Tennessee Valley Authority, Post Office Box 2000, Spring City, Tennessee 37381-2000

JUL 1 0 2001

10 CFR 50.4

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
Washington, D. C. 20555

Gentlemen:

In the Matter of)
Tennessee Valley Authority)

Docket No.50-390

WATTS BAR NUCLEAR PLANT (WBN) UNIT 1 - REACTOR VESSEL FRACTURE TOUGHNESS TESTING (J-R) - SUPPLEMENTAL TESTING OF SURVEILLANCE CAPSULE W SPECIMEN (TAC NO. MB2335)

This letter provides the test results for the unirradiated fracture toughness testing on two modified American Society of Testing and Materials (ASTM) E399 specimens and two standard ASTM E1820 specimens. These Proof-of-Principle test results were developed using ASTM E813 J-R curve analysis and have been certified by the BWXT's Quality Assurance Program. These test results are provided in Enclosure 1.

Revision 2 of the Project Test Plan, "Reactor Vessel Surveillance Program (RVSP) Capsule W ½ T Specimen Fracture Toughness Testing," is provided in Enclosure 2. Technical Procedure (TP)-177, Revision 9, "Automated, Single-Specimen J-Integral Fracture Toughness Testing," is also provided in Enclosure 3.

TVA requests NRC to review and approve the testing procedure and test plan, and determine the test results are acceptable before the radiated testing begins. The NRC's comments have been incorporated into these documents and a draft of the enclosed test results were provide to the NRC WBN Project Manager for NRC's review on June 13, 2001. Currently, the radiated testing

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is scheduled for July 18, 2001, at the BWXT Services facility in Lynchburg, VA. at 9:00 a.m. As with the unirradiated testing, TVA expects that NRC plans to attend to observe the radiated testing. Kevin Hour, telephone number (804) 522-5715 will be the contact at BWXT upon arrival.

If you have any questions concerning this matter, please contact me at (423) 365-1824.

Sincerely,

P. L. Pace
Manager, Site Licensing
and Industry Affairs

Enclosures
cc (Enclosures):

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ENCLOSURE 1

PROOF OF PRINCIPLE TEST RESULTS
AND
QUALITY ASSURANCE CERTIFICATION OF CONFORMANCE

BWXT Services, Inc.
Lynchburg Technology Center

Quality Assurance
Certification of Conformance

BWXS Contract Charge No. 1215-001-00-18-00-00-0000

Tennessee Valley Authorities Purchase Order 00N7D-264485-001

BWXT Services, Inc. hereby certifies that the proof-of-principle testing of unirradiated compact tension specimens was performed in accordance with the requirements of the above-specified Tennessee Valley Authorities purchase order, dated 9/12/00, including Change Order No.1, dated 1/24/01.

This testing was conducted in accordance with the requirements of BWXT Services, Inc., Nuclear & Environmental Operations, Nuclear Materials Engineering Quality Assurance Plan 00001, Revision 00, dated 11/08/00, for the project titled " TVA-RVSP Capsule Evaluation from Watts Bar Nuclear Plant."

6/29/01
Date

David W. Zeff
Manager, ES&H

INTRODUCTION

The United States Nuclear Regulatory Commission (NRC) requires a nuclear power licensee to maintain a reactor vessel surveillance program to monitor fast neutron irradiation-induced changes in the mechanical properties of reactor vessel beltline material. These changes in mechanical properties are measured by testing material specimens that have been exposed to the operating environment of a reactor vessel. Vessel material specimens are assembled into protective capsules and placed inside the vessel. The capsule is then maintained inside the reactor vessel for a specified period of operation. In this way, the material specimens within the capsule are exposed to a neutron flux similar to that experienced by the actual reactor vessel. Upon removal of the capsule, the specimens are retrieved and tested. Test results are then used to calculate pressure-temperature limits within which the reactor can be operated safely or to verify the current limits remain conservative through the next service interval.

Capsule W was received at the BWXT Services, Inc. (BWXS) Lynchburg Technology Center (LTC) in January 2001 and was subsequently disassembled in its Hot Cell Facility. Following the disassembly, specimens were inventoried and stored. There are twelve (12) 1/2 T compact tension specimens and one bend bar in this capsule. Four axial orientation 1/2T compact tension specimens are to be tested to provide necessary information to demonstrate that Watts Bar Unit 1 Nuclear Power Station reactor vessel has a margin of safety equivalent to that required by Appendix G of the ASME code. This is accomplished by performing generic bounding evaluations as per ASME Section XI, Appendix X criteria and requirements.

Some machining on the 1/2T compact tension specimens is expected since the original specimens were manufactured in accordance with ASTM E399 not ASTM E1820, which is the Standard that will be used for testing. BWXS has proposed a modified E399 specimen design (see Appendix A), where an Electrical Discharge Milling (EDM) cut is made between two pin holes to generate knife edges for mounting of the clip gage. No other changes to the specimen are made. Proof-of-principle tests were proposed prior to actual testing.

To simulate the fact that the material of interest has a low upper shelf energy, BWXS identified a reactor vessel steel weld metal with a low upper shelf energy of 70 ft-lb. A total of four unirradiated specimens (2 BWXS design and 2 ASTM E1820 design) were machined and tested at 390 °F. Specimens were tested in accordance with ASTM E1820 to determine the adequacy of the BWXS design. Representatives from TVA as well as NRC were on site to witness the tests.

SPECIMEN MACHINING AND PREPARATION

A total of five (5) specimens were machined in the BWXS LTC Hot Machine Shop (HMS) using a combination of EDM and CNC milling. One specimen was taken from the base metal and four specimens were taken from the weld. The purpose of manufacturing one base metal specimen was two fold - to practice and to demonstrate that other four specimens were taken from weld using base metal test results as benchmark. Specimen identifications are summarized as follows:

Base metal: 1B2
BWXS Design: 2D1 and 2D2
ASTM E1820: 2D3 and 2D5

Specimens were machined in accordance with the engineering drawing shown in Attachment A and ASTM E1820 Fig A 2.1 (0.24W pin hole diameter). Specimens were precracked at room temperature in accordance with ASTM E1820 Section 7.4 to half specimen width. After precracking, a 10% side groove was put on each side of the specimen for a total 20% reduction of thickness to ensure a straight crack front.

SPECIMEN TESTING

All tests were performed per Lynchburg Technology Center Technical Procedure TP-177. The tests were performed in displacement control mode on a servohydraulic test machine equipped with a fifty-kip load cell (10,000 pound range was used for the tests). A double cantilever beam clip gage was mounted onto the knife edges for monitoring the crack mouth opening displacement (CMOD). The CMOD measurements were used to determine the crack length during the test. Force and displacement were monitored continuously through loading and unloading cycles with the load cell and a LVDT interfaced to a personal computer. Crack lengths were calculated based on material compliance relationships using force and CMOD data collected during the unloading portion of each cycle in conjunction with specimen geometry information. All tests were performed in an ATS split type furnace designed to handle both elevated temperature and sub-zero temperature testing. Temperature was determined by placing a Type K thermocouple onto the specimen surface. The soak time for the compact tension specimen after reaching test temperature was 30 minutes to assure uniform temperature distribution in the specimen. Temperature control for maintaining sub-zero temperatures was provided by automated control of a solenoid valve, which regulated the flow rate of liquid nitrogen into the furnace. Test temperatures were controlled to within ± 4 °F of the test temperature.

Actual dimension measurements were used (nominal dimensions will be used for irradiated specimens due to the concern of radiation exposure) as the input parameters for the JTEST software program. JTEST is certified by BWXS for the J-integral test. The percent unloading parameter specified the amount of unload for each unloading cycle during the test. An unloading value of 20% from the current force was specified for each specimen.

The force and the CMOD measurements of the unload were used to calculate the crack length using the compliance method. Because the extreme high and low ends of the unload process are relatively noisy, only the middle portion of the unload process was used to calculate the crack length to achieve higher accuracy. A step size of 0.003 inch with a loading displacement rate of 0.01 inch/minute was used.

Initially, upon program execution, the specimen was loaded to the final precrack load to determine the initial crack length using the compliance method. The measured crack length was used to check against the known precrack final crack length for consistency. This process was then repeated three times. If the measurements were consistent, the crack length checking process was considered complete. If results were not consistent, the test system was checked and the clip gage was examined for proper seating. This process was continued until reproducible results were obtained. Since the force applied to the specimen was significantly lower than the yield and lower than the forces used in the precracking process, no impact to the test results was expected.

Following the initial crack length measurement cycling, the actual test began. The specimen was loaded and unloaded in accordance with the parameters entered prior to the test. Compliance data (force versus CMOD) during each unloading was used for a crack length calculation. Crack length was calculated using equations that are listed in ASTM E1820.

POST TEST MEASUREMENTS

After the test, the specimens were heat-tinted in a furnace between 500 °F to 550 °F for 10 to 15 minutes. The specimens were then removed from the furnace and placed back onto the test fixture and loaded to failure using cyclic loading. The precrack final crack length and test final crack length were measured using a video micrometer system. This system was calibrated prior to and after the measurements were made.

The cracks were measured at nine locations across the crack front spanning the specimen thickness.

These nine measurements were used to determine an average initial and final crack

$$a_{AVG} = \frac{1}{8}\left[\frac{(a_1 + a_9)}{2} + a_2 + a_3 + a_4 + a_5 + a_6 + a_7 + a_8\right]$$

where

a_{AVG} is the average crack length from nine measurements
$a_1 \ldots a_9$ is nine point measured crack length

These values were later used as references to verify the accuracy of the crack length determined from the compliance method.

DATA ANALYSIS AND DISCUSSION

The test data were analyzed by the BWXS certified software JTEST using ASTM E813. The test results are shown in Appendix B. Since only the J-R curve is used to demonstrate that Watts Bar Unit 1 Nuclear Power Station reactor vessel has a margin of

safety equivalent to that required by Appendix G of the ASME code, no discussion or comparison are made for J_{Ic} determination. Furthermore, comparison will be made at 0.1 inch crack extension as reference for all analyses.

Figures 1 to 4 show the J-R curve for each specimen. A third power polynomial curve fitting was used to determine the trend curve for the data. Power-law curve fitting was used first however the results were not satisfactory due to a low coefficient of correlation (R^2). J and dJ/da values at crack extension of 0.1 inch were determined and are summarized in Table 1.

Table 1 J and dJ/da Values at Crack Extension of 0.1 Inch

Specimen ID	J at Δa=0.1" (in-lbs/in^2)	dJ/da at Δa=0.1"
2D1 (BWXS design)	1,611	4,184
2D2 (BWXS design)	1,910	1,279
2D3 (E1820 design)	1,764	3,242
2D4 (E1820 design)	1,874	4,568

Figure 5 shows all four J-R curves as well as three J-R curves obtained from tests conducted at 110°F, 350°F, and 550°F by the same laboratory 20 years ago on the same material. Those specimens were designed in accordance with ASTM E813 (ASTM 813 is a predecessor of ASTM E1820). Several observations are drawn from this figure.

1. Normal scatter of weld is observed among four specimens tested. The test data at 390°F are bounded by 110°F and 550°F test data as expected.

2. Average data of BWXS design are compared to that of E1820 design and the results are summarized in Table 2.

Table 2 Comparison of J and dJ/da Values at Crack Extension of 0.1 Inch

Specimen Design	Average J at Δa=0.1" (in-lbs/in^2)	Difference (%)	Average dJ/da at Δa=0.1"	Difference (%)
E1820 Design	1819	3.2	3905	30
BWXS Design	1761		2732	

The BWXS design results in lower J and dJ/da values compared to those of ASTM E1820 design. The trend curve of the average values for BWXS and ASTM E1820

design are shown in Figure 6. It is concluded that beyond 0.06 inch crack extension, the BWXS design produces conservative results compared to the ASTM E1820 design.

3. It is concluded that there is bias using BWXS design based on the E_M values, which are summarized in Table 3. It should be noted that this conclusion is based on a small population.

Table 3 Comparison of E and E_M

Specimen ID	Input E (ksi)	E_M (ksi)	Average E_M (ksi)
2D1 (BWXS design)	27,509*	25,860	26,150
2D2 (BWXS design)		26,440	
2D3 (E1820 design)		28,600	28,745
2D4 (E1820 design)		28,890	

* Modulus = 29480 - 5.055 x T (°F) (from ASME Code Section II part D)

Although the difference in E_M is close to 10%, the effect on the crack length is less than 3% and is even lower for the J value. Therefore, it is concluded that the bias has a small impact to the test data. This conclusion is consistent with a statement in ASTM E636 "Conducting Supplemental Surveillance Tests for Nuclear Power Reactor Vessels, E706 (IH)" Section 6.1.2.1:

"The pinhole spacings recommended in Test method E399 and Test Method E813 are different. However, this difference does not significantly affect the stress field at the crack tip and therefore either pinhole spacing is acceptable for surveillance testing."

ASTM E636 is now under amendment and the same section reads:

"The pinhole spacings <u>for compact specimens</u> recommended in Test method E399 and Test Method E~~813~~ <u>1820</u> are different. However, this difference does not significantly affect the stress field at the crack tip and therefore either pinhole spacing is acceptable for surveillance testing."

This amendment needs to be approved by ASTM Main Committee before it becomes effective.

4. During the review, it was noticed that the crack extensions determined from the optical measurements were higher than those determined by the compliance method. The BWXS test procedure requires the operator to check the crack length and ensure the measurements are consistent with the final precrack length prior to actual testing. No such problem was noticed at the time of testing. Furthermore, this laboratory usually has

consistent crack length results determined by the compliance method on irradiated specimens. After further examination it was decided that at some point during the test, the stress field at the crack tip did not meet the constraint requirement. This can been seen by the fact that the crack front was not as straight compared to a test with valid J values. Fractograph of failed specimens are shown in Appendix C. Another approach was to determine the capacity of the specimen. The maximum J-integral capacity of a specimen is given by the smaller of the following:

$$J_{max} = b\sigma_Y/20, \text{ or}$$

$$J_{max} = B\sigma_Y/20,$$

where

b =	remaining ligment (=W-a_p)
σ_Y =	average of the 0.2% offset yield strength and the ultimate tensile strength
B =	specimen thickness.

Note that σ_Y = (68+83)/2 = 75.5 ksi[1] and B = 0.5 inch were used in the calculation. In the beginning of the test, the J_{max} was estimated to be 1,850 in-lbs/in^2 and gradually decreased to 1,400 in-lbs/in^2 as crack grew by 0.12". All the specimens had J values exceeding the specimen capacity at the end of the test. This explained (1) why compliance crack length under-predicted the actual crack length since the equation assumes the crack tip constraint is met, (2) why the crack front was not straight, and (3) why this laboratory did not have problem with irradiated specimens since they have a higher σ_Y (~95 ksi) and thus higher capacity. It is expected that the situation will improve when irradiated TVA compact specimens are tested due to higher σ_Y (~89 ksi).

5. Test data of weld metal specimens were compared to those of base metal specimen (specimen ID was 1B2, see Appendix B) and found to be consistent with expectations.

[1] Operator used 90 ksi and 110 ksi for 0.2% offset yield strength and ultimate tensile strength, respectively in the data analysis assuming generic irradiated specimens. The adequate tensile property data were retrieved from a 20-year old report. The impact of σ_Y on J-R curve analysis is small.

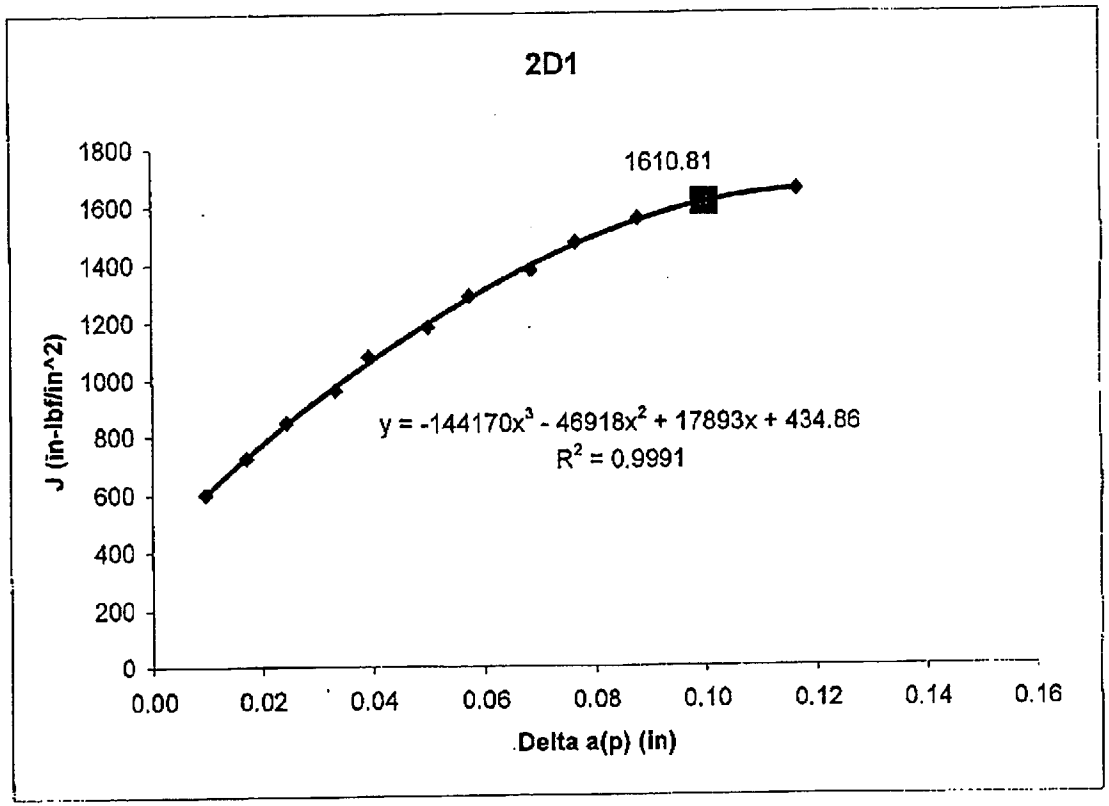
CONCLUSIONS

It is concluded that the BWXS modified E399 specimen design is adequate for an ASTM E1820 test based on test data presented in this report.

RECOMMENDATIONS

1. BWXS recommends that maximum allowable side grooves (25% of specimen thickness) be used on irradiated compact specimen to promote a straight crack front.

2. BWXS shall determine the specimen capacity at 0.1" crack extension for the irradiated specimen and report it as the J value in case of J values exceed specimen capacity. BWXS expects that the specimen capacity should be much higher than the critical J value of 590 in-lbs/in^2.

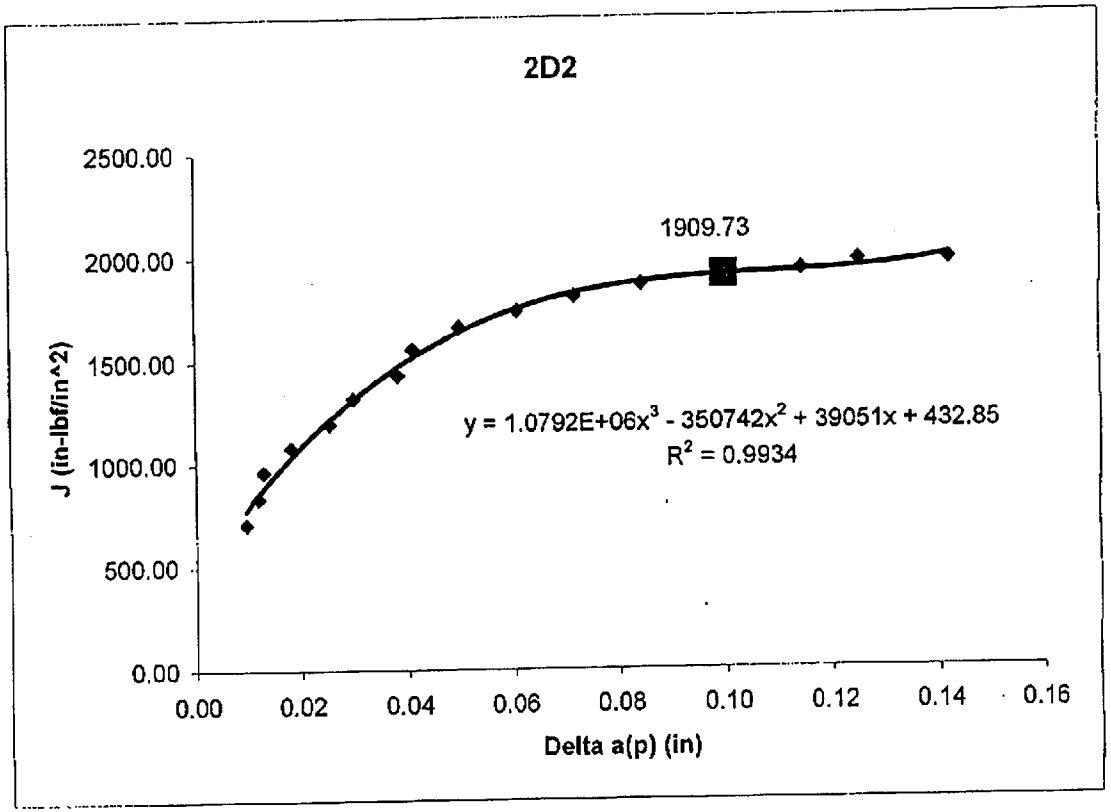


y= -144170x3 - 46918x2 + 17893x + 434.86

y'= -432510x2-93836x+17893

y'(.1)= 4184.3

Figure 1 J-R curve for Specimens 2D1.

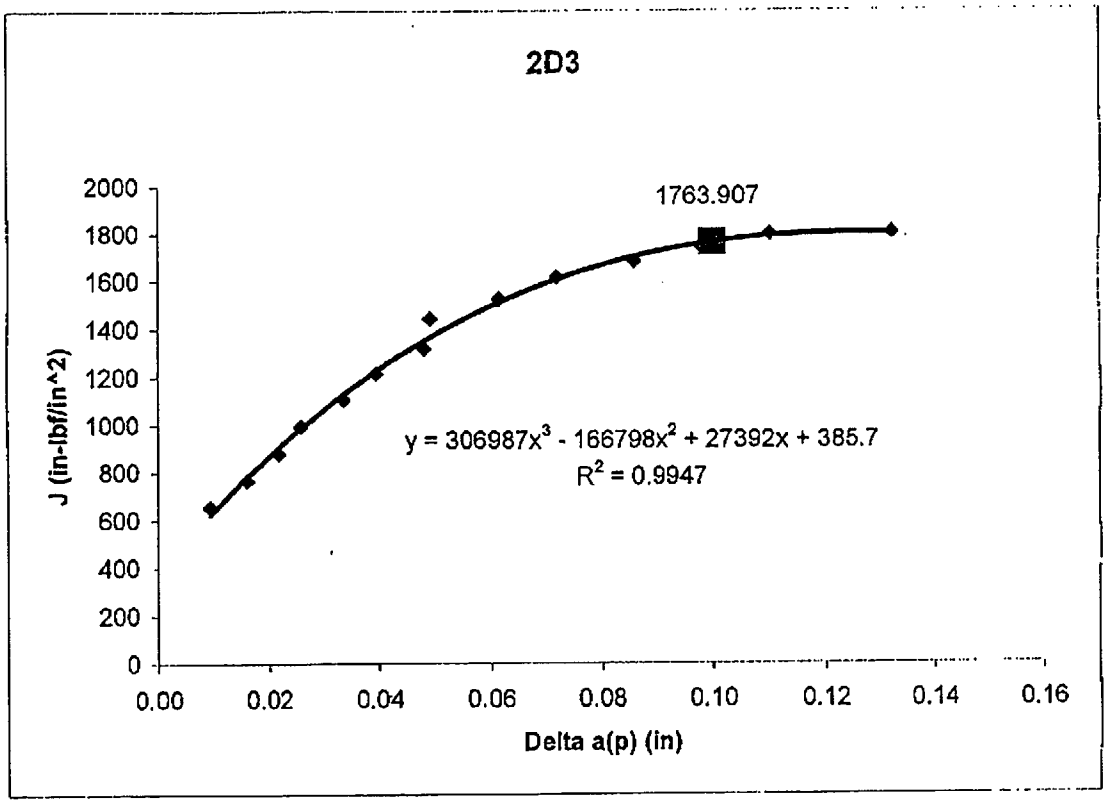


y= 1.0792E+06x3 - 350742x2 + 39051x + 432.85

y'= 3.2376E+06x2-701484x+39051

y'(.1)= 1278.6

Figure 2 J-R curve for Specimens 2D2.

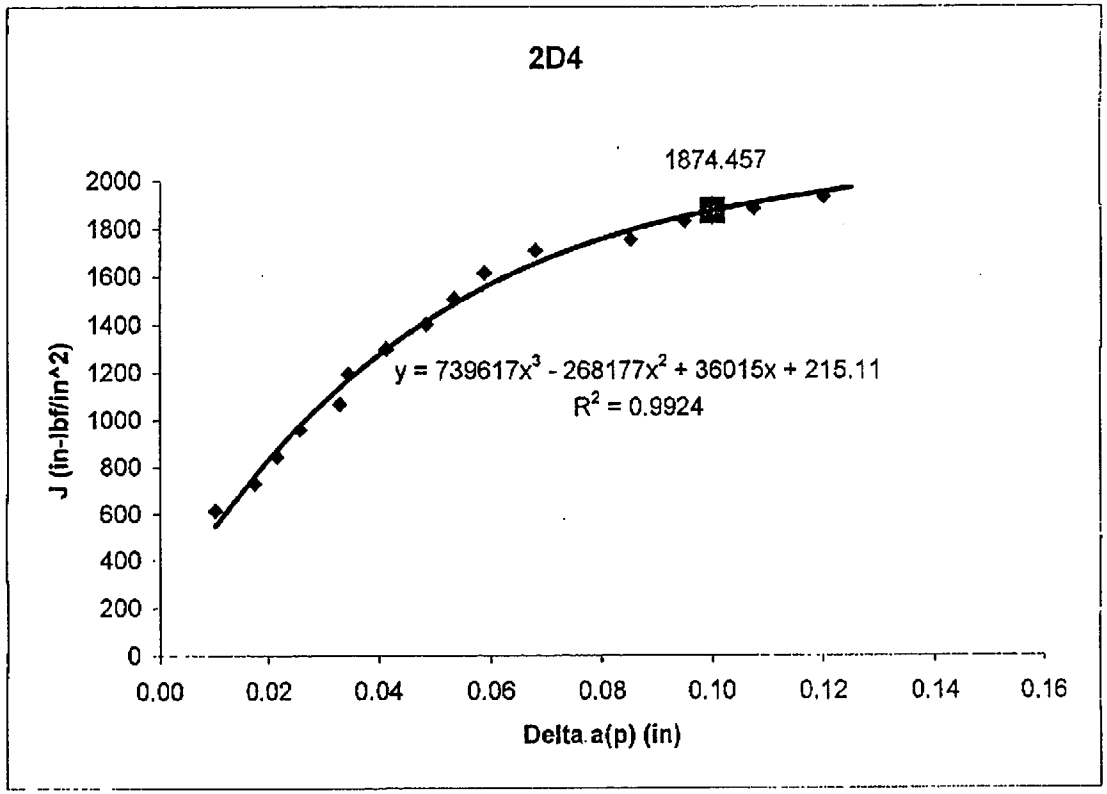


y= 306987x3 - 166798x2 + 27392x + 385.7

y'= 920961x2-333596x+27392

y'(.1)= 3242.01

Figure 3 J-R curve for Specimens 2D3.



y= 739617x3 - 268177x2 + 36015x + 215.11

y'= 2218851x2-536354x+36015

y'(.1)= 4568.11

Figure 4 J-R curve for Specimens 2D4.

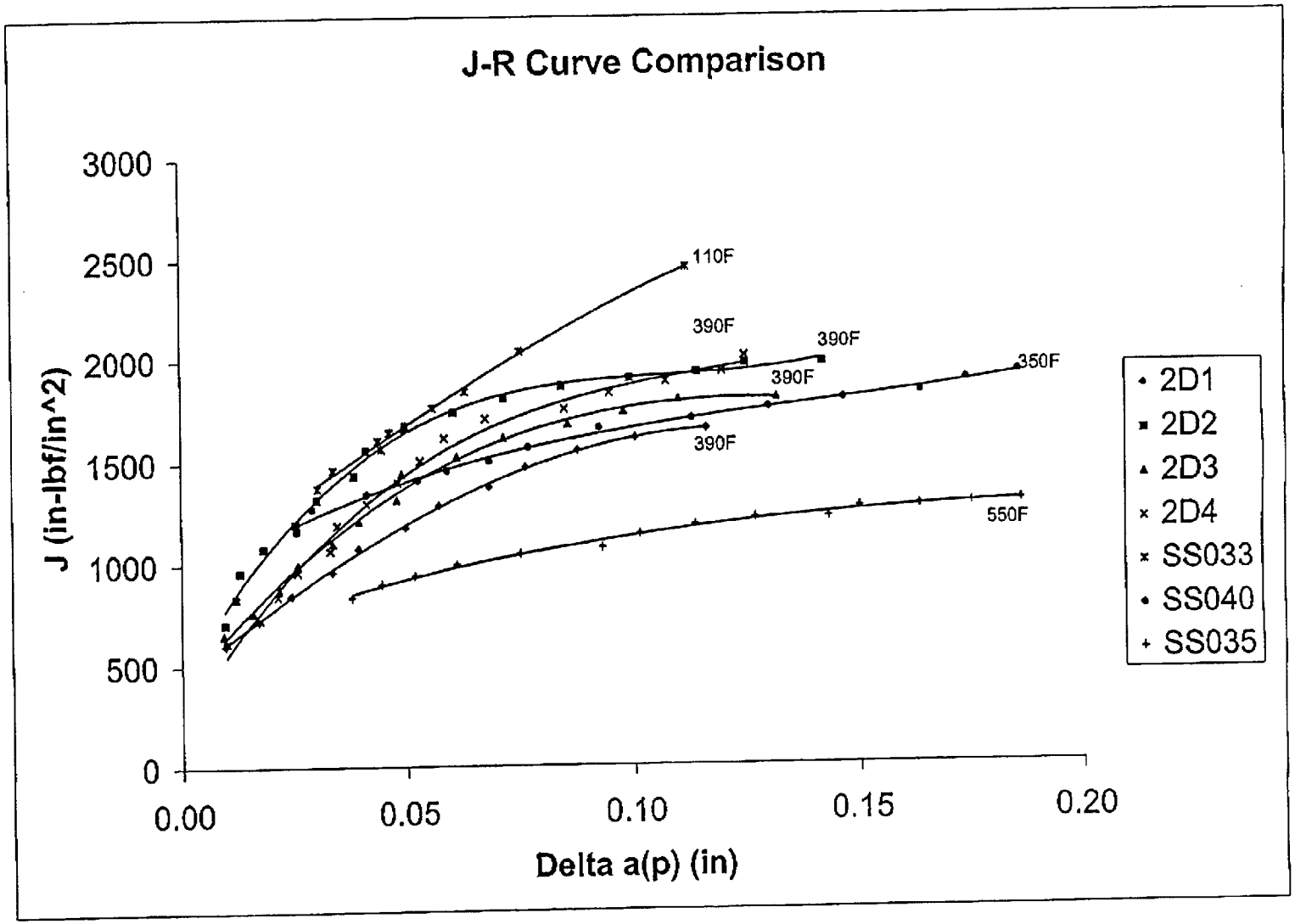


Figure 5 J-R curves comparison between this test program and previous test program.

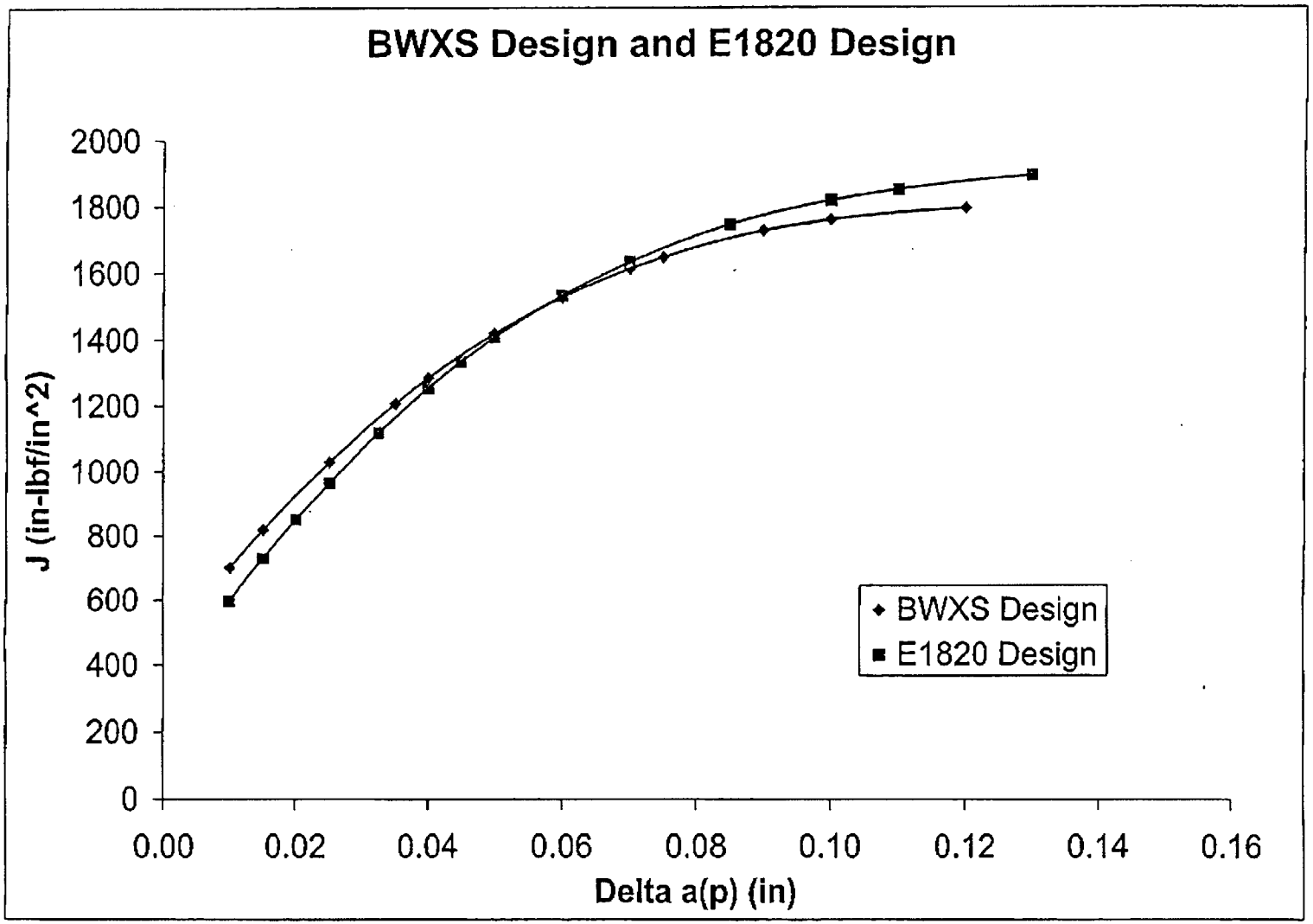
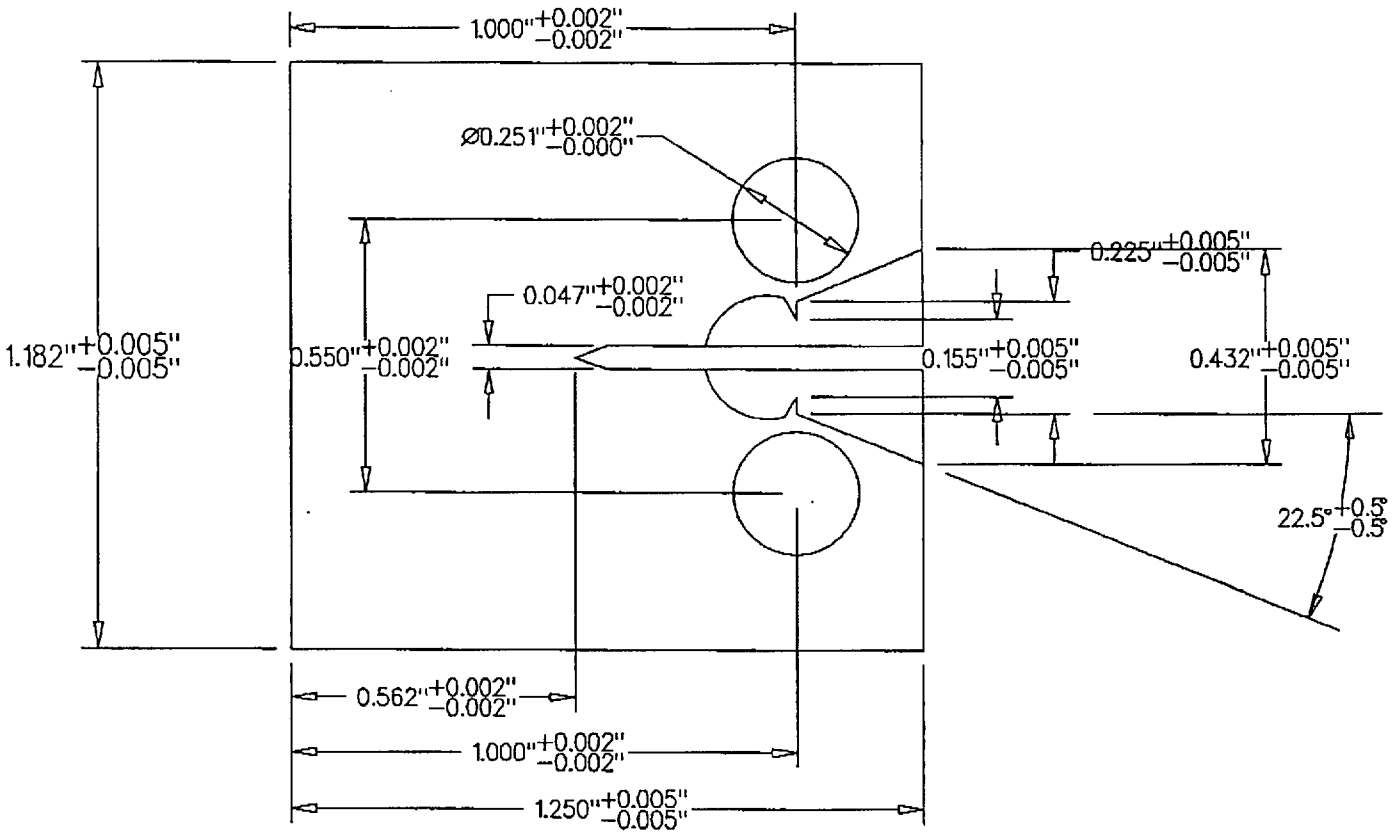


Figure 6 J-R curves comparison between the BWXS design and the ASTM E1802 design.

APPENDIX A

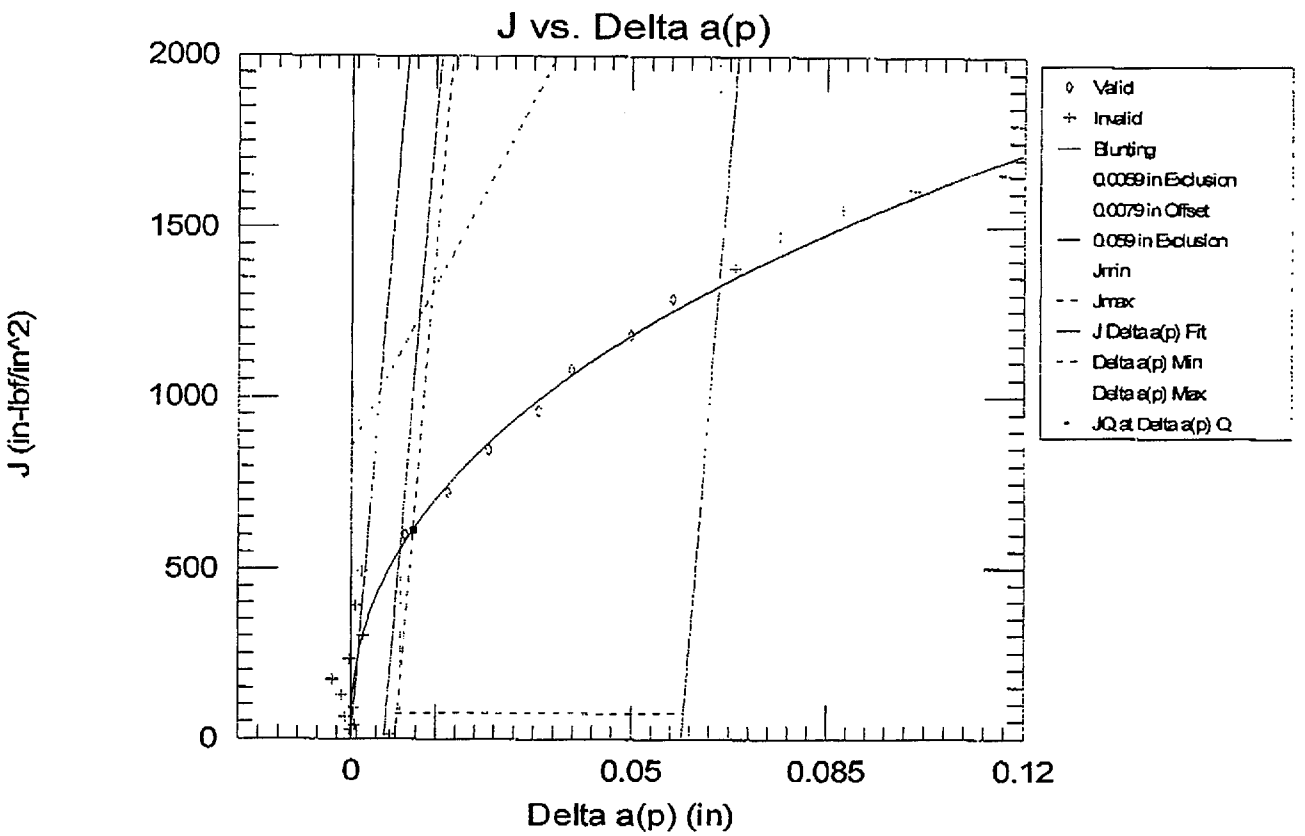
BWXS Specimen Design


1.000" +0.002" −0.002"
Ø0.251" +0.002" −0.000"
0.225" +0.005" −0.005"
0.047" +0.002" −0.002"
1.182" +0.005" −0.005"
0.550" +0.002" −0.002"
0.155" +0.005" −0.005"
0.432" +0.005" −0.005"
22.5° +0.5° −0.5°
0.562" +0.002" −0.002"
1.000" +0.002" −0.002"
1.250" +0.005" −0.005"

APPENDIX B

J-integral Test Results

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D1



J, Delta a(p), Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D1

Step	Step Validity	J (in-lbf/in^2)	Delta a(p) (in)	Load (lbf)	COD (in)
1	Invalid	14.3998	0.00690889	894.888	0.00271519
2	Invalid	26.0598	-0.000235485	1185.40	0.00371799
3	Invalid	41.8246	0.000602247	1473.14	0.00476217
4	Invalid	63.4083	-0.00107645	1779.50	0.00593555
5	Invalid	91.1771	0.000243380	2083.10	0.00720197
6	Invalid	126.884	-0.00173050	2366.38	0.00861311
7	Invalid	173.552	-0.00333500	2628.29	0.0102466
8	Invalid	231.434	-0.000323643	2859.86	0.0120868
9	Invalid	301.151	0.00214581	3042.83	0.0141337
10	Invalid	388.781	0.000730204	3169.67	0.0165322
11	Invalid	490.719	0.00189151	3242.71	0.0192666
12	Valid	600.888	0.00955687	3249.95	0.0223112
13	Valid	724.876	0.0171160	3161.74	0.0257538
14	Valid	847.185	0.0244637	3070.76	0.0292740
15	Valid	961.190	0.0334401	3004.26	0.0327631
16	Valid	1079.21	0.0393156	2905.00	0.0362936
17	Valid	1181.12	0.0499617	2795.41	0.0398705
18	Valid	1287.49	0.0573690	2700.65	0.0434630
19	Invalid	1377.94	0.0685341	2581.08	0.0471280
20	Invalid	1471.83	0.0765046	2464.58	0.0507256
21	Invalid	1553.65	0.0878693	2289.52	0.0546024
22	Invalid	1611.19	0.100636	2169.60	0.0582362
23	Invalid	1654.11	0.116425	1961.46	0.0622114
24	---	---	---	---	---
25	---	---	---	---	---

J, Delta a(p), Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D1

Displacement (in)	Load Line Displacement (in)	Normalized Load Line Compliance	Energy for J Calculation (in-lbf)	Delta a(p) Min/Max Validity	J Exclusion Validity
0.0107316	0.00271519	41.6313	1.27634	Valid	Valid
0.0137467	0.00371799	40.1484	2.32142	Valid	Invalid
0.0167619	0.00476217	40.3114	3.72147	Valid	Invalid
0.0197598	0.00593555	39.9772	5.64248	Valid	Invalid
0.0227578	0.00720197	40.2378	8.10108	Valid	Invalid
0.0257901	0.00861311	39.8447	11.2572	Valid	Invalid
0.0287536	0.0102466	39.5220	15.3687	Valid	Invalid
0.0317687	0.0120868	40.1220	20.4751	Valid	Invalid
0.0346977	0.0141337	40.6295	26.5879	Valid	Invalid
0.0377474	0.0165322	40.3461	34.1376	Valid	Invalid
0.0407453	0.0192666	40.5769	43.0096	Valid	Invalid
0.0437776	0.0223112	42.2017	53.0160	Valid	Valid
0.0467756	0.0257538	43.8855	64.2170	Valid	Valid
0.0497217	0.0292740	45.6052	75.3256	Valid	Valid
0.0528059	0.0327631	47.8254	86.0775	Valid	Valid
0.0557693	0.0362936	49.3549	96.6486	Valid	Valid
0.0587327	0.0398705	52.2924	106.992	Valid	Valid
0.0617654	0.0434630	54.4731	117.000	Valid	Valid
0.0647287	0.0471280	57.9930	126.812	Valid	Invalid
0.0677264	0.0507256	60.6935	136.039	Valid	Invalid
0.0707591	0.0546024	64.8438	145.461	Valid	Invalid
0.0737398	0.0582362	69.9770	153.696	Valid	Invalid
0.0767032	0.0622114	77.1229	161.970	Valid	Invalid
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J Delta a(p), Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D1

J Min/Max Validity

Invalid
Invalid
Invalid
Invalid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D1

Identification

Template	JIC Fracture Toughness
Procedure	FTI 2000 1/2T
General Information	TVA 2001 Linde-80 Unirradiated Welds Operator : Brad Vevera Project Leader : Kevin Hour Job Number : 1215-001-00-18-00-00-0000 Date of Test : 05/2001
Batch	WF-182
Batch Comments	
Specimen	2D1
Specimen Comments	
Platform	TestStar II

Geometry

Specimen Geometry	LLC(T)
Width (W)	1.004 in
Notch Length (a0)	0.45 in
Thickness (B)	0.501 in
Net Thickness (Bn)	0.401 in
Elastic Modulus (E)	27508.4 ksi
Yield Strength	90 ksi
Ultimate Tensile Strength	110 ksi
Poisson's Ratio	0.3 (none)
Crack Plane Orientation	
Pin Center from Crack Plane	0.27575 in
COD Half-Gage Length	0.07775 in
COD Distance from Load Line	0 in
Test Temperature	390 deg_F

Compliance Coefficients

C0	1.0002 (none)
C1	-4.0632 (none)
C2	11.242 (none)
C3	-106.04 (none)
C4	464.33 (none)
C5	-650.68 (none)

K Calibration Coefficients

Calibration coeff. 0	0.886 (none)
Calibration coeff. 1	4.64 (none)
Calibration coeff. 2	-13.32 (none)
Calibration coeff. 3	14.72 (none)
Calibration coeff. 4	-5.6 (none)

Precrack Parameters:

Final Kmax	18 ksi-in^0.5
Test Frequency	10 Hz
Final Crack Length	1 in
Cycle Limited	No
Maximum Number of Cycles	10000
Crack Length Monitoring	compliance
Upper LSF data range	85 %
Lower LSF data range	15 %
Automatic Inspection Hold	No
Inspection Interval (cycles)	10000

Precrack Setup:

PCR Load Signal	Force 312
PCR Load Range	10000 lbf
PCR COD Signal	Clip Gage
PCR COD Range	0.15 in

Precrack Results:

Precrack Cycles	51639
Precrack Kmax	23.317 ksi-in^0.5
Precrack Final K	18.195 ksi-in^0.5
Precrack Pmax	1336 lbf
Precrack Final P	893.85 lbf

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D1

Precrack crack length	0.52002 in
Execution Parameters:	
Test Control	Displacement
Ramp Rate	0.00999999 in/Min
UnLoad on Load Step	No
Load Step	300.001 lbf
UnLoad on COD Step	No
COD Step	0.0025 in
UnLoad on Displacement Step	Yes
Displacement Step	0.003 in
Unload Pct of Current Load	Yes
Percent Unload	20 %
Unload Absolute	No
Absolute Unload	2000 lbf
Number of Unloads	1
Crack Propagation Hold Time	2 Sec
Unload Rate	100 lbf/Sec
Reload Rate	100 lbf/Sec
Ramp To Initial Load	Yes
Pct Of Final Precrack Load	100 %
Load Ramp Rate	100 lbf/Sec
Test Setup:	
Load Channel Name	Force 312
Maximum Load	5000 lbf
COD Channel Name	Clip Gage
Maximum COD	0.15 in
Length Channel Name	Length 312
Maximum Displacement	1 in
Frame Stiffness	130 kip/in
Data Storage:	
Event Log Filename	elog.txt
Data File Name	JIC_FTI 2000 1_2T_WF-182_2D1.RAW
Test Termination:	
End on maximum load	No
Maximum Load	5000 lbf
End on maximum COD	Yes
Maximum COD	0.15 in
End on maximum displ.	No
Maximum Displacement	1 in
End on maximum Crack Length	No
Maximum Crack Length	1 in
End on maximum Crack Extension	No
Maximum Crack Length Extension	1 in
Termination Type	Controlled
Final Precrack Lengths:	
Precrack length 1	0.498799 in
Precrack length 2	0.508201 in
Precrack length 3	0.513098 in
Precrack length 4	0.518201 in
Precrack length 5	0.519598 in
Precrack length 6	0.514701 in
Precrack length 7	0.510598 in
Precrack length 8	0.508 in
Precrack length 9	0.500598 in
Average Precrack:	0.511512 in
Final JIC Crack Lengths:	
Final crack length 1	0.582 in
Final crack length 2	0.604299 in
Final crack length 3	0.633598 in
Final crack length 4	0.663 in
Final crack length 5	0.68 in
Final crack length 6	0.682402 in
Final crack length 7	0.677 in
Final crack length 8	0.6735 in

Test Summary

Template:	JIC Fracture Toughness
Procedure:	FTI 2000 1/2T
Batch:	WF-182
Specimen:	2D1

Final crack length 9	0.637598 in
Average Physical Crack:	0.65295 in

Calculated Crack Lengths:

Pre Test Normalized Compliance:	41.2437 (none)
Calculated Pre Test Crack Length:	0.511512 in
Test Termination Normalized Compliance:	77.1229 (none)
Calculated Test Term. Crack Length:	0.65295 in

Run-Time Report:

Test Duration:	748.465 Sec
Maximum Load:	3320.61 lbf
Maximum COD:	0.0622114 in
Maximum Displacement:	0.0767547 in
Test Terminat Reason	

JIC Analysis Inputs:

Upper LSF data range:	85 %
Lower LSF data range:	15 %
Blunting Factor M:	2 (none)
Minimum J value:	75 in-lbf/in^2
Modulus Factor Lambda:	1 (none)
Delta a(p) Offset	0.005 in

Analysis Calculations:

Effective Yield Strength	Avg. of Yield _Ultimate
Front Face Spcm. Displ.	Calculated from COD
Unload/Reload Compliance	Unload _Reload
JIC ASTM Standard	ASTM E813-89

JIC Test Results ASTM E 813:

Number of Data Points:	25
Number of Valid Data Points:	7
Delta a(p) Min Limit Line:	0.0086867 in
Delta a(p) Max Limit Line:	0.0656909 in
Regression Slope dJQ/da at delta-aQ:	24.0672 ksi
c1	4256.86 (none)
c2	0.428646 (none)
JQ	614.773 in-lbf/in^2
Delta a(Q)	0.0109479 in
Kj Value:	130.044 ksi-in^0.5
Unable to parse unload/reload for step:	24
Unable to parse unload/reload for step:	25

Validation Criteria ASTM E813-89:

ASTM E813-89 Section 8.4.2:	
tp = 106.4 Sec	
Is tp between 6 Sec and 600 Sec?	Yes
ASTM E813-89 Section 7.1.1:	
25 JQ/SFS = 0.1537 in	
Is b0 > 25 JQ/SFS?	Yes
Is B > 25 JQ/SFS?	Yes
ASTM E813-89 Section 7.2.2:	
a0/W = 0.5095	
Is a0/W between 0.5 _0.75?	Yes
ASTM E813-89 Section 7.5:	
Side grooving = 19.96 pct.	
Is side grooving <= 25 pct.?	Yes
ASTM E813-89 Section 7.6.4:	
Precrack extension = 0.06151 in	
Is precrack extension >= 0.05a0 and >= 0.05 in?	Yes
ASTM E813-89 Section 7.6.1:	
PL = 4565 lbf	
ASTM E813-89 Section 8.4.3.6:	
Is the load range of all compliance unloads <= 0.2PL or 0.5 times the current load?	Yes
ASTM E813-89 Section 9.3.1:	

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D1

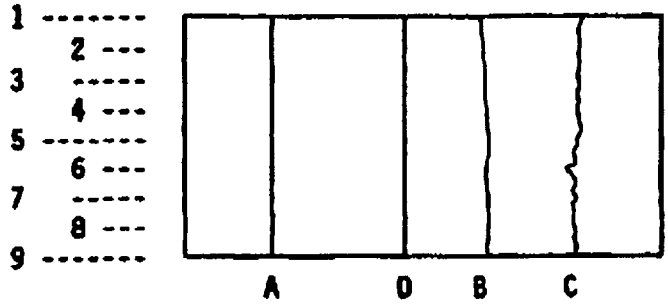
Do all points used for regression lie between Delta a(p) min _max?	Yes
ASTM E813-89 Section 9.2.2:	
Does at least one data point lie betw the 0.005906 in _0.05906 in excl.	Yes
ASTM E813-89 Section 9.4.1.3:	
Is the slope of the regression curve at JQ less than SFS?	Yes
ASTM E813-89 Section 9.4.1.5:	
Are all precrack lengths within 7 pct. of the average?	Yes
Are all final crack lengths within 7 pct. of the average?	No
ASTM E813-89 Section 9.4.1.6:	
Are both near surface crack extensions within 0.02W of the extension at the center?	No
ASTM E813-89 Section 9.4.1.7:	
Is the difference between the crack extensions found from compliance and the 9-point averages within 15 pct. of either of the 9-point average or Delta a(p) max?	No
EM from 9-point precrack front average = 2.586e+004 ksi	
Is EM within 10 pct. of nominal E?	Yes
Is JQ = JIC per ASTM E813-89?	No

FIGURE 3 - CRACK LENGTH MEASUREMENT RECORD

PROGRAM IDENTIFICATION

Project Number: 1215-001 QA Number: 0001
Specimen Number: 2D1 Specimen Size: 1/2T
Operator: B. Vevera Date: 5/14/01
Procedure: TR-177 Rev 9
Measuring Instr.: 1-0000-0538

MEASUREMENT GUIDE



A - Load line
B - End of Fatigue Crack / Beginning of Crack Extension
C - End of Crack Extension
D - End of Machined Notch / Beginning of Fatigue Crack

MEASUREMENTS

	Difference A-B	Difference A-C
1	.4988	.5820
9	.5006	.6376
Edge Average	.4997	.6098
2	.5082	.6043
3	.5131	.6386
4	.5132	.6630
5	.5186	.6800
6	.5147	.6824
7	.5106	.6770
8	.5080	.6735
Specimen Mean	.515125	.65295

Procedure:
Measure the initial crack length (A-B) and final crack length (A-C) for each location. Calculate the mean for locations 1 and 9 to determine the Edge Average. Enter these values as indicated, and calculate the Specimen Mean (the mean of the Edge Average and the seven interior locations).

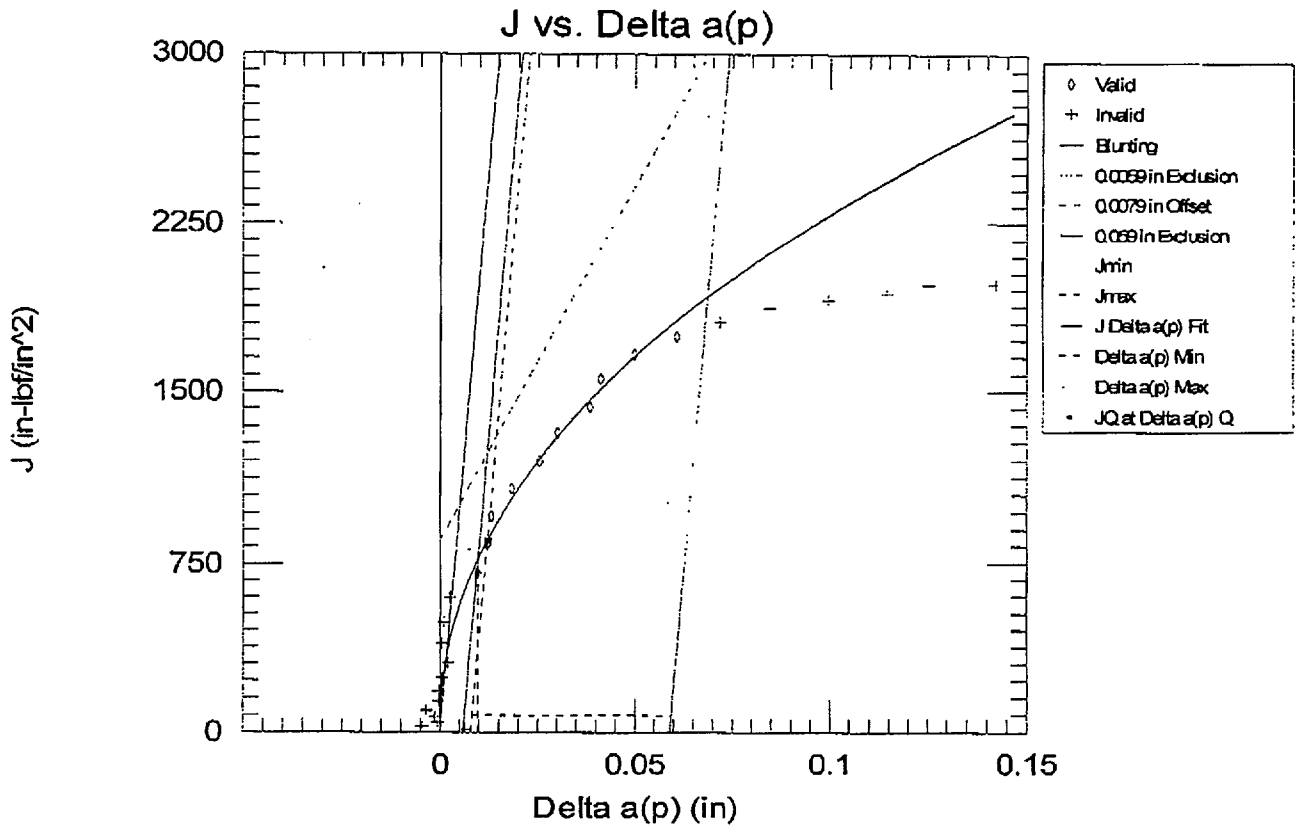
Initial Crack Length = Specimen Mean For A-B Dimension
Final Crack Length = Specimen Mean For A-C Dimension

Crack Extension = (Final Crack Length - Initial Crack Length) = .1414

Measurements and calcs made: B. Vevera Date: 5/14/01

Measurements and calcs checked: [illegible] Date: 5/21/01

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D2



J, Delta a(p), Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D2

Step	Step Validity	J (in-lbf/in^2)	Delta a(p) (in)	Load (lbf)	COD (in)
1	Invalid	14.1557	0.00625293	885.583	0.00272553
2	Invalid	26.6243	-0.00462271	1201.59	0.00379553
3	Invalid	45.3334	-0.000622799	1524.15	0.00499992
4	Invalid	68.3857	-0.00129998	1837.74	0.00620433
5	Invalid	98.2808	-0.00349494	2141.34	0.00752244
6	Invalid	135.863	-0.000409799	2427.01	0.00895429
7	Invalid	181.906	-0.000324419	2675.50	0.0105154
8	Invalid	239.415	-0.000559082	2889.15	0.0122935
9	Invalid	307.578	0.00194758	3059.04	0.0142578
10	Invalid	393.005	0.000484177	3187.59	0.0165683
11	Invalid	488.267	0.000996871	3271.67	0.0190754
12	Invalid	596.807	0.00250792	3322.68	0.0218874
13	Valid	708.122	0.00959440	3345.07	0.0248854
14	Valid	833.566	0.0120680	3323.35	0.0280851
15	Valid	959.796	0.0130426	3309.23	0.0312693
16	Valid	1079.01	0.0183016	3279.24	0.0345206
17	Valid	1198.42	0.0254806	3199.64	0.0379632
18	Valid	1321.67	0.0301205	3118.30	0.0414315
19	Valid	1434.59	0.0383882	3013.54	0.0450449
20	Valid	1558.29	0.0412137	2913.28	0.0485701
21	Valid	1663.78	0.0498996	2740.29	0.0524161
22	Valid	1742.42	0.0607746	2588.99	0.0560654
23	Invalid	1809.25	0.0717546	2456.67	0.0596063
24	Invalid	1867.13	0.0844989	2310.54	0.0633795
25	Invalid	1904.90	0.0994371	2139.28	0.0672256
26	Invalid	1932.54	0.114374	1967.31	0.0710248
27	Invalid	1973.95	0.125118	1854.97	0.0747051
28	Invalid	1976.51	0.142033	1646.48	0.0788299
29	-----	----	---	----	-----

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D2

J min/Max Validity

Invalid
Invalid
Invalid
Invalid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D2

Identification

Template	JIC Fracture Toughness
Procedure	FTI 2000 1/2T
General Information	TVA 2001 Linde-80 Unirradiated Welds Operator : Brad Vevera Project Leader : Kevin Hour Job Number : 1215-001-00-18-00-00-0000 Date of Test : 05/2001
Batch	WF-182
Batch Comments	
Specimen	2D2
Specimen Comments	
Platform	TestStar II

Geometry

Specimen Geometry	LLC(T)
Width (W)	1 in
Notch Length (a0)	0.45 in
Thickness (B)	0.5005 in
Net Thickness (Bn)	0.4005 in
Elastic Modulus (E)	27508.4 ksi
Yield Strength	90 ksi
Ultimate Tensile Strength	110 ksi
Poisson's Ratio	0.3 (none)
Crack Plane Orientation	
Pin Center from Crack Plane	0.275 in
COD Half-Gage Length	0.0785 in
COD Distance from Load Line	0 in
Test Temperature	390 deg_F

Compliance Coefficients

C0	1.0002 (none)
C1	-4.0632 (none)
C2	11.242 (none)
C3	-106.04 (none)
C4	464.33 (none)
C5	-650.68 (none)

K Calibration Coefficients

Calibration coeff. 0	0.886 (none)
Calibration coeff. 1	4.64 (none)
Calibration coeff. 2	-13.32 (none)
Calibration coeff. 3	14.72 (none)
Calibration coeff. 4	-5.6 (none)

Precrack Parameters

Final Kmax	18 ksi-in^0.5
Test Frequency	10 Hz
Final Crack Length	1 in
Cycle Limited	No
Maximum Number of Cycles	10000
Crack Length Monitoring	compliance
Upper LSF data range	85 %
Lower LSF data range	15 %
Automatic Inspection Hold	No
Inspection Interval (cycles)	10000

Precrack Setup

PCR Load Signal	Force 312
PCR Load Range	10000 lbf
PCR COD Signal	Clip Gage
PCR COD Range	0.15 in

Precrack Results

Precrack Cycles	49026
Precrack Kmax	24.047 ksi-in^0.5
Precrack Final K	18.061 ksi-in^0.5
Precrack Pmax	1371.5 lbf
Precrack Final P	877.66 lbf

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D2

Precrack crack length	0.52042 in
Execution Parameters:	
Test Control	Displacement
Ramp Rate	0.00999999 in/Min
UnLoad on Load Step	No
Load Step	300.001 lbf
UnLoad on COD Step	No
COD Step	0.0025 in
UnLoad on Displacement Step	Yes
Displacement Step	0.003 in
Unload Pct of Current Load	Yes
Percent Unload	20 %
Unload Absolute	No
Absolute Unload	2000 lbf
Number of Unloads	1
Crack Propagation Hold Time	2 Sec
Unload Rate	100 lbf/Sec
Reload Rate	100 lbf/Sec
Ramp To Initial Load	Yes
Pct Of Final Precrack Load	100 %
Load Ramp Rate	100 lbf/Sec
Test Setup:	
Load Channel Name	Force 312
Maximum Load	5000 lbf
COD Channel Name	Clip Gage
Maximum COD	0.15 in
Length Channel Name	Length 312
Maximum Displacement	1 in
Frame Stiffness	130 kip/in
Data Storage:	
Event Log Filename	elog.txt
Data File Name	JIC_FTI 2000 1_2T_WF-182_2D2.RAW
Test Termination:	
End on maximum load	No
Maximum Load	5000 lbf
End on maximum COD	Yes
Maximum COD	0.15 in
End on maximum displ.	No
Maximum Displacement	1 in
End on maximum Crack Length	No
Maximum Crack Length	1 in
End on maximum Crack Extension	No
Maximum Crack Length Extension	1 in
Termination Type	Controlled
Final Precrack Lengths:	
Precrack length 1	0.504 in
Precrack length 2	0.5105 in
Precrack length 3	0.513098 in
Precrack length 4	0.517299 in
Precrack length 5	0.518598 in
Precrack length 6	0.516098 in
Precrack length 7	0.515598 in
Precrack length 8	0.511098 in
Precrack length 9	0.508598 in
Average Precrack:	0.513574 in
Final JIC Crack Lengths:	
Final crack length 1	0.679902 in
Final crack length 2	0.682299 in
Final crack length 3	0.689402 in
Final crack length 4	0.69 in
Final crack length 5	0.716598 in
Final crack length 6	0.701098 in
Final crack length 7	0.691799 in
Final crack length 8	0.690598 in

Test Summary

Template:	JIC Fracture Toughness
Procedure:	FTI 2000 1/2T
Batch:	WF-182
Specimen:	2D2
Final crack length 9	0.688098 in
Average Physical Crack:	0.693224 in
Calculated Crack Lengths:	
Pre Test Normalized Compliance:	41.1825 (none)
Calculated Pre Test Crack Length:	0.513574 in
Test Termination Normalized Compliance:	92.4127 (none)
Calculated Test Term. Crack Length:	0.693224 in
Run-Time Report:	
Test Duration:	921.912 Sec
Maximum Load:	3426.4 lbf
Maximum COD:	0.0788559 in
Maximum Displacement:	0.090211 in
Test Terminat Reason	Load drop limit exceeded
JIC Analysis Inputs:	
Upper LSF data range:	85 %
Lower LSF data range:	15 %
Blunting Factor M:	2 (none)
Minimum J value:	75 in-lbf/in^2
Modulus Factor Lambda:	1 (none)
Delta a(p) Offset	0.003 in
Analysis Calculations:	
Effective Yield Strength	Avg. of Yield _Ultimate
Front Face Spcm. Displ.	Calculated from COD
Unload/Reload Compliance	Unload _Reload
JIC ASTM Standard	ASTM E813-89
JIC Test Results ASTM E 813:	
Number of Data Points:	29
Number of Valid Data Points:	10
Delta a(p) Min Limit Line:	0.00976803 in
Delta a(p) Max Limit Line:	0.0686646 in
Regression Slope dJQ/da at delta-aQ:	32.9089 ksi
c1	6719.31 (none)
c2	0.467451 (none)
JQ	853.146 in-lbf/in^2
Delta a(Q)	0.0121397 in
Kj Value:	153.195 ksi-in^0.5
Unable to parse unload/reload for step:	29
Validation Criteria ASTM E 813-89:	
ASTM E813-89 Section 8.4.2:	
tp = 90.64 Sec	
Is tp between 6 Sec and 600 Sec?	Yes
ASTM E813-89 Section 7.1.1:	
25 JQ/SFS = 0.2133 in	
Is b0 > 25 JQ/SFS?	Yes
Is B > 25 JQ/SFS?	Yes
ASTM E813-89 Section 7.2.2:	
a0/W = 0.5136	
Is a0/W between 0.5 _0.75?	Yes
ASTM E813-89 Section 7.5:	
Side grooving = 19.98 pct.	
Is side grooving <= 25 pct.?	Yes
ASTM E813-89 Section 7.6.4:	
Precrack extension = 0.06357 in	
Is precrack extension >= 0.05a0 and >= 0.05 in?	Yes
ASTM E813-89 Section 7.6.1:	
PL = 4549 lbf	
ASTM E813-89 Section 8.4.3.6:	
Is the load range of all compliance unloads <= 0.2PL or 0.5 times the current load?	Yes
ASTM E813-89 Section 9.3.1:	
Do all points used for regression lie	

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D2

between Delta a(p) min _max?	Yes
ASTM E813-89 Section 9.2.2:	
Does at least one data point lie betw the 0.005906 in _0.05906 in excl.	Yes
ASTM E813-89 Section 9.4.1.3:	
Is the slope of the regression curve at JQ less than SFS?	Yes
ASTM E813-89 Section 9.4.1.5:	
Are all precrack lengths within 7 pct. of the average?	Yes
Are all final crack lengths within 7 pct. of the average?	Yes
ASTM E813-89 Section 9.4.1.6:	
Are both near surface crack extensions within 0.02W of the extension at the center?	Yes
ASTM E813-89 Section 9.4.1.7:	
Is the difference between the crack extensions found from compliance and the 9-point averages within 15 pct. of either of the 9-point average or Delta a(p) max?	No
EM from 9-point precrack front average = 2.644e+004 ksi	
Is EM within 10 pct. of nominal E?	Yes
Is JQ = JIC per ASTM E813-89?	No

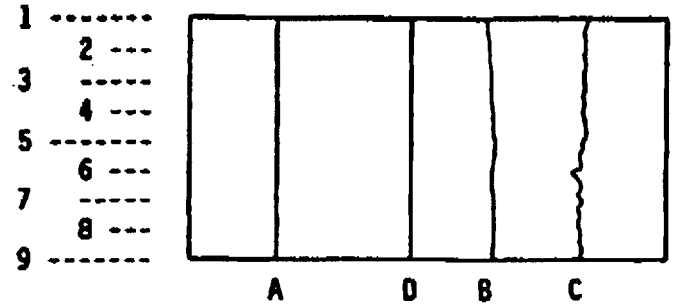
FIGURE 3 - CRACK LENGTH MEASUREMENT RECORD

PROGRAM IDENTIFICATION

Project Number: 1215-001
Specimen Number: 2D2
Operator: B J Vuere
Procedure: TR-177 Rev 9
Measuring Instr.: 1-0000-0538

QA Number: 00001
Specimen Size: 1/2T
Date: 5/14/01

MEASUREMENT GUIDE



A - Load line
B - End of Fatigue Crack / Beginning of Crack Extension
C - End of Crack Extension
D - End of Machined Notch / Beginning of Fatigue Crack

MEASUREMENTS

	Difference A-B	Difference A-C
1	.5040	.6799
9	.5086	.6881
Edge Average	.5063	.6840
2	.5105	.6823
3	.5131	.6894
4	.5173	.6900
5	.5186	.7166
6	.5161	.7011
7	.5156	.6918
8	.5111	.6906
Specimen Mean	.513575	.693225

Procedure: Measure the initial crack length (A-B) and final crack length (A-C) for each location. Calculate the mean for locations 1 and 9 to determine the Edge Average. Enter these values as indicated, and calculate the Specimen Mean (the mean of the Edge Average and the seven interior locations).

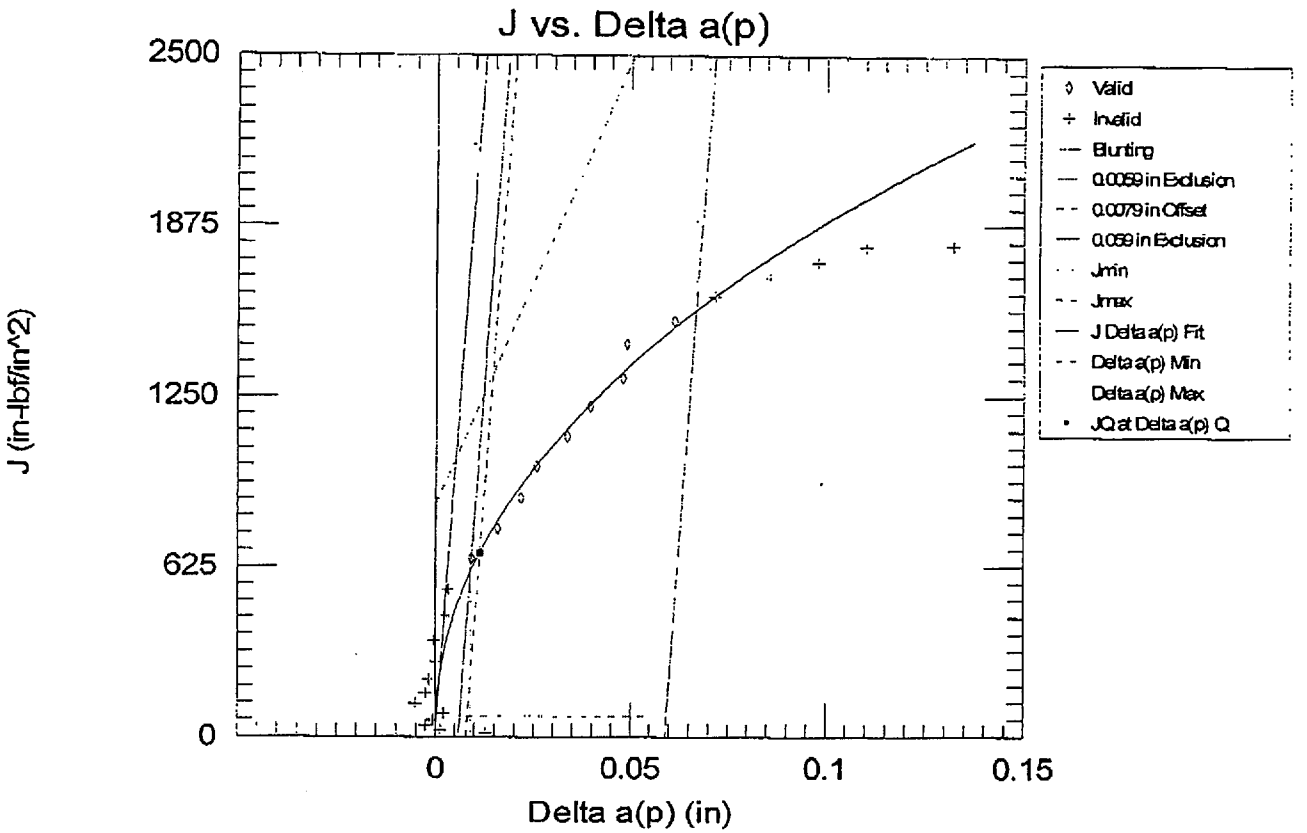
Initial Crack Length = Specimen Mean For A-B Dimension
Final Crack Length = Specimen Mean For A-C Dimension

Crack Extension = (Final Crack Length - Initial Crack Length) = .17965

Measurements and calcs made: B J Vuere Date: 5/14/01

Measurements and calcs checked: [illegible] Date: 5/21/01

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D3



J, Delta a(p), Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D3

Step	Step Validity	J (in-lbf/in^2)	Delta a(p) (in)	Load (lbf)	COD (in)
1	Invalid	14.1494	0.0127617	920.390	0.00263765
2	Invalid	25.0367	0.00126846	1226.06	0.00356809
3	Invalid	41.5464	-0.00261588	1528.28	0.00465358
4	Invalid	61.6319	-0.000673842	1823.61	0.00572358
5	Invalid	87.2590	0.00202461	2109.64	0.00688150
6	Invalid	121.257	-0.00518010	2382.91	0.00822543
7	Invalid	159.287	-0.00263800	2631.73	0.00957457
8	Invalid	210.697	-0.00173253	2844.69	0.0112339
9	Invalid	274.795	0.000159384	3014.94	0.0131619
10	Invalid	350.955	-0.000470229	3133.48	0.0153174
11	Invalid	441.913	0.00223524	3203.08	0.0178503
12	Invalid	542.097	0.00317848	3238.93	0.0205537
13	Valid	653.357	0.00918077	3232.73	0.0236759
14	Valid	764.769	0.0158301	3199.98	0.0268548
15	Valid	877.489	0.0217497	3165.53	0.0300907
16	Valid	993.782	0.0258167	3134.85	0.0333679
17	Valid	1105.25	0.0335773	3054.21	0.0368105
18	Valid	1214.27	0.0394819	2997.69	0.0401496
19	Valid	1316.61	0.0480136	2923.26	0.0436130
20	Valid	1441.77	0.0491246	2828.50	0.0471437
21	Valid	1523.95	0.0613934	2712.36	0.0507827
22	Invalid	1614.69	0.0717126	2552.46	0.0546492
23	Invalid	1681.78	0.0858515	2384.64	0.0586240
24	Invalid	1741.15	0.0980053	2269.20	0.0623098
25	Invalid	1797.71	0.110149	2139.97	0.0661295
26	Invalid	1804.10	0.132084	1872.20	0.0705906
27	---	---	---	---	---
28	---	---	---	---	---

J, Delta a(p), Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D3

Displacement (in)	Load Line Displacement (in)	Normalized Load Line Compliance	Energy for J Calculation (in-lbf)	Delta a(p) Validity	Min/Max J Exclusion Validity
0.0101975	0.00263765	40.2308	1.25897	Valid	Valid
0.0131782	0.00356809	37.9637	2.25318	Valid	Invalid
0.0162450	0.00465358	37.2301	3.74527	Valid	Invalid
0.0192429	0.00572358	37.5853	5.54920	Valid	Invalid
0.0221375	0.00688150	38.0989	7.83820	Valid	Invalid
0.0252215	0.00822543	36.7555	10.8843	Valid	Invalid
0.0282022	0.00957457	37.2168	14.3013	Valid	Invalid
0.0312863	0.0112339	37.3862	18.8885	Valid	Invalid
0.0342498	0.0131619	37.7430	24.6008	Valid	Invalid
0.0372477	0.0153174	37.6331	31.3090	Valid	Invalid
0.0402284	0.0178503	38.1394	39.4393	Valid	Invalid
0.0432606	0.0205537	38.3212	48.2797	Valid	Invalid
0.0462244	0.0236759	39.5037	58.5184	Valid	Valid
0.0491878	0.0268548	40.8673	68.8825	Valid	Valid
0.0521685	0.0300907	42.1314	79.3099	Valid	Valid
0.0552524	0.0333679	43.0287	89.7857	Valid	Valid
0.0582331	0.0368105	44.8092	100.590	Valid	Valid
0.0612654	0.0401496	46.2274	110.854	Valid	Valid
0.0642807	0.0436130	48.3806	121.258	Valid	Valid
0.0672268	0.0471437	48.6705	131.554	Valid	Valid
0.0702764	0.0507827	52.0272	141.805	Valid	Valid
0.0732571	0.0546492	55.0897	152.132	Valid	Invalid
0.0762378	0.0586240	59.6860	162.079	Valid	Invalid
0.0792532	0.0623098	64.0562	170.787	Valid	Invalid
0.0822165	0.0661295	68.8651	179.315	Valid	Invalid
0.0852488	0.0705906	78.8797	188.304	Valid	Invalid
—	—	—	—	—	—
—	—	—	—	—	—

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D3

J Min/Max Validity
Invalid
Invalid
Invalid
Invalid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid
Valid

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D3

Identification:

Template	JIC Fracture Toughness
Procedure	FTI 2000 1/2T
General Information	TVA 2001 Linde-80 Unirradiated Welds Operator : Brad Vevera Project Leader : Kevin Hour Job Number : 1215-001-00-18-00-00-0000 Date of Test : 05/2001
Batch	WF-182
Batch Comments	
Specimen	2D3
Specimen Comments	
Platform	TestStar II

Geometry:

Specimen Geometry	LLC(T)
Width (W)	1 in
Notch Length (a0)	0.45 in
Thickness (B)	0.5005 in
Net Thickness (Bn)	0.4005 in
Elastic Modulus (E)	27508.4 ksi
Yield Strength	90 ksi
Ultimate Tensile Strength	110 ksi
Poisson's Ratio	0.3 (none)
Crack Plane Orientation	
Pin Center from Crack Plane	0.355 in
COD Half-Gage Length	0.0785 in
COD Distance from Load Line	0 in
Test Temperature	390 deg_F

Compliance Coefficients

C0	1.0002 (none)
C1	-4.0632 (none)
C2	11.242 (none)
C3	-106.04 (none)
C4	464.33 (none)
C5	-650.68 (none)

Calibration Coefficients

Calibration coeff. 0	0.886 (none)
Calibration coeff. 1	4.64 (none)
Calibration coeff. 2	-13.32 (none)
Calibration coeff. 3	14.72 (none)
Calibration coeff. 4	-5.6 (none)

Precrack Parameters:

Final Kmax	18 ksi-in^0.5
Test Frequency	10 Hz
Final Crack Length	1 in
Cycle Limited	No
Maximum Number of Cycles	10000
Crack Length Monitoring	compliance
Upper LSF data range	85 %
Lower LSF data range	15 %
Automatic Inspection Hold	No
Inspection Interval (cycles)	10000

Precrack Setup:

PCR Load Signal	Force 312
PCR Load Range	10000 lbf
PCR COD Signal	Clip Gage
PCR COD Range	0.15 in

Precrack Results:

Precrack Cycles	32933
Precrack Kmax	25.34 ksi-in^0.5
Precrack Final K	18.069 ksi-in^0.5
Precrack Pmax	1554 lbf
Precrack Final P	921.77 lbf

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D3

Precrack crack length	0.50505 in
Execution Parameters:	
Test Control	Displacement
Ramp Rate	0.00999999 in/Min
UnLoad on Load Step	No
Load Step	300.001 lbf
UnLoad on COD Step	No
COD Step	0.0025 in
UnLoad on Displacement Step	Yes
Displacement Step	0.003 in
Unload Pct of Current Load	Yes
Percent Unload	20 %
Unload Absolute	No
Absolute Unload	2000 lbf
Number of Unloads	1
Crack Propagation Hold Time	2 Sec
Unload Rate	100 lbf/Sec
Reload Rate	100 lbf/Sec
Ramp To Initial Load	Yes
Pct Of Final Precrack Load	100 %
Load Ramp Rate	100 lbf/Sec
Test Setup:	
Load Channel Name	Force 312
Maximum Load	5000 lbf
COD Channel Name	Clip Gage
Maximum COD	0.15 in
Length Channel Name	Length 312
Maximum Displacement	1 in
Frame Stiffness	130 kip/in
Data Storage:	
Event Log Filename	elog.txt
Data File Name	JIC_FTI 2000 1_2T_WF-182_2D3.RAW
Test Termination:	
End on maximum load	No
Maximum Load	5000 lbf
End on maximum COD	Yes
Maximum COD	0.15 in
End on maximum displ.	No
Maximum Displacement	1 in
End on maximum Crack Length	No
Maximum Crack Length	1 in
End on maximum Crack Extension	No
Maximum Crack Length Extension	1 in
Termination Type	Controlled
Final Precrack Lengths:	
Precrack length 1	0.491902 in
Precrack length 2	0.499 in
Precrack length 3	0.5065 in
Precrack length 4	0.512 in
Precrack length 5	0.516598 in
Precrack length 6	0.517 in
Precrack length 7	0.519098 in
Precrack length 8	0.519098 in
Precrack length 9	0.518598 in
Average Precrack:	0.511818 in
Final JIC Crack Lengths:	
Final crack length 1	0.614201 in
Final crack length 2	0.648902 in
Final crack length 3	0.668 in
Final crack length 4	0.679 in
Final crack length 5	0.683902 in
Final crack length 6	0.686 in
Final crack length 7	0.685 in
Final crack length 8	0.676598 in

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D3

Final crack length 9	0.639799 in
Average Physical Crack:	0.6693 in
Calculated Crack Lengths:	
Pre Test Normalized Compliance:	37.7314 (none)
Calculated Pre Test Crack Length:	0.511818 in
Test Termination Normalized Compliance:	78.8797 (none)
Calculated Test Term. Crack Length:	0.6693 in
Run-Time Report:	
Test Duration:	855.594 Sec
Maximum Load:	3315.77 lbf
Maximum COD:	0.070611 in
Maximum Displacement:	0.0852662 in
Test Terminat Reason	
JIC Analysis Inputs:	
Upper LSF data range:	85 %
Lower LSF data range:	15 %
Blunting Factor M:	2 (none)
Minimum J value:	75 in-lbf/in^2
Modulus Factor Lambda:	1 (none)
Delta a(p) Offset	0 in
Analysis Calculations:	
Effective Yield Strength	Avg. of Yield _Ultimate
Front Face Spcm. Displ.	Calculated from COD
Unload/Reload Compliance	Unload _Reload
JIC ASTM Standard	ASTM E813-89
JIC Test Results ASTM E 813:	
Number of Data Points:	28
Number of Valid Data Points:	9
Delta a(p) Min Limit Line:	0.00894622 in
Delta a(p) Max Limit Line:	0.0668623 in
Regression Slope dJQ/da at delta-aQ:	28.2556 ksi
c1	5572.97 (none)
c2	0.469861 (none)
JQ	676.289 in-lbf/in^2
Delta a(Q)	0.0112555 in
Kj Value:	136.395 ksi-in^0.5
Unable to parse unload/reload for step:	27
Unable to parse unload/reload for step:	28
Validation Criteria ASTM E 813-89:	
ASTM E813-89 Section 8.4.2:	
tp = 113.8 Sec	
Is tp between 6 Sec and 600 Sec?	Yes
ASTM E813-89 Section 7.1.1:	
25 JQ/SFS = 0.1691 in	
Is b0 > 25 JQ/SFS?	Yes
Is B > 25 JQ/SFS?	Yes
ASTM E813-89 Section 7.2.2:	
a0/W = 0.5118	
Is a0/W between 0.5 _0.75?	Yes
ASTM E813-89 Section 7.5:	
Side grooving = 19.98 pct.	
Is side grooving <= 25 pct.?	Yes
ASTM E813-89 Section 7.6.4:	
Precrack extension = 0.06182 in	
Is precrack extension >= 0.05a0 and >= 0.05 in?	Yes
ASTM E813-89 Section 7.6.1:	
PL = 4916 lbf	
ASTM E813-89 Section 8.4.3.6:	
Is the load range of all compliance unloads <= 0.2PL or 0.5 times the current load?	Yes
ASTM E813-89 Section 9.3.1:	

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D3

Do all points used for regression lie between Delta a(p) min _max?	Yes
ASTM E813-89 Section 9.2.2:	
Does at least one data point lie betw the 0.005906 in _0.05906 in excl.	Yes
ASTM E813-89 Section 9.4.1.3:	
Is the slope of the regression curve at JQ less than SFS?	Yes
ASTM E813-89 Section 9.4.1.5:	
Are all precrack lengths within 7 pct. of the average?	Yes
Are all final crack lengths within 7 pct. of the average?	No
ASTM E813-89 Section 9.4.1.6:	
Are both near surface crack extensions within 0.02W of the extension at the center?	No
ASTM E813-89 Section 9.4.1.7:	
Is the difference between the crack extensions found from compliance and the 9-point averages within 15 pct. of either of the 9-point average or Delta a(p) max?	No
EM from 9-point precrack front average = 2.86e+004 ksi	
Is EM within 10 pct. of nominal E?	Yes
Is JQ = JIC per ASTM E813-89?	No

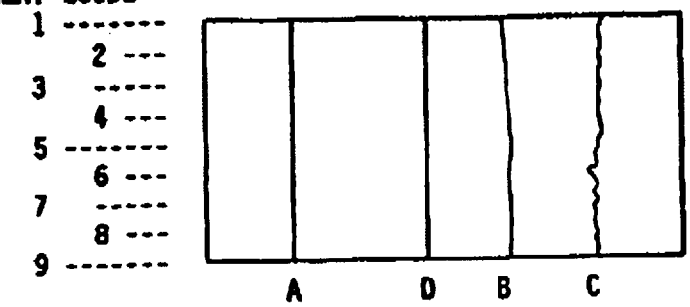
FIGURE 3 - CRACK LENGTH MEASUREMENT RECORD

PROGRAM IDENTIFICATION

Project Number: 1215-001
Specimen Number: 2D3
Operator: BJ Vewen
Procedure: TP-177 Rev 9
Measuring Instr.: 1-0000-0538

QA Number: 00001
Specimen Size: 1/2 T
Date: 5/14/01

MEASUREMENT GUIDE



A - Load line
B - End of Fatigue Crack / Beginning of Crack Extension
C - End of Crack Extension
D - End of Machined Notch / Beginning of Fatigue Crack

MEASUREMENTS

	Difference A-B	Difference A-C
1	.4919	.6142
9	.5186	.6398
Edge Average	.50525	.6270
2	.4990	.6489
3	.5065	.6680
4	.5120	.6790
5	.5166	.6839
6	.5170	.6860
7	.5191	.6850
8	.5191	.6766
Specimen Mean	.5118	.6693

Procedure: Measure the initial crack length (A-B) and final crack length (A-C) for each location. Calculate the mean for locations 1 and 9 to determine the Edge Average. Enter these values as indicated, and calculate the Specimen Mean (the mean of the Edge Average and the seven interior locations).

Initial Crack Length = Specimen Mean For A-B Dimension
Final Crack Length = Specimen Mean For A-C Dimension

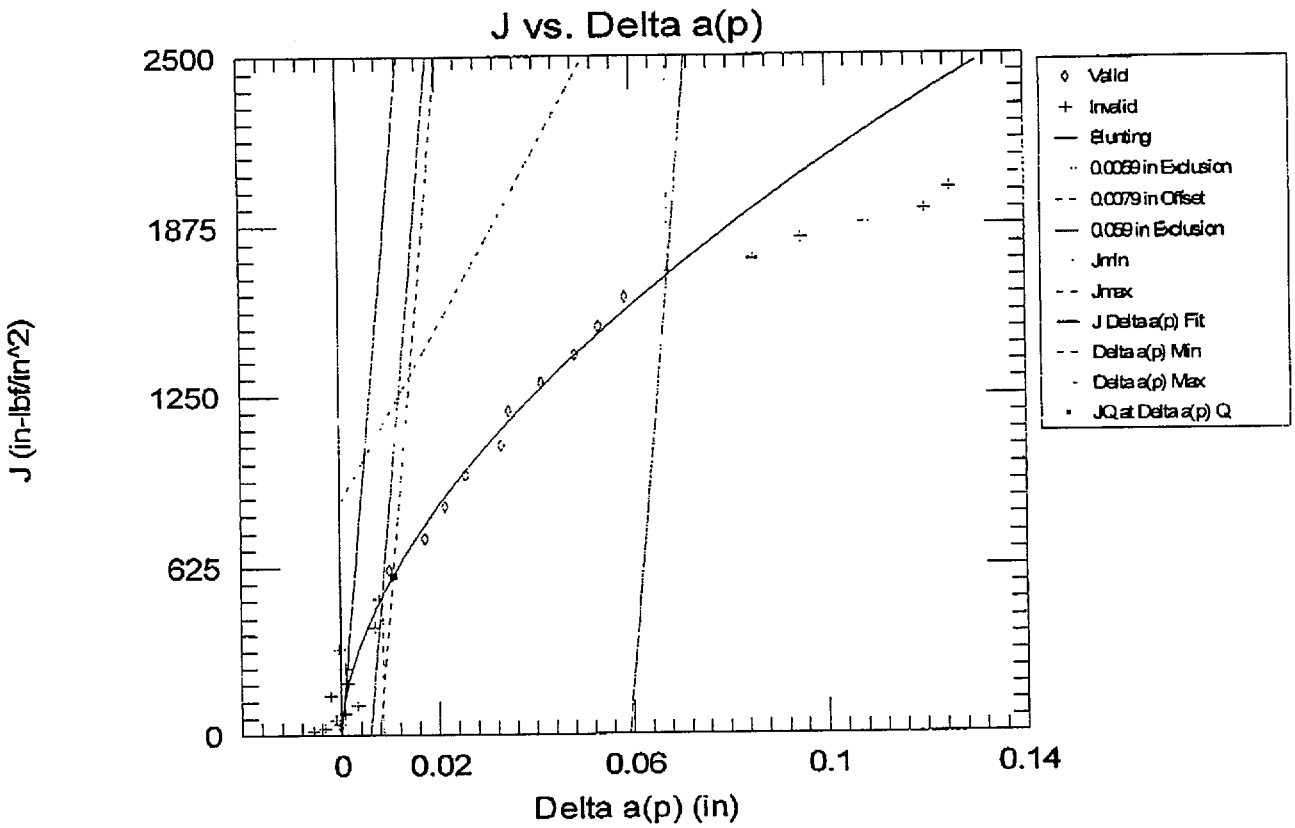
Crack Extension = (Final Crack Length - Initial Crack Length) = .1575

Measurements and calcs made: BJ Vewen Date: 5/14/01

Measurements and calcs checked: Ken Y. Ann Date: 6/6/01

J vs. Delta a(p)

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D4



J: Delta a(p), Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D4

Step	Step Validity	J (in-lbf/in^2)	Delta a(p) (in)	Load (lbf)	COD (in)
1	Invalid	13.5617	-0.00562222	925.215	0.00261698
2	Invalid	23.9223	-0.00331163	1216.75	0.00350089
3	Invalid	38.1523	-0.000490139	1511.40	0.00444685
4	Invalid	56.4444	-0.00113909	1812.93	0.00544965
5	Invalid	79.9814	0.000715508	2092.41	0.00654032
6	Invalid	110.488	0.00336879	2360.52	0.00776539
7	Invalid	147.499	-0.00216072	2606.91	0.00909386
8	Invalid	193.827	0.00134234	2825.40	0.0106187
9	Invalid	250.369	0.000847145	2998.05	0.0123349
10	Invalid	321.584	-0.000371906	3130.71	0.0143767
11	Invalid	405.227	0.00687587	3219.29	0.0167751
12	Invalid	507.138	0.00782402	3262.02	0.0195199
13	Valid	615.368	0.0100062	3273.40	0.0224353
14	Valid	729.673	0.0173127	3249.61	0.0256763
15	Valid	843.615	0.0214691	3225.49	0.0288294
16	Valid	959.513	0.0257498	3184.49	0.0320808
17	Valid	1067.49	0.0330182	3154.83	0.0353425
18	Valid	1193.35	0.0345696	3075.23	0.0387696
19	Valid	1298.13	0.0413053	3041.13	0.0421035
20	Valid	1400.72	0.0483006	2964.96	0.0454843
21	Valid	1505.68	0.0533176	2915.34	0.0488185
22	Valid	1614.70	0.0586935	2804.02	0.0523799
23	Invalid	1708.14	0.0678124	2647.24	0.0561791
24	Invalid	1754.10	0.0850979	2495.60	0.0599941
25	Invalid	1830.34	0.0949310	2355.01	0.0637776
26	Invalid	1884.84	0.107436	2209.23	0.0676185
27	Invalid	1932.02	0.120034	2061.74	0.0715209
28	Invalid	2010.07	0.124970	1941.12	0.0751654
29	---	---	---	---	---
30	---	---	---	---	---

d. Delta a(p) Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D4

Displacement (in)	Load Line Displacement (in)	Normalized Load Line Compliance	Energy for J Calculation (in-lbf)	Delta a(p) Validity	Min/Max J Exclusion Validity
0.0107661	0.00261698	35.5163	1.23774	Valid	Invalid
0.0137467	0.00350089	35.9174	2.18111	Valid	Invalid
0.0167102	0.00444685	36.4255	3.47021	Valid	Invalid
0.0197426	0.00544965	36.3166	5.13241	Valid	Invalid
0.0227750	0.00654032	36.6452	7.25680	Valid	Invalid
0.0257901	0.00776539	37.1347	9.99622	Valid	Invalid
0.0287019	0.00909386	36.1323	13.3200	Valid	Invalid
0.0317687	0.0106187	36.7601	17.5004	Valid	Invalid
0.0347322	0.0123349	36.6782	22.5466	Valid	Invalid
0.0377129	0.0143767	36.4557	28.8739	Valid	Invalid
0.0407106	0.0167751	37.7939	36.5840	Valid	Invalid
0.0437433	0.0195199	37.9747	45.5979	Valid	Invalid
0.0467929	0.0224353	38.3947	55.2598	Valid	Valid
0.0497390	0.0256763	39.8435	65.9921	Valid	Valid
0.0528059	0.0288294	40.6983	76.3411	Valid	Valid
0.0557520	0.0320808	41.6028	86.9094	Valid	Valid
0.0587673	0.0353425	43.1975	97.3977	Valid	Valid
0.0617480	0.0387696	43.5480	108.225	Valid	Valid
0.0647976	0.0421035	45.1118	118.578	Valid	Valid
0.0677610	0.0454843	46.8131	128.850	Valid	Valid
0.0707933	0.0488185	48.0845	138.800	Valid	Valid
0.0737913	0.0523799	49.4969	149.207	Valid	Valid
0.0768063	0.0561791	52.0190	159.714	Valid	Invalid
0.0797528	0.0599941	57.2835	169.673	Valid	Invalid
0.0827677	0.0637776	60.5975	179.033	Valid	Invalid
0.0857658	0.0676185	65.1944	187.927	Valid	Invalid
0.0887811	0.0715209	70.3149	196.376	Valid	Invalid
0.0918134	0.0751654	72.4712	203.765	Valid	Invalid
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---	---	---	---	---	---

J Delta a(p) Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D4

J Min/Max Validity

Valid
Valid
Valid
Valid
Valid
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Valid
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Valid
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Valid
Valid

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D4

Identification

Template	JIC Fracture Toughness
Procedure	FTI 2000 1/2T
General Information	TVA 2001 Linde-80 Unirradiated Welds Operator : Brad Vevera Project Leader : Kevin Hour Job Number : 1215-001-00-18-00-00-0000 Date of Test : 05/2001
Batch	WF-182
Batch Comments	
Specimen	2D4
Specimen Comments	
Platform	TestStar II

Geometry

Specimen Geometry	LLC(T)
Width (W)	1 in
Notch Length (a0)	0.45 in
Thickness (B)	0.5005 in
Net Thickness (Bn)	0.4005 in
Elastic Modulus (E)	27508.4 ksi
Yield Strength	90 ksi
Ultimate Tensile Strength	110 ksi
Poisson's Ratio	0.3 (none)
Crack Plane Orientation	
Pin Center from Crack Plane	0.355 in
COD Half-Gage Length	0.0775 in
COD Distance from Load Line	0 in
Test Temperature	390 deg_F

Compliance Coefficients

C0	1.0002 (none)
C1	-4.0632 (none)
C2	11.242 (none)
C3	-106.04 (none)
C4	464.33 (none)
C5	-650.68 (none)

K Calibration Coefficients

Calibration coeff. 0	0.886 (none)
Calibration coeff. 1	4.64 (none)
Calibration coeff. 2	-13.32 (none)
Calibration coeff. 3	14.72 (none)
Calibration coeff. 4	-5.6 (none)

Precrack Parameters:

Final Kmax	18 ksi-in^0.5
Test Frequency	10 Hz
Final Crack Length	1 in
Cycle Limited	No
Maximum Number of Cycles	10000
Crack Length Monitoring	compliance
Upper LSF data range	85 %
Lower LSF data range	15 %
Automatic Inspection Hold	No
Inspection Interval (cycles)	10000

Precrack Setup

PCR Load Signal	Force 312
PCR Load Range	10000 lbf
PCR COD Signal	Clip Gage
PCR COD Range	0.15 in

Precrack Results

Precrack Cycles	34876
Precrack Kmax	26.439 ksi-in^0.5
Precrack Final K	18.061 ksi-in^0.5
Precrack Pmax	1598.2 lbf
Precrack Final P	920.39 lbf

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D4

Precrack crack length	0.50506 in
Execution Parameters:	
Test Control	Displacement
Ramp Rate	0.00999999 in/Min
UnLoad on Load Step	No
Load Step	300.001 lbf
UnLoad on COD Step	No
COD Step	0.0025 in
UnLoad on Displacement Step	Yes
Displacement Step	0.003 in
Unload Pct of Current Load	Yes
Percent Unload	20 %
Unload Absolute	No
Absolute Unload	2000 lbf
Number of Unloads	1
Crack Propagation Hold Time	2 Sec
Unload Rate	100 lbf/Sec
Reload Rate	100 lbf/Sec
Ramp To Initial Load	Yes
Pct Of Final Precrack Load	100 %
Load Ramp Rate	100 lbf/Sec
Test Setup:	
Load Channel Name	Force 312
Maximum Load	5000 lbf
COD Channel Name	Clip Gage
Maximum COD	0.15 in
Length Channel Name	Length 312
Maximum Displacement	1 in
Frame Stiffness	130 kip/in
Data Storage:	
Event Log Filename	elog.txt
Data File Name	JIC_FTI 2000 1_2T_WF-182_2D4.RAW
Test Termination:	
End on maximum load	No
Maximum Load	5000 lbf
End on maximum COD	Yes
Maximum COD	0.15 in
End on maximum displ.	No
Maximum Displacement	1 in
End on maximum Crack Length	No
Maximum Crack Length	1 in
End on maximum Crack Extension	No
Maximum Crack Length Extension	1 in
Termination Type	Controlled
Final Precrack Lengths:	
Precrack length 1	0.525598 in
Precrack length 2	0.529098 in
Precrack length 3	0.526098 in
Precrack length 4	0.522299 in
Precrack length 5	0.518799 in
Precrack length 6	0.512598 in
Precrack length 7	0.5045 in
Precrack length 8	0.498201 in
Precrack length 9	0.487902 in
Average Precrack:	0.514793 in
Final JIC Crack Lengths:	
Final crack length 1	0.676598 in
Final crack length 2	0.687598 in
Final crack length 3	0.6865 in
Final crack length 4	0.6815 in
Final crack length 5	0.6715 in
Final crack length 6	0.664098 in
Final crack length 7	0.642299 in
Final crack length 8	0.635598 in

Test Summary

Template:	JIC Fracture Toughness
Procedure:	FTI 2000 1/2T
Batch:	WF-182
Specimen:	2D4
Final crack length 9	0.595201 in
Average Physical Crack:	0.663124 in

Calculated Crack Lengths:

Pre Test Normalized Compliance:	37.9315 (none)
Calculated Pre Test Crack Length:	0.514793 in
Test Termination Normalized Compliance:	72.4712 (none)
Calculated Test Term. Crack Length:	0.663124 in

Run-Time Report:

Test Duration:	925.557 Sec
Maximum Load:	3352.31 lbf
Maximum COD:	0.0751654 in
Maximum Displacement:	0.0918134 in
Test Terminat Reason	

JIC Analysis Inputs:

Upper LSF data range:	85 %
Lower LSF data range:	15 %
Blunting Factor M:	2 (none)
Minimum J value:	0 in-lbf/in^2
Modulus Factor Lambda:	1 (none)
Delta a(p) Offset	0.0075 in

Analysis Calculations:

Effective Yield Strength	Avg. of Yield _Ultimate
Front Face Spcm. Displ.	Calculated from COD
Unload/Reload Compliance	Unload _Reload
JIC ASTM Standard	ASTM E813-89

JIC Test Results ASTM E 813:

Number of Data Points:	30
Number of Valid Data Points:	10
Delta a(p) Min Limit Line:	0.00849566 in
Delta a(p) Max Limit Line:	0.0675292 in
Regression Slope dJQ/da at delta-aQ:	31.3983 ksi
c1	7927.07 (none)
c2	0.572339 (none)
JQ	595.549 in-lbf/in^2
Delta a(Q)	0.0108518 in
Kj Value:	127.995 ksi-in^0.5
Unable to parse unload/reload for step:	29
Unable to parse unload/reload for step:	30

Validation Criteria ASTM E 813-89:

ASTM E813-89 Section 8.4.2:	
tp = 114 Sec	
Is tp between 6 Sec and 600 Sec?	Yes
ASTM E813-89 Section 7.1.1:	
25 JQ/SFS = 0.1489 in	
Is b0 > 25 JQ/SFS?	Yes
Is B > 25 JQ/SFS?	Yes
ASTM E813-89 Section 7.2.2:	
a0/W = 0.5148	
Is a0/W between 0.5 _0.75?	Yes
ASTM E813-89 Section 7.5:	
Side grooving = 19.98 pct.	
Is side grooving <= 25 pct.?	Yes
ASTM E813-89 Section 7.6.4:	
Precrack extension = 0.06479 in	
Is precrack extension >= 0.05a0 and >= 0.05 in?	Yes
ASTM E813-89 Section 7.6.1:	
PL = 4893 lbf	
ASTM E813-89 Section 8.4.3.6:	
Is the load range of all compliance unloads <= 0.2PL or 0.5 times the current load?	Yes
ASTM E813-89 Section 9.3.1:	

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 2D4

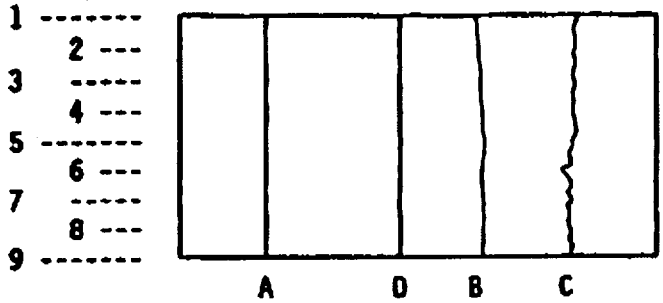
Do all points used for regression lie between Delta a(p) min _max?	Yes
ASTM E813-89 Section 9.2.2:	
Does at least one data point lie betw the 0.005906 in _0.05906 in excl.	Yes
ASTM E813-89 Section 9.4.1.3:	
Is the slope of the regression curve at JQ less than SFS?	Yes
ASTM E813-89 Section 9.4.1.5:	
Are all precrack lengths within 7 pct. of the average?	Yes
Are all final crack lengths within 7 pct. of the average?	No
ASTM E813-89 Section 9.4.1.6:	
Are both near surface crack extensions within 0.02W of the extension at the center?	No
ASTM E813-89 Section 9.4.1.7:	
Is the difference between the crack extensions found from compliance and the 9-point averages within 15 pct. of either of the 9-point average or Delta a(p) max?	No
EM from 9-point precrack front average = 2.889e+004 ksi	
Is EM within 10 pct. of nominal E?	Yes
Is JQ = JIC per ASTM E813-89?	No

FIGURE 3 - CRACK LENGTH MEASUREMENT RECORD

PROGRAM IDENTIFICATION

Project Number: 1215-001 QA Number: D0001
Specimen Number: 204 Specimen Size: .127
Operator: B.J. Vowen Date: 5/14/01
Procedure: TR-177 Rev 9
Measuring Instr.: 1-0000-0538

MEASUREMENT GUIDE



A - Load line
B - End of Fatigue Crack / Beginning of Crack Extension
C - End of Crack Extension
D - End of Machined Notch / Beginning of Fatigue Crack

MEASUREMENTS

	Difference A-B	Difference A-C
1	.5256	.6746
9	.4979	.5952
Edge Average	.50675	.6359
2	.5291	.6876
3	.5261	.6865
4	.5223	.6815
5	.5188	.6715
6	.5126	.6641
7	.5045	.6423
8	.4982	.6356
Specimen Mean	.5148	.6631

Procedure:
Measure the initial crack length (A-B) and final crack length (A-C) for each location. Calculate the mean for locations 1 and 9 to determine the Edge Average. Enter these values as indicated, and calculate the Specimen Mean (the mean of the Edge Average and the seven interior locations).

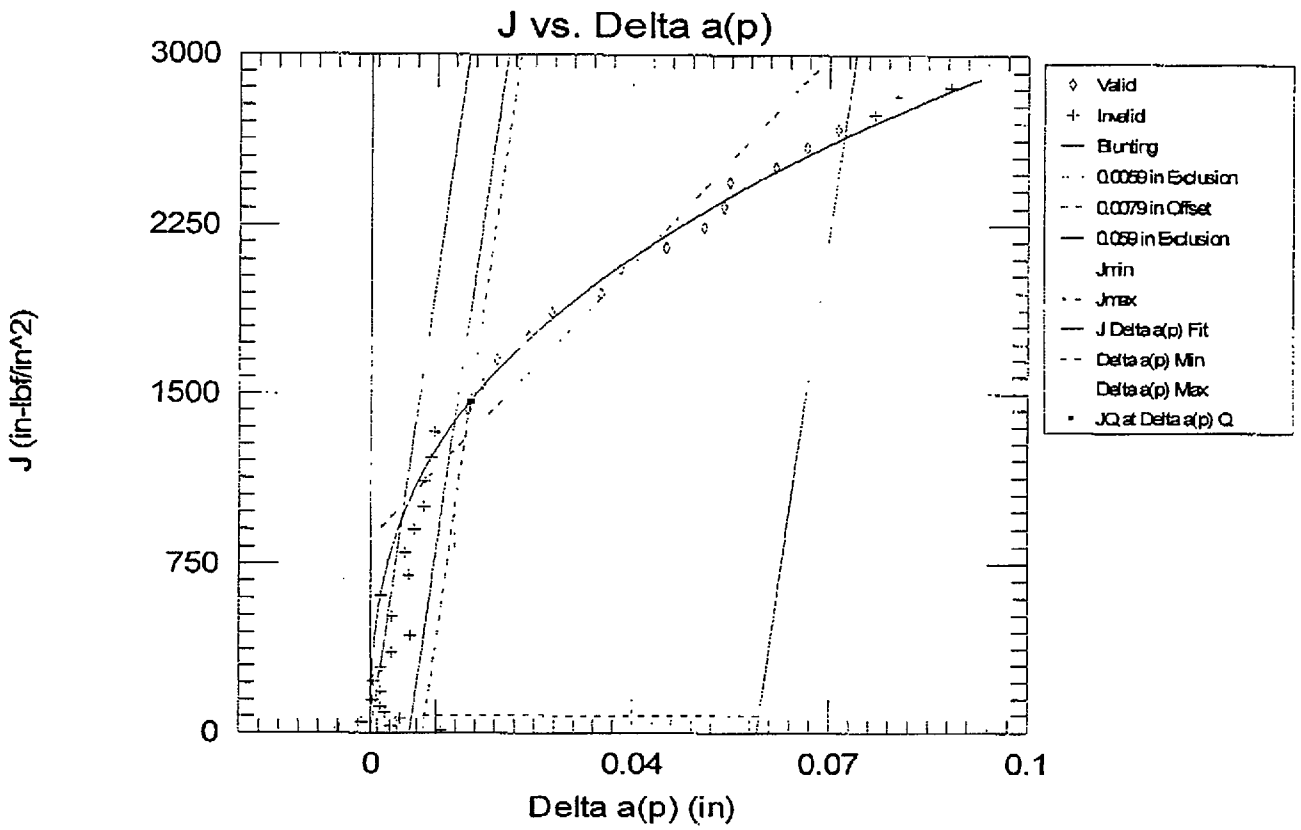
Initial Crack Length = Specimen Mean For A-B Dimension
Final Crack Length = Specimen Mean For A-C Dimension

Crack Extension = (Final Crack Length - Initial Crack Length) = .1483

Measurements and calcs made: B.J. Vowen Date: 5/14/01

Measurements and calcs checked: [illegible] Date: 6/6/01

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 1B2



J, Delta a(p), Validity by Step

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 1B2

Step	Step Validity	J (in-lbf/in^2)	Delta a(p) (in)	Load (lbf)	COD (in)
1	Invalid	12.4761	0.0107231	881.449	0.00272036
2	Invalid	20.9367	-0.00476762	1133.36	0.00359910
3	Invalid	32.0264	0.00299566	1390.09	0.00447783
4	Invalid	46.7323	-0.00138050	1653.03	0.00547547
5	Invalid	64.5428	0.00446282	1901.49	0.00648346
6	Invalid	87.0360	0.00212857	2158.92	0.00761547
7	Invalid	113.675	0.00147658	2391.54	0.00880437
8	Invalid	147.323	0.000228018	2610.71	0.0101690
9	Invalid	186.458	0.00145480	2818.16	0.0116267
10	Invalid	233.465	0.000370243	2991.15	0.0132602
11	Invalid	291.845	0.00162128	3140.38	0.0151882
12	Invalid	359.201	0.00312907	3258.92	0.0173179
13	Invalid	435.463	0.00594650	3349.54	0.0196646
14	Invalid	520.438	0.00317243	3419.16	0.0221200
15	Invalid	612.138	0.00141606	3480.15	0.0247407
16	Invalid	700.464	0.00579320	3532.20	0.0274028
17	Invalid	798.726	0.00521705	3573.20	0.0301372
18	Invalid	898.193	0.00661933	3610.41	0.0329596
19	Invalid	998.903	0.00810128	3641.77	0.0357974
20	Invalid	1106.70	0.00830564	3663.15	0.0387386
21	Invalid	1215.02	0.00923100	3677.27	0.0417264
22	Invalid	1326.19	0.00971269	3673.49	0.0447555
23	Valid	1428.26	0.0148642	3654.18	0.0479398
24	Valid	1539.17	0.0171077	3623.18	0.0511287
25	Valid	1654.29	0.0192729	3573.20	0.0544630
26	Valid	1754.27	0.0240936	3548.05	0.0577248
27	Valid	1863.92	0.0275954	3475.68	0.0611520
28	Valid	1947.31	0.0351298	3422.60	0.0644547
29	Valid	2057.52	0.0381425	3353.68	0.0679335
30	Valid	2150.86	0.0450420	3228.93	0.0716657
31	Valid	2239.30	0.0508482	3152.77	0.0751961
32	Valid	2329.94	0.0538754	3130.37	0.0783598
33	Valid	2436.85	0.0547693	3092.81	0.0816319
34	Valid	2503.03	0.0618813	3034.22	0.0850122
35	Valid	2591.48	0.0665877	2929.13	0.0886461
36	Valid	2670.01	0.0713449	2862.60	0.0921043
37	Invalid	2736.37	0.0769149	2803.68	0.0954795
38	Invalid	2818.63	0.0802203	2738.55	0.0988551
39	Invalid	2859.09	0.0883226	2657.22	0.102313
40	---	---	---	---	---
41	---	---	---	---	---

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 1B2

Identification:

Template	JIC Fracture Toughness
Procedure	FTI 2000 1/2T
General Information	TVA 2001 Linde-80 Unirradiated Welds Operator : Brad Vevera Project Leader : Kevin Hour Job Number : 1215-001-00-18-00-00-0000 Date of Test : 05/2001
Batch	WF-182
Batch Comments	
Specimen	1B2
Specimen Comments	
Platform	TestStar II

Geometry:

Specimen Geometry	LLC(T)
Width (W)	1 in
Notch Length (a0)	0.45 in
Thickness (B)	0.4975 in
Net Thickness (Bn)	0.4875 in
Elastic Modulus (E)	27508.6 ksi
Yield Strength	90 ksi
Ultimate Tensile Strength	110 ksi
Poisson's Ratio	0.3 (none)
Crack Plane Orientation	
Pin Center from Crack Plane	0.27475 in
COD Half-Gage Length	0.078 in
COD Distance from Load Line	0 in
Test Temperature	390 deg_F

Compliance Coefficients:

C0	1.0002 (none)
C1	-4.0632 (none)
C2	11.242 (none)
C3	-106.04 (none)
C4	464.33 (none)
C5	-650.68 (none)

K Calibration Coefficients

Calibration coeff. 0	0.886 (none)
Calibration coeff. 1	4.64 (none)
Calibration coeff. 2	-13.32 (none)
Calibration coeff. 3	14.72 (none)
Calibration coeff. 4	-5.6 (none)

Precrack Parameters:

Final Kmax	18 ksi-in^0.5
Test Frequency	10 Hz
Final Crack Length	1 in
Cycle Limited	No
Maximum Number of Cycles	10000
Crack Length Monitoring	compliance
Upper LSF data range	85 %
Lower LSF data range	15 %
Automatic Inspection Hold	No
Inspection Interval (cycles)	10000

Precrack Setup:

PCR Load Signal	Force 312
PCR Load Range	10000 lbf
PCR COD Signal	Clip Gage
PCR COD Range	0.15 in

Precrack Results:

Precrack Cycles	60021
Precrack Kmax	24.267 ksi-in^0.5
Precrack Final K	18.07 ksi-in^0.5
Precrack Pmax	1384.9 lbf
Precrack Final P	873.52 lbf

Test Summary

Template:	JIC Fracture Toughness
Procedure:	FTI 2000 1/2T
Batch:	WF-182
Specimen:	1B2
Precrack crack length	0.52018 in

Execution Parameters:

Test Control	Displacement
Ramp Rate	0.00999999 in/Min
UnLoad on Load Step	No
Load Step	300.001 lbf
UnLoad on COD Step	No
COD Step	0.0025 in
UnLoad on Displacement Step	Yes
Displacement Step	0.003 in
Unload Pct of Current Load	Yes
Percent Unload	20 %
Unload Absolute	No
Absolute Unload	2000 lbf
Number of Unloads	1
Crack Propagation Hold Time	2 Sec
Unload Rate	100 lbf/Sec
Reload Rate	100 lbf/Sec
Ramp To Initial Load	Yes
Pct Of Final Precrack Load	100 %
Load Ramp Rate	100 lbf/Sec

Test Setup:

Load Channel Name	Force 312
Maximum Load	5000 lbf
COD Channel Name	Clip Gage
Maximum COD	0.15 in
Length Channel Name	Length 312
Maximum Displacement	1 in
Frame Stiffness	130 kip/in

Data Storage:

Event Log Filename	elog.txt
Data File Name	JIC_FTI 2000 1_2T_WF-182_1B2.RAW

Test Termination:

End on maximum load	No
Maximum Load	5000 lbf
End on maximum COD	Yes
Maximum COD	0.15 in
End on maximum displ.	No
Maximum Displacement	1 in
End on maximum Crack Length	No
Maximum Crack Length	1 in
End on maximum Crack Extension	No
Maximum Crack Length Extension	1 in
Termination Type	Controlled

Final Precrack Lengths:

Precrack length 1	0.515201 in
Precrack length 2	0.521299 in
Precrack length 3	0.520598 in
Precrack length 4	0.521201 in
Precrack length 5	0.521 in
Precrack length 6	0.515902 in
Precrack length 7	0.5155 in
Precrack length 8	0.511902 in
Precrack length 9	0.508598 in
Average Precrack:	0.517413 in

Final JIC Crack Lengths:

Final crack length 1	0.618701 in
Final crack length 2	0.601402 in
Final crack length 3	0.644902 in
Final crack length 4	0.647701 in
Final crack length 5	0.637201 in
Final crack length 6	0.645902 in
Final crack length 7	0.6375 in
Final crack length 8	0.621299 in

Test Summary

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 1B2

Final crack length 9	0.6025 in
Average Physical Crack:	0.630813 in

Calculated Crack Lengths:

Pre Test Normalized Compliance:	42.94 (none)
Calculated Pre Test Crack Length:	0.517413 in
Test Termination Normalized Compliance:	70.3493 (none)
Calculated Test Term. Crack Length:	0.630813 in

Run-Time Report:

Test Duration:	1354.1 Sec
Maximum Load:	3756.87 lbf
Maximum COD:	0.10236 in
Maximum Displacement:	0.125807 in
Test Terminat Reason	

JIC Analysis Inputs:

Upper LSF data range:	85 %
Lower LSF data range:	15 %
Blunting Factor M:	2 (none)
Minimum J value:	75 in-lbf/in^2
Modulus Factor Lambda:	1 (none)
Delta a(p) Offset	0 in

Analysis Calculations:

Effective Yield Strength	Avg. of Yield _Ultimate
Front Face Spcm. Displ.	Calculated from COD
Unload/Reload Compliance	Unload _Reload
JIC ASTM Standard	ASTM E813-89

JIC Test Results ASTM E 813:

Number of Data Points:	41
Number of Valid Data Points:	14
Delta a(p) Min Limit Line:	0.0127669 in
Delta a(p) Max Limit Line:	0.0722149 in
Regression Slope dJQ/da at delta-aQ:	36.2912 ksi
c1	7083.36 (none)
c2	0.376334 (none)
JQ	1464.46 in-lbf/in^2
Delta a(Q)	0.0151963 in
Kj Value:	200.712 ksi-in^0.5
Unable to parse unload/reload for step:	40
Unable to parse unload/reload for step:	41

Validation Criteria ASTM E 813-89:

ASTM E813-89 Section 8.4.2:	
tp = 109 Sec	
Is tp between 6 Sec and 600 Sec?	Yes
ASTM E813-89 Section 7.1.1:	
25 JQ/SFS = 0.3661 in	
Is b0 > 25 JQ/SFS?	Yes
Is B > 25 JQ/SFS?	Yes
ASTM E813-89 Section 7.2.2:	
a0/W = 0.5174	
Is a0/W between 0.5 _0.75?	Yes
ASTM E813-89 Section 7.5:	
Side grooving = 2.01 pct.	
Is side grooving <= 25 pct.?	Yes
ASTM E813-89 Section 7.6.4:	
Precrack extension = 0.06741 in	
Is precrack extension >= 0.05a0 and >= 0.05 in?	Yes
ASTM E813-89 Section 7.6.1:	
PL = 4356 lbf	
ASTM E813-89 Section 8.4.3.6:	
Is the load range of all compliance unloads <= 0.2PL or 0.5 times the current load?	Yes
ASTM E813-89 Section 9.3.1:	

Template: JIC Fracture Toughness
Procedure: FTI 2000 1/2T
Batch: WF-182
Specimen: 1B2

Do all points used for regression lie between Delta a(p) min _max?	Yes
ASTM E813-89 Section 9.2.2:	
Does at least one data point lie betw the 0.005906 in _0.05906 in excl.	Yes
ASTM E813-89 Section 9.4.1.3:	
Is the slope of the regression curve at JQ less than SFS?	Yes
ASTM E813-89 Section 9.4.1.5:	
Are all precrack lengths within 7 pct. of the average?	Yes
Are all final crack lengths within 7 pct. of the average?	Yes
ASTM E813-89 Section 9.4.1.6:	
Are both near surface crack extensions within 0.02W of the extension at the center?	Yes
ASTM E813-89 Section 9.4.1.7:	
Is the difference between the crack extensions found from compliance and the 9-point averages within 15 pct. of either of the 9-point average or Delta a(p) max?	No
EM from 9-point precrack front average = 2.586e+004 ksi	
Is EM within 10 pct. of nominal E?	Yes
Is JQ = JIC per ASTM E813-89?	No

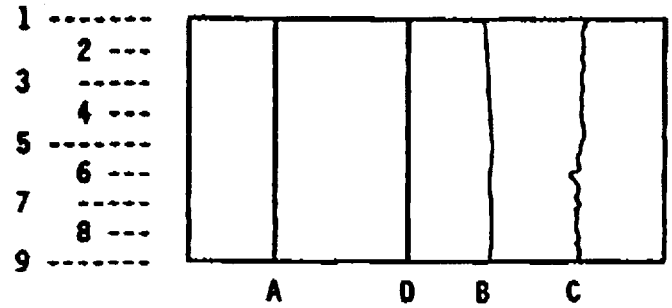
FIGURE 3 - CRACK LENGTH MEASUREMENT RECORD

PROGRAM IDENTIFICATION

Project Number: 1215-001
Specimen Number: 132
Operator: B. Vera
Procedure: TP-177 Rev 9
Measuring Instr.: 1-0000-0538

QA Number: 00001
Specimen Size: ½T
Date: 5/14/01

MEASUREMENT GUIDE



A - Load line
B - End of Fatigue Crack / Beginning of Crack Extension
C - End of Crack Extension
D - End of Machined Notch / Beginning of Fatigue Crack

MEASUREMENTS

	Difference A-B	Difference A-C
1	.5152	.6187
9	.5086	.6025
Edge Average	.5119	.6106
2	.5213	.6014
3	.5206	.6449
4	.5212	.6477
5	.5210	.6372
6	.5159	.6459
7	.5155	.6375
8	.5119	.6213
Specimen Mean	.517412	.630812

Procedure: Measure the initial crack length (A-B) and final crack length (A-C) for each location. Calculate the mean for locations 1 and 9 to determine the Edge Average. Enter these values as indicated, and calculate the Specimen Mean (the mean of the Edge Average and the seven interior locations).

Initial Crack Length = Specimen Mean For A-B Dimension
Final Crack Length = Specimen Mean For A-C Dimension

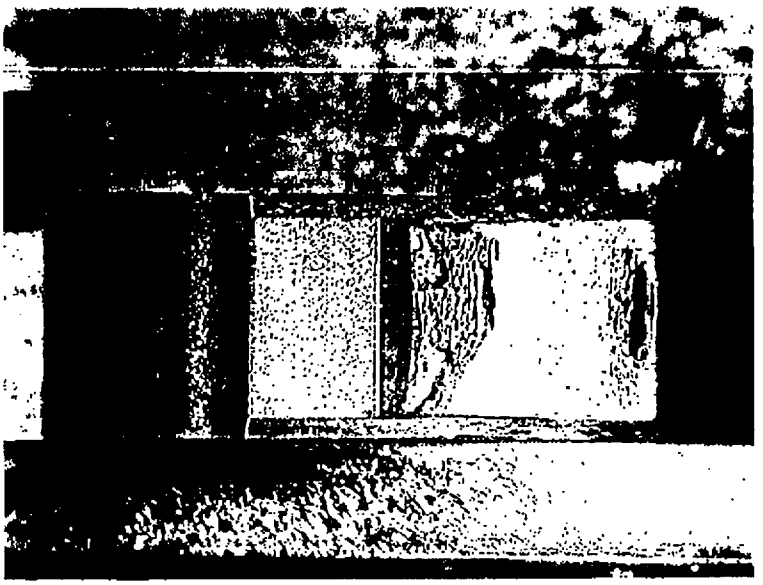
Crack Extension = (Final Crack Length - Initial Crack Length) = .1134

Measurements and calcs made: [signature] Date: 5/14/01

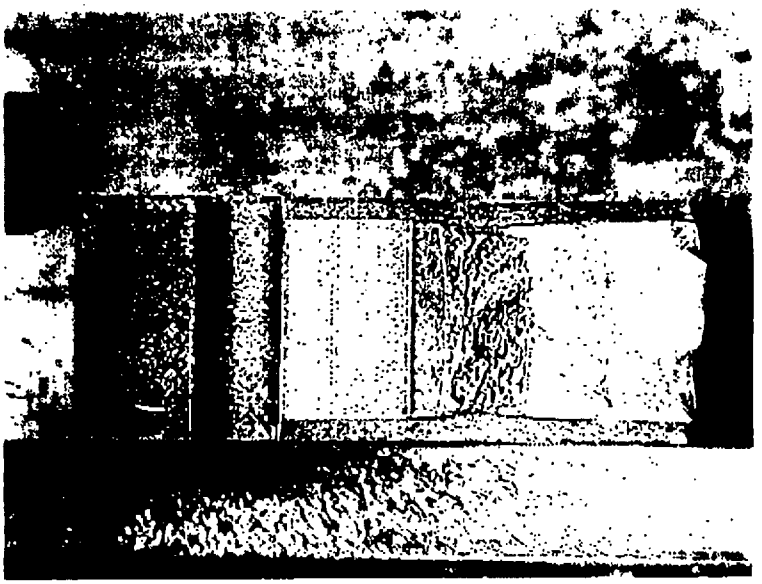
Measurements and calcs checked: [signature] Date: 6/6/01

APPENDIX C

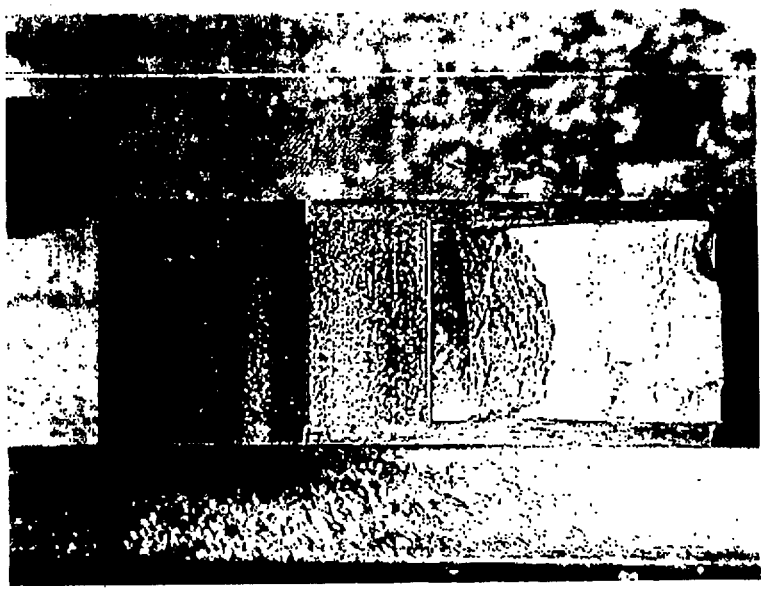
Fractograph



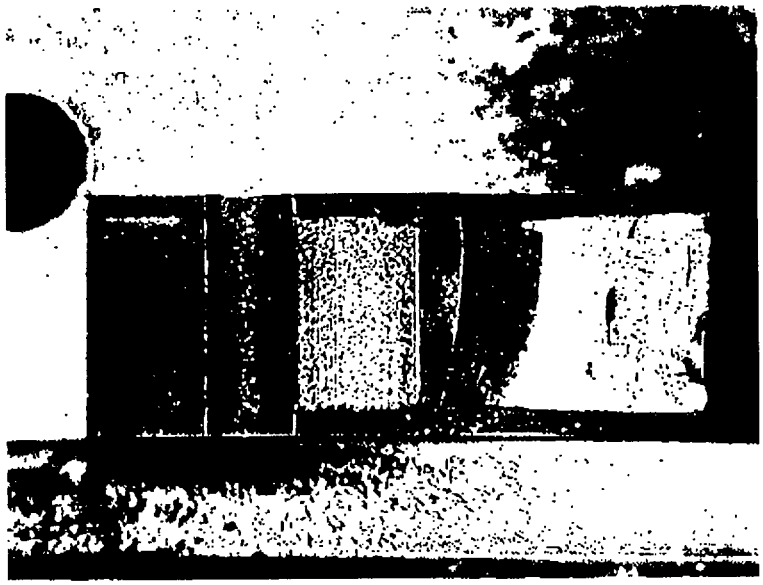
2D1



2D2



2D3



2D4

ENCLOSURE 2

PROJECT TECHNICAL PLAN
FOR
REACTAOR VESSEL SURVEILLANCE PROGRAM (RVSP) CAPSULE W
½ T SPECIMEN FRACTURE TOUGHNESS TESTING
REVISION 2

PROJECT TECHNICAL PLAN

FOR

WATTS BAR UNIT 1
REACTOR VESSEL SURVEILLANCE PROGRAM (RVSP) CAPSULE W
1/2 T SPECIMEN FRACTURE TOUGHNESS TESTING

Revision 2
June 28, 2001

Prepared by: _____
K. Y. Hour
N&EO
BWXT Services, Inc.

Reviewed by: _____
S. M. Jensen
N&EO
BWXT Services, Inc.

Approved by: _____ 29 June 01
C. L. Clark, Manager
N&EO
BWXT Services, Inc.

Approved by: _____ 6/29/01
D. Hindman, N&EO QA Manager
N&EO
BWXT Services, Inc.

Approved by: _____ 6/29/01
D. Briggs, Project Manager
TVA

Revisions Page

Revision	Date	Description
0	2/12/01	Initial release
1	3/29/01	Change proof-of-principle test specimen number from two to four State in 2.2.5 that Westmoreland will analyze the data in accordance with ASTM E1820
2	6/28/01	Change 2.2.5 to reflect ASTM E813 was used in proof-of-principle tests and both ASTM E813 and E1820 will be used for irradiated specimens

1.0 INTRODUCTION

1.1 Purpose

The purpose of this project is to perform machining and testing of 1/2 T compact tension specimens removed from Watts Bar Unit 1 Reactor Vessel Surveillance Program (RVSP) Capsule W.

1.2 Background

The United States Nuclear Regulatory Commission (NRC) requires a nuclear power licensee to maintain a reactor vessel surveillance program to monitor fast neutron irradiation-induced changes in the mechanical properties of reactor vessel beltline material. These changes in mechanical properties are measured by testing material specimens that have been exposed to the operating environment of a reactor vessel. Vessel material specimens are assembled into protective capsules and placed inside the vessel. The capsule is then maintained inside the reactor vessel for a specified period of operation. In this way, the material specimens within the capsule are exposed to a neutron flux similar to that experienced by the actual reactor vessel. Upon removal of the capsule, the specimens are retrieved and tested. Test results are then used to calculate pressure-temperature limits within which the reactor can be operated safely or to verify the current limits remain conservative through the next service interval.

1.3 Workscope

The workscope of this project includes machining and testing of 1/2T compact tension specimens based on an acceptable specimen design, which will be approved by TVA, and the reporting of test results.

2.0 DESCRIPTION OF ACTIVITIES

2.1 Specimen Retrieval

Capsule W was received at the BWXT Services, Inc. (BWXS) Lynchburg Technology Center (LTC) in January 2001 and was subsequently disassembled in its Hot Cell Facility. Following the disassembly, specimens were inventoried and stored. There are twelve (12) 1/2 T compact tension specimens and one bend bar in this capsule. Four axial orientation 1/2T compact tension specimens will be machined and tested.

2.2 Machining and Testing of Unirradiated Specimens

Some machining on the 1/2T compact tension specimens is expected since the original specimens were manufactured in accordance with ASTM E399 not ASTM E1820, which is the Standard that will be used for testing. A draft engineering drawing has been sent to TVA for review (see Attachment A) and will be used as the specimen design basis. Proof-of-principle tests will be performed prior to actual testing.

To simulate the fact that the material of interest has a low upper shelf energy, an A508 Class 2 forging material with a low upper shelf energy is an ideal candidate; however, BWXS has gone

through its inventory and identified a reactor vessel steel weld metal with a low upper shelf energy of 70 ft-lb, which is more representative of the Watts Bar material. A total of four (4) unirradiated specimens will be machined and tested at 390 °F. Two of those four specimens will be machined in accordance with ASTM E1820 and two will be machined in accordance with the BWXS design. Proof-of-principle tests will be conducted in accordance with ASTM E1820 to determine the adequacy of the BWXS design and will be witnessed by NRC representatives.

The compact tension specimen testing will be conducted in accordance with Technical Procedure TP-177 "Automated, Single Specimen J-integral Fracture Toughness Testing" (latest revision, see Attachment B). TP-177 is in compliance with ASTM E1820. The certified software JTEST will be used to control the test machine and acquire the data automatically during the test. The actual test temperature determined by TVA Project Manager is 390 °F. Test temperature is controlled to within ± 5°F.

2.2.1 Specimen Machining

Unirradiated specimens will be machined using a combination of an EDM machine and a milling machine while only an EDM machine will be used for the irradiated specimens. Specimen dimension will be verified and documented prior to testing.

2.2.2 Precracking

Fracture toughness specimens need precracking to grow the cracks to appropriate lengths. In this case, precracking will be conducted per TP-177.

2.2.3 Temperature Control

Elevated temperature testing will be performed in an ATS split type furnace, which is designed to handle both elevated temperature and sub-zero temperature testing. Test temperature is controlled to within ± 5°F.

2.2.4 Fracture Toughness Testing Equipment

Equipment may be replaced by an equivalent or better equipment.

Instrument	QA Status	Range	Accuracy
MTS TestStar System (Digitally Controlled)	N/A	N/A	N/A
MTS 55 or 3 kips Load Cells	Certified	0.1-0.5 (FS) 0.5-1.0 (FS)	± 1% ± 0.05%
Clip Gage	Calibrate prior to use	0.1" 0.15" 0.3" 0.5"	± 1.0% ± 1.0% ± 1.0% ± 1.0%
MTS LVDT	Certified	0-6"	±0.001"
Dial Caliper	Certified	0-6"	±0.001"
ELPH5 Digital Temperature Readout	Certified	-330°F - 2500°F	± 2.0°F
Type K Thermocouples	N/A	--	± 4.0°F
Colorado Video Micrometer	Calibrated prior to use	0-2"	± 0.001"
Micro Head	Certified	0-1"	± 0.001"
Digital Voltmeter	Certified	-20V to +20V	± 1.0%

2.2.5 Data Analysis

Proof-of-principle test data were analyzed using ASTM E813 to validate BWXS specimen design. Irradiated specimen test data will be analyzed in accordance with ASTM E1820 by Westmoreland Mechanical Testing & Research Inc. and with ASTM E813 by BWXS. All test results will be reported.

2.2.6 Reportable Test Results

For each fracture toughness test specimen, the following results shall be reported:

a. Load versus displacement curve
b. J-R curve
c. Test temperature
d. Loading rate
e. J_{IC} (if criteria not violated) or J_c
f. Initial crack length
g. Final crack length
h. Photograph of fracture surface

2.2.7 Approval of Report

A report documenting the test results and findings will be submitted to TVA for review and approval. The actual specimen will not be tested until the approval is obtained from TVA.

2.3 Machining and Testing of Irradiated Specimens

The same procedures used in machining and testing of unirradiated specimens will be used for the actual specimens. A Radiation Work Permit, which provides radiological control of the work, will be obtained prior to work. Appropriate shielding will be built around the equipment to reduce operator exposure. Specimen dimensions will be verified to the extent practical due to the concern of operator exposure. If such measurements are not practical, the information will be obtained from the manufacture report. This testing will also be witnessed by NRC representatives.

2.4 Evaluation of the Equivalent Margin Analysis

As part of the overall scope of work to test and evaluate Reactor Vessel Surveillance Program Capsule W from Watts Bar Nuclear Unit 1, J-R data derived from compact fracture specimens of Capsule W will be evaluated as follows:

1) a review of the equivalent margin analysis performed by Westinghouse
2) a comparison of the J-R data from capsule W and the projected J-R curves used in the equivalent margin analysis and
3) an evaluation regarding the continued validity of the equivalent margin analysis based on the Capsule W J-R data.

3.0 STORAGE OF TEST SPECIMENS

Unless specified by TVA, all tested irradiated compact tension specimens will be catalogued, then placed in a suitably labeled paint can and stored in the LTC Long-Term RVSP Storage Room.

Unless specified by TVA, for untested irradiated specimens, specimens will be catalogued, then placed in a suitably labeled paint can (separated from the tested ones) and be stored in the LTC Long-Term RVSP Storage Room.

4.0 DISPOSAL OF SPECIMENS

TVA may require that both tested and untested specimens be disposed of at the end of the project. Specimens will be disposed with other wastes and the disposal site is Barnwell, SC.

5.0 QUALITY ASSURANCE

This project is designated as safety related and will be performed in accordance with a project specific QA plan (BWXS N&EO QA Plan 00001, dated Nov. 8, 2000), which has been approved by TVA.

6.0 REPORTING

All test data, observations, and conclusions will be reported to TVA in a BWXS formal report. Preliminary data may be transmitted to TVA as it becomes available during the course of the project. These results, however, will not be delivered until the satisfactory completion of a BWXS Quality Assurance project review of all project records.

ENCLOSURE 3

TECHNICAL PROCEDURE (TP)-177
AUTOMATED, SINGLE-SPECIMEN J-INTEGRAL FRACTURE TOUGHNESS TESTING
REVISION 9

103-1 (10/99)

BWXT SERVICES, INC.
LYNCHBURG TECHNOLOGY CENTER

TECHNICAL PROCEDURE

NUMBER TP-177 REV. NO. 9

TITLE AUTOMATED, SINGLE-SPECIMEN J-INTEGRAL FRACTURE TOUGHNESS TESTING

PREPARED BY B. J. Vevera DATE 3/29/01

REVIEWED BY K. Y. Hour DATE 3/29/01

REVIEWED BY S. M. Jensen DATE 3/29/01

APPROVED BY C. L. Clark DATE 29 March 2001

APPROVED BY D. L. Hindman DATE 04/02/01

FOR INFORMATION ONLY

DISTRIBUTED BY QUALITY ASSURANCE _____

PROCEDURE EFFECTIVE DATE 04/02/01

WHEN STAMPED IN RED, THIS IS A CONTROLLED COPY. IF STAMP IS NOT RED, OBTAIN A CONTROLLED COPY FROM QUALITY ASSURANCE BEFORE PROCEEDING WITH WORK UNDER THIS PROCEDURE.

REVISIONS		
REV. NO.	DATE	DESCRIPTION
0	4/09/82	ORIGINAL RELEASE
1	06/08/84	COMPLETE REVISION
2	12/13/91	COMPLETE REVISION
3	03/20/93	DISTRIBUTION CHANGE ONLY
4	07/07/94	MAJOR REVISION IN SECTION 7.0 AND 8.0 TO ADDRESS THE REPLACEMENT OF OLD 442 SYSTEM WITH MORE ADVANCED TESTSTAR SYSTEM AND THE INSTALLATION OF NEW SOFTWARE MTS 790.50 FOR MACHINE CONTROL AND DATA ACQUISITION. PRE-CRACKING WAS ALSO INCLUDED IN THIS TP. MINOR REVISIONS IN OTHER SECTIONS.
5	09/07/94	MINOR REVISIONS WERE MADE IN SECTIONS 1.1, 7.4.2, AND 7.4.5.
6	03/31/97	MAJOR REVISION TO CONFORM WITH NEW STANDARD PRACTICE MANUAL DEFINITIONS AND CHANGES TO THE PROCEDURE
7	02/29/00	CHANGE COMPANY NAME, CHANGE REFERENCES AND REVISED ACCORDING TO NEO-QIP-13.
8	02/14/01	ATTACHMENT FOR CRACK LENGTH MEASUREMENT ADDED. REFERENCES TO ASTM STANDARD E1820 ADDED.
9	3/29/01	REVISED 12.0 AND 12.5 TO INCLUDE ASTM STANDARDS E1737 AND E1820.

1.0 APPLICABILITY

This procedure is to be used by authorized individuals in Nuclear Materials Engineering (NME) trained in the proper performance of the techniques involved.

2.0 PURPOSE

2.1 This technical procedure defines the operator qualifications, equipment requirements, and use of the JTEST.R01 software, which conducts an unloading compliance single specimen J-Test in compliance with ASTM Standards E813, E1152, E 1737, E 1820, and E 1921.

2.2 This procedure assumes the use of compact tension specimens and bend specimens (SE(B)).

3.0 REFERENCES

3.1 ASTM Standard E 813, "Standard Test Method for J_{IC}, A Measure of Fracture Toughness."

3.2 ASTM Standard E 1152, "Standard Test Method for Determining J-R Curves."

3.3 ASTM Standard E 1737, "Standard Test Method for J-Integral Characterization of Fracture Toughness."

3.4 ASTM Standard E 1820, "Standard Test Method for Measurement of Fracture Toughness."

3.5 ASTM Standard, "E 1921 Test Method for Determination of Reference Temperature, T_0, for Ferritic Steels in the Transition Range."

3.6 TP-585, "Calibration Procedure for MTS Clip Gage/Range Card Combination."

3.7 TP-583, "Calibration Procedure for Video Micrometer System."

3.8 MTS 790.50 "Fracture Toughness Test Application Software" manual.

3.9 TP-640, "Calibration Procedure for MTS 490.21 DC Conditioners."

4.0 TRAINING REQUIREMENTS

4.1 All persons working under this procedure shall be trained in its requirements and designated in the Fatigue & Fracture Laboratory operator qualifications list as qualified to perform this procedure. The Project Engineer may qualify himself/herself as an operator.

4.2 The personnel conducting the single specimen J-Test shall have demonstrated their competency in the use of JTEST.R01 software (MTS 790.50 software), automated MTS TestStar test equipment, and supporting laboratory equipment including temperature measurement and dimensional measuring devices to the satisfaction of the Project Engineer.

4.3 The Project Engineer should be familiar with the requirements of ASTM Standards E 813, E 1152, E 1737, E 1820 and E 1921, this technical procedure, and manual of MTS 790.50 software. The operator should be trained in the use of this technical procedure and MTS 790.50 software manual. Training shall be documented on Form 619, Nuclear & Environmental Operations Personnel Training/Qualification Report.

4.4 The individual should be able to conduct one J-integral test without assistance to the satisfaction of the Project Engineer.

5.0 EQUIPMENT AND SUPPLIES

5.1 The following equipment shall be used in performing the J-Test.

5.2 The following equipment constitutes the MTS TestStar servo-hydraulic test system.

Item	Minimum Specifications	Recommended Equipment
MTS 312 Series Load Frame, Series 204 Hydraulic Actuator, Series 252 Servo-valve, Series 294 Hydraulic Service Manifold, Series 506 Hydraulic Power Supply 490 Controller, 490.14 Value Driver 490.30 Work Station Communication Interface 490.05 Load Unit Control Panel	The system must be of sufficient capacity to maintain crack extension of the specimen. Typically, it must be able to exceed the specimen's anticipated limit load.	MTS only

5.3 The following equipment constitutes the MTS TestStar servo-hydraulic test system.

Item	Minimum Specifications	Recommended Equipment
LVDT within Actuator	Must have travel compatible with Actuator working range	MTS-supplied or equivalent
MTS Load Cell	Working range greater than specimen's anticipated limit load	MTS 661.23A or equivalent
Clip gage-style Extensometer	Sufficient range to test intended specimens; cartridge card specific to gage	MTS 632.02 or .03 series, or B&W-made gage, or equivalent
MTS 490.22 AC Conditioner	Connected to the 490 Controller; calibrated as part of the LVDT	MTS 490.22 only
MTS 490.21 DC Conditioner	Connected to the 490 Controller and the load cell	MTS 490.21 only
MTS 490.21 DC Conditioner	Connected to the 490 Controller and the clip gage extensometer	MTS 490.21 only

5.4 The following equipment is also necessary for the J-Test.

Item	Minimum Specifications	Recommended Equipment
Calibration Fixture	Support extensometer and micrometer head	MTS Calibration fixture or equivalent
Certified Micro-meter Head	0.0001-inch resolution	MTS 650.03 or equivalent

5.5 The following equipment is also necessary for the J-Test.

Item	Minimum Specifications	Recommended Equipment
Digital Voltmeter	Resolution 0.001V in 10V range; Accuracy > 0.01% of range	Keitheley 2001 or equivalent
Caliper	0.0005 inch resolution	Mitutoyo 6" caliper or equivalent
IBM Personal Computer	>12 Megabyte RAM	IBM 486 series or better
Monitor and Hard copy unit	Must have graphics capability	
Thermocouple 0.75% of reading	Type K, +/-2.2°C or	From Approved Supplier
Digital Temperature Readout	Accurate to +/- 4°F	Thermoelectric ELPH5 or equivalent
Video Monitor	Monitor capable of capable of functioning with system	Sony Color CVM-1271 or equivalent
Video Camera	Video camera with zoom lens and focus control	Panasonic WV-CP612 or equivalent
Video Micrometer	Range 0" to maximum expected crack length Resolution: .001"	Colorado Video Inc. Model 305 or equivalent
High Intensity Lights	Light sufficient to adequately illuminate darkened test specimens	
Platform Stage	For holding specimens	Microcontrol stage or equivalent

5.6 The following equipment is also necessary for the J-Test.

Item	Minimum Specifications	Recommended Equipment
X-Y Chart Recorder (Optional)	For information use only	HP 7044A or equivalent
Specimen Heating System	Capable of maintaining specimen at test temperature	ATS forced-air oven or equivalent; Heating bands or tape for grips if necessary
Three-point Bend Test Fixture	For holding the bend specimen SE(B)	MTS 642.10A-01 bend test fixture or equivalent
Load Train Cooling System (Optional)		Capable of maintaining Load Cell at temperature less than 100°F

6.0 PREREQUISITE - Not Applicable

7.0 PRECAUTIONS - Not Applicable

8.0 SYSTEM CALIBRATION AND CERTIFICATION

8.1 The MTS load frame, hydraulic actuator, servo-valve, hydraulic service manifold, and hydraulic power supply must be functional. These units are not calibrated.

8.2 The LVDT and the 490.22 AC Conditioner shall be in the CERTIFIED mode.

8.3 The load cell shall be in the CERTIFIED mode.

8.4 The clip gage extensometer and associated 490.21 DC Conditioner shall be calibrated according to TP-585, "Calibration Procedure For MTS Clip Gage/Range Card Combination." These components shall be in the CERTIFIED or CALIBRATE PRIOR TO USE mode. The CALIBRATE PRIOR TO USE mode shall be calibrated before and after testing; the Project Engineer shall determine the calibration interval for CALIBRATE PRIOR TO USE mode (e.g. before and after each test, each day's testing, each week's testing, or some other interval).

The 490.21 DC Conditioner has multiple range capabilities. The size of each range is determined by resistors attached to replaceable range cards. Each clip gage extensometer shall have a cartridge card associated specifically with that particular clip gage extensometer and conditioner model. Be sure to use the appropriate cartridge card when calibrating the clip gage extensometer.

For temperature dependent extensometers, (e.g. B&W high temperature extensometer), calibration coefficients should be obtained from the extensometer calibration performed at the test temperature. The curve fitting of the data points should be performed on spreadsheet application software such as EXCEL. The maximum clip gage travel distance should be selected as instructed by the Project Engineer. If interpolation between or extrapolation beyond temperatures is desired, the pre-test and post-test calibration runs must be completed for the lowest test temperature, the highest test temperature, and a sufficient number of intermediate temperatures to allow accurate interpolation between calibration temperatures. Extrapolation outside the calibrated temperature range is not recommended, and is to be completed only at the discretion of the Project Engineer.

For temperature dependent extensometers, (e.g. B&W high temperature extensometer), if the test program is large enough to require more than the pre- and post-test calibration, those calibrations completed during the test program need only be performed at room temperature.

8.5 The Micrometer Head shall be calibrated at least annually to an accuracy of +/- 0.0001". This component shall be in the CERTIFIED mode. The Calibration Fixture does not require calibration.

8.6 The Digital Voltmeter shall be calibrated at least annually. Accuracy greater than 0.01% of range shall be demonstrated. This component shall be in the CERTIFIED mode.

8.7 The caliper shall be calibrated at least annually to an accuracy of +/- 0.0005". This component shall be in the CERTIFIED mode.

8.8 The Digital Temperature Readout shall be calibrated at least semi-annually. The device shall be accurate to within 4°F for the temperature range of interest. This component shall be in the CERTIFIED mode.

8.9 Thermocouple wire shall be purchased from an approved supplier. The wire shall be accurate to within 2.2°C or 0.75% of reading, whichever is greater.

8.10 The personal computer, monitor, hard copy unit, video monitor, video camera, high intensity lights, platform stage, specimen heating system, compact tension test clevis, three-point bend test fixture, and load train cooling system must be functional. These units are not calibrated.

8.11 The Video Micrometer system shall be calibrated according to TP-583, "Calibration Procedure For Video Micrometer System." The calibration shall be done before and after testing; the project leader shall determine the calibration interval (e.g. before and after each test, each day's testing, each week's testing, or some other interval). This component shall be in the CALIBRATE PRIOR TO USE mode.

8.12 An x-y recorder may be used to record load and displacement signals during the test at the discretion of the project leader. Such a recorder is for information use only according to this procedure and need not be calibrated.

9.0 TEST LOG

9.1 A test log, (e.g., project logbook, project file and computer files), shall be maintained for each specimen tested. The following information shall be recorded in the log:

a. Project number, test specimen ID, project lead engineer, date of test, equipment operator, and the technical procedure used.

b. Necessary specimen information by type, (e.g., compact tension or bend specimen), shall be maintained. Nominal specimen dimensions or measurements should be used.

c. Load cell serial number, serial number for the load cell 490.21 conditioner, cartridge card number, and any form generated by TP-640 (Ref. 3.9).

d. Clip gage extensometer serial number, serial number for the clip gage 490.21 conditioner, cartridge card number, and any form generated by TP-640 (Ref. 3.9).

f. During the test of the specimen, clip gage, and load cell temperatures shall be monitored and entered into the test log. The identification of the thermocouple and digital temperature readout used for these measurements shall be entered into the test log.

9.2 All entries in the log shall be made in ink. The test log must be signed and dated upon completion. In addition, any changes or corrections to the log must be signed and dated.

9.3 Upon completion of all J-Integral testing in the project, the test results will be included in the project file as directed in Section 11.0 or 12.0.

10.0 SYSTEM SETUP

10.1 Log on MTS TestStar II using the appropriate configuration file.

10.2 The following steps should be performed at least once each day as part of the system set-up prompted by the computer program.

10.2.1 Select the load conditioner range needed for the testing. Monitor the load conditioner output from the screen. Auto zero the output voltage to 0 V.

Check the shunt calibration voltage. Record shunt voltage in the test log. Compare this value with the previous calibration and the difference should be no more than $\pm 1\%$.

10.2.2 Select the clip gage extensometer range needed for testing. Auto zero the output voltage to 0 V. Check the shunt calibration voltage. Record shunt voltage in the test logbook.

Compare this value with the previous calibration and the difference should be within by more than $\pm 1\%$.

10.3 If load cell or extensometer are changed during the day, repeat 10.2.1 or 10.2.2 as required.

10.4 Load the computer with JTEST.R01 (MTS 790.50 "Fracture Toughness Testing Application Software") and choose the J_{IC} template and an appropriate procedure in the *DEFINE* mode in the *Main* manual window.

10.4.1 Edit Precracking Parameters (if applicable)

Define the following parameters used for precracking.

a. Final K_{max}
b. Load Ratio, R
c. Test Frequency
d. Final Crack Length (inch)
e. Upper LSF data range
f. Lower LSF data range

10.4.2 Edit Execution Parameters

Define the following parameters used for J_{IC} testing. (Consult the Project Engineer unless otherwise stated.)

a. Precycle Load (lbf)

b. Test Control Mode (Displacement or COD)
c. Ramp Rate (inch/minute)
d. Test Control Mode Step (inch).
e. Percent Unloading (%)
f. Absolute Unload (lbf)
g. Number of Unloads
h. Crack Propagation Hold Time (second)
i. Unload Rate (lbf/sec)
j. Reload Rate (lbf/sec)
k. Frame Stiffness (lbf/inch)

10.4.3 Edit Data Storage Parameters

Choose the Data Storage option so that Load, COD, and displacement data are acquired automatically while the J_{IC} test is run. Define the following parameters.(Consult the Project Engineer unless otherwise stated.)

a. Event Log Filename
b. Upper LSF
c. Lower LSF

10.4.4 Edit Test Termination Parameters

When the J_{IC} test is completed, the machine should automatically switch to Load control and then ramps to zero load. Define the following parameters for proper test termination.

a. Maximum Limit (in Load, COD, or Displacement)
b. Termination Type
c. Machine Response upon termination

10.4.5 Edit a Batch

For compact tension specimens, the displacement control should be used since displacement control was used for the J_{IC} tests in the past. For SE(B) specimen, both COD control and displacement control could be used.

The frame stiffness is critical in a SE(B) specimen testing since this information is used to correct the load-line displacement measurements determined from the LVDT. The specimen used to determine the frame stiffness should have similar material properties as those of the specimens to be tested. Procedures to determine the frame stiffness are described in ASTM E813 Annex A.

790.50 offers an option for specimens of the same geometries be treated as a batch, thus saving the time to redefine parameters related to the specimen dimensions, material properties, and clip gage. The Project Engineer should decide how the specimens should be organized to take advantage of this option.

a. Comments (if any)
b. Specimen Geometry (choose from LLC(T), SE(B), FFC(T), DC(T))
c. Specimen Identification (Unique within a batch)
d. Width (inch)
e. Notch Length (inch)
f. Thickness (inch)
g. Net Thickness (inch)
h. Modulus of Elasticity (ksi)
Modulus values should be adjusted for temperature using the equation: (Note: for low alloy steels only)

Modulus (ksi) = 29480 - (5.055 x (°F))

(Consult the project engineer for materials other than low alloy steels.)

i. Yield Strength (ksi)
j. Ultimate Tensile Strength (ksi)
k. Poisson's Ratio
l. Crack Orientation
m. Pin Center from Crack Plane (inch)
n. C.O.D. Half-Gage Length (inch)
o. C.O.D. Distance from Load Line (inch)
p. Test Temperature (°F)

10.5 The MTS hydraulics and electronics shall be warmed up prior to testing. The electronics will be considered warmed up if they have been powered up for one-half hour before use.

10.6 All fixtures, heating and cooling equipment to be used during the testing should be mounted.

11.0 TEST PROCEDURE

11.1 In the *Main* menu window, choose the *EXECUTE* mode and select the appropriate template, procedure, batch, and specimen.

11.2 Make sure that the appropriate safety interlocks are set up. Mount the specimen in the MTS machine.

11.3 If precracking the specimen is desirable, choose *PreCrack* from the *Parameters* and check the parameters of "Precrack" before running the test. Follow the steps for precracking.

11.3.1 Choose load, COD (clip gage), and displacement as sensors to acquire data.

11.3.2 In *Assign Modulus* menu, choose *Compliance Measurement* to load the specimen and verify that the crack length and modulus are consistent with the user defined values.

11.3.3 Select appropriate display options.

11.3.4 Press *Run* to start precracking. This precracking process is automatically controlled (in force) by the 790.50 software until the final crack length specified by the user is met.

11.3.5 Assign the results of precracking such as number of cycles, final crack length, final and precrack P_{max}, and final and precrack K_{max} will be recorded for use in the J_{IC} testing.

11.3.6 Put the specimen under slight tension force (or compression force for bend specimen) while heating or cooling the specimen.

11.4 Affix a length of thermocouple wire on the specimen adjacent to the crack tip. Make sure that the thermocouple wire will not interfere with the deflection of the specimen.

11.5 Heat/cool the specimen to the desired test temperature. The specimen shall be maintained at the test temperature (+/- 5°F) for a minimum of 20 minutes or 30 min/inch of specimen thickness whichever greater before testing begins.

Record the specimen, clip gage extensometer, and load cell temperatures on the test log at the start of soaking, start of test, and end of test.

11.6 Press OK to enter J_{IC} testing manual.

11.6.1 Choose load, COD (clip gage), and displacement as sensors to acquire data.

In the case of testing large activated specimens, a correlation between the reading of the temperature controlled channel of the furnace and the reading from an unirradiated specimen may be established so that no local thermocouple wire is required to minimize personnel exposure. This calibration shall be repeatable and properly documented.

11.6.2 In *Check Crack Length* menu, choose *Compliance Measurement* to load the specimen and verify that the crack length is consistent with the final crack length from precracking process.

Repeat the measurements at least three times. No individual value shall differ from the mean by more than ±.002W. (For E 813, E 1152, E 1820, and E 1737 test only). If the results are satisfactory, proceed to the next step.

11.6.3 Select appropriate display options.

11.6.4 Press *Run* to start J_{IC} testing.

11.7 Throughout the test, monitor the load cell temperature and maintain below 100°F.

11.8 After completion of the test, the specimen should be removed from the MTS. The crack front of one fracture face will be examined and measured. To improve resolution during examination, the test specimen can be heat tinted (usually at 500 to 600°F for 10 - 30 min) to mark the position of the final crack front. The specimen could either be cooled, perhaps to liquid nitrogen temperatures, and then mounted back into the MTS and pulled apart manually or be fatigue-cycled to failure to minimize further specimen deformation. The loads for the fatigue cycling should be chosen carefully to avoid significant deformation. Care should be taken not to drop the broken halves or mar the fracture surfaces in any way. Any specimens which are accidentally mishandled should be labeled as such.

11.9 The initial and final crack fronts shall be measured on one of the fracture surfaces at nine equally spaced points centered about the specimen centerline and extending to within .005W of the root of the sidegrooves. The readings shall be taken sequentially beginning at one side of the specimen, and shall be entered in order in the test log so that the nine readings provide an accurate portrayal of the crack front profile through the thickness of the specimen. Form TP-177, or some equivalent record, should be used to document the fracture surface measurements.

12.0 <u>DATA ANALYSIS FOR A J-TEST per ASTM E813, E1152, E1820, E1737</u>

J-TEST.R01 software has the ability to perform an E813 and/or E1152 post-test data analysis.

The project engineer shall develop or identify a computer code that has the ability to perform an E1737 or E1820 post data analysis.

12.1 In the 790.50 *Main* menu, choose *ANALYZE* and select the appropriate template, procedure, and batch.

12.2 In the *Input* menu, select desirable *Calculations* and *Methods* for analyzing the data. Consult Project Engineer for the selections.

12.3 Select summaries of the test results. All items displayed in the *Summary Categories* should be chosen.

12.4 Enter precrack length 1-9 and final crack length 1-9 measured after the test using video micrometer.

12.5 Check to see if there are any E813, E1737, or E1820 violations (consistent with the Test Plan or Customer Purchase Order).

12.6 Generate the desirable tables and plots.

13.0 DATA ANALYSIS FOR TRANSITION RANGE TEST per ASTM 1921

Since JTEST.R01 is used to perform a post-test analysis on a J-test with crack extension, this software is not suitable to analyze a transition range fracture toughness test where no or limited crack extension is expected. In such case, JLINK (latest revision) is used to analyze a transition range fracture toughness test.

13.1 Load the JLINK in a BASIC programming environment.

13.2 Run JLINK.

13.3 Input test parameters as required by the software.

13.4 The J_c value is calculated by JLINK. K_{jc} is calculated as follows:

$$K_{jc} = (J_c E)^{1/2}$$

14.0 TEST RECORD FOR A J-TEST

14.1 All test results shall be included in the project log.

14.2 The record for each specimen tested shall include:

a. Summary of test. (Results generated by JTEST.R01)

b. Summary of all crack length measurements.

c. J-R curve for a E 813, E 1152, E 1820, and E 1737 test as required.

d. The output from any analysis requested by the Project Engineer.

e. (Optional) Photograph of fracture surface.

15.0 TEST RECORD FOR A TRANSITION RANGE TEST

15.1 All test results shall be included in the project log.

15.2 The record for each specimen tested shall include:

a. Outputs generated by software JLINK.

b. Summary of all crack length measurements.

c. The output from any analysis requested by the Project Engineer.

d. (Optional) Photograph of fracture surface.

16.0 DEFINITIONS – Not Applicable

17.0 ATTACHMENTS/FORMS

TP-177, "Crack Length Measurement Record"