Temperature Dependence of Incipient Plasticity in Tungsten

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Abstract

Tungsten being a BCC metal is known to exhibit a brittle to ductile transition. Below the transition temperature, tungsten shows brittle fracture because ductility enabling mechanisms like kink-pair-formation of screw dislocations are mostly suppressed. Particularly in safety-critical applications tungsten shall yield instead of fracture. By pushing the yield stress to lower values, we can extend the ductile regime of tungsten and thus lower the temperature for transition. To design tungsten-based materials that can undergo plastic deformation in an extended temperature range, we need to gain a deep understanding of driving mechanisms of ductility. Classical impact tests show the macroscopic material behavior but do not allow insights into the governing mechanisms. Therefor an approach capable of investigating on the nanoscale is required. In present work we analyze yielding in defect-free sample volumes of tungsten via nanoindentation considering crystallographic orientations. Over a thermal range, a wide set of parameters related to the onset and process of plasticity is studied. While hardness expectedly decreases with temperature, the critical load where pop-in occurs seems unaffected or even increasing. This suggests a fundamentally different activation mechanism for hardness and pop-in. In our understanding, pop-in is governed by dislocation nucleation whereas dislocation mobility is the main mechanism determining hardness. For pop-in to occur, a high local stress close to or at the theoretical stress limit is required. Therefore pop-in might be predominantly stress-dominated and less dependent on thermal activation. Analysis of critical stresses and activation parameters is performed to elaborate on the atomic mechanisms. Subsequently, plasticity data like strain hardening behavior is extracted from pile-up around indents. Experimental micromechanical data is accompanied by SEM imaging techniques to analyze the deformation state. The results provide fundamental insights into thermally activated mechanisms essential for tailoring plasticity in future material development.

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