SUMMARY OF THE U.S. SPECIMEN MATRIX FOR THE HFIR 13J VARYING TEMPERATURE IRRADIATION CAPSULE — S. J. Zinkle (Oak Ridge National Laboratory)

OBJECTIVE

The objective of this report is to summarize the U.S. portion of the specimen matrix for the DOE/Monbusho collaborative HFIR 13J varying temperature irradiation capsule.

SUMMARY

The U.S. specimen matrix for the collaborative DOE/Monbusho HFIR 13J varying temperature irradiation capsule contains two ceramics and 29 different metals, including vanadium alloys, ferritic/martensitic steels, pure iron, austenitic stainless steels, nickel alloys, and copper alloys. This experiment is designed to provide fundamental information on the effects of brief low-temperature excursions on the tensile properties and microstructural evolution of a wide range of materials irradiated at nominal temperatures of 350 and 500°C to a dose of ~5 dpa. A total of 340 miniature sheet tensile specimens and 274 TEM disks are included in the U.S.-supplied matrix for the irradiation capsule.

PROGRESS AND STATUS

Introduction

A series of recent neutron irradiation experiments [1-8] have demonstrated that low-temperature excursions at the beginning or during irradiation can have a pronounced effect on the microstructural evolution of face-centered cubic and body-centered cubic metals irradiated at doses up to ~0.2 displacements per atom (dpa). For example a swelling rate of ~10%/dpa was observed in Ti-modified austenitic stainless steel (Fe-16Cr-17Ni-0.25Ti) irradiated at cyclic temperatures of 200/400°C and 300/500°C to a dose of 0.13 dpa [7]. Since temperature transients are likely to occur in fusion reactors (and have routinely occurred in many of the fission reactor irradiation experiments used to establish the current radiation effects data base), there is a pressing need to understand the importance of variations in the irradiation temperature. Unfortunately, the pioneering varying temperature neutron irradiation experiments could not be carried out to doses above ~0.2 dpa due to flux limitations in the RTNS-II and JMTR facilities. Ion [9,10] and electron [11] irradiation experiments suggest that significant effects associated with low-temperature transients may continue to exist at somewhat higher doses of 0.3 to 2 dpa. In order to provide additional neutron irradiation data on this phenomenon at higher doses, the varying temperature experiment was designed to be carried out in the HFIR reactor as part of the DOE/Monbusho JUPITER collaboration.

Information on the capsule design for the HFIR 13J varying temperature experiment has been published in previous semiannual progress reports [12,13]. The capsule utilizes EuO_2-shielding to minimize solid transmutations associated with the high thermal neutron flux in HFIR removable beryllium (RB) position. The capsule consists of four independently controlled temperature zones which are designed for operation at 350, 500, 200/350, and 300/500°C. Electrical heaters are used to maintain a constant temperature during the reactor startup for the 350 and 500°C constant-temperature portions of the capsule. The varying temperature portions of the capsule are designed to operate at the lower temperature (200 and 300°C, respectively) during the first 10% of each reactor cycle. The irradiation will consist of a total of 10 HFIR irradiation cycles, which will produce a dose of ~5 dpa in vanadium alloys, ferritic/martensitic steels, and austenitic alloys and ~7 dpa in copper alloys. The HFIR 13J capsule will be installed in the reactor upon the completion of the HFIR 11J/12J EuO_2-shielded irradiation, which is currently expected to occur in June, 1998.

U.S. Specimen Matrix

A total of 29 different pure metals and alloys and 2 ceramic materials are included in the U.S.-supplied portion of the DOE/Monbusho HFIR 13J varying temperature irradiation capsule. These materials include vanadium alloys, ferritic/martensitic and austenitic steels, nickel alloys, and copper alloys. The U.S. materials were fabricated into miniature sheet tensile specimens and/or transmission electron microscopy (TEM) disks. The U.S. specimen matrix for the HFIR 13J irradiation capsule is summarized in Table 1, along with the researcher who supplied the specimens. The VX-8 heat of V-4Cr-4Ti was supplied to ORNL as thin strips by Dr. V.A. Kazakov, Scientific Research Institute of Atomic Reactors, Dimitrovgrad, Russia. Several of the copper alloys were supplied by Dr. B.N. Singh, Risø National Laboratory, Roskilde, Denmark. The type JP-TN-1 miniature sheet tensile specimens (identified as "SSJ" specimens in Table 1) used in HFIR 13J capsule have an overall length of 16 mm and a thickness of 0.25 mm, with an end tab width of 4 mm. The gage dimensions are 5 mm by 1.2 mm. The thickness of the 3 mm diameter TEM disks was 0.25 mm (± 0.01 mm) except for the Cu-Ni specimens (0.16-0.18 mm thick) and the A533B pressure vessel steel specimens which are intended for microhardness measurements (0.76 mm thick). The manufacturer's heat number (where available) and chemical composition of the various materials are listed in Table 2.

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Table 1. U.S. specimen matrix for the HFIR 13J capsule

Alloy	Number of specimens at each test condition			
	350°C	200/350°C	500°C	300/500°C
Vanadium alloys				
V-4Cr4Ti (832665)[a]	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM
V-4Cr4Ti (VX-8)[a]	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM
V-4Cr4Ti (VX-8)[a],25%CW	2 SSJ, 2 TEM	2 SSJ, 2 TEM	2 SSJ, 2 TEM	2 SSJ, 2 TEM
V-5Ti-5Ti (T87)[a]	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM
V-6Ti-6Ti (T90)[a]	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM
V-3Cr-3Ti (T91)[a]	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM	6 SSJ, 3 TEM
V-3Ti-0.5Si (BL-42)[b]	3 SSJ, 3 TEM	—	4 SSJ, 3 TEM	2 SSJ, 1 TEM
V-2.5Ti-1Si (BL-45)[b]	3 SSJ, 3 TEM	—	4 SSJ, 3 TEM	2 SSJ, 1 TEM
V-5Ti (BL-46)[b]	3 SSJ, 3 TEM	—	4 SSJ, 3 TEM	2 SSJ, 1 TEM
Ferritic steels				
9Cr-2WV[c]	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM
9Cr-2WVTa[c]	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM
9Cr-1MoVNb[c]	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM
9Cr-1MoVNb+2Ni[c]	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM
5Cr-2WV[c]	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM
3Cr-3WV[c]	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM
3Cr-3WVTa[c]	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM	4 SSJ, 2 TEM
A533B, plate[d]	2 TEM	2 TEM	2 TEM	2 TEM
A533B, weld[d]	2 TEM	2 TEM	2 TEM	2 TEM
pure Fe[e]	4 SSJ, 1 TEM	3 SSJ, 1 TEM	3 SSJ	3 SSJ, 1 TEM
Stainless steel/Ni alloys	3 TEM	3 TEM	3 TEM	3 TEM
P7, annealed[d]	3 TEM	3 TEM	3 TEM	3 TEM
P7, 20% CW[d]	3 SSJ, 3 TEM	3 SSJ, 3 TEM	3 SSJ, 3 TEM	3 SSJ, 3 TEM
316 SS, solution anneal[f]	3 SSJ, 3 TEM	3 SSJ, 3 TEM	3 SSJ, 3 TEM	3 SSJ, 3 TEM
316 SS, 20% cold work[f]	—	—	9 TEM	—
Fe-15Cr-35Ni[f]	3 TEM	3 TEM	3 TEM	3 TEM
Ni-18Fe-5Cu-1.5Cr[g]	3 TEM	3 TEM	3 TEM	3 TEM
Ni-Be[g]				
Copper alloys				
GlidCop Al25 DS Cu[a]	3 SSJ, 3 TEM	3 SSJ, 3 TEM	—	—
GlidCop Ti/Al_2O_3 DS Cu[e]	3 SSJ, 1 TEM	3 SSJ, 1 TEM	—	1 TEM
CuCrZr (AT temper)[a]	3 SSJ, 3 TEM	3 SSJ, 3 TEM	—	—
99.999% Cu[e]	3 SSJ, 1 TEM	3 SSJ, 1 TEM	—	1 TEM
Cu-1%Ni[e]	3 SSJ, 1 TEM	3 SSJ, 1 TEM	—	1 TEM
Cu-5%Ni[e]	3 SSJ, 1 TEM	3 SSJ, 1 TEM	—	1 TEM
Ceramics				
$MgTiO_3$ [h]	1 TEM	1 TEM		1 TEM
$MgTi_2O_5$ [h]	1 TEM			1 TEM
Totals:	97 SSJ,75 TEM	87 SSJ,65 TEM	81 SSJ,71 TEM	75 SSJ,63 TEM

[a] supplied by S.J. Zinkle (ORNL)
[b] supplied by H.C. Tsai (ANL)
[c] supplied by R.L. Klueh (ORNL)
[d] supplied by R.E. Stoller (ORNL)
[e] supplied by B.N. Singh (Risø)
[f] supplied by J.P. Robertson (ORNL)
[g] supplied by C.W. Allen (ANL)
[h] supplied by K.E. Sickafus (LANL)

Table 2. Chemical composition of U.S. specimens included in the HFIR 13J capsule

Alloy and heat number	Chemical composition (wt% unless otherwise noted)
Vanadium alloys	
V4Cr4Ti(832665,plate R250)	V-3.8Cr-3.8Ti-0.08Si-0.03Mo-0.02Fe-0.02Al (0.03 O-0.008N-0.008C)
V4Cr4Ti (VX-8)	V-3.7Cr-3.9Ti-0.05Si-0.03Mo-0.03Fe-0.11Al-0.13Nb-0.05Co (0.03 O-0.009N-0.01C)
V-5Ti-5Ti (T87, plate D250)	V-4.9Cr-4.9Ti-0.08Si-0.04Mo-0.02Fe-0.02Al (0.03 O-0.009N-0.01C)
V-6Ti-6Ti (T90, plate F150)	V-5.7Cr-6.0Ti-0.12Si-0.03Mo-0.01Fe-0.02Al (0.025 O-0.008N-0.01C)
V-3Cr-3Ti (T91, plate G250)	V-3.0Cr-3.0Ti-0.11Si-0.04Mo-0.01Fe-0.02Al (0.02 O-0.006N-0.01C)
V-3Ti-0.5Si (BL-42)	V-3.1Ti-0.54Si-0.02Fe (0.058 O-0.02N-0.014C)
V-2.5Ti-1Si (BL-45)	V-2.5Ti-0.99Si-0.01Fe (0.034 O-0.012N-0.009C)
V-5Ti (BL-46)	V-4.6Ti-0.016Si-0.04Al (0.03 O-0.005N-0.009C)
Ferritic steels	
9Cr-2WV, heat 3790	Fe-8.95Cr-2.0W-0.24V-0.51Mn-0.23Si-0.03Cu-0.014P-0.02Al--0.12C-0.03N-0.006 O
9Cr-2WVTa,heat 3791	Fe-8.90Cr-2.0W-0.23V-0.44Mn-0.21Si-0.03Cu-0.015P-0.02Al--0.11C-0.02N-0.006 O
9Cr-1MoVNb(#3590)	Fe-8.6Cr-0.98Mo-0.21V-0.063Nb-0.36Mn-0.08Si-0.03Cu-0.01Al--0.09C-0.05N-0.007 O
9Cr-1MoVNb+2Ni(#3591)	Fe-8.6Cr-0.98Mo-0.22V-0.066Nb-0.36Mn-0.08Si-0.04Cu-0.01Al--0.06C-0.05N-0.006 O
5Cr-2WV, heat 3789	Fe-5.0Cr-2.0W-0.24V-0.49Mn-0.23Si-0.03Cu-0.015P-0.01Al--0.12C-0.02N-0.005 O
3Cr-3WV (#10293)	Fe-3.0Cr-2.8W-0.25V-0.50Mn-0.14Si-0.01Ni-0.097C
3Cr-3WVTa (#10294)	Fe-2.9Cr-2.8W-0.25V-0.1Ta-0.50Mn-0.14Si-0.097C
A533B, plate 02	Fe-1.42Mn-0.70Ni-0.50Mo-0.12Cr-0.22Si-0.14Cu-0.02S-0.01P-0.24C
A533B, weld 73W	Fe-1.56Mn-0.60Ni-0.58Mo-0.25Cr-0.45Si-0.31Cu-0.003V-0.005S-0.005P-0.098C
pure Fe (Goodfellow)	99.999 Fe
FeCrNi/Ni alloys	
316 SS, heat P7	Fe-17Cr-16.7Ni--2.5Mo-0.03Mn-0.1Si-0.068W-0.01Ti-0.005C-0.004N-0.028 O
316F SS, JAERI heat	Fe-16.8Cr-14Ni--2.3Mo-0.23Mn-0.04Si-0.002S-0.01Ti-0.038C-0.011N
Fe-15Cr-35Ni (#15.35-130)	Fe-15Cr-34.5Ni--0.01Mn-0.04Cu-0.02Co-0.01Si-0.004S-0.008Al-0.007C-0.004N-0.04 O
Ni-18Fe-5Cu-1.5Cr	Ni-18Fe-5Cu-1.5Cr (at.%)
Berylco Ni-Be (alloy 440)	Ni-1.95Be-0.5Ti
Copper alloys	
GlidCop Al25(IG0) DS Cu (OMG Americas #C-8064)	Cu-0.25Al-0.22 O-0.025B-0.01Fe-0.01Pb-0.025B
GlidCop Ti/Al_2O_3 DS Cu	Cu-2Ti-0.25Al-0.22 O-0.025B (typical analysis)
CuCrZr (Zollern #882)	Cu-0.85Cr-0.09Zr
pure Cu (Trefimetaux)	99.999% Cu (10 wt. ppm Ag, 3 wt. ppm Si)
Cu-1%Ni(Johnson-Matthey)	Cu-1Ni (fabricated from 99.999% purity Cu, Ni metal foils)
Cu-5%Ni(Johnson-Matthey)	Cu-5Ni (fabricated from 99.999% purity Cu, Ni metal foils)
Ceramics	
$MgTiO_3$ (LANL/Alfa Aesar)	65.1TiO_2-34.2MgO-0.28Al_2O_3-0.01BaO-0.07CaO-0.036Fe_2O_3-0.20Na_2O-0.017SO_3-0.09SiO_2
$MgTi_2O_5$ (LANL/Alfa Aesar)	prepared from stoichiometric mix of $MgTiO_3$ and TiO_2 (99.9TiO_2-0.03Al-0.01Si-0.03Zr)