CONTENTS

conditions, exhibited a high level of resistance to cleavage failure with a DBTT at ~190°C. The alloys containing higher concentrations of Cr and Ti, in a fully recrystallized condition, exhibited a DBTT around -100°C, whereas the V-3Cr-3Ti alloy failed by pure ductile shear at liquid nitrogen temperature without any ductile-to-brittle transition. Tensile testing was conducted on SS-3 tensile specimens punched from 0.762-mm-thick plates of V-3Cr-3Ti and V-6Cr-6Ti. The tests were done in air at room temperature at strain rates ranging from 10^{-3} to 2×10^{-1}/s. For V-6Cr-6Ti, both the 0.2% yield stress (YS) and the ultimate tensile strength (UTS) were higher than those for V-3Cr-3Ti at all strain rates. Both YS and UTS showed a similar trend of incremental increase with strain rate for the two alloys. In the same token, both alloys exhibited an identical behavior of almost no change in uniform and total elongation up to a strain rate of 10^{-1}/s and a decrease with further increase in strain rate.

J-R curves were generated using the single specimen unload-compliance technique on four specimens of V-4Cr-4Ti to determine the effect of specimen dimensions on the fracture behavior. Ductile crack initiation and growth was observed in the 6.35 mm thick specimens but not in the 12.70 mm thick specimens. The J-R curves determined from these tests were not valid per ASTM validity criteria so quantitative measures of the resistance to ductile crack initiation and growth were not obtained. These data suggest that standard fracture toughness tests performed with small-scale DCT specimens may also not be valid.

Oxidation studies were conducted on V-5Cr-5Ti alloy specimens in an air environment to evaluate the oxygen uptake behavior of the alloy as a function of temperature and exposure time. The oxidation rates calculated from parabolic kinetic measurements of thermogravimetric testing and confirmed by microscopic analyses of cross sections of exposed specimens were 5, 17, and 27 µm per year after exposure at 300, 400, and 500°C, respectively. Uniaxial tensile tests were conducted at room temperature and at 500°C on preoxidized specimens of the alloy to examine the effects of oxidation and oxygen migration on tensile strength and ductility. Microstructural characteristics of several of the tested specimens were determined by electron optics techniques. Correlations were developed between tensile strength and ductility of the oxidized alloy and microstructural characteristics such as oxide thickness, depth of hardened layer, depth of intergranular fracture zone, and transverse crack length.

Oxidation studies of V-4Cr-4Ti were conducted in air and reduced oxygen partial pressures (10^{-4}, 10^{-5}, and 10^{-6} torr). Reaction rates were determined by weight change measurements and chemical analyses. Mechanical properties after the exposures were determined by room temperature tensile tests.

In air at 400 and 500°C, oxide films form on the surface. Initially, rates are high but decrease with time reaching similar values to those found in oxygen partial pressures at 10^{-4}, 10^{-5}, and 10^{-6} torr. At 400°C, oxygen pick-up followed a logarithmic function of time and was confined to regions near the surface. Little change in room temperature tensile properties was noted for oxygen increases up to 1500 ppm. Thermal cycling specimens from 400°C to room temperature up to 14 times had no apparent effect on oxidation rate or tensile properties. At 500°C, oxygen pick-up appeared to follow a parabolic relation with time. Rates were ~10 times those at 400°C and correspondingly larger oxygen increases occurred when compared with the 400°C tests after similar time periods. This resulted in a significant decrease in total elongation after 240 h.

At reduced oxygen partial pressures, rates were measured for times ≤100 h. Data are relatively sparse but generally show a slightly higher initial rate before slowing down. At 400°C increases to ~200 ppm oxygen were found with no effect on room temperature elongation. At 500°C increases in oxygen of ~2400 ppm after 50 h/10^{-5} torr resulted in a decrease of around 25% in room temperature elongation. By comparison, exposure to air at 500°C for 12 h caused nearly the same results.

The solubility of hydrogen in V-4Cr-4Ti and liquid lithium was determined at 400-675°C and a hydrogen pressure of 1.76×10^{-4} torr (2.35×10^{-2} Pa). Hydrogen concentration in both materials decreased as temperature increased, and the ratio of the hydrogen concentration in liquid lithium and V-4Cr-4Ti (hydrogen distribution ratio R) increased with temperature, e.g., R was ≈17 at 400°C and ≈80 at 700°C. Desorption of hydrogen from V-4Cr-4Ti is a thermally activated process and the activation energy of the desorption rate is 0.405 eV.

Evaluation of hydrogen sources and transport are needed to assess the mechanical integrity of V structures. Two sources include implantation and transmutation. The proposed coatings for the DEMO and ITER first wall strongly influence retention of hydrogen isotopes. Upper limit calculations of hydrogen inventory were based on recycling to the plasma and an impermeable coolant-side coating. Hydrogen isotope concentrations in V approaching 1,000 appm may be achieved.

Corrosion tests of nonalloyed V, V-5Cr-5Ti, and V-15Cr-5Ti were conducted in high-purity deoxygenated water at 230°C for up to ≈4500 h. The effects of Cr concentration in the alloy and temperature on the corrosion behavior were determined from weight-change measurements and microstructural observations. An expression was obtained for the kinetics of corrosion as a function of Cr content of the alloy and temperature.

The objective of this study is to develop (a) stable CaO insulator coatings at the Liquid-Li/structural-material interface, with emphasis on electrically insulating coatings that prevent adverse MHD-generated currents from passing through the V-alloy wall, and (b) stable Be-V intermetallic coatings for first-wall components that face the plasma. Electrically insulating and corrosion-resistant coatings are required at the liquid-Li/structural interface in fusion first-wall/blanket applications. The electrical resistance of CaO coatings produced on oxygen-enriched surface layers of V-5%Cr-5%Ti by exposing the alloy to liquid Li that contained 0.5-85 wt.% dissolved Ca was measured as a function of time at temperatures between 250 and 600°C. Crack-free Be_2V intermetallic coatings were also produced by exposing V-alloys to liquid Li that contained Be as a solute. These techniques can be applied to various shapes (e.g., inside/outside of tubes, complex geometrical shapes) because the coatings are formed by liquid-phase reactions.

In the Dynamic Helium Charging Experiment (DHCE), helium was produced uniformly in the specimen at linear rates of ≈0.4 to 4.2 appm He/dpa by the decay of tritium during irradiation to 18-31 dpa at 424-600°C in the lithium-filled DHCE capsules in the Fast Flux Test Facility. This report presents results of postirradiation tests of tensile properties of V-5Ti, V-4Cr-4Ti, V-3Ti-1Si. The effect of helium on tensile strength and ductility was insignificant after irradiation and testing at >420°C. Contrary to initial expectation, room-temperature ductility of DHCE specimens was higher than that of non-DHCE specimens, whereas strength was lower, indicating that different types of hardening centers are produced during DHCE and non-DHCE irradiation. In strong contrast to results of tritium-trick experiments, in which dense coalescence of helium bubbles is produced on grain boundaries in the absence of displacement damage, no intergranular fracture was observed in any tensile specimens irradiated in the DHCE.

Combined effects of dynamically charged helium and neutron damage on density decrease (swelling) of V-4Cr-4Ti, V-5Ti, V-3Ti-1Si, and V-8Cr-6Ti alloys have been determined after irradiation to 18-31 dpa at 425-600°C in the Dynamic Helium Charging Experiment (DHCE). To ensure better accuracy in density measurement, broken pieces of tensile specimens ≈10 times heavier than a transmission electron microscopy (TEM) disk were used. Density decreases of the four alloys irradiated in the DHCE were <0.5%. This small change seems to be consistent with the negligible number density of microcavities characterized by TEM. Most of the dynamically produced helium atoms seem to have been trapped in the grain matrix without significant cavity nucleation or growth.

The results of a transmission electron microscopy (TEM) investigation of the microstructural evolution of V-4Cr-4Ti (Heat #832665) that was irradiated with 4.5 MeV $^{58}Ni^{++}$ ions at 200°C are presented. Dose effects were investigated for fluences ranging from 0.5 to 5 dpa. When the irradiation dose was increased, the relative number density of black dots and dislocation loops was nearly constant and accompanied by an increase in the size of the defects. Cavity formation was not observed in any of the specimens, indicating high resistance of the alloy to void swelling at the lower temperature of the experiments.

Extended abstract.

Extended abstract.

The room temperature fatigue performance of F82H has been examined. The fatigue life was determined in a series of strain-controlled tests where the stress level was monitored as a function of the number of accrued cycles. Fatigue lives in the range of 10^3 to 10^6 cycles to failure were examined. The fatigue performance was found to be controlled primarily by the elastic strain range over most of the range of fatigue lives examined. Only at low fatigue lives did the plastic strain range contribute to the response. However, when the significant plastic strain did contribute, the material showed a tendency to cyclically soften. That is, the load carrying capability of the material degrades with accumulated fatigue cycles. The overall fatigue performance of the F82H alloy was found to be similar to other advanced martensitic steels, but lower than more common low alloy steels which possess lower yield strengths.

Extended abstract.

Miniature specimens of six low activation ferritic alloys have been impact tested following irradiation at 370°C to 30 dpa. Comparison of the results with those of control specimens and specimens irradiated to 10 dpa indicates that degradation in the impact behavior appears to have saturated by ~10 dpa in at least four of these alloys. The 7.5Cr-2W alloy referred to as GA3X appears most promising for further consideration as a candidate structural material in fusion reactor applications, although the 9Cr-1V alloy may also warrant further investigation.

Extended abstract.

Extended abstract.

Seven ODS steels, Fe-(5-13.5)Cr-2W-0.5Ti-0.25 Y_2O_3 (in weight percent) were manufactured using the mechanical alloying process. Only the composition Fe-13.5Cr2W-0.5Ti-0.25Y2O3 showed no austenite formation at any temperature using differential thermal analysis and hence was selected as an experimental alloy for the present investigation. Milled powders were consolidated by hot isostatic pressing and hot swaging. Electron microscopy studies indicated high material homogeneity. The hardness of the as-swaged specimen was 65 R_c. Annealing of the as-swaged material at 800, 900, 1000, 1100, and 1200°C showed a minor decrease in the hardness.

Both the fusion and light water reactor program require the use of subsize specimens to obtain sufficient irradiation data on neutron-induced embrittlement of ferritic steels. While the development of fusion-relevant size effects correlations can proceed analytically, it is more cost-effective at this time to use data currently being obtained on embrittlement of pressure vessel steels to test and expand the correlations developed earlier using fusion-relevant steels.

Dynamic finite element modeling of the fracture behavior of fatigue-precracked Charpy specimens was performed to determine the effect of single variable changes in ligament size, width, span, and thickness on the upper shelf energy. A method based on tensile fracture-strain was used for modeling crack initiation and propagation. It was found that the upper shelf energy of precracked specimens (USE_p) is proportional to b^n, where b is ligament size and n varies from about 1.6 for subsize to 1.9 for full size specimens. The USE_p was found to be proportional to width according to W^{25}. The dependence on thickness was found to be linear for all cases studied. Some of the data from the FEM analysis were compared with experimental data and were found to be in reasonable agreement.

Specimen fabrication is underway for an irradiation screening experiment planned to start in January 1996 in the SM-2 reactor in Dimitrovgrad, Russia. The purpose of the experiment is to evaluate the effects of neutron irradiation at ITER-relevant temperatures on the bond integrity and performance of Cu/SS and Be/Cu joints, as well as to further investigate the base metal properties of irradiated copper alloys. Specimens from each of the four ITER parties (U.S., EU, Japan, and RF) will be irradiated to a dose of ~0.2 dpa at two different temperatures, 150 and 300°C. The specimens will consist of Cu/SS and Be/Cu joints in several different geometries, as well as a large number of specimens from the base materials. Fracture toughness data on base metal and Cu/SS bonded specimens will be obtained from specimens supplied by the U.S. Due to a lack of material, the Be/Cu specimens supplied by the U.S. will only be irradiated as TEM disks.

Postirradiation electrical resistivity and tensile measurements have been completed on pure copper and copper alloy sheet tensile specimens irradiated in the SM-2 reactor to doses of ~0.5 to 5 dpa and temperatures between ~80 and 400°C. Considerable radiation hardening and accompanying embrittlement was observed in all of the specimens at irradiation temperatures below 200°C. The radiation-induced electrical conductivity degradation consisted of two main components: solid transmutation effects and radiation damage (defect cluster and particle dissolution) effects. The radiation damage component was nearly

Computer modeling and experimental benchtop tests have demonstrated that a capacitively loaded resonant coaxial cavity can produce accurate in-situ measurements of the loss tangent and dielectric constant of ceramic insulators at a frequency of ~80 MHz during fission reactor irradiation. The start of the reactor irradiations has been postponed indefinitely due to budgetary constraints.

A collaborative DOE/Monbusho series of irradiation experiments is being implemented to determine, in-situ, the effects of irradiation on the electrical resistivity of ceramic materials. The first experiment, TRIST-ER1, has been designed to irradiate 15 Al_2O_3 test specimens at 450°C in an RB* position of the High Flux Isotope Reactor (HFIR). Each test specimen is located in a sealed vanadium subcapsule with instrumentation provided to each subcapsule to measure temperature and resistance, and to place a biasing voltage across the specimen. Twelve of the specimens will be biased with 200 V/mm across the sample at all times, while three will not be biased, but can be if so desired during the irradiation. The experiment design, component fabrication, and subcapsule assembly have been completed. A three cycle irradiation, to a fast neutron (E>0.1 MeV) fluence of about 3×10^{25} n/m^2 (~3 dpa in Al_2O_3), is expected to begin early in March 1996.

An experimental investigation of radiation induced electrical degradation (RIED) has been performed at the High Flux Beam Reactor (HFBR) at Brookhaven National Laboratory. In this study (the third in a series of experiments at the HFBR) the effects of neutron irradiation on the electrical conductivity of Wesgo AL995 polycrystalline alumina has been investigated at approximately 450°C. The capsule design used in this study is very similar to a design used in the first two experiments in this series with some improvements made in the cable terminations. A guard ring configuration was used on the disk shaped sample. Triaxial mineral insulated cable was used as the data lead from the sputter deposited guard ring and central electrode of the sample, and coaxial mineral insulated cable was used as the sample power lead. No evidence for RIED was observed in this series of experiments to a dose level of ~1.8 dpa. The effect of neutron irradiation on the electrical properties of two mineral insulated (MgO) cables was also investigated.

A brief summary is given of research on radiation effects in ceramic insulators for fusion energy applications performed during the last two years in Europe, Canada, Japan, the Russian Federation, the Ukraine and the United States. The IEA round-robin radiation-induced electrical degradation (RIED) experiment on Wesgo AL995 polycrystalline alumina has been completed by 5 research groups, with none of the groups observing clear indications of RIED.

Radioluminescence (RL) from virgin and neutron-irradiated (10^{23} n-m^{-2}) silica fibers has been measured in the temperature interval 4 to 300 K. Unirradiated specimens exhibit a *decrease* in RL intensity with increasing temperature such that the intensity is extremely weak at room temperature. The luminescence is well described by a barrier-limited exciton mechanism. In contrast, the heavily-irradiated samples show an *increase* in RL with elevated temperatures such that the intensity at room temperature is about twice that measured at 4 K. Neutron irradiation presumably produces many luminescence centers that act as radiative sites for exciton decay. Absolute specular reflectance of a series of neutron-irradiated, layered dielectric mirrors was also measured. In addition to structural damage that has already been reported, we typically found approximately 10% reduction in the reflectance following irradiation. These results suggest that neither fibers nor dielectric mirrors are well suited for use near the high radiation area of the ITER plasma.

No contributions.

The U.S./Japan Workshop on Theory and Modeling of Radiation Effects in Materials for Fusion Energy Systems, under Phase III of the DOE/Monbusho collaboration, convened on July 17-18, 1995, at Lawrence Livermore National Laboratory. A brief summary of the workshop is followed by the workshop program.

Extended abstract.

The stochastic annealing simulation code ALSOME is used to investigate quantitatively the differential production of mobile vacancy and SIA defects as a function of temperature for isolated 25 KeV cascades in copper generated by MD simulations. The ALSOME code and cascade annealing simulations are described. The annealing simulations indicate that above Stage V, where the cascade vacancy clusters are unstable, nearly 80% of the post-quench vacancies escape the cascade volume, while about half of the post-quench SIAs remain in clusters. The results are sensitive to the relative fractions of SIAs that occur in small, highly mobile clusters and large stable clusters, respectively, which may be dependent on the cascade energy.

Neutron fluence measurements and radiation damage calculations are reported for the joint U.S./Japanese experiments JP-10, 11, 13, and 16 in the target of the High Flux Isotope

To study the mechanical properties of vanadium alloys under neutron irradiation at low temperatures, an experiment was designed and constructed for irradiation in the Advanced Test Reactor (ATR). The experiment contained Charpy, tensile, compact tension, TEM, and creep specimens of vanadium alloys. It also contained limited low-activation ferritic steel specimens as part of the collaborative agreement with Monbusho of Japan. The design irradiation temperatures for the vanadium alloy specimens in the experiment are ≈200 and 300°C, achieved with passive gas-gap sizing and fill-gas blending. To mitigate vanadium-to-chromium transmutation from the thermal neutron flux, the test specimens are contained inside gadolinium flux filters. All specimens are lithium-bonded. The irradiation started in Cycle 108A (December 3, 1995) and is expected to have a duration of three ATR cycles and a peak fluence of 4.5 dpa.

Capsules containing vanadium alloy specimens from irradiation experiments in FFTF and EBR-II are being processed to remove the lithium bond and retrieve the specimens for testing. The work has progressed smoothly.

A computer program has been rewritten in DOS Basic allowing current state-of-the-art computer equipment to be used for quantitative measurement of microstructural features such as voids, dislocations, and precipitates.

A new, improved passive irradiation temperature monitoring method was examined after an irradiation test at 627°C. The method is based on the analysis of the thermal diffusivity changes during postirradiation annealing of polycrystalline SiC. Based on the results from this test, several advantages for using this new method rather than a method based on length or lattice parameter changes are given.