TEMPERATURE DEPENDENCE OF INDENTATION SIZE EFFECTS, PILE-UP AND STRAIN RATE SENSITIVITY IN POLYCRYSTALLINE TUNGSTEN FROM 25-950 ºC

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Elevated temperature nanoindentation measurements were performed on polycrystalline tungsten to 950 ºC. Tests were carried out under high vacuum conditions as tungsten oxidizes in air at >500 ºC. The temperature dependence of the hardness, elastic modulus, strain rate sensitivity, activation volume and the indentation size effect in hardness were investigated at 25, 750, 800, 850, 900 and 950 ºC. Thermal drift assessed from the last 60% of a hold period at 90% unloading was typically ~0.05 nm/s and it did not vary significantly with load or temperature [1]. The hardness measurements were in good agreement with previous determinations by non-depth sensing hot microhardness.

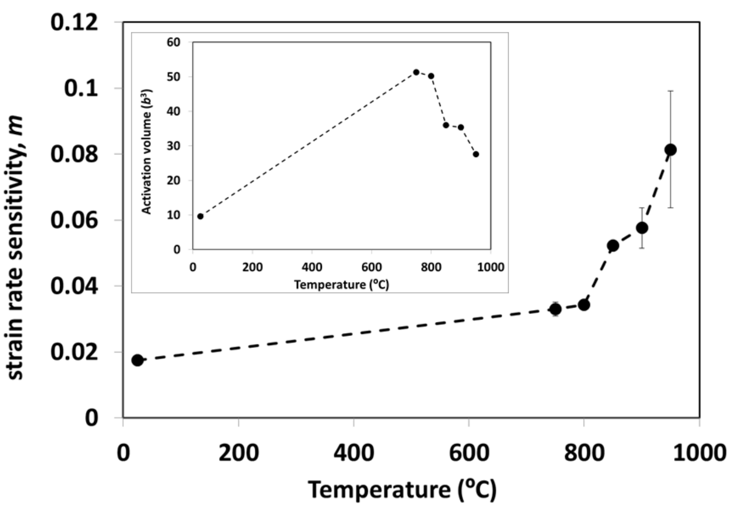

Fig. 1 Strain rate sensitivity and activation volume vs. T

Above 800 ºC the hardness of tungsten changes relatively little but more pronounced time-dependent deformation was observed from the temperature, (850 ºC, see figure 1), around where Milman et al reported changes to dislocation cell structure occur [2]. The strain rate sensitivity determined by analysis of indentation creep data increased with temperature. Activation volume reached a peak of ~50 b^3 at 750-800 ºC (see inset). Decreasing activation volume above 800 ºC was due to the increase in strain rate sensitivity.

Although there have been reports of reduced indentation size effects at elevated temperatures, for a bcc metal such as W, lattice resistance depends on T/T_c (where T_c, the critical temperature, at which flow stress becomes insensitive to temperature = 527 ºC for W) and so size effects would be expected scale with this relative temperature. Pillar compression tests on W(100) to 400 ºC (T/T_c = 0.84) have determined much stronger size effects in strength at higher temperatures [3]. In this current study to T/T_c = 1.56 significantly stronger indentation size effects in hardness were also found at elevated temperatures.

Elastic modulus measurements determined from standard elastic analysis of the unloading curves were higher than literature values, by ~13% at 750-800 ºC and 30-40% at 850-950 ºC. The greater discrepancy starts from the point (850 ºC) at which more pronounced time-dependent deformation was observed. Time-dependency was therefore accounted for by a viscoelastic compliance correction [4]. After correction values of the elastic modulus agree to within ~1% at 750-800 ºC, and to 6% of literature values at 950 ºC. The small remaining discrepancy is consistent with the influence of pile-up since AFM measurements show that pile-up is significant in these high temperature indentations and the pile-up height increases slightly over the range 750-950 ºC.

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