Metallere Plastik Şekil Verme

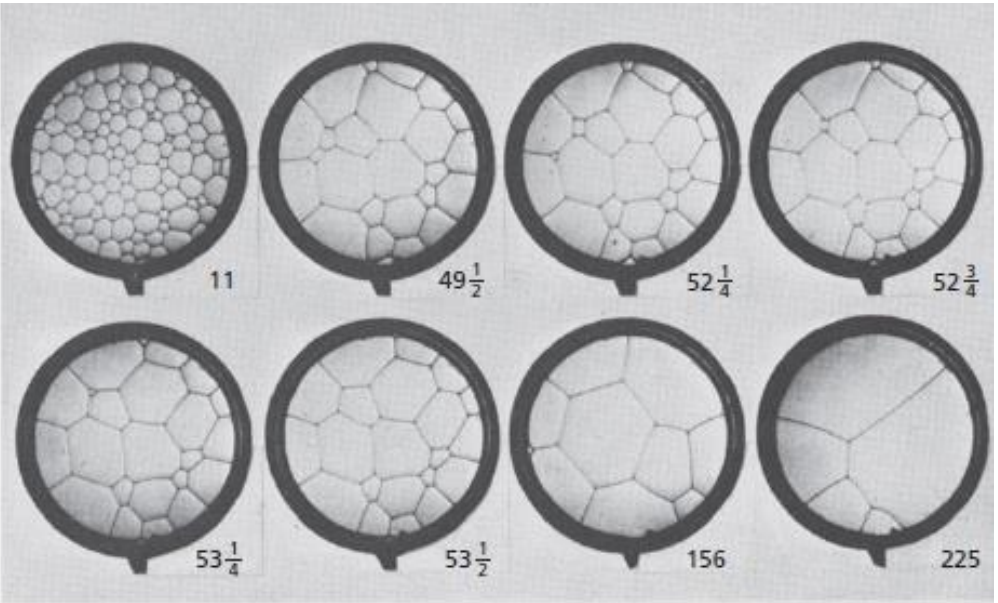


FIG. 8.26 Growth of soap cells in a flat container. (From Smith, C.S., ASM Seminar, *Metal Interfaces*, 1952, p. 65. Reprinted with permission of ASM International(R). All rights reserved. www.asminternational.org)

Soğuk Şekillendirmede depolanan enerji

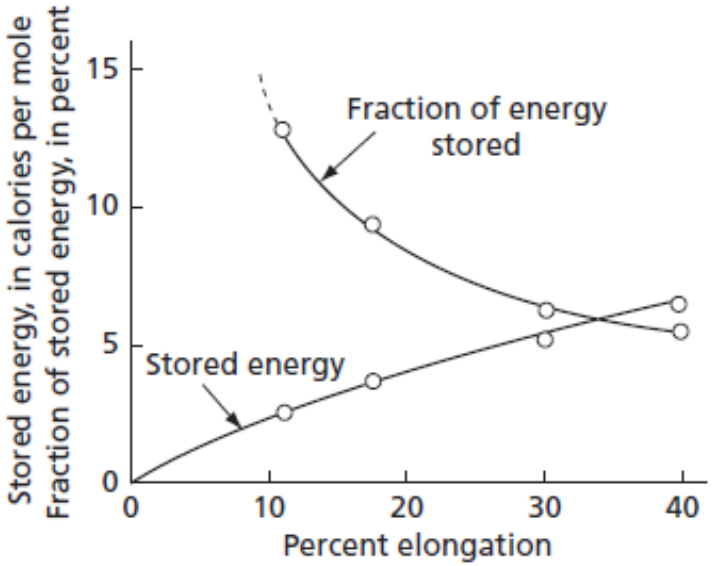


FIG. 8.1 Stored energy of cold work and fraction of the total work of deformation remaining as stored energy for high purity copper plotted as functions of tensile elongation. (Data of Gordon, P., *Trans. AIME*, **203** 1043 (1955).)

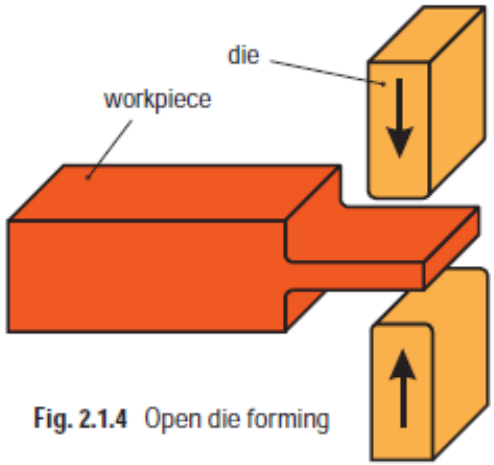


Fig. 2.1.4 Open die forming

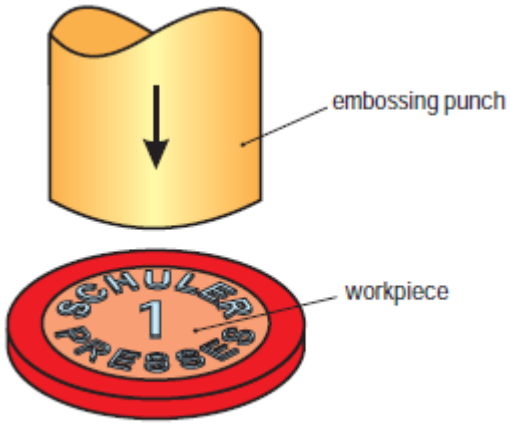


Fig. 2.1.6 Coining

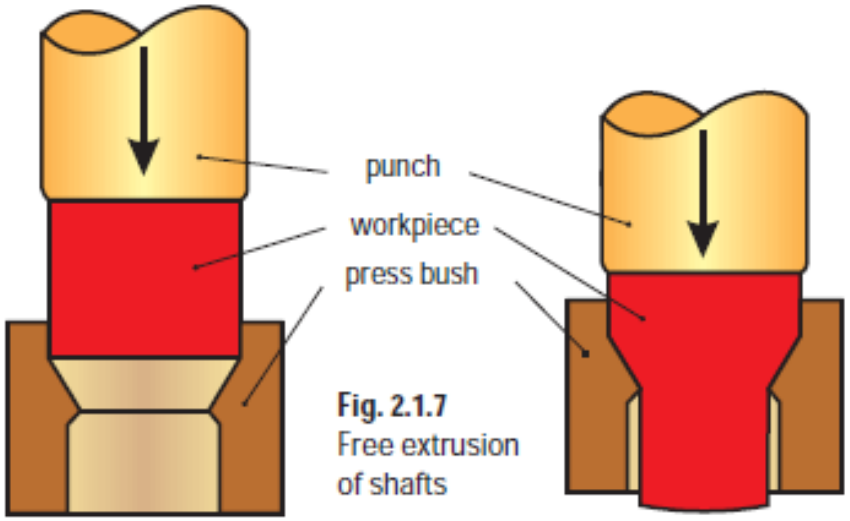
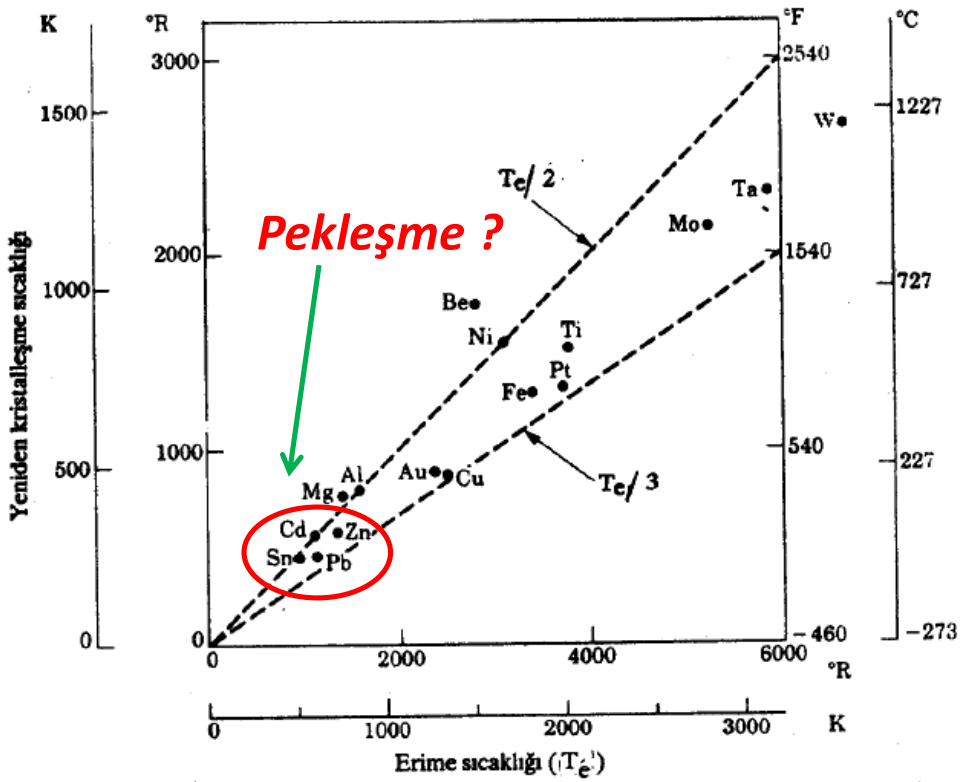


Fig. 2.1.7 Free extrusion of shafts

Yeniden Kristalleşme

Yeniden Kristalleşme Sıcaklığı; *yeni tanelerin 1 saat içinde oluşması için gerekli sıcaklık.*



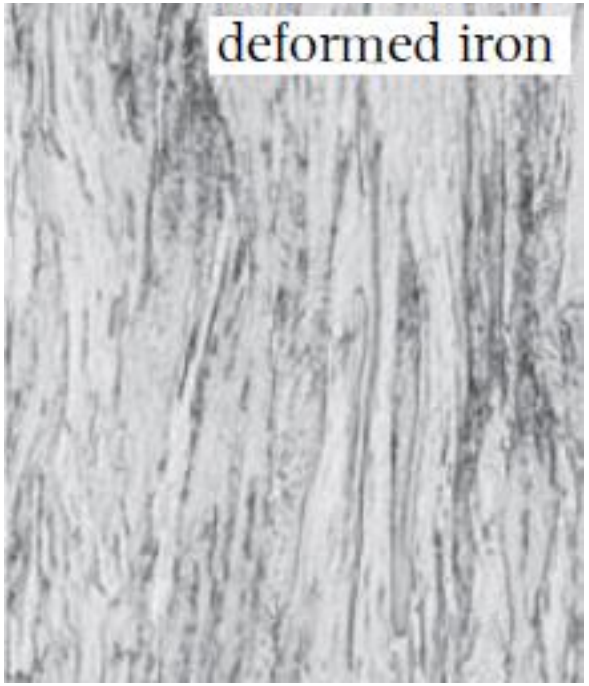
Şekil 2.30. Çeşitli metallerin kristalleşme sıcaklıkları. Yeniden kristalleşme sıcaklığı (°K) $\simeq \frac{1}{2} \cdots \frac{1}{3}$ T_e (°K). (L.H. Van Vlack).

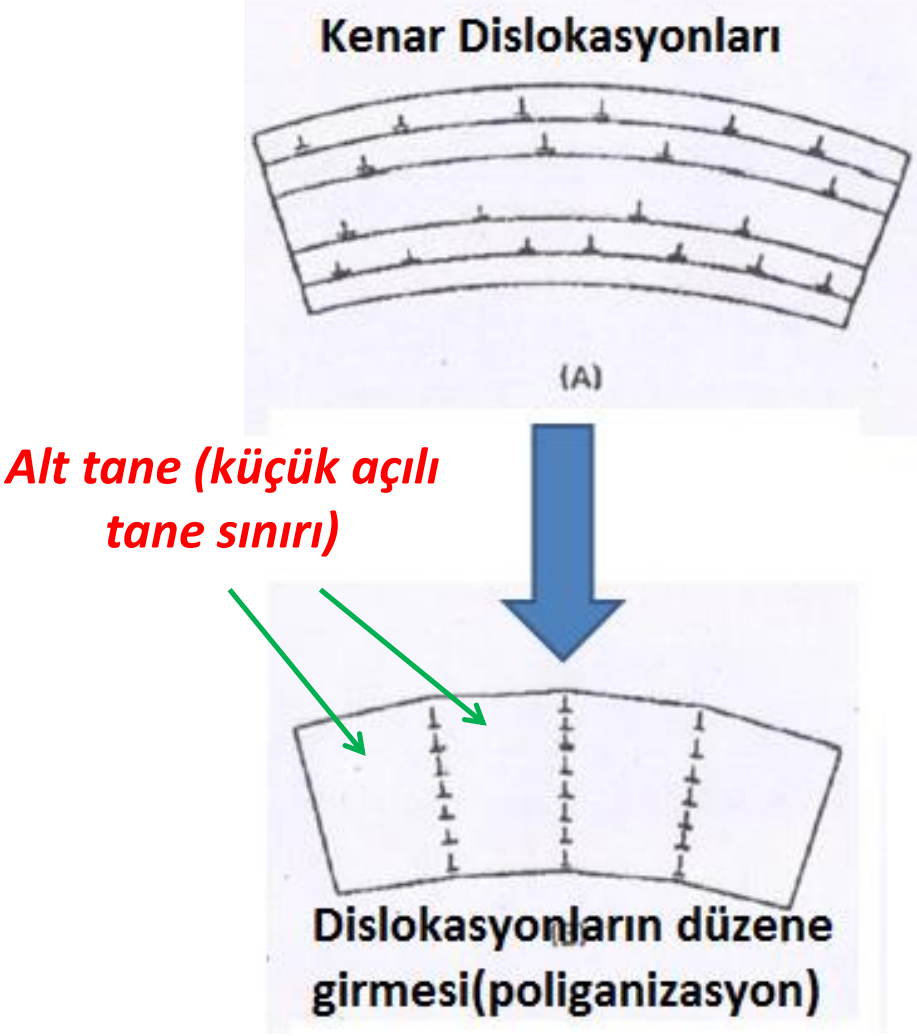
TABLE 7-4 ■ *Typical recrystallization temperatures for selected metals*

Metal	Melting Temperature (°C)	Recrystallization Temperature (°C)
Sn	232	−4
Pb	327	−4
Zn	420	10
Al	660	150
Mg	650	200
Ag	962	200
Cu	1085	200
Fe	1538	450
Ni	1453	600
Mo	2610	900
W	3410	1200

(Source: Adapted from Structure and Properties of Engineering Materials, *by R. Brick, A. Pense, and R. Gordon, 1977. Copyright © 1977 The McGraw-Hill Companies. Adapted by permission.)*

Toparlanma





Toparlanmada dislokasyon yoğunluğu ve mekanik özellikler hemen hemen sabittir.

Toparlanmada dislokasyon hareketi

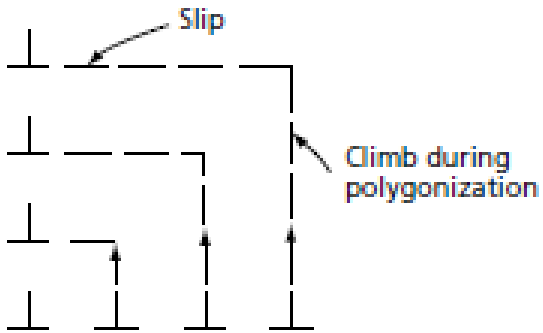


FIG. 8.12 Both climb and slip are involved in the rearrangement of edge dislocations

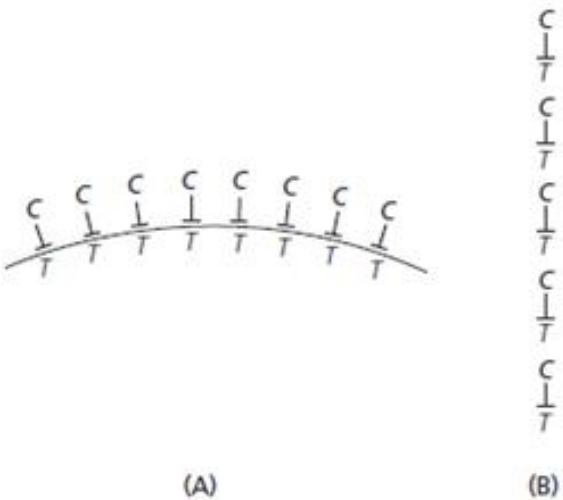


FIG. 8.11 Simple explanation showing why a vertical array of edge dislocations corresponds to a lower state of strain energy than does an array of the same dislocations, all on a single slip plane. The letters *T* and *C* in **(A)** and **(B)** correspond to the tensile and compressive strains associated with each dislocation

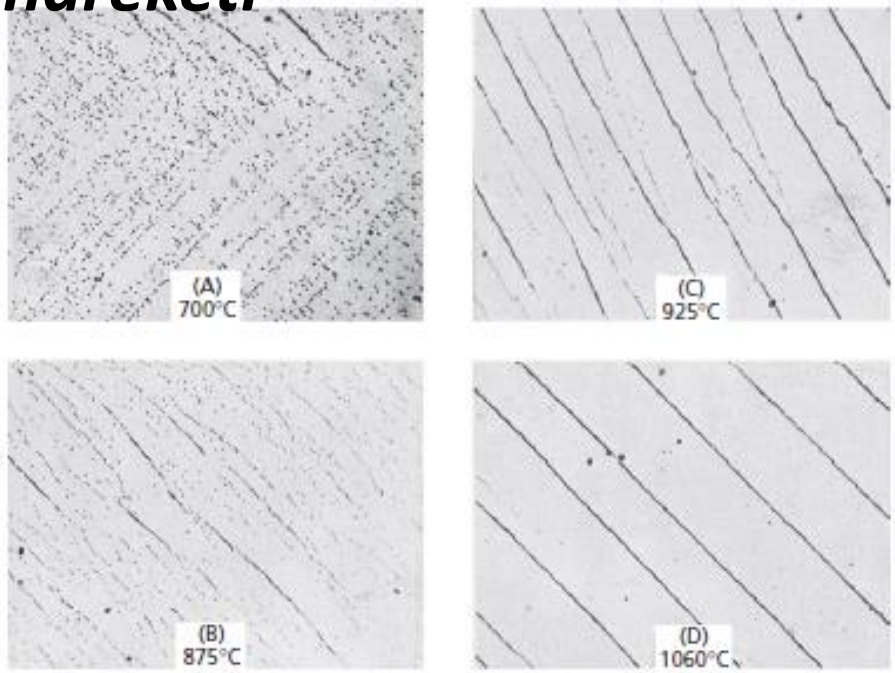
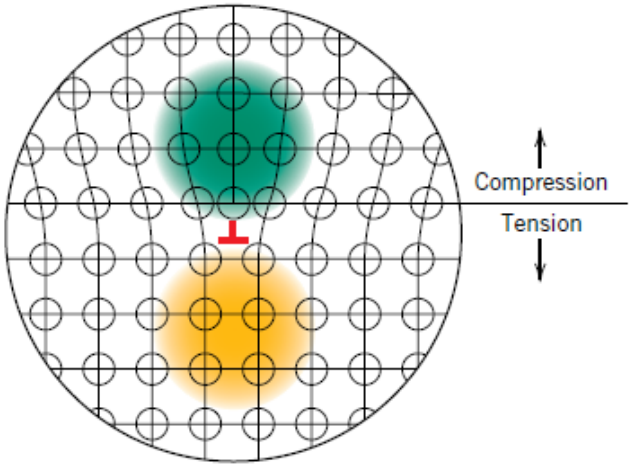
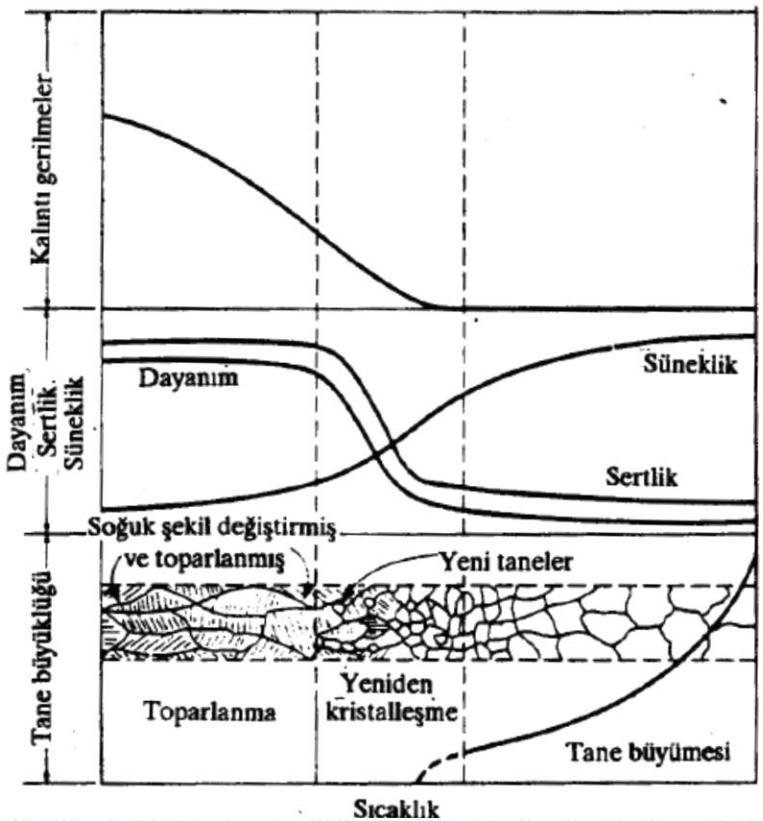


FIG. 8.14 Polygonization in bent and annealed iron-silicon single crystals. All specimens annealed for one hour at the indicated temperatures. Note that polygonization is more complete the higher the temperature of the anneal. All pictures were taken at 750×. (Reprinted from Hibbard, W.R. Jr, and Dunn, C.G., "A study of <112> edge dislocations in bent silicone-iron single crystals", *Acta Met.* **4** 306 (1956), fig. 11, 14, 16 and 19 with permission of Elsevier. www.sciencedirect.com/science/journal/00016160.)

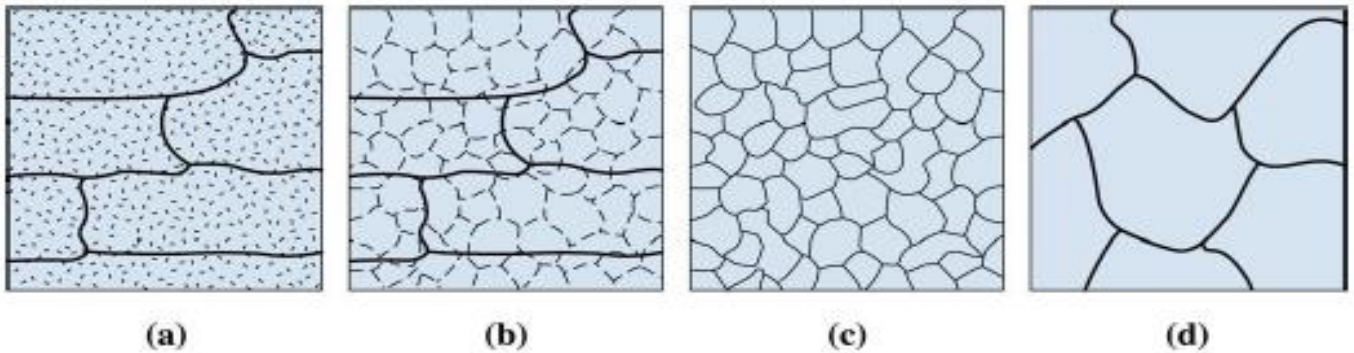


Yeniden Kristalleşme



0.3Tm < T_{Re}< 0.6Tm

- Soğuk Şekillendirme miktarına
- Saflığa



Soğuk işlem görmüş metallerin mikroyapıları üzerine tavlama sıcaklığının etkisi. (a) soğuk işlem görmüş (b) toparlanma sonrası, (c) yeniden kristalleşme sonrası ve (d) tane büyümesi sonrası

Yeni Tane Oluşum Mekanizması

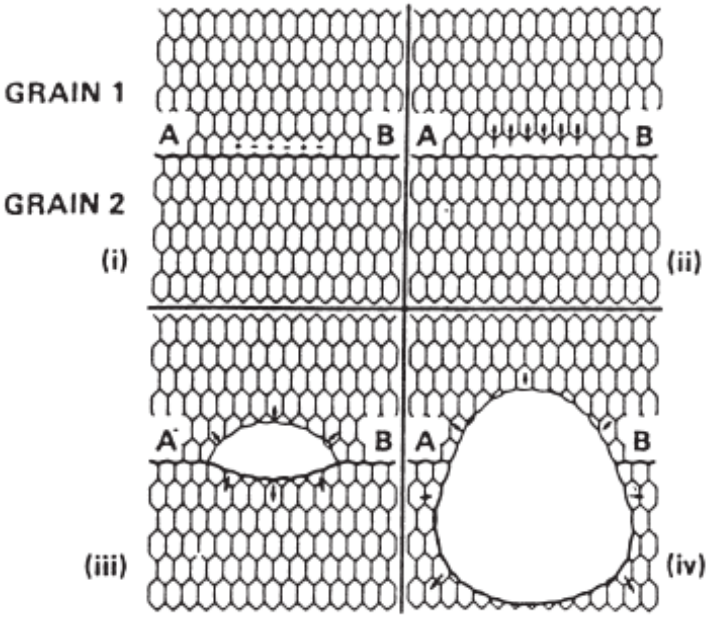


FIGURE 5.11 Schematic model illustrating the nucleation of recrystallized grain based on subgrain coalescence at an original high-angle grain boundary (along AB) in a polygonized structure.[22,24] (*Reprinted by permission of The Metallurgical Society, Warrendale, Pennsylvania.*)

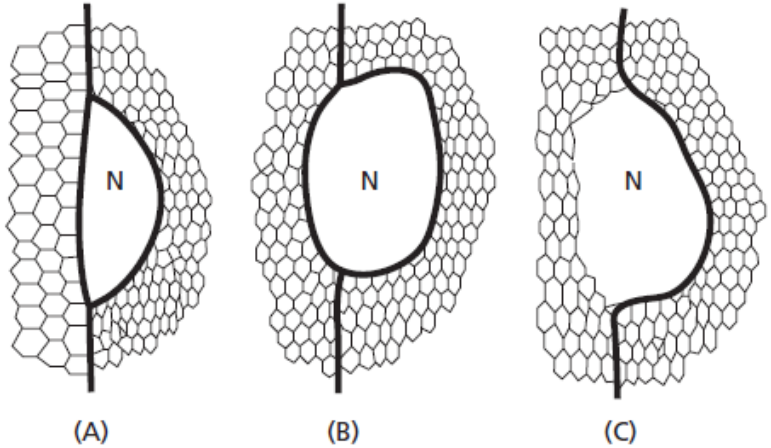


FIG. 8.22 Schematic drawing of grain boundary nuclei, marked by N, between two deformed grains with hexagonal subgrains. (From Ray, B. and Hansen, N., *Met. Trans. A*, **15A** 293 (1984) with kind permission of Springer Science and Business Media.)

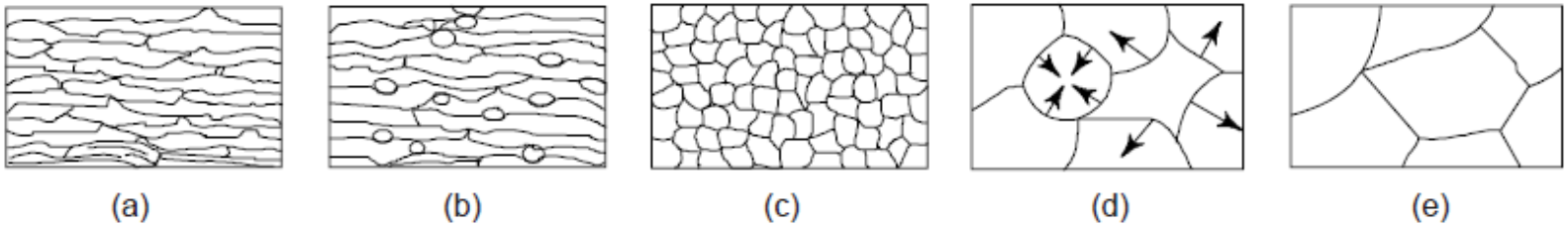


Fig. 11.26 Changes in microstructure of strain-hardened metal during heating: (a) strained hardened metal, (b) beginning of primary recrystallization, (c) end of primary recrystalliztion, (d) and (e) stages of grain growth

Yeniden Kristalleşme

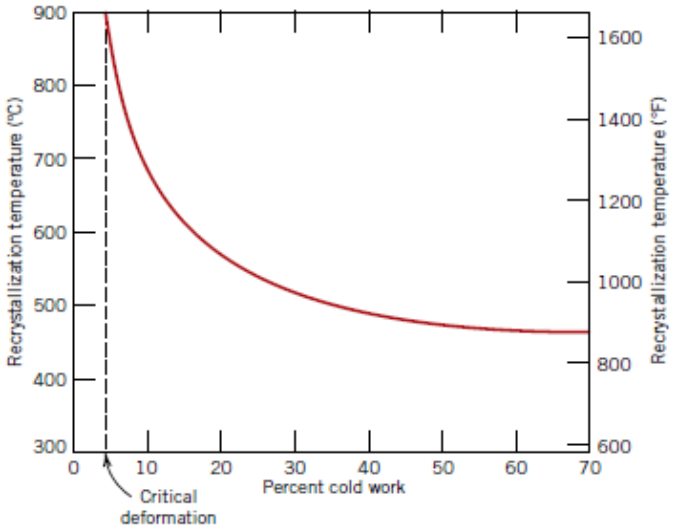
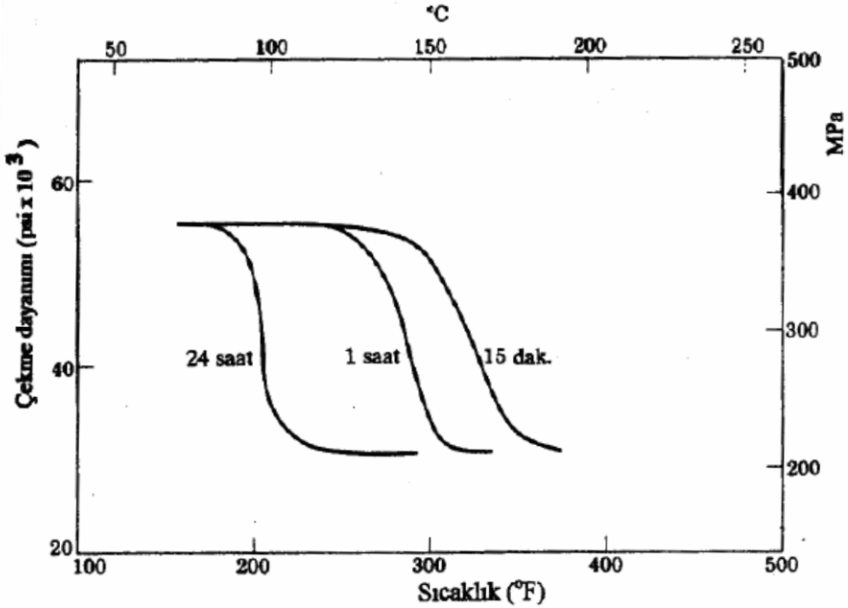


Figure 7.23 The variation of recrystallization temperature with percent cold work for iron. For deformations less than the critical (about 5% CW), recrystallization will not occur.



Şekil 2.35. % 75 soğuk çekilmiş saf bakırda çekme dayanımının tav sıcaklığı ve süresi ile değişimi.

Şekil 2.34. Yeniden kristalleşme sıcaklığı ve süresi ile soğuk şekil değiştirme miktarının dayanım ve sertliğe etkisi.

Yeniden Kristalleşme

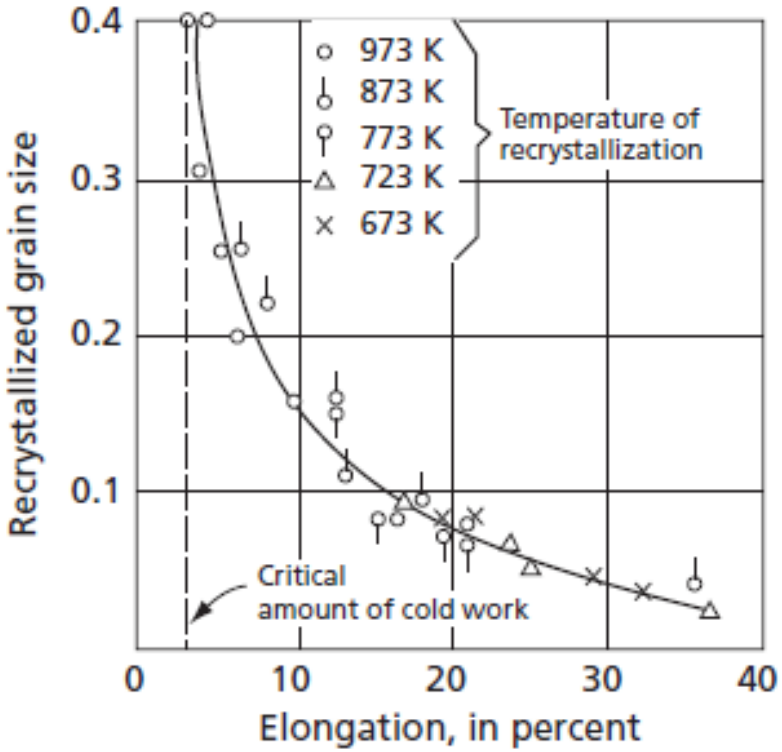
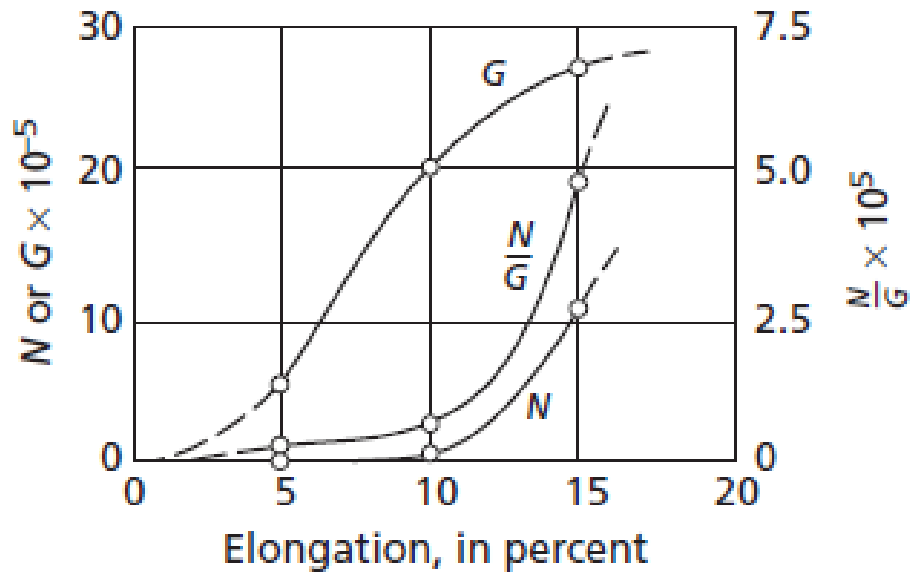


FIG. 8.23 Effect of prior cold work on the recrystallized grain size of alpha-brass. Notice that the grain size at the end of recrystallization does not depend on the temperature of recrystallization. (Smart, J. S., and Smith, A. A., *Trans. AIME*, **152** 103 [1943].)

FIG. 8.24 Variation of the rate of nucleation (N), the rate of growth (G), and their ratio (N/G) as a function of deformation before annealing. (Data for aluminum annealed at 350°C.) (From Anderson, W. A., and Mehl, R. F., *Trans. AIME*, **161** 140 [1945].)



Yeniden Kristalleşme

FIG. 8.25 Effect of impurities on the recrystallization temperature (30 minutes of annealing) of aluminum cold-rolled 80 percent. (From Perryman, E.C.W., ASM Seminar, *Creep and Recovery*, 1957, p. 111. Reprinted with permission of ASM International(R). All rights reserved. www.asminternational.org)

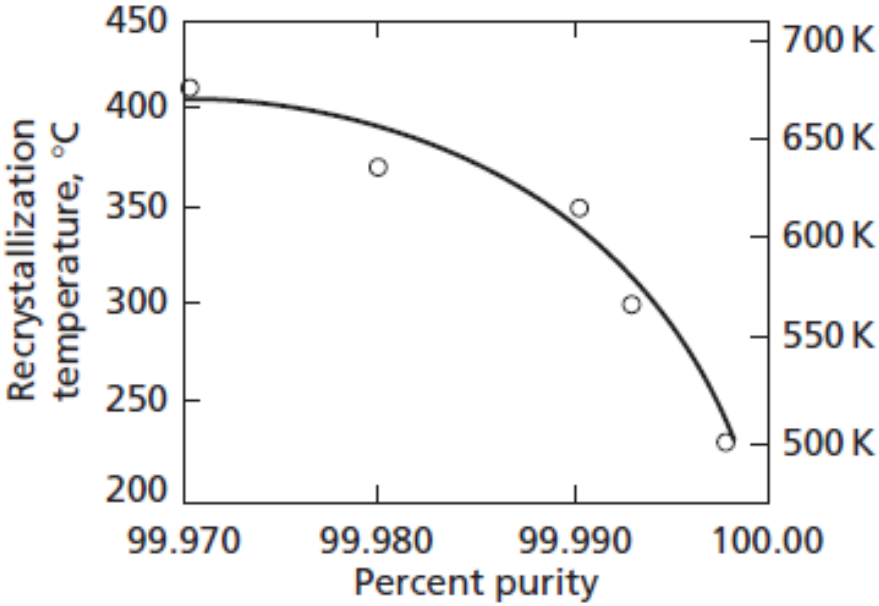
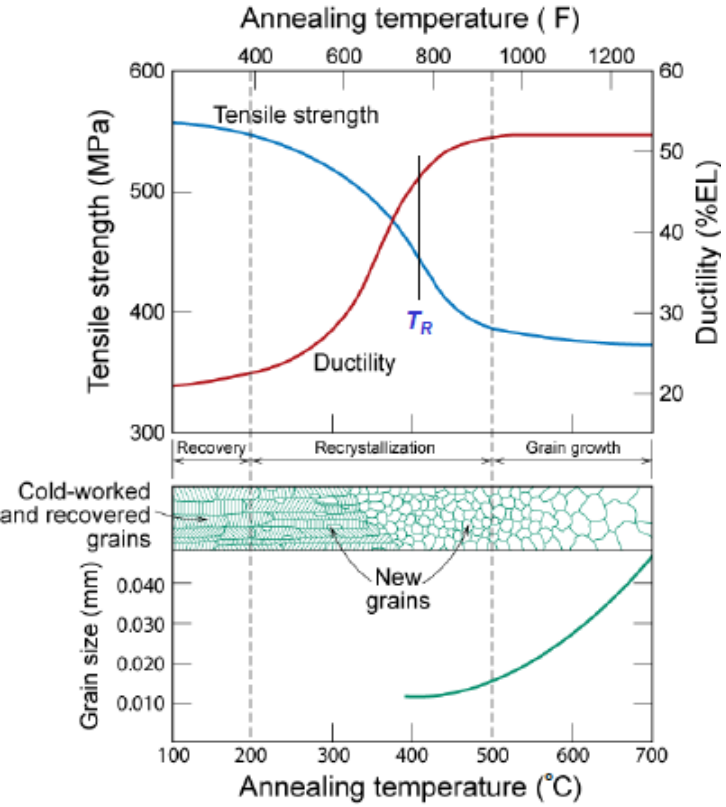


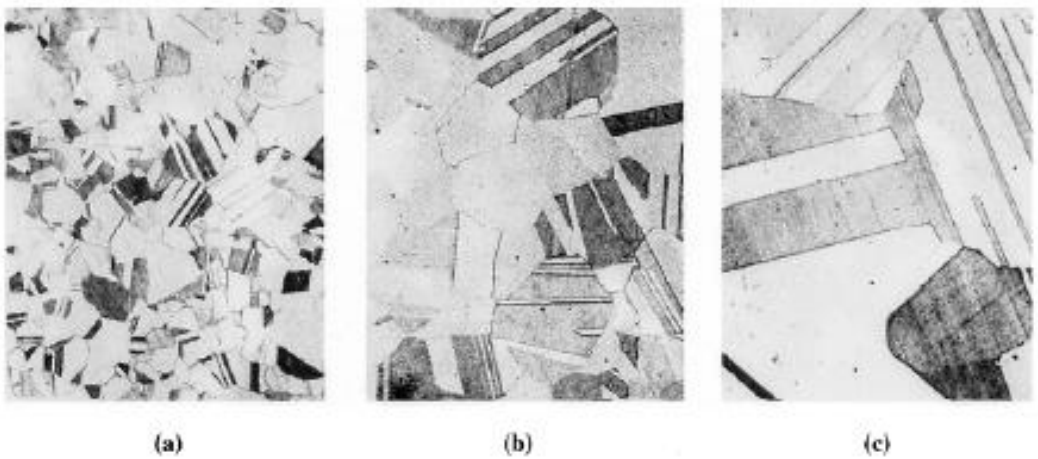
TABLE 8.1 Increase in the Recrystallization Temperature of Pure Copper by the Addition of 0.01 Atomic Percent of the Indicated Element.*

Added Element	Increase in Recrystallization Temperature K
Ni	0
Co	15
Fe	15
Ag	80
Sn	180
Te	240

*Data of Smart, J. S., and Smith, A. A., *Trans. AIME*, **147** 48 (1942); **166** 144 (1946).

Yeniden Kristalleşme (özet)





Pirinçte tane boyutu üzerine tavlama sıcaklığının etkisi. Mikroyapılarda ikiz sınırları da görülmüştür. (a) 400oC de tavlanmış, (b) 650oC de tavlanmış ve (c) 800oC de tavlanmış. (Adapted from Brick, R. and Phillips, A., The Structure and Propertiesof Alloys: McGraw-Hill.)

Soğuk sekil değ. miktarı ↑ Yeniden Kristallenme Sıcaklığı ↓

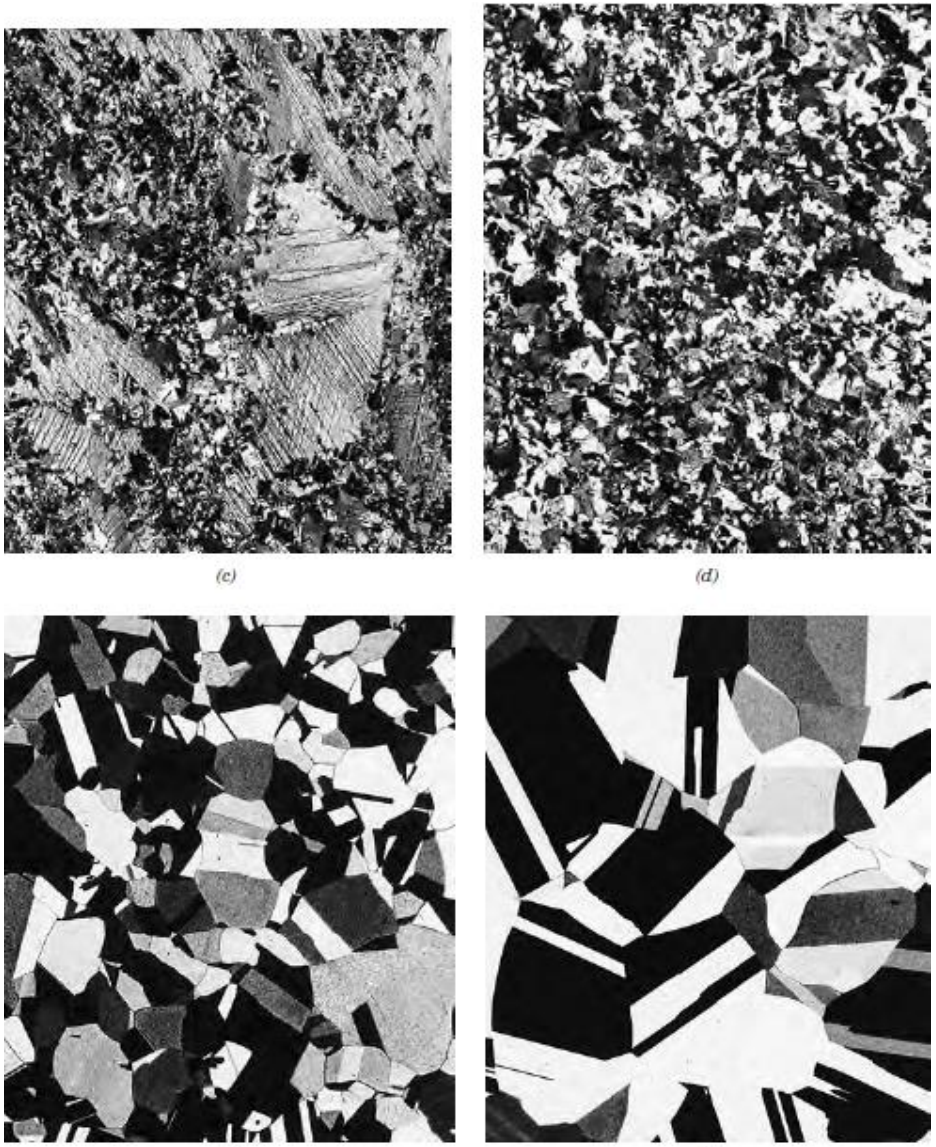
Sıcaklık ↑ Tavlama Süresi ↓

Deformasyon miktarı ↑ Tane boyutu ↓

Saflık ↑ Yeniden Kristallenme Sıcaklığı ↓

Yeniden Kristalleşme

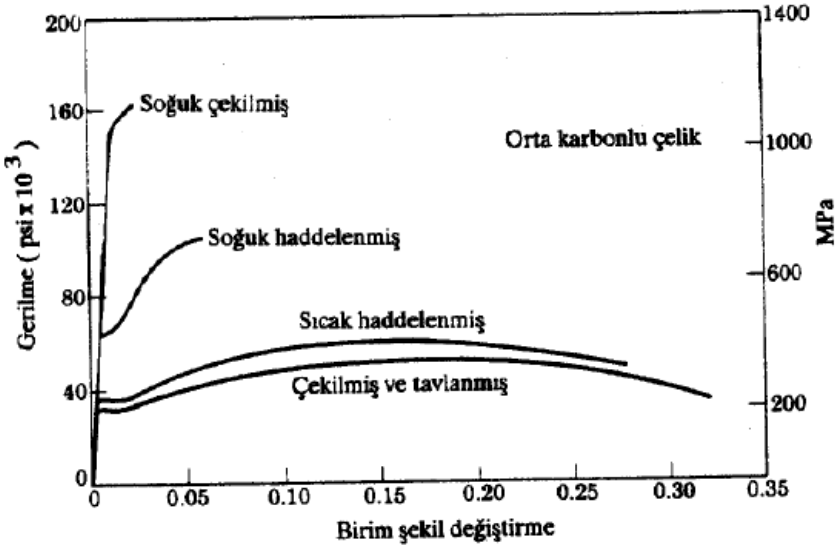
(a) (b)



(c) (d) (e) (f)

Figure 7.21 Photomicrographs showing several stages of the recrystallization and grain growth of brass. (*a*) Cold-worked (33% CW) grain structure. (*b*) Initial stage of recrystallization after heating 3 s at 580°C (1075°F); the very small grains are those that have recrystallized. (*c*) Partial replacement of cold-worked grains by recrystallized ones (4 s at 580°C). (*d*) Complete recrystallization (8 s at 580°C). (*e*) Grain growth after 15 min at 580°C. (*f*) Grain growth after 10 min at 700°C (1290°F). All photomicrographs 75×. (Photomicrographs courtesy of J. E. Burke, General Electric Company.)

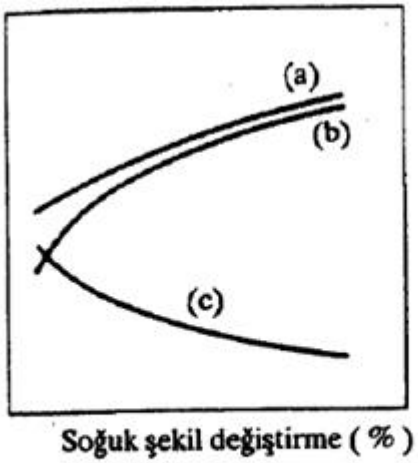
Soğuk, Yarı Sıcak ve Sıcak Şekil Değiştirme



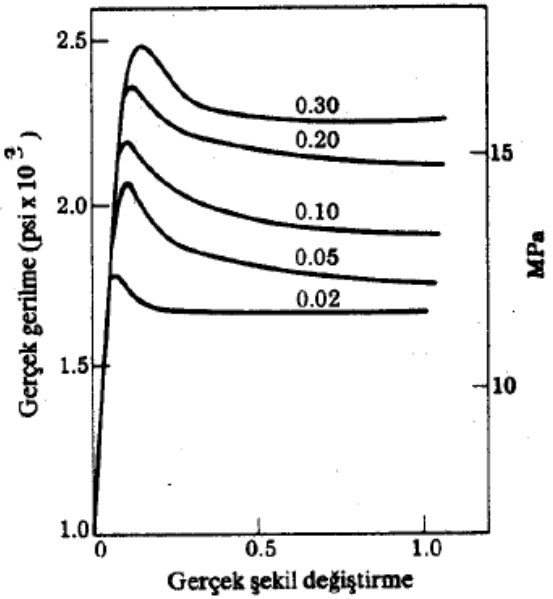
2.38. Sıcak ve soğuk şekil değiştirmenin, orta karbonlu çeliğin çekme diyagramına etkisi (ölçü boyu 8 in = 203 mm). Elastiklik modülünün değişmediğine dikkat ediniz.

Sıcak ve soğuk işlemde Yüzey durumu?

Yarı Sıcak İşlem



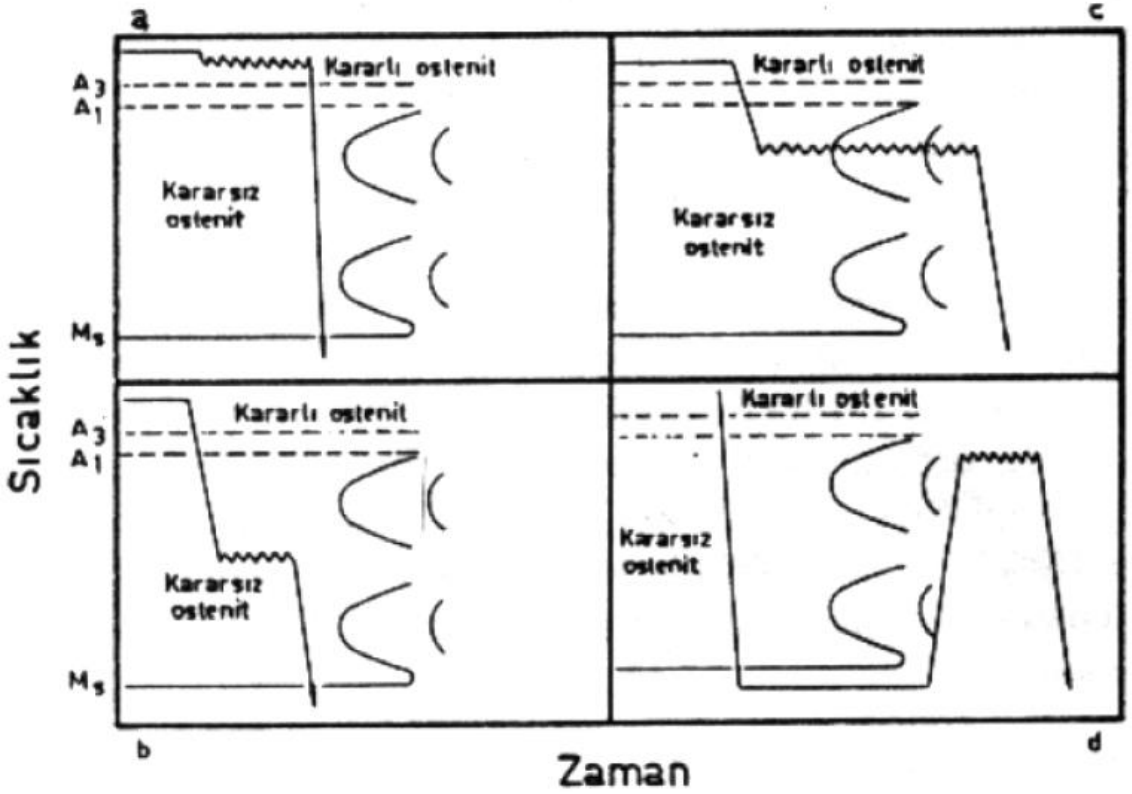
Soğuk şekil değişiminin çeşitli mekanik özelliklere etkisi. (a) Çekme dayanımı. (b) Akma sınırı. (c) Süneklik.

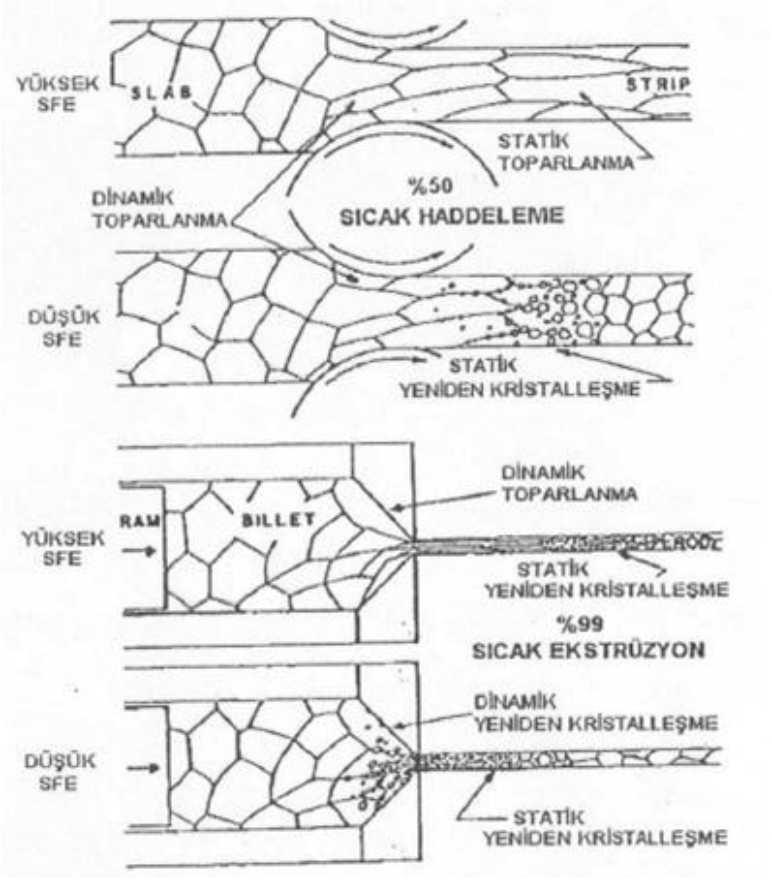


Saf kurşunun basma deneyinde, farklı şekil değiştirme hızları için, gerçek gerilme–gerçek şekil değiştirme eğrileri. Parametre:şekil değiştirme hızı, dakika^{-1}, (S. Kobayashi, Trans. ASME, J. of Eng. for Industry, 81, 1959, p. 232).

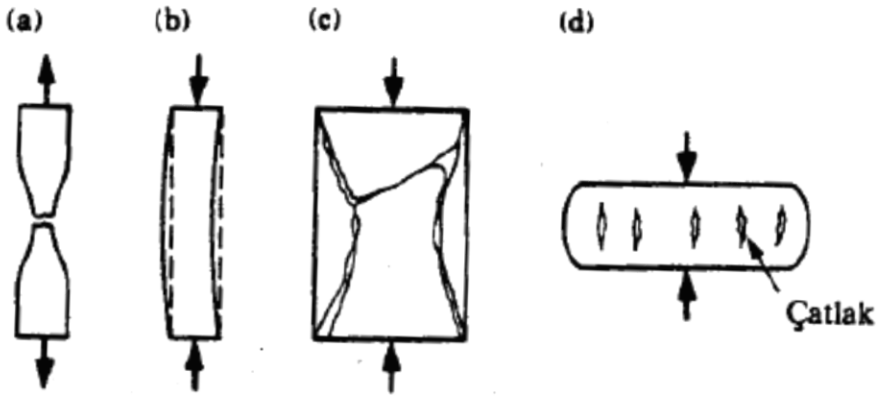
Soğuk, Yarı Sıcak ve Sıcak Şekil Değiştirme

Termomekanik işlem





Şekil Değişiminde Hasar



Hasar tipleri. (a) Sünek malzemelerin çekme deneyinde büzülme ve kopma. (b) Sünek malzemelerin basmada burkulması. (c) Gevrek malzemelerin basmada kırılması. (d) Basmada, sünek malzemelerin fıçılaşmış yan yüzeylerinde çatlak oluşumu.

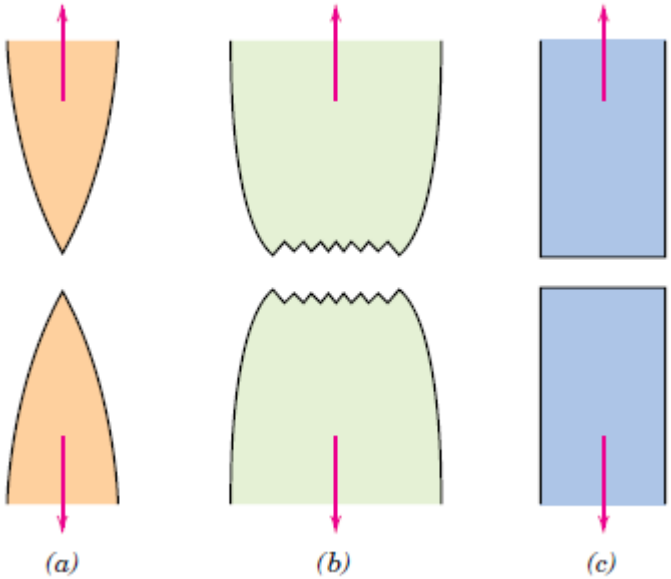
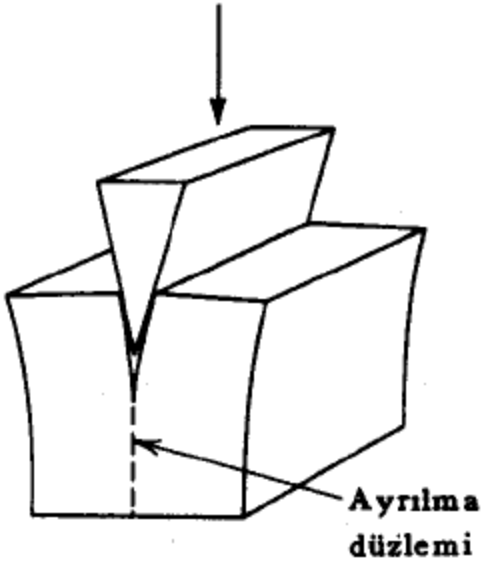


Figure 8.1 (*a*) Highly ductile fracture in which the specimen necks down to a point. (*b*) Moderately ductile fracture after some necking. (*c*) Brittle fracture without any plastic deformation.

Gevrek Kırılma

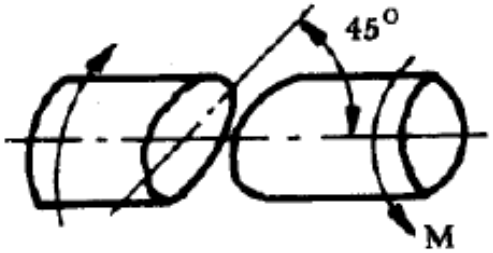
Düşük Sıcaklık ve yüksek şekil değiştirme hızı gevrek kırılmayı teşvik eder.



Şekil 2.41. Ayrılma kırılması.

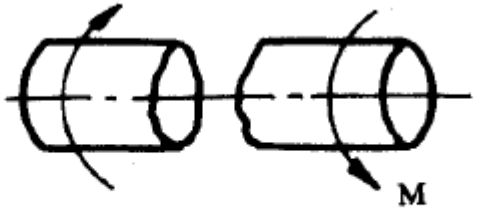
Gevrek malzemelerin basınç etkisi altında, basma kuvveti ile 45° açı yapan düzlem boyunca kırılması.

Basma dayanımı > Çekme dayanımı



Şekil 2.43. Burulmada, silindir biçimindeki gevrek bir malzemenin kırılması.

Sünek Kırılma



Şekil 2.47. Burulmada, silindir biçimindeki sünek bir malzemenin kırılması.

Oksit, sülfür, karbür, silikatlar
Dökümde oluşan gözenekler
MnS ?

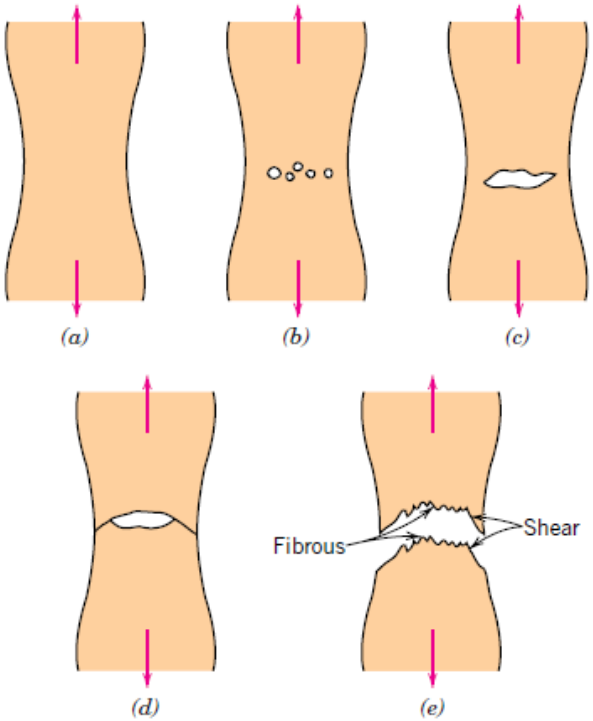
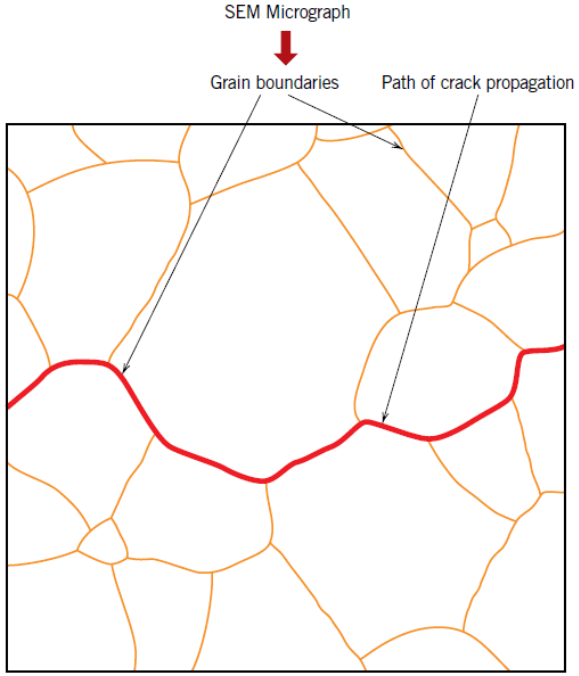


Figure 8.2 Stages in the cup-and-cone fracture. (*a*) Initial necking. (*b*) Small cavity formation. (*c*) Coalescence of cavities to form a crack. (*d*) Crack propagation. (*e*) Final shear fracture at a 45° angle relative to the tensile direction. (From K. M. Ralls, T. H. Courtney, and J. Wulff, *Introduction to Materials Science and Engineering*, p. 468. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

(a) (b)

Figure 8.3 (*a*) Cup-and-cone fracture in aluminum. (*b*) Brittle fracture in a mild steel.

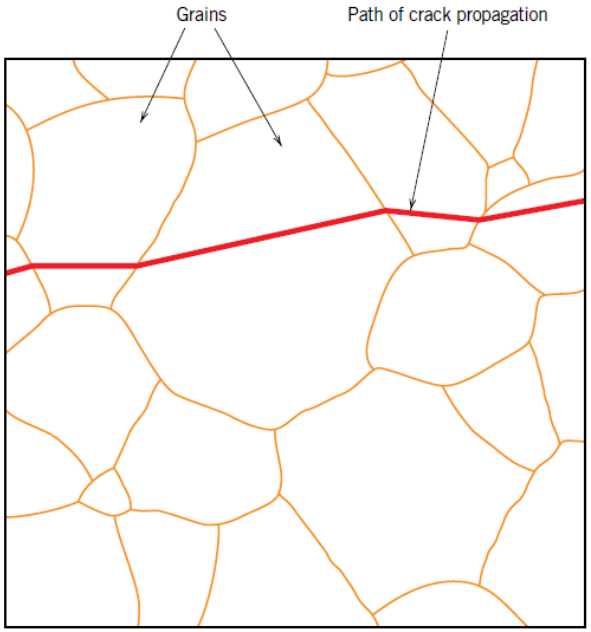
Tanelerarası ve Taneleriçi Kırılma



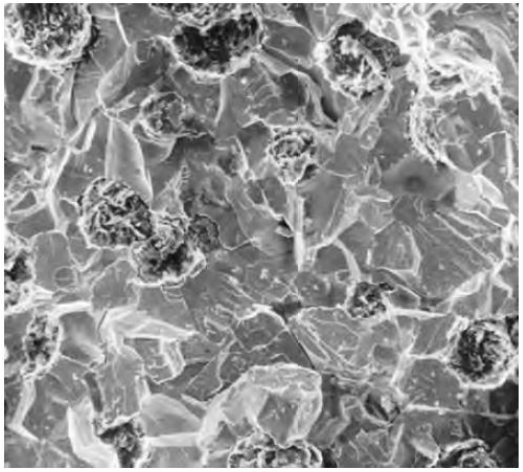
(a)

(b)

Figure 8.7 (*a*) Schematic cross-section profile showing crack propagation along grain boundaries for intergranular fracture. (*b*) Scanning electron fractograph showing an intergranular fracture surface. 50×. [Figure (*b*) reproduced with permission from *ASM Handbook*, Vol. 12, *Fractography*, ASM International, Materials Park, OH, 1987.]



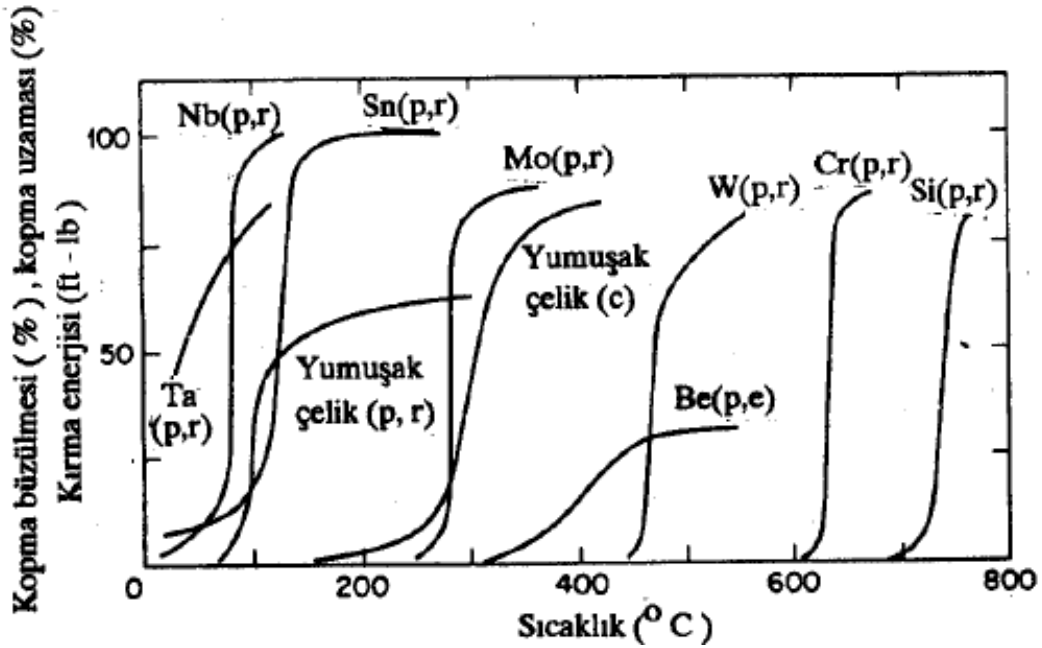
(a)



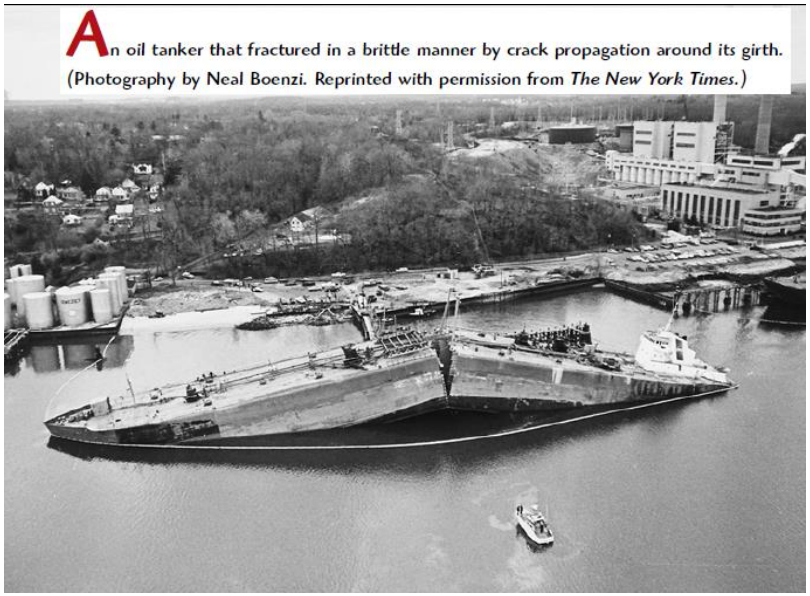
(b)

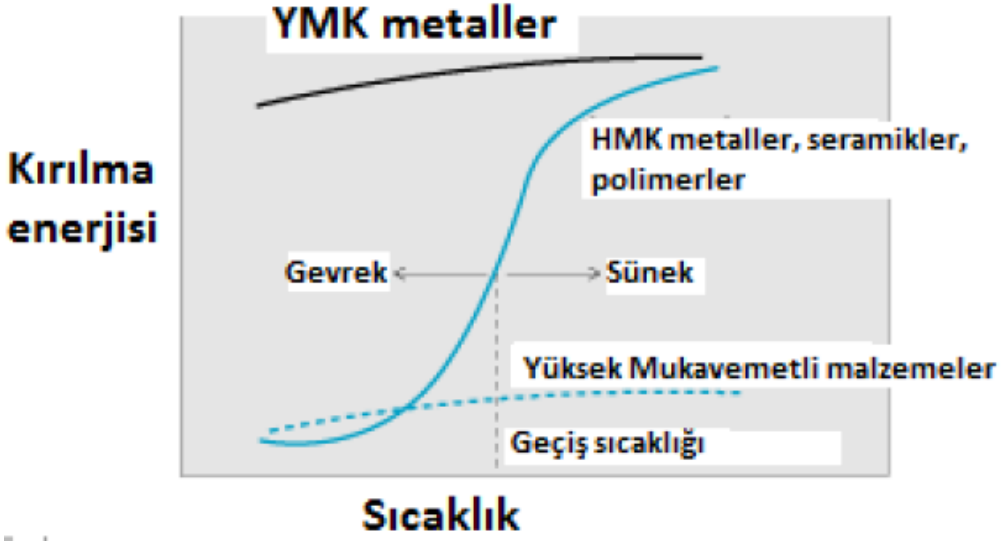
Figure 8.6 (*a*) Schematic cross-section profile showing crack propagation through the interior of grains for transgranular fracture. (*b*) Scanning electron fractograph of ductile cast iron showing a transgranular fracture surface. Magnification unknown. [Figure (*b*) from V. J. Colangelo and F. A. Heiser, *Analysis of Metallurgical Failures*, 2nd edition. Copyright © 1987 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.]

Geçiş Sıcaklığı

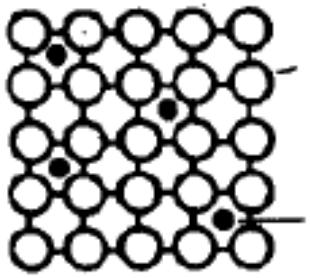


Mikroyapı
Bileşim
Tane boyutu
Yüzey durumu
Yönlenme
Geometri
Şekil değ. Hızı
Kristal yapı


An oil tanker that fractured in a brittle manner by crack propagation around its girth. (Photography by Neal Boenzi. Reprinted with permission from *The New York Times*.)



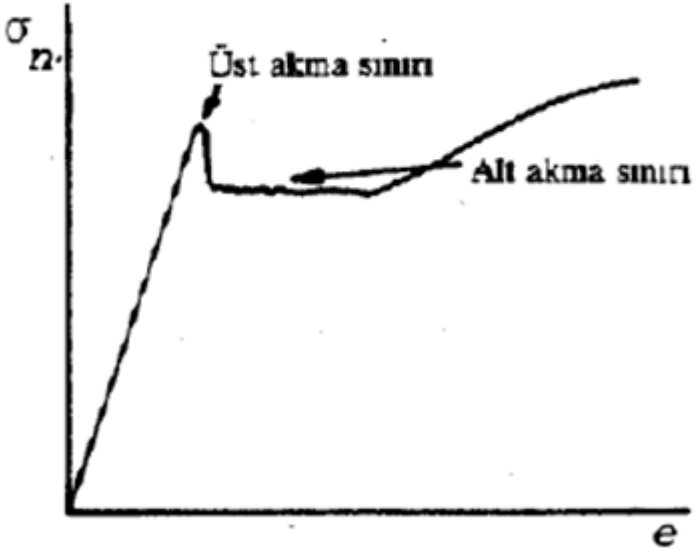
Şekil Değişimi Yaşlanması. Mavi Gevreklik

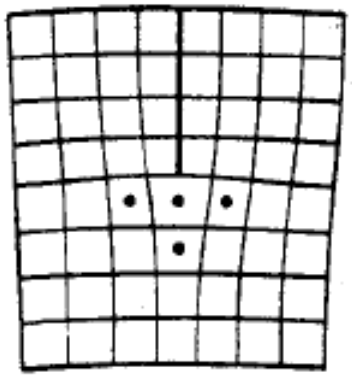


A atomları ana kafesi (matris) oluşturur.

B atomları: alaşım elemanları

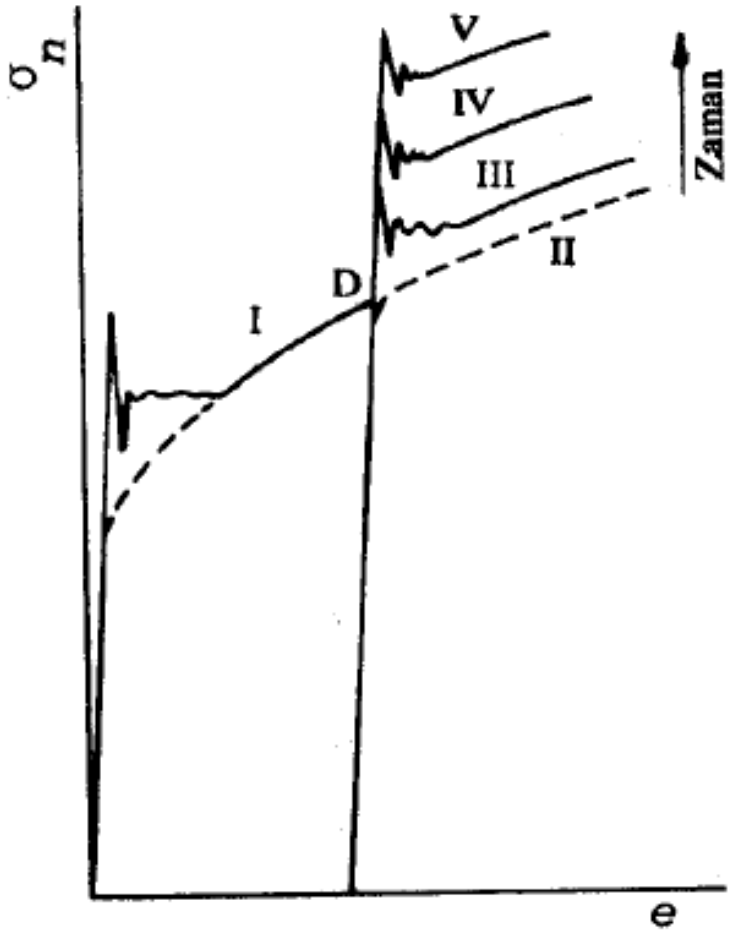
Şekil 2.51. Arayer katı çözeltisi.





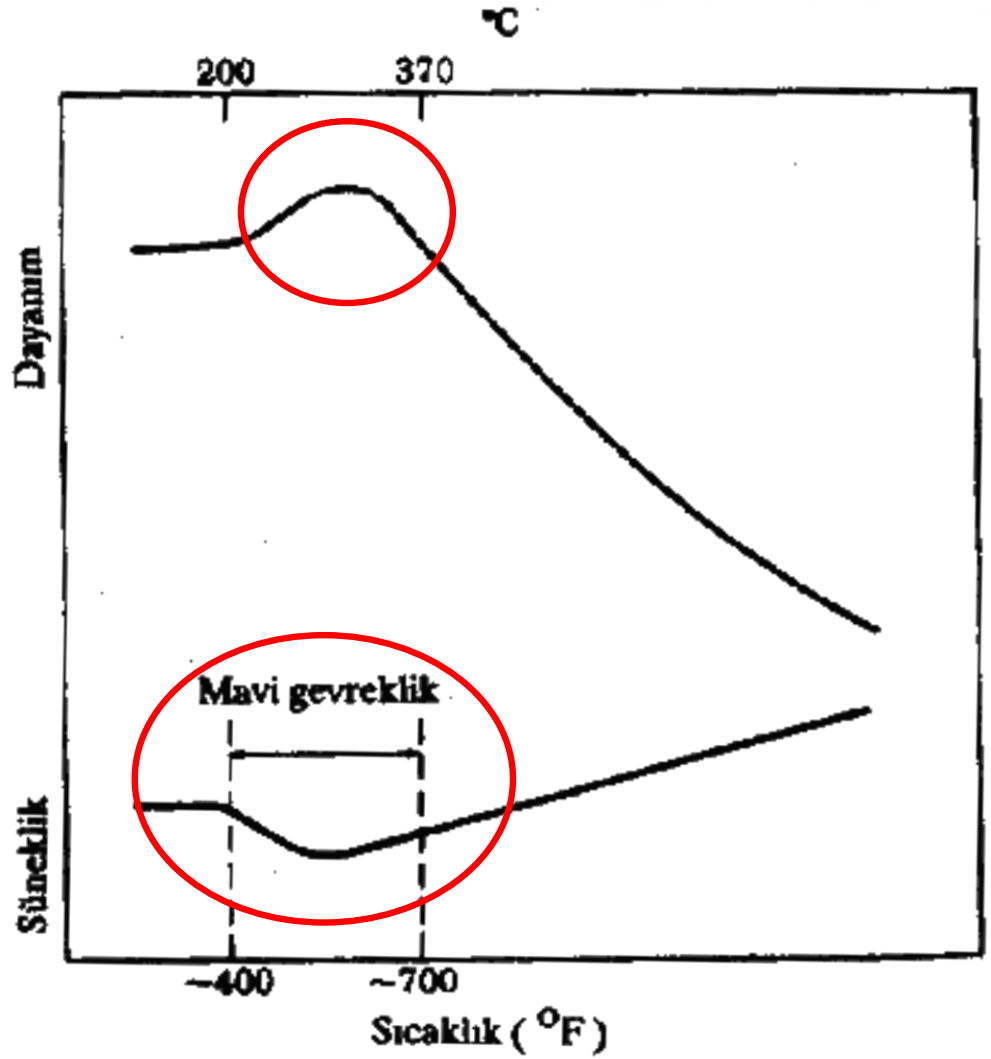
Şekil 2.52. Arayer atomlarının, kenar dislokasyonunun altındaki bölgede toplanması.

Şekil Değişimi Yaşlanması



Şekil 2.53 Şekil değişimi yaşlanmasının çekme diyagramına etkisi.

Mavi Gevreklik

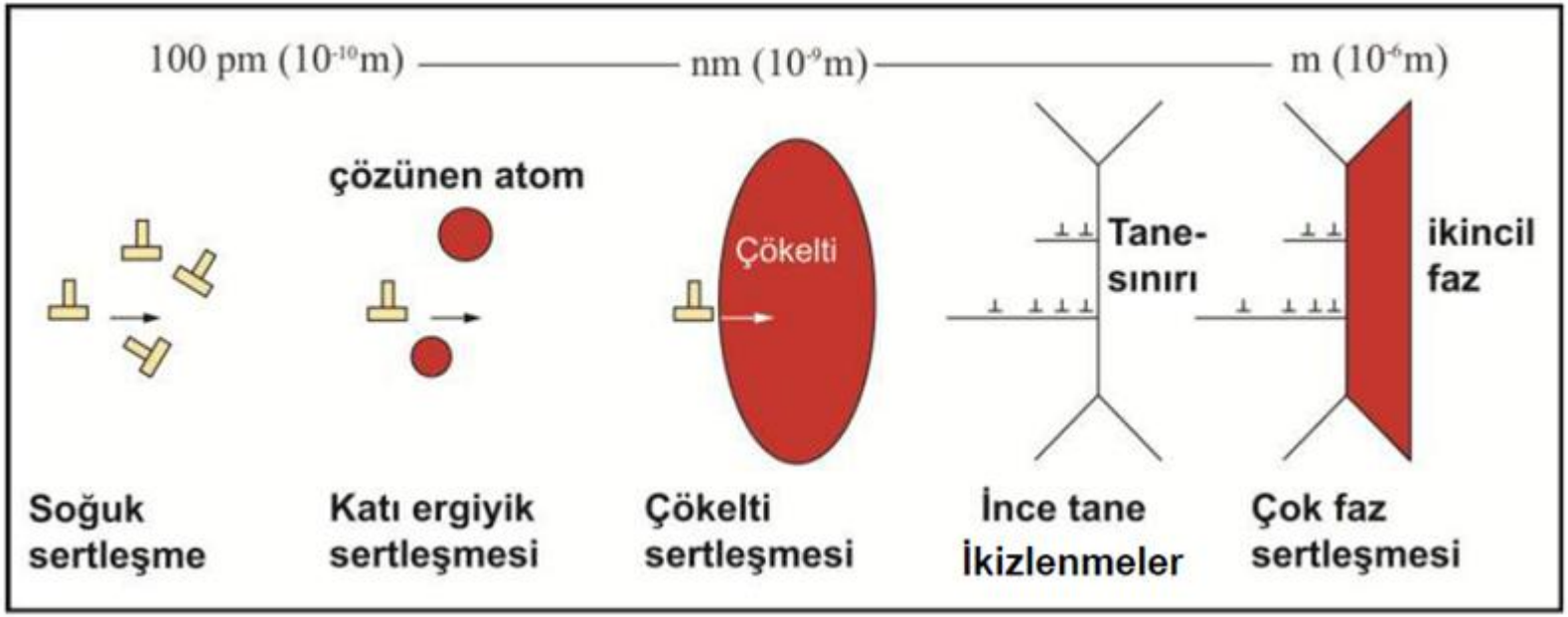


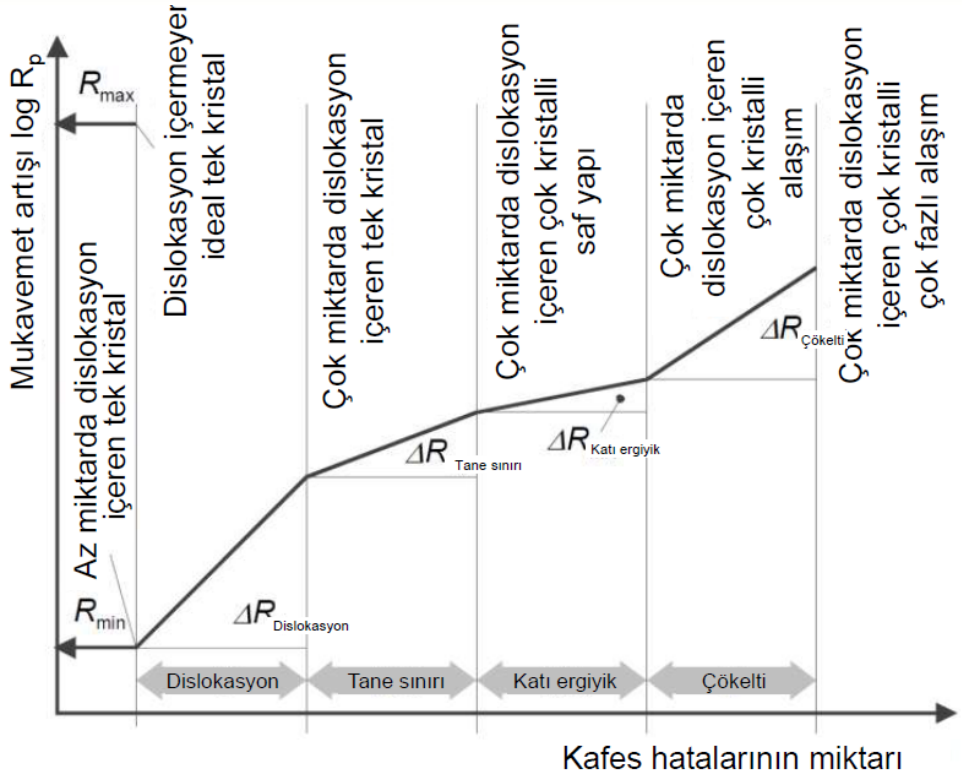
Şekil 2.54. Mavi gevreklik.

Yeniden Kristallenme (YK) Kuralları:

<u>Çekirdeklenme ve büyümenin itici gücü depolanmış deformasyon enerjisinin termal olarak aktive edilmesidir.</u>

1. *YK için gerekli minimum deformasyon miktarı*
2. *Ne kadar küçük deformasyon o kadar büyük YK sıcaklığı*
3. *Tavlama süresini artırmak YK sıcaklığını düşürür*
4. *Y.Kristallenmiş tane boyutu temel olarak deformasyon oranına bağlı*
5. *YK hızı, deformasyon ve sıcaklık artışıyla artar*
6. *Yeni taneler deforme edilmiş tanenin içersinde büyümüyor*
7. *YK'den sonra tavlamaya devam etme tane büyümesine neden olur.*
8. *Belirli bir deformasyon oranında daha düşük ısıtma hızı YK sıcaklığını yükseltiyor.*


100 pm (10^{-10}m)
nm (10^{-9}m)
m (10^{-6}m)
çözünen atom
Çökelti
Tane-
sınırı
ikincil
faz
Soğuk
sertleşme
Katı ergiyik
sertleşmesi
Çökelti
sertleşmesi
İnce tane
İkizlenmeler
Çok faz
sertleşmesi


Mukavemet artışı log R_p
R_{max}
R_{min}
Az miktarda dislokasyon
içeren tek kristal
Dislokasyon içermeyen
ideal tek kristal
Çok miktarda dislokasyon
içeren tek kristal
Çok miktarda dislokasyon
içeren çok kristalli
saf yapı
Çok miktarda
dislokasyon içeren
çok kristalli
alaşım
Çok miktarda dislokasyon
içeren çok kristalli
çok fazlı alaşım
$\Delta R_{Dislokasyon}$
$\Delta R_{Tane\ sınırı}$
$\Delta R_{Katı\ ergiyik}$
$\Delta R_{Çökelti}$
Dislokasyon
Tane sınırı
Katı ergiyik
Çökelti
Kafes hatalarının miktarı