Chapter 5 Dislocation Multiplication and Cutting

5.1 Curved dislocations

under applied shear stress τ

- force acting on a curved (radius r) dislocation segment of length Δs : $\tau b \Delta s$
- force due to the dislocation line tension : $2T_L \sin\theta$
- $\Delta s = 2r\theta$

$$\therefore \tau b \Delta s = 2\tau b r\theta = 2T_L \sin\theta \approx 2T_L\theta$$

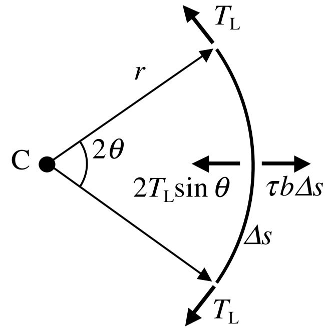

Fig. 5.1 Force balance on a curved dislocation

From (2.8)

$$\boxed{\tau = \frac{T_L}{br} = \frac{\mu b}{2r}} \qquad (5.1)$$

5.2 Dislocation multiplication

$$\begin{cases} \text{in well annealed metal:} \quad \rho = 10^{10} \sim 10^{11}\ \mathrm{m}^{-2} \\ \text{in heavily deformed metal:} \quad \rho = 10^{14} \sim 10^{15}\ \mathrm{m}^{-2} \end{cases}$$

Dislocation multiplication occurs during plastic deformation.

From (5.1) : smaller r $\rightarrow$ larger τ

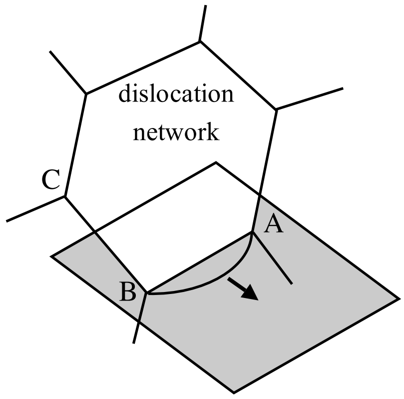

Fig. 5.2 Dislocation bow out between the two nodes A and B.

Which bow out stage in Fig. 5.3 needs the largest applied stress?

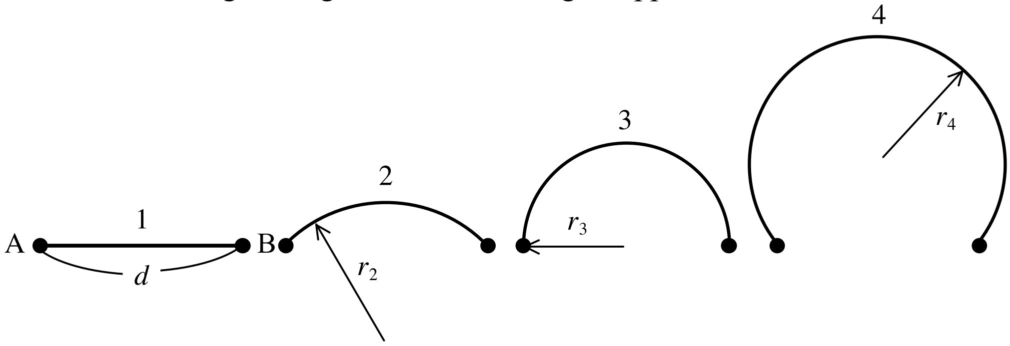

Fig. 5.3 Sequence of dislocation bow out showing the critical stage 3.

Stage 3 : semi-circular dislocation shape

$$\boxed{\tau = \frac{\mu b}{d}} \qquad (5.2)$$

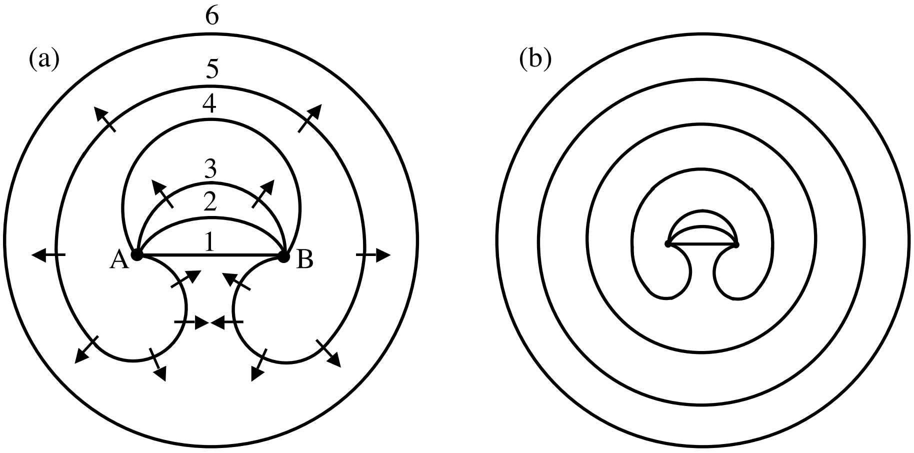

Fig. 5.4 Frank-Read dislocation multiplication mechanisms

5.3 Mutual cutting of dislocations (formation of kinks and jogs)

The case for a screw dislocation A cutting an edge dislocation I and a screw dislocation II

⇩

After cutting, a kink and a jog are formed.

⇩

The jog is difficult to move.

⇩

One origin of work hardening.

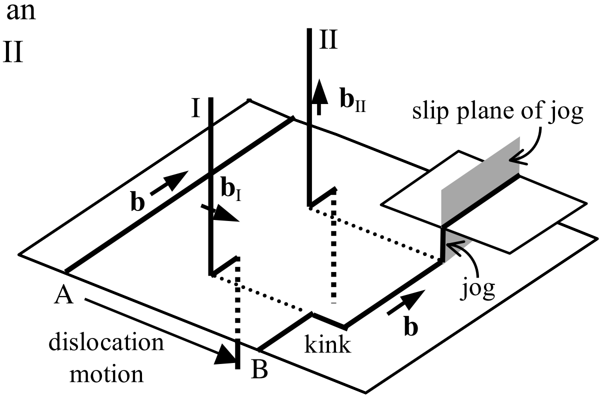

Fig. 5.5 Formation of a kink and a jog by motion of dislocation A cutting through dislocations I and II.

Problem 5.1

(a) In Fig. 5.5, show that the formed jog on dislocation B cannot move with B.

(b) After further motion of B (under the condition of the above (a)), show that an edge dislocation dipole is produced.

(c) Draw a similar picture to Fig. 5.5 for the case that A is an edge dislocation. Explain that a kink and a jog formed on B are easily movable.

Chapter 6 Stress-strain Curves

6.1 Theoretical strength of a perfect crystal

Suppose a unit slip b occurs in a perfect crystal under shear stress τ

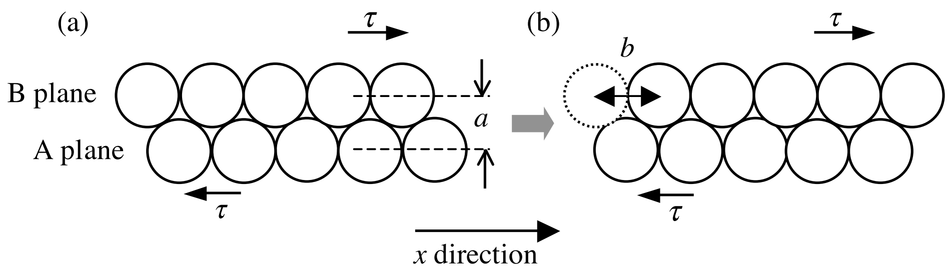

Fig. 6.1 Plastic deformation of a perfect crystal

stress necessary to move atoms on B plane as much as b

$$\tau = \tau_{\rm m} \sin(2\pi x / b)$$

for small x

$$\tau \approx 2\pi\tau_{\rm m} x / b \tag{6.1}$$

from Hooke's law

$$\tau = \mu(x / a) \tag{6.2}$$

Equating (6.1) and (6.2),

$$\boxed{\tau_{\rm m} = \mu b / (2\pi a) \approx \mu / (2\pi)} \quad \text{(theoretical strength)} \tag{6.3}$$

The theoretical strength is much larger than CRSS of single crystals.

6.2 Terminologies for the stress-strain curves

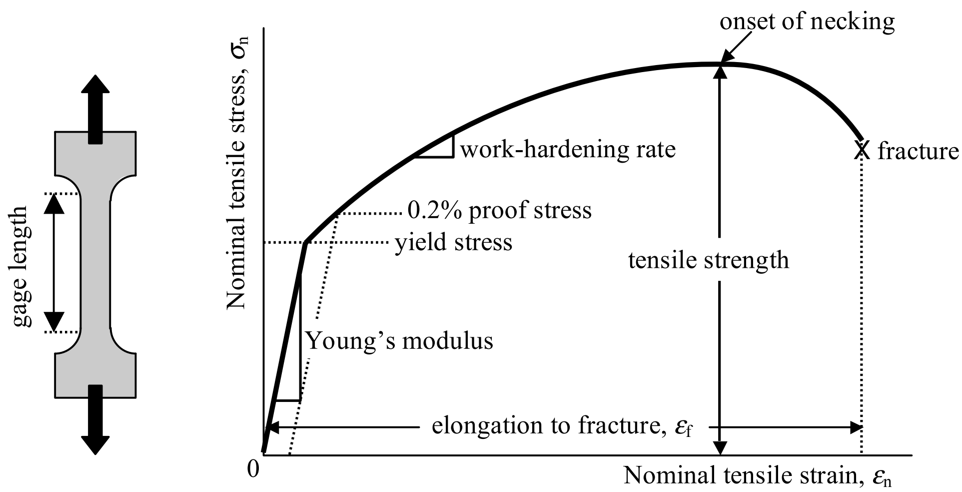

Fig. 6.2 Schematic tensile stress-strain curve of a ductile material.

6.3 Plastic deformation of single crystals

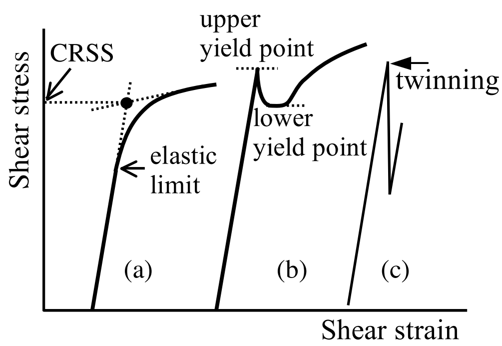

Fig. 6.3 Yielding of single crystals

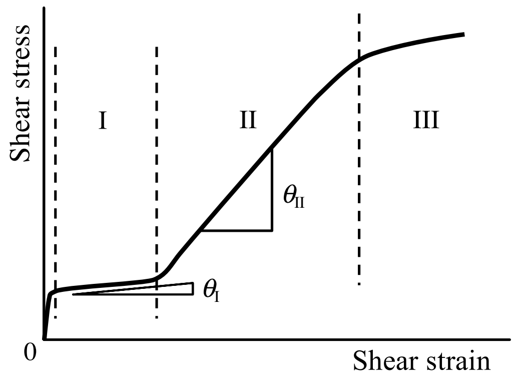

Fig. 6.4 Typical stress-strain curve of a single crystal

Stage I (easy glide stage) : single slip by the primary slip system
Stage II (linear work-hardening stage) : multiple slip and dislocation-dislocation interaction
Stage III (parabolic hardening) : dynamic recovery by cross slip

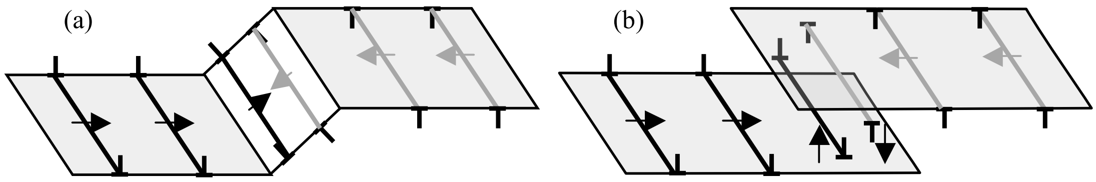

Fig. 6.5 Recovery by dislocation pair annihilation. (a) cross slip, (b) climb.

6.4 Plastic deformation of polycrystals

6.4.1 Taylor factor

$$\boxed{M \equiv \sigma_y / \tau_c} \qquad (6.4)$$

σ_y : yield stress, τ_c : CRSS of a single crystal, M: Taylor factor

6.4.2 Hall-Petch relationship

As the grain size becomes smaller, strength becomes higher.

$$\boxed{\sigma_y = \sigma_0 + k_y d^{-1/2}} \qquad (6.5)$$

$$\begin{cases} \sigma_y : \text{yield stress} \\ \sigma_0 : \text{a constant} \\ k_y : \text{Hall-Petch coefficient} \\ d : \text{grain size} \end{cases}$$

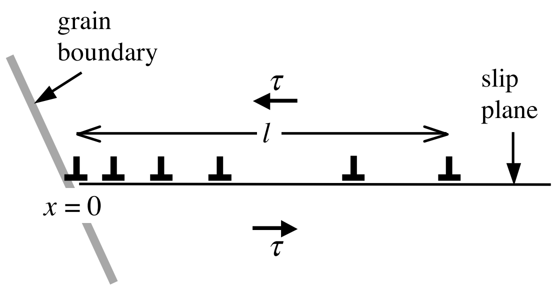

Fig. 6.6 Parallel dislocations piled up on the same slip plane. Stress concentration occurs at $x = 0$.

(1) When n dislocations pile up under shear stress τ, the first dislocation at $x = 0$ feels a concentrated stress of $n\tau$.

(2) Yielding is considered to occur when the concentrated stress $n\tau$ reaches a certain critical value τ_{crit}. That is, $n = \tau_{\text{crit}} / \tau$.

(3) Pile-up distance l and stress τ are related as $l \propto n / \tau$.

(4) From (2) and (3), we have $l \propto 1/\tau^2$ or $\tau \propto l^{-1/2}$.

(5) If $l \propto d$, then we have the second term of (6.5).

6.4.3 von-Mises criterion

plastic deformation → occurs by shear → constant volume ($\varepsilon_{ii} \equiv \varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33} = 0$)

To change the shape of a polycrystal arbitrarily, at least five (5) independent slip systems must exist.

For crystals such as hcp, if the number of independent slip systems is less than five, extensive palstic deformation is not possible. → brittle fracture