

Purdue Materials Engineering

“Radiation Induced Microstructural Evolution and Hardening Influenced by Alloying Elements in Ferritic Iron Based Binary Model Alloys”

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ABSTRACT

The objective of this study is to evaluate the radiation induced microstructural and mechanical differences influenced by alloying elements including phosphorus, chromium, and nitrogen and crystal orientation in iron-based binary alloys. Fe-4.5at%P, Fe-9.5at%Cr, and Fe-2.3at%N binary model alloys were irradiated with 4.4 MeV Fe⁺⁺ ions at 370 °C to 8.5 displacements per atom (DPA). Transmission electron microscopy (TEM) characterization including brightfield scanning electron microscopy (BFSTEM), diffraction, and TEM in situ irradiation, energy dispersive spectroscopy (EDS) compositional analysis, and nanoindentation were used to evaluate the radiation induced microstructural evolution and mechanical responses in these model alloys. Microstructure is of particular interest in irradiated nuclear structural materials because it plays an integral role in the mechanical integrity of these materials. Radiation induced defects present obstacles to dislocation motion and thus lead to hardening and embrittlement. P is highly undersized and forms a strong covalent bond with Fe which progresses to an Fe₃P beta phase in BCC iron when the solubility limit is reached. The covalent nature of the bonding as well as the smaller atomic volume of P leads to enhanced radiation induced defect nucleation, phosphorus segregation, and radiation induced precipitation. The high density of defects in the Fe-P alloy contributed to enhanced hardening of the irradiated Fe-P alloy in comparison to the Fe-Cr and Fe-N alloys. The density of these defects and depth of the ion irradiated damaged layer and thus the mechanical response is also heavily dependent on orientation and is made evident by nanoindentation and indentation cross section BFSTEM imaging.

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