Effects of Hydrostatic Pressure on the Mechanical Behavior of Tungsten

By G. Das* and S. V. Radcliffe*

The effects of the application of hydrostatic pressure on the dislocation substructure and mechanical behavior observed subsequently at atmospheric pressure, and the influence of high pressure on flow and fracture have been investigated for polycrystalline powder metallurgy tungsten and similar material containing second phase additions of thoria and hafnium carbide with the principal objective of elucidating the factors controlling the pressure dependence of the mechanical behavior of a brittle *bcc* metal. Tensile tests were conducted from 25 to 250°C at atmospheric pressure on specimens subjected previously to pressures up to 25 kilobars and at room temperature during subjection to pressures up to 11 kilobars. The sub-structures were examined by optical and transmission electron microscopy.

The ductile-brittle transition behavior of recrystallised tungsten and a tungsten-1.9 vol % thoria alloy are essentially unaffected by pressure cycling up to 25 kilobars at atmospheric temperature. The results for tungsten are in keeping with the scarcity of impurity particles observed and the corresponding absence of pressure-induced dislocations. In tungsten containing additions of second phase particles (ThO_2 or HfC) a similar absence of induced dislocations was found for pressures up to 25 kilobars, but new dislocations were observed at particles after subjection to pressures of some 40 kilobars.

The stress-strain behavior of recrystallised tungsten at constant pressure and atmospheric temperature changes progressively as the environmental pressure is increased. Initially, fracture with no measurable plastic deformation persists, but the fracture stress increases with increasing pressure and, at sufficiently high pressures, a distinct yield drop followed by a substantial plastic deformation and work hardening is developed. The magnitude of the resulting lower yield stress (96,000 psi) is in agreement with the extrapolation to room temperature of the temperature dependence of the yield stress of recrystallized powder metallurgy tungsten as measured at higher temperatures at atmospheric pressure by several different workers. The dislocation substructures developed during plastic straining at high pressure are different from those reported previously for polycrystalline tungsten subjected to similar amounts of plastic strain at higher temperature and atmospheric pressure and the fracture mode is a combination of intergranular separation and transgranular cleavage. The implications of these results for the interpretation of the discontinuous yield phenomena in tungsten and the fracture process are discussed.

I. Introduction

When a single crystal or polycrystalline solid is subjected to external hydrostatic pressure, differential strains will be induced at any localized elastic discontinuities, such as precipitates, impurity particles or internal voids, due to their different compressibilities relative to the matrix. Although the calculated differential stresses in the region of the interface with the matrix appear too small to cause local plastic deformation, transmission electron microscopy observations on iron[1] and chromium[2] have demonstrated that such pressure-induced dislocations can be formed. The influence of these and other types of elastic discontinuity in inducing permanent changes in substructure and associated changes in mechanical behavior on subjection to hydrostatic pressure have been reviewed recently[3]. Such permanent changes have been designated variously as pressure cycling, pressurizing or pressurization effects.

The general effect of a superimposed hydrostatic pressure in enabling "brittle" materials to undergo substantial plastic deformation before fracture under uniaxial loading at pressure was established by Bridgman[4][5] but detailed studies of specific metals have been made only recently. Furthermore, as information is usually lacking as to the precise characteristics of the metallurgical history and structure of the metals studied, it is difficult to make valid comparisons between the results of different workers. Attention to the discontinuous nature of the increase in ductility which can occur in some metals with increasing hydrostatic pressure was first drawn to the non-cubic metals zinc and bismuth by Pugh and coworkers[6]. In the case of the body centered cubic metals (*bcc*), in several of which the nature of the

* Department of Metallurgy, Case Western Reserve University, Cleveland, Ohio, U.S.A.

(1) S. V. Radcliffe and H. Warlimont : Phys. Stat. Solidi, **7** (1964), 67.

(2) R. F. Garrod and H. L. Wain : J. Less-Common Metals, **9** (1965), 81.

(3) S. V. Radcliffe : *Structural Effects in Materials under Pressure*, Chap. 11 in *Mechanical Behavior of Materials Under Pressure* ed. H. Ll. D. Pugh, Elsevier Publishing Co., Amsterdam—in press.

(4) P. W. Bridgman : *Studies in Large Plastic Flow and Fracture*, McGraw Hill Co., New York, (1952).

(5) P. W. Bridgman : J. Appl. Phys., **24** (1953), 560.

(6) (a) H. Ll. D. Pugh and D. Green : *Behavior of Metals Under High Hydrostatic Pressure*, MERL Plasticity Rep. No. 128, National Engineering Laboratory, (1956).

(b) H. Ll. D. Pugh, J. Lees, K. Ashcroft and D. Gunn : Engineer (G. B.), **212** (1961), 258.