Materials Science and Engineering Doctoral Defense

Design of Stable Nanocrystalline Materials for Extreme Applications

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abstract

Nanocrystalline (NC) materials experience inherent microstructural instability when exposed to elevated temperature, deformation rates or loads over long periods of time which limits its applications as well as processing. The instability arises due to the predominance of grain boundary (GB) diffusional processes which hastens coarsening. This dissertation aims to provide a solution for the very first time, through the development and characterization of a bulk NC alloy system. The NC-Cu-Ta discussed here offers exceptional thermal stability in addition to superior strength and creep resistance. The systematic study of the behavior of this material will pave the way for future development of NC materials with a multitude of optimized properties for extreme applications.

In-situ and ex-situ TEM characterization, multiple strain-rate compression testing and atomistic modeling were employed to investigate the behavior of NC-Cu-Ta under intense heating, stress/strain-rate and creep conditions. Results reveal, that temperature influences the misfit strain, leading to a significant change in flow stress, despite which (strength) remains greater than all known NC metals. Further, this alloy was found to achieve and retain strengths which were over two orders of magnitude higher than most NC metals under elevated temperature conditions. Dislocation-based slip was found to predominate at elevated temperatures for both high- and low-strain rate testing whereas twinning was favored during low temperature high-strain rate testing. The solute concentration was also found to play a role in dictating the deformation where heterogeneous twinnability was found to decrease with an increase in Ta concentration. A paradigm-shift in the creep response of NC-materials with unprecedented property combinations is also reported, i.e., high strength with extremely high temperature creep resistance (6-8 orders higher than other NC materials), in this NC-Cu-Ta-alloy. The unique combination of properties in these NC-alloys is achieved through a processing route that creates distinct GB-pinning nanoclusters of the solute that favor kinetic stability of grains.

Overall, this dissertation provides an understanding of the mechanical response of a stable alloy system to extreme conditions, which was previously unattainable, and a perspective on the design of a new class of NC alloys exhibiting a multitude of optimized high temperature properties.

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