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Recent studies associated with light water reactors (LWR) in both the USA and Russia have raised the question of void swelling in austenitic components of core internals. One question of particular interest is the range of temperatures over which voids can develop, especially the lowest temperature. This question is equally relevant to fusion reactors, especially those operating with water cooling and therefore exposed to temperatures below those attainable in various high-flux fast reactors used to generate most of the relevant high fluence data. To address this question a flow restrictor component manufactured from annealed X10H18T was removed from the reflector region of the BN-350 fast reactor. During operation this component spanned temperatures and dpa rates of direct interest not only to pressurized water reactors (PWRs) in the West and VVERs in Russia, but also to various proposed fusion devices. This steel is analogous to AISI 321 and is used in Russian reactors for applications where AISI 304 would be used in the West. This component was sectioned on a very fine scale to determine in what range of conditions voids existed. Microstructural data were obtained for 157 separate locations, with 111 specimens showing voids over the relevant range of temperatures and displacement rates, allowing construction of a parametric map of swelling with temperature, dpa and dpa rate. These data show that void swelling at 10 to 50 dpa persists down to ~306°C for dose rates in the range 0.1×10^{17} to 1.6×10^{7} dpa/sec.

Measurements are presented of electrical resistance and elastic moduli (Young's modulus and shear modulus) of stabilized austenitic fuel pin cladding after irradiation in the BN-600 reactor. Additional data are presented on changes in electrical resistivity of another stabilized austenitic steel irradiated in the BN-350. The elastic moduli are reduced and the electrical resistance is increased as the neutron dose increases. These changes are correlated with void swelling measured on the same specimens. Dependencies of these changes in physical properties on neutron irradiation dose, temperature and swelling level are plotted and it is shown that to the first order, the property changes are dependent on the swelling level in agreement with earlier U.S. and Russian data, and also in agreement with various theoretical predictions. It is also observed, however, that changes in electrical resistance and elastic moduli frequently differ slightly for specimens with equal swelling, but which were obtained at different combinations of temperature and dose. These second-order differences appear to arise from contributions of other radiation-induced structural changes, especially in precipitation, which depends strongly on irradiation temperature in stabilized steels.

The effect of dose rate on neutron-induced microstructural evolution was experimentally estimated. Solution-annealed austenitic model alloys were irradiated at ~400 with fast neutrons at seven different dose rates that vary more than two orders of magnitude. Two different doses were achieved at each dose rate. Both cavity nucleation and growth were found to be enhanced at lower dose rate. Based on a simple assumption concerning the experimental data, the net vacancy flux is calculated from the growth rate of cavities that had already nucleated during the first cycle of irradiation and grown during the second cycle. Using this approach the net vacancy flux was found to be proportional to $(dpa/sec)^{1/2}$ up to 28.8 dpa and 8.4 x 10-7 dpa/sec. This implies that mutual recombination dominates point defect annihilation in this experiment, even though point defect sinks such as cavities and dislocations were well developed. Thus, mutual recombination is thought to be the primary origin of the effect of dose rate on microstructural evolution, although the recombination distance is large and requires a new mechanism for recombination.

A large amount of data on irradiation creep of face centered cubic (FCC) and body centered cubic (BCC) steels have been analyzed and published by the present authors, but a recent reanalysis of these data have provided further insight into irradiation creep behavior. The present paper looks at the stress and temperature dependence of creep at low swelling for selected 316 stainless steels and HT9 steels irradiated at temperatures from 400°C to 670°C. Analysis of the creep data has revealed that a transition from a lower creep rate with a stress exponent of one to a higher creep rate with an unknown stress exponent occurs in FCC and BCC steels at moderate stresses, and the transition stress is approximately the same for both classes of steels. Due to limited data at higher stresses, the nature of the creep behavior at stresses greater than the transition stress cannot be unambiguously defined. One possibility is that the stress exponent is transitioning from a value of one to a value greater than one. Another possibility is that the creep compliance value is transitioning to a higher value while the stress exponent remains at a value of one. The creep compliance coefficients of the FCC and BCC steels have also been carefully reanalyzed in the regime where the stresses are lower than the transition stress, and in this regime there is a clear delineation in the creep compliance values between 316 stainless steels, titanium-modified 316 steels, and HT9 steels as a function of temperature.

These specifications provide metrics for evaluating compatibility results in static Li exposures to determine when bulk ceramic candidate materials are ready for coating development and when coatings are ready for dynamic (i.e. loop) testing.

We have investigated two ways to modify the V-4Cr-4Ti surfaces (Y deposition and Cr-Si-O addition) in preparation for forming CaO coatings on V alloys in liquid Ca-Li. Our earlier experimental studies indicated that sintered Y_2O_3 is compatible with liquid Li. In continuing studies, we have deposited thin (0.2, 0.8, and 1.5 mm) yttrium films on V-4Cr-4Ti substrates by physical vapor deposition (PVD). Annealing the thin Y-metallic PVD film on O-charged V-4Cr-4Ti at 750°C for 17 h formed an oxide film by the solid-state reaction between O and Y. Both energy dispersive spectroscopy (EDS) and X-ray diffraction indicated that the 0.2 and 0.8 mm Y-metallic films converted to either YVO_3 or $Y_8V_2O_{17}$ after annealing, but the thicker (1.5 mm) Y-metallic film developed two phases as $Y_8V_2O_{17}$ and Y_2O_3. When these samples were exposed in 2.8 at.% Ca-Li at temperatures of 700°C for 99 h, a uniform microstructure CaO layer was formed on the top of the Y-V oxides, but localized Y was not detected by cross-sectional EDS analysis. However, the thicker films were shown to have a localized spallation problem between V-4Cr-4Ti and the oxide after annealing, so we ceased the exposure tests. The Si-O addition was performed by $Cr+Cr_2O_3$ equilibrium inside a vacuum-sealed quartz (SiO2) chamber at 950°C for 17 h followed by exposure to 2.8 at.% Ca-Li at temperatures of 700°C for 99 h. This yielded an adhesive, water insoluble, and highly resistive Ca-Si-O film.

We are investigating the in-situ formation of CaO coatings on V-4Cr-4Ti structural material in liquid lithium under various conditions. Initially, the near surface of the V-4Cr-4Ti was oxygen-charged at 710°C and homogenized at 750°C for 17 h, then samples were exposed in 2.8 at.% Ca-Li at temperatures of 600 and 700°C for times between 50 and 747.5 h. The thickness of the in-situ-formed CaO was 4 to 26 μm under the experimental conditions. In the 50 h exposure, thicker CaO films were formed at higher oxygen contents and 700°C, while thinner CaO films were formed at lower oxygen contents and 600°C. For longer exposures at 600°C (623 and 747.5 h), the film thickness stayed the same, but for 700°C exposures (100-425 h) the CaO film chemistry changed, with the film becoming thinner as a result of the net effect from compensating for the film formation and dissolution. We measured the electrical resistivity in an inert-gas environment at between room temperature and 760°C for in-situ formed films at 600°C in 2.8 at.% Ca-Li for 623 and 747.5 h. The measured values for the electrical resistivity were shown to satisfy the design requirement for insulating coatings in the Li/V advanced blanket for the magnetic fusion reactor (MFR). We also performed a Ca-Li compatibility test for single-crystal CaO samples at 600°C for 623 h. The surface of the single-crystal CaO was dissolved 50 μm. These results indicate that the insitu formed film could be a different phase from the pure CaO. As a result of our recent investigations, we may have met the important development issues for obtaining 700°C stable coatings in Li/V advanced MFR blankets.

Coatings of Y_2O_3 (12.5μm thick) were formed on V-4Cr-4Ti substrates using electron-beam assisted, physical vapor deposition (EB-PVD). The resistivity of the as-received, 12.5μm thick coatings was lower than literature values for bulk Y_2O_3, possibly due to cracks or pores in the coating. Coated substrates were exposed to Li in vanadium alloy capsules at 700° and 800°C for up to 1000h. One specimen was exposed to Li for three sequential 100h thermal cycles at 800°C and was cooled to room temperature between cycles. All of the exposed specimens were largely intact after exposure although x-ray diffraction indicated some reaction with the Li. The resistivity of several exposed coatings was measured to 500°C. The specimen exposed for 3, 100h cycles at 800°C showed no drop in resistivity after exposure while the specimen exposed for 1000h at 800°C showed a lower resistivity.

No Contributions

It has been previously shown that for a wide range of BCC and FCC metals, shear punch properties correlate well with uniaxial tensile properties from corresponding miniature tensile tests. However, recent studies of the shear punch test technique have revealed that by more directly measuring punch tip displacement during a shear punch test, the resulting effective shear stress versus displacement trace has a greater similarity to a corresponding tensile test trace. On the assumption that this would lead to shear punch properties that correlate even better with uniaxial tensile properties, shear punch tests were performed on a variety of unirradiated metals, and the shear punch properties were compared to tensile properties from corresponding miniature tensile tests.