Society of Engineering Science 51st Annual Technical Meeting

1–3 October 2014

Purdue University, West Lafayette, Indiana, USA

Deformation mechanisms in bulk nanostructured metals and strategies to improve their ductility

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ABSTRACT

Bulk nanostructured (NS) metals, with structural units falling in the nanometer range, are of interest in part as a result of drastically improved strength over that corresponding to conventional coarse-grained (CG) materials. Examples of ultrahigh-strength bulk NS metals will be provided in this lecture and strengthening mechanisms will be briefly discussed. In the case of conventional CG metals, plastic deformation is based on the motion of lattice dislocations, which are usually unit dislocations nucleated inside grain interiors or at GBs. In the case of bulk NS metals, with significantly reduced grain size and therefore very limited space in grain interiors, and drastically increased grain boundary (GB) volume fraction, the deformation mechanisms are different from those corresponding to CG metals. In this presentation, deformation mechanisms in bulk NS metals will be reviewed and discussed, including full/partial dislocation emission from GBs, deformation twinning, GB sliding, grain rotation induced grain coalescence, stress-coupled GB migration, and de-twinning. Deformation mechanisms during dynamic and cyclic deformation of bulk NS metals, e.g., grain rotation induced grain coalescence and de-twinning, will be discussed in detail. Stress/deformation induced grain growth, with underlying deformation mechanisms of grain rotation-coalescence and stress-coupled GB migration, will be discussed in detail, and a theoretical framework that incorporates the influence of second-phase particles and solute/impurity segregation at GBs on grain growth during hot deformation will be formulated and discussed. Owing to the different deformation mechanisms in bulk NS metals, and particularly to the limited dislocation accumulation and therefore little strain hardening during deformation, bulk NS metals tend to have limited ductility. Strategies to improve ductility will be discussed in detail, e.g., bimodal/multimodal grain size distribution, nanoscale twins, low dislocation density, second-phase nanoscale precipitation within grains, and phase transformations during deformation.