Chapter5

Phase Transformation

Part III

강의명: 기계재료공학 (MFA9009)

정영웅

창원대학교 신소재공학부

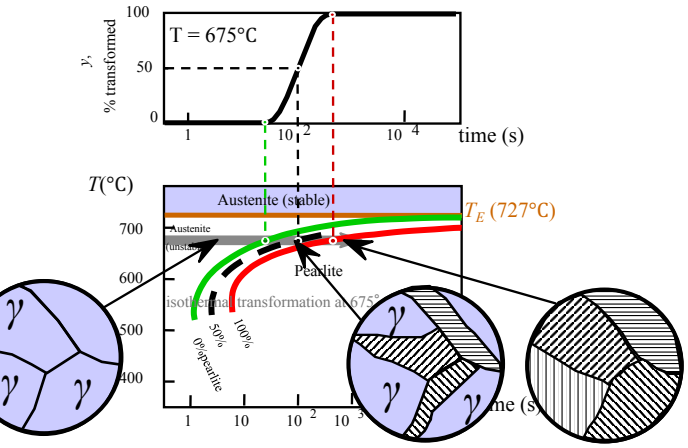
YJEONG@CHANGWON.AC.KR

연구실: #52-208 전화: 055-213-3694

HOMEPAGE: HTTP://YOUNGUNG.GITHUB.IO

Recap

- 등온 변태도: γ-austenite → α-Ferrite + Fe_3C eutectic reaction의 예로 살펴봄



From K. M. Ralls et al., An Introduction to Materials Sci John Wiley & Sons, New York. Reprinted by permissior

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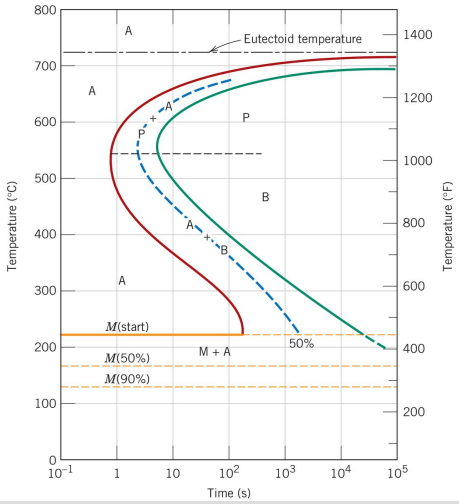
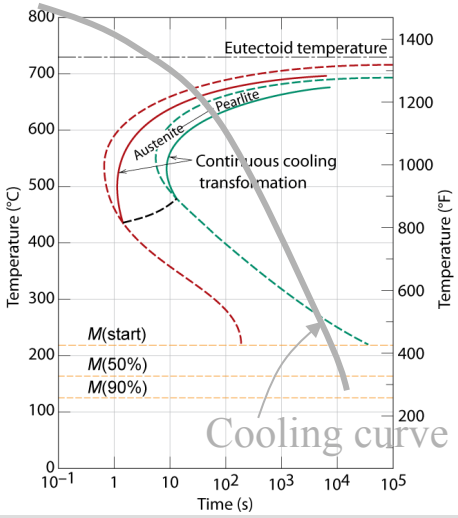
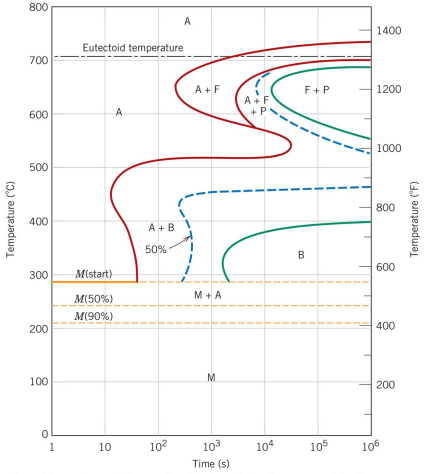
미세 pearlite

조대 pearlite







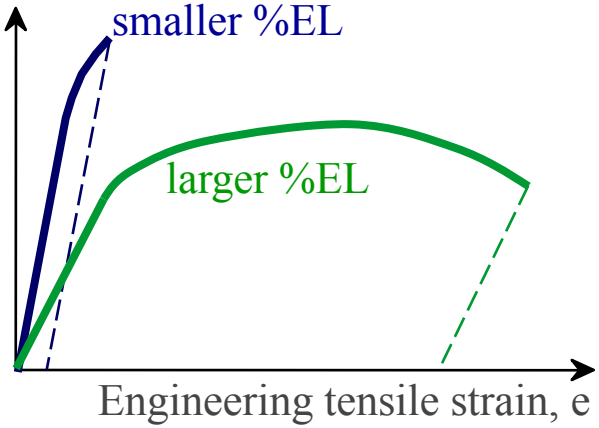
Adapted from H. Boyer (Editor), Atlas of Isothermal Transformation and Cooling Transformation Diagrams, 1977. Reproduced by permission of ASM International, Materials Park, OH.

Outline

- 지금까지 논의해온 미세조직: 펄라이트(pearlite), 스페로이다이트(spheroidite), 베이나이트(bainite), 마텐사이트(martensite)
- 위 구조들을 갖는 Fe-C 합금(alloy)의 기계적 성질에 대해 논의해 볼것이다.
- 기계적 성질 review:
  - Yield stress
  - Ductility
  - Hardness
  - Toughness

기계적 성질 review

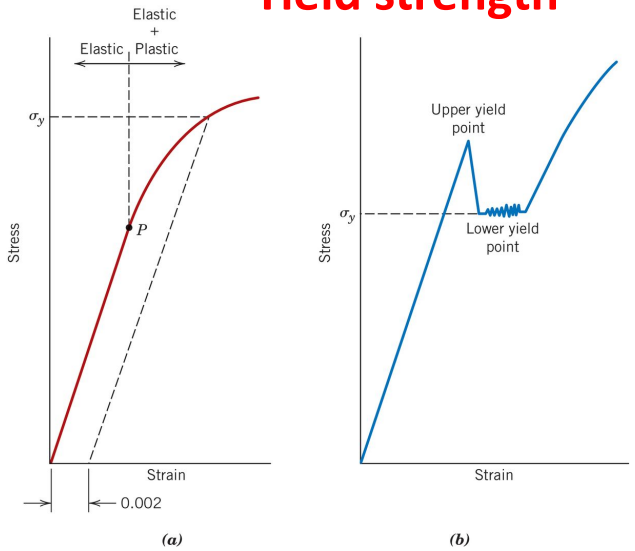
Ductility



Engineering tensile stress, σ

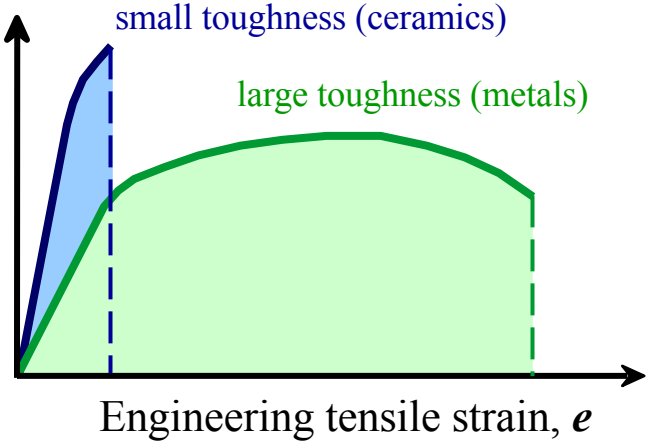
Adapted from Fig. 8.13, Callister & Rethwisch 9e.

Yield strength

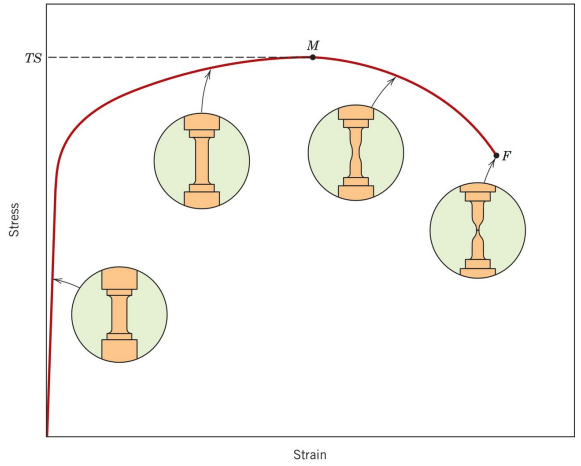


Toughness

Engineering tensile stress, σ



Tensile strength



Pearlite

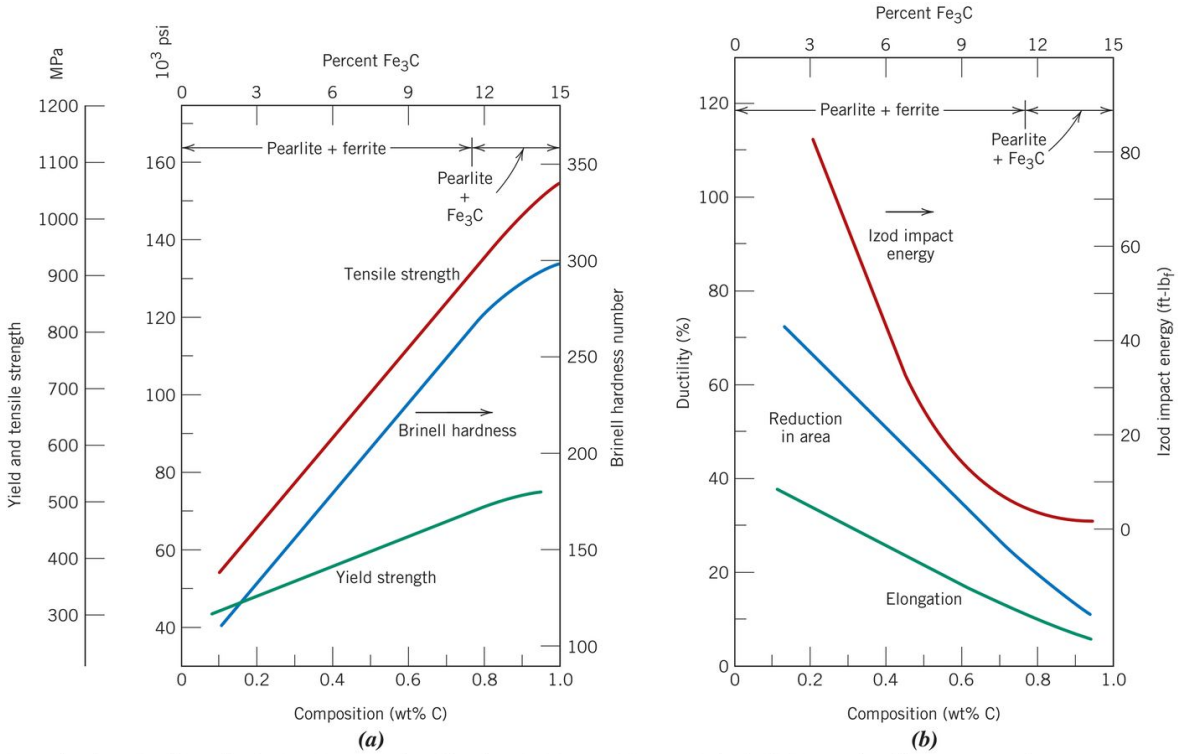
$\text{Hardness}^{Fe_3C} > \text{Hardness}^{\alpha}$ (Brinell, Rockell)

$\text{Strength}^{Fe_3C} > \text{Strength}^{\alpha}$ (TS, YS 포함)

$\text{Ductility}^{Fe_3C} < \text{Ductility}^{\alpha}$ (%RA, %EL)

$\text{Toughness}^{Fe_3C} < \text{Toughness}^{\alpha}$ (energy)

- Cementite의 분율을 carbon의 농도로 표현(ferrite/cementite 중 Carbon은 cementite에만 존재)



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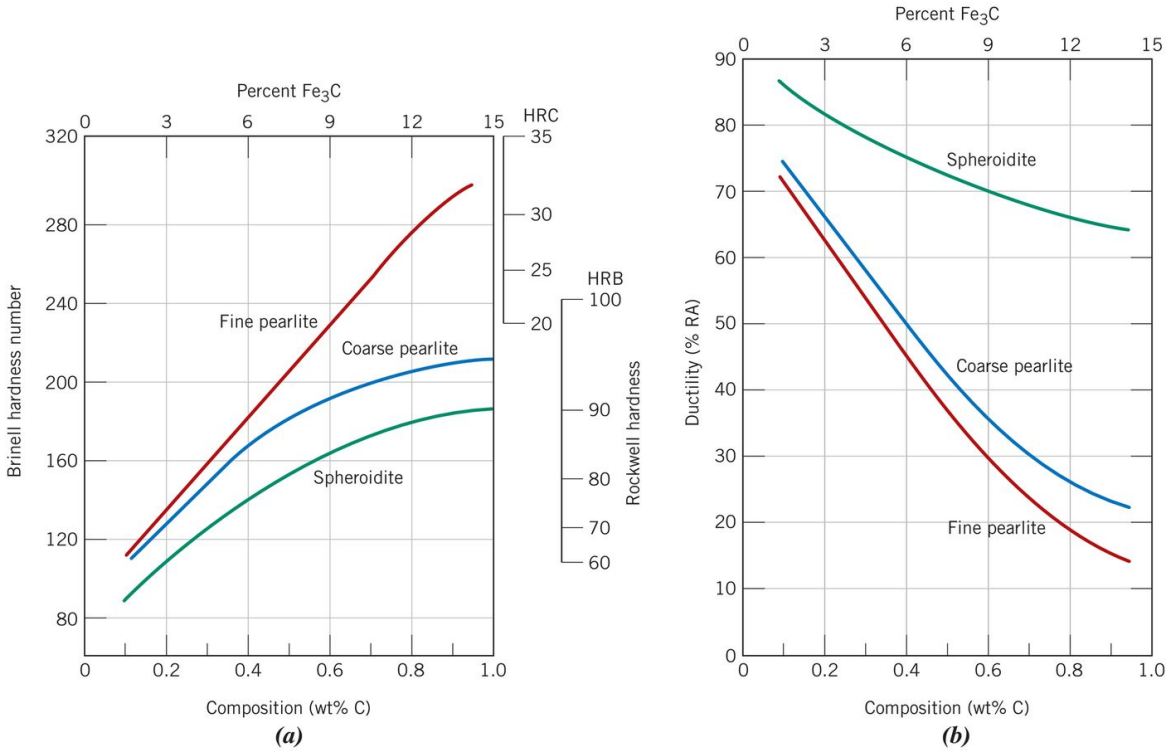
Pearlite and Spheroidite

$$\text{Hardness}^{\text{Fine Pearlite}} > \text{Hardness}^{\text{Coarse Pearlite}} > \text{Hardness}^{\text{Spheroidite}}$$
$$\text{Strength}^{\text{Fine Pearlite}} > \text{Strength}^{\text{Coarse Pearlite}} > \text{Strength}^{\text{Spheroidite}}$$

$$\text{Ductility}^{\text{Fine Pearlite}} < \text{Ductility}^{\text{Coarse Pearlite}} < \text{Ductility}^{\text{Spheroidite}}$$
$$\text{Toughness}^{\text{Fine Pearlite}} < \text{Toughness}^{\text{Coarse Pearlite}} < \text{Toughness}^{\text{Spheroidite}}$$

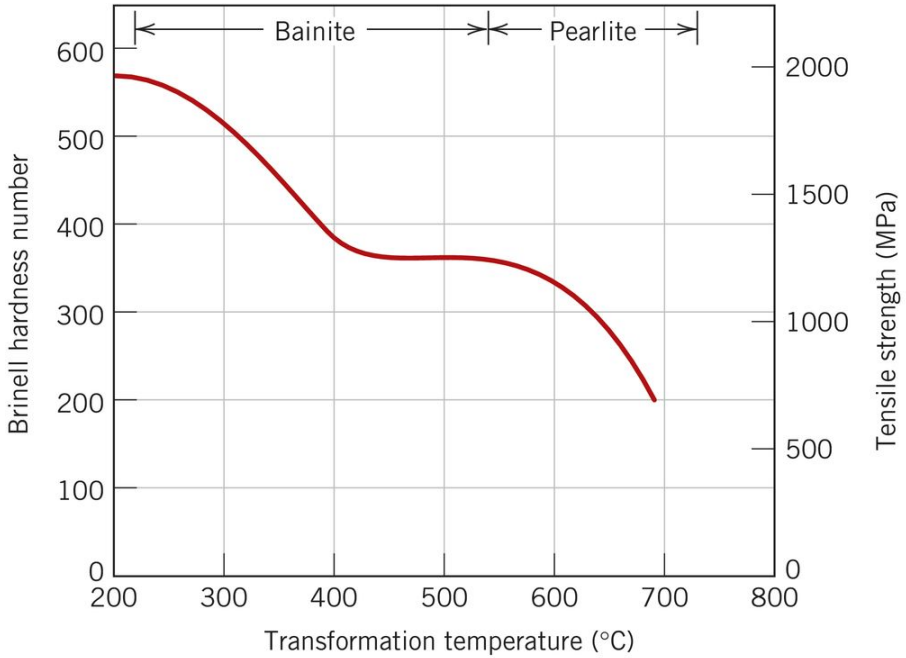
- Cementite의 분율을 carbon의 농도로 표현(ferrite/cementite 중 Carbon은 cementite에만 존재)



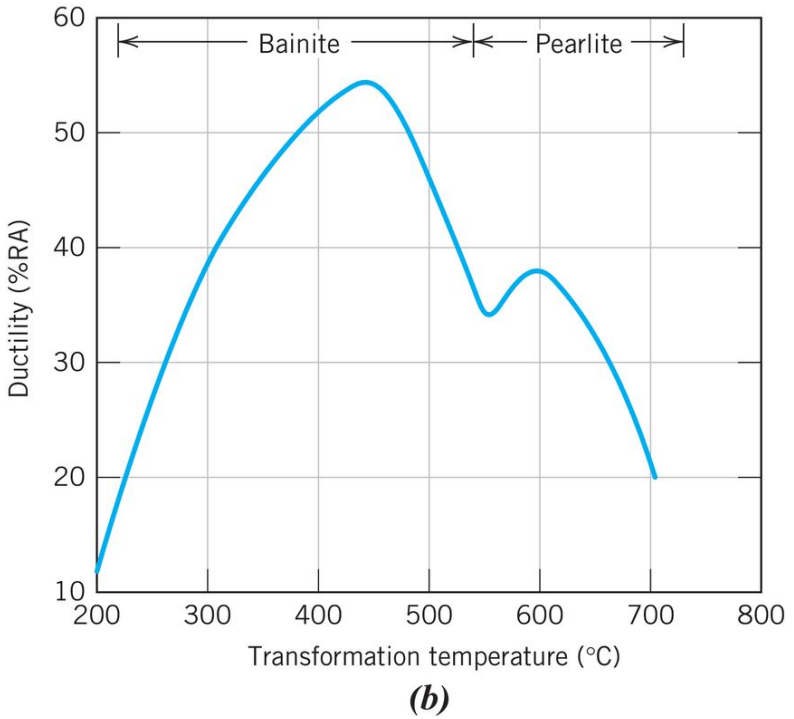
Data taken from Metals Handbook: Heat Treating, Vol. 4, 9th edition, V. Masseria (Managing Editor), 1981. Reproduced by permission of ASM International, Materials Park, OH.

Bainite

- Bainite는 ferrite나 cementite보다 더 미세한 구조 – 전자현미경으로만 관찰가능
- 일반적으로 pearlite보다 강도와 경도가 높다. 그리고 적당한 강도와 연성을 가짐



(a)

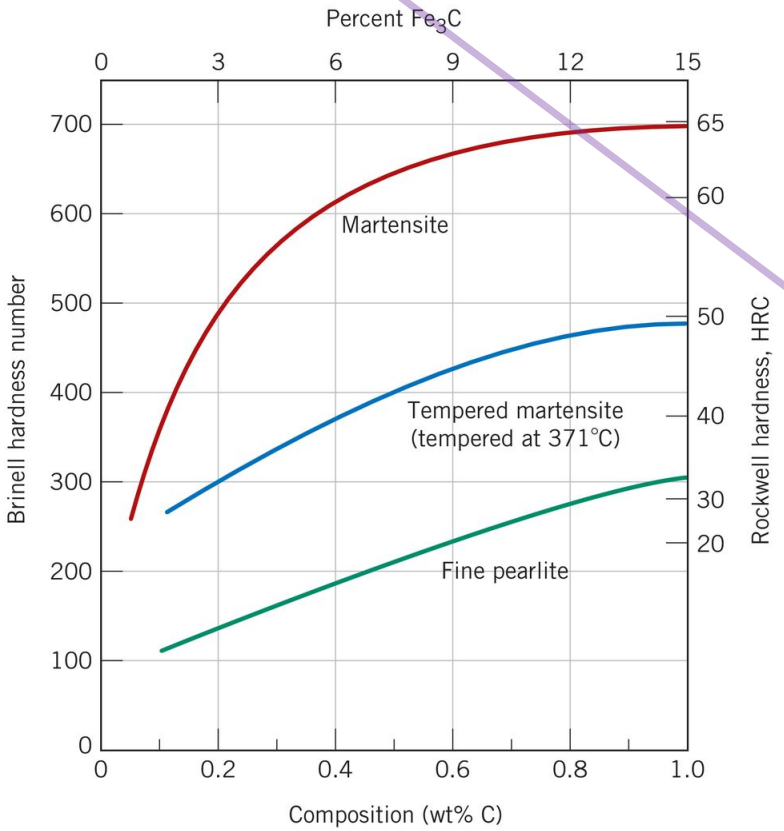


(b)

Figure (a) Adapted from E. S. Davenport, "Isothermal Transformation in Steels," Trans. ASM, 27, 1939, p. 847. Reprinted by permission of ASM International, Materials Park, OH.

Martensite

- Fe-C 합금 시스템에서 얻어지는 미세조직 중 가장 단단하고 강하다. 또한 가장 brittle하고 연성이 거의 없다.



Adapted from Edgar C. Bain, Functions of the Alloying Elements in Steel, 1939; and R. A. Grange, C. R. Hribal, and L. F. Porter, Metall. Trans. A, Vol. 8A. Reproduced by permission of ASM International, Materials Park, OH.

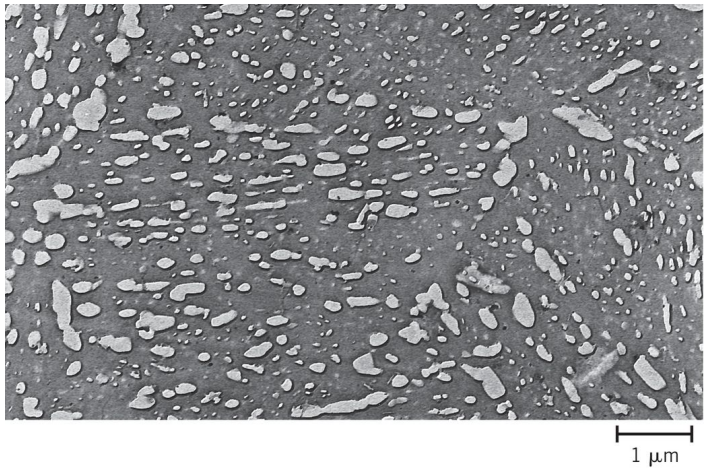
- 침입형 탄소 원자의 전위 이동 방해
- BCT 구조에 slip system이 적은 점

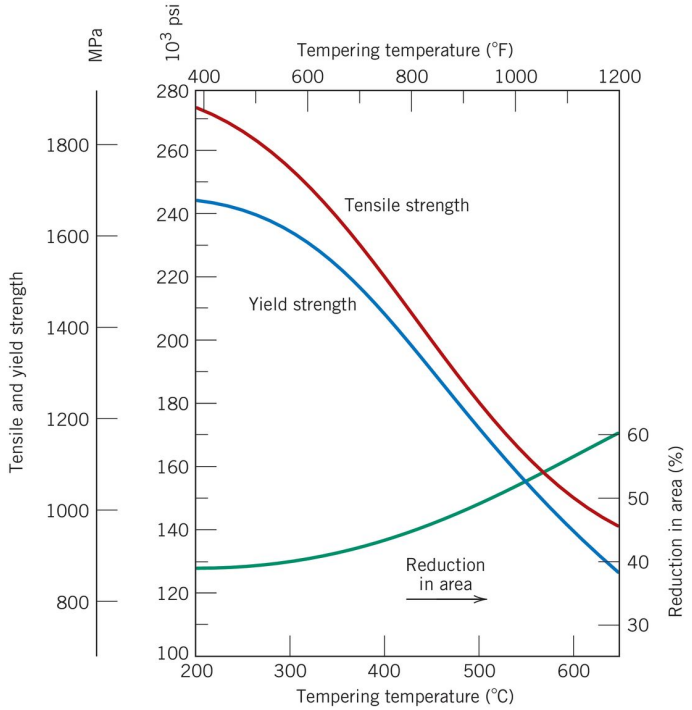
연성이 거의 없어서 대부분의 응용에 부적합할 수 있다. 따라서 Martensite 상을 가진 합금을 사용하기 위해서는 연성을 높이기 위한 열처리가 필요하다.

Tempered martensite

- Tempering (뜨임) – 내부의 응력을 제거하고, 마텐사이트의 연성과 인성을 증가시키기 위한 열처리. 특정 시간 동안 eutectic temperature 이하에서 가열하는 열처리. 일반적으로 250 °C ~ 650 °C 사이에서 수행한다. 마텐사이트 기저(base)에 존재하는 탄소 원자의 확산 발생. 탄소 원자는 해당 온도 구간에서의 평형상인 cementite로 바뀐다. 다만 그 사이즈가 spheroidite에 존재하는 구상 cementite에 비교하여 매우 작다.

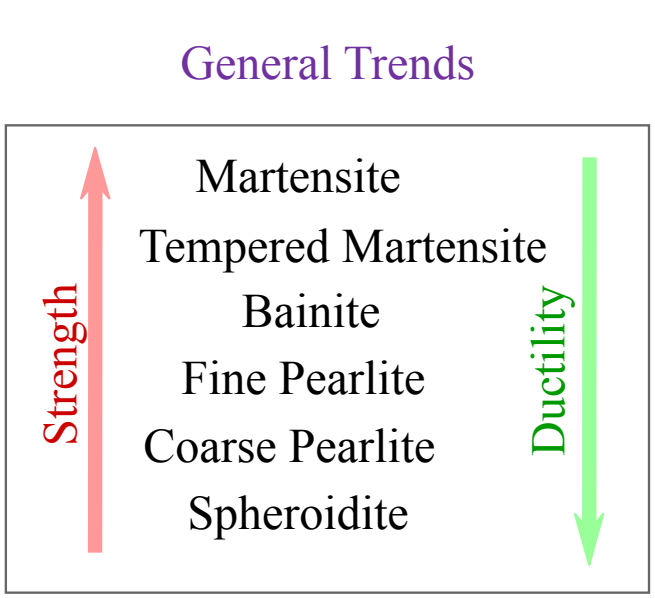
템퍼링 효과
경도와 강도가 약간 줄어드는 대신에 인성과 연성이 현저히 향상된다.

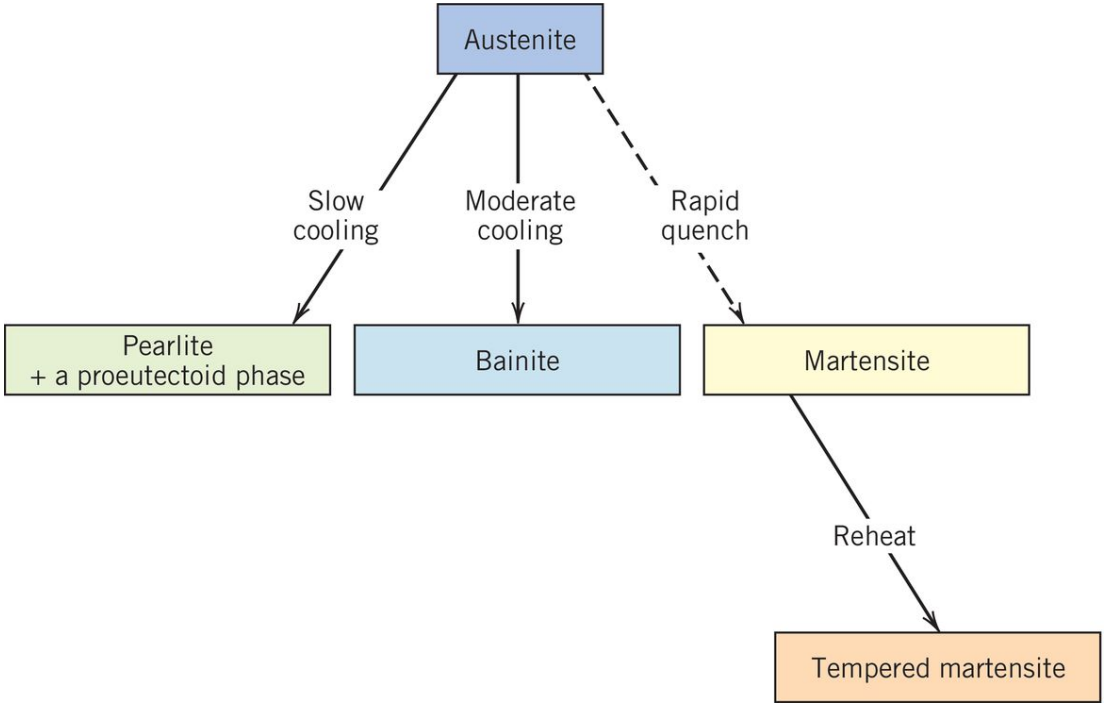




Adapted from Edgar C. Bain, Functions of the Alloying Elements in Steel, 1939. Reproduced by permission of ASM International, Materials Park, OH.

오스테나이트 기저(base)에서 얻을 수 있는 다양한 미세조직





M-Str. And Mech. Props. Summary: Table 12.2

Table 12.2 Microstructures and Mechanical Properties for Iron–Carbon Alloys

Microconstituent	*Phases Present*	*Arrangement of Phases*	*Mechanical Properties (Relative)*
Spheroidite	α-Ferrite + Fe_3C	Relatively small Fe_3C spherelike particles in an α-ferrite matrix	Soft and ductile
Coarse pearlite	α-Ferrite + Fe_3C	Alternating layers of α-ferrite and Fe_3C that are relatively thick	Harder and stronger than spheroidite, but not as ductile as spheroidite
Fine pearlite	α-Ferrite + Fe_3C	Alternating layers of α-ferrite and Fe_3C that are relatively thin	Harder and stronger than coarse pearlite, but not as ductile as coarse pearlite
Bainite	α-Ferrite + Fe_3C	Very fine and elongated particles of Fe_3C in an α-ferrite matrix	Harder and stronger than fine pearlite; less hard than martensite; more ductile than martensite
Tempered martensite	α-Ferrite + Fe_3C	Very small Fe_3C spherelike particles in an α-ferrite matrix	Strong; not as hard as martensite, but much more ductile than martensite
Martensite	Body-centered, tetragonal, single phase	Needle-shaped grains	Very hard and very brittle