Radiation Damage in High-Entropy Alloys

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Materials in fast reactors are expected to withstand high temperatures, damaging radiation levels, and corrosive environments for extended periods of time. They must be resistant to void swelling up to several hundreds of dpa, maintain adequate creep strength up to 650°C, fracture toughness at 320°C, and exhibit high levels of corrosion resistance in liquid-sodium or liquid-lead-alloy coolants. Therefore, the deployment of sodium fast reactors (SFRs) is, in part, limited by the development of materials that can sustain these conditions [1]. High-entropy alloys (HEAs) are composed of four or more metallic elements mixed in equimolar (or near to equimolar) ratio to favor single-phase solid-solution formation [2]. FCC HEAs based on 3d transition metals are characterized by low stacking-fault energy; thus, they deform by twinning, which increases their dislocation-storage capacity and, hence, their ductility [3]. On the other hand, HEAs based on light refractory metals exhibit high strength and limited softening up to very high temperatures [4]. These properties make them potentially attractive candidates for investigations as cladding alloys in the extreme SFR conditions. The goal of this study is to understand the microstructural changes in proposed HEAs under heavy ion irradiation to evaluate its radiation damage to enhance our fundamental understanding of irradiation effects in these multi-component alloys and to assess their potential applications in future SFRs.

Results

Two high entropy alloys, $Cr_{18.1}Fe_{27.3}Mn_{27.3}Ni_{27.3}$, and $Cr_{15}Fe_{35}Mn_{15}Ni_{35}$, along with reference materials (model Alloy 709, Ni, and V) were irradiated at 500 °C with 3.7 MeV self-ions Ni^{2+} to 50 dpa. The irradiations of FCC materials resulted in the formation of perfect dislocation loops against a dislocation network. The average size of all loops is quite similar, ranging from approximately 13 to 20 nm in the longest dimension. Voids (shown in Figure 1) were also found in $Cr_{15}Fe_{35}Mn_{15}Ni_{35}$, but not in $Cr_{18.1}Fe_{27.3}Mn_{27.3}Ni_{27.3}$ beyond the damage peak predicted by the Stopping and Range of Ions in Matter (SRIM), which supports the idea that interstitial loops are generally less mobile with increased compositional complexity.

Conclusion

The mobility of interstitial loops depends on the compositional complexity of the material, decreasing as the complexity increases. In an isotropic neutron-irradiation environment, the formation of dislocations, which are immobile even after unfaulting, may increase the sink strength and reduce the time needed to form a supersaturation of vacancies and for voids to grow to larger sizes.

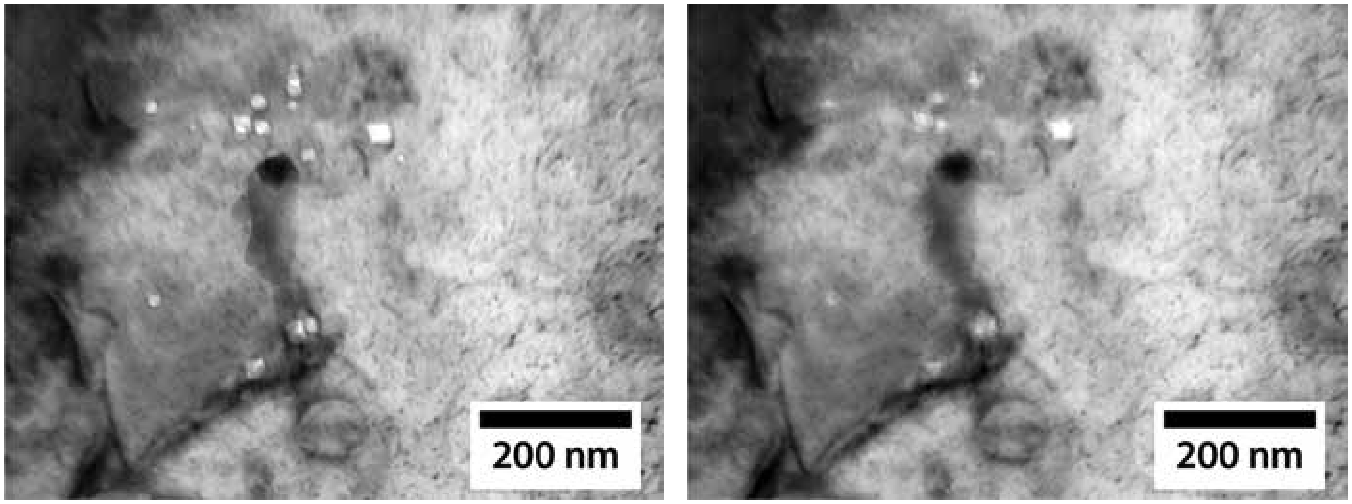

Figure 1. Micrographs of voids seen in $Cr_{15}Fe_{35}Mn_{15}Ni_{35}$ irradiated at 500°C. Left is under focused, and right is over focused to show the features are in fact voids.

References

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