A new void swelling phenomenon revealed during self-ion irradiation of neutron-preconditioned 304 stainless steel

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Ion-irradiation is employed as a surrogate to simulate neutron-induced microstructural changes, especially for void swelling. Use of this technique must address neutron-atypical features of ion-irradiation such as high dpa rate, surface proximity and injected interstitials. One particular problem is that the onset of void swelling is usually preceded or accompanied by a radiation-induced microchemical evolution with different rate sensitivities compared to those of void evolution. This mismatch in rate sensitivities has two major consequences. First, void densities produced by ion-irradiation are generally rather low, unless stimulated by injection of helium. Second, the duration of the transient regime of swelling is different from the neutron case because of the microchemical mismatch.

One approach to address this issue uses previously neutron-irradiated specimens, ensuring that void densities are neutron-representative, and especially that pre-ion-irradiation microchemical evolution is complete or at least headed in the correct direction. This assumes that this state will persist for the duration of ion-irradiation.

We used AISI 304 specimens, previously irradiated to 22dpa at ~450°C as part of an EBR-II reflector assembly, and compared results with corresponding unirradiated material, both in 0.3mm thick by 3mm diameter TEM disk form. The starting neutron-irradiated microstructures were found to be uniform across the disk thickness. Additionally, the issue of "temperature-shifting" at increased displacement rates was studied by ion-irradiating specimens to additional 25, 50, and 75dpa using temperature shifts of 0, 50, 100 and 150°C.

Based on previous 1.0 MeV electron irradiation studies conducted in the 1970s at large temperature shifts, certain features of the ion-induced response were anticipated, especially a relatively fast formation of surface-denuded zones which indeed formed during ion-irradiation. However, it was observed that at zero temperature shift the pre-existing voids progressively disappeared through the ion range at a rate proportional to the local dpa rate and not due to the injected interstitial distribution. At the 50°C shift, the voids essentially ignored new dose accumulation and at higher shifts, swelling increased with dose. Thus, the swelling rates move from negative to zero to positive for shifts of 0-150°C, behavior never before observed and requiring a new theoretical framework now in progress.