

57 Mechanical twins in explosively welded copper. \times 200.

metals but also in f.c.c. metals of low stacking-fault energy. Smith,⁸⁰ Trueb,⁶⁶ Lucas *et al.*,^{28,37} and Brillhart *et al.*⁸¹ have reported macrotwinning and microtwinning in copper, the lowest pressure quoted for twinning being 75 kbar.⁸¹ Figures 57 and 58 are typical of twinning in copper. Pressures of 350 kbar are required to induce twinning in nickel,⁹⁴ and it is unlikely that such pressures would occur in normal welding practice.

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b-..c In addition to mechanical twinning, ferritic iron shows evidence of a reversible phase change giving rise to the shocked structure shown in Fig. 59. Smith⁸⁰ noted the similarity to carbonless martensite, and the structure has been shown⁹⁵ to result from the reversible transition b.c.c. α - ferrite \rightarrow h.c.p. ϵ -martensite which occurs at pressures > 130 kbar. Austenitic stainless steel undergoes permanent transformation by shock waves to form both b.c.c. and h.c.p. martensites.^{28,84}

The useful hardening effect of shock waves in metals has been known for many years. Hardness increases normally attained only after large plastic deformation by conventional metal-working processes have been obtained with very little deformation by shock-hardening. Probably the best-known commercial application is the surface-hardening of Hadfield steel for use in railway points and crusher jaws, &c.⁸²

Slip occurs during shock deformation, though in general the slip lines produced



58 Microtwinning in welded copper. Transmission micrograph. \times 60 000.

are finer and more closely spaced than those observed after slow deformation.⁷⁹ Smith⁸⁰ has proposed a model to represent the passage of a compressive shock front in a metal (Fig. 60). Such a model is completely reversible on passage of a tensile shock wave. However, the large line and point-defect densities found by various workers,^{28,64,66} together with the hardening effects of internally reflected shock waves, clearly indicate that this reversible model is an over-simplification of the atomic arrangement in the shock front.

The effects of shock waves on various properties of metals have been summarised by Rowden⁸⁸ and by Holtzman and Cowan.²¹ Effects similar to those associated with increased strength by conven-



[Courtesy Amer. Inst. Min. Met. Eng. Uniaxial distortion of the lattice. (C. S. Smith.⁸⁰)

61 Spalling in explosively welded copper. × 85.

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