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temperatures of -196°C and 50°C. The dynamic finite element analyses were conducted using ABAQUS/Explicit v5.4. The finite element results were compared to experimental results for the production-scale heat of V-4Cr-4Ti (ANL Heat #832665) as a benchmark. Agreement between the finite element model and experimental data was very good at -196°C, whereas at 50°C the model predicted a slightly lower absorbed energy than actually measured.

The mode I and mixed-mode I/III fracture behavior of the production-scale heat (#832665) of V-4Cr-4Ti has been investigated at 25°C using compact tension (CT) specimens for a mode I crack and modified CT specimens for a mixed-mode I/III crack. The mode III to mode I load ratio was 0.47. Test specimens were vacuum annealed at 1000°C for 1 h after final machining. Both mode I and mixed-mode I/III specimens were fatigue cracked prior to J-integral testing. It was noticed that the mixed-mode I/III crack angle decreased from an initial 25 degrees to approximately 23 degrees due to crack plane rotation during fatigue cracking. No crack plane rotation occurred in the mode I specimen. The crack initiation and propagation behavior was evaluated by generating J-R curves. Due to the high ductility of this alloy and the limited specimen thickness (6.35 mm), plane strain requirements were not met so valid critical J-integral values were not obtained. However, it was found that the crack initiation and propagation behavior was significantly different between the mode I and the mixed-mode I/III specimens. In the mode I specimen crack initiation did not occur, only extensive crack tip blunting due to plastic deformation. During J-integral testing the mixed-mode crack rotated to an increased crack angle (in contrast to fatigue precracking) by crack blunting. When the crack initiated, the crack angle was about 30 degrees. After crack initiation the crack plane remained at 30 degrees until the test was completed. Mixed-mode crack initiation was difficult, but propagation was easy. The fracture surface of the mixed-mode specimen was characterized by microvoid coalescence.

Two fatigue precracked compact tension (CT) specimens of V-4Cr-4Ti were statically loaded to a stress intensity factor of about 30 MPa$\sqrt{m}$ in room temperature DIII-D water. The first specimen was tested for a period of about 30 days and the second specimen for about 54 days. At the conclusion of each test the specimens were fractured, and the fracture surfaces examined with a scanning electron microscope (SEM) to determine if SCC had occurred. No SCC was found in either test specimen.

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. 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 tranverse crack length.

A test program is in progress to evaluate the effect of oxygen at low pO_2 on the tensile properties of V-(4-5)wt.% Cr-(4-5)wt.% Ti alloys. Some of the tensile specimens were precharged with oxygen at low pO_2 at 500°C and reannealed in vacuum at 500°C prior to tensile testing. In another series of tests, specimens were exposed for 250-275 h at 500°C in environments with various pO_2 levels and subsequently tensile tested at room temperature. The preliminary results indicate that both approaches are appropriate for evaluating the effect of oxygen uptake on the tensile properties of the alloys. The data showed that in the relatively short-time tests conducted thus far, the maximum engineering stress slightly increased after oxygen exposure but the uniform and total elongation values exhibited significant decrease after exposure in oxygen-containing environments. The data for a specimen exposed to a helium environment were similar to those obtained in low pO_2 environments.

Hydrogen solubility in V-4Cr-4Ti and liquid lithium-calcium was measured at a hydrogen pressure of 9.09×10^{-4} torr at temperatures between 250 and 700°C. Hydrogen solubility in V-4Cr-4Ti and liquid lithium decreased with temperature. The measured desorption rate of hydrogen in V-4Cr-4Ti is a thermally activated process; the activation energy is 0.067 eV. Oxygen-charged V-4Cr-4Ti specimens were also investigated to determine the effect of oxygen impurity on hydrogen solubility and desorption in the alloy. Oxygen in V-4Cr-4Ti increases hydrogen solubility and desorption kinetics. To determine the effect of a calcium oxide insulator coating on V-4Cr-4Ti, hydrogen solubility in lithium-calcium alloys that contained 0-8.0 percent calcium was also measured. The distribution ratio R of hydrogen between liquid lithium or lithium-calcium and V-4Cr-4Ti increased as temperature decreased ($R \approx 10$ and 100 at 70 and 250°C, respectively). However at <267°C, solubility data could not be obtained by this method because of the slow kinetics of hydrogen permeation through the vanadium alloy.

Previous CaO coatings on V-4%Cr-4%Ti exhibited high-ohmic insulator behavior even though a small amount of vanadium from the alloy was incorporated in the coating. However, when the vanadium concentration in the coating is >15 wt.%, the coating becomes conductive. When the vanadium concentration is high in localized areas, a calcium vanadate phase that exhibits semiconductor behavior can form. To explore this situation, CaO and Ca-V-O coatings were produced on vanadium alloys by chemical vapor deposition (CVD) and by a metallic-vapor process to investigate the electrical resistance of the coatings. Initially, the vanadium alloy specimens were either charged with oxygen in argon that contained trace levels of oxygen, or oxidized for 1.5-3 h in a 1% $CO-CO_2$ gas mixture or in air to form vanadium oxide at 625-650°C. Most of the specimens were exposed to calcium vapor at 800-850°C. Initial and final weights were obtained to monitor each step. and surveillance samples were removed for examination by optical and scanning electron microscopy and electron-energy-dispersive and X-ray diffraction analysis; the electrical resistivity was also measured. We found that Ca-V-O films exhibited insulator behavior when the ratio of calcium concentration to vanadium concentration R in the film was >0.9, and semiconductor or conductor behavior for R<0.8. However, in some cases,

Mode I and mixed-mode I/III fracture toughness tests were performed for the IEA heat of the reduced activation ferritic/martensitic stainless steel F82H at ambient temperature in order to provide comparison with previous measurements on a small heat given a different heat treatment. The results showed that heat to heat variations and heat treatment had negligible consequences on Mode I fracture toughness, but behavior during mixed-mode testing showed unexpected instabilities.

An International Energy Agency (IEA) Working Group on Ferritic/Martensitic Steels for Fusion Applications, consisting of researchers from Japan, the European Union, the United States, and Switzerland, met at the headquarters of the Joint European Torus (JET), Culham, United Kingdom, 24-25 October 1996. At the meeting, preliminary data generated on the large heats of steel purchased for the IEA program and on other heats of steels were presented and discussed. The second purpose of the meeting was to continue planning and coordinating the collaborative test program in progress on reduced-activation ferritic/martensitic steels. The next meeting will be held in conjunction with the International Conference on Fusion Reactor Materials (ICFRM-8) in Sendai, Japan, 23-31 October 1997.

Miniature CVN specimens of four ferritic alloys, GA3X, F82H, GA4X, and HT9, have been impact tested following irradiation at 430°C to 67 dpa. Comparison of the results with those of the previously tested lower dose irradiation condition indicates that the GA3X and F82H alloys, two primary candidate low activation alloys, exhibit virtually identical behavior following irradiation at 430°C to ~67 dpa and at 370°C to ~15 dpa. Very little shift is observed in either DBTT or USE relative to the unirradiated condition. The shifts in DBTT and USE observed in both GA4X and HT9 were smaller after irradiation at 430°C to ~67 dpa than after irradiation at 370°C at ~15 dpa.

The yield and maximum strengths of an irradiated series of isotopically tailored ferritic alloys were evaluated using the shear punch test. The composition of three of the alloys was Fe-12Cr-1.5Ni. Different balances of nickel isotopes were used in each alloy in order to produce different helium levels. A fourth alloy, which contained no nickel, was also irradiated. The additions of nickel at any isotopic balance to the Fe-12Cr base alloy significantly increased the shear yield and maximum strengths of the alloys, and as expected, the strength of the alloys decreased with increasing irradiation temperature. Helium itself, up to 75 appm over 7 dpa appears to have little effect on the mechanical properties of the alloys.

Extended abstract.

The unirradiated tensile properties of wrought GlidCop AL25 (ITER grade zero, IG0), solutionized and aged CuCrZr, and cold-worked and aged and solutionized and aged Hycon 3HP™ CuNiBe have been measured over the temperature range of 20-500°C at strain rates between $4 \times 10^{-4}\ s^{-1}$ and $0.06\ s^{-1}$. The measured room temperature electrical conductivity ranged from 64 to 90% IACS for the different alloys. All of the alloys were relatively insensitive to strain rate at room temperature, but the strain rate sensitivity of GlidCop Al25 increased significantly with increasing temperature. The CuNiBe alloys exhibited the best combination of high strength and high conductivity at room temperature. The strength of CuNiBe decreased slowly with increasing temperature. However, the ductility of CuNiBe decreased rapidly with increasing temperature due to localized deformation near grain boundaries, making these alloy heats unsuitable for typical structural applications above 300°C. The strength and uniform elongation of GlidCop Al25 decreased significantly with increasing temperature at a strain rate of $1 \times 10^{-3}\ s^{-1}$, whereas the total elongation was independent of test temperature. The strength and ductility of CuCrZr decreased slowly with increasing temperature.

Oxide-dispersion strengthened copper alloys and a precipitation-hardened copper-nickel-beryllium alloy showed a significant reduction in toughness at elevated temperatures (250°C). This decrease in toughness was much larger than would be expected from the relatively modest changes in the tensile properties over the same temperature range. However, a copper-chromium-zirconium alloy strengthened by precipitation showed only a small decrease in toughness at the higher temperatures. The embrittled alloys showed a transition in fracture mode, from transgranular microvoid coalescence at room temperature to intergranular with localized ductility at high temperatures. The Cu-Cr-Zr alloy maintained the ductile microvoid coalescence failure mode at all test temperatures.

Tensile specimens of CuCrZr and CuNiBe alloys were given various heat treatments corresponding to solution anneal, prime-aging and bonding thermal treatment with additional specimens re-aged and given a reactor bakeout treatment at 350°C for 100 h. CuAl-25 was also heat treated to simulate the effects of a bonding thermal cycle on the material. A number of heat treated specimens were neutron irradiated at 250°C to a dose level of ~0.3 dpa in the DR-3 reactor at Risø.

The main effect of the bonding thermal cycle heat treatment was a slight decrease in strength of CuCrZr and CuNiBe alloys. The strength of CuAl-25, on the other hand, remained almost unaltered. The post irradiation tests at 250°C showed a severe loss of ductility in the case of the CuNiBe alloy. The irradiated CuAl-25 and CuCrZr specimens exhibited a reasonable amount of uniform elongation, with CuCrZr possessing a lower strength.

Significant progress has been made during the last year in the post-irradiation examinations (PIE) of the specimens from nine DOE ORNL/JAERI collaborative capsules and in the design and fabrication of four additional capsules. JP21, JP22, CTR-62, and CTR-63 were disassembled, JP20 tensile specimens were tested, and a variety of specimens from the RB-60J-1, 200J-1, 330J-1, and 400J-1 capsules were tested. Fabrication of RB-11J and 12J was completed and progress made in the matrix finalization and design of RB-10J and JP25.

The ATR-A1 irradiation experiment in the Advanced Test Reactor (ATR) was a collaborative U.S./Japan effort to study at low temperature the effects of neutron damage on vanadium alloys. The experiment also contained a limited quantity of low-activation ferritic steel specimens from Japan as part of the collaboration agreement. The irradiation was completed on May 5, 1996, as planned, after achieving an estimated neutron damage of 4.7 dpa in vanadium. The capsule has since been kept in the ATR water canal for the required radioactivity cool-down. Planning is underway for disassembly of the capsule and test specimen retrieval.

A varying temperature irradiation experiment is being performed under the framework of the Japan-U.S. Program of Irradiation Tests for Fusion Research (JUPITER) to study the effects of temperature variation on the microstructure and mechanical properties of candidate fusion reactor structural materials. An irradiation capsule has been designed for operation in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) that will allow four sets of metallurgical test specimens to be irradiated to exposure levels ranging from 5 to 10 dpa. Two sets of specimens will be irradiated at constant temperatures of 500 and 350°C. Matching specimen sets will be irradiated to similar exposure levels, with 10% of the exposure to occur at reduced temperatures of 300 and 200°C.

A U.S./Russia (RF) collaborative irradiation experiment, Fusion-1, was completed in June 1996 after reaching a peak exposure of ≈17 dpa in the BOR-60 fast reactor at the Research Institute of Atomic Reactors (RIAR) in Russia. The specimens were vanadium alloys, mainly of recent heats from both countries. In this reporting period, the capsule was disassembled at the RIAR hot cells and all test specimens were successfully retrieved. For the disassembly, an innovative method of using a heated diffusion oil to melt and separate the lithium bond from the test specimens was adopted. This method proved highly successful.

The current status of reactor irradiation experiments is presented in tables summarizing the experimental objectives, conditions, and schedule.