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TENSILE PROPERTIES OF IRRADIATED AND UNIRRADIATED WELDS OF A533 STEEL PLATE AND A508 FORGINGS

Hanford Engineering Development Laboratory

HANFORD ENGINEERING DEVELOPMENT LABORATORY
Operated by Westinghouse Hanford Company
P.O. Box 1970 Richland, WA 99352
A Subsidiary of Westinghouse Electric Corporation
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ABSTRACT

The tensile properties of welds of base metals ASTM A533, Grade B, Class 1 steel plate and ASTM A508, Class 1 forgings were evaluated in irradiated (3 to 21 x 10^{18} n/cm^2) and unirradiated conditions. Yield strength and ultimate strength both increased with increasing fluence, while small ductility losses were generally independent of fluence. Yield strength was found to be more sensitive to irradiation than ultimate strength for all welds. The strength and ductility responses to irradiation varied between the weld materials. These variations were attributed to differences in chemical constituents of the welds.

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FOREWORD

The Heavy Section Steel Technology (HSST) Program is a United States Nuclear Regulatory Commission (NRC) sponsored effort coordinated by the Oak Ridge National Laboratory (ORNL) with G. D. Whitman as the HSST Program Manager.

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This report is designated Heavy Section Steel Technology Program Technical Report No. 55. Prior reports in this series are:

Report No.

1 S. Yukawa, Evaluation of Periodic Proof Testing and Warm Prestressing Procedures for Nuclear Reactor Vessels, HSSTP-TR-1, General Electric Company, Schenectady, NY, July 1, 1969.

2 L. W. Loechel, The Effect of Section Size on the Transition Temperature in Steel, Martin Marietta Company, Denver, CO, 1969.

3 P. N. Randall, Gross Strain Measure of Fracture Toughness of Steels, HSSTP-TR-3, TWR Systems Group, Redondo Beach, CA, November 1, 1969.

4 C. Visser, S. E. Gabrielse and W. VanBuren, A Two-Dimensional Elastic-Plastic Analysis of Fracture Test Specimens, WCAP-7368, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, PA, October 1969.

5 T. R. Mager, F. O. Thomas and W. S. Hazelton, Evaluation by Linear Elastic Fracture Mechanics of Radiation Damage to Pressure Vessel Steels, WCAP-7328, Revised, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, PA, October 1969.

6 W. O. Shabbits, W. H. Pryle and E. T. Wessel, Heavy Section Fracture Toughness Properties of A 533 Grade B Class 1 Steel Plate and Submerged Arc Weldment, WCAP-7414, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, PA, December 1969.

7 F. J. Loss, Dynamic Tear Test Investigations of the Fracture Toughness of Thick-Section Steel, NRL 7056, U.S. Naval Research Laboratory, Washington, DC, May 14, 1970.

8 P. B. Crosley and E. J. Ripling, Crack Arrest Fracture Toughness of A533 Grade B, Class 1 Pressure Vessel Steel, HSSTP-TR-8, Materials Research Laboratory, Inc., Glenwood, IL, March 1970.

Report
No.

9 T. R. Mager, Post-Irradiation Testing of 2 T Compact Tension Specimens, WCAP-7561, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, PA, August 1970.

10 T. R. Mager, Fracture Toughness Characterization Study of A533, Grade B, Class 1 Steel, WCAP-7578, Westinghouse Electric Corporation, PWR System Division, Pittsburgh, PA, October 1970.

11 T. R. Mager, Notch Preparation in Compact Tension Specimens, WCAP-7579, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, PA, November 1970.

12 N. Levy and P. V. Marcal, Three-Dimensional Elastic-Plastic Stress and Strain Analysis for Fracture Mechanics, Phase I: Simple Flawed Specimens, HSSTP-TR-12, Brown University, Providence, RI, December 1970.

13 W. O. Shabbits, Dynamic Fracture Toughness Properties of Heavy Section A533 Grade B, Class 1 Steel Plate, WCAP-7623, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, PA, December 1970.

14 P. N. Randall, Gross Strain Crack Tolerance of A533-B Steel, HSSTP-TR-14, TRW Systems Group, Redondo Beach, CA, May 1, 1971.

15 H. T. Corten and R. H. Sailors, Relationship Between Materials Fracture Toughness Using Fracture Mechanics and Transition Temperature Tests, T&AM Report No. 346, University of Illinois, Urbana, IL, August 1, 1971.

16 T. R. Magner and V. J. McLoughlin, The Effect of an Environment of High Temperature Primary Grade Nuclear Reactor Water and the Fatigue Crack Growth Characteristics of A533 Grade B, Class 1 Plate and Weldment Material, WCAP-7776, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, PA, October 1971.

17 N. Levy and P. V. Marcal, Three-Dimensional Elastic-Plastic Stress and Strain Analysis for Fracture Mechanics, Phase II: Improved Modeling, HSSTP-TR-17, Brown University, Providence, RI, November 1971.

18 S. C. Grigory, Six-Inch-Thick Flawed Tensile Tests, First Technical Summary Report, Longitudinal Specimens 1 Through 7, HSSTP-TR-18, Southwest Research Institute, San Antonio, TX, June 1972.

19 P. N. Randall, Effects of Strain Gradients on the Gross Strain Crack Tolerance of A533-B Steel, HSSTP-TR-19, TRW Systems Group, Redondo Beach, CA, May 1, 1972.

Report
No.

20 S. C. Grigory, Tests of Six-Inch-Thick Flawed Tensile Specimens, Second Technical Summary Report, Transverse Specimens Numbers 8 Through 10, Welded Specimens Numbers 11 Through 13, HSSTP-TR-20, Southwest Research Institute, San Antonio, TX, June 1972.

21 Lee A. James and John A. Williams, The Effect of Temperature and Neutron Irradiation upon the Fatigue-Crack Propagation Behavior of ASTM A533, Grade B, Class 1 Steel, HEDL-TME 72-132, Hanford Engineering Development Laboratory, Richland, WA, September 1972.

22 S. C. Grigory, Tests of Six-Inch-Thick Flawed Tensile Specimens, Third Technical Summary Report, Longitudinal Specimens Numbers 14 Through 16, Unflawed Specimen Number 17, HSSTP-TR-22, Southwest Research Institute, San Antonio, TX, October 1972.

23 S. C. Grigory, Tests of Six-Inch-Thick Flawed Tensile Specimens, Fourth Technical Summary Report, Tests of One-Inch Thick Flawed Tensile Specimens for Size Effect Evaluation, HSSTP-TR-23, Southwest Research Institute, San Antonio, TX, June 1973.

24 S. P. Ying and S. C. Grigory, Tests of Six-Inch-Thick Tensile Specimens, Fifth Technical Summary Report, Acoustic Emission Monitoring of One-Inch and Six-Inch-Thick Tensile Specimens, HSSTP-TR-24, Southwest Research Institute, San Antonio, TX, November 1972.

25 R. W. Derby, et al., Test of Six-Inch-Thick Pressure Vessels, Series 1: Intermediate Test Vessels V-1 and V-2, ORNL-4895, Oak Ridge National Laboratory, Oak Ridge, TN, February 1974.

26 W. J. Stelzman and R. G. Berggren, Radiation Strengthening and Embrittlement in Heavy Section Plates and Welds, ORNL-4871, Oak Ridge National Laboratory, Oak Ridge, TN, June 1973.

27 P. B. Crosley and E. J. Ripling, Crack Arrest in an Increasing K-Field, HSSTP-TR-27, Materials Research Laboratory, Glenwood, IL, January 1973.

28 P. V. Marcal, P. M. Stuart and R. S. Bettes, Elastic-Plastic Behavior of a Longitudinal Semi-Elliptical Crack in a Thick Pressure Vessel, HSSTP-TR-28, Brown University, Providence, RI, June 1973.

31 J. A. Williams, The Irradiation and Temperature Dependence of Tensile and Fracture Properties of ASTM A533, Grade B, Class 1 Steel Plate and Weldment, HEDL-TME 73-75, Hanford Engineering Development Laboratory, Richland, WA, August 1973.

Report
No.

32 J. M. Steichen and J. A. Williams, High Strain Rate Tensile Properties of Irradiated ASTM A533 Grade B, Class 1 Pressure Vessel Steel, HEDL-SA 581, Hanford Engineering Development Laboratory, Richland, WA, July 1973.

33 P. C. Riccardella and J. L. Swedlow, A Combined Analytical-Experimental Fracture Study, WCAP-8224, Westinghouse Electric Corporation, PWR Systems Division, Pittsburgh, PA, October 1973.

34 R. J. Podlasek and R.J. Eiber, Investigation of Mode III Crack Extension in Reactor Piping. Final Report, HSSTP-TR-34, Battelle Columbus Laboratories, Columbus, OH, May 1974.

35 T. R. Mager, et al., Interim Report on the Effect of Low Frequencies on the Fatigue Crack Growth Characteristics of A533 Grade B, Class 1 Plate in an Environment of High-Temperature Primary Grade Nuclear Reactor Water, WCAP-8256, Westinghouse Electric Corporation, Pittsburgh, PA, December 1973.

36 J. A. Williams, The Irradiated Fracture Toughness of ASTM A533, Grade B, Class 1 Steel Measured with a Four-Inch-Thick Compact Tension Specimen, HEDL-TME 75-10, Hanford Engineering Development Laboratory, Richland, WA, January 1975.

37 R. H. Bryan et al., Test of Six-Inch-Thick Pressure Vessels, Series 2: Intermediate Test Vessels V-3, V-4, and V-6, ORNL-5059, Oak Ridge National Laboratory, Oak Ridge, TN, November 1975.

38 T. R. Mager, S. E. Yanichko and L. R. Singer, Fracture Toughness Characterization of HSST Intermediate Pressure Vessel Material, WCAP-8456, Westinghouse Electric Corporation, Pittsburgh, PA, December 1974.

39 J. G. Merkle, G. D. Whitman and R.H. Bryan, An Evaluation of the HSST Program Intermediate Pressure Vessel Tests in Terms of Light-Water Reactor Pressure Vessel Safety, ORNL-TM-5090, Oak Ridge National Laboratory, Oak Ridge TN, November 1975.

40 J. G. Merkle et al., Test of Six-Inch-Thick Pressure Vessels, Series 3: Intermediate Test Vessel V-7, ORNL/NUREG-1, Oak Ridge National Laboratory, Oak Ridge, TN, August 1976.

41 J. A. Davidson, L. J. Ceschini, R. P. Shogan and G. V. Rao, The Irradiated Dynamic Fracture Toughness of ASTM A533, Grade B, Class 1 Steel Plate and Submerged Arc Weldment, WCAP-8775, Westinghouse Electric Corporation, Pittsburgh, PA, October 1976.

Report
No.

42 R. D. Cheverton, Pressure Vessel Fracture Studies Pertaining to a PWR LOCA-ECC Thermal Shock: Experiments TSE-1 and TSE-2, ORNL/NUREG-31, Oak Ridge National Laboratory, Oak Ridge, TN, September 1976.

43 P. P. Holz, J. G. Merkle, G. C. Robinson and J. E. Smith, Test of Six-Inch-Thick Pressure Vessels, Series 4: Intermediate Test Vessels V-5 and V-9, with Inside Nozzle Corner Cracks, ORNL/NUREG-7, Oak Ridge National Laboratory, Oak Ridge, TN, August 1977.

44 J. A. Williams, The Ductile Fracture Toughness of Heavy Section Steel Plate, NUREG/CR-0859, HEDL-TME 77-1, Hanford Engineering Development Laboratory, Richland, WA, September 1979.

45 R. H. Bryan, T. M. Cate, P. P. Holz, T. A. King, J. G. Merkle, G. C. Robinson, G. C. Smith, J. E. Smith and G. D. Whitman, Test of 6-In.-Thick Pressure Vessels. Series 3: Intermediate Test Vessel V-7A Under Sustained Loading, ORNL/NUREG-9, Oak Ridge National Laboratory, Oak Ridge, TN, February 1978.

46 R. D. Cheverton and S. E. Bolt, Pressure Vessel Fracture Studies Pertaining to a PWR LOCA-ECC Thermal Shock: Experiments TSE-3 and TSE-4 and Update of TSE-1 and TSE-2 Analysis, ORNL/NUREG-22, Oak Ridge National Laborat[illegible] Ridge, TN, December 1977.

47 D. A. Canonico, Significance of Reheat Cracks to the Integrity of Pressure Vessels for Light-Water Reactors, ORNL/NUREG-15, Oak Ridge National Laboratory, Oak Ridge, TN, July 1977.

48 G. C. Smity and P. P. Holz, Repair Weld Induced Residual Stresses in Thick-Walled Steel Pressure Vessels, NUREG/CR-0093, ORNL/NUREG/TM-153, Oak Ridge National Laboratory, Oak Ridge, TN, June 1978.

49 P. P. Holz and S. W. Wismer, Half-Bead (Temper) Repair Welding for HSST Vessels, NUREG/CR-0113 ORNL/NUREG/TM-177, Oak Ridge National Laboratory, Oak Ridge, TN, June 1978.

50 G. C. Smith, P. P. Holz and W. J. Stelzman, Crack Extension and Arrest Tests of Axially Flawed Steel Model Pressure Vessels, NUREG/CR-0126, ORNL/NUREG/TM-196, Oak Ridge National Laboratory, Oak Ridge, TN, October 1978.

51 R. H. Bryan, P. P. Holz, J. G. Merkle, G. C. Smith, J. E. Smith and W. J. Stelzman, Test of 6-In.-Thick Pressure Vessels. Series 3: Intermediate Test Vessel V-7B, NUREG/CR-0309, ORNL/NUREG-38, Oak Ridge National Laboratory, Oak Ridge, TN, October 1978.

Report No.	
52	R. D. Cheverton, S. K. Iskander and S. E. Bolt, Applicability of LEFM to the Analysis of PWR Vessels Under LOCA-ECC Thermal Shock Conditions, NUREG/CR-0107, ORNL/NUREG-40, Oak Ridge National Laboratory, Oak Ridge, TN, October 1978.
54	R. D. Cheverton, Application of Static and Dynamic Crack Arrest Theory to TSE-4, NUREG/CR-0767, ORNL/NUREG-57, Oak Ridge National Laboratory, Oak Ridge, TN, June 1979.

CONVERSIONS

Temperature:	$^{o}F = 9/5(^{o}C) + 32$
Length:	1 cm = 0.3937 in.
	1 mm = 0.03937 in.
Stress:	1 MPa = 0.145 ksi

TENSILE PROPERTIES OF IRRADIATED AND UNIRRADIATED WELDS OF A533 STEEL PLATE AND A508 FORGINGS

I. SUMMARY

Tensile properties of one weld of ASTM A533, Grade B, Class 1 plate base metal (Weld 61W) and two welds of A508 Class 1 forging base metal (Welds 62W and 63W) irradiated to 3 to 21 x 10^{18} n/cm^2 (E > 1 MeV) at temperatures between 260^{o}C and 371^{o}C were evaluated. Strength properties of all three welds increased with higher exposures producing higher strengths after irradiation. Yield strength was found to be more sensitive to irradiation than ultimate strength. The tensile ductility was reduced slightly to a level which was independent of fluence. Welds 61W and 63W in general exhibited greater losses in strength and ductility than did Weld 62W, possibly because of differences in chemical composition.

II. INTRODUCTION

The Heavy Section Steel Technology (HSST) program is sponsored by the Nuclear Regulatory Commission (NRC) with the objective of gaining better insight into the mechanisms that could potentially cause reactor vessel failure or improve the quality of reactor vessel steels. In order to assess material behavior, irradiations were conducted by the HSST program office at ORNL to produce a variety of irradiated material conditions representative of reactor environments. Irradiation experiments containing tensile, fracture and impact specimens were conducted. The objective of the work reported herein was to assess the irradiated tensile properties of three weld materials irradiated in the HSST "Second 4T-CT Experiment."

III. EXPERIMENTAL

A. MATERIALS AND SPECIMENS

One weld of base metal ASTM A533, Grade B, Class 1 plate and two welds of base metal ASTM A508 Class 2 forging, hereafter referred to as 61W, 62W and 63W, respectively, were irradiated in the ORNL Bulk Shielding Reactor (BSR). All welds were made by the submerged-arc process. The complete irradiation experiment was conducted by ORNL(1) and tensile specimens, both irradiated and unirradiated, were supplied by ORNL.

The chemical composition of Welds 61W, 62W and 63W are given in Table 1. The analysis represents the range of compositions determined from Charpy specimens and from weld analysis supplied by vendors. The orientation of all tensile specimens was weld transverse. Two types of miniature tensile specimens were used in this study and are shown in Figure 1. Specimen sizes and designs were primarily dictated by the physical space available for specimen irradiation. The specimen gage diameter was 4.52 mm; both short (29.24 mm) and long (31.75 mm) gage length specimens were tested. Table 2 gives the distribution of specimens by irradiation temperature and neutron fluence. The specimens in parentheses had irradiation temperatures in more than one range for a significant period of the irradiation time. Thus, some specimens are shown in two matrix positions or overlapping two positions. The specimen test temperatures are shown in brackets for each specimen. The test temperatures were chosen to yield a range of data which can be treated by a rate-temperature parameter.

B. TESTING AND DATA ANALYSIS

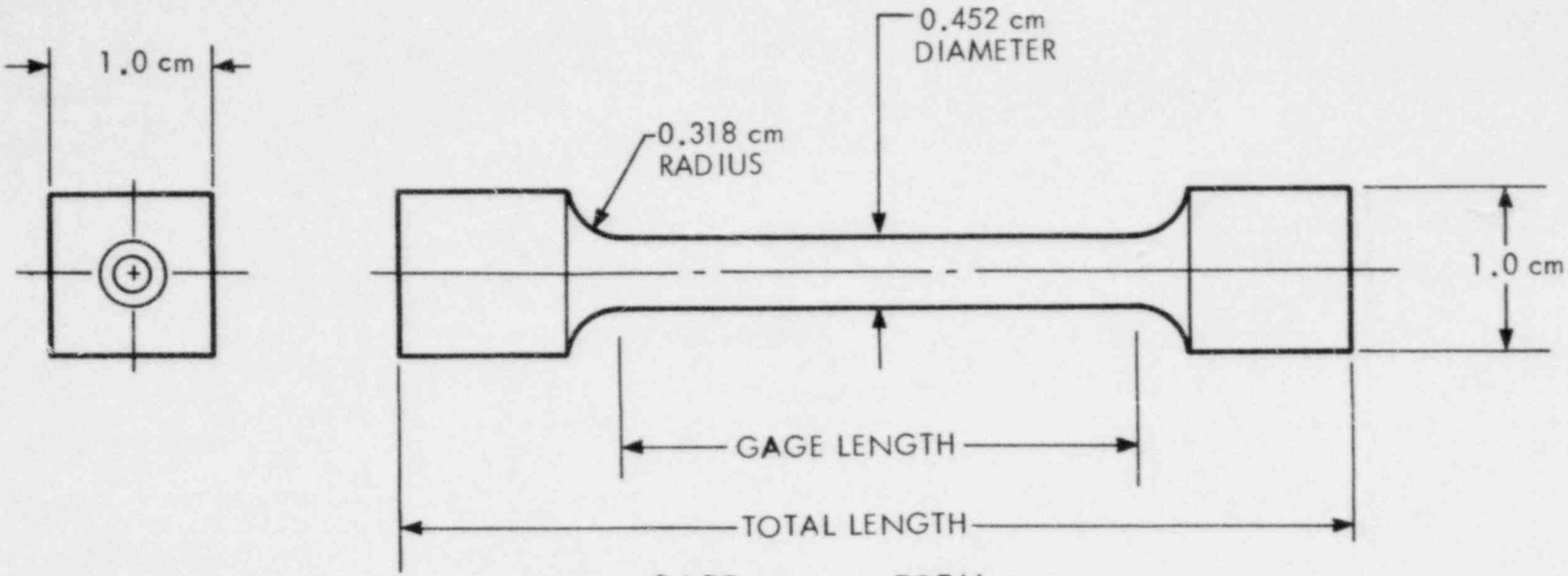
The test setup including the test furnace, specimen grips and extensometer system is shown in Figure 2. The same test apparatus and setup were used for both unirradiated and irradiated tensile tests, all of which were conducted in an air environment.

TABLE 1

CHEMICAL COMPOSITIONS OF WELDS 61W, 62W AND 63W

Material	% Element									
	C	Mn	P	S	Si	Cr	Ni	Mo	Cu	V
Weld 61W	0.10*/0.07	1.52/1.43	0.021/0.018	0.015/0.014	0.58/0.54	0.17/0.16	0.64/0.62	0.38/0.36	0.34/0.24	0.005
Weld 62W	0.088/0.082	1.57/1.41	0.020/0.013	0.008/0.007	0.60/0.57	0.17/0.067	0.550/0.495	0.390/0.367	0.243/0.16	0.011/0.010
Weld 63W	0.109/0.088	1.67/1.618	0.0175/0.0163	0.012/0.010	0.675/0.618	0.118/0.073	0.707/0.603	0.440/0.415	0.326/0.272	0.0125/0.010

*Range of compositions, high/low



	GAGE LENGTH	TOTAL LENGTH
LONG SPECIMEN	3.175 cm	5.5 cm
SHORT SPECIMEN	2.924 cm	5.0 cm

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FIGURE 1. Tensile Specimen Configurations for Both Irradiated and Unirradiated Materials.

TABLE 2

IRRADIATION FLUENCE AND TEMPERATURE DISTRIBUTION FOR TENSILE SPECIMEN
FROM SECOND 4T IRRADIATION

Specimen	Fluence ($n/cm^2 \times 10^{18}$)	Irradiation Temperature (^oC) 232-260	260-293	293-316	316-343	343-371
Capsule A, Weld 61W	4			61W5 [RT]		
				61W6 [288]		
	7-10				61W-7 [RT]*	61W-8 [RT]
					61W-9 [RT]	
	12		61W-3 [RT]			
			61W-4 [149]			
	15		61W-1 [RT]			
			61W-2 [288]			
Capsule B, Weld 62W	5		(62W-13) [149]			
			(62W-19) [288]			
	8-11	(62W-2)** [RT]		(62W-2) (62W-1) [RT]		
				62W-3 [RT]		
	14-15		62W-10 [RT]			
			62W-11 [288]			
			62W-8 [RT]			
			62W-9 [149]			
Capsule C, Weld 63W	4		63W-5 [RT]			
			63W-9 [288]			
	7-10			63W-14 [RT]		
				63W-15 [RT]	(63W-15)	
			(63W-13) [RT]		(63W-13)	
	13		63W-3 [RT]			
			63W-4 [149]			
			63W-1 [RT]			
			63W-2 [288]			

*Brackets [ ] indicate test temperatures (^oC). [RT]= Room Temperature.
**Parentheses ( ) indicate specimens with multiple irradiation temperatures.

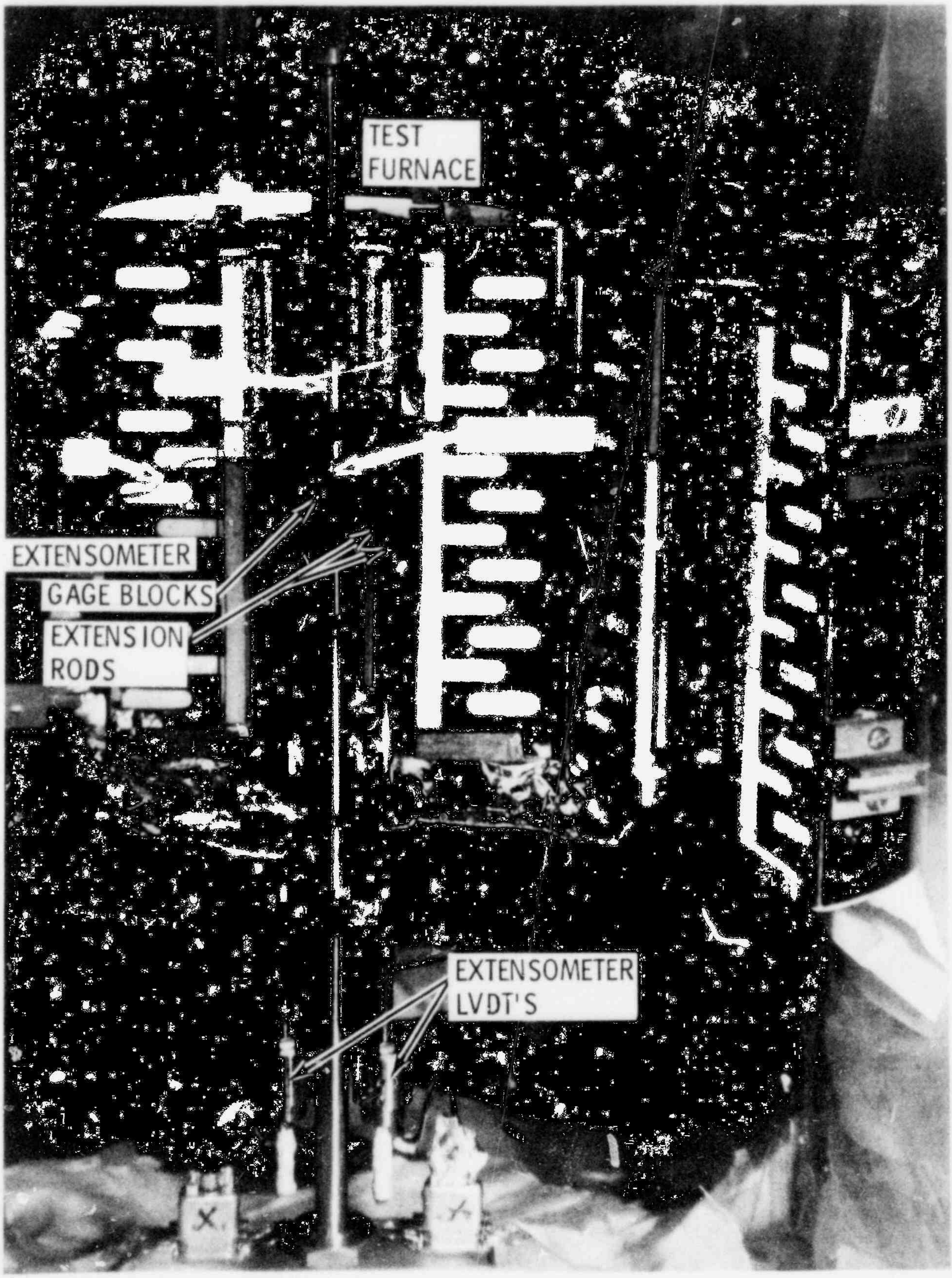

FIGURE 2. Hot Cell Test Setup for Irradiated Tensile Testing of Specimens from 4T Irradiations. Neg 7803376-1

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The tests were conducted at room temperature, at 149°C and at 288°C for all unirradiated weldments; short and long specimens were tested at each temperature. Irradiated specimens, as the number available permitted, were tested at the same temperatures as the unirradiated specimens. However, where only one specimen was available for a given fluence and irradiation temperature condition, the specimen was tested at room temperature. Specimens were tested on a 44.5-kN capacity Instron test machine. Specimen strain rates calculated from extensometer data were in the range of 10^{-4} to 10^{-3} s^{-1}.

An extensometer with a 12.7-mm effective gage length was attached directly to the gage section of the specimens; the extensometer was designed to measure strain through at least the point of maximum load (ultimate strength). The same effective gage length was used on both long and short specimens. Dual LVDTs of the extensometer were algebraically summed to eliminate effects of bending during the initial portion of the test. A verification of the extensometer in actual test application was conducted by high-resolution recording of the elastic load-deflection curve; linearity of the recorded curve was better than 1%, and no hysteresis was observed on unloading. The elastic modulus was observed to 2.04 x 10^5 Mpa, which is within the known range for this class of material. Calibrated accuracy of the extensometer was better than 0.1% of range and within 0.1% linearity.

The extensometer system was developed as part of the test setup to facilitate direct computerization of test results. Thus, a computer-controlled digital data acquisition system recorded load and extension measurement signals directly; the crosshead motion and the load were also recorded on the test machine recorder. Upon completion of the test, specimen measurements of uniform final gage diameter, neck diameter and final total length were made. These were then placed in the computer data bank where they were analyzed by computer program, producing tables and plots of properties. The initial raw data and processed data were stored on a tape cartridge.

IV. RESULTS AND DISCUSSION

The tensile properties of Welds 61W, 62W and 63W are summarized for both irradiated materials and unirradiated materials in Tables 3 and 4, respectively. Preirradiation strength and ductility values are very similar for all three welds, with Weld 62W showing only slightly lower strength properties at the highest test temperature.

A. IRRADIATION EFFECT ON YIELD AND ULTIMATE STRENGTH

Irradiation to a fluence of 4 to 15 x 10^{18} n/cm^2 (E > 1 MeV) at 260°C to 293°C produced a pronounced effect on strength properties of all three welds, as illustrated in Figures 3, 4 and 5. Postirradiation yield strength exceeded preirradiation ultimate strength for all weld materials investigated. The yield strength was more sensitive to irradiation than was the ultimate strength, with yield strength properties at 26°C increased by an average of 30% while ultimate strength increased by about 19% after irradiation. Results in Figure 6 demonstrate that most of the strength increase was already achieved at the lowest fluence levels examined, but that some further strength increase occurs with increasing fluence. All three welds exhibit a similar irradiation sensitivity as measured by the general level of irradiation strengthening, but strength increments are about 20% larger for Welds 61W and 63W than for Weld 62W (Figure 6). The data also suggest that higher irradiation temperatures may produce slightly less strengthening in Weld 61W.

B. IRRADIATION EFFECT ON TENSILE DUCTILITY

The change in ductiltiy properties measured at 26°C is, with the possible exception of reduction of area for Weld 62W, independent of neutron exposure, as illustrated in Figure 7. Table 5 compares the ratios of irradiated material ductility to unirradiated material ductility determined using average ductility values for all exposures at each test temperature. Both Figure 7 and Table 5 illustrate that irradiation-induced losses in ductility are small (i.e. $\leq$ 17% on a relative basis).

TABLE 3

TENSILE PRROPERTIES OF UNIRRADIATED WELDS OF ASTM A533, GRADE B, CLASS 1 STEEL PLATE (WELD TRANSVERSE)

Specimen No.	Test Temp (°C)	Yield Strength (MPa)	Ultimate Strength (MPa)	Uniform Strain (%)	Reduction in Area (%)	Total Elongation (%)
61W10	26	484	601	10.4	.5.7	16.5
61W12*	26	476	597	10.4	66.0	20.3
61W11	149	445	546	8.3	66.2	17.2
61W13*	149	443	549	8.3	64.7	18.2
61W14*	228	420	534	7.1	64.5	15.5
61W15	288	416	539	7.0	63.2	16.4
62W4	26	477	594	10.1	67.0	18.1
62W12*	26	469	588	9.7	65.0	19.5
62W5	149	430	536	9.2	68.0	15.0
62W14*	149	426	531	9.5	69.3	16.7
62W6	288	382	514	8.0	65.5	14.2
62W15*	288	388	513	8.0	61.5	15.2
63W16	26	482	600	10.5	67.9	19.4
63W6*	26	482	601	10.0	66.8	21.5
63W17	149	440	544	8.6	65.7	18.4
63W7*	149	423	546	8.6	68.7	17.6
63W18	288	414	530	8.1	63.3	17.0
63W8*	288	405	530	7.2	63.6	16.2

*Short specimens, all other are long specimens (see Figure 1).

TABLE 4

TENSILE PROPERTIES OF IRRADIATED WELDS OF ASTM A533, GRADE B, CLASS 1 STEEL PLATE (WELD TRANSVERSE)

Specimen No.	Irradiation Fluence $n/cm^2 \times 10^{18}$ ($E > 1$ MeV)	Irrad.* Temp (^oC)	Test Temp (^oC)	Yield Strength (MPa)	Ultimate Strength (MPa)	Uniform Strain (%)	Reduction in Area (%)	Total Elongation (%)
61W8	8	327/360	28	580	678	9.3	59.0	15.7
61W7	10	277	28	594	699	9.3	56.9	17.0
61W9	7	327	28	583	700	9.6	57.4	16.9
61W5**	4	304	28	605	703	8.6	56.8	17.4
61W3**	12	288	28	632	724	8.9	58.9	17.6
61W1**	15	288	28	631	724	8.9	59.7	17.5
61W4**	12	277	149	575	672	9.3	59.7	15.5
61W2**	15	277	288	544	660	8.4	50.1	17.8
61W6**	4	298	288	499	625	6.5	61.4	14.1
62W10**	14	291	26	602	697	10.0	60.8	18.9
62W8**	15	282	26	621	705	9.4	58.6	13.1
62W3	8	303	26	576	678	9.5	67.8	18.4
62W2	8	256/306	26	593	693	10.4	63.5	18.1
62W1	11	313	26	575	678	10.3	61.8	18.2
62W13**	5	267	149	539	627	8.3	57.8	16.3
62W9**	15	277	149	572	661	8.1	61.4	15.0
62W11**	15	274	288	520	632	8.3	53.2	15.7
62W19**	5	269	288	476	605	7.7	58.2	15.5
63W15	8	290/341	28	581	681	10.3	58.5	17.5
63W5**	4	288	28	609	701	9.4	61.9	17.1
63W1**	13	285	27	628	718	9.6	55.9	15.9
63W13	9	286/330	28	603	695	9.4	53.1	17.7
63W3**	13	285	28	625	712	9.0	59.5	17.6
63W14	7	315/290	28	598	694	10.0	63.0	17.1
63W4**	13	278	149	587	683	8.0	56.7	15.7
63W2**	13	278	288	536	636	6.8	57.5	15.6
63W9**	4	286	288	526	639	5.8	56.4	16.6

* Represents average temperatures during irradiation. Refer to Table II for temperature range. Two values are given where temperature ranges were significantly different due to capsule rotation during irradiation.

** Short specimen; all others are long specimens (Figure 1).

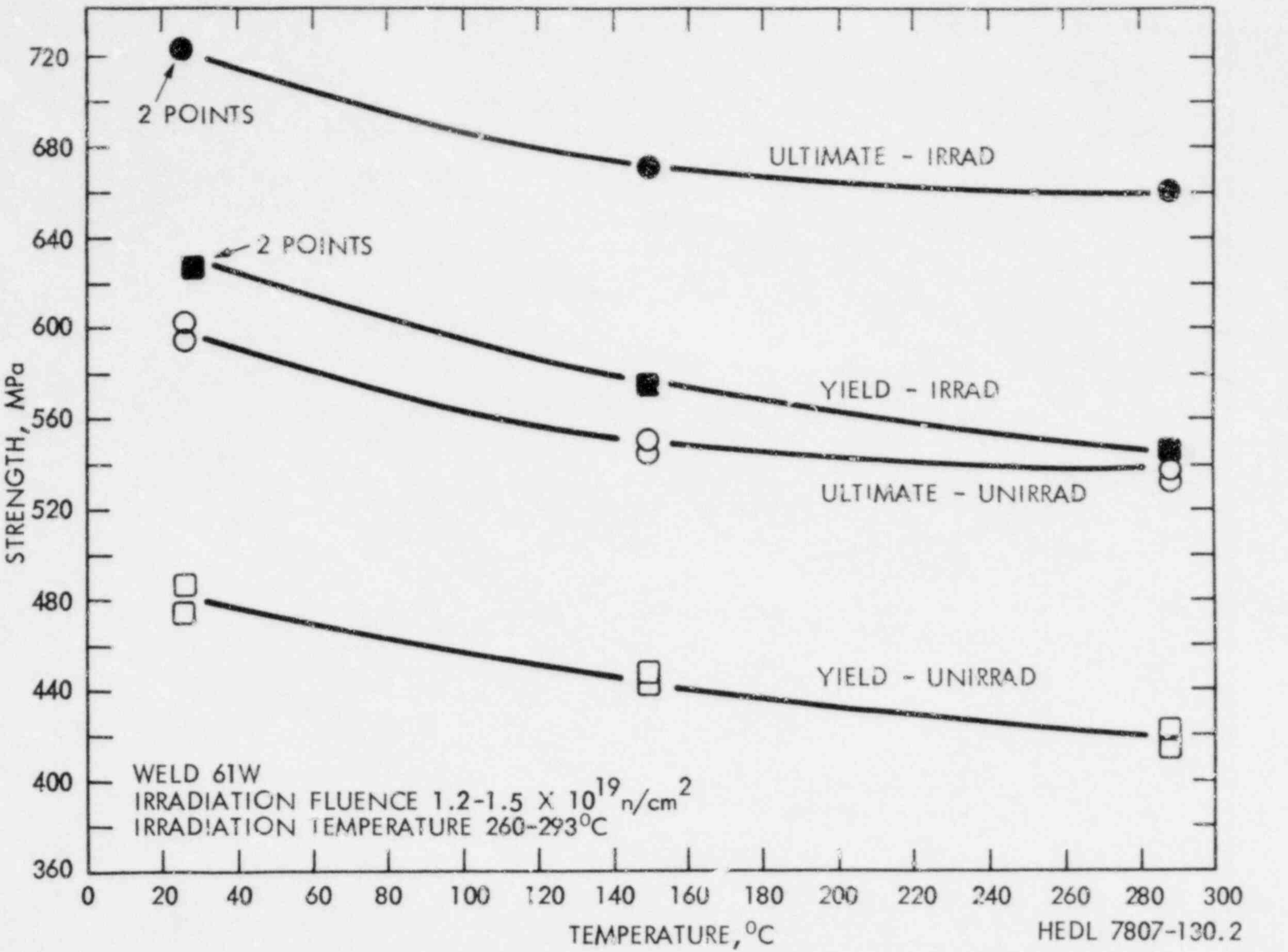

FIGURE 3. Yield and Ultimate Strengths for Unirradiated and Irradiated Weldment 61W from Second 4T Irradiation.

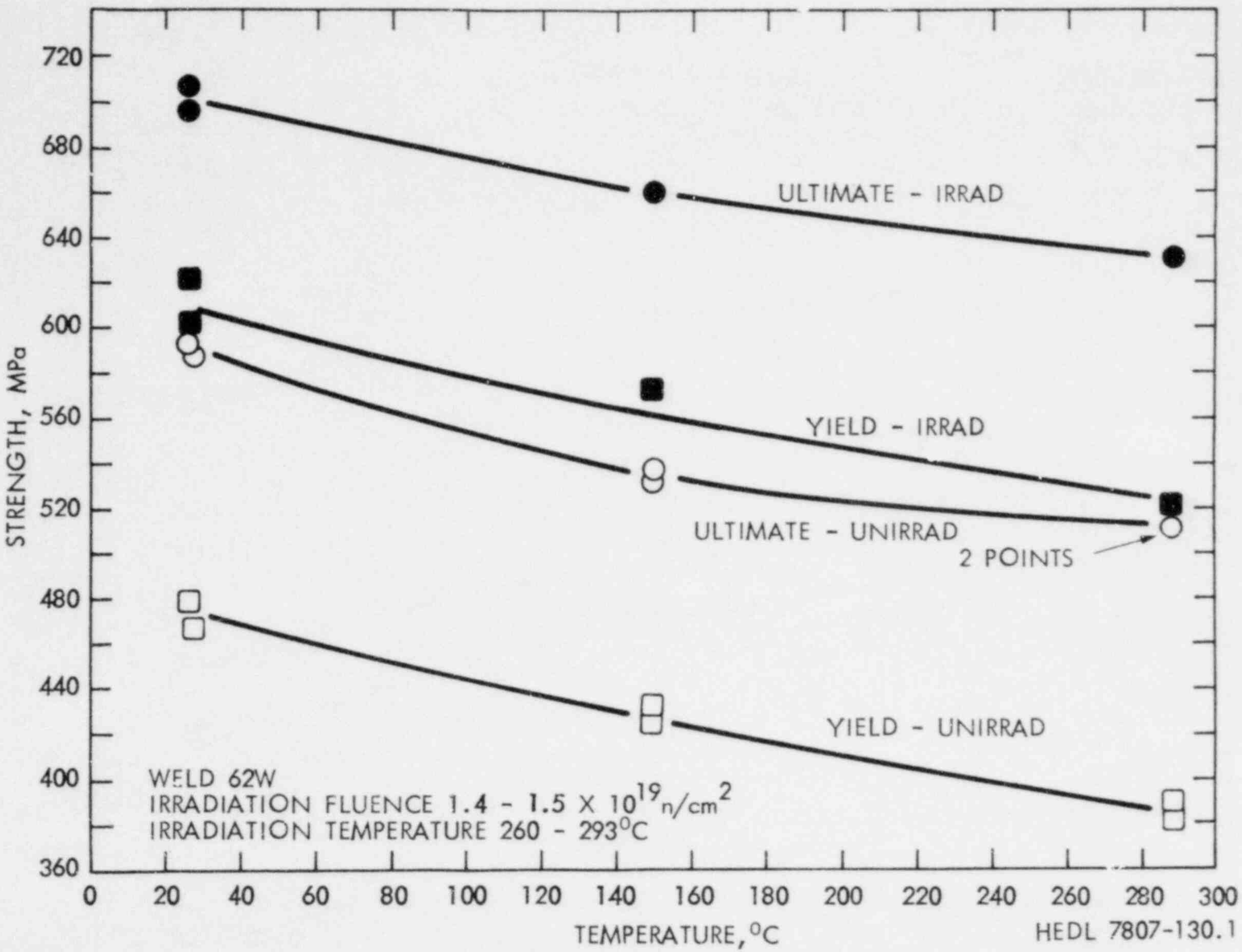

FIGURE 4. Yield and Ultimate Strengths for Unirradiated and Irradiated Weldment 62W from Second 4T Irradiation.

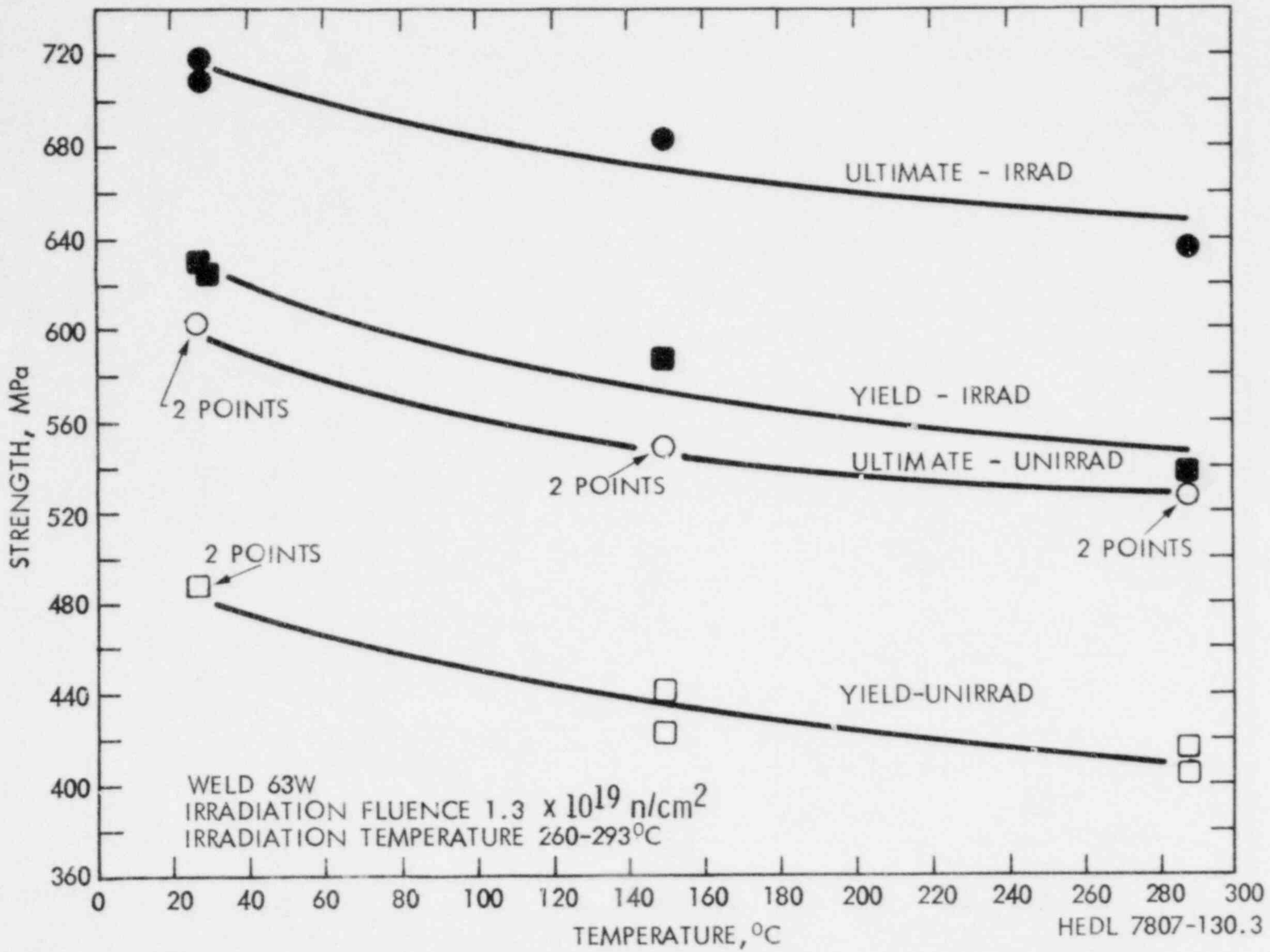

FIGURE 5. Yield and Ultimate Strengths for Unirradiated and Irradiated Weldment 63W from Second 4T Irradiation.

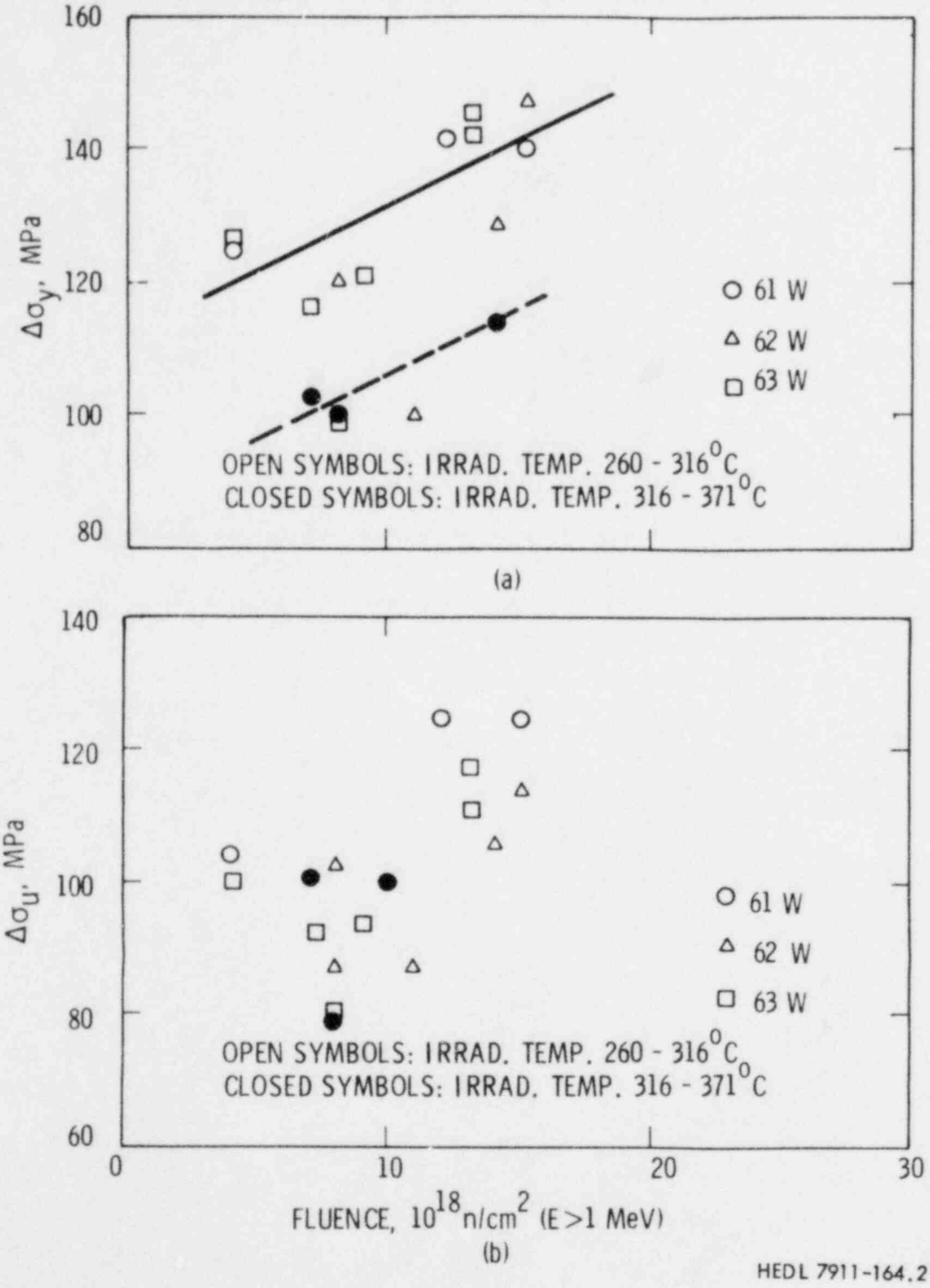

FIGURE 6. The Change in Room Temperature Yield Strength (A) amd Ultimate Strength (B) of Welds 61W, 62W and 63W as a Function of Irradiation Fluence.

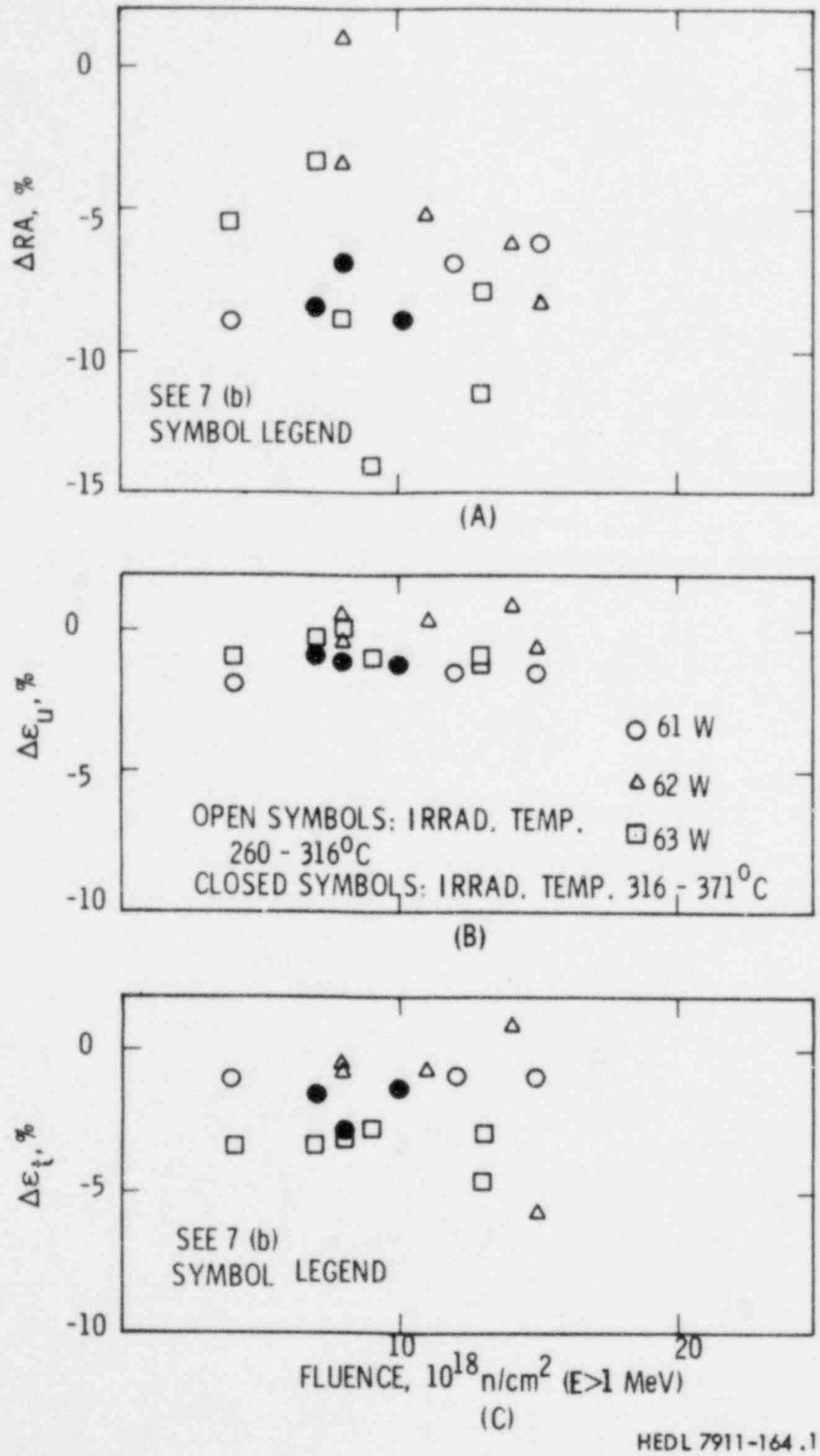

FIGURE 7. The Change in (A) Reduction of Area (RA), (B) Uniform Strain (ε_u), and (C) Total Elongation (ε_t) of Welds 61W, 62W and 63W as a Function of Irradiation Fluence.

TABLE 5

RATIO OF IRRADIATED MATERIAL DUCTILITY
TO UNIRRADIATED MATERIAL DUCTILITY

	Irradiated Property/Unirradiated Property			
Weld Material	Reduction of Area (Neck)	Uniform Strain	Total Elongation	Test Temp (^{o}C)
61W	0.88	0.88	0.92	26
62W	0.95	1.00	0.98	26
63W	0.87	0.93	0.83	26
61W	0.87	1.06	1.00	288
62W	0.89	1.00	1.06	288
63W	0.90	0.83	0.97	288

Losses in reduction of area tend to be larger than changes in the other two ductility properties for Welds 61W and 62W. However, for Weld 63W, the largest property losses are for uniform strain or total elongation, depending on test temperature. Overall the sensitivity of ductility properties to irradiation was less for Weld 62W than for Welds 61W and 63W. Since the composition ranges for Ni, Cu, C and S are higher for Welds 61W and 63W than for Weld 62W, these constituents may contribute to increased sensitivity of tensile ductility to irradiation.

C. TEMPERATURE-STRAIN RATE CORRELATION OF YIELD AND ULTIMATE STRENGTH

It has been demonstrated previously[2,3] that the materials similar to those of this study correlate well with a rate-temperature parameter, Θ , to relate yield and ultimate strength response to test temperatures and test strain rates. In Figures 8, 9 and 10 the theta parameter as described by

$$\Theta = T \ln (10^8/\dot{\varepsilon})$$

where: $T =$ Kelvin

$\dot{\varepsilon} =$ Strain rate

is used to correlate yield and ultimate strengths of Welds 61W, 62W and 63W, respectively.

The yield and ultimate correlations are observed to be of sufficient quality to estimate properties at other test temperatures and strain rates of interest. Similar correlations were attempted for ductility properties; however, the limited number of specimens and the relatively large degree of scatter precluded development of significant correlations.

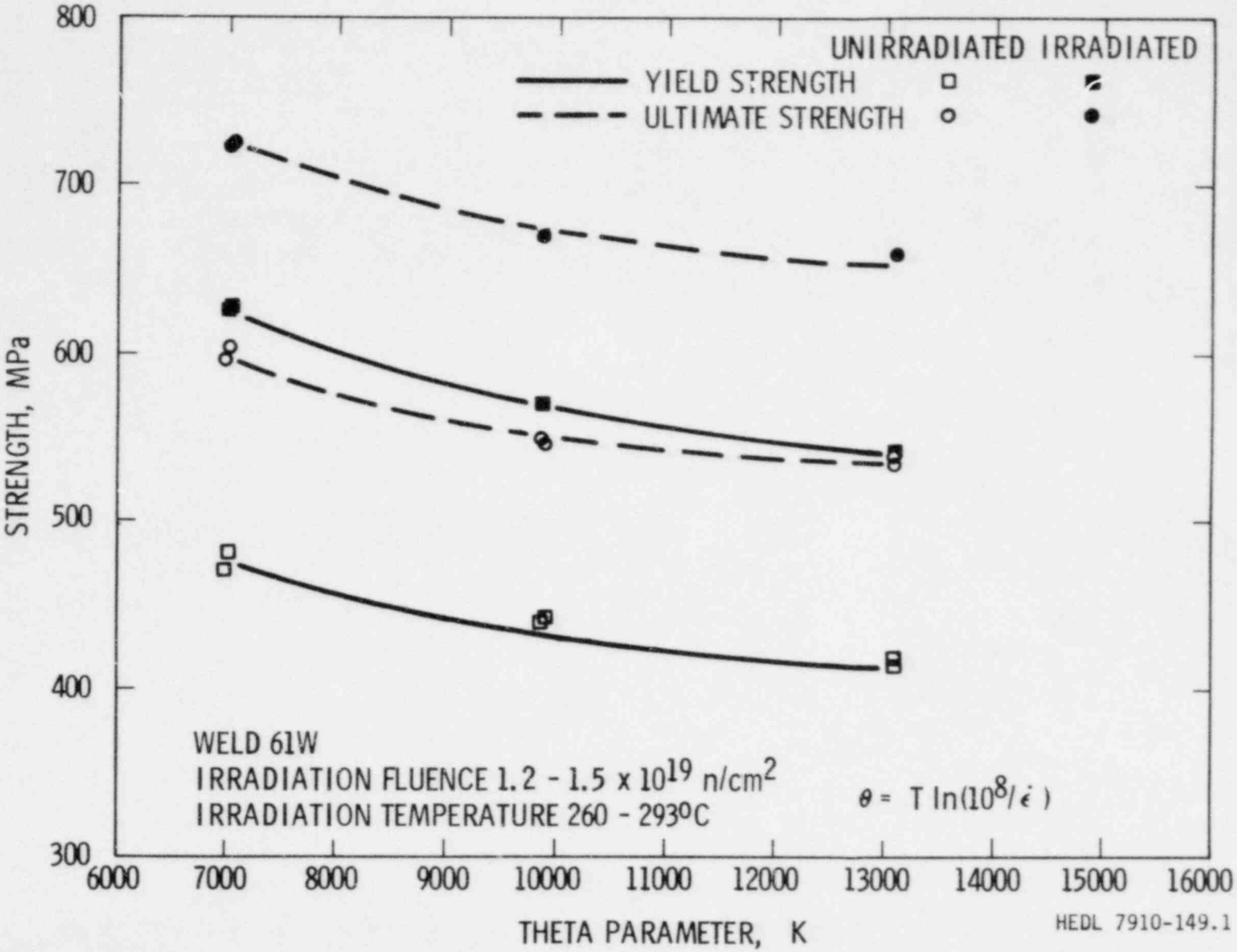

FIGURE 8. Rate-Temperature Correlation of Yield and Ultimate Strength of Irradiated and Unirradiated Weld 61W. Neg P07234-1

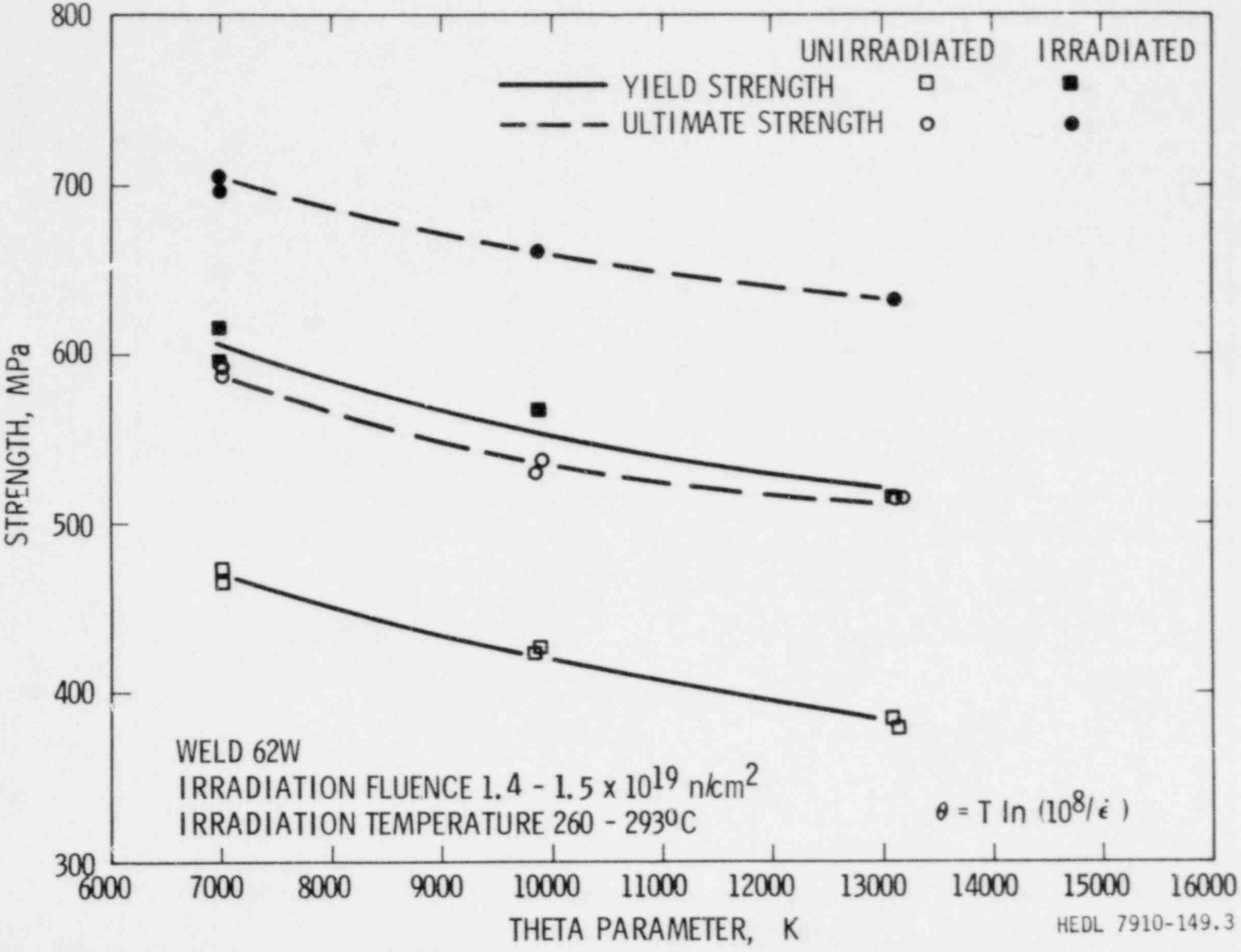

FIGURE 9. Rate-Temperature Correlation of Yield and Ultimate Strength of Irradiated and Unirradiated Weld 62W. Neg P07234-3

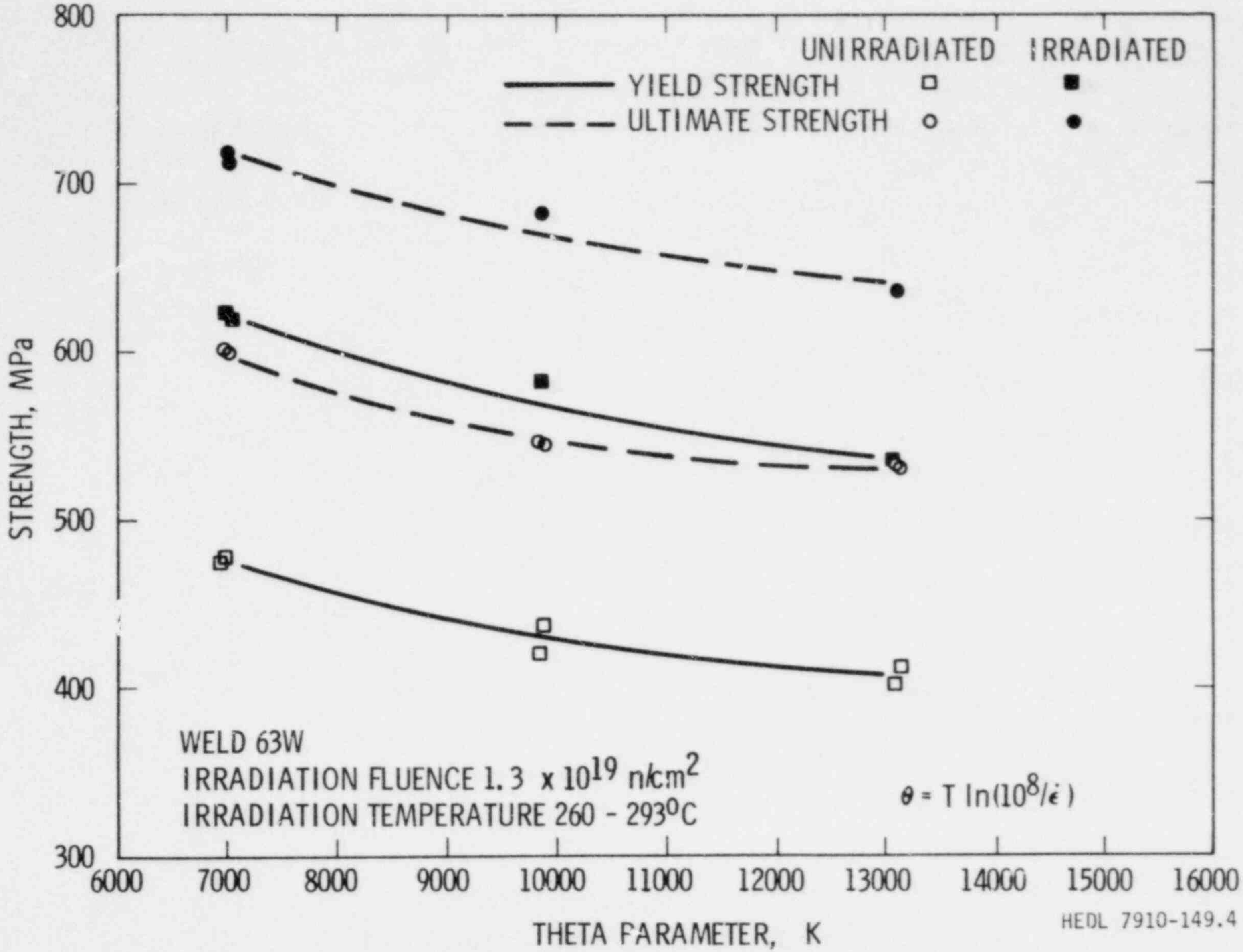

FIGURE 10. Rate-Temperature Correlation of Yield and Ultimate Strength of Irradiated and Unirradiated Weld 63W. Neg P07234-4

V. CONCLUSIONS

1) Irradiation of fluence levels in the range 4 to 15 x 10^{18} n/cm^2 (E > 1 MeV) produced significant strengthening in all three weld materials, with yield strength increases being greater than ultimate strength increases. Losses in ductility were relatively small.

2) Weld 62W exhibited less strength increase and less reduction in ductility than did Welds 61W and 63W. These differences may be associated with chemical composition variations.

3) Yield and ultimate strength properties were correlated with a rate-temperature parameter which can be used to estimate strength properties at other test strain rate or temperature conditions of interest.

VI. REFERENCES

1. R. G. Berggren and G. D. Whitman, "HSST 4T Irradiation Series Results, Testing Plans and Initial Planning for Fourth Irradiation Experiment," Minutes of NRC Vessel Integrity Review Group Meeting, Silver Springs, MD, November 30, 1978.

2. J. A. Williams, The Irradiation and Temperature Dependence of Tensile and Fracture Properties of ASTM A533, Grade B, Class 1 Steel Plate and Weldment, HEDL-TME 73-75, Hanford Engineering Development Laboratory, Richland, WA, August 1973.

3. J. M. Steichen and J. A. Williams, High Strain Rate Tensile Properties of Irradiated ASTM A533 Grade B, Class 1 Pressure Vessel Steel, HEDL-TME 73-16, Hanford Engineering Development Laboratory, Richland, WA, July 1973.

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16. ABSTRACT (200 words or less)

The tensile properties of welds of base metals ASTM A533, Grade B, Class 1 steel plate and ASTM A508, Class 1 forgings were evaluated in irradiated (3 to 21 x 10^{18} n/cm^2) and unirradiated conditions. Yield strength and ultimate strength both increased with increasing fluence, while small ductility losses were generally independent of fluence. Yield strength was found to be more sensitive to irradiation than ultimate strength for all welds. The strength and ductility responses to irradiation varied between the weld materials. These variations were attributed to differences in chemical constituents of the welds.

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