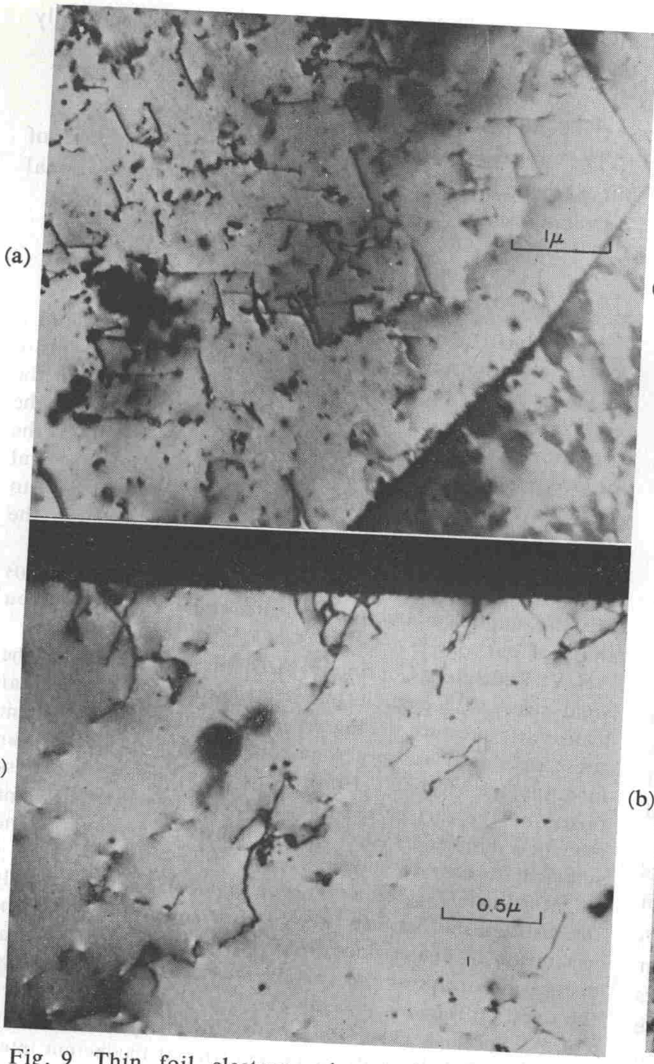

Fig. 9 Thin foil electron micrographs illustrating substructure of recrystallised PM tungsten strained to fracture at 5 kilobars and room temperature. 2 % elongation.

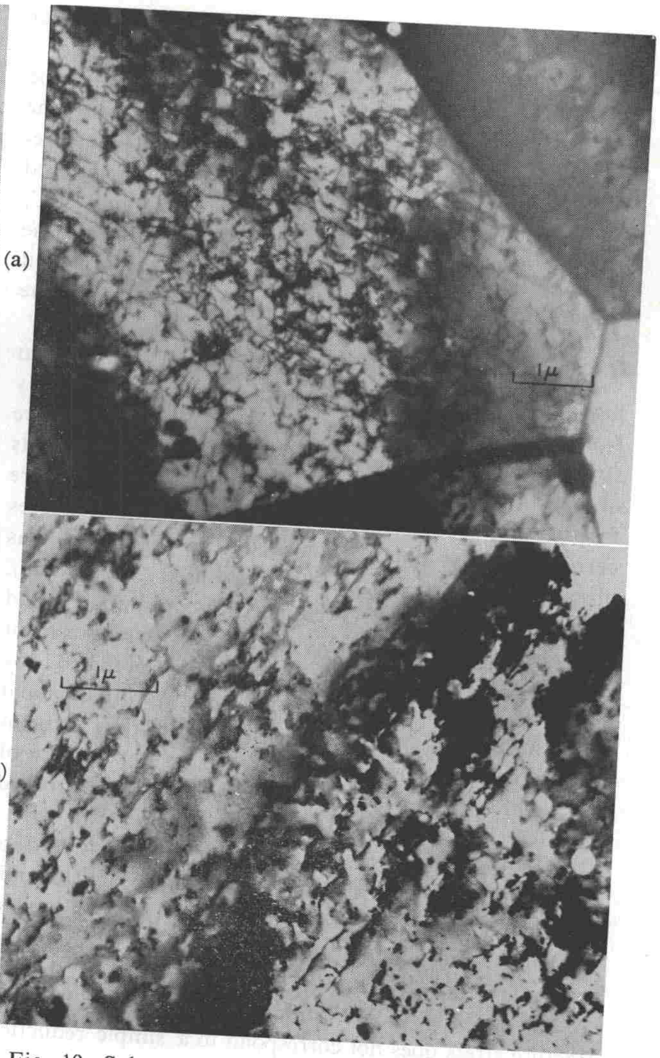

Fig. 10 Substructure of recrystallised PM tungsten strained to fracture at 11 kilobars and room temperature. 8 % elongation.

the two directions of straight dislocation segments visible in the foil. Although the thickness of this particular foil precluded diffraction analysis of the relevant crystallographic directions, this observation has been interpreted as direct evidence of the influence of the presence of the deformation substructure in impeding the propagation of transgranular cleavage. No twinning was observed to occur at any of the pressures investigated.

The substructure developed on plastic straining at high pressure differs from that reported(27) for recrystallized polycrystalline tungsten deformed similar amounts at atmospheric pressure and 200°C, i. e. in the region of the transition temperature, with respect to the density and distribution of dislocations. The density is consistently higher after deformation at room temperature and high pressure, and the "band structure" of alternating light and dark contrast (long parallel cells separated by dislocation walls) observed by Wronski and Fourdeux to be already well developed by 7 % strain does not occur. In this respect and in general appearance, the dislocation structure resembles more closely that observed recently(28) in [010] single crystals of high purity tungsten deformed in tension under ambient conditions. However, the density is considerably higher in the single crystal—for 8 % plastic strain (the largest at pressure) the dislocation density in the high pressure specimens is two to three times that reported for 200°C, whereas that for the single cystal at room temperature is approximately ten times.

In view of the similar high pressure study currently in progress on polycrystalline arc-melted tungsten, it is considered inappropriate to attempt a more detailed analysis of the present results here. In particular, the role of impurity and void effects on yielding and grain boundary rupture may become clearer since preliminary results for the purer material indicate that the lower yield stress is considerably smaller.

IV. Summary and Conclusions

The effects of hydrostatic pressure on the substructure and mechanical behavior of recrystallised PM tungsten have been investigated with respect both to

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(27) A. Wronski and A. Fourdeux : Phil. Mag., **10** (1964), 969.

(28) B. Warlimont-Meier, P. Beardmore and D. Hull : Acta Met., **15** (1967), 1399.

changes during pressure application and to behavior at pressure. The results show that:

1. PM tungsten is essentially unaffected by the simple application of pressure, in keeping with the scarcity of impurity particles and absence of pressure-induced dislocations. Such dislocations can be induced in the presence of added particles of ThO_2 and HfC; the large magnitude of the required pressure (in the region of 40 kilobars) compared with that for iron and chromium is attributed to the higher flow stress of the tungsten matrix.

2. The tensile stress-strain behavior of tungsten at high pressure and room temperature differs substantially from that under ambient conditions. The fracture stress is raised and above 3 kilobars increasing amounts of plastic strain and work hardening occur before fracture. The reduction of area at fracture increases correspondingly but no ductile-brittle transition was observed up to the highest pressure used (11 kilobars).

3. Yielding always takes place discontinuously and the mean lower yield stress (96000 psi) is in agreement with that for atmospheric pressure obtained by extrapolation from published high temperature data and with the highest fracture stresses reported for ambient conditions. A possible small pressure dependence of the yield stress is in keeping with a jog-controlled model for yielding.

4. Below 11 kilobars, the imposed hydrostatic stress inhibits only the initiation of microcracks but cannot prevent catastrophic propagation. At 11 kilobars, numerous intergranular cracks and some transgranular cracks are formed but their rapid propagation appears to be inhibited. The influence of pressure on the fracture stress does not correspond to a simple reduction in the applied stress normal to the crack.

5. While the dislocation structure developed by plastic straining at high pressure exhibits several features characteristic of the *bcc* transition metals, the "band structure" observed after comparable plastic strain in recrystallized PM tungsten in the region of the transition temperature at atmospheric pressure is absent and the dislocation density is substantially higher.

Acknowledgment

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DISCUSSION

M. Yajima (Central Research Laboratory, Hitachi Ltd.): The stress concentration at the surface of second phase under pressure is too small to nucleate dislocations. In the case of iron, a simple calculation shows that, when the pressure applied is 10000 kg/cm², the shear stress at the surface of particle of the second phase is about several kg/mm², which is about one hundredth of the stress to nucleate dislocations, but which is enough to unpin the old dislocations and multiplicate them.

That is, our view is that the pressure-induced dislocations are the unpinned and multiplicated ones. How do you think of our view?

S. V. Radcliffe: Continuum mechanics calculations of the yield stress at a particle in a matrix subjected to external hydrostatic pressure do indeed indicate that the maximum stress developed is only some one hundredth of the shear modulus i. e. G/100. However if steps acting as stress raisers on the surface of the particle are taken into account (see for example, Friedel) the computed stress can become sufficient to operate new sources.

Unfortunately, it has as yet been impossible experimentally to distinguish between new source operation and the generation of dislocations from pre-existing sources such as dislocation arrays at the particle/matrix interface.——thus, the question remains unresolved.

J. W. Spretnak (The Ohio State University): There is a possibility that dislocations pre-existing at incoherent interfaces may be drawn off under pressure. Has this type of pressurization work be done both on coherent and incoherent interfaces?

S. V. Radcliffe: To the best of my knowledge, the various studies of pressure-induced dislocations have been concerned solely with incoherent particles.