DESCRIPTION AND STATUS OF THE U.S./JAERI HFIR-MFE-RB-10J IRRADIATION CAPSULE -- J. P. Robertson, K. E. Lenox, M. L. Grossbeck, and A. F. Rowcliffe (Oak Ridge National Laboratory), and S. Jitsukawa and K. Shiba (Japan Atomic Energy Research Institute)

SUMMARY

This report describes the HFIR-MFE-RB-10J experiment conducted under the U.S. DOE/Japan Atomic Energy Research Institute Collaborative Testing Program. The irradiation will take place in a Removable Beryllium (RB) position in the High Flux Isotope Reactor (HFIR) for approximately 8 cycles (about 4 dpa in steel). The experiment consists of two distinct parts: the upper region of the capsule will contain vanadium specimens operating at either 420 or 480°C and the lower region will contain austenitic and ferritic/martensitic steel specimens operating at 250°C. The capsule will be surrounded by a Eu_2O_3 shield in order to harden the spectrum and prevent unwanted transmutations.

PROGRESS AND STATUS

Introduction

This report describes the HFIR-MFE-RB-10J experiment conducted under the U.S. DOE/Japan Atomic Energy Research Institute Collaborative Testing Program. Specimens will be provided from both the U.S. and Japanese programs. The irradiation will take place in a Removable Beryllium (RB) position in the High Flux Isotope Reactor (HFIR) for approximately 8 cycles (about 4 dpa in steel). The experiment consists of two distinct parts: the upper region of the capsule will contain vanadium specimens and the lower region will contain austenitic and ferritic steel specimens. The dividing line between the two regions will be at the reactor centerline. The vanadium specimens in the upper region will be contained in two separate lithium-filled subcapsules; one subcapsule will operate at 420°C and the other will operate at 480°C. The steel specimens in the lower region will be contained in a single slotted holder similar to previous RB capsules in this program and will operate at 250°C. The capsule will be surrounded by a Eu_2O_3 shield in order to harden the spectrum and prevent unwanted transmutations.

Vanadium Alloy Experiment

Previous HFBR and EBR-II data have shown that radiation-hardening, loss of strain-hardening capacity, and a propensity for brittle cleavage fracture are characteristics of the V-4Cr-4Ti production heat following irradiation at 385°C and below. The diminished radiation hardening at 525°C suggests that fracture properties might improve rapidly over the range 400 to 500°C. The blunt-notch Charpy data generated to date indicate a significant increase in the DBTT of V-4Cr-4Ti in the hardening regime. A master curve-mechanism approach is proposed for modeling the effects of external parameters on the fracture toughness-temperature behavior of vanadium alloys [1]. This needs to be supported by information on the temperature and strain-rate dependence of radiation-hardening, dislocation/defect structure interactions, strain-hardening, and the micromechanics of crack initiation and propagation. Because of the favorable geometry of the RB-10J experiment, it is possible to accommodate a sufficient variety and number of mechanical property specimens to launch such a program. The existing V-4Cr-4Ti alloy, which has many advantageous unirradiated properties, provides a good material on which to base a study of flow and fracture and to establish a mechanism-based approach to modeling the effects of external parameters on fracture. The fundamental information gained and the modeling of the fracture behavior will provide a sound underpinning for future work on compositionally-modified alloys. In addition, there is sufficient space in the RB-10J to accommodate secondary objectives such as radiation hardening and microstructure of some alternative vanadium alloys and also to conduct additional pressurized tube experiments to complement those currently in RB-11J/12J.

Specimens will be irradiated at either 420 ± 15°C and 480 ± 15°C, which will yield specimens at two different degrees of radiation hardening and fracture resistance. To maximize availability of specimen volume and to simplify design, construction, and disassembly, two subcapsules will be stacked vertically with the higher temperature capsule nearer the center line. With this arrangement, these temperatures can be achieved with a Type 316 austenitic steel holder and a Type 316 housing tube; the interior of the capsule will be lined with vanadium to preclude solute pickup. Assuming a 50/50 volume ratio of lithium and specimens, the volume available for specimens is approximately 20 cm^3 at each temperature.

A proposed specimen distribution, based upon the technical objectives described, is shown in Table 1. Vanadium alloys in the form of miniature DC(T) fracture toughness specimens, pre-cracked bend bars (PCVN), flat SS-3 tensile specimens, transmission electron microscopy (TEM) disks, pressurized creep tube specimens, and sheet specimens are to be included.

Austenitic and Ferritic/Martensitic Steel Experiment

The primary technical objectives of the steel experiment are to derive the constitutive equations for 316LN, which is the structural material to be used in the International Thermonuclear Experimental Reactor (ITER), and for F82H, one of the most promising low activation ferritic/martensitic steels. SS-3 flat tensile specimens tested at various temperatures and strain rates will be used to derive the constitutive equations.

An operating temperature of 250°C was chosen because it is in the range where the microstructure of the 316LN alloy is changing from a low temperature regime dominated by small interstitial clusters (1-2 nm in diameter) to a high temperature regime dominated by Frank loops and small cavities. This transition is reflected in the temperature dependence of the tensile properties, where specimens irradiated 250-350°C undergo an especially large increase in yield strength, a severe decrease in uniform elongation, and a significant loss of strain hardening capacity. In addition, this irradiation temperature is one of vital interest to the ITER design team as 100-250°C represents the proposed ITER PW/SB operating temperature. It is important to understand the

Table 1. Proposed Test Matrix for the Vanadium Alloy Region (Each Temperature)

Specimen Type	Specimen Volume (cm^3)	V-4Cr-4Ti Fracture Experiment	Alloy/ Microstructure Variants	V-4Cr-4Ti Creep Experiment
DCT (12.5 mm dia)	0.56	4	—	—
PCVN	0.28	40	—	—
SS-3	0.06	30	40	—
TEM tube (100 disks ea.)	0.11	1.0	3	—
Creep tube	0.11	—	—	4
Mod. SS-3 tensile	0.08	6	—	—
Volume (cm^3)	—	15.8	2.4	0.4

microstructural and mechanical properties changes in this regime in order to ensure adequate safety margins in the ITER design and to protect against alternate failure modes.

A second goal of this experiment is to address the issues surrounding the loss of strain hardening capacity in austenitic stainless steels and to simultaneously gain fundamental understanding into the post-irradiation properties. The loss of strain hardening capability leads to strain localization and increased notch sensitivity. While most of the ITER PW/SB material will be well below any failure limit, a small region of highly localized strain may develop, especially near a notch or surface scratch. This onset of flow localization and increased notch sensitivity may result in the appearance of alternate failure modes. The possibility of these alternate modes needs to be explored experimentally because additional constraints may need to be placed on the primary membrane plus bending stress limit. Type SS-3 flat as well as notched strip (NS) tensile specimens, will be used to investigate the flow localization in 316LN. Some of the tensile specimens will have offset notches. Transmission electron microscopy (TEM) disks will also be included. The notched strip tensile specimens will be combined with numerical calculations to investigate typical structural discontinuities on deformation and fracture. A few thin strip tensile (TS) specimens (0.25 mm thick × 3 mm wide × 25.4 mm long) will be used to punch TEM disks from center after interim deformation to help characterize flow localization. In addition, miniature CVN specimens will be used in 3-point bending for elastic-plastic fracture toughness measurements.

The proposed matrix for this region of the capsule is given in Table 2.

<u>Capsule Description</u>

The experiment is designed using the idea of monitored double containment due to the presence of lithium. Thus, there are two containment vessels - the outer capsule and an inner containment vessel, and the pressures and temperatures within both containment vessels are monitored. Details of the containment capsules for the experiments are provided in the references [2, 3]; the strength requirements and ASME Pressure Vessel Code compliance are , also addressed in these documents. The irradiation capsule has a Type 316 stainless steel containment tube with a 38.2-mm outer diameter in the in-core region. The capsule does not contain a pressure relief device or rupture tube. The inner containment vessel is also Type 316 stainless steel. The containment design incorporates elements used in previous HFIR-MFE RB capsules. The irradiation capsule is designed for straight access into any of the eight 46-mm diameter reflector positions. The capsule will be surrounded by a Eu_2O_3 liner (with a wall thickness that varies from 1.9 to 4.2 mm due to the variation in flux as a function of distance from

Table 2. Proposed Test Matrix for the Steel Alloy Region

Specimen Type	Total Available	Primary Matrix		Secondary Matrix	
		316LN	JPCA	F82H	316LN (extra)
SS-3 flat tensile	94	30	12	30	22
3-point bend bars	21	21	...	...	...
Notched strip tensile	28	24	...	...	4
Thin strip tensile	6	6	...	...	...
TEM disks (65/packet)	1	25 disks	15 disks	10 disks	15 disks

the reactor centerline). The irradiation length (within the HFIR reflector) is 610 mm. There will be six aluminum flux monitors and twelve thermocouples in the capsule.

The vanadium specimens will be sealed within cylindrical Type 316 stainless steel subcapsules. Each subcapsule is approximately 1 inch in diameter. The presence of lithium is required for several reasons: it will be used to assess and understand the chemical compatibility and complex thermodynamics of lithium-vanadium systems; lithium will control the vanadium absorption of interstitial impurities such as carbon, nitrogen, and oxygen, which can embrittle the vanadium and affect post-irradiation testing results; and the liquid lithium is an excellent heat transfer medium and will help provide temperature uniformity in the specimen region. The two subcapsules will be stacked in a Type 316 stainless steel subcapsule holder in the upper section of the capsule. The subcapsule holder serves as the secondary containment vessel. An annular helium gap between each subcapsule and the subcapsule holder will be sized to obtain the different operating temperatures. The Type 316 subcapsule holder containing the two 316 stainless steel subcapsules is contained within the capsule outer housing tube. The housing tube, which serves as the primary reactor coolant pressure boundary, will be seamless 316 steel. The annular gap between the housing tube and subcapsule holder will be purged with a mixture of helium and neon gas to maintain temperature control. The outer surface of the housing tube is in contact with the reactor coolant.

The lower half of the experiment consists of austenitic and ferritic steel specimens placed into holes and slots cut into in an aluminum alloy block. This design duplicates that found in the RB-11J and -12J capsules. The steel specimens and aluminum alloy holder are inside of the capsule housing tube and directly below the subcapsule holder in the upper half of the experiment. The annular gap between the aluminum alloy holder and the housing tube is filled with the control gas mixture and is sized to produce the desired specimen temperature of 250°C.

The capsule will be irradiated in an RB position of HFIR. It is planned that it be in the reactor for eight (8) cycles and will achieve a peak of approximately 4 dpa in steel.

Three temperature regions are required: 250°C, 420°C, and 480°C. Twelve thermocouples placed throughout the experiment will be used to monitor the internal temperatures. The temperature will be controlled in the capsule by varying the composition of the gas flowing through an annulus surrounding the specimen regions in the capsule. The capsule is designed to require a 50% helium, 50% neon (by volume) gas mixture at the middle of cycle and 85 MW full power operation to maintain desired temperatures. The temperature is adjusted in response to the thermocouples by adjusting the gas mixture in the annulus around the specimen holder. Because helium has a higher thermal conductivity, enriching the mixture in this gas will reduce the temperature of specimens. Enriching in neon, with a lower conductivity, will increase the temperature of the specimens. Several factors make the temperature control in this capsule challenging. These include the use of a single control gas to maintain two different specimen temperatures and the variations of the gamma heating rate over each HFIR fuel cycle.

Status

The engineering drawings for the upper and lower regions are complete, as are those for the outer capsule components. Fabrication of components is in progress. The Eu_2O_3 shield is scheduled to be completed at the end of January 1998. Specimen fabrication is 95% complete and all records are being compiled into a central location. A lithium-fill station has been built and prototype testing is underway. High-purity lithium metal (99.9% Li-7) has been procured in order to mitigate the transmutations to tritium.

REFERENCES

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