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XRD analyses were performed on the extraction residue of HFIR 11J-irradiated RAFs to investigate the overall precipitate character. Un-irradiated and aged specimens were examined as well. Results suggested that the distinctive peaks of $M_{23}C_6$ (M; Cr, Fe, W) were observed on all specimens. Peaks possibly related to MX (M;Ta,Ti,V : X ; C, N) were observed on the specimens extracted from un-irradiated JLF-1 and ORNL9Cr, but those peaks were not observed on irradiated specimens.

Transmission electron microscopy (TEM) specimens of F82H-IEA, F82H HT2, JLF-1, and ORNL9Cr steels were prepared from miniature Charpy specimens irradiated up to 5 dpa at 573K by using the Focused Ion Beam (FIB) technique in order to determine the mechanisms that cause the difference in Charpy impact properties. TEM microstructural analysis was performed with emphasis on dislocation structure and precipitate distribution. The TEM specimens indicated no significant difference on dislocation microstructures, such as dislocation loop size and density, in the steels. While precipitate's distribution of each steel was somewhat different in their size and density, larger precipitates were observed on prior austenite grain (PAG) boundaries and martensite packet boundaries of F82H-IEA and F82H HT2 compared to JLF-1 and ORNL9Cr. TEM analysis also suggested that ORNL9Cr had the finest grain structure, and F82H had a coarse grain structure. The microstructure of the deformed region of irradiated F82H-IEA contained dislocation channels. This suggests that dislocation channeling could be the dominant deformation mechanism in the RAFs, resulting in the loss of strain-hardening capacity.

The fracture toughness database for F82H displays some anomalous behavior associated with the center of the 25 mm thick plate. Metallographic carbide etchant reveals larger particles dispersed through the 25 mm thick F82H plate. The particles are found to be rich in Ta and O. Size distribution measurements indicate no enhancement at the center of the plate. However, the spatial distribution is affected so that large particles are more often located next to other large particles in the center of the plate. A mechanism is proposed that promotes easy crack nucleation between large tantalum oxide particles.

We assembled a fracture toughness database for the IEA heat of F82H based on a variety of specimen sizes with an ASTM E1921 nominal master curve (MC) reference temperature, To = -119±3°C. However, the data are not well represented by a MC. To decreases systematically with a decreasing deformation limit Mlim starting at ! 200, which

some specimens 1 h at 750°C; the 9Cr-1MoVNb and 12Cr-1MoVW were tempered 1 h at 760°C. Based on the change in tensile properties, the results demonstrated the superiority of the 9Cr-2WVTa steel over the two commercial steels. Charpy properties of the 9Cr-2WVTa-2Ni steel were similar to those of the 9Cr-2WVTa steel, indicating no adverse effect of the nickel on the properties after irradiation in a fast reactor around 400°C.

We have assembled the available paired datasets on irradiation-induced increases in yield stress ($\Delta\sigma_y$) and transition temperature shifts (ΔT), in order to assess the potential role of high levels of helium on irradiation embrittlement of ≈ 8Cr martensitic steels. Both ΔT versus $\Delta\sigma_y$ scatter plots and variations in the hardening-shift coefficient, $C = \Delta T/\Delta\sigma_y$, are used to evaluate potential non-hardening helium embrittlement (NHHE) contributions to ΔT. The available data is limited, scattered, and potentially confounded. However, collectively the database suggests that there is a minimal NHHE up to a few hundred appm. However, a NHHE contribution appears to emerge at higher helium concentrations, estimated to be more than 400 to 600 appm. The NHHE is accompanied by a transition from transgranular cleavage (TGC) to intergranular fracture (IGF). IGF generally occurs only at high $\Delta\sigma_y$. Synergistic combinations of large $\Delta\sigma_y$ and severe NHHE could lead to very large ΔT in first wall and blanket structures at fusion spectrum dose levels above 50 to 75 dpa. Future research will focus on continued collection and analysis of data, participation in new experiments to better address NHHE and developing detailed micromechanical models of helium effects.

The microstructure of EP-450 ferritic-martensitic steel was determined after irradiation in BN-350, BOR-60 and BR-10 fast reactors at temperatures in the range 275-690°C. The examinations confirm a high resistance of EP-450 steel to void swelling, but the resistance appears to be lower when the dpa rate is reduced. Depending on irradiation dose and temperature the following was observed: voids (285-520°C), dislocation loops and linear dislocations (275-520°C), α′-phase (285-520°C), χ phase (460-590°C), and M_2X precipitates (460-690°C). It appears that the formation of dislocation loops and α' precipitates at high densities is responsible for the low temperature embrittlement observed in this steel.

Data on irradiation hardening and embrittlement of 7-9Cr normalized and tempered martensitic steels (TMS) has been compiled from the literature, including results from neutron, spallation proton (SP) and He-ion (HI) irradiations. Limitations of this database are briefly described. Simple, phenomenological-empirical fitting models were used to assess the dose (displacement-per-atom, dpa), irradiation temperature (T_i) and test temperature (T_t) dependence of yield stress changes ($\Delta\sigma_y$), as well as the corresponding dependence of sub-sized Charpy V-notch impact test transition temperature shifts (ΔT_c). The $\Delta\sigma_y$ are similar for SP and neutron irradiations, with very high and low helium to dpa ratios, respectively. The $\Delta\sigma_y$ trends were found to be remarkably consistent with the T_i and dpa hardening-dependence of low alloy steels irradiated at much lower doses. The some specimens 1 h at 750°C; the 9Cr-1MoVNb and 12Cr-1MoVW were tempered 1 h at 760°C. Based on the change in tensile properties, the results demonstrated the superiority of the 9Cr-2WVTa steel over the two commercial steels. Charpy properties of the 9Cr-2WVTa-2Ni steel were similar to those of the 9Cr-2WVTa steel, indicating no adverse effect of the nickel on the properties after irradiation in a fast reactor around 400°C.

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Results of the investigation confirm these factors can significantly impact cascade damage formation. The effects include enhanced defect survival for PKA directions that lie in close-packed {110} planes, increased point defect clustering and larger defect clusters for cascades initiated near a surface, and reduced defect survival in simulation cells containing defects. The origin and implications of these effects are discussed relative to the interpretation of certain experimental observations and parameters used in other modeling studies.

Extended Abstract

Extended Abstract

Stacking fault tetrahedra (SFTs) are formed under irradiation of fcc metals and alloys with low stacking fault energy. The high number density of SFTs observed suggests that they should contribute to radiation-induced hardening, and, therefore, taken into account when estimating mechanical properties changes of irradiated materials. The central issue is describing the individual interaction between a moving dislocation and an SFT, which is characterized by a very fine size scale on the order of a few to one-hundred nanometers. This scale is amenable to both in-situ TEM experiments and large-scale atomic modeling. In this paper we present results of an atomistic simulation of dislocation-SFT interactions using molecular dynamics (MD). The MD simulations modeled an edge dislocation interacting with SFTs with different sizes and at different temperatures and strain rates. The results are compared with observations from in-situ deformation experiments in which several interactions between moving dislocations and SFTs were observed. It is demonstrated that in some cases the simulations and experimental observations are quite similar, suggesting a reasonable interpretation of experimental observations. Other cases, when modelling does not reproduce experimental observations, are also discussed and the importance of strain rate, dislocation nature and specimen surface effect are indicated.

Under neutron irradiation, primary defect clusters of both self-interstitial atom (SIA) and vacancy type are directly produced in displacement cascades, which have been confirmed by experiments as well as molecular dynamics simulations. The highly mobile SIA clusters play a crucial role in the development of characteristic microstructures, such as rafts of SIA clusters and dislocation decoration, and the corresponding radiation hardening behavior [1]. We have developed a new approach to KMC simulations to investigate the segregation and accumulation of point defects at the atomic scale with incorporating the elastic interaction between defect clusters and microstructures by using the elastic representation of point defects due to Kröner [2]. The decoration of dislocations by SIA clusters and the formation of rafts in bcc-iron are modeled in detail, and the general