Defect Clustering in 316H Stainless Steel and High Entropy Alloy Under In-situ Irradiation at 600-700°C

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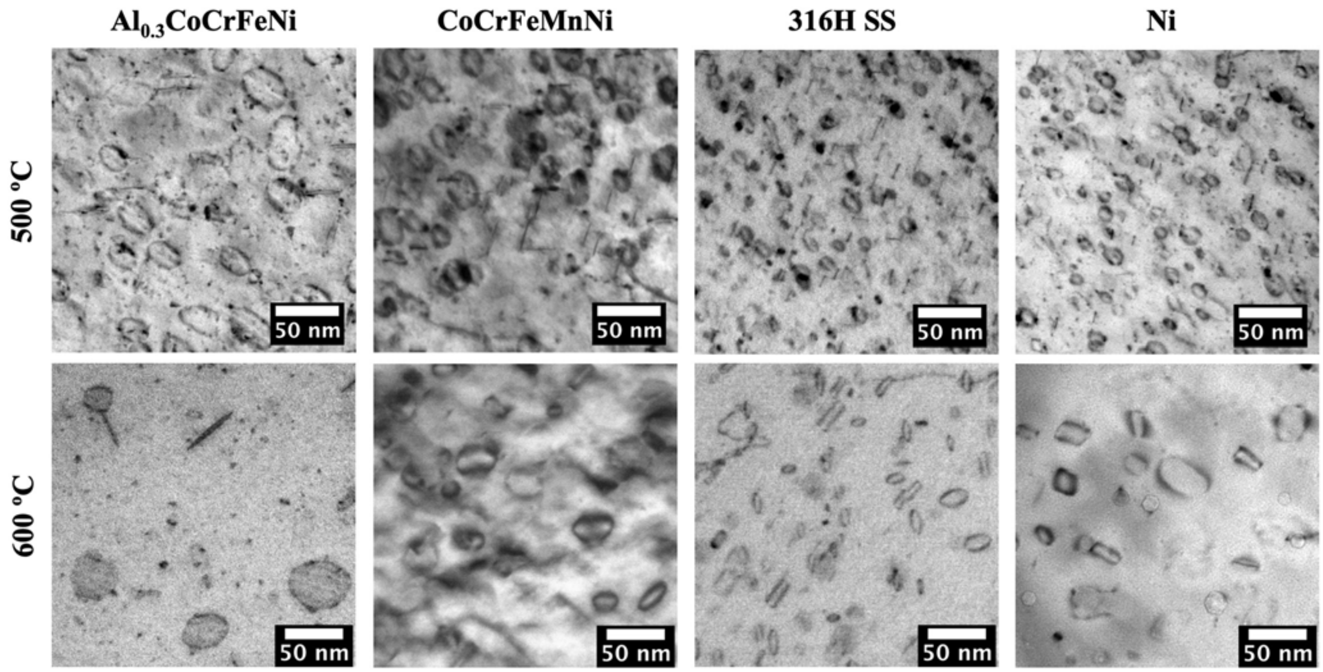
The objective of this study was to understand the irradiation behavior of high entropy alloys (HEAs) at elevated temperatures and to compare the irradiated microstructures between HEAs and 316H stainless steel (SS) and pure nickel. Under irradiation, several dynamic processes, such as cascade condensation, cluster dissociation, and loop unfaulting take place inside materials. A detailed understanding of each individual process and the interactions among them is necessary for unveiling the distinctive microstructure at high doses. This project was an initial attempt to lay down the groundwork for future effort on long term damage modeling and neutron irradiation experiments.

Experimental or Technical Approach

Three millimeter transmission electron microscopy (TEM) specimens of $Al_{0.3}CoCrFeNi$, CoCrFeMnNi, 316H SS, and nickel were prepared and irradiated with 1 MeV krypton ions inside a Hitachi 9000 TEM operated at 300 kV. The irradiation experiments were carried out at 300°C, 500°C, 600°C, and 700°C, with a flux of 6.3×10^{11} ions/cm^2/s or 1.3×10^{12} ions/cm^2/s, reaching a final fluence of 6.3×10^{14} ions/cm^2 (1 dpa). The microstructures of the samples were observed *in situ* during irradiation under bright field (BF) and weak beam dark field imaging conditions. The irradiation induced dislocations, dislocation loops, and stacking fault tetrahedral (SFT) were imaged with a two beam imaging condition of g = 200 near 011 zone axis. The irradiation induced voids were imaged with an underfocused amount of 1 µm. The microstructural evolution was recorded for selected experiments with a range of video frame rates from 1 fps to 100 fps. Nanoindentation tests were also performed



on the specimens to provide complementary hardening information on irradiated materials.

Results

The irradiation induced dislocation loops, SFT, and voids in $Al_{0.3}CoCrFeNi$, CoCrFeMnNi, 316H SS, and nickel were observed and analyzed as a function of irradiation dose and temperature. For the experiments at 500°C and above, a high density of SFT and a depletion of dislocation loops were visible in thin areas near the foil surface for all materials. In the thick regions of the specimens, dislocation loops were observed. A

Figure 1. BF TEM micrographs showing the dislocation loops in $Al_{0.3}CoCrFeNi$, CoCrFeMnNi, 316H SS and nickel irradiated at 500°C and 600ºC to 1 dpa.

through thickness analysis was performed to quantitatively evaluate the effect of foil surface on the observed defects for all samples.

For the materials and irradiation conditions studied in this work, void swelling was only observed in the nickel sample irradiated at 600°C. No voids can be seen under all other conditions and in the HEAs and 316H SS samples. The loop density and size were similar for the HEAs and 316H SS irradiated at 300°C [1]. At 500°C and 600°C, the loop density was much smaller and the size much larger, in the HEAs as compared with the 316H SS, as shown in Figure 1. This observation was consistent with the nanoindentation measurement where the 316H SS exhibited higher post irradiation hardening than the HEAs at 500°C [2].

Discussion/Conclusion

The irradiated microstructures of HEAs, 316H SS, and pure nickel have been compared over a temperature range between 300°C and 700°C. The fundamental effect of the alloying complexity on the irradiation damage process has been revealed. The comparison of the irradiated microstructures of HEAs and 316H SS provides useful information for the potential applications of HEAs in nuclear reactor systems.

References

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Publications

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Distributed Partnership at a Glance

NSUF Institution	Facilities and Capabilities
Argonne National Laboratory	The Intermediate Voltage Electron Microscopy – Tandem Facility
Collaborators	
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