Phase Transformation of Materials

Nong-Moon Hwang

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Grain Growth Kinetics

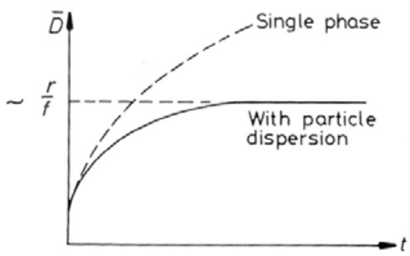
What would be the average velocity of grain growth?

$$v = M \cdot \Delta G / V_m \qquad \Delta G = \frac{2\gamma}{r} \cdot V_m$$

$$\bar{v} = \alpha M \frac{2\gamma}{\bar{D}} = \frac{d\bar{D}}{dt}$$

$$\therefore \frac{1}{2}\bar{D}^2 = 2\alpha M\gamma t + C \qquad C = \frac{1}{2}\bar{D}^2_{(0)}$$

$$\therefore \bar{D}^2 = \bar{D}^2_{(0)} + 4\alpha M\gamma t$$



$$\bar{D}^2 = D_0^2 + Kt \quad \text{where } K = 4\alpha M\gamma$$

r: average radius of particles

f_v = volume fraction of particles

Experimental Observation

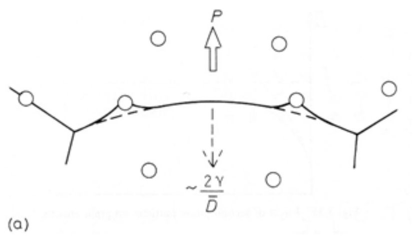
$$\bar{D} = K' t^n$$

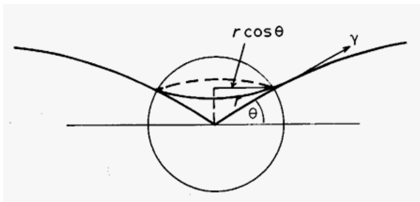
What would be the inhibition mechanism of dispersed particles?

Effect of Second-Phase Particles

Interaction with Particles **Zener Pinning**

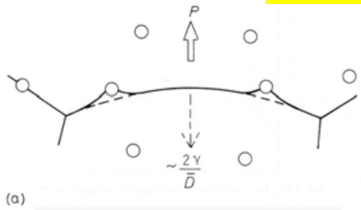
Derive the expression for the pinning effect of grain boundary migration by precipitates.

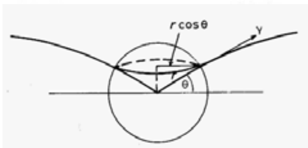




$$(\gamma \sin\theta \cdot 2\pi r \cdot \cos\theta)_{max} = ?$$

Interaction with Particles **Zener Pinning**





f_v = volume fraction of particles

$$N = \frac{f_v}{\frac{4}{3}\pi r^3}$$

N = number of particles per unit volume

The number of particles touching the grain boundary is inside the volume of Ax2r.

→ 2ArN particles

the number of particles per unit area → 2rN = $3f_v/2\pi r^2$

Force exerted by a particle?

$$(\gamma \sin\theta \cdot 2\pi r \cdot \cos\theta)_{max} = ? = \pi r \gamma$$

Inhibiting force?

$$P = \frac{3f_v}{2\pi r^2} \cdot \pi r \gamma = \frac{3f_v \gamma}{2r}$$

This force will oppose the driving force for grain growth, $2\gamma/\bar{D}$

How many particles per unit area of GB?

$$\frac{2\gamma}{\bar{D}} = \frac{3f_v\gamma}{2r} \qquad \bar{D}_{max} = \frac{4r}{3f_v}$$

For fine grain size → a large volume fraction of very small particles

Effect of Second-Phase Particles

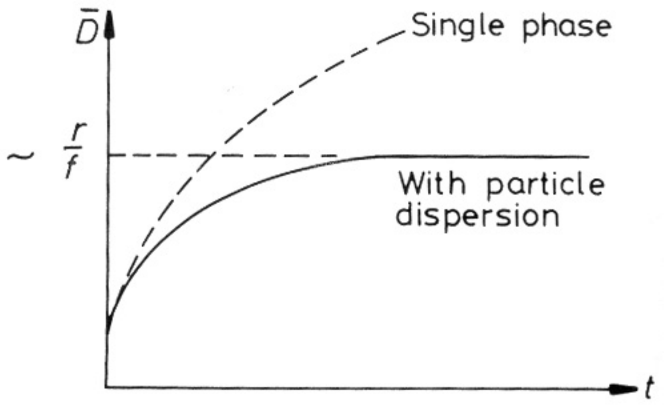


Fig. 3.31 Effect of second-phase particles on grain growth.

Abnormal Grain Growth (Secondary Recrystallization)

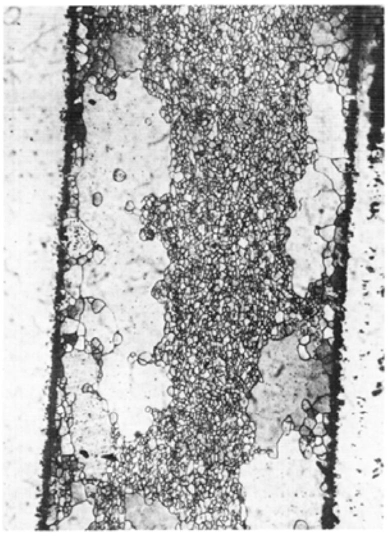


Figure 5.87 Optical micrograph showing abnormal grain growth in a fine grai steel containing 0.4 wt% carbon. The matrix grains are prevented from growin by a fine dispersion of carbide particles that are not revealed. Magnification ×135. (After Gawne and Higgins 1971. Courtesy of the Metals Society.)

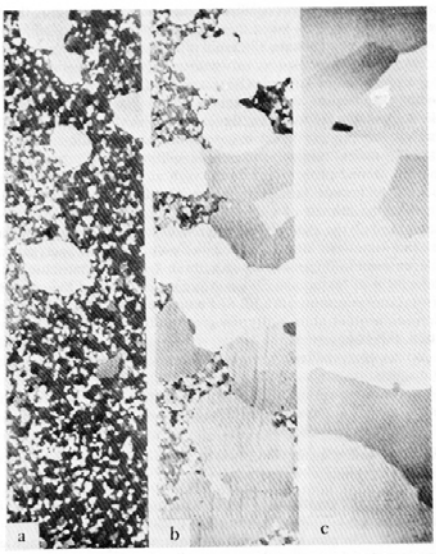


Fig. 5.48. Evidence for the preferential formation of (110)[001]-oriented grains by secondary recrystallization in 5% Si–Fe (Graham [1969]).

3.4 Interphase Interfaces in Solids

How nucleation of β occurs in α ?

- coherent
- semicoherent
- incoherent

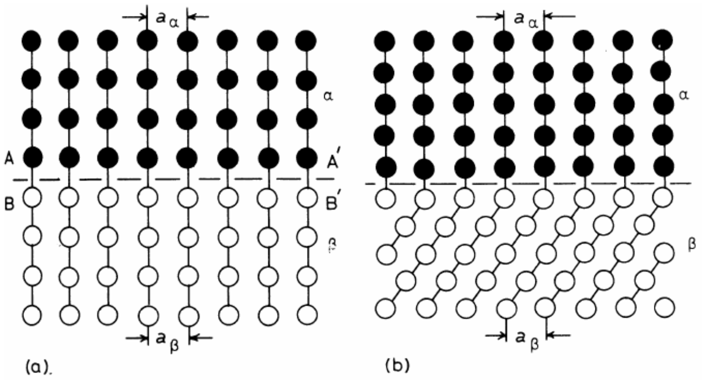


Fig. 3.32 Strain-free coherent interfaces. (a) Each crystal has a different chemical composition but the same crystal structure. (b) The two phases have different lattices.

3.4.1 Interface Coherence

If the hcp second phase is precipitated in the fcc matrix, which interphase interface will make the lowest energy and thereby the lowest nucleation barrier?

What are matching planes and directions?

γ(coherent) = γ_{ch}

$\gamma_{\alpha\text{-}\kappa}$ of Cu-Si ~ 1 mJM^{-2}

In general,
γ(coherent): 1~ 200 mJM^{-2}

1) Fully Coherent Interfaces

→The interfacial plane should have the same atomic configuration in both phases.

Orientation relation between the hcp silicon-rich κ phase and the fcc copper-rich α-matrix in Cu-Si alloys.

$$(111)_\alpha // (0001)_\kappa$$

$$[\bar{1}10]_\alpha // [11\bar{2}0]_\kappa$$

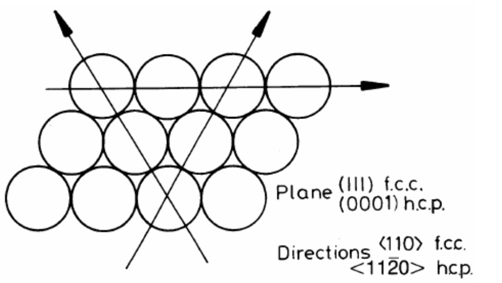


Fig. 3.33 The close-packed plane and directions in fcc and hcp structures.

When the atomic spacing in the interface is not identical between the adjacent phase but slightly different, what would happen?

→ lattice distortion

→ coherency strain

→ strain energy

Crystals are the most stable when atoms are in equilibrium spacing like a spring.

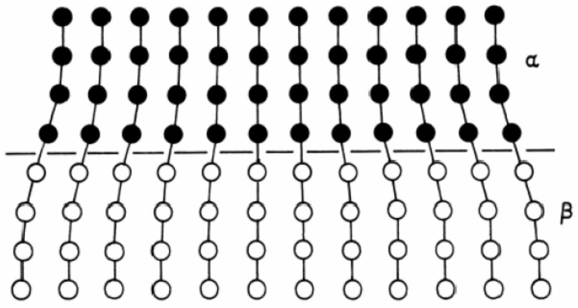
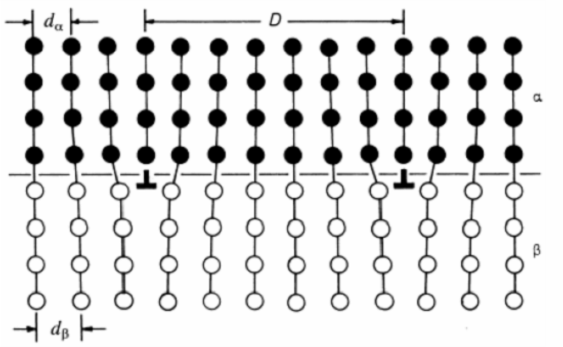


Fig. 3.34 A coherent interface with slight mismatch leads to coherency strains in the adjoining lattices.

How can this coherent strain be reduced?

If coherency strain energy is too large. → **misfit dislocations**

How would you define misfit in terms of d_α and d_β?



$$\delta = \frac{d_\beta - d_\alpha}{d_\alpha}$$

$$D = \frac{b}{\delta}$$

δ: misfit (disregistry)

Fig. 3.35 A semicoherent interface. The misfit parallel to the interface is accommodated by a series of edge dislocations.