CONTENTS

Vanadium alloys were irradiated in Li-bonded stainless steel capsules to ≈4 dpa at ≈390°C in the EBR-II X-530 experiment. This report presents results of postirradiation tests of tensile properties of two large-scale (100 and 500 kg) heats of V-4Cr-Ti and laboratory (15-30 kg) heats of boron-doped V-4Cr-4Ti, V-8Cr-6Ti, V-5Ti, and V-3Ti-1Si alloys. Tensile specimens, divided into two groups, were irradiated in two different capsules under nominally similar conditions. The 500-kg heat (#832665) and the 100-kg heat (VX-8) of V-4Cr-4Ti irradiated in one of the subcapsules exhibited complete loss of work-hardening capability, which was manifested by very low uniform plastic strain. In contrast, the 100-kg heat of V-4Cr-4Ti irradiated in another subcapsule exhibited good tensile properties (uniform plastic strain 2.8-4.0%). A laboratory heat of V-3Ti-1Si irradiated in the latter subcapsule also exhibited good tensile properties. These results indicate that work-hardening capability at low irradiation temperatures varies significantly from heat to heat and is influenced by nominally small differences in irradiation conditions.

Tensile properties of V-4Cr-4Ti (Heat BL-47), 3Ti-1Si (BL-45), and V-5Ti (BL-46) alloys after irradiation in a conventional irradiation experiment and in the Dynamic Helium Charging Experiment (DHCE) were reported previously. This paper presents revised tensile properties of these alloys, with a focus on the effects of dynamically generated helium on ductility and work-hardening capability at <500°C. After conventional irradiation (negligible helium generation) at ≈427°C, a 30-kg heat of V-4Cr-4Ti (BL-47) exhibited very low uniform elongation, manifesting a strong susceptibility to loss of work-hardening capability. In contrast, a 15-kg heat of V-3Ti-1Si (BL-45) exhibited relatively high uniform elongation (≈4%) during conventional irradiation at ≈427°C, showing that the heat is resistant to loss of work-hardening capability.

Helium atoms produced at ≈430°C in dynamic helium charging irradiation seem to be conducive to higher ductility (compared to that under conventional irradiation) and relatively lower yield strength. This seemingly beneficial effect of helium is believed to be important in evaluating the performance of V-4Cr-4Ti and V-3Ti Si alloys, because susceptibility to loss of work-hardening capability at low temperatures under fusion-relevant helium-generating conditions is considered to be a major factor in governing the minimum operating temperature for fusion applications. In this respect, V-3Ti-1Si appears to be more advantageous than V-4Cr-4Ti, although other factors such as creep strength could be inferior. Tensile data from conventional irradiation experiments (i.e., negligible helium generation), especially the data for <500°C, appear to differ significantly from the results obtained with simultaneous helium generated by the DHCE. Therefore, a dynamic helium charging irradiation experiment is strongly recommended with a focus on determining tensile and fracture properties of V-4Cr-4Ti and V-3Ti-1Si alloys at 300-470°C at doses of 10-20 dpa with high helium/dpa rations of ≈4-5 appm He/dpa.

Vanadium alloys were irradiated in a helium environment to ≈10 dpa at ≈200°C in the High Flux Isotope Reactor (HFIR). This report presents results of postirradiation tests of tensile properties of laboratory heats of (V-(1-18)Ti, V-4Cr-4Ti, V-8Cr-6Ti, V-9Cr-5Ti, V-3Ti-1Si, and V-3Ti-0.1C alloys. Because of significant loss of work-hardening capability, all alloys except V-18Ti exhibited a very low uniform plastic strain of <1%. For V-Ti alloys, work-hardening capability increased with Ti content ≥10%, e.g., uniform strain of ≈2.4% for V-18Ti. The mechanism of the loss of work-hardening capability in the other alloys is not understood.

Recent attention to vanadium alloys has focused on significant susceptibility to loss of work-hardening capability in irradiation experiments at <430°C. An evaluation of this phenomenon was conducted on V-Ti, V-Cr-Ti, and V-Ti-Si alloys irradiated in several conventional and helium-charging irradiation experiments in the FFTF-MOTA, HFIR, and EBR-II. Work-hardening capability and uniform tensile elongation appear to vary strongly from alloy to alloy and heat to heat. A strong heat-to-heat variation has been observed in V-4Cr-4Ti alloys tested, i.e., a 500-kg heat (#832665), a 100-kg heat (VX-8), and a 30-kg heat (BL-47). The significant differences in susceptibility to loss of work-hardening capability from one heat to another are estimated to correspond to a difference of ≈100°C or more in minimum allowable operating temperature (e.g., 450 versus 350°C).

Microstructural examination results are reported for two heats of V-(4-5%)Cr-(4-5%) Ti irradiated in the X530 experiment to ~4 dpa at ~400°C to provide an understanding of the microstructural evolution that may be associated with degradation of mechanical properties. Fine precipitates were observed in high density intermixed with small defect clusters for all conditions examined following the irradiation. The irradiation-induced precipitation does not appear to be affected by preirradiation heat treatment at 950-1125°C. There was no evidence for a significant density of large (diameter > 10 nm) dislocation loops or network dislocations.

A systematic study is being conducted to determine the effects of time, temperature, and exposure environment on the oxidation behavior and microstructure of V-Cr-Ti alloys. All samples were from 1-mm-thick cold-rolled sheets, and each was annealed in vacuum at 1050°C for 1 h prior to high-temperature exposure. Different samples from each alloy were heated in air and low-oxygen environments at temperatures between 400 and 650°C for times up to a few hundred hours. Some exposures were conducted in a thermogravimetric analysis (TGA) apparatus, in which continuous measurements of weight change were recorded.

A pack diffusion process was used to enrich surface regions of V-5 wt.% Cr-5 wt.% Ti alloy specimens with aluminum, which is a more stable oxide former than vanadium; also, the oxide has a much slower growth rate than that of vanadium

respectively. In the 316R, C, and K steels, the precipitates are also formed at grain boundaries, and the mean sizes are about 110, 50, and 50 nm, respectively. The number densities of cavities are about $1x10^{22}$ m^{-3} in all the steels. The swelling is low in the steels which form the precipitates.

The effective shear yield and maximum strengths of a set of neutron-irradiated, isotopically tailored austenitic alloys were evaluated using the shear punch test. The dependence on composition and neutron dose showed the same trends as were observed in the corresponding miniature tensile specimen study conducted earlier. A single tensile shear punch correlation was developed for the three alloys in which the maximum shear stress or Tresca criterion was successfully applied to predict the slope. The correlation will predict the tensile yield strength of the three different austenitic alloys tested to within ±53 MPa. The accuracy of the correlation improves with increasing material strength, to within ±43 MPa for predicting tensile yield strengths in the range of 400 to 800 MPa.

Twenty one scientists attended an IEA workshop in Cincinnati, Ohio on May 8-9, 1997, which was mainly devoted to reviewing the current knowledge base on the phenomenon of radiation induced electrical degradation in ceramic insulators. Whereas convincing evidence for bulk RIED behavior has been observed by two research groups in sapphire after electron irradiation, definitive levels of bulk RIED have not been observed in high purity Al_2O_3 by several research groups during energetic ion or fission neutron irradiation. Possible reasons for the conflicting RIED results obtained by different research groups were discussed. It was concluded that RIED does not appear to be of immediate concern for near-term fusion devices such as ITER. However, continued research on the RIED phenomenon with particular emphasis on electron irradiations of single crystal alumina was recommended in order to determine the underlying physical mechanisms. This will allow a better determination of whether RIED might occur under any of the widely varying experimental conditions in a fusion energy device. Several critical issues which are recommended for future study were outlined by the workshop attendees.

The current vs. applied voltage data generated from the HFIR TRIST-ER1 experiment have been analyzed to determine the electrical conductivity of the 15 aluminum oxide specimens and the MgO-insulated electrical cables as a function of irradiation dose. With the exception of the 0.05%Cr-doped sapphire (ruby) specimen, the electrical conductivity of the alumina specimens remained at the expected radiation induced conductivity (RIC) level of $<10^{-6}$ S/m during full-power