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THE EFFECT OF RESIDUAL STRAIN ON TWINNING IN SHOCK-LOADED COPPER

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Under shock-loading, twinning is observed in metals that do not twin under conventional loading conditions, for example copper and nickel where the stacking fault energy is about 78 and 128 ergs/cm², respectively¹. Contradictions in the published data on the twinning stress in copper (from 1.6 GPa in thin films² to 14.5-20 GPa in bulk specimens³) suggest differences associated with experimental techniques. This study examines the role of residual plastic strain (ϵ_{res}) on the deformation substructures, particularly twinning, in shock-loaded copper.

Shock recovery experiments were performed utilizing a 40-mm single-stage gas gun³. Several specimen assemblies were utilized resulting in recovered samples possessing differing amounts of ϵ_{res} . The copper samples were shocked to 10 GPa for 1 μ sec pulse duration by impacting a 2.26mm thick copper flyer plate at 518 m/sec with the specimen assembly in vacuum. Samples for transmission electron microscopy (TEM) were sectioned from the shock-deformed disc and electropolished in 25% H₃PO₄ and 75% H₂O at 0°C utilizing a current density of 80mA/mm. TEM studies were made using a Phillips 400 at 120KV.

The substructure of copper following shock-loading was found to be very dependent on the amount of ϵ_{res} in the specimen. Early specimen designs, while yielding an intact specimen following shock-loading, resulted in large permanent plastic strains of 10 - 13%. In these specimens, deformation twins were observed to be the predominant substructural feature with microbands additionally observed in some grains. Figures 1 and 2 show typical bright field (BF) and selected area diffraction (SAD) electron micrographs of these structures. SAD analysis confirmed that both the twinning plane and microbands lie along $\langle 111 \rangle$ traces. Further, the deformation twins were frequently observed, FIG 1, to occur in packets suggesting they form responding to the same imposed strain in a given grain. Reducing the amount of ϵ_{res} to $\sim$ 2%, by altering momentum ring design, resulted in a substructure exhibiting primarily dislocation cells (FIG 3) with an occasional grain containing twins (FIG 4). Twins in the low ϵ_{res} case are seen to have formed with a spacing between them, not in packets as in FIG 1.

This investigation illustrates the importance of careful specimen design in shock-loading. The large dependency of substructure on the degree of ϵ_{res} illustrates that plastic flow as well as peak loading pressure are important factors influencing shock induced deformation twinning. This finding strongly suggests that differences in the critical pressure for twinning in copper, between bulk and thin film samples, may be a function of not only peak pressure but also strongly related to the amount of residual deformation in the specimen. Metallurgical studies of the role of shock wave parameters must therefore concentrate on assuring as near one-dimensional loading as possible if the actual deformation mechanisms of shock-loading are to be investigated".

References

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FIG. 1. Bright-field micrograph and SAD pattern (110 zone) of twin substructure in high-purity shocked copper.

FIG. 2. Bright-field micrograph and SAD pattern (110 zone) of overbands in high-purity shocked copper.

FIG. 3. Bright-field micrograph (111 zone) of cellular dislocation substructure in low-purity shocked copper.

FIG. 4. Bright-field micrograph and SAD pattern (110 zone) of isolated twins in low-purity shocked copper.

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