Paper Review: Influence of Grain Size and Stacking Fault Energy on Deformation Twinning in FCC Metals

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Sources:

El-Danaf, et al. Metallurgical And Materials Transactions A (30A) May 1999, 1223-33

J. A. Venables J. Phys. Chem. Solids 25 (1964) 693-700

Outline

- Motivation for the paper
- Experimental setup & measurements
- Results
- Discussion
- Conclusions

Motivation for the paper

- More detailed study of the behavior of low stacking fault energy (SFE) FCC metals (SFE < 20 mJ/m^2) that was observed in a previous paper.
- Study the effect of grain size on deformation twinning in FCC metals.

Previous results

- Low SFE FCC metals exhibited a four stage strain hardening behavior
- $(\sigma - \sigma_0)/G$ used as measure of dislocation density

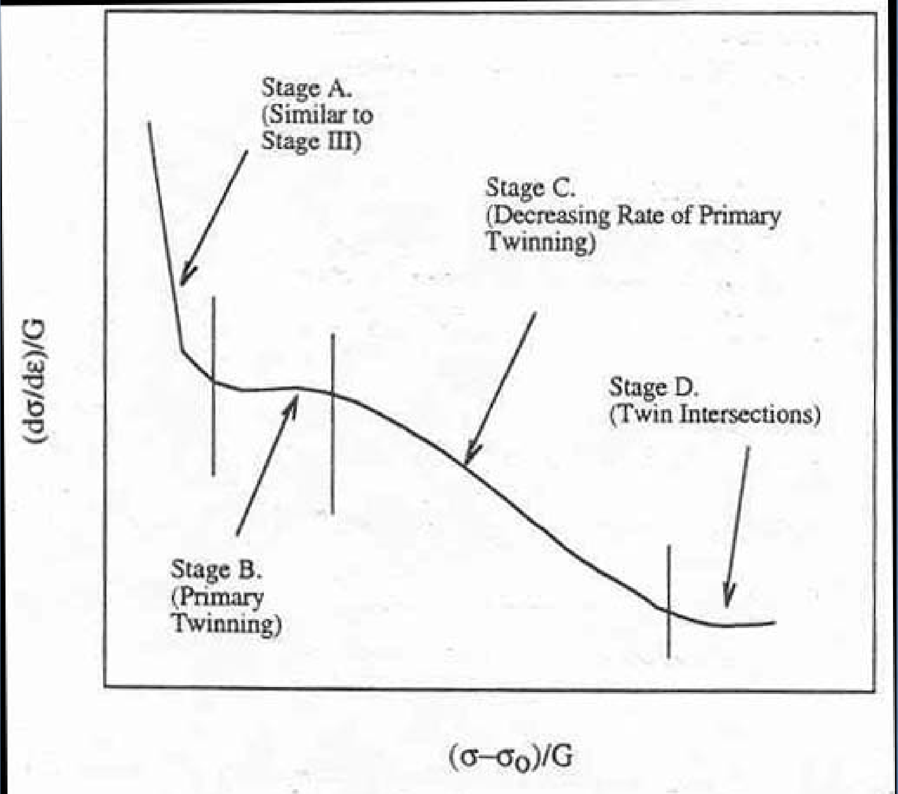


Fig. 1—Schematic representation of the four-stage strain-hardening response in low SFE fcc metals.[1]

Previous Results

- Twin initiation occurred at approximately the same value for two materials (MP35N and 70/30 brass) with different stacking fault energies.
- Noted in other studies that the twin initiation stress decreases with increasing grain size.

Assertions

Two microstructual variables that influence twinning stress are:

- Dislocation density → Some critical dislocation density required for twin initiation at onset of Stage B and twin-twin interactions at onset of Stage D.
- Homogeneous slip length → Region of a grain where there is homogeneity of slip (characterized by parallel slip markings in the grain)
- Criterion for twin initiation in low SFE polycrystalline FCC metals:

$$\frac{(\sigma_{tw} - \sigma_0)}{G} = C\left(\frac{d}{b}\right)^A$$

C = 0.0004 & A = -0.89

Historic View of the Problem

- Venables (1964) model suggests parabolic relation between stress and SFE.
- Problem: Alloys used different solute concentrations → different solid solution strengthening for each
- Author's claim: Using $(\sigma - \sigma_0)/G$ accounts for different solid solution strengthening

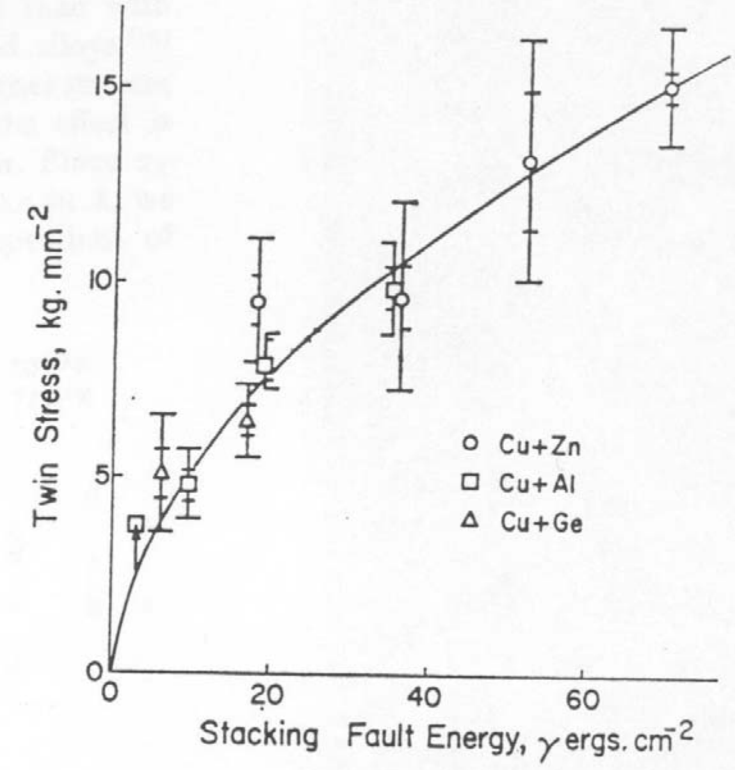


FIG. 2. The twin stress vs. stacking fault energy for copper base alloys, Cu+Zn, Cu+Ge, and Cu+Al. Th vertical lines represent one standard deviation of the observations, and the inner bars denote the standard error of the mean. The Cu+Al alloy with $\gamma = 3$ erg cm^{-2} always contained faults when stressed just above the yield point. Thus the observations give an upper bound to the twin stress.

Experimental Reasoning

- Decouple the effects of grain size and stacking fault energy to study individual effects.
- For SFE effects: For nearly constant grain size, use compression test data and microscopy studies to determine SFE influence on twinning.
- For grain size effects: Use compression test data (for a single SFE material) of a range of grain sizes.

Experimental Procedures & Results

- Room temperature compression tests
- Strain rate: 0.001 s^{-1}
- Sample size: 7-10 mm diameter, 10-15 mm long
- Strain hardening computed from data expressed in Figure 2

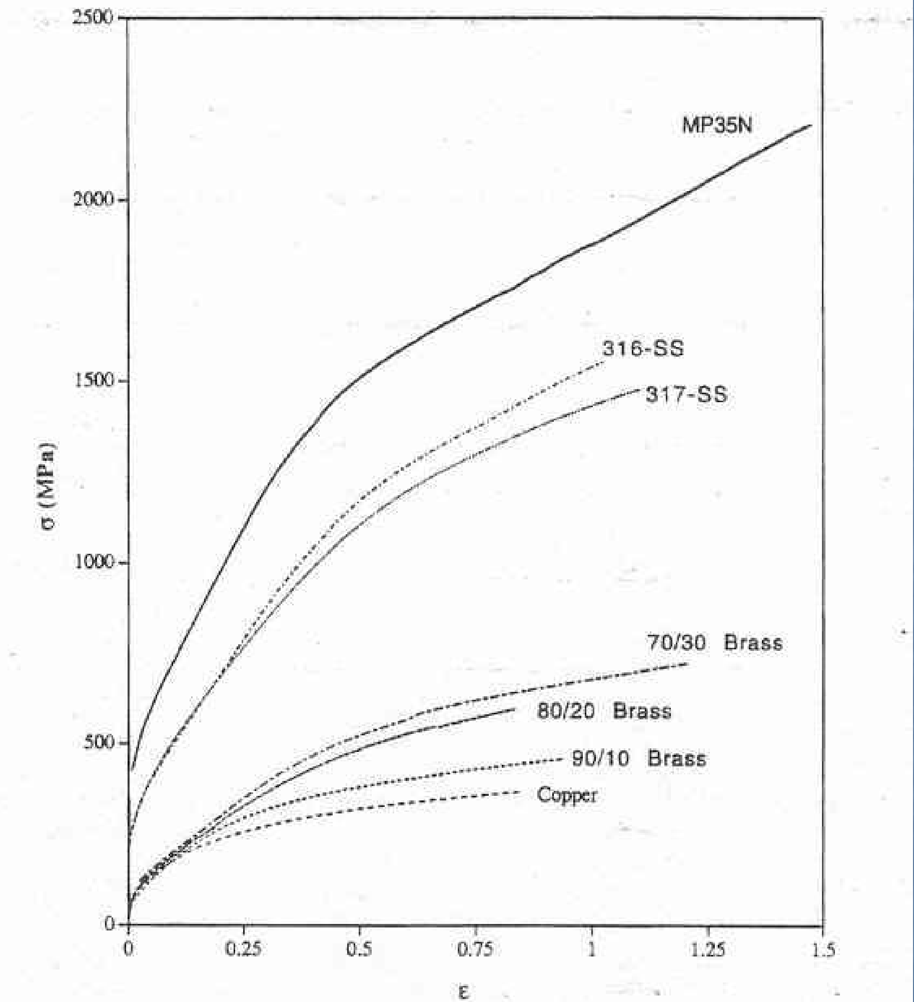


Fig. 2—True stress–true strain curves measured in simple compression for fcc metals with average grain sizes in the range of 30 to 40 μm.

Results--Effects of SFE

- Low SFE metals exhibit 4-stage strain hardening behavior
- Graph shows evidence of a critical dislocation density at 0.003 and at 0.013

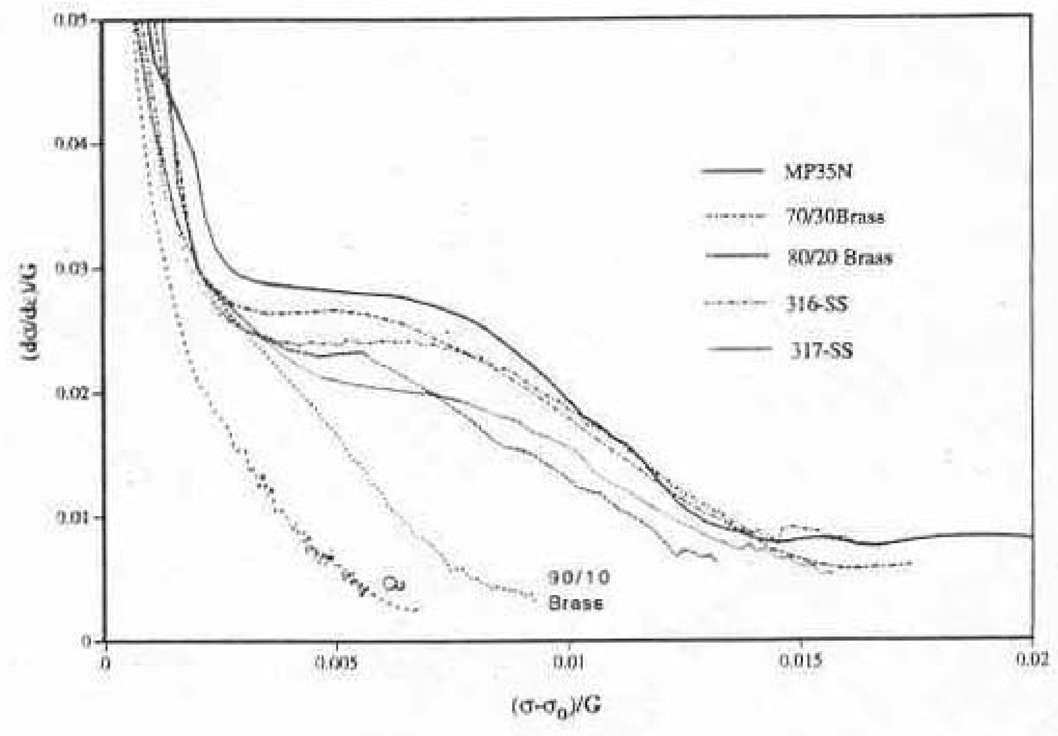


Fig. 3—Normalized plots of the strain-hardening rates against stress for fcc metals with average grain sizes in the range of 30 to 40 μm.

Results--Effects of Grain Size

- Grain size does contribute to the strain hardening behavior
- Indicates twin initiation stress is less for coarse grain materials
- Curves similar for other materials

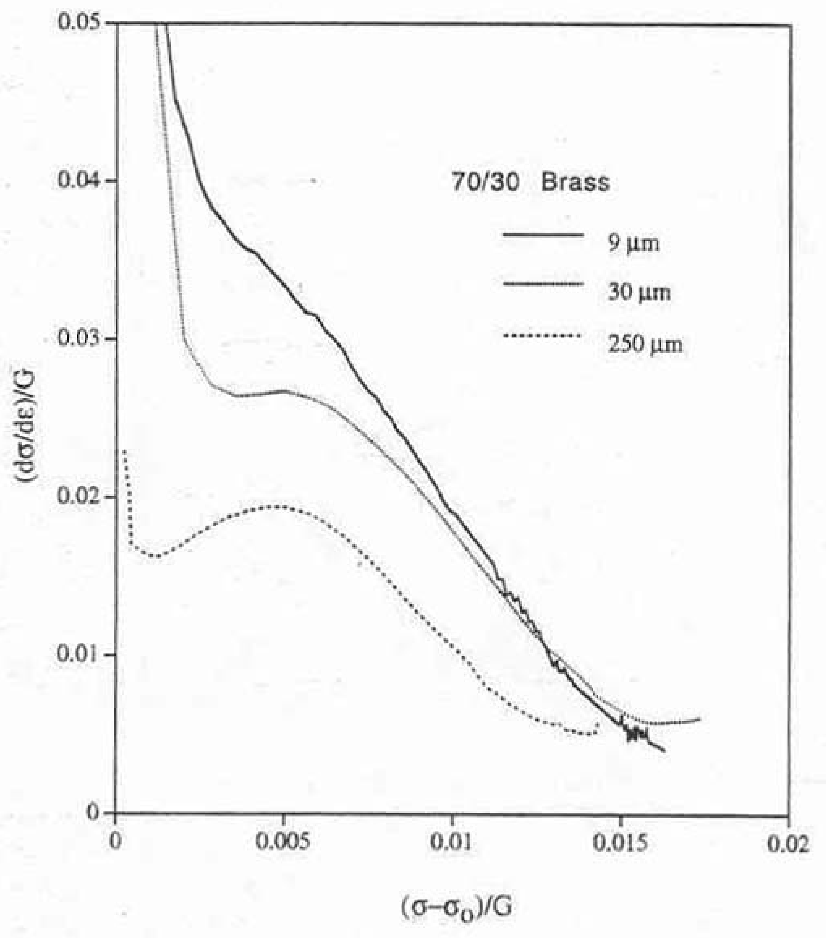
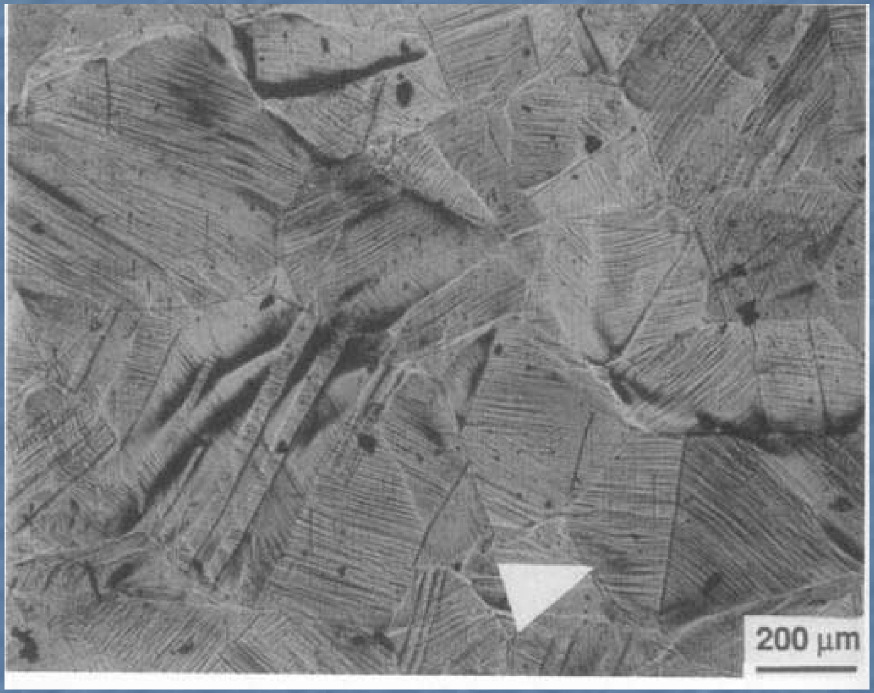
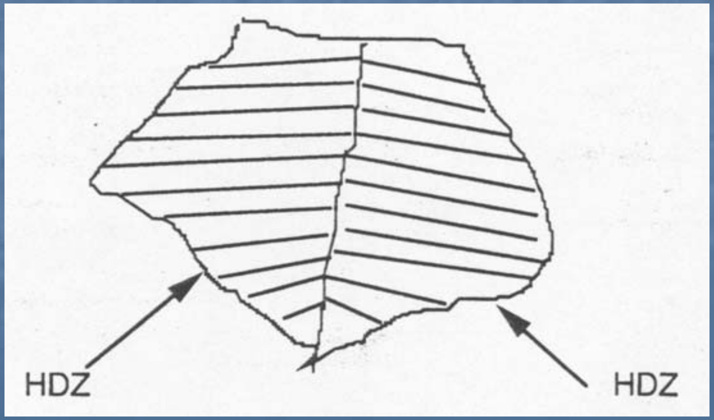


Fig. 9—Normalized plots of the strain-hardening rates against stress for 70/30 brass with three different average grain sizes.

Discussion

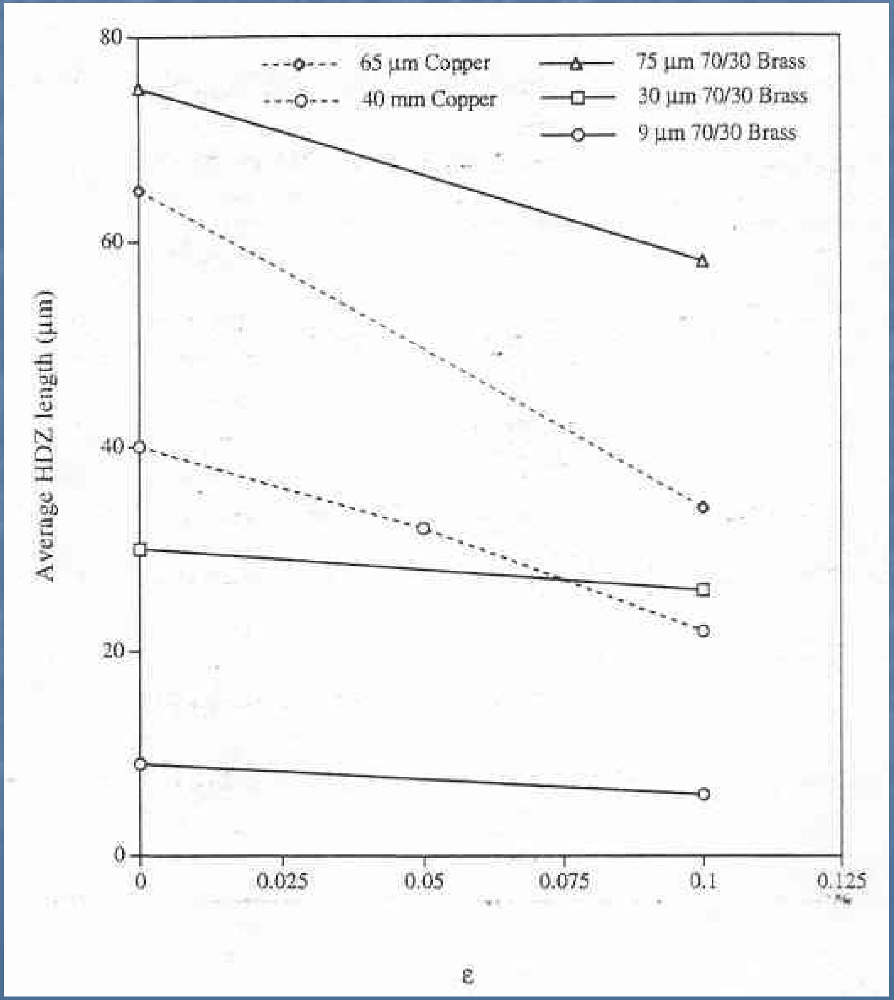


- Homogenous slip length determined by studying homogenous deformation zones (HDZ) length



Discussion

- Increasing stain decreases the HDZ length
- This decrease in HDZ for low SFE is relatively small.
- Authors attribute deformation twinning in low SFE FCC metals to the small change in HDZ.



Criterion for Twinning

- For small change in slip length, large change in strain hardening→ twinning.
- Line serves as dividing regions where twinning will occur.

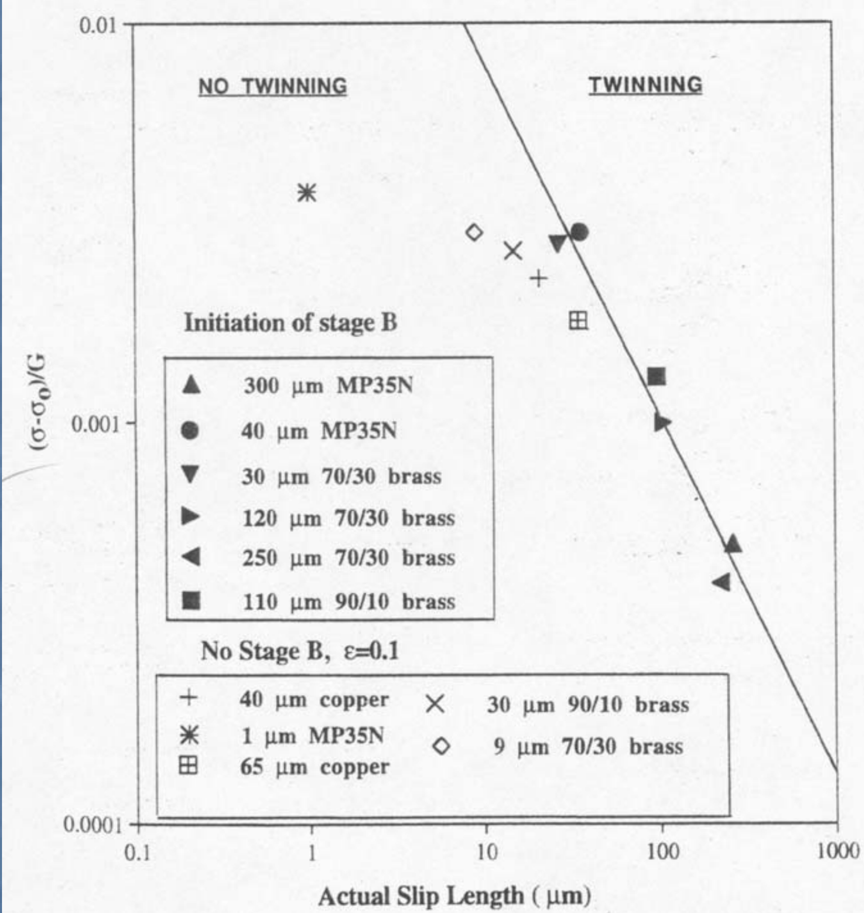


Fig. 15—Variation of $(\sigma - \sigma_0)/G$ in fcc metals as a function of the average HDZ length at twin initiation in the microstructure. A strain of −0.10 was used for metals that did not exhibit deformation twinning.

Conclusions

- Low SFE polycrystalline FCC metals exhibit a 4-stage strain hardening.
- Critical dislocation density is required for nucleation of deformation twins.
- Dislocation density and average homogeneous slip are the microstructural variables controlling deformation twinning.
- Twining is indirectly effected by low SFE→ promotes strain hardening and reduces grain breakup.