The Effect of Bulk Composition on Microstructural Changes in Austenitic Alloys

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Introduction

Changes in bulk composition are known to affect the mechanical properties and microstructural development in austenitic stainless steels under irradiation[1-2]. Judicious choices of major element or impurity element concentrations can be used to alter microstructural development to improve material properties such as void swelling and hardening resistance. In this work, select solutes have been added to an Fe-18Cr-8Ni alloy (bulk composition corresponding to 304 stainless steel) to identify the effect of composition on void and faulted loop size and density. Fe-18Cr-40Ni is analyzed to study the effect of bulk diffusivity increases, Fe-16Cr-13Ni to isolate the effect of major elements in improving swelling resistance in 316 stainless steel, and Fe-18Cr-8Ni+Zr to determine the effect of an oversized element on enhancing point defect recombination. Following irradiation with high-energy protons, the microstructures of irradiated samples are investigated to determine the void and loop size distributions.

Experiment

Melts of Fe-18Cr-8Ni, Fe-18Cr-8Ni+Zr, Fe-18Cr-40-Ni, and Fe-16Cr-13Ni alloys were supplied by GE Corporate Research and Development. These alloys were processed to obtain a grain size of approximately twenty microns. Samples were irradiated using a 3.2 MeV proton beam with a uniform damage depth of approximately 40 microns that, for a grain size of 20 microns, will

include several grain boundaries . The irradiations were performed at 400°C to a final dose of 1 dpa at a dose rate of $7x10^{-6}$ dpa/s. Following irradiation, 3 mm disks were prepared for transmission electron microscopy, and the void and loop size distributions were measured in each alloy. Microscopy was performed using a JEOL 2010 transmission electron microscope.

Results and Discussion

Void swelling must be limited to prevent unacceptable dimensional changes in reactor structural materials. Void distributions were measured for each of the four alloys. The distribution for the Fe-18Cr-8Ni alloy is given in figure 1. The average void size is 6.7 nm with a standard deviation of 2.2 nm. The void density is $2.7x10^{21}$ m^{-3}. The distribution has a slight negative skew, driven by the large tail of voids with less than average diameter size. The kurtosis of the distribution is negative indicating the distribution is flatter than a normal distribution. The majority of the increase in hardening during irradiation arises from the development of faulted dislocation loops. The distribution of faulted loops for the Fe-18Cr-8Ni alloy is provided in figure 2. The average loop size is 19.3 nm with a standard deviation of 7.7 nm. The loop density is $2.2x10^{21}$ m^{-3}. The distribution has a positive skew, driven by the large tail of loops with greater than the average size. The kurtosis of the distribution is positive indicating the distribution is more peaked than a normal distribution. The presentation will compare the void and loop distributions in the Fe-18Cr-40Ni, Fe-18Cr-8Ni+Zr, Fe-16Cr-13Ni, and Fe-18Cr-8Ni alloys.

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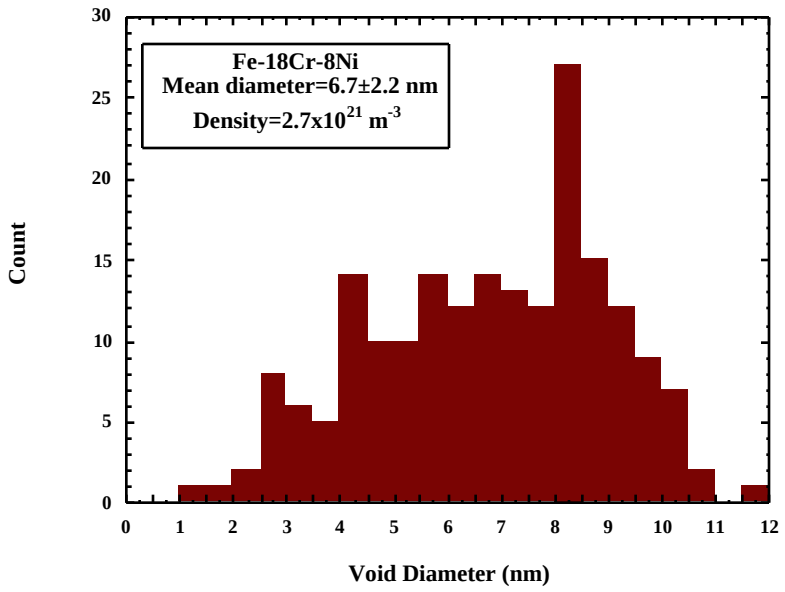

Figure 1. Void size distribution for Fe-18Cr-8Ni

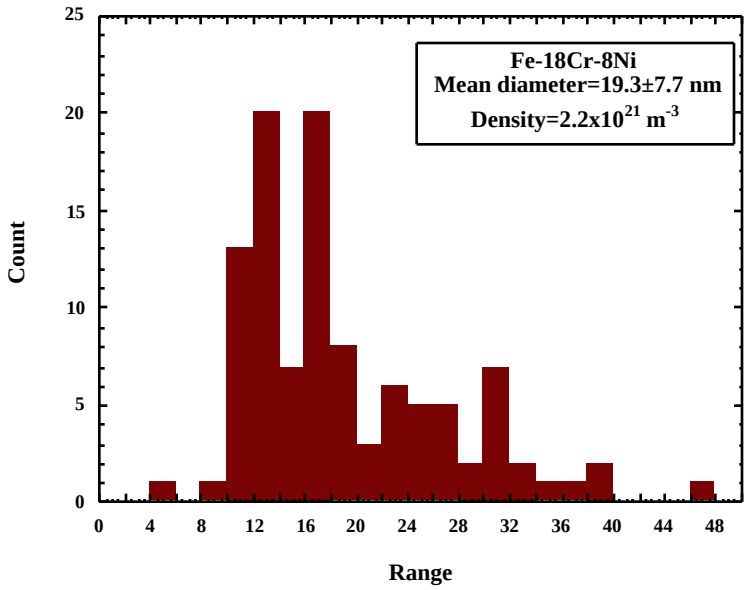

Figure 2. Faulted loop size distribution for Fe-18Cr-8Ni