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Tensile Properties of Irradiated Surveillance Coupons

Prepared for the U.S. Department of Energy
Office of Environmental Restoration and
Waste Management

Westinghouse
Hanford Company Richland, Washington

Hanford Operations and Engineering Contractor for the
U.S. Department of Energy under Contract DE-AC06-87RL10930

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ABSTRACT

Tensile testing of austenitic steel and superalloy samples irradiated in the HMO 13 assembly was performed in support of the Fast Flux Test Facility (FFTF) Surveillance Program. Postirradiation yield stress, ultimate tensile stress, uniform elongation, total elongation, and reduction in area of 304 stainless steel (SS), 308 SS weld, 316 SS, A286, In718, and In718 weld were determined. Results showed the strength of austenitic steels increased while the ductility decreased as a result of irradiation. Low irradiation exposure produced little property change in In718. Overall, the tensile properties of HMO 13 surveillance coupons showed a lower magnitude of irradiation-induced property change than was expected based on earlier studies. Results from these tests gave no indications of unexpectedly severe irradiation damage to FFTF components.

1.0 INTRODUCTION

Surveillance coupons fabricated from the actual heats of materials used for reactor components have been retrieved from irradiation assembly HMO 13. These coupons were located at assembly positions where neutron fluxes were higher than that of the actual reactor component they represent. Swelling measurements on selected coupons have been reported. This report presents results of mechanical property tests.

Tensile tests were conducted on sixteen HMO13 surveillance coupons fabricated from 304 stainless steel (SS), 308 SS, 316 SS, Inconel 718 and alloy A286. Alloy 718 is a high-strength, precipitation hardenable nickel-base superalloy. Testing of these surveillance coupons identifies the extent of radiation-induced degradation in material property for comparison with the results of earlier studies that guided considerations of irradiation effects for FFTF design.

2.0 EXPERIMENTAL

2.1 SPECIMEN PREPARATION

Three types of specimens were irradiated in the HMO 13 assembly but only Fermi tensile specimens were tested in this work. The Fermi specimen and the grips used in the hotcell are shown in Figure 1. The specimen is 47.63mm long with a gauge section diameter of 3.18 mm.

Irradiation temperature was measured in a limited number of subcapsules containing thermal expansion difference (TED) monitors, the temperatures in all subcapsules were estimated by comparing the temperature measured by TED monitors and design temperatures. The temperature profiles for all subcapsules in sample rods A and B are shown in Figure 3. Based on this temperature profile, the irradiation temperature in the subcapsule containing no TED was estimated. Both design and measured temperatures for the subcapsules containing the Fermi tensile specimens tested in this work are listed in Table 1.

The damage levels in the subcapsules containing the dosimeters were analyzed based on the counting results obtained from the dosimetry packets. The results of dosimetry analysis are given in Reference 1. Table 1 lists the neutron fluence for each sample.

2.2 TEST PROCEDURE

Tensile tests were conducted in the hotcell using a screw-driven testing machine. All measurement and test equipment, such as voltmeters, recorders and thermocouples, were calibrated.

The basic procedures for this tensile testing are as follows:

1. All specimens were tested at 471°C using a screw-driven machine operated at a crosshead speed of 0.05 mm/min and an initial load scale of 907 kg.

2. After the test was completed, each broken specimen was reassembled to measure the final length.

3. Yield and ultimate tensile strength, uniforms and total elongation were determined from load-displacement records.

4. The reduction in area was computed from the final cross section of the sample.

3.0 RESULTS

Unirradiated specimens, fabricated from the same heats of materials as the FFTF surveillance coupons, were tested much earlier. The preirradiation tensile properties of HMO 13 control specimens, along with the heat number and test temperature, are compiled in Table 2. The test parameters as well as the 0.2 percent offset yield strength (YS), ultimate tensile strength (UTS), reduction in area, uniform (UE) and total elongation (TE) are summarized in Table 3.

An extensive data base of the effect of irradiation in the Experimental Breeder Reactor II on the tensile properties of 304 SS, 316 SS, and 308 SS weld metal has been analyzed. These earlier studies showed that both irradiation temperature and irradiation exposure can be important in determining the extent of change in a mechanical property. In some cases, differences in the magnitude of irradiation-induced property change were detected between different heats of steel. Results on the change in strength properties for austenitic stainless steels irradiated in HM013 are plotted against neutron exposure in Figures 3 and 4. The yield strength of 304 SS (Figure 3) increases with neutron exposure at low displacement damage levels, but reaches a limiting value of about 286 MPa for exposures of about 8 dpa and higher. Ultimate strength shows some variability, but no consistent change with neutron exposure. This type of response is typical of that observed in prior experiments, but the magnitude of the strength increase is smaller than expected on the basis of the earlier studies cited above. Yield and ultimate strengths for 308 SS (Figure 4) irradiated at about 447°C to exposures below 3 dpa appear to show a small decrease relative to those properties for unirradiated material. The specimen irradiated to 8.5 dpa (displacement per atom) show significantly higher strength because the irradiation temperature was lower (397°C). Once again, comparison with the earlier investigations indicates higher strength values should be expected at the lower irradiation temperature.

Results for uniform and total elongation are plotted in Figures 5 and 6. In the case of 304 SS (Figure 5), the decrease in elongation at low neutron exposures is consistent with the increase in yield strength in this exposure range. The low values of elongation at 5.3 dpa is attributed to data variability rather than to a real data trend. In general, elongation values are somewhat higher than those observed in earlier investigations. The 308 SS weld (Figure 6) exhibits a modest reduction in elongation at low exposures (irradiation temperature about 477°C), although the values seem somewhat lower, relative to the unirradiated condition, than would be expected from the yield strength changes. The low elongations at 8.5 dpa for an irradiation temperature of 397°C are consistent with results from the earlier studies.

Results for Inconel 718 and alloy A286 at low neutron exposures generally indicate small increases in strength and small decreases in ductility relative to properties of unirradiated material. The combination of neutron irradiation and elevated temperature during the in-reactor exposure clearly produced a material with high strength. The relative contributions of neutron displacement damage or irradiation-enhanced precipitation hardening to the observed effect cannot be assessed. Small changes in strength and ductility for precipitation strengthened Inconel 718 are generally consistent with earlier work for an irradiation temperature of about 377°C.

4.0 DISCUSSION

There is no readily acceptable explanation for the low magnitude of irradiation strengthening and generally higher ductility observed in stainless steels from HM013 relative to that expected from earlier studies. The only hypothesis that can be advanced at this time is that irradiation temperatures may actually have been significantly higher than the analysis of TED monitors indicated.

5.0 CONCLUSION

Testing of coupons from the HM013 surveillance assembly showed that the irradiation exposure generally increased strength and reduced elongation for austenitic stainless steels, and had little effect on strength and elongation of In718 and Alloy A286. In general, HMO 13 coupons of austenitic stainless steels exhibited lower values of strength increase and ductility decrease than expected based on results from earlier EBR-II irradiations. Results from these tests give no indications of unexpectedly severe irradiation damage to FFTF components.

6.0 REFERENCES

1. R. L. Simons and R. H. Webb, "FFTF Surveillance Irradiation Assembly, HMO 13 Dosimetry Analysis," WHC-SA-1311-FP, Wstinghouse Hanford Company, Richland, Washington, 1991.

Table 1. Test Matrix for HMO 13 Tensile Specimens.
Test Temperature = 880 °F (471 °C)

Specimen I.D.	Material	Heat Number	Subcapsule	Design Temp. (°F)	Measured Temp. (°F)	Damage (dpa)	Component
N33	304 SS	X23171	12A8	890	919	17.0	RS-5
M32		626577-1	12B7	870	961	15.0	RS-13
F94		8394-1A	12A10	850	880	5.3	CR-6
P56		326284-2B	12A11	855	885	2.9	RS-4
J5		633377	12A17	860	890	0.1	IV-3
M37	308 SS	326284-1B/-2B	12A11	855	885	2.9	RS-6
M35		SAME	12A12	860	890	1.7	RS-6
L62		326284-2/-1A	12A14	860	890	0.6	RS-7
L51		SAME	12B2	700	746	8.5	RS-7
H60	IN718	C52227	12A9	870	900	8.6	CR-8
H75		8-4014	12B16	815	882	0.062	IV-2
L39		C52325	12A16	860	890	0.2	CD-1
L74	IN718 Weld	C523525	12A16	860	890	0.2	CD-3
H67	A286	62570R11	12A17	860	890	0.1	IV-1
E29	316 SS	66236	12A8	890	919	17.0	RR-2b
H29	304 SS	36832	12A9	870	900	8.6	CR-7

NOTE: All tests were conducted at a crosshead speed of 0.002 in/min

Table 2. Pre-Irradiation Tensile Properties of HMO 13 Surveillance Coupons.

Material	Heat Number	Test Temp (°C)	Strength (Mpa)		Elongation (%)		Component
			Yield	Ultimate	Uniform	Total	
304 SS	X23171	475	138.8	434.4	37.4	41.8	RS-5
	626577-1	440	177.9	462.6	34.5	40.5	RS-13
	8394-1A	455	136.1	446.4	34.0	39.7	CR-6
	326284-2B	425	135.7	440.1	34.2	40.7	RS-4
	633377	504	158.2	407.6	30.7	36.4	IV-3
	36832	465	137.3	420.9	32.2	38.2	CR-72
308 SS	326284-1B/2B	455	354.6	475.8	17.1	20.6	RS-6
	326284-2/1A	370	410.2	489.2	16.0	19.3	RS-7
IN718	C52227	465	442.9	833.3	34.8	37.4	CR-8
	8-4014	504	981.8	1123.4	8.4	12.3	IV-2
	C52325	420	944.3	1102.2	12.2	17.7	CD-1
IN718 Weld	C52325	420	962.7	1120.7	9.7	11.3	CD-3
A286	L2570K11	504	711.5	974.7	11.7	16.4	IV-1

Table 3. Tensile Properties of HMO 13 Surveillance Coupons
Test Temperature = 880 °F (471 °C)

Specimen I.D.	Material	Damage (dpa)	Strength (MPa)		Reduction in Area (%)	Elongation (%)		
			Yield	Ultimate		Uniform	Total (X-Y Record)	Total (Direct Measure)
N33	304 SS	17.0	286.9	439.9	15.4	12.4	15.4	15.9
M32		15.0	277.0	433.2	18.3	15.1	17.1	16.9
H29		8.6	286.2	424.2	7.8	11.6	13.1	13.6
F94		5.3	262.7	375.3	10.9	7.7	11.4	10.5
P56		2.9	211.3	420.8	24.0	24.2	27.0	29.8
J5		0.1	144.7	417.4	40.4	32.7	36.2	38.1
E29	316 SS	17.0	290.3	472.5	16.8	12.8	15.6	16.7
L51	308 SS	8.5	586.2	592.2	9.4	0.7	4.2	2.7
M37		2.9	304.8	414.6	22.6	10.8	14.1	14.2
M35		1.7	331.1	433.2	22.6	10.7	13.6	14.7
L62		0.6	281.9	421.4	7.8	12.0	16.7	16.5
H60	IN718	8.6	936.4	1123.7	19.0	12.8	13.4	13.5
L39		0.2	991.1	1095.6	19.7	8.9	11.5	13.4
H75		0.062	1075.1	1193.9	19.7	7.0	9.6	9.9
L74	IN718 Weld	0.2	1016.6	1151.8	16.8	8.3	10.6	11.6
H67	A286	0.1	796.1	1055.1	15.4	11.8	14.6	15.4

Figure 1. Fermi Tensile Specimen and Grips.

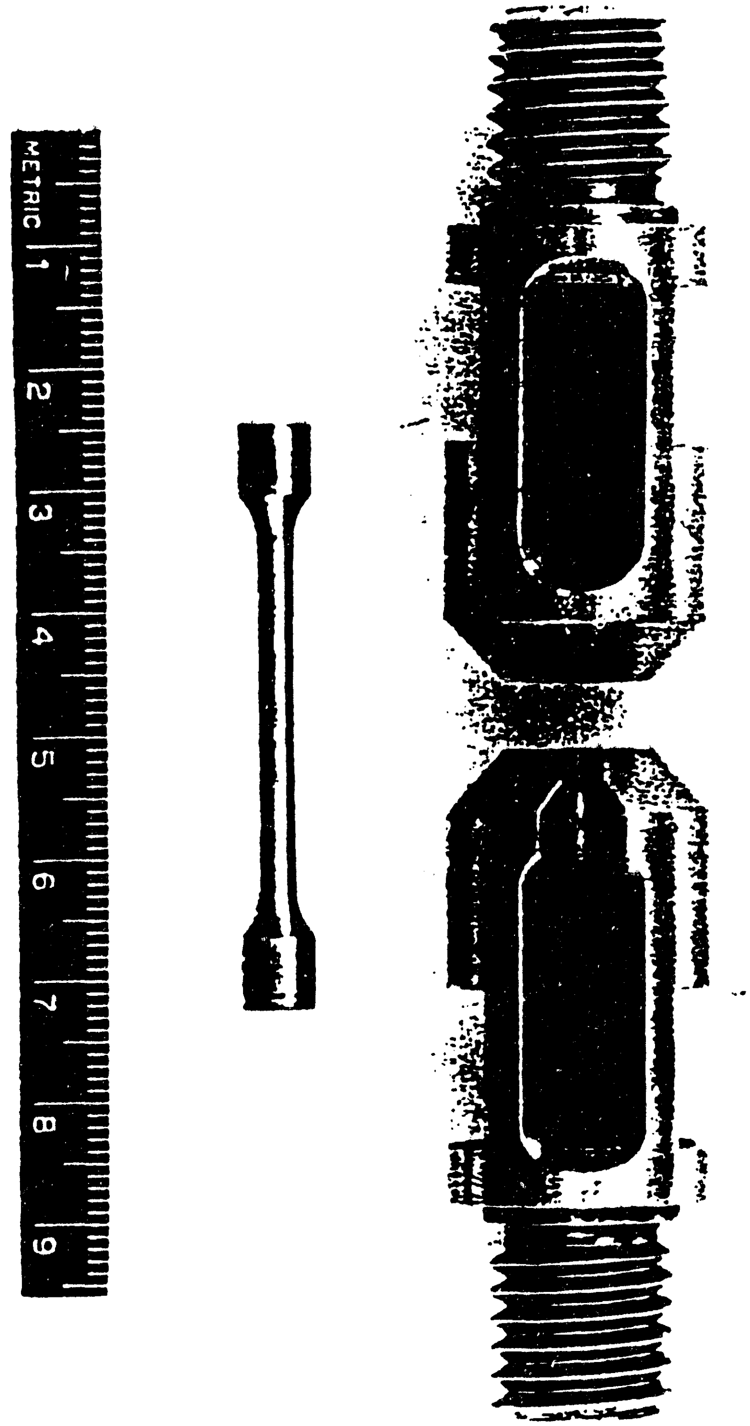

Figure 2. Design Temperature and Irradiation Temperature Measured by TED for Axial Location.

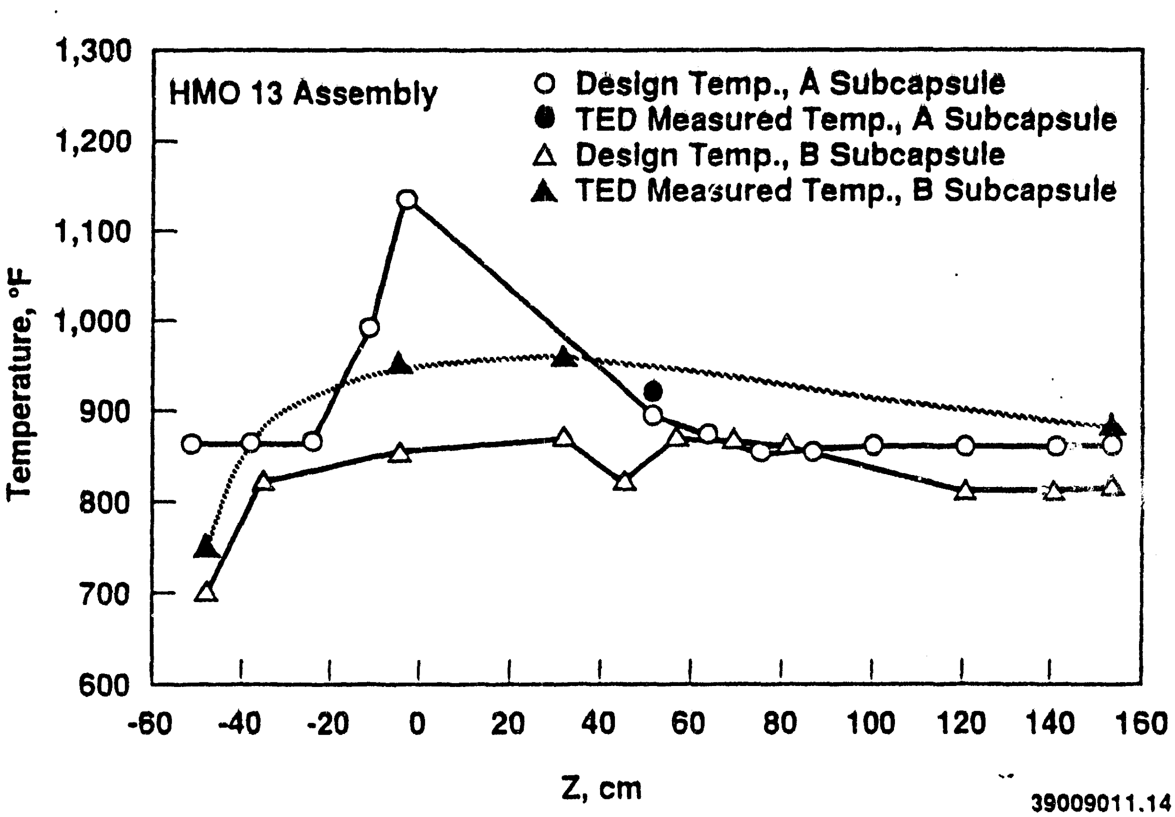

Figure 3. Damage Dependence of Strength for 304 Stainless Steel and 316 Stainless Steel.

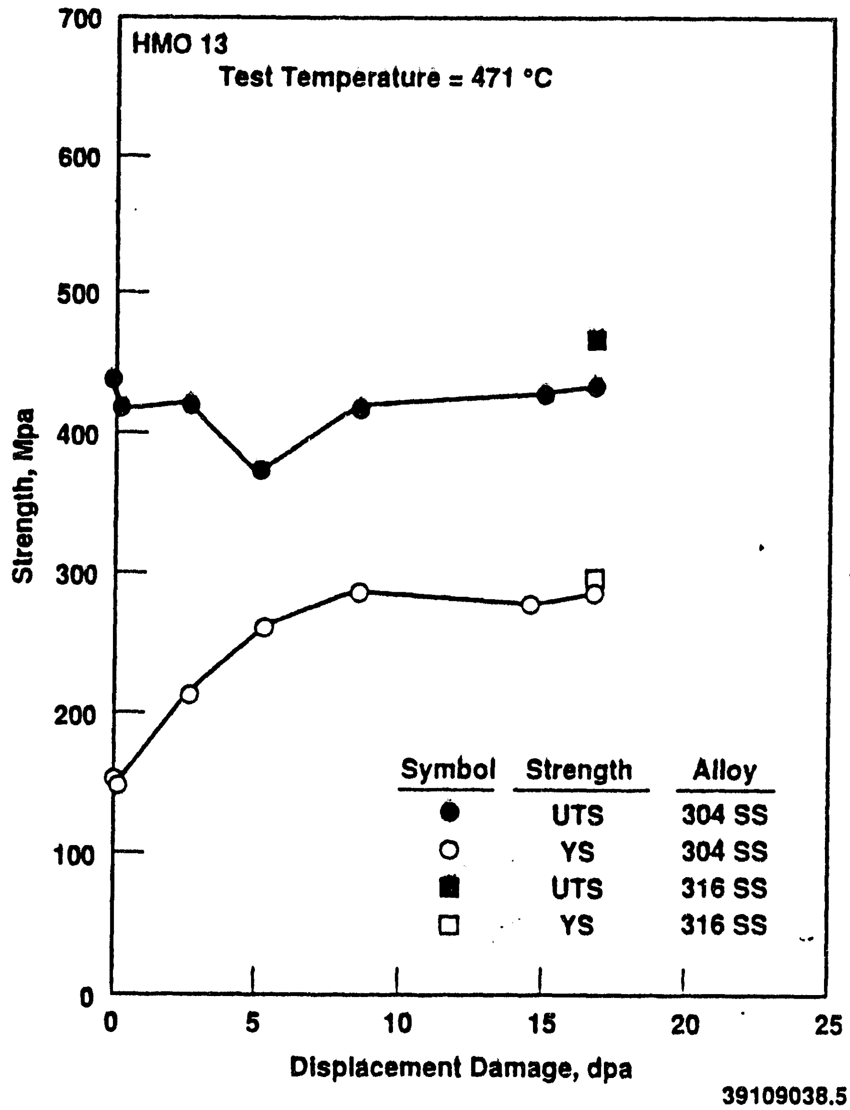

Figure 4. Damage Dependence of Strength for 308 Stainless Steel Weld.

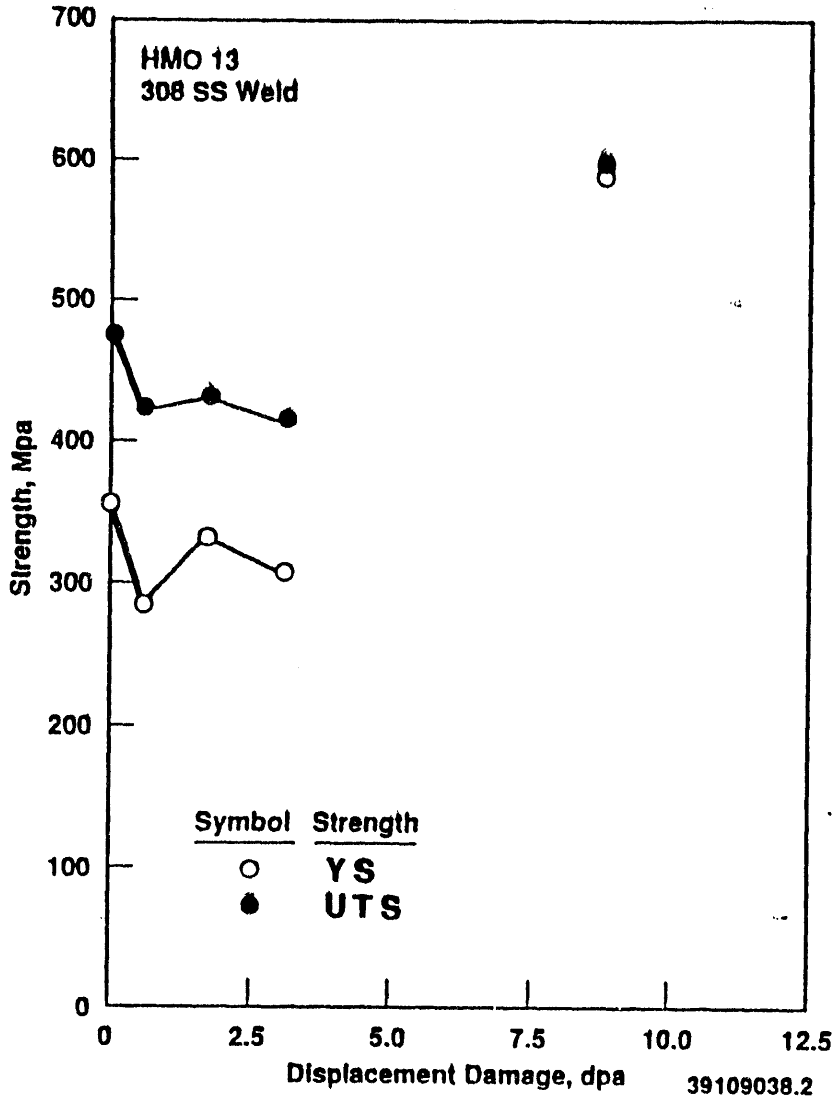

Figure 5. Damage Dependence of Elongation for 304 Stainless Steel and 316 Stainless Steel.

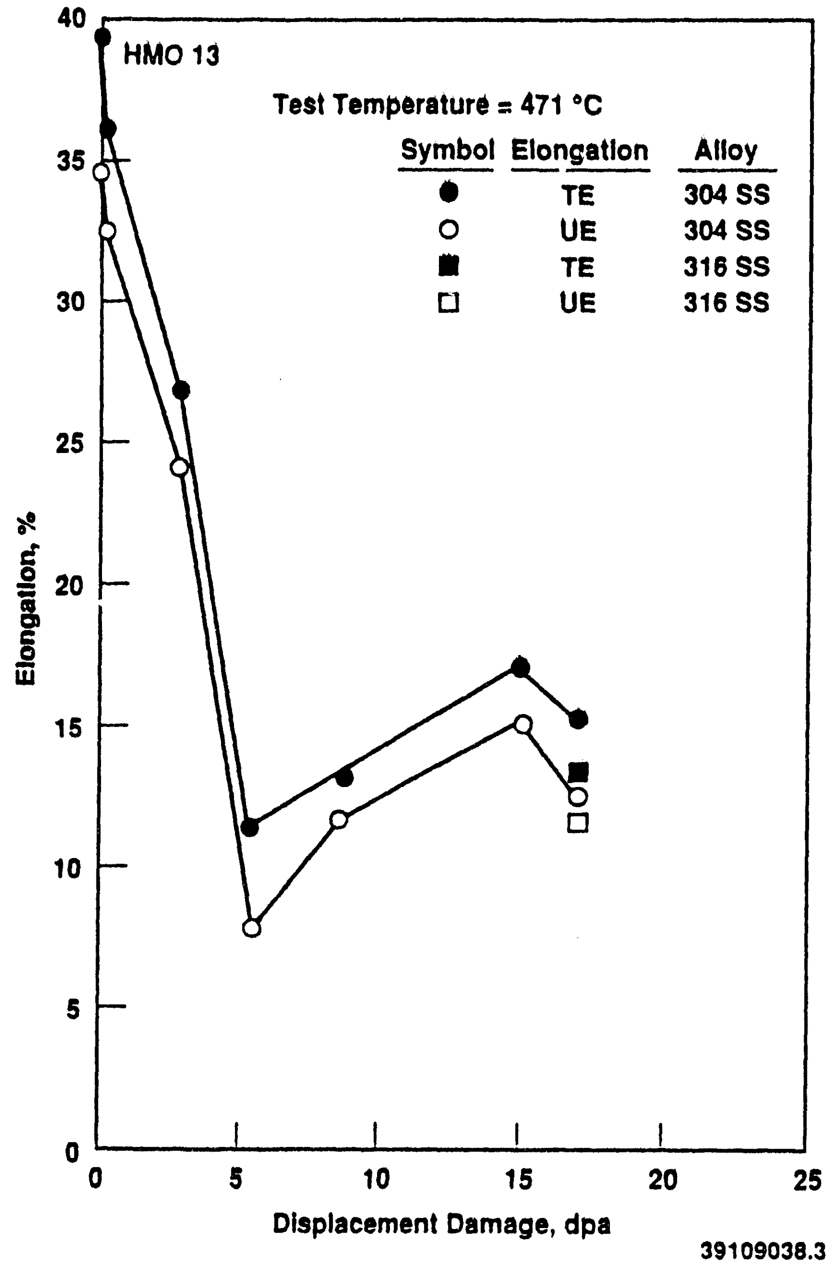

Figure 6. Damage Dependence of Elongation for 308 Stainless Steel Weld.