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MASTER

IRRADIATED TYPE 304 SS BEND TEST DUCTILITY

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DISCLAIMER

The ductility loss of some materials upon exposure to fast neutron fluences can limit their application in core structures. Also, bending deformation is significant in LMFBR core components and can be affected by the ductility loss, especially during seismic loading of core ducts. Thus, a series of tests were performed to determine the available bending deformation capability and ductility of preirradiated Type 304 stainless steel (SS) for core applications.[1] This material was tested under conditions at which it exhibits less ductility than Type 316 SS or other stainless steels currently under considerations for core applications.

Tensile testing of Type 304 SS with specimens from EBR-II ducts which were irradiated to fluences between 5 to 10 x 10^{22} n/cm^2 (E > 0.1 Mev) revealed a significant reduction of uniform elongation (UE) and total elongation (TE), but smaller decreases in reduction of area (RA).[2] These specimens fail with significant but very localized necking. The ductility of this material decreases with decreasing strain rate if the test temperature is above the irradiation temperature. A large reduction in ductility is caused by a change from a transgranular to an intergranular fracture mode. Results of such tensile tests are listed in Table 1.

This tensile material behavior was compared with the deformation and failure characteristics of specimen loaded in bending using material from the same preirradiated EBR-II ducts. These bend test specimens (0.040 inch (0.01 mm) thick and 0.5 inch (12.7 mm) wide) were loaded in the center of a 1.50 inch (38.1 mm) span. The testing limitations of the hot-cell allowed only load and deflection measurements. Bending strain estimates at fracture were obtained by analysis. The results of the bend test measurements and the estimated bending strains at failure are listed in Table 2. The last column of this table compares the bending and the corresponding tensile failure strains of the preirradiated Type 304 SS specimens. It is a well established fact that the failure strain due to the state of stress which exists in a wide bend test specimen is approximately 50% lower than the uniaxial failure strain in a tensile test specimen.[3,4] However, Table 2 indicates that the irradiated bending specimens failed at strains less than 50% of the tensile failure strains.

These results were verified by independently calculating the maximum possible strains in the bend specimen. The end of load push rods had an 0.125 inch (3.2 mm) cylindrical radius. Bending of the specimen over the push rod can only generate a maximum surface strain of approximately 14%. Therefore, the first bend specimen in Table 2 and potentially the fourth specimen should not have failed.

Possible explanations for the limited bending ductility of the irradiated material are:

- Fracture in a ductile-brittle transition mode.
- The variation of the strain rate over the cross section combined with a strain rate sensitivity of the material.
- A very localized tensile instability.

Thus, the bending tests demonstrate that the bending flexibility of irradiated specimen cannot be reliably predicted based on the tensile true fracture strain values. However, the test series also shows that for irradiated Type 304 SS bending failure strains of Table 2 exceed the total elongation strains (TE) of Table 1. Therefore, the TE appears to provide a conservative limit for bending strains. Further evaluation and comparison of the bend test results with the results of a series of additional duct crushing test results[1] demonstrates that irradiation hardening increases the bending strength of Type 304 SS by a factor of two. Also, the material exhibits adequate ductility to satisfy functional deformation requirements typical of LMFBR cores.

References

1. H. D. Garkisch, R. L. Fish and D. R. Haglund, "Clinch River Breeder Reactor Plant, Irradiated EBR-II Duct Crushing Test and Analysis", CRBRP-ARD-0164, April 1977 (Availability: U. S. DOE Technical Information Center).

2. R. L. Fish and C. W. Hunter, "Tensile Properties of Fast Reactor Irradiated Type 304 Stainless Steel", in Irradiation Effects on the Microstructure and Properties of Metals, ASTM-STP-611, pp. 118-138, American Society for Testing and Materials, Philadelphia, PA, 1976.

3. M. J. Manjoine, "Ductility Indices at Elevated Temperature", Trans. ASME, 97, J. Eng. Mat. Tech., pp. 156-161, April 1975.

4. J. Datsko and C. T. Yang, "Correlation of Bendability of Materials with their Tensile Properties", Trans. ASME, 82, J. Eng. Ind., pp. 309-314, November 1960.

TABLE 1

TENSILE TEST RESULTS

Specimen Number	Irrad. Temp. (°F)	Test Temp. (°F)	Fluence (10^{22} n/cm^2 E>0.1 MeV)	Strain Rate (1/min)	Strength KSI YS	Strength KSI UTS	Ductility % UE	Ductility % TE	Ductility % RA	Corresponding Bend Test No.
1	800	900	5.7	0.2	87.6	90.2	0.6	1.7	42.0	1
2	800	1000	5.5	0.2	77.3	80.2	0.9	2.5	20.0	3
3	735	1000	8.6	0.2	76.4	86.2	0.8	3.1	29.1	4
4	800	1000	5.5	0.002	73.1	73.5	0.2	0.5	11.8	5 & 2
5	835	1100	4.1	0.2	71.0	73.5	0.7	1.9	15.4	6
6	835	1100	4.1	0.02	71.5	72.6	0.4	1.0	10.9	-
7	835	1100	4.1	0.002	64.1	64.8	0.3	0.7	8.7	-
8	835	1150	3.9	0.2	55.3	58.4	1.3	2.7	18.2	7

TABLE 2

BEND TEST RESULTS

Specimen Number	Irrad. Temp. (°F)	Test Temp. (°F)	(10^{22} n/cm^2 E>0.1 MeV)	Crosshead Speed (in/min)	Max. Load (lbs.)	Deflection at Max. Load (in.)	Bend Failure Strain** %	Tensile Failure Strain*** %
1	800	900	5.7	0.2	57.5	0.161	>4	35
2	800	900	5.7	0.002	44.5	0.076	0.5	11****
3	800	1000	5.5	0.2	54.0	0.136	4	18
4	735	1000	8.6	0.2	64.0	0.125	3	26
5	800	1000	5.5	0.002	32.0*	0.058	÷	11
6	835	1100	4.1	0.2	46.0	0.133	>4	14
7	835	1150	3.9	0.2	40.5	0.111	5	17

*Premature Elastic Failure

**Estimated Based on Analyses

***Calculated from RA Values of Table 1

****Corresponding Low Strain Rate Tensile Test at 900° Test Temperature not Available