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Void Swelling in Self-Ion Irradiated Ferritic-Martensitic Alloy T91

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Determining the microstructural behavior of body centered cubic (BCC) ferritic-martensitic alloys is important for predicting the safety and structural integrity of fast spectrum reactors. Of particular interest is the phenomenon of radiation-induced void swelling, which could potentially cause dimensional changes in key structural components in reactors. Irradiations performed with heavy ion irradiations can be used to model neutron irradiations with the benefits of accelerated dose rate, decreased irradiation time required and excellent temperature control of irradiated samples.

Self-ion irradiation experiments have been performed on ferritic-martensitic alloy T91 to determine swelling behavior at 440°C to doses of 280 dpa and 375 dpa, in order to examine the effect of irradiation dose on void size, density and swelling. T91 is a modified 9Cr-1Mo alloy, which has demonstrated swelling resistance in previous neutron irradiation studies.[1] Samples were preimplanted with 100±10 atom parts per million (appm) helium at a depth of 300-1000 nm from the sample surface. Irradiations were performed with 5 MeV Fe++ ions on samples using raster scanning on a Tandetron accelerator at the Michigan Ion Beam Laboratory. The effect of dose on void swelling was determined by examining the void distribution using transmission electron microscopy (TEM). TEM samples were prepared using the liftout technique on a FEI Quanta Focused Ion Beam (FIB) system.

The irradiated microstructure at 280 dpa is shown in Figure 2. The microstructure includes many dislocation loops, lines and precipitates, which is characteristic of ferritic-martensitic alloys. The damage curve and the pre-implanted helium distribution were superimposed over the sample irradiated to 375 dpa as shown in Figure 1. A comparison of void data at both doses is given in Table 1. Voids preferentially nucleated over the area pre-implanted with helium. The additional 100 dpa of dose greatly increased void diameter, density and swelling, which indicates that the sample is still in the nucleating regime at 280 dpa but is entering the steady state growth regime by 375 dpa. Despite the large increase in void number, density and swelling at 375 dpa, T91 demonstrates superior swelling resistance to high doses, relative to stainless steel alloys which reach swelling rates as high as 1%/dpa. [2] Though the amount of neutron data is limited, T91 irradiated in the Fast Flux Test Facility at 420^{o}C to 203 dpa showed swelling of 1.76%. [1] This, when compared to the self-ion irradiated data, indicates that self-ion irradiations may include a longer nucleation regime before entering the growth regime. The swelling-dose curve is plotted in Figure 3 and the steady state swelling rate was calculated to be 0.003%/dpa based upon these two conditions. This is similar to the swelling rate of 0.002% calculated by Sencer et al. in a neutron irradiation of HT9, another ferritic-martensitic alloy, up to 155 dpa at 443^{o}C.[3]

Further work will include irradiations to higher doses to map out the steady state swelling rate, as well as examining the effect of temperature on void nucleation and growth behavior. Additionally, other alloys including various heats and heat treatments of HT9, will be irradiated and examined, in order to determine an accurate method for modeling neutron damage with heavy ions.

References:

[1] D. Gelles, Journal of Nuclear Materials 237 (1996) 293–298.

[2] F. Garner, M.B. Toloczko, B.H. Sencer, Journal of Nuclear Materials 276 (2000) 123–142.
[3] B.H. Sencer, J.R. Kennedy, J.I. Cole, S.A Maloy, F.A Garner, Journal of Nuclear Materials 393 (2009) 235-241.
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Table 1. Comparison of void diameter, density and swelling in samples irradiated to 280 dpa and 375 dpa at 480°C at a dose rate of 7.92 x 10^{-4} and 5.4 x 10^{-4} dpa/s, respectively.

Alloy	Temperature (°C)	Dose (dpa)	He Implanted (appm)	# of Voids	Void Density (m^{-3})	Average Diameter (nm)	Swelling (%)
T91	440	280	100	529	2.82 x 10^{20}	9.44	0.023%
T91	440	375	100	785	8.85 x 10^{20}	12.5	0.33

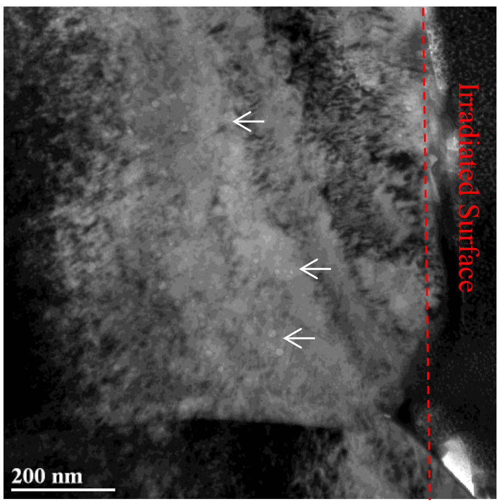

Figure 2. T91 irradiated to 280 dpa at 440°C and at 7.92 x 10^{-4} dpa/s. Selected voids marked with white arrows.

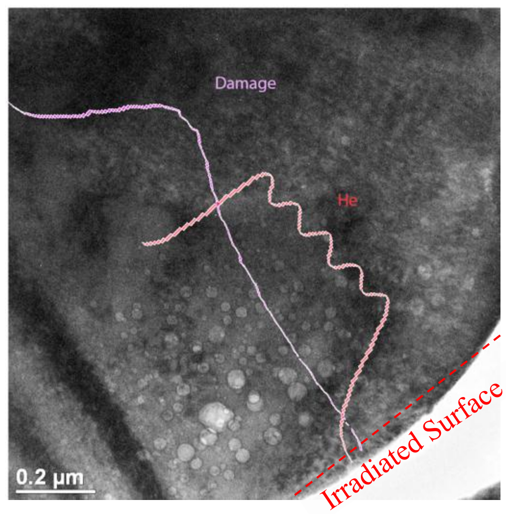

Figure 1. Fe^{++} irradiation damage curve and implanted helium distributed superimposed over sample irradiated to 375 dpa at 480°C with a dose rate of 5.4 x 10^{-4} dpa/s.

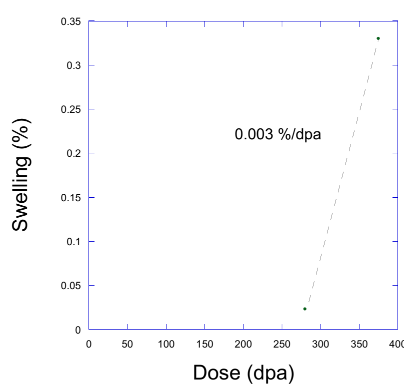

Figure 3. Swelling versus dose in irradiated T91 at 440°C

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