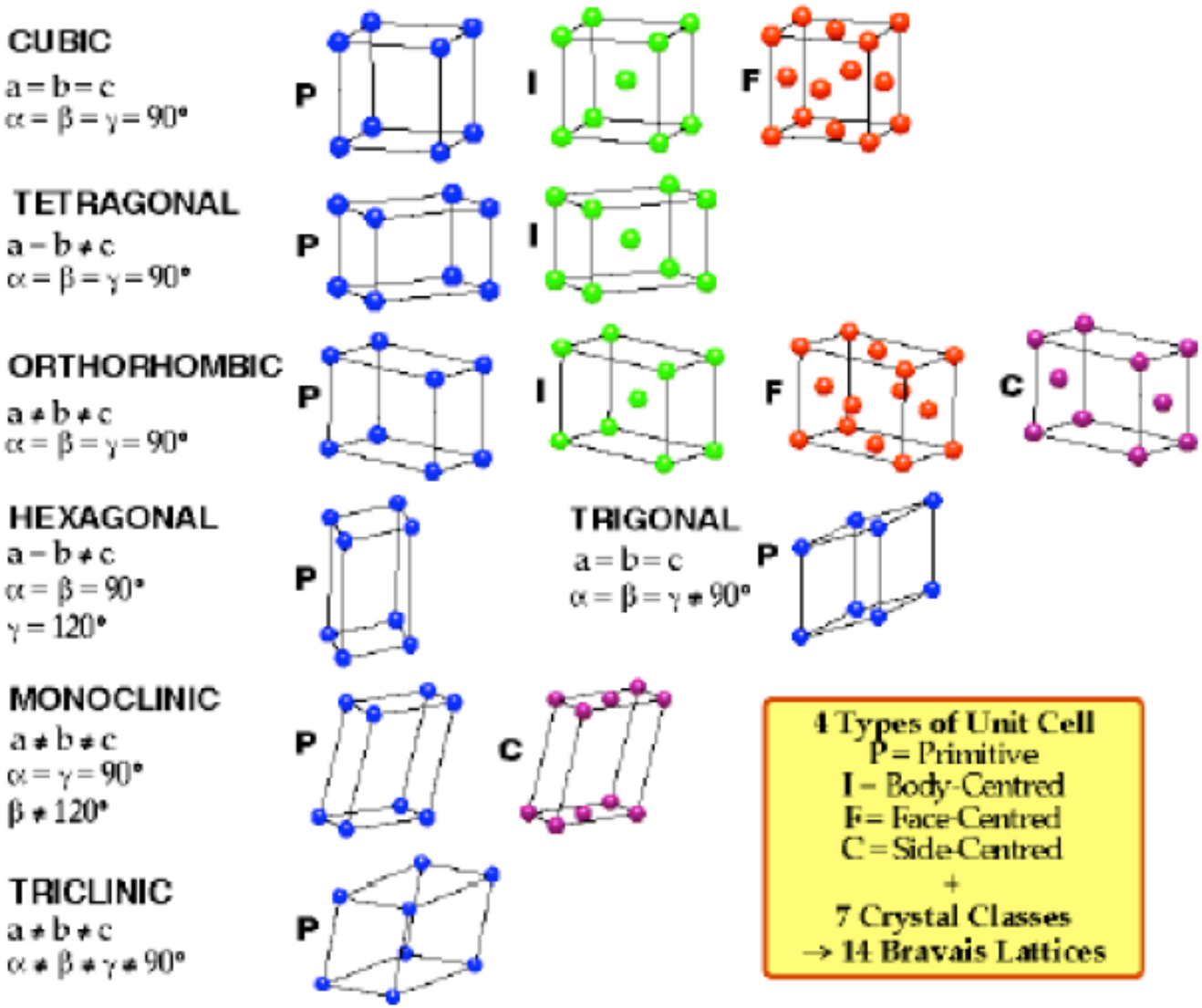
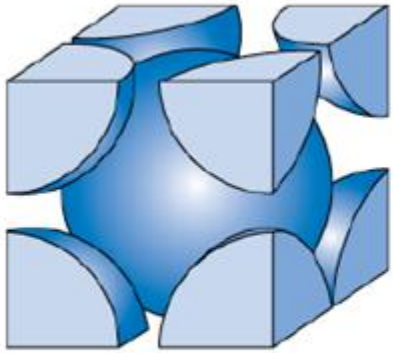
Metallere Plastik Şekil Verme

Adapted from Fig. K, color inset pages of *Callister 5e*. (Fig. K is courtesy of Paul E. Danielson, Teledyne Wah Chang Albany)

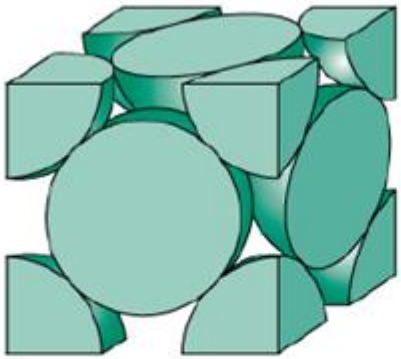
BÖLÜM 2 METALURJİK ESASLAR

The 14 Bravais Lattices!

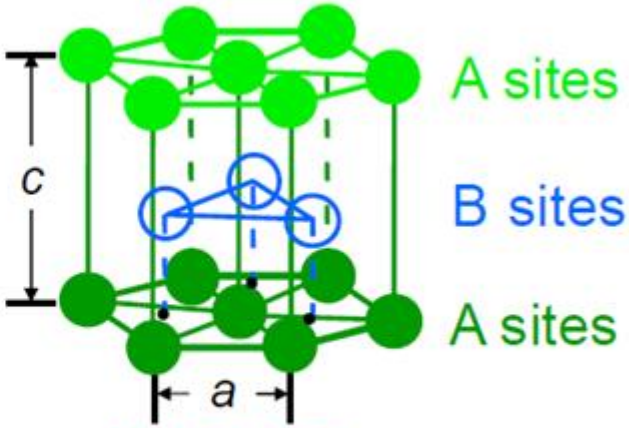




(BCC)



(FCC)

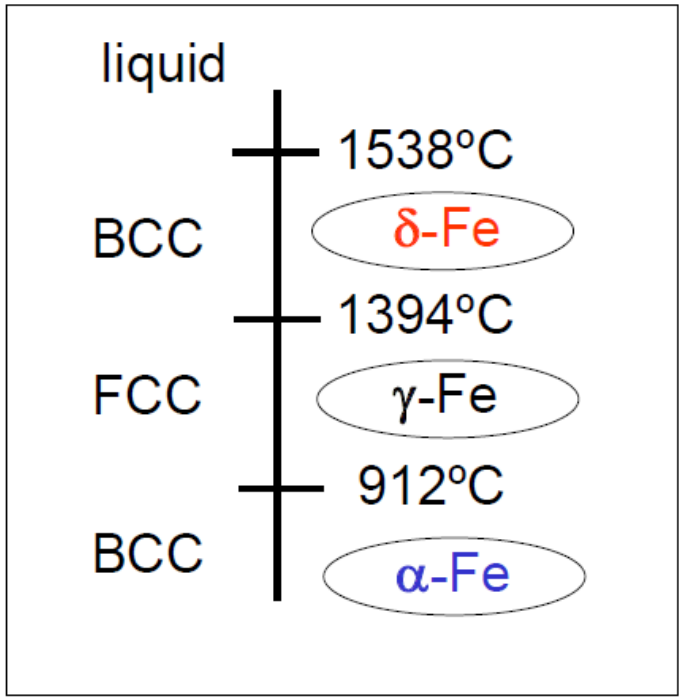


(HCP)

Polimorfizm (allotropi) ?

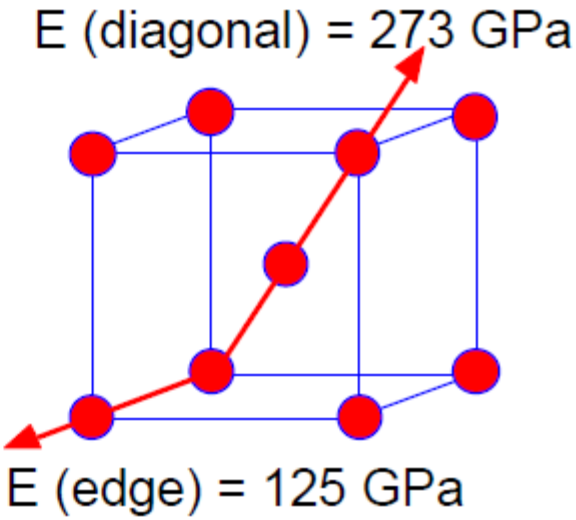
TABLO 2.1
Çeşitli metallerin kristal yapısı

Hacım merkezli kübik	Yüzey merkezli kübik	Sıkı düzenli hegzagonal
Krom	Alüminyum	Berilyum
Demir (α)	Demir (γ)	Magnezyum
Molibden	Bakır	Çinko
Tungsten	Altın	Kobalt (α)
Vanadyum	Kurşun	Titanyum (α)
Tantal	Nikel	Zirkonyum (α)
Titanyum (β)	Gümüş	
Zirkonyum (β)	Kobalt (β)	

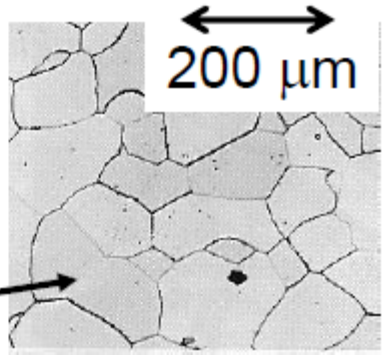


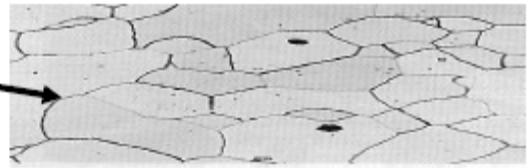
Single vs Polycrystals

- Single Crystals
  - -Properties vary with direction: anisotropic.
  - -Example: the modulus of elasticity (E) in BCC iron:



- Polycrystals
  - -Properties may/may not vary with direction.
  - -If grains are randomly oriented: isotropic. ($E_{poly\ iron}$ = 210 GPa)
  - -If grains are textured, anisotropic.

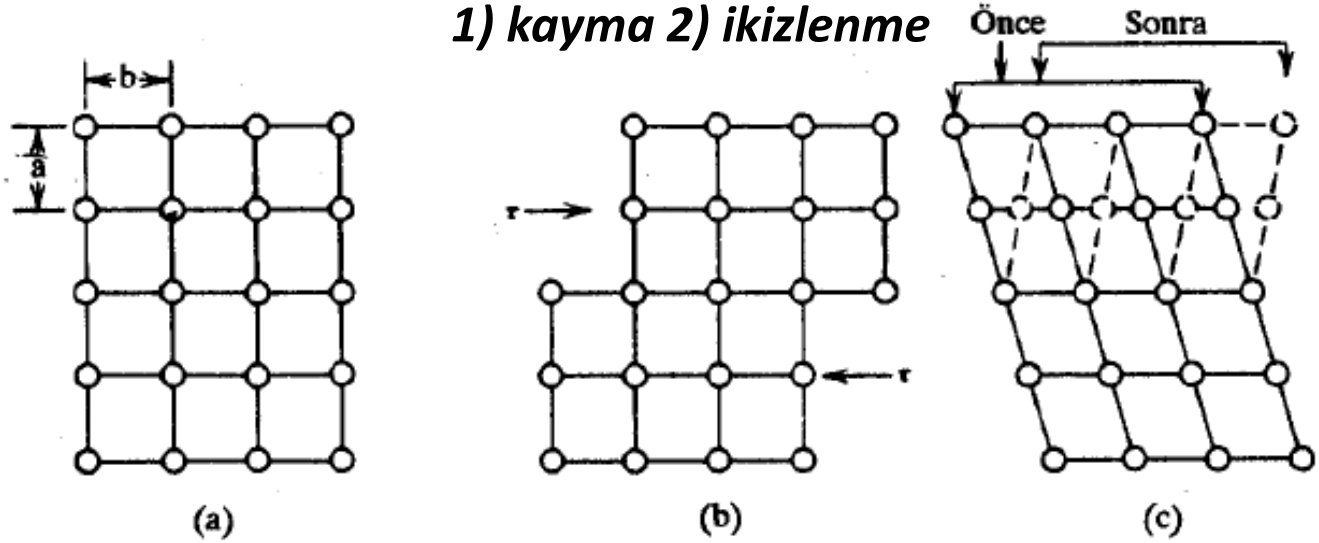




Tek Kristallerde Şekil Değişimi

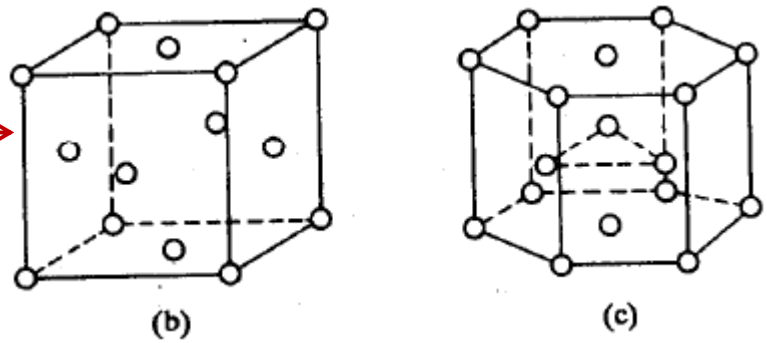
Kristal yapılarda plastik şekil değişimini meydana getiren 2 mekanizma vardır:

1) kayma 2) ikizlenme



Tek kristalin şekil değişimi. (a) Şekil değişiminden önce kristal yapı. (b) Kayma. (c) Mekanik ikizlenme.

12 kayma sistemi



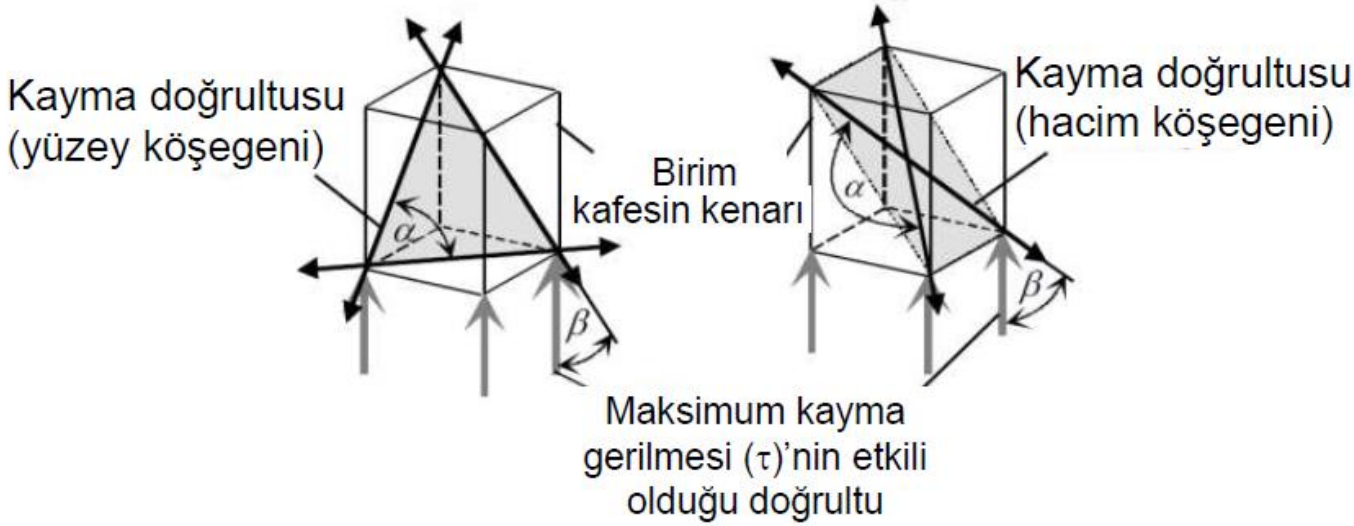
3 kayma sistemi

YMK

Ymk: α=60°

HMK

Hmk: α=90°



Ymk: $\beta_{maksimum}$=45° **Hmk: $\beta_{maksimum} \approx$ 54,74°**

α = kayma doğrultuları arasındaki açı

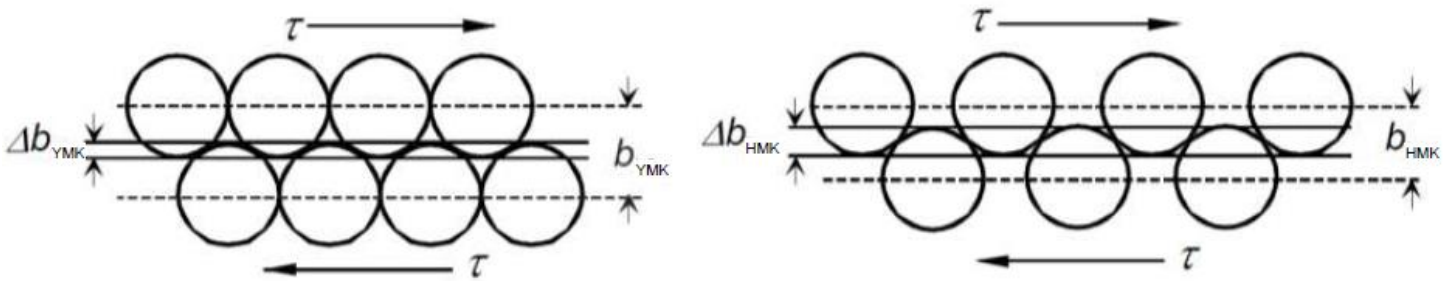
β = Maksimum kayma gerilmesi ile kayma doğrultuları arasındaki açı

YMK

Düzlemde kaymanın doğrultusu

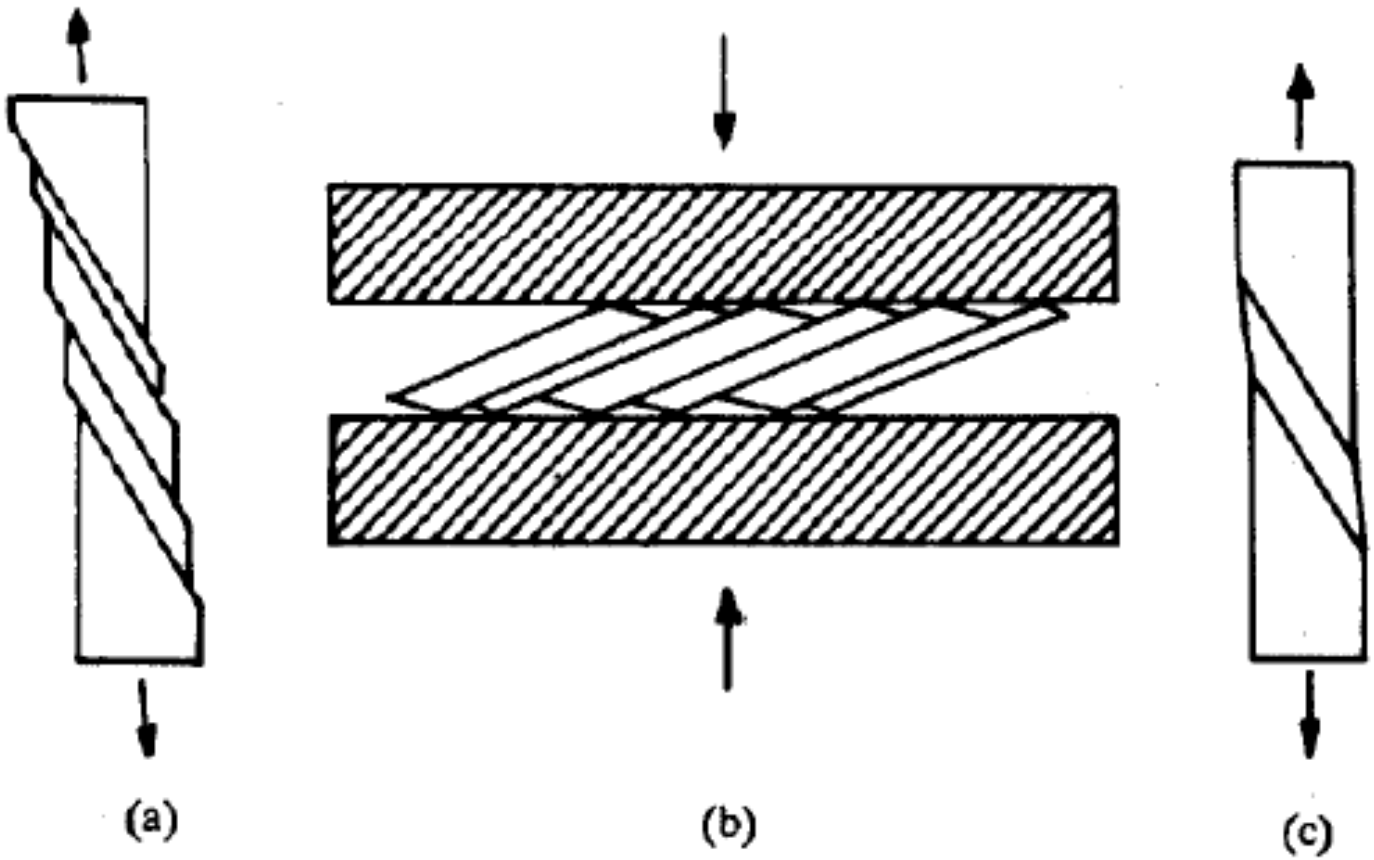
HMK

Düzlemde kaymanın doğrultusu

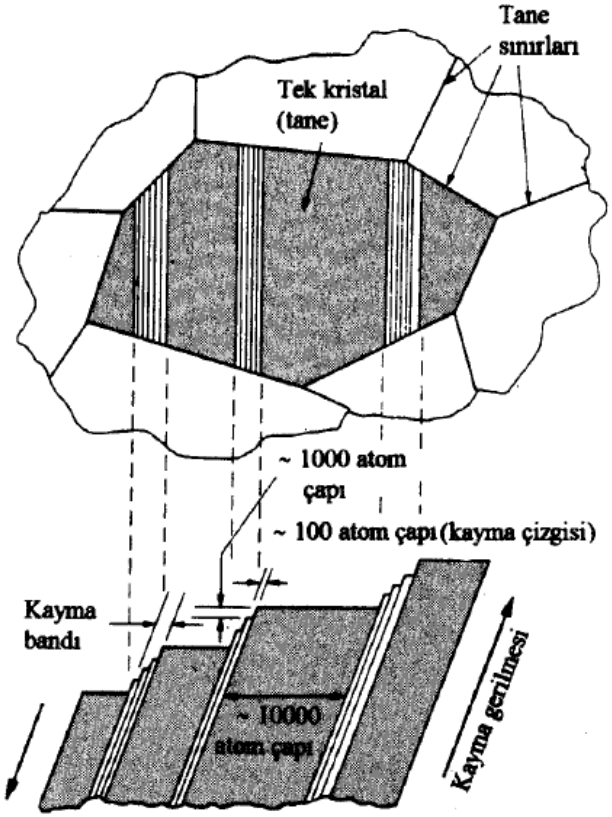


——— $\Delta b_{YMK} < \Delta b_{HMK}$ Δb = Aşılması gereken boşluk mesafesi

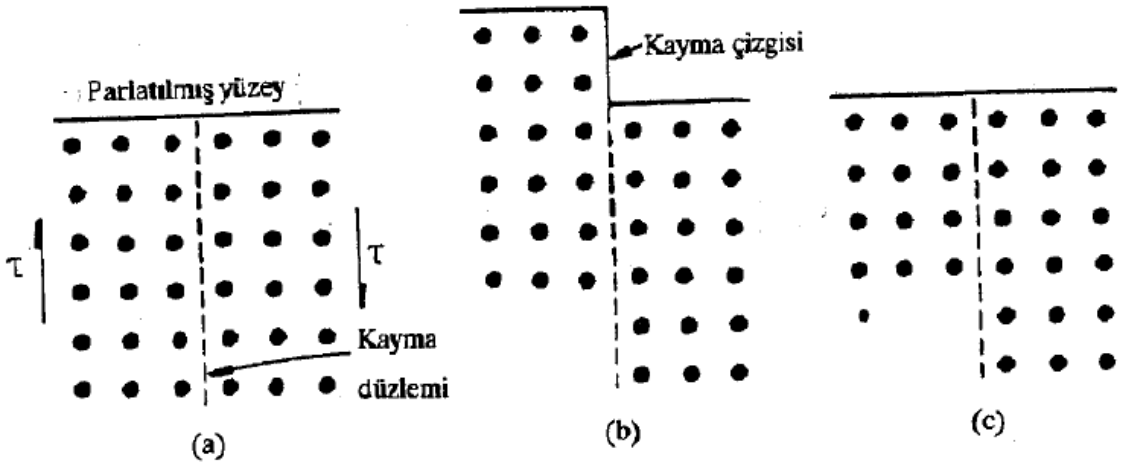
---------- $b_{YMK} > b_{HMK}$ b = Kayma düzlemleri arası mesafe



Tek kristalin şekil değişimi. (a) Çekmede kayma. (b) Basmada kayma. Çekmede kayma düzlemleri çekme kuvveti doğrultusuna, basmada ise basma kuvvetine dik doğrultuya dönerler. (c) Çekmede ikizlenme.



Tek kristalde kayma çizgileri ve kayma bantları (10000 atom çapı yaklaşık 10^{-3} mm dir).



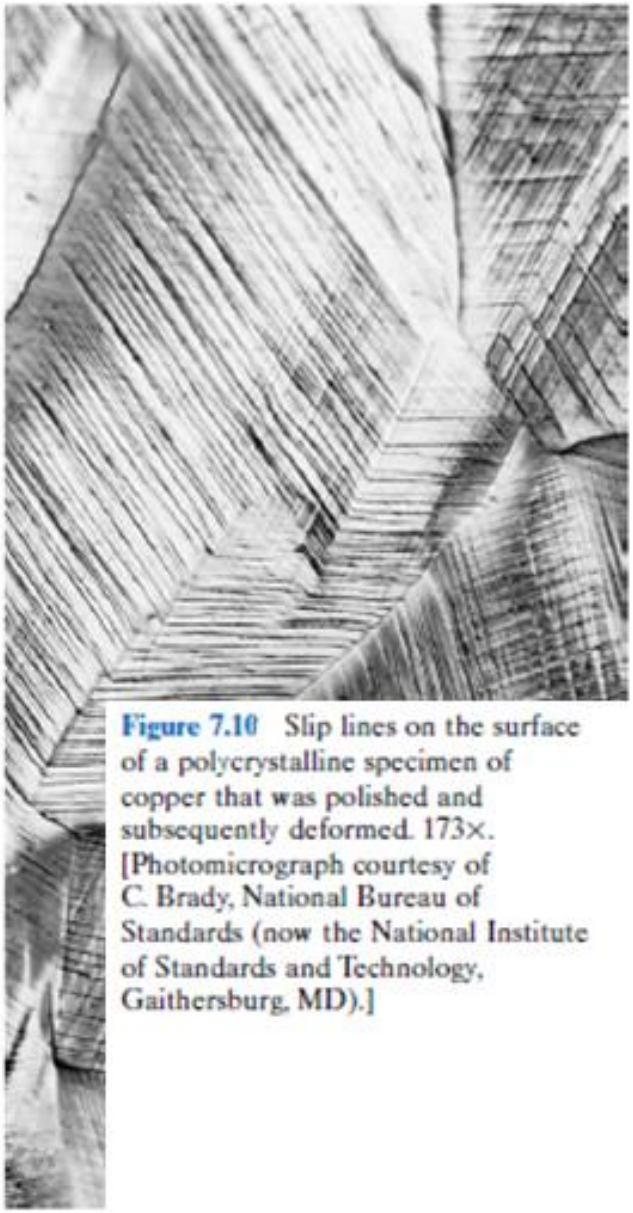


Figure 7.10 Slip lines on the surface of a polycrystalline specimen of copper that was polished and subsequently deformed. 173×. [Photomicrograph courtesy of C. Brady, National Bureau of Standards (now the National Institute of Standards and Technology, Gaithersburg, MD).]

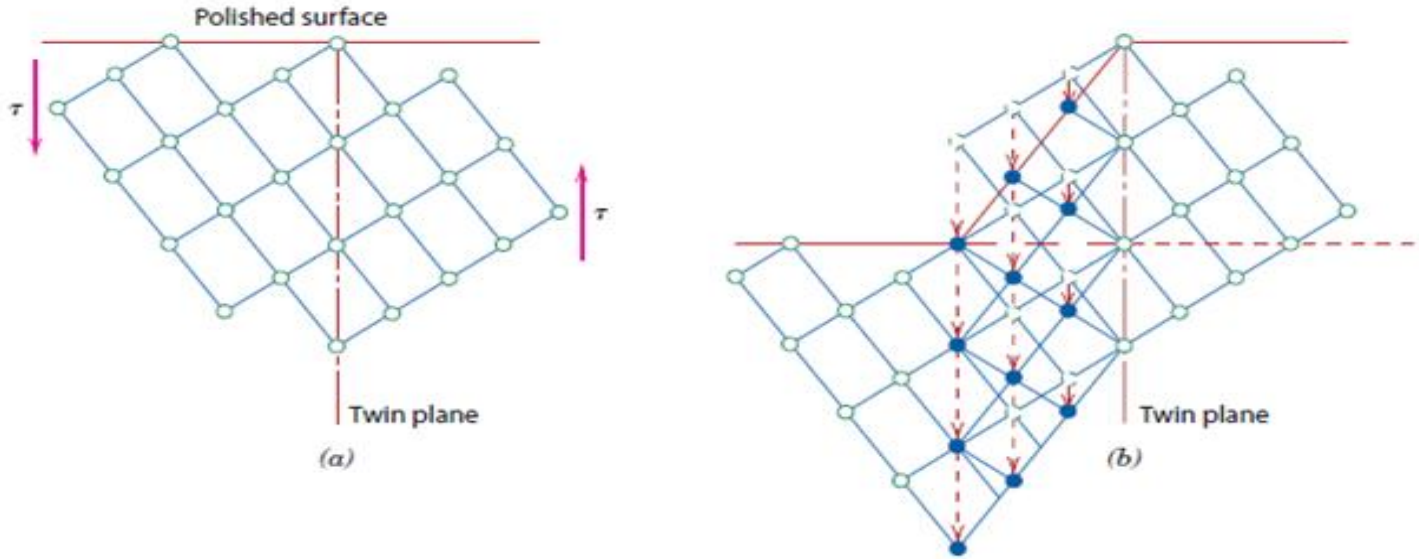


Figure 7.12 Schematic diagram showing how twinning results from an applied shear stress τ. In (*b*), open circles represent atoms that did not change position; dashed and solid circles represent original and final atom positions, respectively. (From G. E. Dieter, *Mechanical Metallurgy,* 3rd edition. Copyright © 1986 by McGraw-Hill Book Company, New York. Reproduced with permission of McGraw-Hill Book Company.)

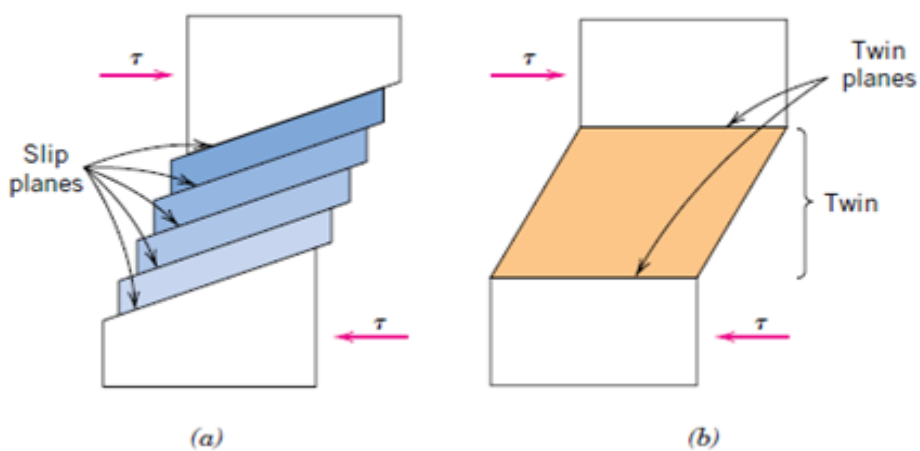
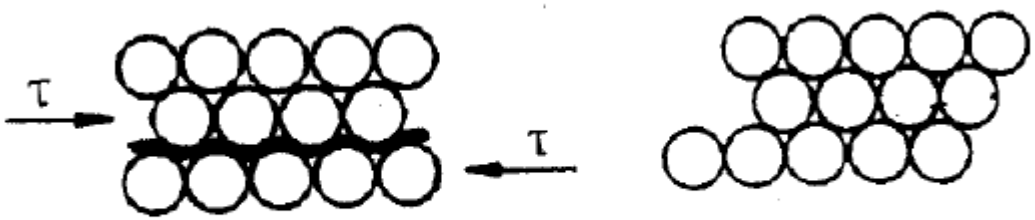


Figure 7.13 For a single crystal subjected to a shear stress τ, (*a*) deformation by slip; (*b*) deformation by twinning.

Tek Kristallerin Teorik Kayma Dayanımı



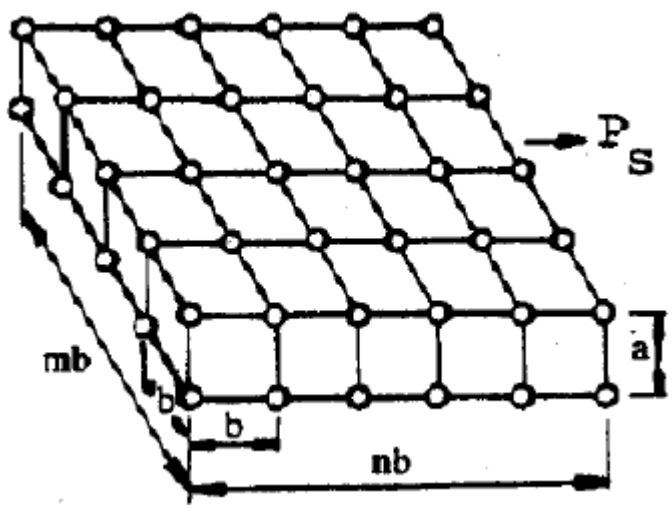
Şekil 2.8.Kayma.

Kaymada, atomlarası mesafenin tam katı kadar ötelenir.

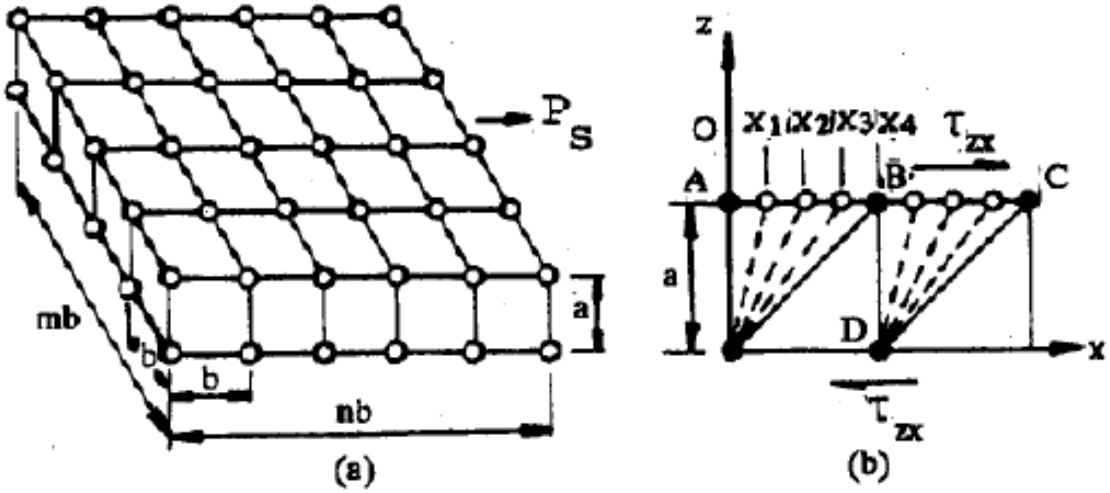
Kayma için gerekli kayma gerilmesi (τ) –kusursuz kristal için-

$$\tau = \frac{P_s}{mnb^2}$$

Kayma kuvveti



Tek Kristallerin Teorik Kayma Dayanımı

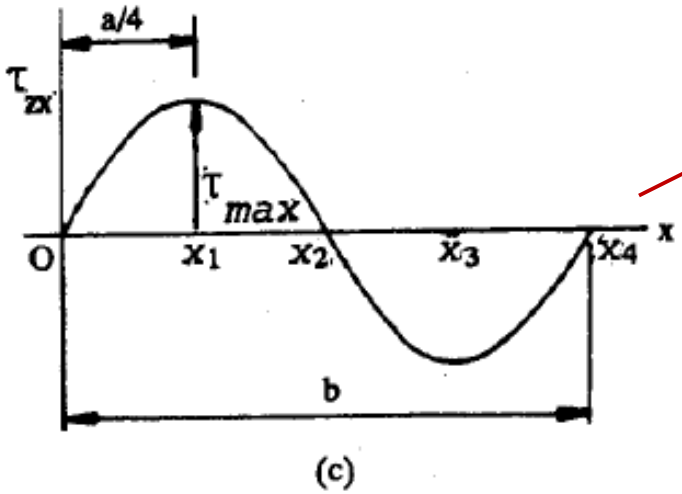


Kayma modülü

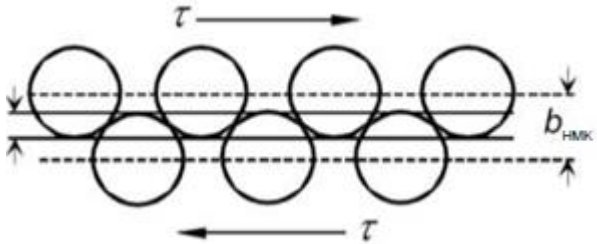
$$\tau_{maks} = \frac{G}{2\pi} \cdot \frac{b}{a}$$

a ≈ b alınırsa

$$\tau_{maks} = \frac{G}{2\pi}$$



$$\sin\frac{2\pi x}{b} \approx \frac{2\pi x}{b}$$



Şekil 2.9. Kusursuz kristal. (a) İki komşu atom düzlemi. (b) Üst düzlemdeki atomların hareketi. (c) τ kayma gerilmesinin değişimi.

Whiskers

6/23/2010
10:07:03 PM
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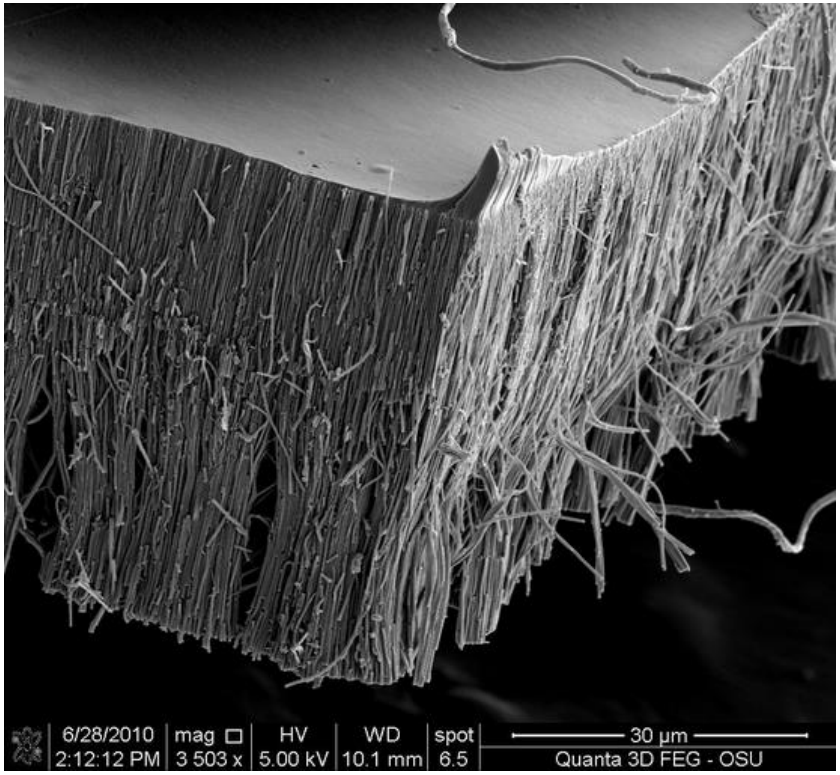
35 000 x
HV
5.00 kV
WD
10.1 mm
spot
4.5
3 µm
Quanta 3D FEG - OSU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spot
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30 µm
Quanta 3D FEG - OSU

2.4 Kristal Kusurları

Ticari metal ve alaşımlarda çeşitli kristal kusurları vardır. Bu kusurlar aşağıdaki şekilde sınıflandırılabilir:

a) Noktasal (sıfır boyutlu) kusurlar: Bunlara örnek olarak boş kafes noktaları (boşyerler) verilebilir.

b) Çizgisel (tek boyutlu) kusurlar: Bu kusurlara dislokasyon denir.

c) Yüzeysel (iki boyutlu) kusurlar: Bunlara örnek olarak tane sınırları verilebilir.

d) Hacımsal (üç boyutlu) kusurlar: Bunlara örnek olarak inklüzyonlar (kalıntılar) ve boşluklar verilebilir.

Noktasal Kusurlar

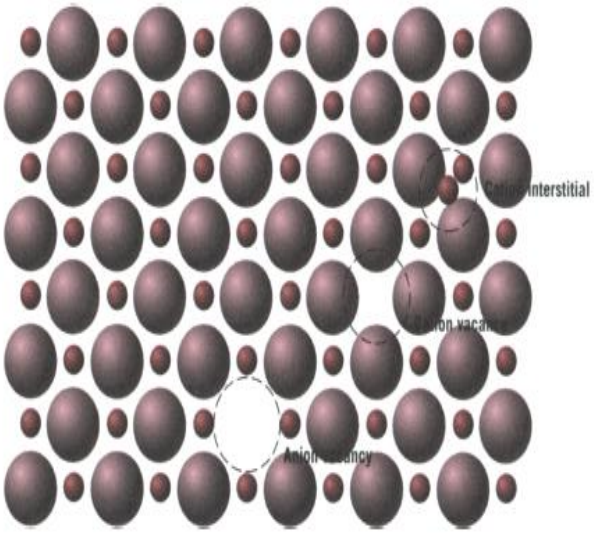


FIGURE 5.2 Schematic representations of cation and anion vacancies and a cation interstitial. (From W. G. Moffatt, G. W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. 1, *Structure*, p. 78. Copyright © 1964 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

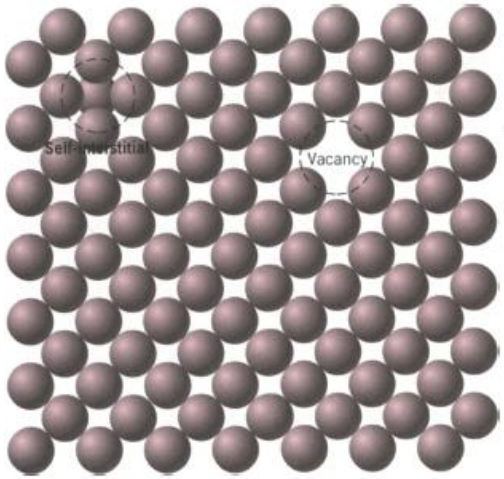


FIGURE 5.1 Two-dimensional representations of a vacancy and a self-interstitial. (Adapted from W. G. Moffatt, G. W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. I, *Structure*, p. 77. Copyright © 1964 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

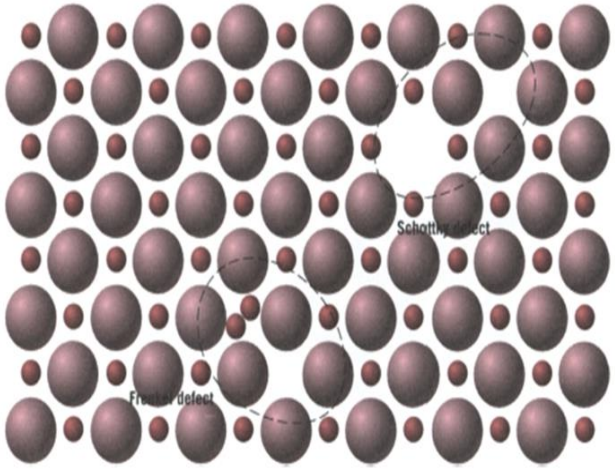
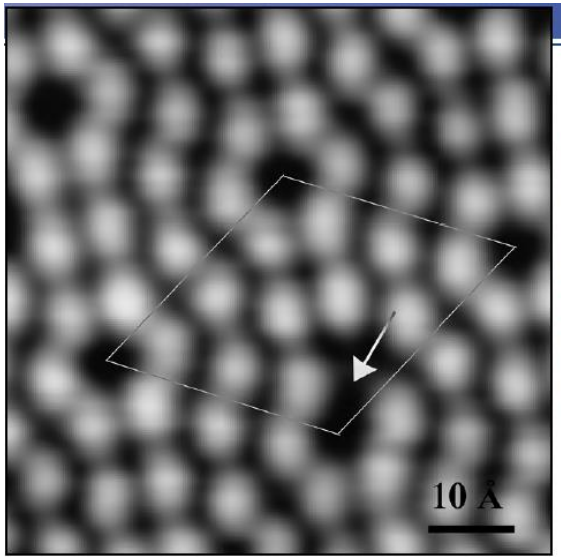
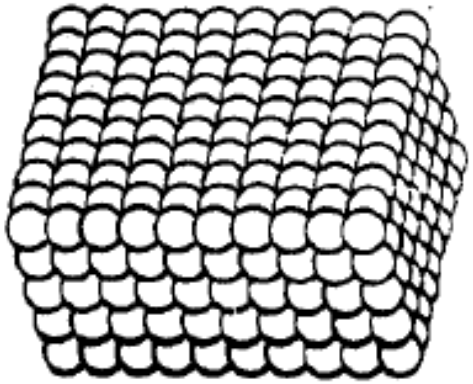


FIGURE 5.3 Schematic diagram showing Frenkel and Schottky defects in ionic solids. (From W. G. Moffatt, G. W. Pearsall, and J. Wulff, *The Structure and Properties of Materials*, Vol. 1, *Structure*, p. 78. Copyright © 1964 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

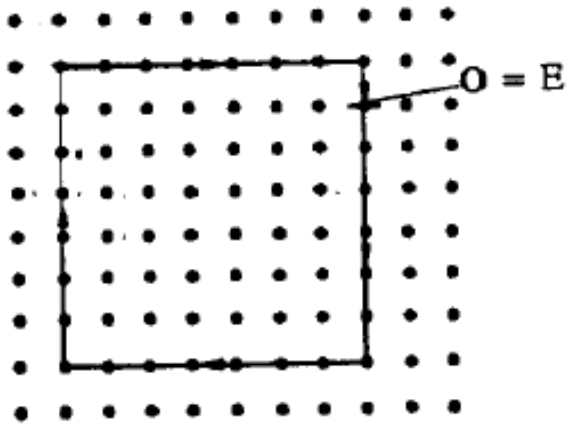


A scanning probe micrograph (generated using a scanning-tunneling microscope) that shows a (111)-type surface plane* for silicon. The arrow points to the location of a silicon atom that was removed using a tungsten nanotip probe. This site from which an atom is missing is the surface analogue of a vacancy defect—that is, a vacant lattice site within the bulk material. Approximately 20,000,000×. (Micrograph courtesy of D. Huang, Stanford University.)

Dislokasyonlar

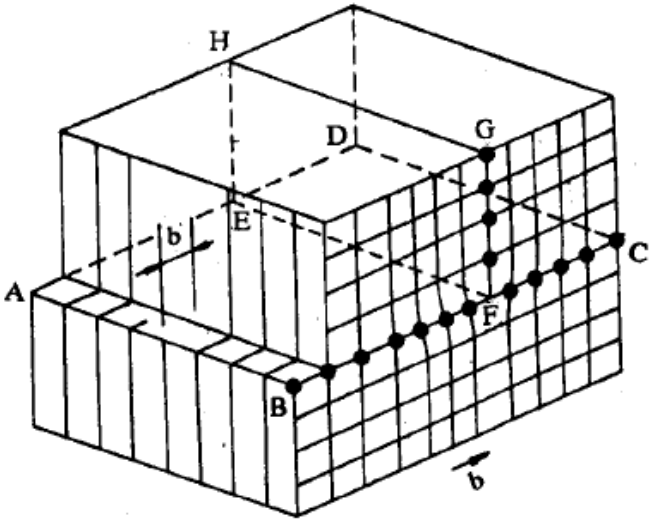


Şekil 2.11. Kusursuz basit kübik tek kristal

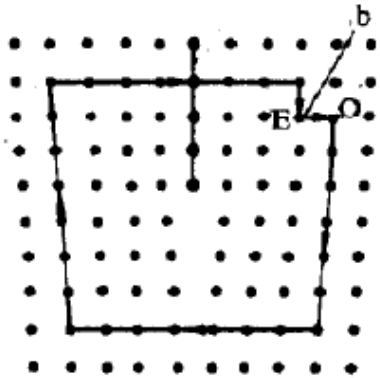


Şekil 2.12. Burgers çevrimi (şekil değiştirmemiş kristal).

Kenar Dislokasyonu



Şekil 2.13. Kenar dislokasyonu.



Şekil 2.14. Burgers çevrimi (kenar dislokasyonu içeren kristal).

Kenar Dislokasyonu

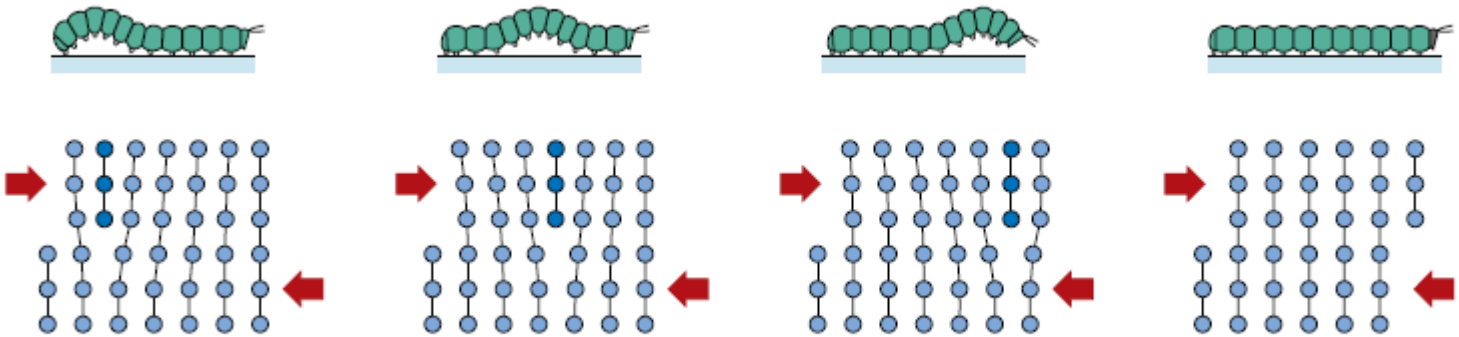


Figure 7.3 Representation of the analogy between caterpillar and dislocation motion.

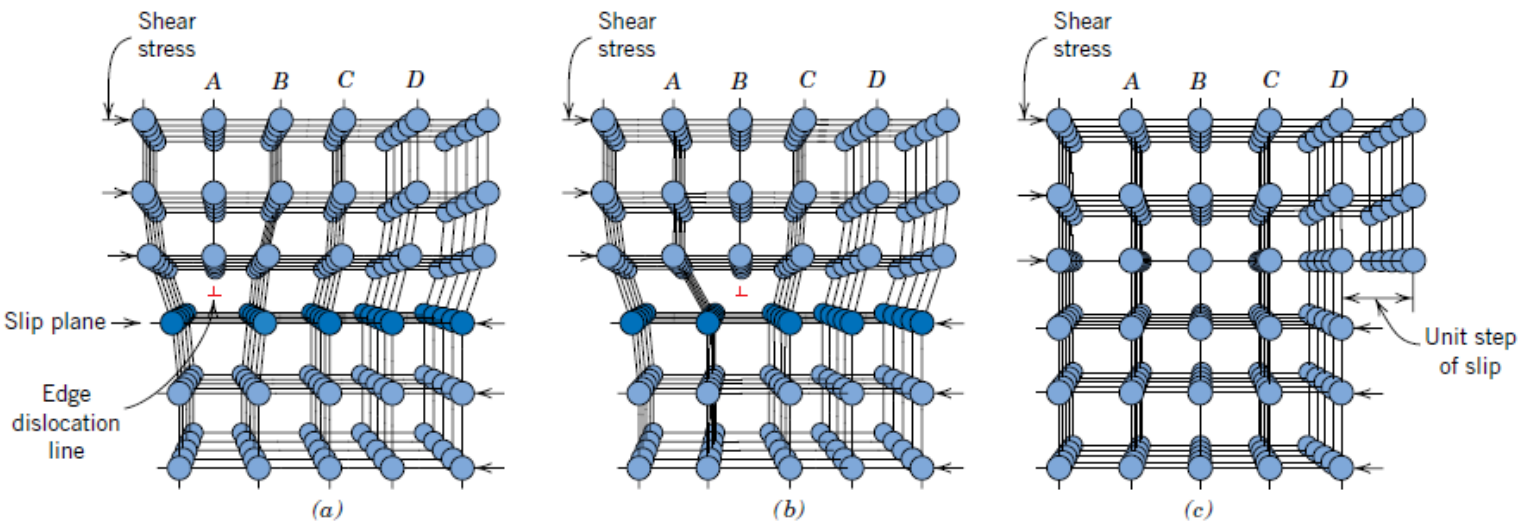
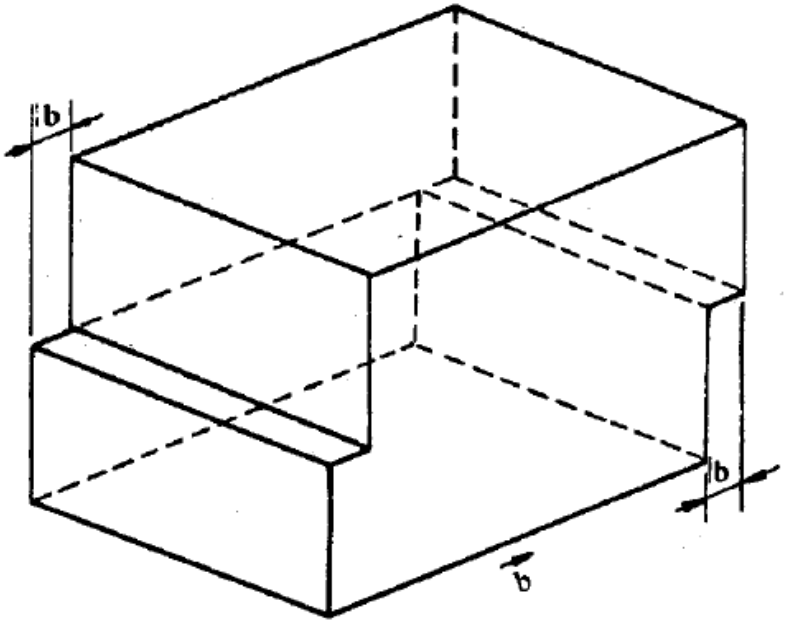


Figure 7.1 Atomic rearrangements that accompany the motion of an edge dislocation as it moves in response to an applied shear stress. (*a*) The extra half-plane of atoms is labeled *A*. (*b*) The dislocation moves one atomic distance to the right as *A* links up to the lower portion of plane *B*; in the process, the upper portion of *B* becomes the extra half-plane. (*c*) A step forms on the surface of the crystal as the extra half-plane exits. (Adapted from A. G. Guy, *Essentials of Materials Science,* McGraw-Hill Book Company, New York, 1976, p. 153.)

Kenar Dislokasyonu



Kenar Dislokasyonu, burgers vektörüne diktir fakat aynı yönde hareket eder.

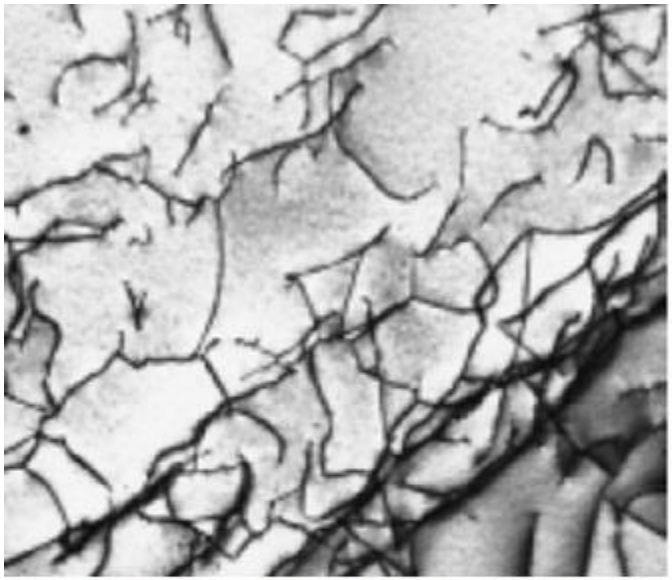


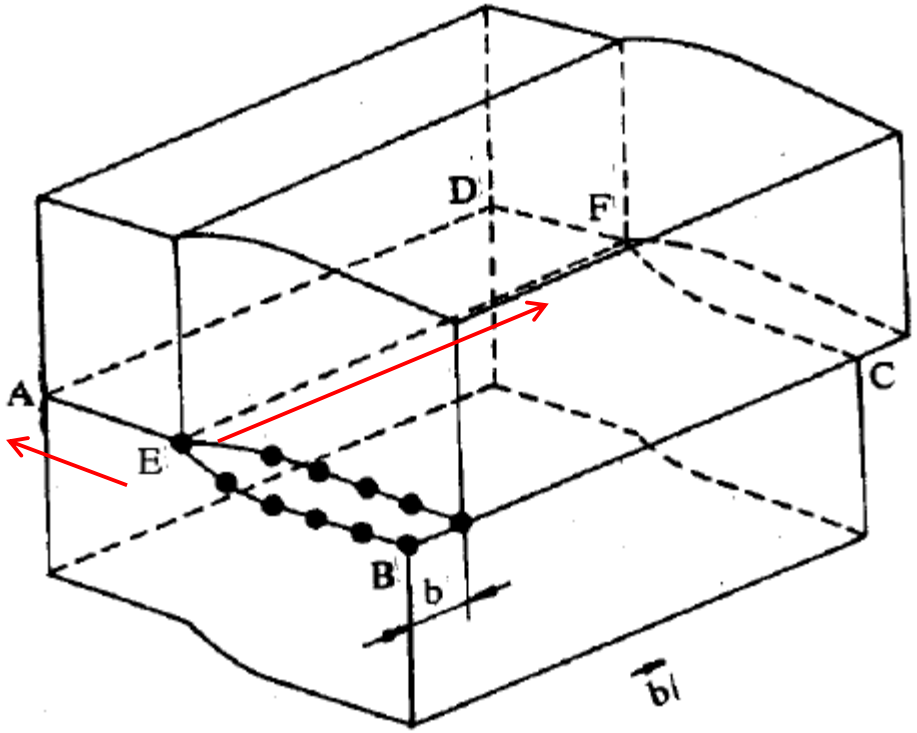
FIGURE 5.10 A transmission electron micrograph of a titanium alloy in which the dark lines are dislocations. 51,450×. (Courtesy of M. R. Plichta, Michigan Technological University.)

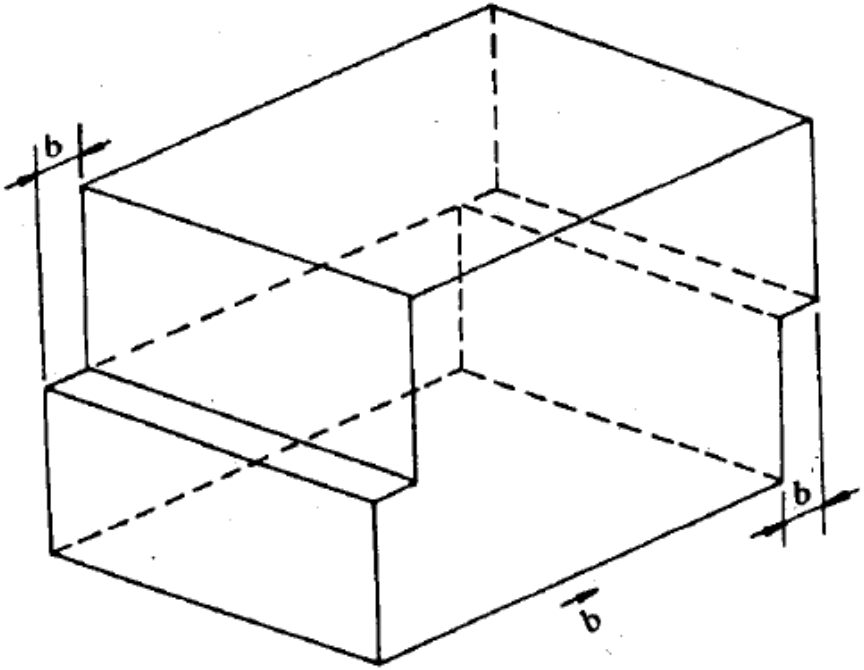
Kaymanın meydana geldiği düzleme kayma düzlemi; kayma düzlemi içinde kaymanın meydana geldiği doğrultuya kayma doğrultusu denir.

Bir kayma düzlemi ile bir kayma doğrultusu bir kayma sistemi oluşturur.

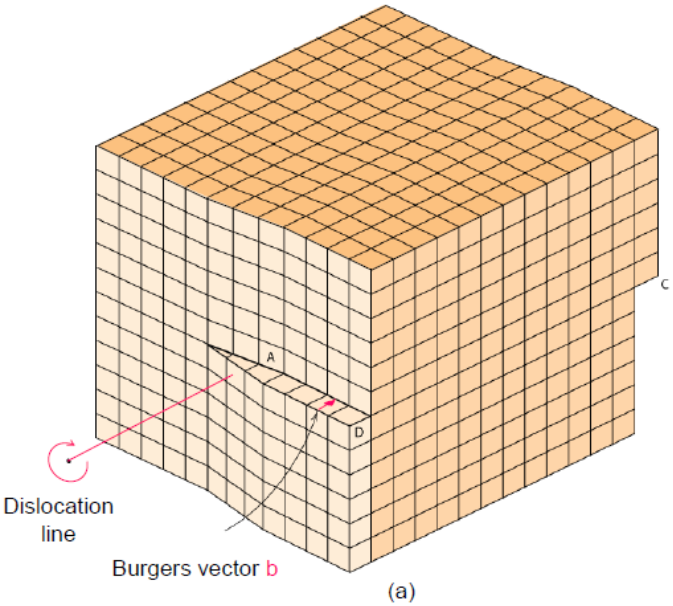
Bir kristalin, kayma düzleminin bir tarafındaki kısmının diğer taraftakine kıyasla, kayma düzlemi içindeki kayma doğrultusu boyunca, bu doğrultudaki atomlararası uzaklığın tam katı kadar ötelenmesine kayma denir.

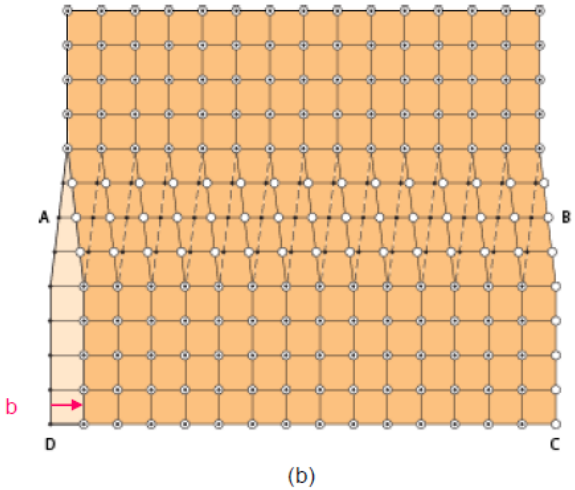
Vida Dislokasyonu



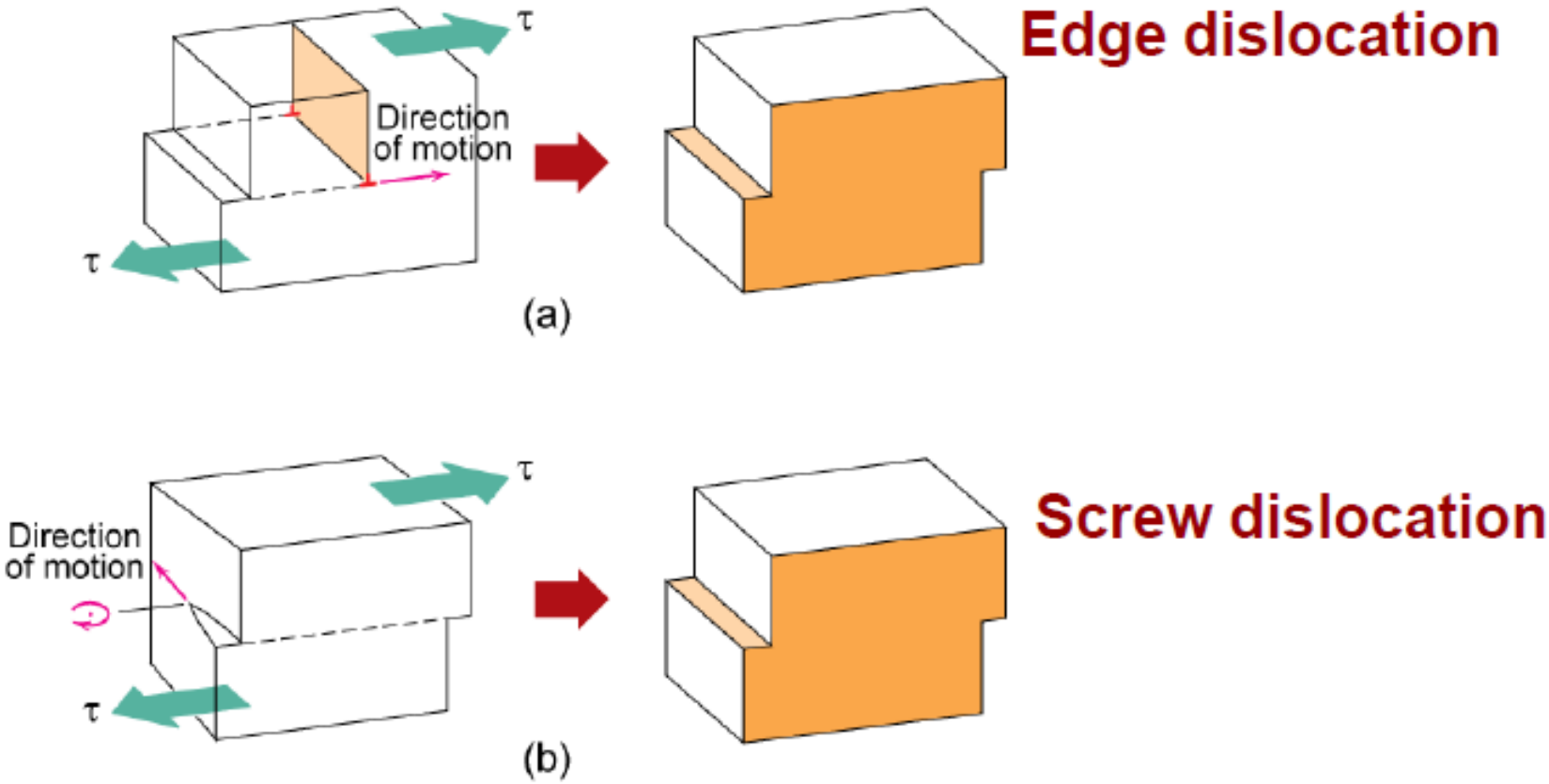


Vida Dislokasyonu, burgers vektörüne paraleldir fakat dik yönde hareket eder.





Dislokasyon Hareketi



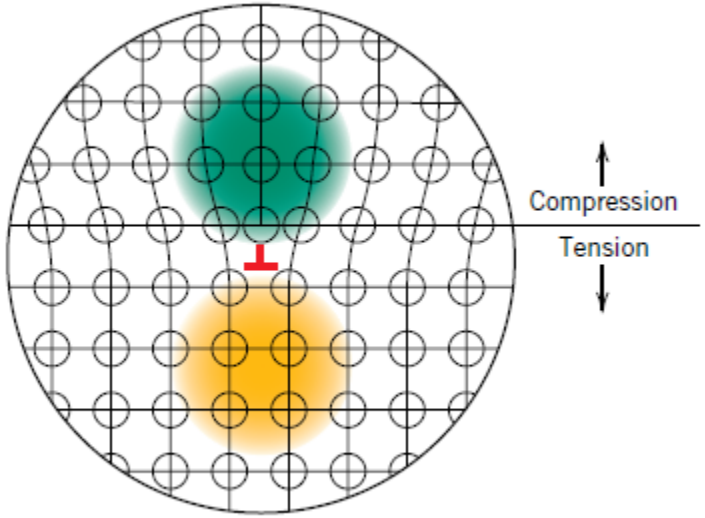


Figure 7.4 Regions of compression (green) and tension (yellow) located around an edge dislocation. (Adapted from W. G. Moffatt, G. W. Pearsall, and J. Wulff, *The Structure and Properties of Materials,* Vol. I, *Structure,* p. 85. Copyright © 1964 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

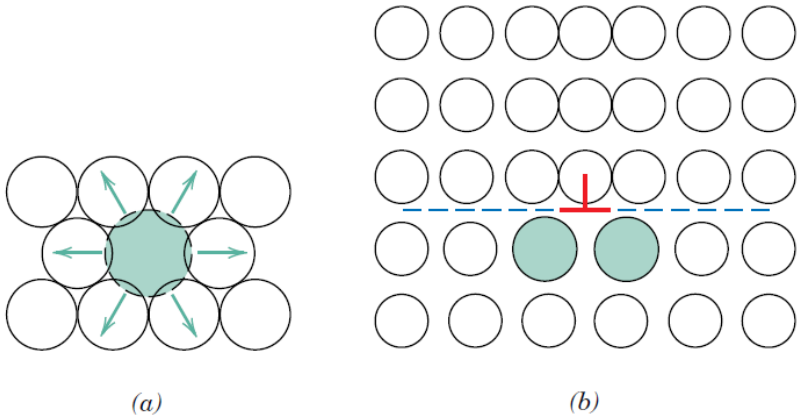


Figure 7.18 (*a*) Representation of compressive strains imposed on host atoms by a larger substitutional impurity atom. (*b*) Possible locations of larger impurity atoms relative to an edge dislocation such that there is partial cancellation of impurity–dislocation lattice strains.

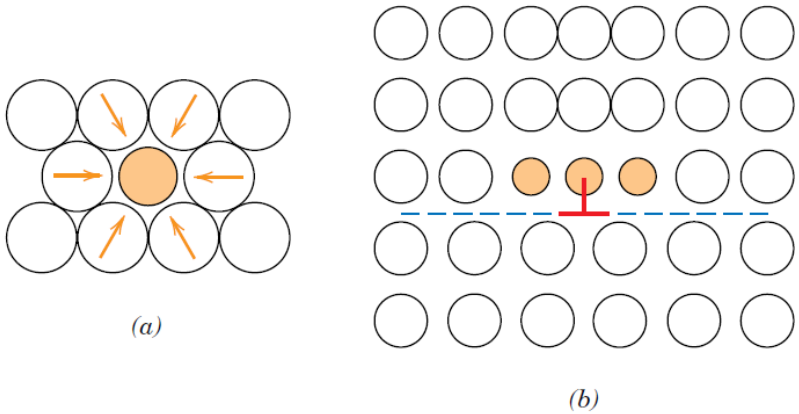
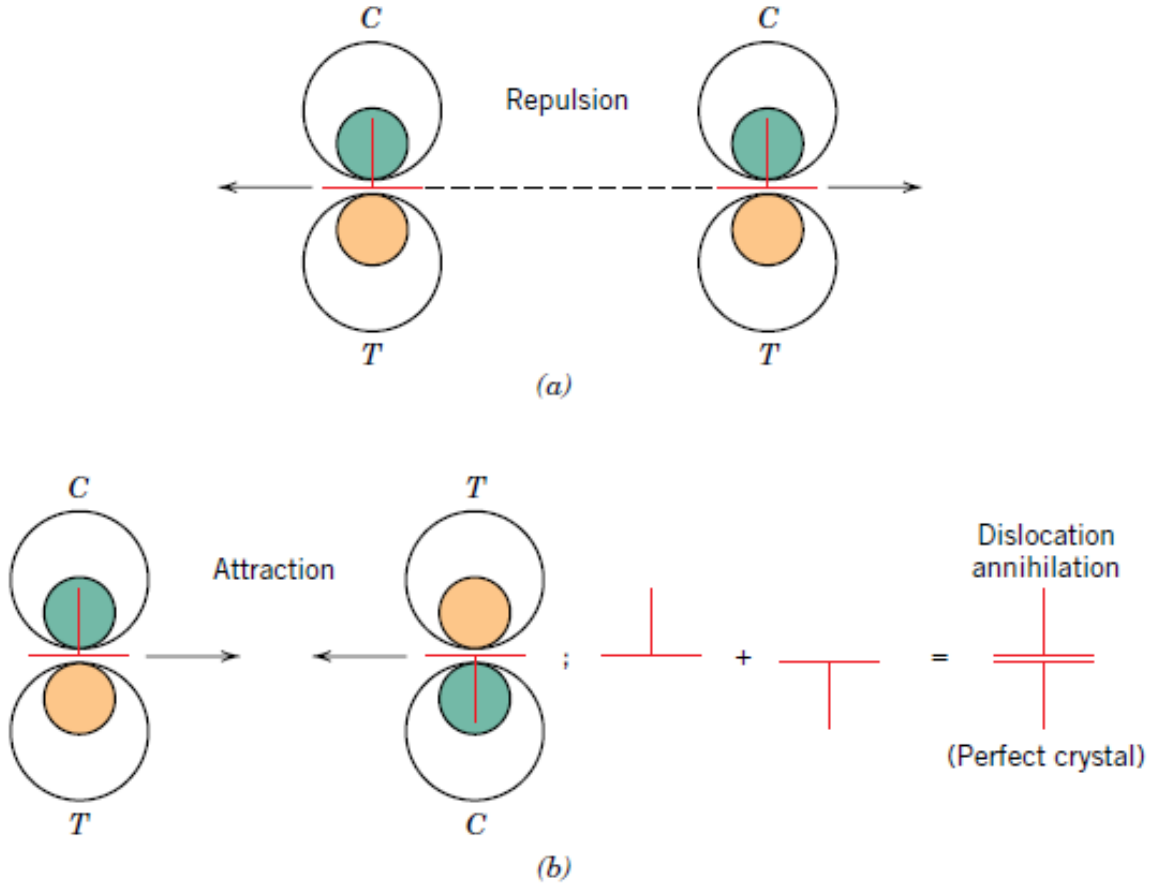
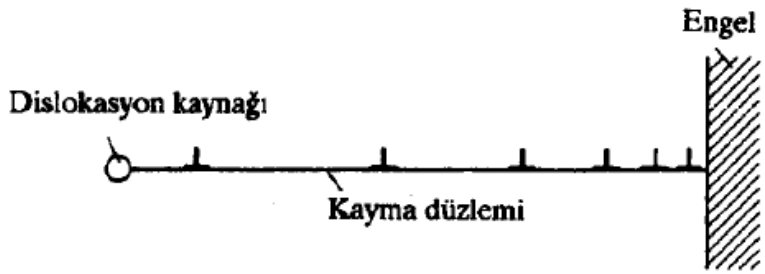


Figure 7.17 (*a*) Representation of tensile lattice strains imposed on host atoms by a smaller substitutional impurity atom. (*b*) Possible locations of smaller impurity atoms relative to an edge dislocation such that there is partial cancellation of impurity–dislocation lattice strains.

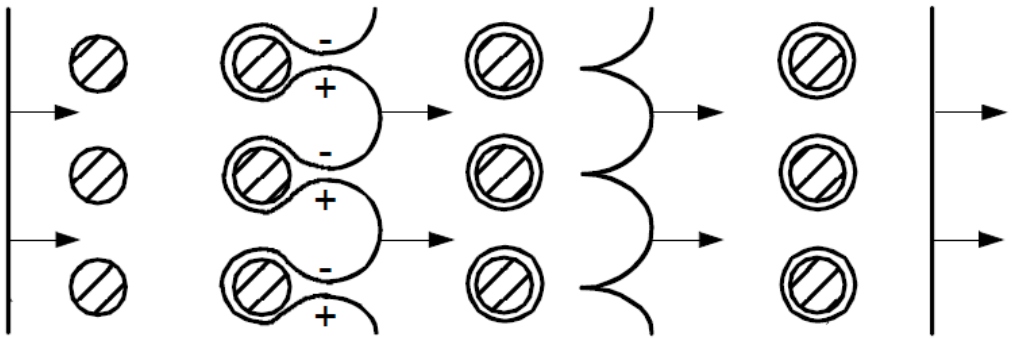
Figure 7.5 (*a*) Two edge dislocations of the same sign and lying on the same slip plane exert a repulsive force on each other; *C* and *T* denote compression and tensile regions, respectively. (*b*) Edge dislocations of opposite sign and lying on the same slip plane exert an attractive force on each other. Upon meeting, they annihilate each other and leave a region of perfect crystal. (Adapted from H. W. Hayden, W. G. Moffatt, and J. Wulff, *The Structure and Properties of Materials,* Vol. III, *Mechanical Behavior,* p. 75. Copyright © 1965 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons.)

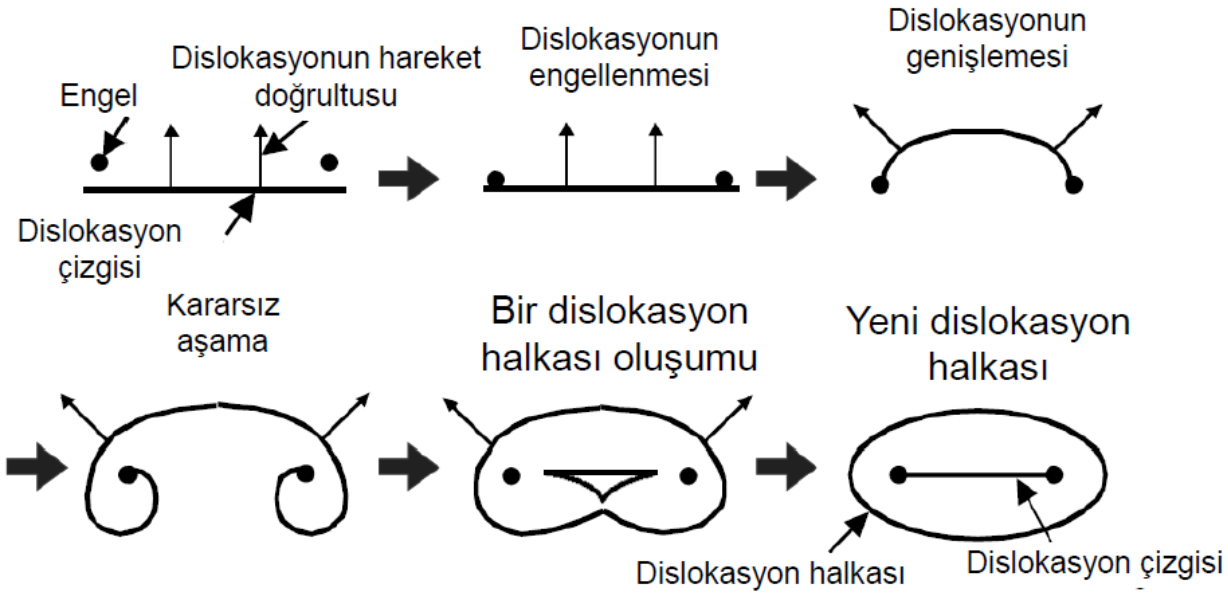


Dislokasyon Oluşum Mekanizması (Frank-Read)



Şekil 2.19. Dislokasyonların bir engel önünde yığılması.



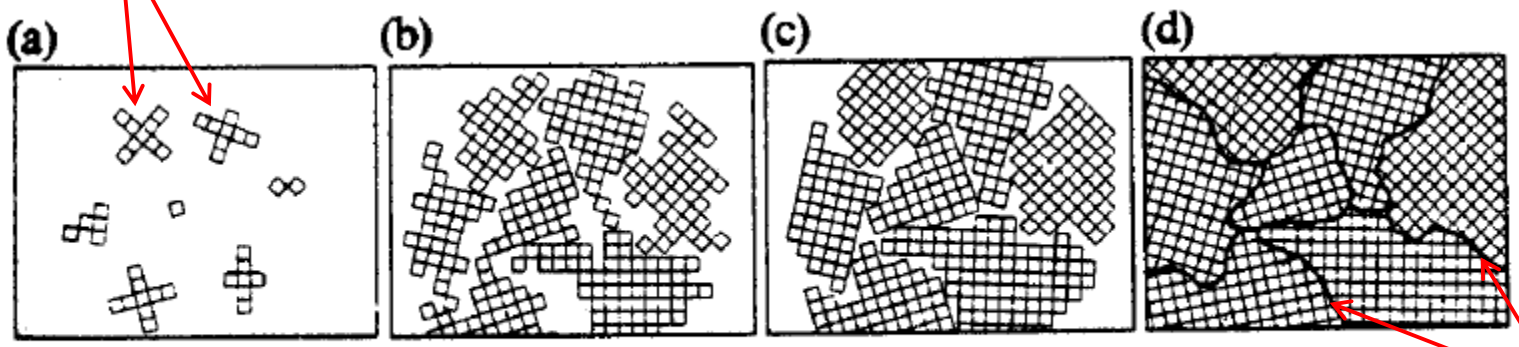


Frank-Read Kaynağı

Taneler ve Tane Sınırları

Tane; kafes doğrultusu aynı ve tek olan kristal

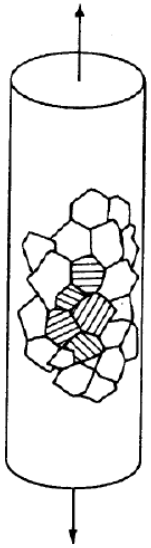
Çekirdek; sıvı metal içerisinde var olabilecek en küçük atom topluluğu



Şekil 2.20. Sıvı metalin katılaşması ve tane sınırlarının oluşumu (şematik).

Amorf

Tek kristal metaller anizotrop
Polikristal metaller izotrop



Şekil 2.21. Bir deney çubuğunda taneler ve kafes doğrultuları.

Kristal Hataları;

Ergime sıcaklığı, özgül ısı etkilenmez.

Akma sınırı, elektrik iletkenliği etkilenir.

Tane büyüklüğü hesaplama

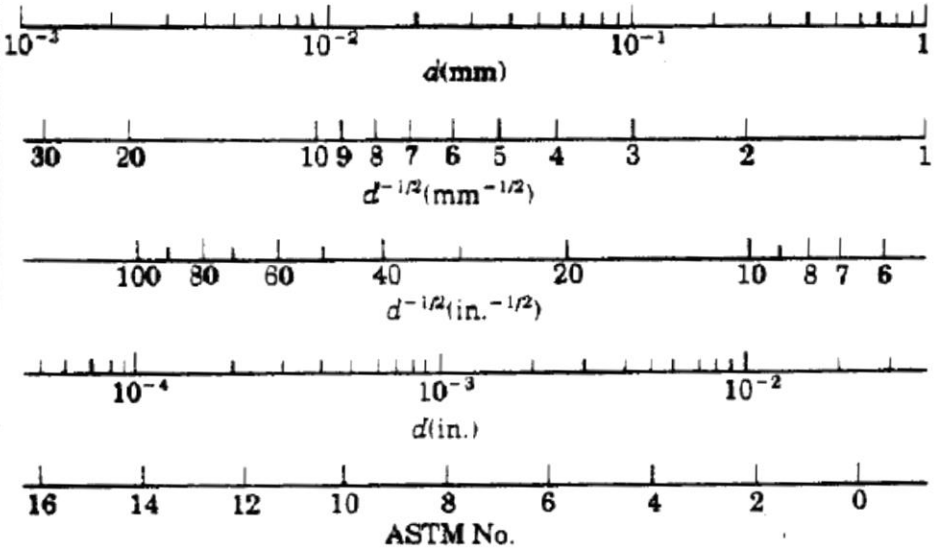
Tane büyüklükleri

ASTM	Tane/mm^2	Tane/mm^3
–3	1	0.7
–2	2	2
–1	4	5,6
0	8	16
1	16	45
2	32	128
3	64	360
4	128	1020
5	256	2900
6	512	8200
7	1024	23000
8	2048	65000
9	4096	185000
10	8200	520000
11	16400	1500000
12	32800	4200000

ASTM tane büyüklüğü numarası

$$N = 2^{n-1}$$

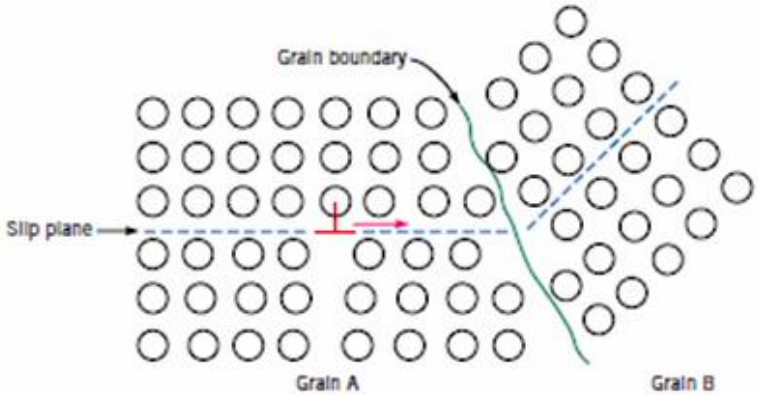
100 büyütmede
1 in^2
alandaki tane adeti



Şekil 2.22. ASTM tane büyüklükleri ve karşılığındaki tane çapları.

Hall-Petch Bağıntısı

$$\sigma_{yield} = \sigma_o + k_y d^{-1/2}$$

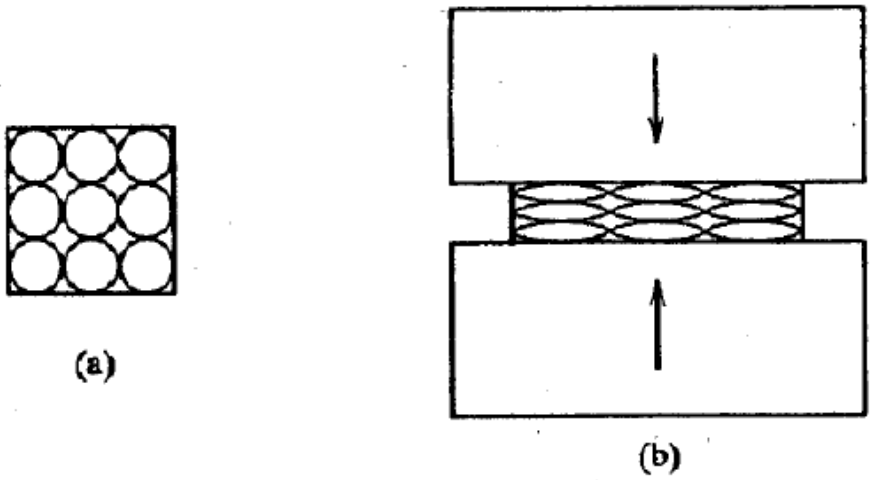


Taneler ve Tane Sınırları

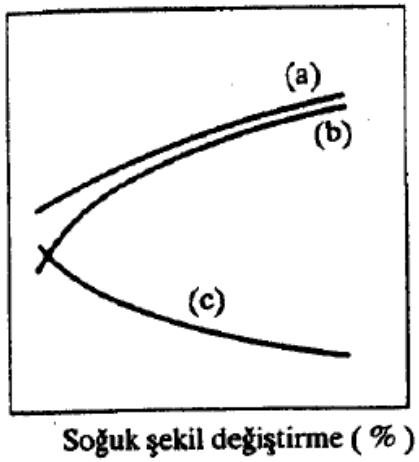
Kükürtün demir içinde çözünürlüğü yok denecek kadar az olduğundan, kükürtlü çeliklerde demir sülfür (FeS) fazı ortaya çıkar. FeS , tane sınırı maddesini meydana getirerek iki olumsuz sonuç yaratır. Bunlardan biri, demir sülfürün şekil değiştirme kabiliyetinin düşük olması nedeniyle, 800...1000°C arasında şekil verme sırasında tane sınırı kırılmasına yol açmasıdır (kızıl sıcaklık kırılganlığı). İkinci olumsuz etki ise, demir sülfürün 1200 °C sıcaklıkta erimesi nedeniyle, bu sıcaklığın üstünde yapılan şekil vermelerde tanelerin birbirinden ayrılmasıdır (akkor sıcaklık kırılganlığı).

Alaşımlı çelikler 480...590 °C arasında ısıtılırsa veya temperlemeden sonra soğutma yavaş yapıldığı takdirde yine bu sıcaklıklar arasında, katışkıların tane sınırlarında çökelmesi sonucunda malzeme gevrekleşir. Bu olay "temper gevrekliği" olarak anılır.

Çok Kristalli Metallerin Şekil Değişimi



İdeal küresel çok kristalli bir metalin soğuk plastik şekil değişimi (basma). (a) Şekil değişiminden önce. (b) Şekil değişiminden sonra.



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

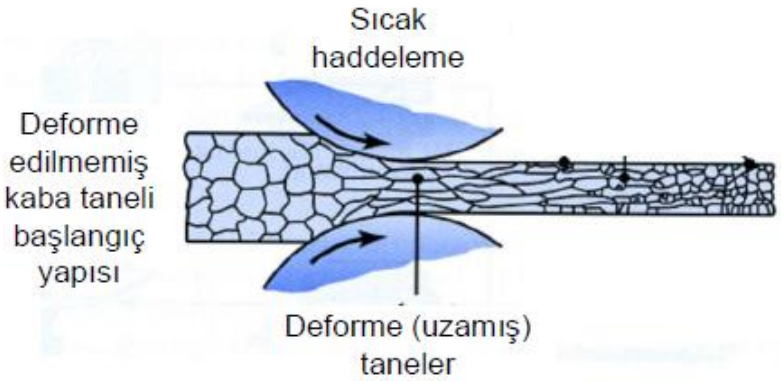
Soğuk şekil değişimi ile;

Elektrik iletkenliği ↓

Korozyon direnci ↓

Yoğunluk ↓

Çok Kristalli Metallerin Şekil Değişimi



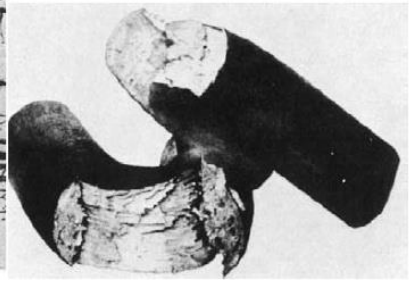
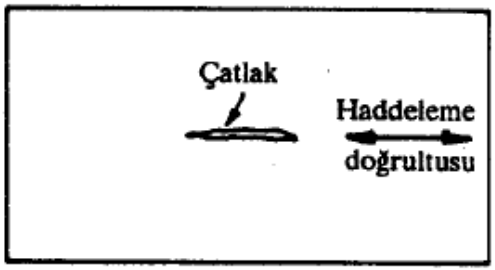
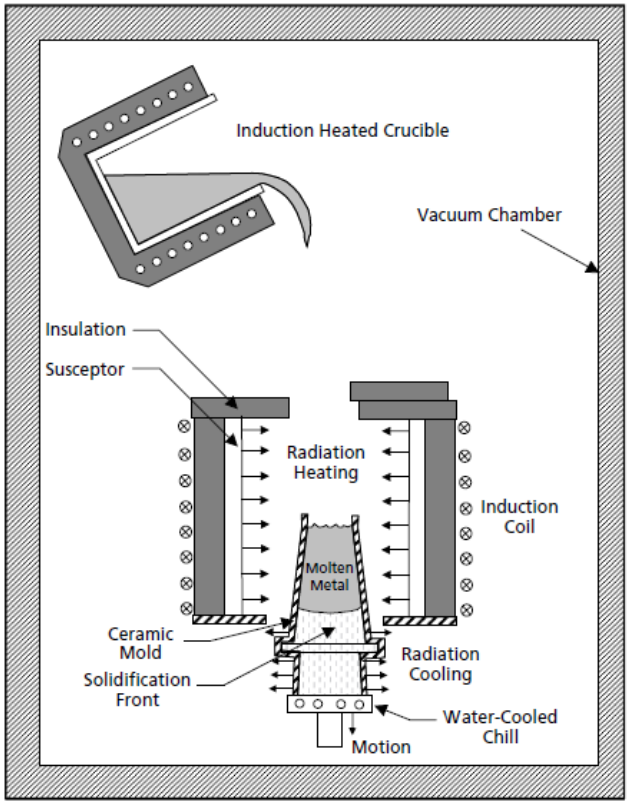


Figure 12.4. Microstructure of wrought iron (top) showing elongated glassy silicates inclusions and the woody fracture (bottom) caused by cracking along the inclusions. From J. Aston and E. B. Story, *Wrought Iron and Its Manufacture, Characteristics and Applications*, Byer Co. Pittsburg, 1939.



Şekil 2.28. Bükme ve haddeleme doğrultusu. Anizotrop bir saçın, bükme kıvrımının haddeleme doğrultusuna dik olmaması halinde çatlaması (şematik). Çatlağın boyu, haddeleme doğrultusundadır.

Tek Kristal Üretimi



Directional Solidification Process for Superalloy Castings

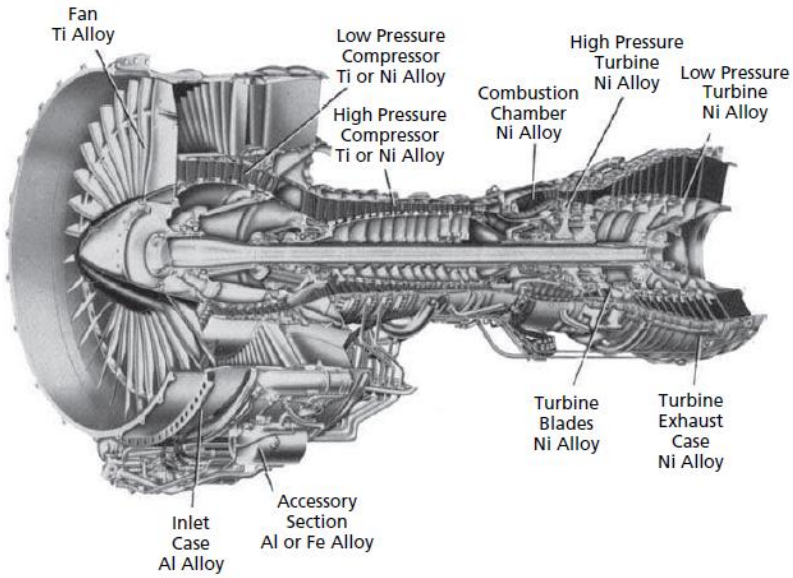
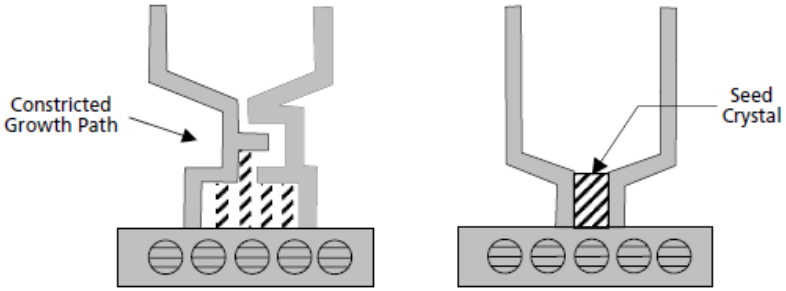
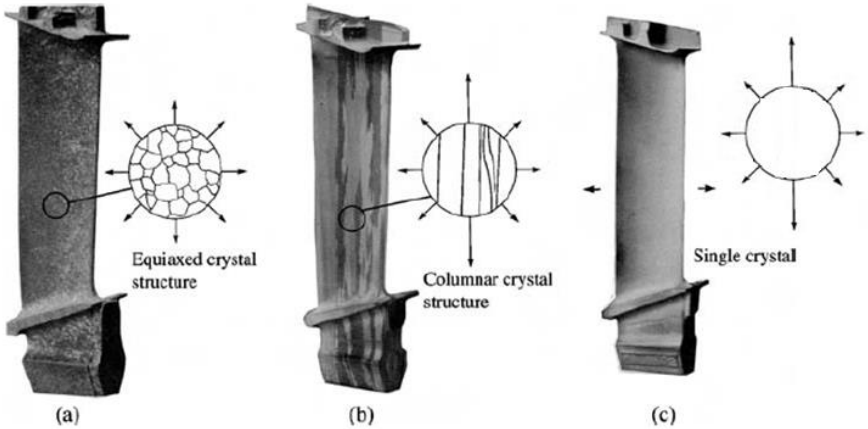


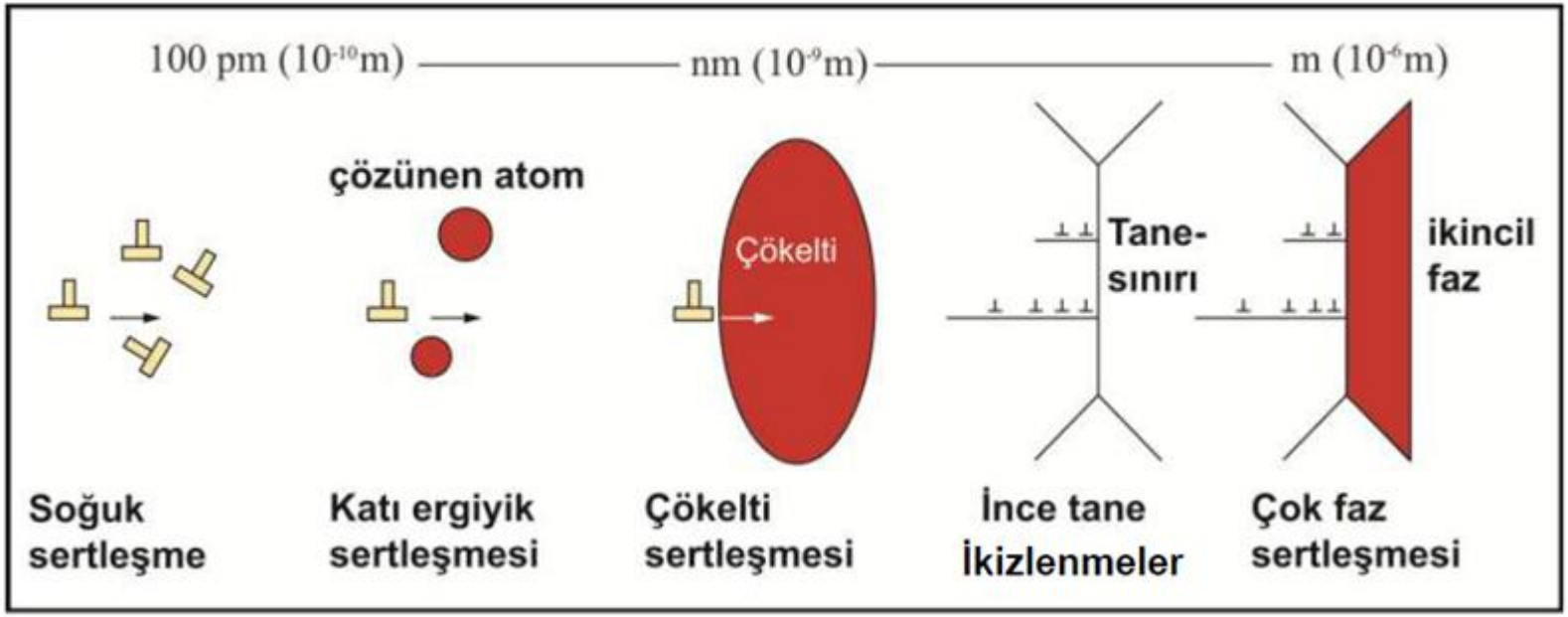
Fig. 6.1. Typical Material Distribution in Jet Engine

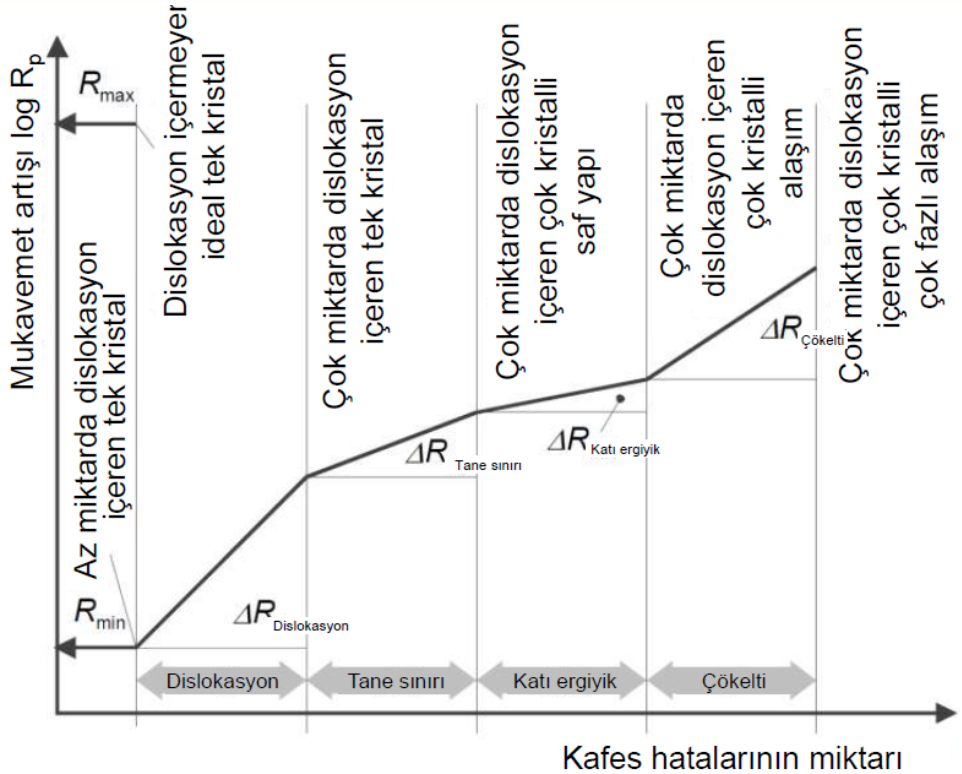


Single Crystal Initiation



6.10 Turbine blade made with nickel-based superalloy using: (a) investment casting resulting in a polycrystalline grain structure, (b) directional solidification resulting in a columnar grain structure and (c) single crystal solidification resulting in no grain boundaries.


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