Mechanical Engineering Doctoral Defense

Anomalous Dynamic Behavior of Stable Nanograined Materials

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abstract

The stability of nanocrystalline microstructural features allows structural materials to be synthesized and tested in ways that have heretofore been pursued only on a limited basis, especially under dynamic loading combined with temperature effects. Thus, a recently developed, stable nanocrystalline alloy is analyzed here for quasi-static (<100 s-1) and dynamic loading (103 to 104 s-1) under uniaxial compression and tension at multiple temperatures ranging from 298-1073 K. After mechanical tests, microstructures are analyzed and possible deformation mechanisms are proposed. Following this, strain and strain rate history effects on mechanical behavior are analyzed using a combination of quasi-static and dynamic strain rate Bauschinger testing. The stable nanocrystalline material is found to exhibit limited flow stress increase with increasing strain rate as compared to that of both pure, coarse grained and nanocrystalline Cu. Further, the material microstructural features, which includes Ta nano-dispersions, is seen to pin dislocation at quasi-static strain rates, but the deformation becomes dominated by twin nucleation at high strain rates. These twins are pinned from further growth past nucleation by the Ta nano-dispersions. Testing of thermal and load history effects on the mechanical behavior reveal that when thermal energy is increased beyond 200 °C, an upturn in flow stress is present at strain rates below 104 s-1. Overall, in this study, we discovered that this simple assumption, established 50-years ago, breaks-down when the average grain size and microstructural length-scale is decreased and stabilized below 100nm. This divergent strain-rate behavior is attributed to a unique microstructure that alters slip-processes and its interactions with phonon; thus enabling materials response with a constant flow-stress even at extreme conditions. Hence, the present study provides a pathway for designing and synthesizing a new-level of tough and high-energy absorbing materials.

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