Deformation-based recovery of irradiation-induced Ostwald ripening in nanocrystalline CuTa alloy

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The objective of this study is to understand how mechanical deformation can lead to partial recovery of nanostructuring lost during proton irradiation-induced Ostwald ripening in nanostructured Cu-10at%Ta alloy. Nanostructured immiscible Cu-10at%Ta, processed by equal channel angular extrusion (ECAE) at 700°C, offers promise for engineering mechanically stable nanostructures for extreme environments. The alloy contains a bimodal size distribution of Ta phases, with nanocrystalline Ta grains ~70 nm and Ta nanoclusters <10 nm; it can thus be studied as a model system for oxide dispersion strengthened (ODS) nanostructured ferritic alloys (NFAs). But like many ODS NFAs, Cu-10at%Ta undergoes irradiation-induced Ostwald ripening of the nanoclusters, which can be detrimental to the mechanical integrity and high temperature stability of the alloy. Thus, there is an opportunity to engineer a method of recovering the irradiation damage to the nanostructure.

We irradiate the Cu-10at%Ta with 2 MeV protons to 1 displacement per atom (dpa) at 500°C. After irradiation, the Cu grains are free of irradiation induced defects, consistent with radiation tolerance typically of nanocrystalline materials. However, atom probe tomography (APT) indicates that Ta nanoclusters exhibit Ostwald ripening. We subsequently conduct transmission electron microscopic (TEM) *in situ* indentation, which revealed that harder Ta nanoparticles remain generally undeformed while the surrounding Cu matrix deforms readily. The TEM *in situ* indentation process was also intermitted with automated crystal orientation mapping (ACOM-TEM), to reveal the formation of substructures in the Ta phases during indentation. These Ta substructures align to the loading direction and ultimately become dispersed in the Cu matrix, which does not re-orient with deformation. Ultimately, these effects culminate in thinning of the Ta phase, allowing us to recover some of the pre-irradiation nanostructure. A finite element model confirms the magnitude of stress and strain needed for such a phenomenon to take place, and will further reveal the stress and strain fields associated with the Cu-Ta interfaces to understand the mechanisms of this damage recovery.

These results suggest that compressive deformation-based surface treatments such as peening could be valuable tools for irradiation degradation management of ODS and NFA components.