**DATA PACKAGE
FRACTURE TOUGHNESS OF WELDS 61W, 62W AND 63W
FROM SECOND 4T IRRADIATIONS --
0.5TCT SPECIMEN TESTS**

Hanford Engineering Development Laboratory

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ABSTRACT

Fracture toughness determinations were made on irradiated welds 61W, 62W and 63W from the HSST second 4T irradiations. All fracture specimens were 0.5 in. thick compact specimens. Tests were conducted from upper transition through upper shelf in the range of 75 to 500°F. The data package includes testing and analysis methods, tabulations of fracture toughness data, toughness versus temperature curves, J-R curves, J-R data for each unloading compliance test specimen, calculated and measured physical crack lengths, fracture specimen photographs with descriptive information and strength property curves of each weld material.

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TESTING METHOD

The fracture toughness tests of this data package were conducted as per the procedure given below. A quality assurance plan submitted to G. D. Whitman, January 29, 1979, outlines Q.A. requirements of HSST program operations at HEDL. Calibrations of all test machines, measuring devices, and data indicating and recording devices are directly traceable to NBS.

The tests were conducted as follows:

1. Specimens were visually examined as to their general appearance and integrity.
2. Specimens were loaded into the test machine. During this step load-line extensometers and thermocouples were attached to the specimen and the specimens were aligned in the specimen grips. Shims were used to assure centering of specimen in grips; shims were subsequently removed after setting a small preload (specimen thickness X 50 lb.) on the specimen. Preload was necessary for maintaining alignment of the test specimen and was accounted for within the computer program.
3. A "Test Ready" analysis was conducted at room temperature. The following steps are included.
 - 3.1 System stability analysis is conducted by sampling the load signal and load-line extensometer systems. For each signal, 100 readings are taken and a 95% confident limit on the signal stability is obtained. Generally, the 95% confident level of stability was 4.5 lbs. or better for load, 15 microinches or better for the dual LVDT load-line extensometer and 80 microinches or better for the clip gage load-line extensometer.
 - 3.2 Ten unloadings were conducted at low elastic load. Approximately 250 load-deflection pairs were taken and analyzed by the computer to determine the compliance of each unloading.

- 3.3 The computer analysis determined the mean and standard deviations of compliances and crack lengths for the ten unloadings as indicated by each load-line extensometer used on the system.
- 3.4 When standard deviations of calculated crack length of less than 0.001 inch were obtained for the dual LVDT load-line extensometer system, a "Test-Ready" condition was considered to exist. The clip gage system standard deviation was generally in the range of 0.005 or less. The irradiated test specimens of this series had machined knife edges which are unsuitable for obtaining highly reproducible (low standard deviation on calculated crack length) clip gage results and were therefore considered unreliable indicators of "Test-Ready" conditions. Standard deviations of less than 0.001 have been achieved on 1TCT specimens using clip gage systems seated on razor blade knife edges attached to the specimen.
4. The specimen was heated to test temperature. Soak time of specimen was one hour/inch of specimen thickness in the furnace at test temperature.
5. After attaining test temperature, the "Test-Ready" analysis is repeated (see Section 3 above).
6. With a positive "Test-Ready" indication, the test was started. An initial unloading at the same load level of the "Test-Ready" analysis was conducted and if the measured crack length was within the 95% confidence limit of the "Test-Ready" analysis the testing was continued.
- 6.1 For tests being conducted in the transition region, no further unloadings were necessary. The test loading was continued to first pop-in or unstable fracture. If unstable fracture occurs without arrest the test was terminated. If pop-in or unstable fracture with

arrest was observed, the specimen was unloaded, the unloading compliance data is obtained and the test unloading completed, at which time the test is terminated.

6.2 For tests conducted on the upper shelf, unloading compliance procedures were continued incrementally throughout the course of the test. The number of unloadings conducted ranged from 20 to 25. Real time computer analysis of the unloadings gave J and Δa printouts for monitoring the progress of the tests.

7. Post-test measurements of initial crack length and the final crack extension were made from the fracture surfaces of specimens after heat tinting at 650°F and fracturing at low temperature. Crack length measurements of irradiated specimens were made from enlarged photographs of the fracture surfaces.

ANALYSIS

J-Integral Calculations

To compute J for the compact specimens, the formula developed by Rice, et al.⁽¹⁾ modified for the tensile component of load after Merkle and Corten,⁽²⁾ and shortened by the ASTM Task Group E24.01.09,⁽³⁾ was used.

This equation is

$$J = \frac{2A}{Bb} \frac{(1 + \alpha)}{(1 + \alpha^2)} \quad [1]$$

where $\alpha = \left[\left(\frac{2a_0}{b} \right)^2 + \frac{4a_0}{b} + 2 \right]^{1/2} - \left(\frac{2a_0}{b} + 1 \right)$ [2]

A = area (energy) under the load deflection record

B = thickness (net section thickness for face grooved specimens)

b = remaining uncracked ligament

a_0 = initial crack length

Compliance Based Crack Length Calculations

The compliance equation developed by Saxena and Hudak⁽⁴⁾ was used to calculate the crack length from the measured compliance data of clip gage load-line extensometers. An experimentally determined crack length compliance equation was used for analysis of dual LVDT load-line extensometer compliance measurements. The experimental compliance equation developed at HEDL, has been shown to be general for both 1TCT specimens and 0.5TCT specimens.

The initial crack length was computed from the mean of ten compliance measurements at very low load levels. Crack extension, Δa , was computed by subtracting this value from subsequent computed crack lengths.

J-R Curve

The intersection of the lines representing crack blunting and crack extension was taken as the J_{IC} value. The blunting line was taken as following the relationship

$$\Delta a = J/2 \sigma_0, \text{ for } \sigma_0 = \text{flow stress} = \frac{\sigma_{ts} + \sigma_{ys}}{2} \quad [3]$$

The data points utilized for the construction of the crack extension line were those contained in an interval defined by offset lines parallel to the blunting line, Eq. [4], offset 0.020 and 0.070 in. "ahead" of the blunting line as shown in Figure 1. The crack extension portion of the R-curve was a least squares linear regression through these points. The large offsets were used because of the consistent behavior of unloading compliance blunting data to exhibit greater apparent crack blunting than predicted by the theoretical blunting line (refer to R-Curve section). Inclusion of these points would have yielded inordinately low toughness values.

Tearing Modulus

After Paris, et al.⁽⁵⁾ the tearing modulus, T , was calculated

$$T = \frac{dJ}{da} \cdot \frac{E}{\sigma_0^2} \quad [4]$$

where dJ/da = slope of the crack extension line
 E = modulus of elasticity
 σ_0 = flow stress

Stress Intensity Calculations

Stress intensity calculations were made for tests which exhibited unstable crack extension by the equation after Rice⁽¹⁾ for small scale yielding

$$K_I^2 = \frac{J E}{1-\nu^2} \quad [5]$$

where ν is Poisson's ratio and J is determined by Eq. [1] for the area under the curve to unstable fracture. Eq. [5] was also used for the calculation of critical stress intensity from J_{Ic} determined by J-R curve methods. The value of critical stress intensity determined by Eq. [5] is reported in

the tabulations as K_J to avoid confusion with the K_{IC} calculation by ASTM E399 methods.

The value of stress intensity at the load of unstable fracture, K_M , was calculated by K_Q equation of ASTM E399 for a compact tension specimen.

Physical Crack Measurements

After completion of the test, specimens were heat tinted in a furnace at 650°F and then fractured after cooling in liquid nitrogen. The blue oxide coating clearly delineates the fatigue crack and crack extension. Crack measurements were made at nine equally-spaced points along the fatigue crack front and the final crack front. The crack measurement was taken as the mean of eight points: the seven interior measurements plus the average of the two surface measurements. The initial crack length as measured on the specimen fracture surface was used to recompute the J values.

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Figure 1. J-R Curve Analysis for J_{Ic} .

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DESCRIPTION OF TABLES 1, 2 AND 3
FRACTURE TOUGHNESS OF IRRADIATED WELD XXX

Specimen Number	Irrad. Fluence $10^{18}n/cm^2$	Irradiation Temperature °F	Test Temp. °F	K_M ksi $\sqrt{in}$	K_J ksi $\sqrt{in}$	J_{IC} in-lb/in ²	T	$2.5(K_M/\sigma_y)^2$ in	$25(J_{IC}/\sigma_{flow})$ in	Notes
1	2	3	4	5	6	7	8	9	10	11

- 1) Specimen Numbers: 61W-XX, 62W-XX or 63W-XX.
- 2) Irradiation Fluence for E>1 MeV: Total Fluence (Forward Position/Reverse Position).
- 3) Irradiation Temperature: Forward Position Range, Reverse Position Range.
- 4) Test Temperature.
- 5) K_M : Toughness calculated at the load of unstable fracture.
- 6) K_J : The critical stress intensity calculated from the J_{IC} analysis of an unstable fracture or from the R-curve, Eq. [5].
- 7) J_{IC} : The J_{IC} determined at unstable fracture or from R-curve.
- 6, 7, 8, 10) Clip Gage Data/LVDT Data; single values from LVDT or clip gage only; see notes.
- 8) T: Tearing Modulus; Eq. [4].
- 9) Stress intensity size criteria for a, B.
- 10) J-integral size criteria for b, B.
- 11) Letter code of applicable notes —
 - a) Standard CT Specimen.
 - b) J-Modified Specimen.
 - c) J-Modified Specimen — 10% Side Grooves.
 - d) Unstable Fracture.
 - e) Unstable Fracture — Arrest.
 - f) Stable Crack Extension.
 - g) Calculated at Maximum Specimen Load Where Noted in Table.
 - h) LVDT Data Only.
 - i) Clip Gage Data Only.
 - j) Clip Gage Data/LVDT Data.
 - k) Test Stopped at Maximum Load; Special Note at Bottom of Table.
 - l) J_{IC} and K_J Determined from Crack Instability.
 - m) J_{IC} and K_J Determined from R-Curve.

TABLE 1
FRACTURE TOUGHNESS OF IRRADIATED A533 WELD 61W

Specimen Number	Irrad. Fluence 10 ¹⁸ n/cm ²	Irradiation Temperature °F		Test Temp. °F	K _M ksi√in	K _J ksi√in	J _{Ic} in-lb/in ²	T	2.5(K _Q /σ _y) ² in	25(J _{Ic} /σ _{flow}) in	Notes
Smooth Specimens											
61W-104	11 (8/3)	555-560	570-580	79	76	92	254	--	1.7	0.06	a,d,h,l
61W-103	14 (3/11)	575-590	600-615	100	81	105	333	--	2.0	0.09	a,d,h,l
61W-112	12 (9/3)	575-585	550-585	125	86	127	484	--	2.3	0.13	a,e,h,l
61W-106	12 (10/2)	555-560	570-580	175	88	123	456	--	2.5	0.12	a,e,h,l
61W-113	11 (8/3)	575-585	550-585	275	--	76	176	73	---	0.05	a,f,h,m
10% Side Grooved Specimens											
61W-123	16 (13/3)	550-570	550-570	350	--	136/156	574/760	48/51	---	0.16/0.21	c,f,j,m
61W-124	14 (3/11)	530-550	530-550	500	--	129/124	537/491	45/48	---	0.15/0.14	c,f,j,m
Low Fluence Smooth Specimens											
61W-125	7 (4/3)	560-580	560-575	350	--	129/102	520/321	53/61	---	0.15/0.009	b,f,j,m
61W-126	7 (4/3)	560-580	560-575	350	--	106/121	348/453	79/75	---	0.10/0.13	b,f,j,m
Low Fluence 10% Side Grooved Specimens											
61W-127	7 (4/3)	560-580	560-575	350	--	156/153	759/727	56/67	---	0.21/0.20	c,f,j,m
61W-128	7 (4/3)	550-570	550-570	350	--	113/106	396/346	60/63	---	0.11/0.10	c,f,j,m

TABLE 2
FRACTURE TOUGHNESS OF IRRADIATED WELD 62W

Specimen Number	Irrad. Fluence 10 ¹⁸ n/cm ²	Irradiation Temperature °F		Test Temp. °F	K _M ksi√in	K _J ksi√in	J _{Ic} in-lb/in ²	T	2.5(K _Q /σ _y) ² in	25(J _{Ic} /σ _f low) in	Notes
Smooth Specimens											
62W-117	12 (7/5)	550-565	565-590	77	82	108	345	--	2.2	0.09	a,d,h,l
62W-152	12 (10/2)	530-550	560-570	100	77	94	277	--	1.9	0.07	a,d,h,l
62W-120	10 (8/2)	555-570	545-560	125		135	---	--		----	a,g,h,k
62W-119	10 (8/2)	555-570	545-560	150		141	---	--		----	a,g,h,k
10% Side Grooved Specimens											
62W-106	12 (10/2)	555-575	575-590	350	--	134/151	555/709	90/86	---	0.16/0.20	c,f,j,m
62W-159	11 (1/10)	530-550	570-590	500	--	122/103	482/338	58/62	---	0.14/0.10	c,f,j,m

K: Special Note

The value of K_J was determined from the analysis of the area under the load-deflection curve to maximum load. These values do not represent crack initiation for specimens 62W-120 and 62W-119. Examination of fracture surfaces of both specimens (see photographs) indicate small amounts of stable crack extension and therefore represent upper bounds of the fracture toughness at the temperatures indicated. The test of 62W-120 was stopped at maximum load and 62W-119 just after maximum load since no unstable crack extension had occurred.

TABLE 3
FRACTURE TOUGHNESS OF IRRADIATED WELD 63W

Specimen Number	Irrad. Fluence 10 ¹⁸ n/cm ²	Irradiation Temperature °F		Test Temp. °F	K _M ksi√in	K _J ksi√in	J _{Ic} in-lb/in ²	T	2.5(K _Q /σ _y) ² in	25(J _{Ic} /σ _{flow}) in	Notes
Smooth Specimens											
63W-100	14 (3/11)	545-575	555-585	75	48	54	88		0.7	0.02	a,e,h,l
63W-101	14 (11/3)	545-575	510-540	125	64	74	162		1.3	0.04	a,e,h,l
10% Side Grooved Specimens											
63W-135	9 (6/3)	550-580	560-580	200	--	138	575	53	---	0.16	c,f,i,m
63W-109	12 (10/2)	565-595	550-580	300	--	137/143	573/627	72/68	---	0.16/0.17	c,f,j,m
63W-123	10 (3/7)	560-595	530-540	500	--	96/94	288/282	49/45	---	0.09/0.08	c,f,j,m

- $7 \times 10^{18} \text{ n/cm}^2$
- $11-14 \times 10^{18} \text{ n/cm}^2$
- 1 CLIP GAGE DATA
- 2 LVDT DATA
- TIE INDICATES DATA FROM SAME SPECIMEN
- A SMOOTH SPECIMEN
- B 10% SIDE GROOVED SPECIMEN

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Figure 2. Toughness Vs. Temperature Curve for Weld 61W.

- $10-12 \times 10^{18} \text{ n/cm}^2$
- A SMOOTH SPECIMEN
- B 10% SIDE GROOVED SPEC.
- 1 CLIP GAGE DATA
- 2 LVDT DATA
- TIE INDICATES DATA FROM SAME SPECIMEN

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Figure 3. Toughness Vs. Temperature Curve for Weld 62W.

- 9-14x10¹⁸n/cm²
- 1 CLIP GAGE DATA
- ⌈ TIE INDICATES DATA FROM SAME SPECIMEN
- 2 LVDT DATA
- A SMOOTH SPECIMEN
- B 10% SIDE GROOVED SPECIMEN

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Figure 4. Toughness Vs. Temperature Curve for Weld 63W.

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J-INTEGRAL

2000

1500

1000

500

0

FINAL R-CURVE

DUAL LVDT DATA

JIC = 176 IN-LB/IN^{3/2}

T = 73

61W-113, 136C

ASME WELD IRRADIATED

0.00

0.02

0.04

0.06

0.08

DELTA CRACK, IN

Figure 5. J-R Curve of Specimen 61W-113 at 136°C for Dual LVDT Data.

Figure 7. J-R Curve of Specimen 61W-123 at 177°C for Dual LVDT Data.

Figure 8. J-R Curve of Specimen 61W-124 at 260°C for Clip Gage Data.

Figure 9. J-R Curve of Specimen 61W-124 at 260°C for Dual LVDT Data.

Figure 10. J-R Curve of Specimen 61W-125 at 177°C for Clip Gage Data.

Figure 11. J-R Curve of Specimen 61W-125 at 177°C for Dual LVDT Data.

Figure 12. J-R Curve of Specimen 61W-126 at 177°C for Clip Gage Data.

J-INTEGRAL

Figure 13. J-R Curve of Specimen 61W-126 at 177°C for Dual LVDT Data.

J-INTEGRAL

2000

1500

1000

500

0

FINAL R-CURVE

CLIP GAGE DATA

JIC = 758 IN-LB/IN^{3/2}

T = 56

61W-127, 177C

A533 WELD IRRAD, 7.00E 18 N/CM²

0.0

20.0

40.0

60.0

80.0

DELTA CRACK, IN

Figure 14. J-R Curve of Specimen 61W-127 at 177°C for Clip Gage Data.

Figure 15. J-R Curve of Specimen 61W-127 at 177°C for Dual LVDT Data.

Figure 16. J-R Curve of Specimen 61W-128 at 177°C for Clip Gage Data.

Figure 17. J-R Curve of Specimen 61W-128 at 177°C for Dual LVDT Data.

Figure 18. J-R Curve of Specimen 62W-106 at 177°C for Clip Gage Data.

Figure 19. J-R Curve of Specimen 62W-106 at 177°C for Dual LVDT Data.

Figure 20. J-R Curve of Specimen 62W-159 at 260°C for Clip Gage Data.

Figure 21. J-R Curve of Specimen 62W-159 at 260°C for Dual LVDT Data.

Figure 22. J-R Curve of Specimen 63W-135 at 93°C for Clip Gage Data.

Figure 23. J-R Curve of Specimen 63W-109 at 149°C for Clip Gage Data.

Figure 24. J-R Curve of Specimen 63W-109 at 149°C for Dual LVDT Data.

Figure 25. J-R Curve of Specimen 63W-123 at 260°C for Dual LVDT Data.

Figure 26. J-R Curve of Specimen 63W-123 at 260°C for Clip Gage Data.

TABLE 4
J-R CURVE DATA OF SPECIMENS 61W-123 AND 61W-124
FOR CLIP GAGE LOAD-LINE EXTENSOMETER

61W-123		61W-124	
Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)
0.0078	10	-0.0145	14
0.0028	25	0.0027	60
-0.0026	44	0.0018	150
0.0040	72	0.0084	267
0.0074	108	0.0100	395
0.0024	156	0.0115	521
-0.0028	225	0.0161	622
0.0059	303	0.0206	733
0.0056	404	0.0293	837
0.0125	508	0.0358	945
0.0128	621	0.0519	1164
0.0152	725	0.0627	1268
0.0256	818	0.0729	1373
0.0261	922		
0.0389	1021		
0.0464	1126		
0.0498	1215		
0.0588	1300		
0.0675	1377		
0.0659	1441		
0.0763	1496		
0.0771	1555		

TABLE 5
J-R CURVE DATA OF SPECIMENS 61W-113, 61W-123 AND 61W-124
FOR DUAL LVDT LOAD-LINE EXTENSOMETER

61W-113		61W-123		61W-124	
Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)
-0.0001	12	-0.0017	12	0.0017	15
0.0029	27	0.0007	28	0.0049	63
0.0054	48	-0.0051	50	0.0040	155
0.0024	78	-0.0006	82	0.0046	273
0.0045	119	0.0018	122	0.0093	409
0.0060	173	0.0028	177	0.0133	543
0.0087	216	0.0049	259	0.0198	636
0.0084	249	0.0050	358	0.0240	745
0.0087	279	0.0083	489	0.0315	849
0.0113	333	0.0116	613	0.0368	952
0.0119	366	0.0144	732	0.0538	1170
0.0135	422	0.0199	850	0.0602	1266
0.0148	467	0.0247	950	0.0709	1368
0.0164	519	0.0226	1063		
0.0191	582	0.0351	1170		
0.0242	642	0.0418	1280		
0.0274	708	0.0488	1381		
0.0306	775	0.0550	1474		
0.0327	850	0.0602	1556		
0.0375	926	0.0671	1627		
0.0400	998	0.0715	1689		
0.0452	1074	0.0767	1749		
0.0488	1157				
0.0533	1240				

TABLE 6
J-R CURVE DATA OF SPECIMENS 61W-125, 61W-126 AND 61W-127
FOR CLIP GAGE LOAD-LINE EXTENSOMETER

61W-125		61W-126		61W-127	
Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)
0.0048	10	0.0008	12	0.0054	11
-0.0076	23	0.0025	27	0.0040	26
0.0039	44	0.0095	50	-0.0020	46
-0.0052	69	-0.0045	82	0.0057	75
-0.0091	106	0.0029	127	-0.0063	114
0.0003	155	0.0036	185	0.0013	168
-0.0004	231	0.0091	271	-0.0015	235
-0.0014	371	0.0111	326	0.0000	294
0.0048	510	0.0147	375	0.0042	392
0.0176	633	0.0147	432	0.0110	468
0.0253	731	0.0090	507	0.0110	565
0.0209	800	0.0158	589	0.0078	659
0.0281	881	0.0190	668	0.0127	738
0.0307	954	0.0260	802	0.0206	841
0.0359	1010	0.0258	886	0.0199	953
0.0354	1072	0.0319	974	0.0280	1058
0.0527	1137	0.0305	1072	0.0321	1160
0.0486	1191	0.0432	1153	0.0299	1248
0.0468	1239	0.0463	1235	0.0419	1338
0.0563	1307	0.0457	1311	0.0484	1442
0.0579	1362	0.0518	1397	0.0580	1534
0.0648	1418	0.0561	1458	0.0585	1622
0.0690	1449	0.0535	1522	0.0649	1699
0.0700	1481	0.0580	1617	0.0713	1766
		0.0640	1677	0.0726	1828

TABLE 7
J-R CURVE DATA OF SPECIMENS 61W-125, 61W-126 AND 61W-127
FOR DUAL LVDT LOAD-LINE EXTENSOMETER

61W-125		61W-126		61W-127	
Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)
0.0021	11	0.0002	11	0.0011	12
0.0032	25	0.0008	27	0.0005	29
0.0009	47	0.0048	48	0.0024	52
0.0063	77	0.0043	77	0.0011	85
0.0072	117	0.0046	117	0.0050	130
0.0105	172	0.0065	175	0.0056	190
0.0086	260	0.0087	263	0.0026	273
0.0161	416	0.0103	316	0.0030	338
0.0220	569	0.0104	364	0.0054	451
0.0294	696	0.0128	419	0.0061	538
0.0309	801	0.0131	489	0.0094	641
0.0349	874	0.0164	564	0.0105	740
0.0393	964	0.0175	640	0.0155	830
0.0456	1040	0.0224	762	0.0174	936
0.0512	1098	0.0245	840	0.0254	1057
0.0511	1169	0.0269	921	0.0294	1170
0.0577	1237	0.0310	1013	0.0342	1275
0.0609	1298	0.0310	1088	0.0390	1373
0.0639	1352	0.0379	1166	0.0440	1470
0.0700	1422	0.0405	1234	0.0487	1576
0.0549	1480	0.0451	1315	0.0562	1675
0.0772	1540	0.0466	1371	0.0609	1769
0.0781	1574	0.0513	1429	0.0649	1852
0.0823	1609	0.0544	1517	0.0697	1926
		0.0577	1574	0.0736	1989

TABLE 8
J-R CURVE DATA OF SPECIMEN 61W-128 FOR
CLIP GAGE AND DUAL LVDT LOAD-LINE EXTENSOMETERS

61W-128 LVDT		61W-128 Clip Gage	
Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)
0.0018	15	0.0035	13
0.0011	34	0.0086	31
0.0055	63	0.0022	57
0.0055	104	0.0050	93
0.0047	161	-0.0037	142
0.0093	245	0.0045	216
0.0104	304	0.0078	270
0.0122	362	0.0080	322
0.0136	434	0.0135	387
0.0159	528	0.0089	477
0.0217	617	0.0166	558
0.0239	681	0.0163	621
0.0268	761	0.0209	695
0.0309	844	0.0263	773
0.0361	922	0.0357	845
0.0387	1003	0.0388	923
0.0435	1080	0.0375	997
0.0479	1157	0.0366	1073
0.0515	1239	0.0479	1152
0.0565	1314	0.0512	1225
0.0625	1384	0.0563	1290
0.0658	1451	0.0609	1351
0.0702	1516	0.0686	1410
0.0741	1577	0.0669	1468
0.0785	1631	0.0706	1518

TABLE 9
J-R CURVE DATA OF SPECIMENS 62W-106 AND 62W-159
FOR CLIP GAGE LOAD-LINE EXTENSOMETER

62W-106		62W-159	
Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)
0.0050	14	-0.0051	18
0.0028	16	0.0043	80
-0.0059	81	0.0052	137
-0.0002	163	0.0005	233
0.0075	285	0.0055	338
0.0073	406	0.0067	423
0.0130	540	0.0159	526
0.0137	677	0.0136	609
0.0222	846	0.0216	687
0.0266	1026	0.0275	788
0.0341	1175	0.0290	857
0.0355	1292	0.0351	922
0.0412	1390	0.0338	994
0.0334	1522	0.0452	1039
0.0592	1613	0.0445	1093
0.0464	1707	0.0469	1158
0.0617	1925	0.0498	1242
0.0645	2002	0.0564	1302
0.0673	2085	0.0617	1378
0.0715	2153	0.0731	1436
0.0696	2245		

TABLE 10
J-R CURVE DATA OF SPECIMENS 62W-106 AND 62W-159
FOR DUAL LVDT LOAD-LINE EXTENSOMETER

62W-106		62W-159	
Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)
0.0042	16	0.0000	19
0.0013	16	0.0064	82
0.0068	84	0.0071	140
0.0068	169	0.0076	236
0.0054	297	0.0132	349
0.0081	423	0.0157	429
0.0101	560	0.0185	534
0.0126	698	0.0232	618
0.0163	864	0.0255	697
0.0224	1042	0.0326	799
0.0290	1192	0.0366	874
0.0336	1309	0.0407	940
0.0349	1405	0.0441	1011
0.0393	1536	0.0466	1079
0.0419	1627	0.0525	1139
0.0475	1721	0.0556	1206
0.0573	1939	0.0639	1290
0.0582	2018	0.0666	1352
0.0647	2096	0.0726	1426
0.0686	2166	0.0791	1488
0.0774	2258		

TABLE 11
J-R CURVE DATA OF SPECIMENS 63W-135, 63W-109 AND 63W-123
FOR CLIP GAGE LOAD-LINE EXTENSOMETER

63W-135		63W-109		63W-123	
Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)
0.0004	14	-0.0049	16	0.0021	16
0.0054	62	0.0024	70	0.0053	67
0.0032	103	0.0070	205	0.0075	111
-0.0036	159	-0.0003	310	0.0054	174
0.0062	244	0.0100	481	0.0111	264
0.0080	309	0.0071	548	0.0204	403
0.0093	388	0.0180	668	0.0171	503
0.0139	566	0.0209	755	0.0226	595
0.0130	652	0.0210	850	0.0326	688
0.0257	901	0.0214	937	0.0359	756
0.0300	981	0.0291	1030	0.0440	836
0.0394	1054	0.0320	1117	0.0547	925
0.0441	1148	0.0339	1203	0.0509	998
0.0466	1216	0.0391	1315	0.0628	1072
0.0489	1293	0.0442	1391	0.0669	1150
0.0519	1371	0.0473	1463	0.0720	1223
0.0569	1439	0.0522	1535		
0.0619	1494	0.0578	1604		
0.0618	1550	0.0571	1670		
0.0771	1612	0.0605	1724		
0.0791	1679	0.0630	1782		
0.0827	1725	0.0692	1839		
0.0881	1776	0.0722	1907		

TABLE 12
J-R CURVE DATA OF SPECIMENS 63W-109 AND 63W-123
FOR DUAL LVDT LOAD-LINE EXTENSOMETER

63W-109		63W-123	
Δa (in)	J (in-lb/in ²)	Δa (in)	J (in-lb/in ²)
0.0005	17	0.0000	16
0.0035	73	0.0039	66
0.0050	221	0.0036	110
0.0043	351	0.0076	172
0.0113	536	0.0102	260
0.0112	603	0.0173	400
0.0156	718	0.0222	496
0.0179	807	0.0279	582
0.0219	897	0.0339	667
0.0253	984	0.0405	729
0.0307	1073	0.0443	804
0.0331	1162	0.0502	887
0.0372	1247	0.0563	958
0.0435	1359	0.0643	1029
0.0451	1429	0.0724	1104
0.0462	1502	0.0808	1175
0.0544	1574		
0.0573	1643		
0.0598	1705		
0.0628	1758		
0.0661	1816		
0.0727	1870		
0.0765	1938		

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TABLE 13
MEASURED AND CALCULATED CRACK LENGTHS

Specimen Number	a_o , in			a_f , in			Δa , in		
	Measured ^a	LVDT ^b	CG ^c	Measured ^a	LVDT ^b	CG ^c	Measured ^a	LVDT ^b	CG ^c
61W-104	0.502	0.476	-----	0.762	UF	-----	0.260	UF	-----
103	0.481	0.472	-----	0.824	UF	-----	0.343	UF	-----
112	0.499	0.489	-----	0.514	0.510	-----	0.015	0.022	-----
106	0.503	0.488	-----	0.556	0.524	-----	0.053	0.036	-----
125	0.490	0.475	0.481	0.612	0.557	0.551	0.122	0.082	0.070
126	0.493	0.477	0.490	0.572	0.535	0.554	0.079	0.058	0.064
127	0.484	0.476	0.472	0.592	0.550	0.544	0.108	0.074	0.073
128	0.511	0.500	0.500	0.604	0.579	0.571	0.093	0.079	0.071
113	0.499	0.481	-----	0.560	0.534	-----	0.061	0.053	-----
123	0.488	0.473	0.467	0.595	0.549	0.544	0.107	0.077	0.077
124	0.497	0.495	0.506	0.602	0.566	0.579	0.105	0.071	0.073
62W-117	0.527	0.506	-----	0.898	UF	-----	0.371	UF	-----
152	0.493	0.495	-----	0.782	UF	-----	0.289	UF	-----
120	0.508	0.505	-----	0.516	0.520	-----	0.008	0.015	-----
119	0.490	0.490	-----	0.503	0.513	-----	0.013	0.022	-----
106	0.516	0.509	0.520	0.639	0.586	0.590	0.123	0.077	0.070
159	0.552	0.532	0.542	0.645	0.611	0.615	0.092	0.079	0.073
63W-100	0.535	0.528	-----	0.635	NR	-----	0.100	NR	-----
101	0.523	0.530	-----	0.547	0.538	-----	0.024	0.009	-----
135	0.525	-----	0.521	0.643	-----	0.604	0.118	-----	0.083
109	0.540	0.522	0.535	0.645	0.599	0.607	0.105	0.077	0.072
123	0.511	0.503	0.523	0.625	0.584	0.595	0.114	0.081	0.072

^aMeasured from photographs using the weighted nine-point average.

^bComputed from the LVDT compliance using the experimental compliance equation.

^cComputed from the clip gage compliance using the Saxena-Hudak compliance equation.

NR = No Reading.

UF = Unstable Fracture.

SPECIMEN PHOTOGRAPH INFORMATION
61W-104, 61W-103, 61W-112 AND 61W-106

61W-104

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 79°F (26°C)
Type of Fracture: Unstable Fracture
Comments: This specimen was used to develop the temperature transition curve.

61W-103

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 100°F (38°C)
Type of Fracture: Unstable Fracture
Comments: This specimen was used to develop the temperature transition curve.

61W-112

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 125°F (52°C)
Type of Fracture: Unstable Fracture Which Arrested
Comments: This specimen was used to develop the temperature transition curve.

61W-106

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 175°F (80°C)
Type of Fracture: Unstable Fracture Which Arrested
Comments: This specimen was used to develop the temperature transition curve.

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SPECIMEN PHOTOGRAPH INFORMATION
61W-113, 61W-123 AND 61W-124

61W-113

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 275°F (135°C)
Type of Fracture: Stable Crack Extension
Comments: Specimen exhibits upper shelf behavior.

61W-123

Notch Type: J Modified
Side Grooving: 10% Side Grooves
Test Temperature: 350°F (177°C)
Type of Fracture: Stable Crack Extension
Comments: Specimen exhibits upper shelf behavior. The side grooves had no effect on crack front straightness.

61W-124

Notch Type: J Modified
Side Grooving: 10% Side Grooves
Test Temperature: 500°F (260°C)
Type of Fracture: Stable Crack Extension
Comments: Specimen exhibits upper shelf behavior. The side grooves had no effect on crack front straightness.

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SPECIMEN PHOTOGRAPH INFORMATION
62W-117, 62W-152, 62W-120 AND 62W-119

62W-117

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 77°F (25°C)
Type of Fracture: Unstable Fracture
Comments: This specimen was used to develop the temperature transition curve.

62W-152

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 100°F (38°C)
Type of Fracture: Unstable Fracture
Comments: This specimen was used to develop the temperature transition curve.

62W-120

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 125°F (52°C)
Type of Fracture: Stable Crack Extension up to the point of unloading which was just barely beyond maximum load.
Comments: Specimen appears to be on the upper shelf. At the point of final unloading, J was 580 in-lb/in² and Δa was 0.008 in.

62W-119

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 150°F (66°C)
Type of Fracture: Stable Crack Extension
Comments: Specimen was unloaded at a point somewhat beyond maximum load. Specimen appears to be on the upper shelf. At the point of final unloading, J was 686 in-lb/in² and Δa was 0.013 in.

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SPECIMEN PHOTOGRAPH INFORMATION
61W-125, 61W-126, 61W-127 AND 61W-128

61W-125

Notch Type: J Modified
Side Grooving: Smooth
Test Temperature: 350°F (177°C)
Type of Fracture: Stable Crack Extension
Comments: Specimen subjected to lower irradiation fluence.

61W-126

Notch Type: J Modified
Side Grooving: Smooth
Test Temperature: 350°F (177°C)
Type of Fracture: Stable Crack Extension
Comments: Specimen subjected to lower irradiation fluence.

61W-127

Notch Type: J Modified
Side Grooving: 10% Side Grooves
Test Temperature: 350°F (177°C)
Type of Fracture: Stable Crack Extension
Comments: Specimen subjected to lower irradiation fluence. The side grooves had no effect on crack front straightness.

61W-128

Notch Type: J Modified
Side Grooving: 10% Side Grooves
Test Temperature: 350°F (177°C)
Type of Fracture: Stable Crack Extension
Comments: Specimen subjected to lower irradiation fluence. The side grooves had no effect on crack front straightness.

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SPECIMEN PHOTOGRAPH INFORMATION

62W-153, 62W-106 AND 62W-159

62W-153

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 150°F (66°C)
Type of Fracture: Stable Crack Extension
Comments: R-curve results were not obtained for this specimen because of extensometer failure.

62W-106

Notch Type: J Modified
Side Grooving: 10% Side Grooves
Test Temperature: 350°F (177°C)
Type of Fracture: Stable Crack Extension
Comments: The side grooves had no effect on crack front straightness.

62W-159

Notch Type: J Modified
Side Grooving: 10% Side Grooves
Test Temperature: 500°F (260°C)
Type of Fracture: Stable Crack Extension
Comments: The side grooves had no effect on crack front straightness.

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SPECIMEN PHOTOGRAPH INFORMATION

63W-100 AND 63W-101

63W-100

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 75°F (24°C)
Type of Fracture: Unstable Fracture Which Arrested
Comments: This specimen was used to develop the temperature transition curve.

63W-101

Notch Type: Standard
Side Grooving: Smooth
Test Temperature: 125°F (52°C)
Type of Fracture: Unstable Fracture Which Arrested
Comments: This specimen was used to develop the temperature transition curve.

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SPECIMEN PHOTOGRAPH INFORMATION

63W-135, 63W-109 AND 63W-123

63W-135

Notch Type: J Modified
Side Grooving: 10% Side Grooves
Test Temperature: 200°F (93°C)
Type of Fracture: Stable Crack Extension
Comments: The side grooves had no effect on the crack front straightness.

63W-109

Notch Type: J Modified
Side Grooving: 10% Side Grooves
Test Temperature: 300°F (149°C)
Type of Fracture: Stable Crack Extension
Comments: The side grooves had no effect on the crack front straightness.

63W-123

Notch Type: J Modified
Side Grooving: 10% Side Grooves
Test Temperature: 500°F (260°C)
Type of Fracture: Stable Crack Extension
Comments: The side grooves had no effect on the crack front straightness.

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HEDL 7807-130.2

Figure 27. Yield and Ultimate Strengths for Unirradiated and Irradiated Weldment 61W from Second 4T Irradiation.

HEDL 7807-130.1

Figure 28. Yield and Ultimate Strengths for Unirradiated and Irradiated Weldment 62W from Second 4T Irradiation.

HEDL 7807-130.3

Figure 29. Yield and Ultimate Strengths for Unirradiated and Irradiated Weldment 63W from Second 4T Irradiation.

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