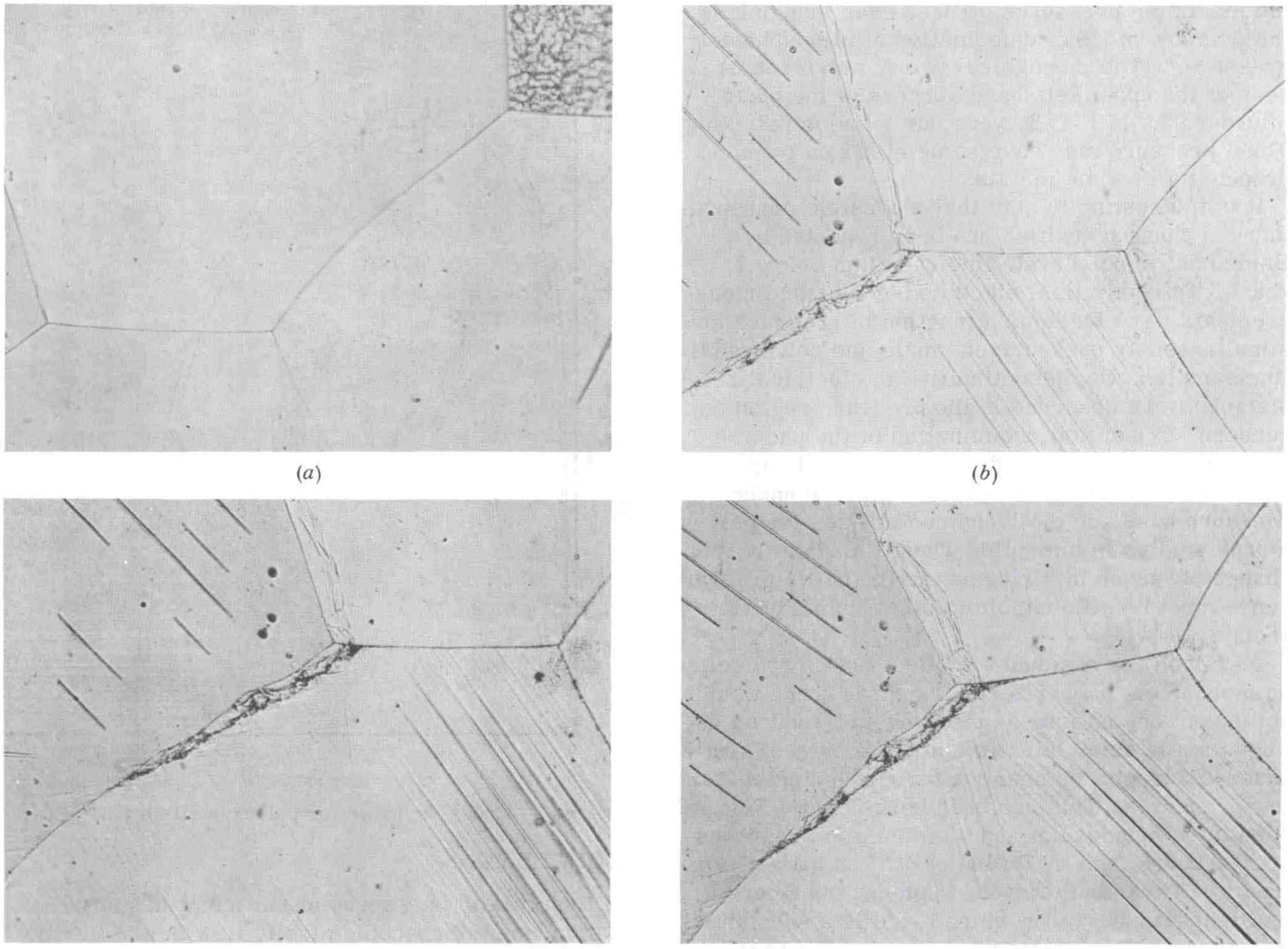
(a) (b) (c) (d)

Fig. 3—Structural changes in polycrystalline bismuth induced by hydrostatic pressure. (a) Original structure; (b) after 10,000 bars; (c) after 15,000 bars; (d) after 20,000 bars. X100. Reduced approximately 10 pct for reproduction.

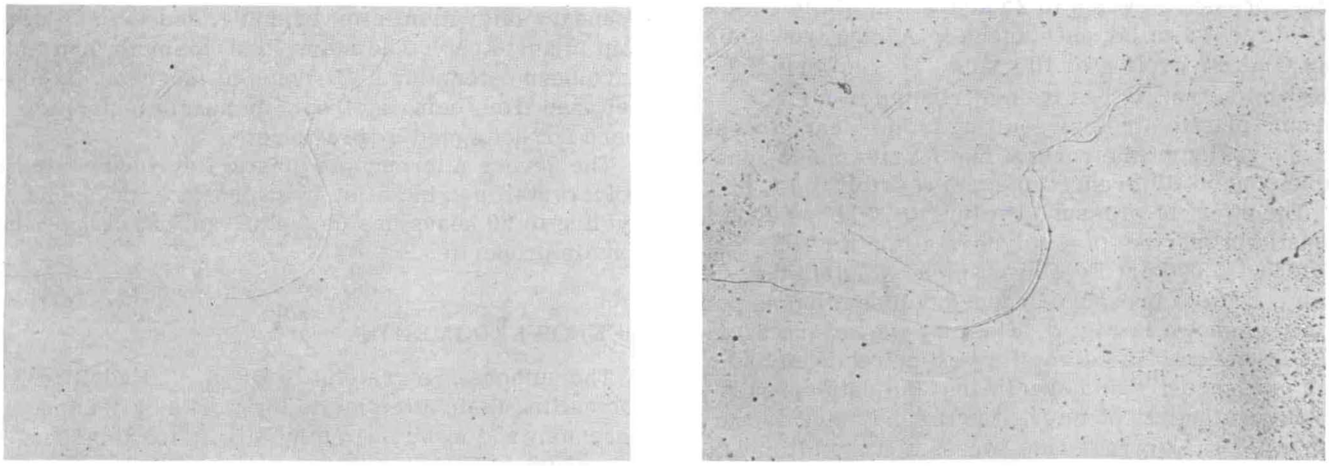
(a) (b)

Fig. 4—Structural changes in polycrystalline tin induced by hydrostatic pressure. (a) Original structure; (b) after 26,000 bars. X100. Reduced approximately 10 pct for reproduction.

nitude of the boundary migration increased with increasing pressure in zinc, cadmium, and bismuth. In tin, deformation only initiated at 26 kbars and was also in the form of boundary migration. At increasing pressure, slip, multiple slip, and twinning became quite evident in the case of zinc and cadmium. In contrast, it is interesting to note that in bismuth no mechanical twinning was observed even at the maximum pressures utilized even though it is the primary mode of deformation at atmospheric pressure.[2] (The mechanical twins, which can be seen at the upper left-hand corners of the photomicrographs in Fig. 3, were due to prior polishing.) Thus, pressure may have some effect on twinning propensity in some metals.

It is interesting to note that a possible pressure-induced phase transition has been reported by Bridgman[7] in polycrystalline cadmium below 7 kbars. To verify this, electrical-resistance measurements were taken as a function of pressure for simultaneously pressurized single and polycrystalline samples. No discontinuities in electrical resistance were observed in the pressure region of concern. In addition, examination of the photomicrographs for cadmium do not show any images indicative of a phase change taking place under pressure based on the technique utilized for polymorph studies in bismuth.[8] Thus, the resistivity change observed by Bridgman in the above pressure range must be attributable to other than a phase change.

As far as the residual effects of pressure cycling on mechanical properties is concerned, one would not expect any as long as the pressure-induced deformation is solely elastic, as in the case of single phase, isotropic, or nearly isotropic materials at low pressures. This has been borne out by Ferron's[9] results on magnesium and aluminum to pressures of 13.8 kbars, and by Bullen *et al.*[10] on high-purity iron to 10 kbars. However, when one considers a multiphase material in which there is a substantial difference in the elastic properties of the various phases, or a polycrystalline anisotropic material, pressure cycling may have an effect. Radcliffe[11] found a loss in the sharp yield point and a substantial lowering of the yield strength in annealed mild steel pressure cycled to 25 kbars, and Bullen *et al.*[10] observed a similar phenomena in Armco iron (0.03 pct C) after cycling to 10 kbars. This lowering of the yield strength has been attributed to microscopic plastic strains resulting from shear stresses in the region of the carbide and ferrite phase boundaries due to differences in compressibility.

The effect of pressure cycling to 20 kbars upon the tensile properties of a polycrystalline Zn + 0.27 pct Cu + 0.005 pct Fe alloy, which exhibited the same form of pressure-induced deformation as pure zinc, is shown in Fig. 5. This is a plot of the average stress-strain curves for six as-received and six pressure-treated specimens; the data spreads at several points of interest being indicated by the arrows. The average flow stress and the ultimate tensile stress have been slightly increased by pressure cycling. However, the data spreads overlap; thus the effects of pressure cycling upon tensile properties are considered insignificant. The data spread in the total elongation is much greater for the pressure-cycled specimens.

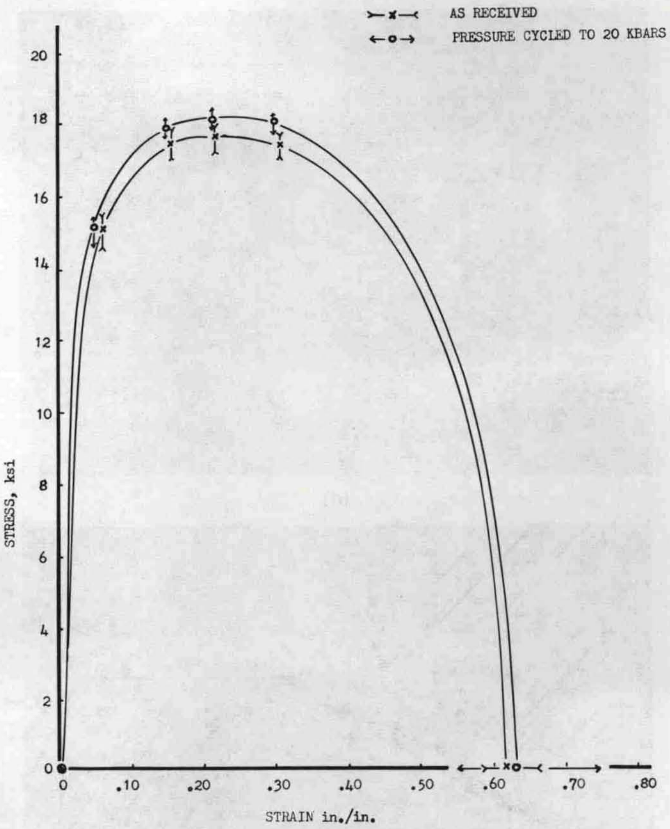

Fig. 5—Stress vs strain for polycrystalline zinc alloy.

CONCLUSIONS

Hydrostatic pressures of sufficient magnitude can induce microscopic plastic flow in elastically anisotropic polycrystalline metals but not in homogeneous single crystals or elastically isotropic polycrystals. The propensity to deform is related directly to the linear-compressibility ratio.

The approximate pressures for the onset of grain boundary migration, slip, twinning, and/or multiple slip in anisotropic cadmium, zinc, bismuth, and tin have been determined. Zirconium, magnesium, copper, and iron, being isotropic or nearly isotropic, were not deformed by pressure.

The severe microscopic plastic flow induced in a polycrystalline zinc alloy by hydrostatic pressure cycling to 20 kbars has no significant effect upon the tensile properties.

ACKNOWLEDGMENTS

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