Chapter5

Phase Transformation

Part III

강의명: 기계재료공학 (MFA9009)

정영웅

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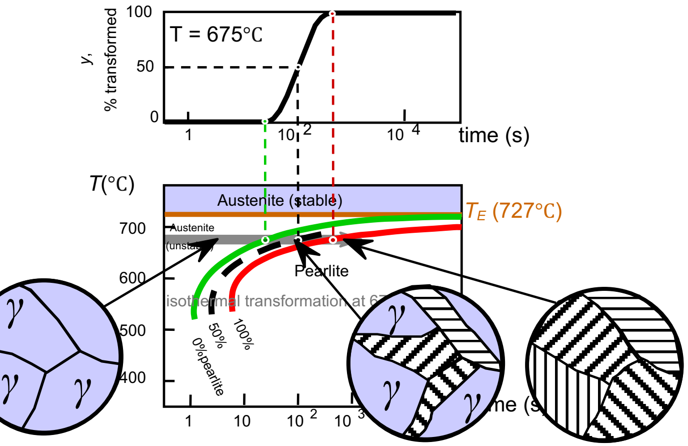
Recap

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



From K. M. Ralls et al., An Introduction to Materials Sci
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조대
pearlite

and Engineering, p. 361. Copyright © 1976 by
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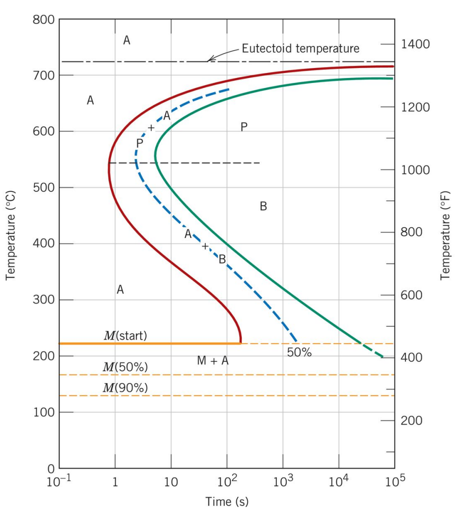
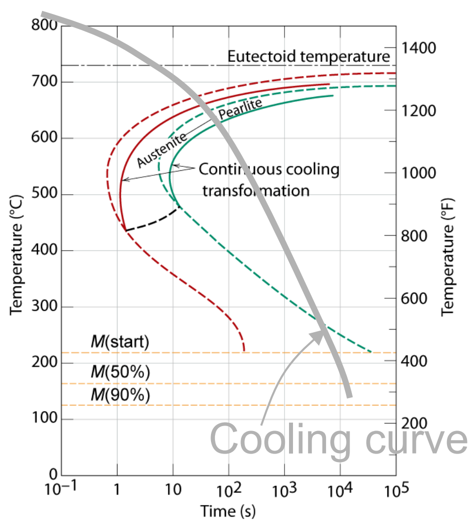
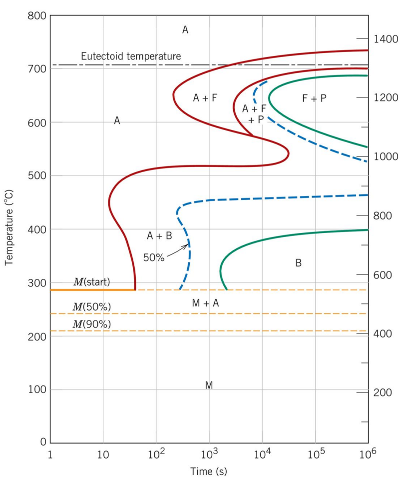
미세
pearlite







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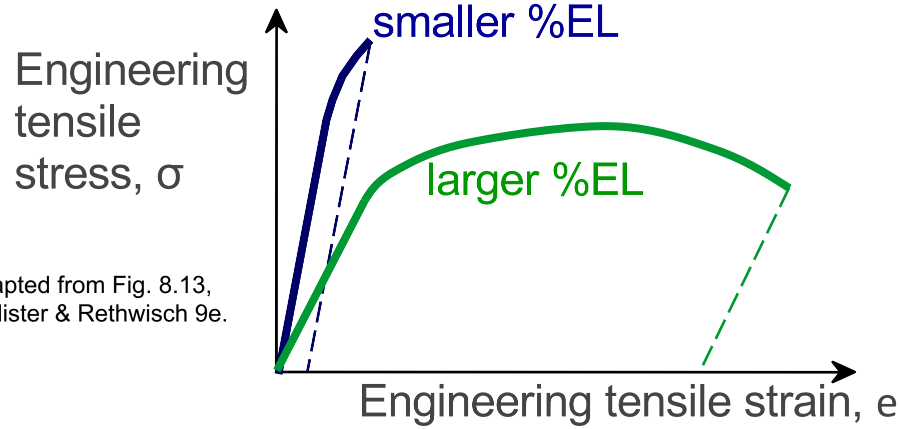
Outline

- 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

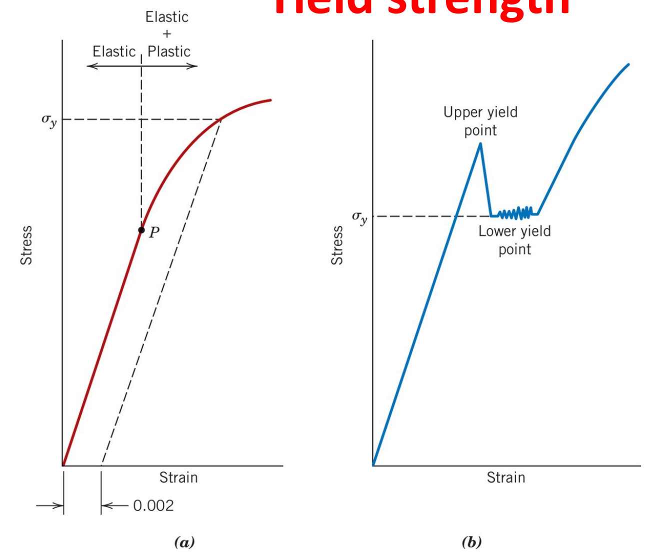
기계적 성질 review

Ductility

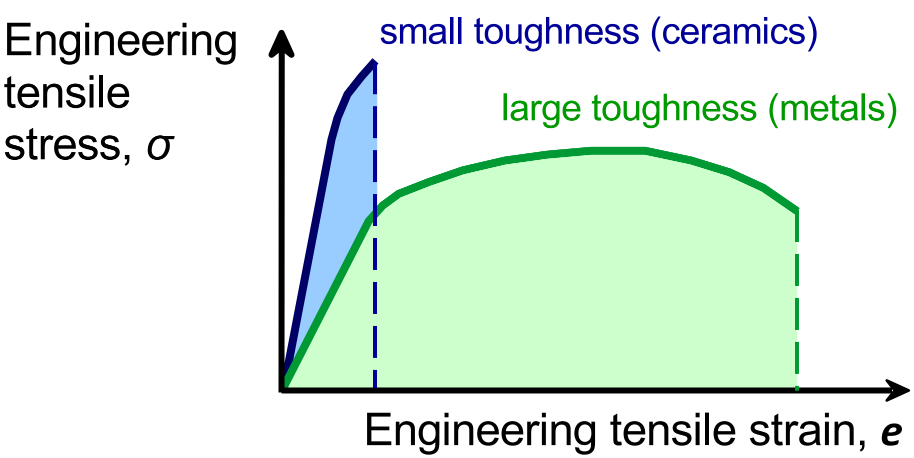


Adapted from Fig. 8.13, Callister & Rethwisch 9e.

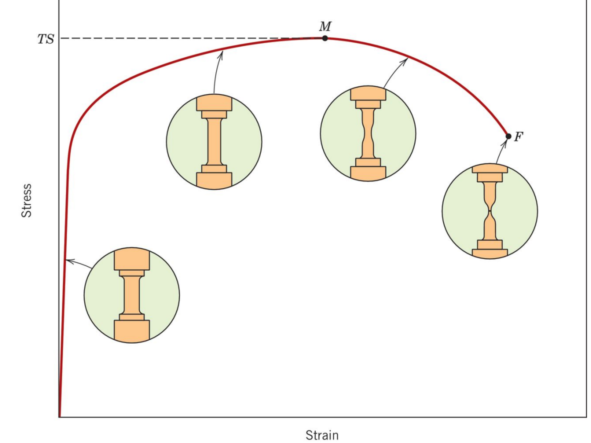
Yield strength



Toughness



Tensile strength

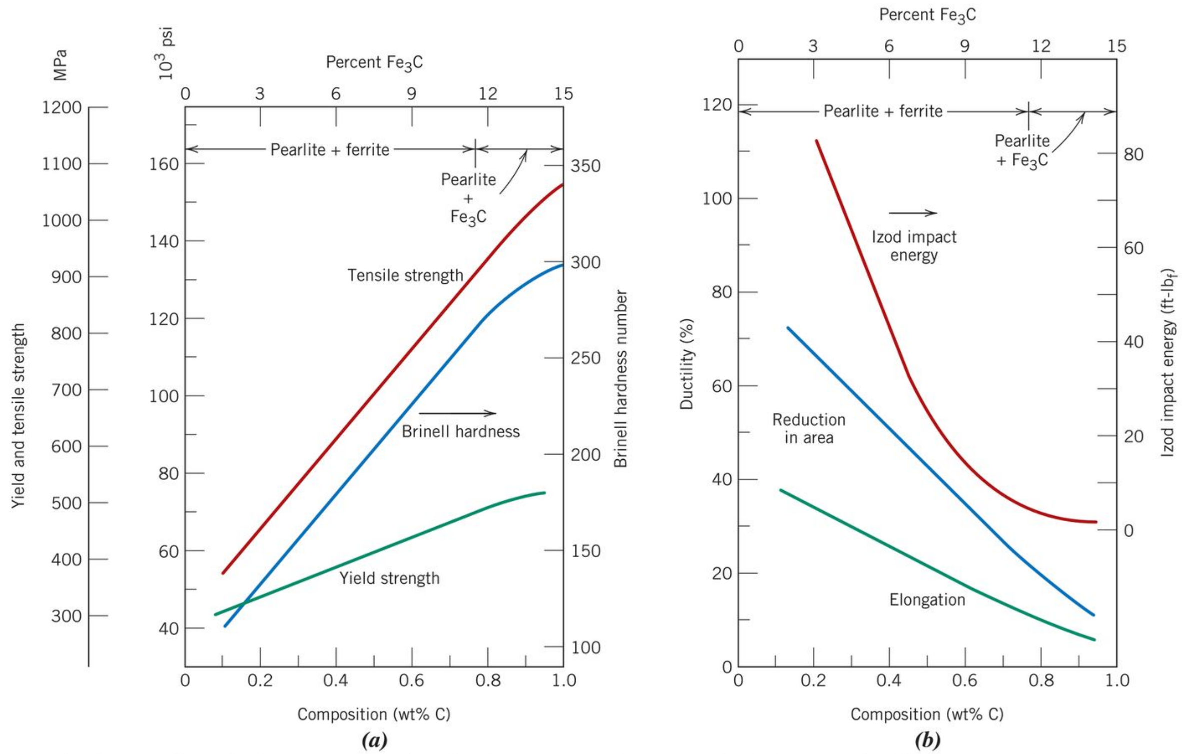


Pearlite

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

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

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



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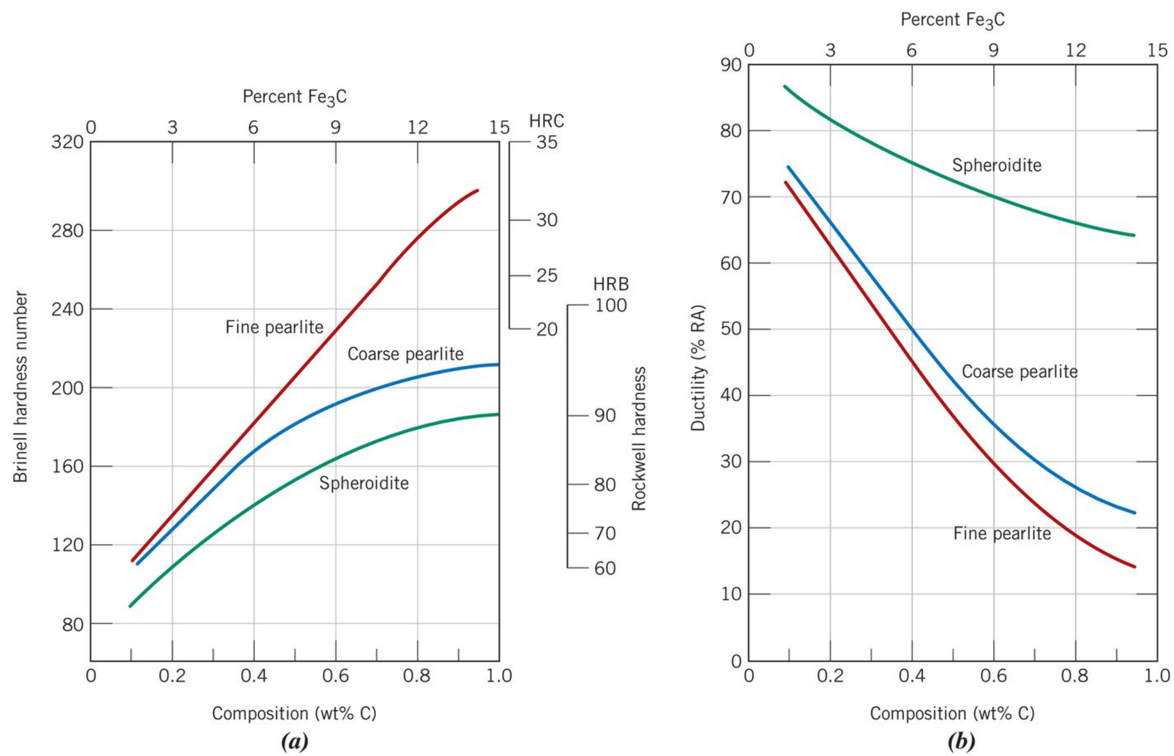
Pearlite and Spheroidite comparison

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

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

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



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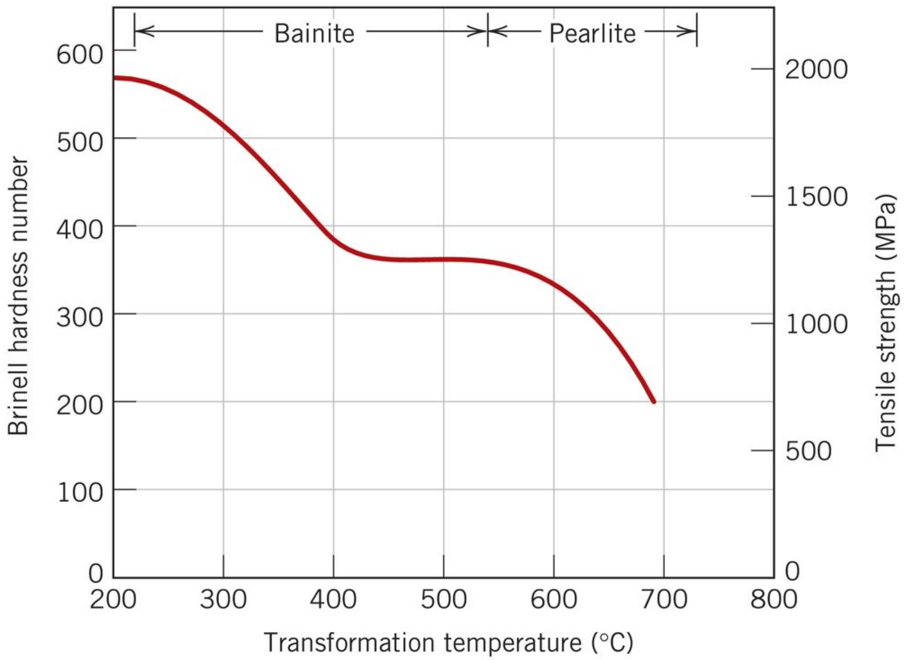
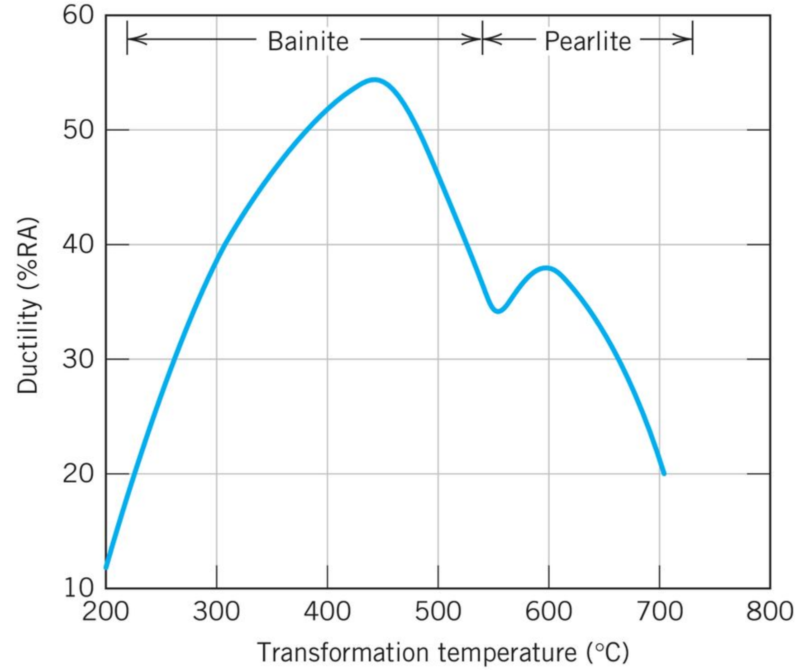
Bainite

- Bainite는 ferrite나 cementite보다 더 미세한 구조 – 전자현미경으로만 관찰 가능
- 일반적으로 pearlite보다 강도(strength)와 경도(hardness)가 높다. 그리고 적당한 강도와 연성(ductility)을 가짐



(a)

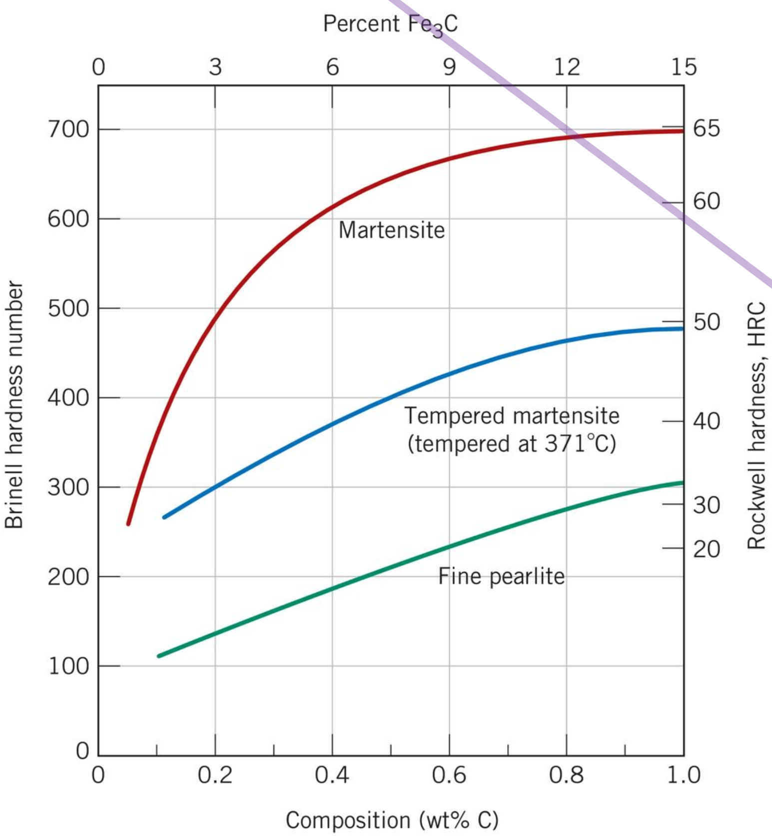
Figure (a) Adapted from E. S. Davenport, "Isothermal Transformation in Steels," Trans. ASM, 27, 1939, p. 847. Reprinted by permission of ASM International, Materials Park, OH.



(b)

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.

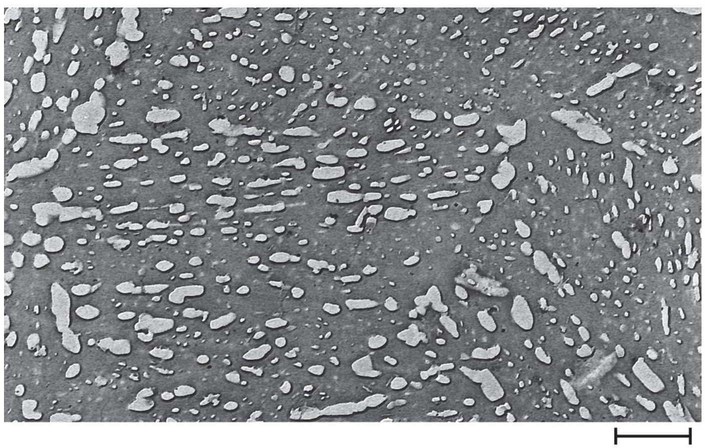
- 침입형 탄소 원자의 전위 이동 방해
- BCT 구조에 slip system이 적은 점

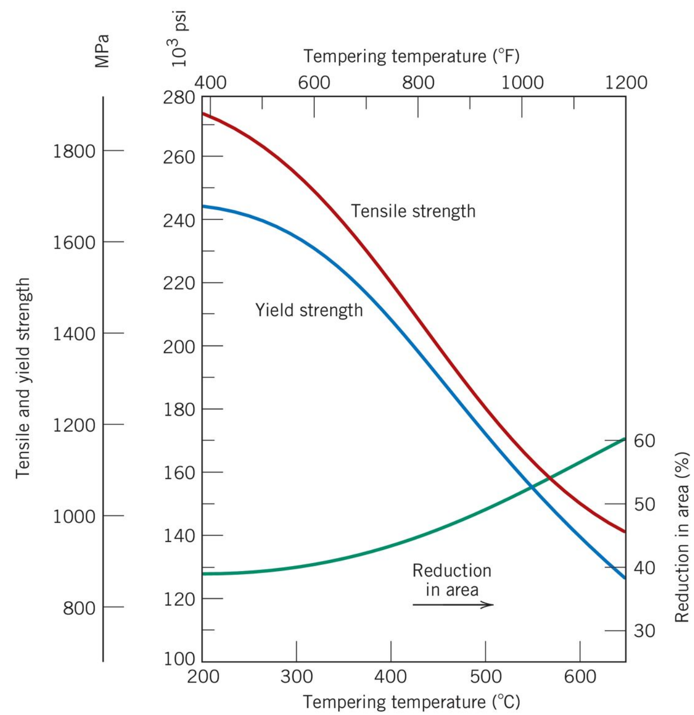
연성이 거의 없어서 대부분의 응용에 부적합할 수 있다. 따라서 Martensite 상을 가진 합금을 사용하기 위해서는 재료의 연성을 높이기 위한 열처리가 필요하다.

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 Fe와 결합하여 해당 온도 구간에서의 평형상인 cementite(Fe_3C)로 바뀐다. <u>다만 이때 발생하는 Cementite의 사이즈가 spheroidite에 존재하는 구상 cementite에 비교하여 매우 작다 (본래 martensite가 bainite나 pearlite에 비교해 많이 미세한 구조였으므로)</u>

템퍼링으로 얻어진 효과
경도와 강도가 약간 줄어드는 대신에 인성과 연성이 현저히 향상된다.





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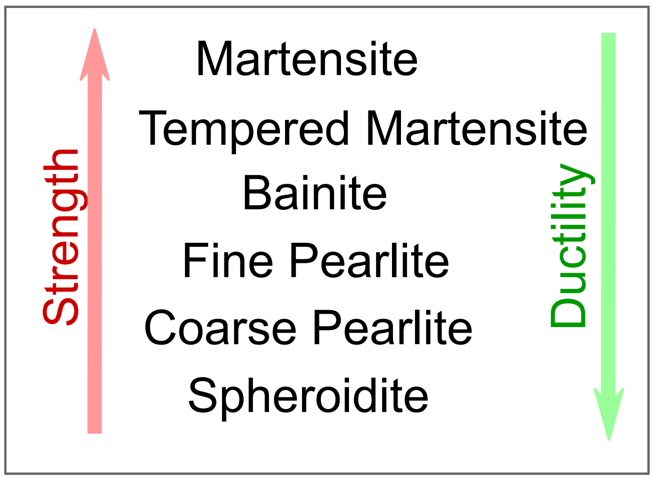
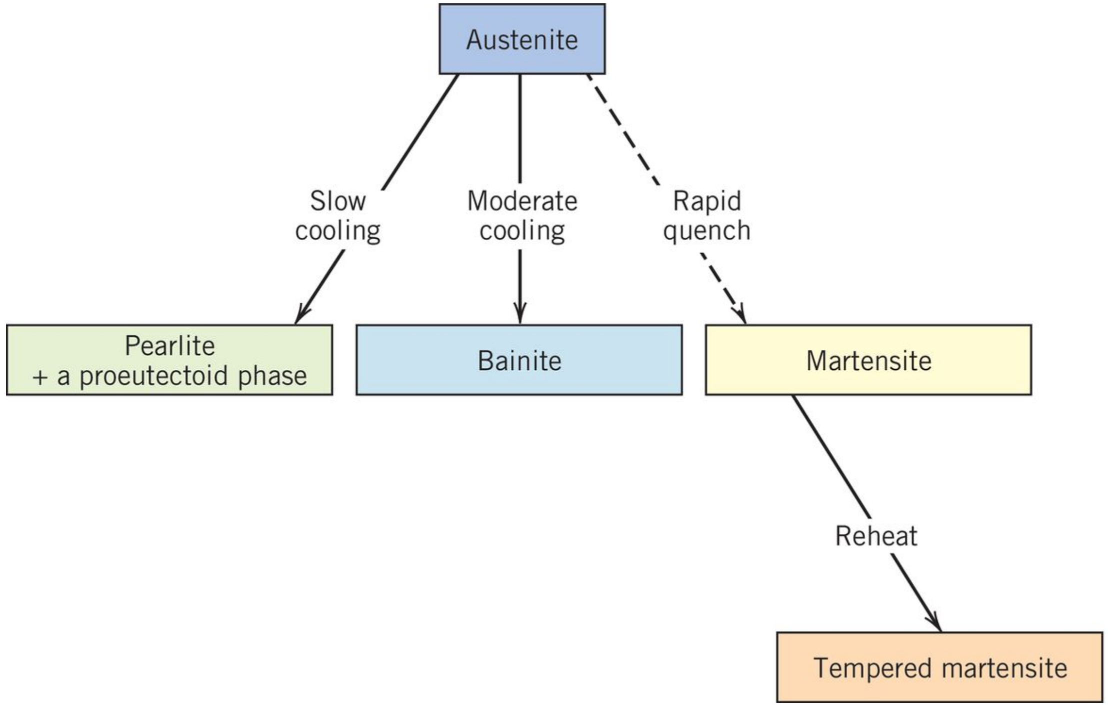
오스테나이트 기저(base)에서 얻을 수 있는 다양한 미세조직

General Trends





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