

PY2N20

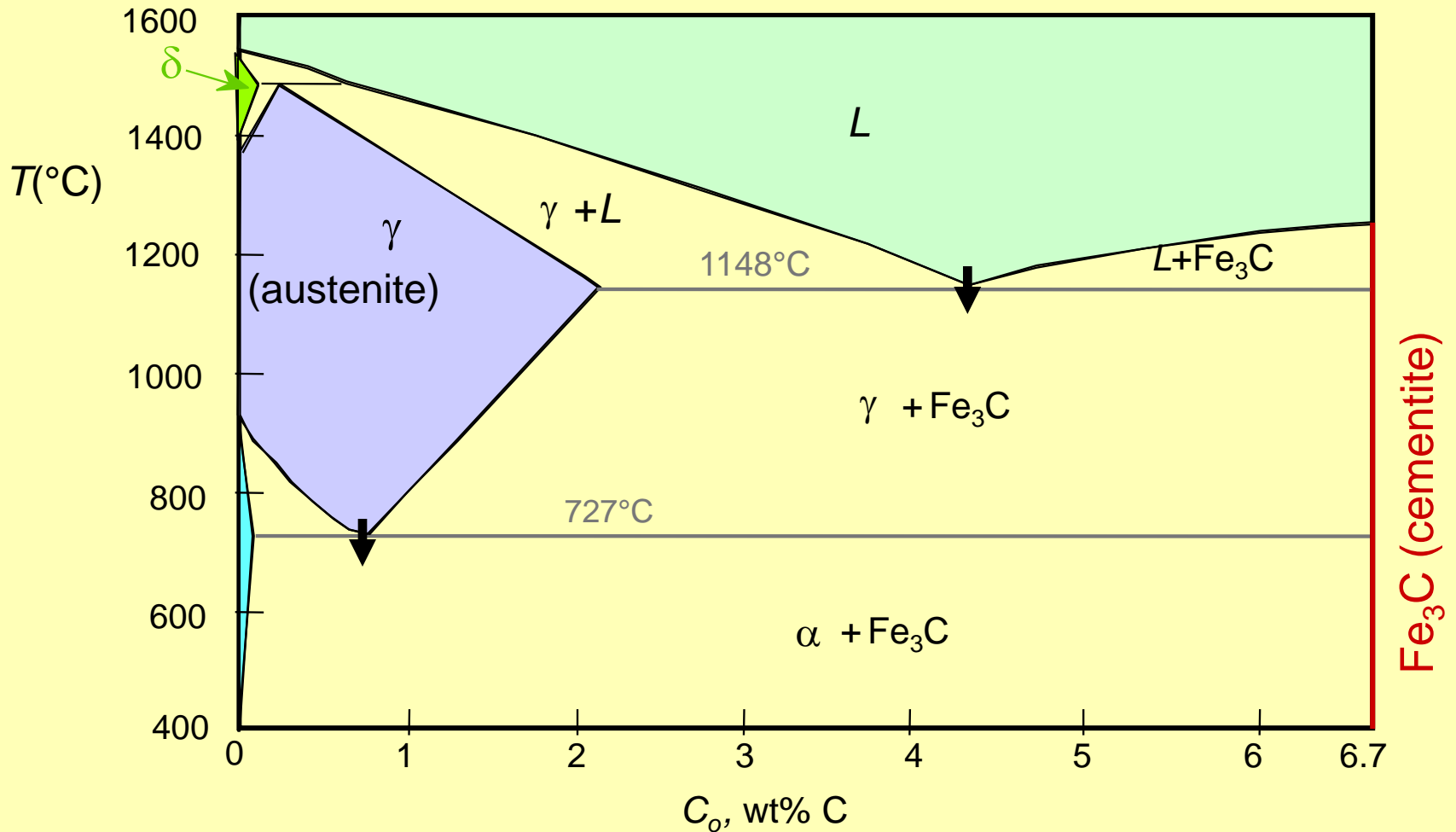
**Material Properties and
Phase Diagrams**

Lecture 8

P. Stamenov, PhD

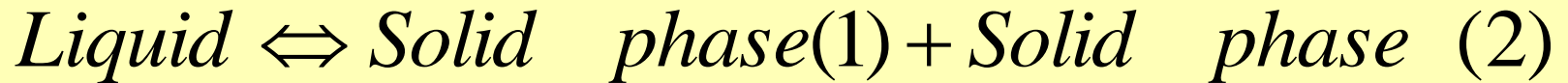
School of Physics, TCD

Phase transformations

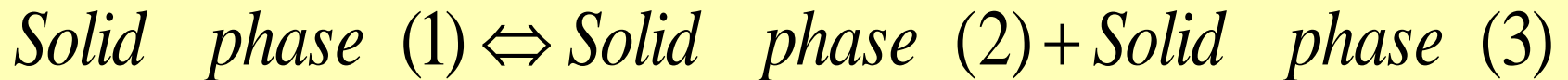


Eutectic, Eutectoid and Peritectic Reactions

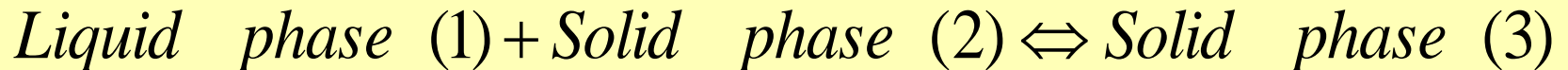
Eutectic Reaction



Eutectoid reaction



Peritectic Reaction



Phase Transformations

Nucleation

- nuclei act as seed points to grow crystals
- for nucleus to form
rate of addition of atoms > rate of loss
- once nucleated, growth → equilibrium

Driving force to nucleate increases as we increase ΔT

- supercooling (eutectic, eutectoid)
- superheating (peritectic)

Small supercooling → few nuclei - large crystals

Large supercooling → rapid nucleation - many nuclei,
small crystals

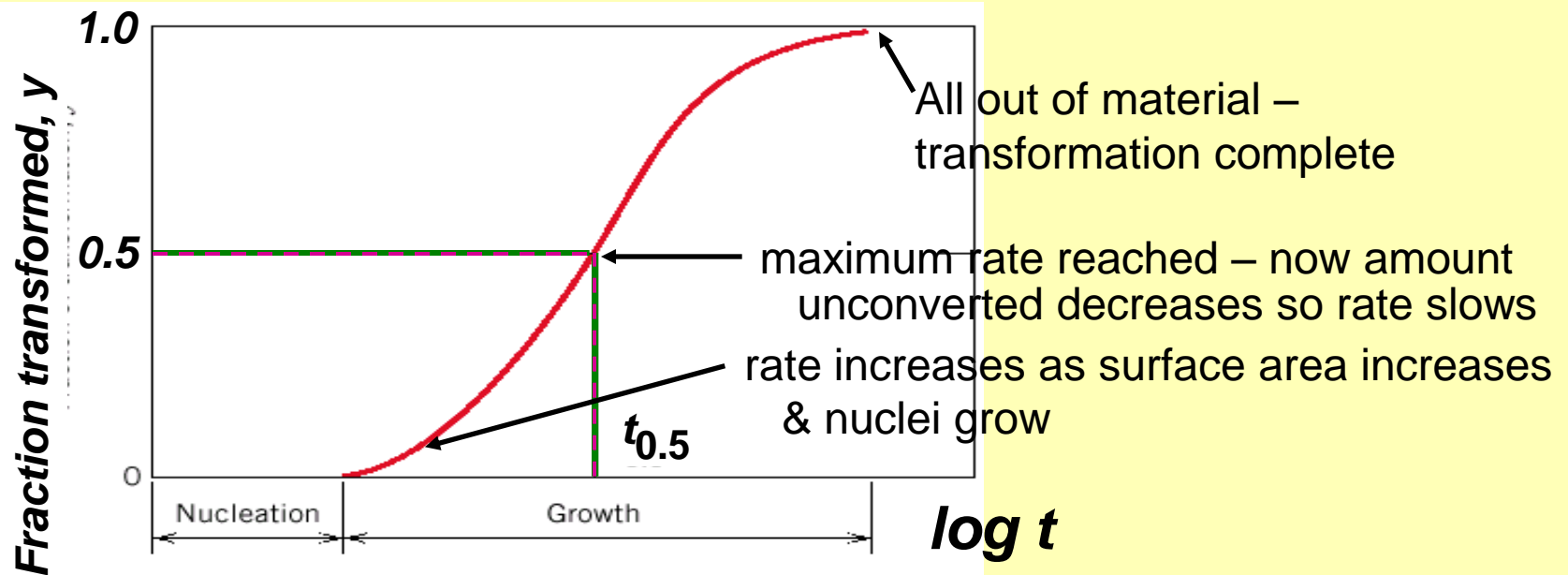
Solidification: Nucleation Processes

- **Homogeneous nucleation**
 - nuclei form in the bulk of liquid metal
 - requires supercooling (typically 80-300 °C max)
- **Heterogeneous nucleation**
 - much easier since stable “nucleus” is already present
 - Could be wall of mold or impurities in the liquid phase

Think of why you'd been asked never to put a used spoon back into a honey jar...

- allows solidification with only 0.1-10 °C supercooling
- concentration drive is also possible and often used!

Rate of Phase Transformation



Avrami (JMAK) rate equation:

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

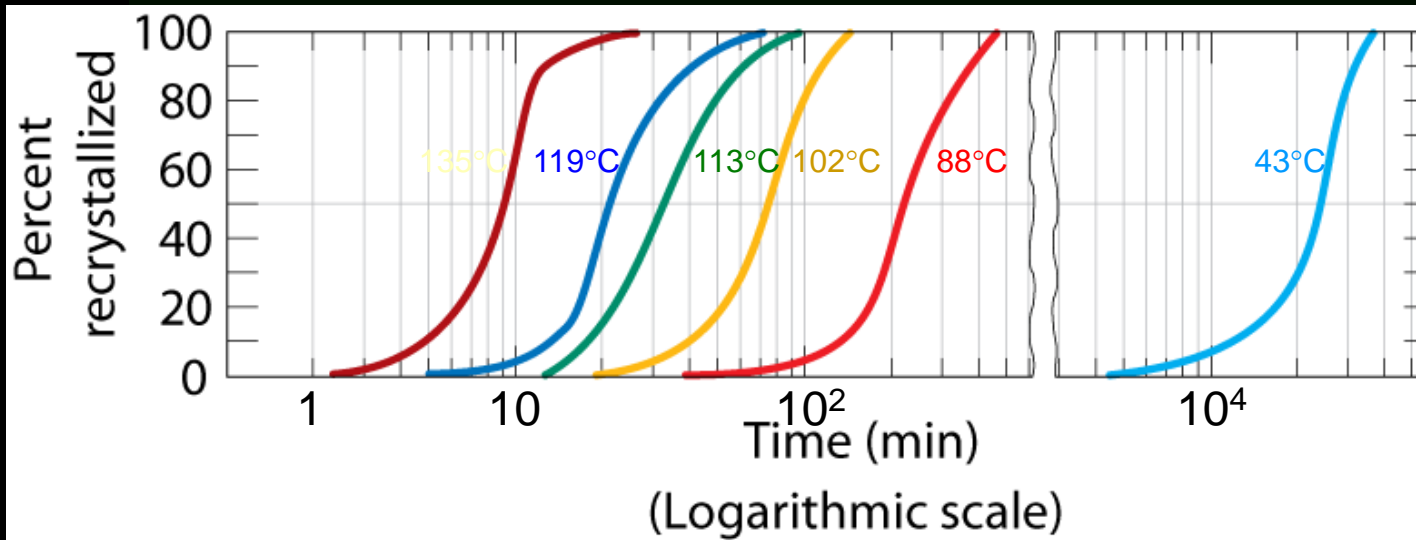
- k & n are constants for specific system – n is roughly related to the growth front dimensionality + 1

The rate is:

$$r = 1 / t_{0.5}$$

JMAK – Johnson, Mehl, Avrami, Kolmogorov

Rate of Phase Transformations



Adapted from Fig. 10.11, *Callister 7e*. (Fig. 10.11 adapted from B.F. Decker and D. Harker, "Recrystallization in Rolled Copper", *Trans AIME*, **188**, 1950, p. 888.)

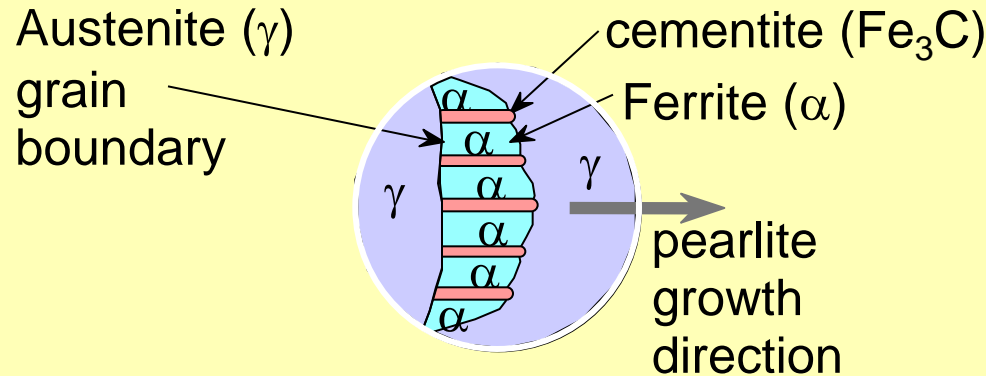
- In general, rate increases as $T \uparrow$

$$r = 1/t_{0.5} = A e^{-Q/RT}$$

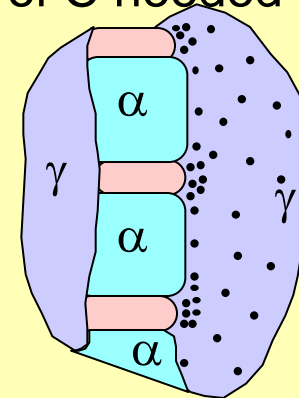
- R = gas constant
- T = temperature (K)
- A = pre-exponential factor
- Q = activation energy
- r often small: equilibrium not possible!

Eutectoid Transformation Rate

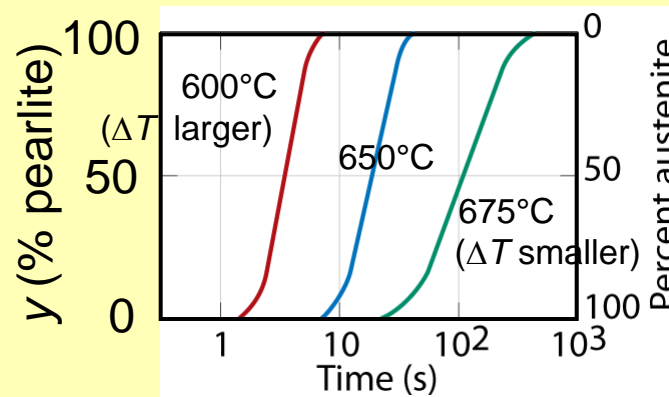
- Growth of pearlite from austenite:



Diffusive flow of C needed



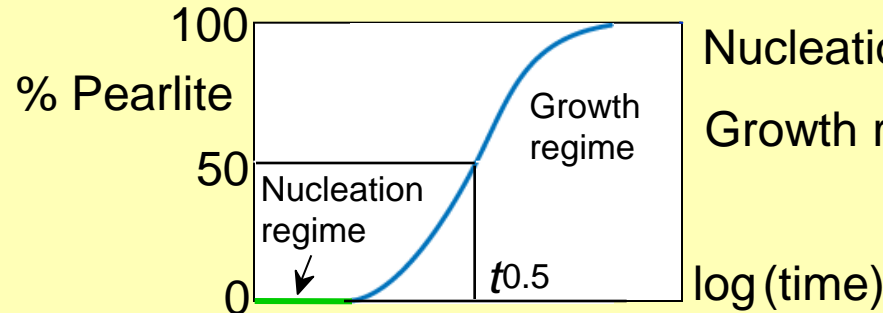
- Eutectoid transformation rate increases with ΔT .



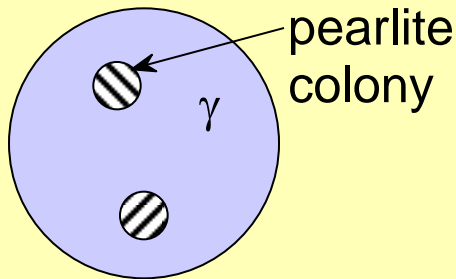
Course pearlite → formed at higher T - softer
Fine pearlite → formed at low T - harder

Nucleation and Growth

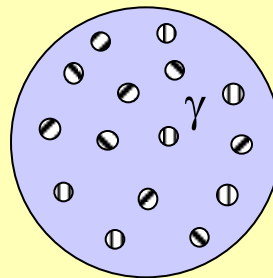
- Reaction rate is a result of nucleation and growth of crystals.



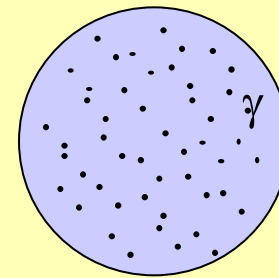
- Examples:



T just below T_E
Nucleation rate low
Growth rate high



T moderately below T_E
Nucleation rate med.
Growth rate med.



T way below T_E
Nucleation rate high
Growth rate low

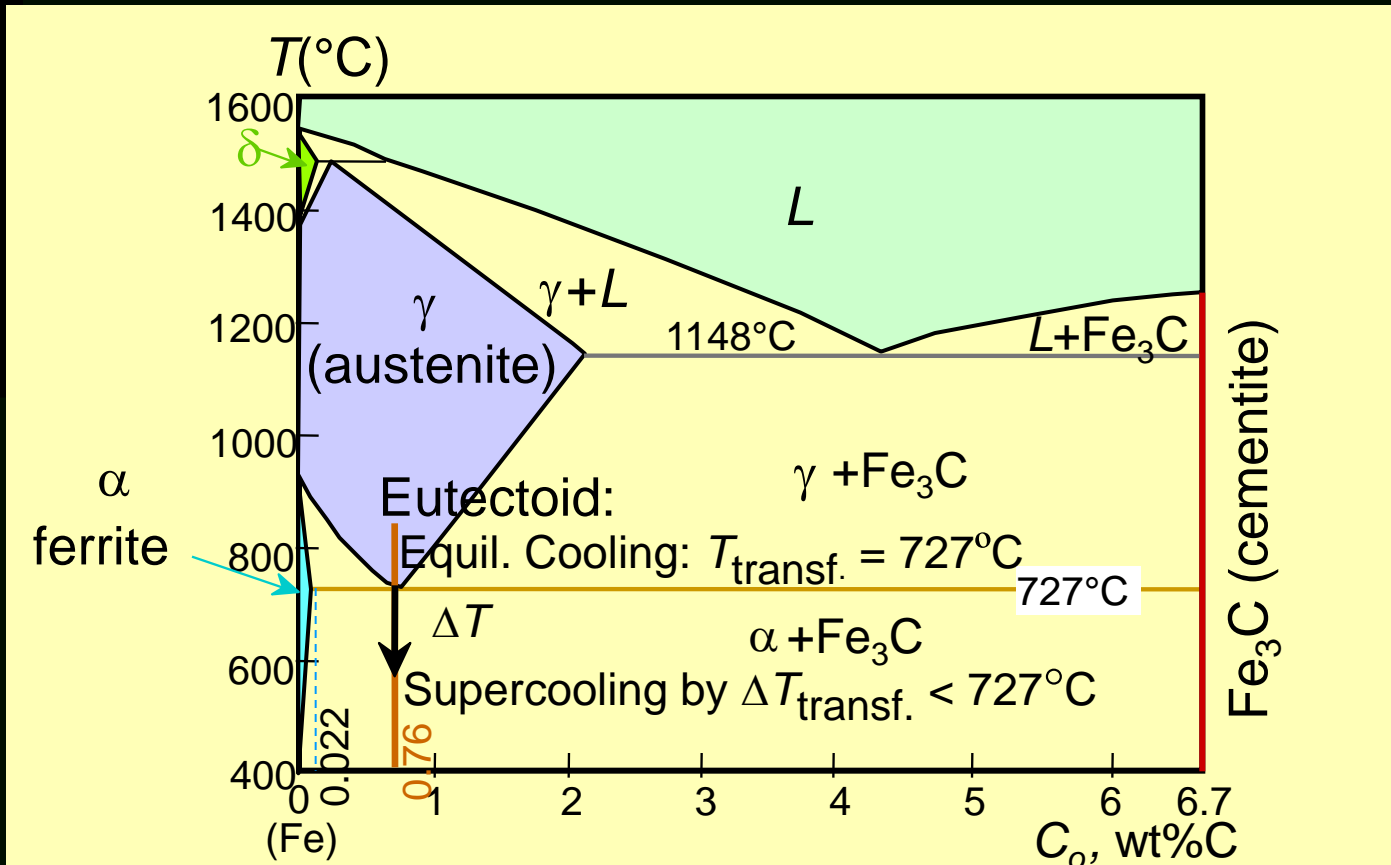
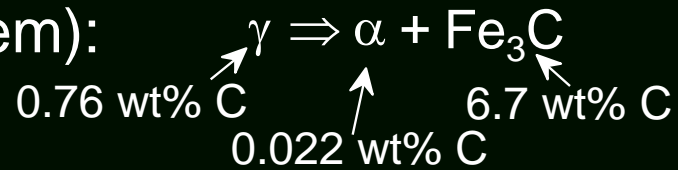
Transformations & Supercooling

Eutectoid transf. (Fe-C System):

Can make it occur at:

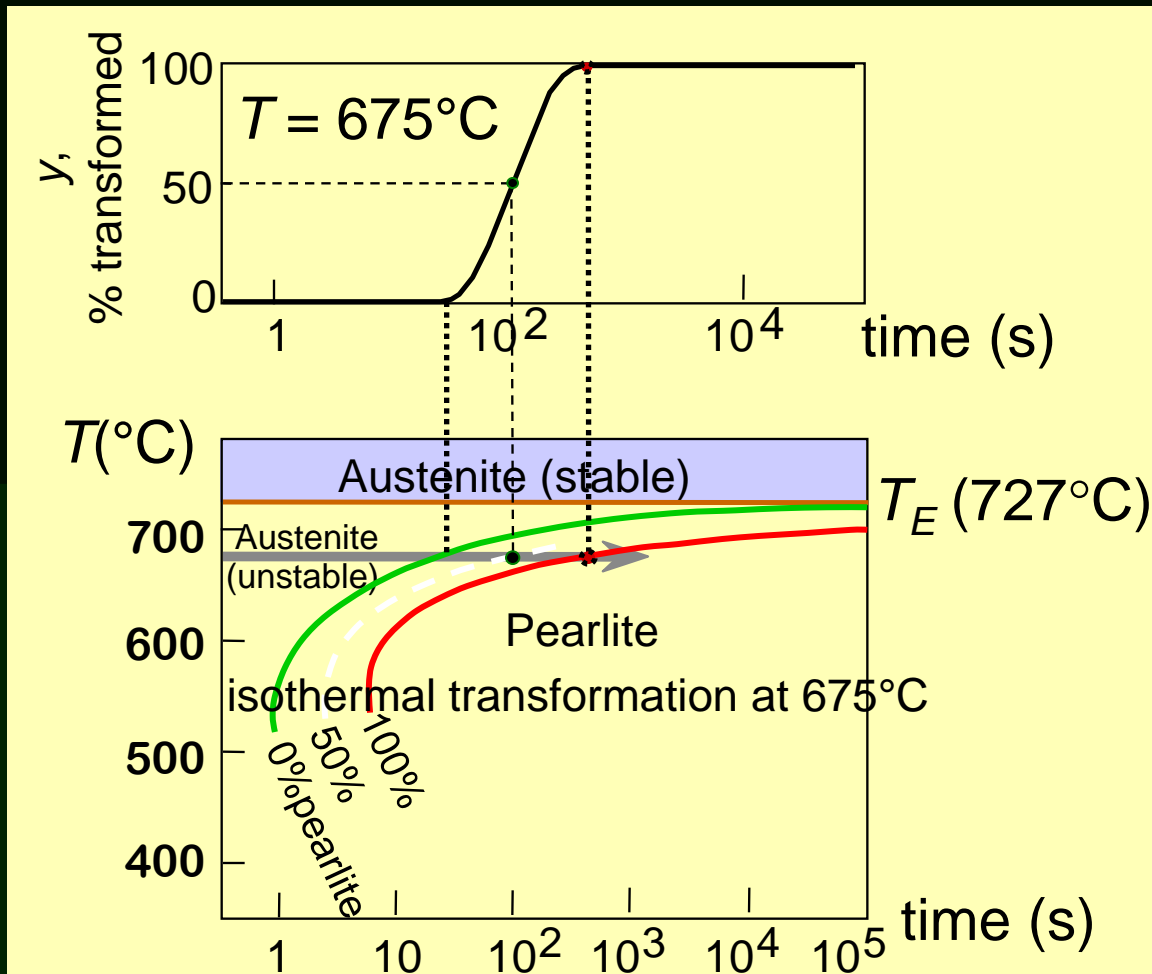
...727°C (cool it slowly)

...below 727°C (“supercool” it!)



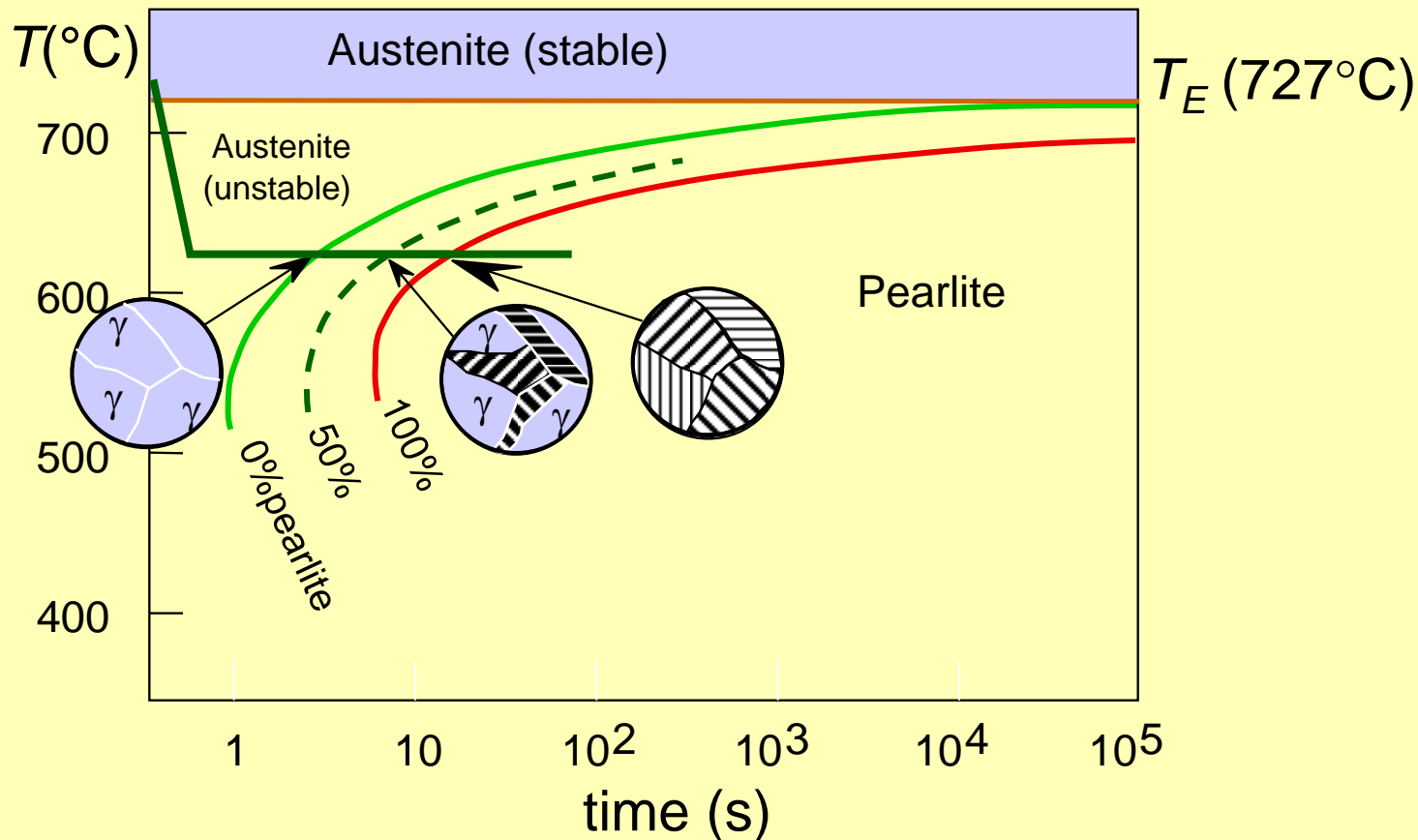
Isothermal Transformation Diagrams

- Fe-C system, $C_o = 0.76 \text{ wt\% C}$
- Transformation at $T = 675^\circ\text{C}$.



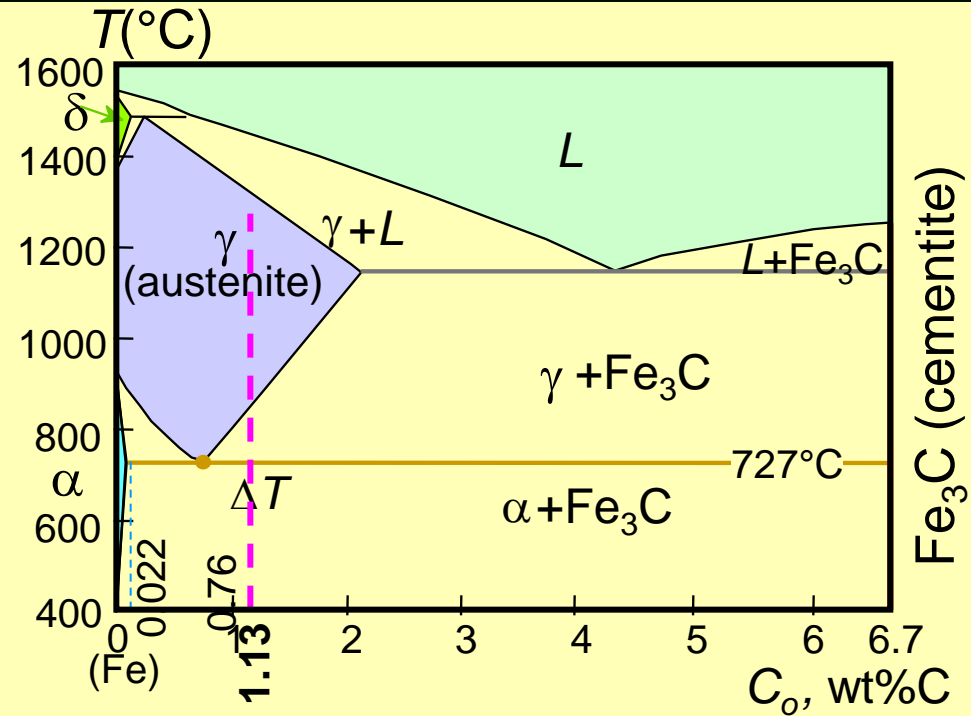
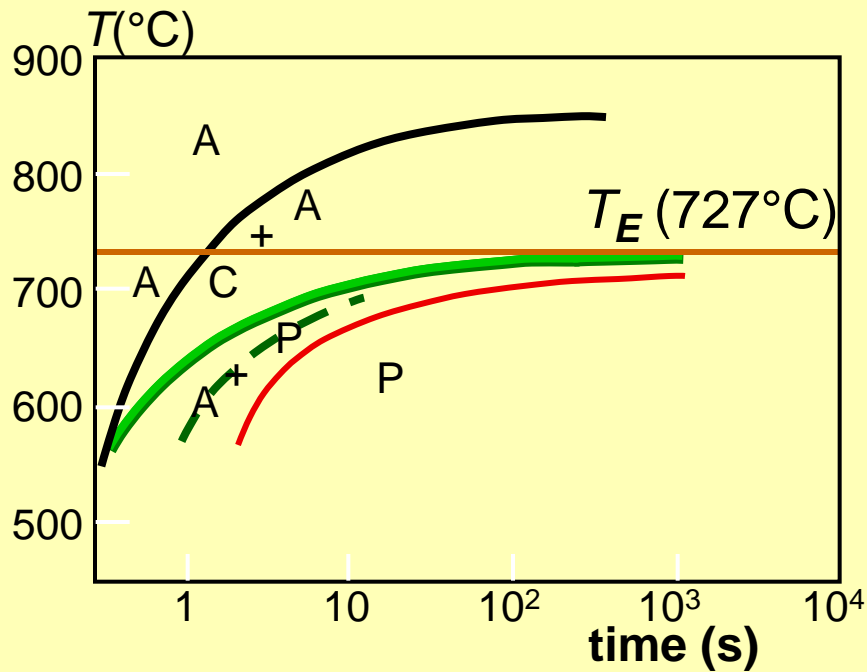
Effect of Cooling History in Fe-C System

- Eutectoid composition, $C_o = 0.76 \text{ wt\% C}$
- Begin at $T > 727^\circ\text{C}$
- Rapidly cool to 625°C and hold isothermally.



Transformations with Proeutectoid Materials

$$C_o = 1.13 \text{ wt\% C}$$

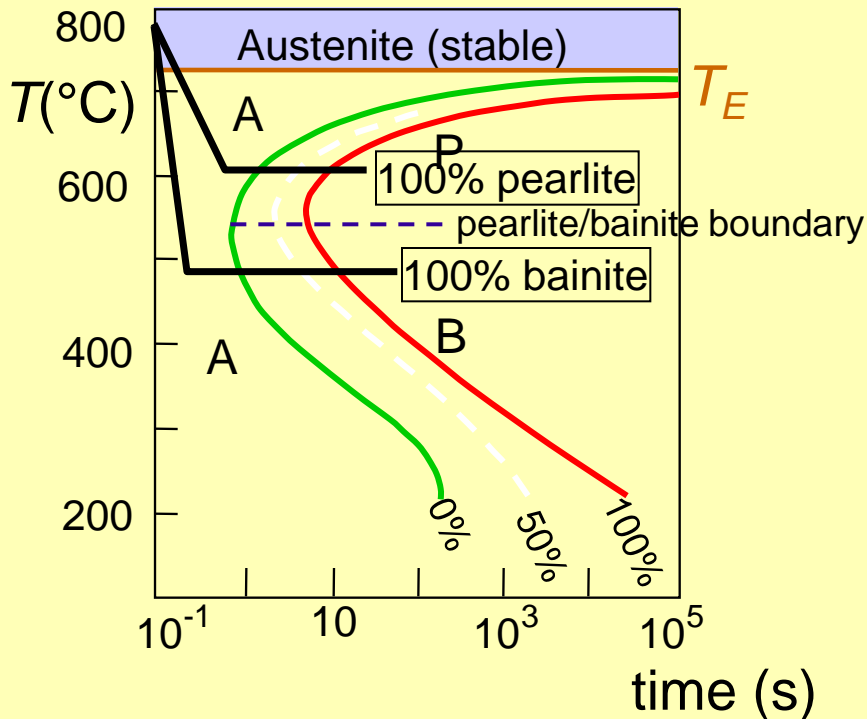


Hypereutectoid composition – proeutectoid cementite

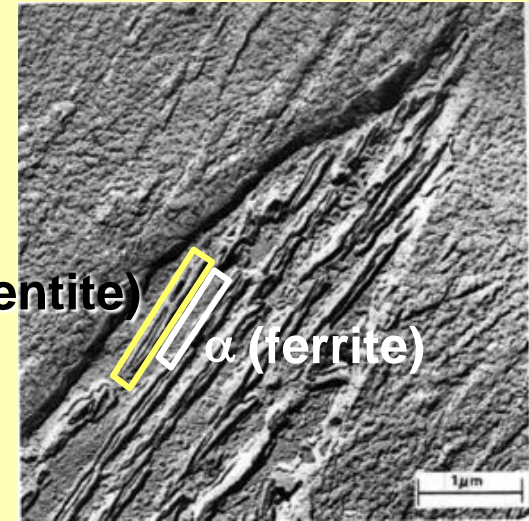
Non-Equilibrium Transformation

Products: Fe-C

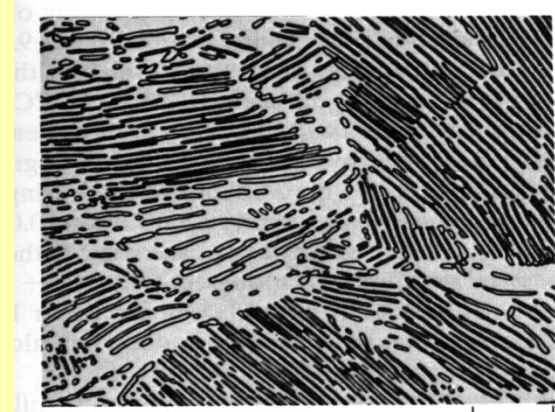
- Bainite: (Davenport & Bain)
 - α strips with long needles of Fe_3C
 - diffusion controlled.
- Isothermal Transf. Diagram



Fe_3C
(cementite)



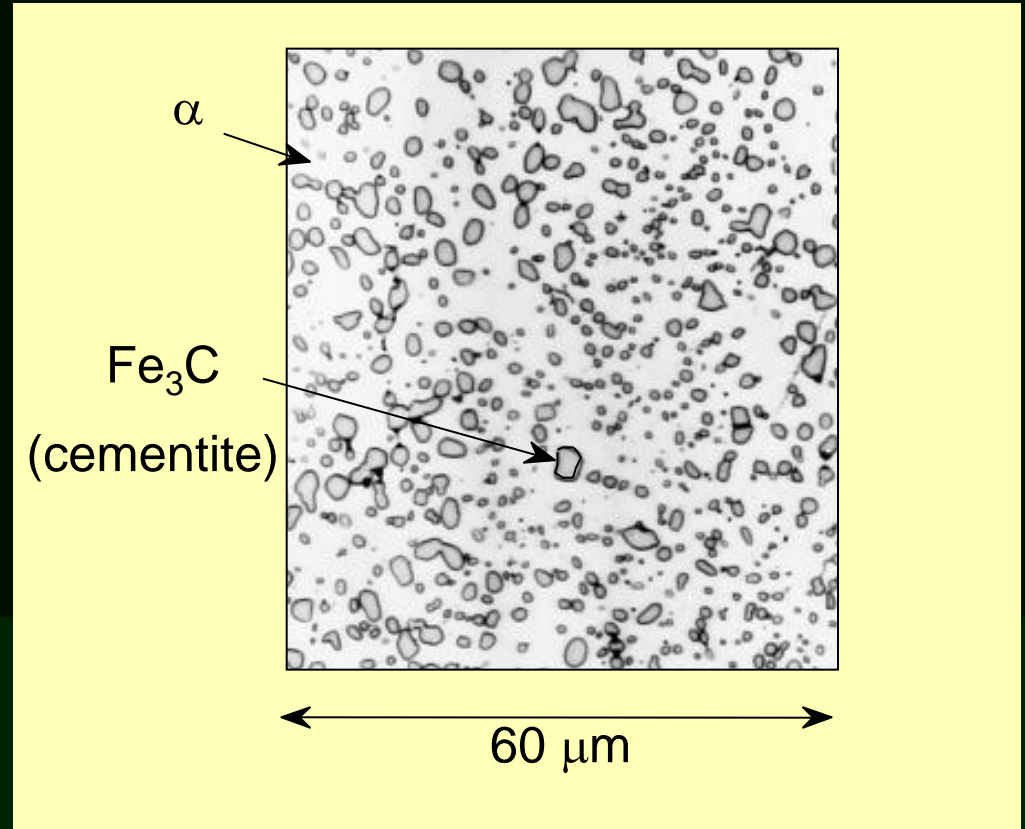
5 μm



cf: Pearlite

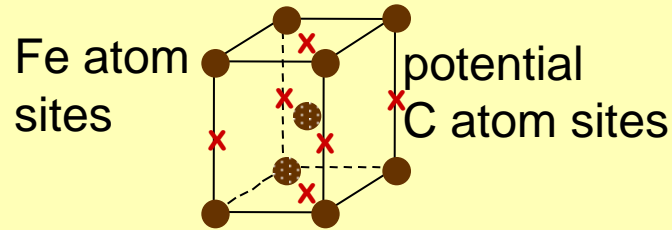
Spheroidite: Fe-C System

- α + grains with spherical Fe_3C
- diffusion dependent.
- heat bainite or pearlite for long times (e.g. 18 h at 700°C)
- reduces interfacial area (driving force)

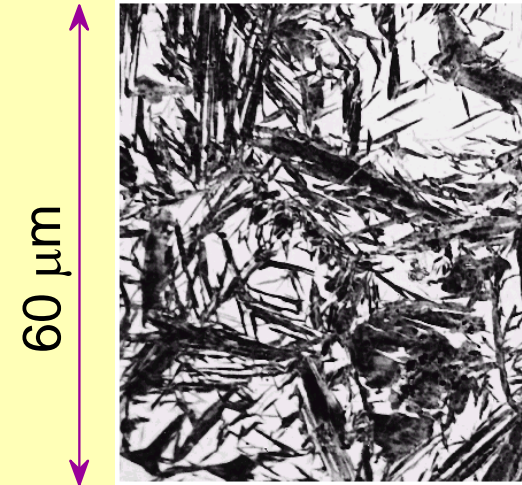
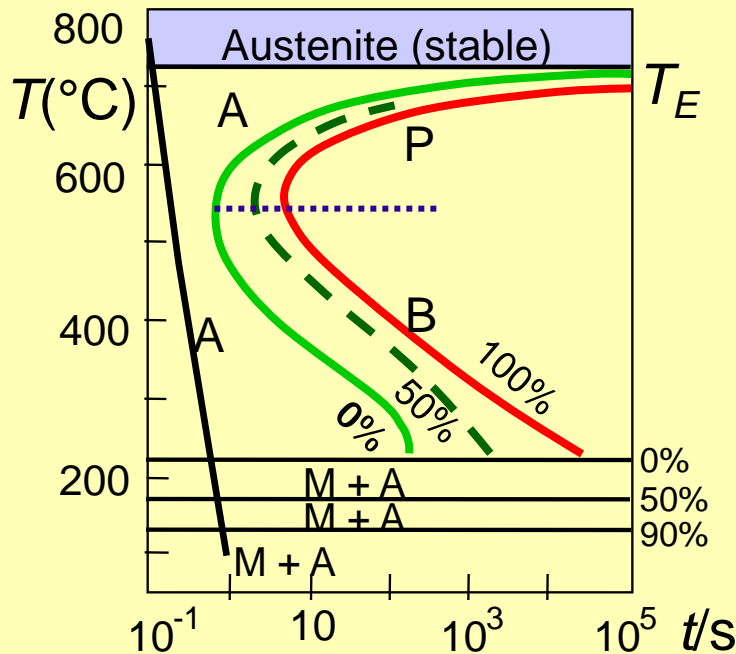


Martensite: Fe-C System

- Martensite: (Martens)
 - γ (FCC) to Martensite (BCT)
 - (involves single atom jumps)



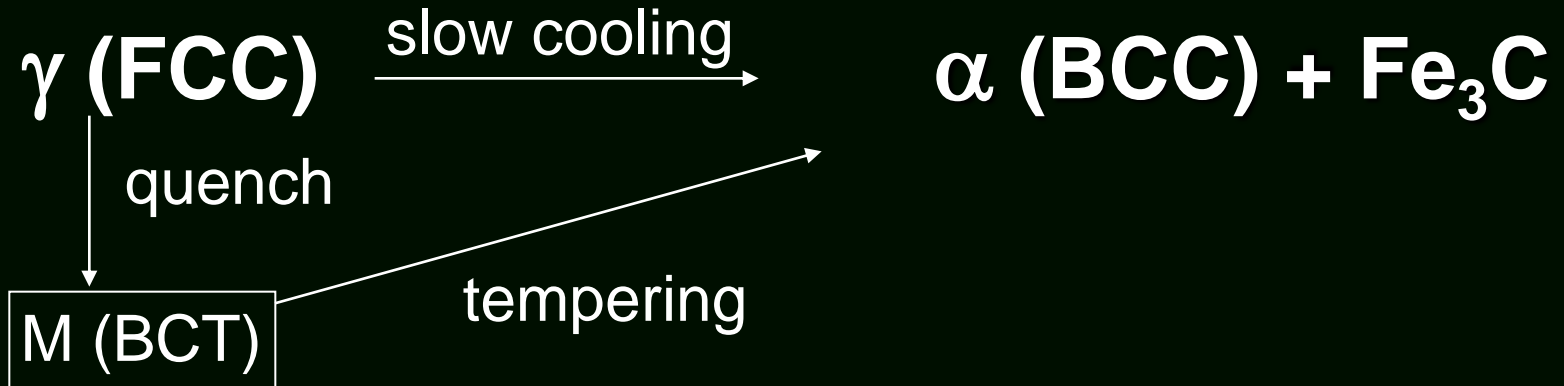
- Isothermal Transf. Diagram



— Martensite needles
 — Austenite

- γ to M transformation..
 - is rapid!
 - % transf. depends on T only.
 - can be stress-induced

Martensite Formation



M = martensite is body centered tetragonal (BCT)

Diffusionless transformation BCT if $C > 0.15$ wt%

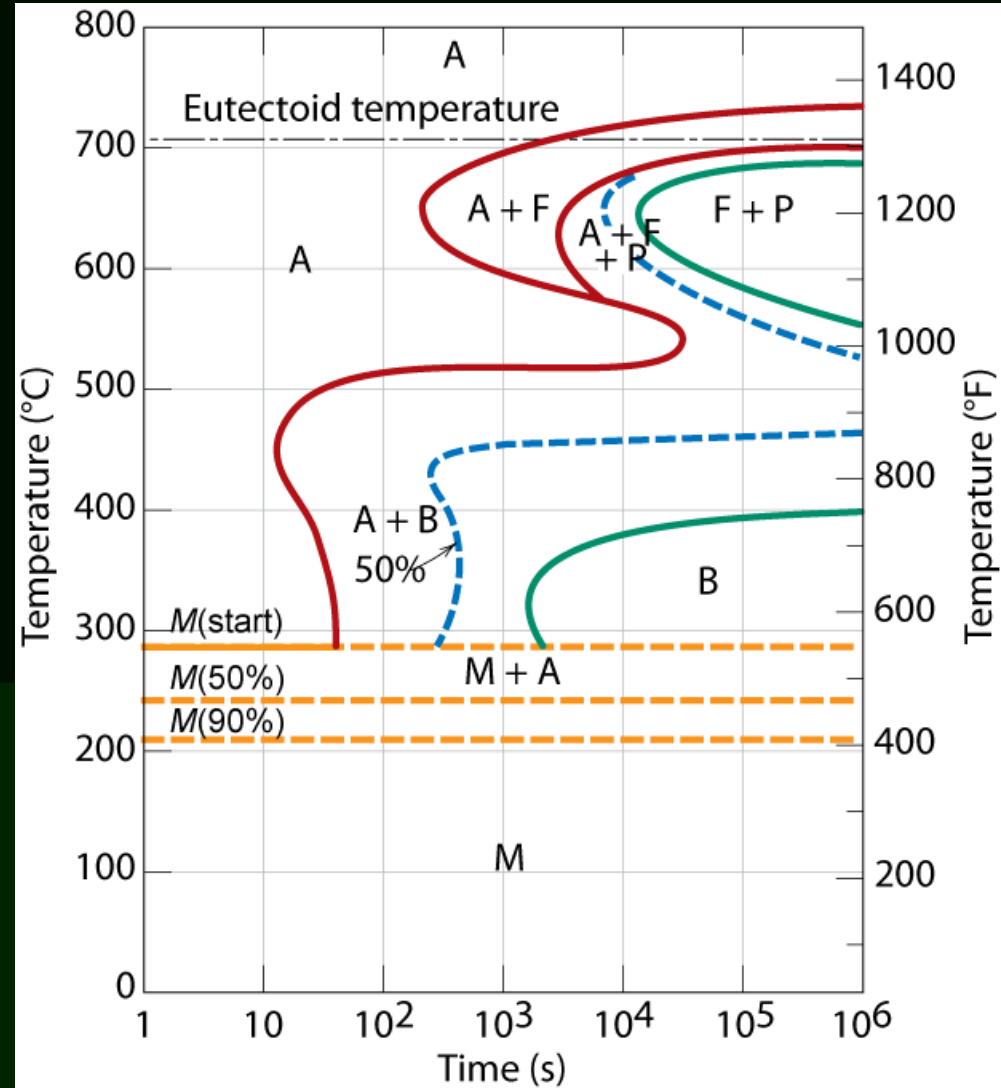
BCT \rightarrow few slip planes \rightarrow hard, brittle

Phase Transformations of Alloys

Effect of adding
other elements
Change transition
temp.

Cr, Ni, Mo, Si, Mn
retard

$\gamma \rightarrow \alpha + \text{Fe}_3\text{C}$
transformation



Dynamic Phase Transformations

On the isothermal transformation diagram for 0.45 wt% C Fe-C alloy, sketch and label the time-temperature paths to produce the following microstructures:

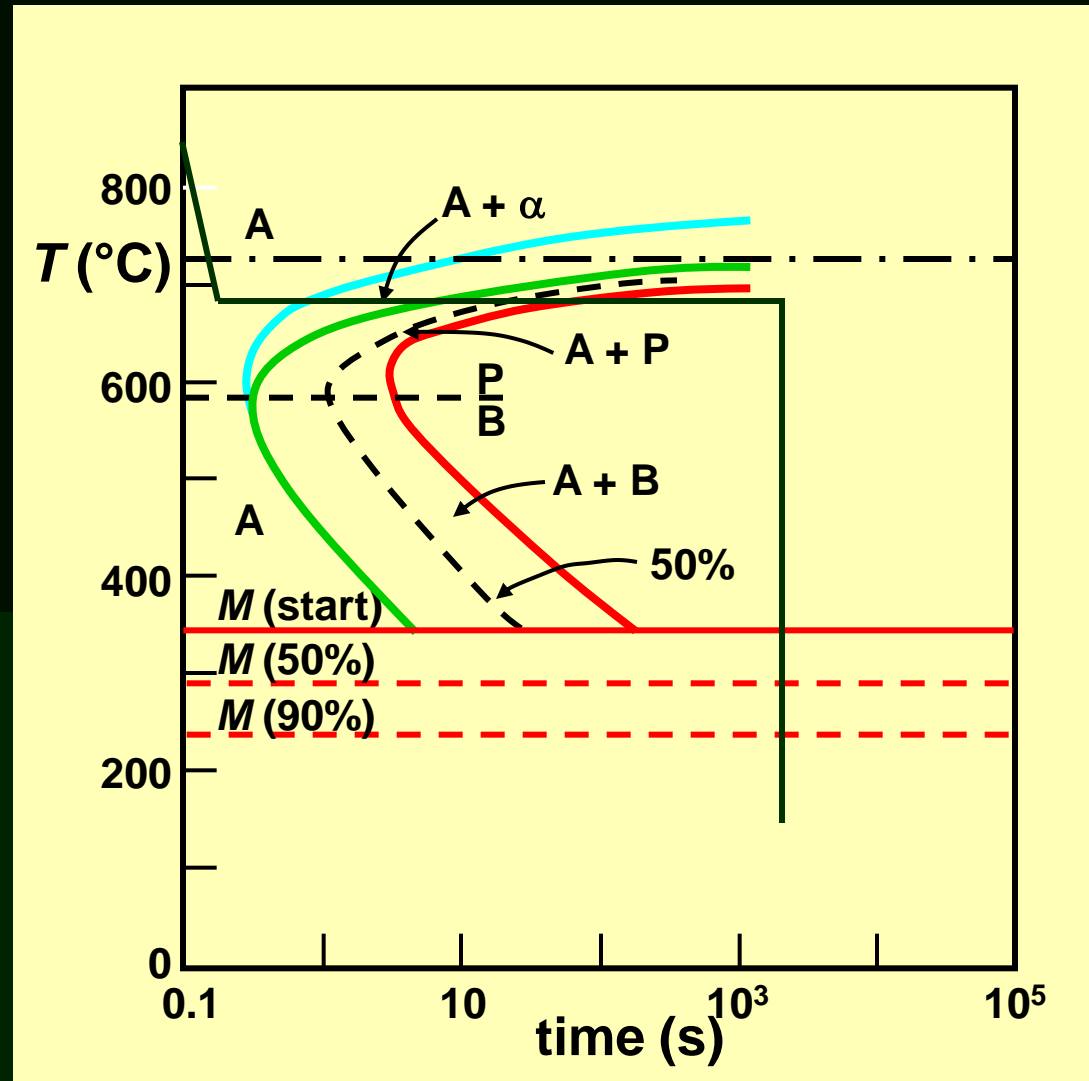
- a) 42 % proeutectoid ferrite and 58 % coarse pearlite
- b) 50 % fine pearlite and 50 % bainite
- c) 100 % martensite
- d) 50 % martensite and 50 % austenite

Example Problem for $C_o = 0.45 \text{ wt}\%$

a) 42 %
proeutectoid
ferrite and 58 %
coarse pearlite
(amounts
determined by
phase diagram)

first make
ferrite
then pearlite

coarse pearlite
 \therefore higher T



Example Problem for $C_o = 0.45 \text{ wt\%}$

- a. the amount of pearlite and proeutectoid ferrite (α)
 note: amount of pearlite = amount of γ just above T_E

$$C_o = 0.45 \text{ wt\% C}$$

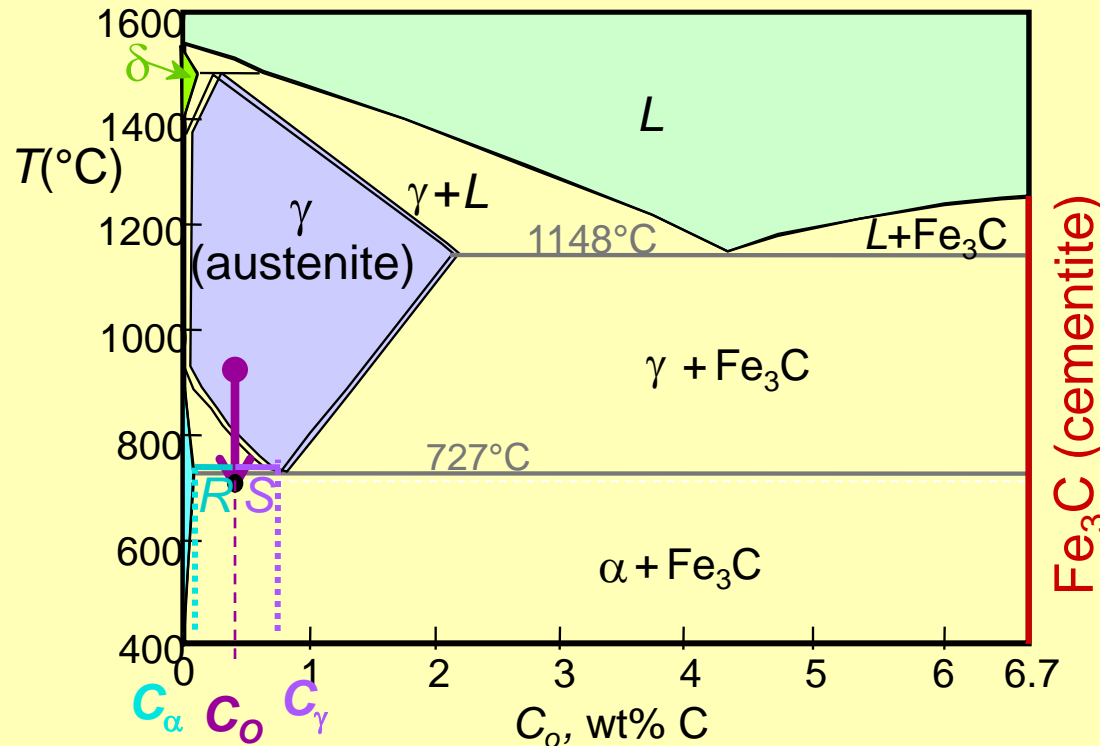
$$C_\alpha = 0.022 \text{ wt\% C}$$

$$C_{\text{pearlite}} = C_\gamma = 0.76 \text{ wt\% C}$$

$$\frac{\gamma}{\gamma + \alpha} = \frac{C_o - C_\alpha}{C_\gamma - C_\alpha} \times 100 = 57.9\%$$

pearlite = 58 %

proeutectoid α = 42 %

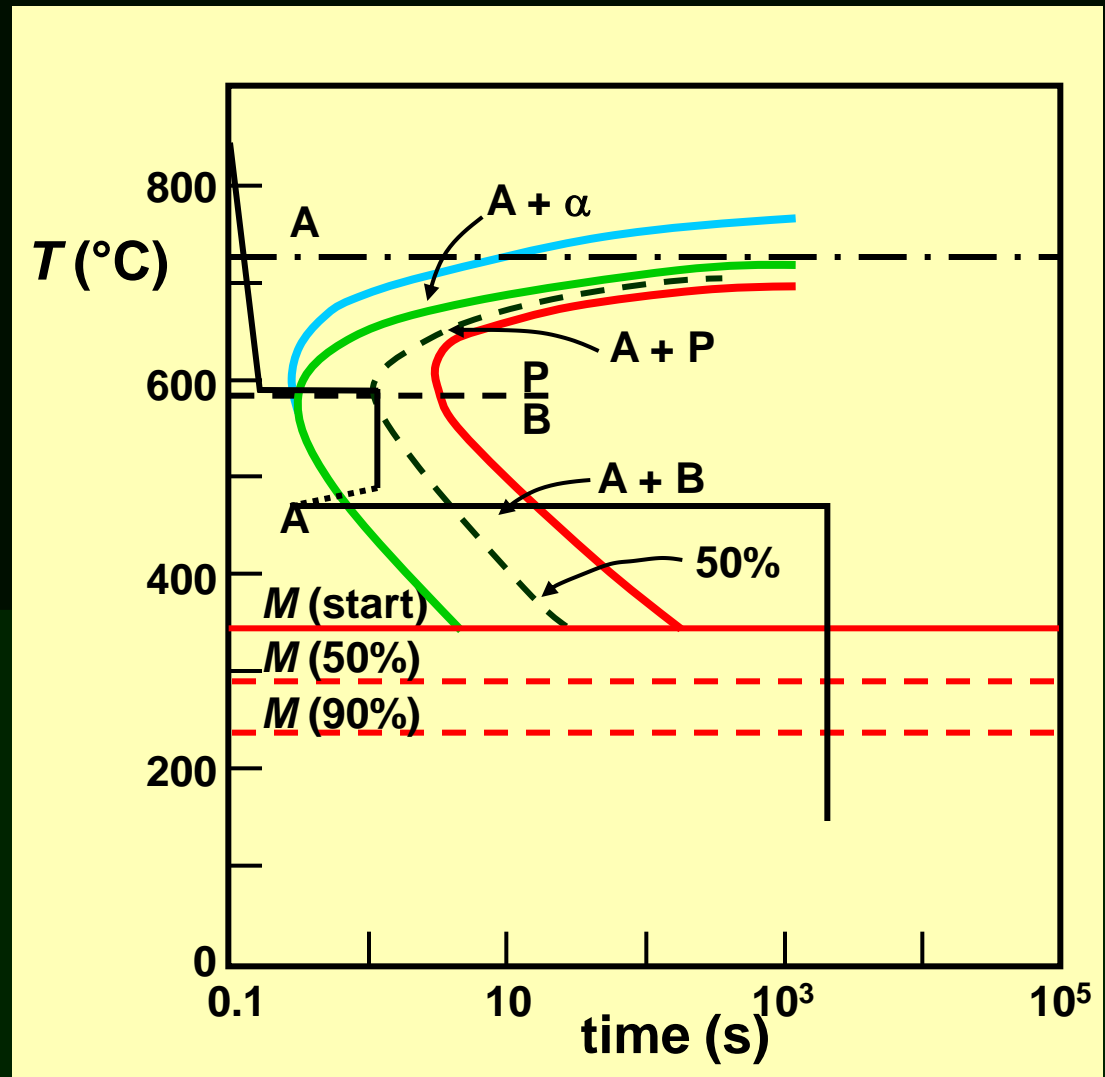


Example Problem for $C_o = 0.45 \text{ wt}\%$

b) 50 % fine
pearlite and
50% bainite

first make pearlite
then bainite

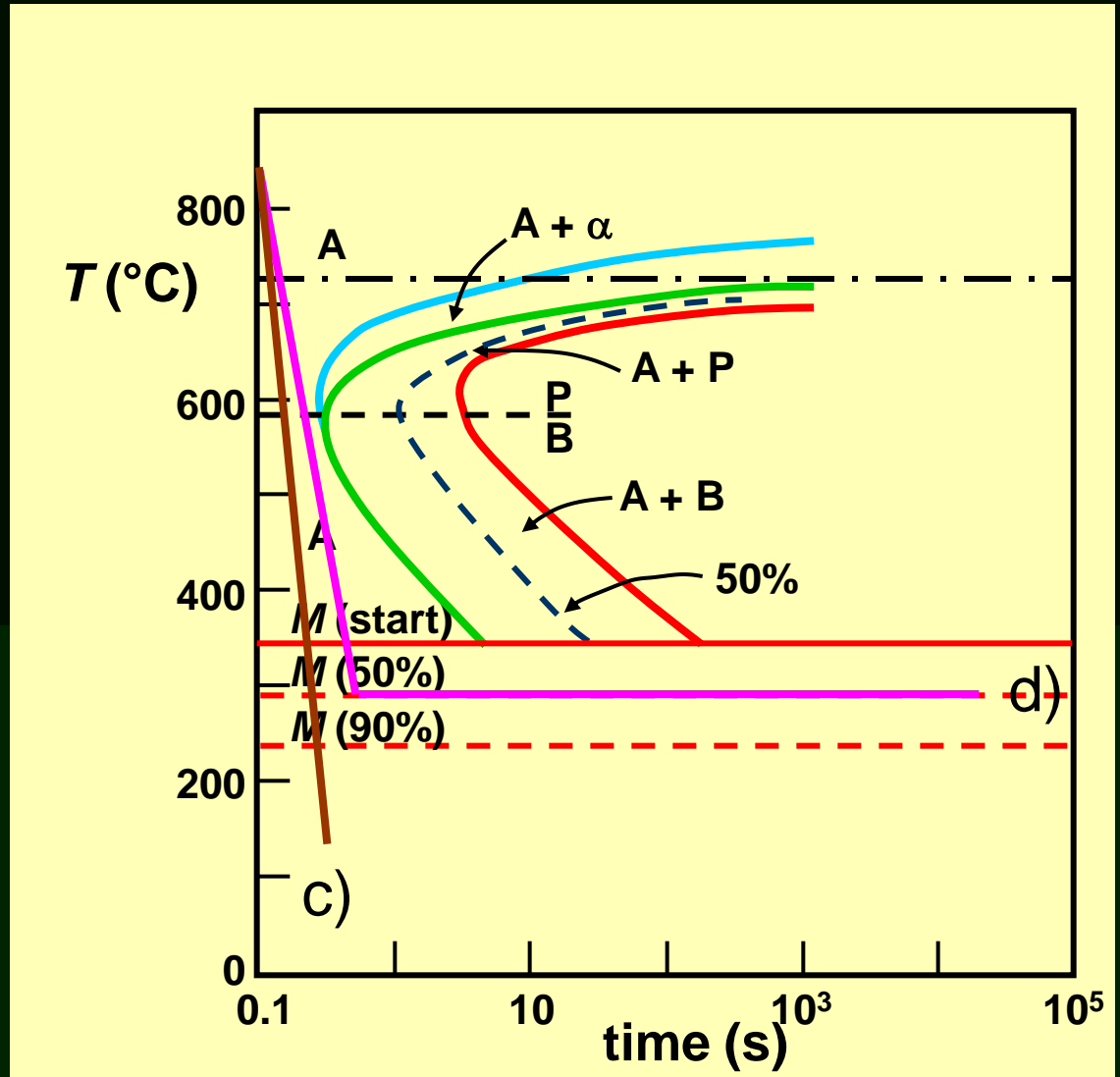
fine pearlite
 \therefore lower T



Example Problem for $C_o = 0.45 \text{ wt}\%$

c) 100 %
martensite
– quench =
rapid cool

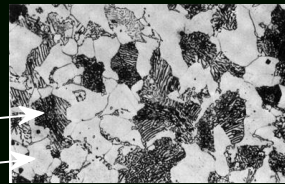
d) 50 % martensite
and 50 %
austenite



Mechanical Prop: Fe-C System (1)

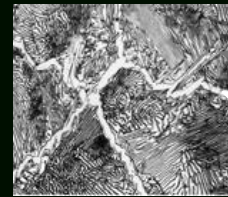
- Effect of wt% C

Pearlite (med)
ferrite (soft)

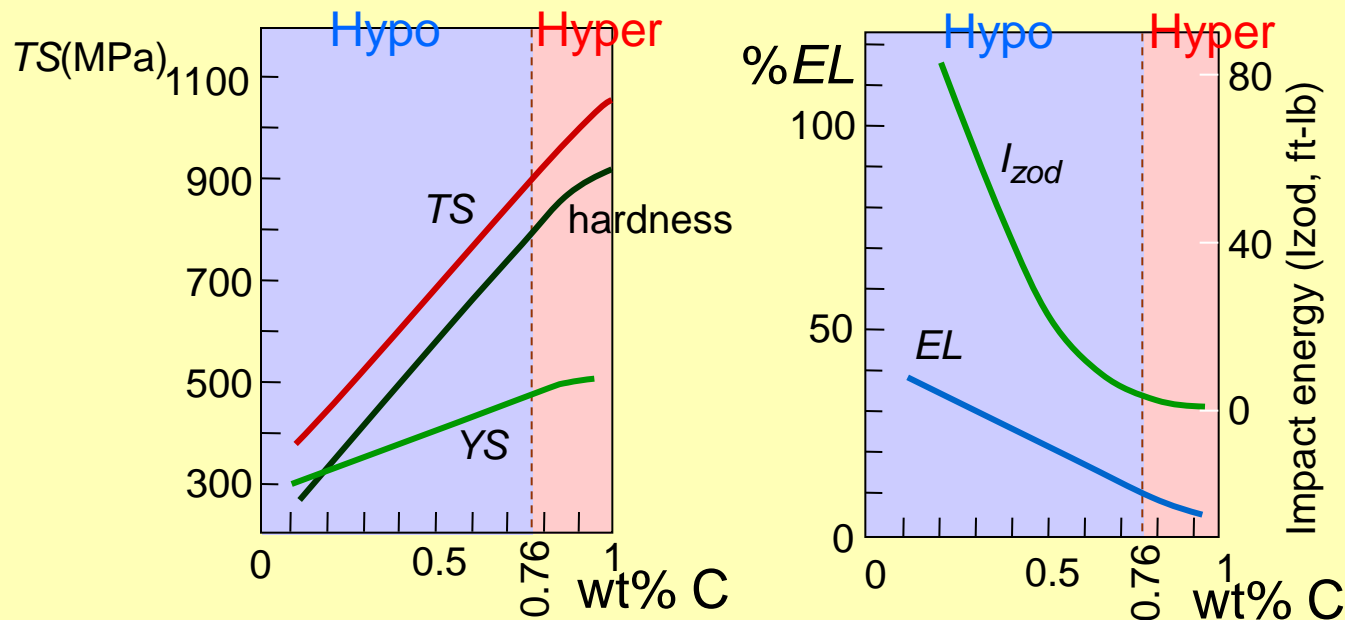


$C_o < 0.76 \text{ wt\% C}$
Hypoeutectoid

Pearlite (med)
Cementite (hard)



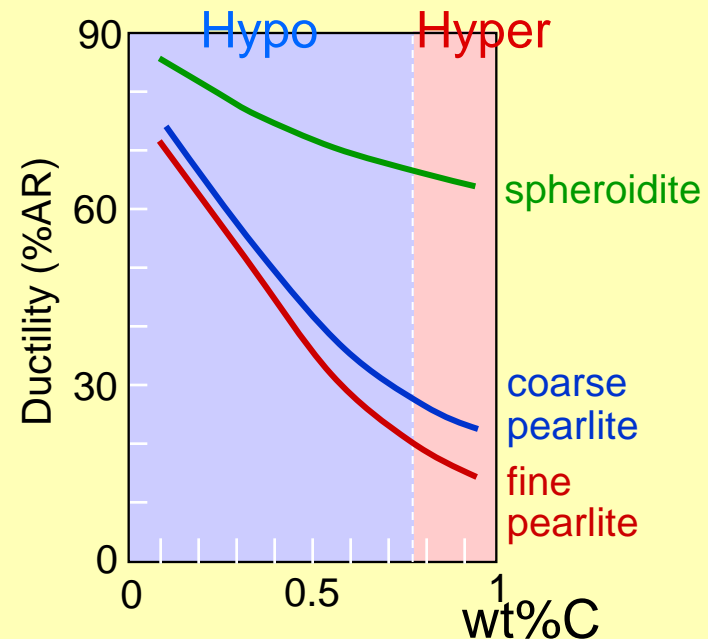
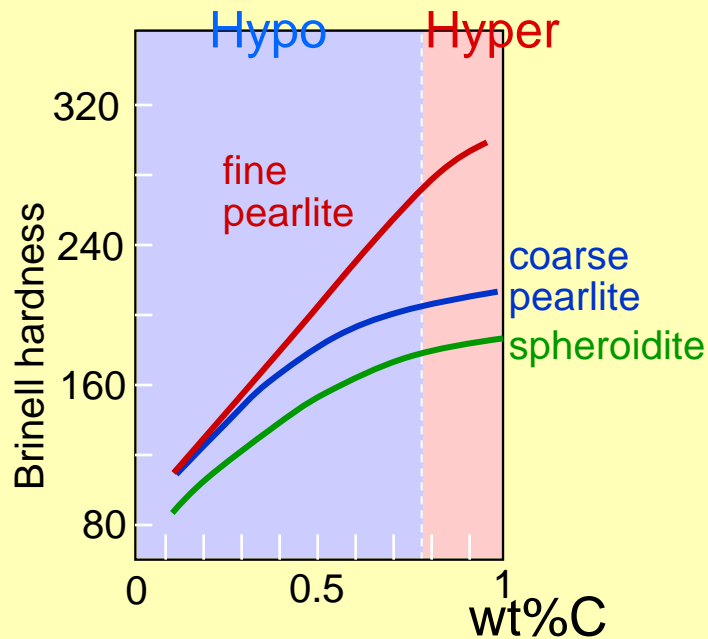
$C_o > 0.76 \text{ wt\% C}$
Hypereutectoid



- More wt% C: TS and YS increase, $\%EL$ decreases.

Mechanical Prop: Fe-C System (2)

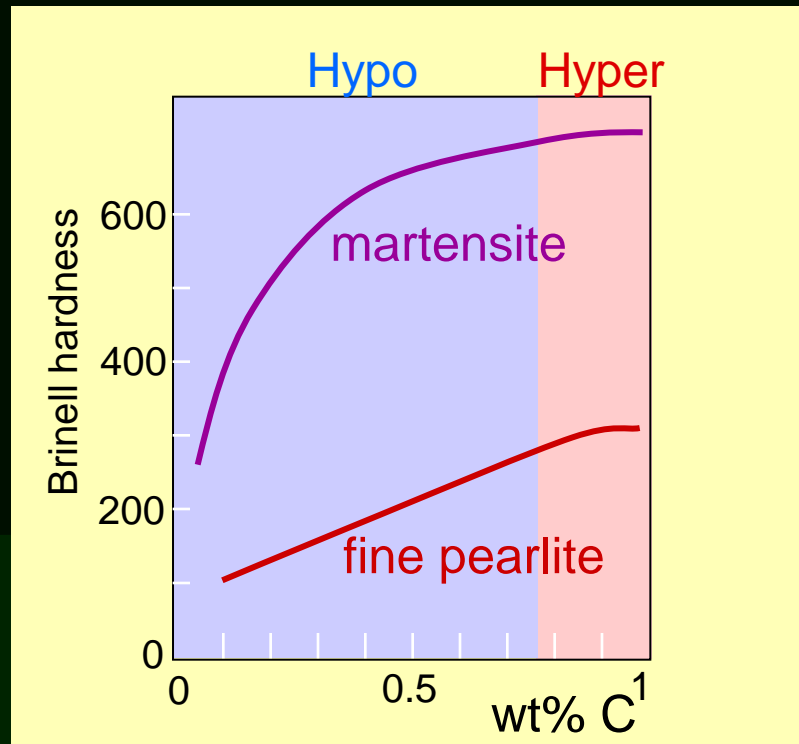
- Fine vs coarse pearlite vs spheroidite



- Hardness: fine > coarse > spheroidite
- %RA: fine < coarse < spheroidite

Mechanical Prop: Fe-C System (3)

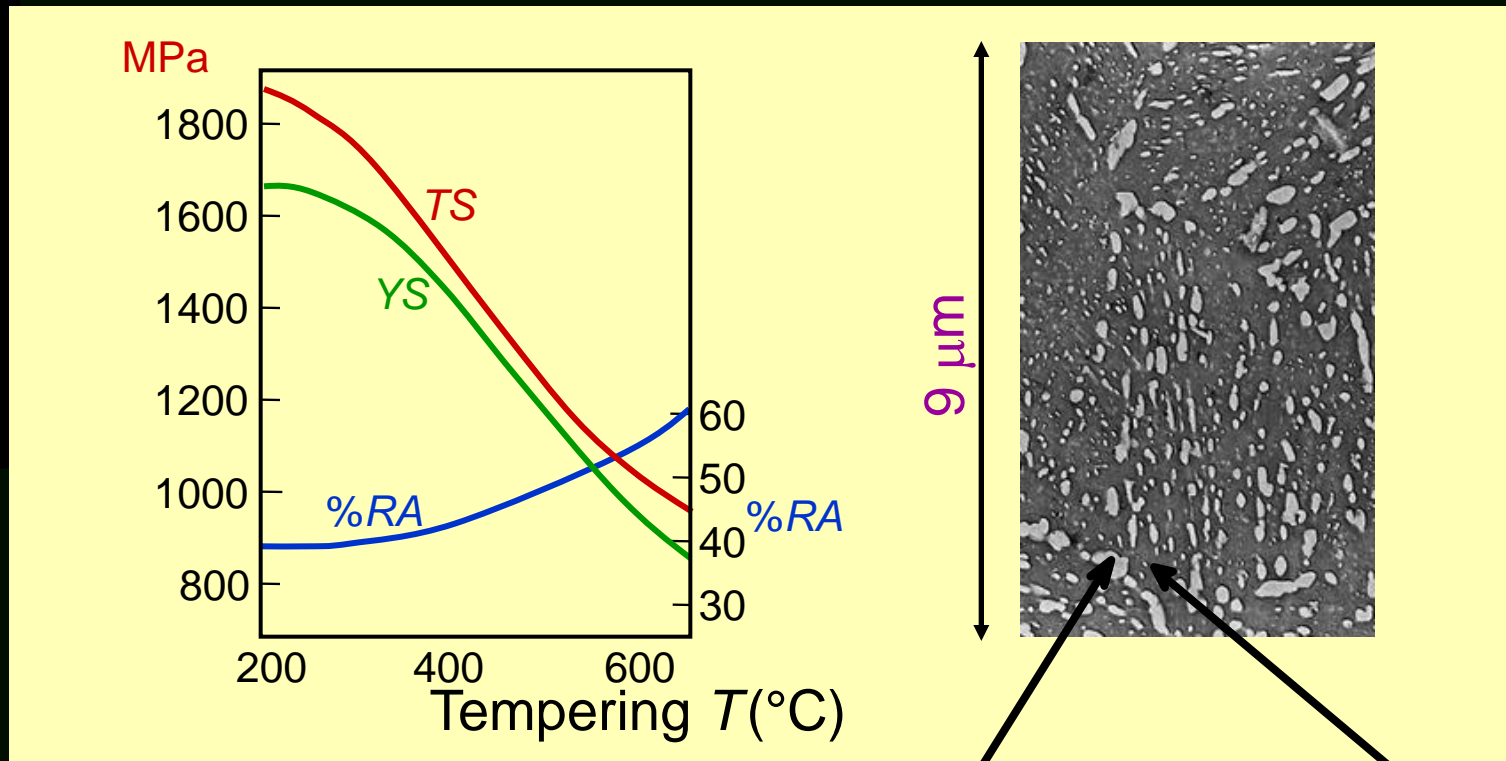
- Fine Pearlite vs Martensite:



- Hardness: fine pearlite \ll martensite.

Tempering Martensite

- reduces brittleness of martensite,
- reduces internal stress caused by quenching.



- produces extremely small Fe_3C particles surrounded by α .
- decreases TS , YS but increases $\%RA$

Summary: Processing Options

