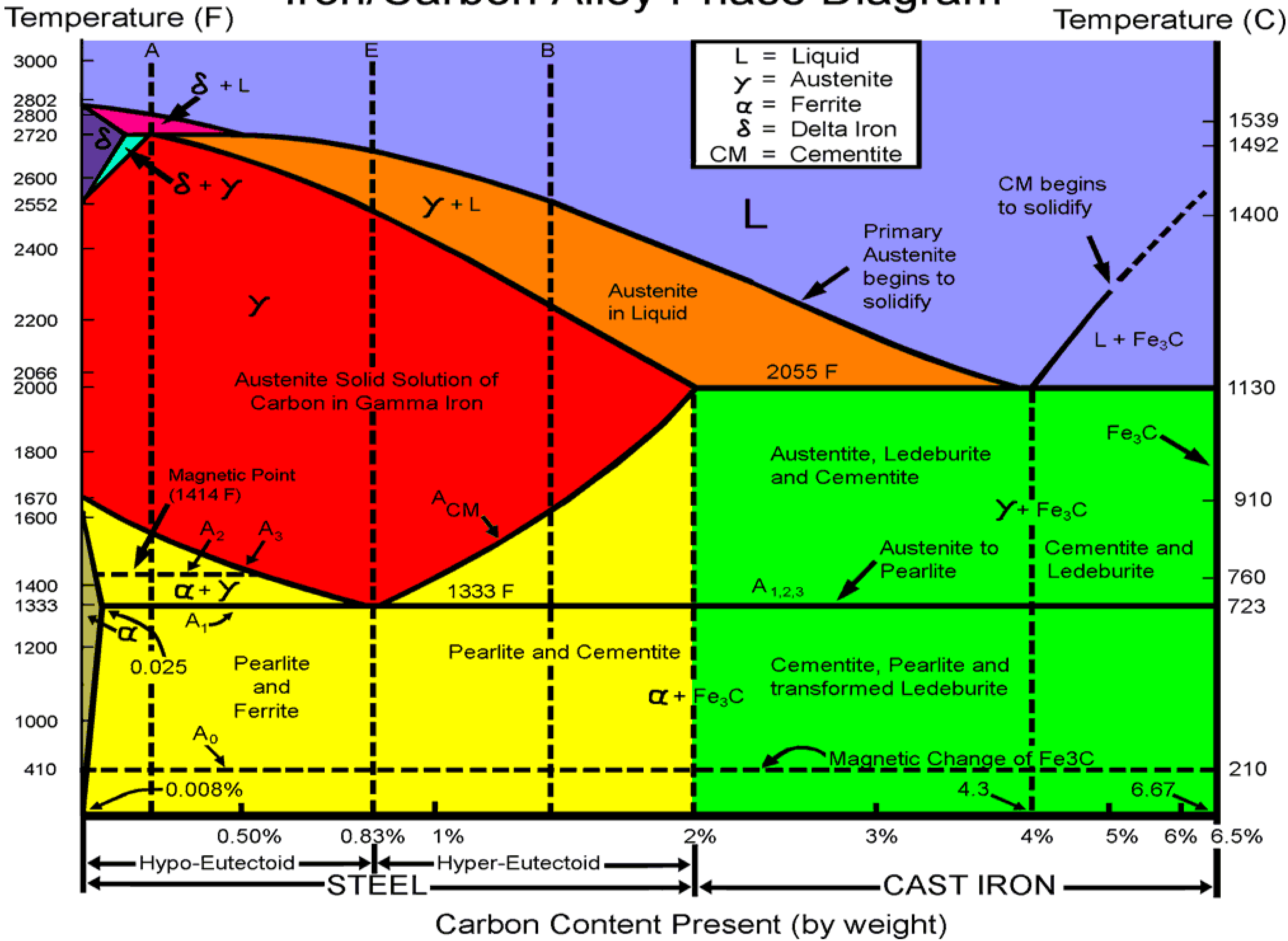
HMSC Metallurgy

- These slides were blended from two fine sources:
- California State University

And

- The Institute of Materials Science University of Connecticut

Iron/Carbon Alloy Phase Diagram



COOLING AUSTENITE

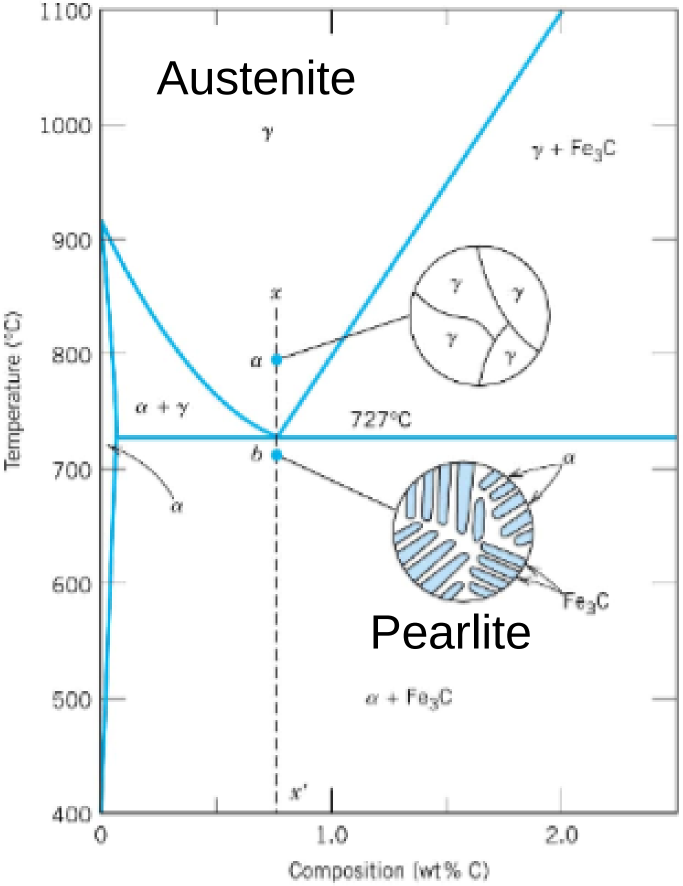


FIGURE 9.23 Schematic representations of the microstructures for an iron–carbon alloy of eutectoid composition (0.76 wt% C) above and below the eutectoid tempe

□ □ + Fe_3C (pearlite), 0.77 wt% C

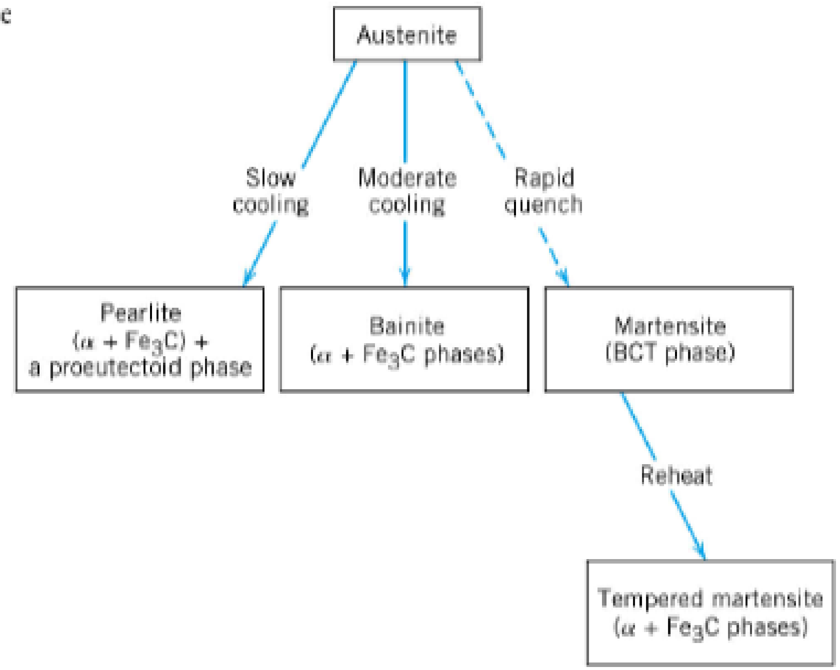


FIGURE 10.27 Possible transformations involving the decomposition of austenite. Solid arrows, transformations involving diffusion; dashed arrow, diffusionless transformation.

MECHANICAL PROPERTIES

Strength ↑

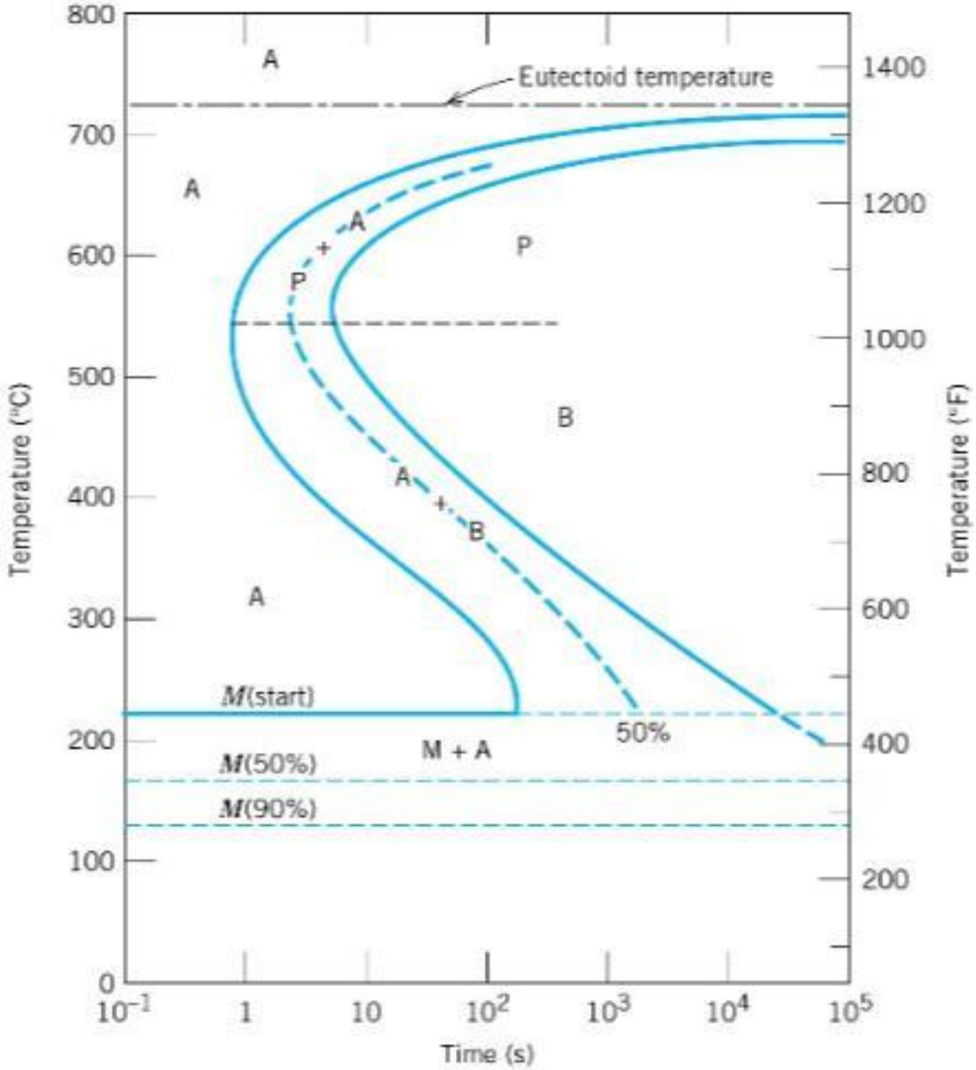
- Martensite
- Tempered martensite
- Bainite
- Fine pearlite
- Coarse pearlite

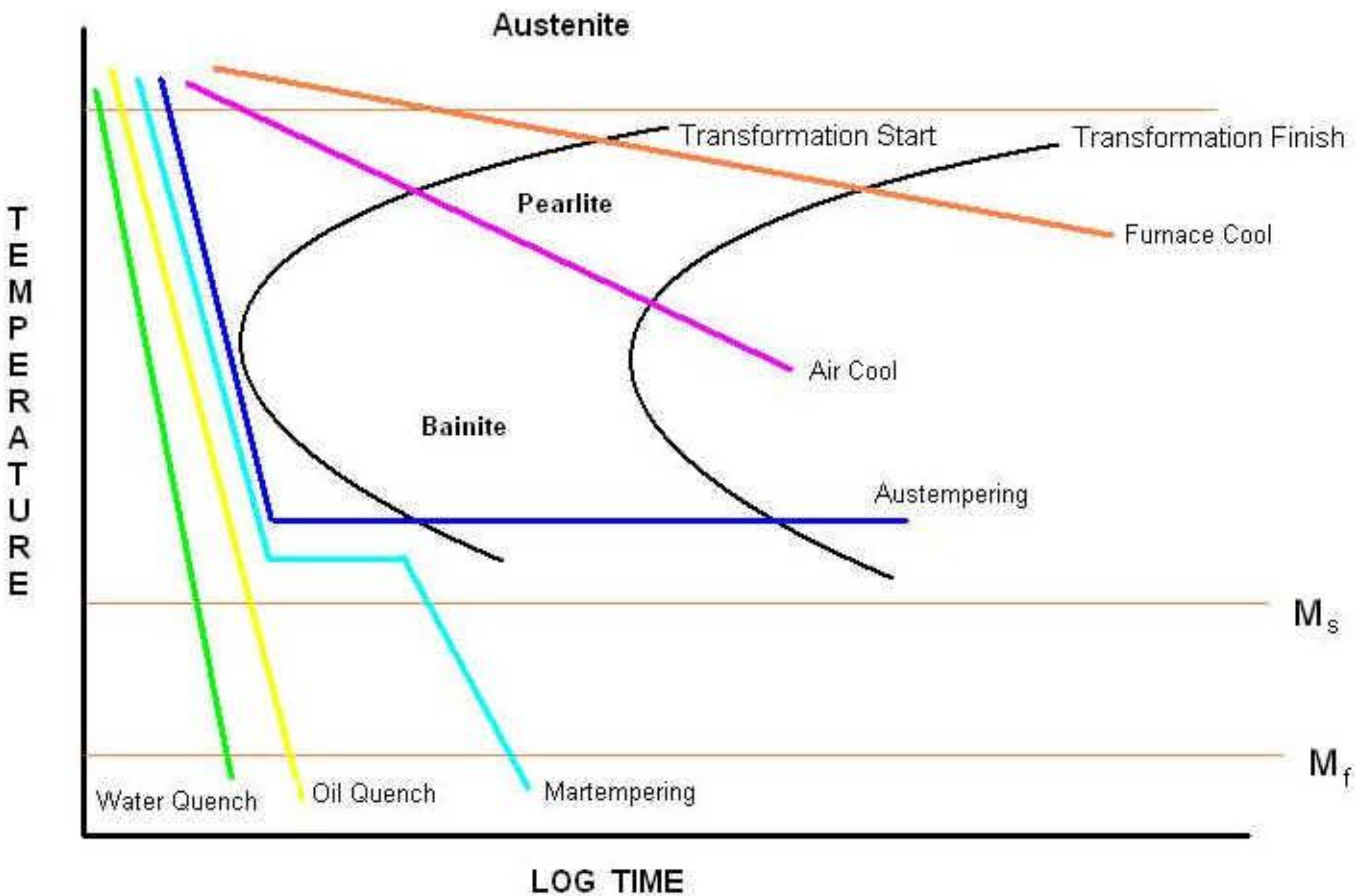
↓ Ductility

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

PRODUCTS OF COOLING AUSTENITE

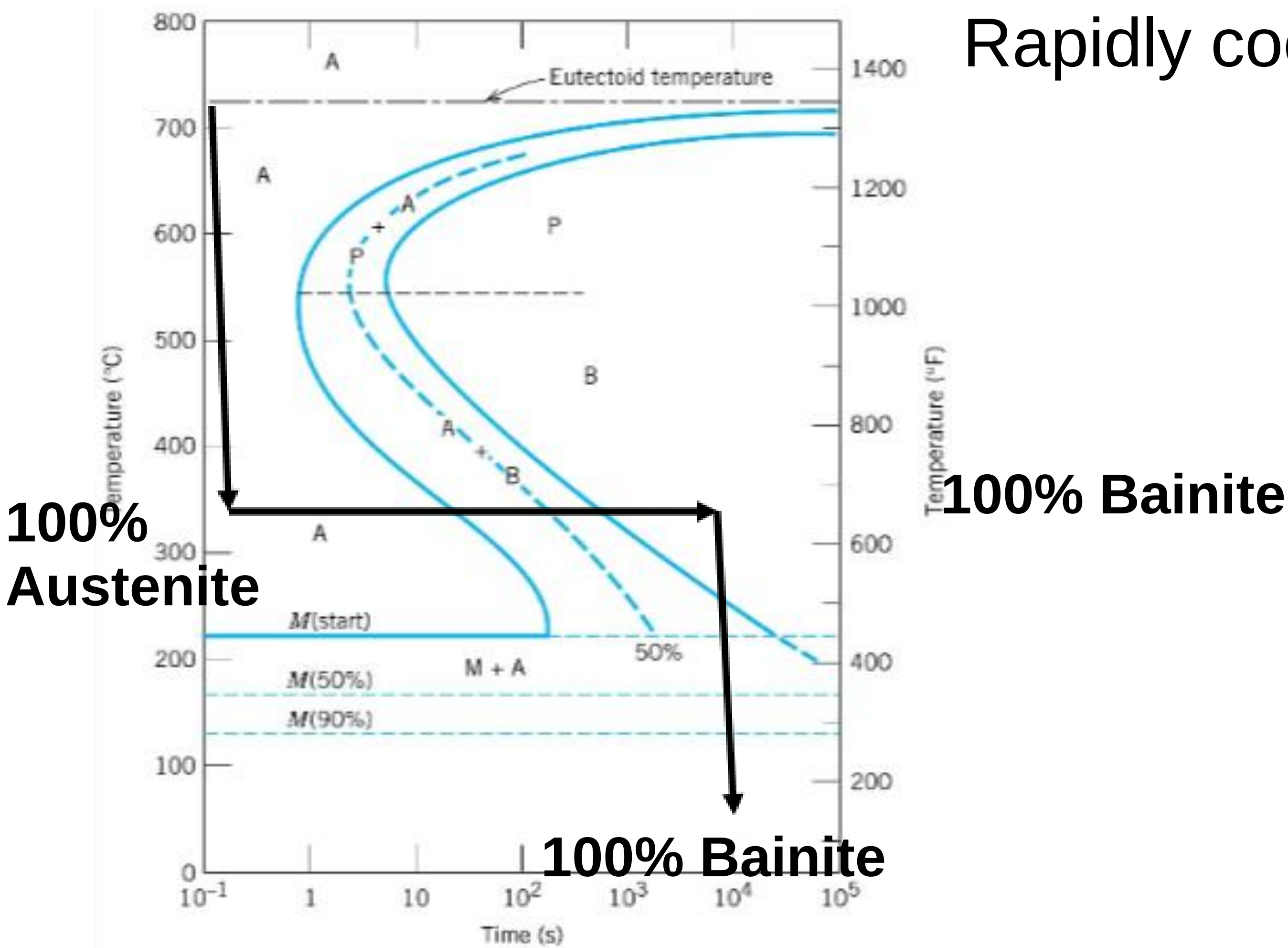
- Slow cooling pearlite
- Cool rapidly to upto 550 C, and hold pearlite
- Cool rapidly to 550-225 C and hold bainite
- Cool rapidly to below 225 C martensite




Austenite
Transformation Start
Transformation Finish
Pearlite
Furnace Cool
TEMPERATURE
Air Cool
Bainite
Austempering
M_s
M_f
Water Quench
Oil Quench
Martempering
LOG TIME

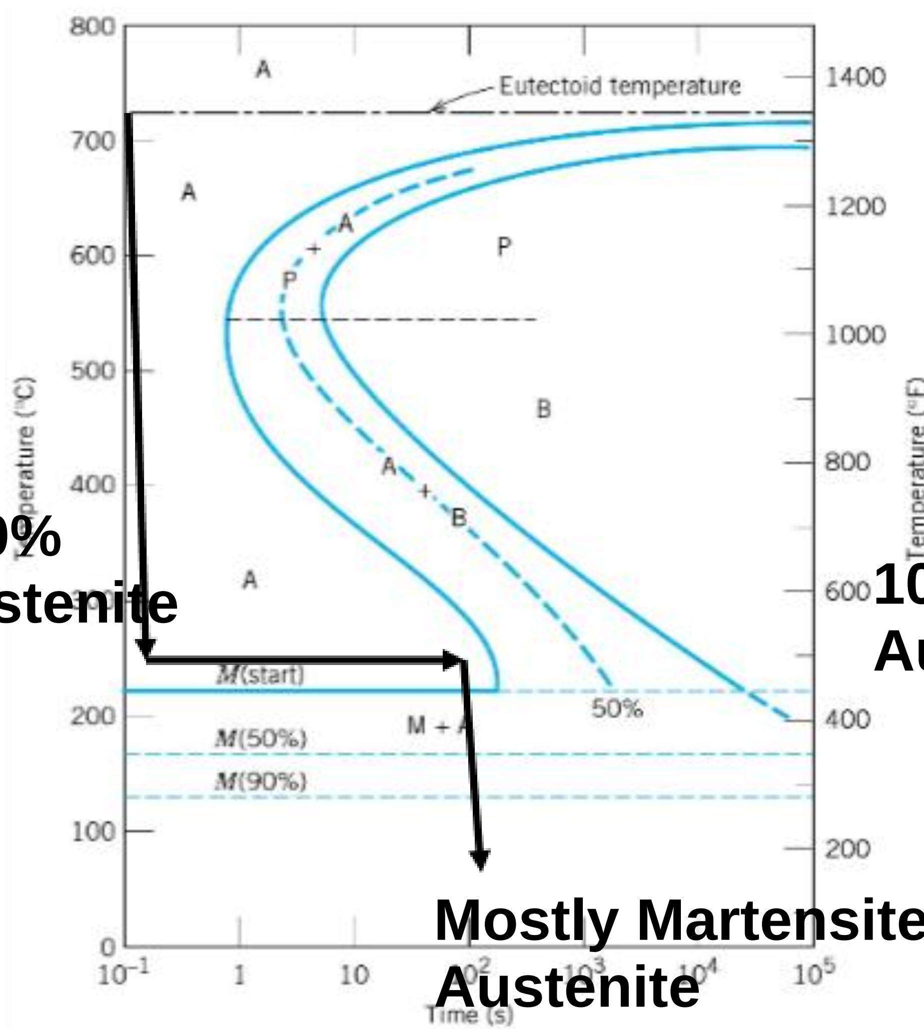
COOLING EX: Fe-C SYSTEM (1)

Rapidly cool to 350 C
Hold for 10000 seconds
Rapidly cool to room T



COOLING EX: Fe-C SYSTEM (2)

Rapidly cool to 250 C
Hold for 100 seconds
Rapidly cool to room T

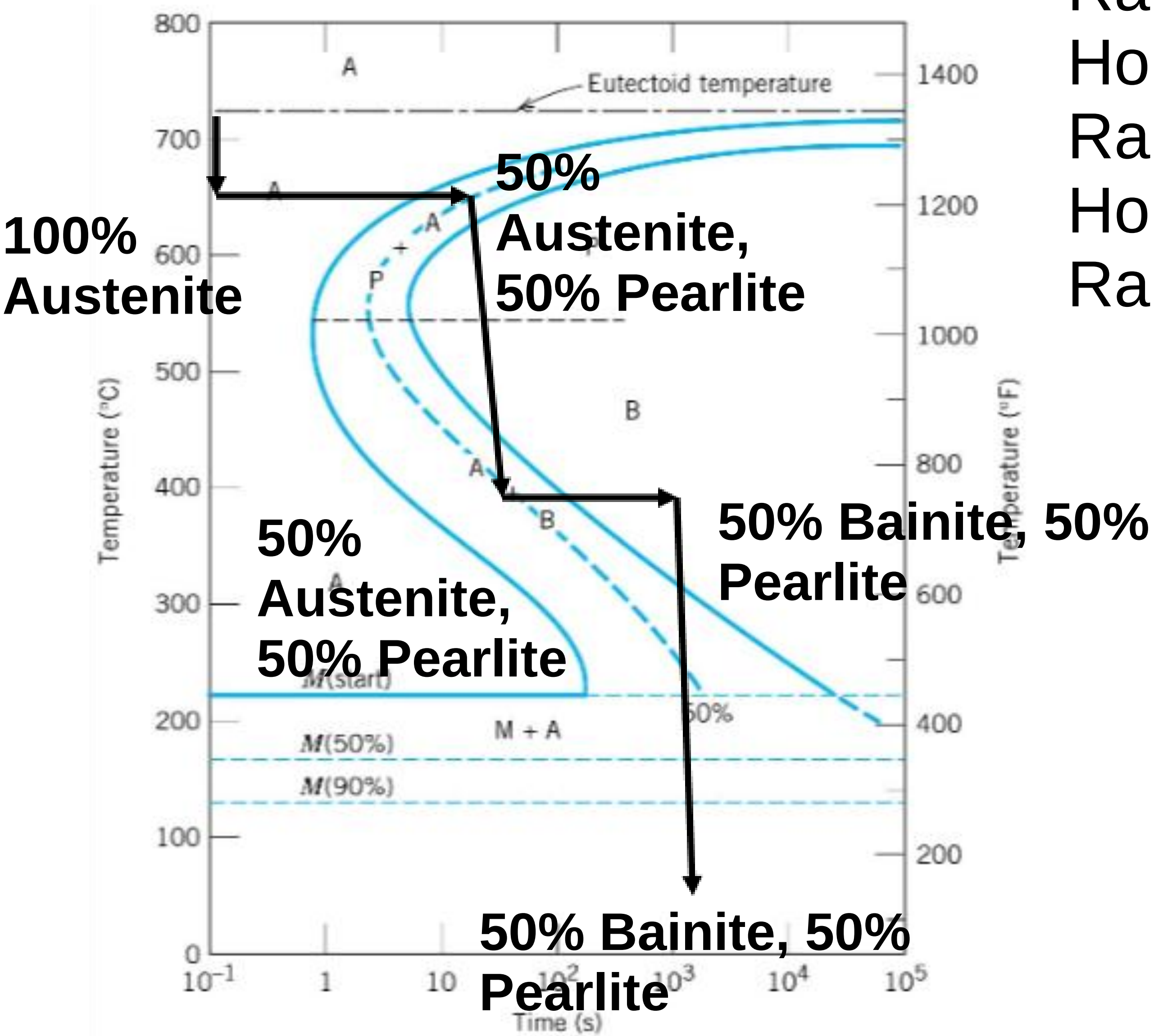


100% Austenite

100% Austenite

Mostly Martensite + traces of Austenite

COOLING EX: Fe-C SYSTEM (3)

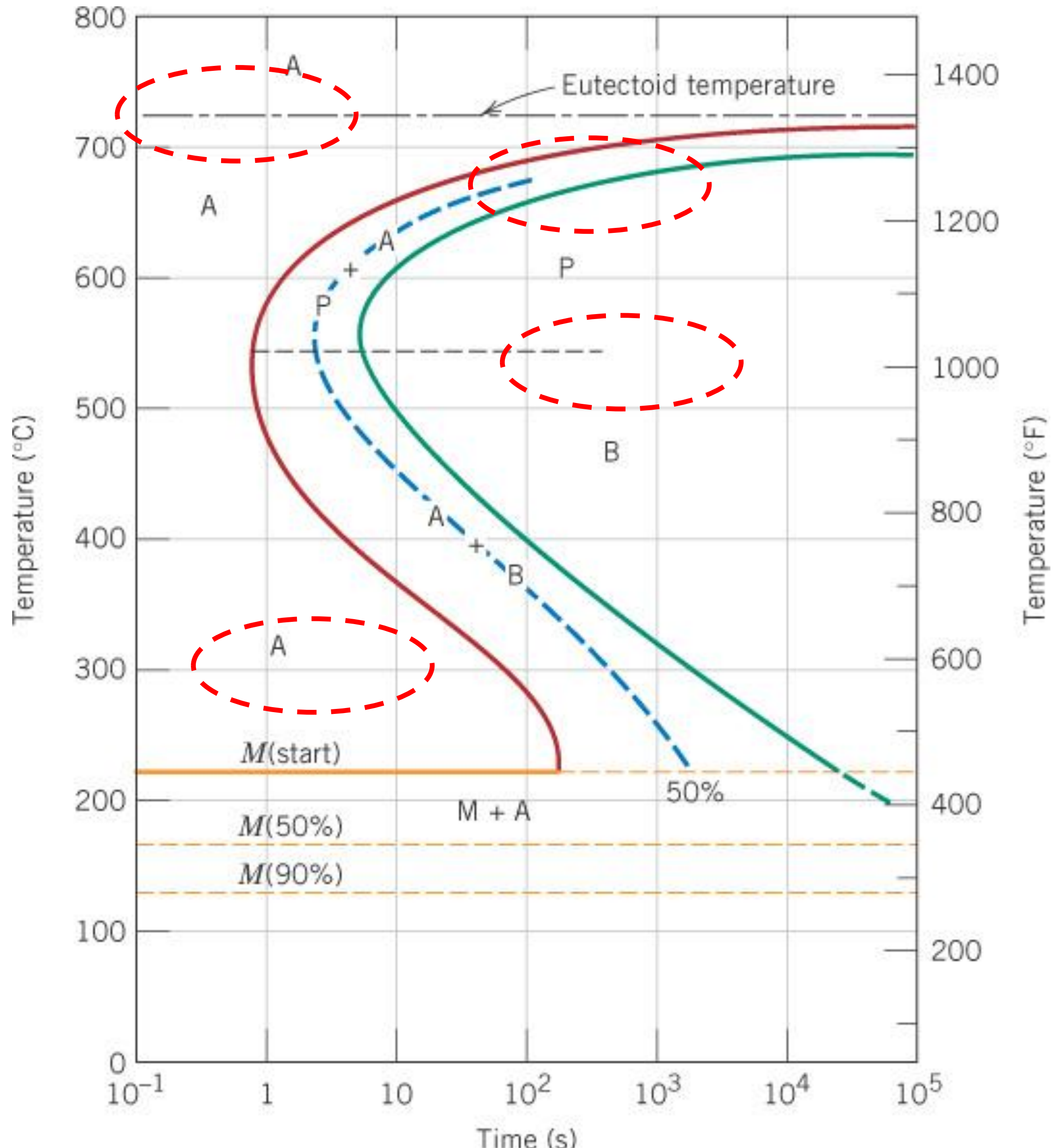


Rapidly cool to 650 C
Hold for 20 seconds
Rapidly cool to 400 C
Hold for 1000 seconds
Rapidly cool to room T

Isothermal Transformation Diagram

Iron-carbon alloy with eutectoid composition.

- A: Austenite
- P: Pearlite
- B: Bainite
- M: Martensite

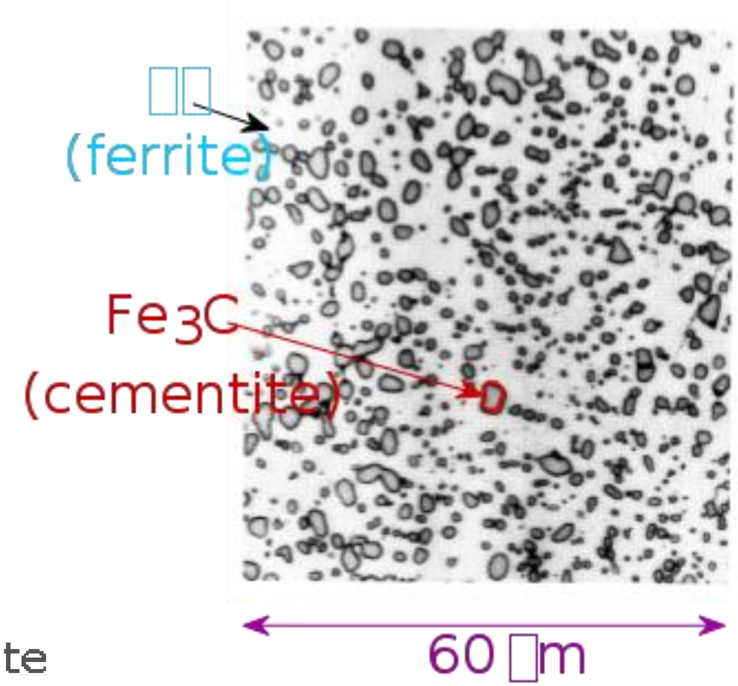


OTHER PRODUCTS: Fe-C SYSTEM (1)

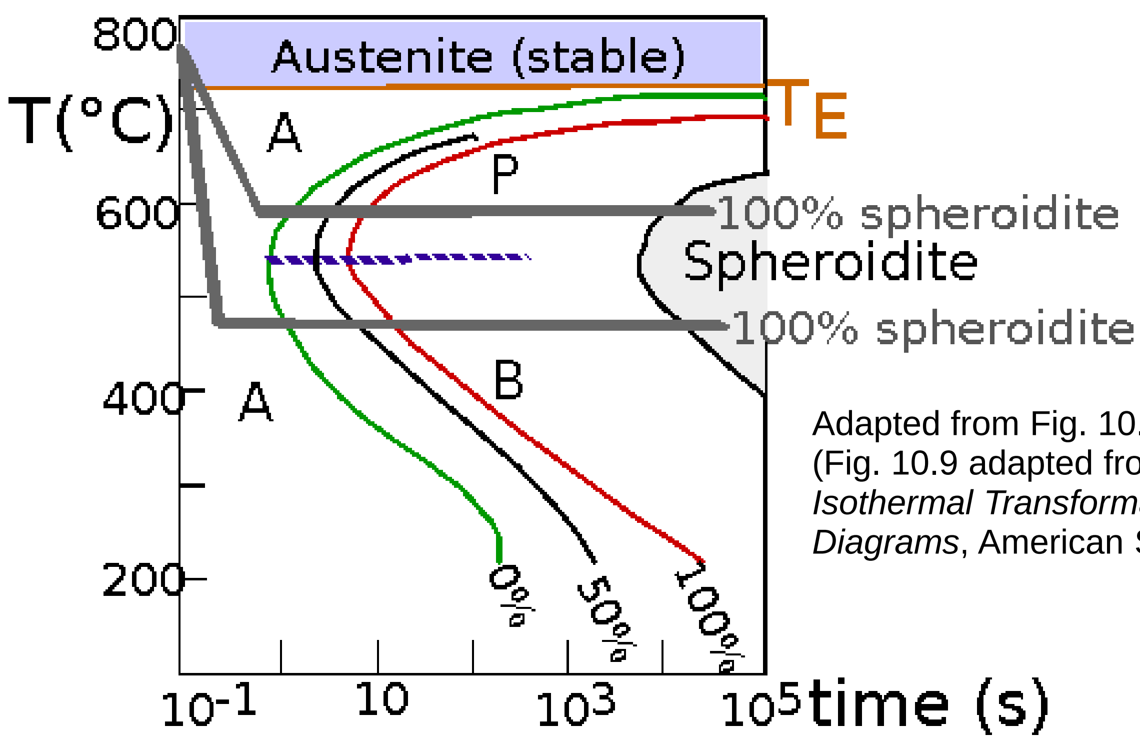
- Spheroidite:

--□ crystals with spherical Fe_3C
--diffusion dependent.
--heat bainite or pearlite for long times
--reduces interfacial area (driving force)

- Isothermal Transf. Diagram



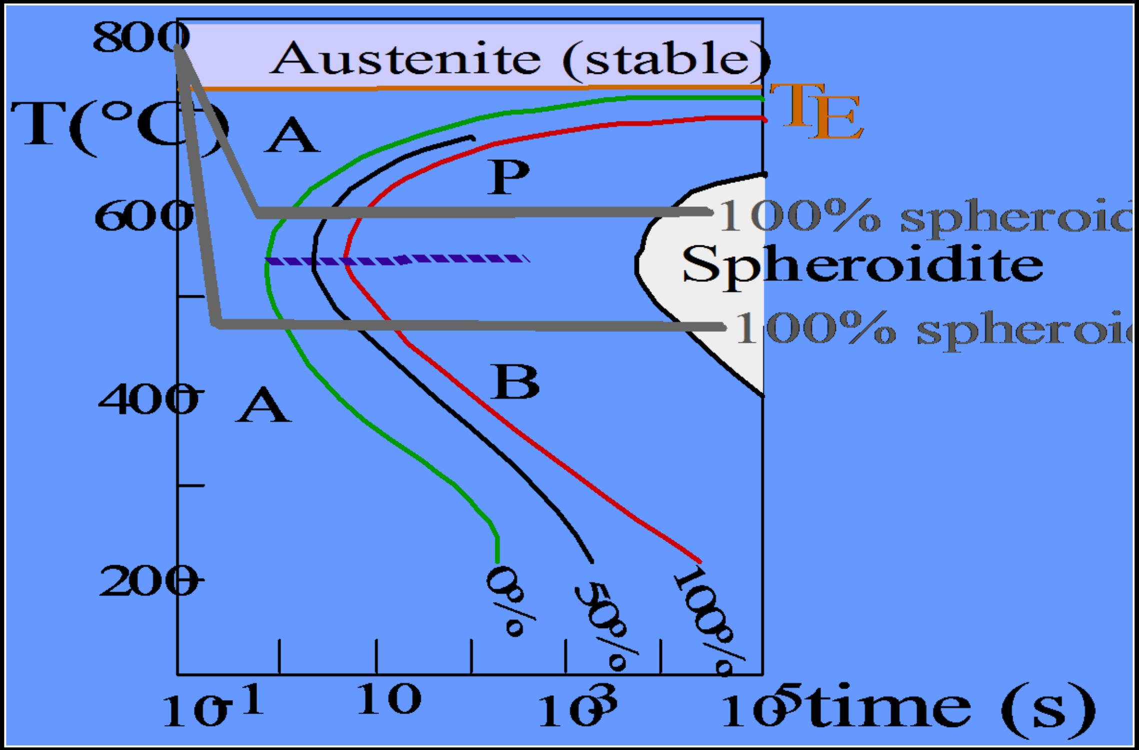
(Adapted from Fig. 10.10, *Callister, 6e*. (Fig. 10.10 copyright United States Steel Corporation, 1971.)

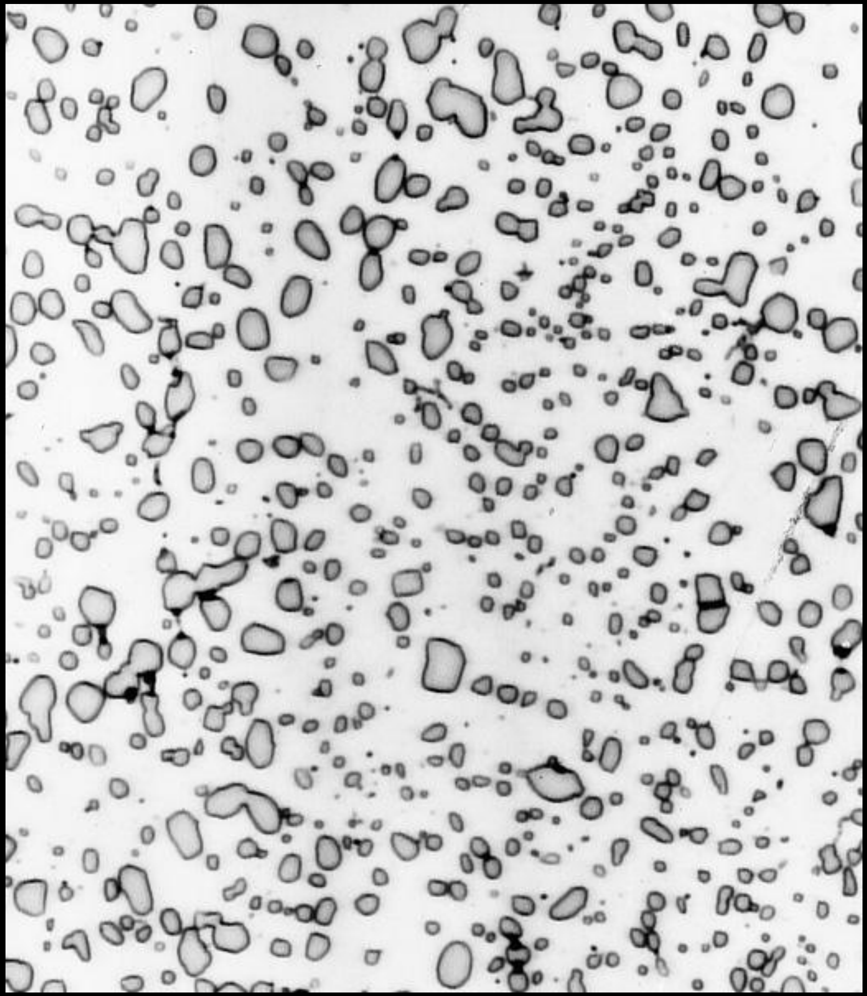


Adapted from Fig. 10.9,*Callister 6e*. (Fig. 10.9 adapted from H. Boyer (Ed.) *Atlas of Isothermal Transformation and Cooling Transformation Diagrams*, American Society for Metals, 1997, p. 28.)

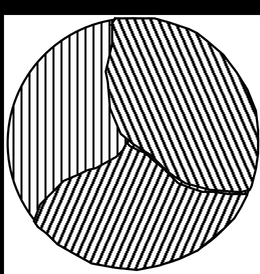
Spheroidite: Nonequilibrium Transformation

- Fe_3C particles within an α-ferrite matrix
- diffusion dependent
- heat bainite or pearlite at temperature just below eutectoid for long times
- driving force – reduction of α-ferrite/Fe_3C interfacial area

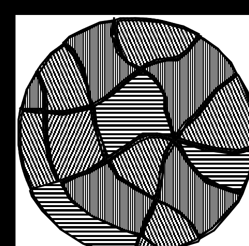




Coarse pearlite (high diffusion rate) and (b) fine pearlite



- Smaller ΔT: colonies are larger



- Larger ΔT: colonies are smaller

MECHANICAL PROPERTIES

Strength ↑

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

Ductility ↓

• Can control the formation of specific phases and microstructure through a cooling schedule so that desired properties result

SUMMARY: PROCESSING OPTIONS

Adapted from Fig. 10.27, *Callister 6e*.

Austenite (□)

slow cool → **Pearlite**
(□ + Fe_3C layers + a
proeutectoid phase)

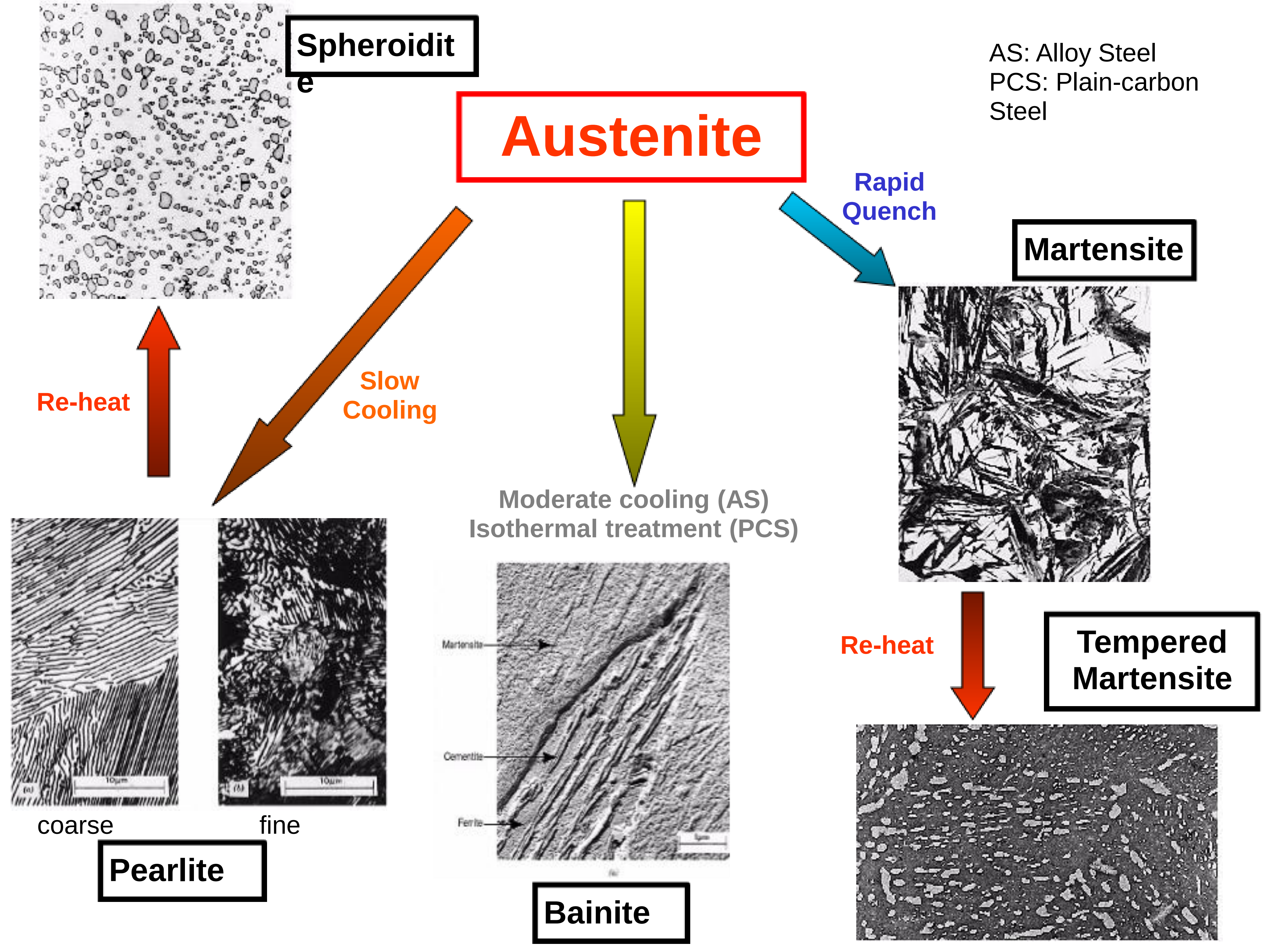
moderate cool → **Bainite**
(□ + Fe_3C plates/needles)

rapid quench → **Martensite**
(BCT phase
diffusionless
transformation)

reheat → **Tempered Martensite**
(□ + very fine
Fe_3C particles)

General Trends (Strength ↑, Ductility ↓):

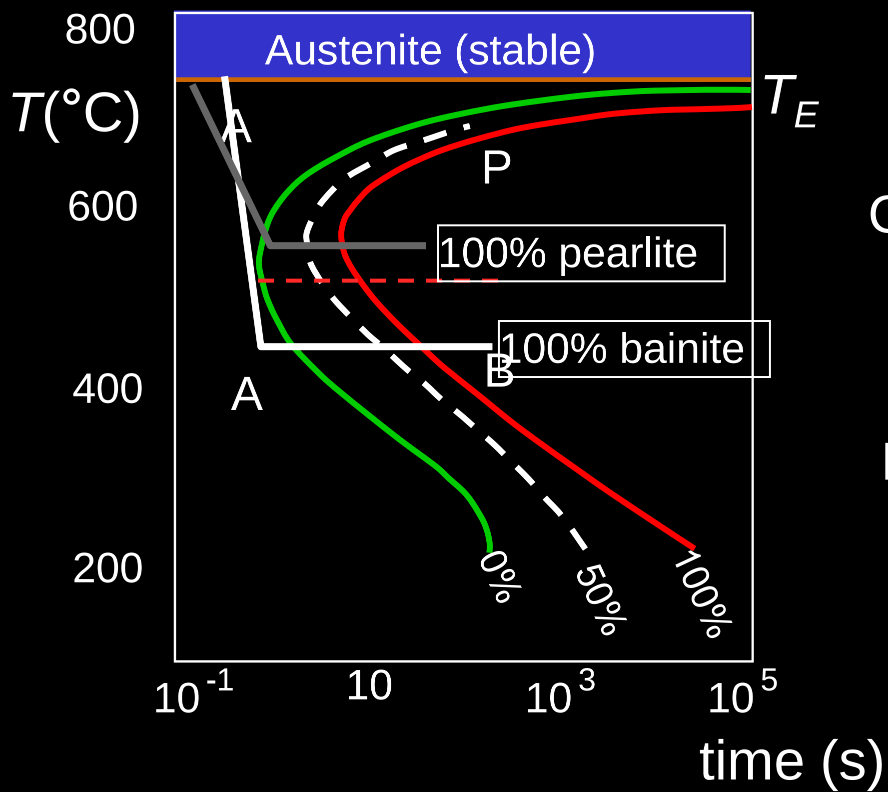
- Martensite
- T Martensite
- bainite
- fine pearlite
- coarse pearlite
- spheroidite

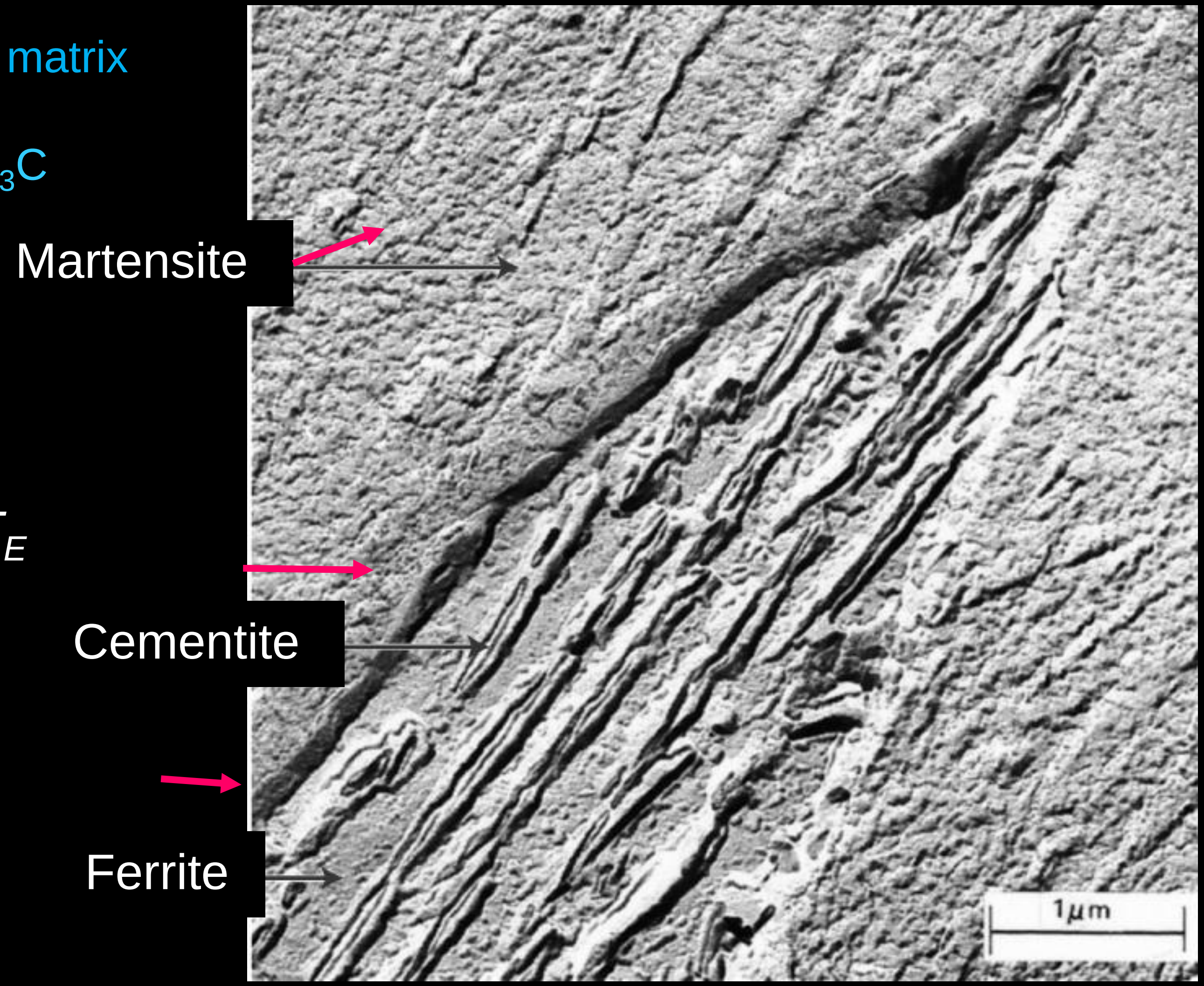


Spheroidite
Austenite
AS: Alloy Steel
PCS: Plain-carbon Steel
Rapid Quench
Martensite
Slow Cooling
Re-heat
Moderate cooling (AS)
Isothermal treatment (PCS)
Martensite
Cementite
Ferrite
coarse
fine
Pearlite
Bainite
Re-heat
Tempered Martensite

Bainite: Non-Equil Transformation Products

- elongated Fe_3C particles in α-ferrite matrix
- diffusion controlled
- α lathes (strips) with long rods of Fe_3C



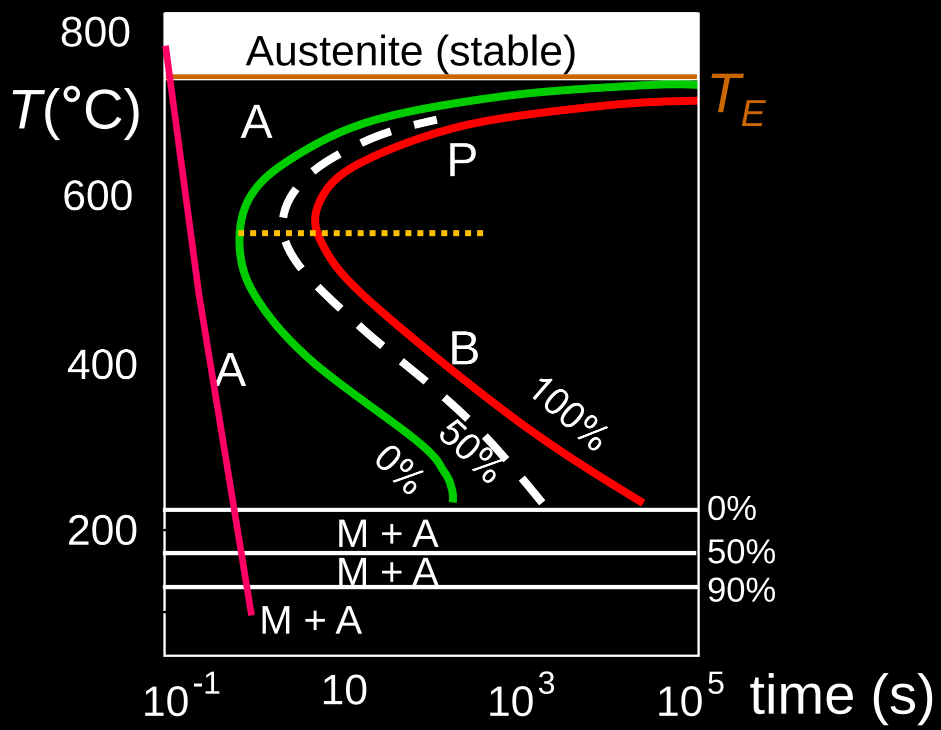


Bainite Microstructure

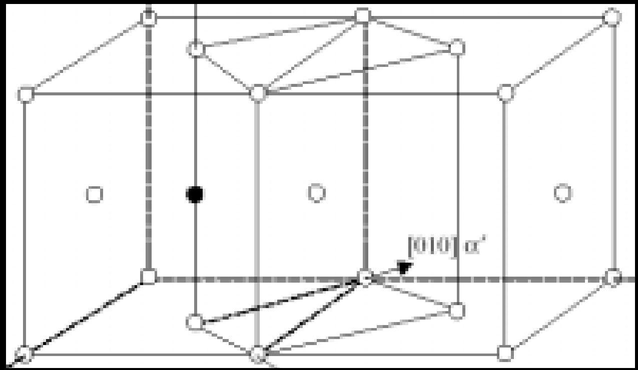
- Bainite consists of acicular (needle-like) ferrite with very small cementite particles dispersed throughout.
- The carbon content is typically greater than 0.1%.
- Bainite transforms to iron and cementite with sufficient time and temperature (considered semi-stable below 150°C).

Martensite Formation

- Isothermal Transformation Diagram



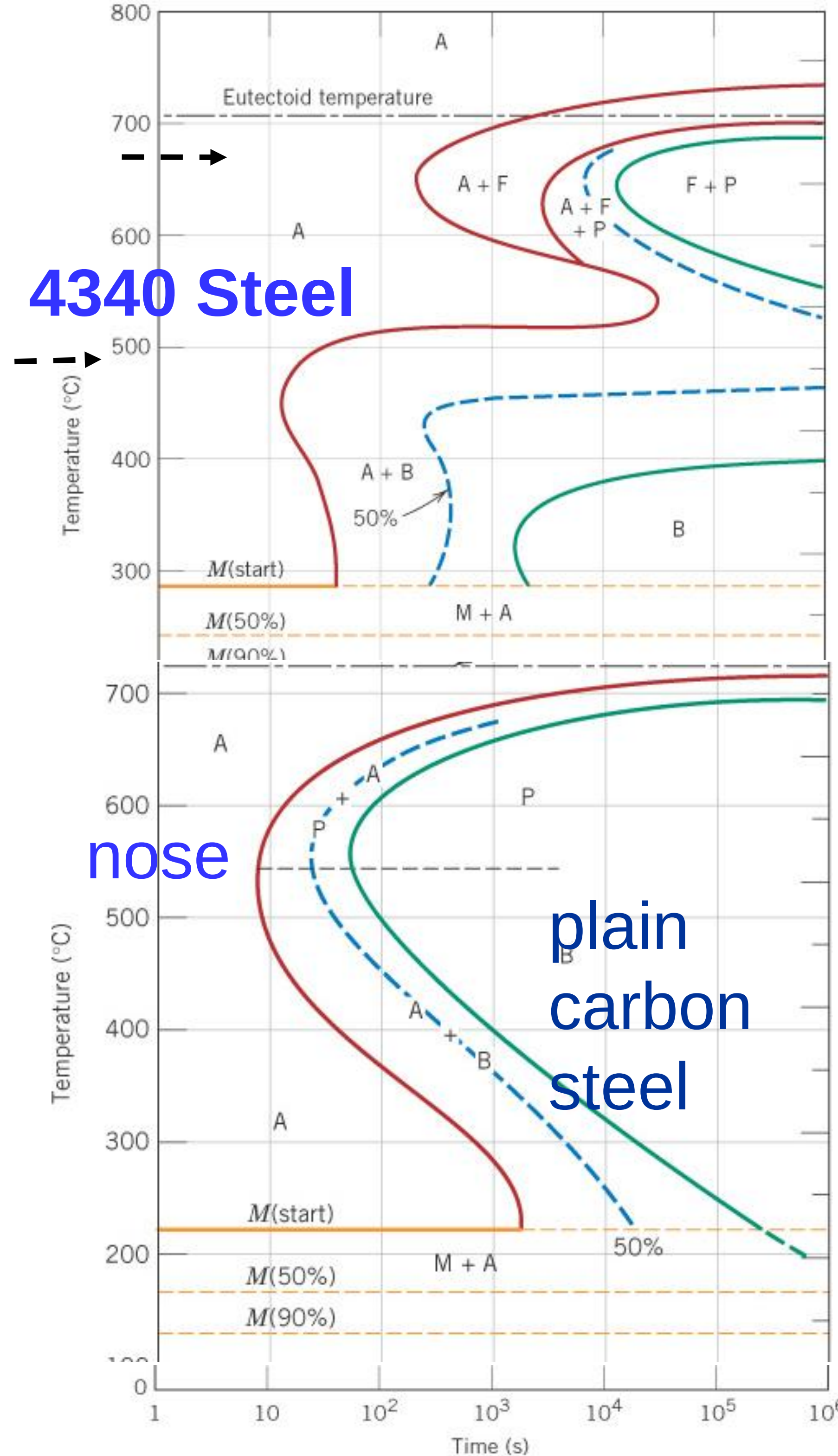
Martensite needles
Austenite



- ❑ single phase
- ❑ body centered tetragonal (BCT) crystal structure
- ❑ BCT if C_0 > 0.15 wt% C
- ❑ Diffusionless transformation
- ❑ BCT → few slip planes → hard, brittle
- ❑ % transformation depends only on T of rapid cooling

Effect of Adding Other Elements

- Other elements (Cr, Ni, Mo, Si and W) may cause significant changes in the positions and shapes of the TTT curves:
- Change transition temperature;
- Shift the nose of the austenite-to-pearlite transformation to longer times;
- Shift the pearlite and bainite noses to longer times (decrease critical cooling rate);
- Form a separate bainite nose;



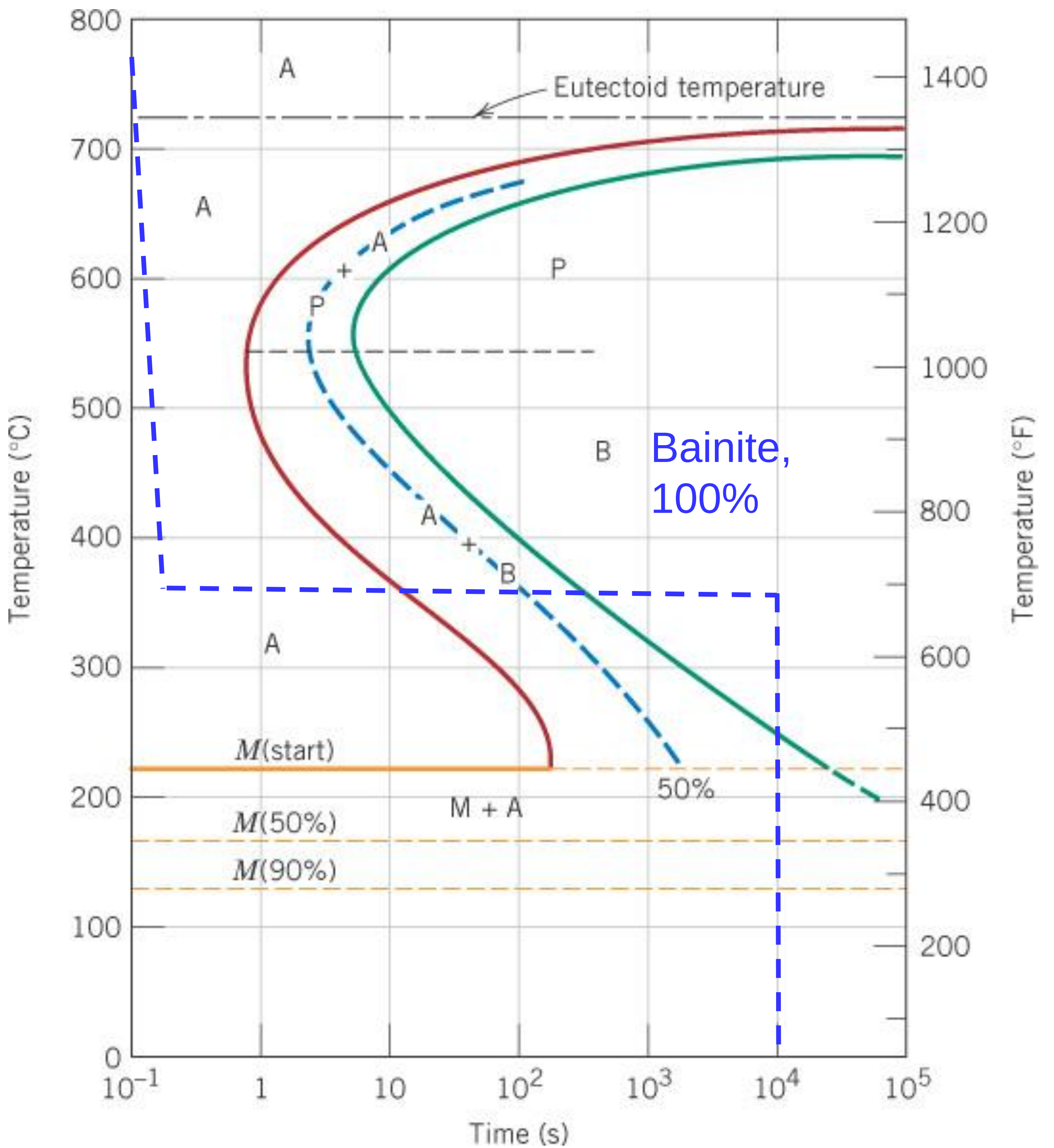
- Plain carbon steel: primary alloying element is carbon.

Example 11.2:

- Iron-carbon alloy with eutectoid composition.
- Specify the nature of the final microstructure (% bainite, martensite, pearlite etc) for the alloy that is subjected to the following time–temperature treatments:
- Alloy begins at 760˚C and has been held long enough to achieve a complete and homogeneous austenitic structure.

Treatment (a)

- Rapidly cool to 350 ˚C
- Hold for 10^4 seconds
- Quench to room temperature



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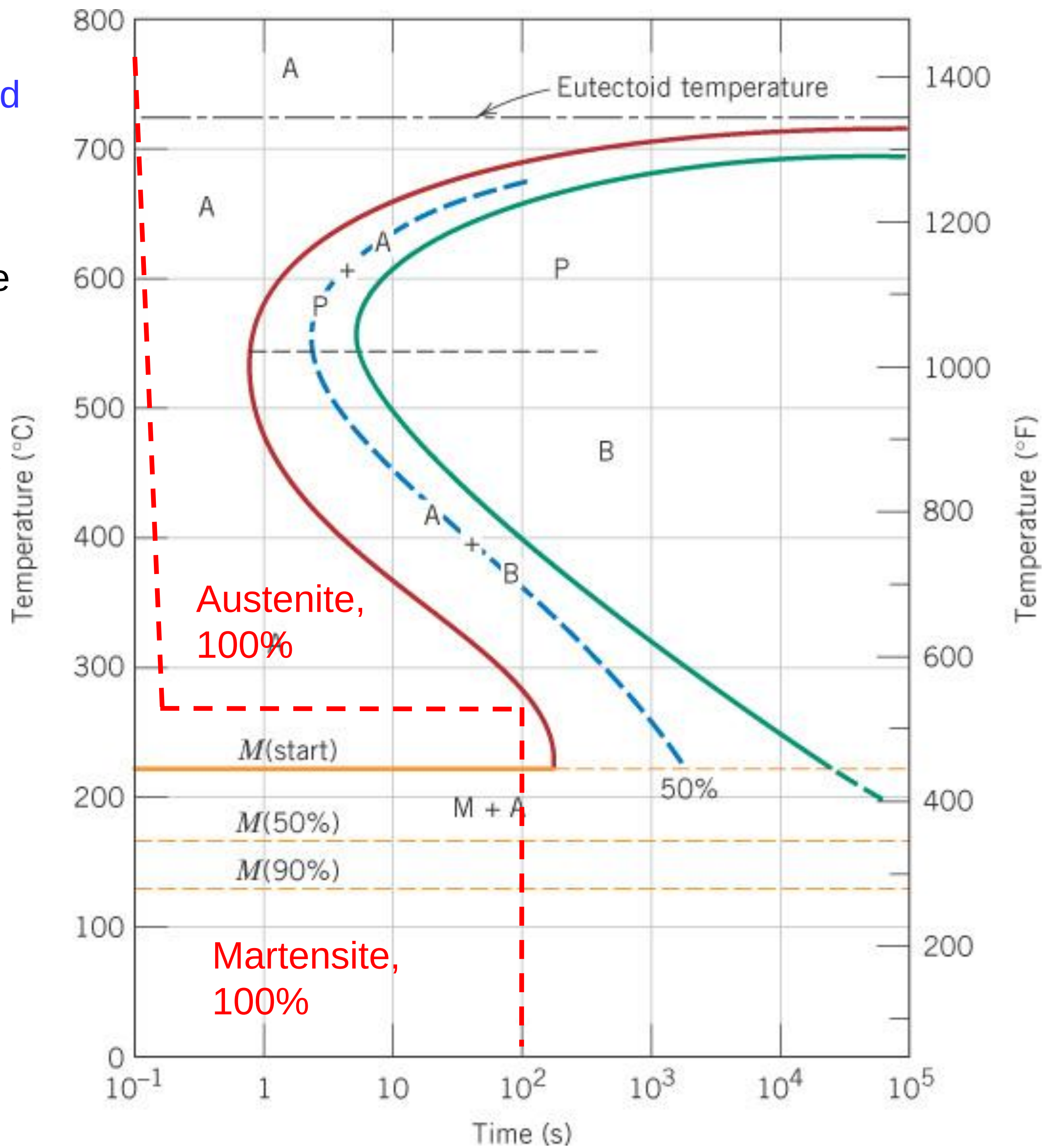
Treatment (b)

- Rapidly cool to 250 ˚C
- Hold for 100 seconds
- Quench to room temperature



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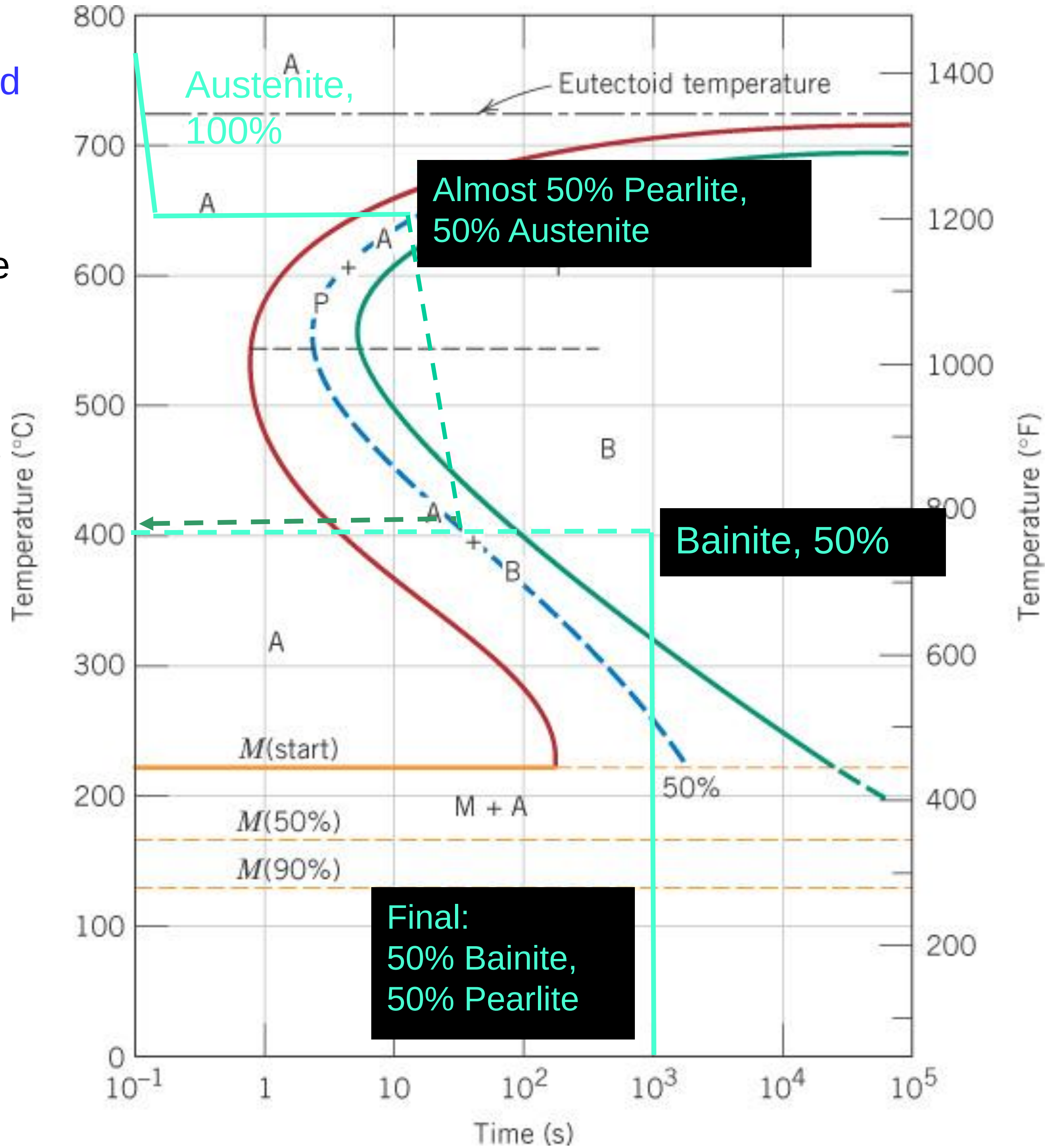
- Alloy begins at 760˚C and has been held long enough to achieve a complete and homogeneous austenitic structure.

Treatment (c)

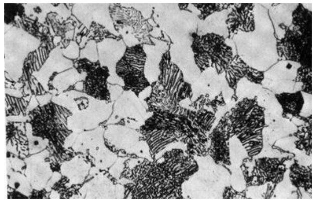
- Rapidly cool to 650˚C
- Hold for 20 seconds
- Rapidly cool to 400˚C
- Hold for 10^3 seconds
- Quench to room temperature

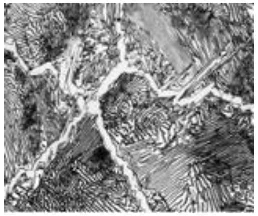


Mechanical Properties: Influence of Carbon Content

Pearlite (med)

ferrite (soft)





Pearlite (med)

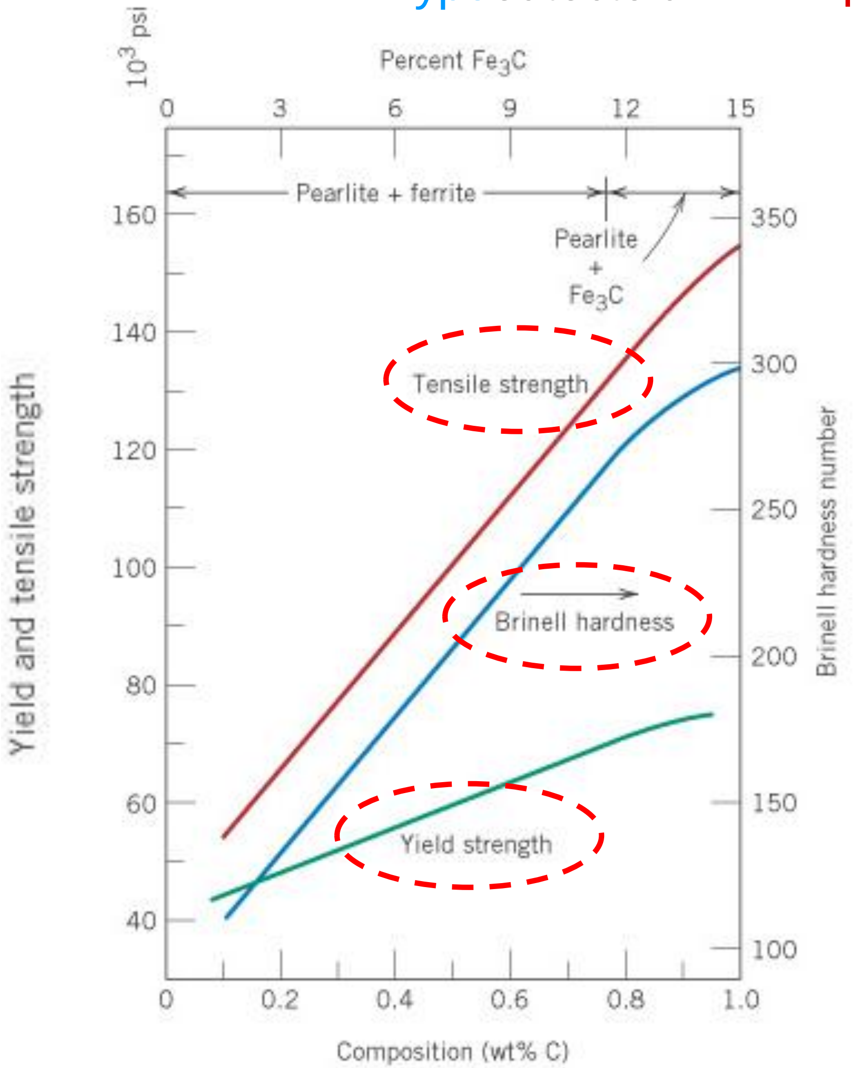
Cementite (hard)

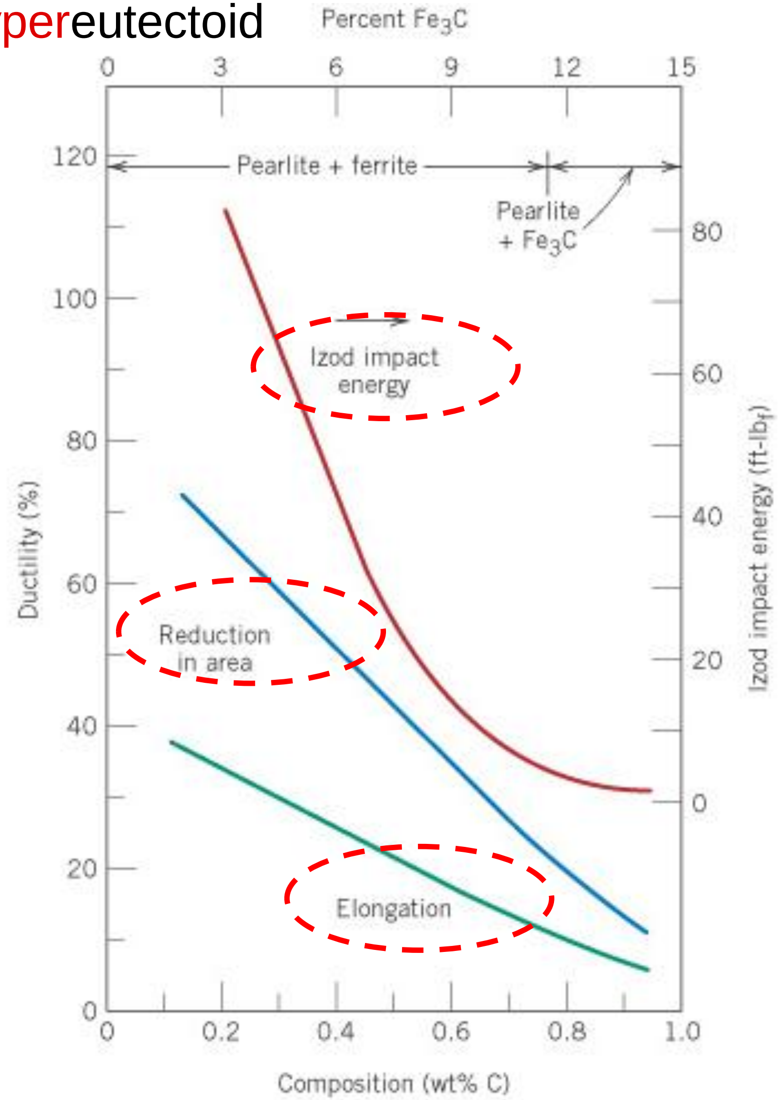
$C_0 < 0.76$ wt% C

Hypoeutectoid

$C_0 > 0.76$ wt% C

Hypereutectoid





Hardness as a function of carbon concentration for steels