Fall 10-4-2015

Investigating the plastic deformation of Molybdenum from -196°C to 950°C using nanoand micro-indentation

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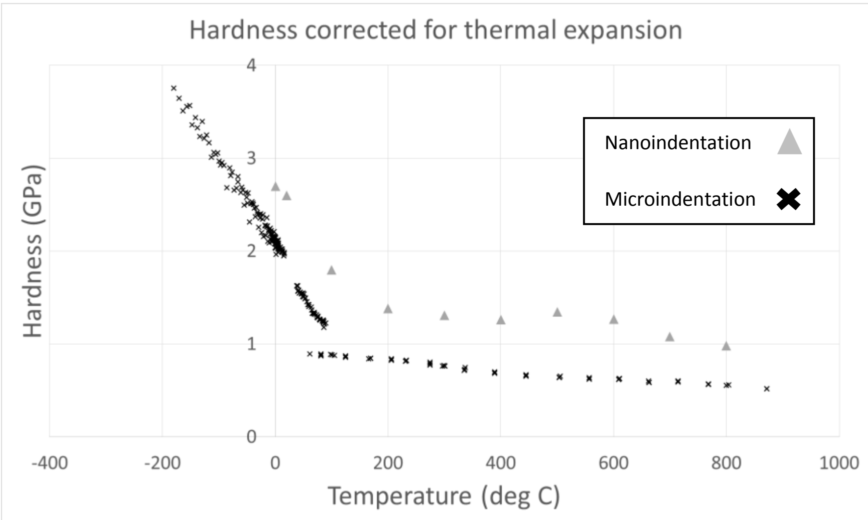
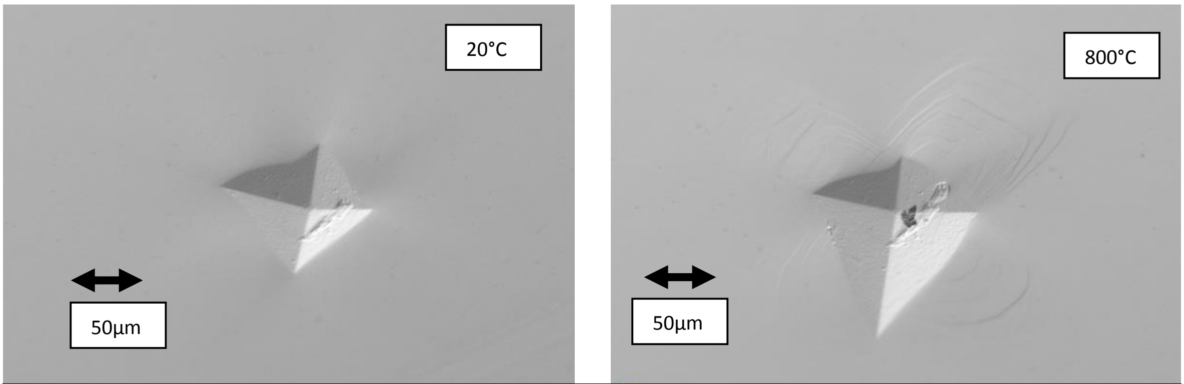
Understanding the plastic deformation at non-ambient conditions is critical to understanding materials' behaviour in many applications including nuclear power. Molybdenum is seen as a potential candidate for nuclear fusion reactors due to its combination of high melting point and ease of processing. However it will be utilized under some of the most extreme engineering conditions anywhere – temperatures up to 1000K alongside high fluxes of both neutrons and alpha particles. For safe engineering design information on the behaviour of molybdenum under these conditions is needed.

In this work the temperature dependence of plasticity in single crystal Mo (bcc) has been observed using temperature-controlled nanoindentation under vacuum from -30°C to 950°C. This work was carried out alongside temperature-dependent microindentation, also under vacuum at temperatures above from -196°C to 800°C. Samples were aligned with the [001] direction normal to the sample surface, with the indentation long axis aligned with <100> directions where possible using electron back scattered diffraction (EBSD).

In both nano- and micro-indentation, hardness decreased with increasing temperature. Microhardness results showed a value of 3.8GPa at -196°C dropping to 0.5GPa at 860°C and nanoindentation 2.7GPa at 0°C and 0.9GPa at 800°C. Microindentation also showed a sharp knee in hardness-temperature variation between 20 and 100°C, as well as some small inflexions at higher temperatures. At all temperatures, nanoindentation showed a greater hardness than microindentation, for example 2.7 and 2.1GPa respectively at 0°C.

High resolution electron back scattered diffraction (HR-EBSD) has been used to examine selected indentations at several temperatures. The focus of this was the knee temperature (T_k), below which screw dislocation mobility is restricted and is highly thermal- and strain rate-dependent. Above T_k the thermally-activated 'kink-pair' mechanism is responsible for higher mobility of screw dislocations. HR-EBSD maps of elastic strain variations and lattice rotations were used to match plastic deformation mechanisms to the hardness at each temperature, with the intention of observing the deformation responsible for each particular hardness value and length scale (nano- or micro-indentation), and linking this to lattice friction stress.





Microhardness indentations in single crystal Mo showing the large change in plastic behaviour above and below T_K