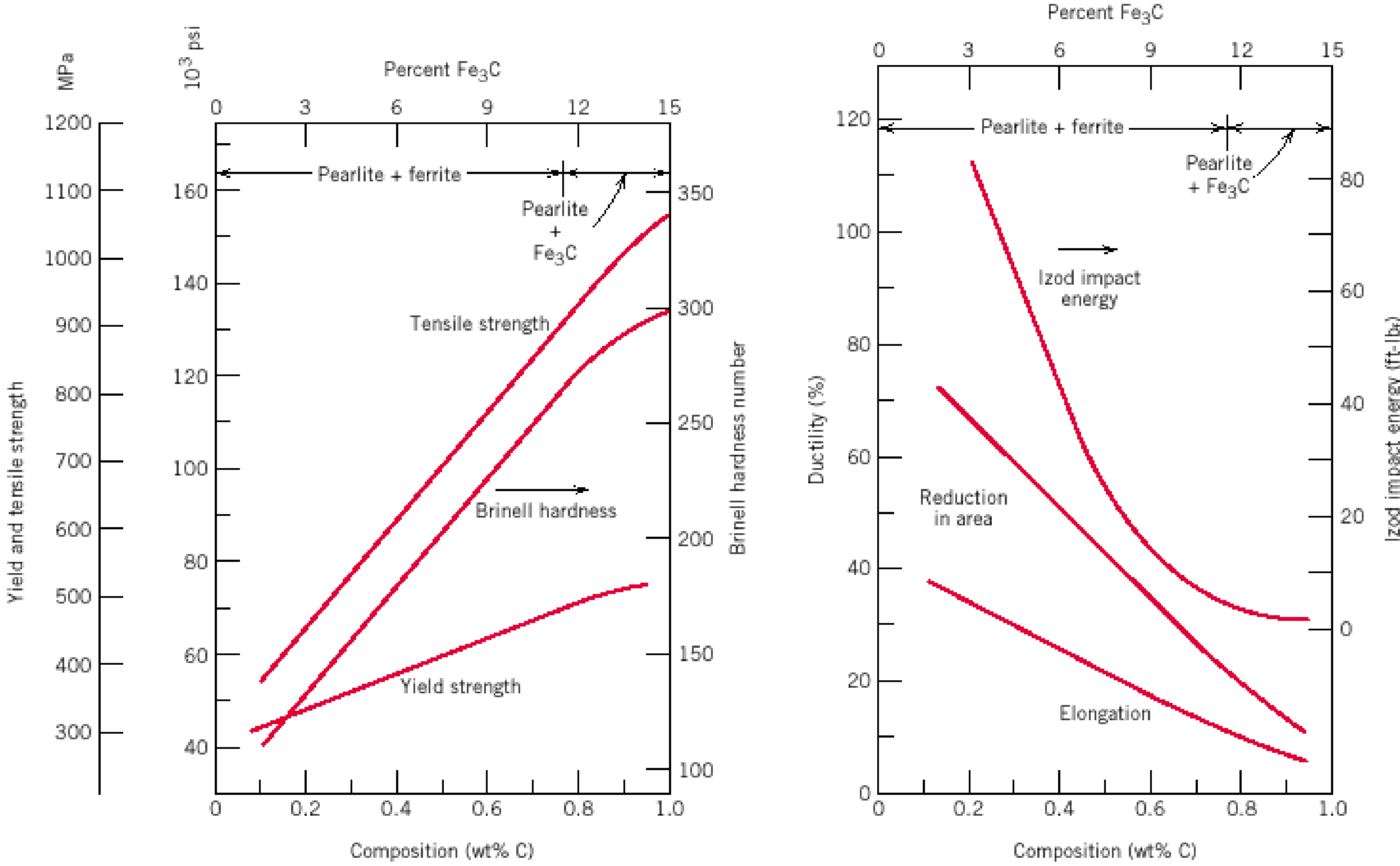
Difference:

During continuous cooling, all available austenite transforms to pearlite by the time the bainite transformation becomes possible. Therefore, bainite is not represented on the CCT diagrams. Any remaining γ simply transforms to martensite



The volume fraction of martensite depends on cooling rate:

Fe-C alloys: mechanical properties

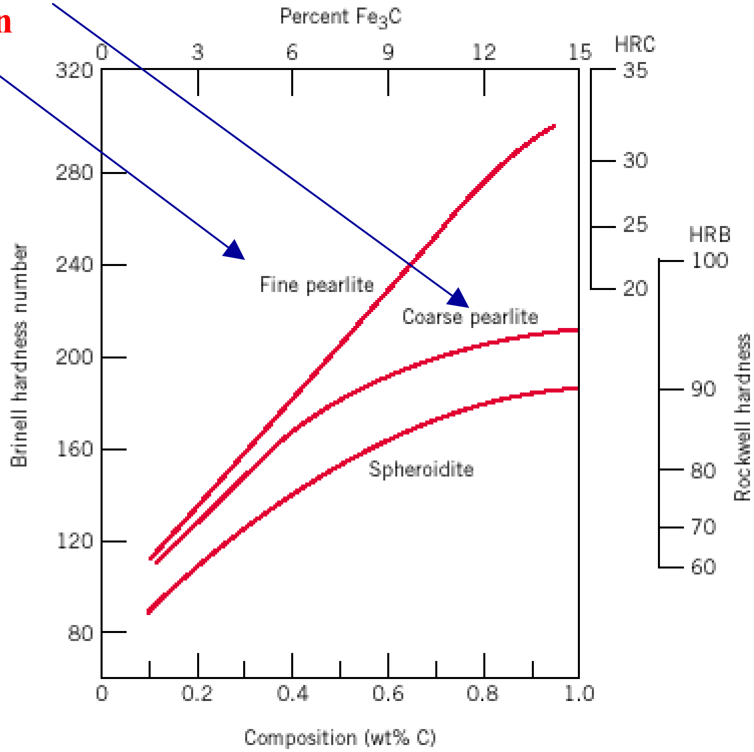


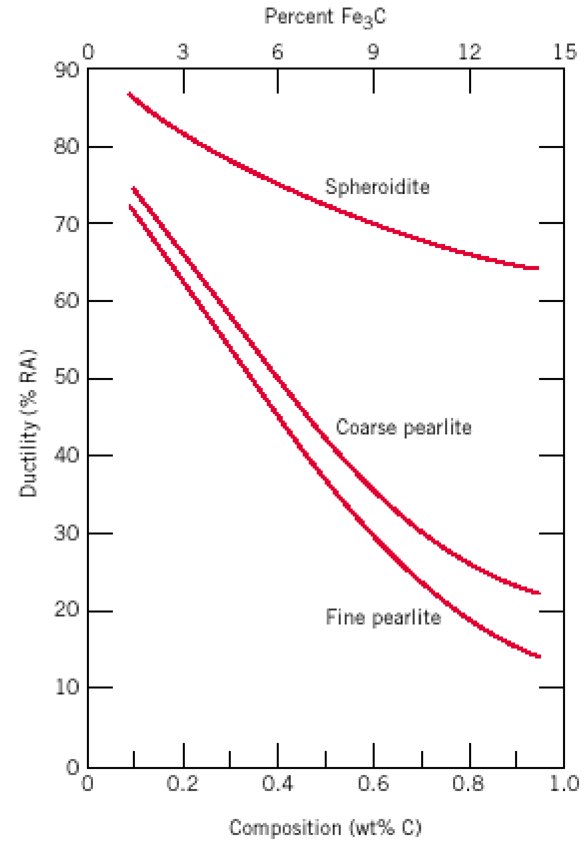
As carbon content in steels increases, strength also increases but at the expense of ductility

Fe-C alloys: mechanical properties

Note the difference in hardness

could you explain the reason for this?

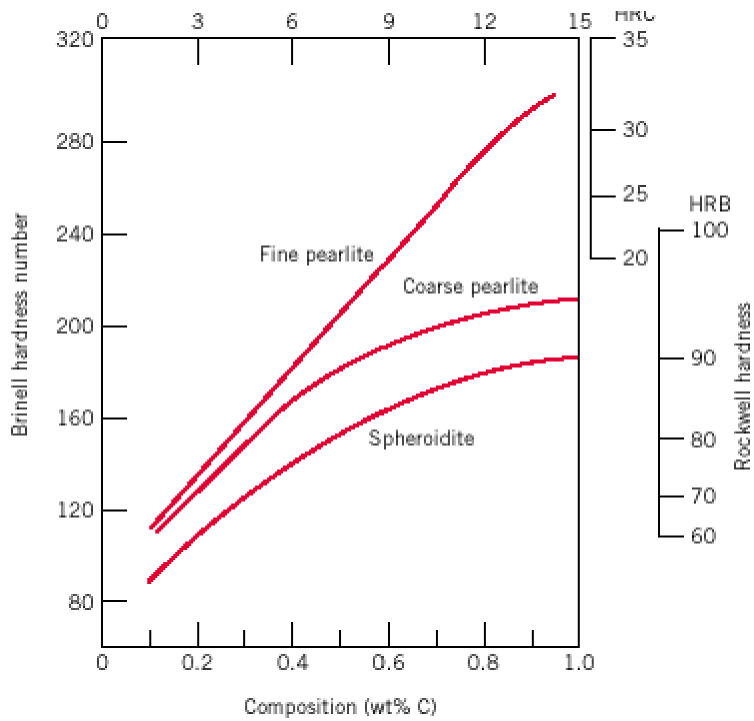


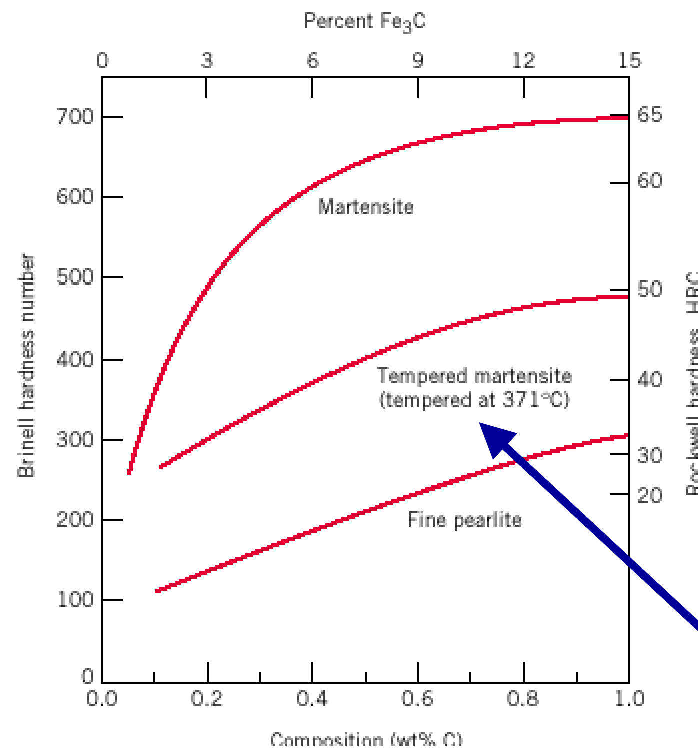


Increasing carbon (i.e., Fe_3C) results in increased hardness.
Note how hardness depends on eutectoid lamellar spacing (fine pearlite vs. coarse pearlite)

Fe-C alloys: mechanical properties

How does the hardness of martensite compare with fine pearlite?





What is this?

The extreme hardness of martensite is thought to be more of a result of its crystal structure (BCT - limited # of slip systems) than its microstructure

Tempered Martensite

As-quenched:

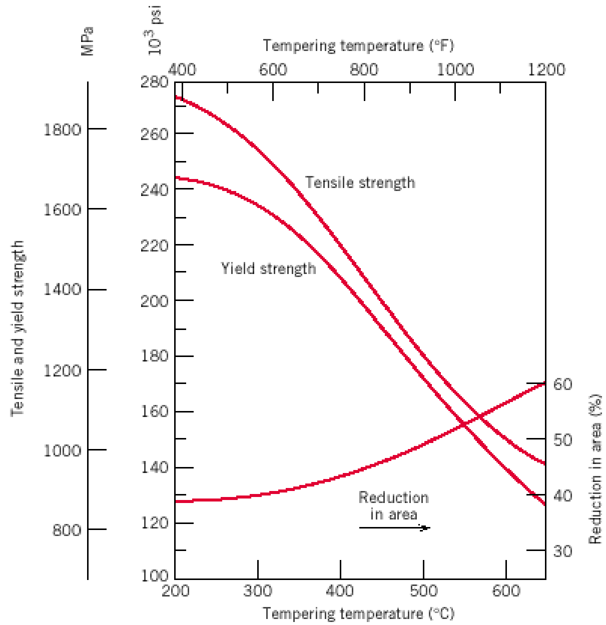
Martensite is extremely brittle; so much so that it is not appropriate for most structural applications.

Tempering:

Suppose a martensitic microstructure is heat treated for some time below the eutectoid temperature (250 to 650°C).

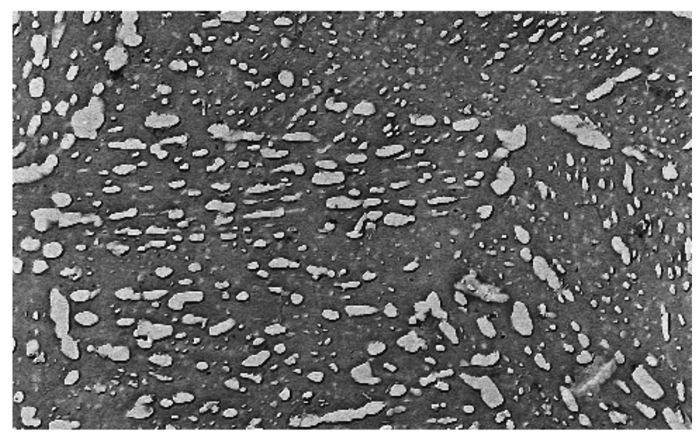
Martensite, being metastable, transforms into ferrite + cementite. However, the size of the Fe3C is microscopically small; much smaller than in spherodite.

These serve as very effective barriers to dislocation motion.

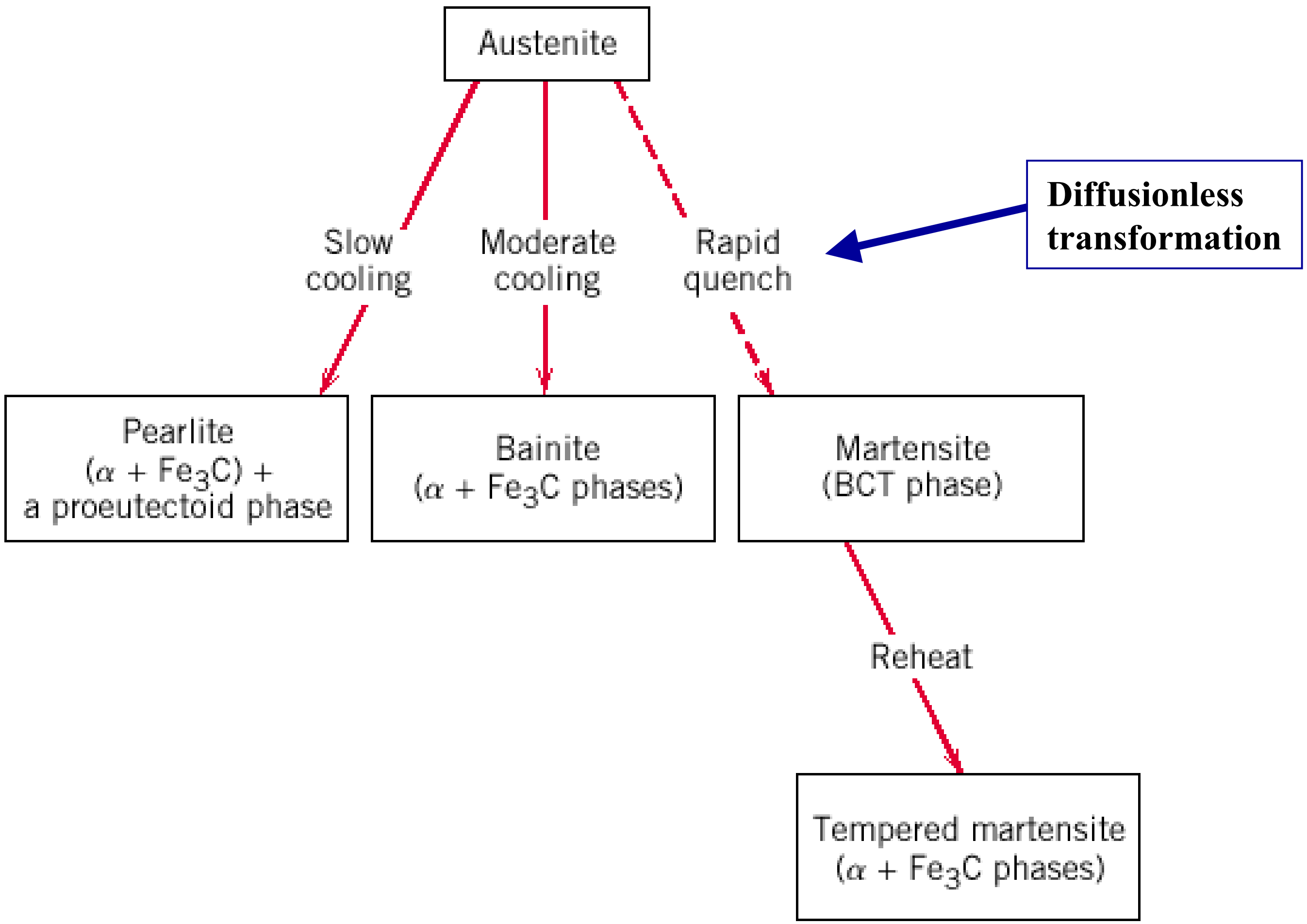


Yield and tensile strength both decrease but ductility is increased. Overall, this material is more usable than quenched martensite.

Note the fine particles of cementite in a ferrite matrix. This image was magnified nearly 10,000X

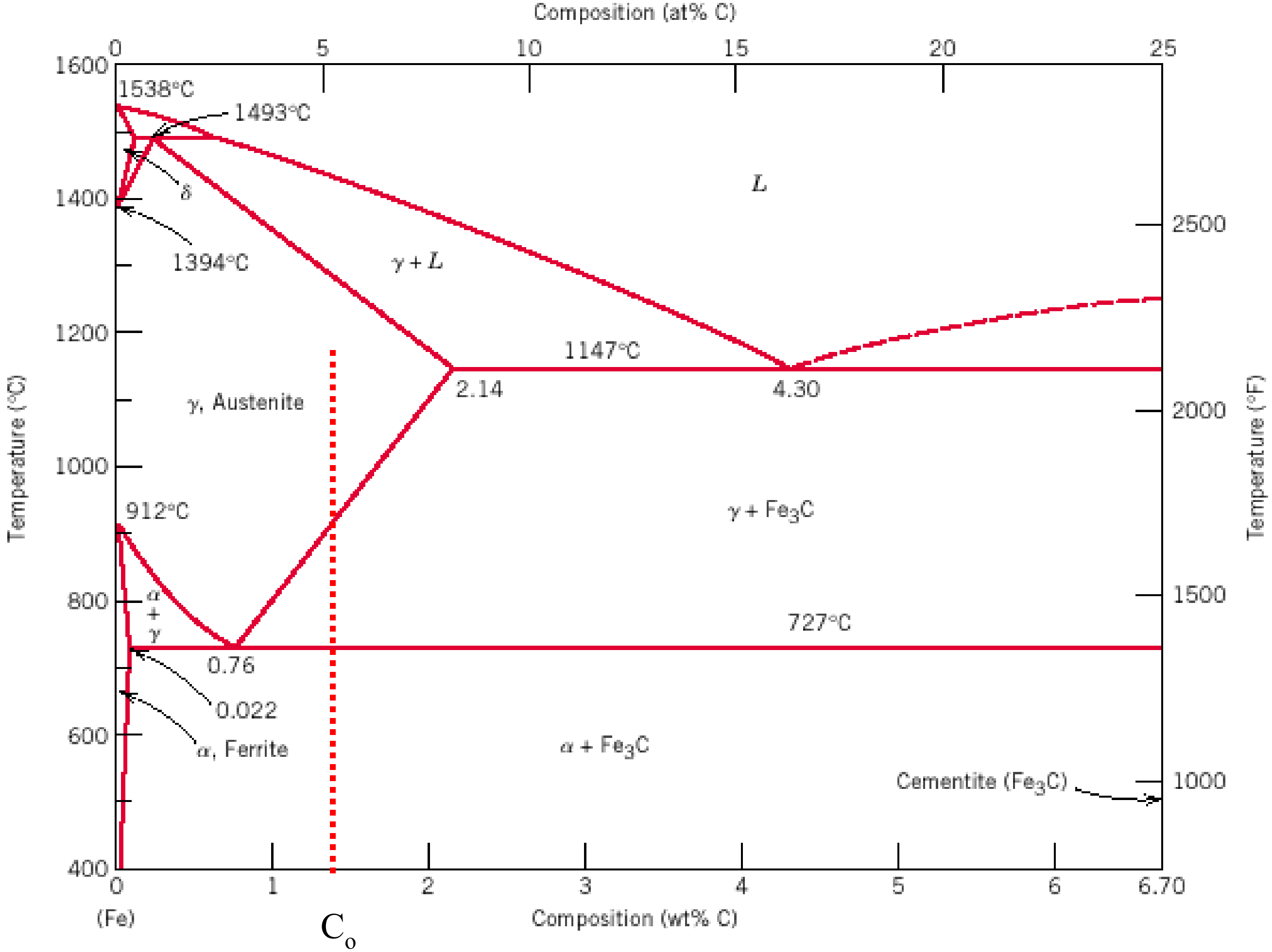


To summarize...



Prediction of equilibrium microstructures - I

Given a steel of composition C_o, can you predict what the room temperature microstructure would look like, assuming equilibrium cooling from the austenite phase?



Prediction of equilibrium microstructures - II

Now, given a steel of composition C_1, can you predict what the room temperature microstructure would look like, assuming equilibrium cooling from the austenite phase?

Based on your predictions, how would you expect the mechanical properties of the two metals to differ?