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LOW EXPOSURE SPECTRAL EFFECTS EXPERIMENT: IRRADIATIONS AT 473 K IN OMEGA WEST REACTOR - H. L. Heinisch and M. L. Hamilton (Pacific Northwest Laboratory)

PURPOSE

The purpose of this work is to determine the effect of the neutron spectrum on radiation induced changes in mechanical properties of metals.

SUMMARY

Tensile tests have been performed on specimens from the last set of Omega West Reactor (OWR) irradiations performed as part of the Low Exposure Spectral Effects Experiment (LESEX). Tensile data are reported.

PROGRESS AND STATUS

Introduction

The LESEX experiment was designed to allow direct comparisons of the damage caused by both fission and fusion neutrons on the tensile properties and microstructures of metals and alloys.^{1,2} During the lifetime of the Rotating Target Neutron Source (RTNS-II), miniature tensile specimens and TEM disks of pure copper, 316 stainless steel, A302B pressure vessel steel and various copper alloys were irradiated with 14 MeV d-t fusion neutrons to doses ranging from 0.0003 to 0.04 dpa at temperatures of 25, 90, 150, 200, 290, and 450°C. Companion irradiations with fission reactor neutrons to comparable doses in these materials were performed at OWR at temperatures of 90, 200 and 290°C.

Tensile tests and microscopy were performed previously on specimens irradiated in both environments at 90 and 290°C.² The final OWR irradiations were performed at 200°C to three fluence levels. Mechanical difficulties with the OWR irradiation vehicle, including the burn-out of the electrical resistance heating coils, precluded its use for further irradiations, and it was decommissioned.

Experimental Procedures and Results

Tensile tests were recently performed at room temperature on the specimens irradiated at 200°C in OWR using the same procedures as in the previous tests.¹ The results are given in Table 1.

As is shown in the table, the thickness measurements on each batch of specimens were generally quite consistent, varying by less than 0.025 mm from specimen to specimen. The exceptions to this are the A302B specimens, which were punched from slices of bar that varied in thickness much more than the rolled sheet typically used for punched specimens. In addition, the two Cu5Ni specimens irradiated in O14 (PX68 and PX71) appeared to be slightly thinner than those irradiated in O12 and O13. No explanation is readily available for this observation.

A number of specimens exhibited a relatively sharp 'yield point' relative to the remainder of the tests, where 'yield point' is used here to refer to a fairly sharp turn-over in the load-displacement trace at the end of the initial elastic loading, followed by a brief plateau at approximately constant load before the more typical increase in load observed with increasing strain. All of the SA316 specimens irradiated in both OWR and RTNS-II have exhibited this phenomenon, the effect becoming stronger with increasing dose. The duration of the plateau in terms of strain ranged from roughly 0.2 to 1%. The SA316 specimens irradiated in O14 actually exhibited a small (~3.5 MPa) yield drop rather than just a plateau. Other SA316 specimens in this experiment have exhibited yield drops as well, especially at the higher doses and higher irradiation temperatures. The Cu5Ni specimens irradiated in O13 and O14, i.e., to the two higher dose levels, also exhibited yield points. The fact that the Cu5Ni specimens exhibited the yield point plateau at only the higher dose levels, coupled with the transition in the SA316 from a plateau to a drop in load, suggests that the phenomenon is real, that it is a result of microstructural changes induced by neutron radiation, and that it is probably similar in nature to the yield drops traditionally produced by the pinning of dislocations by interstitial atmospheres.

Discussion

Figure 1 shows a comparison of the yield strength data from RTNS-II and OWR for solution annealed 316 stainless steel as a function of displacements per atom (dpa). Individual data points are shown only for the current tests. Trend lines are shown for 200°C along with those for 90°C and 290°C for comparison. At 90°C the yield strength change data from RTNS-II and OWR correlate well on the basis of dpa, while at 290 and 200°C irradiation in OWR produces more hardening per dpa than in RTNS-II. When the microstructures of specimens from RTNS-II and OWR at 90 and 290°C were examined by TEM,³ it was determined that the very small clusters of point defects that were observed could account for the radiation induced hardening, independent

Table 1. Tensile Data on Specimens Irradiated in OWR at 200°C

Alloy	Specimen ID	Capsule ID	Fluence (10E18 n/cm ²)	Thickness (mm)	YS (MPa)	UTS (MPa)	UE (%)	TE (%)
Cu	--	--	0.0	--	48±4	205±11	--	--
	C59	012	8.5	0.257	126	204	18.8	23.2
	C60	012	8.5	0.244	134	223	23.3	27.1
	C64	013	37.8	0.234	185	244	16.2	21.3
	C65	013	37.8	0.241	170	225	16.2	20.0
	C70	014	82.8	0.236	197	236	13.4	17.1
	C73	014	82.8	0.236	193	238	10.9	14.0
SA316	--	--	0.0	--	220±11	574±20	--	--
	A58	012	8.5	0.295	303	616	46.7	54.5
	A59	012	8.5	0.274	319	629	54.6	62.4
	A63	013	37.8	0.277	398	687	42.9	53.6
	A64	013	37.8	0.297	336	625	39.5	NA
	A68	014	82.8	0.297	446	681	36.1	42.6
	A69	014	82.8	0.302	449	696	39.6	50.5
A302B	--	--	0.0	--	495±4	645±10	--	--
	E63	012	8.5	0.274	557	645	3.8	7.6
	P64	012	8.5	0.244	512	571	4.6	6.5
	E68	013	37.8	0.373	650	705	2.5	4.1
	P65	013	37.8	0.338	652	729	4.0	7.0
	P55	014	82.8	0.241	732	756	0.5	0.9
A212B	--	--	0.0	--	428±10	565±6	--	--
	H19	012	8.5	0.277	455	519	3.3	4.7
	H20	012	8.5	0.277	350	417	3.0	4.5
	H31	014	82.8	0.244	471	525	3.5	4.7
	H32	014	82.8	0.274	409	435	1.9	3.0
Cu5Al	--	--	0.0	--	50±6	219±15	--	--
	SX49	012	8.5	0.249	103	229	25.7	30.8
	SX50	012	8.5	0.244	110	244	31.6	33.3
	SX56	013	37.8	0.239	124	244	26.5	31.7
	SX61	013	37.8	0.236	137	246	22.4	26.1
	SX68	014	82.8	0.226	125	214	13.7	16.5
	SX71	014	82.8	0.213	137	239	14.1	16.5
Cu5Mn	--	--	0.0	--	66±2	235±8	--	--
	CX62	012	8.5	0.241	133	270	22.9	25.6
	CX64	012	8.5	0.236	131	269	20.9	23.8
	CX68	013	37.8	0.231	146	273	20.1	22.5
	CX69	013	37.8	0.236	145	283	22.5	25.9
	CX73	014	82.8	0.246	140	270	22.6	24.6
Cu5Ni	--	--	0.0	--	50±4	219±2	--	--
	PX55	012	8.5	0.246	134	231	22.2	27.8
	PX56	012	8.5	0.234	108	237	22.5	25.7
	PX62	013	37.8	0.241	173	245	20.4	26.4
	PX66	013	37.8	0.241	191	251	18.0	24.6
	PX68	014	82.8	0.201	225	278	15.0	18.1
CuAl25	--	--	0.0	--	417±16	456±16	--	--
	JX21	012	8.5	0.274	545	571	0.6	4.4
	JX22	012	8.5	0.254	509	575	0.7	3.3
	JX29	013	37.8	0.257	543	566	0.6	3.6
	JX38	013	37.8	0.259	531	547	0.6	2.7
	JX63	014	82.8	0.259	540	566	0.6	2.5
	JX70	014	82.8	0.257	541	547	0.6	2.6

Figure 1. The changes in 0.2% offset yield stress of solution annealed 316 stainless steel irradiated at 90, 200 and 290°C in RTNS-II and OWR as a function of dpa. Individual data points are shown for only the 200°C irradiation in OWR.

of irradiation temperature. It was suggested that these clusters nucleated in OWR at temperatures below the target irradiation temperature during the daily ascent to power. This effect would be expected to be small at 90°C, and indeed, no difference in the OWR and RTNS-II data was observed. The same effect, however, may well be responsible for the differences observed at 200°C, although the magnitude of the effect at this temperature is somewhat surprising. Examination of the microstructures of the SA316 TEM specimens irradiated at 200°C will provide additional information for understanding this behavior.

Detailed analysis of the yield stress data on copper, the copper alloys and the pressure vessel steels is in progress. Some preliminary information on trends in the data are reported below.

At 200°C the yield stress changes of A302B pressure vessel steel irradiated in RTNS-II and OWR correlate well when compared on the basis of dpa. This was also observed at 90°C and 290°C.¹ The yield stresses for A212 pressure vessel steel are anomalously low. At 90°C A302 and A212 were found to behave the same.⁴ An assortment of difficulties were encountered during the testing of the A212 specimens irradiated at 200°C. Fortunately, several more irradiated specimens are available for testing.

Yield stress changes of pure copper irradiated in RTNS-II and OWR at 200°C do not correlate on the basis of dpa. A factor of 10 less dose in dpa is needed in OWR to produce the same yield stress change as in RTNS-II. This is quite different from the factor of 2 more dpa needed to produce the same effect at 90°C.¹ At 290°C the data from the two spectra were found to correlate with dpa.¹ These results may be a further indication of temperature history effects in the OWR irradiations.

The binary copper alloys in OWR show a variety of temperature sensitivities. Cu5Mn shows essentially no difference in yield stress with increasing dose at 200°C, while Cu5Al shows a slight increase with dose. At 90°C these alloys display yield stress changes similar to that of pure copper. Cu5Ni displayed about the same changes in yield stress at 200°C as at 90°C, indicating very little temperature dependence in this fluence and temperature range.

CONCLUSIONS

The yield stress data for the 200°C OWR irradiations of the Low Exposure Spectral Effects Experiment show very interesting differences from what would be expected based on projections from the earlier data at 90°C and 290°C. At least some of the apparent inconsistencies might be related to temperature history effects we suspect were occurring during the daily ascent to power of the OWR. Since the various materials have responded in different ways to the temperature history, at least on the basis of tensile property changes, the data may be quite useful in sorting out the operation of specific mechanisms involved in the effects. Characterization of the microstructures using TEM will provide additional information to consider in the analysis.

FUTURE WORK

Microstructural analyses and further tensile data analyses will be done on the materials irradiated at 200°C.

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