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Multilayer Pressure Vessel Materials Testing and Analysis

Phase 2

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Table One

Revision Number	Issue Date
Final Report	August 30, 2013
Revision 01	September 13, 2013

Issue dates for the original document and all subsequent changes are given in Table One. Table Two lists all pages affected by the latest revision or by any previously issued revision. Pages not listed in Table Two are the same as issued with the original document

Table Two

Revision No.	Page No.	Description
01	1	Section 1.0 – paragraph 2 – revised
01	2	Section 2.0 – paragraph 3 – last sentence revised; Section 2.0 – paragraph 5 – last sentence revised
01	7	Section 3.1.1 – paragraph 2 – revised
01	8	Table 3-2 revised
01	11	last sentence on page revised
01	13	Section 3.1.4 – paragraph 2 – last two sentences revised
01	19	Table 3-9 – revised
01	23	Table 3-13 – revised
01	34	Table 4-1 – column heading revised
01	43	Section 5.4 – Item a – sentence added to end (including footnote 4) Section 5.4 – Item c – last sentence revised
01	44	Section 6.1 – Item c – sentence added to end
01	45	Section 6.2 – Item b – sentence added to end
01	46	Section 6.3 – Item d added
01	49	Appendix A now begins on page 49 due to revisions made in body of report
01	51-52	new flysheet and test certificate added
01	53	table revised to add footnote "c" (formerly page 49 in orig report)
01	112	table revised and footnote added (formerly page 108 in orig report)
01	125	flysheet revised and footnote added (formerly page 121 orig report)

Table Two ***(Continued)***

Revision No.	Page No.	Description
01	183	Appendix B now begins on page 183
01	185-186	new flysheet and test certificate added
01	191	new certification sheet added
01	297	table revised (formerly page 289 in orig report)

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1.0 INTRODUCTION

The National Aeronautics and Space Administration (NASA) owns and operates several hundred multilayer pressure vessels, some of which are more than fifty years old. While available construction records show that generally good design, fabrication, and inspection processes were followed, these vessels are "non-Code" vessels and actual records do not exist for many of these vessels. In addition, the materials used typically correspond to a proprietary manufacturer's specification, not an ASME or ASTM material grade. Furthermore, due to their age and operating history, it is possible that cracks have developed over time and could provide a potential failure mechanism during future operation. Therefore, a mechanical characterization of these pressure vessel materials is necessary in order to ensure their safe future operation.

To provide NASA with a suite of materials strength, fracture toughness and crack growth rate test results for use in remaining life calculations for the vessels described above, Southwest Research Institute® (SwRI®) was contracted in two phases to obtain relevant material property data from a representative vessel. An initial characterization of the strength, fracture and fatigue crack growth properties was performed in Phase 1. The Phase 1 effort also included a fractographic evaluation of an induced flaw that was subjected to cyclic pressure in an attempt by Digital Wave Corporation to use modal acoustic emissions to monitor fatigue crack growth. Fracture mechanics and fatigue crack growth analyses of this flaw were also performed with the NASGRO® software using the data generated in the Phase 1 effort to demonstrate the ability to perform remaining safe service life assessments on similar vessels.

Based on the results and recommendations of Phase 1, a more extensive material property characterization effort was developed in this Phase 2 effort. This Phase 2 characterization included additional strength, fracture and fatigue crack growth of the multilayer vessel and head materials. In addition, some more limited characterization of the welds and heat affected zones (HAZs) were performed.

2.0 PRESSURE VESSEL AND MATERIALS

The multilayer pressure vessel provided by NASA was manufactured by AO Smith in 1959 (serial number MV50466-8) and the name plate is shown in Figure 2-1. The vessel was not ASME Code stamped. The vessel was nominally 36.25 inches in outside diameter and approximately 7 feet 4 inches long (see Figure 2-2).

The body of the vessel was constructed from twelve layers (shells), with the inner (first) layer 3/8-inch thick and the remaining eleven layers each 1/4-inch thick for a total nominal wall thickness of 3.125 inches. The shells are fabricated from AO Smith 1146a, a proprietary, non-ASME material specification. During Phase 1, the shell material was found to meet the requirements of ASTM A-299 and A-225, Grade C (see Table 2-1).

Successive layers were formed into shells such that the inner diameter closely matched the outer diameter of the previous shell. With the exception of the outer-most layer, seam welds were ground flush with the shell diameter. The seam welds were staggered from shell to shell and seam welds penetrated into the inner shell about 25-30% of the shell thickness (see Figure 2-3). All layers but the inner-most contained periodic arrays of weep holes, providing a leak path should the inner layer rupture or otherwise develop a leak.

Monolithic, hemi-spherical heads, nominally 2.5 inches thick, were girth welded to the layered vessel body to form the pressure vessel. A cross-section of the head-vessel body interface is shown in Figure 2-4. The heads were fabricated from A-225, Gr. B, a standard ASTM material (see Table 2-1).

As described in the Phase 1 report [1], the multilayer AO Smith pressure vessel was sent to SwRI and sectioned for material testing using facilities at the SwRI Fabrication Shop in the Structural Engineering Department. The Phase 1 effort used only a portion of the vessel material with a larger number of additional samples having been excised for the Phase 2 efforts. A considerable amount of the vessel heads and shell remain and are being retained in storage at SwRI. These remnants could be used to provide additional material for future studies on this type of vessel.

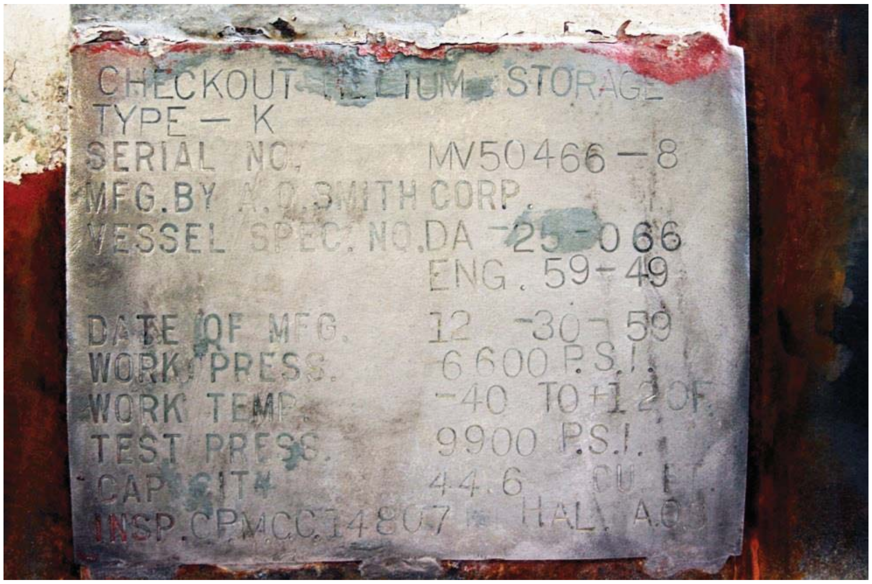


Figure 2-1. Nameplate from AO Smith Multilayer Pressure Vessel (MV50466-8)

Figure 2-2. As-Received Layered Pressure Vessel at SwRI Fabrication Shop

Figure 2-3. Outer Layer Seam Weld and Penetration into Inner Layer

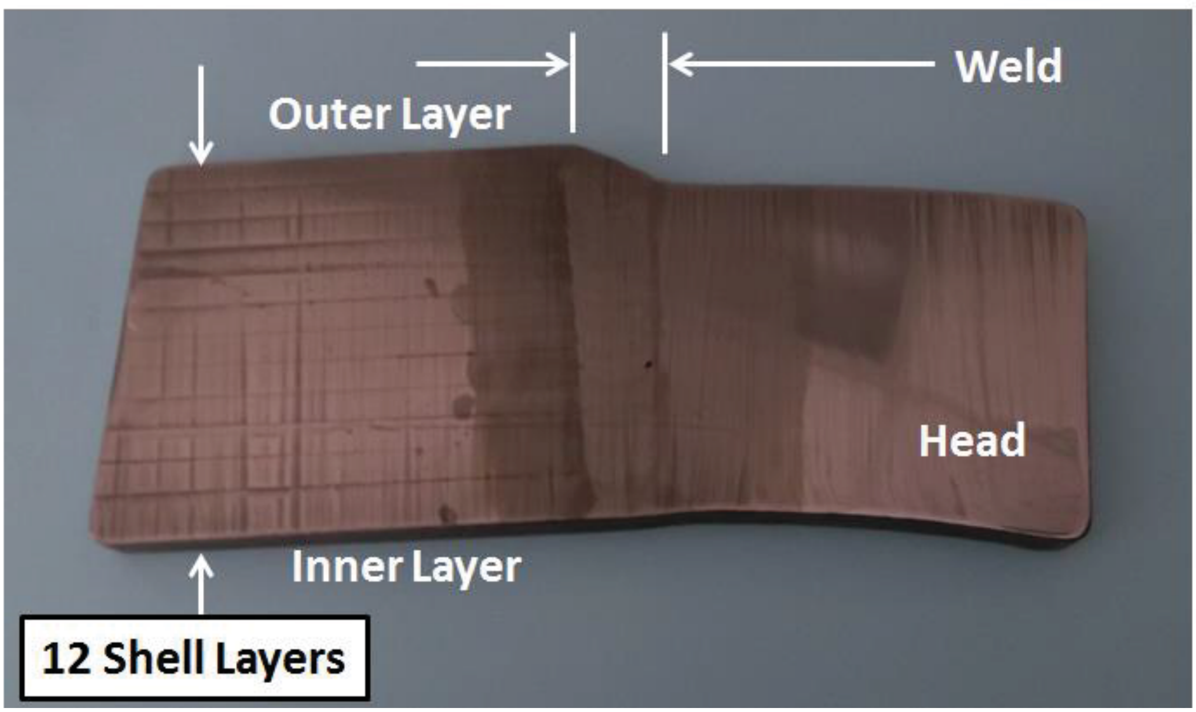


Figure 2-4. Cross-section of Head-Body Interface

Table 2-1. Chemical Composition of Head and Outer Shell Materials [1]

Material	Composition, wt.%										
	C	**Mn**	**P**	**S**	**Si**	**Ni**	**Cr**	**Mo**	**Cu**	**V**	**Al**
Head	0.16	1.40	0.033	0.028	0.20	0.20	0.19	0.02	0.02	NM[1]	<0.01
Outer Shell	0.21	1.36	0.025	0.018	0.26	0.53	0.07	0.01	0.04	NM[1]	0.05
AISI 1513	0.10-0.16	1.1-1.4	0.040 max	0.050 max	—	—	—	—	—	—	—
AISI 1522	0.18-0.24	1.1-1.4	0.040 max	0.050 max	—	—	—	—	—	—	—
AISI 1524	0.19-0.25	1.35-1.65	0.040 max	0.050 max	—	—	—	—	—	—	—
ASTM A-225 Gr. C[2]	0.25 max	1.72 max	0.035 max	0.035 max	0.13-0.45	0.37-0.73	—	—	—	0.11-0.20	—
ASTM A-299[2]	0.28 max	0.84-1.52	0.035 max	0.035 max	0.13-0.45	—	—	—	—	—	—
ASTM A-225 Gr. B[3]	0.20 max	1.45 max	0.04 max	0.05 max	0.15-0.30					0.09-0.14	
AO Smith 1146a	0.18-0.25	1.10-1.50	0.04 max	0.05 max	0.20-0.35	0.40-0.70				0.13-0.18	

[1] Not measured
[2] 1999 vintage ASTM specification
[3] 1956 vintage ASTM specification

3.0 MATERIAL CHARACTERIZATION AND ANALYSIS

Based on the results of Phase 1, a more extensive material property characterization effort was developed in this Phase 2 effort. The characterization included strength, fracture and fatigue crack growth of the multilayer vessel and head materials. In addition, some more limited characterization of the welds and heat affected zones (HAZs) was performed. This section provides the material characterization results for the multilayer pressure vessel materials.

3.1 AO Smith 1146a Shell Material Characterization

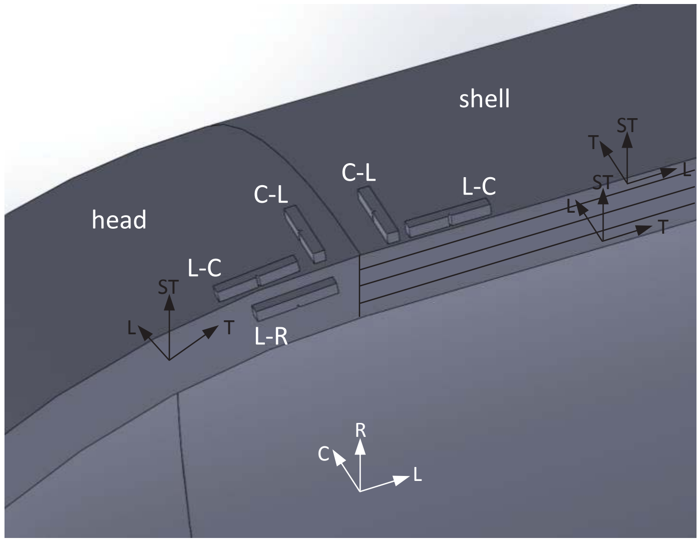
The test matrix for the AO Smith 1146a shell material characterization is shown in Table 3-1 and includes hardness, tensile, Charpy V-notch (CVN), fracture toughness and fatigue crack growth (FCG) testing. It should be noted that a test matrix was originally developed with the assumption that all shell layers had the same material orientation. However, as testing and characterization progressed, it became apparent that the inner and outer shells likely had different orientations.

Both the inner and outer shells were subjected to a metallurgical polish and light etch in order to confirm the rolling (longitudinal) orientation of the shell plate material. The material rolling (L) direction of the outer shell was oriented in the longitudinal (L) direction of the vessel while the material rolling direction of the inner shell was oriented in the circumferential (C) direction of the vessel.[1]

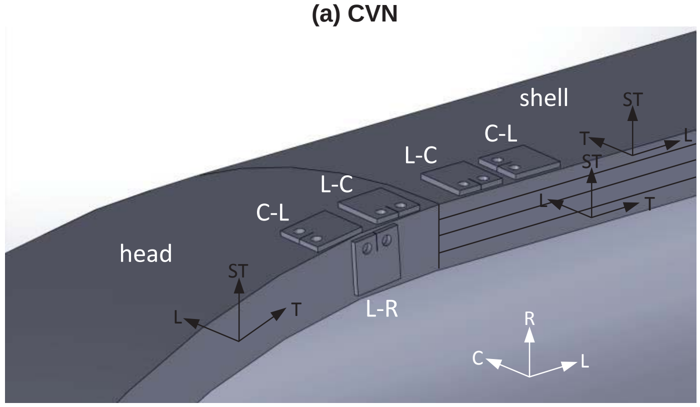
A schematic of the specimen and material orientations is shown in Figure 3-1. Material orientations are shown in black while vessel orientations are shown in white. As previously noted, there is a difference in orientation of the inner and outer layers of the shell. The CVN, toughness and FCG specimens use a standard orientation scheme in which the first designates the direction of the applied load and the second designates the direction of crack growth. Using this schematic, specimen orientation with respect to the vessel can be mapped to the more relevant material orientation.

The difference in inner and outer shell material orientation was discovered midway through execution of the original test matrix and the remaining shell testing was re-prioritized in light of this finding. The test matrix shown in Table 3-1 represents the actual test matrix that was performed.

[1] As appropriate, distinctions between material and pressure vessel orientations are maintained throughout this report. Material orientations are relative to the plate directions and correspond to longitudinal (L), transverse (T) and short-transverse (ST). Vessel orientations are relative to the pressure vessel and correspond to the vessel longitudinal (L), hoop/circumferential (C) and radial (R) directions.



(a) CVN



(b) Toughness and FCG

Figure 3-1. Vessel, Material and Specimen Orientations

(12-layer shell illustrated with 4 layers)

3.1.1 Basic Tensile and Hardness Properties

Tensile testing was performed according to ASTM E8 [2] on the AO Smith 1146a outer shell material. Tensile specimens were removed from the outer shell in the vessel circumferential (C) direction, which is the primary outer shell loading direction. This orientation corresponds to the rolling (L) direction of the outer shell. Tensile testing was performed at room temperature (RT) in Phase 1 [1] and at -20^{o}F during this Phase 2 effort.

The results of the tensile testing are presented in Table 3-2 for the 1146a shell material. By way of reference, the tensile properties are compared to data available in a NASA Tech Memo [3]. The room-temperature properties of the 1146a outer shell material are in reasonable agreement with the reference data (no reference data was available at -20^{o}F) but demonstrate a slight increase in strength and a slight reduction in elongation at failure. While the source of the reference material is unclear, testing on both these Phase 1 and 2 activities was performed on material extracted from the actual pressure vessel described in Section 2. The slight differences in shell properties may be the result of the forming process in creating the multilayered body of the vessel.

Table 3-1. AO Smith 1146a Shell Material Test Matrix

<table>
<tr><th colspan="2" rowspan="2">Material</th><th rowspan="2">Orientation</th><th colspan="3">Test</th><th rowspan="2">Notes/Comments</th></tr>
<tr><th>RT</th><th>0 °F</th><th>-20 °F</th></tr>
<tr><td rowspan="10">AO Smith 1146a Layered Shell</td><td rowspan="3">Outer</td><td>L-T (vessel L-C)</td><td>Toughness</td><td>none</td><td>Toughness</td><td>Secondary loading orientation</td></tr>
<tr><td>T-L (vessel C-L)</td><td>Hardness Tensile CVN FCG</td><td>none</td><td>Tensile CVN</td><td>Primary loading and weak material orientation; some CVN, toughness and FCG testing performed in Phase 1</td></tr>
<tr><td>T-ST (vessel L-R)</td><td>---</td><td>---</td><td>---</td><td>Primary loading and weak material orientation, but thickness limits testing</td></tr>
<tr><td rowspan="3">Inner</td><td>L-T (vessel C-L)</td><td>Hardness CVN Toughness FCG</td><td>CVN</td><td>CVN Toughness FCG</td><td>Primary loading orientation</td></tr>
<tr><td>T-L (vessel L-C)</td><td>CVN</td><td>CVN</td><td>CVN</td><td>Weak material orientation but secondary loading orientation</td></tr>
<tr><td>T-ST (vessel L-R)</td><td>---</td><td>---</td><td>---</td><td>Primary loading and weak material orientation, but thickness limits testing</td></tr>
<tr><td rowspan="2">Outer Seam HAZ</td><td>T-L (vessel C-L)</td><td>CVN</td><td>CVN</td><td>CVN</td><td>Primary loading and weak material orientation</td></tr>
<tr><td>T-ST (vessel C-R)</td><td>---</td><td>---</td><td>---</td><td>Primary loading and weak material orientation, but thickness limits testing</td></tr>
<tr><td rowspan="2">Outer Seam Weld</td><td>T-L (vessel C-L)</td><td>CVN</td><td>CVN</td><td>CVN</td><td>Primary loading and weak material orientation</td></tr>
<tr><td>T-ST (vessel C-R)</td><td>---</td><td>---</td><td>---</td><td>Primary loading and weak material orientation, but thickness limits testing</td></tr>
</table>

Table 3-2. AO Smith 1146a Outer Shell Tensile Properties

<table>
<tr><th rowspan="2">ID</th><th rowspan="2">Temp (°F)</th><th colspan="2">Yield (ksi)</th><th colspan="2">UTS (ksi)</th><th colspan="2">Elongation (%)</th></tr>
<tr><th>Test</th><th>Ref [3]</th><th>Test</th><th>Ref [3]</th><th>Test</th><th>Ref [3]</th></tr>
<tr><td>1</td><td rowspan="4">RT*</td><td>86.1</td><td rowspan="4">75.0</td><td>118.7</td><td rowspan="4">101.3</td><td>23.0</td><td rowspan="4">31</td></tr>
<tr><td>2</td><td>79.3</td><td>119.4</td><td>24.0</td></tr>
<tr><td>3</td><td>81.3</td><td>119.2</td><td>23.0</td></tr>
<tr><td>Ave</td><td>82.2</td><td>119.1</td><td>23.3</td></tr>
<tr><td>1</td><td rowspan="4">-20°F</td><td>89.1</td><td rowspan="4"></td><td>121.7</td><td rowspan="4"></td><td>20.0</td><td rowspan="4"></td></tr>
<tr><td>2</td><td>92.6</td><td>122.2</td><td>25.0</td></tr>
<tr><td>3</td><td>91.1</td><td>121.7</td><td>23.0</td></tr>
<tr><td>Ave</td><td>90.9</td><td>121.9</td><td>22.7</td></tr>
</table>

* From ref [1].

As previously mentioned, during the course of the shell characterization, unanticipated differences in properties were found between the inner and outer shells, which were ultimately attributed to differences in material orientation with respect to the vessel. In addition, hardness testing was performed on both the inner and outer shell. Vickers hardness measurements were performed on the metallurgical samples (in the vessel C-L plane) used to determine shell orientation.

The results of the hardness testing are provided in Table 3-3. The Vickers hardness results correspond to relative low hardness – high Rockwell B or very low Rockwell C – but do indicate a significant difference in hardness between the inner and outer shells. As hardness is indicative of yield strength, it is likely that there is a difference in tensile behavior in the inner and outer shells. However, tensile testing was not performed on the inner shell material in this program.

Table 3-3. AO Smith 1146a Inner and Outer Shell Hardness Results

Material		***Vickers Hardness (HV)***	
		Test	***Ave***
Layered Shell	Outer	255	265
		271	
		271	
		264	
		265	
	Inner	175	172
		168	
		170	
		175	
		173	

3.1.2 Charpy V-Notch Testing

Charpy V-notch (CVN) testing was performed in keeping with ASTM E23 [4] on the AO Smith 1146a inner and outer shell material. The limited thickness of shells required the use of sub-sized CVN specimens in the vessel C-L and L-C orientations[2,3]. As such, CVN specimens had a 2-mm notch in a 10-mm width but were only 5 mm thick instead of the standard 10-mm thickness. Note that sub-sized specimens are not suitable in the vessel L-R orientation as this would result in a significant reduction in the un-notched ligament and invalidate results scaling.

A scaling factor [5, 6] was used to adjust the sub-size CVN data in order to facilitate comparison to available CVN values from standard 10-mm x 10-mm specimens. This scaling applies to sub-sized specimens of reduced thickness by simply scaling the measured sub-sized CVN energy by the ratio of the thickness reduction to the standard 10-mm thickness. However, the thinner specimens have reduced notch-tip constraint, which can result in increased CVN energy. As the correction does not account for changes in notch-tip constraint, the thickness-corrected CVN energy may be an overestimation.

[2] The first direction corresponds to the loading direction and the second indicates the crack growth direction.
[3] The ASME B&PV Code (Section VIII, Div. 3, Article KM-2) allows the use of sub-size CVN specimens when material size or shape precludes the use of full-size CVN specimens, and recommends appropriate scaling of results.

A summary of the Charpy testing is presented in Table 3-4 for the 1146a shell material (complete CVN results for the shell material are presented in Appendix A). Given the sub-size nature of the CVN specimens, the results presented were scaled to represent a standard, full-size Charpy specimen.

As indicated in Figure 3-2, the CVN of the AO Smith 1146a shell material is generally independent of temperature between RT and 0^oF and shows a drop between 0 and -20^oF. It should be noted that this testing was not designed to determine the ductile-to-brittle transition temperature and it is not clear that these data establish an upper/lower shelf. However, these data are consistent with a reported decrease in CVN with temperature between RT and -20^oF for the 1146a material, although a nil-ductility temperature was not reported in the NASA Tech Memo[3]. Unfortunately, however, the Tech Memo does not reference specimen orientation, which obfuscates comparisons with these results.

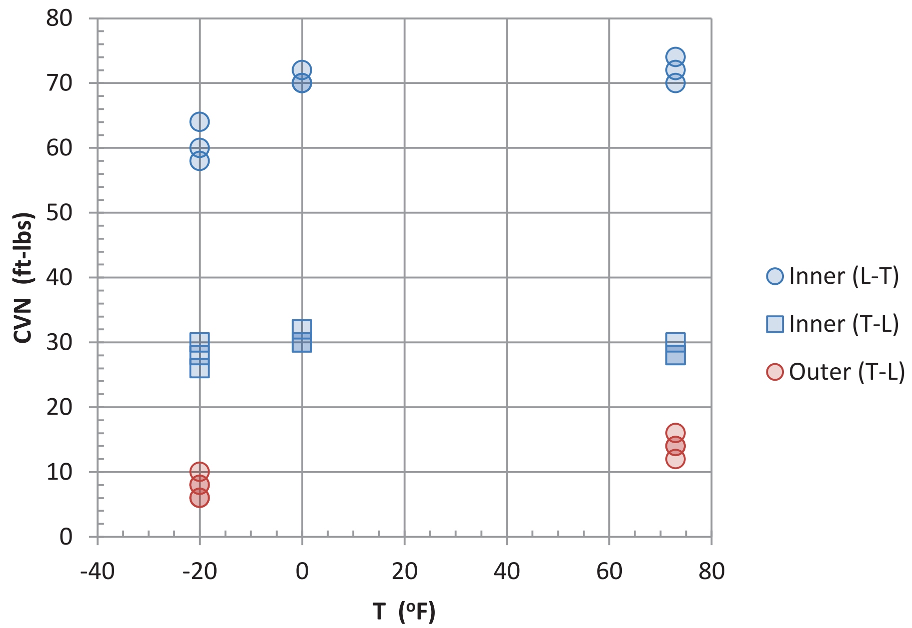


Figure 3-2. AO Smith 1146a Charpy V-Notch Results

Based on the results of the inner shell, there is a significant dependence of CVN on material orientation. As expected, CVN is higher in the L-T orientation as crack growth is transverse to the rolling direction and principal grain orientation. There also appears to be some difference in CVN between the inner and outer shells. Recall that differences in hardness between the inner and outer shells were also reported (see Table 3-3), though the connection to CVN is unknown.

Table 3-4. AO Smith 1146a Shell Charpy V-Notch Results

Material	*Orientation*	*Average CVN (ft-lbs)*[a]			*Notes/Comments*
		RT	*0 °F*	*-20 °F*	
Outer	L-T (vessel L-C)	not tested	not tested	not tested	Secondary loading; CVN deferred to inner shell
	T-L (vessel C-L)	12 15[b]	not tested	9 7[b]	Testing only to confirm Phase 1 results
	L-ST (vessel L-R)	---	---	---	Not suitable to sub-size CVN in crack growth direction
Inner	L-T (vessel C-L)	72	62	60	Primary loading orientation
	T-L (vessel L-C)	28	30	28	Weak material orientation
	T-ST (vessel L-R)	---	---	---	Not suitable to sub-size CVN in crack growth direction
Ref [3]	unknown	79	35	41	Reference CVN with unknown specimen orientation

a Average based on three tests
b Obtained during Phase 1, refer to reference [1]

CVN testing was also performed on the HAZ and seam weld of the outer shell (see Table 3-5). The results in the HAZ are reasonably consistent with those of the base outer shell material (see Figure 3-3). The outer seam weld demonstrated significantly increased CVN toughness over the outer layer material.

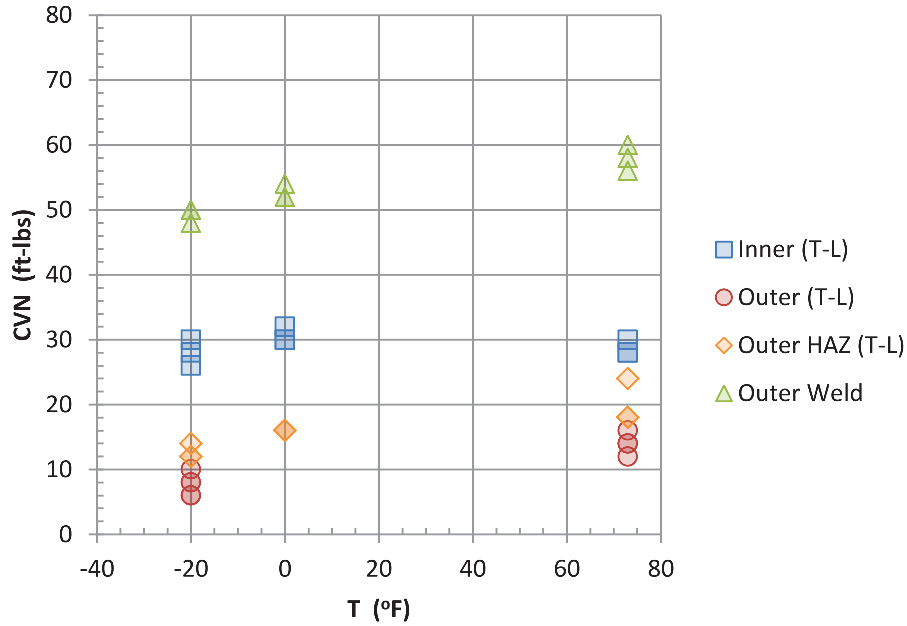


Figure 3-3. AO Smith 1146a Seam Weld and HAZ Charpy V-Notch Results

Table 3-5. AO Smith 1146a Shell Weld Charpy V-Notch Results

Material	***Orientation***	***Average CVN (ft-lbs)****			***Notes/Comments***
		RT	***0 °F***	***-20 °F***	
Seam HAZ (outer)	T-L (vessel C-L)	20	16	12	Weak material and primary loading orientation
	L-ST (vessel L-R)	---	---	---	Not suitable to sub-size CVN in crack growth direction
Seam Weld (outer)	vessel C-L	58	52	50	Primary loading and failure orientation
	vessel C-R	---	---	---	Not suitable to sub-size CVN in crack growth direction

* Average based on three tests

3.1.3 Fracture Toughness Testing

Given the limited thickness of the shell material, determining a valid plane strain toughness was deemed unlikely. Initially, a K-R approach per ASTM E561 [7] was attempted to determine the plane stress toughness based on the apparent toughness results from Phase 1 [1]. Ultimately, however, valid plane stress toughness measurements could not be achieved due to insufficient remaining ligament which was not possible to resolve given the limited shell dimensions. As such, a limited amount of elastoplastic J_{Ic} toughness testing was performed per ASTM E1820 [8].

The results of the fracture toughness testing are summarized in Table 3-6 (complete toughness results for the shell material are presented in Appendix A). Unfortunately, not all of the testing resulted in meeting the strict validation conditions with ASTM E1820. The violations were typically associated with minor deviations in crack front planarity and growth. Thus, while strictly invalid, these results are believed to be representative of expected values.

Table 3-6. AO Smith 1146a Shell Fracture Toughness Results

Material	*Orientation*	*Toughness (ksi√in.)*		*Notes/Comments*
		RT	*-20 °F*	
Outer	L-T (vessel L-C)	149[a,b]	163[a]	
	T-L (vessel C-L)	90[c]	86[c]	Invalid K_c results from Phase 1. Weak material and primary loading orientation.
	T-ST (vessel L-R)	---	---	Primary failure orientation but not practical due to material limitations.
Inner	L-T (vessel C-L)	170[a]	171[a,b]	Primary vessel loading orientation.
	T-L (vessel L-C)	not tested	not tested	Secondary loading; T-L toughness characterized on outer shell
	T-ST (vessel L-R)	---	---	Primary failure orientation but not practical due to material limitations.

Notes:
a. Reported as $K = \sqrt{J \cdot E/(1-\upsilon^2)}$ with $E = 28.3 \times 10^6$ psi and $\upsilon = 0.3$
b. Strictly invalid per ASTM E1820 but believed to be representative
c. Result invalid plane stress toughness per ASTM E561 due to insufficient remaining ligament

3.1.4 Fatigue Crack Growth Testing

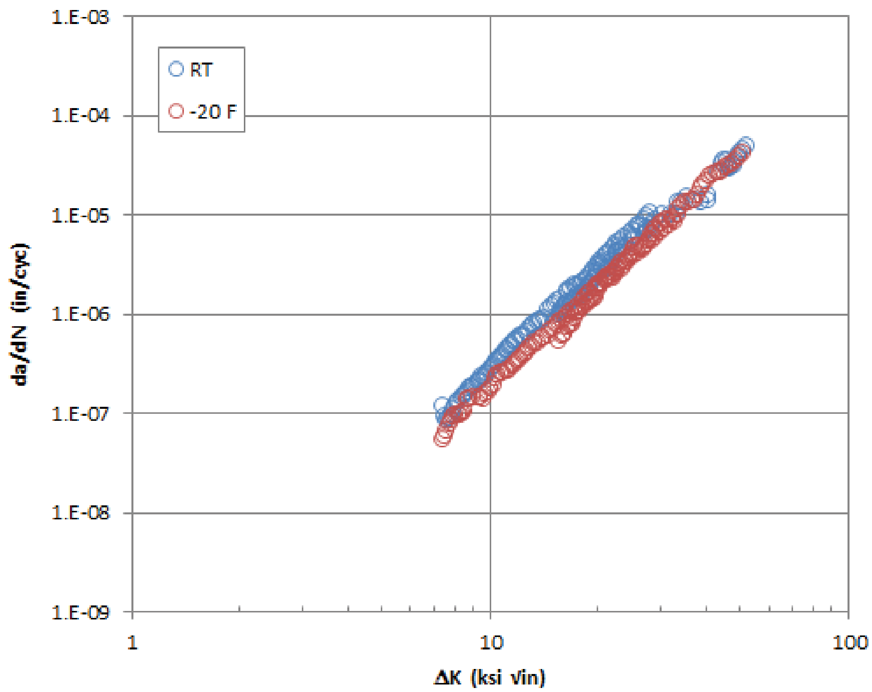
Fatigue crack growth (FCG) testing was performed per ASTM E647 [9] on the AO Smith 1146a materials. Testing was performed using standard compact tension, C(T), specimens. Phase 2 FCG testing was designed to target the upper range of the FCG da/dN-ΔK behavior by testing at high ΔK. The strategy employed for this testing was to perform some testing at very high ΔK, which would result in a very limited amount of valid FCG behavior. Other tests were designed to start lower on the da/dN-ΔK curve and develop data up to these higher ΔK tests. Due to the low yield, high toughness nature of the shell material and limited specimen size, it was only possible to obtain FCG data up to approximately 50 ksi√in. at R = 0.15. A summary of the AO Smith 1146a shell material FCG test conditions is shown in Table 3-7.

Figure 3-4 shows the FCG behavior for the inner shell material in the L-T orientation for each R ratio as a function of temperature. Note that the FCG behavior exhibits negligible temperature dependence. A comparison of the FCG behavior between the inner shell in the L-T orientation and the outer shell in the T-L orientation is shown in Figure 3-5. Only slight differences are noted.

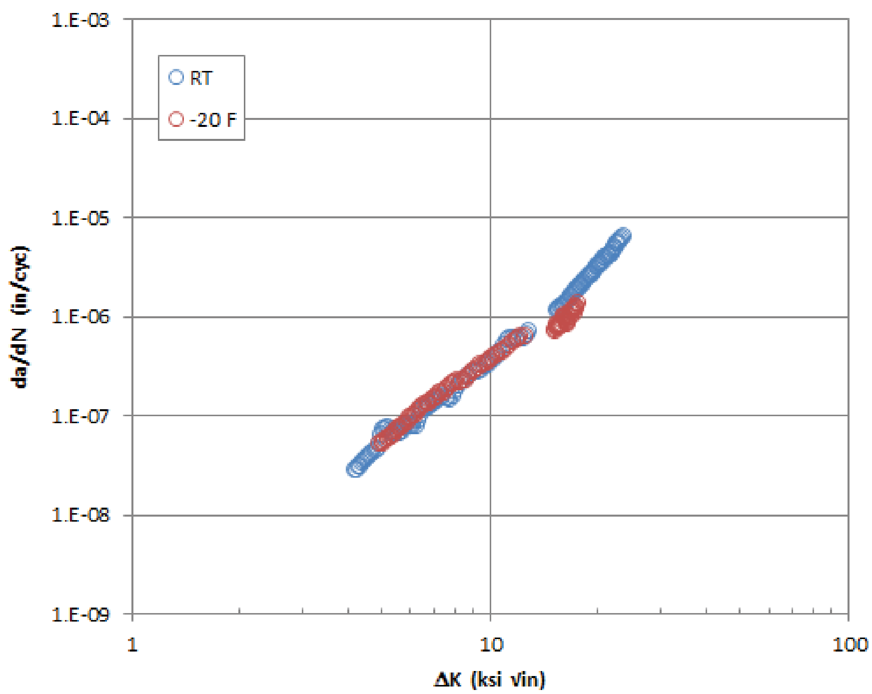
A composite of the AO Smith 1146a shell material FCG behavior is shown in Figure 3-6. The minimal R-ratio dependence indicated by these data is typical of most steels.

Table 3-7. AO Smith 1146a Shell FCG Testing

Material	*Orientation*	*FCG Testing*		*Notes/Comments*
		RT	*-20 °F*	
Outer	L-T (vessel L-C)	not tested	not tested	L-T FCG behavior from outer shell
	T-L (vessel C-L)	R = 0.7	not tested	R = 0.15 at RT performed in Phase 1
	T-ST (vessel L-R)	---	---	Primary failure orientation but not practical due to material limitations
Inner	L-T (vessel C-L)	R = 0.15 R = 0.7	R = 0.15 R = 0.7	Primary loading and weak material orientation
	T-L (vessel L-C)	not tested	not tested	T-L FCG behavior from outer shell
	T-ST (vessel L-R)	---	---	Primary failure orientation but not practical due to material limitations

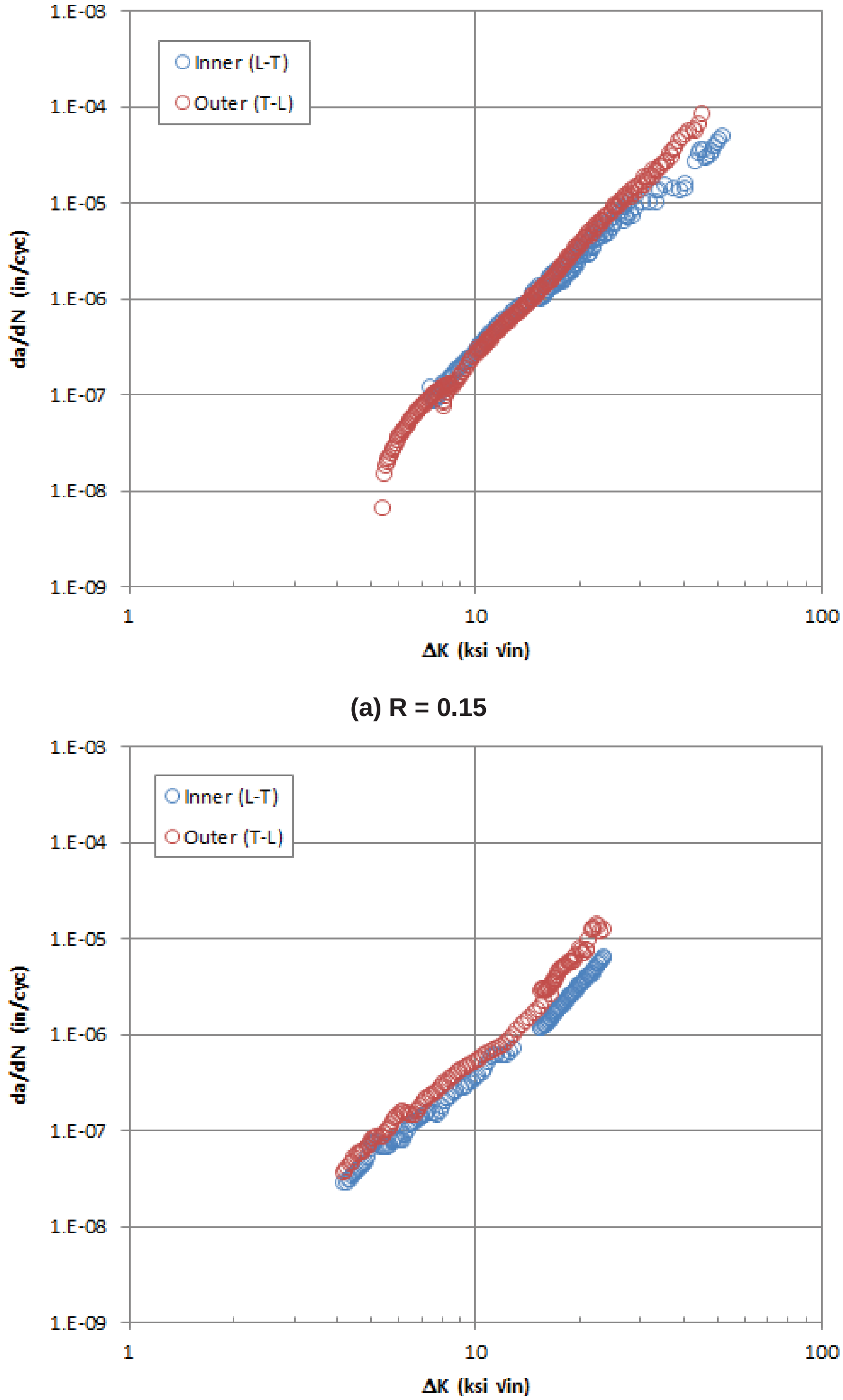


(a) R = 0.15



(b) R = 0.7

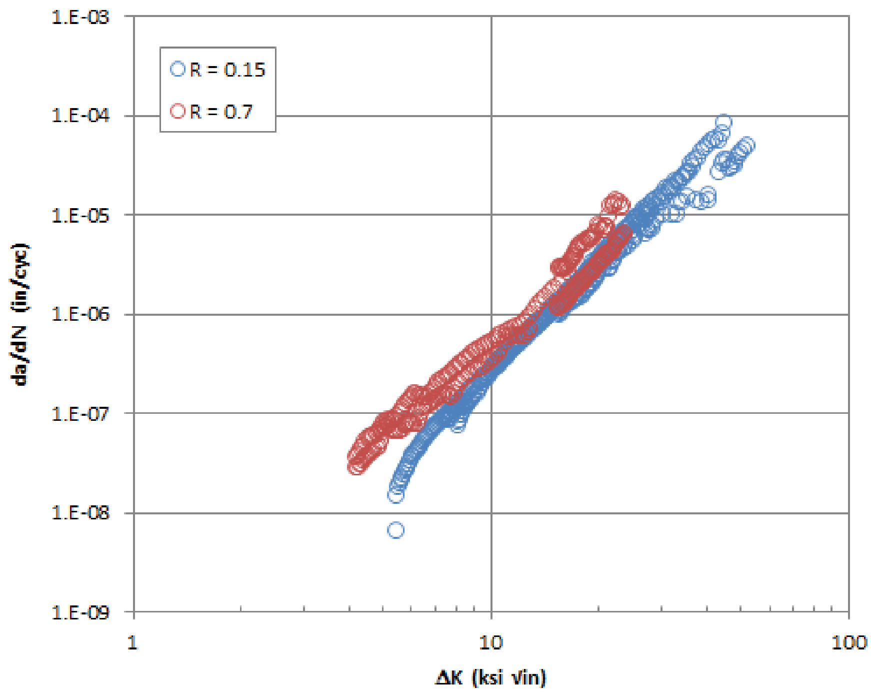
Figure 3-4. AO Smith 1146a Inner Shell FCG Behavior in L-T Orientation



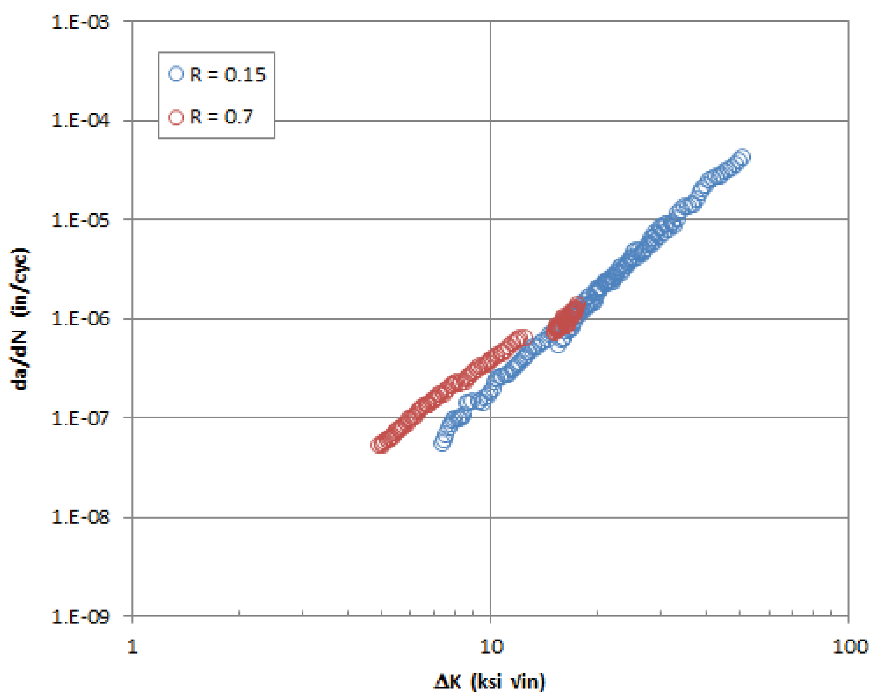
(a) R = 0.15

(b) R = 0.7

Figure 3-5. AO Smith 1146a Shell FCG Behavior at RT



(a) room temperature



(b) -20^{o}F

Figure 3-6. AO Smith 1146a Shell FCG Behavior

3.2 A-225, Gr. B Head Characterization

The test matrix for the A-225 Gr. B head material characterization is shown in Table 3-8 and includes tensile, Charpy V-notch (CVN), fracture toughness and fatigue crack growth (FCG) testing. For consistency with the Phase 1 effort, all characterization of the head material was limited to the same head. Given the axisymmetric nature of the head, a metallurgical polish and light etch was used to determine the rolling direction of the head plate material in order to extract specimens with known material orientations.

The angle between the head rolling direction and girth weld varies around the circumference of the head weld. Thus, a region of the head-vessel interface was specifically selected where the head rolling direction was parallel to the head girth weld for testing of the head HAZ (refer to Figure 3-1).

Table 3-8. A-225 Gr. B Head Material Test Matrix

Material		***Orientation***	***Test***			***Notes/Comments***
			RT	***0 °F***	***-20 °F***	
A-225 Gr. B Head	Base Head Material	vessel L-C	CVN FCG	not tested	CVN	Phase 1 results but actual material orientation unknown
		T-L (vessel L-C)	CVN Toughness FCG	CVN	CVN Toughness FCG	Primary loading and weak material orientation
		T-ST (vessel L-R)	CVN	CVN	CVN	Primary loading and weak material orientation
	Outer HAZ	T-L (vessel L-C)	none	none	none	Characterization focused on inner HAZ to minimize material constraints
		T-ST (vessel L-R)	---	---	---	Primary loading orientation but not suitable for conventional specimens and testing
	Inner HAZ	T-L (vessel L-C)	CVN Toughness FCG	CVN	CVN Toughness	Primary loading and weak material orientation
		T-ST (vessel L-R)	---	---	---	Primary loading orientation but not suitable for conventional specimens and testing
	Weld	vessel L-C	CVN Toughness FCG	CVN	CVN Toughness	Primary loading orientation
		vessel L-R	---	---	---	Primary loading orientation but not suitable for conventional specimens and testing

3.2.1 Basic Tensile Properties

Tensile testing was performed according to ASTM E8 [2] on the A-225, Gr. B head material. Tensile specimens were removed from the head circumferential (C) direction of the vessel, corresponding to the transverse (T) direction of the head material. Tensile testing was performed at room temperature (RT) in Phase 1 [1] and at -20°F during this Phase 2 effort.

The results of the tensile testing are presented in Table 3-9 for the A-225 Gr. B head material. By way of reference, the tensile properties are compared to data available in a NASA Tech Memo

[3]. The room-temperature properties of the head material are in very good agreement with the reference data. No reference data was available at -20^{o}F.

Table 3-9. A-225 Gr. B Head Tensile Properties

ID	Temp (^{o}F)	Yield (ksi)		UTS (ksi)		Elongation (%)	
		Test	Ref [3]	Test	Ref [3]	Test	Ref [3]
1	RT*	53.1	58.4	80.0	82.1	34.0	34
2		51.7		77.5		36.0	
3		52.7		80.4		33.0	
Ave		**52.5**		**79.3**		**34.3**	
1	-20^{o}F	59.1		84.1		34.0	
2		57.7		82.7		34.0	
3		60.3		83.6		37.0	
Ave		**59.0**		**83.5**		**35.0**	

* From ref [1].

3.2.2 Charpy V-Notch Testing

Charpy V-notch (CVN) testing was performed in keeping with ASTM E23 [4] on the A-225 Gr. B head material and the head weld and associated HAZ. Testing was performed in the T-L and T-ST orientations, which are the weak material and primary loading orientations. CVN testing was only performed in the T-L orientation for the HAZ and the vessel L-C orientation for the weld. As CVN specimens for the HAZ and weld span into the layered portion of the vessel body, it was not reasonable to test the HAZ and weld with the notch in the radial direction.

A summary of the CVN results are presented in Table 3-10 for the A-225 Gr. B head material (complete CVN results for the head material are presented in Appendix B). Figure 3-7 presents the CVN results for the head material in the T-L and T-ST orientations. While some difference is noted at 0^{o}F, very little difference is noted at RT and -20^{o}F.

However, a significant drop in CVN from RT to -20^{o}F is noted in the data. Although this testing was not designed to determine the ductile-to-brittle transition temperature, the data suggest that the transition temperature might be somewhat above 0^{o}F in the T-L orientation given the relatively low CVN toughness at 0 and -20^{o}F. The transition temperature in the T-ST orientation appears to be near 0^{o}F as the CVN toughness at 0^{o}F in the T-ST orientation is about mid-way between the toughness at RT and -20^{o}F, which, given its especially low toughness, is almost certainly on the lower shelf. These results are consistent with the reported decrease in CVN with temperature between RT and -20^{o}F. However, the reported nil-ductility temperature of -25^{o}F is considerably lower than these data suggest [3]. Unfortunately, the Tech Memo does not reference specimen orientation, which obfuscates comparisons with these results.

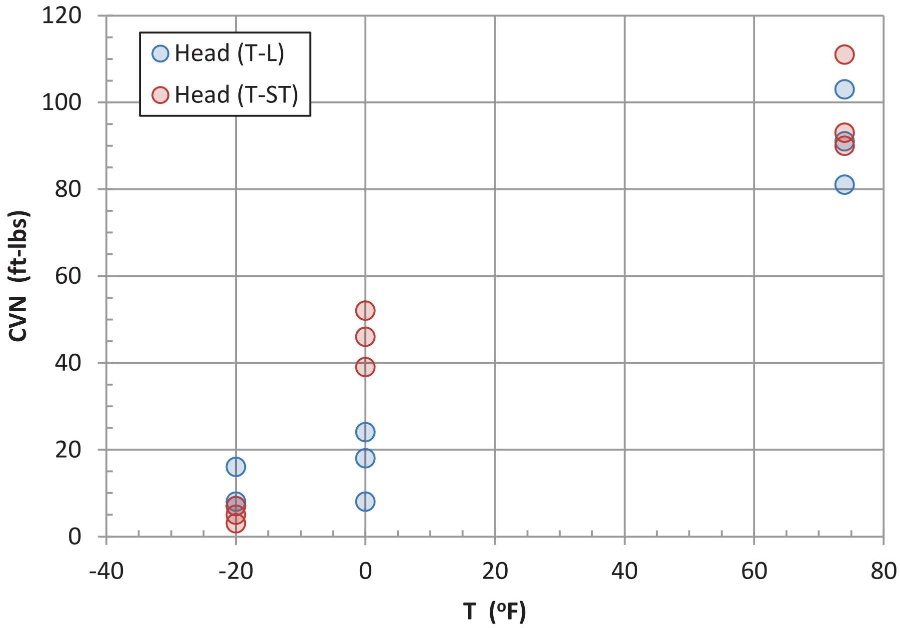


Figure 3-7. A-225 Gr. B Head Charpy V-Notch Results

Table 3-10. A-225 Gr. B Head Charpy V-Notch Results

Material	***Orientation***	***Average CVN (ft-lbs)****			***Notes/Comments***
		RT	***0 °F***	***-20 °F***	
A-225 Gr. B Head	T-L (vessel L-C)	90	17	10	Primary loading and weak material orientation
	T-ST (vessel L-R)	98	46	5	Primary loading and weak material orientation
Ref [3]	Unknown	41	25	20	Reference CVN with unknown specimen orientation

* Average based on three tests

A summary of the CVN results of the head weld and HAZ are shown in Table 3-11. Note that the geometry of the head-shell interface inhibited testing of the outermost portion of the weld and HAZ. However, the CVN results of the inner HAZ are very consistent with the base A-225 head material (see Figure 3-8). The results of the head weld indicate a significant drop in CVN toughness between RT and 0°F and no significant further reduction at -20°F, suggesting that the transition temperature may be greater than 0°F.

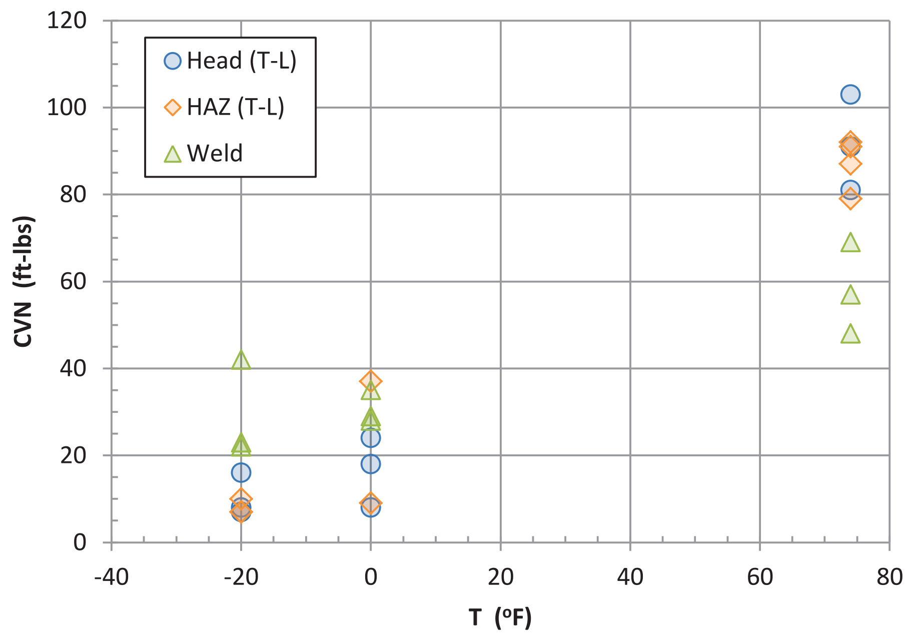


Figure 3-8. A-225 Gr. B Head Weld and HAZ Charpy V-Notch Results

Table 3-11. A-225 Gr. B Head Weld Charpy V-Notch Results

Material	*Orientation*	*Average CVN (ft-lbs)**			*Notes/Comments*
		RT	*0 °F*	*-20 °F*	
Outer HAZ	T-L (vessel L-C)	---	---	---	Vessel construct inhibits testing in this orientation
	T-ST (vessel L-R)	---	---	---	Vessel construct inhibits testing in this orientation
Inner HAZ	T-L (vessel L-C)	90	23	8	Primary loading and weak material orientation
	T-ST (vessel L-R)	---	---	---	Vessel construct inhibits testing in this orientation
Weld	vessel L-C	58	30	29	Primary loading orientation
	vessel L-R	---	---	---	Vessel construct inhibits testing in this orientation

* Average based on three tests

3.2.3 Fracture Toughness Testing

Based on the findings and recommendations of Phase 1 [1], elastoplastic J_{Ic} toughness testing was performed per ASTM E1820 [8]. The results of the fracture toughness testing are summarized in Table 3-12 (complete toughness results for the head material are presented in Appendix B). Because specimens from the weld and HAZ extended into the layered shell, testing was performed on the inner weld and HAZ, which eased specimen size constraints with the thicker inner shell.

Unfortunately, as noted, not all testing resulted in valid J_{Ic} results. In some instances, unstable growth occurred prior to obtaining sufficient stable tearing to determine J_{Ic}. Nevertheless, in most instances, a valid J_C result was obtained (though this measure does not strictly satisfy plane strain conditions).

The fracture toughness results are very consistent with the CVN behavior. Like CVN, a noted drop in toughness was observed between RT and -20^{o}F. Similarly, the toughness behavior of the HAZ is similar to the base head material. While the weld toughness was lower than the HAZ at RT, it was comparable in toughness at -20^{o}F.

Table 3-12. A-225 Gr. B Head Weld Fracture Toughness Results

Material	*Orientation*	*Toughness (ksi√in.)*[a]		*Notes/Comments*
		RT	*-20 ^{o}F*	
A-225 Gr. B Head	T-L (vessel L-C)	217	140[b]	
	T-ST (vessel L-R)	---	---	Head thickness minimized ability to obtain valid result
Outer HAZ	T-L (vessel L-C)	not tested	not tested	Inner HAZ tested; inner shell thickness eased specimen size constraints
	T-ST (vessel L-R)	---	---	Vessel construct inhibits testing in this orientation
Inner HAZ	T-L (vessel L-C)	197	93[b]	
	T-ST (vessel L-R)	---	---	Vessel construct inhibits testing in this orientation
Weld	vessel L-C	121[c]	97[b]	
	vessel L-R	---	---	Vessel construct inhibits testing in this orientation

Notes:
a. Reported as $K = \sqrt{(J \cdot E/(1-\upsilon^2))}$ with $E = 28.3 \times 10^6$ psi and $\upsilon = 0.3$
b. Invalid for J_{Ic} due to lack of stable tearing but valid Jc result
c. Strictly invalid per ASTM E1820 but believed to be representative

3.2.4 Fatigue Crack Growth Testing

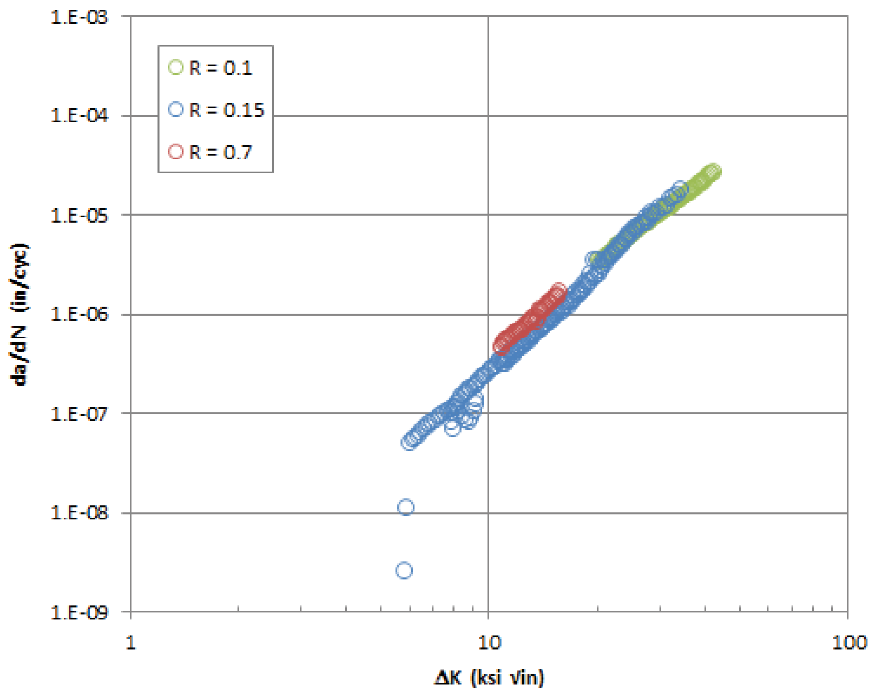
Fatigue crack growth (FCG) testing was performed per ASTM E647 [9] on the A-225 Gr. B head and the head weld and associated HAZ. A summary of the A-225 Gr. B head material FCG test conditions is shown in Table 3-13.

As with FCG of the shell material, this Phase 2 FCG testing of the head material was also designed to target the upper range of the FCG da/dN-ΔK behavior by testing at high ΔK. The same strategy was employed for this testing by performing some testing at very high ΔK, which would result in a very limited amount of valid FCG behavior. Additional tests were designed to start lower on the da/dN-ΔK curve and develop data up to these higher ΔK tests. Due to the low yield, high toughness nature of the head material and limited specimen size, it was only possible to obtain FCG data up to approximately 40 ksi√in. at R = 0.15.

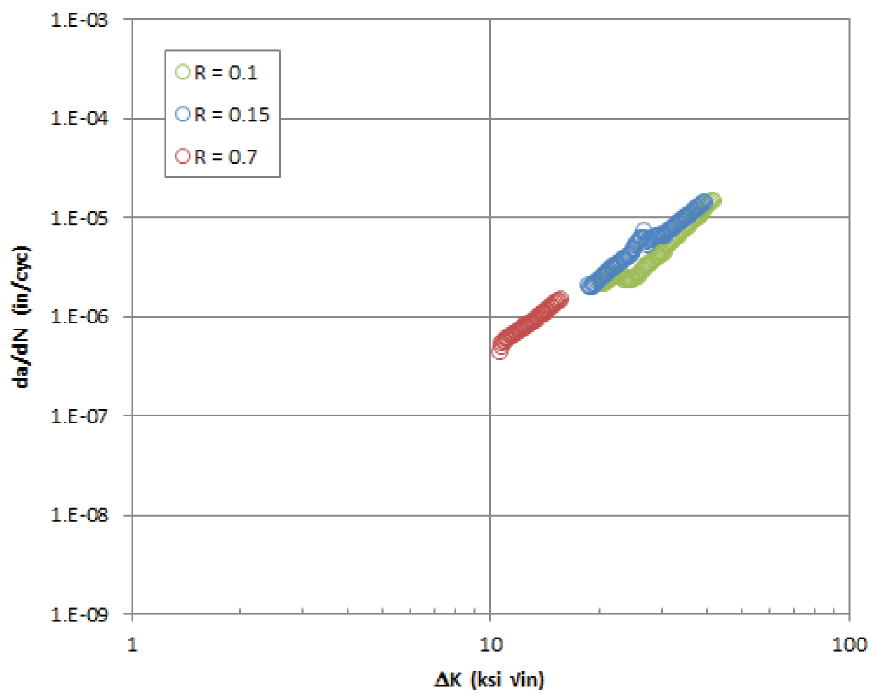
The FCG behavior of the A-225 Gr. B head material at RT and -20°F is shown in Figure 3-9. The minimal R-ratio dependence indicated by these data is typical of most steels. A comparison of the RT and -20°F behavior at each R ratio is shown in Figure 3-10, indicating negligible temperature dependence on the FCG behavior.

Table 3-13. A-225 Gr. B Head FCG Testing

Material	***Orientation***	***FCG Testing***		***Notes/Comments***
		RT	***-20 °F***	
A-225 Gr. B Head	T-L (vessel L-C)	R = 0.1 R = 0.7	R = 0.1 R = 0.15 R = 0.7	R = 0.15 at RT performed in Phase 1
	T-ST (vessel L-R)	none	none	FCG of weld and HAZ prioritized over additional characterization of head FCG
Outer HAZ	T-L (vessel L-C)	none	none	Inner HAZ tested; inner shell thickness eased specimen size constraints
	T-ST (vessel L-R)	---	---	Vessel construct inhibits testing in this orientation
Inner HAZ	T-L (vessel L-C)	R = 0.15 R = 0.7	none	R ratio characterization prioritized over temperature
	T-ST (vessel L-R)	---	---	Vessel construct inhibits testing in this orientation
Weld	vessel L-C	R = 0.15 R = 0.7	none	R ratio characterization prioritized over temperature
	vessel L-R	---	---	Vessel construct inhibits testing in this orientation

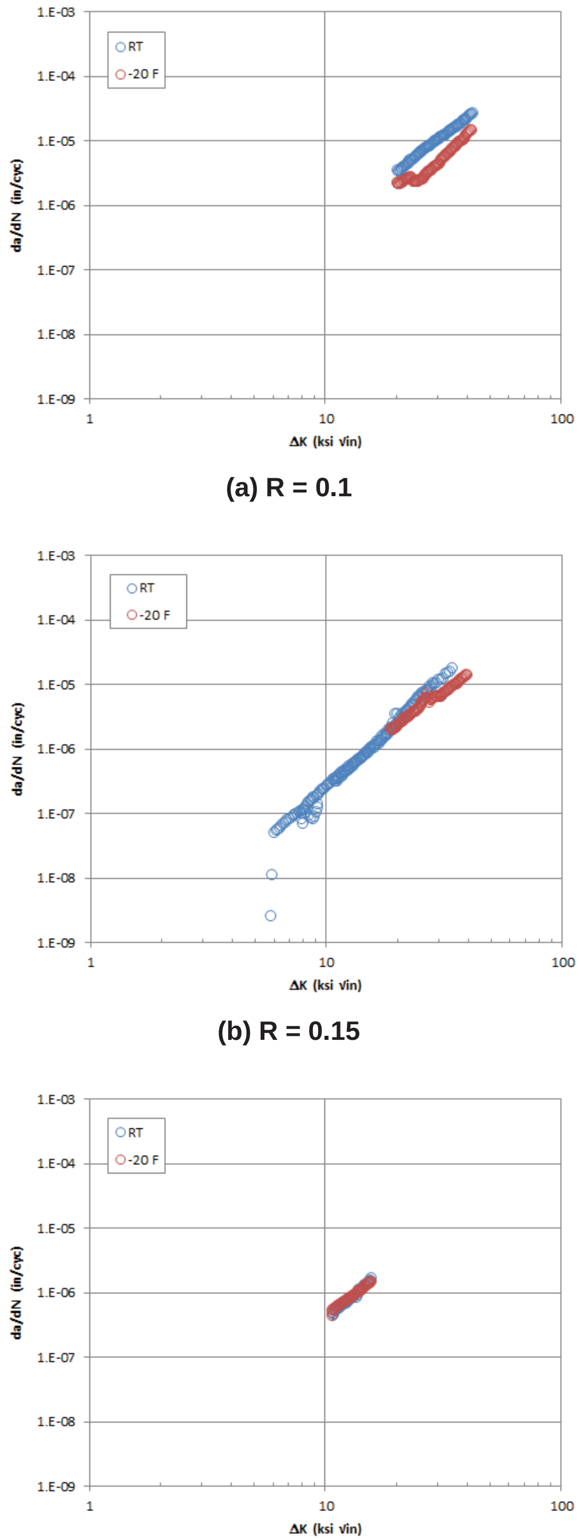


(a) RT



(b) -20^{o}F

Figure 3-9. A-225 Gr. B FCG Behavior



(a) R = 0.1

(b) R = 0.15

(c) R = 0.7

Figure 3-10. A-225 Gr. B FCG Behavior as a Function of Temperature

Producing adequate FCG specimens from the head weld and HAZ was problematic. A schematic indicating FCG specimen extraction from the weld is shown in Figure 3-11 and is similar for FCG specimens extracted from the HAZ in the head. As individual shell layers are not joined together (except at their seam welds), the layers separated during specimen extraction, only being joined at the head weld. Thus, producing a viable specimen was difficult, especially for specimens extracted from the weld, which extended further into the layered shell.

Because both specimen types extended into the layered shell, specimens were extracted from the inner weld and HAZ associated with the thicker inner shell. As a result, specimens only extended into two layers – extraction anywhere else would have resulted in specimens extending into three shell layers, further complicating specimen extraction and testing.

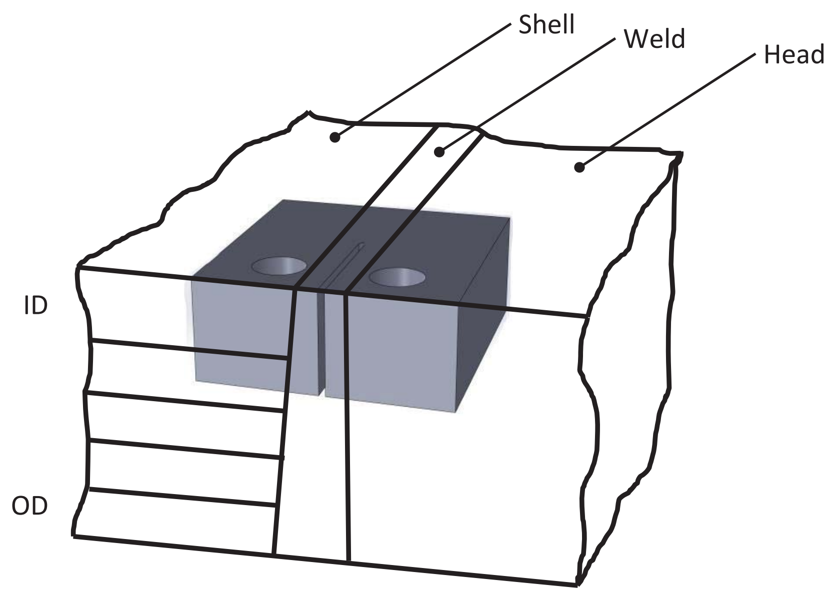
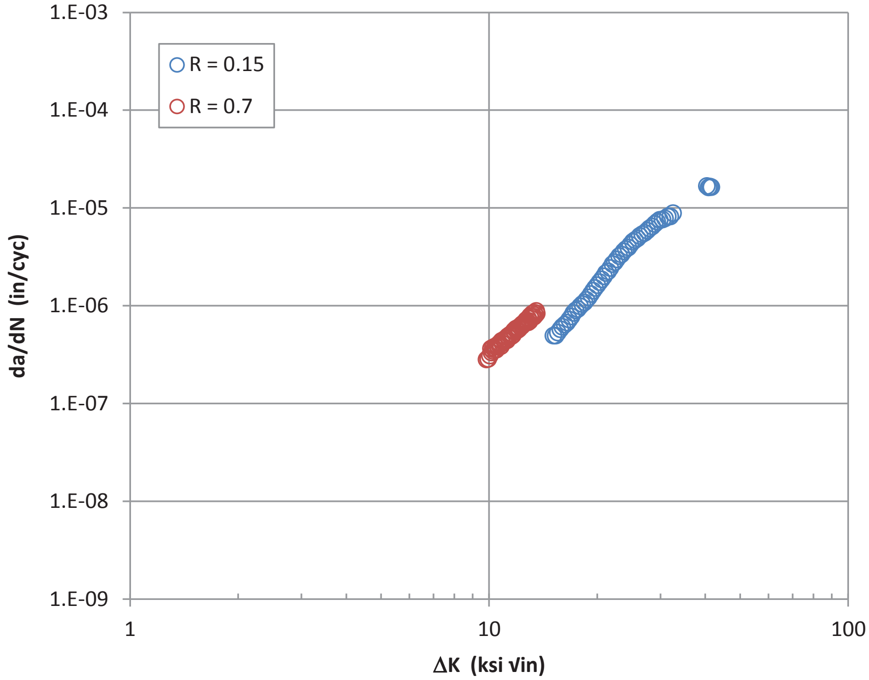


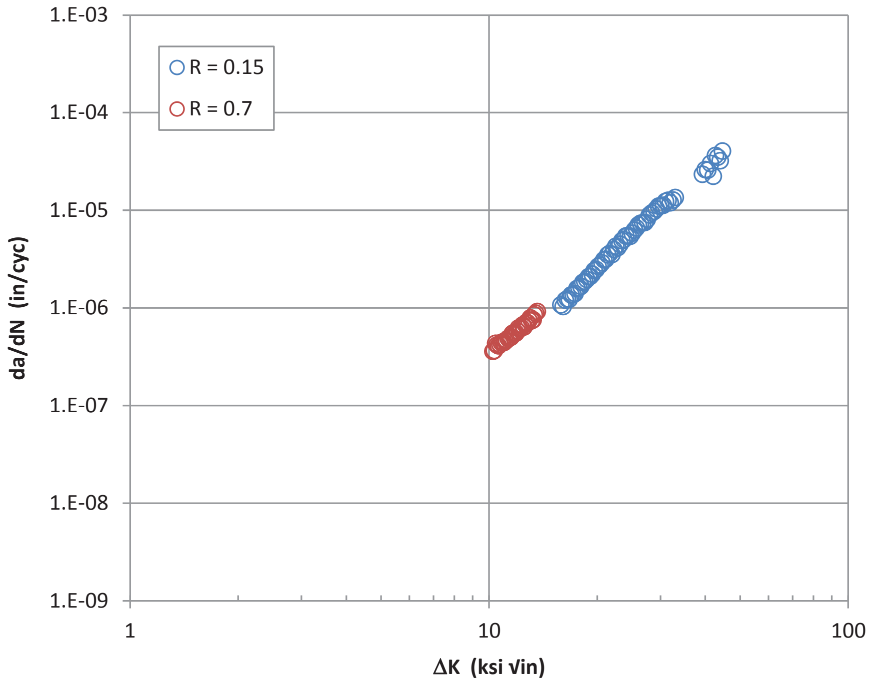
Figure 3-11. Schematic of Head Weld FCG Specimen Extraction

Fatigue crack growth testing of the head weld and HAZ was similarly challenging. Particularly at higher crack driving forces, crack growth tended to extend out-of-plane toward the layered shells. As such, the resulting valid FCG behavior was more limited, particularly for the higher R-ratio of 0.7.

The FCG behavior of the inner head weld and HAZ is shown in Figure 3-12. The same FCG testing strategy as that used for the base head material was employed by performing some testing at very high ΔK, which would result in a very limited amount of valid FCG behavior, followed by additional testing designed to start lower on the da/dN-ΔK curve and develop data up to these higher ΔK tests. However, out-of-plane growth limited the range of valid data. It should also be noted that the tensile properties of the base A-225 Gr. B head material were used to assess the validity of the weld and HAZ FCG data – obtaining tensile properties of the weld and HAZ will be challenging and was not performed as part of this Phase 2 effort.



(a) Inner Head Weld



(b) Inner Head HAZ

Figure 3-12. Inner Head Weld and HAZ FCG Behavior

4.0 FATIGUE CRACK GROWTH MODELING

This section first provides a review of fatigue crack growth (FCG) data and how they are modeled using the NASGRO equation [10]. This is followed by a discussion of fits of the NASGRO equation to the data obtained in this effort. While the NASGRO software contains some data for these materials from the 1975 NASA Langley report [3], these legacy data sets are not as extensive as one would hope, exhibit considerable scatter, and are of questionable validity considering current testing methods [1] and hence, motivated the testing documented in this current effort.

The limited sets of FCG data generated in the Phase 1 [1] were combined with the more extensive range of data generated in this Phase 2 effort and used to develop fits to the NASGRO equation as described below.

4.1 Fatigue Crack Growth Rate Modeling Background

Fatigue crack growth rate data are generally characterized on log-log plots of growth rate, *da*/*dN* (in./cycle) versus stress intensity factor range, ΔK (ksi√in.). It is commonplace to consider FCG data to be divided into three regions as shown schematically in Figure 4-1. Region I is the fatigue "threshold" region where cracks propagate very slowly and the data usually exhibit a threshold (ΔK_{th}) below which cracks do not propagate. Region II is the linear or steady-state region where the relationship between *da*/*dN* and ΔK is linear on a log-log plot. Region II is also commonly referred to as the Paris region after the power law equation [$da/dN = C(\Delta K)^n$] that has been used to model fatigue crack growth in this region for many years. Region III is the near instability region where rapid unstable crack growth occurs as fracture instability is approached.

Crack growth rate calculations in NASGRO use a relationship called the NASGRO equation given by:

$$\frac{da}{dN} = C\left[\left(\frac{1-f}{1-R}\right)\Delta K\right]^n \frac{\left(1-\frac{\Delta K_{th}}{\Delta K}\right)^p}{\left(1-\frac{K_{\max}}{K_c}\right)^q} \tag{4.1}$$

where N is the number of applied fatigue cycles, a is the crack length, R is the stress ratio, ΔK is the stress intensity factor range, and C, n, p, and q are empirically derived constants. The NASGRO equation is a "full-range" crack growth model in that it can represent all three crack growth regions as well as account for the dependence of FCG rate on the stress ratio. Closure is modeled using the Newman crack opening function, f. For additional detail on the NASGRO equation, the reader is referred to the documentation for the NASGRO software [10].

To fit the NASGRO equation to fatigue crack growth rate data, one generally needs multiple sets of data at different R values. In the Phase 1 effort, FCG rate data were obtained only at an R of 0.15; Phase 2 testing at a higher R value (0.70) was conducted to determine the extent of the variation on da/dN as a function of R, and in addition, the effect of temperature (-20^{o}F) at both R values for both materials. Fits to the NASGRO equation for each material and for each temperature were obtained using the NASMAT module contained in the NASGRO software [10] and are presented below. Note that only the "valid" FCG data were used in the NASGRO equation fits.

One of the key features of the NASGRO equation is its ability to model closure and the variation in FCG rate data as a function of R which, in many materials, can be significant. However, for many steels, the variation in FCG data as a function of R is small and the testing performed herein confirmed this expectation. Therefore, because of the NASGRO equation's use of the closure function, *f*, as described above, modeling a tight set of da/dN data with the NASGRO equation can become problematic. The strategy adopted herein was to focus the NASGRO equation fit on the low R data (i.e., R = 0.10 and 0.15) because the pressure cycling of the vessels is generally anticipated to be from zero or very low pressures to peak values and back again.

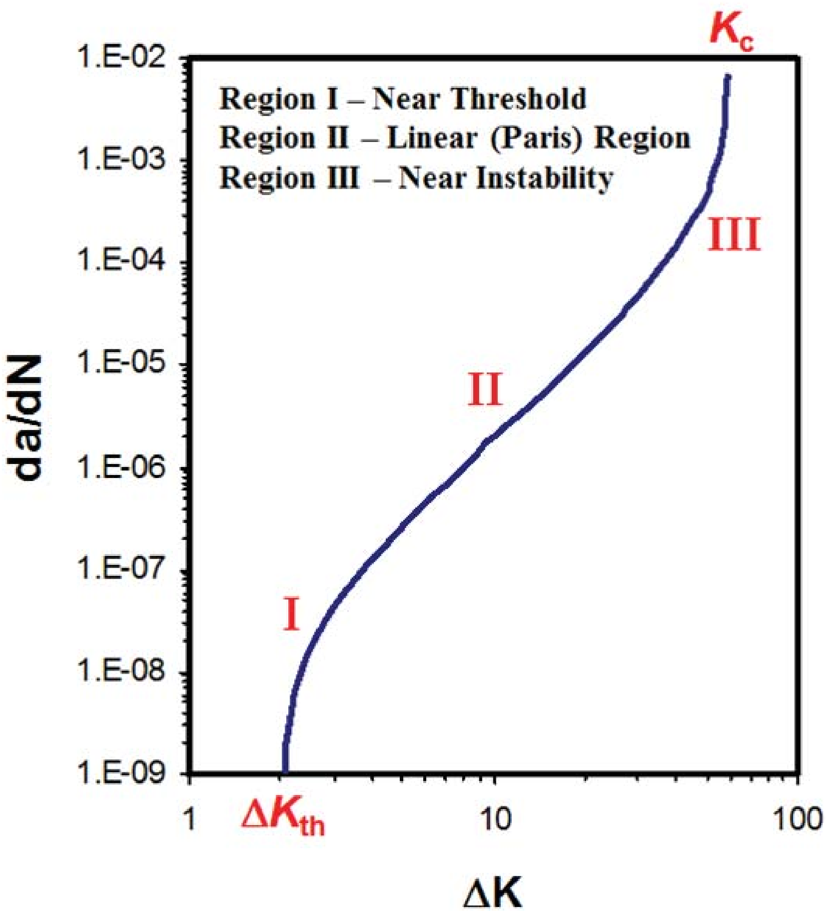


Figure 4-1. Schematic of Fatigue Crack Growth Behavior Illustrating the Three Regions of Fatigue Crack Growth

4.2 NASGRO Equation Fits for the AO Smith 1146a Shell Material

The fit to the NASGRO equation for the AO Smith 1146a shell material at room temperature (RT) is shown in Figure 4-2. In this plot the Phase 1 data are the black circles (R = 0.15, t = 0.236) and are the only data set that approach the threshold region. Figure 4-3 plots the

NASGRO equation fit for AO Smith 1146a shell material at -20^{o}F. There were no data obtained in the threshold region at -20^{o}F and the "fit" in this region was based on what was obtained at RT in Figure 4-2. The principal difference, albeit slight, between these two fits is that the -20^{o}F exhibit a somewhat shallower slope, *n*, than shown in the RT condition (2.57 versus 2.75). In general, the RT data/fit is slightly above the -20^{o}F data/fit and would be conservative choice to use in an analysis. The NASGRO equation parameters for the AO Smith 1146a shell material are summarized in Table 4-1.

4.3 NASGRO Equation Fits for the A-225 Gr. B Head Material

The fit to the NASGRO equation for the A-225 Gr B. head material at room temperature is shown in Figure 4-4. In this plot the Phase 1 data are represented by the pink "X" symbols" (R = 0.15, t = 0.25) and are the only data set that approach the threshold region. Figure 4-5 plots the NASGRO equation fit for the A-225 Gr B. head material at -20^{o}F. There were no data obtained in the threshold region at -20^{o}F and the "fit" in this region was based on what was obtained at RT in Figure 4-4. For the head material at both conditions, the slopes of the data are about the same (2.75); again, the RT data/fit is slightly above the -20^{o}F data/fit and would be conservative choice to use in an analysis. The NASGRO equation parameters for the A-225 Gr. B head material are summarized in Table 4-1.

4.4 Comparison of NASGRO Equation Fits to the Barsom Equation

For fatigue crack growth in ferrite-pearlite steels, Barsom [11] developed an "upper bound" Paris equation that the Langley report recommended be used [3]:

$$da/dN = 3.6\text{E-}10\ (\Delta K)^{3.0} \tag{4.2}$$

This relationship is shown plotted in Figure 4-6 for comparison against the head and shell NASGRO equation for R = 0.15 and RT. The Barsom equation matches the NASGRO equation at R = 0.15 quite well in the linear, Paris region. However, the Barsom equation should not be considered an upper bound over the full range of R or ΔK for these materials.

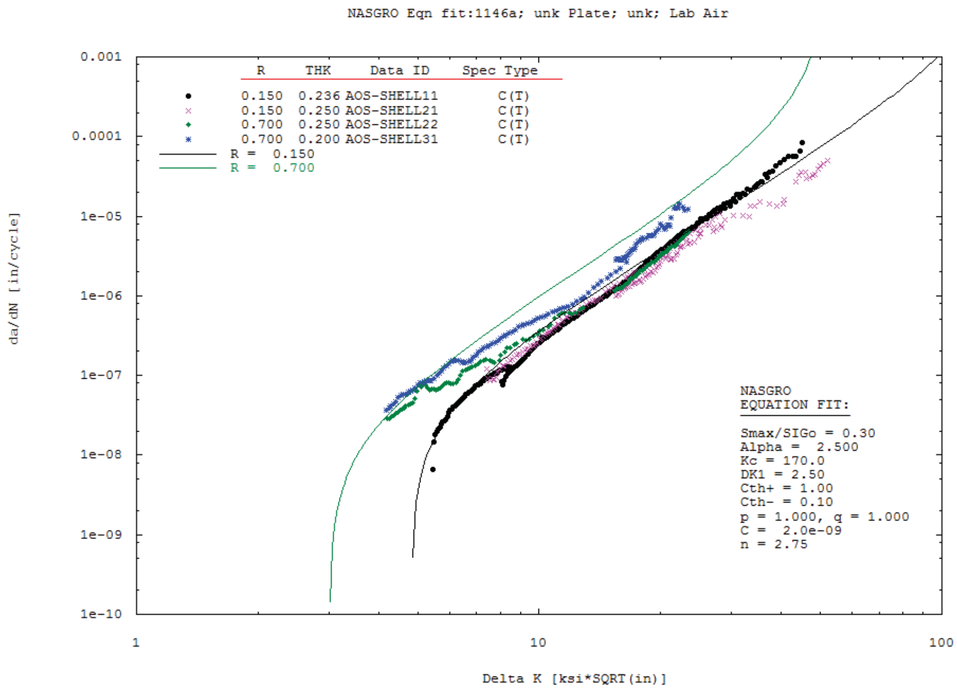


Figure 4-2. NASGRO Equation Fit for AO Smith 1146a Shell at Room Temperature

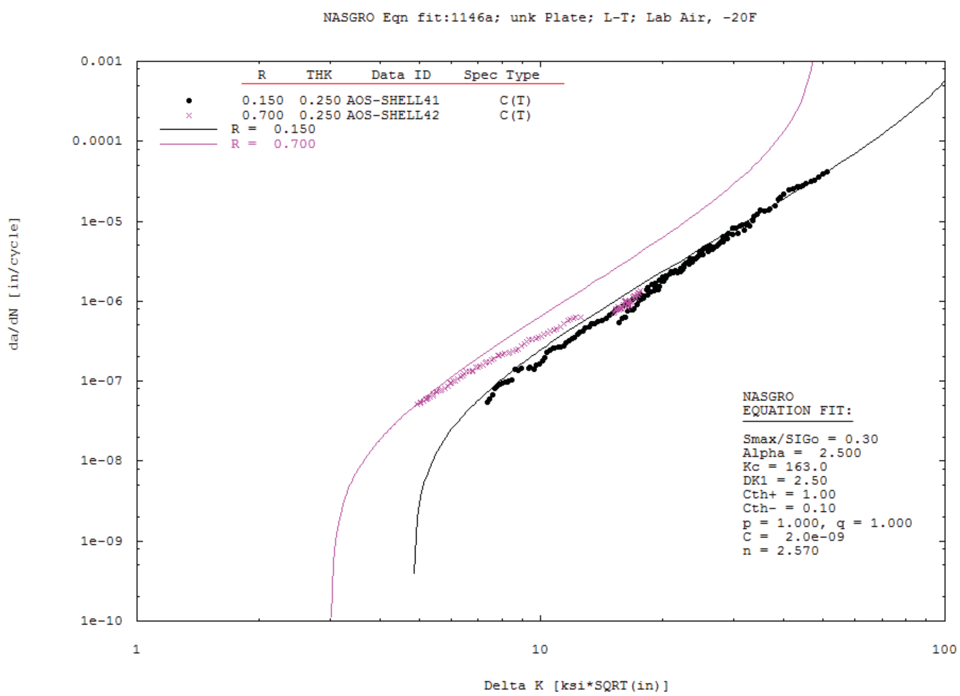


Figure 4-3. NASGRO Equation Fit for AO Smith 1146a Shell at -20^{o}F

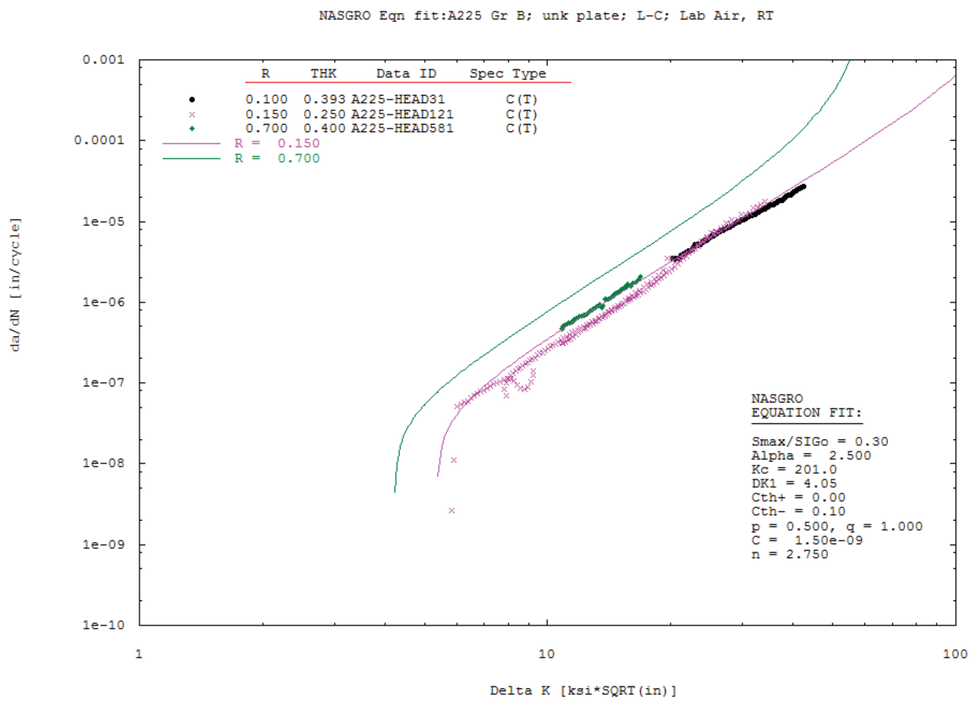


Figure 4-4. NASGRO Equation Fit for A-225 Gr B Head at Room Temperature

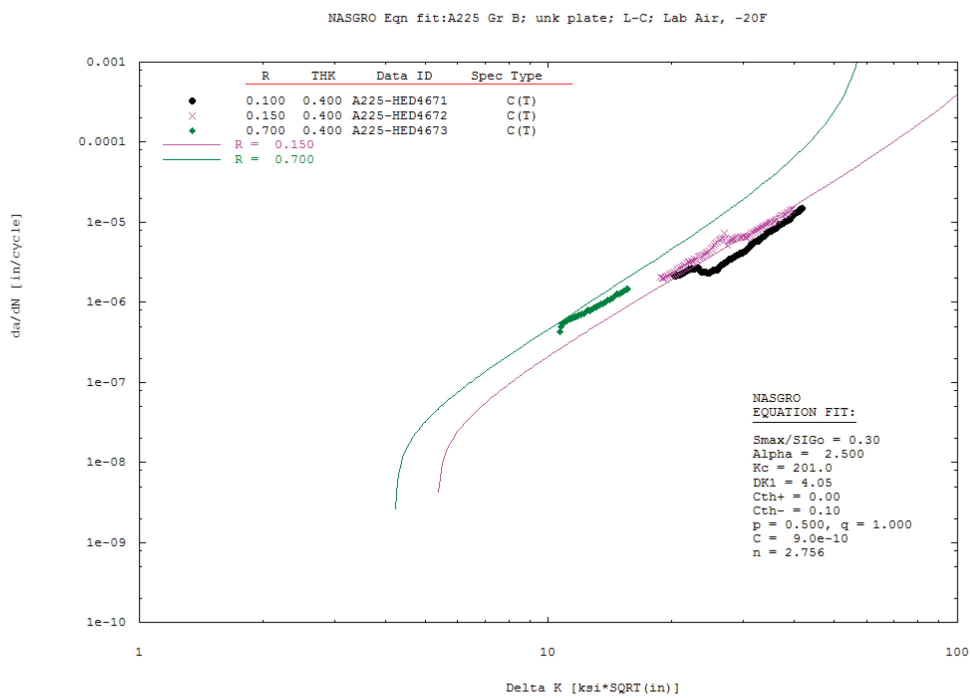


Figure 4-5. NASGRO Equation Fit for A-225 Gr B Head at -20°F

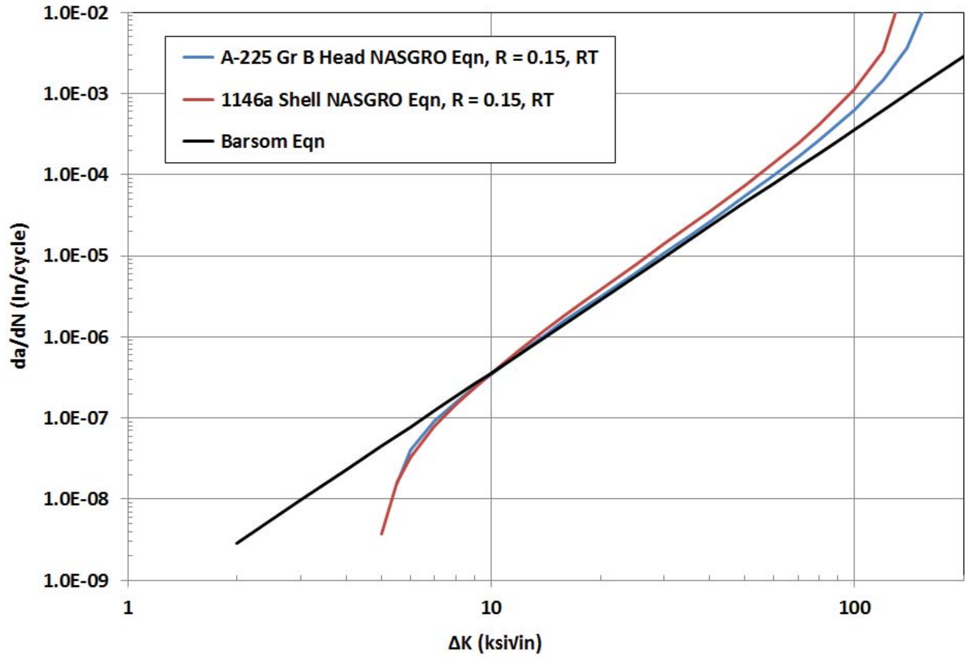


Figure 4-6. Comparison of NASGRO Equation Fits to Barsom Equation at R = 0.15 and Room Temperature

Table 4-1. NASGRO Equation Parameters Obtained for the Shell and Head Materials

NASGRO Equation Parameters	*Shell*		*Head*		*Notes (a)*
	AO Smith 1146a Plate		*A-225 Gr. B Plate*		
	RT	*-20°F*	*RT*	*-20°F*	
Crack Growth:					
C	2.00E-09	2.00E-09	1.50E-09	9.00E-10	
n	2.75	2.57	2.75	2.756	
p	1.00	1.00	0.50	0.50	
q	1.00	1.00	1.00	1.00	
DK1	2.50	2.50	4.05	4.05	
Cth	1.00	1.00	0.00	0.00	
Cth-	0.10	0.10	0.10	0.10	(b)
Alpha	2.50	2.50	2.50	2.50	
Smax/Sflow	0.30	0.30	0.30	0.30	(b)
a_0	0.0015	0.0015	0.0015	0.0015	(b)
Kth(s)/Kth(l)	0.2	0.2	0.2	0.2	(b)
Strength/Toughness:					
UTS (ksi)	119.1	121.9	79.3	84.1	
Yield (ksi)	82.2	90.9	52.5	59.1	
K_c (K_{Ie}, K_{Ic}) (ksi√in.)	170.0	163.0	201.0	201.0	(c)
A_k	1.0	1.0	1.0	1.0	(c)
B_k	0.0	0.0	0.0	0.0	(c)

Notes:

(a) Refer to Section 4.1 and the NASGRO manual [10] for details of the NASGRO equation and parameters.

(b) These parameters are typical NASGRO equation default values.

(c) The choice of B_k = 0.0 implies no dependence of toughness on thickness. In the absence of any other data, K_{Ic} and K_{Ie} are assumed to be equal to the value of K_c obtained in this test program. Setting B_k = 0.0 is generally a conservative policy, with the rationale being that you need toughness data as a function of thickness in order to justify use of the NASGRO toughness relationship as a function of thickness (Eqn 2.14 in the NASGRO manual). If you are using a true value of K_{Ic}, then setting B_k = 0.0 forces $K_c = K_{Ic}$ as a lower bound and is conservative. However, in this case, a "strictly valid" toughness value is not available, only a toughness for a given thickness. Therefore, to ensure the use of this value (only), B_k is set equal to zero and $K_c = K_{Ic} = K_{Ie}$.

4.5 NASGRO Equation Fits for the Head-to-Shell Weld and HAZ Materials

The fit to the NASGRO equation for the head-to-shell weld material at room temperature (RT) is shown in Figure 4-7 and the corresponding fit for the HAZ material is shown in Figure 4-8. There were no data obtained in the threshold region for these materials and the "fit" in this region was based on what was obtained at RT for the head in Figure 4-4. The NASGRO equation parameters for the weld and HAZ materials are summarized in Table 4-2.

4.6 Comparison of NASGRO Equation Fits for Base Metal and Weld Materials

The fits to the NASGRO equation for R = 0.15 at RT for the AO Smith 1146a shell, the A-225 Gr. B head and the weld and HAZ are plotted together for comparison in Figure 4-9. The Barsom Equation is also shown for reference. This figure shows that the fatigue growth rates in the weld and HAZ are generally below that of the base metals up to a ΔK of about 50 ksi√in. For higher ΔKs the fits somewhat converge; however, recognize that there were not any valid FCG data in this range. Therefore, using the base metal FCG data would appear to be conservative when compared to the weld/HAZ data at least for the majority of the crack growth curve.

4.7 Re-Evaluation of the FCG Analysis of the Notch in the Outer Shell

In Phase 1 of this effort [1], the NASGRO software was used to perform fatigue crack growth analyses of the notch in the AO Smith 1146a outer shell material in an attempt to predict the crack growth behavior that occurred at this location during the cyclic pressure tests on the vessel [12]. These analyses were repeated herein using the new Phase 2 shell material properties (the NASGRO equation fit shown in Figure 4-2 and the parameters listed in Table 4-1). The key difference between the two analyses was that a fracture toughness of 90 ksi√in. was used in the Phase 1 analysis whereas the toughness of 170 ksi√in. obtained in Phase 2 for the shell was used herein (see Table 3-6). The NASGRO material data input screens for each of these Phase 2 analyses are shown in Figures 4-10 and 4-11.

Table 4-3 compares the results of the crack growth analyses from the Phase 1 effort (i.e., Table 7-1 from Ref. [1]) with analyses using the new Phase 2 shell NASGRO equation fit and the higher toughness value. Also shown is the Barsom equation analysis using the higher toughness of 170 ksi√in. In each case $K_c = K_{Ic} = K_{Ie} = 170.0$ ksi√in. There is essentially no practical difference in the crack growth life up until the surface crack transitions to a through crack. However, once the surface crack transitions to a through crack, the crack remains stable for much longer (because of the higher toughness now being used: 170 vs 90 ksi√in.). This is not unexpected. Using the lower toughness value of 90 ksi√in., once the part through crack transitions to a through crack, the computed K is such that not much or no life is computed after transition (Phase 1). But now that a much higher toughness (from Phase 2) is being used, the through crack is calculated to grow stably for quite a while longer.

The failure analysis conducted in Phase 1 indicated that the crack from the notch grew through the thickness of the outer shell just before the testing was terminated [1]. The FCG analyses performed in Phase 2 indicate that after transition to a through crack, the crack in the shell would have continued to grow in a stable fashion as a through crack for many, many more cycles had the test continued.

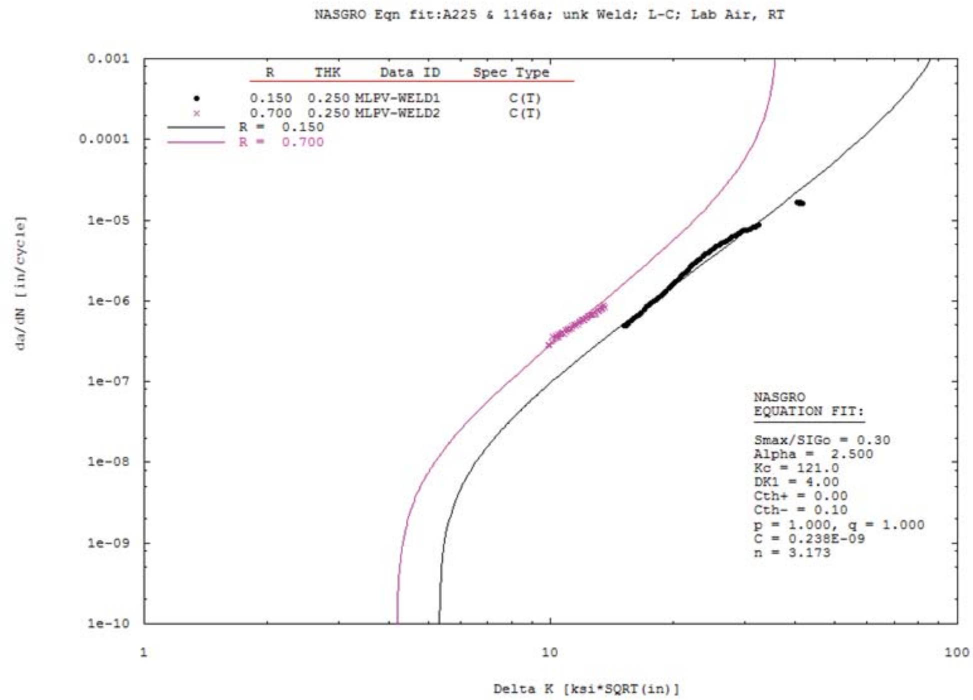


Figure 4-7. NASGRO Equation Fit for Head-to-Shell Weld Material at Room Temperature

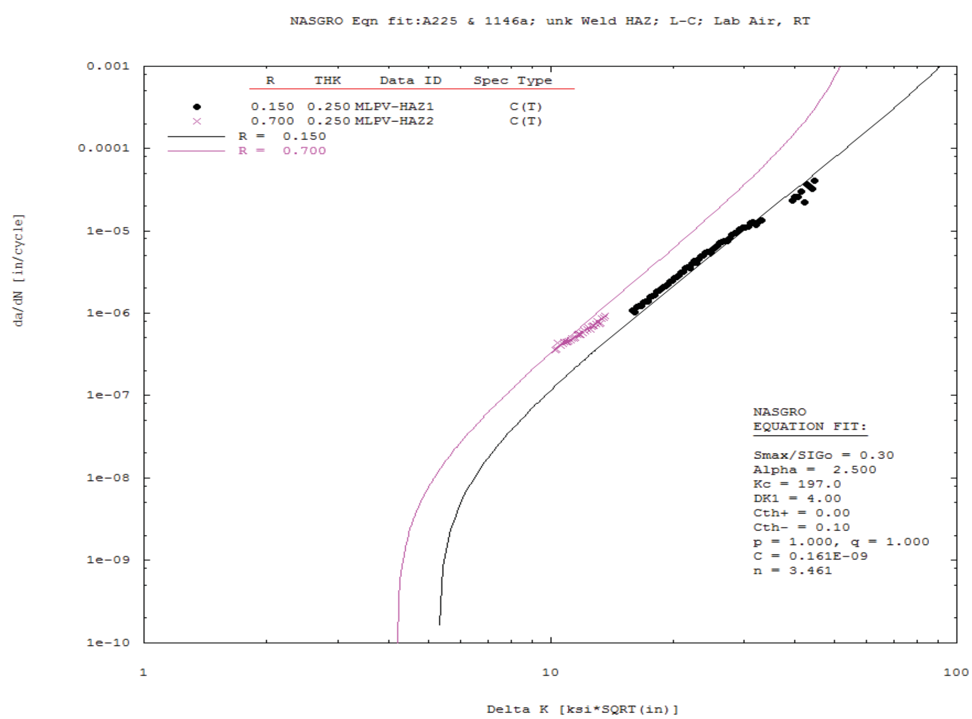


Figure 4-8. NASGRO Equation Fit for Head-to-Shell HAZ Material at Room Temperature

Table 4-2. NASGRO Equation Parameters Obtained for the Head-to-Shell Weld and HAZ Materials

NASGRO Equation Parameters	***Head-to-Shell***		***Notes (a)***
	Room Temperature		
	Weld	***HAZ***	
Crack Growth:			
C	2.38E-10	1.61E-10	
n	3.173	3.461	
p	1.00	1.00	
q	1.00	1.00	
DK1	4.0	4.0	
Cth	0.00	0.00	
Cth-	0.10	0.10	(b)
Alpha	2.50	2.50	
Smax/Sflow	0.30	0.30	(b)
a_0	0.0015	0.0015	(b)
Kth(s)/Kth(l)	0.2	0.2	(b)
Strength/Toughness:			
UTS (ksi)	79.3	84.1	
Yield (ksi)	52.5	59.1	
K_c (K_{Ie}, K_{Ic}) (ksi√in.)	121.0	197.0	(c)
A_k	1.0	1.0	(c)
B_k	0.0	0.0	(c)

Notes:

(a) Refer to Section 4.1 and the NASGRO manual [10] for details of the NASGRO equation and parameters.
(b) These parameters are typical NASGRO equation default values.
(c) The choice of B_k = 0.0 implies no dependence of toughness on thickness. In the absence of any other data, K_{Ic} and K_{Ie} are assumed to be equal to the value of K_c obtained in this test program. Setting B_k = 0.0 is generally a conservative policy, with the rationale being that you need toughness data as a function of thickness in order to justify use of the NASGRO toughness relationship as a function of thickness (Eqn 2.14 in the NASGRO manual). If you are using a true value of K_{Ic}, then setting B_k = 0.0 forces $K_c = K_{Ic}$ as a lower bound and is conservative. However, in this case, a “strictly valid” toughness value is not available, only a toughness for a given thickness. Therefore, to ensure the use of this value (only), B_k is set equal to zero and $K_c = K_{Ic} = K_{Ie}$.

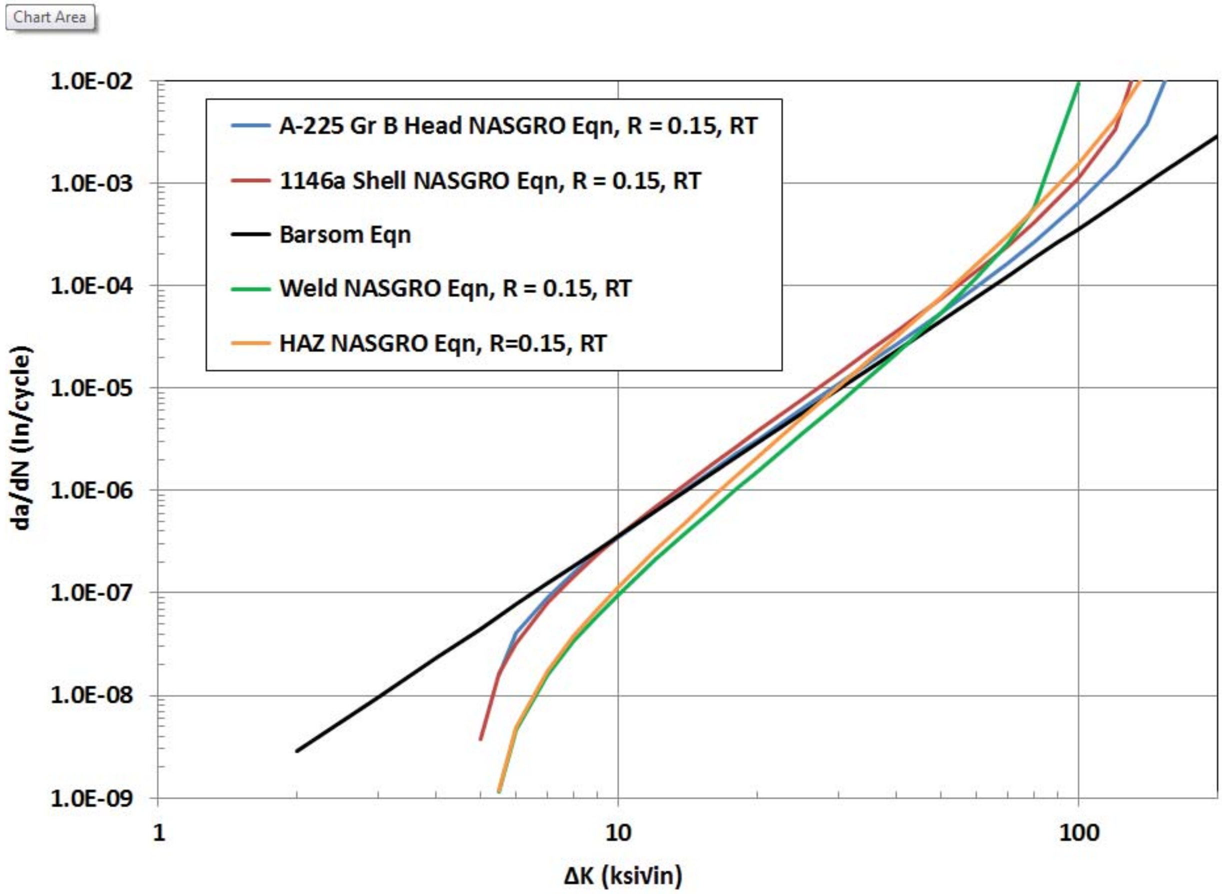


Figure 4-9. Comparison of NASGRO Equation Fits at R = 0.15 for Base Metal and Weld Materials

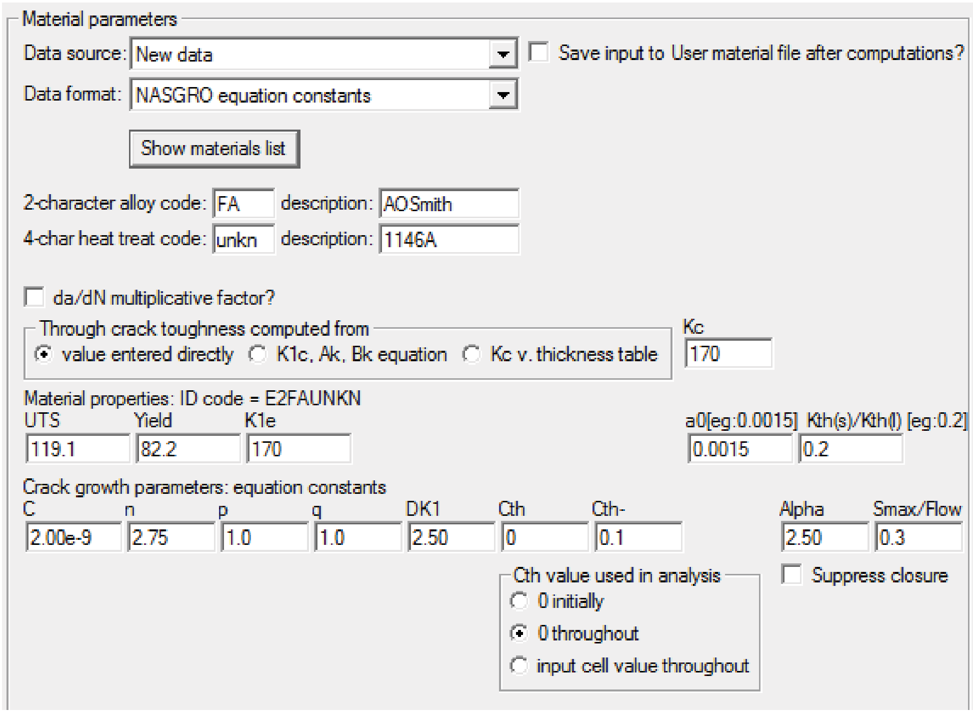


Figure 4-10. NASGRO Input Screen for NASGRO Equation for AOS 1146a Shell Material (RT)

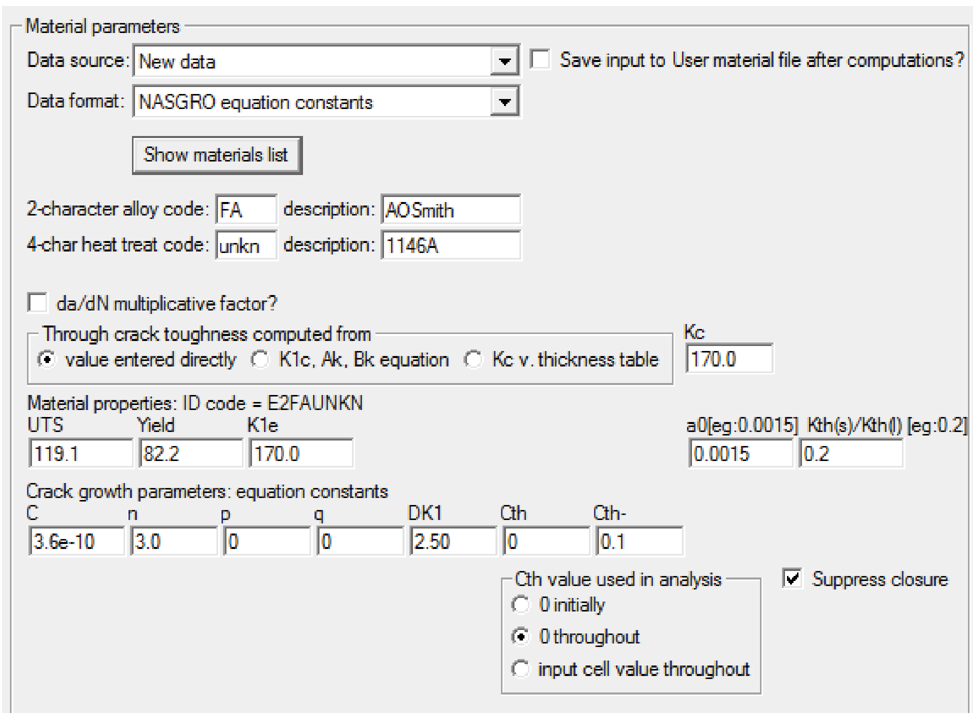


Figure 4-11. NASGRO Input Screen for Barsom Equation

Table 4-3. Comparison of Results of FCG Analyses between Phase 1 and Phase 2 (Phase 1 K_c = 90 ksi√in., Phase 2 K_c = 170 ksi√in.)

PHASE 1 FCG Material Model	Nthru (cycles)	Nf (cycles)	Nthru/Ntest	Nf/Ntest	Comments
NASGRO Equation	3,674 a = 0.260 c = 1.012	4,582 c = 1.353	0.78	0.98	surface crack transitioned to through crack before failure occurred
Barsom Equation	4,661 a = 0.257 c = 1.020	4,661 c = 1.020	0.99	0.99	surface crack failed by fracture, transitioned to through crack, and failed immediately

PHASE 2 FCG Material Model	Nthru (cycles)	Nf (cycles)	Nthru/Ntest	Nf/Ntest	Comments
NASGRO Equation	3,750 a = 0.260 c = 1.012	13,948 c = 4.193	0.80	2.98	surface crack transitioned to through crack before failure occurred
Barsom Equation	4,908 0.260 c = 1.021	23,413 c = 2.952	1.05	4.99	surface crack transitioned to through crack before failure occurred

Notes:

(1) Ntest is the total number of pressure cycles during the test (4,688).

(2) Nthru is the number of cycles to a through crack.

(3) Nf is the number of cylces at failure by fracture.

(4) Crack sizes are in units of inches.

5.0 SUMMARY AND CONCLUSIONS

NASA owns and operates several hundred multilayer pressure vessels, some of which are more than fifty years old. While available construction records show that generally good design, fabrication, and inspection processes were followed, these vessels are “non-Code” vessels and actual records do not exist for many of these vessels. To provide NASA with materials strength, fracture toughness and crack growth rate test results for use in remaining life calculations, a material property characterization effort has been performed in two phases. An initial characterization of the strength, fracture and fatigue crack growth properties was performed in Phase 1 [1], and, based on the results and recommendations of Phase 1, a more extensive material property characterization effort was developed in this Phase 2 effort.

The following results summarize the culmination of the findings for the material characterization of both Phase 1 and 2.

5.1 Vessel Construction

a. The body of the vessel was constructed from twelve layers (shells), with the inner (first) layer 3/8-inch thick and the remaining eleven layers each 1/4-inch thick for a total nominal wall thickness of 3.125 inches. The shells are fabricated from AO Smith 1146a, a proprietary, non-ASME material specification. During Phase 1, the shell material was found to satisfy the compositional requirements of ASTM A-299 and A-225, Gr. C.
b. Successive layers were formed into shells such that the inner diameter closely matched the outer diameter of the previous shell. With the exception of the outer-most layer, seam welds were ground flush with the shell diameter. The seam welds were staggered from layer to layer and seam welds penetrated into the inner shell about 25-30% of the shell thickness. All layers but the inner-most contained periodic arrays of weep holes, providing a leak path should the inner layer rupture.
c. The material orientations of the shells were different. The material rolling direction of the outer shell was oriented in the longitudinal direction of the vessel while the material rolling direction of the inner shell was oriented in the circumferential direction of the vessel. The orientation of the intermediate layers is unknown.
d. Monolithic, hemi-spherical heads, nominally 2.5 inches thick, were girth welded to the layered vessel body to form the pressure vessel. The heads were fabricated from A-225, Gr. B, a standard ASTM material.

5.2 AO Smith 1146a Shell Material Characterization

a. Tensile properties of the outer shell are indicative of a modest strength steel and only slight differences in tensile properties between RT and -20^{o}F were noted.
b. Hardness measurements indicated a significant difference in hardness between the inner and outer shells. This difference in hardness suggests a difference in tensile behavior between the inner and outer shells.
c. Only a slight decrease in CVN toughness between RT and -20^{o}F was noted. However, there was a significant dependence on material orientation, with CVN toughness in the T-L orientation of nominally half that in the L-T orientation.
d. There appears to be a difference in the CVN toughness between the inner and outer shell layers.

e. The CVN toughness of the outer shell seam weld HAZ was consistent with the outer shell material. The outer shell seam weld CVN toughness was significantly greater than and demonstrated less temperature dependence than the outer shell material.
f. Albeit based on very limited sample size, fracture toughness testing did not indicate any significant dependence of fracture toughness on temperature between RT and -20^{o}F for the shell material. Similar to CVN, a slight difference in toughness was noted between the inner and outer shell, though based on very limited test results.
g. FCG characterization of the shell material focused on the upper range of the da/dN-ΔK behavior. Only a slight dependence on R ratio, typical of steels, was noted.
h. Negligible dependence of FCG behavior on temperature between RT and -20^{o}F was noted. Similarly, only slight differences in FCG behavior between the outer shell in the T-L orientation and the inner shell in the L-T orientation were noted. Unfortunately, because FCG testing was performed with specimens of the same vessel orientation but not the same material orientation, no comparison between inner and outer shells with the same material orientation was possible.

5.3 A-225 Gr. B Head Material Characterization

a. Tensile properties of the A-225 Gr. B head material are indicative of a low-strength steel and only slight differences in tensile properties between RT and -20^{o}F were noted.
b. A significant drop in CVN from RT to -20^{o}F was noted. Although this testing was not designed to determine the ductile-to-brittle transition temperature, the data suggest a transition temperature might be somewhat above 0^{o}F in the T-L orientation and near 0^{o}F in the T-ST orientation.
c. CVN results indicated only a slight dependence on orientation between the T-L and T-ST orientations for the A-225 head material.
d. CVN results of the inner HAZ are very consistent with the base A-225 head material. The results of the head weld indicate a significant drop in CVN toughness between RT and 0^{o}F and no further reduction at -20^{o}F.
e. The fracture toughness results for the A-225 Gr. B head material were consistent with the CVN behavior. A noted drop in toughness was observed between RT and -20^{o}F.
f. The fracture toughness behavior of the HAZ was similar to the base head material. While the weld toughness was lower than the HAZ and base head material at RT, it was comparable in toughness at -20^{o}F.
g. The FCG behavior of the A-225 Gr. B head material at RT and -20^{o}F indicated minimal R-ratio dependence, typical of most steels. Negligible temperature dependence on the FCG behavior was noted.
h. Obtaining valid FCG behavior of the head weld and HAZ was challenging as specimens extended into the layered shell. Particularly at the higher crack driving forces, fatigue crack growth tended to occur out-of-plane toward the layered shell, which limited the extent of valid FCG behavior.

5.4 Fatigue Crack Growth Modeling

a. NASGRO equation fits were developed for the shell and head materials and represent the FCG behavior at room temperature and -20^{o}F. NASGRO equation fits were also developed for the head-to-shell weld and HAZ materials albeit only at room temperature. As discussed in Section 4.1, the fitting strategy adopted herein focused on representing the low R data

(0.10, 0.15) as a priority and consequently this results in a conservative fit to the high R data (0.7) in some cases[4].

b. As the main goal of the fatigue crack growth testing performed in this Phase 2 effort was to obtain data in the linear and upper regions of the FCG curve, the NASGRO equation fits for these materials in the threshold region must be considered approximate since they relied on only the limited amount of near-threshold data obtained in Phase 1.
c. The Barsom equation recommended in the Langley report [3] does *not* provide an upper bound for the shell or head materials. However, it does serve as a good approximation for the low R fatigue crack growth rate behavior in the Paris region.
d. The slopes (exponent, n) of the NASGRO equation fits to the weld and HAZ materials are larger (steeper) than those determined for the shell and head base metals. However, fatigue growth rates at $R = 0.15$ in the weld and HAZ are generally below those of the base metals up to a ΔK of about 50 ksi√in.
e. The failure analysis conducted in Phase 1 indicated that the crack from the notch grew through the thickness of the outer shell just before the testing was terminated [1]. The FCG analyses performed in Phase 2 indicate that after transition to a through crack, the crack in the shell would have continued to grow in a stable fashion as a through crack for many, many more cycles had the test [12] continued.

[4] NASGRO also has the capability to represent FCG data in tabular form instead of using the NASGRO equation and this feature can be used to overcome deficiencies in curve fitting. However, for these steels, there are not enough data (for multiple R values over a full range of ΔK) to use the tabular da/dN input approach.

6.0 RECOMMENDATIONS

Based on the culmination of results during both Phase 1 and Phase 2 of the material characterization effort for the multilayer pressure vessel, the following summarize the recommendations for future material characterization. These recommendations for additional characterization should be prioritized in concert with specific fitness-for-service analyses of these pressure vessels.

A considerable amount of pressure vessel shell and head material still remains from the sectioned vessel and is in storage at SwRI. While it cannot be retained indefinitely, these remnants can be used to extract samples for additional material testing as recommended below.

6.1 AO Smith 1146a Shell Material

With the apparent differences in some material properties between the inner and outer shells, chemical analysis should be performed on the inner shell to confirm its composition.

a. Given differences in shell plate material orientation in the construction of the vessel and the noted differences in properties in the in-plane orientations, the full characterization of tensile, CVN and toughness properties in the L-T and T-L orientations of both the inner and outer shell should be completed. Similarly, FCG testing should be performed on the outer shell in the L-T orientation and on the inner shell in the T-L orientation to more definitively characterize the FCG behavior of each shell.
b. Because only a limited number of valid fracture toughness results exist, additional toughness testing should be performed to develop a more statistically-robust measure of fracture toughness. Although obtaining valid toughness results will remain challenging given the material constraints, additional data will contribute to the robustness of the toughness that is currently based on very minimal sample sizes.
c. Additional FCG testing designed specifically to capture the lower ΔK, near-threshold behavior should be performed. If the previously mentioned additional FCG testing were to indicate no significant dependence on orientation or inner/outer shell, and due to the demonstrated lack of temperature dependence of the existing FCG behavior, this near-threshold FCG characterization could be limited to a single orientation and shell (inner or outer).
d. FCG characterization should be performed on the shell seam weld and HAZ. The properties of the seam weld are likely to be largely independent of shell material orientation and, as such, FCG characterization could be performed on either the inner or outer seam weld. However, properties of the HAZ are likely dependent on the base shell orientation. Thus, FCG characterization of the inner and outer seam weld HAZ should be considered.
e. The HAZ in the shell at the head weld has not been characterized in either of the Phase 1 or Phase 2 efforts. Although the vessel construct inhibits characterization of this HAZ, similar characterization of the HAZ should be performed as material limitations allow.
f. While the current material characterization has been limited to the AO Smith 1146a shell material extracted from a single vessel, layer-to-layer and vessel-to-vessel variation in material properties may exist. For example, some differences in mechanical behavior were noted between the inner and outer layers, which could be an indication of lot-to-lot variability. Variation in weld properties may also be significant as welding techniques may

vary from person to person and/or with the size of the vessel. Thus, additional mechanical characterization, in keeping with the specific fitness-for-service analyses, should be performed on multiple layers from the same vessel and/or layers from multiple vessels.

6.2 A-225 Gr. B Head Material

a. Tensile properties should be determined for the head weld and HAZ. Although it is anticipated to have minimal impact, the validity of the weld and HAZ FCG behavior should be re-assessed with the actual tensile properties as opposed to the base head tensile properties used in this effort.
b. Because only a limited number of valid fracture toughness results exist, additional toughness testing should be performed to develop a more statistically-robust measure of fracture toughness. Although obtaining valid toughness results will remain challenging given the material constraints, additional data will contribute to the robustness of the toughness that is currently based on very minimal sample sizes.
c. As the T-ST orientation is a primary loading and weak material orientation, fracture toughness and FCG testing in this orientation should also be considered.
d. Additional FCG testing designed specifically to capture the lower ΔK, near-threshold behavior of the head, weld and HAZ should be performed.
e. While the current material characterization has been limited to the A-225 Gr. B head material extracted from a single head, head-to-head and vessel-to-vessel variation in material properties may exist. Variation in weld properties may also be significant as welding techniques may vary from person to person and/or with the size of the vessel. Thus, additional mechanical characterization, in keeping with the specific fitness-for-service analyses, should be performed on both heads from the same vessel and/or heads from multiple vessels.

6.3 Fatigue Crack Growth Modeling

a. The material characterization data (tensile, fracture toughness and fatigue crack growth data) for these pressure vessel steels should be incorporated into the NASMAT database in NASGRO.
b. The curve fits (NASGRO equation parameters) to the FCG data for these materials should be incorporated into the library of NASGRO equation curve fits in the NASFLA module of NASGRO.
c. As warranted, the NASGRO equation fits should be reviewed and updated pending additional near-threshold FCG testing.
d. As mentioned in conclusion 5.4.b and elsewhere, the NASGRO equation fits for these materials in the threshold region must be considered as approximate estimates since they were based on the trend from only a small amount of near-threshold data. If one is concerned about using the fits as presented in the threshold region, one could eliminate the threshold downturn by choosing to set the exponent "*p*" in the NASGRO equation to zero. This would extend the linear region of the fit backwards as a straight line, effectively eliminating the threshold behavior in the model. This would be a conservative approach; however, in many cases it could be overly conservative.

7.0 REFERENCES

[1] J.W. Cardinal, C.F. Popelar and R.A. Page, "Multilayer Pressure Vessel Materials Testing and Analysis (Phase 1)," Final Report, Southwest Research Institute Project No. 18.17408, Rev. 1, October 2012.

[2] ASTM E8, "Standard Test Methods for Tension Testing of Metallic Materials," Vol. 03.01, ASTM International, West Conshohocken, PA, 2010.

[3] C.M. Hudson, J.C. Newman, Jr., and P.E. Lewis, NASA Technical Memorandum, "An Investigation of Fracture Toughness, Fatigue Crack Growth, and Impact Properties of Three Pressure Vessel Steels," NASA TM X-3316, NASA LaRC, Hampton, VA, December, 1975.

[4] ASTM E23, "Standard Test Methods for Notched Bar Impact Testing of Metallic Materials," Vol. 03.01, ASTM International, West Conshohocken, PA, 2010.

[5] Towers, O., "Testing Sub Size Charpy Specimens – Parts 1, 2 and 3," Metal Construction, March, April, and May, 1986.

[6] API RP 579/ASME FFS-1, Fitness-For-Service, API Recommended Practice 579, Second Edition, American Petroleum Institute, Washington, DC, June 2007.

[7] ASTM E561, "Standard Test Method for K-R Curve Determination," Vol. 03.01, ASTM International, West Conshohocken, PA, 2010.

[8] ASTM E1820, "Standard Test Method for Measurement of Fracture Toughness," Vol. 03.01, ASTM International, West Conshohocken, PA, 2010.

[9] ASTM E647, "Standard Test Method for Measurement of Fatigue Crack Growth Rates," Vol. 03.01, ASTM International, West Conshohocken, PA, 2010.

[10] NASGRO® Fracture Mechanics and Fatigue Crack Growth Analysis Software, Version 7.0, Southwest Research Institute and NASA Johnson Space Center, November 2012.

[11] Barsom, J.M. and Rolfe, S.T., *Fracture and Fatigue Control in Structures: Applications of Fracture Mechanics*, Third Edition, ASTM, West Conshohocken, PA, 1999.

[12] Ziola, S.M., "Cyclic Crack Growth Testing of an A.O. Smith Multilayer Pressure Vessel with Modal Acoustic Emission Monitoring and Data Assessment," Final Report, Digital Wave Corporation, November 13, 2012.

APPENDIX A: AO SMITH 1146A SHELL MATERIAL CHARACTERIZATION RESULTS

AO SMITH 1146a

OUTER LAYER

TENSILE RESULTS

-20°F

Exova
194 Internationale Boulevard
Glendale Heights
Illinois
USA
60139

T: +1 (630) 221-0385
F: +1 (630) 221-0796
E: sales@exova.com
W: www.exova.com

Exova

Test Certificate

Southwest Research Institute
P.O. Drawer 28510
6220 Culebra Rd
San Antonio, TX
78228-0510

Attn: Fassett Hickey

REF No T 313096 : Issue 2
Page 1 of 1
Ord No F65327IR
Date Tested 07/25/13
Date Printed 07/25/13
Date Received 07/10/13

Item - TENSILE TESTING AT -20F OF A SAMPLE IDENTIFIED AS SHELL

Specification - Not Applicable

Tensile Test - ASTM E8 -11

	Dimensions [in]	Area [in^2]	GL [in]	0.20%YS [psi]	UTS [psi]	%El	%RA	Comments
001:Tangential	0.1615	0.0205	0.64	89100	121700	20.3	49.3	at -20F
002:Tangential	0.1600	0.0201	0.64	92600	122200	25.0	45.6	at -20F
003:Tangential	0.1600	0.0201	0.64	91100	121700	23.4	45.6	at -20F

Elongation determined after fracture unless otherwise indicated.

Certificate Comments

Specimens 2 and 3 fractured outside the middle half of the gauge.

This document replaces Issue 1 of the same number, which has been withdrawn. It contains supplementary information to that presented in the previous issue- two additional tests were included.

TM Tonon

Tami M Tonon
Operations Mgr/Sr Metallurgist
For and on behalf of
Exova Inc.

ID	Material	Type	Orientation	Temp (°F)	CVN[a] (ft-lbs)	Lat. Expansion (mils)[b,c]
CVN-I-B-1	Base	Inner	L-T	73	72	53
CVN-I-B-2	Base	Inner	L-T	73	70	57
CVN-I-B-3	Base	Inner	L-T	73	74	56
CNV-I-B-8	Base	Inner	L-T	0	72	57
CVN-I-B-7	Base	Inner	L-T	0	70	52
CVN-I-B-9	Base	Inner	L-T	0	70	55
CVN-I-B-4	Base	Inner	L-T	-20	64	53
CVN-I-B-5	Base	Inner	L-T	-20	60	42
CVN-I-B-6	Base	Inner	L-T	-20	58	44
CVN-I-B-10	Base	Inner	T-L	73	28	30
CVN-I-B-11	Base	Inner	T-L	73	28	27
CVN-I-B-12	Base	Inner	T-L	73	30	30
CVN-I-B-16	Base	Inner	T-L	0	30	29
CVN-I-B-17	Base	Inner	T-L	0	30	24
CVN-I-B-18	Base	Inner	T-L	0	32	27
CVN-I-B-13	Base	Inner	T-L	-20	26	21
CVN-I-B-14	Base	Inner	T-L	-20	30	25
CVN-I-B-15	Base	Inner	T-L	-20	28	28
CVN-O-B-1	Base	Outer	T-L	73	12	0
CVN-O-B-2	Base	Outer	T-L	-20	8	0
CVN-O-B-3	Base	Outer	T-L	-20	10	0
CVN-O-H-1	HAZ	Outer	T-L	73	18	14
CVN-O-H-2	HAZ	Outer	T-L	73	24	20
CVN-O-H-3	HAZ	Outer	T-L	73	18	8
CNV-O-H-8	HAZ	Outer	T-L	0	16	8
CVN-O-H-7	HAZ	Outer	T-L	0	16	8
CVN-O-H-9	HAZ	Outer	T-L	0	16	6
CVN-O-H-4	HAZ	Outer	T-L	-20	12	9
CVN-O-H-5	HAZ	Outer	T-L	-20	12	5
CVN-O-H-6	HAZ	Outer	T-L	-20	14	11
CVN-O-W-1	Weld	Outer	C-L	73	58	46
CVN-O-W-2	Weld	Outer	C-L	73	56	30
CVN-O-W-3	Weld	Outer	C-L	73	60	50
CVN-O-W-7	Weld	Outer	C-L	0	52	20
CVN-O-W-8	Weld	Outer	C-L	0	52	39
CVN-O-W-9	Weld	Outer	C-L	0	54	45
CVN-0-W-6	Weld	Outer	C-L	-20	48	41
CVN-O-W-4	Weld	Outer	C-L	-20	50	38
CVN-O-W-5	Weld	Outer	C-L	-20	50	37

a CVN reported as full-size equivalent

b Lateral expansion in 1000th of an inch

c SwRI measurements

TESTING CERT 621-01 & 621-02

Materials Testing Laboratory

CERTIFICATION

Page IM1 of 2

WMT&R Report No. 3-55962
P.O. No. F58154BT
WMT&R Quote No. QN121622 Rev.1

March 17, 2013
Southwest Research
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78238

Attention: Carl Popelar

Subject: All processes, performed upon the material as received, were conducted at WMT&R, Inc. in accordance with the WMT&R Quality Assurance Manual, Rev. 11, dated 12/03/2008. The following tests were performed on this order: FATIGUE, FRACTURE and IMPACT

IMPACT RESULTS: ASTM E23-12c

No Requirements

MATERIAL: Steel

SAMPLE TYPE: Charpy V-Notch **DISPOSITION: Report**

SID	TestLog Number	Sample Size	Temp. °F	Energy ft-lbs	A\U\R
CVN-O-W-4	S41349	1/2 Subsize	-20	25	Report
CVN-O-W-5	S41350	1/2 Subsize	-20	25	Report
CVN-O-W-6	S41351	1/2 Subsize	-20	24	Report
CVN-O-H-4	S41361	1/2 Subsize	-20	6	Report
CVN-O-H-5	S41362	1/2 Subsize	-20	6	Report
CVN-O-H-6	S41363	1/2 Subsize	-20	7	Report
CVN-I-B-4	S41370	1/2 Subsize	-20	32	Report
CVN-I-B-5	S41371	1/2 Subsize	-20	30	Report
CVN-I-B-6	S41372	1/2 Subsize	-20	29	Report
CVN-I-B-13	S41379	1/2 Subsize	-20	13	Report
CVN-I-B-14	S41380	1/2 Subsize	-20	15	Report
CVN-I-B-15	S41381	1/2 Subsize	-20	14	Report

Roy E. Starr \ Matt J. Wojton
___ Technical Services Manager___ Tensile Foreperson

March 17, 2013

ACCREDITED
TESTING CERT 621-01 & 621-02

Accredited Nadcap Materials Testing Laboratory

CERTIFICATION

March 17, 2013
Southwest Research

Page IM2 of 2
WMT&R Report No. 3-55962
P.O. No. F58154BT

IMPACT RESULTS: ASTM E23-12c
No Requirements
MATERIAL: Steel
SAMPLE TYPE: Charpy V-Notch **DISPOSITION: Report**

SID	TestLog Number	Sample Size	Temp. °F	Energy ft-lbs	A\U\R
CVN-O-W-1	S41346	1/2 Subsize	73	29	Report
CVN-O-W-2	S41347	1/2 Subsize	73	28	Report
CVN-O-W-3	S41348	1/2 Subsize	73	30	Report
CVN-O-H-1	S41358	1/2 Subsize	73	9	Report
CVN-O-H-2	S41359	1/2 Subsize	73	12	Report
CVN-O-H-3	S41360	1/2 Subsize	73	9	Report
CVN-I-B-1	S41367	1/2 Subsize	73	36	Report
CVN-I-B-2	S41368	1/2 Subsize	73	35	Report
CVN-I-B-3	S41369	1/2 Subsize	73	37	Report
CVN-I-B-10	S41376	1/2 Subsize	73	14	Report
CVN-I-B-11	S41377	1/2 Subsize	73	14	Report
CVN-I-B-12	S41378	1/2 Subsize	73	15	Report

UNOFFICIAL DATA
NOT APPROVED

Roy E. Starr \ Matt J. Wojton
___ Technical Services Manager___ Tensile Foreperson

March 17, 2013

AO SMITH 1146a
PLANE STRESS FRACTURE TOUGHNESS

ID	*Layer*	*Orientation*	*Temp*	*Result*
KC-I-B-1	Inner	L-T	RT	Invalid
KC-I-B-2				
KC-I-B-3				
KC-O-B-1	Outer	L-T	RT	Invalid
KC-O-B-2				
KC-O-B-3				
KC-I-B-4	Inner	L-T	-20°F	Invalid
KC-I-B-5				
KC-I-B-6				

Westmoreland Mechanical Testing & Research, Inc.
P.O.Box 388; 221 Westmoreland Drive
Youngstown, PA 15696-0388 U.S.A.
Telephone: 724-537-3131 Fax: 724-537-3151
Website: www.wmtr.com E-Mail: admin@wmtr.com
WMT&R is a technical leader in the material testing industry.

Accredited Nadcap Materials Testing Laboratory

April 12, 2013

Southwest Research
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78238

WMT&R Report No. 3-55962
P.O. No. F58154BT
WMT&R Quote No. QN121622 Rev. 1

Attention: Carl Popelar

Subject: Six (6) 0.625-C(T) Compact Tension Fracture Toughness Specimens for R-curve Testing

Introduction: Six (6) specimens were machined, precracked, and tested at +75°F. The alloy is Steel. All yield strength data used in calculations was customer supplied.

The following tests were performed on this order: FATIGUE, FRACTURE, and IMPACT

Results:

Specimen ID	Kc (Pmax) KSI (In.)$^{1/2}$	K_{app} KSI (In.)$^{1/2}$	Valid/ Invalid
KC-I-B-1	175.3	70.1	Invalid
KC-I-B-2	185.5	71.3	Invalid
KC-I-B-3	171.7	72.1	Invalid
KC-O-B-1	256.6	122.1	Invalid
KC-O-B-2	296.1	120.9	Invalid
KC-O-B-3	258.1	121.2	Invalid

Reference: ASTM E561-08e1.
All Data and Chart Information Enclosed.
If you have any questions, please contact Mr. Thomas S. Fedor at (724) 537-3131.

Testing Specialists for Aerospace, Automotive, and Material Testing Fields
Locations in Youngstown, PA U.S.A. ~ Tel. (724) 537-3131 and
Banbury, Oxon U.K. ~ Tel. +44 (0) 1295 261211

Thomas Fedor
T. Fedor/Fracture/Fatigue Manager

KC-I-B-1

AO SMITH 1146a

INNER LAYER

PLANE STRESS FRACTURE TOUGHNESS

L-T

RT

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

COMPACT TENSION FRACTURE TOUGHNESS TEST REPORT (ASTM E561-08e1)

PRELIMINARY INFORMATION :

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SID : KC-I-B-1

MATERIAL SPEC : N/A

WMT&R NO. : 3-55962
ALLOY & TEMPER : Steel-N/A
PRODUCT THICKNESS: N/A
TEST TYPE : 0.625-C(T) N/A
TEST DATE : 04-11-13
TEST YIELD STR.(YS2) : 82.2 ksi

TESTLOG : S41398
PRODUCT: N/A

TEST PLANE : N/A
TEST TEMPERATURE : 75°F
MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS :

THICKNESS (*B*)	= 0.219 in.
WIDTH (*W*)	= 1.252 in.
ORIGINAL CRACK LENGTH (*aN*)	= 0.348 in.
EFFECTIVE CRACK LENGTH (*ae*)	= 0.819 in.
PHYSICAL CRACK LENGTH (*ap*)	= 0.609 in.
TOTAL CRACK LENGTH (*ao*)	= 0.473 in.
TYPE OF CRACK	FATIGUE PRECRACKED

CRACK LENGTHS:

R-SURFACE	= 0.112 in.
R-CENTER	= 0.126 in.
MID-CENTER	= 0.127 in.
L-CENTER	= 0.123 in.
L-SURFACE	= 0.108 in.

FATIGUE PRECRACKING SUMMARY

MAXIMUM FATIGUE LOAD	= 657 lbs	LOAD RATIO	= 0.1
KF (MAX)	= 18.4 ksi(sqrt. in.)	CYCLES	= 104589
FATIGUE CRACKING DATE			

TEST RESULTS :

MAXIMUM LOAD (Pmax)	= 2501 lbs	DEPARTURE LOAD (PDL)	= 810 lbs
STRESS INTENSITY (Kc)	= 175.3 ksi(sqrt. in.)	STRESS INTENSITY AT PD	= 22.7 ksi(sqrt. in.)
DISPLACEMENT AT Pmax	= 0.0481 in.	DISPLACEMENT AT PD	= 0.0043 in.
NET SECTION STRESS (SIGMA)	= 172.0 ksi	K-RATE	= 1.77 ksi(sqrt. in.)/s
Kapp	= 70.1 ksi(sqrt. in.)	EFFECTIVE MODULUS	= 28.5 Msi
r_y	= 0.2104 in.	E/E_{EFF}	= 1.05

VALIDITY CHECKS PER ASTM E561-08e1

1. (E561 8.6.2) THE FATIGUE PRECRACK SHALL EXTEND FROM THE STARTER NOTCH BY >= 0.05 in.	VALID
2. (E561 8.6.2) THE FATIGUE PRECRACK MUST EXTEND BEYOND THE ENVELOPE.	VALID
3. (E561 8.6.3) THE ORIGINAL CRACK SIZE, ao, SHALL BE WITHIN THE RANGE OF 0.35 TO 0.55W. Original Crack Size (ao) = 0.473 in. 0.432 in < Original Crack Size < 0.695 in	VALID
4. (E561 9.5) APPLY A DISPLACEMENT RATE DURING THE INITIAL LINEAR PORTION OF THE FORCE-CMOD CURVE THAT WILL RESULT IN A CHANGE IN K BETWEEN 0.5 AND 2.5 KSI. SQ.RT.IN/S. = 1.77 ksi(sqrt. in.)/s	VALID
5. (E561 8.6.5) THE REMAINING UNCRACKED LIGAMENT (W-ap) MUST BE > 4/π(KR/YS)^2. (W -ap) = 0.643 in. Limit = 1.686 in.	INVALID

TEST IS INVALID: * KC = 175.3 ksi(sqrt. in.)**

***** KAPP = 70.1 ksi(sqrt. in.)**

STEVEN ZASADNY - JD ROSSI - TOM FEDOR - KEN GALLO

Westmoreland Mechanical Testing & Research, Inc.

R-Curve Graph

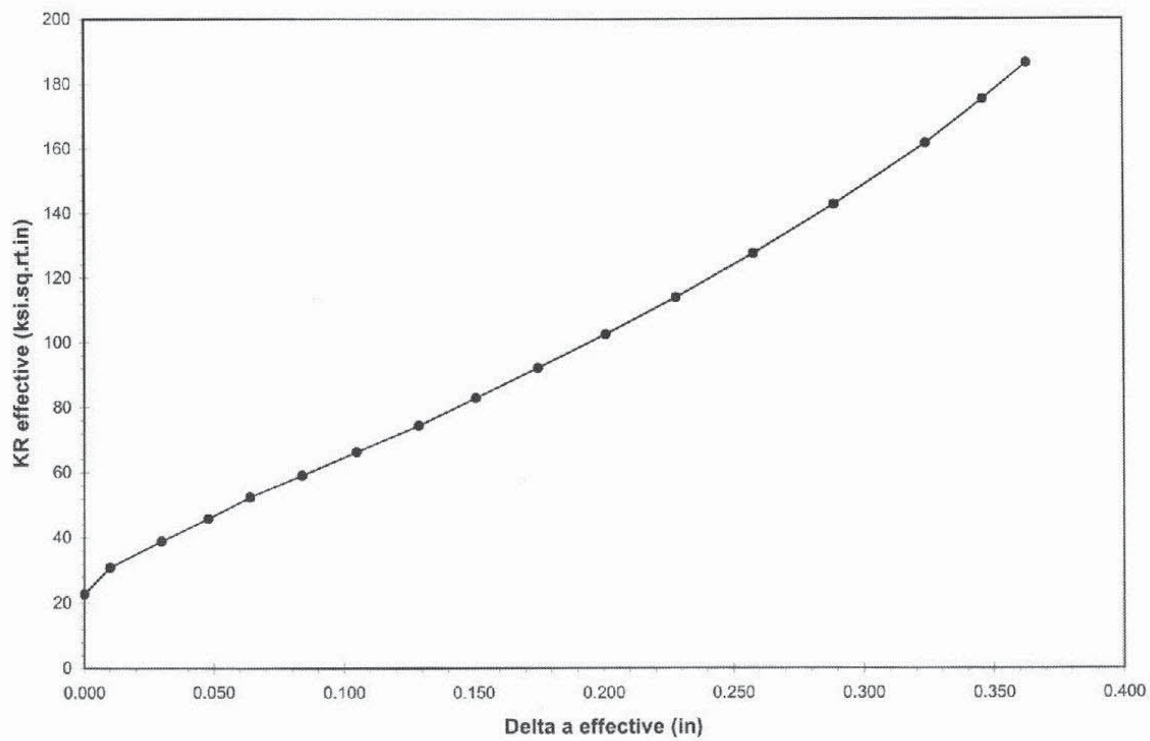
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE NO. : QN121622 REV.1

TESTLOG : S41398
TEST DATE : 04-11-13

ALLOY & TEMPER : Steel-N/A

SID : KC-I-B-1



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WESTMORELAND MECHANICAL TESTING & RESEARCH
Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

COMPACT TENSION FRACTURE TOUGHNESS R-CURVE TABULAR DATA (ASTM E561-08e1)

CUSTOMER : SOUTHWEST RESEARCH
SID : KC-I-B-1

WMT&R NO. : 3-55962
TESTLOG : S41398

Secant (%)	Force (lbs)	CMOD (in)	a_{eff} (in)	Δa_{eff} (in)	K_{Reff} (ksi.sqrtin)	a_{phys} (in)	Δa_{phys} (in)	K_{Rphys} (ksi.sqrtin)	r_Y	σ_{net} (ksi)	K_{app} (ksi.sqrtin)	$R_v = 8 * R_y/(W-a_p)$	VALID
0.0	810	0.0043	0.473	0.000	22.7	0.461	0.000	22.1	0.0116	35.1	22.7	0.12	0
5.0	1079	0.0059	0.483	0.010	30.9	0.462	0.001	29.6	0.0206	46.8	30.2	0.21	0
10.0	1304	0.0076	0.503	0.030	38.9	0.472	0.011	36.5	0.0313	58.3	36.5	0.32	0
15.0	1476	0.0091	0.521	0.048	45.8	0.480	0.019	42.0	0.0414	67.5	41.4	0.43	0
20.0	1631	0.0106	0.537	0.064	52.4	0.485	0.024	46.9	0.0518	75.7	45.7	0.54	0
25.0	1760	0.0122	0.557	0.084	59.0	0.494	0.033	51.5	0.0626	83.9	49.3	0.66	0
30.0	1884	0.0140	0.578	0.105	66.3	0.503	0.042	56.2	0.0746	92.2	52.8	0.80	0
35.0	2000	0.0161	0.602	0.129	74.4	0.514	0.053	61.1	0.0879	101.2	56.0	0.95	0
40.0	2113	0.0184	0.624	0.151	82.9	0.522	0.061	65.7	0.1017	109.6	59.2	1.11	1
45.0	2213	0.0210	0.648	0.175	92.2	0.532	0.071	70.3	0.1162	118.4	62.0	1.29	1
50.0	2302	0.0240	0.674	0.201	102.6	0.542	0.081	74.7	0.1317	127.0	64.5	1.48	1
55.0	2375	0.0275	0.701	0.228	114.0	0.554	0.093	79.1	0.1473	136.1	66.6	1.69	1
60.0	2435	0.0318	0.731	0.258	127.5	0.567	0.106	83.5	0.1642	145.5	68.2	1.92	1
65.0	2476	0.0369	0.762	0.289	142.8	0.581	0.120	87.7	0.1811	154.9	69.4	2.16	1
70.0	2494	0.0434	0.797	0.324	161.6	0.598	0.137	91.9	0.1989	165.2	69.9	2.43	1
72.9P	2501	0.0481	0.819	0.346	175.3	0.609	0.148	94.6	0.2104	172.0	70.1	2.62	1
75.0	2496	0.0521	0.836	0.363	186.5	0.617	0.156	96.2	0.2186	176.4	70.0	2.75	1

a_{eff} - effective crack length (in)
Δa_{eff} - change in a-effective (in)
K_{Reff} - incremental r-curve stress intensity values based on effective crack length (ksi.sqrtin)
a_{phys} - physical crack Length (in)
Δa_{phys} - change in a-physical (in)
K_{Rphys} - incremental r-curve stress Intensity values based on physical crack length (ksi.sqrtin)
r_Y - plastic zone adjustment (in)
σ_{net} - net section stress (ksi)
K_{app} - apparent stress intensity (ksi.sqrtin)
R_v - validity check 8 * ry / (w - ap) < or = 1.0

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'0' indicates a valid check '1' indicates an invalid check

KC-I-B-2

AO SMITH 1146a

INNER LAYER

PLANE STRESS FRACTURE TOUGHNESS

L-T

RT

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

COMPACT TENSION FRACTURE TOUGHNESS TEST REPORT (ASTM E561-08e1)

PRELIMINARY INFORMATION :

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SID : KC-I-B-2 MATERIAL SPEC : N/A

WMT&R NO. : 3-55962 TESTLOG : S41399
ALLOY & TEMPER : Steel-N/A PRODUCT: N/A
PRODUCT THICKNESS: N/A
TEST TYPE : 0.625-C(T) N/A TEST PLANE : N/A
TEST DATE : 04-11-13 TEST TEMPERATURE : 75°F
TEST YIELD STR.(YS2) : 82.2 ksi MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS :

THICKNESS (*B*)	= 0.219 in.	**CRACK LENGTHS:**	
WIDTH (*W*)	= 1.252 in.	R-SURFACE	= 0.122 in.
ORIGINAL CRACK LENGTH (*aN*)	= 0.350 in.	R-CENTER	= 0.130 in.
EFFECTIVE CRACK LENGTH (*ae*)	= 0.831 in.	MID-CENTER	= 0.128 in.
PHYSICAL CRACK LENGTH (*ap*)	= 0.612 in.	L-CENTER	= 0.121 in.
TOTAL CRACK LENGTH (*ao*)	= 0.476 in.	L-SURFACE	= 0.105 in.
TYPE OF CRACK	FATIGUE PRECRACKED		

FATIGUE PRECRACKING SUMMARY

MAXIMUM FATIGUE LOAD	= 631 lbs	LOAD RATIO	= 0.1
KF (MAX)	= 17.8 ksi(sqrt. in.)	CYCLES	= 106737
FATIGUE CRACKING DATE			

TEST RESULTS :

MAXIMUM LOAD (Pmax)	= 2530 lbs	DEPARTURE LOAD (PDL)	= 882 lbs
STRESS INTENSITY (Kc)	= 185.5 ksi(sqrt. in.)	STRESS INTENSITY AT PD	= 24.9 ksi(sqrt. in.)
DISPLACEMENT AT Pmax	= 0.0522 in.	DISPLACEMENT AT PD	= 0.0048 in.
NET SECTION STRESS (SIGMA)	= 175.8 ksi	K-RATE	= 1.74 ksi(sqrt. in.)/s
Kapp	= 71.3 ksi(sqrt. in.)	EFFECTIVE MODULUS	= 28.1 Msi
r_y	= 0.2189 in.	E/E_{EFF}	= 1.07

VALIDITY CHECKS PER ASTM E561-08e1

1. (E561 8.6.2) THE FATIGUE PRECRACK SHALL EXTEND FROM THE STARTER NOTCH BY >= 0.05 in. VALID
2. (E561 8.6.2) THE FATIGUE PRECRACK MUST EXTEND BEYOND THE ENVELOPE. VALID
3. (E561 8.6.3) THE ORIGINAL CRACK SIZE, ao, SHALL BE WITHIN THE RANGE OF 0.35 TO 0.55W. VALID
   Original Crack Size (ao) = 0.476 in. 0.432 in < Original Crack Size < 0.695 in
4. (E561 9.5) APPLY A DISPLACEMENT RATE DURING THE INITIAL LINEAR PORTION OF THE FORCE-CMOD CURVE THAT WILL RESULT IN A CHANGE IN K BETWEEN 0.5 AND 2.5 KSI. SQ.RT.IN/S. VALID
   = 1.74 ksi(sqrt. in.)/s
5. (E561 8.6.5) THE REMAINING UNCRACKED LIGAMENT (W-ap) MUST BE > 4/π(KR/YS)^2. INVALID
   (W -ap) = 0.640 in. Limit = 1.751 in.

TEST IS INVALID: * KC = 185.5 ksi(sqrt. in.)**
***** KAPP = 71.3 ksi(sqrt. in.)**

STEVEN ZASADNY - JD ROSSI - TOM FEDOR - KEN GALLO

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Westmoreland Mechanical Testing & Research, Inc.

R-Curve Graph

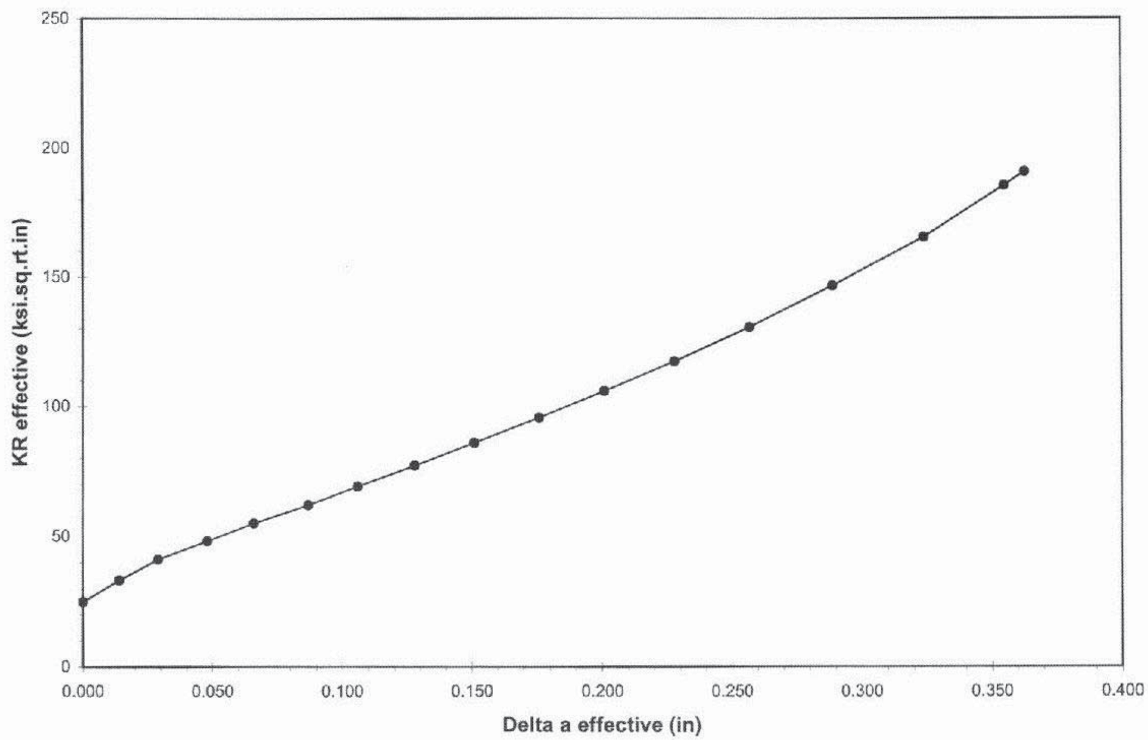
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE NO. : QN121622 REV.1

TESTLOG : S41399
TEST DATE : 04-11-13

ALLOY & TEMPER : Steel-N/A

SID : KC-I-B-2



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COMPACT TENSION FRACTURE TOUGHNESS R-CURVE TABULAR DATA (ASTM E561-08e1)

CUSTOMER : SOUTHWEST RESEARCH WMT&R NO. : 3-55962

SID : KC-I-B-2 TESTLOG : S41399

Secant (%)	Force (lbs)	CMOD (in)	a_{eff} (in)	Δa_{eff} (in)	K_{Reff} (ksi.sqrtin)	a_{phys} (in)	Δa_{phys} (in)	K_{Rphys} (ksi.sqrtin)	r_Y	σ_{net} (ksi)	K_{app} (ksi.sqrtin)	$R_v = 8 * R_y/(W-a_p)$	VALID
0.0	882	0.0048	0.476	0.000	24.9	0.462	0.000	24.2	0.0138	38.3	24.9	0.14	0
5.0	1142	0.0065	0.490	0.014	33.2	0.467	0.005	31.6	0.0235	50.3	32.2	0.24	0
10.0	1376	0.0082	0.505	0.029	41.2	0.470	0.008	38.3	0.0346	61.1	38.8	0.35	0
15.0	1549	0.0098	0.524	0.048	48.3	0.479	0.017	44.0	0.0454	70.6	43.7	0.47	0
20.0	1698	0.0114	0.542	0.066	55.1	0.486	0.024	48.9	0.0562	79.0	47.9	0.59	0
25.0	1825	0.0131	0.563	0.087	62.1	0.495	0.033	53.6	0.0676	87.2	51.5	0.71	0
30.0	1946	0.0149	0.582	0.106	69.1	0.503	0.041	58.1	0.0793	95.3	54.9	0.85	0
35.0	2064	0.0170	0.604	0.128	77.1	0.511	0.049	62.6	0.0926	103.5	58.2	1.00	0
40.0	2174	0.0194	0.627	0.151	85.9	0.520	0.058	67.3	0.1067	112.0	61.3	1.17	1
45.0	2273	0.0222	0.652	0.176	95.6	0.530	0.068	71.9	0.1218	120.8	64.1	1.35	1
50.0	2357	0.0253	0.677	0.201	105.9	0.540	0.078	76.2	0.1368	129.2	66.5	1.54	1
55.0	2423	0.0289	0.704	0.228	117.3	0.552	0.090	80.4	0.1522	138.0	68.3	1.74	1
60.0	2477	0.0332	0.733	0.257	130.5	0.565	0.103	84.6	0.1683	147.1	69.9	1.96	1
65.0	2519	0.0386	0.765	0.289	146.7	0.579	0.117	88.8	0.1859	156.6	71.0	2.21	1
70.0	2526	0.0452	0.800	0.324	165.4	0.597	0.135	92.9	0.2031	166.7	71.2	2.48	1
74.0P	2530	0.0522	0.831	0.355	185.5	0.612	0.150	96.4	0.2189	175.8	71.3	2.74	1
75.0	2526	0.0542	0.839	0.363	190.9	0.616	0.154	97.2	0.2227	177.9	71.2	2.80	1

a_{eff} - effective crack length (in)

Δa_{eff} - change in a-effective (in)

K_{Reff} - incremental r-curve stress intensity values based on effective crack length (ksi.sqrtin)

a_{phys} - physical crack Length (in)

Δa_{phys} - change in a-physical (in)

K_{Rphys} - incremental r-curve stress Intensity values based on physical crack length (ksi.sqrtin)

r_Y - plastic zone adjustment (in)

σ_{net} - net section stress (ksi)

K_{app} - apparent stress intensity (ksi.sqrtin)

R_v - validity check 8 * ry / (w - ap) < or = 1.0

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'0' indicates a valid check '1' indicates an invalid check.

KC-I-B-3

AO SMITH 1146a

INNER LAYER

PLANE STRESS FRACTURE TOUGHNESS

L-T

RT

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

COMPACT TENSION FRACTURE TOUGHNESS TEST REPORT (ASTM E561-08e1)

PRELIMINARY INFORMATION :

CUSTOMER : SOUTHWEST RESEARCH	
P.O. NO. : F58154BT	
SID : KC-I-B-3	MATERIAL SPEC : N/A
WMT&R NO. : 3-55962	TESTLOG : S41400
ALLOY & TEMPER : Steel-N/A	PRODUCT: N/A
PRODUCT THICKNESS: N/A	
TEST TYPE : 0.625-C(T) N/A	TEST PLANE : N/A
TEST DATE : 04-11-13	TEST TEMPERATURE : 75°F
TEST YIELD STR.(YS2) : 82.2 ksi	MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS :

THICKNESS (*B*)	= 0.219 in.
WIDTH (*W*)	= 1.250 in.
ORIGINAL CRACK LENGTH (*aN*)	= 0.351 in.
EFFECTIVE CRACK LENGTH (*ae*)	= 0.812 in.
PHYSICAL CRACK LENGTH (*ap*)	= 0.605 in.
TOTAL CRACK LENGTH (*ao*)	= 0.486 in.
TYPE OF CRACK	FATIGUE PRECRACKED

CRACK LENGTHS:

R-SURFACE	= 0.129 in.
R-CENTER	= 0.140 in.
MID-CENTER	= 0.136 in.
L-CENTER	= 0.128 in.
L-SURFACE	= 0.108 in.

FATIGUE PRECRACKING SUMMARY

MAXIMUM FATIGUE LOAD	= 657 lbs	LOAD RATIO	= 0.1
KF (MAX)	= 19.0 ksi(sqrt. in.)	CYCLES	= 107680
FATIGUE CRACKING DATE			

TEST RESULTS :

MAXIMUM LOAD (Pmax)	= 2498 lbs	DEPARTURE LOAD (PDL)	= 855 lbs
STRESS INTENSITY (Kc)	= 171.7 ksi(sqrt. in.)	STRESS INTENSITY AT PD	= 24.7 ksi(sqrt. in.)
DISPLACEMENT AT Pmax	= 0.0464 in.	DISPLACEMENT AT PD	= 0.0047 in.
NET SECTION STRESS (SIGMA)	= 170.3 ksi	K-RATE	= 1.88 ksi(sqrt. in.)/s
Kapp	= 72.1 ksi(sqrt. in.)	EFFECTIVE MODULUS	= 28.8 Msi
r_y	= 0.2073 in.	E/E_{EFF}	= 1.04

VALIDITY CHECKS PER ASTM E561-08e1

1. (E561 8.6.2) THE FATIGUE PRECRACK SHALL EXTEND FROM THE STARTER NOTCH BY >= 0.05 in. VALID
2. (E561 8.6.2) THE FATIGUE PRECRACK MUST EXTEND BEYOND THE ENVELOPE. VALID
3. (E561 8.6.3) THE ORIGINAL CRACK SIZE, ao, SHALL BE WITHIN THE RANGE OF 0.35 TO 0.55W. VALID
   Original Crack Size (ao) = 0.486 in. 0.431 in < Original Crack Size < 0.694 in
4. (E561 9.5) APPLY A DISPLACEMENT RATE DURING THE INITIAL LINEAR PORTION OF THE FORCE-CMOD CURVE THAT WILL RESULT IN A CHANGE IN K BETWEEN 0.5 AND 2.5 KSI. SQ.RT.IN/S. VALID
   = 1.88 ksi(sqrt. in.)/s
5. (E561 8.6.5) THE REMAINING UNCRACKED LIGAMENT (W-ap) MUST BE > 4/π(KR/YS)^2. INVALID
   (W -ap) = 0.645 in. Limit = 1.661 in.

TEST IS INVALID: * KC = 171.7 ksi(sqrt. in.)**
***** KAPP = 72.1 ksi(sqrt. in.)**

STEVEN ZASADNY - JD ROSSI - TOM FEDOR - KEN GALLO

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Westmoreland Mechanical Testing & Research, Inc.

R-Curve Graph

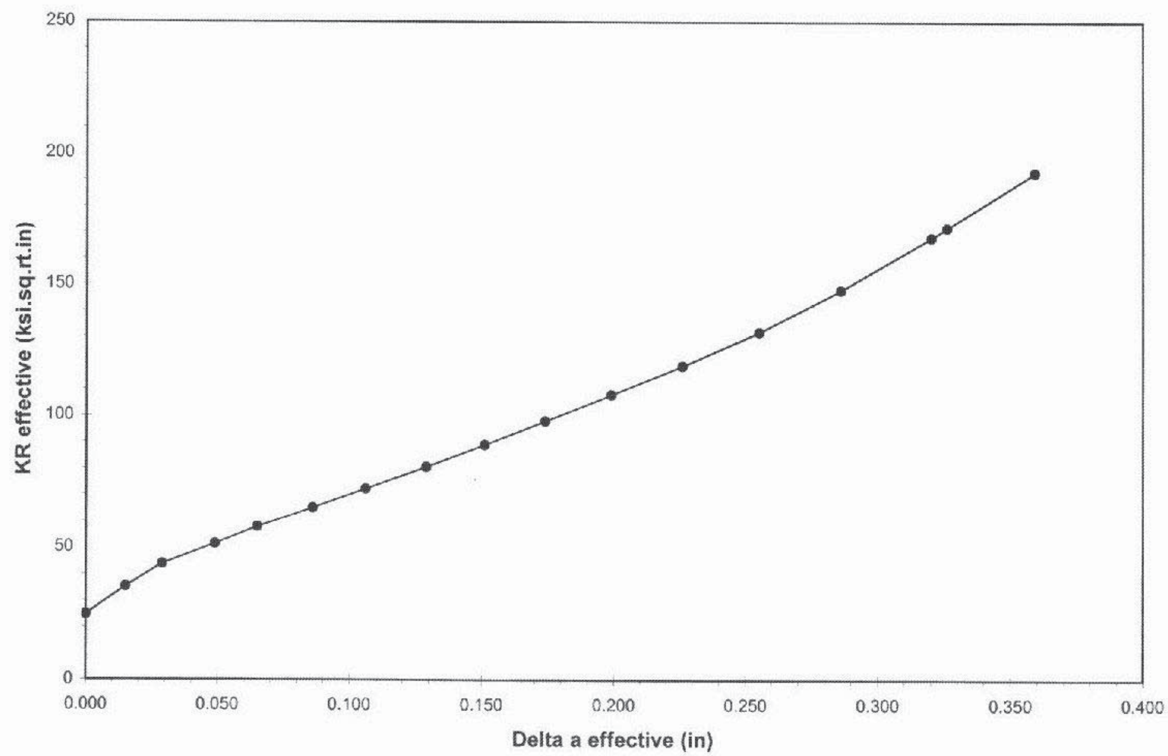
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE NO. : QN121622 REV.1

TESTLOG : S41400
TEST DATE : 04-11-13

ALLOY & TEMPER : Steel-N/A

SID : KC-I-B-3



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WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

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COMPACT TENSION FRACTURE TOUGHNESS R-CURVE TABULAR DATA (ASTM E561-08e1)

CUSTOMER : SOUTHWEST RESEARCH WMT&R NO. : 3-55962

SID : KC-I-B-3 TESTLOG : S41400

Secant (%)	Force (lbs)	CMOD (in)	a_{eff} (in)	Δa_{eff} (in)	K_{Reff} (ksi.sqrtin)	a_{phys} (in)	Δa_{phys} (in)	K_{Rphys} (ksi.sqrtin)	r_Y	σ_{net} (ksi)	K_{app} (ksi.sqrtin)	$R_v = 8 * R_y/(W-a_p)$	VALID
0.0	855	0.0047	0.486	0.000	24.7	0.472	0.000	24.0	0.0136	38.3	24.7	0.14	0
5.0	1181	0.0068	0.501	0.015	35.2	0.475	0.003	33.3	0.0261	53.4	34.1	0.27	0
10.0	1426	0.0086	0.515	0.029	43.8	0.477	0.005	40.4	0.0384	64.9	41.2	0.40	0
15.0	1604	0.0103	0.535	0.049	51.4	0.485	0.013	46.2	0.0502	74.7	46.3	0.52	0
20.0	1744	0.0118	0.551	0.065	57.9	0.490	0.018	50.8	0.0608	82.4	50.3	0.64	0
25.0	1864	0.0135	0.572	0.086	64.9	0.500	0.028	55.4	0.0722	90.8	53.8	0.77	0
30.0	1977	0.0153	0.592	0.106	72.1	0.508	0.036	59.8	0.0841	98.6	57.1	0.91	0
35.0	2089	0.0175	0.615	0.129	80.4	0.517	0.045	64.4	0.0978	107.1	60.3	1.07	1
40.0	2184	0.0198	0.637	0.151	88.8	0.526	0.054	68.6	0.1109	115.1	63.0	1.23	1
45.0	2272	0.0224	0.660	0.174	97.9	0.535	0.063	72.8	0.1249	123.2	65.6	1.40	1
50.0	2341	0.0254	0.685	0.199	107.9	0.546	0.074	76.9	0.1390	131.4	67.6	1.58	1
55.0	2390	0.0289	0.712	0.226	118.9	0.559	0.087	80.8	0.1534	139.8	69.0	1.78	1
60.0	2430	0.0330	0.741	0.255	131.8	0.572	0.100	84.6	0.1687	148.3	70.1	1.99	1
65.0	2469	0.0383	0.772	0.286	147.8	0.586	0.114	88.7	0.1857	157.8	71.3	2.24	1
70.0	2496	0.0452	0.806	0.320	167.9	0.602	0.130	93.1	0.2041	168.4	72.0	2.52	1
70.7P	2498	0.0464	0.812	0.326	171.7	0.605	0.133	93.9	0.2073	170.3	72.1	2.57	1
75.0	2475	0.0538	0.845	0.359	192.7	0.623	0.151	97.2	0.2222	179.6	71.4	2.84	1

a_{eff} - effective crack length (in)

Δa_{eff} - change in a-effective (in)

K_{Reff} - incremental r-curve stress intensity values based on effective crack length (ksi.sqrtin)

a_{phys} - physical crack Length (in)

Δa_{phys} - change in a-physical (in)

K_{Rphys} - incremental r-curve stress Intensity values based on physical crack length (ksi.sqrtin)

r_Y - plastic zone adjustment (in)

σ_{net} - net section stress (ksi)

K_{app} - apparent stress intensity (ksi.sqrtin)

R_v - validity check 8 * ry / (w - ap) < or = 1.0

'0' indicates a valid check '1' indicates an invalid check.

KC-O-B-1

AO SMITH 1146a

OUTER LAYER

PLANE STRESS FRACTURE TOUGHNESS

L-T

RT

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

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COMPACT TENSION FRACTURE TOUGHNESS TEST REPORT (ASTM E561-08e1)

PRELIMINARY INFORMATION :

CUSTOMER : SOUTHWEST RESEARCH	
P.O. NO. : F58154BT	
SID : KC-O-B-1	MATERIAL SPEC : N/A
WMT&R NO. : 3-55962	TESTLOG : S41395
ALLOY & TEMPER : Steel-N/A	PRODUCT: N/A
PRODUCT THICKNESS: N/A	
TEST TYPE : 0.625-C(T) N/A	TEST PLANE : N/A
TEST DATE : 04-05-13	TEST TEMPERATURE : 75°F
TEST YIELD STR.(YS2) : 82.2 ksi	MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS :

THICKNESS (*B*)	= 0.219 in.
WIDTH (*W*)	= 1.251 in.
ORIGINAL CRACK LENGTH (*aN*)	= 0.349 in.
EFFECTIVE CRACK LENGTH (*ae*)	= 0.763 in.
PHYSICAL CRACK LENGTH (*ap*)	= 0.469 in.
TOTAL CRACK LENGTH (*ao*)	= 0.465 in.
TYPE OF CRACK	FATIGUE PRECRACKED

CRACK LENGTHS:

R-SURFACE	= 0.114 in.
R-CENTER	= 0.123 in.
MID-CENTER	= 0.118 in.
L-CENTER	= 0.108 in.
L-SURFACE	= 0.090 in.

FATIGUE PRECRACKING SUMMARY

MAXIMUM FATIGUE LOAD	= 656 lbs	LOAD RATIO	= 0.1
KF (MAX)	= 18.1 ksi(sqrt. in.)	CYCLES	= 112292
FATIGUE CRACKING DATE			

TEST RESULTS :

MAXIMUM LOAD (Pmax)	= 4426 lbs	DEPARTURE LOAD (PDL)	= 1092 lbs
STRESS INTENSITY (Kc)	= 256.6 ksi(sqrt. in.)	STRESS INTENSITY AT PD	= 30.1 ksi(sqrt. in.)
DISPLACEMENT AT Pmax	= 0.0657 in.	DISPLACEMENT AT PD	= 0.0056 in.
NET SECTION STRESS (SIGMA)	= 196.4 ksi	K-RATE	= 1.93 ksi(sqrt. in.)/s
Kapp	= 122.1 ksi(sqrt. in.)	EFFECTIVE MODULUS	= 28.9 Msi
r_y	= 0.2939 in.	E/E_{EFF}	= 1.04

VALIDITY CHECKS PER ASTM E561-08e1

1. (E561 8.6.2) THE FATIGUE PRECRACK SHALL EXTEND FROM THE STARTER NOTCH BY >= 0.05 in. — VALID
2. (E561 8.6.2) THE FATIGUE PRECRACK MUST EXTEND BEYOND THE ENVELOPE. — VALID
3. (E561 8.6.3) THE ORIGINAL CRACK SIZE, ao, SHALL BE WITHIN THE RANGE OF 0.35 TO 0.55W. — VALID
   Original Crack Size (ao) = 0.465 in. 0.432 in < Original Crack Size < 0.694 in
4. (E561 9.5) APPLY A DISPLACEMENT RATE DURING THE INITIAL LINEAR PORTION OF THE FORCE-CMOD CURVE THAT WILL RESULT IN A CHANGE IN K BETWEEN 0.5 AND 2.5 KSI. SQ.RT.IN/S. — VALID
   = 1.93 ksi(sqrt. in.)/s
5. (E561 8.6.5) THE REMAINING UNCRACKED LIGAMENT (W-ap) MUST BE > 4/π(KR/YS)^2. — INVALID
   (W -ap) = 0.782 in. Limit = 2.860 in.

TEST IS INVALID: * KC = 256.6 ksi(sqrt. in.)**

***** KAPP = 122.1 ksi(sqrt. in.)**

STEVEN ZASADNY - JD ROSSI - TOM FEDOR - KEN GALLO

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Westmoreland Mechanical Testing & Research, Inc.

R-Curve Graph

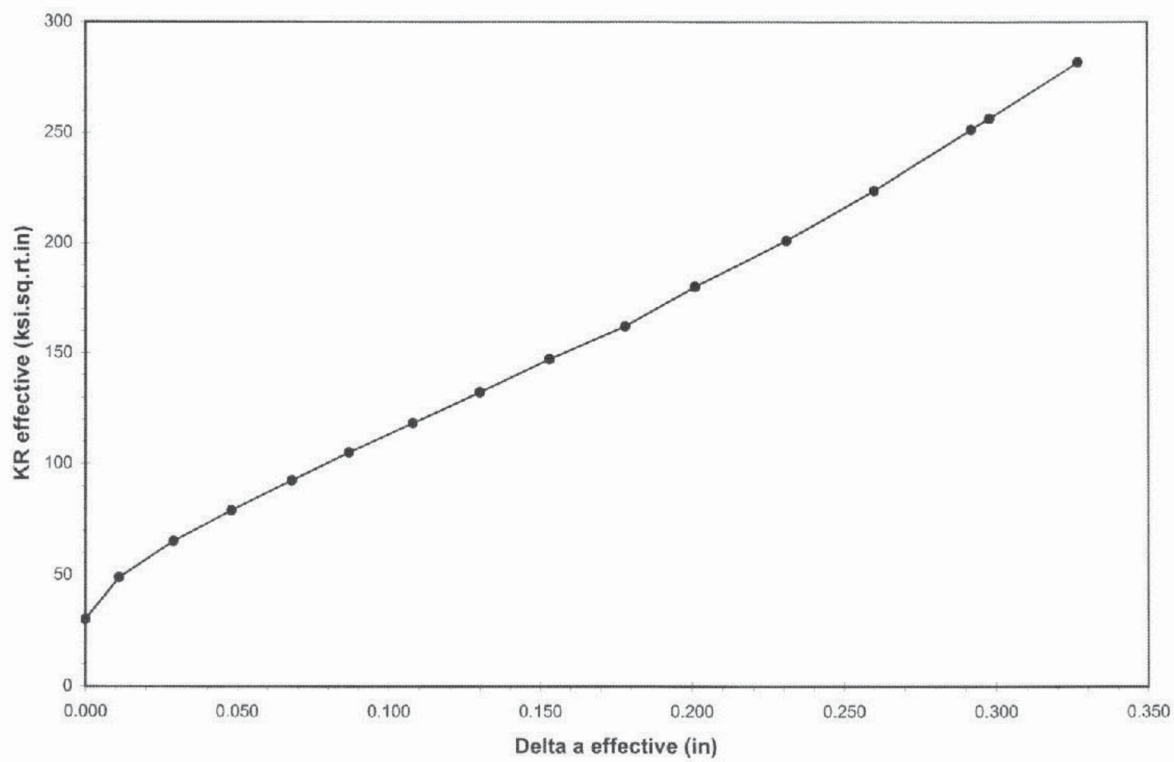
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE NO. : QN121622 REV.1

TESTLOG : S41395
TEST DATE : 04-05-13

ALLOY & TEMPER : Steel-N/A

SID : KC-O-B-1



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COMPACT TENSION FRACTURE TOUGHNESS R-CURVE TABULAR DATA (ASTM E561-08e1)

CUSTOMER : SOUTHWEST RESEARCH WMT&R NO. : 3-55962
SID : KC-O-B-1 TESTLOG : S41395

Secant (%)	Force (lbs)	CMOD (in)	a_{eff} (in)	Δa_{eff} (in)	K_{Reff} (ksi.sqrtin)	a_{phys} (in)	Δa_{phys} (in)	K_{Rphys} (ksi.sqrtin)	r_y	σ_{net} (ksi)	K_{app} (ksi.sqrtin)	$R_v = 8 * R_y/(W-a_p)$	VALID
0.0	1092	0.0056	0.465	0.000	30.1	0.445	0.000	28.9	0.0197	45.2	30.1	0.20	0
5.0	1732	0.0092	0.476	0.011	48.9	0.430	-0.015	44.5	0.0465	68.8	47.8	0.45	0
10.0	2227	0.0125	0.494	0.029	65.3	0.420	-0.025	56.0	0.0740	86.1	61.5	0.71	0
15.0	2588	0.0154	0.513	0.048	79.0	0.415	-0.030	64.4	0.0979	98.6	71.4	0.94	0
20.0	2900	0.0184	0.533	0.068	92.4	0.412	-0.033	71.8	0.1212	109.6	80.0	1.16	1
25.0	3166	0.0214	0.552	0.087	105.2	0.409	-0.036	77.9	0.1429	118.7	87.4	1.36	1
30.0	3397	0.0246	0.573	0.108	118.3	0.409	-0.036	83.6	0.1643	127.4	93.7	1.56	1
35.0	3610	0.0281	0.595	0.130	132.3	0.409	-0.036	88.8	0.1858	135.4	99.6	1.77	1
40.0	3804	0.0321	0.618	0.153	147.3	0.411	-0.034	93.9	0.2075	143.4	105.0	1.98	1
45.0	3937	0.0363	0.643	0.178	162.2	0.416	-0.029	98.2	0.2271	150.5	108.6	2.18	1
50.0	4122	0.0413	0.666	0.201	180.2	0.416	-0.029	102.9	0.2496	157.5	113.8	2.39	1
55.0	4239	0.0477	0.696	0.231	201.1	0.424	-0.021	107.5	0.2721	165.6	117.0	2.63	1
60.0	4341	0.0550	0.725	0.260	223.8	0.431	-0.014	111.7	0.2939	172.9	119.8	2.87	1
65.0	4421	0.0640	0.757	0.292	251.5	0.463	0.018	121.5	0.2939	192.8	122.0	2.98	1
65.9P	4426	0.0657	0.763	0.298	256.6	0.469	0.024	123.2	0.2939	196.4	122.1	3.01	1
70.0	4416	0.0746	0.792	0.327	282.0	0.498	0.053	130.6	0.2939	213.4	121.9	3.12	1

a_{eff} - effective crack length (in)
Δa_{eff} - change in a-effective (in)
K_{Reff} - incremental r-curve stress intensity values based on effective crack length (ksi.sqrtin)
a_{phys} - physical crack Length (in)
Δa_{phys} - change in a-physical (in)
K_{Rphys} - incremental r-curve stress Intensity values based on physical crack length (ksi.sqrtin)
r_y - plastic zone adjustment (in)
σ_{net} - net section stress (ksi)
K_{app} - apparent stress intensity (ksi.sqrtin)
R_v - validity check 8 * ry / (w - ap) < or = 1.0
'0' indicates a valid check '1' indicates an invalid check.

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KC-O-B-2

AO SMITH 1146a

OUTER LAYER

PLANE STRESS FRACTURE TOUGHNESS

L-T

RT

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COMPACT TENSION FRACTURE TOUGHNESS TEST REPORT (ASTM E561-08e1)

PRELIMINARY INFORMATION :

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SID : KC-O-B-2

MATERIAL SPEC : N/A

WMT&R NO. : 3-55962
ALLOY & TEMPER : Steel-N/A
PRODUCT THICKNESS: N/A
TEST TYPE : 0.625-C(T) N/A
TEST DATE : 04-05-13
TEST YIELD STR.(YS2) : 82.2 ksi

TESTLOG : S41396
PRODUCT: N/A
TEST PLANE : N/A
TEST TEMPERATURE : 75°F
MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS :

THICKNESS (*B*)	= 0.219 in.
WIDTH (*W*)	= 1.252 in.
ORIGINAL CRACK LENGTH (*aN*)	= 0.350 in.
EFFECTIVE CRACK LENGTH (*ae*)	= 0.815 in.
PHYSICAL CRACK LENGTH (*ap*)	= 0.505 in.
TOTAL CRACK LENGTH (*ao*)	= 0.476 in.
TYPE OF CRACK	FATIGUE PRECRACKED

CRACK LENGTHS:

R-SURFACE	= 0.117 in.
R-CENTER	= 0.127 in.
MID-CENTER	= 0.128 in.
L-CENTER	= 0.124 in.
L-SURFACE	= 0.110 in.

FATIGUE PRECRACKING SUMMARY

MAXIMUM FATIGUE LOAD	= 653 lbs	LOAD RATIO	= 0.1
KF (MAX)	= 18.4 ksi(sqrt. in.)	CYCLES	= 113092
FATIGUE CRACKING DATE			

TEST RESULTS :

MAXIMUM LOAD (Pmax)	= 4286 lbs	DEPARTURE LOAD (PDL)	= 1103 lbs
STRESS INTENSITY (Kc)	= 296.1 ksi(sqrt. in.)	STRESS INTENSITY AT PD	= 31.1 ksi(sqrt. in.)
DISPLACEMENT AT Pmax	= 0.0796 in.	DISPLACEMENT AT PD	= 0.0058 in.
NET SECTION STRESS (SIGMA)	= 211.1 ksi	K-RATE	= 1.94 ksi(sqrt. in.)/s
Kapp	= 120.9 ksi(sqrt. in.)	EFFECTIVE MODULUS	= 29.1 Msi
r_y	= 0.3097 in.	E/E_{EFF}	= 1.03

VALIDITY CHECKS PER ASTM E561-08e1

1. (E561 8.6.2) THE FATIGUE PRECRACK SHALL EXTEND FROM THE STARTER NOTCH BY >= 0.05 in. — VALID
2. (E561 8.6.2) THE FATIGUE PRECRACK MUST EXTEND BEYOND THE ENVELOPE. — VALID
3. (E561 8.6.3) THE ORIGINAL CRACK SIZE, ao, SHALL BE WITHIN THE RANGE OF 0.35 TO 0.55W. — VALID
   Original Crack Size (ao) = 0.476 in. 0.432 in < Original Crack Size < 0.695 in
4. (E561 9.5) APPLY A DISPLACEMENT RATE DURING THE INITIAL LINEAR PORTION OF THE FORCE-CMOD CURVE THAT WILL RESULT IN A CHANGE IN K BETWEEN 0.5 AND 2.5 KSI. SQ.RT.IN/S. — VALID
   = 1.94 ksi(sqrt. in.)/s
5. (E561 8.6.5) THE REMAINING UNCRACKED LIGAMENT (W-ap) MUST BE > 4/π(KR/YS)^2. — INVALID
   (W -ap) = 0.747 in. Limit = 3.107 in.

TEST IS INVALID: * KC = 296.1 ksi(sqrt. in.)**
***** KAPP = 120.9 ksi(sqrt. in.)**

STEVEN ZASADNY - JD ROSSI - TOM FEDOR - KEN GALLO

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Westmoreland Mechanical Testing & Research, Inc.

R-Curve Graph

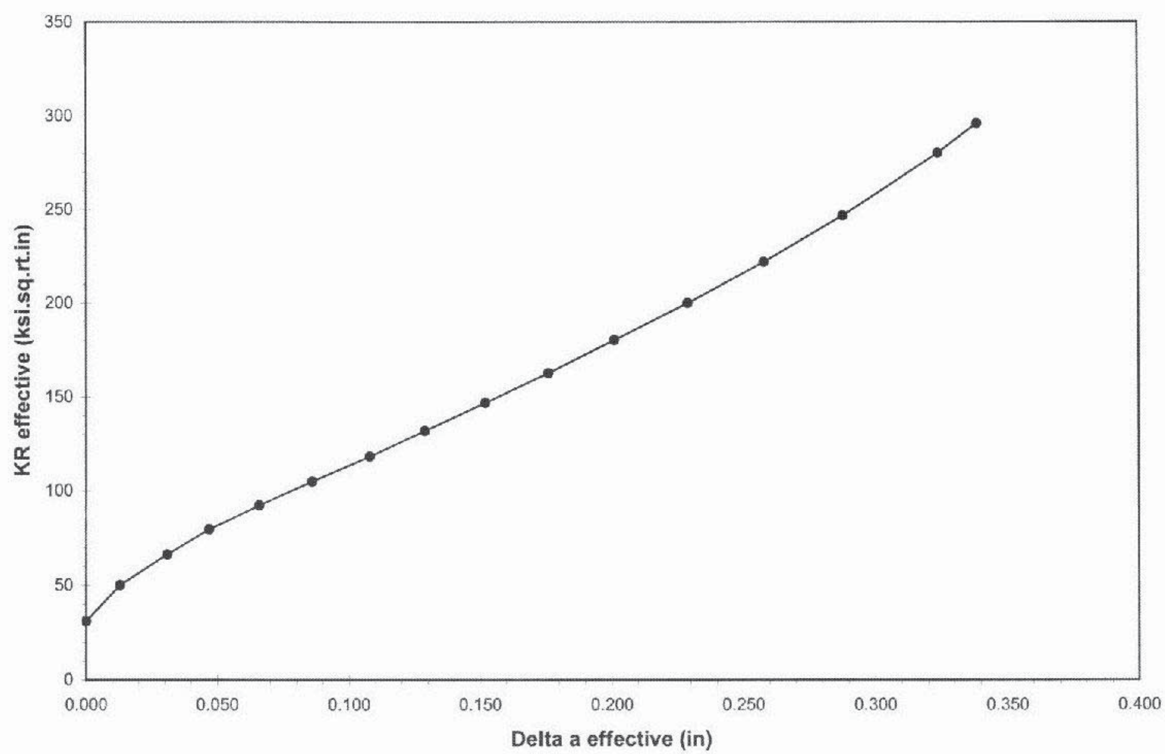
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE NO. : QN121622 REV.1

TESTLOG : S41396
TEST DATE : 04-05-13

ALLOY & TEMPER : Steel-N/A

SID : KC-O-B-2



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COMPACT TENSION FRACTURE TOUGHNESS R-CURVE TABULAR DATA (ASTM E561-08e1)

CUSTOMER : SOUTHWEST RESEARCH WMT&R NO. : 3-55962

SID : KC-O-B-2 TESTLOG : S41396

Secant (%)	Force (lbs)	CMOD (in)	a_{eff} (in)	Δa_{eff} (in)	K_{Reff} (ksi sqrtin)	a_{phys} (in)	Δa_{phys} (in)	K_{Rphys} (ksi sqrtin)	r_Y	σ_{net} (ksi)	K_{app} (ksi sqrtin)	$R_y = 8 * R_y/(W-a_p)$	VALID
0.0	1103	0.0058	0.476	0.000	31.1	0.455	0.000	29.8	0.0209	46.9	31.1	0.21	0
5.0	1733	0.0095	0.489	0.013	50.2	0.440	-0.015	45.4	0.0486	70.7	48.9	0.48	0
10.0	2211	0.0128	0.507	0.031	66.5	0.431	-0.024	56.8	0.0760	87.9	62.4	0.74	0
15.0	2558	0.0156	0.523	0.047	79.7	0.424	-0.031	64.8	0.0989	99.8	72.1	0.96	0
20.0	2843	0.0184	0.542	0.066	92.3	0.421	-0.034	71.6	0.1208	110.0	80.2	1.16	1
25.0	3093	0.0214	0.562	0.086	104.9	0.420	-0.035	77.7	0.1422	119.3	87.2	1.37	1
30.0	3313	0.0246	0.584	0.108	118.2	0.420	-0.035	83.3	0.1635	127.8	93.4	1.57	1
35.0	3518	0.0281	0.605	0.129	131.8	0.421	-0.034	88.6	0.1845	136.1	99.2	1.78	1
40.0	3707	0.0321	0.628	0.152	146.8	0.422	-0.033	93.5	0.2061	143.8	104.5	1.99	1
45.0	3865	0.0365	0.652	0.176	162.6	0.425	-0.030	98.1	0.2269	151.2	109.0	2.19	1
50.0	4010	0.0416	0.677	0.201	180.2	0.429	-0.026	102.6	0.2481	158.6	113.1	2.41	1
55.0	4119	0.0475	0.705	0.229	200.0	0.436	-0.019	107.0	0.2693	166.1	116.2	2.64	1
60.0	4198	0.0545	0.734	0.258	221.9	0.444	-0.011	110.8	0.2897	173.1	118.4	2.87	1
65.0	4252	0.0627	0.764	0.288	246.8	0.454	-0.001	114.6	0.3097	180.4	119.9	3.10	1
70.0	4279	0.0740	0.800	0.324	280.2	0.490	0.035	124.2	0.3097	201.5	120.7	3.25	1
72.0P	4286	0.0796	0.815	0.339	296.1	0.505	0.050	128.4	0.3097	211.1	120.9	3.32	1

a_{eff} - effective crack length (in)

Δa_{eff} - change in a-effective (in)

K_{Reff} - incremental r-curve stress intensity values based on effective crack length (ksi.sqrtin)

a_{phys} - physical crack Length (in)

Δa_{phys} - change in a-physical (in)

K_{Rphys} - incremental r-curve stress Intensity values based on physical crack length (ksi.sqrtin)

r_Y - plastic zone adjustment (in)

σ_{net} - net section stress (ksi)

K_{app} - apparent stress intensity (ksi.sqrtin)

R_y - validity check 8 * ry / (w - ap) < or = 1.0

'0' indicates a valid check '1' indicates an invalid check

KC-O-B-3

AO SMITH 1146a

OUTER LAYER

PLANE STRESS FRACTURE TOUGHNESS

L-T

RT

WESTMOORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

COMPACT TENSION FRACTURE TOUGHNESS TEST REPORT (ASTM E561-08e1)

PRELIMINARY INFORMATION :

CUSTOMER : SOUTHWEST RESEARCH	
P.O. NO. : F58154BT	
SID : KC-O-B-3	MATERIAL SPEC : N/A
WMT&R NO. : 3-55962	TESTLOG : S41397
ALLOY & TEMPER : Steel-N/A	PRODUCT: N/A
PRODUCT THICKNESS: N/A	
TEST TYPE : 0.625-C(T) N/A	TEST PLANE : N/A
TEST DATE : 04-08-13	TEST TEMPERATURE : 75°F
TEST YIELD STR.(YS2) : 82.2 ksi	MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS :

THICKNESS (B)	= 0.216 in.
WIDTH (W)	= 1.251 in.
ORIGINAL CRACK LENGTH (aN)	= 0.350 in.
EFFECTIVE CRACK LENGTH (ae)	= 0.774 in.
PHYSICAL CRACK LENGTH (ap)	= 0.480 in.
TOTAL CRACK LENGTH (ao)	= 0.476 in.
TYPE OF CRACK	FATIGUE PRECRACKED

CRACK LENGTHS:

R-SURFACE	= 0.110 in.
R-CENTER	= 0.124 in.
MID-CENTER	= 0.128 in.
L-CENTER	= 0.125 in.
L-SURFACE	= 0.110 in.

FATIGUE PRECRACKING SUMMARY

MAXIMUM FATIGUE LOAD	= 647 lbs	LOAD RATIO	= 0.1
KF (MAX)	= 18.5 ksi(sqrt. in.)	CYCLES	= 104678
FATIGUE CRACKING DATE			

TEST RESULTS :

MAXIMUM LOAD (Pmax)	= 4235 lbs	DEPARTURE LOAD (PDL)	= 1480 lbs
STRESS INTENSITY (Kc)	= 258.1 ksi(sqrt. in.)	STRESS INTENSITY AT PD	= 42.4 ksi(sqrt. in.)
DISPLACEMENT AT Pmax	= 0.0722 in.	DISPLACEMENT AT PD	= 0.0086 in.
NET SECTION STRESS (SIGMA)	= 196.7 ksi	K-RATE	= 1.44 ksi(sqrt. in.)/s
Kapp	= 121.2 ksi(sqrt. in.)	EFFECTIVE MODULUS	= 26.7 Msi
r_y	= 0.2935 in.	E/E_{EFF}	= 1.12

VALIDITY CHECKS PER ASTM E561-08e1

1. (E561 8.6.2) THE FATIGUE PRECRACK SHALL EXTEND FROM THE STARTER NOTCH BY > = 0.05 in. VALID
2. (E561 8.6.2) THE FATIGUE PRECRACK MUST EXTEND BEYOND THE ENVELOPE. VALID
3. (E561 8.6.3) THE ORIGINAL CRACK SIZE, ao, SHALL BE WITHIN THE RANGE OF 0.35 TO 0.55W. VALID
   Original Crack Size (ao) = 0.476 in. 0.432 in < Original Crack Size < 0.694 in
4. (E561 9.5) APPLY A DISPLACEMENT RATE DURING THE INITIAL LINEAR PORTION OF THE FORCE-CMOD CURVE THAT WILL RESULT IN A CHANGE IN K BETWEEN 0.5 AND 2.5 KSI. SQ.RT IN/S VALID
   = 1.44 ksi(sqrt. in.)/s
5. (E561 8.6.5) THE REMAINING UNCRACKED LIGAMENT (W-ap) MUST BE > 4/π(KR/YS)^2. INVALID
   (W -ap) = 0.771 in. Limit = 2.814 in.

TEST IS INVALID: * KC = 258.1 ksi(sqrt. in.)**

***** KAPP = 121.2 ksi(sqrt. in.)**

STEVEN ZASADNY - JD ROSSI - TOM FEDOR - KEN GALLO

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Westmoreland Mechanical Testing & Research, Inc.

R-Curve Graph

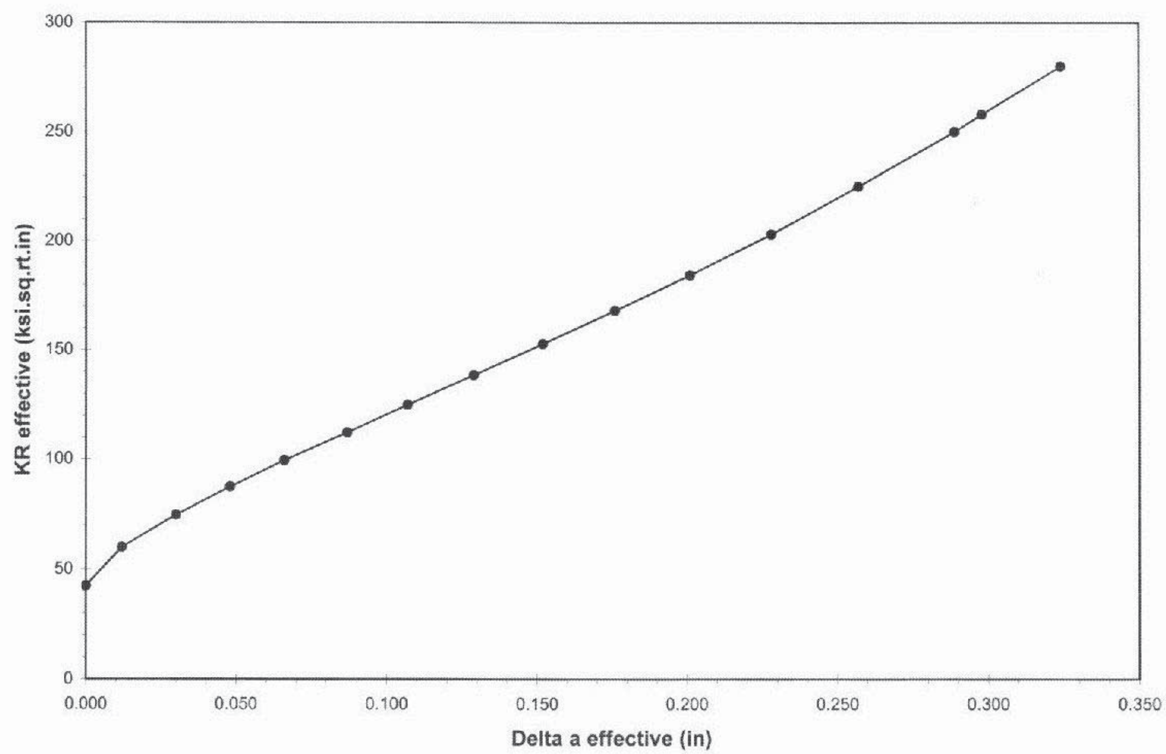
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE NO. : QN121622 REV.1

TESTLOG : S41397
TEST DATE : 04-08-13

ALLOY & TEMPER : Steel-N/A

SID : KC-O-B-3



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WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

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COMPACT TENSION FRACTURE TOUGHNESS R-CURVE TABULAR DATA (ASTM E561-08e1)

CUSTOMER : SOUTHWEST RESEARCH WMT&R NO. : 3-55962

SID : KC-O-B-3 TESTLOG : S41397

Secant (%)	Force (lbs)	CMOD (in)	a_{eff} (in)	Δa_{eff} (in)	K_{Reff} (ksi.sqrtin)	a_{phys} (in)	Δa_{phys} (in)	K_{Rphys} (ksi.sqrtin)	r_Y	σ_{net} (ksi)	K_{app} (ksi.sqrtin)	$R_v = 8 * R_y/(W-a_p)$	VALID
0.0	1480	0.0086	0.476	0.000	42.4	0.440	0.000	39.3	0.0364	61.3	42.4	0.36	0
5.0	2041	0.0123	0.488	0.012	59.9	0.423	-0.017	52.4	0.0647	80.6	58.4	0.63	0
10.0	2447	0.0156	0.506	0.030	74.6	0.416	-0.024	61.9	0.0902	94.8	70.0	0.86	0
15.0	2754	0.0186	0.524	0.048	87.3	0.412	-0.028	69.1	0.1123	105.6	78.8	1.07	1
20.0	3018	0.0216	0.542	0.066	99.4	0.409	-0.031	75.3	0.1332	114.7	86.4	1.27	1
25.0	3251	0.0249	0.563	0.087	112.2	0.409	-0.031	81.1	0.1545	123.6	93.1	1.47	1
30.0	3454	0.0283	0.583	0.107	124.8	0.409	-0.031	86.1	0.1744	131.3	98.9	1.66	1
35.0	3638	0.0321	0.605	0.129	138.4	0.410	-0.030	90.9	0.1948	138.7	104.1	1.85	1
40.0	3795	0.0363	0.628	0.152	152.7	0.413	-0.027	95.4	0.2147	145.9	108.6	2.05	1
45.0	3930	0.0410	0.652	0.176	168.0	0.418	-0.022	99.8	0.2344	153.1	112.5	2.25	1
50.0	4038	0.0463	0.677	0.201	184.3	0.423	-0.017	103.6	0.2535	159.5	115.6	2.45	1
55.0	4128	0.0526	0.704	0.228	203.0	0.431	-0.009	107.7	0.2731	166.7	118.2	2.66	1
60.0	4205	0.0603	0.733	0.257	225.1	0.439	-0.001	111.5	0.2935	173.7	120.4	2.89	1
65.0	4228	0.0693	0.765	0.289	250.2	0.471	0.031	119.8	0.2935	191.3	121.0	3.01	1
66.3P	4235	0.0722	0.774	0.298	258.1	0.480	0.040	122.2	0.2935	196.7	121.2	3.05	1
70.0	4207	0.0805	0.800	0.324	280.1	0.506	0.066	128.3	0.2935	211.1	120.4	3.15	1

a_{eff} - effective crack length (in)

Δa_{eff} - change in a-effective (in)

K_{Reff} - incremental r-curve stress intensity values based on effective crack length (ksi.sqrtin)

a_{phys} - physical crack Length (in)

Δa_{phys} - change in a-physical (in)

K_{Rphys} - incremental r-curve stress Intensity values based on physical crack length (ksi.sqrtin)

r_Y - plastic zone adjustment (in)

σ_{net} - net section stress (ksi)

K_{app} - apparent stress intensity (ksi.sqrtin)

R_v - validity check 8 * ry / (w - ap) < or = 1.0

'0' indicates a valid check '1' indicates an invalid check.

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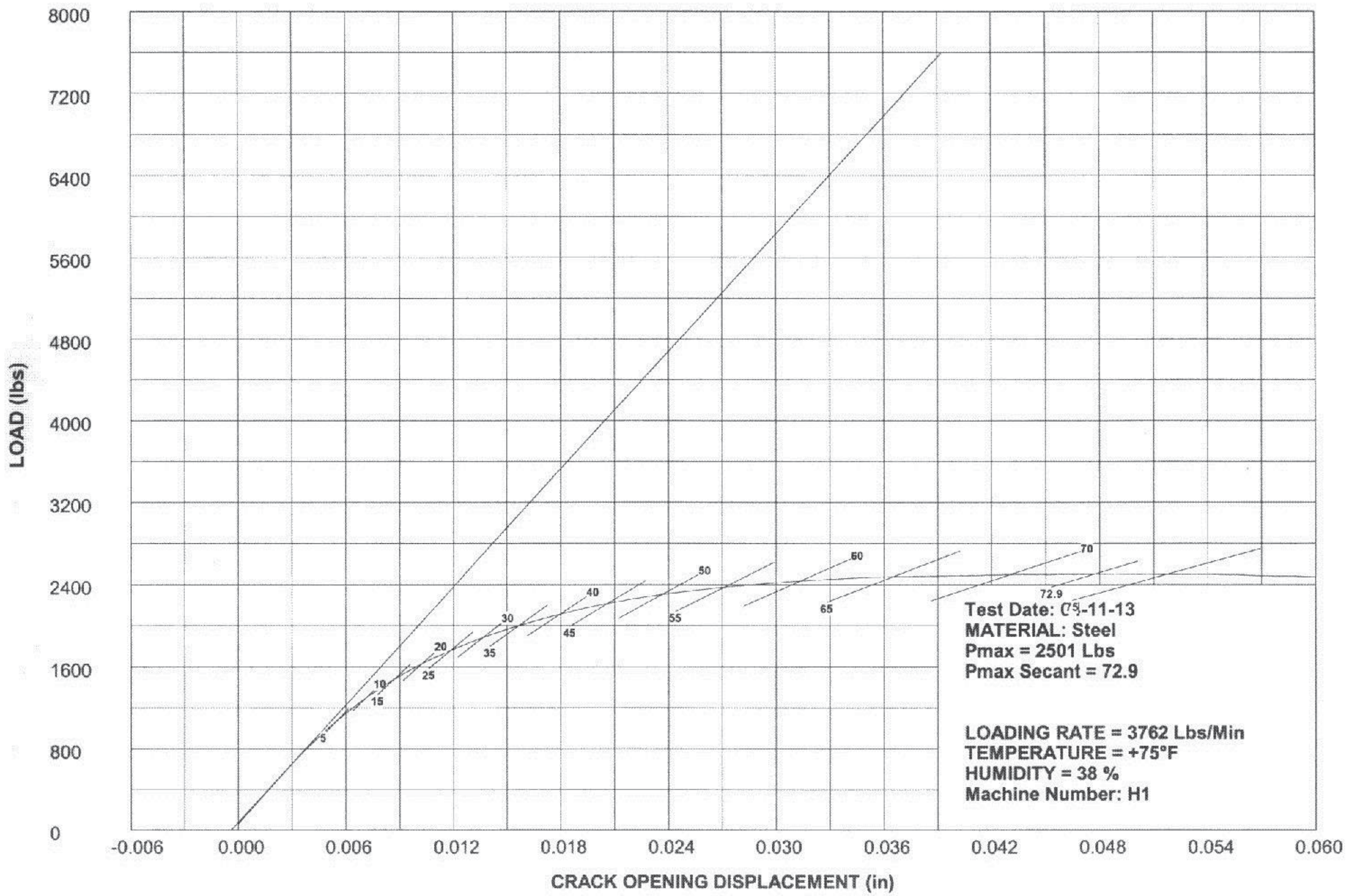
WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.
LOAD vs CRACK OPENING DISPLACEMENT
Phone 724-537-3131

Customer: Southwest Research
SID: KC-I-B-1

WMT&R Report: 3-55962
P.O. No.: F58154BT
WMT&R Quote No.: QN121622 Rev.1



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TESTLOG S41398

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

LOAD vs CRACK OPENING DISPLACEMENT

Phone 724-537-3131

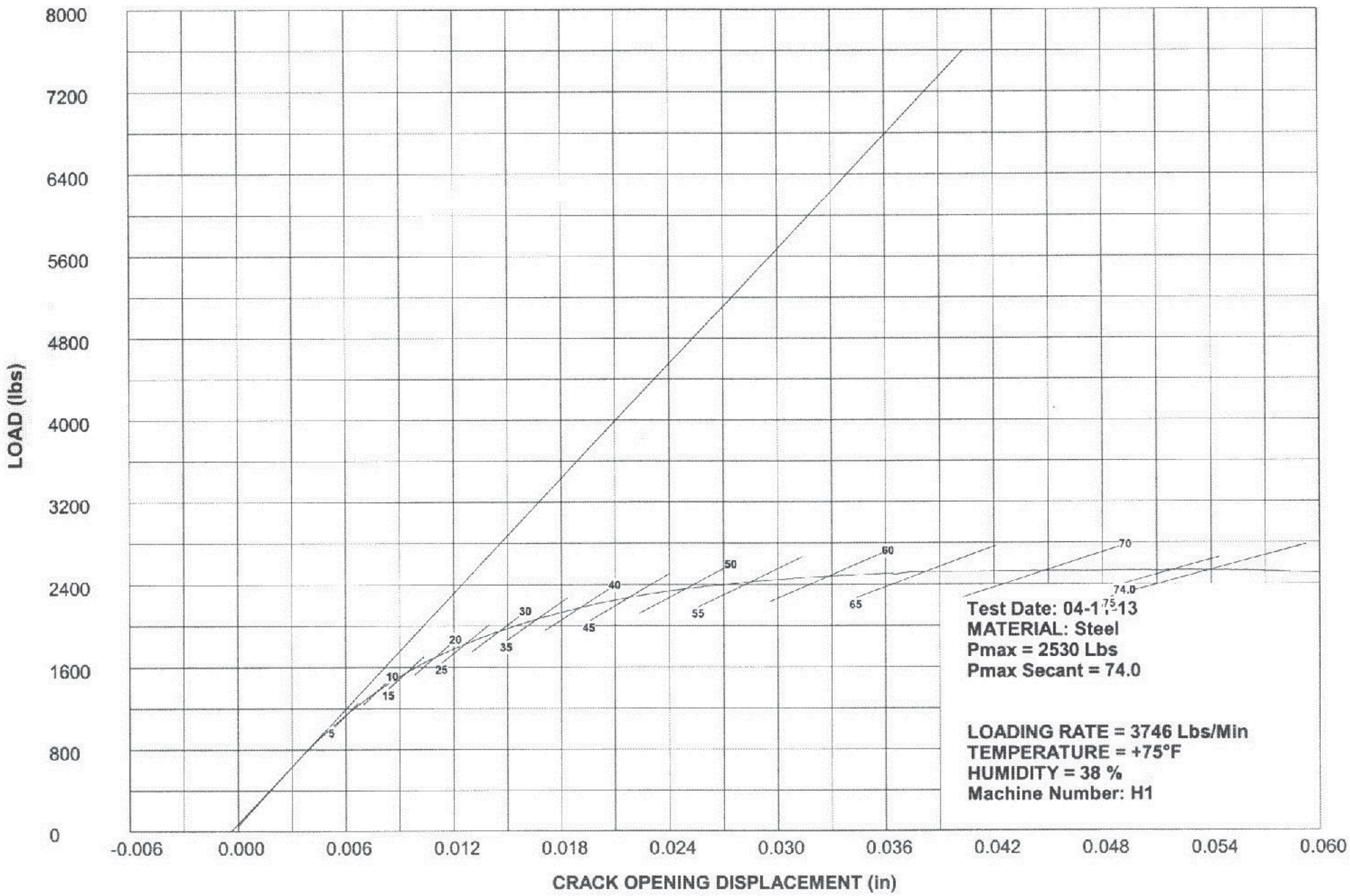
Customer: Southwest Research

SID: KC-I-B-2

WMT&R Report: 3-55962

P.O. No.: F58154BT

WMT&R Quote No.: QN121622 Rev.1



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TESTLOG S41399

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

LOAD vs CRACK OPENING DISPLACEMENT **Phone 724-537-3131**

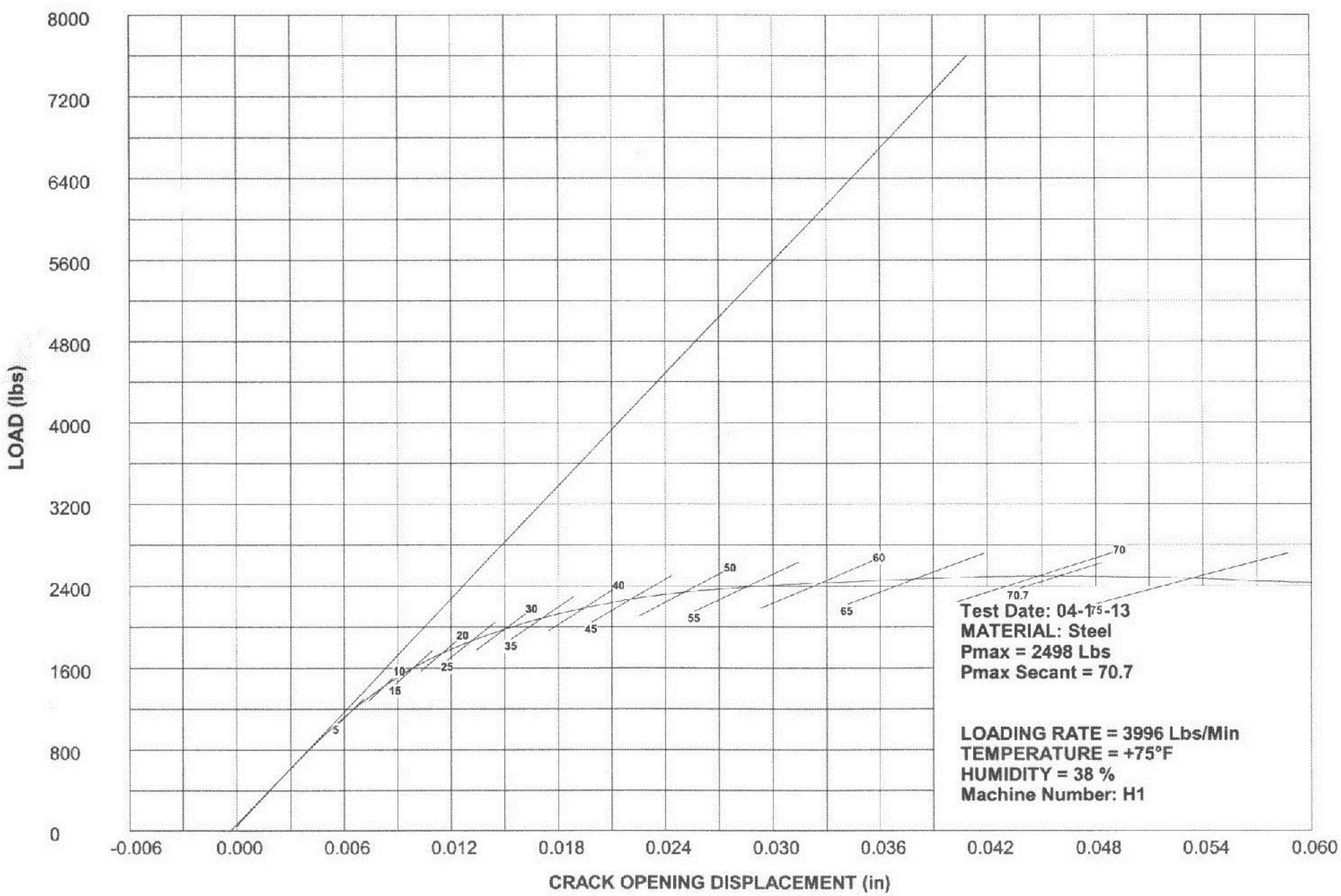
Customer: Southwest Research

SID: KC-I-B-3

WMT&R Report: 3-55962

P.O. No.: F58154BT

WMT&R Quote No.: QN121622 Rev.1



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TESTLOG S41400

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

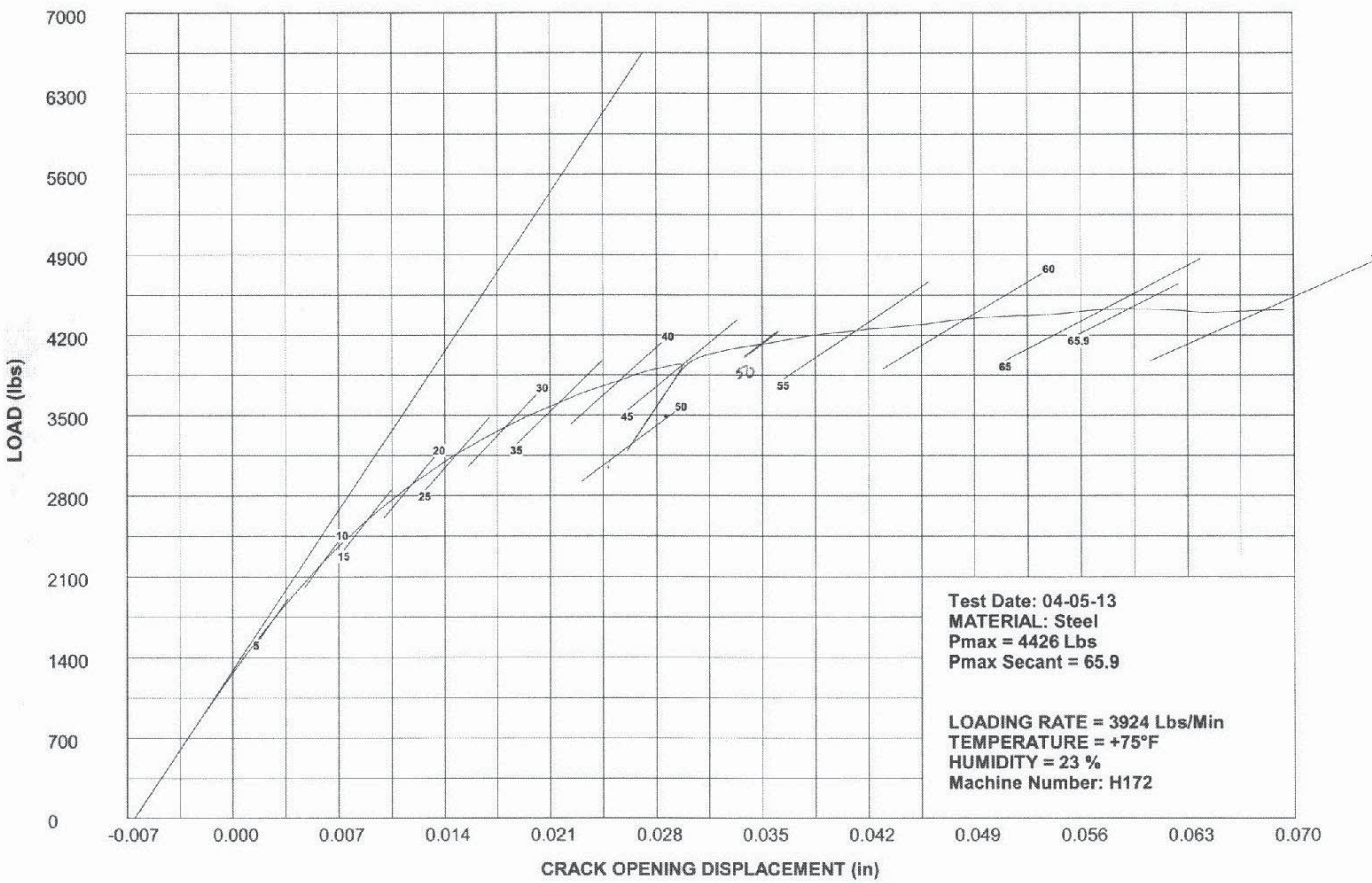
LOAD vs CRACK OPENING DISPLACEMENT — Phone 724-537-3131

Customer: Southwest Research — **WMT&R Report: 3-55962**

SID: KC-O-B-1

P.O. No.: F58154BT

WMT&R Quote No.: QN121622 Rev.1



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TESTLOG S41395

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LOAD vs CRACK OPENING DISPLACEMENT **Phone 724-537-3131**

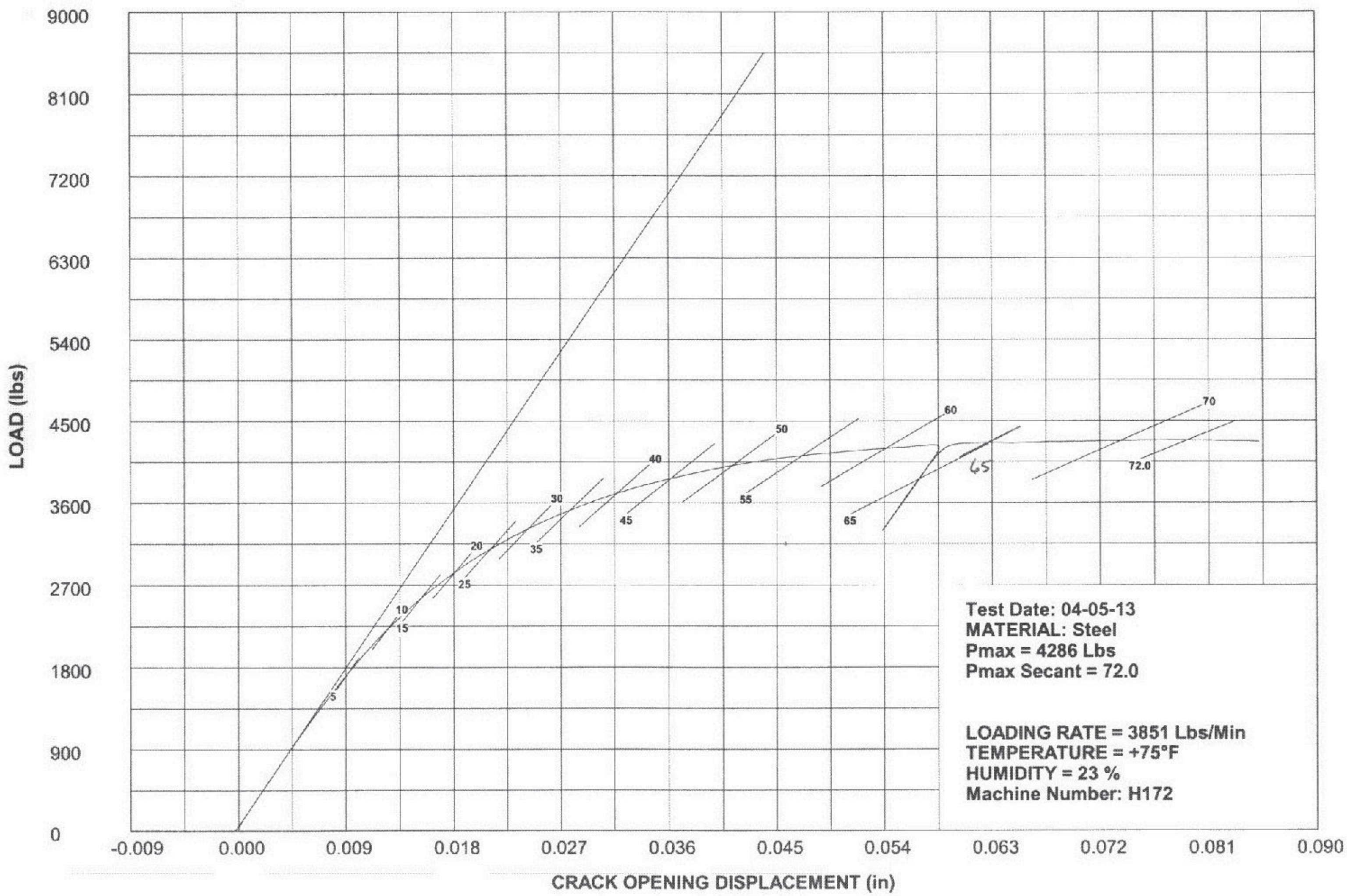
Customer: Southwest Research

SID: KC-O-B-2

WMT&R Report: 3-55962

P.O. No.: F58154BT

WMT&R Quote No.: QN121622 Rev.1



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TESTLOG S41396

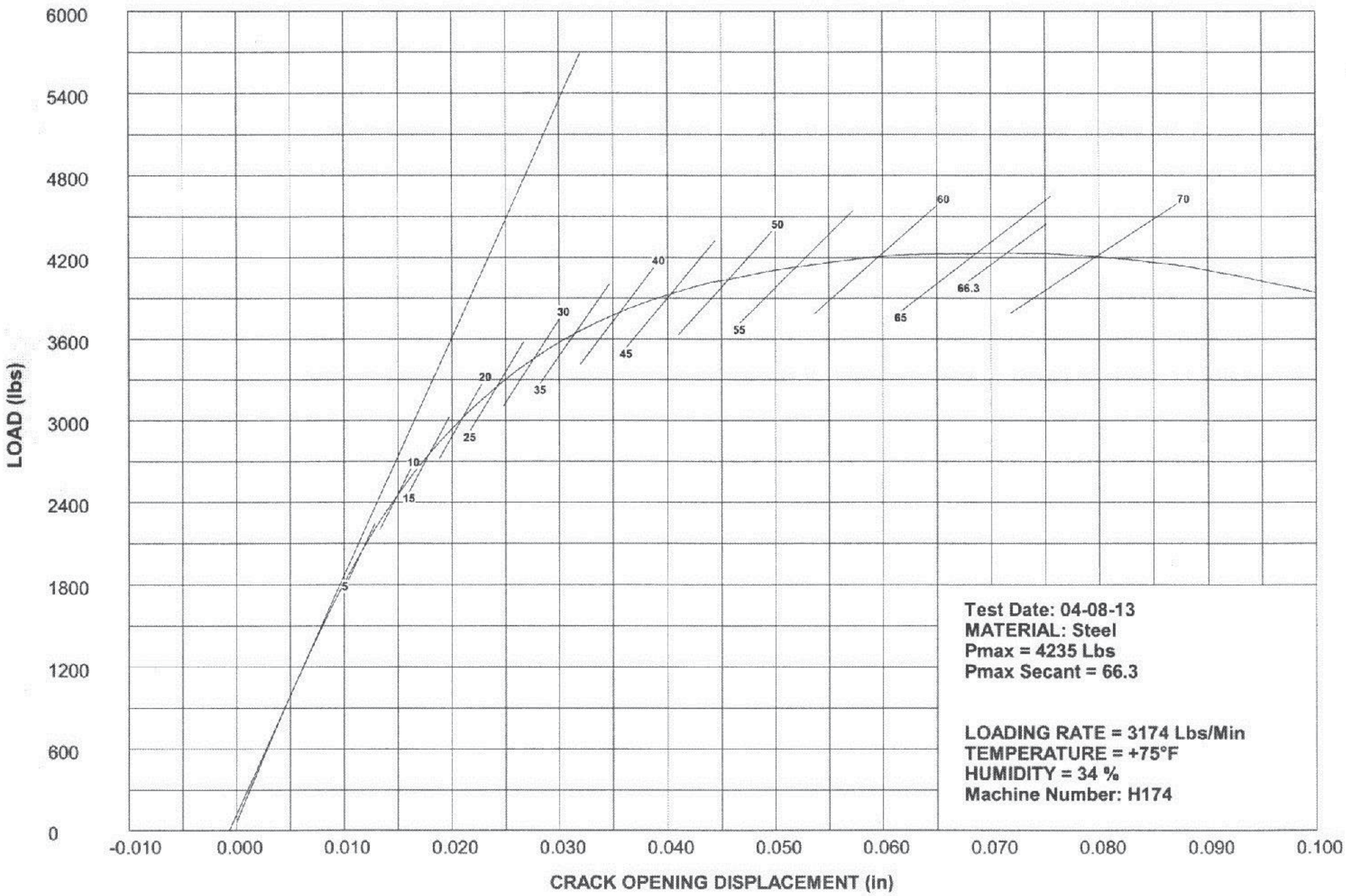
WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

LOAD vs CRACK OPENING DISPLACEMENT — Phone 724-537-3131

Customer: Southwest Research — **WMT&R Report: 3-55962**

SID: KC-O-B-3 — P.O. No.: F58154BT

WMT&R Quote No.: QN121622 Rev.1



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TESTLOG 541397

KC-I-B-4

AO SMITH 1146a

INNER LAYER

PLANE STRESS FRACTURE TOUGHNESS

L-T

-20ºF

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

COMPACT TENSION FRACTURE TOUGHNESS TEST REPORT (ASTM E561-08e1)

PRELIMINARY INFORMATION :

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SID : KC-I-B-4 MATERIAL SPEC : N/A

WMT&R NO. : 3-55962 TESTLOG : S41401
ALLOY & TEMPER : Steel-N/A PRODUCT: N/A
PRODUCT THICKNESS: N/A
TEST TYPE : 0.625-C(T) N/A TEST PLANE : N/A
TEST DATE : 04-12-13 TEST TEMPERATURE : -20°F
TEST YIELD STR.(YS2) : 82.2 ksi MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS :

THICKNESS (*B*)	= 0.219 in.
WIDTH (*W*)	= 1.251 in.
ORIGINAL CRACK LENGTH (*aN*)	= 0.350 in.
EFFECTIVE CRACK LENGTH (*ae*)	= 0.811 in.
PHYSICAL CRACK LENGTH (*ap*)	= 0.578 in.
TOTAL CRACK LENGTH (*ao*)	= 0.469 in.
TYPE OF CRACK	FATIGUE PRECRACKED

CRACK LENGTHS:

R-SURFACE	= 0.101 in.
R-CENTER	= 0.115 in.
MID-CENTER	= 0.121 in.
L-CENTER	= 0.121 in.
L-SURFACE	= 0.111 in.

FATIGUE PRECRACKING SUMMARY

MAXIMUM FATIGUE LOAD	= 657 lbs	LOAD RATIO	= 0.1
KF (MAX)	= 18.3 ksi(sqrt. in.)	CYCLES	= 97091
FATIGUE CRACKING DATE			

TEST RESULTS :

MAXIMUM LOAD (Pmax)	= 2821 lbs	DEPARTURE LOAD (PDL)	= 987 lbs
STRESS INTENSITY (Kc)	= 192.6 ksi(sqrt. in.)	STRESS INTENSITY AT PD	= 27.5 ksi(sqrt. in.)
DISPLACEMENT AT Pmax	= 0.0536 in.	DISPLACEMENT AT PD	= 0.0053 in.
NET SECTION STRESS (SIGMA)	= 175.2 ksi	K-RATE	= 1.58 ksi(sqrt. in.)/s
Kapp	= 78.5 ksi(sqrt. in.)	EFFECTIVE MODULUS	= 27.9 Msi
r_y	= 0.2328 in.	E/E_{EFF}	= 1.08

VALIDITY CHECKS PER ASTM E561-08e1

1. (E561 8.6.2) THE FATIGUE PRECRACK SHALL EXTEND FROM THE STARTER NOTCH BY >= 0.05 in. VALID
2. (E561 8.6.2) THE FATIGUE PRECRACK MUST EXTEND BEYOND THE ENVELOPE. VALID
3. (E561 8.6.3) THE ORIGINAL CRACK SIZE, ao, SHALL BE WITHIN THE RANGE OF 0.35 TO 0.55W. VALID
   Original Crack Size (ao) = 0.469 in. 0.432 in < Original Crack Size < 0.694 in
4. (E561 9.5) APPLY A DISPLACEMENT RATE DURING THE INITIAL LINEAR PORTION OF THE FORCE-CMOD CURVE THAT WILL RESULT IN A CHANGE IN K BETWEEN 0.5 AND 2.5 KSI. SQ.RT.IN/S. VALID
   = 1.58 ksi(sqrt. in.)/s
5. (E561 8.6.5) THE REMAINING UNCRACKED LIGAMENT (W-ap) MUST BE > 4/π(KR/YS)^2. INVALID
   (W -ap) = 0.673 in. Limit = 1.862 in.

TEST IS INVALID: *** KC = 192.6 ksi(sqrt. in.)
*** KAPP = 78.5 ksi(sqrt. in.)

STEVEN ZASADNY - JD ROSSI - TOM FEDOR - KEN GALLO

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Westmoreland Mechanical Testing & Research, Inc.

R-Curve Graph

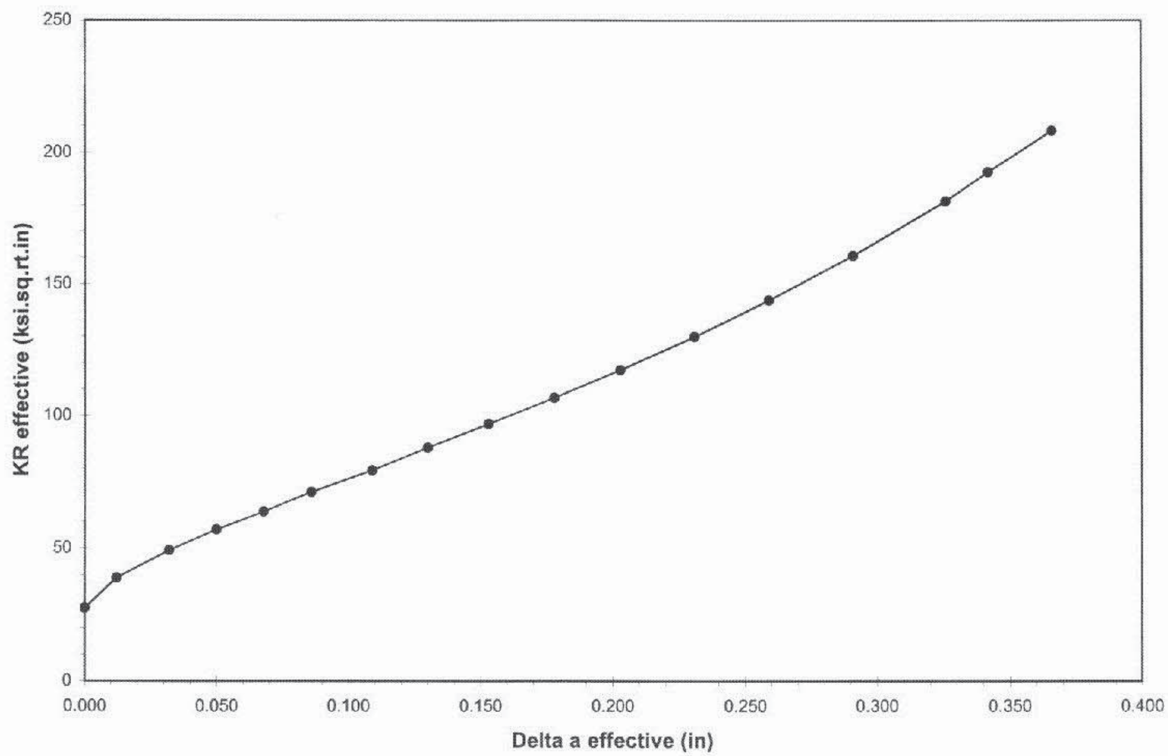
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE NO. : QN121622 REV.1

TESTLOG : S41401
TEST DATE : 04-12-13

ALLOY & TEMPER : Steel-N/A

SID : KC-I-B-4



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COMPACT TENSION FRACTURE TOUGHNESS R-CURVE TABULAR DATA (ASTM E561-08e1)

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962

SID : KC-I-B-4
TESTLOG : S41401

Secant (%)	Force (lbs)	CMOD (in)	a_{eff} (in)	Δa_{eff} (in)	K_{Reff} (ksi.sqrtin)	a_{phys} (in)	Δa_{phys} (in)	K_{Rphys} (ksi.sqrtin)	r_Y	σ_{net} (ksi)	K_{app} (ksi.sqrtin)	$R_v = 8 * R_y/(W-a_p)$	VALID
0.0	987	0.0053	0.469	0.000	27.5	0.452	0.000	26.5	0.0166	41.7	27.5	0.17	0
5.0	1362	0.0076	0.481	0.012	38.9	0.450	-0.002	36.4	0.0312	57.2	37.9	0.31	0
10.0	1652	0.0098	0.501	0.032	49.2	0.454	0.002	44.6	0.0468	70.2	46.0	0.47	0
15.0	1848	0.0116	0.519	0.050	57.1	0.459	0.007	50.4	0.0598	79.7	51.4	0.60	0
20.0	1984	0.0132	0.537	0.068	63.8	0.466	0.014	54.9	0.0709	87.3	55.2	0.72	0
25.0	2125	0.0150	0.555	0.086	71.1	0.472	0.020	59.5	0.0833	95.1	59.1	0.86	0
30.0	2251	0.0171	0.578	0.109	79.3	0.481	0.029	64.2	0.0971	103.4	62.6	1.01	1
35.0	2375	0.0194	0.599	0.130	87.9	0.488	0.036	68.8	0.1112	111.4	66.1	1.17	1
40.0	2478	0.0219	0.622	0.153	96.9	0.496	0.044	73.0	0.1256	119.0	69.0	1.33	1
45.0	2567	0.0248	0.647	0.178	106.8	0.506	0.054	77.2	0.1406	127.1	71.4	1.51	1
50.0	2640	0.0280	0.672	0.203	117.3	0.517	0.065	81.3	0.1553	135.1	73.5	1.69	1
55.0	2708	0.0320	0.700	0.231	129.9	0.528	0.076	85.4	0.1718	143.4	75.4	1.90	1
60.0	2766	0.0367	0.728	0.259	143.9	0.540	0.088	89.5	0.1884	152.0	77.0	2.12	1
65.0	2799	0.0425	0.760	0.291	160.7	0.554	0.102	93.4	0.2057	160.8	77.9	2.36	1
70.0	2815	0.0498	0.795	0.326	181.6	0.571	0.119	97.6	0.2242	170.8	78.3	2.64	1
72.1P	2821	0.0536	0.811	0.342	192.6	0.578	0.126	99.4	0.2328	175.2	78.5	2.77	1
75.0	2792	0.0593	0.835	0.366	208.4	0.592	0.140	101.6	0.2431	181.7	77.7	2.95	1

a_{eff} - effective crack length (in)

Δa_{eff} - change in a-effective (in)

K_{Reff} - incremental r-curve stress intensity values based on effective crack length (ksi.sqrtin)

a_{phys} - physical crack Length (in)

Δa_{phys} - change in a-physical (in)

K_{Rphys} - incremental r-curve stress Intensity values based on physical crack length (ksi.sqrtin)

r_Y - plastic zone adjustment (in)

σ_{net} - net section stress (ksi)

K_{app} - apparent stress intensity (ksi.sqrtin)

R_v - validity check 8 * ry / (w - ap) < or = 1.0

'0' indicates a valid check '1' indicates an invalid check.

"NOTE: THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHABLE AS A FELONY UNDER FEDERAL STATUTE."

KC-I-B-5

AO SMITH 1146a

INNER LAYER

PLANE STRESS FRACTURE TOUGHNESS

L-T

-20ºF

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

COMPACT TENSION FRACTURE TOUGHNESS TEST REPORT (ASTM E561-08e1)

PRELIMINARY INFORMATION :

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SID : KC-I-B-5

MATERIAL SPEC : N/A

WMT&R NO. : 3-55962
ALLOY & TEMPER : Steel-N/A
PRODUCT THICKNESS: N/A
TEST TYPE : 0.625-C(T) N/A
TEST DATE : 04-12-13
TEST YIELD STR.(YS2) : 82.2 ksi

TESTLOG : S41402
PRODUCT: N/A

TEST PLANE : N/A
TEST TEMPERATURE : -20°F
MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS :

THICKNESS (*B*)	= 0.219 in.
WIDTH (*W*)	= 1.252 in.
ORIGINAL CRACK LENGTH (*aN*)	= 0.350 in.
EFFECTIVE CRACK LENGTH (*ae*)	= 0.786 in.
PHYSICAL CRACK LENGTH (*ap*)	= 0.567 in.
TOTAL CRACK LENGTH (*ao*)	= 0.476 in.
TYPE OF CRACK	FATIGUE PRECRACKED

CRACK LENGTHS:

R-SURFACE	= 0.122 in.
R-CENTER	= 0.129 in.
MID-CENTER	= 0.129 in.
L-CENTER	= 0.120 in.
L-SURFACE	= 0.103 in.

FATIGUE PRECRACKING SUMMARY

MAXIMUM FATIGUE LOAD	= 641 lbs	LOAD RATIO	= 0.1
KF (MAX)	= 18.1 ksi(sqrt. in.)	CYCLES	= 132730
FATIGUE CRACKING DATE			

TEST RESULTS :

MAXIMUM LOAD (Pmax)	= 2813 lbs	DEPARTURE LOAD (PDL)	= 1029 lbs
STRESS INTENSITY (Kc)	= 175.6 ksi(sqrt. in.)	STRESS INTENSITY AT PD	= 29 ksi(sqrt. in.)
DISPLACEMENT AT Pmax	= 0.0482 in.	DISPLACEMENT AT PD	= 0.0057 in.
NET SECTION STRESS (SIGMA)	= 168.1 ksi	K-RATE	= 1.62 ksi(sqrt. in.)/s
Kapp	= 79.3 ksi(sqrt. in.)	EFFECTIVE MODULUS	= 27.6 Msi
r_y	= 0.2192 in.	E/E_{EFF}	= 1.09

VALIDITY CHECKS PER ASTM E561-08e1

1. (E561 8.6.2) THE FATIGUE PRECRACK SHALL EXTEND FROM THE STARTER NOTCH BY > = 0.05 in. VALID
2. (E561 8.6.2) THE FATIGUE PRECRACK MUST EXTEND BEYOND THE ENVELOPE. VALID
3. (E561 8.6.3) THE ORIGINAL CRACK SIZE, ao, SHALL BE WITHIN THE RANGE OF 0.35 TO 0.55W. VALID
   Original Crack Size (ao) = 0.476 in. 0.432 in < Original Crack Size < 0.695 in
4. (E561 9.5) APPLY A DISPLACEMENT RATE DURING THE INITIAL LINEAR PORTION OF THE FORCE-CMOD CURVE THAT WILL RESULT IN A CHANGE IN K BETWEEN 0.5 AND 2.5 KSI. SQ.RT.IN/S. VALID
   = 1.62 ksi(sqrt. in.)/s
5. (E561 8.6.5) THE REMAINING UNCRACKED LIGAMENT (W-ap) MUST BE > 4/π(KR/YS)^2. INVALID
   (W -ap) = 0.685 in. Limit = 1.755 in.

TEST IS INVALID: * KC = 175.6 ksi(sqrt. in.)**

***** KAPP = 79.3 ksi(sqrt. in.)**

STEVEN ZASADNY - JD ROSSI - TOM FEDOR - KEN GALLO

Westmoreland Mechanical Testing & Research, Inc.

R-Curve Graph

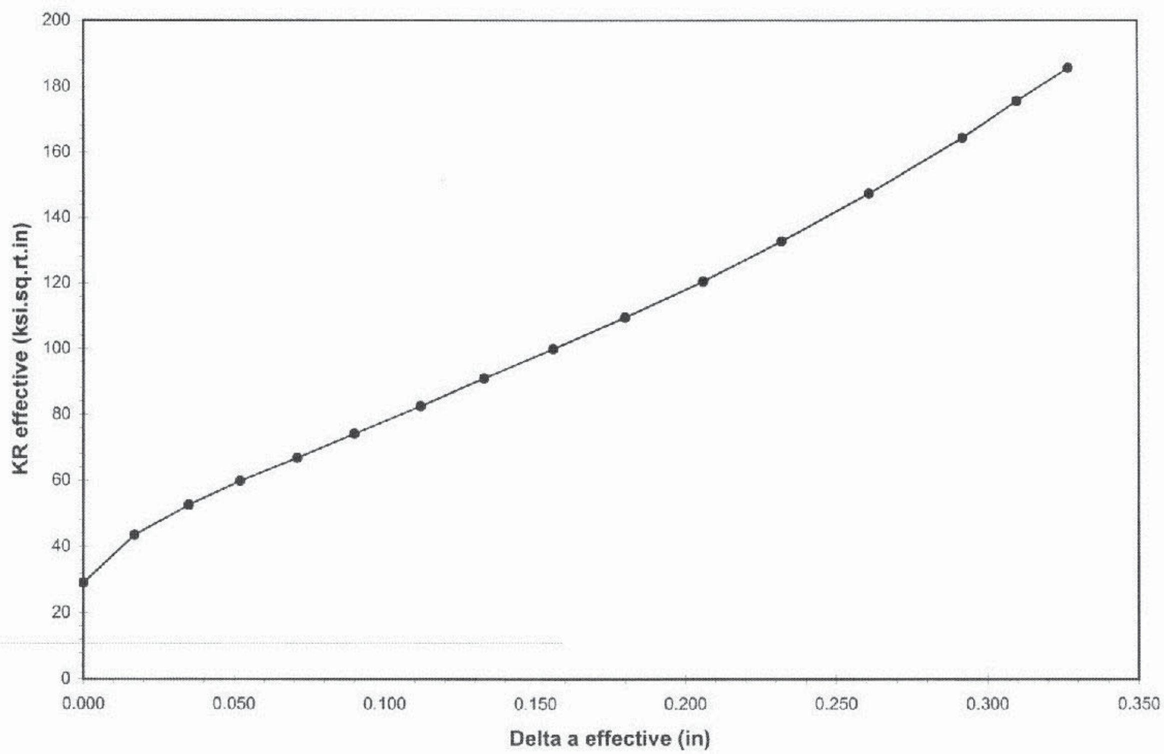
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE NO. : QN121622 REV.1

TESTLOG : S41402
TEST DATE : 04-12-13

ALLOY & TEMPER : Steel-N/A

SID : KC-I-B-5



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WESTMORELAND MECHANICAL TESTING & RESEARCH
Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

COMPACT TENSION FRACTURE TOUGHNESS R-CURVE TABULAR DATA (ASTM E561-08e1)

CUSTOMER : SOUTHWEST RESEARCH WMT&R NO. : 3-55962
SID : KC-I-B-5 TESTLOG : S41402

Secant (%)	Force (lbs)	CMOD (in)	a_{eff} (in)	Δa_{eff} (in)	K_{Reff} (ksi.sqrtin)	a_{phys} (in)	Δa_{phys} (in)	K_{Rphys} (ksi.sqrtin)	r_Y	σ_{net} (ksi)	K_{app} (ksi.sqrtin)	$R_v = 8 * R_y/(W-a_p)$	VALID
0.0	1029	0.0057	0.476	0.000	29.0	0.458	0.000	28.0	0.0184	44.2	29.0	0.19	0
5.0	1488	0.0087	0.493	0.017	43.5	0.455	-0.003	40.2	0.0380	63.3	42.0	0.38	0
10.0	1731	0.0107	0.511	0.035	52.5	0.459	0.001	47.1	0.0522	74.5	48.8	0.53	0
15.0	1901	0.0124	0.528	0.052	59.8	0.464	0.006	52.3	0.0643	83.0	53.6	0.65	0
20.0	2036	0.0141	0.547	0.071	66.8	0.471	0.013	56.8	0.0760	90.7	57.4	0.78	0
25.0	2165	0.0160	0.566	0.090	74.1	0.478	0.020	61.3	0.0884	98.4	61.1	0.91	0
30.0	2292	0.0182	0.588	0.112	82.5	0.486	0.028	66.0	0.1024	106.7	64.6	1.07	1
35.0	2406	0.0205	0.609	0.133	91.0	0.493	0.035	70.3	0.1163	114.3	67.8	1.23	1
40.0	2497	0.0231	0.632	0.156	99.9	0.502	0.044	74.4	0.1301	121.9	70.4	1.39	1
45.0	2579	0.0260	0.656	0.180	109.6	0.511	0.053	78.3	0.1446	129.3	72.7	1.56	1
50.0	2647	0.0294	0.682	0.206	120.6	0.522	0.064	82.3	0.1596	137.3	74.6	1.75	1
55.0	2711	0.0334	0.708	0.232	132.8	0.533	0.075	86.3	0.1752	145.4	76.5	1.95	1
60.0	2766	0.0383	0.737	0.261	147.5	0.545	0.087	90.4	0.1922	154.1	78.0	2.17	1
65.0	2797	0.0443	0.768	0.292	164.4	0.559	0.101	94.3	0.2092	162.9	78.9	2.42	1
67.6P	2813	0.0482	0.786	0.310	175.6	0.567	0.109	96.5	0.2192	168.1	79.3	2.56	1
70.0	2805	0.0518	0.803	0.327	185.7	0.576	0.118	98.2	0.2271	172.7	79.1	2.69	1

a_{eff} - effective crack length (in)
Δa_{eff} - change in a-effective (in)
K_{Reff} - incremental r-curve stress intensity values based on effective crack length (ksi.sqrtin)
a_{phys} - physical crack Length (in)
Δa_{phys} - change in a-physical (in)
K_{Rphys} - incremental r-curve stress Intensity values based on physical crack length (ksi.sqrtin)
r_Y - plastic zone adjustment (in)
σ_{net} - net section stress (ksi)
K_{app} - apparent stress intensity (ksi.sqrtin)
R_v - validity check 8 * ry / (w - ap) < or = 1.0
'0' indicates a valid check '1' indicates an invalid check.

"NOTE: THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHABLE AS A FELONY UNDER FEDERAL STATUTE."

KC-I-B-6

AO SMITH 1146a

INNER LAYER

PLANE STRESS FRACTURE TOUGHNESS

L-T

-20°F

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

COMPACT TENSION FRACTURE TOUGHNESS TEST REPORT (ASTM E561-08e1)

PRELIMINARY INFORMATION :

CUSTOMER : SOUTHWEST RESEARCH	
P.O. NO. : F58154BT	
SID : KC-I-B-6	MATERIAL SPEC : N/A
WMT&R NO. : 3-55962	TESTLOG : S41403
ALLOY & TEMPER : Steel-N/A	PRODUCT: N/A
PRODUCT THICKNESS: N/A	
TEST TYPE : 0.625-C(T) N/A	TEST PLANE : N/A
TEST DATE : 04-12-13	TEST TEMPERATURE : -20°F
TEST YIELD STR (YS2) : 82.2 ksi	MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS :

THICKNESS (*B*)	= 0.220 in.
WIDTH (*W*)	= 1.252 in.
ORIGINAL CRACK LENGTH (*aN*)	= 0.350 in.
EFFECTIVE CRACK LENGTH (*ae*)	= 0.794 in.
PHYSICAL CRACK LENGTH (*ap*)	= 0.579 in.
TOTAL CRACK LENGTH (*ao*)	= 0.478 in.
TYPE OF CRACK	FATIGUE PRECRACKED

CRACK LENGTHS:

R-SURFACE	= 0.116 in.
R-CENTER	= 0.128 in.
MID-CENTER	= 0.131 in.
L-CENTER	= 0.126 in.
L-SURFACE	= 0.111 in.

FATIGUE PRECRACKING SUMMARY

MAXIMUM FATIGUE LOAD	= 584 lbs	LOAD RATIO	= 0.1
KF (MAX)	= 16.5 ksi(sqrt. in.)	CYCLES	= 121864
FATIGUE CRACKING DATE			

TEST RESULTS :

MAXIMUM LOAD (Pmax)	= 2724 lbs	DEPARTURE LOAD (PDL)	= 934 lbs
STRESS INTENSITY (Kc)	= 173.9 ksi(sqrt. in.)	STRESS INTENSITY AT PD	= 26.3 ksi(sqrt. in.)
DISPLACEMENT AT Pmax	= 0.0464 in.	DISPLACEMENT AT PD	= 0.0050 in.
NET SECTION STRESS (SIGMA)	= 168.6 ksi	K-RATE	= 1.79 ksi(sqrt. in.)/s
Kapp	= 76.8 ksi(sqrt. in.)	EFFECTIVE MODULUS	= 28.6 Msi
r_y	= 0.2152 in.	E/E_{EFF}	= 1.05

VALIDITY CHECKS PER ASTM E561-08e1

1. (E561 8.6.2) THE FATIGUE PRECRACK SHALL EXTEND FROM THE STARTER NOTCH BY > = 0.05 in. VALID
2. (E561 8.6.2) THE FATIGUE PRECRACK MUST EXTEND BEYOND THE ENVELOPE. VALID
3. (E561 8.6.3) THE ORIGINAL CRACK SIZE, ao, SHALL BE WITHIN THE RANGE OF 0.35 TO 0.55W. VALID
   Original Crack Size (ao) = 0.478 in. 0.432 in < Original Crack Size < 0.695 in
4. (E561 9.5) APPLY A DISPLACEMENT RATE DURING THE INITIAL LINEAR PORTION OF THE FORCE-CMOD CURVE THAT WILL RESULT IN A CHANGE IN K BETWEEN 0.5 AND 2.5 KSI. SQ.RT.IN/S. VALID
   = 1.79 ksi(sqrt. in.)/s
5. (E561 8.6.5) THE REMAINING UNCRACKED LIGAMENT (W-ap) MUST BE > 4/π(KR/YS)^2. INVALID
   (W -ap) = 0.673 in. Limit = 1.722 in.

TEST IS INVALID: *** KC = 173.9 ksi(sqrt. in.)
*** KAPP = 76.8 ksi(sqrt. in.)

STEVEN ZASADNY - JD ROSSI - TOM FEDOR - KEN GALLO

Westmoreland Mechanical Testing & Research, Inc.

R-Curve Graph

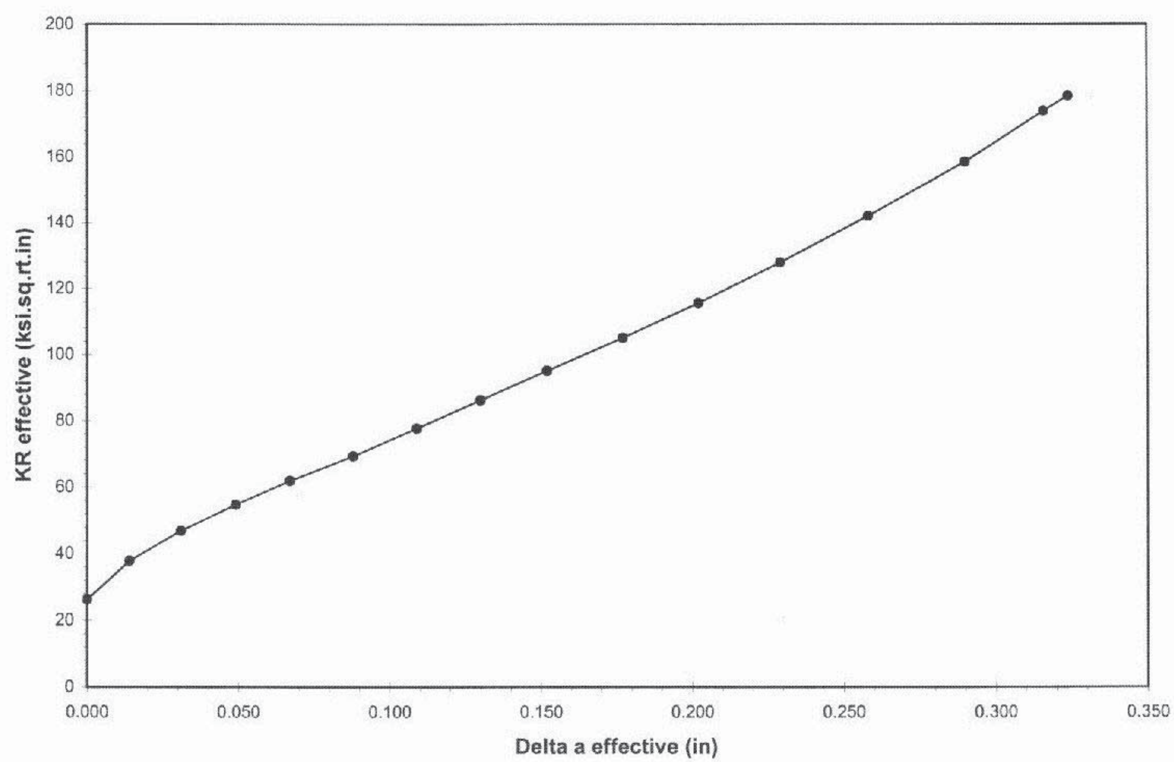
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE NO. : QN121622 REV.1

TESTLOG : S41403
TEST DATE : 04-12-13

ALLOY & TEMPER : Steel-N/A

SID : KC-I-B-6



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WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

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COMPACT TENSION FRACTURE TOUGHNESS R-CURVE TABULAR DATA (ASTM E561-08e1)

CUSTOMER : SOUTHWEST RESEARCH — WMT&R NO. : 3-55962

SID : KC-I-B-6 — TESTLOG : S41403

Secant (%)	Force (lbs)	CMOD (in)	a_{eff} (in)	Δa_{eff} (in)	K_{Reff} (ksi.sqrtin)	a_{phys} (in)	Δa_{phys} (in)	K_{Rphys} (ksi sqrtin)	r_Y	σ_{net} (ksi)	K_{app} (ksi.sqrtin)	$R_v = 8 * R_y/(W-a_p)$	VALID
0.0	934	0.0050	0.478	0.000	26.3	0.463	0.000	25.5	0.0153	40.5	26.3	0.16	0
5.0	1305	0.0073	0.492	0.014	37.9	0.462	-0.001	35.6	0.0298	56.4	36.8	0.30	0
10.0	1560	0.0092	0.509	0.031	46.9	0.466	0.003	42.9	0.0433	68.2	44.0	0.44	0
15.0	1748	0.0109	0.527	0.049	54.7	0.471	0.008	48.6	0.0556	77.5	49.3	0.57	0
20.0	1902	0.0126	0.545	0.067	61.9	0.477	0.014	53.5	0.0676	85.8	53.6	0.70	0
25.0	2035	0.0144	0.566	0.088	69.3	0.486	0.023	58.3	0.0801	94.3	57.4	0.84	0
30.0	2173	0.0165	0.587	0.109	77.7	0.493	0.030	63.2	0.0941	102.8	61.3	0.99	0
35.0	2294	0.0187	0.608	0.130	86.2	0.500	0.037	67.7	0.1080	110.8	64.7	1.15	1
40.0	2401	0.0212	0.630	0.152	95.1	0.508	0.045	72.1	0.1223	118.8	67.7	1.32	1
45.0	2490	0.0240	0.655	0.177	105.1	0.518	0.055	76.4	0.1372	127.0	70.2	1.50	1
50.0	2565	0.0272	0.680	0.202	115.7	0.528	0.065	80.4	0.1521	134.9	72.3	1.68	1
55.0	2631	0.0310	0.707	0.229	127.9	0.539	0.076	84.4	0.1679	143.2	74.2	1.88	1
60.0	2684	0.0356	0.736	0.258	142.1	0.551	0.088	88.4	0.1846	151.7	75.7	2.11	1
65.0	2709	0.0411	0.768	0.290	158.5	0.567	0.104	92.5	0.2013	161.2	76.4	2.35	1
68.9P	2724	0.0464	0.794	0.316	173.9	0.579	0.116	95.6	0.2152	168.6	76.8	2.56	1
70.0	2719	0.0481	0.802	0.324	178.5	0.583	0.120	96.3	0.2187	170.5	76.6	2.62	1

a_{eff} - effective crack length (in)
Δa_{eff} - change in a-effective (in)
K_{Reff} - incremental r-curve stress intensity values based on effective crack length (ksi.sqrtin)
a_{phys} - physical crack Length (in)
Δa_{phys} - change in a-physical (in)
K_{Rphys} - incremental r-curve stress Intensity values based on physical crack length (ksi.sqrtin)
r_Y - plastic zone adjustment (in)
σ_{net} - net section stress (ksi)
K_{app} - apparent stress intensity (ksi.sqrtin)
R_v - validity check 8 * ry / (w - ap) < or = 1.0
'0' indicates a valid check '1' indicates an invalid check.

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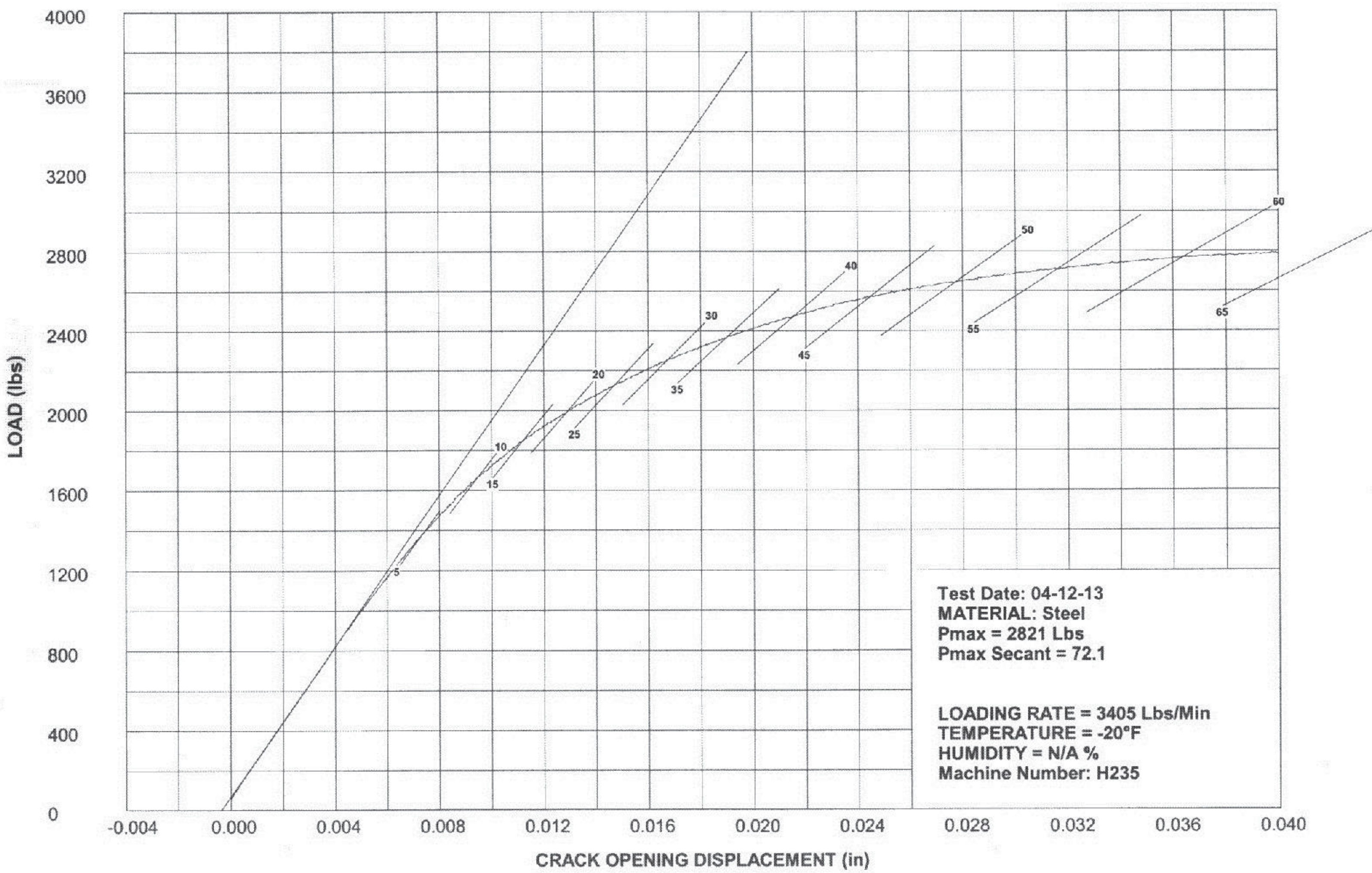
WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.
LOAD vs CRACK OPENING DISPLACEMENT Phone 724-537-3131

Customer: Southwest Research
SID: KC-I-B-4

WMT&R Report: 3-55962
P.O. No.: F58154BT
WMT&R Quote No.: QN121622 Rev.1



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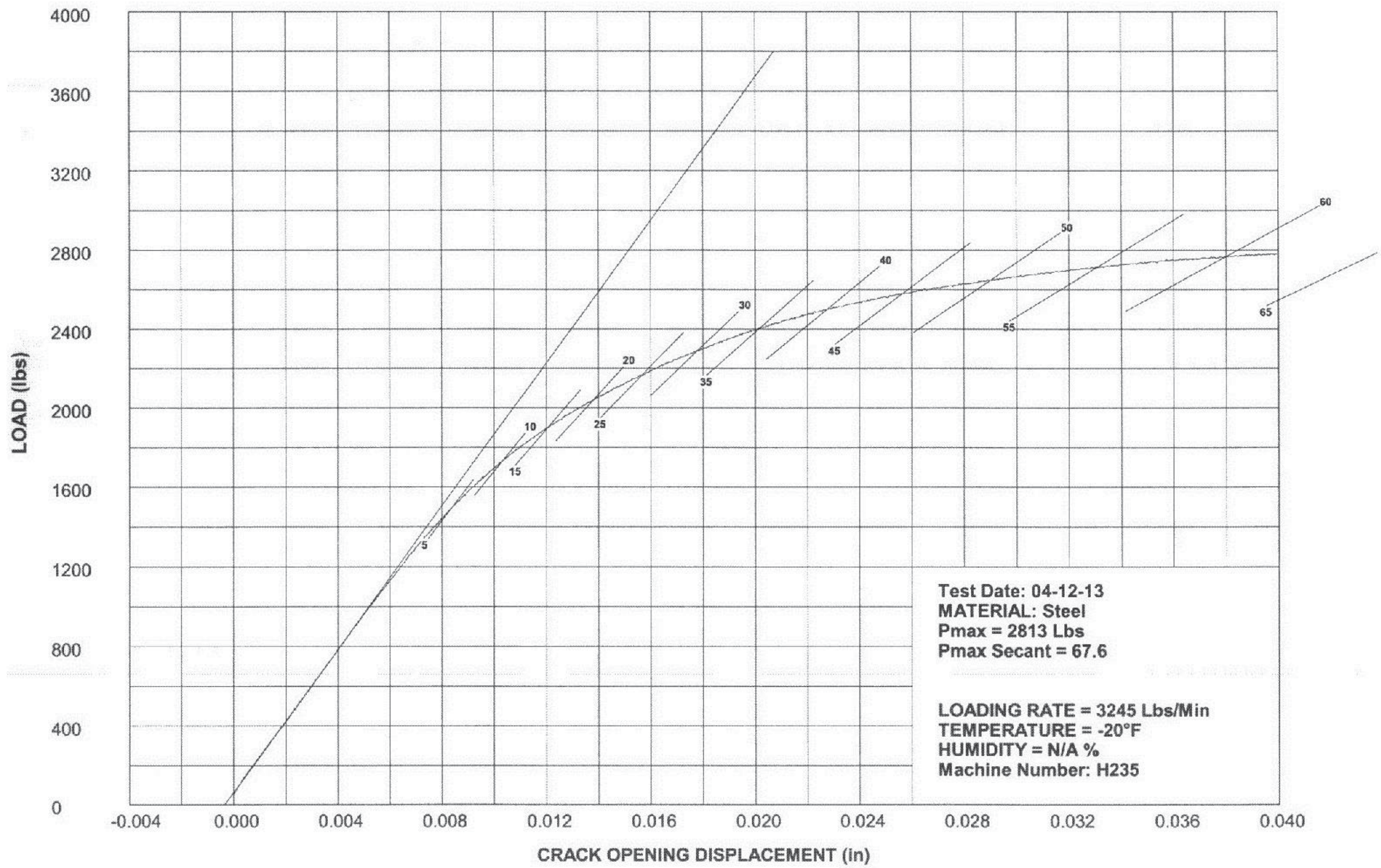
TESTLOG S41401

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.

LOAD vs CRACK OPENING DISPLACEMENT Phone 724-537-3131

Customer: Southwest Research
SID: KC-I-B-5

WMT&R Report: 3-55962
P.O. No.: F58154BT
WMT&R Quote No.: QN121622 Rev.1



1.4

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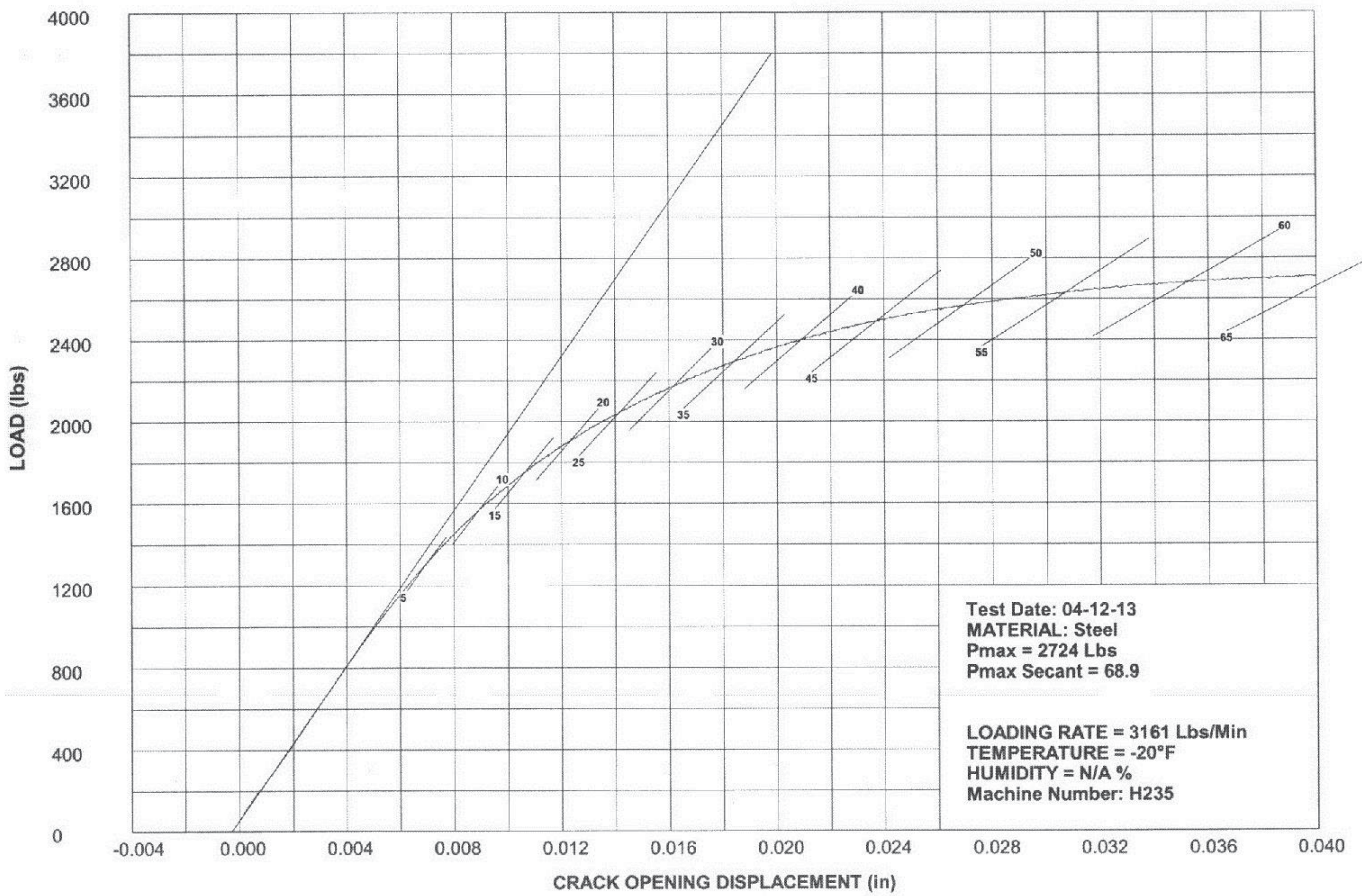
TESTLOG S41402

WESTMORELAND MECHANICAL TESTING & RESEARCH, Inc.
LOAD vs CRACK OPENING DISPLACEMENT
Phone 724-537-3131

Customer: Southwest Research
SID: KC-I-B-6

WMT&R Report: 3-55962
P.O. No.: F58154BT
WMT&R Quote No.: QN121622 Rev.1



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TESTLOG S41403

AO SMITH 1146a
J_{IC} FRACTURE TOUGHNESS

ID	*Layer*	*Orientation*	*Temp*
J-I-B-1	Inner	L-T	RT
J-I-B-2*			-20°F
J-O-B-1	Outer	L-T	RT
J-O-B-2			-20°F

* Specimen data sheet inadvertently refers to repeated Specimen ID J-I-B-1.

Westmoreland Mechanical Testing & Research, Inc.
P.O.Box 388; 221 Westmoreland Drive
Youngstown, PA 15696-0388 U.S.A.
Telephone: 724-537-3131 Fax: 724-537-3151
Website: www.wmtr.com E-Mail: admin@wmtr.com
WMT&R is a technical leader in the material testing industry.

June 14, 2013

Southwest Research Institute
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78238

WMT&R Report 3-55962
P.O.No. F58154BT
WMT&R Quote QN121622 Rev. 1

Attention: Mr. Carl Popelar

Subject: J-Integral Test Results

Introduction:

Four (4) compact tension specimens submitted as Steel material were received by Westmoreland Mechanical Testing and Research, Inc. for J-Integral testing per ASTM E1820-11. The specimens were machined to a nominal width (W) measuring 1.00 in., fatigue precracked to a final a/W of approximately 0.50, and then side grooved to a depth equal to 20% of the nominal thickness (10% per side).

Two (2) specimens were tested at room temperature and two (2) at -20°F. The specimens were tested using an Instron servo-hydraulic test stand and an automated computer controlled testing procedure. Analysis of the test data was done using tensile data provided by Southwest Research Institute.

Results are summarized in Table 1.

Data sheets containing validity and tabular data are enclosed for the specimens. Graphs of J vs. a and *Force* vs. *COD* are also included.

If you have any questions concerning this report, please feel free to contact me. If I am unavailable, you may also speak with Mr. Douglas M. Bruce, Materials Engineering Manager.

At your service,

Gerald W. Boice
R&D Manager

mr

K:\JERRY\3W55962J.SOU.DOC

Westmoreland Mechanical Testing & Research, Inc.

Table 1 - JIC Results (ASTM E1820-11)

Phone (724) 537-3131

Customer : Southwest Research Institute
P.O. No. : F58154BT
WMT&R Quote : QN121622 Rev. 1

WMT&R Report : 3-55962
Material : Steel

Testlog Number	Specimen	Temperature	J_{Ic} (in lb/in^2)	K_{JIc} (ksi$\sqrt{in}$)	J_Q (in lb/in^2)	K_{JQ} (ksi$\sqrt{in}$)	K_{Ic} Determination (Annex 5)		Unstable
							P_Q (lb)	K_Q (ksi$\sqrt{in}$)	
S70801	J-I-B-1	Room	848.82	170.46	---	---	1025.9	35.2	No
S70802	J-I-B-1	-20°F	---	---	829.57	170.61	1196.9	39.7	No
S70803	J-O-B-1	Room	---	---	629.19	148.56	1176.9	54.5	No
S70804	J-O-B-2	-20°F	772.72	162.51	---	---	1081.4	49.0	Yes

Gerald W. Boice -- Thomas S. Fedor

J-I-B-1

AO SMITH 1146a

INNER LAYER

J_{IC} FRACTURE TOUGHNESS

L-T

RT

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
SID : J-I-B-1
TESTLOG : S70801
TEST DATE : 5/7/2013

MATERIAL : STEEL
WMT&R QUOTE : QN121622 REV. 1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.15 Msi
ULTIMATE STRENGTH : 119.1 ksi
YIELD STRENGTH : 82.2 ksi
EFFECTIVE YIELD STRENGTH : 100.7 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.324 in	TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.01 in/min
NET THICKNESS (B_N)	: 0.258 in	TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.01 in/min
EFFECTIVE THICKNESS (B_e)	: 0.311 in	ORIENTATION	: T-L	PARTIAL UNLOADING RATE	: 0.01 in/min
WIDTH (W)	: 1.002 in	TEST MACHINE	: H1	UNLOADING INTERVAL	: 0.0005 in
UNCRACKED LIGAMENT (b_o)	: 0.492 in	CLIP GAGE	: 10277363C	HOLDTIME	: 5.0 sec.
NOTCH LENGTH (a_n)	: 0.457 in	CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

(TEST PARAMETERS)

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.505 in	0.509 in	0.511 in	0.513 in	0.515 in	0.512 in	0.510 in	0.507 in	0.503 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.562 in	0.567 in	0.561 in	0.564 in	0.586 in	0.590 in	0.575 in	0.580 in	0.577 in

PRECRACK AVERAGE : 0.5101 in — FINAL AVERAGE : 0.5741 in
PRECRACK a/W : 0.5091 — FINAL a/W : 0.5729

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 574 lb	FINAL P_{max}	: 506 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 110737	FINAL K_{max}	: 15.50 ksi(in)$^{1/2}$		

ORIGINAL CRACK		FINAL CRACK		MODULUS	
PHYSICAL CRACK SIZE (a_o)	: 0.5101 in	PHYSICAL CRACK SIZE (a_p)	: 0.5741 in	MODULUS	: 31.15 Msi
EST. CRACK SIZE (a_{oq})	: 0.5099 in	EST. CRACK SIZE ($a_{predicted}$)	: 0.5757 in	EFFECTIVE MODULUS	: 31.18 Msi
PERCENT DIFFERENCE	: 0.04 %	PERCENT DIFFERENCE	: 0.29 %	PERCENT DIFFERENCE	: 0.10 %

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE FATIGUE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, *a/W*) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   $a/W = 0.5091$
2. (9.1.5.2) DIFFERENCE BETWEEN PREDICTED ($\Delta a_{predicted}$) AND MEASURED (Δa_p) CRACK EXTENSION SHALL NOT EXCEED 0.15 Δa_p FOR CRACK EXTENSIONS LESS THAN 0.2 b_o AND 0.03 b_o THEREAFTER — VALID
   Difference = 0.0019 in $0.15\Delta a_p = 0.0096$ in
3. (A9.7.2.1) a_{oq} SHALL NOT DIFFER FROM a_o BY MORE THAN THE LARGER OF 0.01 W OR 0.0197 IN. — VALID
   Difference = 0.0002 in Limit = 0.0197 in
4. (A9.7.2.2) NUMBER OF DATA AVAILABLE TO CALCULATE a_{oq} SHALL BE ≥ 8; NUMBER OF DATA BETWEEN $0.4J_Q$ AND J_Q SHALL BE ≥ 3; CORRELATION COEFFICIENT OF THE LEAST SQUARES FIT SHALL BE > 0.96 — VALID
   a_{oq} Points = 42 Data Points = 16 C.C. = 0.99916
5. (A9.7.1) POWER COEFFICIENT C_2 SHALL BE LESS THAN 1.0 — VALID
   $C_2 = 0.5884$
6. (A9.8.1) THICKNESS, $B > 10J_Q/\sigma_Y$ — VALID
   $B = 0.3240$ in $10J_Q/\sigma_Y = 0.0843$ in
7. (A9.8.2) INITIAL LIGAMENT, $b_o > 10J_Q/\sigma_Y$ — VALID
   $b_o = 0.4919$ in $10J_Q/\sigma_Y = 0.0843$ in
8. (A9.6.6.6) AT LEAST FIVE DATA POINTS MUST REMAIN BETWEEN a_{min} AND a_{limit} AND J_{limit} — VALID
   Data Points = 45
9. (A9.6.4) AT LEAST ONE *J-Δa* POINT SHALL LIE BETWEEN THE 0.006-in EXCLUSION LINE AND A 0.02-in OFFSET LINE. AT LEAST ONE *J-Δa* POINT SHALL LIE BETWEEN THE 0.02-in OFFSET LINE AND THE 0.06-in EXCLUSION LINE. — VALID

TEST IS VALID: $J_{Ic} = 848.82$ in-lb/in^2

$K_{JIc} = 170.46$ ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
SID : J-I-B-1
TESTLOG : S70801
TEST DATE : 5/7/2013

MATERIAL : STEEL

WMT&R QUOTE : QN121622 REV. 1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.15 Msi
ULTIMATE STRENGTH : 119.1 ksi
YIELD STRENGTH : 82.2 ksi
EFFECTIVE YIELD STRENGTH : 100.7 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.324 in	WIDTH (W)	: 1.002 in
NET THICKNESS (B_N)	: 0.258 in	UNCRACKED LIGAMENT (b_o)	: 0.492 in
EFFECTIVE THICKNESS (B_e)	: 0.311 in	NOTCH LENGTH (a_n)	: 0.457 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.01 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.01 in/min
ORIENTATION	: T-L	PARTIAL UNLOADING RATE	: 0.01 in/min
TEST MACHINE	: H1	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10277363C	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.505 in	0.509 in	0.511 in	0.513 in	0.515 in	0.512 in	0.510 in	0.507 in	0.503 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.562 in	0.567 in	0.561 in	0.564 in	0.586 in	0.590 in	0.575 in	0.580 in	0.577 in

PRECRACK AVERAGE	: 0.5101 in	FINAL AVERAGE	: 0.5741 in
PRECRACK a/W	: 0.5091	FINAL a/W	: 0.5729

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 574 lb	FINAL P_{max}	: 506 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 110737	FINAL K_{max}	: 15.50 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 1948.1 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0531 in $0.05B$ = 0.0162 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING, THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}{}^{f} / \sigma_{YS}{}^{T})(0.4\sigma_{YS}{}^{f}\ ksi\sqrt{in})$, WHERE $\sigma_{YS}{}^{f}$ AND $\sigma_{YS}{}^{T}$ ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 15.0 ksi(in)$^{1/2}$ K_{max} Limit = 32.9 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\ (\sigma_{YS}{}^{f} / \sigma_{YS}{}^{T}) * K_F$, WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 15.5 ksi(in)$^{1/2}$ K_{max} Limit = 102.3 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0071 in $0.05B$ = 0.0162 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0159 in $0.05B$ = 0.0162 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0500 in 50% of the Average = 0.0320 in

ALL GENERAL VALIDITY CHECKS ARE VALID

GERALD W. BOICE - THOMAS S. FEDOR

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
SID : J-I-B-1
TESTLOG : S70801
TEST DATE : 5/7/2013

MATERIAL : STEEL
WMT&R QUOTE : QN121622 REV. 1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.15 Msi
ULTIMATE STRENGTH : 119.1 ksi
YIELD STRENGTH : 82.2 ksi
EFFECTIVE YIELD STRENGTH : 100.7 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.324 in
NET THICKNESS (B_N)	: 0.258 in
EFFECTIVE THICKNESS (B_e)	: 0.311 in
WIDTH (W)	: 1.002 in
UNCRACKED LIGAMENT (b_o)	: 0.492 in
NOTCH LENGTH (a_n)	: 0.457 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.01 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.01 in/min
ORIENTATION	: T-L	PARTIAL UNLOADING RATE	: 0.01 in/min
TEST MACHINE	: H1	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10277363C	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.505 in	0.509 in	0.511 in	0.513 in	0.515 in	0.512 in	0.510 in	0.507 in	0.503 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.562 in	0.567 in	0.561 in	0.564 in	0.586 in	0.590 in	0.575 in	0.580 in	0.577 in

PRECRACK AVERAGE	: 0.5101 in	FINAL AVERAGE	: 0.5741 in
PRECRACK a/W	: 0.5091	FINAL a/W	: 0.5729

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 574 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 506 lb	CYCLES	: 110737
FINAL K_{max}	: 15.50 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 1025.9 lb	MAXIMUM FORCE (P_{max})	: 1948.1 lb
K_Q	: 35.2 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 1.91

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   $a/W = 0.5091$
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE $\leq$ 1.10 — INVALID
   $P_{max}/P_Q = 1.8990$
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — VALID
   $2.5(K_Q/\sigma_{YS})^2 = 0.4590$ in $b_o = 0.4919$ in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^f / \sigma_{YS}^t) * K_F$, WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 15.5 ksi(in)$^{1/2}$ K_{max} Limit = 21.1 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 35.2 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-I-B-1
TESTLOG : S70801
TEST DATE : 5/7/2013

MATERIAL : STEEL

TEMPERATURE : 75°F

WMT&R QUOTE : QN121622 REV. 1

ORIGINAL COMPLIANCE CALCULATION : 0.5099 in
ORIGINAL PHYSICAL MEASUREMENT : 0.5101 in
MODULUS (E) : 31.15 Msi

WIDTH (W) : 1.002 in
TOTAL THICKNESS (B) : 0.324 in
NET THICKNESS (B_N) : 0.258 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0045	1064.2	0.12	1.17	39.11	40.28	4.002E-06	38.79	0.9998	0.5106	0.0006
2	0.0051	1166.3	0.39	5.95	46.94	52.89	4.000E-06	38.77	0.9998	0.5105	0.0006
3	0.0059	1269.6	0.80	13.31	55.59	68.90	3.996E-06	38.75	0.9999	0.5104	0.0005
4	0.0065	1342.9	1.20	20.45	62.16	82.61	3.993E-06	38.73	0.9998	0.5103	0.0004
5	0.0071	1409.9	1.70	29.23	68.56	97.79	3.994E-06	38.75	0.9998	0.5104	0.0005
6	0.0078	1482.2	2.32	40.32	75.87	116.19	3.997E-06	38.79	0.9998	0.5106	0.0007
7	0.0085	1524.0	3.01	52.61	80.26	132.87	3.998E-06	38.81	0.9998	0.5107	0.0008
8	0.0092	1567.0	3.80	66.56	84.93	151.49	4.000E-06	38.84	0.9998	0.5108	0.0009
9	0.0099	1608.6	4.69	82.28	89.84	172.12	4.011E-06	38.96	0.9998	0.5114	0.0015
10	0.0108	1654.8	5.89	103.61	95.14	198.75	4.011E-06	38.98	0.9998	0.5115	0.0016
11	0.0117	1680.7	7.16	126.11	98.32	224.43	4.016E-06	39.04	0.9998	0.5118	0.0019
12	0.0126	1700.0	8.44	148.96	100.77	249.74	4.020E-06	39.10	0.9997	0.5121	0.0022
13	0.0137	1718.2	10.21	180.41	103.03	283.44	4.021E-06	39.12	0.9996	0.5123	0.0023
14	0.0144	1730.0	11.35	200.52	104.75	305.27	4.029E-06	39.21	0.9997	0.5127	0.0028
15	0.0153	1739.9	12.81	226.22	106.24	332.47	4.036E-06	39.30	0.9997	0.5131	0.0032
16	0.0164	1769.6	14.42	254.72	110.30	365.02	4.046E-06	39.41	0.9997	0.5137	0.0038
17	0.0172	1770.4	15.95	281.94	110.54	392.48	4.049E-06	39.45	0.9996	0.5139	0.0040
18	0.0183	1794.6	17.64	311.62	113.94	425.56	4.057E-06	39.55	0.9996	0.5144	0.0045
19	0.0194	1797.3	19.52	345.05	114.52	459.57	4.062E-06	39.62	0.9996	0.5147	0.0048
20	0.0202	1799.9	20.92	369.70	115.20	484.90	4.070E-06	39.71	0.9996	0.5152	0.0053
21	0.0213	1813.8	22.71	400.75	117.72	518.46	4.089E-06	39.91	0.9995	0.5162	0.0063
22	0.0223	1825.5	24.53	433.47	119.25	552.72	4.087E-06	39.91	0.9996	0.5162	0.0063
23	0.0231	1818.9	25.94	457.40	119.20	576.59	4.109E-06	40.13	0.9996	0.5173	0.0074
24	0.0239	1823.4	27.36	482.92	119.82	602.74	4.108E-06	40.14	0.9995	0.5173	0.0074
25	0.0247	1829.7	28.79	507.68	121.14	628.82	4.120E-06	40.27	0.9995	0.5180	0.0080
26	0.0258	1851.0	30.54	537.78	124.77	662.55	4.139E-06	40.48	0.9995	0.5190	0.0090
27	0.0268	1857.6	32.34	568.77	126.43	695.21	4.158E-06	40.68	0.9995	0.5199	0.0100
28	0.0278	1851.1	34.20	601.44	125.96	727.40	4.167E-06	40.79	0.9995	0.5205	0.0105
29	0.0288	1870.7	35.76	628.77	129.13	757.90	4.178E-06	40.91	0.9995	0.5210	0.0111
30	0.0298	1866.4	37.70	663.11	128.85	791.97	4.184E-06	40.99	0.9996	0.5214	0.0115
31	0.0308	1878.4	39.36	691.56	131.27	822.82	4.201E-06	41.18	0.9995	0.5223	0.0124
32	0.0316	1875.8	40.86	718.18	131.19	849.37	4.207E-06	41.25	0.9995	0.5227	0.0127

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-I-B-1
TESTLOG : S70801
TEST DATE : 5/7/2013

MATERIAL : STEEL

TEMPERATURE : 75°F

WMT&R QUOTE : QN121622 REV. 1

ORIGINAL COMPLIANCE CALCULATION : 0.5099 in
ORIGINAL PHYSICAL MEASUREMENT : 0.5101 in
MODULUS (E) : 31.15 Msi

WIDTH (W) : 1.002 in
TOTAL THICKNESS (B) : 0.324 in
NET THICKNESS (B_N) : 0.258 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
33	0.0325	1880.5	42.56	748.90	131.92	880.82	4.208E-06	41.27	0.9994	0.5227	0.0128
34	0.0337	1897.6	44.64	784.45	135.25	919.70	4.228E-06	41.49	0.9994	0.5238	0.0139
35	0.0347	1894.5	46.37	814.66	135.26	949.91	4.238E-06	41.60	0.9995	0.5243	0.0144
36	0.0357	1900.4	48.11	843.68	137.14	980.82	4.261E-06	41.85	0.9995	0.5255	0.0156
37	0.0367	1908.1	50.00	876.13	138.99	1015.12	4.278E-06	42.03	0.9993	0.5263	0.0164
38	0.0375	1896.6	51.50	903.27	137.45	1040.72	4.280E-06	42.06	0.9994	0.5265	0.0165
39	0.0382	1897.5	52.84	925.52	138.34	1063.85	4.297E-06	42.25	0.9994	0.5273	0.0174
40	0.0393	1913.4	54.63	955.82	141.52	1097.34	4.316E-06	42.45	0.9994	0.5282	0.0183
41	0.0405	1912.6	57.00	996.64	142.29	1138.93	4.335E-06	42.66	0.9993	0.5292	0.0193
42	0.0416	1912.7	58.92	1029.78	142.98	1172.76	4.349E-06	42.82	0.9994	0.5299	0.0200
43	0.0428	1927.0	61.11	1066.00	146.44	1212.44	4.378E-06	43.13	0.9993	0.5313	0.0214
44	0.0439	1917.5	63.13	1100.95	145.68	1246.63	4.392E-06	43.29	0.9994	0.5320	0.0221
45	0.0450	1926.2	65.16	1135.92	147.77	1283.69	4.408E-06	43.47	0.9995	0.5328	0.0229
46	0.0460	1915.2	67.02	1167.39	146.95	1314.34	4.427E-06	43.67	0.9993	0.5337	0.0238
47	0.0470	1914.8	69.00	1201.51	147.66	1349.16	4.443E-06	43.85	0.9993	0.5345	0.0246
48	0.0481	1907.4	71.06	1236.12	147.50	1383.62	4.464E-06	44.08	0.9994	0.5355	0.0256
49	0.0492	1912.9	73.02	1270.26	149.00	1419.25	4.478E-06	44.23	0.9993	0.5361	0.0262
50	0.0509	1917.6	76.08	1322.66	150.97	1473.63	4.504E-06	44.52	0.9992	0.5374	0.0275
51	0.0524	1899.8	79.02	1367.39	150.69	1518.08	4.561E-06	45.11	0.9993	0.5399	0.0300
52	0.0540	1885.6	81.92	1414.28	150.32	1564.60	4.603E-06	45.56	0.9991	0.5418	0.0318
53	0.0556	1864.5	84.78	1454.16	150.25	1604.41	4.680E-06	46.35	0.9991	0.5450	0.0351
54	0.0569	1846.2	87.12	1488.91	149.53	1638.43	4.732E-06	46.89	0.9991	0.5472	0.0373
55	0.0582	1835.3	89.46	1525.30	149.59	1674.89	4.775E-06	47.35	0.9991	0.5490	0.0391
56	0.0598	1825.9	92.24	1566.44	150.70	1717.15	4.838E-06	48.00	0.9992	0.5516	0.0417
57	0.0611	1814.5	94.63	1604.60	150.48	1755.08	4.877E-06	48.42	0.9992	0.5532	0.0433
58	0.0627	1799.6	97.39	1646.12	150.50	1796.62	4.938E-06	49.04	0.9990	0.5556	0.0457
59	0.0639	1795.5	99.56	1679.72	151.57	1831.29	4.980E-06	49.49	0.9991	0.5573	0.0474
60	0.0652	1783.3	101.83	1714.83	151.33	1866.16	5.024E-06	49.95	0.9990	0.5590	0.0491
61	0.0666	1774.8	104.26	1751.76	151.99	1903.76	5.075E-06	50.49	0.9991	0.5610	0.0511
62	0.0681	1774.8	106.70	1791.33	153.62	1944.95	5.114E-06	50.91	0.9991	0.5625	0.0526
63	0.0696	1771.4	109.19	1832.16	154.64	1986.80	5.152E-06	51.32	0.9991	0.5640	0.0540
64	0.0710	1757.9	111.66	1872.55	153.85	2026.40	5.189E-06	51.72	0.9990	0.5654	0.0555

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-I-B-1
TESTLOG : S70801
TEST DATE : 5/7/2013

MATERIAL : STEEL
TEMPERATURE : 75°F

WMT&R QUOTE : QN121622 REV. 1

ORIGINAL COMPLIANCE CALCULATION : 0.5099 in
ORIGINAL PHYSICAL MEASUREMENT : 0.5101 in
MODULUS (E) : 31.15 Msi

WIDTH (W) : 1.002 in
TOTAL THICKNESS (B) : 0.324 in
NET THICKNESS (B_N) : 0.258 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
65	0.0722	1752.0	113.73	1905.75	154.29	2060.04	5.225E-06	52.10	0.9991	0.5668	0.0568
66	0.0735	1743.9	115.96	1941.48	154.42	2095.90	5.263E-06	52.51	0.9991	0.5682	0.0582
67	0.0748	1743.8	118.20	1977.78	155.90	2133.68	5.299E-06	52.90	0.9990	0.5695	0.0596
68	0.0763	1730.8	120.78	2019.87	155.26	2175.13	5.340E-06	53.34	0.9990	0.5710	0.0611
69	0.0776	1719.5	122.91	2055.70	154.44	2210.14	5.369E-06	53.66	0.9991	0.5721	0.0622
70	0.0789	1700.7	125.30	2092.38	152.98	2245.36	5.417E-06	54.17	0.9990	0.5738	0.0639
71	0.0804	1685.8	127.80	2130.00	152.41	2282.41	5.472E-06	54.75	0.9989	0.5757	0.0658

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

Phone (724) 537-3131

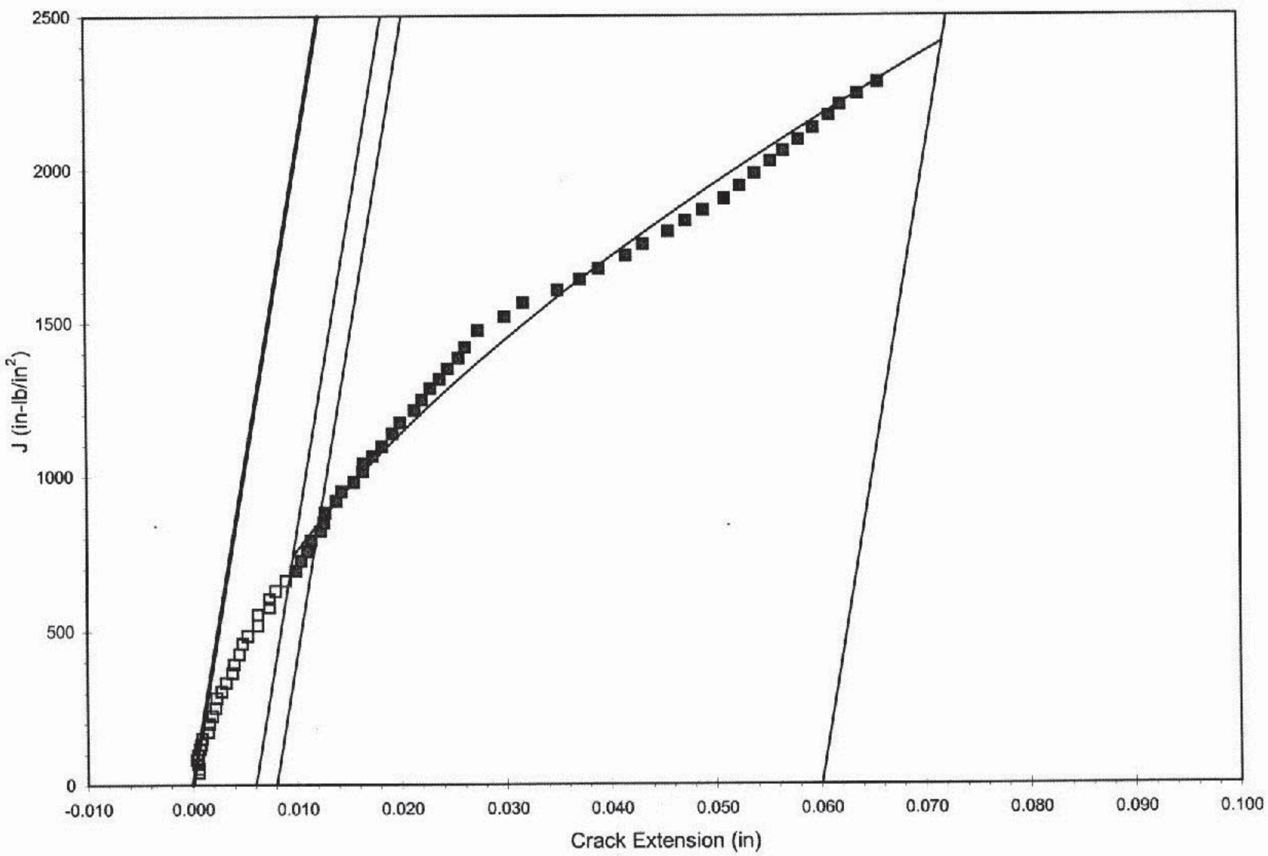
CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV. 1

TESTLOG : S70801
TEST DATE : 5/7/2013
TEMPERATURE : 75°F
MATERIAL : STEEL

SID : J-I-B-1

J_{Ic} = 848.82 in-lb/in^2

$J = 1694.1\ (a / 0.0394)^{0.5884}$



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Force vs. COD Graph

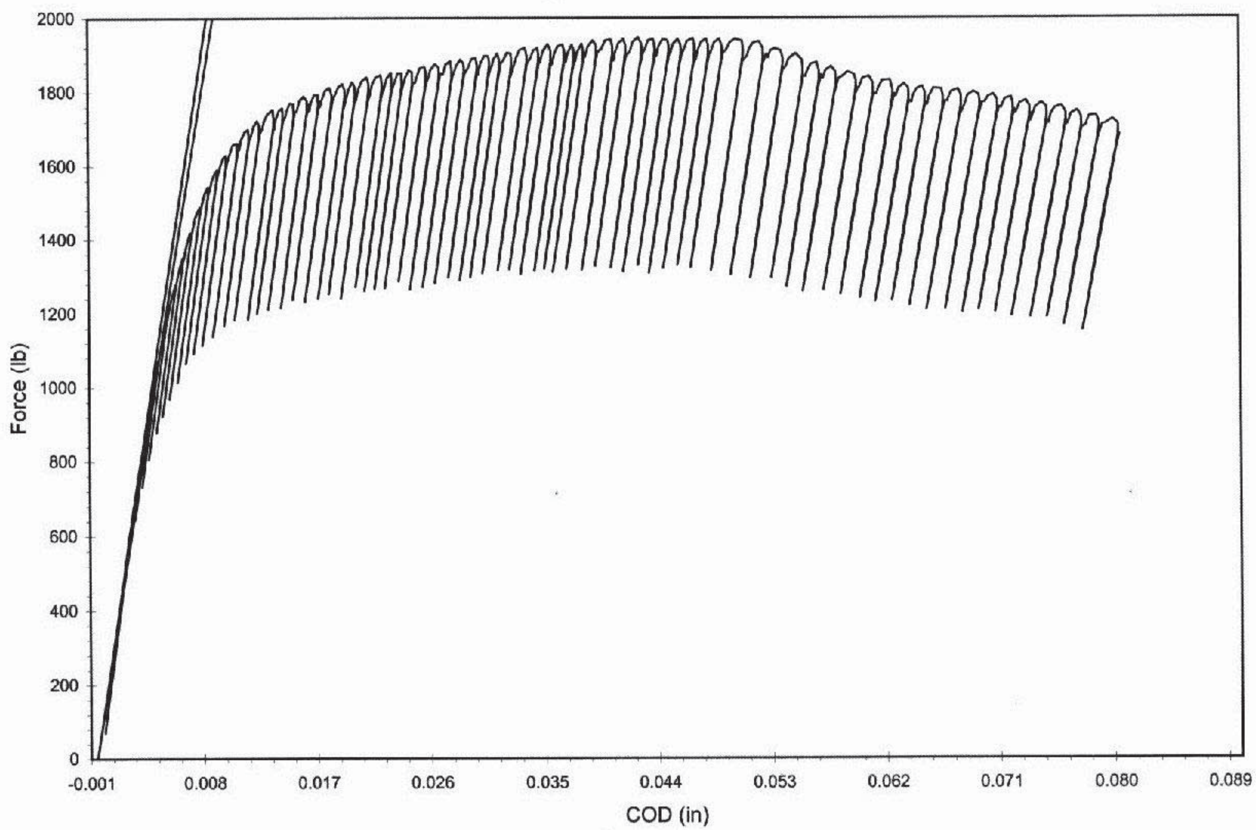
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV. 1

TESTLOG : S70801
TEST DATE : 5/7/2013
TEMPERATURE : 75°F
MATERIAL : STEEL

SID : J-I-B-1

P_{max} = 1948.1 lb
P_Q = 1025.9 lb
K_Q = 35.2 ksi(in)$^{1/2}$



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J-I-B-2*

AO SMITH 1146a

INNER LAYER

J_{IC} FRACTURE TOUGHNESS

L-T

-20°F

- The following data sheets inadvertently refer to repeated Specimen ID J-I-B-1.

WESTMORELAND MECHANICAL TESTING & RESEARCH

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J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-55962	MATERIAL : STEEL	MODULUS : 31.93 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 119.1 ksi
SID : J-I-B-1	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 82.2 ksi
TESTLOG : S70802		EFFECTIVE YIELD STRENGTH : 100.7 ksi
TEST DATE : 5/13/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS / TEST PARAMETERS

TOTAL THICKNESS (B)	: 0.324 in	TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
NET THICKNESS (B_N)	: 0.258 in	TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
EFFECTIVE THICKNESS (B_e)	: 0.311 in	ORIENTATION	: T-L	PARTIAL UNLOADING RATE	: 0.02 in/min
WIDTH (W)	: 1.001 in	TEST MACHINE	: II20	UNLOADING INTERVAL	: 0.0005 in
UNCRACKED LIGAMENT (b_o)	: 0.503 in	CLIP GAGE	: 1261635	HOLDTIME	: 5.0 sec.
NOTCH LENGTH (a_n)	: 0.454 in	CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.494 in	0.498 in	0.499 in	0.499 in	0.499 in	0.499 in	0.500 in	0.499 in	0.494 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.591 in	0.578 in	0.565 in	0.535 in	0.516 in	0.550 in	0.556 in	0.584 in	0.602 in

PRECRACK AVERAGE	: 0.4984 in	FINAL AVERAGE	: 0.5601 in
PRECRACK a/W	: 0.4979	FINAL a/W	: 0.5595

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 577 lb	FINAL P_{max}	: 506 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 95238	FINAL K_{max}	: 14.98 ksi(in)$^{1/2}$		

ORIGINAL CRACK / FINAL CRACK / MODULUS

PHYSICAL CRACK SIZE (a_o)	: 0.4984 in	PHYSICAL CRACK SIZE (a_p)	: 0.5601 in	MODULUS	: 31.93 Msi
EST. CRACK SIZE (a_{oq})	: 0.4984 in	EST. CRACK SIZE ($a_{predicted}$)	: 0.5659 in	EFFECTIVE MODULUS	: 31.93 Msi
PERCENT DIFFERENCE	: 0.00 %	PERCENT DIFFERENCE	: 1.04 %	PERCENT DIFFERENCE	: 0.00 %

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE FATIGUE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   $a/W = 0.4979$
2. (9.1.5.2) DIFFERENCE BETWEEN PREDICTED ($\Delta a_{predicted}$) AND MEASURED (Δa_p) CRACK EXTENSION SHALL NOT EXCEED 0.15 Δa_p FOR CRACK EXTENSIONS LESS THAN 0.2 b_o AND 0.03 b_o THEREAFTER — VALID
   Difference = 0.0058 in $0.15\Delta a_p = 0.0092$ in
3. (A9.7.2.1) a_{oq} SHALL NOT DIFFER FROM a_o BY MORE THAN THE LARGER OF 0.01 W OR 0.0197 IN. — VALID
   Difference = 0.0000 in Limit = 0.0197 in
4. (A9.7.2.2) NUMBER OF DATA AVAILABLE TO CALCULATE a_{oq} SHALL BE ≥ 8; NUMBER OF DATA BETWEEN $0.4J_Q$ AND J_Q SHALL BE ≥ 3; CORRELATION COEFFICIENT OF THE LEAST SQUARES FIT SHALL BE > 0.96 — VALID
   a_{oq} Points = 53 Data Points = 20 C.C. = 0.99595
5. (A9.7.1) POWER COEFFICIENT C_2 SHALL BE LESS THAN 1.0 — VALID
   $C_2 = 0.6647$
6. (A9.8.1) THICKNESS, $B > 10J_Q/\sigma_Y$ — VALID
   $B = 0.3240$ in $10J_Q/\sigma_Y = 0.0824$ in
7. (A9.8.2) INITIAL LIGAMENT, $b_o > 10J_Q/\sigma_Y$ — VALID
   $b_o = 0.5026$ in $10J_Q/\sigma_Y = 0.0824$ in
8. (A9.6.6.6) AT LEAST FIVE DATA POINTS MUST REMAIN BETWEEN a_{min} AND a_{limit} AND J_{limit} — VALID
   Data Points = 83
9. (A9.6.4) AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.006-in EXCLUSION LINE AND A 0.02-in OFFSET LINE. AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.02-in OFFSET LINE AND THE 0.06-in EXCLUSION LINE. — VALID

TEST IS INVALID: $J_Q = 829.57$ in-lb/in^2

$K_{JQ} = 170.61$ ksi(in)$^{1/2}$

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GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-55962	MATERIAL : STEEL	MODULUS : 31.93 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 119.1 ksi
SID : J-I-B-1	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 82.2 ksi
TESTLOG : S70802		EFFECTIVE YIELD STRENGTH : 100.7 ksi
TEST DATE : 5/13/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.324 in	WIDTH (W)	: 1.001 in
NET THICKNESS (B_N)	: 0.258 in	UNCRACKED LIGAMENT (b_o)	: 0.503 in
EFFECTIVE THICKNESS (B_e)	: 0.311 in	NOTCH LENGTH (a_n)	: 0.454 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: T-L	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H20	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 1261635	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.494 in	0.498 in	0.499 in	0.499 in	0.499 in	0.499 in	0.500 in	0.499 in	0.494 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.591 in	0.578 in	0.565 in	0.535 in	0.516 in	0.550 in	0.556 in	0.584 in	0.602 in

PRECRACK AVERAGE	: 0.4984 in	FINAL AVERAGE	: 0.5601 in
PRECRACK a/W	: 0.4979	FINAL a/W	: 0.5595

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 577 lb	FINAL P_{max}	: 506 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 95238	FINAL K_{max}	: 14.98 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 2103.0 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — INVALID

   Extension = 0.0444 in $0.05B$ = 0.0162 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING, THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^{f} / \sigma_{YS}^{t})(0.4\sigma_{YS}^{f}\ ksi\sqrt{in})$, WHERE σ_{YS}^{f} AND σ_{YS}^{t} ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 15.0 ksi(in)$^{1/2}$ K_{max} Limit = 32.9 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{f} / \sigma_{YS}^{t}) * K_F$ WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 15.0 ksi(in)$^{1/2}$ K_{max} Limit = 102.4 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0044 in $0.05B$ = 0.0162 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — INVALID

   Maximum Difference = 0.0441 in $0.05B$ = 0.0162 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — INVALID

   Minimum Extension = 0.0170 in   50% of the Average = 0.0308 in

ALL GENERAL VALIDITY CHECKS ARE NOT VALID

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
SID : J-I-B-1
TESTLOG : S70802
TEST DATE : 5/13/2013

MATERIAL : STEEL
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.93 Msi
ULTIMATE STRENGTH : 119.1 ksi
YIELD STRENGTH : 82.2 ksi
EFFECTIVE YIELD STRENGTH : 100.7 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.324 in
NET THICKNESS (B_N)	: 0.258 in
EFFECTIVE THICKNESS (B_e)	: 0.311 in
WIDTH (W)	: 1.001 in
UNCRACKED LIGAMENT (b_o)	: 0.503 in
NOTCH LENGTH (a_n)	: 0.454 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: T-L	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H20	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 1261635	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.494 in	0.498 in	0.499 in	0.499 in	0.499 in	0.499 in	0.500 in	0.499 in	0.494 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.591 in	0.578 in	0.565 in	0.535 in	0.516 in	0.550 in	0.556 in	0.584 in	0.602 in

PRECRACK AVERAGE	: 0.4984 in	FINAL AVERAGE	: 0.5601 in
PRECRACK a/W	: 0.4979	FINAL a/W	: 0.5595

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 577 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 506 lb	CYCLES	: 95238
FINAL K_{max}	: 14.98 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 1196.9 lb	MAXIMUM FORCE (P_{max})	: 2103.0 lb
K_Q	: 39.7 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 1.96

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   $a/W = 0.4979$
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   $P_{max}/P_Q = 1.7571$
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2 = 0.5833$ in $b_o = 0.5026$ in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY — VALID
   $K_{max} = 0.6\,(\sigma_{YS}^f / \sigma_{YS}^i) * K_F$, WHERE $K_F = K_Q$
   K_{max} Applied = 15.0 ksi(in)$^{1/2}$ K_{max} Limit = 23.8 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 39.7 ksi(in)$^{1/2}$

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-I-B-1
TESTLOG : S70802
TEST DATE : 5/13/2013

MATERIAL : STEEL

TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.4984 in
ORIGINAL PHYSICAL MEASUREMENT : 0.4984 in
MODULUS (E) : 31.93 Msi

WIDTH (W) : 1.001 in
TOTAL THICKNESS (B) : 0.324 in
NET THICKNESS (B_N) : 0.258 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0050	1226.3	0.28	2.69	47.13	49.82	3.678E-06	36.55	0.9997	0.4982	-0.0001
2	0.0055	1316.5	0.49	6.40	54.39	60.79	3.682E-06	36.59	0.9998	0.4985	0.0001
3	0.0060	1395.8	0.78	11.44	61.28	72.72	3.688E-06	36.66	0.9998	0.4988	0.0005
4	0.0065	1469.6	1.18	18.50	67.69	86.19	3.676E-06	36.55	0.9999	0.4982	-0.0001
5	0.0076	1600.1	2.10	34.52	80.48	115.00	3.683E-06	36.64	0.9999	0.4987	0.0003
6	0.0082	1652.2	2.66	44.06	86.38	130.44	3.702E-06	36.84	0.9998	0.4998	0.0014
7	0.0088	1700.8	3.38	56.92	90.87	147.79	3.679E-06	36.62	0.9999	0.4986	0.0002
8	0.0094	1741.8	4.11	69.55	95.65	165.20	3.690E-06	36.73	0.9998	0.4992	0.0009
9	0.0100	1778.4	4.95	83.89	100.32	184.21	3.707E-06	36.91	0.9998	0.5002	0.0018
10	0.0107	1811.2	5.98	102.13	103.74	205.87	3.697E-06	36.83	0.9998	0.4997	0.0014
11	0.0113	1839.0	7.01	120.30	106.83	227.13	3.692E-06	36.79	0.9998	0.4995	0.0012
12	0.0120	1860.6	8.07	138.48	109.70	248.18	3.700E-06	36.88	0.9997	0.5000	0.0017
13	0.0127	1880.3	9.12	156.57	112.58	269.15	3.714E-06	37.03	0.9998	0.5008	0.0025
14	0.0133	1898.1	10.29	177.44	114.25	291.69	3.701E-06	36.91	0.9998	0.5002	0.0018
15	0.0140	1912.2	11.43	196.51	117.03	313.54	3.728E-06	37.19	0.9997	0.5017	0.0033
16	0.0148	1923.3	12.76	219.71	118.67	338.38	3.733E-06	37.25	0.9998	0.5020	0.0037
17	0.0155	1933.2	14.15	244.56	119.30	363.86	3.717E-06	37.10	0.9997	0.5012	0.0029
18	0.0163	1944.4	15.48	267.01	121.54	388.54	3.737E-06	37.32	0.9997	0.5024	0.0040
19	0.0170	1949.6	16.81	290.48	122.17	412.65	3.735E-06	37.31	0.9997	0.5023	0.0040
20	0.0177	1956.1	18.04	310.85	124.08	434.93	3.761E-06	37.58	0.9997	0.5038	0.0054
21	0.0184	1959.0	19.39	334.39	124.62	459.02	3.764E-06	37.62	0.9997	0.5040	0.0056
22	0.0192	1966.0	20.88	360.84	125.36	486.20	3.759E-06	37.59	0.9997	0.5038	0.0054
23	0.0199	1975.4	22.20	383.00	127.39	510.38	3.778E-06	37.79	0.9997	0.5049	0.0065
24	0.0207	1978.6	23.67	409.31	127.56	536.87	3.771E-06	37.73	0.9996	0.5046	0.0062
25	0.0214	1985.6	24.98	430.56	129.69	560.25	3.799E-06	38.02	0.9997	0.5061	0.0077
26	0.0222	1991.5	26.47	457.89	129.87	587.75	3.784E-06	37.88	0.9997	0.5054	0.0070
27	0.0229	1997.1	27.86	481.71	131.02	612.73	3.792E-06	37.98	0.9998	0.5059	0.0075
28	0.0236	2002.0	29.19	503.13	132.84	635.97	3.818E-06	38.25	0.9996	0.5073	0.0089
29	0.0244	2004.7	30.58	526.63	133.84	660.47	3.832E-06	38.40	0.9997	0.5081	0.0097
30	0.0251	2012.0	32.01	552.49	134.57	687.06	3.825E-06	38.34	0.9997	0.5078	0.0094
31	0.0259	2018.1	33.46	578.41	135.31	713.72	3.822E-06	38.33	0.9996	0.5077	0.0093
32	0.0266	2023.1	34.87	601.80	136.77	738.57	3.839E-06	38.50	0.9996	0.5086	0.0102

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-I-B-1
TESTLOG : S70802
TEST DATE : 5/13/2013

MATERIAL : STEEL

TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.4984 in
ORIGINAL PHYSICAL MEASUREMENT : 0.4984 in
MODULUS (E) : 31.93 Msi

WIDTH (W) : 1.001 in
TOTAL THICKNESS (B) : 0.324 in
NET THICKNESS (B_N) : 0.258 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
33	0.0274	2026.3	36.33	626.62	137.76	764.38	3.850E-06	38.63	0.9996	0.5093	0.0109
34	0.0281	2031.0	37.65	648.54	139.11	787.65	3.865E-06	38.79	0.9996	0.5101	0.0117
35	0.0289	2037.4	39.18	675.28	140.26	815.54	3.869E-06	38.85	0.9996	0.5104	0.0120
36	0.0296	2043.3	40.57	698.55	141.73	840.28	3.883E-06	39.00	0.9997	0.5111	0.0127
37	0.0304	2044.8	42.18	728.43	141.45	869.88	3.871E-06	38.89	0.9996	0.5106	0.0122
38	0.0311	2047.1	43.64	753.29	142.29	895.57	3.881E-06	39.00	0.9996	0.5112	0.0128
39	0.0318	2051.2	45.08	777.84	143.33	921.17	3.890E-06	39.11	0.9996	0.5117	0.0133
40	0.0325	2053.2	46.43	799.70	144.49	944.19	3.908E-06	39.30	0.9996	0.5126	0.0143
41	0.0333	2057.6	47.87	825.70	145.06	970.76	3.905E-06	39.29	0.9996	0.5126	0.0142
42	0.0340	2057.6	49.35	851.31	145.38	996.69	3.911E-06	39.36	0.9995	0.5129	0.0146
43	0.0347	2061.1	50.75	874.06	146.77	1020.83	3.929E-06	39.55	0.9996	0.5139	0.0155
44	0.0355	2060.3	52.30	900.96	146.97	1047.92	3.935E-06	39.62	0.9996	0.5143	0.0159
45	0.0363	2064.1	53.80	926.45	148.02	1074.48	3.944E-06	39.73	0.9996	0.5148	0.0164
46	0.0370	2062.6	55.17	948.26	148.78	1097.04	3.964E-06	39.94	0.9995	0.5158	0.0175
47	0.0377	2065.5	56.62	972.14	149.97	1122.10	3.979E-06	40.10	0.9994	0.5166	0.0183
48	0.0384	2068.2	57.98	994.47	151.09	1145.56	3.993E-06	40.26	0.9995	0.5174	0.0190
49	0.0392	2069.9	59.49	1020.68	151.73	1172.41	4.000E-06	40.34	0.9994	0.5178	0.0194
50	0.0399	2071.1	60.93	1043.51	152.90	1196.40	4.020E-06	40.55	0.9995	0.5188	0.0205
51	0.0407	2070.2	62.43	1067.54	153.82	1221.36	4.040E-06	40.78	0.9995	0.5199	0.0215
52	0.0414	2070.5	63.90	1091.28	154.78	1246.06	4.058E-06	40.97	0.9995	0.5208	0.0225
53	0.0422	2072.0	65.38	1114.85	156.04	1270.89	4.079E-06	41.19	0.9995	0.5219	0.0235
54	0.0430	2077.2	66.86	1140.19	157.31	1297.50	4.087E-06	41.29	0.9996	0.5223	0.0240
55	0.0437	2069.0	68.52	1168.68	156.59	1325.27	4.097E-06	41.40	0.9995	0.5228	0.0245
56	0.0445	2077.2	69.85	1188.36	159.26	1347.62	4.125E-06	41.70	0.9994	0.5242	0.0259
57	0.0453	2067.9	71.50	1213.70	159.25	1372.95	4.153E-06	42.00	0.9994	0.5256	0.0273
58	0.0460	2077.2	72.81	1235.66	161.30	1396.96	4.164E-06	42.12	0.9994	0.5262	0.0278
59	0.0468	2068.5	74.44	1263.73	160.47	1424.20	4.174E-06	42.23	0.9994	0.5267	0.0283
60	0.0475	2069.0	75.88	1286.70	161.53	1448.24	4.192E-06	42.44	0.9994	0.5276	0.0293
61	0.0483	2070.5	77.34	1308.69	163.10	1471.79	4.219E-06	42.72	0.9995	0.5289	0.0305
62	0.0490	2077.2	78.84	1336.22	164.21	1500.43	4.218E-06	42.72	0.9994	0.5290	0.0306
63	0.0498	2070.8	80.47	1364.43	163.72	1528.15	4.227E-06	42.83	0.9994	0.5294	0.0311
64	0.0506	2073.1	81.97	1387.85	165.21	1553.06	4.249E-06	43.06	0.9995	0.5305	0.0321

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-I-B-1
TESTLOG : S70802
TEST DATE : 5/13/2013

MATERIAL : STEEL

TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.4984 in
ORIGINAL PHYSICAL MEASUREMENT : 0.4984 in
MODULUS (E) : 31.93 Msi

WIDTH (W) : 1.001 in
TOTAL THICKNESS (B) : 0.324 in
NET THICKNESS (B_N) : 0.258 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
65	0.0513	2077.2	83.37	1409.54	167.02	1576.56	4.271E-06	43.30	0.9995	0.5315	0.0332
66	0.0522	2065.8	85.13	1440.92	165.52	1606.44	4.276E-06	43.37	0.9994	0.5318	0.0335
67	0.0529	2067.6	86.57	1466.01	166.18	1632.20	4.282E-06	43.45	0.9994	0.5322	0.0338
68	0.0536	2072.0	87.98	1487.99	167.96	1655.95	4.303E-06	43.67	0.9994	0.5332	0.0348
69	0.0544	2064.7	89.56	1512.57	168.00	1680.57	4.326E-06	43.92	0.9994	0.5343	0.0359
70	0.0551	2070.5	90.87	1533.54	169.80	1703.34	4.342E-06	44.10	0.9995	0.5350	0.0366
71	0.0559	2070.2	92.41	1560.40	170.21	1730.62	4.350E-06	44.19	0.9994	0.5354	0.0371
72	0.0567	2060.9	94.03	1586.31	169.73	1756.04	4.370E-06	44.41	0.9994	0.5364	0.0380
73	0.0574	2062.0	95.52	1611.49	170.61	1782.10	4.382E-06	44.55	0.9994	0.5370	0.0386
74	0.0582	2051.5	97.15	1634.00	170.77	1804.76	4.419E-06	44.94	0.9994	0.5386	0.0403
75	0.0590	2050.9	98.58	1656.76	171.60	1828.36	4.437E-06	45.13	0.9994	0.5395	0.0411
76	0.0597	2044.8	100.11	1680.89	171.67	1852.56	4.458E-06	45.36	0.9993	0.5404	0.0420
77	0.0605	2043.3	101.63	1705.11	172.44	1877.54	4.477E-06	45.57	0.9994	0.5413	0.0429
78	0.0613	2035.7	103.14	1729.55	172.12	1901.67	4.495E-06	45.77	0.9994	0.5421	0.0438
79	0.0620	2031.6	104.63	1754.47	172.14	1926.61	4.509E-06	45.92	0.9993	0.5427	0.0444
80	0.0628	2027.2	106.12	1777.18	172.61	1949.79	4.532E-06	46.18	0.9994	0.5438	0.0454
81	0.0635	2022.8	107.63	1802.96	172.50	1975.46	4.544E-06	46.31	0.9994	0.5443	0.0460
82	0.0642	2019.0	108.95	1820.69	173.45	1994.14	4.575E-06	46.65	0.9994	0.5457	0.0473
83	0.0650	2018.4	110.42	1840.75	175.09	2015.84	4.610E-06	47.01	0.9994	0.5472	0.0488
84	0.0657	2014.3	111.87	1867.13	174.63	2041.76	4.613E-06	47.06	0.9993	0.5474	0.0490
85	0.0665	2014.0	113.26	1886.95	176.02	2062.97	4.642E-06	47.37	0.9994	0.5486	0.0502
86	0.0672	2010.5	114.60	1908.42	176.31	2084.74	4.659E-06	47.56	0.9993	0.5493	0.0510
87	0.0679	2009.3	116.08	1933.99	176.71	2110.70	4.670E-06	47.68	0.9993	0.5498	0.0515
88	0.0686	2011.7	117.45	1958.84	177.41	2136.25	4.674E-06	47.74	0.9994	0.5501	0.0517
89	0.0693	2012.6	118.75	1980.36	178.28	2158.64	4.687E-06	47.89	0.9994	0.5506	0.0523
90	0.0701	2009.3	120.24	2002.68	179.03	2181.71	4.713E-06	48.17	0.9994	0.5517	0.0533
91	0.0708	2011.7	121.49	2021.42	180.52	2201.95	4.733E-06	48.39	0.9994	0.5526	0.0542
92	0.0715	2014.6	122.93	2048.63	181.17	2229.80	4.734E-06	48.42	0.9995	0.5527	0.0543
93	0.0723	2013.1	124.39	2072.88	181.70	2254.58	4.749E-06	48.58	0.9994	0.5533	0.0549
94	0.0730	2009.3	125.90	2100.01	181.44	2281.45	4.756E-06	48.67	0.9994	0.5537	0.0553
95	0.0738	2009.3	127.31	2120.96	182.69	2303.65	4.780E-06	48.93	0.9994	0.5546	0.0563
96	0.0745	2010.8	128.72	2146.04	183.40	2329.44	4.787E-06	49.02	0.9994	0.5550	0.0566

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-I-B-1
TESTLOG : S70802
TEST DATE : 5/13/2013

MATERIAL : STEEL

TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.4984 in
ORIGINAL PHYSICAL MEASUREMENT : 0.4984 in
MODULUS (E) : 31.93 Msi

WIDTH (W) : 1.001 in
TOTAL THICKNESS (B) : 0.324 in
NET THICKNESS (B_N) : 0.258 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
97	0.0752	2009.3	130.07	2167.42	184.08	2351.51	4.805E-06	49.22	0.9994	0.5557	0.0574
98	0.0760	2001.7	131.76	2199.09	182.92	2382.01	4.808E-06	49.27	0.9994	0.5559	0.0575
99	0.0768	2009.3	133.08	2220.24	185.19	2405.42	4.824E-06	49.45	0.9994	0.5566	0.0582
100	0.0775	2002.3	134.50	2241.55	185.09	2426.64	4.847E-06	49.70	0.9994	0.5575	0.0591
101	0.0782	2001.4	135.92	2265.63	185.64	2451.27	4.859E-06	49.85	0.9994	0.5581	0.0597
102	0.0789	1998.5	137.28	2285.41	186.34	2471.75	4.883E-06	50.10	0.9994	0.5590	0.0606
103	0.0797	1997.6	138.71	2310.90	186.65	2497.55	4.891E-06	50.20	0.9994	0.5594	0.0610
104	0.0804	1994.7	140.08	2332.49	187.09	2519.58	4.910E-06	50.41	0.9994	0.5601	0.0618
105	0.0811	1992.4	141.55	2359.24	187.01	2546.25	4.915E-06	50.48	0.9994	0.5604	0.0620
106	0.0818	1991.8	142.90	2381.77	187.64	2569.41	4.929E-06	50.64	0.9993	0.5610	0.0626
107	0.0826	1988.0	144.38	2406.64	187.66	2594.31	4.942E-06	50.79	0.9993	0.5615	0.0632
108	0.0833	1984.2	145.77	2429.94	187.67	2617.60	4.955E-06	50.94	0.9993	0.5621	0.0637
109	0.0840	1981.5	147.18	2452.63	188.07	2640.70	4.972E-06	51.13	0.9994	0.5628	0.0644
110	0.0847	1977.4	148.58	2475.34	188.16	2663.50	4.988E-06	51.31	0.9993	0.5634	0.0650
111	0.0854	1975.4	149.89	2494.31	189.00	2683.31	5.012E-06	51.57	0.9993	0.5643	0.0659
112	0.0862	1968.9	151.32	2518.42	188.49	2706.91	5.025E-06	51.72	0.9993	0.5649	0.0665
113	0.0869	1964.8	152.78	2539.20	189.09	2728.29	5.052E-06	52.02	0.9993	0.5659	0.0675

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

Phone (724) 537-3131

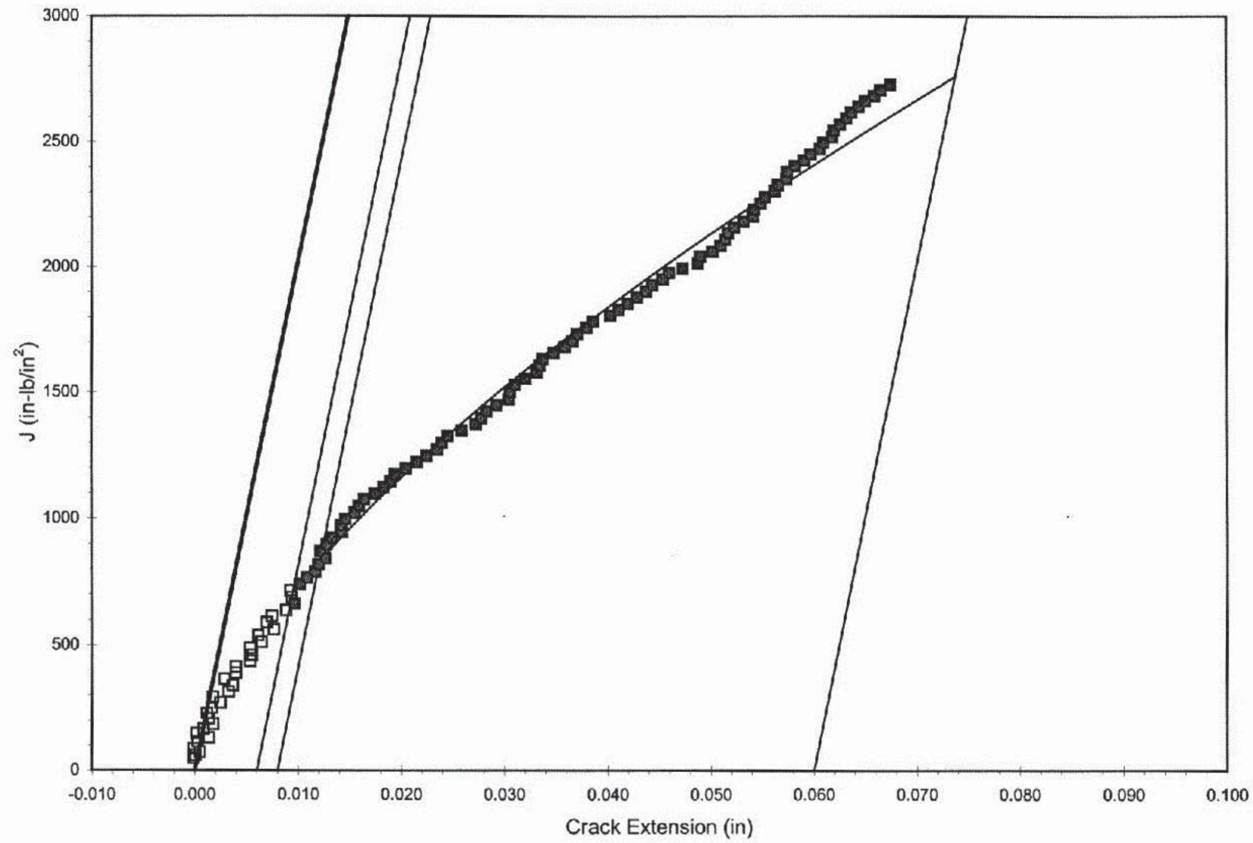
CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : S70802
TEST DATE : 5/13/2013
TEMPERATURE : -20°F
MATERIAL : STEEL

SID : J-I-B-1

J_Q = 829.57 in-lb/in^2

$J = 1820.2\ (a / 0.0394)^{0.6647}$



"NOTE: THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHABLE AS A FELONY UNDER FEDERAL STATUTE."

Westmoreland Mechanical Testing & Research, Inc.

Force vs. COD Graph

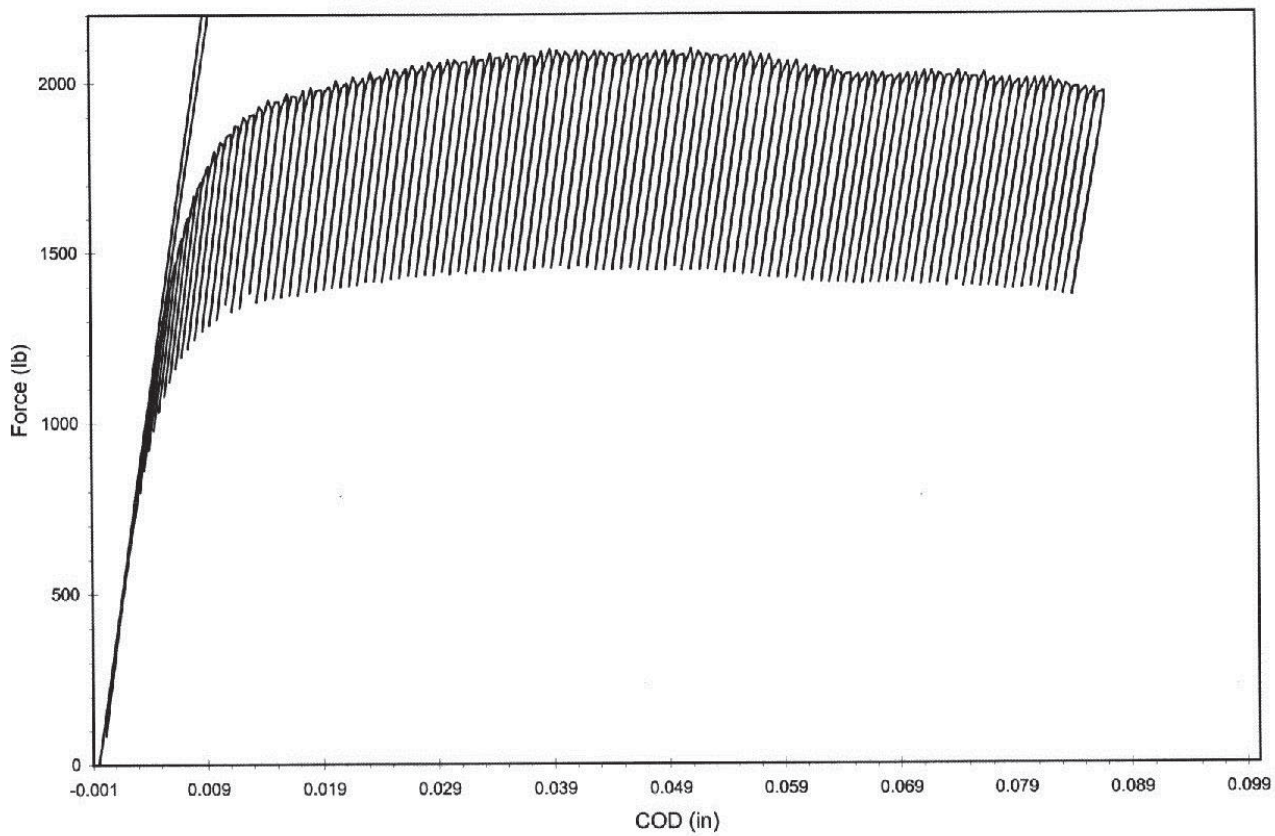
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : S70802
TEST DATE : 5/13/2013
TEMPERATURE : -20°F
MATERIAL : STEEL

SID : J-I-B-1

P_{max} = 2103.0 lb
P_Q = 1196.9 lb
K_Q = 39.7 ksi(in)$^{1/2}$



"NOTE: THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHABLE AS A FELONY UNDER FEDERAL STATUTE."

J-O-B-1

AO SMITH 1146a

OUTER LAYER

J_{IC} FRACTURE TOUGHNESS

L-T

RT

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
SID : J-O-B-1
TESTLOG : S70803
TEST DATE : 5/7/2013

MATERIAL : STEEL
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.92 Msi
ULTIMATE STRENGTH : 119.1 ksi
YIELD STRENGTH : 82.2 ksi
EFFECTIVE YIELD STRENGTH : 100.7 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.251 in
NET THICKNESS (B_N)	: 0.179 in
EFFECTIVE THICKNESS (B_e)	: 0.230 in
WIDTH (W)	: 1.003 in
UNCRACKED LIGAMENT (b_o)	: 0.496 in
NOTCH LENGTH (a_n)	: 0.458 in

TEST TEMPERATURE	: 75°F
TEST TYPE	: CT
ORIENTATION	: L-T
TEST MACHINE	: H1
CLIP GAGE	: 10277363C
CLIP GAGE LOCATION	: LOAD LINE

TEST PARAMETERS

MAIN RAMP RATE	: 0.01 in/min
PARTIAL LOADING RATE	: 0.01 in/min
PARTIAL UNLOADING RATE	: 0.01 in/min
UNLOADING INTERVAL	: 0.0005 in
HOLDTIME	: 5.0 sec.
OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.499 in	0.504 in	0.505 in	0.507 in	0.510 in	0.508 in	0.509 in	0.511 in	0.507 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.543 in	0.551 in	0.561 in	0.570 in	0.581 in	0.593 in	0.612 in	0.623 in	0.623 in

PRECRACK AVERAGE	: 0.5071 in	FINAL AVERAGE	: 0.5843 in
PRECRACK a/W	: 0.5056	FINAL a/W	: 0.5825

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 443 lb	FINAL P_{max}	: 389 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 111236	FINAL K_{max}	: 15.21 ksi(in)$^{1/2}$		

ORIGINAL CRACK

PHYSICAL CRACK SIZE (a_o)	: 0.5071 in
EST. CRACK SIZE (a_{oq})	: 0.5071 in
PERCENT DIFFERENCE	: 0.00 %

FINAL CRACK

PHYSICAL CRACK SIZE (a_p)	: 0.5843 in
EST. CRACK SIZE ($a_{predicted}$)	: 0.5816 in
PERCENT DIFFERENCE	: 0.45 %

MODULUS

MODULUS	: 31.92 Msi
EFFECTIVE MODULUS	: 31.92 Msi
PERCENT DIFFERENCE	: 0.00 %

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE FATIGUE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   a/W = 0.5056
2. (9.1.5.2) DIFFERENCE BETWEEN PREDICTED ($\Delta a_{predicted}$) AND MEASURED (Δa_p) CRACK EXTENSION SHALL NOT EXCEED 0.15 Δa_p FOR CRACK EXTENSIONS LESS THAN 0.2 b_o AND 0.03 b_o THEREAFTER — VALID
   Difference = 0.0026 in $0.15\Delta a_p$ = 0.0116 in
3. (A9.7.2.1) a_{oq} SHALL NOT DIFFER FROM a_o BY MORE THAN THE LARGER OF 0.01 W OR 0.0197 IN. — VALID
   Difference = 0.0000 in Limit = 0.0197 in
4. (A9.7.2.2) NUMBER OF DATA AVAILABLE TO CALCULATE a_{oq} SHALL BE ≥ 8; NUMBER OF DATA BETWEEN $0.4J_Q$ AND J_Q SHALL BE ≥ 3; CORRELATION COEFFICIENT OF THE LEAST SQUARES FIT SHALL BE > 0.96 — VALID
   a_{oq} Points = 19 Data Points = 6 C.C. = 0.99825
5. (A9.7.1) POWER COEFFICIENT C_2 SHALL BE LESS THAN 1.0 — VALID
   $C_2 = 0.5656$
6. (A9.8.1) THICKNESS, $B > 10J_Q/\sigma_Y$ — VALID
   B = 0.2510 in $10J_Q/\sigma_Y$ = 0.0625 in
7. (A9.8.2) INITIAL LIGAMENT, $b_o > 10J_Q/\sigma_Y$ — VALID
   b_o = 0.4959 in $10J_Q/\sigma_Y$ = 0.0625 in
8. (A9.6.6.6) AT LEAST FIVE DATA POINTS MUST REMAIN BETWEEN a_{min} AND a_{limit} AND J_{limit} — VALID
   Data Points = 18
9. (A9.6.4) AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.006-in EXCLUSION LINE AND A 0.02-in OFFSET LINE. AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.02-in OFFSET LINE AND THE 0.06-in EXCLUSION LINE. — VALID

TEST IS INVALID: J_Q = 629.19 in-lb/in^2

K_{JQ} = 148.56 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
SID : J-O-B-1
TESTLOG : S70803
TEST DATE : 5/7/2013

MATERIAL : STEEL

WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.92 Msi
ULTIMATE STRENGTH : 119.1 ksi
YIELD STRENGTH : 82.2 ksi
EFFECTIVE YIELD STRENGTH : 100.7 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.251 in	WIDTH (W)	: 1.003 in
NET THICKNESS (B_N)	: 0.179 in	UNCRACKED LIGAMENT (b_o)	: 0.496 in
EFFECTIVE THICKNESS (B_e)	: 0.230 in	NOTCH LENGTH (a_n)	: 0.458 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.01 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.01 in/min
ORIENTATION	: L-T	PARTIAL UNLOADING RATE	: 0.01 in/min
TEST MACHINE	: H1	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10277363C	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.499 in	0.504 in	0.505 in	0.507 in	0.510 in	0.508 in	0.509 in	0.511 in	0.507 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.543 in	0.551 in	0.561 in	0.570 in	0.581 in	0.593 in	0.612 in	0.623 in	0.623 in

PRECRACK AVERAGE	: 0.5071 in	FINAL AVERAGE	: 0.5843 in
PRECRACK a/W	: 0.5056	FINAL a/W	: 0.5825

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 443 lb	FINAL P_{max}	: 389 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 111236	FINAL K_{max}	: 15.21 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 2067.3 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — INVALID
   Extension = 0.0491 in $0.05B = 0.0126$ in
2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING, THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^f / \sigma_{YS}^T)(0.4\sigma_{YS}^f\ ksi\sqrt{in})$, WHERE σ_{YS}^f AND σ_{YS}^T ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID
   K_{max} Applied = 15.0 ksi(in)$^{1/2}$ K_{max} Limit = 32.9 ksi(in)$^{1/2}$
3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^f / \sigma_{YS}^T) * K_F$ WHERE $K_F = K_{JQ}, K_{JQC}$, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID
   K_{max} Applied = 15.2 ksi(in)$^{1/2}$ K_{max} Limit = 89.1 ksi(in)$^{1/2}$
4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID
   Maximum Difference = 0.0081 in $0.05B = 0.0126$ in
5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — INVALID
   Maximum Difference = 0.0413 in $0.05B = 0.0126$ in
6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID
   Minimum Extension = 0.0440 in 50% of the Average = 0.0386 in

ALL GENERAL VALIDITY CHECKS ARE NOT VALID

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
SID : J-O-B-1
TESTLOG : S70803
TEST DATE : 5/7/2013

MATERIAL : STEEL
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.92 Msi
ULTIMATE STRENGTH : 119.1 ksi
YIELD STRENGTH : 82.2 ksi
EFFECTIVE YIELD STRENGTH : 100.7 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B) : 0.251 in
NET THICKNESS (B_N) : 0.179 in
EFFECTIVE THICKNESS (B_e) : 0.230 in
WIDTH (W) : 1.003 in
UNCRACKED LIGAMENT (b_o) : 0.496 in
NOTCH LENGTH (a_n) : 0.458 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.01 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.01 in/min
ORIENTATION	: L-T	PARTIAL UNLOADING RATE	: 0.01 in/min
TEST MACHINE	: H1	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10277363C	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.499 in	0.504 in	0.505 in	0.507 in	0.510 in	0.508 in	0.509 in	0.511 in	0.507 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.543 in	0.551 in	0.561 in	0.570 in	0.581 in	0.593 in	0.612 in	0.623 in	0.623 in

PRECRACK AVERAGE : 0.5071 in FINAL AVERAGE : 0.5843 in
PRECRACK a/W : 0.5056 FINAL a/W : 0.5825

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 443 lb R-RATIO (P_{min} / P_{max}) : 0.1
FINAL P_{max} : 389 lb CYCLES : 111236
FINAL K_{max} : 15.21 ksi(in)$^{1/2}$

TEST RESULTS

CANDIDATE FORCE (P_Q) : 1176.9 lb MAXIMUM FORCE (P_{max}) : 2067.3 lb
K_Q : 54.5 ksi(in)$^{1/2}$ SPECIMEN STRENGTH RATIO : 2.87

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   $a/W = 0.5056$
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   $P_{max}/P_Q = 1.7565$
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2 = 1.0986$ in $b_o = 0.4959$ in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^f / \sigma_{YS}^T) * K_F$, WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 15.2 ksi(in)$^{1/2}$ K_{max} Limit = 32.7 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 54.5 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-O-B-1
TESTLOG : S70803
TEST DATE : 5/7/2013

MATERIAL : STEEL

TEMPERATURE : 75°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.5071 in
ORIGINAL PHYSICAL MEASUREMENT : 0.5071 in
MODULUS (E) : 31.92 Msi

WIDTH (W) : 1.003 in
TOTAL THICKNESS (B) : 0.251 in
NET THICKNESS (B_N) : 0.179 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0020	447.4	0.00	0.00	12.22	12.22	5.163E-06	37.99	0.9997	0.5070	-0.0002
2	0.0028	599.2	0.00	0.00	21.96	21.96	5.170E-06	38.06	0.9998	0.5073	0.0002
3	0.0036	736.9	0.00	0.00	33.28	33.28	5.176E-06	38.11	0.9999	0.5076	0.0005
4	0.0044	879.5	0.00	0.00	47.40	47.40	5.173E-06	38.11	0.9999	0.5076	0.0004
5	0.0053	1011.7	0.02	0.45	62.73	63.18	5.173E-06	38.12	0.9999	0.5076	0.0005
6	0.0061	1142.4	0.21	5.39	79.96	85.35	5.169E-06	38.10	0.9999	0.5076	0.0004
7	0.0069	1254.6	0.47	11.83	96.68	108.51	5.178E-06	38.18	0.9999	0.5079	0.0008
8	0.0077	1358.9	0.83	21.05	113.07	134.12	5.163E-06	38.08	0.9999	0.5074	0.0003
9	0.0088	1488.0	1.44	36.51	136.11	172.63	5.177E-06	38.21	0.9999	0.5081	0.0010
10	0.0096	1567.5	1.97	50.09	151.28	201.37	5.182E-06	38.26	0.9999	0.5083	0.0012
11	0.0107	1669.5	2.74	69.52	172.73	242.24	5.207E-06	38.46	0.9999	0.5094	0.0022
12	0.0119	1753.3	4.00	101.58	191.29	292.87	5.222E-06	38.59	0.9999	0.5100	0.0029
13	0.0133	1841.8	5.64	143.20	212.00	355.19	5.237E-06	38.72	0.9999	0.5107	0.0036
14	0.0145	1899.5	7.29	184.86	226.98	411.84	5.262E-06	38.92	0.9998	0.5118	0.0046
15	0.0160	1958.4	9.39	237.78	243.57	481.35	5.299E-06	39.22	0.9998	0.5133	0.0062
16	0.0174	1990.9	11.61	293.19	254.92	548.11	5.350E-06	39.62	0.9998	0.5153	0.0081
17	0.0185	2024.3	13.33	336.34	265.68	602.02	5.382E-06	39.88	0.9998	0.5166	0.0094
18	0.0200	2043.8	15.91	400.50	275.06	675.56	5.446E-06	40.38	0.9998	0.5190	0.0119
19	0.0212	2041.1	17.93	449.24	279.46	728.70	5.524E-06	40.98	0.9997	0.5219	0.0148
20	0.0227	2059.6	20.54	513.26	289.85	803.10	5.603E-06	41.59	0.9997	0.5248	0.0176
21	0.0241	2051.2	23.23	579.50	292.39	871.89	5.676E-06	42.15	0.9996	0.5274	0.0203
22	0.0259	2046.4	26.39	654.36	299.68	954.04	5.805E-06	43.14	0.9996	0.5319	0.0248
23	0.0273	2035.8	29.02	719.59	301.09	1020.68	5.871E-06	43.66	0.9996	0.5342	0.0270
24	0.0286	2039.3	31.36	776.24	307.57	1083.80	5.951E-06	44.28	0.9996	0.5369	0.0297
25	0.0304	2043.1	34.37	847.82	316.43	1164.24	6.064E-06	45.15	0.9996	0.5406	0.0335
26	0.0318	2006.7	37.26	916.42	312.67	1229.10	6.176E-06	46.00	0.9996	0.5442	0.0370
27	0.0338	1980.6	40.83	997.65	315.92	1313.57	6.350E-06	47.34	0.9996	0.5496	0.0424
28	0.0354	1959.3	43.84	1071.52	315.10	1386.62	6.440E-06	48.04	0.9997	0.5523	0.0452
29	0.0371	1924.0	47.12	1148.90	312.15	1461.05	6.572E-06	49.06	0.9995	0.5562	0.0491
30	0.0392	1899.2	50.78	1235.29	313.33	1548.62	6.720E-06	50.20	0.9994	0.5605	0.0533
31	0.0410	1872.9	54.03	1309.84	313.89	1623.73	6.871E-06	51.36	0.9994	0.5647	0.0576
32	0.0425	1842.3	56.76	1369.17	313.16	1682.33	7.030E-06	52.58	0.9995	0.5690	0.0619
33	0.0439	1823.3	59.08	1422.53	313.46	1735.99	7.144E-06	53.46	0.9995	0.5720	0.0649
34	0.0455	1800.2	61.94	1491.42	312.09	1803.51	7.256E-06	54.33	0.9995	0.5749	0.0678
35	0.0474	1757.3	65.04	1548.77	312.35	1861.12	7.527E-06	56.40	0.9992	0.5816	0.0745

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J vs. a Graph

Phone (724) 537-3131

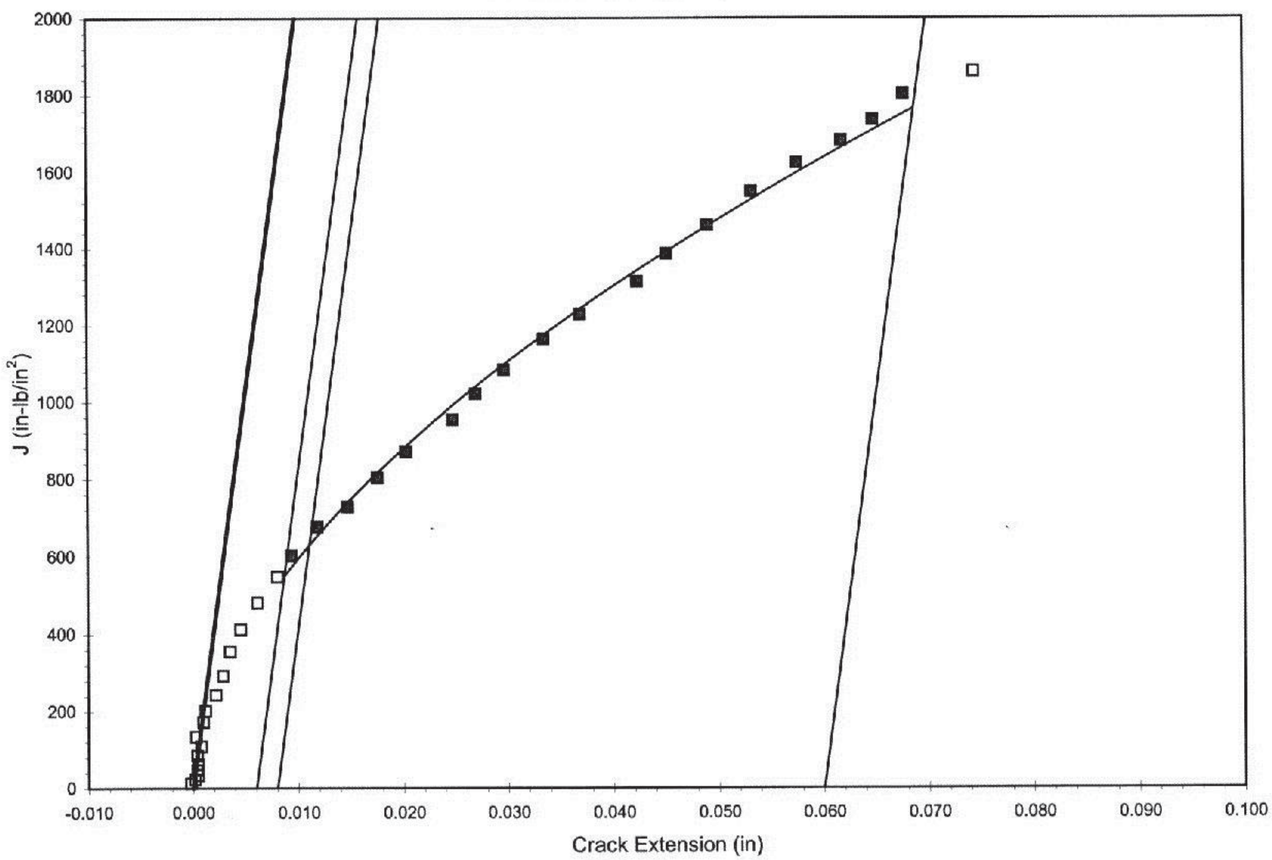
CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : S70803
TEST DATE : 5/7/2013
TEMPERATURE : 75°F
MATERIAL : STEEL

SID : J-O-B-1

$$J_Q = 629.19 \text{ in-lb/in}^2$$

$$J = 1288.6\,(a / 0.0394)^{0.5656}$$



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Westmoreland Mechanical Testing & Research, Inc.

Force vs. COD Graph

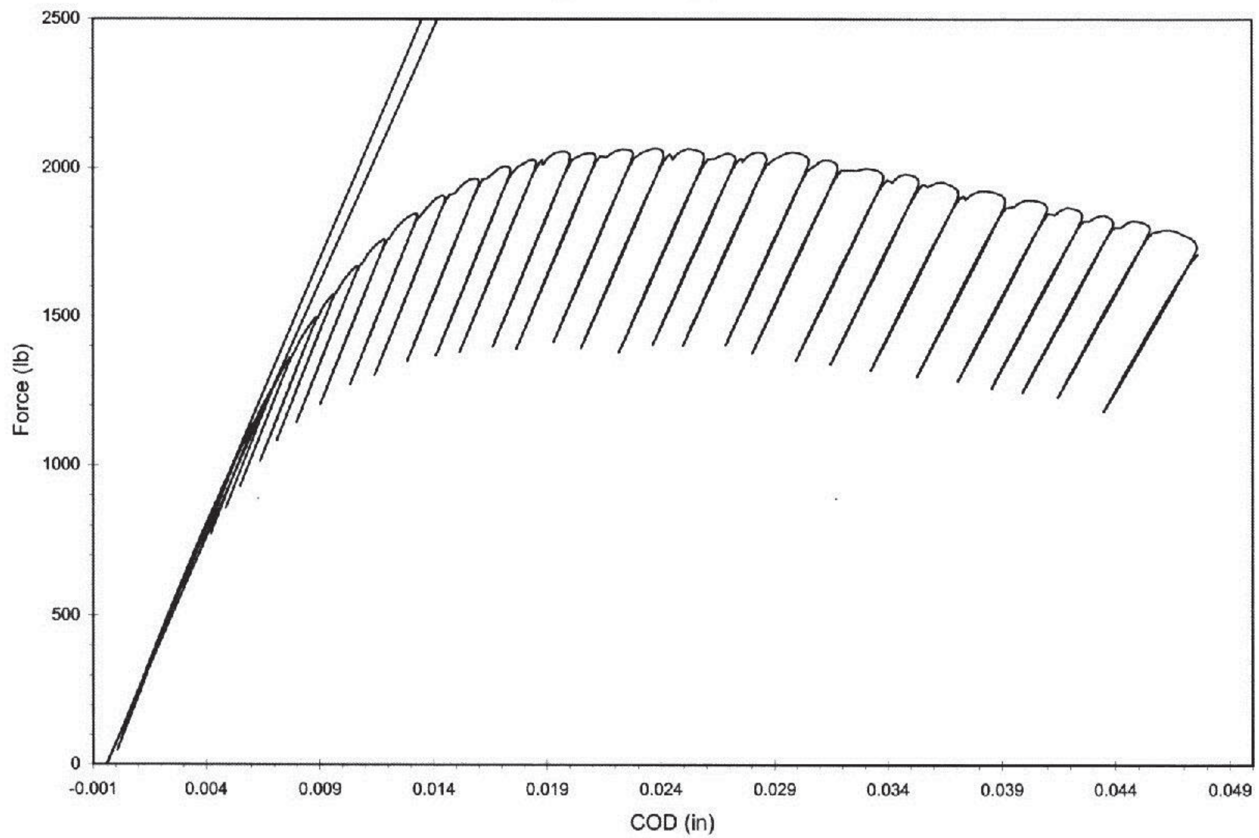
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : S70803
TEST DATE : 5/7/2013
TEMPERATURE : 75°F
MATERIAL : STEEL

SID : J-O-B-1

P_{max} = 2067.3 lb
P_Q = 1176.9 lb
K_Q = 54.5 ksi(in)$^{1/2}$



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J-O-B-2

AO SMITH 1146a

OUTER LAYER

J_{IC} FRACTURE TOUGHNESS

L-T

-20ºF

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Testing Specialists for Aerospace, Automotive, and Nuclear Fields

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J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-55962	MATERIAL : STEEL	MODULUS : 31.10 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 119.1 ksi
SID : J-O-B-2	WMT&R QUOTE : QN121622 REV. 1	YIELD STRENGTH : 82.2 ksi
TESTLOG : S70804		EFFECTIVE YIELD STRENGTH : 100.7 ksi
TEST DATE : 5/10/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS / TEST PARAMETERS

TOTAL THICKNESS (B)	: 0.251 in	TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
NET THICKNESS (B_N)	: 0.186 in	TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
EFFECTIVE THICKNESS (B_e)	: 0.234 in	ORIENTATION	: L-T	PARTIAL UNLOADING RATE	: 0.02 in/min
WIDTH (W)	: 1.004 in	TEST MACHINE	: H20	UNLOADING INTERVAL	: 0.0005 in
UNCRACKED LIGAMENT (b_o)	: 0.497 in	CLIP GAGE	: 1261635	HOLDTIME	: 5.0 sec.
NOTCH LENGTH (a_n)	: 0.453 in	CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.499 in	0.507 in	0.508 in	0.510 in	0.510 in	0.508 in	0.506 in	0.505 in	0.503 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.571 in	0.570 in	0.563 in	0.560 in	0.559 in	0.557 in	0.552 in	0.551 in	0.547 in

PRECRACK AVERAGE	: 0.5069 in	FINAL AVERAGE	: 0.5589 in
PRECRACK a/W	: 0.5049	FINAL a/W	: 0.5566

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 450 lb	FINAL P_{max}	: 394 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 109238	FINAL K_{max}	: 15.36 ksi(in)$^{1/2}$		

ORIGINAL CRACK / FINAL CRACK / MODULUS

ORIGINAL CRACK		FINAL CRACK		MODULUS	
PHYSICAL CRACK SIZE (a_o)	: 0.5069 in	PHYSICAL CRACK SIZE (a_p)	: 0.5589 in	MODULUS	: 31.10 Msi
EST. CRACK SIZE (a_{oq})	: 0.5069 in	EST. CRACK SIZE ($a_{predicted}$)	: 0.5520 in	EFFECTIVE MODULUS	: 31.10 Msi
PERCENT DIFFERENCE	: 0.00 %	PERCENT DIFFERENCE	: 1.23 %	PERCENT DIFFERENCE	: 0.01 %

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE FATIGUE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   a/W = 0.5049
2. (9.1.5.2) DIFFERENCE BETWEEN PREDICTED ($\Delta a_{predicted}$) AND MEASURED (Δa_p) CRACK EXTENSION SHALL NOT EXCEED 0.15 Δa_p FOR CRACK EXTENSIONS LESS THAN 0.2 b_o AND 0.03 b_o THEREAFTER — VALID
   Difference = 0.0069 in $0.15\Delta a_p$ = 0.0078 in
3. (A9.7.2.1) a_{oq} SHALL NOT DIFFER FROM a_o BY MORE THAN THE LARGER OF 0.01 W OR 0.0197 IN. — VALID
   Difference = 0.0000 in Limit = 0.0197 in
4. (A9.7.2.2) NUMBER OF DATA AVAILABLE TO CALCULATE a_{oq} SHALL BE ≥ 8; NUMBER OF DATA BETWEEN $0.4J_Q$ AND J_Q SHALL BE ≥ 3; CORRELATION COEFFICIENT OF THE LEAST SQUARES FIT SHALL BE > 0.96 — VALID
   a_{oq} Points = 26 Data Points = 14 C.C. = 0.99415
5. (A9.7.1) POWER COEFFICIENT C_2 SHALL BE LESS THAN 1.0 — VALID
   C_2 = 0.3810
6. (A9.8.1) THICKNESS, $B > 10J_Q/\sigma_Y$ — VALID
   B = 0.2510 in $10J_Q/\sigma_Y$ = 0.0768 in
7. (A9.8.2) INITIAL LIGAMENT, $b_o > 10J_Q/\sigma_Y$ — VALID
   b_o = 0.4971 in $10J_Q/\sigma_Y$ = 0.0768 in
8. (A9.6.6.6) AT LEAST FIVE DATA POINTS MUST REMAIN BETWEEN a_{min} AND a_{limit} AND J_{limit} — VALID
   Data Points = 13
9. (A9.6.4) AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.006-in EXCLUSION LINE AND A 0.02-in OFFSET LINE. AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.02-in OFFSET LINE AND THE 0.06-in EXCLUSION LINE. — VALID

TEST IS VALID: J_{Ic} = 772.72 in-lb/in^2

K_{JIc} = 162.51 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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WESTMOORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
SID : J-O-B-2
TESTLOG : S70804
TEST DATE : 5/10/2013

MATERIAL : STEEL
WMT&R QUOTE : QN121622 REV. 1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.10 Msi
ULTIMATE STRENGTH : 119.1 ksi
YIELD STRENGTH : 82.2 ksi
EFFECTIVE YIELD STRENGTH : 100.7 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.251 in	WIDTH (W)	: 1.004 in
NET THICKNESS (B_N)	: 0.186 in	UNCRACKED LIGAMENT (b_o)	: 0.497 in
EFFECTIVE THICKNESS (B_e)	: 0.234 in	NOTCH LENGTH (a_n)	: 0.453 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-T	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H20	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 1261635	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.499 in	0.507 in	0.508 in	0.510 in	0.510 in	0.508 in	0.506 in	0.505 in	0.503 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.571 in	0.570 in	0.563 in	0.560 in	0.559 in	0.557 in	0.552 in	0.551 in	0.547 in

PRECRACK AVERAGE	: 0.5069 in	FINAL AVERAGE	: 0.5589 in
PRECRACK a/W	: 0.5049	FINAL a/W	: 0.5566

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 450 lb	FINAL P_{max}	: 394 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 109238	FINAL K_{max}	: 15.36 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 2152.2 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0539 in   0.05B = 0.0126 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING, THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^f / \sigma_{YS}^t)(0.4\sigma_{YS}^f\ ksi\sqrt{in})$, WHERE σ_{YS}^f AND σ_{YS}^T ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 15.0 ksi(in)$^{1/2}$ K_{max} Limit = 32.9 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\ (\sigma_{YS}^f / \sigma_{YS}^t) * K_F$ WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 15.4 ksi(in)$^{1/2}$ K_{max} Limit = 97.5 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0079 in   0.05B = 0.0126 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0121 in   0.05B = 0.0126 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0440 in   50% of the Average = 0.0260 in

ALL GENERAL VALIDITY CHECKS ARE VALID

GERALD W. BOICE - THOMAS S. FEDOR

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
SID : J-O-B-2
TESTLOG : S70804
TEST DATE : 5/10/2013

MATERIAL : STEEL
WMT&R QUOTE : QN121622 REV. 1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.10 Msi
ULTIMATE STRENGTH : 119.1 ksi
YIELD STRENGTH : 82.2 ksi
EFFECTIVE YIELD STRENGTH : 100.7 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B) : 0.251 in
NET THICKNESS (B_N) : 0.186 in
EFFECTIVE THICKNESS (B_e) : 0.234 in
WIDTH (W) : 1.004 in
UNCRACKED LIGAMENT (b_o) : 0.497 in
NOTCH LENGTH (a_n) : 0.453 in

TEST PARAMETERS

TEST TEMPERATURE : -20°F
TEST TYPE : CT
ORIENTATION : L-T
TEST MACHINE : H20
CLIP GAGE : 1261635
CLIP GAGE LOCATION : LOAD LINE

MAIN RAMP RATE : 0.02 in/min
PARTIAL LOADING RATE : 0.02 in/min
PARTIAL UNLOADING RATE : 0.02 in/min
UNLOADING INTERVAL : 0.0005 in
HOLDTIME : 5.0 sec.
OPERATOR : DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.499 in	0.507 in	0.508 in	0.510 in	0.510 in	0.508 in	0.506 in	0.505 in	0.503 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.571 in	0.570 in	0.563 in	0.560 in	0.559 in	0.557 in	0.552 in	0.551 in	0.547 in

PRECRACK AVERAGE : 0.5069 in FINAL AVERAGE : 0.5589 in
PRECRACK a/W : 0.5049 FINAL a/W : 0.5566

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 450 lb
FINAL P_{max} : 394 lb
FINAL K_{max} : 15.36 ksi(in)$^{1/2}$

R-RATIO (P_{min} / P_{max}) : 0.1
CYCLES : 109238

TEST RESULTS

CANDIDATE FORCE (P_Q) : 1081.4 lb
K_Q : 49.0 ksi(in)$^{1/2}$

MAXIMUM FORCE (P_{max}) : 2152.2 lb
SPECIMEN STRENGTH RATIO : 2.87

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   $a/W = 0.5049$
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   $P_{max}/P_Q = 1.9902$
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2 = 0.8875$ in $b_o = 0.4971$ in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{\,J} / \sigma_{YS}^{\,I}) * K_F$ WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 15.4 ksi(in)$^{1/2}$ K_{max} Limit = 29.4 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 49.0 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-O-B-2
TESTLOG : S70804
TEST DATE : 5/10/2013

MATERIAL : STEEL

TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV. 1

ORIGINAL COMPLIANCE CALCULATION : 0.5069 in
ORIGINAL PHYSICAL MEASUREMENT : 0.5069 in
MODULUS (E) : 31.10 Msi

WIDTH (W) : 1.004 in
TOTAL THICKNESS (B) : 0.251 in
NET THICKNESS (B_N) : 0.186 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0073	1241.0	0.51	6.90	93.01	99.91	5.212E-06	38.07	0.9999	0.5079	0.0010
2	0.0078	1303.9	0.71	11.62	102.74	114.37	5.213E-06	38.09	0.9999	0.5080	0.0011
3	0.0083	1373.0	0.93	17.15	114.18	131.33	5.222E-06	38.16	0.9999	0.5084	0.0015
4	0.0089	1432.7	1.24	24.65	123.96	148.61	5.208E-06	38.07	0.9999	0.5079	0.0010
5	0.0094	1492.7	1.54	32.08	134.78	166.85	5.214E-06	38.12	0.9999	0.5081	0.0013
6	0.0099	1544.5	1.87	40.26	144.14	184.40	5.208E-06	38.09	0.9999	0.5080	0.0011
7	0.0104	1597.8	2.25	49.37	154.42	203.78	5.211E-06	38.12	0.9999	0.5081	0.0013
8	0.0109	1647.0	2.71	60.68	164.21	224.89	5.214E-06	38.15	0.9999	0.5083	0.0014
9	0.0115	1690.6	3.19	72.33	173.08	245.41	5.214E-06	38.16	0.9999	0.5083	0.0015
10	0.0120	1735.9	3.77	86.52	182.76	269.28	5.219E-06	38.20	0.9999	0.5086	0.0017
11	0.0127	1778.7	4.42	102.30	192.34	294.65	5.228E-06	38.28	0.9999	0.5090	0.0021
12	0.0132	1816.7	5.10	118.88	200.88	319.76	5.231E-06	38.31	0.9999	0.5091	0.0023
13	0.0139	1850.1	5.79	135.58	209.74	345.32	5.258E-06	38.52	0.9999	0.5102	0.0033
14	0.0144	1882.3	6.62	155.98	216.62	372.60	5.248E-06	38.45	0.9999	0.5099	0.0030
15	0.0150	1909.8	7.43	175.81	223.49	399.30	5.256E-06	38.52	0.9999	0.5102	0.0033
16	0.0156	1933.2	8.22	194.55	230.54	425.08	5.283E-06	38.73	0.9999	0.5113	0.0044
17	0.0162	1958.4	9.01	213.54	237.92	451.46	5.305E-06	38.90	0.9999	0.5122	0.0053
18	0.0169	1984.8	10.01	238.05	244.48	482.52	5.306E-06	38.92	0.9999	0.5123	0.0054
19	0.0175	2004.7	10.93	260.09	251.08	511.17	5.333E-06	39.13	0.9998	0.5133	0.0065
20	0.0181	2024.9	12.03	287.25	255.93	543.19	5.328E-06	39.10	0.9999	0.5132	0.0063
21	0.0188	2043.3	13.02	310.82	262.26	573.08	5.353E-06	39.30	0.9999	0.5142	0.0073
22	0.0197	2065.3	14.56	348.11	269.54	617.64	5.377E-06	39.49	0.9998	0.5151	0.0083
23	0.0206	2083.7	16.16	386.70	275.93	662.63	5.400E-06	39.67	0.9998	0.5160	0.0092
24	0.0215	2098.3	17.79	426.17	281.44	707.61	5.423E-06	39.85	0.9998	0.5169	0.0101
25	0.0225	2111.2	19.49	467.14	286.67	753.81	5.447E-06	40.05	0.9998	0.5179	0.0111
26	0.0234	2120.6	21.19	506.70	292.89	799.59	5.500E-06	40.46	0.9998	0.5199	0.0130
27	0.0244	2127.0	22.90	546.68	297.92	844.60	5.547E-06	40.81	0.9998	0.5216	0.0148
28	0.0254	2126.7	24.78	590.88	301.28	892.16	5.596E-06	41.19	0.9997	0.5234	0.0166
29	0.0264	2117.1	26.78	636.35	303.67	940.02	5.669E-06	41.75	0.9996	0.5261	0.0192
30	0.0275	2100.4	28.87	683.69	304.57	988.26	5.752E-06	42.38	0.9997	0.5290	0.0221
31	0.0285	2086.0	30.62	719.39	308.61	1028.00	5.874E-06	43.29	0.9995	0.5331	0.0262
32	0.0296	2083.1	32.73	771.01	310.06	1081.08	5.906E-06	43.55	0.9997	0.5342	0.0274

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT

SID : J-O-B-2
TESTLOG : S70804
TEST DATE : 5/10/2013

MATERIAL : STEEL

TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV. 1

ORIGINAL COMPLIANCE CALCULATION : 0.5069 in
ORIGINAL PHYSICAL MEASUREMENT : 0.5069 in
MODULUS (E) : 31.10 Msi

WIDTH (W) : 1.004 in
TOTAL THICKNESS (B) : 0.251 in
NET THICKNESS (B_N) : 0.186 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
33	0.0306	2077.2	34.60	813.10	313.56	1126.66	5.983E-06	44.13	0.9997	0.5368	0.0299
34	0.0316	2057.3	36.52	854.57	314.17	1168.74	6.081E-06	44.87	0.9997	0.5400	0.0331
35	0.0327	2043.3	38.26	886.91	320.36	1207.26	6.239E-06	46.06	0.9996	0.5449	0.0381
36	0.0337	2021.3	39.60	902.91	328.85	1231.76	6.474E-06	47.81	0.9926	0.5520	0.0451

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

Phone (724) 537-3131

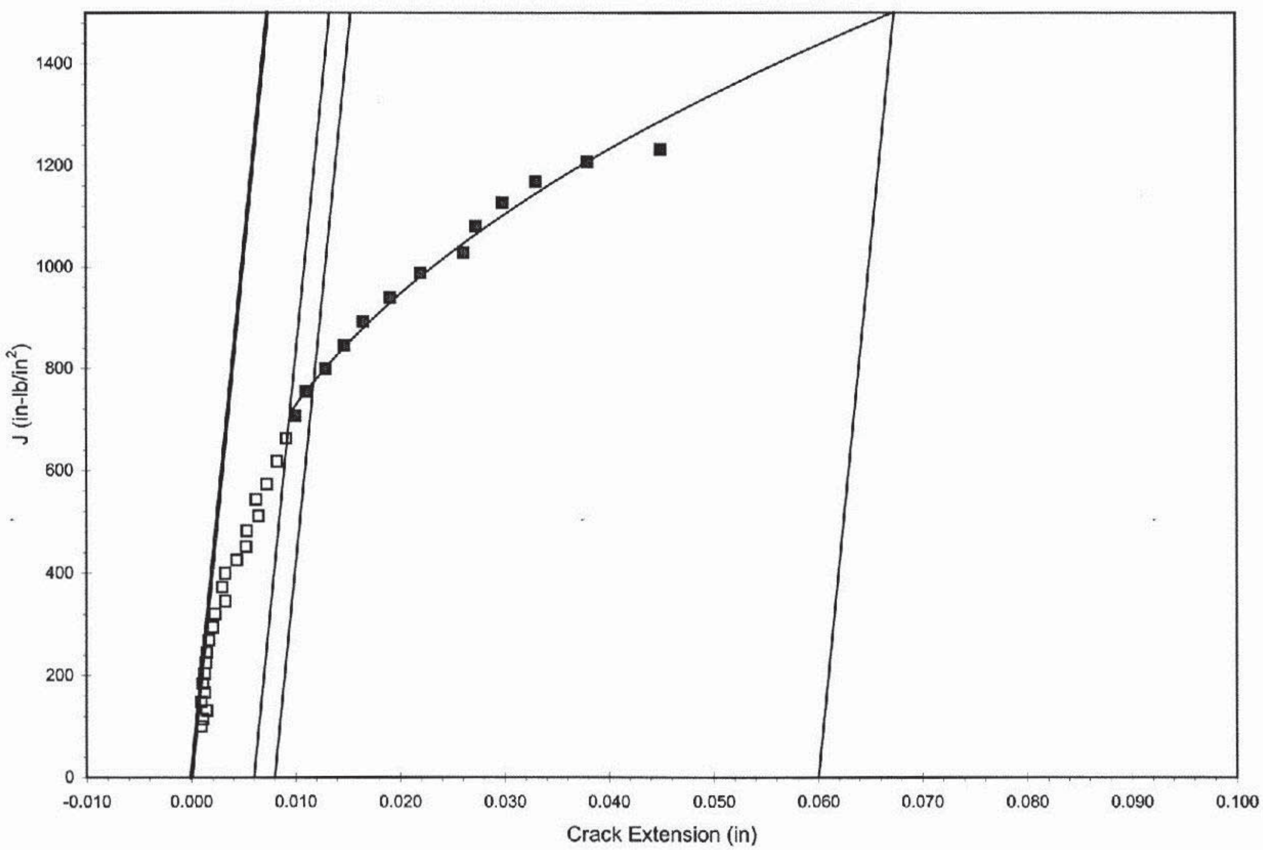
CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV. 1

TESTLOG : S70804
TEST DATE : 5/10/2013
TEMPERATURE : -20°F
MATERIAL : STEEL

SID : J-O-B-2

$$J_{Ic} = 772.72 \text{ in-lb/in}^2$$

$$J = 1223.3\,(a / 0.0394)^{0.3810}$$



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Westmoreland Mechanical Testing & Research, Inc.

Force vs. COD Graph

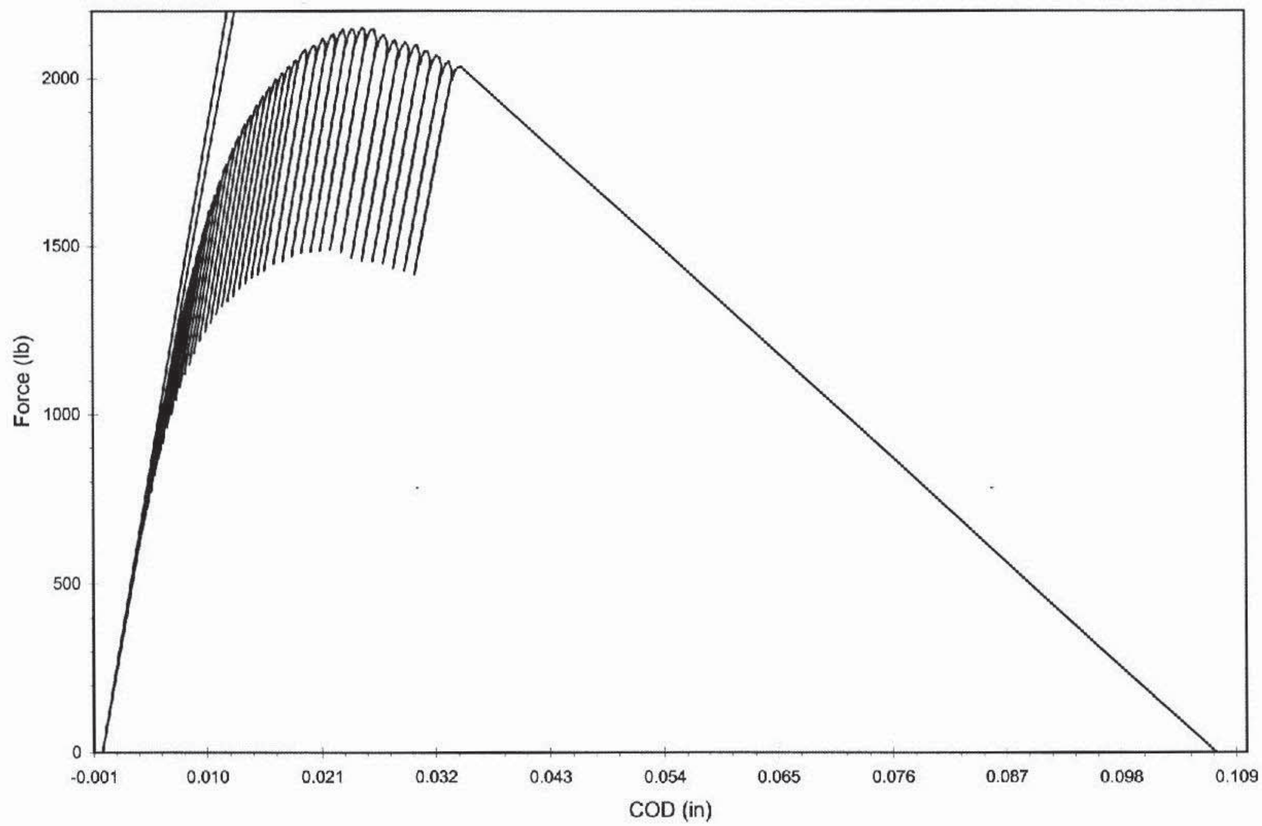
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-55962
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV. 1

TESTLOG : S70804
TEST DATE : 5/10/2013
TEMPERATURE : -20°F
MATERIAL : STEEL

SID : J-O-B-2

P_{max} = 2152.2 lb
P_Q = 1081.4 lb
K_Q = 49.0 ksi(in)$^{1/2}$



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AO SMITH 1146a
INNER LAYER
FATIGUE CRACK GROWTH

ID	*Layer*	*Orientation*	*R*	*Temp*
FCG-I-B-1	Inner	L-T	0.15	RT
FCG-I-B-2				
FCG-I-B-3	Inner	L-T	0.7	RT
FCG-I-B-4				
FCG-I-B-5	Inner	L-T	0.15	-20°F
FCG-I-B-6				
FCG-I-B-7	Inner	L-T	0.7	-20°F
FCG-I-B-8				

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-I-B-1
YIELD STRENGTH : 150.0 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : S41387
MATERIAL : Inner Layer
TEST MACHINE : H53

WMT&R REPORT NO. : 3-55962
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 4/12/2013
CRACK PLANE ORIENTATION : L-T

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2504 in
WIDTH (W) : 2.0035 in
NOTCH (An) : 0.4005 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 1354.80 lb
MINIMUM LOAD : 203.2 lb
LOAD RANGE : 1151.6 lb

STRESS RATIO : 0.15
FREQUENCY : 15 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : ROOM
HUMIDITY : 22% - 36%
ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
1354	0.1494	0.4797	25478	0.0061	5706	1.0056E-06	15.534	0
1354	0.1509	0.4863	32623	0.0067	7145	1.0389E-06	15.683	0
1355	0.1525	0.4935	38522	0.0072	5899	1.0605E-06	15.834	0
1354	0.1540	0.5002	45280	0.0067	6758	1.1344E-06	15.969	0
1355	0.1554	0.5065	50984	0.0063	5704	1.2123E-06	16.132	0
1355	0.1570	0.5132	57112	0.0066	6128	1.2261E-06	16.294	0
1354	0.1586	0.5204	61130	0.0072	4018	1.2882E-06	16.397	0
1355	0.1601	0.5270	66200	0.0066	5070	1.3051E-06	16.565	0
1355	0.1622	0.5356	74018	0.0087	7818	1.3187E-06	16.780	0
1355	0.1644	0.5453	79937	0.0096	5919	1.3801E-06	16.957	0
1355	0.1659	0.5514	86701	0.0062	6764	1.4432E-06	17.172	0
1355	0.1675	0.5583	89646	0.0069	2945	1.444E-06	17.273	0
1354	0.1700	0.5686	95962	0.0103	6316	1.4578E-06	17.465	0
1355	0.1719	0.5764	101874	0.0078	5912	1.5931E-06	17.685	0
1355	0.1735	0.5829	107152	0.0065	5278	1.4889E-06	17.889	0
1355	0.1751	0.5892	110744	0.0063	3592	1.536E-06	18.002	0
1355	0.1773	0.5984	114337	0.0092	3593	1.597E-06	18.138	0
1355	0.1791	0.6055	121944	0.0070	7607	1.7345E-06	18.421	0
1356	0.1813	0.6141	125325	0.0086	3381	1.8538E-06	18.558	0
1355	0.1830	0.6211	129978	0.0070	4653	1.849E-06	18.753	0
1355	0.1855	0.6307	133778	0.0095	3800	2.0019E-06	18.968	0
1355	0.1876	0.6391	137371	0.0084	3593	1.9467E-06	19.132	0
1355	0.1892	0.6452	142232	0.0061	4861	2.099E-06	19.373	0
1354	0.1913	0.6535	145399	0.0083	3167	2.2742E-06	19.516	0
1355	0.1936	0.6622	150464	0.0087	5065	2.3737E-06	19.828	0
1355	0.1954	0.6691	151098	0.0069	634	2.514E-06	19.891	0
1355	0.1974	0.6767	154260	0.0076	3162	2.6941E-06	20.073	0

1355	0.1997	0.6853	158908	0.0087	4648	3.1655E-06	20.410	0
1354	0.2019	0.6935	161021	0.0082	2113	2.8737E-06	20.578	0
1355	0.2038	0.7006	162290	0.0070	1269	3.0451E-06	20.692	0
1355	0.2062	0.7096	165037	0.0090	2747	3.3136E-06	20.955	0
1355	0.2080	0.7160	168630	0.0065	3593	2.8375E-06	21.276	0
1355	0.2098	0.7225	169476	0.0065	846	2.8972E-06	21.299	0
1355	0.2126	0.7328	173068	0.0103	3592	2.9412E-06	21.593	0
1355	0.2143	0.7389	177085	0.0060	4017	3.2928E-06	21.947	0
1355	0.2178	0.7516	178141	0.0127	1056	3.5293E-06	22.025	0
1355	0.2199	0.7587	182155	0.0071	4014	4.1241E-06	22.476	0
1355	0.2216	0.7648	182367	0.0061	212	4.208E-06	22.506	0
1355	0.2242	0.7740	184478	0.0092	2111	4.2442E-06	22.740	0
1355	0.2279	0.7869	187648	0.0128	3170	4.8614E-06	23.239	0
1355	0.2298	0.7934	189126	0.0066	1478	4.4767E-06	23.480	0
1355	0.2333	0.8054	190819	0.0120	1693	4.5623E-06	23.717	0
1355	0.2388	0.8241	195042	0.0187	4223	4.7751E-06	24.314	0
1355	0.2417	0.8339	199062	0.0098	4020	5.5222E-06	24.964	0
1355	0.2449	0.8443	199906	0.0104	844	6.0879E-06	25.086	0
1355	0.2484	0.8558	200540	0.0115	634	6.0003E-06	25.213	0
1355	0.2527	0.8698	203713	0.0140	3173	7.748E-06	26.035	0
1355	0.2577	0.8859	205402	0.0160	1689	7.6124E-06	26.494	0
1355	0.2619	0.8992	207515	0.0133	2113	6.4425E-06	27.098	0
1355	0.2657	0.9111	207938	0.0119	423	7.2289E-06	27.289	0
1355	0.2679	0.9180	209629	0.0069	1691	6.8697E-06	27.660	0
1355	0.2702	0.9251	211948	0.0071	2319	7.7545E-06	28.238	0
1355	0.2736	0.9357	212369	0.0106	421	7.329E-06	28.407	0
1353	0.2784	0.9501	214052	0.0144	1683	8.8825E-06	29.015	0
1354	0.2886	0.9805	217008	0.0304	2956	1.0215E-05	30.381	0
1355	0.3013	1.0170	220594	0.0366	3586	1.0142E-05	32.096	0
1356	0.3089	1.0384	222917	0.0214	2323	9.9709E-06	33.336	0
1354	0.3118	1.0465	223550	0.0081	633	1.3447E-05	33.583	0
1355	0.3159	1.0578	224606	0.0112	1056	1.3304E-05	34.352	0
1355	0.3192	1.0667	225663	0.0090	1057	1.5062E-05	35.468	0
1355	0.3390	1.1188	227777	0.0521	2114	1.4188E-05	37.411	0
1354	0.3454	1.1348	229468	0.0160	1691	1.3269E-05	39.003	0
1354	0.3490	1.1439	230948	0.0091	1480	1.4214E-05	40.431	0
1355	0.3551	1.1588	231581	0.0149	633	1.5923E-05	40.675	0
1354	0.3639	1.1800	233482	0.0213	1901	2.6954E-05	43.553	0
1359	0.3739	1.2036	233717	0.0069	24	3.2819E-05	44.255	0
1355	0.3769	1.2104	234014	0.0068	297	3.5876E-05	44.802	0
1355	0.3799	1.2172	234225	0.0067	211	3.6041E-05	45.839	0
1355	0.3830	1.2242	234437	0.0070	212	2.9616E-05	46.284	0
1355	0.3865	1.2321	234719	0.0078	282	3.0165E-05	47.128	0
1355	0.3900	1.2398	235002	0.0077	283	3.2231E-05	47.926	0
1355	0.3928	1.2460	235142	0.0062	140	3.3709E-05	48.342	0
1355	0.3959	1.2529	235424	0.0068	282	3.9545E-05	49.348	0
1355	0.3998	1.2612	235565	0.0083	141	4.2323E-05	49.931	0
1355	0.4035	1.2691	235776	0.0079	211	4.5605E-05	50.958	0
1355	0.4092	1.2811	235988	0.0121	212	4.9622E-05	52.192	0
1355	0.4125	1.2879	236129	0.0067	141	5.0442E-05	52.973	1

1355	0.4174	1.2979	236340	0.0100	211	5.5525E-05	54.278	1
1355	0.4213	1.3059	236481	0.0080	141	5.6505E-05	55.232	1
1355	0.4252	1.3137	236622	0.0078	141	6.0357E-05	56.271	1
1355	0.4308	1.3246	236763	0.0109	141	6.6981E-05	57.436	1
1355	0.4342	1.3312	236904	0.0066	141	7.4088E-05	58.750	1
1355	0.4373	1.3373	236974	0.0060	70	7.7892E-05	59.464	1
1355	0.4439	1.3498	237115	0.0125	141	8.9276E-05	61.092	1
1354	0.4472	1.3559	237186	0.0061	71	0.00010075	62.111	1
1355	0.4506	1.3622	237256	0.0063	70	0.00012208	63.179	1
1354	0.4548	1.3700	237327	0.0078	71	0.00014879	64.385	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-I-B-2
YIELD STRENGTH : 82.2 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : S41388
MATERIAL : Inner Layer
TEST MACHINE : H176

WMT&R REPORT NO. : 3-55962
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 5/9/2013
CRACK PLANE ORIENTATION : L-T

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2500 in
WIDTH (W) : 0.9990 in
NOTCH (An) : 0.2002 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 407.00 lb
MINIMUM LOAD : 61.1 lb
LOAD RANGE : 345.9 lb

STRESS RATIO : 0.15
FREQUENCY : 15 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : ROOM
HUMIDITY : 29% - 34%
ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
407	0.0575	0.2799	86134	0.0039	57644	1.1883E-07	7.413	0
407	0.0585	0.2850	119694	0.0051	33560	9.2264E-08	7.472	0
407	0.0593	0.2891	170453	0.0041	50759	8.656E-08	7.559	0
407	0.0602	0.2938	249612	0.0047	79159	8.8574E-08	7.693	0
407	0.0610	0.2980	279722	0.0042	30110	8.9823E-08	7.738	0
407	0.0617	0.3019	326191	0.0039	46469	9.5594E-08	7.824	0
407	0.0625	0.3057	362331	0.0039	36140	1.1046E-07	7.897	0
407	0.0633	0.3098	405354	0.0041	43023	1.1948E-07	7.996	0
407	0.0643	0.3150	452677	0.0051	47323	1.303E-07	8.128	0
407	0.0653	0.3198	466450	0.0048	13773	1.333E-07	8.154	0
407	0.0671	0.3287	536138	0.0089	69688	1.4414E-07	8.383	0
407	0.0681	0.3333	573982	0.0046	37844	1.5327E-07	8.484	0
407	0.0689	0.3371	600660	0.0038	26678	1.5784E-07	8.586	0
407	0.0701	0.3426	630771	0.0055	30111	1.6682E-07	8.678	0
407	0.0710	0.3468	652280	0.0042	21509	1.8015E-07	8.773	0
407	0.0719	0.3512	680674	0.0044	28394	1.8461E-07	8.898	0
407	0.0730	0.3560	706487	0.0047	25813	1.867E-07	9.002	0
407	0.0742	0.3617	729722	0.0057	23235	1.9472E-07	9.110	0
407	0.0752	0.3659	758120	0.0043	28398	2.0743E-07	9.232	0
407	0.0761	0.3702	778774	0.0043	20654	2.1368E-07	9.349	0
407	0.0770	0.3742	793399	0.0040	14625	2.1528E-07	9.425	0
407	0.0780	0.3784	812327	0.0042	18928	2.3372E-07	9.522	0
407	0.0791	0.3832	834696	0.0049	22369	2.3616E-07	9.665	0
407	0.0800	0.3871	851898	0.0039	17202	2.4498E-07	9.774	0
407	0.0812	0.3921	868240	0.0050	16342	2.5782E-07	9.857	0
407	0.0824	0.3971	892332	0.0049	24092	2.8099E-07	10.033	0

407	0.0834	0.4011	902654	0.0041	10322	2.9226E-07	10.093	0
407	0.0846	0.4062	920726	0.0051	18072	3.0682E-07	10.249	0
407	0.0856	0.4101	932782	0.0039	12056	3.2629E-07	10.364	0
407	0.0866	0.4142	944829	0.0040	12047	3.37E-07	10.481	0
407	0.0877	0.4187	959462	0.0045	14633	3.542E-07	10.605	0
407	0.0887	0.4226	968926	0.0039	9464	3.6408E-07	10.700	0
407	0.0898	0.4269	980113	0.0043	11187	3.8454E-07	10.838	0
407	0.0908	0.4309	991311	0.0040	11198	4.1091E-07	10.960	0
407	0.0920	0.4354	1002496	0.0045	11185	4.3964E-07	11.095	0
407	0.0930	0.4392	1010236	0.0038	7740	4.345E-07	11.209	0
407	0.0944	0.4441	1020563	0.0049	10327	4.7013E-07	11.376	0
407	0.0955	0.4486	1029168	0.0044	8605	4.9752E-07	11.481	0
407	0.0966	0.4524	1041210	0.0039	12042	5.3975E-07	11.704	0
407	0.0977	0.4563	1043789	0.0038	2579	5.3898E-07	11.739	0
407	0.0988	0.4602	1051529	0.0039	7740	5.666E-07	11.882	0
407	0.1006	0.4667	1062717	0.0066	11188	6.068E-07	12.144	0
407	0.1021	0.4718	1071321	0.0051	8604	6.0116E-07	12.320	0
407	0.1036	0.4772	1079928	0.0053	8607	6.1507E-07	12.484	0
407	0.1050	0.4817	1087668	0.0045	7740	6.5986E-07	12.694	0
407	0.1063	0.4860	1093692	0.0043	6024	7.0178E-07	12.816	0
407	0.1082	0.4922	1104019	0.0063	10327	7.7995E-07	13.118	0
407	0.1101	0.4985	1110043	0.0063	6024	8.1646E-07	13.317	0
407	0.1120	0.5046	1116923	0.0060	6880	8.4602E-07	13.571	0
407	0.1133	0.5084	1122086	0.0039	5163	8.6719E-07	13.776	0
407	0.1147	0.5129	1127245	0.0045	5159	8.6935E-07	13.922	0
407	0.1170	0.5198	1134990	0.0069	7745	9.2542E-07	14.236	0
407	0.1194	0.5267	1143594	0.0069	8604	1.1228E-06	14.636	0
407	0.1216	0.5331	1147898	0.0064	4304	1.2098E-06	14.874	0
407	0.1230	0.5371	1152201	0.0040	4303	1.242E-06	15.144	0
407	0.1251	0.5428	1154783	0.0057	2582	1.3621E-06	15.326	0
407	0.1278	0.5501	1160807	0.0072	6024	1.4181E-06	15.761	0
407	0.1316	0.5601	1168552	0.0100	7745	1.6458E-06	16.405	0
407	0.1333	0.5643	1170273	0.0043	1721	1.7298E-06	16.553	0
407	0.1352	0.5689	1173020	0.0041	1888	1.8422E-06	16.846	0
407	0.1372	0.5737	1175314	0.0048	2294	1.9511E-06	17.162	0
407	0.1392	0.5785	1178068	0.0048	2754	1.9317E-06	17.458	0
407	0.1409	0.5824	1179902	0.0038	1834	1.9831E-06	17.699	0
407	0.1427	0.5864	1181738	0.0040	1836	2.0303E-06	17.948	0
407	0.1444	0.5903	1184034	0.0039	2296	2.1492E-06	18.281	0
407	0.1464	0.5946	1185868	0.0043	1834	2.2479E-06	18.553	0
407	0.1484	0.5989	1187705	0.0042	1837	2.4398E-06	18.846	0
407	0.1506	0.6035	1189542	0.0046	1837	2.6671E-06	19.224	0
407	0.1529	0.6082	1191377	0.0047	1835	2.8735E-06	19.611	0
407	0.1553	0.6128	1192754	0.0046	1377	3.1106E-06	19.921	0
407	0.1575	0.6169	1194132	0.0041	1378	3.3753E-06	20.269	0
407	0.1599	0.6214	1195508	0.0045	1376	3.6587E-06	20.711	0
407	0.1630	0.6269	1196885	0.0055	1377	3.9441E-06	21.139	0
407	0.1652	0.6307	1197804	0.0038	919	4.1867E-06	21.469	0
407	0.1675	0.6346	1198722	0.0038	918	4.4721E-06	21.884	0

407	0.1699	0.6385	1199639	0.0040	917	4.7706E-06	22.244	0
407	0.1728	0.6431	1200557	0.0045	918	5.1543E-06	22.716	0
407	0.1761	0.6480	1201475	0.0049	918	5.5838E-06	23.208	0
407	0.1799	0.6534	1202393	0.0054	918	6.0469E-06	23.777	0
408	0.1841	0.6592	1203311	0.0057	918	6.5322E-06	24.443	0
407	0.1889	0.6652	1204229	0.0061	918	7.0981E-06	25.124	0
407	0.1946	0.6719	1205146	0.0066	917	7.838E-06	25.929	0
407	0.2015	0.6792	1206064	0.0073	918	8.9746E-06	26.926	0
407	0.2059	0.6834	1206522	0.0042	458	9.7472E-06	27.474	0
407	0.2110	0.6880	1206981	0.0045	459	1.0685E-05	28.108	0

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-I-B-3
YIELD STRENGTH : 82.2 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : S41389
MATERIAL : Inner Layer
TEST MACHINE : H137

WMT&R REPORT NO. : 3-55962
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 5/9/2013
CRACK PLANE ORIENTATION : L-T

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2514 in
WIDTH (W) : 2.0042 in
NOTCH (An) : 0.4454 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 3699.70 lb
MINIMUM LOAD : 2589.8 lb
LOAD RANGE : 1109.9 lb

STRESS RATIO : 0.70
FREQUENCY : 15 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : ROOM
HUMIDITY : 29% - 34%
ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
3699	0.0560	0.5055	17828	0.0050	4661	1.1508E-06	15.463	0
3699	0.0565	0.5107	21842	0.0052	4014	1.1771E-06	15.566	0
3697	0.0571	0.5169	26854	0.0062	5012	1.2272E-06	15.657	0
3700	0.0577	0.5234	31889	0.0065	5035	1.2432E-06	15.829	0
3702	0.0582	0.5287	36568	0.0053	4679	1.2613E-06	15.977	0
3701	0.0588	0.5339	40564	0.0053	3996	1.2608E-06	16.067	0
3699	0.0593	0.5394	44918	0.0054	4354	1.2935E-06	16.174	0
3701	0.0599	0.5450	48920	0.0056	4002	1.3541E-06	16.320	0
3699	0.0604	0.5500	53262	0.0050	4342	1.3915E-06	16.384	0
3700	0.0610	0.5568	57678	0.0068	4416	1.4438E-06	16.556	0
3700	0.0617	0.5632	61664	0.0064	3986	1.5015E-06	16.667	0
3700	0.0622	0.5686	65674	0.0054	4010	1.6074E-06	16.814	0
3701	0.0628	0.5740	69036	0.0053	3362	1.6276E-06	16.943	0
3700	0.0635	0.5808	73037	0.0068	4001	1.651E-06	17.075	0
3700	0.0643	0.5881	76707	0.0074	3670	1.7202E-06	17.216	0
3701	0.0650	0.5952	81368	0.0071	4661	1.7989E-06	17.418	0
3700	0.0655	0.6003	84720	0.0051	3352	1.8666E-06	17.516	0
3700	0.0661	0.6058	87057	0.0055	2337	1.8699E-06	17.610	0
3700	0.0669	0.6126	90405	0.0068	3348	1.9988E-06	17.761	0
3698	0.0675	0.6185	93407	0.0058	3002	2.0865E-06	17.894	0
3700	0.0681	0.6239	96408	0.0054	3001	2.0808E-06	18.062	0
3700	0.0687	0.6291	98408	0.0053	2000	2.1191E-06	18.182	0
3700	0.0693	0.6351	101077	0.0059	2669	2.2245E-06	18.292	0
3701	0.0700	0.6415	104412	0.0064	3335	2.3366E-06	18.472	0
3700	0.0707	0.6480	107091	0.0065	2679	2.4195E-06	18.604	0
3700	0.0716	0.6555	109748	0.0074	2657	2.4908E-06	18.805	0

3702	0.0724	0.6626	112760	0.0072	3012	2.6016E-06	19.013	0
3700	0.0730	0.6684	114771	0.0058	2011	2.672E-06	19.081	0
3701	0.0737	0.6737	117098	0.0053	2327	2.6489E-06	19.281	0
3699	0.0743	0.6790	118782	0.0053	1684	2.7179E-06	19.365	0
3701	0.0752	0.6867	121456	0.0077	2674	2.7986E-06	19.573	0
3701	0.0758	0.6919	123791	0.0052	2335	2.9968E-06	19.744	0
3700	0.0766	0.6985	125795	0.0065	2004	3.2032E-06	19.858	0
3699	0.0772	0.7038	127464	0.0054	1669	3.193E-06	19.977	0
3699	0.0779	0.7102	129139	0.0063	1675	3.3314E-06	20.143	0
3700	0.0788	0.7176	131146	0.0074	2007	3.3705E-06	20.317	0
3699	0.0796	0.7235	133486	0.0059	2340	3.4704E-06	20.504	0
3699	0.0803	0.7295	135151	0.0059	1665	3.6353E-06	20.675	0
3700	0.0810	0.7353	136482	0.0058	1331	3.6435E-06	20.790	0
3700	0.0818	0.7414	138146	0.0061	1664	3.8936E-06	20.999	0
3699	0.0825	0.7471	139482	0.0056	1336	3.9482E-06	21.102	0
3701	0.0831	0.7524	141161	0.0054	1679	4.0505E-06	21.323	0
3700	0.0838	0.7576	142158	0.0052	997	4.1734E-06	21.413	0
3701	0.0845	0.7628	143491	0.0052	1333	4.1946E-06	21.621	0
3699	0.0852	0.7688	144824	0.0060	1333	4.3331E-06	21.735	0
3699	0.0860	0.7751	146161	0.0063	1337	4.3742E-06	21.881	0
3700	0.0868	0.7811	147831	0.0061	1670	4.5866E-06	22.109	0
3701	0.0876	0.7874	149159	0.0062	1328	4.8391E-06	22.307	0
3700	0.0884	0.7932	150156	0.0058	997	5.1068E-06	22.441	0
3699	0.0893	0.7996	151503	0.0064	1347	5.3753E-06	22.676	0
3700	0.0900	0.8054	152515	0.0058	1012	5.5018E-06	22.790	0
3700	0.0909	0.8117	153525	0.0062	1010	5.6891E-06	22.973	0
3700	0.0918	0.8184	154864	0.0067	1339	6.0632E-06	23.200	0
3700	0.0926	0.8244	155862	0.0060	998	6.2789E-06	23.419	0
3699	0.0933	0.8295	156531	0.0051	669	6.3738E-06	23.519	0
3701	0.0942	0.8361	157532	0.0066	1001	6.6732E-06	23.761	1
3699	0.0951	0.8426	158531	0.0065	999	6.7797E-06	23.951	1
3699	0.0961	0.8494	159538	0.0068	1007	6.9732E-06	24.184	1
3700	0.0971	0.8561	160533	0.0068	995	7.529E-06	24.471	1
3700	0.0978	0.8612	161202	0.0050	669	7.8154E-06	24.582	1
3699	0.0989	0.8692	162203	0.0080	1001	8.371E-06	24.852	1
3699	0.0999	0.8760	162877	0.0068	674	8.7181E-06	25.039	1
3700	0.1007	0.8810	163546	0.0051	669	8.975E-06	25.285	1
3699	0.1016	0.8874	164224	0.0064	678	9.3114E-06	25.442	1
3700	0.1026	0.8937	164894	0.0063	670	9.8624E-06	25.696	1
3701	0.1035	0.9000	165562	0.0063	668	1.0644E-05	25.969	1
3700	0.1046	0.9073	166233	0.0072	671	1.1669E-05	26.205	1
3700	0.1060	0.9159	166895	0.0087	662	1.3068E-05	26.522	1
3699	0.1072	0.9239	167559	0.0080	664	1.5405E-05	26.819	1
3700	0.1081	0.9297	167892	0.0058	333	1.74E-05	27.023	1
3698	0.1090	0.9350	168224	0.0054	332	1.9159E-05	27.233	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-I-B-4
YIELD STRENGTH : 82.2 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : S41390
MATERIAL : Inner Layer
TEST MACHINE : H176

WMT&R REPORT NO. : 3-55962
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 5/10/2013
CRACK PLANE ORIENTATION : L-T

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2503 in
WIDTH (W) : 0.9999 in
NOTCH (An) : 0.2030 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 642.90 lb
MINIMUM LOAD : 450.0 lb
LOAD RANGE : 192.9 lb

STRESS RATIO : 0.70
FREQUENCY : 15 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : ROOM
HUMIDITY : 16% - 39%
ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
642	0.0582	0.2877	444536	0.0048	165617	2.8962E-08	4.195	0
642	0.0591	0.2923	610209	0.0046	165673	2.8873E-08	4.248	0
642	0.0599	0.2970	754212	0.0046	144003	3.0666E-08	4.296	0
642	0.0608	0.3015	908258	0.0046	154046	3.1398E-08	4.351	0
643	0.0617	0.3063	1060529	0.0048	152271	3.3038E-08	4.404	0
643	0.0625	0.3109	1189411	0.0045	128882	3.4475E-08	4.451	0
642	0.0634	0.3154	1335255	0.0045	145844	3.6814E-08	4.510	0
642	0.0643	0.3200	1442480	0.0046	107225	3.7919E-08	4.557	0
642	0.0652	0.3245	1562439	0.0045	119959	3.934E-08	4.614	0
642	0.0661	0.3293	1674098	0.0048	111659	4.141E-08	4.665	0
643	0.0671	0.3343	1805666	0.0050	131568	4.2604E-08	4.734	0
642	0.0681	0.3391	1916482	0.0048	110816	4.4071E-08	4.793	0
643	0.0691	0.3444	2022623	0.0053	106141	4.5625E-08	4.855	0
642	0.0701	0.3491	2132276	0.0047	109653	5.1619E-08	4.911	0
642	0.0710	0.3537	2228452	0.0046	96176	6.4034E-08	4.972	0
642	0.0720	0.3582	2317828	0.0045	89376	7.2684E-08	5.053	0
642	0.0729	0.3628	2351292	0.0046	33464	7.1644E-08	5.091	0
642	0.0740	0.3679	2397310	0.0050	46018	7.6109E-08	5.138	0
642	0.0750	0.3725	2478004	0.0047	80694	7.6084E-08	5.223	0
643	0.0760	0.3771	2545802	0.0046	67798	6.9317E-08	5.289	0
643	0.0770	0.3819	2614108	0.0048	68306	6.6067E-08	5.354	0
642	0.0780	0.3864	2677214	0.0045	63106	6.702E-08	5.408	0
642	0.0791	0.3911	2749673	0.0047	72459	6.6306E-08	5.474	0
643	0.0801	0.3959	2830125	0.0047	80452	6.6203E-08	5.557	0
642	0.0811	0.4004	2892981	0.0045	62856	6.7034E-08	5.608	0
643	0.0822	0.4052	2967004	0.0048	74023	7.0292E-08	5.692	0

643	0.0833	0.4099	3032355	0.0047	65351	7.4837E-08	5.769	0
642	0.0844	0.4145	3096546	0.0046	64191	7.8291E-08	5.828	0
643	0.0855	0.4191	3150406	0.0045	53860	8.1372E-08	5.903	0
642	0.0866	0.4237	3202357	0.0047	51951	8.0421E-08	5.975	0
642	0.0877	0.4286	3262110	0.0048	59753	7.9507E-08	6.053	0
642	0.0888	0.4331	3314515	0.0045	52405	7.8473E-08	6.114	0
642	0.0900	0.4377	3390104	0.0046	75589	7.9698E-08	6.221	0
642	0.0911	0.4425	3451691	0.0048	61587	8.8381E-08	6.302	0
642	0.0924	0.4474	3501646	0.0049	49955	9.893E-08	6.379	0
642	0.0935	0.4520	3552024	0.0046	50378	1.1303E-07	6.468	0
643	0.0947	0.4566	3585718	0.0046	33694	1.1709E-07	6.560	0
642	0.0960	0.4616	3627610	0.0050	41892	1.2015E-07	6.645	0
642	0.0972	0.4664	3660392	0.0048	32782	1.2585E-07	6.725	0
642	0.0986	0.4714	3705655	0.0050	45263	1.2691E-07	6.828	0
642	0.1001	0.4770	3754418	0.0056	48763	1.3306E-07	6.953	0
642	0.1015	0.4823	3788090	0.0053	33672	1.402E-07	7.046	0
643	0.1029	0.4874	3825559	0.0051	37469	1.4693E-07	7.172	0
643	0.1042	0.4922	3857206	0.0048	31647	1.5304E-07	7.284	0
642	0.1058	0.4977	3889745	0.0055	32539	1.598E-07	7.371	0
642	0.1075	0.5036	3930106	0.0059	40361	1.5209E-07	7.537	0
642	0.1089	0.5086	3959548	0.0050	29442	1.4951E-07	7.658	0
643	0.1104	0.5135	3982284	0.0049	22736	1.4657E-07	7.734	0
643	0.1122	0.5195	4045872	0.0060	63588	1.5552E-07	7.953	0
643	0.1138	0.5249	4075744	0.0054	29872	1.7838E-07	8.048	0
642	0.1155	0.5303	4111233	0.0054	35489	1.9915E-07	8.226	0
642	0.1171	0.5355	4125519	0.0053	14286	2.1981E-07	8.313	0
642	0.1189	0.5410	4151595	0.0054	26076	2.2329E-07	8.484	0
642	0.1205	0.5459	4178349	0.0049	26754	2.4543E-07	8.665	0
642	0.1229	0.5531	4197072	0.0072	18723	2.5261E-07	8.787	0
642	0.1249	0.5589	4234462	0.0058	37390	2.8365E-07	9.112	0
642	0.1279	0.5677	4252893	0.0087	18431	2.7815E-07	9.280	0
642	0.1298	0.5730	4270852	0.0054	17959	2.8549E-07	9.449	0
642	0.1316	0.5779	4290033	0.0049	19181	3.1311E-07	9.670	0
642	0.1334	0.5829	4312593	0.0050	22560	3.3167E-07	9.900	0
642	0.1355	0.5885	4325462	0.0056	12869	3.5952E-07	10.064	0
643	0.1375	0.5937	4336154	0.0052	10692	3.7482E-07	10.231	0
643	0.1400	0.5998	4354347	0.0062	18193	4.0652E-07	10.552	0
642	0.1414	0.6034	4362115	0.0045	2429	4.3089E-07	10.650	0
643	0.1438	0.6093	4377507	0.0059	15392	5.234E-07	10.937	0
643	0.1460	0.6144	4388432	0.0052	10925	5.726E-07	11.214	0
642	0.1484	0.6199	4395229	0.0055	6797	6.0058E-07	11.386	0
643	0.1504	0.6244	4400321	0.0046	5092	6.1751E-07	11.568	0
642	0.1526	0.6293	4410756	0.0048	10435	6.1391E-07	11.894	0
642	0.1548	0.6339	4417308	0.0047	6552	5.9379E-07	12.074	0
643	0.1570	0.6386	4426774	0.0047	9466	6.1324E-07	12.369	0
643	0.1596	0.6438	4435278	0.0052	8504	6.6552E-07	12.650	0
642	0.1619	0.6485	4441344	0.0047	6066	7.1455E-07	12.885	0
643	0.1648	0.6540	4449350	0.0056	8006	8.2312E-07	13.255	1
642	0.1674	0.6587	4455178	0.0047	5828	9.1766E-07	13.533	1

642	0.1699	0.6634	4460036	0.0046	4858	1.0371E-06	13.826	1
642	0.1729	0.6686	4464644	0.0052	4608	1.2124E-06	14.138	1
642	0.1763	0.6743	4469737	0.0057	5093	1.4758E-06	14.590	1
642	0.1794	0.6792	4472893	0.0050	3156	1.6422E-06	14.961	1
642	0.1828	0.6844	4475565	0.0052	2672	2.0027E-06	15.279	1
642	0.1860	0.6892	4477992	0.0047	2427	2.6641E-06	15.693	1
643	0.1893	0.6939	4480660	0.0047	2668	4.1909E-06	16.374	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-I-B-5
YIELD STRENGTH : 150.0 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : S41391
MATERIAL : Inner Layer
TEST MACHINE : H288

WMT&R REPORT NO. : 3-55962
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 4/22/2013
CRACK PLANE ORIENTATION : L-T

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2500 in
WIDTH (W) : 2.0031 in
NOTCH (An) : 0.4019 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 1355.30 lb
MINIMUM LOAD : 203.3 lb
LOAD RANGE : 1152.0 lb

STRESS RATIO : 0.15
FREQUENCY : 15 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE (F) : -20
HUMIDITY : N/A
ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
1355	0.0553	0.4840	67502	0.0091	8797	5.406E-07	15.584	0
1355	0.0560	0.4923	94460	0.0083	26958	6.0823E-07	15.898	0
1355	0.0567	0.5005	107924	0.0082	13464	6.3734E-07	16.060	0
1355	0.0575	0.5091	114903	0.0086	6979	6.3094E-07	16.172	0
1355	0.0585	0.5202	131169	0.0111	16266	7.43E-07	16.432	0
1355	0.0593	0.5288	145576	0.0086	14407	7.7341E-07	16.672	0
1355	0.0600	0.5364	156709	0.0076	11133	7.7854E-07	16.858	0
1355	0.0609	0.5465	165086	0.0101	8377	8.1316E-07	17.009	0
1356	0.0619	0.5572	179018	0.0108	13932	8.9683E-07	17.286	0
1355	0.0627	0.5661	190622	0.0089	11604	1.0375E-06	17.516	0
1355	0.0635	0.5743	198506	0.0081	7884	1.0535E-06	17.691	0
1356	0.0645	0.5841	206840	0.0098	8334	1.0754E-06	17.924	0
1355	0.0654	0.5938	211946	0.0098	5106	1.1634E-06	18.065	0
1356	0.0664	0.6043	224012	0.0105	12066	1.1973E-06	18.410	0
1356	0.0673	0.6135	233763	0.0092	9751	1.2927E-06	18.670	0
1356	0.0682	0.6219	237485	0.0084	3722	1.2921E-06	18.779	0
1354	0.0691	0.6316	244906	0.0097	7421	1.3646E-06	19.025	0
1355	0.0700	0.6397	250489	0.0081	5583	1.414E-06	19.236	0
1355	0.0711	0.6505	258388	0.0108	7899	1.4092E-06	19.496	0
1355	0.0719	0.6583	264888	0.0078	6500	1.5127E-06	19.710	0
1355	0.0728	0.6671	270917	0.0088	6029	1.7956E-06	19.950	0
1356	0.0736	0.6750	274633	0.0080	3716	1.8012E-06	20.129	0
1354	0.0744	0.6830	279281	0.0079	4648	1.9714E-06	20.339	0
1355	0.0754	0.6924	282072	0.0094	2791	2.0627E-06	20.528	0
1355	0.0763	0.7005	288093	0.0081	6021	2.2036E-06	20.838	0
1355	0.0772	0.7087	290871	0.0082	2778	2.2763E-06	21.005	0

1355	0.0782	0.7176	295056	0.0089	4185	2.2545E-06	21.279	0
1355	0.0791	0.7260	297846	0.0084	2790	2.4269E-06	21.471	0
1356	0.0804	0.7384	302949	0.0123	5103	2.2974E-06	21.844	0
1355	0.0817	0.7495	308536	0.0112	5587	2.3699E-06	22.146	0
1355	0.0826	0.7576	312246	0.0081	3710	2.5183E-06	22.392	0
1356	0.0836	0.7661	315960	0.0085	3714	2.8451E-06	22.661	0
1355	0.0847	0.7763	318749	0.0102	2789	2.9488E-06	22.915	0
1355	0.0858	0.7854	321990	0.0091	3241	3.1785E-06	23.227	0
1355	0.0871	0.7967	324775	0.0113	2785	3.3343E-06	23.497	0
1354	0.0880	0.8045	328012	0.0078	3237	3.3833E-06	23.822	0
1355	0.0892	0.8142	330332	0.0097	2320	3.4243E-06	24.098	0
1355	0.0903	0.8241	333109	0.0099	2777	3.5773E-06	24.399	0
1355	0.0913	0.8318	335434	0.0077	2325	4.0081E-06	24.676	0
1356	0.0924	0.8412	338216	0.0094	2782	4.194E-06	25.066	0
1355	0.0938	0.8526	340534	0.0114	2318	4.5773E-06	25.391	0
1355	0.0953	0.8647	342391	0.0121	1857	4.7929E-06	25.722	0
1356	0.0969	0.8768	345638	0.0122	3247	4.9376E-06	26.317	0
1356	0.0991	0.8947	348424	0.0179	2786	4.7372E-06	26.846	0
1355	0.1003	0.9035	350741	0.0089	2317	4.8834E-06	27.204	0
1356	0.1017	0.9141	353053	0.0105	2312	5.3967E-06	27.706	0
1355	0.1027	0.9218	354902	0.0077	1849	5.7514E-06	28.045	0
1355	0.1039	0.9307	355828	0.0089	926	6.4691E-06	28.257	0
1355	0.1049	0.9386	356762	0.0078	934	6.4791E-06	28.551	0
1355	0.1061	0.9467	358613	0.0081	1851	7.1506E-06	29.102	0
1355	0.1072	0.9553	359074	0.0085	461	6.9444E-06	29.199	0
1355	0.1086	0.9655	361392	0.0103	2318	8.1931E-06	29.888	0
1355	0.1106	0.9794	362320	0.0139	928	8.3145E-06	30.311	0
1355	0.1125	0.9929	364180	0.0135	1860	8.8418E-06	31.046	0
1355	0.1143	1.0051	365104	0.0122	924	9.0583E-06	31.524	0
1356	0.1160	1.0170	366966	0.0118	1862	8.9834E-06	32.336	0
1355	0.1172	1.0249	367432	0.0079	466	9.3006E-06	32.537	0
1355	0.1192	1.0383	369288	0.0134	1856	1.0296E-05	33.414	0
1355	0.1205	1.0464	369756	0.0081	468	1.1603E-05	33.670	0
1355	0.1220	1.0560	370679	0.0096	923	1.2189E-05	34.274	0
1355	0.1236	1.0662	371608	0.0102	929	1.3638E-05	34.944	0
1355	0.1266	1.0855	372541	0.0193	933	1.341E-05	35.788	0
1355	0.1280	1.0936	373470	0.0081	929	1.3776E-05	36.564	0
1354	0.1295	1.1029	373938	0.0093	468	1.4177E-05	36.997	0
1354	0.1321	1.1185	375326	0.0157	1388	1.5501E-05	38.121	0
1356	0.1336	1.1272	375787	0.0087	461	1.8471E-05	38.661	0
1356	0.1351	1.1359	376250	0.0087	463	2.0182E-05	39.268	0
1355	0.1364	1.1436	376714	0.0076	464	2.2035E-05	39.972	0
1355	0.1401	1.1641	377417	0.0162	241	2.44E-05	41.230	0
1355	0.1421	1.1747	377884	0.0107	467	2.5875E-05	42.146	0
1355	0.1440	1.1850	378348	0.0102	464	2.7091E-05	43.184	0
1355	0.1459	1.1951	378656	0.0101	308	2.7217E-05	43.851	0
1355	0.1476	1.2039	378966	0.0088	310	2.8298E-05	44.609	0
1355	0.1494	1.2131	379275	0.0092	309	2.9978E-05	45.389	0
1355	0.1519	1.2255	379737	0.0124	462	3.1625E-05	46.636	0

1355	0.1539	1.2354	380050	0.0099	313	3.2917E-05	47.616	0
1355	0.1565	1.2476	380358	0.0122	308	3.5158E-05	48.636	0
1355	0.1587	1.2582	380666	0.0107	308	3.8555E-05	49.802	0
1355	0.1610	1.2687	380976	0.0104	310	4.1379E-05	51.118	0
1354	0.1641	1.2826	381286	0.0139	310	4.5983E-05	52.553	1
1355	0.1662	1.2915	381441	0.0089	155	4.8172E-05	53.424	1
1355	0.1694	1.3051	381751	0.0136	310	5.3986E-05	55.405	1
1355	0.1718	1.3152	381906	0.0101	155	5.8761E-05	56.421	1
1354	0.1737	1.3228	382061	0.0077	155	6.6764E-05	57.596	1
1354	0.1764	1.3335	382214	0.0106	153	7.6185E-05	59.014	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-I-B-6
YIELD STRENGTH : 82.2 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : S41392
MATERIAL : Inner Layer
TEST MACHINE : H288

WMT&R REPORT NO. : 3-55962
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 5/14/2013
CRACK PLANE ORIENTATION : L-T

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2504 in
WIDTH (W) : 1.0002 in
NOTCH (An) : 0.2006 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 419.50 lb
MINIMUM LOAD : 62.9 lb
LOAD RANGE : 356.6 lb

STRESS RATIO : 0.15
FREQUENCY : 15 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE (F) : -20
HUMIDITY : 18% - 32%
ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
419	0.0754	0.2682	493974	0.0053	101406	5.4321E-08	7.371	0
419	0.0768	0.2743	584902	0.0062	90928	5.918E-08	7.457	0
419	0.0780	0.2796	686134	0.0053	101232	6.6655E-08	7.589	0
419	0.0793	0.2849	768948	0.0053	82814	8.0355E-08	7.698	0
419	0.0805	0.2902	834229	0.0053	65281	8.6853E-08	7.793	0
419	0.0818	0.2955	893004	0.0053	58775	9.2373E-08	7.915	0
420	0.0831	0.3013	927554	0.0058	34550	9.5247E-08	8.009	0
420	0.0844	0.3065	1000037	0.0052	72483	9.5884E-08	8.149	0
420	0.0858	0.3121	1056378	0.0056	56341	9.5656E-08	8.271	0
419	0.0871	0.3174	1118850	0.0053	62472	9.8792E-08	8.343	0
419	0.0884	0.3228	1169627	0.0054	50777	1.0328E-07	8.466	0
421	0.0898	0.3282	1219148	0.0054	49521	1.4093E-07	8.630	0
419	0.0911	0.3334	1263376	0.0052	44228	1.3713E-07	8.762	0
419	0.0925	0.3386	1314845	0.0052	51469	1.4471E-07	8.939	0
419	0.0976	0.3582	1428622	0.0071	111539	1.4603E-07	9.328	0
419	0.0993	0.3645	1462356	0.0063	33734	1.4687E-07	9.414	0
420	0.1008	0.3699	1506198	0.0054	43842	1.4168E-07	9.614	0
419	0.1028	0.3774	1540831	0.0074	34633	1.5787E-07	9.731	0
419	0.1045	0.3835	1587751	0.0061	46920	1.6414E-07	9.912	0
419	0.1061	0.3891	1627598	0.0056	39847	1.8085E-07	10.078	0
419	0.1078	0.3950	1656107	0.0060	28509	1.9509E-07	10.223	0
420	0.1094	0.4007	1683715	0.0056	27608	2.2585E-07	10.372	0
419	0.1110	0.4062	1707377	0.0056	23662	2.4273E-07	10.513	0
420	0.1127	0.4121	1734120	0.0059	26743	2.6171E-07	10.739	0
419	0.1145	0.4181	1749015	0.0060	14895	2.5932E-07	10.827	0
419	0.1161	0.4235	1773141	0.0054	24126	2.6482E-07	11.056	0

419	0.1177	0.4288	1790209	0.0053	17068	2.701E-07	11.167	0
420	0.1195	0.4348	1819132	0.0060	28923	2.7606E-07	11.401	0
419	0.1213	0.4407	1837294	0.0059	18162	2.9825E-07	11.561	0
420	0.1230	0.4461	1855018	0.0053	17724	3.1879E-07	11.771	0
420	0.1247	0.4516	1872750	0.0055	17732	3.4299E-07	11.959	0
420	0.1264	0.4568	1886114	0.0053	13364	3.562E-07	12.134	0
420	0.1283	0.4626	1902570	0.0058	16456	3.8766E-07	12.364	0
419	0.1300	0.4679	1916360	0.0052	13790	4.0626E-07	12.510	0
419	0.1317	0.4733	1929704	0.0054	13344	4.2825E-07	12.708	0
419	0.1336	0.4789	1940429	0.0056	10725	4.5857E-07	12.888	0
420	0.1355	0.4847	1954887	0.0058	14458	4.7798E-07	13.153	0
419	0.1376	0.4908	1966679	0.0061	11792	5.1464E-07	13.329	0
418	0.1397	0.4968	1976741	0.0061	10062	5.2475E-07	13.572	0
419	0.1418	0.5028	1990762	0.0060	14021	5.5228E-07	13.855	0
418	0.1447	0.5111	2001711	0.0083	10949	5.7715E-07	14.148	0
419	0.1467	0.5164	2013521	0.0053	11810	6.1754E-07	14.488	0
420	0.1486	0.5219	2022489	0.0054	8968	6.7504E-07	14.747	0
419	0.1510	0.5282	2031030	0.0063	8541	7.0087E-07	15.022	0
420	0.1531	0.5337	2038690	0.0055	7660	7.8134E-07	15.337	0
419	0.1554	0.5399	2045478	0.0061	6788	8.2392E-07	15.562	0
419	0.1576	0.5457	2054253	0.0059	8775	8.6703E-07	15.978	0
419	0.1599	0.5515	2058641	0.0057	4388	9.1178E-07	16.203	0
419	0.1620	0.5567	2065198	0.0052	6557	9.8841E-07	16.526	0
419	0.1641	0.5620	2071116	0.0054	5918	1.058E-06	16.911	0
418	0.1667	0.5683	2076378	0.0063	5262	1.1385E-06	17.210	0
419	0.1693	0.5747	2081419	0.0064	5041	1.2296E-06	17.641	0
421	0.1719	0.5806	2086921	0.0060	5502	1.3903E-06	18.235	0
419	0.1741	0.5859	2090005	0.0053	3084	1.4589E-06	18.374	0
419	0.1764	0.5911	2094158	0.0052	4153	1.5984E-06	18.827	0
419	0.1789	0.5966	2096564	0.0055	2406	1.6976E-06	19.130	0
419	0.1812	0.6019	2100280	0.0053	3716	1.8313E-06	19.631	0
420	0.1840	0.6080	2103324	0.0061	3044	1.981E-06	20.033	0
420	0.1865	0.6132	2105942	0.0052	2618	2.0864E-06	20.444	0
420	0.1892	0.6190	2108570	0.0058	2628	2.3149E-06	21.016	0
419	0.1922	0.6251	2111185	0.0061	2615	2.3908E-06	21.527	0
419	0.1953	0.6314	2113811	0.0063	2626	2.5972E-06	22.173	0
419	0.1983	0.6374	2115573	0.0059	1762	2.659E-06	22.563	0
419	0.2010	0.6426	2118204	0.0052	2631	2.896E-06	23.302	0
419	0.2040	0.6482	2119509	0.0056	1305	3.1188E-06	23.690	0
420	0.2071	0.6540	2121917	0.0058	2408	3.6751E-06	24.579	0
419	0.2103	0.6598	2123237	0.0058	1320	3.8684E-06	25.133	0
419	0.2141	0.6665	2124768	0.0066	1531	4.1276E-06	25.903	0
420	0.2178	0.6728	2126078	0.0064	1310	4.5104E-06	26.677	0
418	0.2210	0.6782	2127609	0.0054	1531	4.9635E-06	27.443	0
420	0.2244	0.6839	2128703	0.0057	1094	5.4615E-06	28.246	0
419	0.2277	0.6892	2129582	0.0053	879	6.063E-06	28.947	0
420	0.2315	0.6950	2130462	0.0059	880	6.7568E-06	29.859	0
420	0.2351	0.7005	2131340	0.0055	878	7.1511E-06	30.809	0
419	0.2401	0.7077	2132210	0.0072	870	7.8289E-06	31.833	0

420	0.2438	0.7130	2132862	0.0053	652	8.722E-06	32.806	0
419	0.2509	0.7226	2134144	0.0054	846	1.1916E-05	35.183	1
419	0.2551	0.7281	2134509	0.0055	365	1.5511E-05	35.938	1
419	0.2598	0.7341	2134875	0.0060	366	1.8824E-05	37.231	1
419	0.2645	0.7398	2135167	0.0057	292	2.1282E-05	38.500	1
420	0.2705	0.7467	2135456	0.0069	289	2.4645E-05	40.120	1
419	0.2753	0.7520	2135676	0.0053	220	2.7081E-05	41.548	1
419	0.2807	0.7578	2135896	0.0058	220	3.1395E-05	43.290	1
419	0.2884	0.7655	2136116	0.0077	220	3.9346E-05	45.256	1
419	0.2957	0.7724	2136336	0.0069	220	6.168E-05	48.295	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-I-B-7
YIELD STRENGTH : 150.0 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : S41393
MATERIAL : Inner Layer
TEST MACHINE : H288

WMT&R REPORT NO. : 3-55962
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 4/23/2013
CRACK PLANE ORIENTATION : L-T

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2502 in
WIDTH (W) : 0.9996 in
NOTCH (An) : 0.2025 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 2286.30 lb
MINIMUM LOAD : 1600.4 lb
LOAD RANGE : 685.9 lb

STRESS RATIO : 0.70
FREQUENCY : 15 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE (F) : -20
HUMIDITY : N/A
ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
2286	0.0904	0.2946	14862	0.0017	3007	7.0602E-07	15.196	0
2286	0.0910	0.2967	17525	0.0021	2663	7.4021E-07	15.273	0
2286	0.0915	0.2981	20218	0.0014	2693	7.9946E-07	15.356	0
2285	0.0919	0.2994	21566	0.0013	1348	7.7575E-07	15.380	0
2286	0.0923	0.3005	22569	0.0011	1003	7.6784E-07	15.434	0
2286	0.0926	0.3016	23908	0.0011	1339	8.4025E-07	15.485	0
2285	0.0931	0.3032	26255	0.0015	2347	8.0072E-07	15.551	0
2286	0.0936	0.3049	28593	0.0018	2338	7.7533E-07	15.621	0
2286	0.0940	0.3062	29590	0.0013	997	8.1486E-07	15.667	0
2286	0.0946	0.3080	31932	0.0018	2342	8.0049E-07	15.730	0
2286	0.0951	0.3094	34279	0.0014	2347	8.3617E-07	15.811	0
2286	0.0955	0.3106	34614	0.0012	335	8.0088E-07	15.835	0
2286	0.0960	0.3123	37952	0.0017	3338	8.4388E-07	15.942	0
2286	0.0967	0.3145	39287	0.0022	1335	9.0726E-07	15.987	0
2286	0.0971	0.3158	41638	0.0013	2351	9.7935E-07	16.063	0
2286	0.0978	0.3179	43640	0.0021	2002	1.015E-06	16.175	0
2286	0.0985	0.3200	44983	0.0021	1343	9.8685E-07	16.216	0
2286	0.0989	0.3210	46322	0.0010	1339	9.8961E-07	16.303	0
2286	0.0993	0.3223	47663	0.0012	1341	9.2668E-07	16.351	0
2285	0.1000	0.3246	49998	0.0023	2335	8.2646E-07	16.392	0
2286	0.1004	0.3258	52660	0.0012	2662	8.8306E-07	16.497	0
2286	0.1008	0.3269	53658	0.0012	998	9.2549E-07	16.536	0
2286	0.1012	0.3281	53995	0.0011	337	8.8189E-07	16.548	0
2286	0.1018	0.3298	56338	0.0018	2343	1.0123E-06	16.637	0
2286	0.1023	0.3313	57680	0.0015	1342	9.7275E-07	16.701	0
2286	0.1029	0.3331	59698	0.0018	2018	9.8858E-07	16.787	0

2286	0.1035	0.3349	61707	0.0018	2009	1.1378E-06	16.860	0
2285	0.1039	0.3361	62370	0.0012	663	1.1145E-06	16.900	0
2286	0.1046	0.3381	64371	0.0020	2001	1.1611E-06	17.021	0
2286	0.1054	0.3404	65702	0.0024	1331	1.1681E-06	17.084	0
2286	0.1061	0.3423	67713	0.0019	2011	1.0742E-06	17.177	0
2286	0.1066	0.3439	69386	0.0016	1673	1.1909E-06	17.272	0
2286	0.1070	0.3449	70388	0.0010	1002	1.186E-06	17.322	0
2286	0.1074	0.3460	71386	0.0011	998	1.1936E-06	17.364	0
2285	0.1081	0.3479	72051	0.0019	665	1.2698E-06	17.403	0
2286	0.1085	0.3493	73718	0.0014	1667	1.2743E-06	17.499	0
2287	0.1091	0.3507	75052	0.0014	1334	1.3634E-06	17.582	0
2286	0.1096	0.3522	76060	0.0015	1008	1.369E-06	17.638	1
2286	0.1100	0.3534	76731	0.0011	671	1.5129E-06	17.699	1
2286	0.1106	0.3551	77754	0.0017	1023	1.6262E-06	17.764	1
2286	0.1110	0.3561	78751	0.0011	997	1.5885E-06	17.838	1
2285	0.1114	0.3574	79083	0.0012	332	1.5906E-06	17.841	1
2286	0.1122	0.3595	80417	0.0022	1334	1.5348E-06	17.969	1
2286	0.1126	0.3606	81425	0.0011	1008	1.5739E-06	18.040	1
2286	0.1131	0.3619	82096	0.0013	671	1.5346E-06	18.062	1
2285	0.1135	0.3631	83098	0.0012	1002	1.6231E-06	18.135	1
2286	0.1141	0.3647	83769	0.0016	671	1.6805E-06	18.181	1
2286	0.1146	0.3661	84770	0.0014	1001	1.7433E-06	18.284	1
2286	0.1152	0.3675	85444	0.0015	674	1.8417E-06	18.350	1
2286	0.1157	0.3690	86450	0.0015	1006	1.9597E-06	18.416	1
2285	0.1163	0.3706	87116	0.0015	666	2.1653E-06	18.474	1
2287	0.1168	0.3720	87781	0.0014	665	2.2547E-06	18.573	1
2285	0.1174	0.3735	88449	0.0016	668	2.327E-06	18.629	1
2286	0.1178	0.3746	88783	0.0011	334	2.4387E-06	18.658	1
2285	0.1183	0.3760	89453	0.0013	670	2.5695E-06	18.724	1
2286	0.1189	0.3775	90118	0.0015	665	2.8568E-06	18.825	1
2286	0.1195	0.3789	90459	0.0014	341	2.8375E-06	18.888	1
2287	0.1201	0.3807	91134	0.0017	675	3.2167E-06	19.018	1
2285	0.1207	0.3822	91472	0.0016	338	3.2224E-06	19.030	1
2286	0.1213	0.3838	92148	0.0016	676	3.1863E-06	19.154	1
2286	0.1221	0.3857	92487	0.0019	339	3.2471E-06	19.238	1
2286	0.1226	0.3872	93152	0.0014	665	3.2678E-06	19.322	1
2286	0.1232	0.3885	93485	0.0013	333	3.3639E-06	19.353	1
2285	0.1236	0.3896	93819	0.0011	334	3.4544E-06	19.399	1
2285	0.1240	0.3908	94156	0.0011	337	3.8387E-06	19.478	1
2286	0.1250	0.3932	94825	0.0024	669	4.603E-06	19.619	1
2286	0.1257	0.3951	95162	0.0019	337	5.1299E-06	19.693	1
2285	0.1265	0.3969	95495	0.0019	333	5.6789E-06	19.786	1
2286	0.1272	0.3988	95834	0.0019	339	6.4529E-06	19.892	1
2286	0.1281	0.4010	96165	0.0022	331	7.0766E-06	20.004	1
2286	0.1291	0.4033	96498	0.0024	333	7.637E-06	20.127	1
2286	0.1304	0.4064	96832	0.0031	334	8.2368E-06	20.316	1
2286	0.1315	0.4092	97164	0.0028	332	8.8862E-06	20.452	1
2286	0.1326	0.4119	97496	0.0026	332	1.0276E-05	20.595	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-I-B-8
YIELD STRENGTH : 82.2 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : S41394
MATERIAL : Inner Layer
TEST MACHINE : H288

WMT&R REPORT NO. : 3-55962
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 5/20/2013
CRACK PLANE ORIENTATION : L-T

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2502 in
WIDTH (W) : 1.0003 in
NOTCH (An) : 0.2020 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 607.80 lb
MINIMUM LOAD : 425.5 lb
LOAD RANGE : 182.3 lb

STRESS RATIO : 0.70
FREQUENCY : 15 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE (F) : -20
HUMIDITY : N/A
ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
607	0.1031	0.3732	598106	0.0043	83328	5.146E-08	4.939	0
608	0.1042	0.3773	687134	0.0041	89028	5.2809E-08	5.033	0
608	0.1055	0.3816	769084	0.0043	81950	5.4735E-08	5.023	0
608	0.1066	0.3856	828370	0.0040	59286	5.6521E-08	5.123	0
609	0.1080	0.3905	919613	0.0049	91243	5.9532E-08	5.188	0
608	0.1092	0.3946	989036	0.0040	69423	5.966E-08	5.223	0
607	0.1105	0.3990	1056121	0.0044	67085	6.1385E-08	5.265	0
608	0.1117	0.4031	1121605	0.0041	65484	6.2823E-08	5.317	0
609	0.1129	0.4071	1196754	0.0040	75149	6.4818E-08	5.420	0
607	0.1142	0.4112	1245575	0.0041	48821	7.0144E-08	5.429	0
608	0.1154	0.4154	1317758	0.0042	72183	7.2984E-08	5.522	0
608	0.1167	0.4195	1372282	0.0041	54524	7.6736E-08	5.574	0
608	0.1180	0.4237	1402773	0.0042	30491	7.5788E-08	5.650	0
608	0.1192	0.4278	1475642	0.0041	72869	7.8914E-08	5.690	0
608	0.1209	0.4332	1534579	0.0054	58937	8.1536E-08	5.788	0
608	0.1222	0.4373	1598300	0.0041	63721	8.7182E-08	5.884	0
609	0.1236	0.4417	1644382	0.0044	46082	9.3716E-08	5.972	0
608	0.1251	0.4463	1684716	0.0046	40334	9.5207E-08	5.991	0
608	0.1265	0.4509	1734136	0.0046	49420	9.9464E-08	6.082	0
608	0.1279	0.4552	1773430	0.0043	39294	1.0114E-07	6.159	0
607	0.1293	0.4594	1821506	0.0043	48076	1.0597E-07	6.220	0
609	0.1307	0.4636	1862820	0.0042	41314	1.1426E-07	6.346	0
608	0.1322	0.4679	1897752	0.0044	34932	1.1793E-07	6.408	0
607	0.1337	0.4726	1932986	0.0046	35234	1.2431E-07	6.442	0
608	0.1353	0.4771	1966495	0.0045	33509	1.3062E-07	6.541	0
608	0.1367	0.4812	2003775	0.0041	37280	1.3165E-07	6.665	0

609	0.1381	0.4853	2032832	0.0041	29057	1.3218E-07	6.758	0
608	0.1395	0.4894	2058244	0.0041	25412	1.3601E-07	6.768	0
607	0.1410	0.4934	2092492	0.0040	34248	1.4727E-07	6.886	0
608	0.1424	0.4975	2122646	0.0041	30154	1.4936E-07	7.001	0
609	0.1441	0.5022	2150450	0.0047	27804	1.5364E-07	7.085	0
608	0.1455	0.5062	2169425	0.0040	18975	1.5958E-07	7.177	0
608	0.1471	0.5104	2202981	0.0042	33556	1.6777E-07	7.264	0
608	0.1486	0.5146	2227403	0.0043	24422	1.728E-07	7.349	0
608	0.1502	0.5188	2252125	0.0041	24722	1.7371E-07	7.446	0
607	0.1518	0.5230	2270714	0.0042	18589	1.852E-07	7.537	0
608	0.1534	0.5271	2294451	0.0041	23737	1.929E-07	7.649	0
609	0.1550	0.5314	2321150	0.0042	26699	2.0719E-07	7.823	0
608	0.1569	0.5363	2340786	0.0049	19636	2.0815E-07	7.879	0
609	0.1586	0.5408	2361139	0.0045	20353	2.1621E-07	8.040	0
608	0.1603	0.5450	2377749	0.0042	16610	2.2317E-07	8.125	0
608	0.1622	0.5496	2403224	0.0047	25475	2.1871E-07	8.318	0
608	0.1641	0.5544	2423190	0.0048	19966	2.2803E-07	8.364	0
608	0.1659	0.5586	2442514	0.0042	19324	2.3227E-07	8.523	0
608	0.1676	0.5627	2460774	0.0041	18260	2.4517E-07	8.685	0
608	0.1695	0.5673	2475686	0.0047	14912	2.5417E-07	8.794	0
608	0.1713	0.5715	2495726	0.0042	20040	2.7425E-07	8.943	0
608	0.1732	0.5759	2509988	0.0043	14262	2.9122E-07	9.097	0
609	0.1750	0.5802	2524910	0.0043	14922	3.0716E-07	9.246	0
608	0.1770	0.5847	2538488	0.0045	13578	3.2595E-07	9.363	0
608	0.1792	0.5895	2552714	0.0048	14226	3.3416E-07	9.534	0
609	0.1811	0.5938	2565244	0.0042	12530	3.4464E-07	9.753	0
608	0.1832	0.5983	2578471	0.0046	13227	3.5477E-07	9.887	0
608	0.1851	0.6023	2590354	0.0040	11883	3.6765E-07	10.047	0
608	0.1870	0.6064	2600866	0.0041	10512	3.835E-07	10.176	0
608	0.1890	0.6107	2611738	0.0042	10872	4.0038E-07	10.391	0
608	0.1914	0.6155	2623544	0.0048	11806	4.1757E-07	10.541	0
608	0.1934	0.6197	2633070	0.0042	9526	4.3381E-07	10.793	0
608	0.1959	0.6245	2644297	0.0049	11227	4.526E-07	10.916	0
608	0.1980	0.6286	2653736	0.0041	9439	4.8368E-07	11.164	0
607	0.2001	0.6329	2661853	0.0042	8117	5.1671E-07	11.391	0
608	0.2023	0.6371	2670719	0.0042	8866	5.6465E-07	11.645	0
609	0.2046	0.6413	2677112	0.0042	6393	5.8824E-07	11.826	0
607	0.2067	0.6453	2683910	0.0040	6798	6.0282E-07	12.014	0
609	0.2095	0.6503	2691319	0.0050	7409	6.2184E-07	12.212	0
606	0.2118	0.6545	2698439	0.0041	7120	6.2518E-07	12.524	0
610	0.2142	0.6586	2705564	0.0041	7125	6.3353E-07	12.792	1
608	0.2166	0.6629	2711990	0.0043	6426	6.361E-07	13.021	1
606	0.2190	0.6670	2718090	0.0041	6100	6.5439E-07	13.261	1
607	0.2217	0.6714	2724897	0.0044	6807	7.0305E-07	13.532	1
609	0.2241	0.6755	2731318	0.0041	6421	7.4398E-07	13.813	1
608	0.2268	0.6797	2737102	0.0043	5784	8.0811E-07	14.086	1
607	0.2301	0.6850	2742195	0.0052	5093	8.6604E-07	14.501	1
607	0.2331	0.6896	2748299	0.0047	6104	9.6312E-07	14.823	1
607	0.2363	0.6943	2752680	0.0047	4381	1.0349E-06	15.223	1

607	0.2391	0.6986	2757138	0.0042	4458	1.3532E-06	15.579	1
608	0.2420	0.7027	2760184	0.0041	3046	1.3899E-06	15.935	1
608	0.2450	0.7069	2763864	0.0043	3680	1.5819E-06	16.495	1
606	0.2506	0.7147	2765604	0.0143	28	1.7667E-06	16.292	1
608	0.2542	0.7193	2770785	0.0047	5181	2.2907E-06	17.680	1
608	0.2578	0.7239	2772202	0.0046	1417	2.9334E-06	17.989	1
608	0.2615	0.7286	2773518	0.0047	1316	3.8927E-06	18.338	1
608	0.2649	0.7327	2774731	0.0041	1213	5.1974E-06	18.951	1
608	0.2685	0.7369	2775618	0.0042	887	7.8012E-06	19.550	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

AO SMITH 1146a
OUTER LAYER
FATIGUE CRACK GROWTH

ID	*Layer*	*Orientation*	*R*	*Temp*
FCG-O-B-1	Outer	T-L	0.7	RT
FCG-O-B-2				

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-O-B-1
YIELD STRENGTH : 150.0 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : S41385
MATERIAL : Outer Layer
TEST MACHINE : H53

WMT&R REPORT NO. : 3-55962
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 4/12/2013
CRACK PLANE ORIENTATION : T-L

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2038 in
WIDTH (W) : 2.0029 in
NOTCH (An) : 0.3999 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 2960.10 lb
MINIMUM LOAD : 2072.1 lb
LOAD RANGE : 888.0 lb

STRESS RATIO : 0.70
FREQUENCY : 15 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : ROOM
HUMIDITY : 25% - 36%
ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
2960	0.2013	0.5179	8150	0.0057	2325	2.8382E-06	15.534	0
2960	0.2030	0.5233	9418	0.0055	1268	2.913E-06	15.612	0
2960	0.2048	0.5292	11532	0.0058	2114	2.9405E-06	15.747	0
2960	0.2064	0.5345	13435	0.0053	1903	2.912E-06	15.866	0
2960	0.2080	0.5397	15336	0.0052	1901	2.8021E-06	15.988	0
2960	0.2101	0.5463	17496	0.0067	2160	2.8405E-06	16.106	0
2960	0.2117	0.5514	19532	0.0051	2036	2.9595E-06	16.230	0
2960	0.2133	0.5566	21298	0.0052	1766	2.9854E-06	16.336	0
2960	0.2149	0.5617	22919	0.0050	1621	3.0486E-06	16.450	0
2960	0.2168	0.5675	24538	0.0058	1619	3.2718E-06	16.561	0
2960	0.2186	0.5729	26579	0.0055	2041	3.4048E-06	16.699	0
2960	0.2202	0.5780	28026	0.0051	1447	3.5067E-06	16.811	0
2960	0.2219	0.5832	29058	0.0051	1032	3.5604E-06	16.893	0
2960	0.2235	0.5882	30720	0.0050	1662	3.8428E-06	17.023	0
2960	0.2259	0.5955	32609	0.0073	1889	3.8101E-06	17.197	0
2960	0.2277	0.6011	34077	0.0056	1468	4.0408E-06	17.314	0
2960	0.2299	0.6076	35337	0.0065	1260	4.4245E-06	17.423	0
2960	0.2317	0.6129	37229	0.0053	1892	4.7313E-06	17.629	0
2960	0.2339	0.6197	38069	0.0068	840	4.8801E-06	17.713	0
2960	0.2370	0.6289	39750	0.0092	1681	4.9943E-06	17.918	0
2960	0.2388	0.6339	41013	0.0050	1263	5.3336E-06	18.086	0
2960	0.2413	0.6413	42274	0.0074	1261	5.1486E-06	18.223	0
2960	0.2443	0.6500	44170	0.0086	1896	5.3596E-06	18.453	0
2960	0.2480	0.6607	45860	0.0107	1690	5.6749E-06	18.675	0
2960	0.2500	0.6666	47121	0.0059	1261	5.637E-06	18.854	0
2960	0.2521	0.6724	47962	0.0058	841	5.6235E-06	18.967	0

2960	0.2552	0.6813	49432	0.0089	1470	5.6073E-06	19.163	0
2960	0.2573	0.6872	50692	0.0059	1260	5.9466E-06	19.335	0
2960	0.2595	0.6933	51954	0.0060	1262	6.5024E-06	19.503	0
2960	0.2628	0.7024	53216	0.0091	1262	6.8542E-06	19.733	0
2960	0.2669	0.7138	54691	0.0114	1475	7.8634E-06	20.013	0
2960	0.2701	0.7225	55536	0.0087	845	7.5285E-06	20.214	0
2960	0.2741	0.7333	57225	0.0108	1689	6.8996E-06	20.548	0
2960	0.2768	0.7405	57647	0.0072	422	7.0396E-06	20.635	0
2960	0.2788	0.7459	59339	0.0054	1692	7.6668E-06	20.920	0
2960	0.2808	0.7512	59761	0.0053	422	7.6145E-06	20.998	0
2960	0.2828	0.7567	60396	0.0055	635	7.442E-06	21.125	0
2960	0.2857	0.7643	61028	0.0076	632	9.5247E-06	21.299	0
2960	0.2898	0.7750	62510	0.0108	1482	1.2426E-05	21.682	0
2960	0.2921	0.7808	63362	0.0057	852	1.3106E-05	22.004	0
2960	0.2976	0.7951	63572	0.0143	210	1.2435E-05	22.084	0
2960	0.3006	0.8027	64206	0.0077	634	1.4175E-05	22.369	0
2960	0.3052	0.8142	65263	0.0115	1057	1.3171E-05	22.792	0
2960	0.3077	0.8204	65897	0.0062	634	1.1688E-05	22.999	0
2960	0.3138	0.8356	67164	0.0152	1267	1.2337E-05	23.486	0
2960	0.3204	0.8517	68432	0.0161	1268	1.2669E-05	24.006	1
2960	0.3227	0.8573	68644	0.0055	212	1.354E-05	24.095	1
2960	0.3287	0.8718	69911	0.0145	1267	1.6962E-05	24.650	1
2960	0.3343	0.8849	70969	0.0131	1058	1.8846E-05	25.291	1
2960	0.3387	0.8952	71181	0.0104	212	2.0761E-05	25.413	1
2960	0.3473	0.9151	71816	0.0199	635	2.4773E-05	25.896	1
2960	0.3511	0.9238	72660	0.0087	844	3.1346E-05	26.755	1
2960	0.3632	0.9509	73295	0.0271	635	3.2976E-05	27.577	1
2960	0.3712	0.9682	73718	0.0173	423	3.8105E-05	28.134	1
2960	0.3803	0.9877	74140	0.0195	422	4.2004E-05	28.958	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH | TESTLOG NO. : S41386 | WMT&R REPORT NO. : 3-55962
P.O. NO. : F58154BT | MATERIAL : Outer Layer | WMT&R QUOTE : QN121622 Rev.1
SPECIMEN NUMBER : FCG-O-B-2 | TEST MACHINE : H176 | TEST DATE : 5/16/2013
YIELD STRENGTH : 82.2 ksi | CRACK PLANE ORIENTATION : T-L
MODULUS : 30.0 Msi

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2040 in
WIDTH (W) : 2.0034 in
NOTCH (An) : 0.4008 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE | STRESS RATIO : 0.70 | ENVIRONMENT : LAB AIR
MAXIMUM LOAD : 754.90 lb | FREQUENCY : 15 Hz | TEMPERATURE : ROOM
MINIMUM LOAD : 528.4 lb | WAVEFORM : SINE | HUMIDITY : 25% - 35%
LOAD RANGE : 226.5 lb | SPECIMEN TYPE : C(T) | ANALYSIS METHOD : 7 PT. POLY.

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
755	0.0728	0.5602	1314334	0.0109	319461	3.6179E-08	4.184	0
755	0.0741	0.5711	1548539	0.0110	234205	3.8229E-08	4.241	0
755	0.0753	0.5815	1724954	0.0104	176415	4.13E-08	4.280	0
755	0.0765	0.5918	2082256	0.0103	357302	4.3838E-08	4.366	0
755	0.0777	0.6018	2308425	0.0100	226169	4.7192E-08	4.414	0
755	0.0790	0.6133	2528828	0.0115	220403	5.338E-08	4.471	0
755	0.0803	0.6243	2730897	0.0109	202069	5.6066E-08	4.547	0
755	0.0816	0.6347	2900974	0.0104	170077	5.7332E-08	4.602	0
755	0.0829	0.6449	3042052	0.0102	141078	5.8215E-08	4.655	0
755	0.0842	0.6558	3268483	0.0109	226431	6.0408E-08	4.734	0
755	0.0856	0.6664	3449892	0.0106	181409	6.2948E-08	4.791	0
755	0.0869	0.6767	3620799	0.0102	170907	6.5972E-08	4.864	0
755	0.0882	0.6873	3741354	0.0106	120555	6.98E-08	4.921	0
755	0.0895	0.6975	3900342	0.0102	158988	7.6067E-08	4.989	0
755	0.0909	0.7076	4044544	0.0101	144202	8.1748E-08	5.061	0
755	0.0922	0.7179	4166210	0.0103	121666	8.1881E-08	5.137	0
755	0.0936	0.7284	4265868	0.0105	99658	8.4244E-08	5.179	0
755	0.0950	0.7387	4382386	0.0102	116518	8.6807E-08	5.255	0
755	0.0964	0.7487	4524906	0.0100	142520	8.6128E-08	5.335	0
755	0.0978	0.7589	4640852	0.0102	115946	8.7138E-08	5.396	0
755	0.0994	0.7709	4763465	0.0120	122613	9.2603E-08	5.480	0
755	0.1009	0.7811	4887996	0.0103	124531	1.008E-07	5.567	0
755	0.1023	0.7914	4986434	0.0103	98438	1.0491E-07	5.640	0
755	0.1038	0.8019	5078074	0.0105	91640	1.1219E-07	5.707	0
755	0.1054	0.8126	5166295	0.0106	88221	1.2227E-07	5.784	0
755	0.1068	0.8226	5262294	0.0100	95999	1.3263E-07	5.880	0
755	0.1083	0.8327	5328318	0.0101	66024	1.3992E-07	5.955	0

755	0.1098	0.8428	5394228	0.0101	65910	1.4776E-07	6.033	0
755	0.1115	0.8534	5465752	0.0106	71524	1.5476E-07	6.127	0
755	0.1131	0.8639	5532633	0.0105	66881	1.5591E-07	6.206	0
755	0.1147	0.8743	5595151	0.0104	62518	1.5387E-07	6.297	0
755	0.1162	0.8844	5662513	0.0101	67362	1.5012E-07	6.395	0
755	0.1179	0.8949	5728075	0.0105	65562	1.4572E-07	6.471	0
755	0.1195	0.9050	5804894	0.0101	76819	1.4285E-07	6.566	0
755	0.1212	0.9154	5885464	0.0104	80570	1.4694E-07	6.681	0
755	0.1229	0.9255	5954054	0.0101	68590	1.5507E-07	6.774	0
755	0.1246	0.9360	6018847	0.0105	64793	1.6691E-07	6.870	0
755	0.1263	0.9461	6076267	0.0101	57420	1.804E-07	6.967	0
755	0.1281	0.9567	6135284	0.0106	59017	1.9579E-07	7.079	0
755	0.1298	0.9668	6186871	0.0101	51587	2.0966E-07	7.187	0
755	0.1317	0.9773	6233945	0.0105	47074	2.2018E-07	7.293	0
755	0.1335	0.9874	6276792	0.0101	42847	2.2907E-07	7.410	0
755	0.1354	0.9980	6321727	0.0106	44935	2.3772E-07	7.529	0
755	0.1372	1.0081	6365360	0.0101	43633	2.4826E-07	7.656	0
755	0.1390	1.0181	6406721	0.0100	41361	2.5935E-07	7.779	0
755	0.1409	1.0282	6444892	0.0101	38171	2.761E-07	7.910	0
755	0.1428	1.0383	6478544	0.0101	33652	2.9137E-07	8.013	0
755	0.1448	1.0484	6514702	0.0101	36158	3.1005E-07	8.153	0
755	0.1467	1.0585	6544360	0.0101	29658	3.2131E-07	8.291	0
755	0.1487	1.0686	6576421	0.0102	32061	3.3625E-07	8.421	0
755	0.1508	1.0790	6605148	0.0103	28727	3.5037E-07	8.574	0
755	0.1529	1.0892	6636128	0.0103	30980	3.7248E-07	8.734	0
755	0.1552	1.1001	6663797	0.0109	27669	4.0377E-07	8.891	0
754	0.1573	1.1102	6690763	0.0101	26966	4.2598E-07	9.048	0
754	0.1595	1.1202	6711020	0.0101	20257	4.3857E-07	9.189	0
754	0.1619	1.1313	6733389	0.0110	22369	4.5222E-07	9.375	0
754	0.1641	1.1413	6757480	0.0101	24091	4.6649E-07	9.557	0
755	0.1664	1.1517	6780921	0.0104	23441	4.8464E-07	9.744	0
755	0.1689	1.1624	6802593	0.0107	21672	5.1504E-07	9.919	0
755	0.1713	1.1726	6822410	0.0101	19817	5.3682E-07	10.146	0
755	0.1740	1.1836	6840642	0.0111	18232	5.6387E-07	10.319	0
755	0.1766	1.1942	6858471	0.0106	17829	5.9464E-07	10.533	0
755	0.1792	1.2047	6878690	0.0105	20219	6.3056E-07	10.781	0
755	0.1823	1.2168	6896764	0.0121	18074	6.5418E-07	11.040	0
755	0.1852	1.2277	6911580	0.0109	14816	6.8322E-07	11.251	0
755	0.1882	1.2388	6927403	0.0111	15823	7.1652E-07	11.516	0
755	0.1913	1.2498	6944039	0.0110	16636	7.3773E-07	11.806	0
755	0.1947	1.2618	6959080	0.0119	15041	7.8179E-07	12.084	0
755	0.1979	1.2729	6973700	0.0112	14620	8.5432E-07	12.387	0
755	0.2010	1.2830	6986328	0.0101	12628	9.0429E-07	12.694	0
755	0.2043	1.2937	6996560	0.0107	10232	9.7729E-07	12.959	0
755	0.2076	1.3040	7006270	0.0103	9710	1.1023E-06	13.270	0
755	0.2113	1.3152	7018595	0.0112	12325	1.2758E-06	13.673	0
755	0.2149	1.3258	7026036	0.0106	7441	1.3942E-06	13.978	0
755	0.2189	1.3372	7032294	0.0114	6258	1.5108E-06	14.267	0
755	0.2228	1.3478	7039870	0.0106	7576	1.6928E-06	14.751	0
755	0.2267	1.3581	7046130	0.0102	6260	1.8141E-06	15.096	0

755	0.2312	1.3693	7052121	0.0113	5991	2.0037E-06	15.516	0
755	0.2358	1.3805	7057181	0.0112	5060	2.2302E-06	15.929	0
755	0.2413	1.3930	7063167	0.0125	5986	2.6364E-06	16.536	0
755	0.2470	1.4054	7067548	0.0124	4381	2.9487E-06	17.060	1
755	0.2523	1.4162	7071272	0.0108	3724	3.4812E-06	17.580	1
755	0.2580	1.4271	7073793	0.0109	2521	4.1873E-06	18.034	1
755	0.2621	1.4346	7076438	0.0101	1581	5.5196E-06	18.602	1
755	0.2679	1.4447	7078034	0.0101	1596	7.4418E-06	19.069	1
755	0.2743	1.4550	7079366	0.0103	1332	1.1219E-05	19.628	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

APPENDIX B: A-225 GR. B HEAD MATERIAL CHARACTERIZATION RESULTS

A-225 Gr. B

HEAD

TENSILE RESULTS

-20°F

Exova
194 Internationale Boulevard
Glendale Heights
Illinois
USA
60139

T: +1 (630) 221-0385
F: +1 (630) 221-0796
E: sales@exova.com
W: www.exova.com

Exova

Test Certificate

Southwest Research Institute
P.O. Drawer 28510
6220 Culebra Rd
San Antonio, TX
78228-0510

Attn: Fassett Hickey

REF No T 313095 : Issue 2
Page 1 of 1
Ord No F65327IR
Date Tested 07/26/13
Date Printed 07/26/13
Date Received 07/10/13

Item - TENSILE TESTING AT -20F OF A SAMPLE IDENTIFIED AS HEAD

Specification - Not Applicable

Tensile Test - ASTM E8 -11

	Dimensions [in]	Area [in^2]	GL [in]	0.20%YS [psi]	UTS [psi]	%El	%RA	Comments
001:Tangential	0.2500	0.0491	1.00	59100	84100	34.0	70.0	at -20F
002:Tangential	0.2500	0.0491	1.00	57700	82700	34.0	69.5	at -20F
003:Tangential	0.2510	0.0495	1.00	60300	83600	37.0	67.5	at -20F

Elongation determined after fracture unless otherwise indicated.

Certificate Comments

Specimen 2 fractured outside the middle half of the gauge.

This document replaces Issue 1 of the same number, which has been withdrawn. It contains supplementary information to that presented in the previous issue- two additional tests were included.

TMTonon

Tami M Tonon
Operations Mgr/Sr Metallurgist
For and on behalf of
Exova Inc.

ACCREDITED
TESTING CERT# 0104.01 & 0104.02

Accredited Nadcap
Materials Testing Laboratory

A-225 Gr. B

CHARPY V-NOTCH

ID	Material	Orientation	Temp (^oF)	CVN (ft-lbs)	Lat. Expansion (mils)[a]
CVN-H-B-1	Base	T-L	74	81	61
CVN-H-B-2	Base	T-L	74	103	71
CVN-H-B-3	Base	T-L	74	91	67
CVN-H-B-7	Base	T-L	0	8	4
CVN-H-B-8	Base	T-L	0	18	13
CVN-H-B-9	Base	T-L	0	24	19
CVN-H-B-4	Base	T-L	-20	16	11
CVN-H-B-5	Base	T-L	-20	8	4
CVN-H-B-6	Base	T-L	-20	7	3
CVN-H-B-10	Base	T-ST	74	90	68
CVN-H-B-11	Base	T-ST	74	93	68
CVN-H-B-12	Base	T-ST	74	111	74
CVN-H-B-16	Base	T-ST	0	39	32
CVN-H-B-17	Base	T-ST	0	46	36
CVN-H-B-18	Base	T-ST	0	52	39
CVN-H-B-13	Base	T-ST	-20	3	1
CVN-H-B-14	Base	T-ST	-20	5	2
CVN-H-B-15	Base	T-ST	-20	7	3
CVN-H-H-1	HAZ	T-L	74	92	66
CVN-H-H-2	HAZ	T-L	74	87	63
CVN-H-H-3	HAZ	T-L	74	91	62
CVN-H-H-9	HAZ	T-L	74	79	58
CVN-H-H-7	HAZ	T-L	0	9	4
CVN-H-H-8	HAZ	T-L	0	37	26
CVN-H-H-4	HAZ	T-L	-20	7	3
CVN-H-H-5	HAZ	T-L	-20	7	4
CVN-H-H-6	HAZ	T-L	-20	10	5
CVN-H-W-1	Weld	L-C	74	69	53
CVN-H-W-2	Weld	L-C	74	48	36
CVN-H-W-3	Weld	L-C	74	57	44
CVN-H-W-7	Weld	L-C	0	29	18
CVN-H-W-8	Weld	L-C	0	35	29
CVN-H-W-9	Weld	L-C	0	28	15
CVN-H-W-4	Weld	L-C	-20	42	27
CVN-H-W-5	Weld	L-C	-20	23	17
CVN-H-W-6	Weld	L-C	-20	22	17

a Lateral expansion in 1000th of an inch

TESTING CERT 621-01 & 621-02

Accredited Nadcap Materials Testing Laboratory

CERTIFICATION

WMT&R Report No. 3-67089
P.O. No. F58154BT
WMT&R Quote No. QN121622 Rev.1

July 15, 2013
Southwest Research
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78238

Attention: Carl Popelar

Subject: All processes, performed upon the material as received, were conducted at WMT&R, Inc. in accordance with the WMT&R Quality Assurance Manual, Rev. 11, dated 12/03/2008. The following tests were performed on this order: FATIGUE, FRACTURE and IMPACT

IMPACT RESULTS: ASTM E23-12c

No Requirements

MATERIAL: Steel

SAMPLE TYPE: Charpy V-Notch **DISPOSITION: Report**

SID	TestLog Number	Sample Size	Temp. °F	Energy ft-lbs	Mils Lat Exp	% Shear Fracture	A\U\R
CVN-H-B-4	T05217	Standard	-20	16	11	5	Report
CVN-H-B-5	T05218	Standard	-20	8	4	0	Report
CVN-H-B-6	T05219	Standard	-20	7	3	0	Report
CVN-H-B-13	T05226	Standard	-20	3	1	0	Report
CVN-H-B-14	T05227	Standard	-20	5	2	5	Report
CVN-H-B-15	T05228	Standard	-20	7	3	0	Report
CVN-H-H-4	T05235	Standard	-20	7	3	0	Report
CVN-H-H-5	T05236	Standard	-20	7	4	0	Report
CVN-H-H-6	T05237	Standard	-20	10	5	5	Report
CVN-H-W-4	T05244	Standard	-20	42	27	40	Report
CVN-H-W-5	T05245	Standard	-20	23	17	25	Report
CVN-H-W-6	T05246	Standard	-20	22	17	25	Report

PARTIAL
PRELIMINARY DATA

Roy E. Starr \ Matt J. Wojton
___ Technical Services Manager___ Tensile Foreperson July 15, 2013

ACCREDITED
TESTING CERT 621-01 & 621-02

Accredited Nadcap Materials Testing Laboratory

WMT&R Report No. 3-67089
P.O. No. F58154BT

CERTIFICATION

July 15, 2013
Southwest Research

IMPACT RESULTS: ASTM E23-12c

No Requirements

MATERIAL: Steel

SAMPLE TYPE: Charpy V-Notch

DISPOSITION: Report

SID	TestLog Number	Sample Size	Temp. °F	Energy ft-lbs	Mils Lat Exp	% Shear Fracture	A\U\R
CVN-H-B-1	T05214	Standard	74	81	61	80	Report
CVN-H-B-2	T05215	Standard	74	103	71	90	Report
CVN-H-B-3	T05216	Standard	74	91	67	90	Report
CVN-H-B-10	T05223	Standard	74	90	68	85	Report
CVN-H-B-11	T05224	Standard	74	93	68	85	Report
CVN-H-B-12	T05225	Standard	74	111	74	95	Report
CVN-H-H-1	T05232	Standard	74	92	66	90	Report
CVN-H-H-2	T05233	Standard	74	87	63	80	Report
CVN-H-H-3	T05234	Standard	74	91	62	90	Report
CVN-H-H-9	T05240	Standard	74	79	58	75	Report
CVN-H-W-1	T05241	Standard	74	69	53	65	Report
CVN-H-W-2	T05242	Standard	74	48	36	50	Report
CVN-H-W-3	T05243	Standard	74	57	44	60	Report

PARTIAL
PRELIMINARY DATA

Roy E. Starr \ Matt J. Wojton
___ Technical Services Manager___ Tensile Foreperson

July 15, 2013

Westmoreland Mechanical Testing & Research, Inc.
P.O.Box 388; 221 Westmoreland Drive
Youngstown, PA 15696-0388 U.S.A.
Telephone: 724-537-3131 Fax: 724-537-3151
Website: www.wmtr.com E-Mail: admin@wmtr.com
WMT&R is a technical leader in the material testing industry.

ACCREDITED
TESTING CERT 621-01 & 621-02

Accredited Nadcap Materials Testing Laboratory

July 24, 2013
Southwest Research

CERTIFICATION

WMT&R Report No. 3-67089
P.O. No. F58154BT

IMPACT RESULTS: ASTM E23-12c
No Requirements
MATERIAL: Steel
SAMPLE TYPE: Charpy V-Notch **DISPOSITION: Report**

SID	TestLog Number	Sample Size	Temp. °F	Energy ft-lbs	Mils Lat Exp	% Shear Fracture	A\U\R
CVN-H-B-7	T05220	Standard	0	8	4	5	Report
CVN-H-B-8	T05221	Standard	0	18	13	5	Report
CVN-H-B-9	T05222	Standard	0	24	19	10	Report
CVN-H-B-16	T05229	Standard	0	39	32	20	Report
CVN-H-B-17	T05230	Standard	0	46	36	25	Report
CVN-H-B-18	T05231	Standard	0	52	39	30	Report
CVN-H-H-7	T05238	Standard	0	9	4	5	Report
CVN-H-H-8	T05239	Standard	0	37	26	20	Report
CVN-H-W-7	T05247	Standard	0	29	18	30	Report
CVN-H-W-8	T05248	Standard	0	35	29	30	Report
CVN-H-W-9	T05249	Standard	0	28	15	30	Report

Matt Wojton
Tensile Supervisor

July 24, 2013

Testing Specialists for Aerospace, Automotive, and Material Testing Fields
Locations in Youngstown, PA U.S.A. ~ Tel. (724) 537-3131 and
Banbury, Oxon U.K. ~ Tel. +44 (0) 1295 261211

A-225 Gr. B HEAD
J_{IC} FRACTURE TOUGHNESS

ID	*Material*	*Orientation*	*Temp*
KC-H-B-1	Base Head	T-L	RT
KC-H-B-2			
KC-H-B-3			-20°F
KC-H-B-4			
KC-H-H-1	Head HAZ	T-L	RT
KC-H-H-2			
KC-H-H-3			-20°F
KC-H-H-4			
KC-H-W-1	Head Weld	L-C (vessel)	RT
KC-H-W-2			
KC-H-W-3			-20°F
KC-H-W-4			

Westmoreland Mechanical Testing & Research, Inc.
P.O.Box 388; 221 Westmoreland Drive
Youngstown, PA 15696-0388 U.S.A.
Telephone: 724-537-3131 Fax: 724-537-3151
Website: www.wmtr.com E-Mail: admin@wmtr.com
WMT&R is a technical leader in the material testing industry.

July 29, 2013

Southwest Research Institute
6220 Culebra Road
P.O. Drawer 28510
San Antonio, TX 78238

WMT&R Report 3-67089
P.O.No. F58154BT
WMT&R Quote QN121622 Rev. 1

Attention: Mr. Carl Popelar

Subject: J-Integral Test Results

Introduction:

Twelve (12) compact tension specimens submitted as Steel material were received by Westmoreland Mechanical Testing and Research, Inc. for J-Integral testing per ASTM E1820-11. Four (4) specimens were machined to a nominal width (*W*) measuring 2.00 in. and eight (8) to a nominal width measuring 1.50 in. The specimens were then fatigue precracked to a final *a/W* of approximately 0.50 and side grooved to a depth equal to 20% of the nominal thickness (10% per side).

Six (6) specimens were tested at room temperature and six (6) at -20°F. The specimens were tested using an Instron servo-hydraulic test stand and an automated computer controlled testing procedure. Analysis of the test data was done using tensile data provided by Southwest Research Institute.

Results are summarized in Table 1.

Data sheets containing validity and tabular data are enclosed for the specimens. Graphs of *J* vs. *a* and *Force* vs. *COD* are also included.

If you have any questions concerning this report, please feel free to contact me. If I am unavailable, you may also speak with Mr. Douglas M. Bruce, Materials Engineering Manager.

At your service,

Gerald W. Boice

Gerald W. Boice
R&D Manager

mr

K:\JERRY\3W67089J.SOU.DOC

Testing Specialists for Aerospace, Automotive, and Material Testing Fields
Locations in Youngstown, PA U.S.A. ~ Tel. (724) 537-3131 and
Banbury, Oxon U.K. ~ Tel. +44 (0) 1295 261211

Westmoreland Mechanical Testing & Research, Inc.

Table 1 - JIC Results (ASTM E1820-11)

Phone (724) 537-3131

Customer : Southwest Research Institute
P.O. No. : F58154BT
WMT&R Quote : QN121622 REV.1

WMT&R Report : 3-67089
Material : Steel

Specimen	Testlog Number	Temp.	J_{Ic} (in lb/in^2)	K_{JIc} (ksi$\sqrt{in}$)	J_Q (in lb/in^2)	K_{JQ} (ksi$\sqrt{in}$)	J_c (in lb/in^2)	K_{Jc} (ksi$\sqrt{in}$)	J_{Qc} (in lb/in^2)	K_{JQc} (ksi$\sqrt{in}$)	K_{Ic} Determination (Annex 5) P_Q (lb)	K_{Ic} Determination (Annex 5) K_Q (ksi$\sqrt{in}$)	Unstable
KC-H-B-1	T05258	Room	1415.95	216.88	---	---	---	---	---	---	6426.2	50.0	No
KC-H-B-2	T05259	Room	---	---	---	---	---	---	1016.39	186.08	5609.4	43.5	Yes
KC-H-B-3	T05260	-20°F	---	---	---	---	---	---	1003.09	184.85	5652.0	45.4	Yes
KC-H-B-4	T05261	-20°F	---	---	---	---	577.18	140.22	---	---	5569.3	44.0	Yes
KC-H-H-1	T05262	Room	---	---	1696.63	242.69	---	---	---	---	3460.1	42.6	No
KC-H-H-2	T05263	Room	1135.56	196.56	---	---	---	---	---	---	3288.5	41.1	No
KC-H-H-3	T05264	-20°F	---	---	---	---	265.52	95.11	---	---	2718.4	33.9	Yes
KC-H-H-4	T05265	-20°F	---	---	---	---	240.29	90.47	---	---	2980.5	37.3	Yes
KC-H-W-1	T05266	Room	---	---	320.30	104.66	---	---	---	---	5324.3	65.9	No
KC-H-W-2	T05267	Room	---	---	557.54	137.39	---	---	---	---	5944.6	74.8	No
KC-H-W-3	T05268	-20°F	---	---	---	---	251.11	92.49	---	---	4828.8	64.6	Yes
KC-H-W-4	T05269	-20°F	---	---	---	---	290.20	99.43	---	---	4907.7	60.7	Yes

Gerald W. Boice

Gerald W. Boice -- Thomas S. Fedor

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

Dup page

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 30.23 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 79.3 ksi
SPECIMEN : KC-H-B-1	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 52.5 ksi
TESTLOG : T05258		EFFECTIVE YIELD STRENGTH : 65.9 ksi
TEST DATE : 7/10/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS / TEST PARAMETERS

TOTAL THICKNESS (B)	: 1.001 in	TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
NET THICKNESS (B_N)	: 0.800 in	TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
EFFECTIVE THICKNESS (B_e)	: 0.961 in	ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
WIDTH (W)	: 1.996 in	TEST MACHINE	: H5	UNLOADING INTERVAL	: 0.0005 in
UNCRACKED LIGAMENT (b_o)	: 0.986 in	CLIP GAGE	: 1391	HOLDTIME	: 5.0 sec.
NOTCH LENGTH (a_n)	: 0.915 in	CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.994 in	1.010 in	1.015 in	1.015 in	1.017 in	1.015 in	1.010 in	1.004 in	0.998 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.097 in	1.055 in	1.065 in	1.073 in	1.080 in	1.087 in	1.064 in	1.051 in	1.065 in

PRECRACK AVERAGE	: 1.0103 in	FINAL AVERAGE	: 1.0695 in
PRECRACK a/W	: 0.5062	FINAL a/W	: 0.5358

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 2154 lb	FINAL P_{max}	: 1900 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 259423	FINAL K_{max}	: 13.23 ksi(in)$^{1/2}$		

ORIGINAL CRACK / FINAL CRACK / MODULUS

ORIGINAL CRACK		FINAL CRACK		MODULUS	
PHYSICAL CRACK SIZE (a_o)	: 1.0103 in	PHYSICAL CRACK SIZE (a_p)	: 1.0695 in	MODULUS	: 30.23 Msi
EST. CRACK SIZE (a_{oq})	: 1.0103 in	EST. CRACK SIZE ($a_{predicted}$)	: 1.0729 in	EFFECTIVE MODULUS	: 30.23 Msi
PERCENT DIFFERENCE	: 0.00 %	PERCENT DIFFERENCE	: 0.32 %	PERCENT DIFFERENCE	: 0.01 %

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE FATIGUE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   a/W = 0.5062
2. (9.1.5.2) DIFFERENCE BETWEEN PREDICTED ($\Delta a_{predicted}$) AND MEASURED (Δa_p) CRACK EXTENSION SHALL NOT EXCEED 0.15 Δa_p FOR CRACK EXTENSIONS LESS THAN 0.2 b_o AND 0.03 b_o THEREAFTER — VALID
   Difference = 0.0034 in $0.15\Delta a_p = 0.0089$ in
3. (A9.7.2.1) a_{oq} SHALL NOT DIFFER FROM a_o BY MORE THAN THE LARGER OF 0.01 W OR 0.0197 IN. — VALID
   Difference = 0.0000 in $0.01W = 0.0200$
4. (A9.7.2.2) NUMBER OF DATA AVAILABLE TO CALCULATE a_{oq} SHALL BE ≥ 8; NUMBER OF DATA BETWEEN $0.4J_Q$ AND J_Q SHALL BE ≥ 3; CORRELATION COEFFICIENT OF THE LEAST SQUARES FIT SHALL BE > 0.96 — VALID
   a_{oq} Points = 109   Data Points = 26   C.C. = 0.99604
5. (A9.7.1) POWER COEFFICIENT C_2 SHALL BE LESS THAN 1.0 — VALID
   $C_2 = 0.8843$
6. (A9.8.1) THICKNESS, $B > 10J_Q/\sigma_Y$ — VALID
   B = 1.0010 in $10J_Q/\sigma_Y$ = 0.2149 in
7. (A9.8.2) INITIAL LIGAMENT, $b_o > 10J_Q/\sigma_Y$ — VALID
   b_o = 0.9857 in $10J_Q/\sigma_Y$ = 0.2149 in
8. (A9.6.6.6) AT LEAST FIVE DATA POINTS MUST REMAIN BETWEEN a_{min} AND a_{limit} AND J_{limit} — VALID
   Data Points = 65
9. (A9.6.4) AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.006-in EXCLUSION LINE AND A 0.02-in OFFSET LINE. AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.02-in OFFSET LINE AND THE 0.06-in EXCLUSION LINE. — VALID

TEST IS VALID: J_{Ic} = 1415.95 in-lb/in^2

K_{JIc} = 216.88 ksi(in)$^{1/2}$

Gerald W. Boice

GERALD W. BOICE - THOMAS S. FEDOR

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KC-H-B-1

A-225 Gr. B HEAD

J_{IC} FRACTURE TOUGHNESS

BASE HEAD MATERIAL

L-T

RT

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 30.23 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 79.3 ksi
SPECIMEN : KC-H-B-1	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 52.5 ksi
TESTLOG : T05258		EFFECTIVE YIELD STRENGTH : 65.9 ksi
TEST DATE : 7/10/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 1.001 in	WIDTH (W)	: 1.996 in
NET THICKNESS (B_N)	: 0.800 in	UNCRACKED LIGAMENT (b_o)	: 0.986 in
EFFECTIVE THICKNESS (B_e)	: 0.961 in	NOTCH LENGTH (a_n)	: 0.915 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H5	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 1391	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.994 in	1.010 in	1.015 in	1.015 in	1.017 in	1.015 in	1.010 in	1.004 in	0.998 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.097 in	1.055 in	1.065 in	1.073 in	1.080 in	1.087 in	1.064 in	1.051 in	1.065 in

PRECRACK AVERAGE	: 1.0103 in	FINAL AVERAGE	: 1.0695 in
PRECRACK a/W	: 0.5062	FINAL a/W	: 0.5358

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 2154 lb	FINAL P_{max}	: 1900 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 259423	FINAL K_{max}	: 13.23 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 12059.8 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0953 in $0.05B$ = 0.0501 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING, THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^{f} / \sigma_{YS}^{T})(0.4\sigma_{YS}^{f}\ ksi\sqrt{in})$, WHERE σ_{YS}^{f} AND σ_{YS}^{T} ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ K_{max} Limit = 21.0 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6 (\sigma_{YS}^{f} / \sigma_{YS}^{T}) * K_F$ WHERE $K_F = K_{JQ}, K_{JQC}$, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.2 ksi(in)$^{1/2}$ K_{max} Limit = 130.1 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0162 in $0.05B$ = 0.0501 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0275 in $0.05B$ = 0.0501 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0450 in   50% of the Average = 0.0296 in

ALL GENERAL VALIDITY CHECKS ARE VALID

GERALD W. BOICE - THOMAS S. FEDOR

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-B-1
TESTLOG : T05258
TEST DATE : 7/10/2013

MATERIAL : Steel

WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 30.23 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.5 ksi
EFFECTIVE YIELD STRENGTH : 65.9 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 1.001 in
NET THICKNESS (B_N)	: 0.800 in
EFFECTIVE THICKNESS (B_e)	: 0.961 in
WIDTH (W)	: 1.996 in
UNCRACKED LIGAMENT (b_o)	: 0.986 in
NOTCH LENGTH (a_n)	: 0.915 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H5	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 1391	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.994 in	1.010 in	1.015 in	1.015 in	1.017 in	1.015 in	1.010 in	1.004 in	0.998 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.097 in	1.055 in	1.065 in	1.073 in	1.080 in	1.087 in	1.064 in	1.051 in	1.065 in

PRECRACK AVERAGE	: 1.0103 in	FINAL AVERAGE	: 1.0695 in
PRECRACK a/W	: 0.5062	FINAL a/W	: 0.5358

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 2154 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 1900 lb	CYCLES	: 259423
FINAL K_{max}	: 13.23 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 6426.2 lb	MAXIMUM FORCE (P_{max})	: 12059.8 lb
K_Q	: 50.0 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 2.96

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID

   $a/W = 0.5062$

2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID

   $P_{max}/P_Q = 1.8767$

3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID

   $2.5(K_Q/\sigma_{YS})^2 = 2.2710$ in $b_o = 0.9857$ in

4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{f} / \sigma_{YS}^{T}) * K_F$ WHERE $K_F = K_Q$ — VALID

   K_{max} Applied = 13.2 ksi(in)$^{1/2}$ K_{max} Limit = 30.0 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 50.0 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SPECIMEN : KC-H-B-1 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05258
P.O. NO. : F58154BT TEST DATE : 7/10/2013 TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 1.0103 in
ORIGINAL PHYSICAL MEASUREMENT : 1.0103 in
MODULUS (E) : 30.23 Msi

WIDTH (W) : 1.996 in
TOTAL THICKNESS (B) : 1.001 in
NET THICKNESS (B_N) : 0.800 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0031	2513.9	0.00	0.00	11.42	11.42	1.301E-06	37.81	0.9996	1.0069	-0.0033
2	0.0048	3753.3	0.00	0.00	25.59	25.59	1.307E-06	37.98	0.9999	1.0087	-0.0015
3	0.0060	4569.4	0.30	0.86	37.85	38.72	1.304E-06	37.92	0.9999	1.0081	-0.0022
4	0.0067	4989.7	0.78	2.24	44.98	47.22	1.300E-06	37.81	1.0000	1.0070	-0.0033
5	0.0073	5386.1	1.33	3.81	52.49	56.30	1.302E-06	37.86	1.0000	1.0075	-0.0028
6	0.0079	5755.7	2.05	5.88	59.75	65.63	1.298E-06	37.76	0.9999	1.0065	-0.0038
7	0.0085	6125.6	2.82	8.06	67.83	75.89	1.301E-06	37.83	0.9999	1.0071	-0.0031
8	0.0091	6480.6	3.80	10.84	75.98	86.82	1.301E-06	37.85	0.9999	1.0074	-0.0028
9	0.0098	6830.0	5.05	14.41	84.47	98.88	1.302E-06	37.88	1.0000	1.0077	-0.0026
10	0.0104	7176.8	6.06	17.25	93.94	111.19	1.310E-06	38.10	0.9999	1.0100	-0.0002
11	0.0111	7496.2	8.05	23.00	101.86	124.86	1.303E-06	37.91	0.9999	1.0081	-0.0022
12	0.0117	7797.8	10.03	28.67	110.15	138.83	1.302E-06	37.90	0.9999	1.0079	-0.0024
13	0.0124	8076.7	11.99	34.15	118.99	153.14	1.309E-06	38.11	0.9999	1.0101	-0.0002
14	0.0131	8355.3	14.88	42.42	127.36	169.79	1.309E-06	38.11	0.9999	1.0101	-0.0002
15	0.0139	8629.3	18.04	51.42	136.24	187.65	1.312E-06	38.20	1.0000	1.0110	0.0007
16	0.0146	8873.5	22.25	63.60	143.43	207.03	1.307E-06	38.06	0.9999	1.0096	-0.0007
17	0.0154	9073.4	26.53	75.63	150.95	226.57	1.314E-06	38.27	0.9999	1.0117	0.0014
18	0.0162	9282.0	31.68	90.59	157.18	247.78	1.309E-06	38.11	0.9999	1.0101	-0.0002
19	0.0171	9459.0	36.50	103.89	165.00	268.89	1.320E-06	38.44	0.9999	1.0136	0.0033
20	0.0179	9602.6	42.80	122.20	169.37	291.57	1.315E-06	38.32	0.9999	1.0123	0.0020
21	0.0197	9881.7	55.80	159.01	180.58	339.59	1.322E-06	38.53	0.9998	1.0145	0.0042
22	0.0206	10000.9	63.43	180.84	185.16	366.00	1.323E-06	38.56	0.9998	1.0148	0.0045
23	0.0216	10100.8	72.07	205.71	188.83	394.54	1.322E-06	38.56	0.9998	1.0147	0.0044
24	0.0226	10185.0	80.73	230.44	192.25	422.69	1.324E-06	38.60	0.9998	1.0151	0.0049
25	0.0236	10258.9	89.37	254.94	195.65	450.59	1.327E-06	38.69	0.9998	1.0161	0.0058
26	0.0244	10302.2	97.97	279.73	197.27	477.00	1.326E-06	38.69	0.9998	1.0161	0.0058
27	0.0255	10350.3	108.47	310.06	198.96	509.02	1.325E-06	38.66	0.9998	1.0158	0.0055
28	0.0265	10383.0	117.13	334.00	201.54	535.55	1.332E-06	38.87	0.9998	1.0179	0.0076
29	0.0276	10428.5	128.32	366.90	202.50	569.41	1.328E-06	38.74	0.9998	1.0166	0.0064
30	0.0287	10465.7	138.97	397.01	204.59	601.60	1.331E-06	38.84	0.9998	1.0176	0.0074
31	0.0297	10478.1	149.09	425.93	205.34	631.28	1.332E-06	38.88	0.9998	1.0180	0.0078
32	0.0307	10509.3	159.12	454.86	206.57	661.43	1.332E-06	38.88	0.9998	1.0180	0.0078

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SPECIMEN : KC-H-B-1 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05258
P.O. NO. : F58154BT TEST DATE : 7/10/2013 TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 1.0103 in
ORIGINAL PHYSICAL MEASUREMENT : 1.0103 in
MODULUS (E) : 30.23 Msi

WIDTH (W) : 1.996 in
TOTAL THICKNESS (B) : 1.001 in
NET THICKNESS (B_N) : 0.800 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
33	0.0317	10534.1	169.76	485.12	207.95	693.08	1.333E-06	38.95	0.9998	1.0187	0.0084
34	0.0328	10570.5	180.64	515.85	209.99	725.84	1.336E-06	39.03	0.9997	1.0196	0.0093
35	0.0339	10603.4	191.41	547.27	211.01	758.28	1.334E-06	38.99	0.9998	1.0191	0.0089
36	0.0350	10642.2	201.93	576.81	213.25	790.06	1.338E-06	39.09	0.9997	1.0202	0.0099
37	0.0361	10667.8	213.77	610.97	214.30	825.28	1.337E-06	39.10	0.9997	1.0202	0.0099
38	0.0372	10703.6	225.16	643.54	216.00	859.54	1.338E-06	39.14	0.9997	1.0206	0.0103
39	0.0384	10722.6	236.68	675.67	217.60	893.27	1.342E-06	39.26	0.9997	1.0218	0.0115
40	0.0395	10762.1	248.50	711.07	218.37	929.44	1.338E-06	39.14	0.9997	1.0206	0.0103
41	0.0405	10772.8	258.68	738.37	220.22	958.59	1.345E-06	39.34	0.9997	1.0226	0.0124
42	0.0416	10794.2	269.86	771.62	220.54	992.16	1.342E-06	39.26	0.9996	1.0218	0.0116
43	0.0426	10822.6	280.45	801.22	222.33	1023.55	1.344E-06	39.35	0.9996	1.0227	0.0125
44	0.0437	10846.4	292.05	834.44	223.54	1057.97	1.345E-06	39.38	0.9996	1.0230	0.0128
45	0.0449	10885.4	303.50	865.47	226.40	1091.87	1.351E-06	39.56	0.9997	1.0248	0.0145
46	0.0460	10901.4	315.55	900.10	227.26	1127.35	1.352E-06	39.58	0.9996	1.0251	0.0148
47	0.0472	10928.6	327.57	935.09	228.32	1163.41	1.351E-06	39.57	0.9996	1.0250	0.0147
48	0.0483	10955.9	338.96	966.72	230.23	1196.95	1.354E-06	39.68	0.9997	1.0260	0.0157
49	0.0494	10968.2	350.63	1000.53	230.78	1231.31	1.354E-06	39.69	0.9997	1.0261	0.0158
50	0.0505	10999.1	362.13	1032.88	232.61	1265.49	1.356E-06	39.76	0.9996	1.0268	0.0165
51	0.0515	11006.0	373.32	1065.02	233.09	1298.11	1.357E-06	39.78	0.9996	1.0270	0.0168
52	0.0526	11032.7	383.96	1094.88	234.74	1329.62	1.359E-06	39.85	0.9996	1.0277	0.0174
53	0.0537	11051.7	395.76	1127.58	236.32	1363.90	1.362E-06	39.96	0.9996	1.0287	0.0185
54	0.0548	11070.4	407.98	1162.77	237.30	1400.07	1.363E-06	39.98	0.9996	1.0290	0.0187
55	0.0560	11102.3	419.95	1195.89	239.45	1435.34	1.366E-06	40.09	0.9997	1.0300	0.0197
56	0.0571	11115.4	432.40	1232.25	239.99	1472.24	1.366E-06	40.08	0.9996	1.0300	0.0197
57	0.0582	11134.6	444.19	1267.08	240.62	1507.69	1.365E-06	40.06	0.9996	1.0297	0.0194
58	0.0593	11142.6	456.05	1299.88	241.69	1541.58	1.368E-06	40.15	0.9995	1.0307	0.0204
59	0.0604	11172.6	466.85	1329.85	243.63	1573.48	1.370E-06	40.24	0.9996	1.0315	0.0212
60	0.0614	11189.7	478.30	1362.18	244.82	1607.00	1.372E-06	40.30	0.9996	1.0320	0.0218
61	0.0625	11204.8	490.42	1399.37	244.78	1644.14	1.368E-06	40.20	0.9996	1.0311	0.0209
62	0.0636	11236.7	501.22	1426.89	247.72	1674.61	1.375E-06	40.41	0.9996	1.0331	0.0228
63	0.0646	11243.8	512.40	1459.28	248.14	1707.42	1.375E-06	40.42	0.9996	1.0332	0.0230
64	0.0657	11275.0	523.98	1493.77	249.29	1743.06	1.374E-06	40.39	0.9996	1.0330	0.0227

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SPECIMEN : KC-H-B-1 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05258
P.O. NO. : F58154BT TEST DATE : 7/10/2013 TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 1.0103 in
ORIGINAL PHYSICAL MEASUREMENT : 1.0103 in
MODULUS (E) : 30.23 Msi

WIDTH (W) : 1.996 in
TOTAL THICKNESS (B) : 1.001 in
NET THICKNESS (B_N) : 0.800 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
65	0.0668	11291.1	535.62	1524.02	251.39	1775.41	1.380E-06	40.57	0.9996	1.0347	0.0244
66	0.0678	11296.9	546.42	1554.78	251.96	1806.74	1.381E-06	40.61	0.9996	1.0351	0.0248
67	0.0689	11328.9	558.76	1591.47	253.20	1844.68	1.380E-06	40.58	0.9996	1.0348	0.0246
68	0.0700	11353.0	570.58	1624.53	254.82	1879.35	1.382E-06	40.65	0.9995	1.0355	0.0252
69	0.0710	11357.0	581.49	1653.88	255.91	1909.79	1.386E-06	40.77	0.9995	1.0366	0.0263
70	0.0727	11382.9	599.49	1703.50	258.16	1961.66	1.390E-06	40.91	0.9996	1.0379	0.0276
71	0.0742	11408.0	616.53	1752.45	259.66	2012.11	1.391E-06	40.95	0.9995	1.0383	0.0281
72	0.0759	11435.1	635.19	1808.19	260.60	2068.79	1.389E-06	40.92	0.9995	1.0380	0.0277
73	0.0775	11460.6	652.59	1854.91	263.16	2118.07	1.395E-06	41.09	0.9994	1.0396	0.0294
74	0.0791	11482.1	669.73	1900.17	265.77	2165.93	1.401E-06	41.29	0.9995	1.0415	0.0313
75	0.0808	11501.9	688.91	1957.83	266.32	2224.16	1.399E-06	41.25	0.9995	1.0411	0.0308
76	0.0824	11528.2	706.94	2009.62	267.94	2277.56	1.400E-06	41.29	0.9995	1.0416	0.0313
77	0.0841	11549.3	725.03	2059.67	269.88	2329.55	1.404E-06	41.41	0.9994	1.0427	0.0324
78	0.0857	11564.5	743.10	2111.92	270.90	2382.81	1.405E-06	41.45	0.9994	1.0430	0.0327
79	0.0872	11589.7	759.95	2156.53	273.54	2430.07	1.410E-06	41.63	0.9995	1.0447	0.0344
80	0.0888	11611.0	777.60	2206.66	275.11	2481.78	1.412E-06	41.69	0.9994	1.0453	0.0350
81	0.0903	11621.4	795.11	2256.70	276.08	2532.79	1.414E-06	41.75	0.9994	1.0458	0.0356
82	0.0919	11652.0	813.26	2310.50	277.51	2588.01	1.413E-06	41.75	0.9995	1.0458	0.0355
83	0.0936	11667.3	831.17	2358.06	279.69	2637.75	1.419E-06	41.92	0.9994	1.0474	0.0371
84	0.0952	11686.9	848.83	2407.52	281.39	2688.91	1.421E-06	42.01	0.9995	1.0482	0.0380
85	0.0968	11704.0	868.01	2463.09	282.54	2745.63	1.422E-06	42.05	0.9995	1.0486	0.0383
86	0.0985	11716.3	886.53	2514.72	283.98	2798.70	1.425E-06	42.15	0.9994	1.0495	0.0392
87	0.1001	11731.3	904.52	2564.45	285.63	2850.08	1.428E-06	42.26	0.9994	1.0505	0.0402
88	0.1017	11750.8	922.92	2617.25	287.04	2904.29	1.429E-06	42.31	0.9994	1.0510	0.0407
89	0.1033	11779.3	940.29	2661.93	290.15	2952.08	1.436E-06	42.51	0.9994	1.0528	0.0425
90	0.1049	11787.5	958.59	2716.49	290.54	3007.03	1.435E-06	42.51	0.9994	1.0528	0.0425
91	0.1065	11797.0	977.24	2769.79	291.54	3061.33	1.437E-06	42.57	0.9994	1.0534	0.0431
92	0.1081	11813.4	995.62	2818.75	293.72	3112.47	1.442E-06	42.73	0.9994	1.0548	0.0445
93	0.1098	11824.1	1014.61	2869.26	295.68	3164.93	1.447E-06	42.89	0.9993	1.0563	0.0460
94	0.1114	11831.2	1033.09	2924.07	296.13	3220.20	1.447E-06	42.90	0.9993	1.0564	0.0461
95	0.1130	11838.3	1050.80	2971.27	297.78	3269.05	1.451E-06	43.05	0.9994	1.0577	0.0474
96	0.1146	11843.4	1069.21	3021.08	299.21	3320.29	1.455E-06	43.19	0.9993	1.0589	0.0486

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SPECIMEN : KC-H-B-1 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05258
P.O. NO. : F58154BT TEST DATE : 7/10/2013 TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 1.0103 in
ORIGINAL PHYSICAL MEASUREMENT : 1.0103 in
MODULUS (E) : 30.23 Msi

WIDTH (W) : 1.996 in
TOTAL THICKNESS (B) : 1.001 in
NET THICKNESS (B_N) : 0.800 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
97	0.1164	11802.1	1091.64	3084.94	297.86	3382.80	1.458E-06	43.27	0.9993	1.0596	0.0493
98	0.1181	11866.7	1108.91	3125.52	303.58	3429.11	1.467E-06	43.55	0.9994	1.0621	0.0518
99	0.1197	11873.7	1128.19	3185.16	303.57	3488.73	1.465E-06	43.51	0.9994	1.0617	0.0514
100	0.1213	11879.2	1146.09	3231.53	305.43	3536.96	1.470E-06	43.69	0.9994	1.0633	0.0530
101	0.1229	11883.8	1164.27	3279.18	307.16	3586.33	1.475E-06	43.85	0.9993	1.0647	0.0545
102	0.1245	11892.5	1182.82	3334.18	307.79	3641.96	1.476E-06	43.88	0.9991	1.0649	0.0546
103	0.1261	11895.2	1200.25	3377.32	309.88	3687.20	1.483E-06	44.10	0.9993	1.0668	0.0566
104	0.1277	11901.2	1220.42	3440.28	309.76	3750.04	1.480E-06	44.05	0.9993	1.0664	0.0561
105	0.1295	11909.2	1239.40	3486.94	312.33	3799.27	1.488E-06	44.29	0.9993	1.0685	0.0582
106	0.1311	11907.4	1258.47	3537.60	313.64	3851.24	1.493E-06	44.44	0.9993	1.0698	0.0596
107	0.1327	11909.0	1277.16	3589.13	314.73	3903.86	1.496E-06	44.56	0.9993	1.0708	0.0605
108	0.1343	11910.7	1295.28	3640.17	315.58	3955.76	1.499E-06	44.64	0.9993	1.0715	0.0612
109	0.1359	11918.0	1313.70	3685.95	317.94	4003.89	1.505E-06	44.86	0.9993	1.0734	0.0631
110	0.1376	11922.4	1333.64	3749.28	317.64	4066.91	1.503E-06	44.80	0.9943	1.0729	0.0626

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

Phone (724) 537-3131

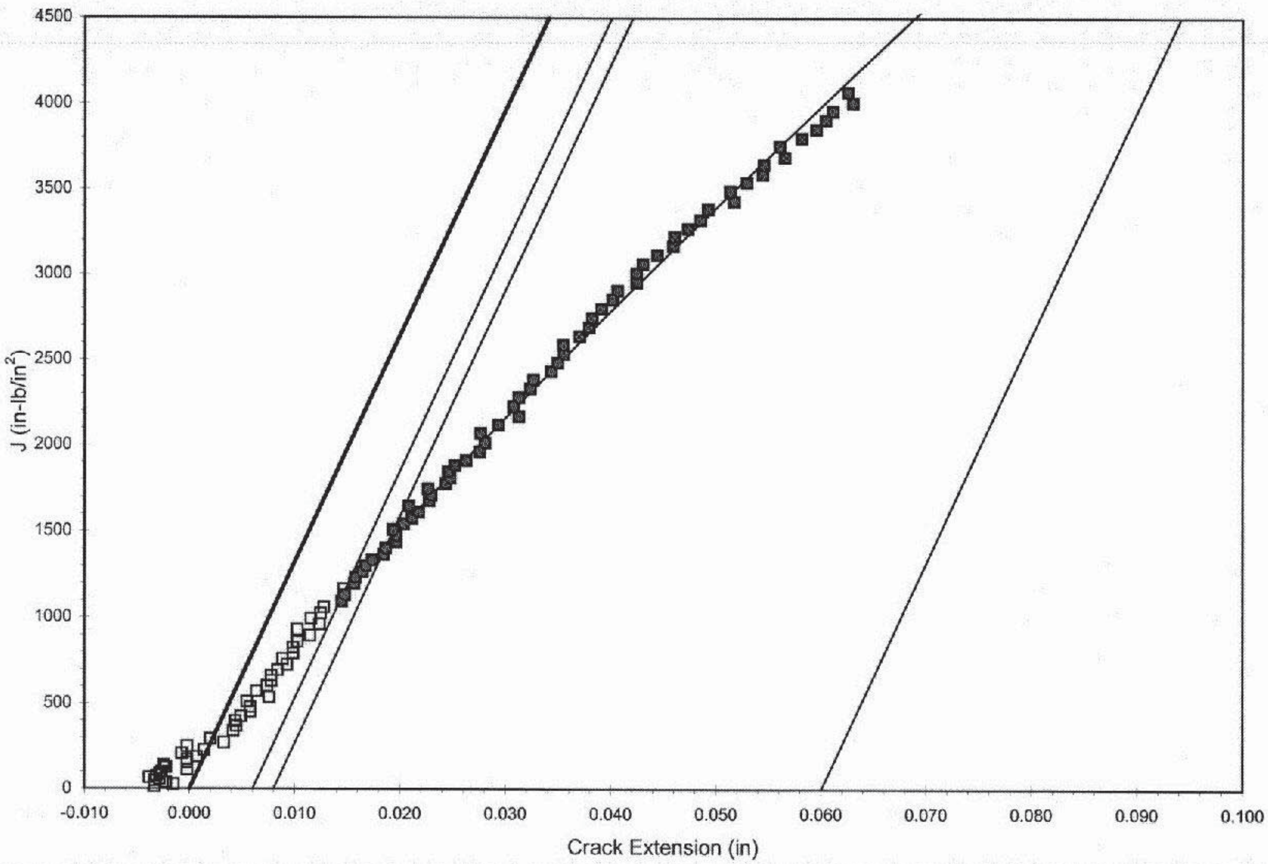
CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05258
TEST DATE : 7/10/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SPECIMEN : KC-H-B-1

J_{Ic} = 1415.95 in-lb/in^2

$J = 2745.1\ (a / 0.0394)^{0.8843}$



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Force vs. COD Graph

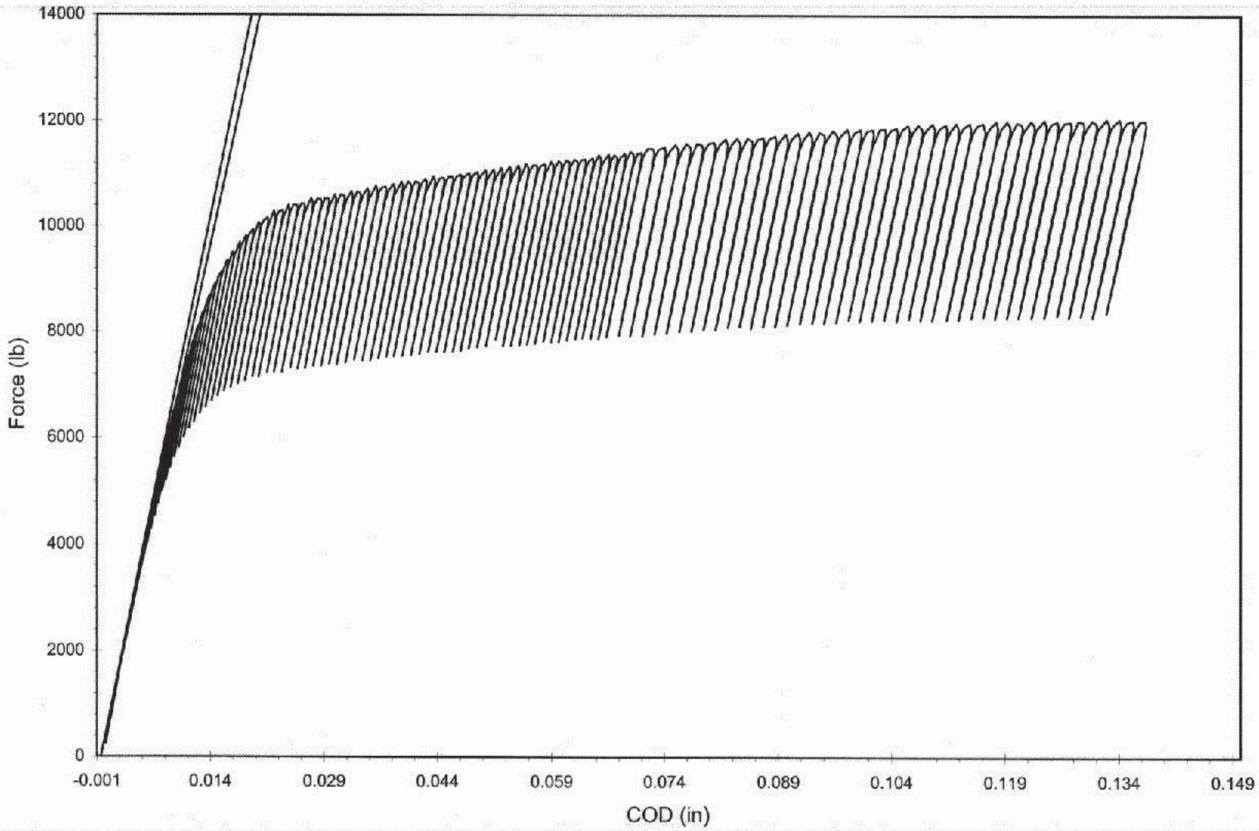
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05258
TEST DATE : 7/10/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SPECIMEN : KC-H-B-1

P_{max} = 12059.8 lb
P_Q = 6426.2 lb
K_Q = 50.0 ksi(in)$^{1/2}$



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KC-H-B-2

A-225 Gr. B HEAD

J_{IC} FRACTURE TOUGHNESS

BASE HEAD MATERIAL

T-L

RT

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-B-2
TESTLOG : T05259
TEST DATE : 7/11/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.5 ksi
EFFECTIVE YIELD STRENGTH : 65.9 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B) : 1.004 in
NET THICKNESS (B_N) : 0.798 in
EFFECTIVE THICKNESS (B_e) : 0.962 in
WIDTH (W) : 2.000 in
UNCRACKED LIGAMENT (b_o) : 0.990 in
NOTCH LENGTH (a_n) : 0.920 in

TEST PARAMETERS

TEST TEMPERATURE : 75°F
TEST TYPE : CT
ORIENTATION : L-C
TEST MACHINE : H3
CLIP GAGE : 614
CLIP GAGE LOCATION : LOAD LINE

MAIN RAMP RATE : 0.02 in/min
PARTIAL LOADING RATE : 0.02 in/min
PARTIAL UNLOADING RATE : 0.02 in/min
UNLOADING INTERVAL : 0.001 in
HOLDTIME : 5.0 sec.
OPERATOR : CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.000 in	1.008 in	1.015 in	1.017 in	1.016 in	1.011 in	1.009 in	1.005 in	0.997 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.915 in	1.906 in	1.888 in	1.905 in	1.868 in	1.889 in	1.860 in	1.868 in	1.842 in

PRECRACK AVERAGE : 1.0099 in FINAL AVERAGE : 1.8828 in
PRECRACK a/W : 0.5050 FINAL a/W : 0.9414

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 2152 lb FINAL P_{max} : 1915 lb R-RATIO (P_{min} / P_{max}) : 0.1
CYCLES : 234919 FINAL K_{max} : 13.23 ksi(in)$^{1/2}$

ORIGINAL CRACK

PHYSICAL CRACK SIZE (a_o) : 1.0099 in
EST. CRACK SIZE (a_{oq}) : 1.0083 in
PERCENT DIFFERENCE : 0.16 %

J_c VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   $a/W = 0.5050$
2. (A6.2.2) THICKNESS, $B \geq 100J_Q/\sigma_Y$ — INVALID
   $B = 1.0040$ in $100J_Q/\sigma_Y = 1.5423$ in
3. (A6.2.2) INITIAL LIGAMENT, $b_o \geq 100J_Q/\sigma_Y$ — INVALID
   $b_o = 0.9901$ in $100J_Q/\sigma_Y = 1.5423$ in
4. (A6.2.2) CRACK EXTENSION, $\Delta a_p < 0.008 + J_Q/2\,\sigma_y$ — INVALID
   $\Delta a_p = 0.8729$ in Limit = 0.0156 in

FAST FRACTURE RESPONSE
SMALL SCALE YIELDING CRITERIA ARE NOT MET

TEST IS INVALID: J_{Qc} = 1016.39 in-lb/in^2
K_{JQc} = 186.08 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-B-2
TESTLOG : T05259
TEST DATE : 7/11/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.5 ksi
EFFECTIVE YIELD STRENGTH : 65.9 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 1.004 in	WIDTH (W)	: 2.000 in
NET THICKNESS (B_N)	: 0.798 in	UNCRACKED LIGAMENT (b_o)	: 0.990 in
EFFECTIVE THICKNESS (B_e)	: 0.962 in	NOTCH LENGTH (a_n)	: 0.920 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.001 in
CLIP GAGE	: 614	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.000 in	1.008 in	1.015 in	1.017 in	1.016 in	1.011 in	1.009 in	1.005 in	0.997 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.915 in	1.906 in	1.888 in	1.905 in	1.868 in	1.889 in	1.860 in	1.868 in	1.842 in

PRECRACK AVERAGE	: 1.0099 in	FINAL AVERAGE	: 1.8828 in
PRECRACK a/W	: 0.5050	FINAL a/W	: 0.9414

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 2152 lb	FINAL P_{max}	: 1915 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 234919	FINAL K_{max}	: 13.23 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 11193.5 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0899 in — $0.05B$ = 0.0502 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}{}^{f} / \sigma_{YS}{}^{T})(0.4\sigma_{YS}{}^{f}\ ksi\sqrt{in})$, WHERE $\sigma_{YS}{}^{f}$ AND $\sigma_{YS}{}^{T}$ ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ — K_{max} Limit = 21.0 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}{}^{f} / \sigma_{YS}{}^{T}) * K_F$, WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.2 ksi(in)$^{1/2}$ — K_{max} Limit = 111.6 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0129 in — $0.05B$ = 0.0502 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0408 in — $0.05B$ = 0.0502 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.8450 in — 50% of the Average = 0.4364 in

ALL GENERAL VALIDITY CHECKS ARE VALID

Gerald W. Boice

GERALD W. BOICE - THOMAS S. FEDOR

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

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WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-B-2
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POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

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NET THICKNESS (B_N) : 0.798 in
EFFECTIVE THICKNESS (B_e) : 0.962 in
WIDTH (W) : 2.000 in
UNCRACKED LIGAMENT (b_o) : 0.990 in
NOTCH LENGTH (a_n) : 0.920 in

TEST PARAMETERS

TEST TEMPERATURE : 75°F
TEST TYPE : CT
ORIENTATION : L-C
TEST MACHINE : H3
CLIP GAGE : 614
CLIP GAGE LOCATION : LOAD LINE

MAIN RAMP RATE : 0.02 in/min
PARTIAL LOADING RATE : 0.02 in/min
PARTIAL UNLOADING RATE : 0.02 in/min
UNLOADING INTERVAL : 0.001 in
HOLDTIME : 5.0 sec.
OPERATOR : CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.000 in	1.008 in	1.015 in	1.017 in	1.016 in	1.011 in	1.009 in	1.005 in	0.997 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.915 in	1.906 in	1.888 in	1.905 in	1.868 in	1.889 in	1.860 in	1.868 in	1.842 in

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 2152 lb
FINAL P_{max} : 1915 lb
FINAL K_{max} : 13.23 ksi(in)$^{1/2}$

R-RATIO (P_{min} / P_{max}) : 0.1
CYCLES : 234919

TEST RESULTS

CANDIDATE FORCE (P_Q) : 5609.4 lb
K_Q : 43.5 ksi(in)$^{1/2}$

MAXIMUM FORCE (P_{max}) : 11193.5 lb
SPECIMEN STRENGTH RATIO : 2.73

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   a/W = 0.5050
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   P_{max}/P_Q = 1.9955
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2$ = 1.7136 in b_o = 0.9901 in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^f / \sigma_{YS}^T) * K_F$ WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 13.2 ksi(in)$^{1/2}$ K_{max} Limit = 111.6 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 43.5 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
SPECIMEN : KC-H-B-2
MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089
TESTLOG : T05259
P.O. NO. : F58154BT
TEST DATE : 7/11/2013
TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 1.0083 in
ORIGINAL PHYSICAL MEASUREMENT : 1.0099 in
MODULUS (E) : 31.00 Msi

WIDTH (W) : 2.000 in
TOTAL THICKNESS (B) : 1.004 in
NET THICKNESS (B_N) : 0.798 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0022	1523.8	0.19	0.30	4.09	4.38	1.269E-06	37.86	0.9952	1.0095	0.0011
2	0.0021	1509.5	0.15	0.18	3.97	4.15	1.259E-06	37.55	0.9961	1.0062	-0.0021
3	0.0039	2913.8	0.21	0.36	14.93	15.30	1.268E-06	37.84	0.9990	1.0093	0.0010
4	0.0048	3540.4	0.44	1.02	22.07	23.09	1.269E-06	37.88	0.9995	1.0097	0.0014
5	0.0057	4187.7	0.70	1.76	30.53	32.30	1.257E-06	37.53	0.9992	1.0060	-0.0023
6	0.0065	4827.4	1.15	3.04	40.39	43.43	1.253E-06	37.39	0.9986	1.0045	-0.0038
7	0.0091	6416.1	4.30	12.02	71.47	83.49	1.254E-06	37.44	0.9991	1.0051	-0.0033
8	0.0099	6921.1	5.44	15.25	83.24	98.49	1.254E-06	37.47	0.9992	1.0053	-0.0030
9	0.0117	7804.5	9.90	27.90	106.33	134.23	1.259E-06	37.61	0.9998	1.0068	-0.0015
10	0.0134	8571.7	16.23	45.94	128.25	174.19	1.258E-06	37.60	0.9992	1.0068	-0.0015
11	0.0154	9215.7	26.62	75.52	148.33	223.85	1.258E-06	37.62	0.9994	1.0070	-0.0013
12	0.0164	9462.5	32.11	90.94	157.37	248.30	1.265E-06	37.81	0.9993	1.0090	0.0007
13	0.0174	9696.9	39.55	112.20	165.17	277.36	1.264E-06	37.80	0.9995	1.0089	0.0005
14	0.0206	10206.5	64.51	183.38	183.18	366.56	1.264E-06	37.83	0.9994	1.0092	0.0009
15	0.0231	10441.8	86.89	247.06	192.20	439.26	1.266E-06	37.91	0.9993	1.0100	0.0017
16	0.0242	10532.4	96.68	274.11	197.03	471.14	1.274E-06	38.14	0.9995	1.0124	0.0041
17	0.0255	10599.9	109.07	308.86	200.67	509.52	1.279E-06	38.31	0.9996	1.0142	0.0059
18	0.0267	10680.7	121.16	343.89	203.25	547.14	1.276E-06	38.23	0.9995	1.0134	0.0051
19	0.0280	10691.0	133.64	378.93	204.57	583.50	1.281E-06	38.37	0.9994	1.0149	0.0065
20	0.0293	10761.2	148.82	425.30	204.21	629.51	1.265E-06	37.92	0.9995	1.0101	0.0018
21	0.0307	10770.0	162.75	464.25	205.42	669.68	1.269E-06	38.05	0.9997	1.0115	0.0032
22	0.0320	10833.4	175.49	499.23	209.23	708.46	1.276E-06	38.25	0.9992	1.0136	0.0053
23	0.0334	10876.1	190.35	542.66	210.17	752.83	1.272E-06	38.15	0.9997	1.0125	0.0042
24	0.0347	10914.0	202.45	573.46	214.84	788.30	1.287E-06	38.61	0.9996	1.0173	0.0090
25	0.0359	10919.7	213.80	603.71	217.00	820.71	1.296E-06	38.89	0.9996	1.0202	0.0119
26	0.0372	10962.1	228.65	648.21	217.44	865.65	1.290E-06	38.71	0.9995	1.0184	0.0100
27	0.0384	11022.8	240.60	683.13	219.49	902.63	1.288E-06	38.66	0.9996	1.0178	0.0095
28	0.0396	11058.8	252.44	713.47	223.52	936.99	1.300E-06	39.03	0.9995	1.0215	0.0132
29	0.0409	11065.3	267.98	761.12	221.98	983.10	1.291E-06	38.78	0.9996	1.0190	0.0107

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

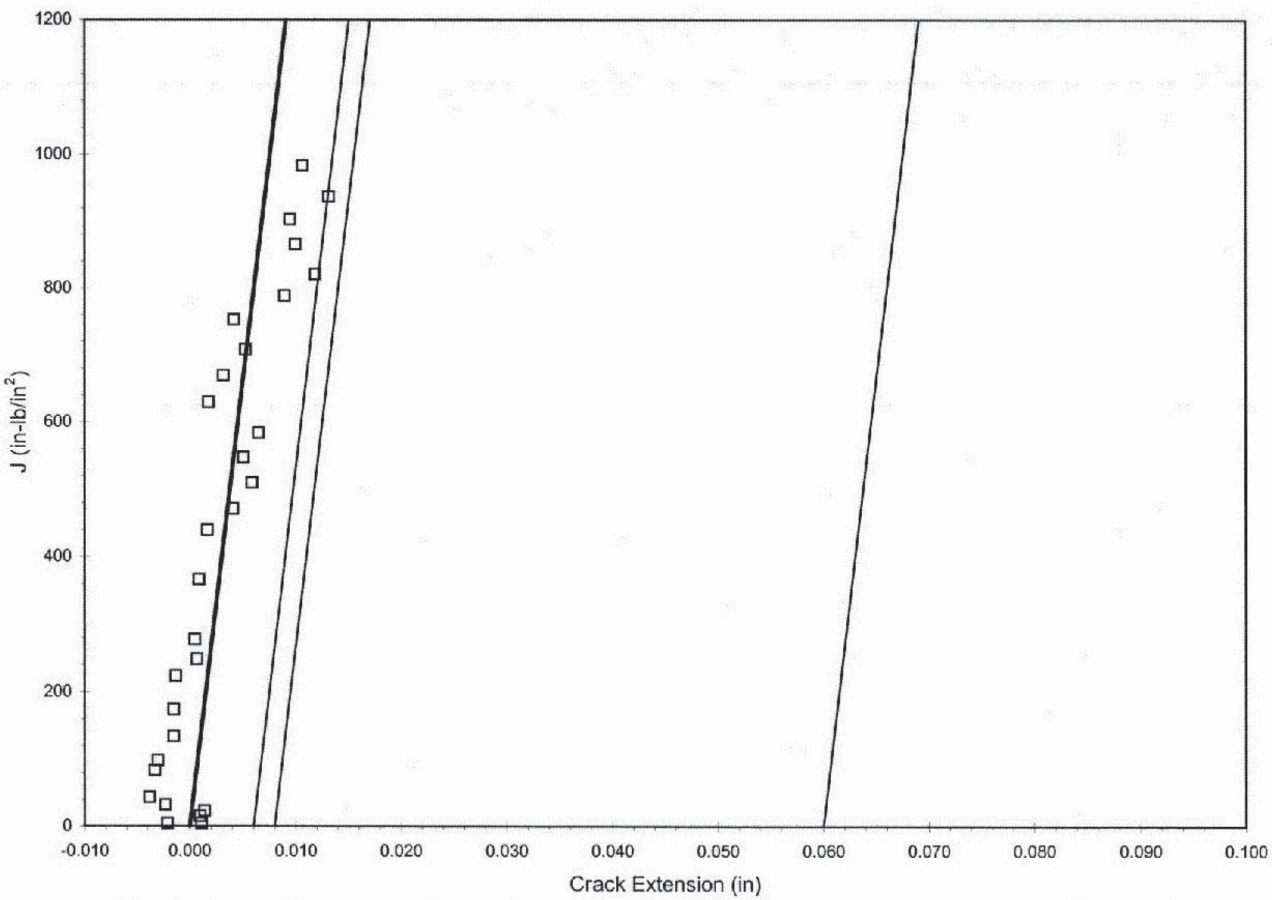
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05259
TEST DATE : 7/11/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SPECIMEN : KC-H-B-2

J_{Qc} = 1016.39 in-lb/in^2



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Force vs. COD Graph

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

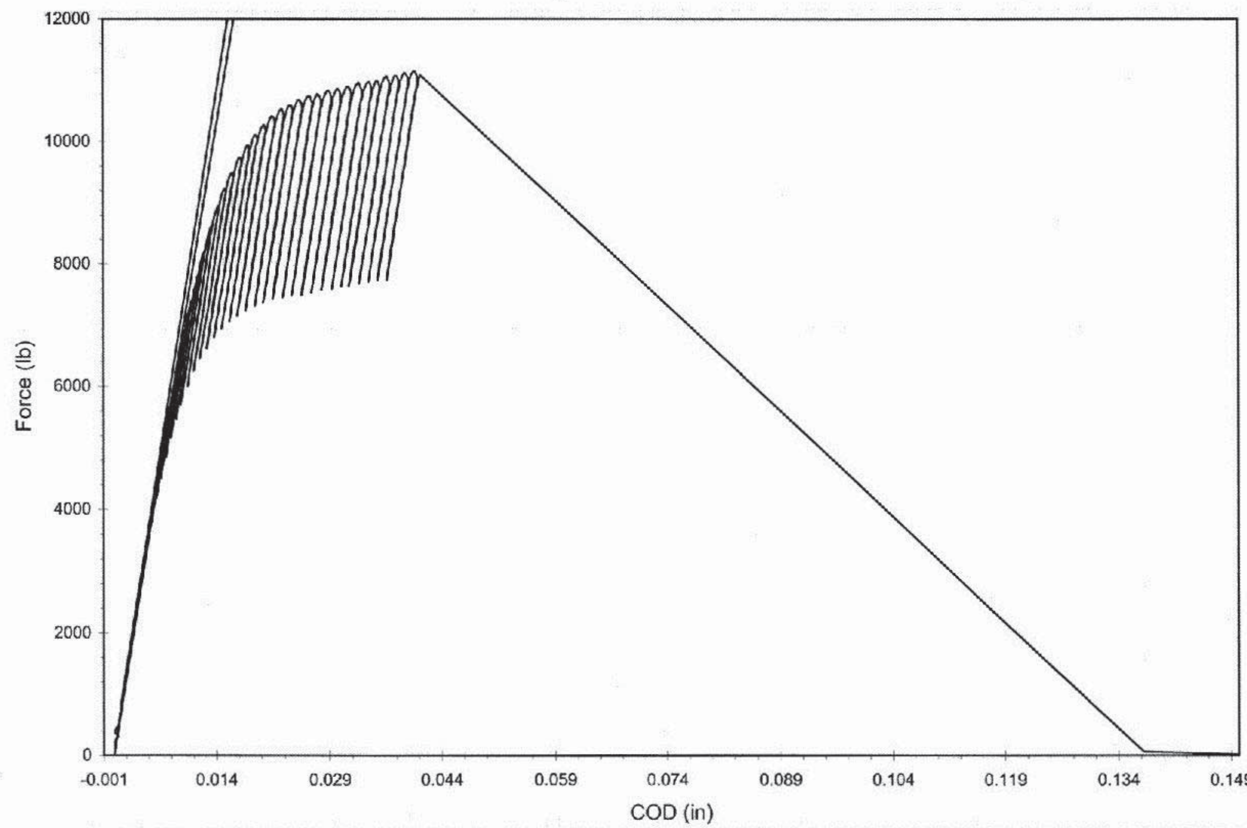
TESTLOG : T05259
TEST DATE : 7/11/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SPECIMEN : KC-H-B-2

P_{max} = 11193.5 lb

P_Q = 5609.4 lb

K_Q = 43.5 ksi(in)$^{1/2}$



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KC-H-B-3

A-225 Gr. B HEAD

J_{IC} FRACTURE TOUGHNESS

BASE HEAD MATERIAL

T-L

-20°F

WESTMORELAND MECHANICAL TESTING & RESEARCH

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J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-B-3
TESTLOG : T05260
TEST DATE : 7/17/2013

MATERIAL : Steel

WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 1.002 in
NET THICKNESS (B_N)	: 0.787 in
EFFECTIVE THICKNESS (B_e)	: 0.956 in
WIDTH (W)	: 2.008 in
UNCRACKED LIGAMENT (b_o)	: 0.975 in
NOTCH LENGTH (a_n)	: 0.919 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H20	UNLOADING INTERVAL	: 0.00075 in
CLIP GAGE	: 1261632	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.020 in	1.027 in	1.033 in	1.039 in	1.039 in	1.040 in	1.038 in	1.031 in	1.011 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.030 in	1.037 in	1.043 in	1.049 in	1.049 in	1.050 in	1.048 in	1.041 in	1.021 in

PRECRACK AVERAGE	: 1.0328 in	FINAL AVERAGE	: 1.0428 in
PRECRACK a/W	: 0.5143	FINAL a/W	: 0.5193

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 2166 lb	FINAL P_{max}	: 1925 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 303922	FINAL K_{max}	: 13.70 ksi(in)$^{1/2}$		

ORIGINAL CRACK

PHYSICAL CRACK SIZE (a_o)	: 1.0328 in
EST. CRACK SIZE (a_{oq})	: 1.0262 in
PERCENT DIFFERENCE	: 0.64 %

J_c VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   $a/W = 0.5143$
2. (A6.2.2) THICKNESS, $B \geq 100J_Q/\sigma_Y$ — INVALID
   $B = 1.0020$ in — $100J_Q/\sigma_Y = 1.4029$ in
3. (A6.2.2) INITIAL LIGAMENT, $b_o \geq 100J_Q/\sigma_Y$ — INVALID
   $b_o = 0.9752$ in — $100J_Q/\sigma_Y = 1.4029$ in
4. (A6.2.2) CRACK EXTENSION, $\Delta a_p < 0.008 + J_Q/2\sigma_y$ — VALID
   $\Delta a_p = 0.0100$ in — Limit = 0.0149 in

FAST FRACTURE RESPONSE
SMALL SCALE YIELDING CRITERIA ARE NOT MET

TEST IS INVALID: J_{Qc} = 1003.09 in-lb/in^2

K_{JQc} = 184.85 ksi(in)$^{1/2}$

Gerald W. Bo

GERALD W. BOICE - THOMAS S. FEDOR

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Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-B-3
TESTLOG : T05260
TEST DATE : 7/17/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 1.002 in	WIDTH (W)	: 2.008 in
NET THICKNESS (B_N)	: 0.787 in	UNCRACKED LIGAMENT (b_o)	: 0.975 in
EFFECTIVE THICKNESS (B_e)	: 0.956 in	NOTCH LENGTH (a_n)	: 0.919 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H20	UNLOADING INTERVAL	: 0.00075 in
CLIP GAGE	: 1261632	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.020 in	1.027 in	1.033 in	1.039 in	1.039 in	1.040 in	1.038 in	1.031 in	1.011 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.030 in	1.037 in	1.043 in	1.049 in	1.049 in	1.050 in	1.048 in	1.041 in	1.021 in

PRECRACK AVERAGE	: 1.0328 in	FINAL AVERAGE	: 1.0428 in
PRECRACK a/W	: 0.5143	FINAL a/W	: 0.5193

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 2166 lb	FINAL P_{max}	: 1925 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 303922	FINAL K_{max}	: 13.70 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 11191.2 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.1138 in   0.05B = 0.0501 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^{f} / \sigma_{YS}^{T})(0.4\sigma_{YS}^{f}\ ksi\sqrt{in})$, WHERE σ_{YS}^{f} AND σ_{YS}^{T} ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ K_{max} Limit = 18.7 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{f} / \sigma_{YS}^{T}) * K_F$, WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.7 ksi(in)$^{1/2}$ K_{max} Limit = 98.7 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0218 in   0.05B = 0.0501 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0218 in   0.05B = 0.0501 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0100 in   50% of the Average = 0.0050 in

ALL GENERAL VALIDITY CHECKS ARE VALID

GERALD W. BOICE - THOMAS S. FEDOR

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-B-3
TESTLOG : T05260
TEST DATE : 7/17/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B) : 1.002 in
NET THICKNESS (B_N) : 0.787 in
EFFECTIVE THICKNESS (B_e) : 0.956 in
WIDTH (W) : 2.008 in
UNCRACKED LIGAMENT (b_o) : 0.975 in
NOTCH LENGTH (a_n) : 0.919 in

TEST PARAMETERS

TEST TEMPERATURE : -20°F
TEST TYPE : CT
ORIENTATION : L-C
TEST MACHINE : H20
CLIP GAGE : 1261632
CLIP GAGE LOCATION : LOAD LINE

MAIN RAMP RATE : 0.02 in/min
PARTIAL LOADING RATE : 0.02 in/min
PARTIAL UNLOADING RATE : 0.02 in/min
UNLOADING INTERVAL : 0.00075 in
HOLDTIME : 5.0 sec.
OPERATOR : DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.020 in	1.027 in	1.033 in	1.039 in	1.039 in	1.040 in	1.038 in	1.031 in	1.011 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.030 in	1.037 in	1.043 in	1.049 in	1.049 in	1.050 in	1.048 in	1.041 in	1.021 in

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 2166 lb
FINAL P_{max} : 1925 lb
FINAL K_{max} : 13.70 ksi(in)$^{1/2}$

R-RATIO (P_{min} / P_{max}) : 0.1
CYCLES : 303922

TEST RESULTS

CANDIDATE FORCE (P_Q) : 5652.0 lb
K_Q : 45.4 ksi(in)$^{1/2}$

MAXIMUM FORCE (P_{max}) : 11191.2 lb
SPECIMEN STRENGTH RATIO : 2.56

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID

   $a/W = 0.5143$

2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID

   $P_{max}/P_Q = 1.9800$

3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID

   $2.5(K_Q/\sigma_{YS})^2 = 1.4786$ in $b_o = 0.9752$ in

4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}{}^f / \sigma_{YS}{}^T) * K_F$, WHERE $K_F = K_Q$ — VALID

   K_{max} Applied = 13.7 ksi(in)$^{1/2}$ K_{max} Limit = 98.7 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 45.4 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SPECIMEN : KC-H-B-3 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05260
P.O. NO. : F58154BT TEST DATE : 7/17/2013 TEMPERATURE : -20°F

ORIGINAL COMPLIANCE CALCULATION : 1.0262 in
ORIGINAL PHYSICAL MEASUREMENT : 1.0328 in
MODULUS (E) : 31.00 Msi

WIDTH (W) : 2.008 in
TOTAL THICKNESS (B) : 1.002 in
NET THICKNESS (B_N) : 0.787 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0048	3641.5	0.00	0.00	24.55	24.55	1.317E-06	39.06	1.0000	1.0259	-0.0002
2	0.0063	4644.3	0.51	1.49	39.99	41.48	1.318E-06	39.10	1.0000	1.0264	0.0002
3	0.0085	6050.2	2.66	7.78	67.81	75.59	1.317E-06	39.08	1.0000	1.0262	0.0000
4	0.0093	6511.6	3.82	11.15	78.55	89.70	1.317E-06	39.08	1.0000	1.0262	0.0000
5	0.0108	7321.5	6.75	19.68	99.48	119.16	1.318E-06	39.13	1.0000	1.0267	0.0005
6	0.0116	7713.2	8.82	25.73	110.35	136.09	1.317E-06	39.12	1.0000	1.0265	0.0004
7	0.0124	8080.2	11.14	32.50	121.24	153.73	1.318E-06	39.15	1.0000	1.0269	0.0007
8	0.0132	8415.7	13.85	40.38	131.78	172.16	1.320E-06	39.22	1.0000	1.0275	0.0014
9	0.0140	8721.6	17.70	51.66	141.36	193.02	1.319E-06	39.18	1.0000	1.0271	0.0010
10	0.0149	8992.0	22.04	64.32	150.32	214.64	1.319E-06	39.19	1.0000	1.0273	0.0011
11	0.0158	9259.0	26.67	77.70	160.04	237.74	1.323E-06	39.32	1.0000	1.0286	0.0024
12	0.0167	9493.1	32.56	94.94	168.14	263.09	1.322E-06	39.30	1.0000	1.0284	0.0023
13	0.0176	9696.6	39.05	113.98	175.28	289.26	1.321E-06	39.28	1.0000	1.0281	0.0020
14	0.0186	9881.3	45.71	133.24	182.63	315.87	1.325E-06	39.38	1.0000	1.0292	0.0030
15	0.0195	10063.4	52.76	153.93	189.29	343.23	1.324E-06	39.36	1.0000	1.0290	0.0028
16	0.0205	10208.5	60.91	177.68	195.03	372.71	1.325E-06	39.40	1.0000	1.0294	0.0032
17	0.0216	10332.1	69.72	203.37	200.00	403.36	1.326E-06	39.43	1.0000	1.0297	0.0036
18	0.0227	10443.9	79.25	231.24	204.43	435.67	1.326E-06	39.45	1.0000	1.0299	0.0037
19	0.0237	10525.2	89.12	259.98	207.91	467.89	1.327E-06	39.49	1.0000	1.0303	0.0041
20	0.0248	10600.8	99.35	289.81	211.13	500.94	1.328E-06	39.52	0.9999	1.0306	0.0045
21	0.0259	10667.2	109.90	320.43	214.27	534.69	1.330E-06	39.60	1.0000	1.0313	0.0052
22	0.0270	10732.8	121.08	353.22	216.87	570.09	1.330E-06	39.59	1.0000	1.0313	0.0051
23	0.0282	10786.1	132.86	387.91	218.85	606.76	1.328E-06	39.56	1.0000	1.0310	0.0049
24	0.0294	10825.6	144.38	421.03	221.22	642.25	1.332E-06	39.67	0.9999	1.0321	0.0060
25	0.0305	10852.5	156.66	456.94	222.45	679.39	1.332E-06	39.69	1.0000	1.0323	0.0061
26	0.0317	10882.9	168.50	491.30	224.11	715.41	1.334E-06	39.75	1.0000	1.0329	0.0067
27	0.0328	10915.1	180.89	528.04	225.09	753.13	1.332E-06	39.70	1.0000	1.0324	0.0062
28	0.0340	10947.3	193.02	563.05	226.96	790.01	1.334E-06	39.78	1.0000	1.0331	0.0070
29	0.0352	10975.4	205.24	598.12	228.82	826.94	1.337E-06	39.87	1.0000	1.0341	0.0079
30	0.0364	11004.1	217.32	633.24	230.33	863.58	1.338E-06	39.92	1.0000	1.0345	0.0084
31	0.0375	11031.6	229.50	668.61	231.84	900.45	1.340E-06	39.97	1.0000	1.0350	0.0089
32	0.0387	11063.3	241.88	704.53	233.55	938.09	1.341E-06	40.02	1.0000	1.0355	0.0094
33	0.0399	11090.8	254.12	739.93	235.16	975.10	1.343E-06	40.08	1.0000	1.0361	0.0100

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Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

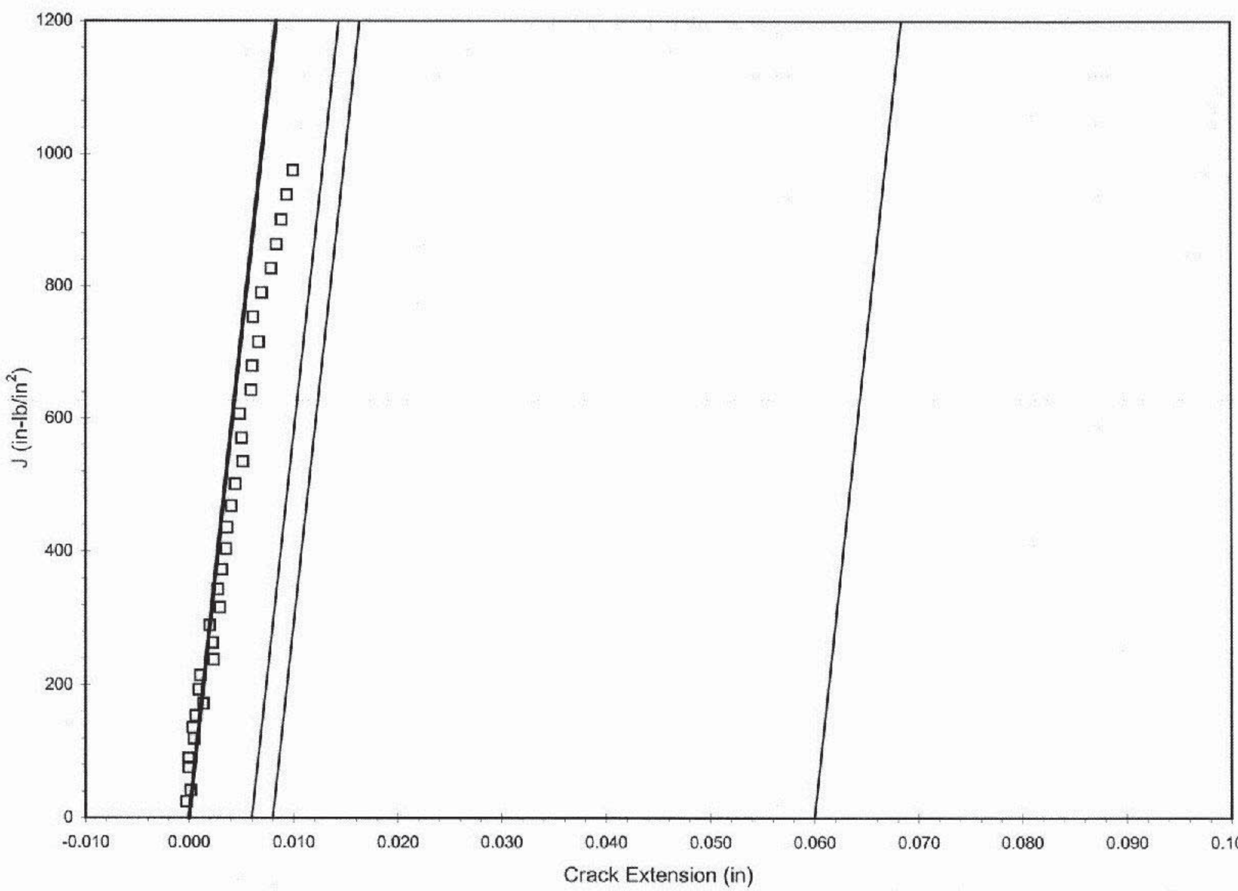
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05260
TEST DATE : 7/17/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-B-3

J_{Qc} = 1003.09 in-lb/in^2



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Westmoreland Mechanical Testing & Research, Inc.

Force vs. COD Graph

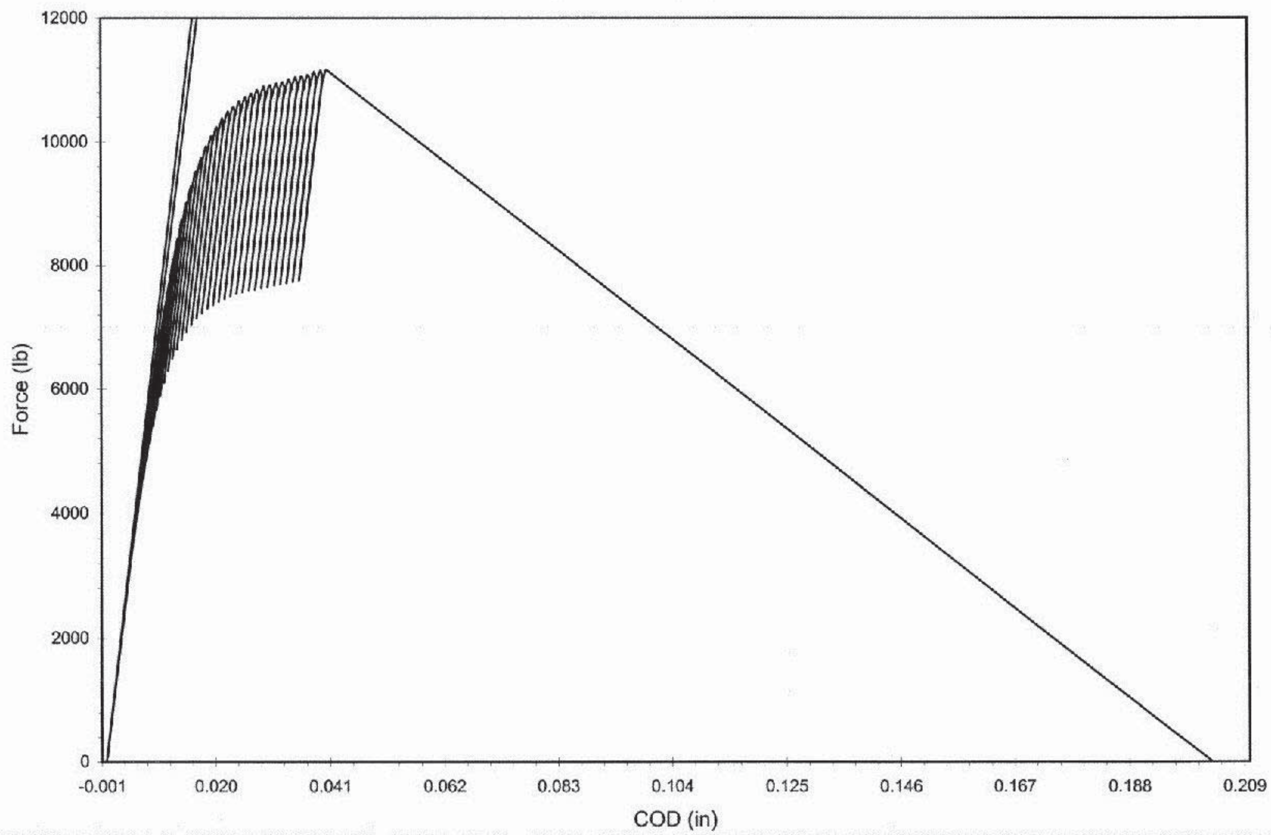
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05260
TEST DATE : 7/17/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-B-3

P_{max} = 11191.2 lb
P_Q = 5652.0 lb
K_Q = 45.4 ksi(in)$^{1/2}$



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KC-H-B-4

A-225 Gr. B HEAD

J_{IC} FRACTURE TOUGHNESS

BASE HEAD MATERIAL

T-L

-20ºF

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J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 31.00 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 84.0 ksi
SPECIMEN : KC-H-B-4	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 59.0 ksi
TESTLOG : T05261		EFFECTIVE YIELD STRENGTH : 71.5 ksi
TEST DATE : 7/17/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 1.003 in
NET THICKNESS (B_N)	: 0.799 in
EFFECTIVE THICKNESS (B_e)	: 0.962 in
WIDTH (W)	: 2.001 in
UNCRACKED LIGAMENT (b_o)	: 0.978 in
NOTCH LENGTH (a_n)	: 0.915 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H20	UNLOADING INTERVAL	: 0.00075 in
CLIP GAGE	: 1261632	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.010 in	1.019 in	1.023 in	1.028 in	1.030 in	1.031 in	1.028 in	1.019 in	1.003 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.018 in	1.027 in	1.031 in	1.036 in	1.038 in	1.039 in	1.036 in	1.027 in	1.011 in

PRECRACK AVERAGE	: 1.0231 in	FINAL AVERAGE	: 1.0312 in
PRECRACK a/W	: 0.5113	FINAL a/W	: 0.5153

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 2167 lb	FINAL P_{max}	: 1912 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 294305	FINAL K_{max}	: 13.48 ksi(in)$^{1/2}$		

ORIGINAL CRACK

PHYSICAL CRACK SIZE (a_o)	: 1.0231 in
EST. CRACK SIZE (a_{oq})	: 1.0216 in
PERCENT DIFFERENCE	: 0.15 %

J_c VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   $a/W = 0.5113$
2. (A6.2.2) THICKNESS, $B \geq 100J_Q/\sigma_Y$ — VALID
   $B = 1.0030$ in $100J_Q/\sigma_Y = 0.8072$ in
3. (A6.2.2) INITIAL LIGAMENT, $b_o \geq 100J_Q/\sigma_Y$ — VALID
   $b_o = 0.9779$ in $100J_Q/\sigma_Y = 0.8072$ in
4. (A6.2.2) CRACK EXTENSION, $\Delta a_p < 0.008 + J_Q/2\,\sigma_y$ — VALID
   $\Delta a_p = 0.0081$ in   Limit = 0.0119 in

FAST FRACTURE RESPONSE
SMALL SCALE YIELDING CRITERIA ARE MET

TEST IS VALID: $J_c = 577.18$ in-lb/in^2
$K_{Jc} = 140.22$ ksi(in)$^{1/2}$

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Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 31.00 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 84.0 ksi
SPECIMEN : KC-H-B-4	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 59.0 ksi
TESTLOG : T05261		EFFECTIVE YIELD STRENGTH : 71.5 ksi
TEST DATE : 7/17/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 1.003 in	WIDTH (W)	: 2.001 in
NET THICKNESS (B_N)	: 0.799 in	UNCRACKED LIGAMENT (b_o)	: 0.978 in
EFFECTIVE THICKNESS (B_e)	: 0.962 in	NOTCH LENGTH (a_n)	: 0.915 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H20	UNLOADING INTERVAL	: 0.00075 in
CLIP GAGE	: 1261632	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.010 in	1.019 in	1.023 in	1.028 in	1.030 in	1.031 in	1.028 in	1.019 in	1.003 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.018 in	1.027 in	1.031 in	1.036 in	1.038 in	1.039 in	1.036 in	1.027 in	1.011 in

PRECRACK AVERAGE	: 1.0231 in	FINAL AVERAGE	: 1.0312 in
PRECRACK a/W	: 0.5113	FINAL a/W	: 0.5153

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 2167 lb	FINAL P_{max}	: 1912 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 294305	FINAL K_{max}	: 13.48 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 10886.2 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.1081 in 0.05B = 0.0502 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^f / \sigma_{YS}^t)(0.4\sigma_{YS}^f\ ksi\sqrt{in})$, WHERE σ_{YS}^f AND σ_{YS}^T ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ K_{max} Limit = 18.7 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\ (\sigma_{YS}^f / \sigma_{YS}^t) * K_F$ WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.5 ksi(in)$^{1/2}$ K_{max} Limit = 74.9 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0201 in 0.05B = 0.0502 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0201 in 0.05B = 0.0502 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0081 in 50% of the Average = 0.0041 in

ALL GENERAL VALIDITY CHECKS ARE VALID

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-B-4
TESTLOG : T05261
TEST DATE : 7/17/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B) : 1.003 in
NET THICKNESS (B_N) : 0.799 in
EFFECTIVE THICKNESS (B_e) : 0.962 in
WIDTH (W) : 2.001 in
UNCRACKED LIGAMENT (b_o) : 0.978 in
NOTCH LENGTH (a_n) : 0.915 in

TEST PARAMETERS

TEST TEMPERATURE : -20°F
TEST TYPE : CT
ORIENTATION : L-C
TEST MACHINE : H20
CLIP GAGE : 1261632
CLIP GAGE LOCATION : LOAD LINE

MAIN RAMP RATE : 0.02 in/min
PARTIAL LOADING RATE : 0.02 in/min
PARTIAL UNLOADING RATE : 0.02 in/min
UNLOADING INTERVAL : 0.00075 in
HOLDTIME : 5.0 sec.
OPERATOR : DAVE KALO

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.010 in	1.019 in	1.023 in	1.028 in	1.030 in	1.031 in	1.028 in	1.019 in	1.003 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
1.018 in	1.027 in	1.031 in	1.036 in	1.038 in	1.039 in	1.036 in	1.027 in	1.011 in

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 2167 lb
FINAL P_{max} : 1912 lb
FINAL K_{max} : 13.48 ksi(in)$^{1/2}$

R-RATIO (P_{min} / P_{max}) : 0.1
CYCLES : 294305

TEST RESULTS

CANDIDATE FORCE (P_Q) : 5569.3 lb
K_Q : 44.0 ksi(in)$^{1/2}$

MAXIMUM FORCE (P_{max}) : 10886.2 lb
SPECIMEN STRENGTH RATIO : 2.43

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   a/W = 0.5113
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   P_{max}/P_Q = 1.9547
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2$ = 1.3903 in b_o = 0.9779 in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}{}^{f} / \sigma_{YS}{}^{T}) * K_F$, WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 13.5 ksi(in)$^{1/2}$ K_{max} Limit = 74.9 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 44.0 ksi(in)$^{1/2}$

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT

SPECIMEN : KC-H-B-4
TESTLOG : T05261
TEST DATE : 7/17/2013

MATERIAL : Steel

TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 1.0216 in
ORIGINAL PHYSICAL MEASUREMENT : 1.0231 in
MODULUS (E) : 31.00 Msi

WIDTH (W) : 2.001 in
TOTAL THICKNESS (B) : 1.003 in
NET THICKNESS (B_N) : 0.799 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0040	3116.6	0.00	0.00	17.68	17.68	1.305E-06	38.92	1.0000	1.0209	-0.0007
2	0.0047	3633.8	0.00	0.00	24.13	24.13	1.309E-06	39.05	1.0000	1.0223	0.0007
3	0.0054	4138.8	0.07	0.21	31.24	31.45	1.307E-06	38.98	1.0000	1.0216	0.0000
4	0.0062	4637.6	0.40	1.15	39.32	40.47	1.309E-06	39.06	1.0000	1.0224	0.0008
5	0.0069	5123.8	0.95	2.73	47.96	50.69	1.308E-06	39.04	1.0000	1.0222	0.0006
6	0.0077	5593.9	1.53	4.42	57.25	61.67	1.309E-06	39.08	1.0000	1.0226	0.0010
7	0.0084	6045.8	2.35	6.78	66.91	73.70	1.310E-06	39.10	1.0000	1.0228	0.0012
8	0.0091	6473.5	3.32	9.56	76.88	86.44	1.312E-06	39.17	1.0000	1.0235	0.0019
9	0.0099	6888.0	4.63	13.34	87.08	100.42	1.312E-06	39.18	1.0000	1.0236	0.0020
10	0.0106	7288.4	6.38	18.41	97.27	115.68	1.310E-06	39.11	1.0000	1.0229	0.0013
11	0.0114	7671.0	8.30	23.95	107.85	131.80	1.310E-06	39.14	1.0000	1.0232	0.0016
12	0.0122	8045.4	10.55	30.43	118.81	149.25	1.312E-06	39.19	1.0000	1.0237	0.0020
13	0.0130	8392.0	13.34	38.47	129.38	167.84	1.313E-06	39.21	1.0000	1.0239	0.0023
14	0.0138	8703.7	16.66	48.01	139.44	187.44	1.314E-06	39.27	1.0000	1.0245	0.0029
15	0.0146	8989.4	20.66	59.54	148.86	208.40	1.315E-06	39.30	1.0000	1.0248	0.0032
16	0.0155	9249.9	25.12	72.34	158.08	230.42	1.318E-06	39.39	1.0000	1.0257	0.0041
17	0.0164	9484.9	30.62	88.26	166.22	254.48	1.318E-06	39.39	1.0000	1.0257	0.0041
18	0.0173	9704.2	36.72	105.90	174.03	279.93	1.318E-06	39.40	1.0000	1.0258	0.0042
19	0.0183	9897.7	43.33	124.92	181.36	306.29	1.319E-06	39.46	1.0000	1.0264	0.0048
20	0.0192	10079.5	49.84	143.58	188.63	332.21	1.322E-06	39.55	1.0000	1.0273	0.0057
21	0.0202	10225.2	57.88	166.89	194.10	360.98	1.322E-06	39.54	1.0000	1.0272	0.0056
22	0.0212	10346.7	66.42	191.59	198.82	390.41	1.322E-06	39.56	1.0000	1.0274	0.0058
23	0.0222	10459.7	74.93	215.99	203.73	419.72	1.325E-06	39.64	1.0000	1.0282	0.0066
24	0.0232	10559.2	84.53	244.08	207.14	451.22	1.322E-06	39.57	0.9999	1.0275	0.0059
25	0.0242	10640.6	93.93	270.76	211.31	482.07	1.327E-06	39.72	0.9999	1.0289	0.0073
26	0.0254	10678.0	105.27	303.44	213.17	516.61	1.328E-06	39.77	1.0000	1.0295	0.0079
27	0.0264	10759.4	115.22	332.23	216.58	548.81	1.329E-06	39.79	1.0000	1.0297	0.0081

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J vs. a Graph

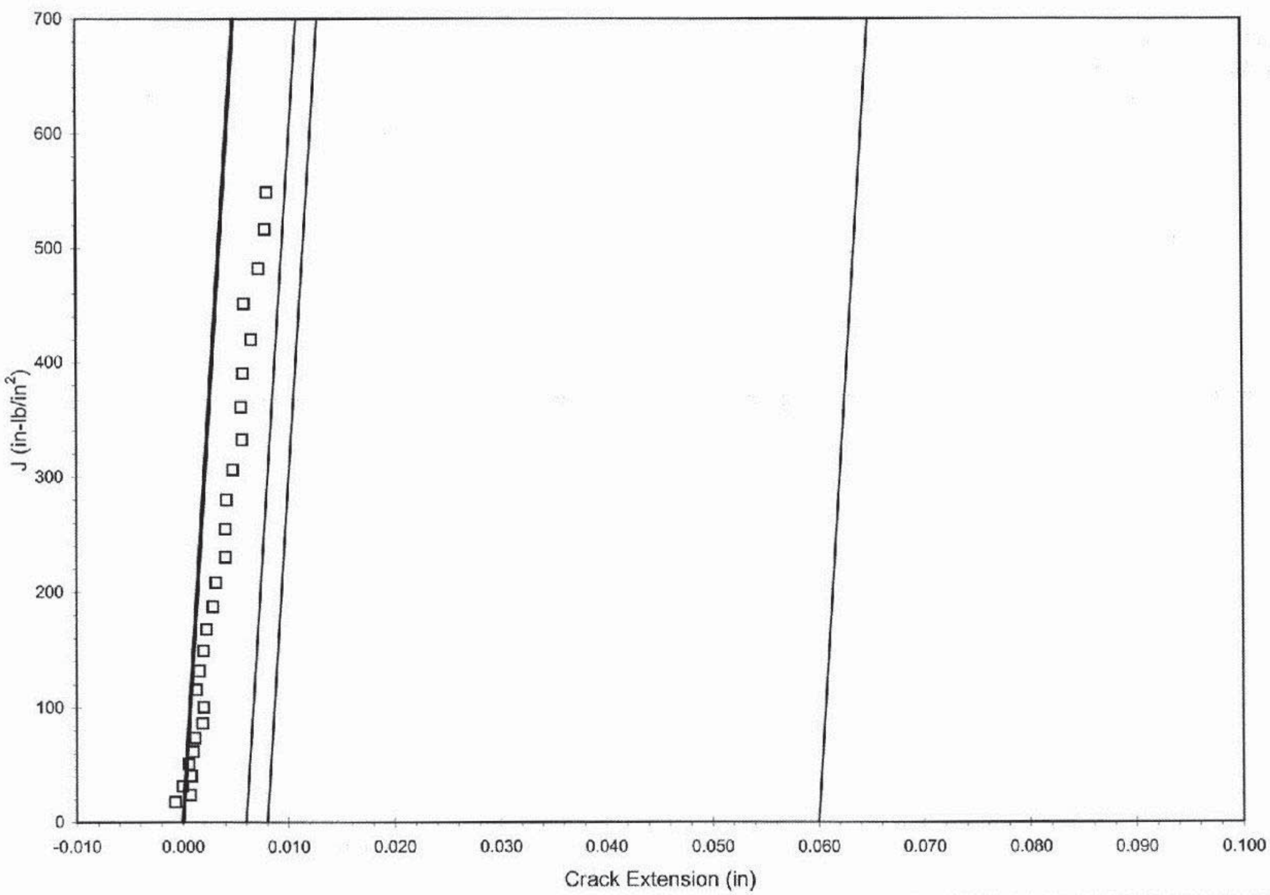
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05261
TEST DATE : 7/17/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-B-4

$J_c = 577.18$ in-lb/in^2



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Force vs. COD Graph

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

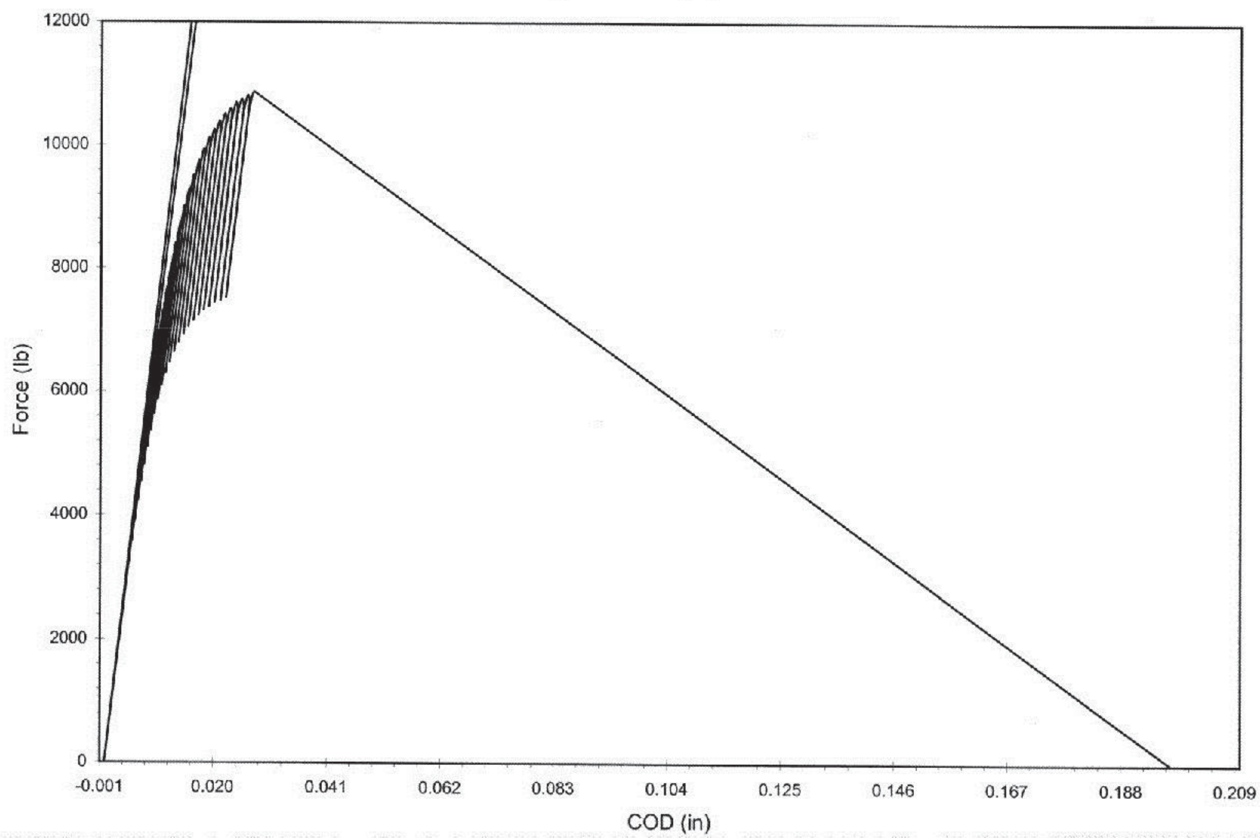
TESTLOG : T05261
TEST DATE : 7/17/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-B-4

P_{max} = 10886.2 lb

P_Q = 5569.3 lb

K_Q = 44.0 ksi(in)$^{1/2}$



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KC-H-H-1

A-225 Gr. B HAZ

J_{IC} FRACTURE TOUGHNESS

T-L

RT

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J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SID : KC-H-H-1
TESTLOG : T05262
TEST DATE : 7/12/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.59 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.2 ksi
EFFECTIVE YIELD STRENGTH : 65.8 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.748 in	TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
NET THICKNESS (B_N)	: 0.580 in	TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
EFFECTIVE THICKNESS (B_e)	: 0.710 in	ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
WIDTH (W)	: 1.499 in	TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.001 in
UNCRACKED LIGAMENT (b_o)	: 0.736 in	CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
NOTCH LENGTH (a_n)	: 0.692 in	CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

TEST PARAMETERS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.750 in	0.759 in	0.761 in	0.762 in	0.763 in	0.766 in	0.766 in	0.768 in	0.764 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.878 in	0.806 in	0.832 in	0.834 in	0.843 in	0.847 in	0.822 in	0.839 in	0.877 in

PRECRACK AVERAGE	: 0.7627 in	FINAL AVERAGE	: 0.8376 in
PRECRACK a/W	: 0.5088	FINAL a/W	: 0.5587

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1381 lb	FINAL P_{max}	: 1231 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 180801	FINAL K_{max}	: 13.34 ksi(in)$^{1/2}$		

ORIGINAL CRACK		FINAL CRACK		MODULUS	
PHYSICAL CRACK SIZE (a_o)	: 0.7627 in	PHYSICAL CRACK SIZE (a_p)	: 0.8376 in	MODULUS	: 31.59 Msi
EST. CRACK SIZE (a_{oq})	: 0.7627 in	EST. CRACK SIZE ($a_{predicted}$)	: 0.8375 in	EFFECTIVE MODULUS	: 31.59 Msi
PERCENT DIFFERENCE	: 0.00 %	PERCENT DIFFERENCE	: 0.01 %	PERCENT DIFFERENCE	: 0.01 %

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE FATIGUE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   a/W = 0.5088
2. (9.1.5.2) DIFFERENCE BETWEEN PREDICTED ($\Delta a_{predicted}$) AND MEASURED (Δa_p) CRACK EXTENSION SHALL NOT EXCEED 0.15 Δa_p FOR CRACK EXTENSIONS LESS THAN 0.2 b_o AND 0.03 b_o THEREAFTER — VALID
   Difference = 0.0000 in $0.15\Delta a_p$ = 0.0112 in
3. (A9.7.2.1) a_{oq} SHALL NOT DIFFER FROM a_o BY MORE THAN THE LARGER OF 0.01 W OR 0.0197 IN. — VALID
   Difference = 0.0000 in Limit = 0.0197 in
4. (A9.7.2.2) NUMBER OF DATA AVAILABLE TO CALCULATE a_{oq} SHALL BE ≥ 8; NUMBER OF DATA BETWEEN $0.4J_Q$ AND J_Q SHALL BE ≥ 3; CORRELATION COEFFICIENT OF THE LEAST SQUARES FIT SHALL BE > 0.96 — VALID
   a_{oq} Points = 67 Data Points = 22 C.C. = 0.99770
5. (A9.7.1) POWER COEFFICIENT C_2 SHALL BE LESS THAN 1.0 — VALID
   C_2 = 0.6847
6. (A9.8.1) THICKNESS, $B > 10J_Q/\sigma_Y$ — VALID
   B = 0.7480 in $10J_Q/\sigma_Y$ = 0.2580 in
7. (A9.8.2) INITIAL LIGAMENT, $b_o > 10J_Q/\sigma_Y$ — VALID
   b_o = 0.7363 in $10J_Q/\sigma_Y$ = 0.2580 in
8. (A9.6.6.6) AT LEAST FIVE DATA POINTS MUST REMAIN BETWEEN a_{min} AND a_{limit} AND J_{limit} — VALID
   Data Points = 56
9. (A9.6.4) AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.006-in EXCLUSION LINE AND A 0.02-in OFFSET LINE. AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.02-in OFFSET LINE AND THE 0.06-in EXCLUSION LINE. — VALID

TEST IS INVALID: J_Q = 1696.63 in-lb/in^2

K_{JQ} = 242.69 ksi(in)$^{1/2}$

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GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 31.59 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 79.3 ksi
SID : KC-H-H-1	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 52.2 ksi
TESTLOG : T05262		EFFECTIVE YIELD STRENGTH : 65.8 ksi
TEST DATE : 7/12/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.748 in	WIDTH (W)	: 1.499 in
NET THICKNESS (B_N)	: 0.580 in	UNCRACKED LIGAMENT (b_o)	: 0.736 in
EFFECTIVE THICKNESS (B_e)	: 0.710 in	NOTCH LENGTH (a_n)	: 0.692 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.001 in
CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.750 in	0.759 in	0.761 in	0.762 in	0.763 in	0.766 in	0.766 in	0.768 in	0.764 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.878 in	0.806 in	0.832 in	0.834 in	0.843 in	0.847 in	0.822 in	0.839 in	0.877 in

PRECRACK AVERAGE	: 0.7627 in	FINAL AVERAGE	: 0.8376 in
PRECRACK a/W	: 0.5088	FINAL a/W	: 0.5587

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1381 lb	FINAL P_{max}	: 1231 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 180801	FINAL K_{max}	: 13.34 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 7051.0 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0708 in $0.05B$ = 0.0374 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING, THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^f / \sigma_{YS}^T)(0.4\sigma_{YS}^f\ ksi\sqrt{in})$, WHERE σ_{YS}^f AND σ_{YS}^T ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ K_{max} Limit = 20.9 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^f / \sigma_{YS}^T) * K_F$ WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.3 ksi(in)$^{1/2}$ K_{max} Limit = 145.6 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0128 in $0.05B$ = 0.0374 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — INVALID

   Maximum Difference = 0.0404 in $0.05B$ = 0.0374 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0470 in 50% of the Average = 0.0374 in

ALL GENERAL VALIDITY CHECKS ARE NOT VALID

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SID : KC-H-H-1
TESTLOG : T05262
TEST DATE : 7/12/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.59 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.2 ksi
EFFECTIVE YIELD STRENGTH : 65.8 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.748 in
NET THICKNESS (B_N)	: 0.580 in
EFFECTIVE THICKNESS (B_e)	: 0.710 in
WIDTH (W)	: 1.499 in
UNCRACKED LIGAMENT (b_o)	: 0.736 in
NOTCH LENGTH (a_n)	: 0.692 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.001 in
CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.750 in	0.759 in	0.761 in	0.762 in	0.763 in	0.766 in	0.766 in	0.768 in	0.764 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.878 in	0.806 in	0.832 in	0.834 in	0.843 in	0.847 in	0.822 in	0.839 in	0.877 in

PRECRACK AVERAGE	: 0.7627 in	FINAL AVERAGE	: 0.8376 in
PRECRACK a/W	: 0.5088	FINAL a/W	: 0.5587

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1381 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 1231 lb	CYCLES	: 180801
FINAL K_{max}	: 13.34 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 3460.1 lb	MAXIMUM FORCE (P_{max})	: 7051.0 lb
K_Q	: 42.6 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 3.23

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   a/W = 0.5088
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE $\leq$ 1.10 — INVALID
   $P_{max}/P_Q = 2.0378$
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2 = 1.6648$ in $b_o = 0.7363$ in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{\,l} / \sigma_{YS}^{\,T}) * K_F$, WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 13.3 ksi(in)$^{1/2}$ K_{max} Limit = 25.6 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 42.6 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SID : KC-H-H-1 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05262
P.O. NO. : F58154BT TEST DATE : 7/12/2013 TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 0.7627 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7627 in
MODULUS (E) : 31.59 Msi

WIDTH (W) : 1.499 in
TOTAL THICKNESS (B) : 0.748 in
NET THICKNESS (B_N) : 0.580 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0092	4421.1	3.67	10.66	84.61	95.27	1.707E-06	38.38	0.9998	0.7607	-0.0020
2	0.0103	4704.2	6.30	24.49	96.29	120.77	1.714E-06	38.54	0.9998	0.7619	-0.0008
3	0.0114	4941.4	9.76	42.78	106.19	148.97	1.712E-06	38.53	0.9999	0.7618	-0.0009
4	0.0125	5140.1	13.53	62.66	115.01	177.66	1.713E-06	38.56	0.9999	0.7620	-0.0007
5	0.0137	5309.3	17.84	85.16	123.47	208.63	1.721E-06	38.75	0.9999	0.7635	0.0008
6	0.0149	5443.3	22.79	111.26	129.94	241.20	1.723E-06	38.79	0.9998	0.7638	0.0011
7	0.0161	5567.3	28.29	140.31	136.00	276.31	1.723E-06	38.81	0.9999	0.7639	0.0012
8	0.0173	5662.6	33.78	168.82	141.72	310.54	1.733E-06	39.03	0.9998	0.7657	0.0029
9	0.0186	5748.3	40.09	202.03	146.46	348.48	1.736E-06	39.12	0.9998	0.7664	0.0036
10	0.0198	5817.9	46.39	235.19	150.47	385.66	1.740E-06	39.21	0.9998	0.7670	0.0043
11	0.0211	5884.6	53.30	271.55	154.36	425.91	1.743E-06	39.30	0.9996	0.7677	0.0050
12	0.0224	5936.9	60.35	308.73	157.44	466.17	1.745E-06	39.37	0.9996	0.7682	0.0055
13	0.0237	5991.8	67.31	345.63	160.50	506.14	1.746E-06	39.39	0.9996	0.7684	0.0057
14	0.0250	6044.0	74.72	384.85	163.52	548.36	1.747E-06	39.43	0.9997	0.7687	0.0060
15	0.0263	6086.1	81.99	423.24	166.04	589.28	1.749E-06	39.48	0.9997	0.7690	0.0063
16	0.0276	6133.5	89.53	462.68	169.22	631.90	1.753E-06	39.59	0.9995	0.7699	0.0071
17	0.0290	6173.3	97.11	502.74	171.70	674.45	1.755E-06	39.64	0.9996	0.7702	0.0075
18	0.0303	6204.6	104.73	543.22	173.53	716.75	1.755E-06	39.65	0.9996	0.7703	0.0076
19	0.0316	6249.1	112.47	583.62	176.63	760.25	1.759E-06	39.76	0.9997	0.7712	0.0084
20	0.0329	6283.8	119.78	620.54	179.95	800.49	1.769E-06	40.01	0.9997	0.7729	0.0102
21	0.0342	6312.9	127.64	663.86	180.84	844.70	1.762E-06	39.87	0.9997	0.7719	0.0092
22	0.0355	6347.8	135.54	705.07	183.43	888.50	1.766E-06	39.97	0.9996	0.7727	0.0099
23	0.0368	6376.0	143.35	745.00	186.10	931.10	1.774E-06	40.15	0.9996	0.7740	0.0113
24	0.0382	6414.6	151.60	789.43	188.24	977.66	1.772E-06	40.13	0.9996	0.7738	0.0111
25	0.0394	6436.2	158.94	827.01	190.40	1017.41	1.778E-06	40.28	0.9995	0.7749	0.0122
26	0.0408	6470.5	167.07	869.12	193.17	1062.29	1.783E-06	40.40	0.9997	0.7758	0.0131
27	0.0421	6495.6	175.31	912.09	195.30	1107.39	1.787E-06	40.51	0.9994	0.7766	0.0139
28	0.0435	6522.3	183.87	957.89	197.00	1154.89	1.787E-06	40.52	0.9995	0.7767	0.0140
29	0.0448	6548.4	192.38	1003.55	198.60	1202.15	1.787E-06	40.52	0.9994	0.7767	0.0140
30	0.0461	6573.5	200.61	1046.93	200.50	1247.44	1.789E-06	40.58	0.9994	0.7772	0.0144
31	0.0475	6600.2	209.12	1090.67	202.96	1293.64	1.794E-06	40.72	0.9995	0.7781	0.0154
32	0.0489	6620.5	217.79	1136.66	204.52	1341.17	1.796E-06	40.77	0.9995	0.7785	0.0157

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SID : KC-H-H-1
WMT&R NO. : 3-67089 TESTLOG : T05262
P.O. NO. : F58154BT TEST DATE : 7/12/2013

MATERIAL : Steel
TEMPERATURE : 75°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.7627 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7627 in
MODULUS (E) : 31.59 Msi

WIDTH (W) : 1.499 in
TOTAL THICKNESS (B) : 0.748 in
NET THICKNESS (B_N) : 0.580 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
33	0.0502	6639.8	225.98	1177.96	206.80	1384.77	1.803E-06	40.94	0.9994	0.7797	0.0170
34	0.0516	6663.4	234.62	1224.51	208.30	1432.82	1.802E-06	40.94	0.9996	0.7797	0.0170
35	0.0529	6684.2	242.98	1265.75	211.05	1476.80	1.812E-06	41.17	0.9994	0.7813	0.0186
36	0.0543	6703.9	251.74	1313.32	212.22	1525.54	1.811E-06	41.16	0.9995	0.7813	0.0185
37	0.0556	6721.9	260.58	1360.47	213.59	1574.06	1.812E-06	41.19	0.9994	0.7815	0.0188
38	0.0569	6740.8	268.86	1401.46	216.09	1617.55	1.820E-06	41.39	0.9993	0.7829	0.0202
39	0.0584	6757.5	278.13	1450.95	217.40	1668.35	1.821E-06	41.43	0.9994	0.7832	0.0204
40	0.0597	6775.9	286.75	1493.23	220.05	1713.28	1.830E-06	41.65	0.9995	0.7847	0.0220
41	0.0611	6790.5	295.92	1543.00	221.01	1764.01	1.829E-06	41.65	0.9994	0.7847	0.0220
42	0.0624	6805.1	304.66	1588.81	222.47	1811.28	1.832E-06	41.72	0.9993	0.7852	0.0225
43	0.0639	6817.4	313.67	1632.79	224.82	1857.61	1.841E-06	41.96	0.9995	0.7868	0.0241
44	0.0652	6829.6	323.05	1684.41	225.46	1909.87	1.840E-06	41.93	0.9993	0.7867	0.0239
45	0.0666	6842.5	332.11	1729.74	227.49	1957.23	1.847E-06	42.10	0.9994	0.7879	0.0251
46	0.0680	6848.2	341.03	1775.29	228.74	2004.04	1.852E-06	42.23	0.9995	0.7887	0.0260
47	0.0694	6860.7	349.77	1818.53	230.86	2049.39	1.859E-06	42.42	0.9991	0.7900	0.0273
48	0.0707	6861.2	358.94	1865.13	231.87	2097.00	1.865E-06	42.56	0.9993	0.7910	0.0283
49	0.0721	6868.8	368.23	1915.89	232.41	2148.30	1.864E-06	42.56	0.9991	0.7910	0.0283
50	0.0734	6874.2	376.60	1954.99	234.59	2189.58	1.875E-06	42.83	0.9992	0.7928	0.0301
51	0.0748	6882.9	385.31	1996.98	236.74	2233.72	1.884E-06	43.05	0.9993	0.7943	0.0316
52	0.0761	6892.1	394.58	2048.30	237.26	2285.56	1.883E-06	43.03	0.9994	0.7942	0.0315
53	0.0774	6897.3	402.89	2090.73	238.46	2329.19	1.888E-06	43.15	0.9994	0.7950	0.0323
54	0.0788	6908.2	411.82	2134.11	240.66	2374.78	1.896E-06	43.36	0.9994	0.7964	0.0337
55	0.0800	6911.7	420.28	2175.91	242.13	2418.04	1.903E-06	43.54	0.9993	0.7975	0.0348
56	0.0813	6921.5	429.04	2223.73	242.93	2466.66	1.903E-06	43.55	0.9993	0.7976	0.0349
57	0.0827	6927.9	437.80	2263.32	245.53	2508.84	1.916E-06	43.86	0.9994	0.7996	0.0369
58	0.0840	6931.8	446.74	2311.57	246.10	2557.67	1.917E-06	43.90	0.9992	0.7999	0.0372
59	0.0854	6945.2	455.82	2358.32	247.88	2606.20	1.921E-06	44.01	0.9994	0.8007	0.0379
60	0.0867	6948.1	465.04	2407.22	248.60	2655.82	1.924E-06	44.08	0.9993	0.8011	0.0384
61	0.0881	6948.8	474.20	2454.77	249.39	2704.16	1.928E-06	44.19	0.9992	0.8018	0.0391
62	0.0894	6955.0	483.04	2497.02	251.38	2748.40	1.936E-06	44.40	0.9993	0.8032	0.0405
63	0.0908	6959.3	492.22	2548.89	251.50	2800.39	1.935E-06	44.38	0.9994	0.8030	0.0403
64	0.0921	6962.8	500.93	2586.75	254.10	2840.85	1.948E-06	44.70	0.9993	0.8051	0.0424

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SID : KC-H-H-1 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05262
P.O. NO. : F58154BT TEST DATE : 7/12/2013 TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 0.7627 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7627 in
MODULUS (E) : 31.59 Msi

WIDTH (W) : 1.499 in
TOTAL THICKNESS (B) : 0.748 in
NET THICKNESS (B_N) : 0.580 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
65	0.0935	6963.3	510.20	2637.37	254.36	2891.72	1.949E-06	44.73	0.9993	0.8053	0.0426
66	0.0948	6964.2	519.47	2688.92	254.45	2943.38	1.948E-06	44.74	0.9993	0.8053	0.0426
67	0.0961	6958.0	528.24	2729.96	255.67	2985.62	1.958E-06	44.97	0.9992	0.8068	0.0441
68	0.0973	6969.8	536.32	2769.49	257.71	3027.20	1.964E-06	45.13	0.9992	0.8078	0.0451
69	0.0987	6948.9	545.61	2810.77	258.40	3069.17	1.977E-06	45.44	0.9992	0.8097	0.0470
70	0.1001	6936.2	554.96	2857.57	258.60	3116.18	1.983E-06	45.60	0.9991	0.8107	0.0480
71	0.1014	6924.5	563.44	2897.05	259.39	3156.44	1.992E-06	45.83	0.9993	0.8122	0.0494
72	0.1027	6914.0	572.06	2933.78	260.97	3194.75	2.006E-06	46.15	0.9992	0.8142	0.0515
73	0.1041	6903.2	580.97	2974.75	262.03	3236.78	2.017E-06	46.41	0.9991	0.8158	0.0530
74	0.1054	6884.2	589.98	3020.87	261.53	3282.39	2.022E-06	46.54	0.9993	0.8166	0.0538
75	0.1067	6867.4	599.17	3064.32	261.92	3326.24	2.031E-06	46.78	0.9991	0.8180	0.0552
76	0.1081	6857.8	608.26	3106.10	263.07	3369.17	2.042E-06	47.04	0.9992	0.8195	0.0568
77	0.1095	6844.2	617.41	3148.48	263.86	3412.34	2.052E-06	47.30	0.9993	0.8211	0.0583
78	0.1108	6832.5	626.24	3188.83	264.83	3453.66	2.063E-06	47.56	0.9992	0.8226	0.0599
79	0.1121	6812.7	634.76	3227.31	265.20	3492.50	2.074E-06	47.83	0.9990	0.8242	0.0615
80	0.1135	6804.1	643.41	3267.76	266.20	3533.96	2.084E-06	48.06	0.9992	0.8256	0.0628
81	0.1148	6815.0	651.62	3306.95	268.51	3575.46	2.092E-06	48.26	0.9991	0.8267	0.0640
82	0.1162	6778.1	661.15	3350.67	267.62	3618.28	2.103E-06	48.55	0.9991	0.8284	0.0656
83	0.1175	6761.6	670.20	3393.23	268.02	3661.25	2.113E-06	48.79	0.9991	0.8298	0.0670
84	0.1189	6740.6	679.65	3443.83	267.03	3710.86	2.116E-06	48.88	0.9992	0.8303	0.0676
85	0.1202	6720.4	687.62	3474.31	268.17	3742.48	2.133E-06	49.27	0.9991	0.8325	0.0698
86	0.1215	6704.5	696.21	3513.77	268.68	3782.45	2.143E-06	49.53	0.9991	0.8339	0.0712
87	0.1228	6707.8	703.94	3544.84	271.36	3816.20	2.157E-06	49.87	0.9992	0.8358	0.0731
88	0.1242	6665.8	713.47	3588.02	270.08	3858.10	2.169E-06	50.17	0.9992	0.8375	0.0748

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

Phone (724) 537-3131

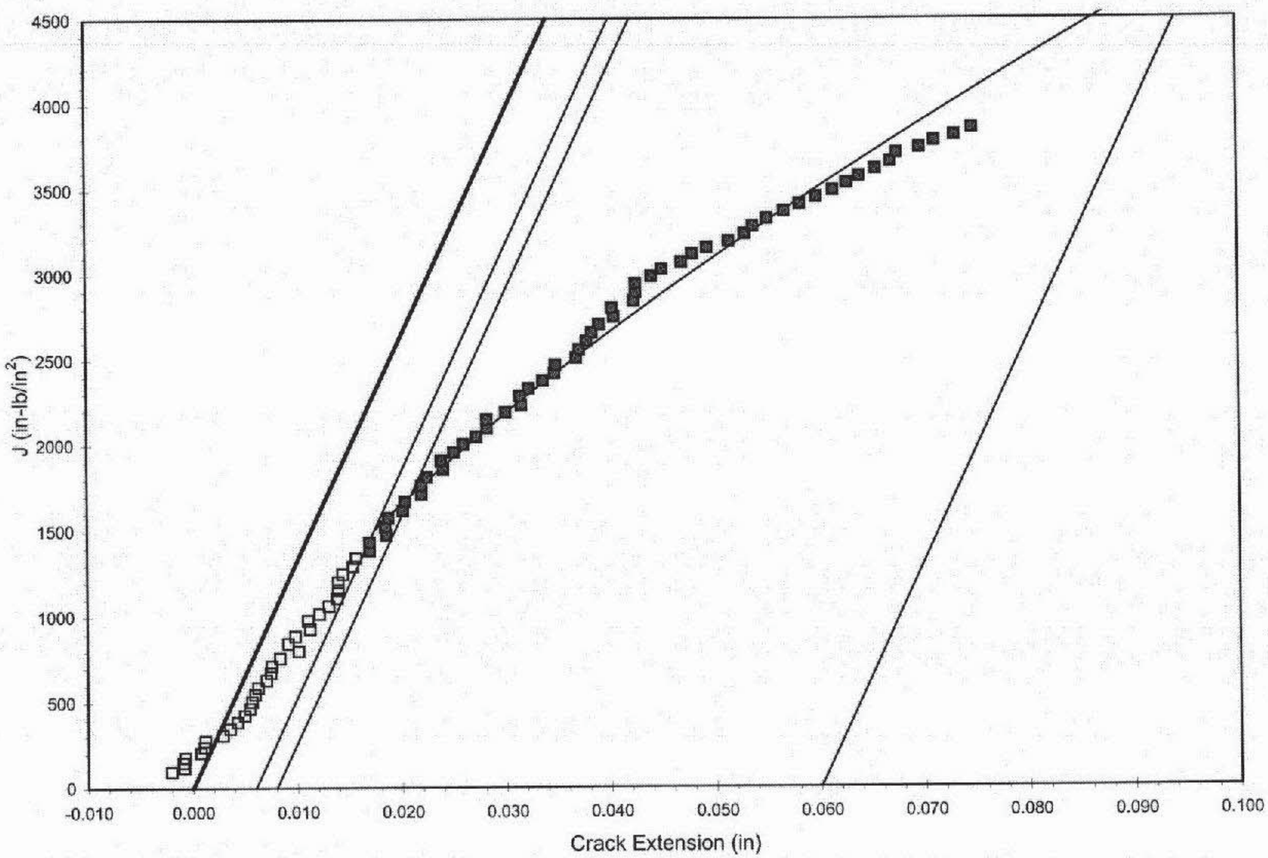
CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05262
TEST DATE : 7/12/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SID : KC-H-H-1

$J_Q = 1696.63$ in-lb/in^2

$J = 2629.9\,(a / 0.0394)^{0.6847}$



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Westmoreland Mechanical Testing & Research, Inc.

Force vs. COD Graph

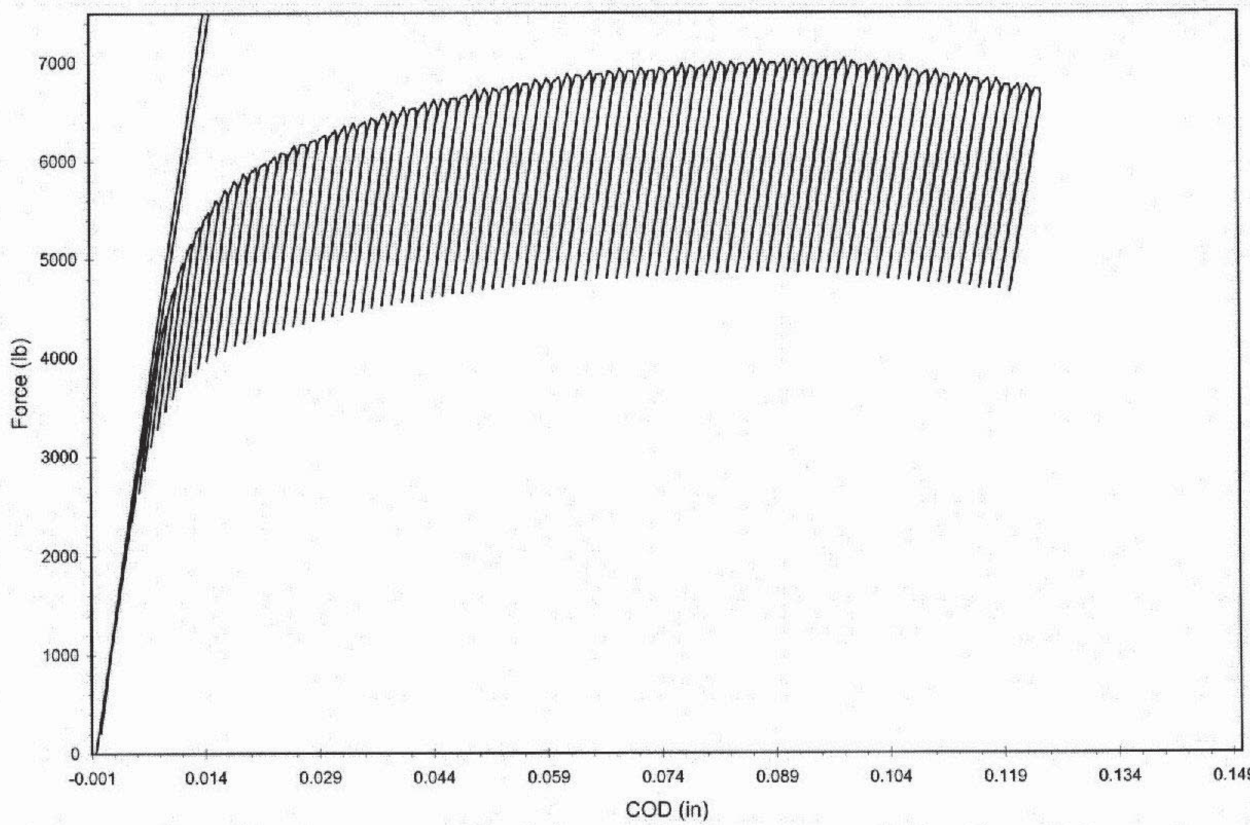
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05262
TEST DATE : 7/12/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SID : KC-H-H-1

P_{max} = 7051.0 lb
P_Q = 3460.1 lb
K_Q = 42.6 ksi(in)$^{1/2}$



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KC-H-H-2

A-225 Gr. B HAZ

J_{IC} FRACTURE TOUGHNESS

T-L

RT

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 30.96 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 79.3 ksi
SID : KC-H-H-2	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 52.2 ksi
TESTLOG : T05263		EFFECTIVE YIELD STRENGTH : 65.8 ksi
TEST DATE : 7/12/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS / TEST PARAMETERS

TOTAL THICKNESS (B)	: 0.752 in	TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
NET THICKNESS (B_N)	: 0.572 in	TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
EFFECTIVE THICKNESS (B_e)	: 0.709 in	ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
WIDTH (W)	: 1.501 in	TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.0015 in
UNCRACKED LIGAMENT (b_o)	: 0.732 in	CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
NOTCH LENGTH (a_n)	: 0.691 in	CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.744 in	0.758 in	0.768 in	0.773 in	0.776 in	0.778 in	0.775 in	0.775 in	0.762 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.837 in	0.821 in	0.836 in	0.842 in	0.858 in	0.845 in	0.839 in	0.837 in	0.859 in

PRECRACK AVERAGE	: 0.7695 in	FINAL AVERAGE	: 0.8407 in
PRECRACK a/W	: 0.5127	FINAL a/W	: 0.5601

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1394 lb	FINAL P_{max}	: 1217 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 192300	FINAL K_{max}	: 13.27 ksi(in)$^{1/2}$		

ORIGINAL CRACK / FINAL CRACK / MODULUS

PHYSICAL CRACK SIZE (a_o)	: 0.7695 in	PHYSICAL CRACK SIZE (a_p)	: 0.8407 in	MODULUS	: 30.96 Msi
EST. CRACK SIZE (a_{oq})	: 0.7695 in	EST. CRACK SIZE ($a_{predicted}$)	: 0.8487 in	EFFECTIVE MODULUS	: 30.96 Msi
PERCENT DIFFERENCE	: 0.00 %	PERCENT DIFFERENCE	: 0.95 %	PERCENT DIFFERENCE	: 0.01 %

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE FATIGUE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   a/W = 0.5127
2. (9.1.5.2) DIFFERENCE BETWEEN PREDICTED ($\Delta a_{predicted}$) AND MEASURED (Δa_p) CRACK EXTENSION SHALL NOT EXCEED 0.15 Δa_p FOR CRACK EXTENSIONS LESS THAN 0.2 b_o AND 0.03 b_o THEREAFTER — VALID
   Difference = 0.0080 in $0.15\Delta a_p$ = 0.0107 in
3. (A9.7.2.1) a_{oq} SHALL NOT DIFFER FROM a_o BY MORE THAN THE LARGER OF 0.01 W OR 0.0197 IN. — VALID
   Difference = 0.0000 in Limit = 0.0197 in
4. (A9.7.2.2) NUMBER OF DATA AVAILABLE TO CALCULATE a_{oq} SHALL BE ≥ 8; NUMBER OF DATA BETWEEN $0.4J_Q$ AND J_Q SHALL BE ≥ 3; CORRELATION COEFFICIENT OF THE LEAST SQUARES FIT SHALL BE > 0.96 — VALID
   a_{oq} Points = 42 Data Points = 12 C.C. = 0.99433
5. (A9.7.1) POWER COEFFICIENT C_2 SHALL BE LESS THAN 1.0 — VALID
   C_2 = 0.8059
6. (A9.8.1) THICKNESS, $B > 10J_Q/\sigma_Y$ — VALID
   B = 0.7520 in $10J_Q/\sigma_Y$ = 0.1727 in
7. (A9.8.2) INITIAL LIGAMENT, $b_o > 10J_Q/\sigma_Y$ — VALID
   b_o = 0.7315 in $10J_Q/\sigma_Y$ = 0.1727 in
8. (A9.6.6.6) AT LEAST FIVE DATA POINTS MUST REMAIN BETWEEN a_{min} AND a_{limit} AND J_{limit} — VALID
   Data Points = 47
9. (A9.6.4) AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.006-in EXCLUSION LINE AND A 0.02-in OFFSET LINE. AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.02-in OFFSET LINE AND THE 0.06-in EXCLUSION LINE. — VALID

TEST IS VALID: J_{Ic} = 1135.56 in-lb/in^2

K_{JIc} = 196.56 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 30.96 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 79.3 ksi
SID : KC-H-H-2	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 52.2 ksi
TESTLOG : T05263		EFFECTIVE YIELD STRENGTH : 65.8 ksi
TEST DATE : 7/12/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.752 in	WIDTH (W)	: 1.501 in
NET THICKNESS (B_N)	: 0.572 in	UNCRACKED LIGAMENT (b_o)	: 0.732 in
EFFECTIVE THICKNESS (B_e)	: 0.709 in	NOTCH LENGTH (a_n)	: 0.691 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.0015 in
CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.744 in	0.758 in	0.768 in	0.773 in	0.776 in	0.778 in	0.775 in	0.775 in	0.762 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.837 in	0.821 in	0.836 in	0.842 in	0.858 in	0.845 in	0.839 in	0.837 in	0.859 in

PRECRACK AVERAGE	: 0.7695 in	FINAL AVERAGE	: 0.8407 in
PRECRACK a/W	: 0.5127	FINAL a/W	: 0.5601

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1394 lb	FINAL P_{max}	: 1217 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 192300	FINAL K_{max}	: 13.27 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 6757.9 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0785 in $0.05B$ = 0.0376 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING, THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}{}^{f} / \sigma_{YS}{}^{T})(0.4\sigma_{YS}{}^{f}\ ksi\sqrt{in})$, WHERE $\sigma_{YS}{}^{f}$ AND $\sigma_{YS}{}^{T}$ ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ K_{max} Limit = 20.9 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}{}^{f} / \sigma_{YS}{}^{T}) * K_F$, WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.3 ksi(in)$^{1/2}$ K_{max} Limit = 117.9 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0255 in $0.05B$ = 0.0376 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0198 in $0.05B$ = 0.0376 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0620 in 50% of the Average = 0.0356 in

ALL GENERAL VALIDITY CHECKS ARE VALID

GERALD W. BOICE - THOMAS S. FEDOR

"NOTE: THE RECORDING OF FALSE, FICTITIOUS, OR FRAUDULENT STATEMENTS OR ENTRIES ON THIS DOCUMENT MAY BE PUNISHABLE AS A FELONY UNDER FEDERAL STATUTE."

WESTMORELAND MECHANICAL TESTING & RESEARCH

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Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SID : KC-II-II-2
TESTLOG : T05263
TEST DATE : 7/12/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 30.96 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.2 ksi
EFFECTIVE YIELD STRENGTH : 65.8 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.752 in
NET THICKNESS (B_N)	: 0.572 in
EFFECTIVE THICKNESS (B_e)	: 0.709 in
WIDTH (W)	: 1.501 in
UNCRACKED LIGAMENT (b_o)	: 0.732 in
NOTCH LENGTH (a_n)	: 0.691 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.0015 in
CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.744 in	0.758 in	0.768 in	0.773 in	0.776 in	0.778 in	0.775 in	0.775 in	0.762 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.837 in	0.821 in	0.836 in	0.842 in	0.858 in	0.845 in	0.839 in	0.837 in	0.859 in

PRECRACK AVERAGE	: 0.7695 in	FINAL AVERAGE	: 0.8407 in
PRECRACK a/W	: 0.5127	FINAL a/W	: 0.5601

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1394 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 1217 lb	CYCLES	: 192300
FINAL K_{max}	: 13.27 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 3288.5 lb	MAXIMUM FORCE (P_{max})	: 6757.9 lb
K_Q	: 41.1 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 3.19

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   $a/W = 0.5127$
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   $P_{max}/P_Q = 2.0550$
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2 = 1.5515$ in $b_o = 0.7315$ in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{J} / \sigma_{YS}^{T}) * K_F$, WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 13.3 ksi(in)$^{1/2}$ K_{max} Limit = 24.7 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 41.1 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SID : KC-H-H-2 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05263
P.O. NO. : F58154BT TEST DATE : 7/12/2013 TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 0.7695 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7695 in
MODULUS (E) : 30.96 Msi

WIDTH (W) : 1.501 in
TOTAL THICKNESS (B) : 0.752 in
NET THICKNESS (B_N) : 0.572 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0043	2393.4	0.10	0.29	25.98	26.27	1.774E-06	38.99	0.9998	0.7663	-0.0032
2	0.0058	3032.1	1.01	5.19	41.74	46.93	1.775E-06	39.02	0.9998	0.7666	-0.0029
3	0.0089	4090.5	5.25	27.87	76.36	104.23	1.781E-06	39.18	0.9997	0.7678	-0.0017
4	0.0105	4491.8	8.95	47.67	92.47	140.14	1.787E-06	39.31	0.9999	0.7688	-0.0007
5	0.0122	4806.0	13.73	73.18	106.55	179.74	1.796E-06	39.52	0.9999	0.7704	0.0008
6	0.0138	5041.9	19.36	103.15	118.30	221.45	1.807E-06	39.80	0.9998	0.7724	0.0029
7	0.0154	5237.8	26.11	139.73	127.55	267.28	1.805E-06	39.77	0.9998	0.7722	0.0027
8	0.0172	5393.6	33.60	179.98	135.63	315.61	1.809E-06	39.86	0.9998	0.7729	0.0034
9	0.0189	5512.6	41.61	222.69	142.63	365.32	1.818E-06	40.07	0.9996	0.7745	0.0049
10	0.0207	5621.7	50.31	269.24	149.05	418.29	1.824E-06	40.23	0.9997	0.7756	0.0061
11	0.0225	5706.8	59.38	317.97	154.18	472.15	1.829E-06	40.35	0.9996	0.7765	0.0070
12	0.0243	5779.5	68.98	369.86	158.36	528.22	1.830E-06	40.40	0.9995	0.7768	0.0073
13	0.0261	5847.3	78.49	420.50	163.01	583.51	1.838E-06	40.58	0.9996	0.7781	0.0086
14	0.0280	5909.0	88.68	475.93	166.54	642.47	1.837E-06	40.59	0.9995	0.7782	0.0087
15	0.0298	5968.4	98.71	528.42	171.43	699.85	1.850E-06	40.88	0.9996	0.7803	0.0108
16	0.0317	6023.9	109.16	585.15	174.88	760.03	1.851E-06	40.93	0.9996	0.7807	0.0111
17	0.0336	6074.0	119.85	641.32	179.19	820.50	1.862E-06	41.18	0.9996	0.7825	0.0130
18	0.0355	6122.4	130.49	698.40	182.72	881.12	1.866E-06	41.30	0.9995	0.7833	0.0138
19	0.0373	6160.6	141.06	755.77	185.32	941.09	1.868E-06	41.36	0.9995	0.7837	0.0142
20	0.0392	6203.3	152.00	814.95	188.32	1003.26	1.870E-06	41.43	0.9996	0.7842	0.0147
21	0.0411	6245.5	163.06	874.80	191.30	1066.10	1.873E-06	41.50	0.9994	0.7847	0.0152
22	0.0429	6297.1	173.90	932.02	195.56	1127.58	1.880E-06	41.69	0.9994	0.7860	0.0165
23	0.0448	6335.3	184.86	990.16	198.90	1189.05	1.887E-06	41.85	0.9994	0.7871	0.0176
24	0.0467	6360.1	196.79	1055.29	200.69	1255.99	1.888E-06	41.89	0.9995	0.7874	0.0179
25	0.0487	6374.8	208.36	1113.47	203.90	1317.38	1.904E-06	42.26	0.9994	0.7900	0.0205
26	0.0505	6409.2	219.50	1172.25	207.23	1379.48	1.911E-06	42.44	0.9993	0.7913	0.0217
27	0.0525	6418.3	231.18	1232.81	209.37	1442.18	1.921E-06	42.70	0.9994	0.7930	0.0234
28	0.0543	6457.9	242.57	1294.50	212.51	1507.01	1.924E-06	42.78	0.9994	0.7936	0.0240
29	0.0562	6482.3	254.17	1359.27	214.00	1573.27	1.923E-06	42.76	0.9995	0.7934	0.0239
30	0.0581	6489.2	266.12	1420.39	216.24	1636.63	1.934E-06	43.05	0.9993	0.7953	0.0258
31	0.0600	6527.7	277.41	1478.85	220.27	1699.12	1.944E-06	43.27	0.9995	0.7968	0.0273
32	0.0619	6529.8	289.83	1546.41	220.95	1767.36	1.947E-06	43.36	0.9994	0.7974	0.0279

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SID : KC-H-H-2
WMT&R NO. : 3-67089 TESTLOG : T05263
P.O. NO. : F58154BT TEST DATE : 7/12/2013

MATERIAL : Steel
TEMPERATURE : 75°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.7695 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7695 in
MODULUS (E) : 30.96 Msi

WIDTH (W) : 1.501 in
TOTAL THICKNESS (B) : 0.752 in
NET THICKNESS (B_N) : 0.572 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
33	0.0637	6548.1	300.91	1603.86	223.57	1827.43	1.955E-06	43.57	0.9992	0.7988	0.0293
34	0.0656	6566.6	312.77	1669.53	225.02	1894.55	1.956E-06	43.60	0.9994	0.7990	0.0295
35	0.0674	6601.7	324.29	1729.78	228.66	1958.44	1.963E-06	43.78	0.9993	0.8002	0.0307
36	0.0693	6617.0	336.03	1793.22	230.39	2023.61	1.967E-06	43.88	0.9993	0.8009	0.0314
37	0.0711	6629.9	347.84	1856.78	232.03	2088.81	1.971E-06	43.99	0.9992	0.8016	0.0321
38	0.0731	6628.2	360.14	1918.42	233.93	2152.35	1.983E-06	44.30	0.9993	0.8036	0.0340
39	0.0749	6651.9	371.45	1977.07	236.96	2214.03	1.991E-06	44.50	0.9993	0.8049	0.0353
40	0.0767	6662.8	383.31	2041.04	238.48	2279.52	1.995E-06	44.61	0.9994	0.8056	0.0360
41	0.0786	6662.8	395.45	2102.19	240.37	2342.56	2.007E-06	44.88	0.9991	0.8073	0.0378
42	0.0805	6664.1	407.72	2168.56	241.21	2409.77	2.011E-06	44.99	0.9992	0.8080	0.0385
43	0.0824	6668.1	419.94	2228.76	243.71	2472.47	2.024E-06	45.32	0.9992	0.8101	0.0406
44	0.0843	6651.0	432.21	2290.21	244.43	2534.64	2.036E-06	45.60	0.9992	0.8119	0.0424
45	0.0862	6648.7	444.33	2352.41	245.85	2598.26	2.046E-06	45.84	0.9991	0.8133	0.0438
46	0.0881	6646.0	456.02	2408.81	248.03	2656.84	2.060E-06	46.18	0.9992	0.8155	0.0459
47	0.0900	6635.4	468.26	2470.07	249.22	2719.29	2.072E-06	46.47	0.9990	0.8172	0.0477
48	0.0919	6630.6	480.75	2535.05	250.32	2785.37	2.081E-06	46.69	0.9993	0.8185	0.0490
49	0.0938	6628.8	493.00	2598.88	251.60	2850.48	2.089E-06	46.89	0.9992	0.8198	0.0502
50	0.0957	6620.4	505.22	2660.83	252.75	2913.58	2.100E-06	47.15	0.9990	0.8213	0.0518
51	0.0976	6613.3	517.16	2720.92	254.04	2974.97	2.110E-06	47.42	0.9991	0.8229	0.0534
52	0.0995	6608.4	529.30	2783.52	255.22	3038.74	2.120E-06	47.65	0.9991	0.8242	0.0547
53	0.1014	6594.7	541.32	2841.71	256.49	3098.20	2.134E-06	47.99	0.9991	0.8262	0.0567
54	0.1033	6570.0	553.55	2898.92	257.34	3156.26	2.151E-06	48.39	0.9991	0.8286	0.0591
55	0.1051	6550.3	565.41	2959.96	257.36	3217.31	2.160E-06	48.62	0.9990	0.8299	0.0604
56	0.1070	6522.0	577.15	3010.14	258.70	3268.85	2.182E-06	49.15	0.9991	0.8329	0.0634
57	0.1089	6491.4	588.74	3060.88	259.59	3320.47	2.203E-06	49.64	0.9990	0.8357	0.0661
58	0.1108	6469.1	600.61	3119.88	259.84	3379.72	2.215E-06	49.94	0.9991	0.8373	0.0678
59	0.1126	6444.2	611.86	3169.49	260.98	3430.46	2.235E-06	50.40	0.9991	0.8399	0.0704
60	0.1144	6416.3	622.85	3216.97	261.98	3478.95	2.256E-06	50.89	0.9990	0.8426	0.0730
61	0.1163	6402.8	634.60	3270.43	263.87	3534.30	2.275E-06	51.34	0.9991	0.8450	0.0755
62	0.1181	6379.7	645.85	3326.74	263.90	3590.64	2.287E-06	51.63	0.9992	0.8465	0.0770
63	0.1200	6370.6	657.38	3380.28	265.90	3646.18	2.304E-06	52.05	0.9989	0.8487	0.0792

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J vs. a Graph

Phone (724) 537-3131

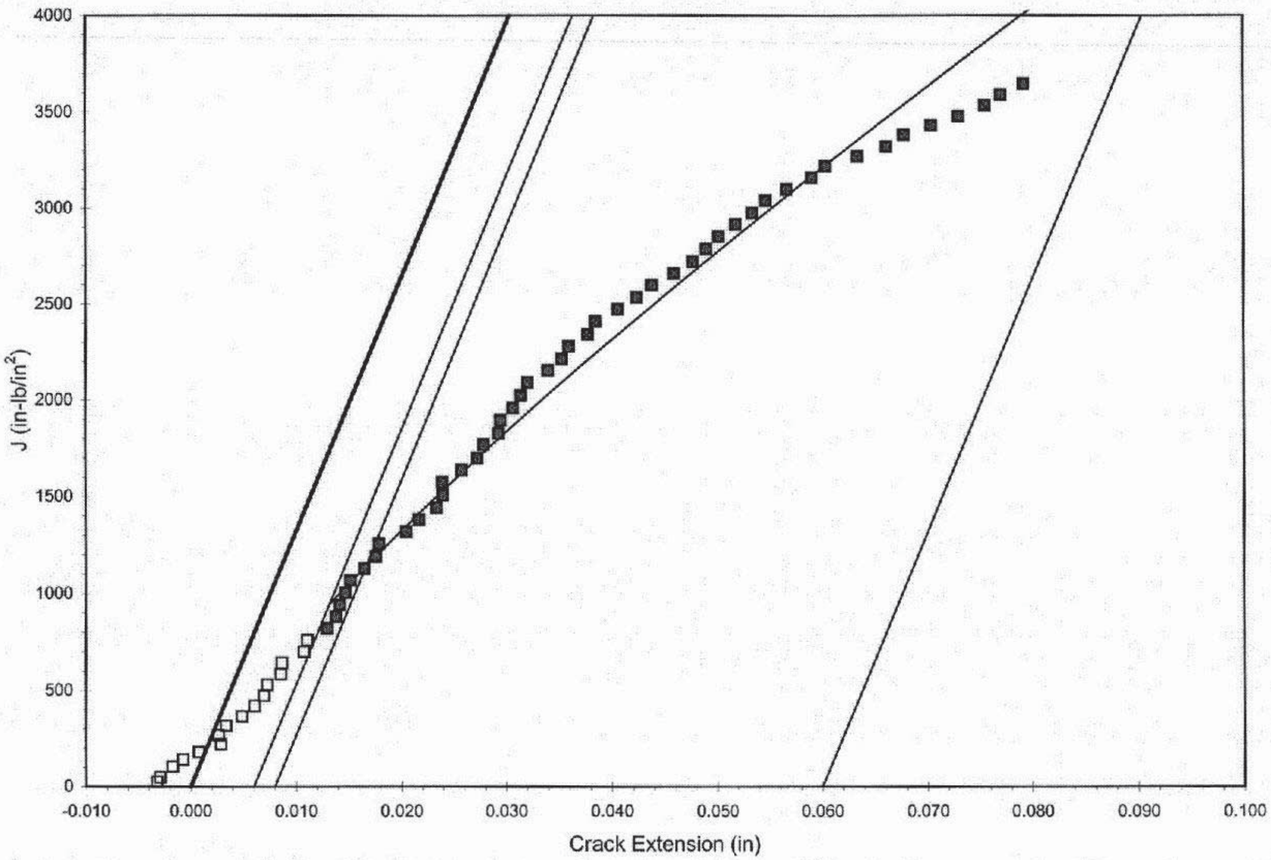
CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05263
TEST DATE : 7/12/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SID : KC-H-H-2

$J_{Ic} = 1135.56$ in-lb/in^2

$J = 2284.7\ (a / 0.0394)^{0.8059}$



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Westmoreland Mechanical Testing & Research, Inc.

Force vs. COD Graph

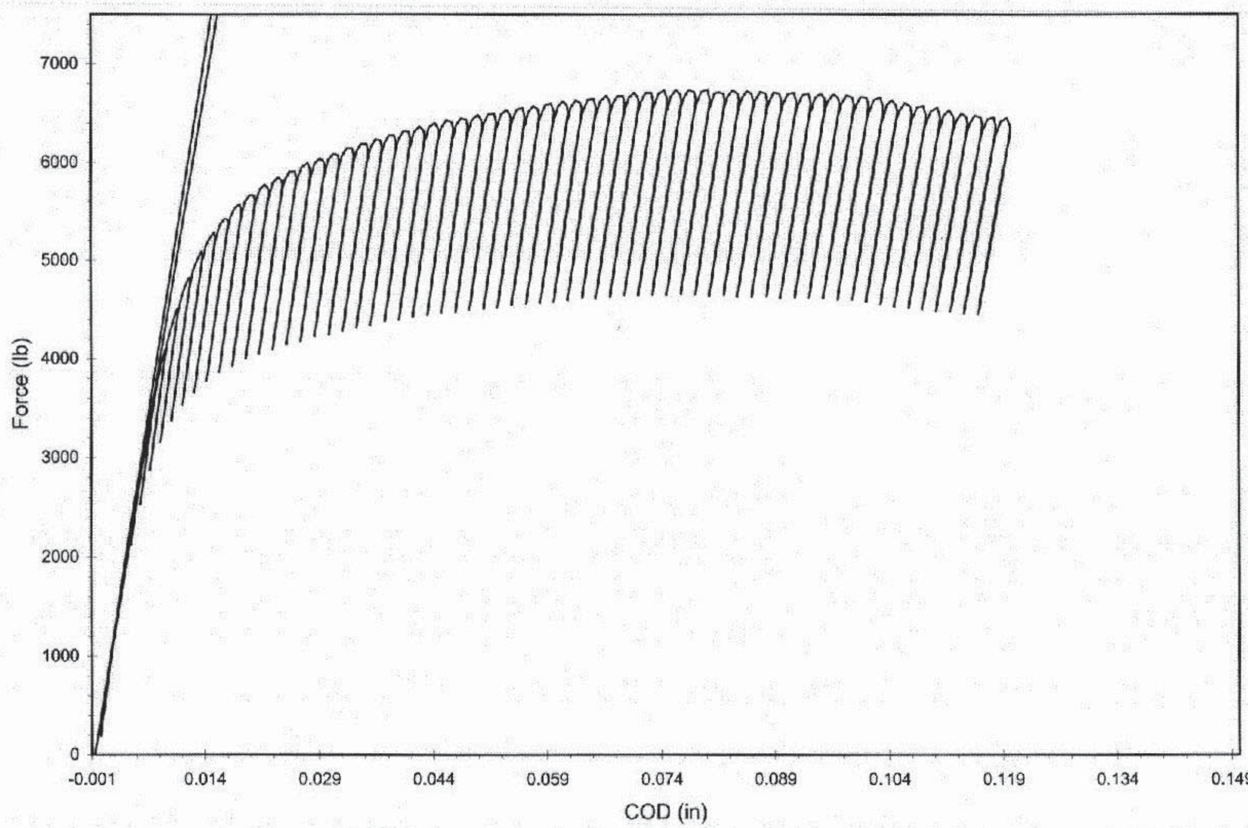
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05263
TEST DATE : 7/12/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SID : KC-H-H-2

$P_{max} = 6757.9$ lb
$P_Q = 3288.5$ lb
$K_Q = 41.1$ ksi(in)$^{1/2}$



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KC-H-H-3

A-225 Gr. B HAZ

J_{IC} FRACTURE TOUGHNESS

T-L

-20°F

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-H-3
TESTLOG : T05264
TEST DATE : 7/19/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B) : 0.752 in
NET THICKNESS (B_N) : 0.575 in
EFFECTIVE THICKNESS (B_e) : 0.710 in
WIDTH (W) : 1.500 in
UNCRACKED LIGAMENT (b_o) : 0.732 in
NOTCH LENGTH (a_n) : 0.689 in

TEST PARAMETERS

TEST TEMPERATURE : -20°F
TEST TYPE : CT
ORIENTATION : L-C
TEST MACHINE : H235
CLIP GAGE : 10243952A
CLIP GAGE LOCATION : LOAD LINE

MAIN RAMP RATE : 0.02 in/min
PARTIAL LOADING RATE : 0.02 in/min
PARTIAL UNLOADING RATE : 0.02 in/min
UNLOADING INTERVAL : 0.0005 in
HOLDTIME : 5.0 sec.
OPERATOR : CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.753 in	0.765 in	0.770 in	0.772 in	0.772 in	0.773 in	0.771 in	0.766 in	0.758 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.759 in	0.771 in	0.776 in	0.778 in	0.778 in	0.779 in	0.777 in	0.772 in	0.764 in

PRECRACK AVERAGE : 0.7681 in FINAL AVERAGE : 0.7745 in
PRECRACK a/W : 0.5121 FINAL a/W : 0.5163

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 1400 lb FINAL P_{max} : 1213 lb R-RATIO (P_{min} / P_{max}) : 0.1
CYCLES : 212701 FINAL K_{max} : 13.21 ksi(in)$^{1/2}$

ORIGINAL CRACK

PHYSICAL CRACK SIZE (a_o) : 0.7681 in
EST. CRACK SIZE (a_{oq}) : 0.7631 in
PERCENT DIFFERENCE : 0.65 %

J_c VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   $a/W = 0.5121$
2. (A6.2.2) THICKNESS, $B \geq 100J_Q/\sigma_Y$ — VALID
   $B = 0.7520$ in $100J_Q/\sigma_Y = 0.3714$ in
3. (A6.2.2) INITIAL LIGAMENT, $b_o \geq 100J_Q/\sigma_Y$ — VALID
   $b_o = 0.7319$ in $100J_Q/\sigma_Y = 0.3714$ in
4. (A6.2.2) CRACK EXTENSION, $\Delta a_p < 0.008 + J_Q/2\,\sigma_y$ — VALID
   $\Delta a_p = 0.0064$ in Limit = 0.0097 in

FAST FRACTURE RESPONSE
SMALL SCALE YIELDING CRITERIA ARE MET

TEST IS VALID: $J_c = 265.52$ in-lb/in^2

$K_{Jc} = 95.11$ ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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WESTMORELAND MECHANICAL TESTING & RESEARCH

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Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-H-3
TESTLOG : T05264
TEST DATE : 7/19/2013

MATERIAL : Steel

WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.752 in	WIDTH (W)	: 1.500 in
NET THICKNESS (B_N)	: 0.575 in	UNCRACKED LIGAMENT (b_o)	: 0.732 in
EFFECTIVE THICKNESS (B_e)	: 0.710 in	NOTCH LENGTH (a_n)	: 0.689 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.753 in	0.765 in	0.770 in	0.772 in	0.772 in	0.773 in	0.771 in	0.766 in	0.758 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.759 in	0.771 in	0.776 in	0.778 in	0.778 in	0.779 in	0.777 in	0.772 in	0.764 in

PRECRACK AVERAGE	: 0.7681 in	FINAL AVERAGE	: 0.7745 in
PRECRACK a/W	: 0.5121	FINAL a/W	: 0.5163

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1400 lb	FINAL P_{max}	: 1213 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 212701	FINAL K_{max}	: 13.21 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 5671.5 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0791 in $0.05B$ = 0.0376 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^f / \sigma_{YS}^T)(0.4\sigma_{YS}^f\ ksi\sqrt{in})$, WHERE σ_{YS}^f AND σ_{YS}^T ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ K_{max} Limit = 18.7 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^f / \sigma_{YS}^T) * K_F$, WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.2 ksi(in)$^{1/2}$ K_{max} Limit = 50.8 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0151 in $0.05B$ = 0.0376 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0151 in $0.05B$ = 0.0376 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0064 in   50% of the Average = 0.0032 in

ALL GENERAL VALIDITY CHECKS ARE VALID

GERALD W. BOICE - THOMAS S. FEDOR

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-H-3
TESTLOG : T05264
TEST DATE : 7/19/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.752 in
NET THICKNESS (B_N)	: 0.575 in
EFFECTIVE THICKNESS (B_e)	: 0.710 in
WIDTH (W)	: 1.500 in
UNCRACKED LIGAMENT (b_o)	: 0.732 in
NOTCH LENGTH (a_n)	: 0.689 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.753 in	0.765 in	0.770 in	0.772 in	0.772 in	0.773 in	0.771 in	0.766 in	0.758 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.759 in	0.771 in	0.776 in	0.778 in	0.778 in	0.779 in	0.777 in	0.772 in	0.764 in

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1400 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 1213 lb	CYCLES	: 212701
FINAL K_{max}	: 13.21 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 2718.4 lb	MAXIMUM FORCE (P_{max})	: 5671.5 lb
K_Q	: 33.9 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 2.35

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   $a/W = 0.5121$
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   $P_{max}/P_Q = 2.0863$
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2 = 0.8229$ in $b_o = 0.7319$ in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^f/\sigma_{YS}^t) * K_F$, WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 13.2 ksi(in)$^{1/2}$ K_{max} Limit = 50.8 ksi(in)$^{1/2}$

TEST IS INVALID: $K_Q = 33.9$ ksi(in)$^{1/2}$

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Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT

SPECIMEN : KC-H-H-3
TESTLOG : T05264
TEST DATE : 7/19/2013

MATERIAL : Steel
TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.7631 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7681 in
MODULUS (E) : 31.00 Msi

WIDTH (W) : 1.500 in
TOTAL THICKNESS (B) : 0.752 in
NET THICKNESS (B_N) : 0.575 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0020	1151.0	0.00	0.00	5.88	5.88	1.748E-06	38.51	0.9989	0.7622	-0.0008
2	0.0029	1654.6	0.00	0.01	12.16	12.17	1.748E-06	38.52	0.9997	0.7623	-0.0008
3	0.0034	1915.1	0.00	0.00	16.46	16.46	1.762E-06	38.84	0.9997	0.7647	0.0016
4	0.0039	2200.2	0.12	0.66	21.61	22.27	1.754E-06	38.67	0.9997	0.7634	0.0003
5	0.0048	2657.2	0.36	1.93	31.66	33.60	1.761E-06	38.81	0.9998	0.7645	0.0015
6	0.0053	2860.0	0.81	4.33	36.41	40.74	1.750E-06	38.58	0.9997	0.7627	-0.0003
7	0.0064	3329.5	1.37	7.30	49.77	57.07	1.762E-06	38.85	0.9998	0.7648	0.0017
8	0.0069	3525.9	1.99	10.60	55.70	66.30	1.758E-06	38.78	0.9999	0.7643	0.0012
9	0.0083	4081.6	3.68	19.58	74.81	94.39	1.761E-06	38.86	0.9999	0.7648	0.0018
10	0.0089	4264.2	4.71	25.06	81.76	106.82	1.763E-06	38.90	0.9998	0.7652	0.0021
11	0.0094	4418.9	5.64	30.02	87.95	117.98	1.765E-06	38.95	0.9998	0.7656	0.0025
12	0.0100	4606.2	6.88	36.72	95.08	131.80	1.758E-06	38.79	0.9998	0.7643	0.0013
13	0.0105	4746.9	8.30	44.31	100.78	145.09	1.755E-06	38.73	0.9997	0.7639	0.0008
14	0.0111	4919.5	9.72	51.78	108.82	160.60	1.762E-06	38.90	0.9989	0.7651	0.0021
15	0.0118	5077.8	11.57	61.83	115.19	177.01	1.752E-06	38.69	0.9997	0.7636	0.0005
16	0.0125	5234.8	13.91	74.18	122.96	197.13	1.758E-06	38.83	0.9999	0.7646	0.0016
17	0.0131	5341.6	15.82	84.12	128.81	212.92	1.767E-06	39.02	0.9999	0.7661	0.0030
18	0.0137	5457.0	17.77	94.30	135.26	229.55	1.775E-06	39.21	0.9999	0.7676	0.0045
19	0.0143	5536.5	19.94	105.55	140.35	245.90	1.787E-06	39.47	0.9999	0.7695	0.0064

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

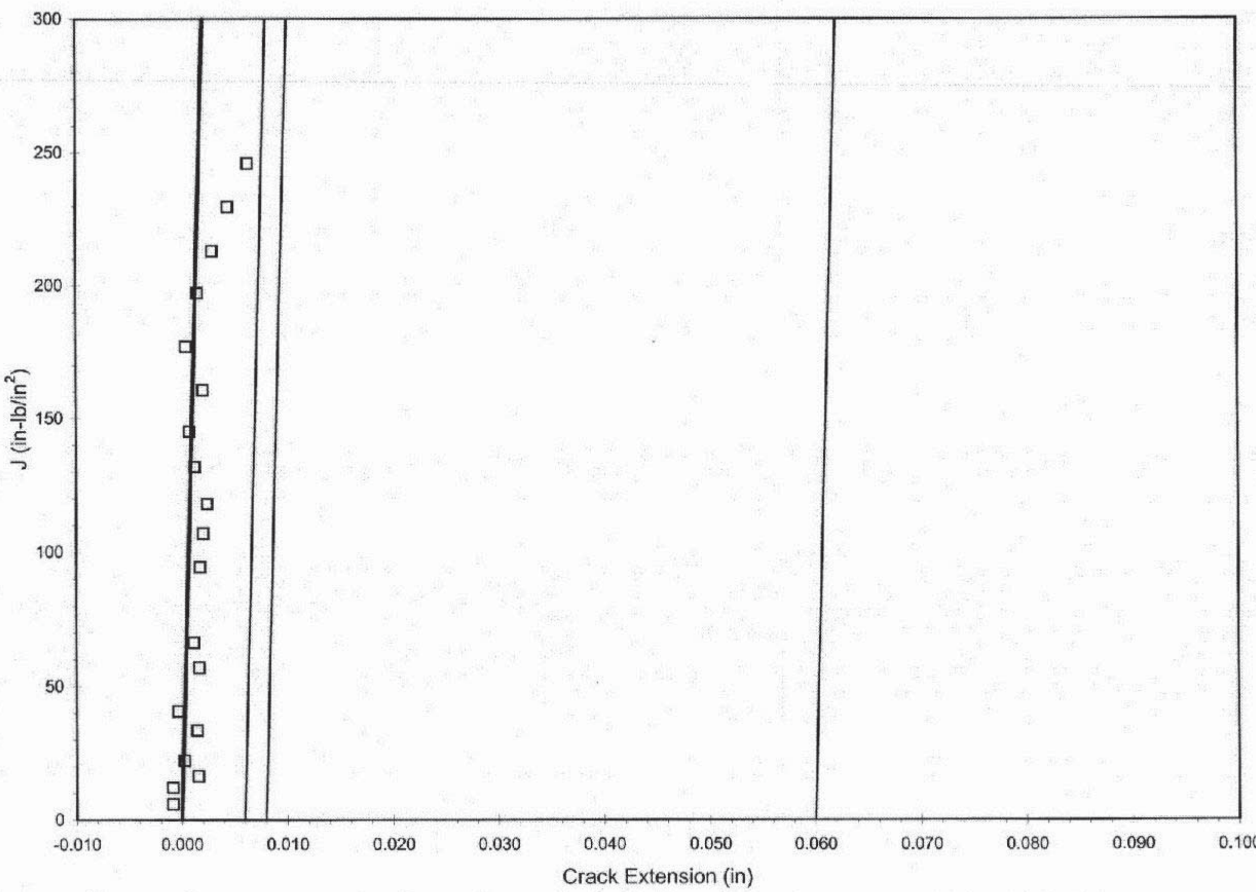
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05264
TEST DATE : 7/19/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-H-3

J_c = 265.52 in-lb/in^2



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Force vs. COD Graph

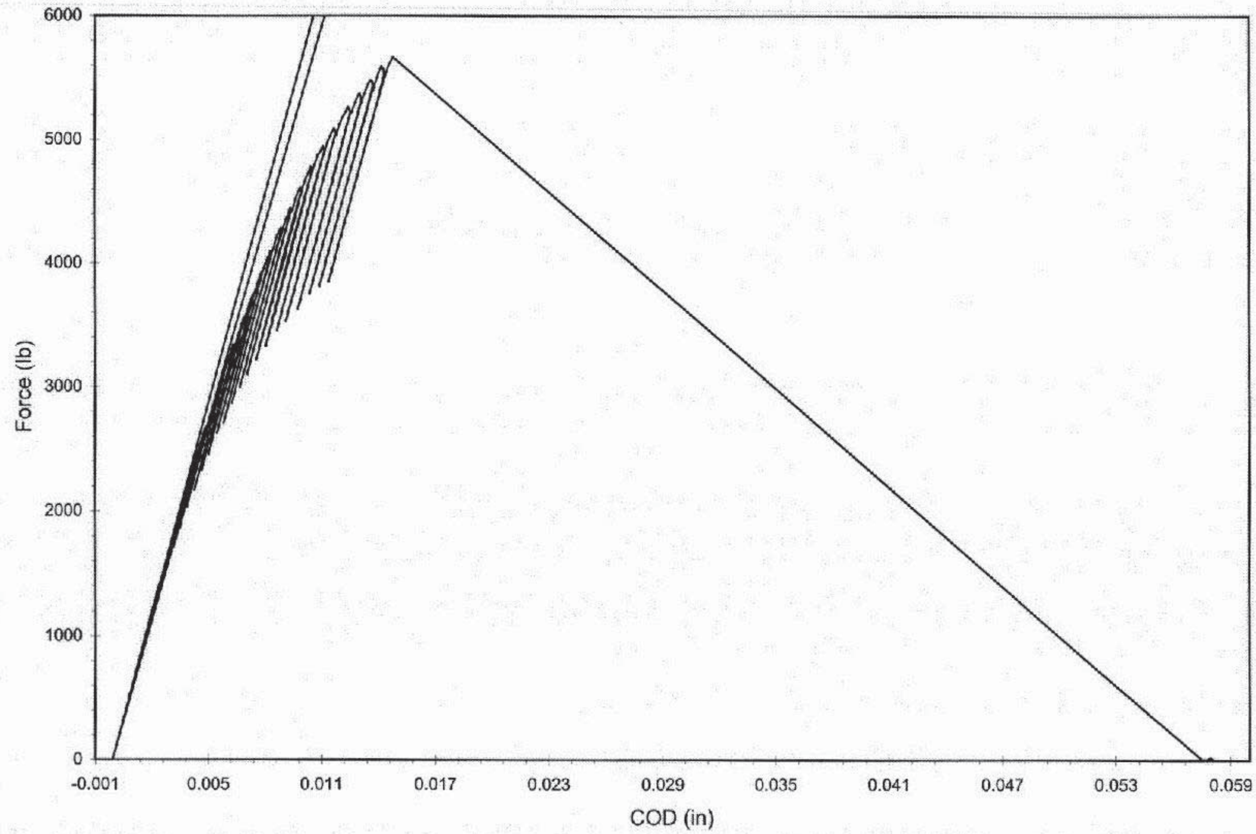
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05264
TEST DATE : 7/19/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-H-3

P_{max} = 5671.5 lb
P_Q = 2718.4 lb
K_Q = 33.9 ksi(in)$^{1/2}$



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KC-H-H-4

A-225 Gr. B HAZ

J_{IC} FRACTURE TOUGHNESS

T-L

-20°F

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J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-H-4
TESTLOG : T05265
TEST DATE : 7/19/2013

MATERIAL : Steel

WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B) : 0.751 in
NET THICKNESS (B_N) : 0.578 in
EFFECTIVE THICKNESS (B_e) : 0.711 in
WIDTH (W) : 1.502 in
UNCRACKED LIGAMENT (b_o) : 0.730 in
NOTCH LENGTH (a_n) : 0.693 in

TEST PARAMETERS

TEST TEMPERATURE : -20°F
TEST TYPE : CT
ORIENTATION : L-C
TEST MACHINE : H235
CLIP GAGE : 10243952A
CLIP GAGE LOCATION : LOAD LINE

MAIN RAMP RATE : 0.02 in/min
PARTIAL LOADING RATE : 0.02 in/min
PARTIAL UNLOADING RATE : 0.02 in/min
UNLOADING INTERVAL : 0.0005 in
HOLDTIME : 5.0 sec.
OPERATOR : CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.764 in	0.771 in	0.778 in	0.778 in	0.777 in	0.772 in	0.770 in	0.770 in	0.762 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.768 in	0.775 in	0.782 in	0.782 in	0.781 in	0.776 in	0.774 in	0.774 in	0.766 in

PRECRACK AVERAGE : 0.7724 in
PRECRACK a/W : 0.5142

FINAL AVERAGE : 0.7761 in
FINAL a/W : 0.5167

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 1389 lb
CYCLES : 273904

FINAL P_{max} : 1245 lb
FINAL K_{max} : 13.66 ksi(in)$^{1/2}$

R-RATIO (P_{min} / P_{max}) : 0.1

ORIGINAL CRACK

PHYSICAL CRACK SIZE (a_o) : 0.7724 in
EST. CRACK SIZE (a_{oq}) : 0.7757 in
PERCENT DIFFERENCE : 0.43 %

J_c VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   $a/W = 0.5142$
2. (A6.2.2) THICKNESS, $B \geq 100J_Q/\sigma_Y$ — VALID
   $B = 0.7510$ in $100J_Q/\sigma_Y = 0.3361$ in
3. (A6.2.2) INITIAL LIGAMENT, $b_o \geq 100J_Q/\sigma_Y$ — VALID
   $b_o = 0.7296$ in $100J_Q/\sigma_Y = 0.3361$ in
4. (A6.2.2) CRACK EXTENSION, $\Delta a_p < 0.008 + J_Q/2\sigma_y$ — VALID
   $\Delta a_p = 0.0037$ in   Limit = 0.0096 in

FAST FRACTURE RESPONSE
SMALL SCALE YIELDING CRITERIA ARE MET

TEST IS VALID: J_c = 240.29 in-lb/in^2
K_{Jc} = 90.47 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-II-4
TESTLOG : T05265
TEST DATE : 7/19/2013

MATERIAL : Steel

WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.751 in	WIDTH (W)	: 1.502 in
NET THICKNESS (B_N)	: 0.578 in	UNCRACKED LIGAMENT (b_o)	: 0.730 in
EFFECTIVE THICKNESS (B_e)	: 0.711 in	NOTCH LENGTH (a_n)	: 0.693 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.764 in	0.771 in	0.778 in	0.778 in	0.777 in	0.772 in	0.770 in	0.770 in	0.762 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.768 in	0.775 in	0.782 in	0.782 in	0.781 in	0.776 in	0.774 in	0.774 in	0.766 in

PRECRACK AVERAGE	: 0.7724 in	FINAL AVERAGE	: 0.7761 in
PRECRACK a/W	: 0.5142	FINAL a/W	: 0.5167

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1389 lb	FINAL P_{max}	: 1245 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 273904	FINAL K_{max}	: 13.66 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 5589.4 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0794 in — 0.05B = 0.0376 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}{}^{f} / \sigma_{YS}{}^{T})(0.4\sigma_{YS}{}^{f}\ ksi\sqrt{in})$, WHERE $\sigma_{YS}{}^{f}$ AND $\sigma_{YS}{}^{T}$ ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ — K_{max} Limit = 18.7 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\ (\sigma_{YS}{}^{f} / \sigma_{YS}{}^{T}) * K_F$, WHERE $K_F = K_{JQ}, K_{JQC}$, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.7 ksi(in)$^{1/2}$ — K_{max} Limit = 48.3 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0104 in — 0.05B = 0.0376 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0104 in — 0.05B = 0.0376 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0037 in — 50% of the Average = 0.0018 in

ALL GENERAL VALIDITY CHECKS ARE VALID

GERALD W. BOICE - THOMAS S. FEDOR

WESTMORELAND MECHANICAL TESTING & RESEARCH

Testing Specialists for Aerospace, Automotive, and Nuclear Fields

Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-H-4
TESTLOG : T05265
TEST DATE : 7/19/2013

MATERIAL : Steel

WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.751 in
NET THICKNESS (B_N)	: 0.578 in
EFFECTIVE THICKNESS (B_e)	: 0.711 in
WIDTH (W)	: 1.502 in
UNCRACKED LIGAMENT (b_o)	: 0.730 in
NOTCH LENGTH (a_n)	: 0.693 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.764 in	0.771 in	0.778 in	0.778 in	0.777 in	0.772 in	0.770 in	0.770 in	0.762 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.768 in	0.775 in	0.782 in	0.782 in	0.781 in	0.776 in	0.774 in	0.774 in	0.766 in

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1389 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 1245 lb	CYCLES	: 273904
FINAL K_{max}	: 13.66 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 2980.5 lb	MAXIMUM FORCE (P_{max})	: 5589.4 lb
K_Q	: 37.3 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 2.33

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID

   $a/W = 0.5142$

2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID

   $P_{max}/P_Q = 1.8754$

3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID

   $2.5(K_Q/\sigma_{YS})^2 = 0.9979$ in $b_o = 0.7296$ in

4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{f} / \sigma_{YS}^{T}) * K_F$, WHERE $K_F = K_Q$ — VALID

   K_{max} Applied = 13.7 ksi(in)$^{1/2}$ K_{max} Limit = 48.3 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 37.3 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT

SPECIMEN : KC-H-H-4
TESTLOG : T05265
TEST DATE : 7/19/2013

MATERIAL : Steel
TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.7757 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7724 in
MODULUS (E) : 31.00 Msi

WIDTH (W) : 1.502 in
TOTAL THICKNESS (B) : 0.751 in
NET THICKNESS (B_N) : 0.578 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(II) (in/lb)	EBV/P(II)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0022	1357.0	0.00	0.00	8.52	8.52	1.812E-06	39.96	0.9991	0.7741	-0.0015
2	0.0027	1605.6	0.00	0.00	12.06	12.06	1.828E-06	40.33	0.9991	0.7768	0.0012
3	0.0031	1861.7	0.00	0.00	16.16	16.16	1.823E-06	40.21	0.9994	0.7760	0.0003
4	0.0040	2280.9	0.00	0.00	24.31	24.31	1.826E-06	40.29	0.9996	0.7766	0.0009
5	0.0044	2510.7	0.00	0.00	29.14	29.14	1.810E-06	39.93	0.9998	0.7740	-0.0017
6	0.0053	2947.9	0.00	0.00	40.35	40.35	1.816E-06	40.08	0.9998	0.7751	-0.0006
7	0.0058	3152.5	0.14	0.76	46.31	47.07	1.821E-06	40.20	0.9998	0.7759	0.0002
8	0.0062	3333.0	0.47	2.50	51.82	54.33	1.822E-06	40.23	0.9997	0.7761	0.0005
9	0.0067	3552.6	0.61	3.27	59.05	62.32	1.827E-06	40.33	0.9977	0.7768	0.0012
10	0.0071	3731.7	1.21	6.49	64.60	71.09	1.814E-06	40.05	0.9984	0.7748	-0.0008
11	0.0077	3962.9	1.58	8.44	73.63	82.07	1.829E-06	40.39	0.9997	0.7773	0.0017
12	0.0082	4154.3	2.30	12.35	80.81	93.16	1.827E-06	40.35	0.9999	0.7770	0.0014
13	0.0088	4357.9	3.24	17.39	88.54	105.94	1.820E-06	40.21	0.9998	0.7760	0.0003
14	0.0094	4535.3	4.24	22.74	96.37	119.10	1.827E-06	40.37	0.9999	0.7772	0.0015
15	0.0100	4722.5	5.42	29.03	104.83	133.86	1.832E-06	40.47	0.9999	0.7779	0.0023
16	0.0106	4892.6	6.93	37.14	112.60	149.74	1.833E-06	40.50	0.9998	0.7781	0.0024
17	0.0112	5016.3	8.54	45.84	118.23	164.07	1.831E-06	40.46	0.9999	0.7778	0.0022
18	0.0120	5229.5	10.76	57.70	128.78	186.48	1.834E-06	40.53	0.9998	0.7784	0.0027
19	0.0124	5309.0	12.14	65.14	132.89	198.03	1.835E-06	40.57	0.9999	0.7786	0.0030
20	0.0131	5442.9	14.40	77.42	139.16	216.58	1.830E-06	40.46	0.9999	0.7778	0.0021
21	0.0137	5552.8	16.30	87.37	145.80	233.18	1.839E-06	40.67	0.9977	0.7793	0.0037

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

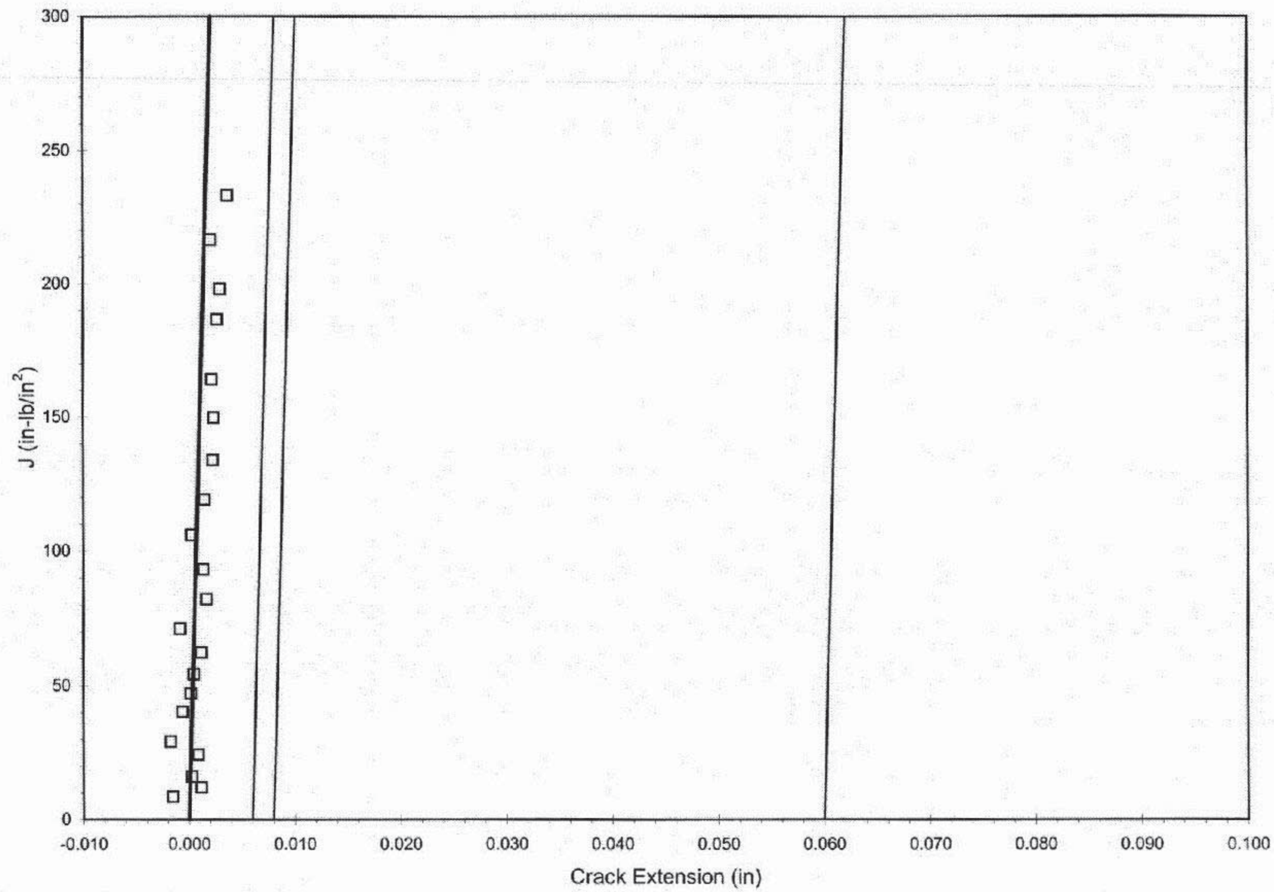
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05265
TEST DATE : 7/19/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-H-4

J_c = 240.29 in-lb/in^2



Westmoreland Mechanical Testing & Research, Inc.

Force vs. COD Graph

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

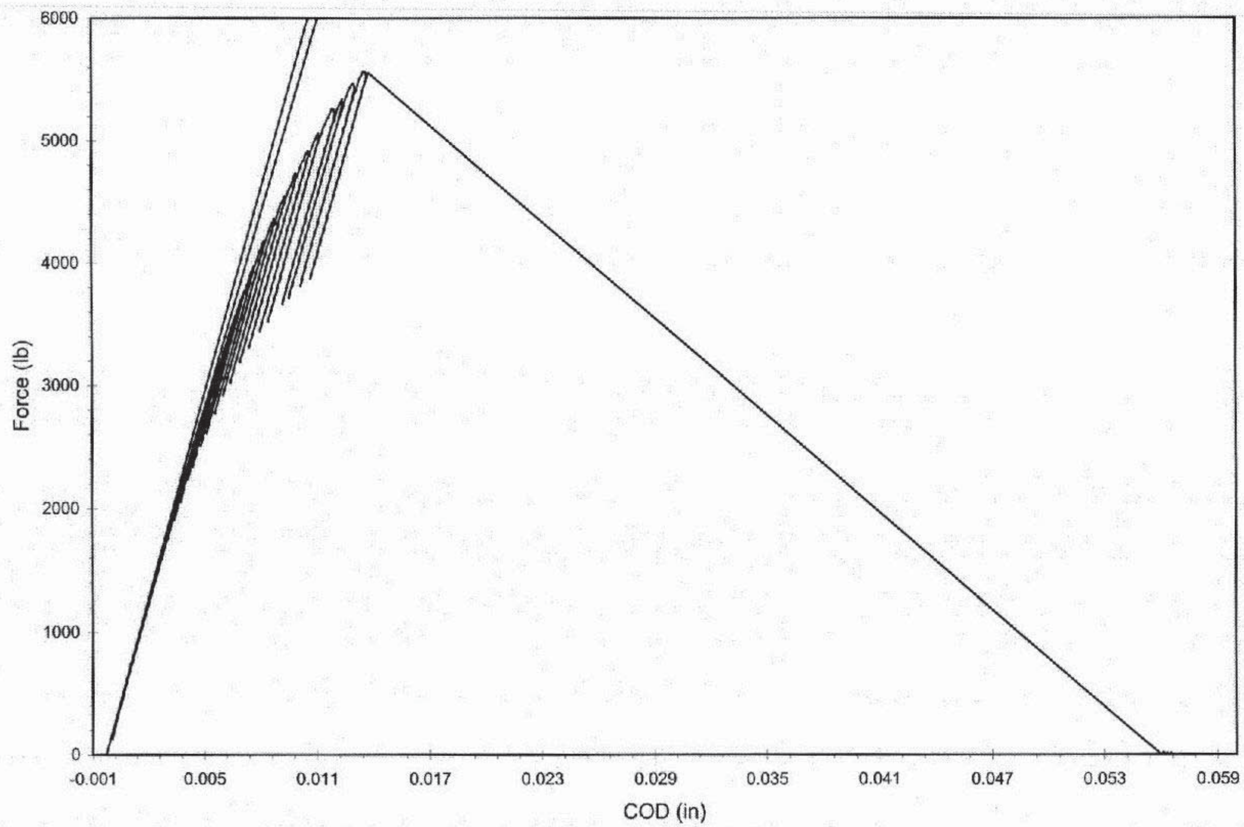
TESTLOG : T05265
TEST DATE : 7/19/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-H-4

$P_{max} = 5589.4$ lb

$P_Q = 2980.5$ lb

$K_Q = 37.3$ ksi(in)$^{1/2}$



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KC-H-W-1

A-225 Gr. B WELD

J_{IC} FRACTURE TOUGHNESS

L-C (VESSEL)

RT

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J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SID : KC-H-W-1
TESTLOG : T05266
TEST DATE : 7/14/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.12 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.2 ksi
EFFECTIVE YIELD STRENGTH : 65.8 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.749 in
NET THICKNESS (B_N)	: 0.578 in
EFFECTIVE THICKNESS (B_e)	: 0.710 in
WIDTH (W)	: 1.499 in
UNCRACKED LIGAMENT (b_o)	: 0.734 in
NOTCH LENGTH (a_n)	: 0.692 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.0015 in
CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.797 in	0.782 in	0.756 in	0.742 in	0.749 in	0.762 in	0.767 in	0.770 in	0.788 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.859 in	0.797 in	0.776 in	0.768 in	0.770 in	0.821 in	0.859 in	0.866 in	0.892 in

PRECRACK AVERAGE	: 0.7651 in	FINAL AVERAGE	: 0.8166 in
PRECRACK a/W	: 0.5104	FINAL a/W	: 0.5447

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1384 lb	FINAL P_{max}	: 1233 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 434306	FINAL K_{max}	: 13.41 ksi(in)$^{1/2}$		

ORIGINAL CRACK		FINAL CRACK		MODULUS	
PHYSICAL CRACK SIZE (a_o)	: 0.7651 in	PHYSICAL CRACK SIZE (a_p)	: 0.8166 in	MODULUS	: 31.12 Msi
EST. CRACK SIZE (a_{oq})	: 0.7651 in	EST. CRACK SIZE ($a_{predicted}$)	: 0.8208 in	EFFECTIVE MODULUS	: 31.12 Msi
PERCENT DIFFERENCE	: 0.00 %	PERCENT DIFFERENCE	: 0.52 %	PERCENT DIFFERENCE	: 0.00 %

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE FATIGUE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   a/W = 0.5104
2. (9.1.5.2) DIFFERENCE BETWEEN PREDICTED ($\Delta a_{predicted}$) AND MEASURED (Δa_p) CRACK EXTENSION SHALL NOT EXCEED 0.15 Δa_p FOR CRACK EXTENSIONS LESS THAN 0.2 b_o AND 0.03 b_o THEREAFTER — VALID
   Difference = 0.0042 in 0.15Δa_p = 0.0077 in
3. (A9.7.2.1) a_{oq} SHALL NOT DIFFER FROM a_o BY MORE THAN THE LARGER OF 0.01 W OR 0.0197 IN. — VALID
   Difference = 0.0000 in Limit = 0.0197 in
4. (A9.7.2.2) NUMBER OF DATA AVAILABLE TO CALCULATE a_{oq} SHALL BE ≥ 8; NUMBER OF DATA BETWEEN 0.4J_Q AND J_Q SHALL BE ≥ 3; CORRELATION COEFFICIENT OF THE LEAST SQUARES FIT SHALL BE > 0.96 — VALID
   a_{oq} Points = 14 Data Points = 4 C.C. = 0.99562
5. (A9.7.1) POWER COEFFICIENT C_2 SHALL BE LESS THAN 1.0 — VALID
   C_2 = 0.4917
6. (A9.8.1) THICKNESS, $B > 10J_Q/\sigma_Y$ — VALID
   B = 0.7490 in $10J_Q/\sigma_Y$ = 0.0487 in
7. (A9.8.2) INITIAL LIGAMENT, $b_o > 10J_Q/\sigma_Y$ — VALID
   b_o = 0.7339 in $10J_Q/\sigma_Y$ = 0.0487 in
8. (A9.6.6.6) AT LEAST FIVE DATA POINTS MUST REMAIN BETWEEN a_{min} AND a_{limit} AND J_{limit} — VALID
   Data Points = 8
9. (A9.6.4) AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.006-in EXCLUSION LINE AND A 0.02-in OFFSET LINE. AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.02-in OFFSET LINE AND THE 0.06-in EXCLUSION LINE. — VALID

TEST IS INVALID: J_Q = 320.30 in-lb/in^2

K_{JQ} = 104.66 ksi(in)$^{1/2}$

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GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 31.12 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 79.3 ksi
SID : KC-H-W-1	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 52.2 ksi
TESTLOG : T05266		EFFECTIVE YIELD STRENGTH : 65.8 ksi
TEST DATE : 7/14/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.749 in	WIDTH (W)	: 1.499 in
NET THICKNESS (B_N)	: 0.578 in	UNCRACKED LIGAMENT (b_o)	: 0.734 in
EFFECTIVE THICKNESS (B_e)	: 0.710 in	NOTCH LENGTH (a_n)	: 0.692 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.0015 in
CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.797 in	0.782 in	0.756 in	0.742 in	0.749 in	0.762 in	0.767 in	0.770 in	0.788 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.859 in	0.797 in	0.776 in	0.768 in	0.770 in	0.821 in	0.859 in	0.866 in	0.892 in

PRECRACK AVERAGE	: 0.7651 in	FINAL AVERAGE	: 0.8166 in
PRECRACK a/W	: 0.5104	FINAL a/W	: 0.5447

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1384 lb	FINAL P_{max}	: 1233 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 434306	FINAL K_{max}	: 13.41 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 8498.4 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0731 in 0.05B = 0.0375 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING, THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^{f} / \sigma_{YS}^{T})(0.4\sigma_{YS}^{f}\ ksi\sqrt{in})$, WHERE σ_{YS}^{f} AND σ_{YS}^{T} ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ K_{max} Limit = 20.9 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{f} / \sigma_{YS}^{T}) * K_F$, WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.4 ksi(in)$^{1/2}$ K_{max} Limit = 62.8 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0319 in 0.05B = 0.0375 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — INVALID

   Maximum Difference = 0.0754 in 0.05B = 0.0375 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — INVALID

   Minimum Extension = 0.0150 in 50% of the Average = 0.0258 in

ALL GENERAL VALIDITY CHECKS ARE NOT VALID

GERALD W. BOICE - THOMAS S. FEDOR

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SID : KC-H-W-1
TESTLOG : T05266
TEST DATE : 7/14/2013

MATERIAL : Steel

WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.12 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.2 ksi
EFFECTIVE YIELD STRENGTH : 65.8 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B) : 0.749 in
NET THICKNESS (B_N) : 0.578 in
EFFECTIVE THICKNESS (B_e) : 0.710 in
WIDTH (W) : 1.499 in
UNCRACKED LIGAMENT (b_o) : 0.734 in
NOTCH LENGTH (a_n) : 0.692 in

TEST PARAMETERS

TEST TEMPERATURE : 75°F
TEST TYPE : CT
ORIENTATION : L-C
TEST MACHINE : H3
CLIP GAGE : E81919
CLIP GAGE LOCATION : LOAD LINE

MAIN RAMP RATE : 0.02 in/min
PARTIAL LOADING RATE : 0.02 in/min
PARTIAL UNLOADING RATE : 0.02 in/min
UNLOADING INTERVAL : 0.0015 in
HOLDTIME : 5.0 sec.
OPERATOR : CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.797 in	0.782 in	0.756 in	0.742 in	0.749 in	0.762 in	0.767 in	0.770 in	0.788 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.859 in	0.797 in	0.776 in	0.768 in	0.770 in	0.821 in	0.859 in	0.866 in	0.892 in

PRECRACK AVERAGE : 0.7651 in FINAL AVERAGE : 0.8166 in
PRECRACK a/W : 0.5104 FINAL a/W : 0.5447

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 1384 lb
FINAL P_{max} : 1233 lb
FINAL K_{max} : 13.41 ksi(in)$^{1/2}$

R-RATIO (P_{min} / P_{max}) : 0.1
CYCLES : 434306

TEST RESULTS

CANDIDATE FORCE (P_Q) : 5324.3 lb
K_Q : 65.9 ksi(in)$^{1/2}$

MAXIMUM FORCE (P_{max}) : 8498.4 lb
SPECIMEN STRENGTH RATIO : 3.94

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   a/W = 0.5104
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   P_{max}/P_Q = 1.5962
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2$ = 3.9887 in b_o = 0.7339 in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^f / \sigma_{YS}^T) * K_F$ WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 13.4 ksi(in)$^{1/2}$ K_{max} Limit = 39.6 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 65.9 ksi(in)$^{1/2}$

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SID : KC-H-W-1 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05266
P.O. NO. : F58154BT TEST DATE : 7/14/2013 TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 0.7651 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7651 in
MODULUS (E) : 31.12 Msi

WIDTH (W) : 1.499 in
TOTAL THICKNESS (B) : 0.749 in
NET THICKNESS (B_N) : 0.578 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0043	2573.2	0.00	0.00	29.84	29.84	1.768E-06	39.11	0.9998	0.7663	0.0012
2	0.0058	3365.0	0.00	0.00	50.93	50.93	1.765E-06	39.04	0.9999	0.7658	0.0007
3	0.0073	4124.4	0.00	0.00	76.76	76.76	1.769E-06	39.15	0.9999	0.7665	0.0015
4	0.0088	4830.8	0.93	4.94	105.72	110.66	1.774E-06	39.27	1.0000	0.7675	0.0024
5	0.0103	5494.7	2.46	13.08	137.29	150.37	1.779E-06	39.39	1.0000	0.7684	0.0033
6	0.0118	6111.4	4.46	23.72	170.45	194.18	1.783E-06	39.50	1.0000	0.7692	0.0042
7	0.0133	6656.1	7.40	39.30	203.87	243.16	1.794E-06	39.77	1.0000	0.7712	0.0061
8	0.0148	7135.9	11.07	58.59	237.44	296.03	1.813E-06	40.19	1.0000	0.7743	0.0092
9	0.0163	7554.0	15.54	82.12	269.76	351.87	1.832E-06	40.63	0.9999	0.7775	0.0125
10	0.0179	7923.6	21.12	111.68	300.27	411.95	1.849E-06	41.01	0.9999	0.7802	0.0152
11	0.0198	8088.6	29.43	153.50	327.81	481.32	1.918E-06	42.56	0.9999	0.7910	0.0259
12	0.0215	8199.6	37.85	196.67	348.91	545.58	1.971E-06	43.76	0.9999	0.7990	0.0339
13	0.0232	8325.4	47.06	244.43	370.73	615.16	2.018E-06	44.81	0.9999	0.8058	0.0408
14	0.0251	8392.1	57.67	299.69	388.71	688.39	2.067E-06	45.93	0.9998	0.8128	0.0478
15	0.0269	8421.4	68.49	355.09	405.86	760.95	2.126E-06	47.25	0.9998	0.8208	0.0557

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

Phone (724) 537-3131

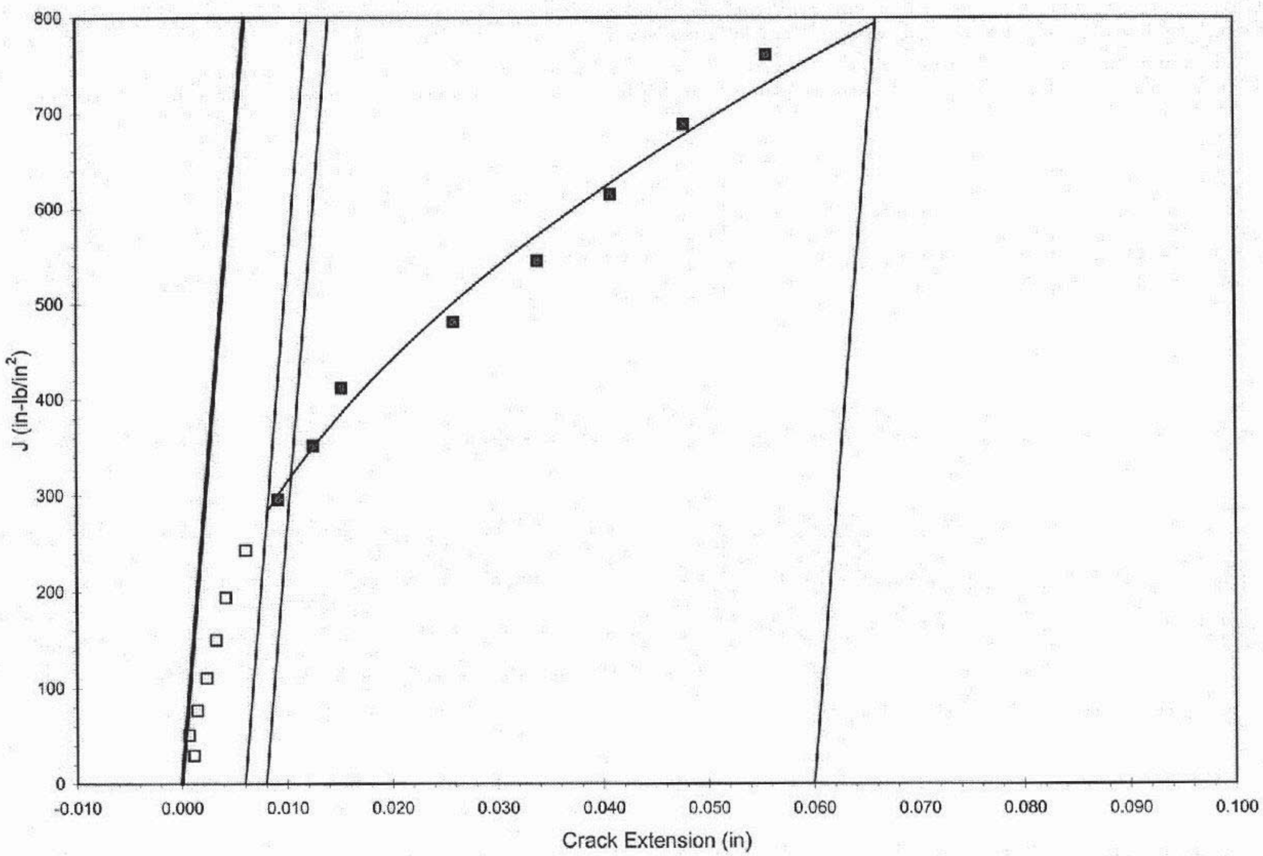
CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05266
TEST DATE : 7/14/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SID : KC-H-W-1

J_Q = 320.30 in-lb/in^2

$J = 616.3\ (a / 0.0394)^{0.4917}$



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Force vs. COD Graph

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

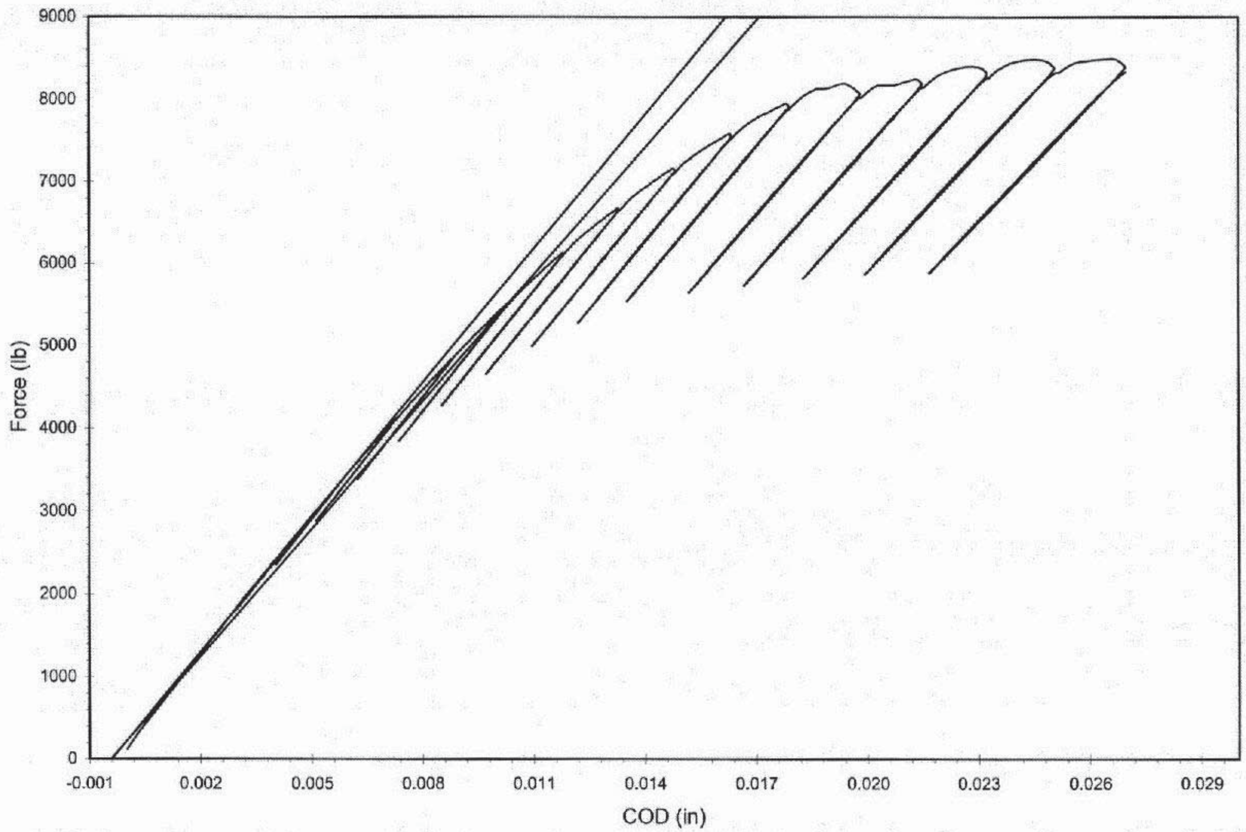
TESTLOG : T05266
TEST DATE : 7/14/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SID : KC-H-W-1

P_{max} = 8498.4 lb

P_Q = 5324.3 lb

K_Q = 65.9 ksi(in)$^{1/2}$



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KC-H-W-2

A-225 Gr. B WELD

J_{IC} FRACTURE TOUGHNESS

L-C (VESSEL)

RT

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J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SID : KC-H-W-2
TESTLOG : T05267
TEST DATE : 7/14/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 30.81 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.2 ksi
EFFECTIVE YIELD STRENGTH : 65.8 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.752 in	TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
NET THICKNESS (B_N)	: 0.567 in	TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
EFFECTIVE THICKNESS (B_e)	: 0.706 in	ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
WIDTH (W)	: 1.501 in	TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.001 in
UNCRACKED LIGAMENT (b_o)	: 0.731 in	CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
NOTCH LENGTH (a_n)	: 0.692 in	CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

TEST PARAMETERS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.806 in	0.807 in	0.769 in	0.775 in	0.774 in	0.743 in	0.760 in	0.743 in	0.774 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.869 in	0.865 in	0.813 in	0.792 in	0.797 in	0.780 in	0.796 in	0.805 in	0.806 in

PRECRACK AVERAGE	: 0.7701 in	FINAL AVERAGE	: 0.8107 in
PRECRACK a/W	: 0.5131	FINAL a/W	: 0.5401

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1390 lb	FINAL P_{max}	: 1241 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 629111	FINAL K_{max}	: 13.55 ksi(in)$^{1/2}$		

ORIGINAL CRACK		FINAL CRACK		MODULUS	
PHYSICAL CRACK SIZE (a_o)	: 0.7701 in	PHYSICAL CRACK SIZE (a_p)	: 0.8107 in	MODULUS	: 30.81 Msi
EST. CRACK SIZE (a_{oq})	: 0.7701 in	EST. CRACK SIZE ($a_{predicted}$)	: 0.8165 in	EFFECTIVE MODULUS	: 30.81 Msi
PERCENT DIFFERENCE	: 0.00 %	PERCENT DIFFERENCE	: 0.72 %	PERCENT DIFFERENCE	: 0.01 %

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE FATIGUE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   a/W = 0.5131
2. (9.1.5.2) DIFFERENCE BETWEEN PREDICTED ($\Delta a_{predicted}$) AND MEASURED (Δa_p) CRACK EXTENSION SHALL NOT EXCEED 0.15 Δa_p FOR CRACK EXTENSIONS LESS THAN 0.2 b_o AND 0.03 b_o THEREAFTER — VALID
   Difference = 0.0058 in $0.15\Delta a_p$ = 0.0061 in
3. (A9.7.2.1) a_{oq} SHALL NOT DIFFER FROM a_o BY MORE THAN THE LARGER OF 0.01 W OR 0.0197 IN. — VALID
   Difference = 0.0000 in   Limit = 0.0197 in
4. (A9.7.2.2) NUMBER OF DATA AVAILABLE TO CALCULATE a_{oq} SHALL BE ≥ 8; NUMBER OF DATA BETWEEN $0.4J_Q$ AND J_Q SHALL BE ≥ 3; CORRELATION COEFFICIENT OF THE LEAST SQUARES FIT SHALL BE > 0.96 — VALID
   a_{oq} Points = 22   Data Points = 8   C.C. = 0.99698
5. (A9.7.1) POWER COEFFICIENT C_2 SHALL BE LESS THAN 1.0 — VALID
   C_2 = 0.3967
6. (A9.8.1) THICKNESS, $B > 10J_Q/\sigma_Y$ — VALID
   B = 0.7520 in $10J_Q/\sigma_Y$ = 0.0848 in
7. (A9.8.2) INITIAL LIGAMENT, $b_o > 10J_Q/\sigma_Y$ — VALID
   b_o = 0.7309 in $10J_Q/\sigma_Y$ = 0.0848 in
8. (A9.6.6.6) AT LEAST FIVE DATA POINTS MUST REMAIN BETWEEN a_{min} AND a_{limit} AND J_{limit} — VALID
   Data Points = 8
9. (A9.6.4) AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.006-in EXCLUSION LINE AND A 0.02-in OFFSET LINE. AT LEAST ONE J-Δa POINT SHALL LIE BETWEEN THE 0.02-in OFFSET LINE AND THE 0.06-in EXCLUSION LINE. — VALID

TEST IS INVALID: J_Q = 557.54 in-lb/in^2

K_{JQ} = 137.39 ksi(in)$^{1/2}$

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GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 30.81 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 79.3 ksi
SID : KC-H-W-2	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 52.2 ksi
TESTLOG : T05267		EFFECTIVE YIELD STRENGTH : 65.8 ksi
TEST DATE : 7/14/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.752 in	WIDTH (W)	: 1.501 in
NET THICKNESS (B_N)	: 0.567 in	UNCRACKED LIGAMENT (b_o)	: 0.731 in
EFFECTIVE THICKNESS (B_e)	: 0.706 in	NOTCH LENGTH (a_n)	: 0.692 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.001 in
CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.806 in	0.807 in	0.769 in	0.775 in	0.774 in	0.743 in	0.760 in	0.743 in	0.774 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.869 in	0.865 in	0.813 in	0.792 in	0.797 in	0.780 in	0.796 in	0.805 in	0.806 in

PRECRACK AVERAGE	: 0.7701 in	FINAL AVERAGE	: 0.8107 in
PRECRACK a/W	: 0.5131	FINAL a/W	: 0.5401

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1390 lb	FINAL P_{max}	: 1241 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 629111	FINAL K_{max}	: 13.55 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 9355.1 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0781 in   0.05B = 0.0376 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING, THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^{f} / \sigma_{YS}^{T})(0.4\sigma_{YS}^{f}\ ksi\sqrt{in})$, WHERE σ_{YS}^{f} AND σ_{YS}^{T} ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ K_{max} Limit = 20.9 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\ (\sigma_{YS}^{f} / \sigma_{YS}^{T}) * K_F$ WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.6 ksi(in)$^{1/2}$ K_{max} Limit = 82.4 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0369 in   0.05B = 0.0376 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — INVALID

   Maximum Difference = 0.0583 in   0.05B = 0.0376 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — INVALID

   Minimum Extension = 0.0170 in   50% of the Average = 0.0203 in

ALL GENERAL VALIDITY CHECKS ARE NOT VALID

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SID : KC-H-W-2
TESTLOG : T05267
TEST DATE : 7/14/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 30.81 Msi
ULTIMATE STRENGTH : 79.3 ksi
YIELD STRENGTH : 52.2 ksi
EFFECTIVE YIELD STRENGTH : 65.8 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.752 in
NET THICKNESS (B_N)	: 0.567 in
EFFECTIVE THICKNESS (B_e)	: 0.706 in
WIDTH (W)	: 1.501 in
UNCRACKED LIGAMENT (b_o)	: 0.731 in
NOTCH LENGTH (a_n)	: 0.692 in

TEST PARAMETERS

TEST TEMPERATURE	: 75°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H3	UNLOADING INTERVAL	: 0.001 in
CLIP GAGE	: E81919	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.806 in	0.807 in	0.769 in	0.775 in	0.774 in	0.743 in	0.760 in	0.743 in	0.774 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.869 in	0.865 in	0.813 in	0.792 in	0.797 in	0.780 in	0.796 in	0.805 in	0.806 in

PRECRACK AVERAGE	: 0.7701 in	FINAL AVERAGE	: 0.8107 in
PRECRACK a/W	: 0.5131	FINAL a/W	: 0.5401

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1390 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 1241 lb	CYCLES	: 629111
FINAL K_{max}	: 13.55 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 5944.6 lb	MAXIMUM FORCE (P_{max})	: 9355.1 lb
K_Q	: 74.8 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 4.46

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   $a/W = 0.5131$
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   $P_{max}/P_Q = 1.5737$
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2 = 5.1282$ in $b_o = 0.7309$ in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING, THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{f} / \sigma_{YS}^{t}) * K_F$ WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 13.6 ksi(in)$^{1/2}$ K_{max} Limit = 44.9 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 74.8 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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Tabular Data (ASTM E1820) Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE SID : KC-H-W-2 MATERIAL : Steel WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089 TESTLOG : T05267
P.O. NO. : F58154BT TEST DATE : 7/14/2013 TEMPERATURE : 75°F

ORIGINAL COMPLIANCE CALCULATION : 0.7701 in WIDTH (W) : 1.501 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7701 in TOTAL THICKNESS (B) : 0.752 in
MODULUS (E) : 30.81 Msi NET THICKNESS (B_N) : 0.567 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0034	1947.1	0.00	0.00	17.75	17.75	1.816E-06	39.55	0.9999	0.7706	0.0005
2	0.0044	2492.2	0.00	0.00	29.04	29.04	1.814E-06	39.52	1.0000	0.7703	0.0002
3	0.0053	2994.4	0.00	0.00	41.87	41.87	1.811E-06	39.47	1.0000	0.7700	-0.0001
4	0.0063	3503.2	0.00	0.00	57.39	57.39	1.813E-06	39.52	1.0000	0.7704	0.0003
5	0.0073	4006.1	0.09	0.51	75.01	75.51	1.812E-06	39.50	1.0000	0.7702	0.0001
6	0.0083	4489.2	0.52	2.83	94.14	96.97	1.811E-06	39.49	1.0000	0.7701	0.0000
7	0.0092	4955.9	1.03	5.59	115.11	120.70	1.815E-06	39.59	1.0000	0.7709	0.0008
8	0.0103	5408.6	1.93	10.48	137.29	147.77	1.816E-06	39.63	1.0000	0.7712	0.0011
9	0.0112	5841.2	2.73	14.82	161.10	175.91	1.825E-06	39.83	1.0000	0.7726	0.0025
10	0.0122	6264.3	4.33	23.54	184.77	208.31	1.820E-06	39.74	1.0000	0.7720	0.0019
11	0.0132	6660.8	5.70	30.98	210.01	240.99	1.828E-06	39.91	1.0000	0.7732	0.0031
12	0.0143	7036.8	7.73	42.00	235.10	277.10	1.832E-06	40.00	1.0000	0.7740	0.0039
13	0.0153	7375.1	10.17	55.23	259.29	314.52	1.837E-06	40.13	1.0000	0.7749	0.0048
14	0.0163	7699.3	13.10	71.16	283.34	354.49	1.841E-06	40.22	1.0000	0.7755	0.0054
15	0.0173	7992.8	16.46	89.39	306.74	396.14	1.847E-06	40.37	1.0000	0.7766	0.0065
16	0.0183	8262.6	20.29	110.14	329.38	439.52	1.854E-06	40.52	1.0000	0.7777	0.0076
17	0.0194	8501.9	24.54	133.10	351.03	484.13	1.863E-06	40.73	1.0000	0.7793	0.0092
18	0.0205	8717.2	29.35	158.82	372.98	531.80	1.878E-06	41.08	1.0000	0.7817	0.0116
19	0.0216	8912.9	35.36	191.57	391.80	583.37	1.885E-06	41.24	1.0000	0.7829	0.0128
20	0.0229	9031.1	42.69	230.19	409.56	639.75	1.912E-06	41.83	1.0000	0.7871	0.0169
21	0.0241	9155.6	49.45	265.81	427.93	693.74	1.936E-06	42.38	1.0000	0.7909	0.0208
22	0.0254	9209.0	57.10	305.11	443.87	748.98	1.975E-06	43.23	1.0000	0.7966	0.0265
23	0.0267	9265.0	65.33	348.14	458.93	807.07	2.007E-06	43.96	1.0000	0.8014	0.0313
24	0.0281	9250.9	75.20	399.25	469.85	869.10	2.049E-06	44.89	1.0000	0.8074	0.0373
25	0.0300	9128.8	89.57	472.68	476.53	949.21	2.115E-06	46.35	1.0000	0.8165	0.0464

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

Phone (724) 537-3131

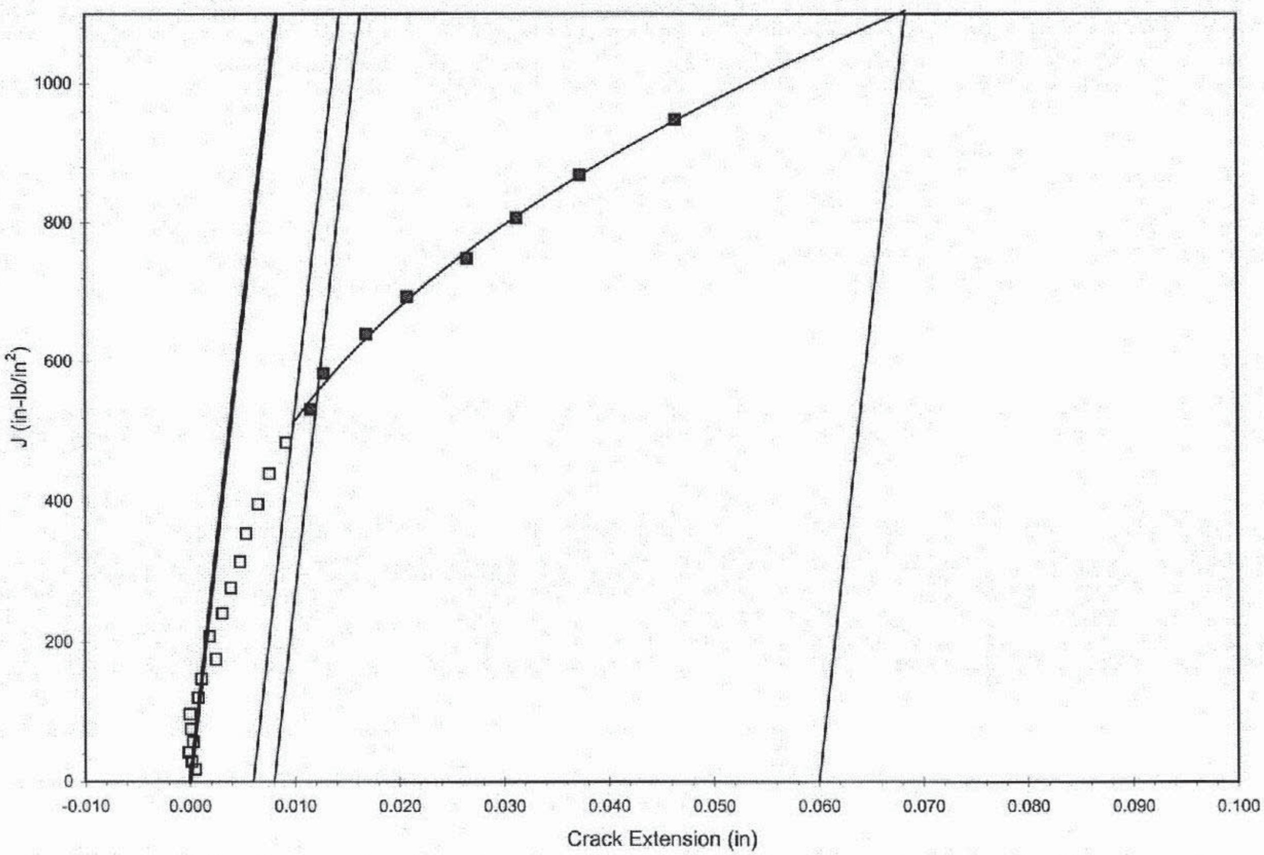
CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05267
TEST DATE : 7/14/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SID : KC-H-W-2

$J_Q = 557.54$ in-lb/in^2

$J = 887.7\,(a / 0.0394)^{0.3967}$



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Force vs. COD Graph

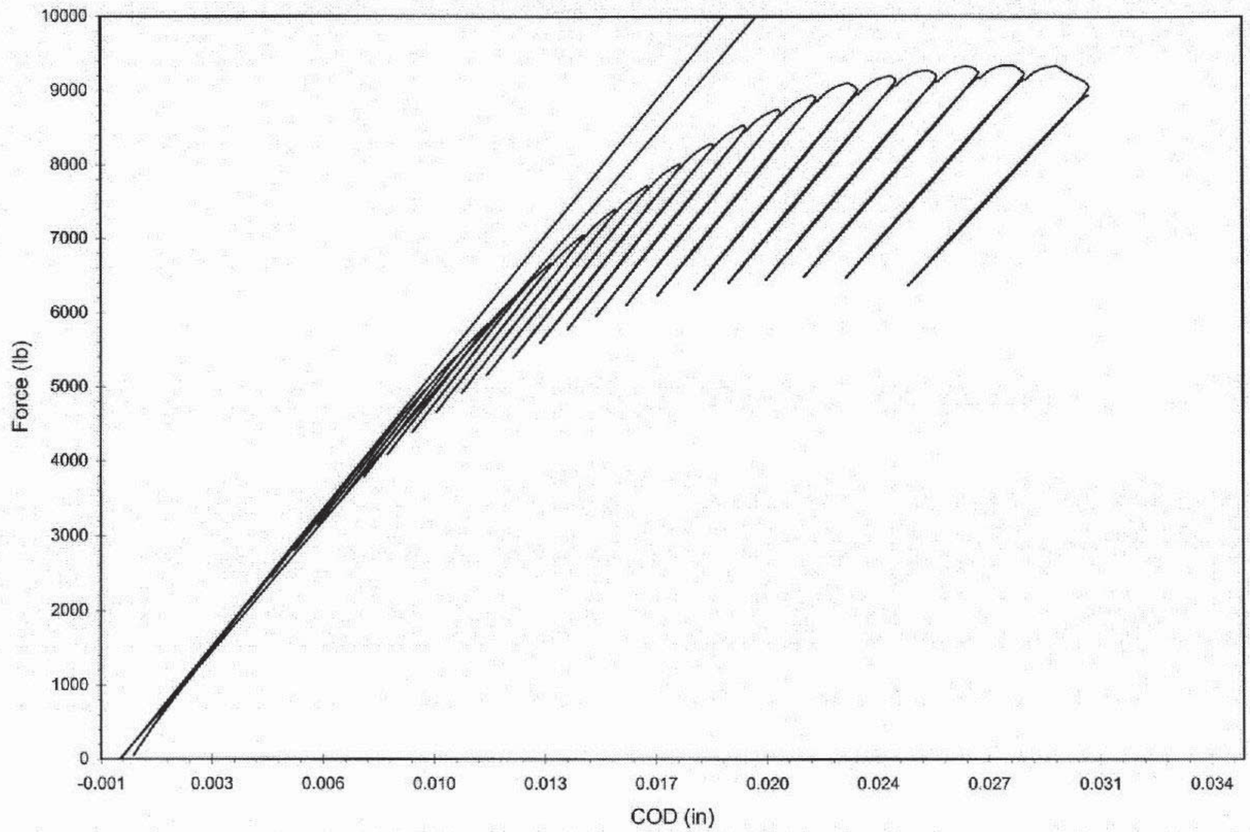
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH INSTITUTE
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05267
TEST DATE : 7/14/2013
TEMPERATURE : 75°F
MATERIAL : Steel

SID : KC-H-W-2

P_{max} = 9355.1 lb
P_Q = 5944.6 lb
K_Q = 74.8 ksi(in)$^{1/2}$



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KC-H-W-3

A-225 Gr. B WELD

J_{IC} FRACTURE TOUGHNESS

L-C (VESSEL)

-20°F

WESTMORELAND MECHANICAL TESTING & RESEARCH

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Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-W-3
TESTLOG : T05268
TEST DATE : 7/18/2013

MATERIAL : Steel

WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B) : 0.747 in
NET THICKNESS (B_N) : 0.581 in
EFFECTIVE THICKNESS (B_e) : 0.710 in
WIDTH (W) : 1.502 in
UNCRACKED LIGAMENT (b_o) : 0.699 in
NOTCH LENGTH (a_n) : 0.693 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.792 in	0.822 in	0.830 in	0.790 in	0.776 in	0.800 in	0.796 in	0.824 in	0.786 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.795 in	0.825 in	0.833 in	0.793 in	0.779 in	0.803 in	0.799 in	0.827 in	0.789 in

PRECRACK AVERAGE : 0.8034 in FINAL AVERAGE : 0.8064 in
PRECRACK a/W : 0.5349 FINAL a/W : 0.5369

FATIGUE PRECRACKING SUMMARY

STARTING P_{max} : 1381 lb FINAL P_{max} : 1236 lb R-RATIO (P_{min} / P_{max}) : 0.1
CYCLES : 751214 FINAL K_{max} : 14.58 ksi(in)$^{1/2}$

ORIGINAL CRACK

PHYSICAL CRACK SIZE (a_o) : 0.8034 in
EST. CRACK SIZE (a_{oq}) : 0.8024 in
PERCENT DIFFERENCE : 0.12 %

J_c VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   $a/W = 0.5349$
2. (A6.2.2) THICKNESS, $B \geq 100J_Q/\sigma_Y$ — VALID
   $B = 0.7470$ in $100J_Q/\sigma_Y = 0.3512$ in
3. (A6.2.2) INITIAL LIGAMENT, $b_o \geq 100J_Q/\sigma_Y$ — VALID
   $b_o = 0.6986$ in $100J_Q/\sigma_Y = 0.3512$ in
4. (A6.2.2) CRACK EXTENSION, $\Delta a_p < 0.008 + J_Q/2\,\sigma_y$ — VALID
   $\Delta a_p = 0.0030$ in Limit = 0.0096 in

FAST FRACTURE RESPONSE
SMALL SCALE YIELDING CRITERIA ARE MET

TEST IS VALID: $J_c = 251.11$ in-lb/in^2
$K_{Jc} = 92.49$ ksi(in)$^{1/2}$

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GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH		SPECIFICATION : ASTM E1820-11
WMT&R NO. : 3-67089	MATERIAL : Steel	MODULUS : 31.00 Msi
P.O. NO. : F58154BT		ULTIMATE STRENGTH : 84.0 ksi
SPECIMEN : KC-H-W-3	WMT&R QUOTE : QN121622 REV.1	YIELD STRENGTH : 59.0 ksi
TESTLOG : T05268		EFFECTIVE YIELD STRENGTH : 71.5 ksi
TEST DATE : 7/18/2013		POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.747 in	WIDTH (W)	: 1.502 in
NET THICKNESS (B_N)	: 0.581 in	UNCRACKED LIGAMENT (b_o)	: 0.699 in
EFFECTIVE THICKNESS (B_e)	: 0.710 in	NOTCH LENGTH (a_n)	: 0.693 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.792 in	0.822 in	0.830 in	0.790 in	0.776 in	0.800 in	0.796 in	0.824 in	0.786 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.795 in	0.825 in	0.833 in	0.793 in	0.779 in	0.803 in	0.799 in	0.827 in	0.789 in

PRECRACK AVERAGE	: 0.8034 in	FINAL AVERAGE	: 0.8064 in
PRECRACK a/W	: 0.5349	FINAL a/W	: 0.5369

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1381 lb	FINAL P_{max}	: 1236 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 751214	FINAL K_{max}	: 14.58 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 6214.2 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.1104 in — $0.05B$ = 0.0374 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}^{f} / \sigma_{YS}^{T})(0.4\sigma_{YS}^{f}\ ksi\sqrt{in})$, WHERE σ_{YS}^{f} AND σ_{YS}^{T} ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ — K_{max} Limit = 18.7 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\ (\sigma_{YS}^{f} / \sigma_{YS}^{T}) * K_F$ WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 14.6 ksi(in)$^{1/2}$ — K_{max} Limit = 49.4 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0274 in — $0.05B$ = 0.0374 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0274 in — $0.05B$ = 0.0374 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0030 in — 50% of the Average = 0.0015 in

ALL GENERAL VALIDITY CHECKS ARE VALID

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-W-3
TESTLOG : T05268
TEST DATE : 7/18/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.747 in
NET THICKNESS (B_N)	: 0.581 in
EFFECTIVE THICKNESS (B_e)	: 0.710 in
WIDTH (W)	: 1.502 in
UNCRACKED LIGAMENT (b_o)	: 0.699 in
NOTCH LENGTH (a_n)	: 0.693 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.792 in	0.822 in	0.830 in	0.790 in	0.776 in	0.800 in	0.796 in	0.824 in	0.786 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.795 in	0.825 in	0.833 in	0.793 in	0.779 in	0.803 in	0.799 in	0.827 in	0.789 in

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1381 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 1236 lb	CYCLES	: 751214
FINAL K_{max}	: 14.58 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 4828.8 lb	MAXIMUM FORCE (P_{max})	: 6214.2 lb
K_Q	: 64.6 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 2.83

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   a/W = 0.5349
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE ≤ 1.10 — INVALID
   P_{max}/P_Q = 1.2869
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2$ = 2.9950 in b_o = 0.6986 in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^{f}\,/\,\sigma_{YS}^{T})\,*\,K_F$, WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 14.6 ksi(in)$^{1/2}$ K_{max} Limit = 49.4 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 64.6 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT

SPECIMEN : KC-H-W-3
TESTLOG : T05268
TEST DATE : 7/18/2013

MATERIAL : Steel

TEMPERATURE : -20°F

WMT&R QUOTE : QN121622 REV.1

ORIGINAL COMPLIANCE CALCULATION : 0.8024 in
ORIGINAL PHYSICAL MEASUREMENT : 0.8034 in
MODULUS (E) : 31.00 Msi

WIDTH (W) : 1.502 in
TOTAL THICKNESS (B) : 0.747 in
NET THICKNESS (B_N) : 0.581 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0018	1054.4	0.00	0.00	5.78	5.78	1.992E-06	43.87	0.9967	0.8013	-0.0011
2	0.0021	1232.0	0.00	0.00	7.96	7.96	2.004E-06	44.14	0.9984	0.8031	0.0007
3	0.0031	1755.3	0.00	0.00	16.13	16.13	2.002E-06	44.09	0.9988	0.8028	0.0004
4	0.0036	1941.6	0.00	0.00	19.77	19.77	2.004E-06	44.14	0.9978	0.8031	0.0007
5	0.0041	2187.1	0.00	0.00	24.70	24.70	1.980E-06	43.62	0.9990	0.7996	-0.0028
6	0.0045	2391.1	0.00	0.00	29.67	29.67	1.987E-06	43.78	0.9996	0.8007	-0.0017
7	0.0050	2628.7	0.00	0.00	36.19	36.19	2.001E-06	44.10	0.9992	0.8028	0.0004
8	0.0054	2853.6	0.00	0.00	42.36	42.36	1.990E-06	43.86	0.9964	0.8013	-0.0011
9	0.0059	3052.5	0.00	0.00	48.58	48.58	1.993E-06	43.94	0.9988	0.8018	-0.0006
10	0.0064	3285.9	0.00	0.00	55.88	55.88	1.982E-06	43.69	0.9996	0.8001	-0.0023
11	0.0068	3479.3	0.00	0.00	62.64	62.64	1.981E-06	43.68	0.9997	0.8001	-0.0023
12	0.0073	3699.1	0.00	0.00	70.94	70.94	1.984E-06	43.75	0.9998	0.8005	-0.0019
13	0.0078	3912.5	0.00	0.00	80.16	80.16	2.000E-06	44.10	0.9998	0.8028	0.0004
14	0.0082	4104.8	0.00	0.00	88.12	88.12	1.997E-06	44.05	0.9997	0.8025	0.0001
15	0.0087	4306.3	0.29	1.60	96.66	98.27	1.992E-06	43.94	0.9997	0.8018	-0.0007
16	0.0091	4521.4	0.45	2.46	106.88	109.34	1.997E-06	44.04	0.9996	0.8024	0.0000
17	0.0095	4699.4	0.76	4.20	115.07	119.27	1.991E-06	43.92	0.9995	0.8017	-0.0007
18	0.0100	4909.2	1.15	6.38	125.30	131.68	1.987E-06	43.85	0.9997	0.8012	-0.0012
19	0.0105	5112.3	1.59	8.75	136.16	144.91	1.990E-06	43.92	0.9997	0.8016	-0.0008
20	0.0111	5208.6	2.58	14.13	144.19	158.31	2.022E-06	44.61	0.9997	0.8061	0.0037
21	0.0116	5422.0	2.89	15.76	157.16	172.92	2.031E-06	44.82	0.9998	0.8075	0.0051
22	0.0121	5575.4	3.59	19.66	166.34	186.00	2.032E-06	44.85	0.9999	0.8077	0.0053
23	0.0126	5760.0	4.82	26.54	176.64	203.18	2.024E-06	44.67	0.9999	0.8065	0.0041
24	0.0131	5956.1	5.94	32.86	187.41	220.27	2.011E-06	44.40	0.9999	0.8048	0.0024
25	0.0137	6122.9	6.98	38.62	198.58	237.19	2.015E-06	44.49	0.9998	0.8054	0.0030

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

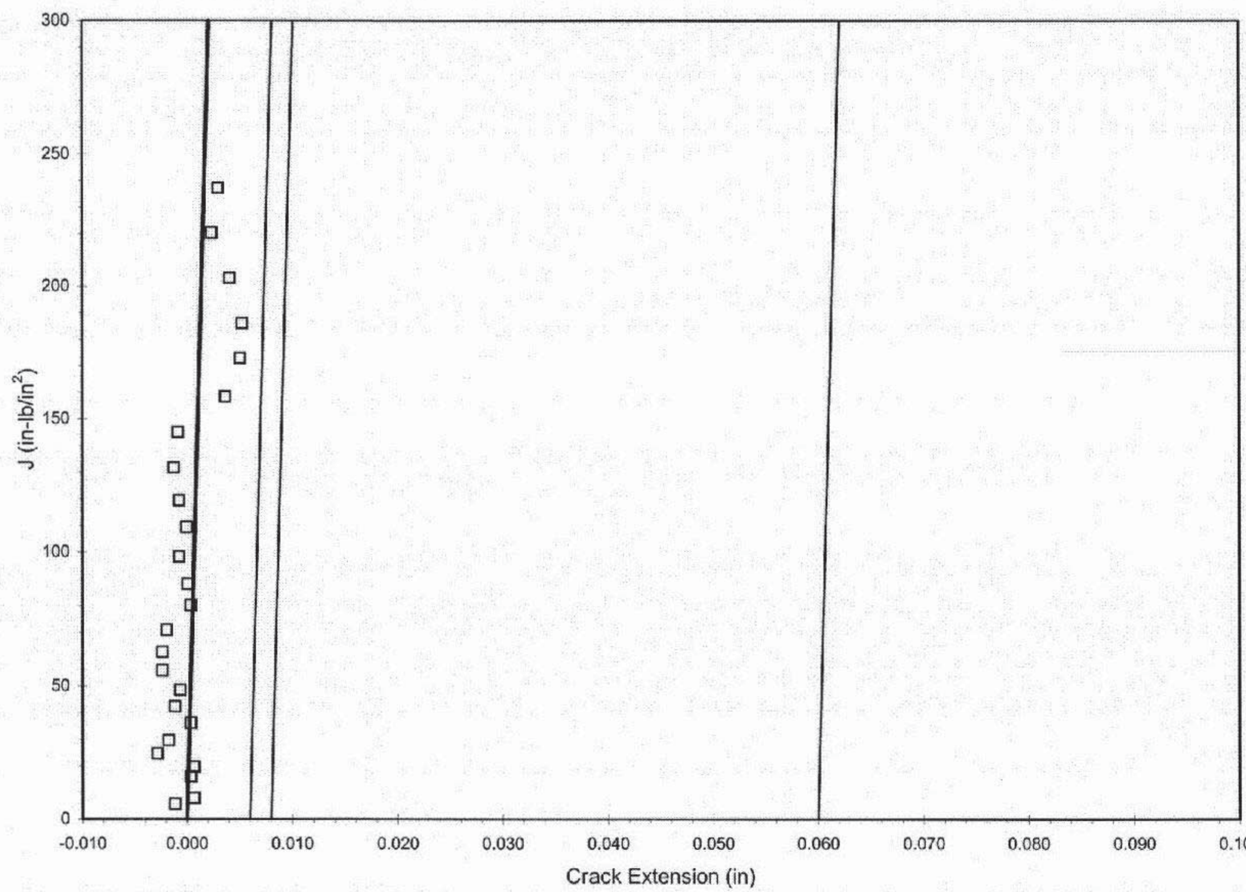
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05268
TEST DATE : 7/18/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-W-3

$J_c = 251.11$ in-lb/in^2



Westmoreland Mechanical Testing & Research, Inc.

Force vs. COD Graph

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

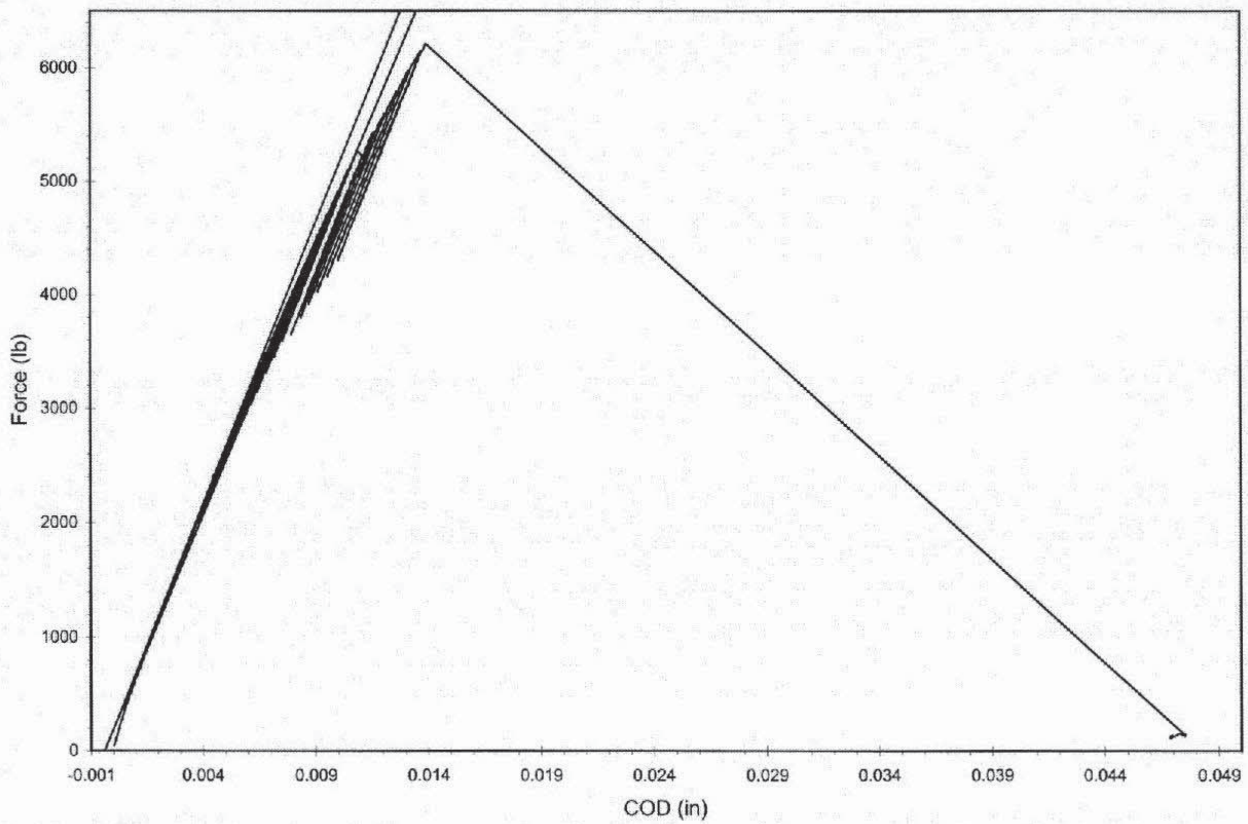
TESTLOG : T05268
TEST DATE : 7/18/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-W-3

P_{max} = 6214.2 lb

P_Q = 4828.8 lb

K_Q = 64.6 ksi(in)$^{1/2}$



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KC-H-W-4

A-225 Gr. B WELD

J_{IC} FRACTURE TOUGHNESS

L-C (VESSEL)

-20°F

WESTMORELAND MECHANICAL TESTING & RESEARCH

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Phone: (724) 537-3131 Fax: (724) 537-3151 Email: admin@wmtr.com

J-INTEGRAL TEST REPORT (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-W-4
TESTLOG : T05269
TEST DATE : 7/18/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.749 in
NET THICKNESS (B_N)	: 0.587 in
EFFECTIVE THICKNESS (B_e)	: 0.714 in
WIDTH (W)	: 1.503 in
UNCRACKED LIGAMENT (b_o)	: 0.732 in
NOTCH LENGTH (a_n)	: 0.692 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.772 in	0.783 in	0.755 in	0.773 in	0.754 in	0.758 in	0.786 in	0.781 in	0.781 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.780 in	0.791 in	0.763 in	0.781 in	0.762 in	0.766 in	0.794 in	0.789 in	0.789 in

PRECRACK AVERAGE	: 0.7708 in	FINAL AVERAGE	: 0.7784 in
PRECRACK a/W	: 0.5128	FINAL a/W	: 0.5179

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1389 lb	FINAL P_{max}	: 1240 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 534398	FINAL K_{max}	: 13.58 ksi(in)$^{1/2}$		

ORIGINAL CRACK

PHYSICAL CRACK SIZE (a_o)	: 0.7708 in
EST. CRACK SIZE (a_{oq})	: 0.7652 in
PERCENT DIFFERENCE	: 0.73 %

J_c VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) THE CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) SHALL BE BETWEEN 0.45 AND 0.70 — VALID
   $a/W = 0.5128$
2. (A6.2.2) THICKNESS, $B \geq 100J_Q/\sigma_Y$ — VALID
   $B = 0.7490$ in $100J_Q/\sigma_Y = 0.4059$ in
3. (A6.2.2) INITIAL LIGAMENT, $b_o \geq 100J_Q/\sigma_Y$ — VALID
   $b_o = 0.7322$ in $100J_Q/\sigma_Y = 0.4059$ in
4. (A6.2.2) CRACK EXTENSION, $\Delta a_p < 0.008 + J_Q/2\,\sigma_y$ — VALID
   $\Delta a_p = 0.0076$ in   Limit = 0.0099 in

FAST FRACTURE RESPONSE
SMALL SCALE YIELDING CRITERIA ARE MET

TEST IS VALID: $J_c = 290.20$ in-lb/in^2

$K_{Jc} = 99.43$ ksi(in)$^{1/2}$

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GENERAL VALIDITY CHECKS (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-W-4
TESTLOG : T05269
TEST DATE : 7/18/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.749 in	WIDTH (W)	: 1.503 in
NET THICKNESS (B_N)	: 0.587 in	UNCRACKED LIGAMENT (b_o)	: 0.732 in
EFFECTIVE THICKNESS (B_e)	: 0.714 in	NOTCH LENGTH (a_n)	: 0.692 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.772 in	0.783 in	0.755 in	0.773 in	0.754 in	0.758 in	0.786 in	0.781 in	0.781 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.780 in	0.791 in	0.763 in	0.781 in	0.762 in	0.766 in	0.794 in	0.789 in	0.789 in

PRECRACK AVERAGE	: 0.7708 in	FINAL AVERAGE	: 0.7784 in
PRECRACK a/W	: 0.5128	FINAL a/W	: 0.5179

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1389 lb	FINAL P_{max}	: 1240 lb	R-RATIO (P_{min} / P_{max})	: 0.1
CYCLES	: 534398	FINAL K_{max}	: 13.58 ksi(in)$^{1/2}$		

TEST CURVE RESULTS

MAXIMUM FORCE (P_{max}) : 7309.8 lb

GENERAL VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.5.1) LENGTH OF THE FATIGUE PRECRACK EXTENSION FROM THE MACHINED NOTCH SHALL NOT BE LESS THAN 0.05B, AND NOT LESS THAN 0.05 IN. — VALID

   Extension = 0.0788 in $0.05B$ = 0.0375 in

2. (7.4.5.1) FOR THE FIRST STEP OF PRECRACKING THE MAXIMUM STRESS INTENSITY (K_{max}) APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = (\sigma_{YS}{}^f / \sigma_{YS}{}^T)(0.4\sigma_{YS}{}^f \ ksi\sqrt{in})$, WHERE $\sigma_{YS}{}^f$ AND $\sigma_{YS}{}^T$ ARE THE MATERIAL YIELD STRESSES AT THE FATIGUE PRECRACK AND TEST TEMPERATURES RESPECTIVELY. — VALID

   K_{max} Applied = 13.0 ksi(in)$^{1/2}$ K_{max} Limit = 18.7 ksi(in)$^{1/2}$

3. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\ (\sigma_{YS}{}^f / \sigma_{YS}{}^T) * K_F$ WHERE $K_F = K_{JQ}$, K_{JQC}, OR K_{JQu}, DEPENDING ON THE RESULT OF THE TEST — VALID

   K_{max} Applied = 13.6 ksi(in)$^{1/2}$ K_{max} Limit = 53.1 ksi(in)$^{1/2}$

4. (9.1.4.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF INITIAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_o — VALID

   Maximum Difference = 0.0168 in $0.05B$ = 0.0375 in

5. (9.1.4.2) NONE OF THE NINE PHYSICAL MEASUREMENTS OF FINAL PHYSICAL CRACK SIZE SHALL DIFFER BY MORE THAN 0.05B FROM THE AVERAGE a_p — VALID

   Maximum Difference = 0.0168 in $0.05B$ = 0.0375 in

6. (9.1.5.1) NONE OF THE NINE PHYSICAL MEASUREMENTS OF CRACK EXTENSION SHALL BE LESS THAN 50% OF THE AVERAGE CRACK EXTENSION — VALID

   Minimum Extension = 0.0076 in   50% of the Average = 0.0038 in

ALL GENERAL VALIDITY CHECKS ARE VALID

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K_{Ic} DETERMINATION (ASTM E1820)

PRELIMINARY INFORMATION

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
SPECIMEN : KC-H-W-4
TESTLOG : T05269
TEST DATE : 7/18/2013

MATERIAL : Steel
WMT&R QUOTE : QN121622 REV.1

SPECIFICATION : ASTM E1820-11
MODULUS : 31.00 Msi
ULTIMATE STRENGTH : 84.0 ksi
YIELD STRENGTH : 59.0 ksi
EFFECTIVE YIELD STRENGTH : 71.5 ksi
POISSON'S RATIO : 0.300

SPECIMEN MEASUREMENTS

TOTAL THICKNESS (B)	: 0.749 in
NET THICKNESS (B_N)	: 0.587 in
EFFECTIVE THICKNESS (B_e)	: 0.714 in
WIDTH (W)	: 1.503 in
UNCRACKED LIGAMENT (b_o)	: 0.732 in
NOTCH LENGTH (a_n)	: 0.692 in

TEST PARAMETERS

TEST TEMPERATURE	: -20°F	MAIN RAMP RATE	: 0.02 in/min
TEST TYPE	: CT	PARTIAL LOADING RATE	: 0.02 in/min
ORIENTATION	: L-C	PARTIAL UNLOADING RATE	: 0.02 in/min
TEST MACHINE	: H235	UNLOADING INTERVAL	: 0.0005 in
CLIP GAGE	: 10243952A	HOLDTIME	: 5.0 sec.
CLIP GAGE LOCATION	: LOAD LINE	OPERATOR	: CHRIS HICKINS

PHYSICAL CRACK LENGTHS

PRECRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.772 in	0.783 in	0.755 in	0.773 in	0.754 in	0.758 in	0.786 in	0.781 in	0.781 in

FINAL CRACK LENGTHS :

Side 1	1/8 Point	1/4 Point	3/8 Point	1/2 Point	5/8 Point	3/4 Point	7/8 Point	Side 2
0.780 in	0.791 in	0.763 in	0.781 in	0.762 in	0.766 in	0.794 in	0.789 in	0.789 in

FATIGUE PRECRACKING SUMMARY

STARTING P_{max}	: 1389 lb	R-RATIO (P_{min} / P_{max})	: 0.1
FINAL P_{max}	: 1240 lb	CYCLES	: 534398
FINAL K_{max}	: 13.58 ksi(in)$^{1/2}$		

TEST RESULTS

CANDIDATE FORCE (P_Q)	: 4907.7 lb	MAXIMUM FORCE (P_{max})	: 7309.8 lb
K_Q	: 60.7 ksi(in)$^{1/2}$	SPECIMEN STRENGTH RATIO	: 2.97

VALIDITY CHECKS PER ASTM E1820-11

1. (7.4.2) CRACK SIZE (TOTAL AVERAGE LENGTH OF THE CRACK STARTER CONFIGURATION PLUS THE FATIGUE CRACK, a/W) MUST BE BETWEEN 0.45 AND 0.55 — VALID
   a/W = 0.5128
2. (A5.4.2) THE RATIO P_{max}/P_Q MUST BE $\leq$ 1.10 — INVALID
   P_{max}/P_Q = 1.4895
3. (A5.4.3) THE QUANTITY $2.5\,(K_Q/\sigma_{YS})^2$, WHERE σ_{YS} IS THE 0.2% OFFSET YIELD STRENGTH IN TENSION, MUST BE LESS THAN THE LENGTH OF THE INITIAL UNCRACKED LIGAMENT, b_o — INVALID
   $2.5(K_Q/\sigma_{YS})^2$ = 2.6461 in b_o = 0.7322 in
4. (7.4.5.2) FOR THE SECOND STEP OF PRECRACKING THE K_{max} APPLIED TO THE SPECIMEN SHALL BE LIMITED BY $K_{max} = 0.6\,(\sigma_{YS}^f / \sigma_{YS}^T) * K_F$, WHERE $K_F = K_Q$ — VALID
   K_{max} Applied = 13.6 ksi(in)$^{1/2}$ K_{max} Limit = 53.1 ksi(in)$^{1/2}$

TEST IS INVALID: K_Q = 60.7 ksi(in)$^{1/2}$

GERALD W. BOICE - THOMAS S. FEDOR

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Westmoreland Mechanical Testing & Research, Inc.

Tabular Data (ASTM E1820)

Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH   SPECIMEN : KC-H-W-4   MATERIAL : Steel   WMT&R QUOTE : QN121622 REV.1
WMT&R NO. : 3-67089   TESTLOG : T05269
P.O. NO. : F58154BT   TEST DATE : 7/18/2013   TEMPERATURE : -20°F

ORIGINAL COMPLIANCE CALCULATION : 0.7652 in   WIDTH (W) : 1.503 in
ORIGINAL PHYSICAL MEASUREMENT : 0.7708 in   TOTAL THICKNESS (B) : 0.749 in
MODULUS (E) : 31.00 Msi   NET THICKNESS (B_N) : 0.587 in

Unload Number	V - start of unloading (in)	Load - start of unloading (lb)	Area Plastic (in-lb)	J Plastic (in-lb/in^2)	J Elastic (in-lb/in^2)	J Deformation (in-lb/in^2)	V/P(ll) (in/lb)	EBV/P(ll)	Correlation (r^2)	Crack Length (in)	Crack Growth (in)
1	0.0021	1301.1	0.00	0.00	7.47	7.47	1.757E-06	38.91	0.9987	0.7668	0.0016
2	0.0030	1787.1	0.00	0.00	13.93	13.93	1.740E-06	38.54	0.9988	0.7639	-0.0013
3	0.0039	2307.6	0.00	0.00	23.32	23.32	1.745E-06	38.66	0.9995	0.7649	-0.0003
4	0.0043	2535.8	0.00	0.00	28.30	28.30	1.752E-06	38.81	0.9997	0.7660	0.0008
5	0.0052	3011.5	0.00	0.00	40.25	40.25	1.763E-06	39.07	0.9997	0.7680	0.0028
6	0.0056	3243.9	0.00	0.00	45.94	45.94	1.740E-06	38.56	0.9997	0.7641	-0.0011
7	0.0061	3474.8	0.00	0.00	53.69	53.69	1.766E-06	39.13	0.9997	0.7685	0.0033
8	0.0065	3717.2	0.00	0.00	62.15	62.15	1.782E-06	39.50	0.9998	0.7712	0.0060
9	0.0074	4158.3	0.07	0.35	77.40	77.74	1.774E-06	39.34	0.9998	0.7700	0.0049
10	0.0078	4378.4	0.55	2.90	84.84	87.74	1.758E-06	38.98	0.9998	0.7673	0.0022
11	0.0084	4650.6	0.85	4.47	95.50	99.97	1.755E-06	38.91	0.9998	0.7668	0.0016
12	0.0089	4882.2	1.17	6.11	105.44	111.55	1.757E-06	38.97	0.9999	0.7672	0.0021
13	0.0093	5106.7	1.37	7.17	115.31	122.49	1.756E-06	38.96	0.9999	0.7671	0.0020
14	0.0097	5277.0	1.87	9.78	123.50	133.29	1.760E-06	39.05	0.9999	0.7679	0.0027
15	0.0102	5509.1	2.26	11.79	134.88	146.67	1.763E-06	39.11	0.9999	0.7683	0.0032
16	0.0107	5744.4	2.76	14.43	146.62	161.05	1.763E-06	39.11	0.9999	0.7683	0.0031
17	0.0111	5936.2	2.74	14.24	158.28	172.53	1.778E-06	39.45	0.9999	0.7709	0.0057
18	0.0116	6107.9	3.53	18.37	168.14	186.51	1.783E-06	39.56	0.9998	0.7717	0.0065
19	0.0121	6342.0	4.09	21.29	181.12	202.41	1.781E-06	39.53	0.9981	0.7715	0.0063
20	0.0126	6544.2	4.43	23.05	193.75	216.80	1.788E-06	39.68	0.9999	0.7726	0.0074
21	0.0131	6750.0	5.73	29.96	204.74	234.71	1.778E-06	39.47	0.9999	0.7710	0.0058
22	0.0136	6939.6	6.60	34.45	217.43	251.88	1.784E-06	39.61	0.9998	0.7721	0.0069
23	0.0141	7132.5	7.68	40.10	230.32	270.42	1.788E-06	39.70	0.9993	0.7728	0.0076

Westmoreland Mechanical Testing & Research, Inc.

J vs. a Graph

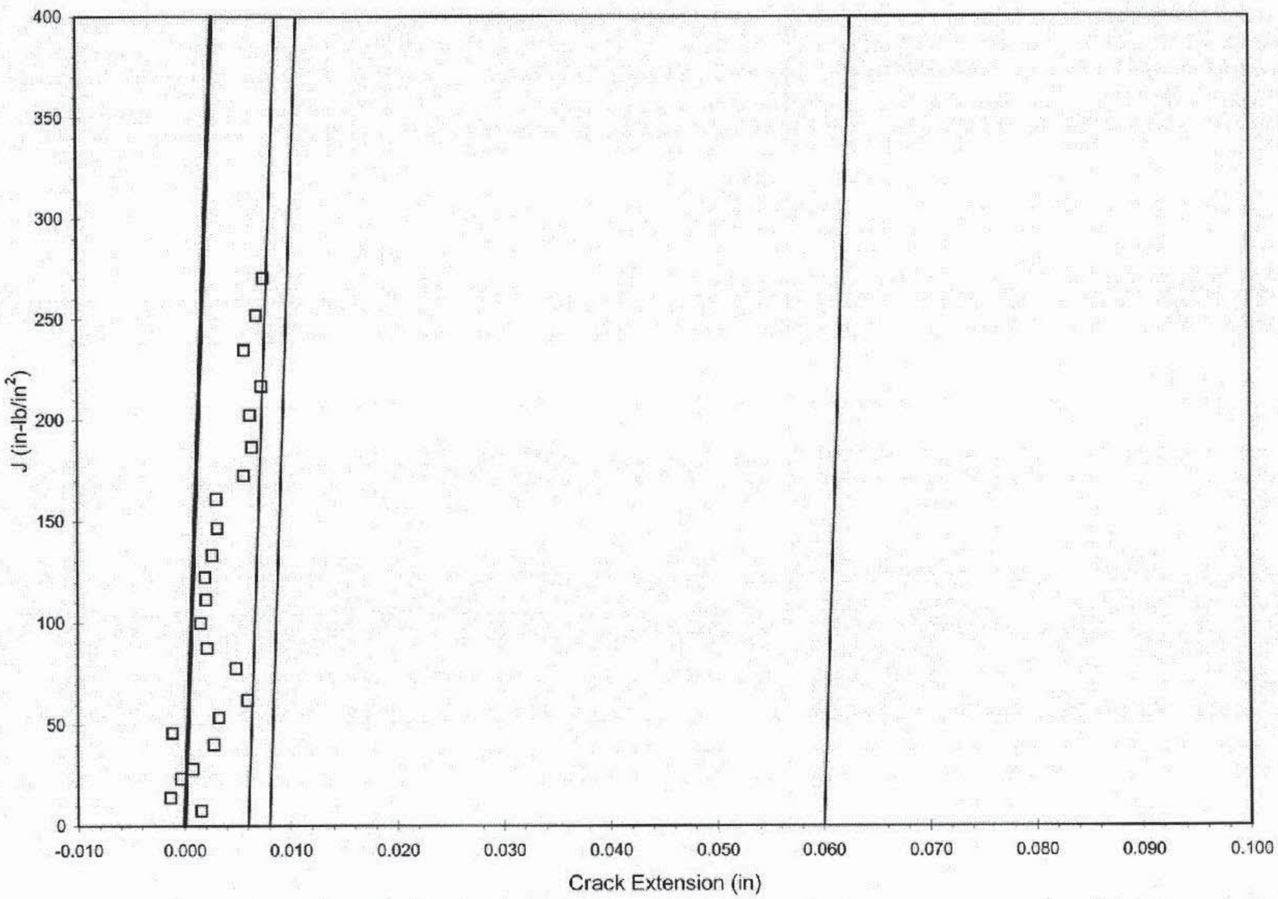
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05269
TEST DATE : 7/18/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-W-4

J_c = 290.20 in-lb/in^2



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Westmoreland Mechanical Testing & Research, Inc.

Force vs. COD Graph

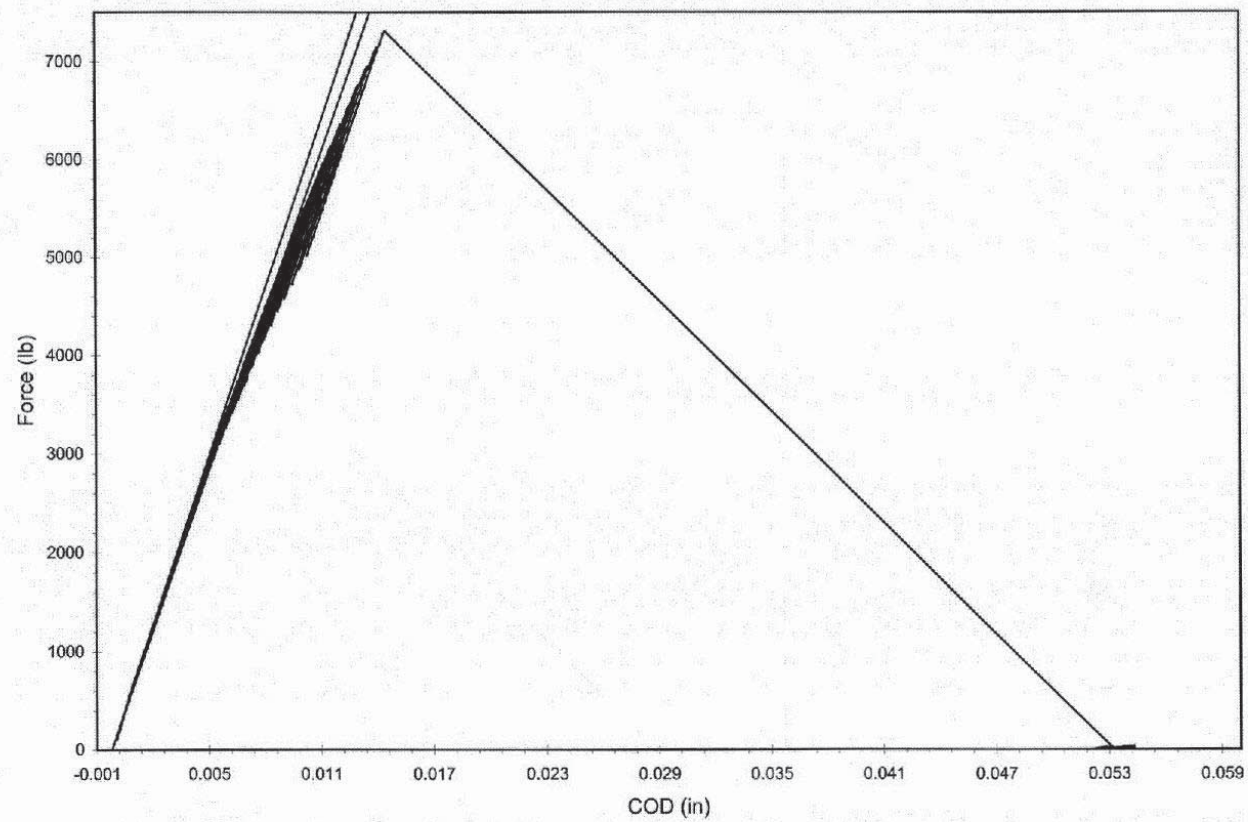
Phone (724) 537-3131

CUSTOMER : SOUTHWEST RESEARCH
WMT&R NO. : 3-67089
P.O. NO. : F58154BT
WMT&R QUOTE : QN121622 REV.1

TESTLOG : T05269
TEST DATE : 7/18/2013
TEMPERATURE : -20°F
MATERIAL : Steel

SPECIMEN : KC-H-W-4

P_{max} = 7309.8 lb
P_Q = 4907.7 lb
K_Q = 60.7 ksi(in)$^{1/2}$



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A-225 Gr. B HEAD
FATIGUE CRACK GROWTH

ID	*Material*	*Orientation*	*Temp*	*R*
FCG-3	Base Head	T-L	RT	0.10
FCG-5				0.70
FCG-8				0.70
FCG-4			-20°F	0.10
FCG-7				0.15
FCG-6				0.70
FCG-H-H-1	Head HAZ	T-L	RT	0.15
FCG-H-H-2				
FCG-H-H-3				0.70
FCG-H-H-4				
FCG-H-W-1	Head Weld	L-C (vessel)	RT	0.15
FCG-H-W-2				
FCG-H-W-3				0.70
FCG-H-W-4				

Automated Fatigue Crack
Growth Rate Analysis

Test ID	fcg-3	Geometry	C(T)
Contract	Head	Orientation	T-L
Material	Steel	Yield (ksi)	52.5
Temperature (F)	71	Modulus (Msi)	27.5
Environment	lab air		

Specimen Dimensions (in)

Thickness	0.393	Height	0.000
Net Thickness	0.393	Notch Depth	0.000
Width	1.998	Gage Length	0.700

Precrack Parameters

Pmax (lbs)	1800.0	Stress Ratio	0.10
Final a (in)	0.430	Kmax (ksi sqr[in])	14.48

Test Parameters

EvBP	Freq	Pmax	R	Ai	Kmaxi	C	DKi
18.626	20.32	2800	0.10	0.000	0.00	0.00	0.00

K Coeff	C Coeff
.886	1.001
4.64	-4.6695
-13.32	18.46
14.72	-236.82
-5.6	1214.9
.	-2143.6

Visual Observations

EvB/P	Crack(EvB/P)	Crack(visual)	Error	CAF
18.626	0.427	0.430	0.003	0.994
22.838	0.546	0.544	-0.002	0.993
29.965	0.696	0.695	-0.001	0.993
40.032	0.846	0.847	0.001	0.992
54.956	0.997	0.997	0.000	0.991

Comments

Date of test: 7/8/2013
Waveform Type Sine

Test ID fcg-3 Page 1

Pmax (lb)	EvB/P	a (in)	N	da (in)	dN	da/dN (in/cyc)	Kmax (ksi[in]^.5)	deltaK
	18.63	0.4275	15					
2800	18.72	0.4306	889	0.0095	2731	3.475E-6	22.550	20.302
2800	18.92	0.4369	2746	0.0133	3889	3.425E-6	22.760	20.484
2800	19.15	0.4440	4778	0.0140	4057	3.449E-6	22.977	20.679
2800	19.37	0.4509	6803	0.0140	4005	3.485E-6	23.206	20.885
2800	19.60	0.4579	8783	0.0142	3910	3.633E-6	23.440	21.096
2800	19.84	0.4651	10713	0.0143	3765	3.791E-6	23.671	21.304
2800	20.08	0.4722	12548	0.0140	3602	3.894E-6	23.907	21.516
2800	20.32	0.4792	14315	0.0140	3489	4.005E-6	24.140	21.726
2800	20.57	0.4862	16037	0.0140	3359	4.154E-6	24.373	21.936
2800	20.82	0.4931	17674	0.0142	3274	4.340E-6	24.612	22.151
2800	21.08	0.5004	19311	0.0144	3274	4.387E-6	24.850	22.365
2800	21.34	0.5075	20948	0.0140				

2800	21.59	0.5144	22463	0.0140	2910	4.825E-6	25.332	22.799	
2800	21.86	0.5215	23858	0.0140	2728	5.123E-6	25.566	23.010	
2800	22.13	0.5284	25191	0.0139	2727	5.106E-6	25.812	23.230	
2800	22.40	0.5355	26585	0.0143	2789	5.113E-6	26.053	23.448	
2800	22.69	0.5426	27980	0.0139	2670	5.215E-6	26.294	23.665	
2800	22.96	0.5494	29255	0.0138	2549	5.429E-6	26.543	23.889	
2800	23.24	0.5564	30529	0.0144	2547	5.638E-6	26.790	24.111	
2800	23.55	0.5637	31802	0.0141	2425	5.823E-6	27.036	24.333	
2800	23.83	0.5706	32954	0.0135	2279	5.942E-6	27.285	24.557	
2800	24.12	0.5773	34081	0.0136	2243	6.075E-6	27.532	24.779	
2800	24.42	0.5842	35197	0.0139	2183	6.350E-6	27.778	25.000	
2800	24.72	0.5911	36264	0.0140	2134	6.576E-6	28.032	25.229	
2800	25.04	0.5982	37331	0.0140	2086	6.714E-6	28.286	25.457	
2800	25.35	0.6051	38350	0.0141	2037	6.907E-6	28.548	25.693	
2800	25.68	0.6123	39368	0.0144	2036	7.081E-6	28.811	25.930	
2800	26.02	0.6196	40386	0.0141	1940	7.264E-6	29.072	26.165	
2800	26.34	0.6264	41308	0.0137	1825	7.523E-6	29.339	26.405	
2800	26.68	0.6333	42211	0.0138	1798	7.692E-6	29.600	26.640	
2800	27.02	0.6402	43106	0.0139	1789	7.790E-6	29.865	26.879	
2800	27.36	0.6472	44000	0.0143	1789	7.972E-6	30.139	27.125	
2800	27.73	0.6545	44895	0.0141	1712	8.231E-6	30.408	27.367	
2800	28.08	0.6613	45712	0.0137	1634	8.390E-6	30.685	27.617	
2800	28.44	0.6682	46529	0.0138	1634	8.458E-6	30.958	27.862	
2800	28.81	0.6751	47346	0.0141	1633	8.619E-6	31.237	28.113	
2800	29.19	0.6823	48162	0.0142	1595	8.887E-6	31.519	28.367	
2800	29.57	0.6893	48941	0.0138	1505	9.201E-6	31.802	28.622	
2800	29.95	0.6961	49667	0.0139	1447	9.572E-6	32.091	28.882	
2800	30.35	0.7032	50388	0.0141	1441	9.802E-6	32.379	29.141	
2800	30.75	0.7102	51108	0.0140	1409	9.921E-6	32.671	29.404	
2800	31.15	0.7171	51797	0.0138	1348	1.020E-5	32.965	29.669	
2800	31.56	0.7240	52456	0.0141	1348	1.046E-5	33.267	29.941	
2800	32.00	0.7312	53145	0.0143	1346	1.063E-5	33.568	30.211	
2800	32.43	0.7383	53802	0.0140	1284	1.088E-5	33.876	30.489	
2800	32.86	0.7452	54429	0.0141	1253	1.127E-5	34.191	30.772	
2800	33.31	0.7524	55055	0.0142	1221	1.163E-5	34.501	31.051	
2800	33.76	0.7594	55650	0.0138	1175	1.175E-5	34.817	31.335	
2800	34.21	0.7662	56230	0.0137	1149	1.193E-5	35.134	31.620	
2800	34.66	0.7731	56799	0.0138	1138	1.213E-5	35.451	31.905	
2800	35.13	0.7800	57368	0.0139	1138	1.225E-5	35.775	32.198	
2800	35.61	0.7871	57937	0.0139	1114	1.246E-5	36.101	32.490	
2800	36.09	0.7939	58482	0.0141	1089	1.298E-5	36.442	32.798	
2800	36.61	0.8012	59026	0.0144	1065	1.355E-5	36.782	33.103	
2800	37.13	0.8083	59547	0.0141	1016	1.385E-5	37.130	33.416	
2800	37.64	0.8153	60042	0.0139	990	1.407E-5	37.481	33.733	
2800	38.16	0.8223	60537	0.0139	965	1.436E-5	37.828	34.045	
2800	38.69	0.8291	61007	0.0138	935	1.475E-5	38.183	34.365	
2800	39.23	0.8361	61472	0.0140	930	1.506E-5	38.542	34.688	
2800	39.78	0.8431	61937	0.0142	912	1.553E-5	38.910	35.019	
2800	40.36	0.8502	62384	0.0140	872	1.605E-5	39.281	35.352	
2800	40.92	0.8571	62809	0.0139	850	1.630E-5	39.659	35.693	
2800	41.50	0.8641	63234	0.0140	849	1.647E-5	40.039	36.035	
2800	42.10	0.8711	63658	0.0140	828	1.693E-5	40.426	36.383	
2800	42.71	0.8781	64062	0.0140	788	1.773E-5	40.819	36.736	
2800	43.32	0.8851	64446	0.0138	759	1.820E-5	41.213	37.092	
2800	43.93	0.8919	64821	0.0141	763	1.842E-5	41.624	37.461	
2800	44.60	0.8991	65209	0.0144	760	1.899E-5	42.037	37.833	
2800	45.27	0.9063	65581	0.0142	711	1.995E-5	42.459	38.213	
2800	45.93	0.9133	65920	0.0138	663	2.088E-5	42.887	38.598	
2800	46.60	0.9202	66244	0.0139	664	2.091E-5	43.316	38.984	
2800	47.29	0.9272	66584	0.0140	663	2.112E-5	43.751	39.375	
2800	48.00	0.9342	66907	0.0137	620	2.216E-5	44.186	39.767	
2800	48.69	0.9409	67204	0.0138	600	2.303E-5	44.642	40.177	
2800	49.43	0.9480	67507	0.0142	594	2.384E-5	45.094	40.585	
2800	50.19	0.9551	67798	0.0140	569	2.459E-5	45.561	41.004	
2800	50.95	0.9620	68076	0.0141	555	2.535E-5	46.044	41.440	
2800	51.74	0.9692	68353	0.0142	542	2.614E-5	46.524	41.871	
2800	52.54	0.9762	68618	0.0140	518	2.708E-5	47.022	42.320	
2800	53.36	0.9832	68871	0.0141	505	2.793E-5	47.525	42.772	*
2800	54.20	0.9903	69123	0.0142	494	2.880E-5	48.039	43.235	*
2800	55.06	0.9974	69365	0.0143	468	3.055E-5	48.567	43.709	*
2800	55.95	1.0046	69591	0.0139					

2800	56.80	1.0113	69803	0.0135	425	3.171E-5	49.623	44.660	*
2800	57.66	1.0180	70016	0.0141	436	3.227E-5	50.173	45.155	*
2800	58.63	1.0254	70239	0.0146	435	3.348E-5	50.729	45.655	*
2800	59.60	1.0326	70451	0.0143	404	3.551E-5	51.314	46.181	*
2800	60.58	1.0397	70643	0.0137	364	3.774E-5	51.888	46.697	*
2800	61.51	1.0464	70815	0.0135	349	3.880E-5	52.478	47.229	*
2800	62.51	1.0533	70992	0.0141	355	3.964E-5	53.070	47.762	*
2800	63.56	1.0604	71170	0.0140	340	4.108E-5	53.670	48.301	*
2800	64.58	1.0672	71332	0.0141	323	4.356E-5	54.314	48.881	*
2800	65.70	1.0745	71493	0.0143	315	4.538E-5	54.943	49.447	*
2800	66.81	1.0815	71647	0.0139	299	4.651E-5	55.599	50.038	*
2800	67.91	1.0884	71792	0.0138	283	4.868E-5	56.260	50.631	*
2800	69.05	1.0953	71930	0.0141	275	5.141E-5	56.941	51.245	*
2800	70.28	1.1025	72067	0.0143	269	5.318E-5	57.631	51.864	*
2800	71.50	1.1096	72199	0.0140	252	5.544E-5	58.343	52.507	*
2800	72.72	1.1165	72319	0.0142	242	5.860E-5	59.081	53.169	*
2800	74.05	1.1238	72441	0.0142	233	6.086E-5	59.806	53.823	*
2800	75.33	1.1307	72552	0.0138	216	6.366E-5	60.566	54.505	*
2800	76.64	1.1375	72657	0.0142	214	6.616E-5	61.343	55.205	*
2800	78.07	1.1448	72766	0.0143	218	6.571E-5	62.121	55.903	*
2800	79.48	1.1519	72875	0.0141	214	6.595E-5	62.947	56.648	*
2800	80.94	1.1590	72980	0.0141	200	7.055E-5	63.769	57.385	*
2800	82.43	1.1660	73075	0.0140	182	7.670E-5	64.609	58.142	*
2800	83.93	1.1729	73162	0.0146	145	1.006E-4	65.507	58.946	*
2799	85.64	1.1806	73220	0.0141	109	1.298E-4	66.353	59.708	*
2800	87.13	1.1871	73271	0.0134	115	1.164E-4	67.283	60.542	*
2800	88.75	1.1940	73335	0.0138	131	1.050E-4	68.164	61.338	*
2800	90.41	1.2008	73402	0.0144	130	1.108E-4	69.126	62.202	*
2799	92.28	1.2084	73465	0.0143	113	1.267E-4	70.064	63.042	*

Automated Fatigue Crack
Growth Rate Analysis

Test ID	fcg-5	Geometry	C(T)
Contract	Head	Orientation	T-L
Material	Steel	Yield (ksi)	52.5
Temperature (F)	71	Modulus (Msi)	26.8
Environment	lab air		

Specimen Dimensions (in)

Thickness	0.399	Height	0.000
Net Thickness	0.399	Notch Depth	0.000
Width	1.997	Gage Length	0.700

Precrack Parameters

Pmax (lbs)	4500.0	Stress Ratio	0.10
Final a (in)	0.432	Kmax (ksi sqr[in])	35.78

Test Parameters

EvBP	Freq	Pmax	R	Ai	Kmaxi	C	DKi
18.594	14.32	4500	0.70	0.000	0.00	0.00	0.00

K Coeff	C Coeff
.886	1.001
4.64	-4.6695
-13.32	18.46
14.72	-236.82
-5.6	1214.9
.	-2143.6

Visual Observations

EvB/P	Crack(EvB/P)	Crack(visual)	Error	CAF
18.602	0.433	0.432	-0.001	1.006
20.942	0.506	0.507	0.001	1.010
24.961	0.609	0.610	0.001	1.016
36.282	0.814	0.814	-0.001	1.028

Comments

Date of test: 7/15/2013
Waveform Type Sine

Test ID fcg-5 Page 1

Pmax (lb)	EvB/P	a (in)	N	da (in)	dN	da/dN (in/cyc)	Kmax (ksi[in]^.5)	deltaK
	18.59	0.4332	861					
4500	18.63	0.4344	3500	0.0056	12244	4.598E-7	35.984	10.830
4500	18.76	0.4389	13105	0.0119	24603	4.817E-7	36.205	10.862
4500	18.99	0.4462	28103	0.0146	28980	5.046E-7	36.508	10.952
4500	19.21	0.4535	42085	0.0144	27430	5.262E-7	36.887	11.066
4500	19.44	0.4607	55533	0.0145	26740	5.429E-7	37.267	11.180
4500	19.67	0.4680	68825	0.0146	26443	5.516E-7	37.646	11.294
4500	19.91	0.4753	81976	0.0145	25894	5.590E-7	38.028	11.408
4500	20.15	0.4825	94719	0.0145	25050	5.790E-7	38.412	11.524
4500	20.39	0.4898	107026	0.0145	24132	6.012E-7	38.795	11.638
4500	20.64	0.4970	118851	0.0145	23121	6.277E-7	39.184	11.755
4500	20.89	0.5043	130147	0.0146	22289	6.553E-7	39.573	11.872
4500	21.15	0.5116	141140	0.0146	21784	6.686E-7	39.964	11.989
4500	21.40	0.5188	151931	0.0145	21410	6.757E-7	40.357	12.107

4500	21.66	0.5260	162550	0.0147	21369	6.858E-7	40.757	12.227	
4500	21.94	0.5335	173300	0.0147	21240	6.916E-7	41.152	12.346	
4500	22.21	0.5407	183790	0.0146	20548	7.089E-7	41.558	12.468	
4500	22.49	0.5481	193848	0.0147	19756	7.423E-7	41.962	12.589	
4500	22.77	0.5554	203546	0.0145	18678	7.747E-7	42.364	12.709	
4500	23.05	0.5625	212526	0.0142	17600	8.080E-7	42.768	12.831	
4500	23.33	0.5696	221146	0.0144	17241	8.331E-7	43.174	12.952	
4500	23.62	0.5769	229767	0.0144	16883	8.556E-7	43.579	13.074	
4500	23.91	0.5841	238029	0.0146	16524	8.808E-7	43.998	13.199	
4500	24.22	0.5914	246291	0.0147	16164	9.110E-7	44.415	13.325	
4500	24.53	0.5988	254193	0.0142	15086	9.416E-7	44.828	13.448	
4500	24.82	0.6057	261377	0.0130	15448	8.422E-7	45.221	13.566	
4500	25.09	0.6118	269641	0.0145	16166	8.939E-7	45.667	13.700	
4500	25.46	0.6201	277543	0.0157	14585	1.074E-6	46.067	13.820	
4500	25.79	0.6275	284226	0.0146	13294	1.098E-6	46.531	13.959	
4500	26.12	0.6347	290837	0.0144	13223	1.092E-6	46.969	14.091	
4500	26.45	0.6419	297449	0.0143	12936	1.109E-6	47.406	14.222	
4500	26.79	0.6490	303773	0.0142	12360	1.151E-6	47.843	14.353	
4500	27.13	0.6561	309809	0.0145	12074	1.203E-6	48.293	14.488	
4500	27.49	0.6636	315847	0.0146	11500	1.267E-6	48.736	14.621	
4500	27.84	0.6707	321309	0.0141	10807	1.305E-6	49.189	14.757	
4500	28.19	0.6777	326654	0.0141	10861	1.302E-6	49.643	14.893	
4500	28.55	0.6848	332170	0.0145	10803	1.345E-6	50.102	15.031	
4500	28.94	0.6922	337457	0.0145	10115	1.429E-6	50.563	15.169	
4500	29.31	0.6993	342285	0.0144	9654	1.489E-6	51.042	15.312	
4500	29.70	0.7066	347111	0.0146	9653	1.514E-6	51.518	15.455	
4500	30.10	0.7139	351938	0.0144	9195	1.563E-6	51.995	15.598	
4500	30.49	0.7209	356306	0.0142	8643	1.646E-6	52.484	15.745	
4500	30.89	0.7281	360581	0.0144	8505	1.695E-6	52.970	15.891	*
4500	31.30	0.7354	364811	0.0143	8275	1.733E-6	53.462	16.039	*
4500	31.72	0.7425	368856	0.0144	7907	1.820E-6	53.967	16.190	*
4500	32.15	0.7498	372718	0.0143	7540	1.896E-6	54.464	16.339	*
4500	32.57	0.7568	376396	0.0141	7172	1.959E-6	54.973	16.492	*
4500	33.00	0.7638	379890	0.0142	6919	2.058E-6	55.486	16.646	*
4500	33.45	0.7710	383315	0.0143	6819	2.104E-6	56.002	16.801	*
4500	33.90	0.7782	386709	0.0143	6639	2.152E-6	56.531	16.959	*
4500	34.36	0.7853	389954	0.0144	6491	2.220E-6	57.069	17.121	*
4500	34.83	0.7926	393200	0.0146	6343	2.303E-6	57.617	17.285	*
4500	35.32	0.7999	396297	0.0142	5901	2.414E-6	58.158	17.447	*

Automated Fatigue Crack
Growth Rate Analysis

Test ID	fcg-8	Geometry	C(T)
Contract	Head	Orientation	T-L
Material	Steel	Yield (ksi)	52.5
Temperature (F)	71	Modulus (Msi)	27.5
Environment	lab air		

Specimen Dimensions (in)

Thickness	0.401	Height	0.000
Net Thickness	0.401	Notch Depth	0.000
Width	1.996	Gage Length	0.700

Precrack Parameters

Pmax (lbs)	6500.0	Stress Ratio	0.10
Final a (in)	0.448	Kmax (ksi sqr[in])	52.64

Test Parameters

EvBP	Freq	Pmax	R	Ai	Kmaxi	C	DKi
18.969	26.32	6500	0.70	0.000	0.00	0.00	0.00

K Coeff (T1)	C Coeff
.886	1.001
4.64	-4.6695
-13.32	18.46
14.72	-236.82
-5.6	1214.9
.	-2143.6

Visual Observations

EvB/P	Crack(EvB/P)	Crack(visual)	Error	CAF
18.783	0.446	0.448	0.002	1.018
22.866	0.563	0.561	-0.002	1.022
27.359	0.664	0.663	-0.001	1.026
36.371	0.817	0.818	0.001	1.031

Comments

Date of test: 7/2/2013
Waveform Type Sine

Pmax (lb)	EvB/P	a (in)	N	da/dN in/cyc)	Kmax (ksi[in]^.5)	deltaK	
6500	19.3200	0.46325	11306	1.57E-06	53.3638	16.0240	
6500	19.6312	0.47288	16820	1.75E-06	54.1442	16.2433	
6500	19.9435	0.48234	22123	1.79E-06	54.8671	16.4601	
6500	20.2646	0.49188	27167	1.89E-06	55.5908	16.6772	
6500	20.5888	0.50132	31768	2.05E-06	56.3176	16.8952	
6500	20.9186	0.51073	36170	2.14E-06	57.0441	17.1132	*
6500	21.2610	0.52031	40385	2.27E-06	57.7807	17.3343	*
6500	21.6059	0.52976	44302	2.41E-06	58.5239	17.5572	*
6500	21.9594	0.53925	48076	2.52E-06	59.2691	17.7807	*
6500	22.3254	0.54888	51766	2.61E-06	60.0271	18.0081	*
6500	22.6932	0.55836	55208	2.75E-06	60.7906	18.2371	*
6500	23.0819	0.56818	58507	2.98E-06	61.5678	18.4703	*
6500	23.4579	0.57748	61568	3.04E-06	62.3445	18.7034	*
6500	23.8446	0.58686	64511	3.19E-06	63.1101	18.9330	*
6500	24.2573	0.59666	67454	3.33E-06	63.9033	19.1709	*
6500	24.6693	0.60625	70162	3.54E-06	64.7127	19.4138	*
6500	25.0768	0.61553	72751	3.59E-06	65.5083	19.6525	*

6500	25.5080	0.62516	75222	3.90E-06	66.3138	19.8943	*
6500	25.9403	0.63462	77577	4.01E-06	67.1348	20.1405	*
6500	26.3717	0.64386	79813	4.13E-06	67.9479	20.3843	*
6500	26.8109	0.65308	81911	4.39E-06	68.7596	20.6279	*
6500	27.2606	0.66233	83896	4.66E-06	69.5806	20.8740	*
6500	27.7392	0.67197	85882	4.85E-06	70.4302	21.1289	*
6500	28.2264	0.68157	87866	4.84E-06	71.3063	21.3918	*
6500	28.7228	0.69115	89756	5.07E-06	72.1906	21.6571	*
6500	29.2251	0.70063	91551	5.28E-06	73.0807	21.9241	*
6500	29.7215	0.70980	93159	5.71E-06	73.9635	22.1889	*
6500	30.2345	0.71909	94751	5.83E-06	74.8485	22.4544	*
6500	30.7745	0.72865	96342	6.01E-06	75.7644	22.7293	*
6500	31.3023	0.73780	97858	6.03E-06	76.6865	23.0059	*
6500	31.8705	0.74743	99373	6.36E-06	77.6256	23.2875	*
6500	32.4516	0.75706	100812	6.69E-06	78.6033	23.5809	*
6500	33.0204	0.76628	102162	6.83E-06	79.5747	23.8723	*
6500	33.5991	0.77546	103496	6.88E-06	80.5374	24.1611	*
6500	34.2076	0.78489	104829	7.08E-06	81.5267	24.4579	*
6500	34.8183	0.79415	106102	7.27E-06	82.5363	24.7608	*
6500	35.4801	0.80395	107255	8.50E-06	83.5829	25.0748	*
6500	36.0968	0.81288	108285	8.67E-06	84.6291	25.3888	*
6500	36.8758	0.82375	109113	1.31E-05	85.7546	25.7265	*
6500	37.4830	0.83197	109842	1.13E-05	86.8597	26.0579	*
6500	38.1403	0.84068	110658	1.07E-05	87.8569	26.3569	*
6500	38.8283	0.84960	111397	1.21E-05	88.9122	26.6734	*
6500	39.6918	0.86050	111834	2.50E-05	90.1209	27.0357	*
6500	40.3600	0.86873	112083	3.31E-05	91.3108	27.3924	*
6500	41.1610	0.87837	112348	3.64E-05	92.4428	27.7313	*

Automated Fatigue Crack
Growth Rate Analysis

Test ID	fcg-4	Geometry	C(T)
Contract	Head	Orientation	T-L
Material	Steel	Yield (ksi)	52.5
Temperature (F)	-20	Modulus (Msi)	27.7
Environment	cold chamber		

Specimen Dimensions (in)

Thickness	0.400	Height	0.000
Net Thickness	0.400	Notch Depth	0.000
Width	1.996	Gage Length	0.200

Precrack Parameters

Pmax (lbs)	1800.0	Stress Ratio	0.10
Final a (in)	0.432	Kmax (ksi sqr[in])	14.30

Test Parameters

EvBP	Freq	Pmax	R	Ai	Kmaxi	C	DKi
18.652	14.00	2800	0.10	0.000	0.00	0.00	0.00

K Coeff	C Coeff
.886	1.001
4.64	-4.6695
-13.32	18.46
14.72	-236.82
-5.6	1214.9
.	-2143.6

Visual Observations

EvB/P	Crack(EvB/P)	Crack(visual)	Error	CAF
18.369	0.432	0.432	0.000	1.016
96.621	1.221	1.221	0.000	0.984

Comments

Date of test: 7/11/2013
Waveform Type Sine

Test ID fcg-4 Page 1

Pmax (lb)	EvB/P	a (in)	N	da (in)	dN	da/dN (in/cyc)	Kmax (ksi[in]^.5)	deltaK
	18.65	0.4409	128					
2800	18.72	0.4432	1213	0.0045	2061	2.196E-6	22.533	20.280
2800	18.80	0.4454	2189	0.0031	1395	2.191E-6	22.654	20.389
2800	18.82	0.4462	2608	0.0052	2417	2.135E-6	22.761	20.485
2800	18.97	0.4506	4606	0.0112	5174	2.170E-6	22.885	20.596
2800	19.19	0.4575	7782	0.0137	6327	2.167E-6	23.066	20.759
2800	19.42	0.4643	10933	0.0138	6291	2.192E-6	23.291	20.962
2800	19.66	0.4713	14073	0.0139	6121	2.266E-6	23.515	21.164
2800	19.90	0.4782	17054	0.0136	5801	2.348E-6	23.739	21.365
2800	20.13	0.4849	19874	0.0135	5635	2.399E-6	23.965	21.569
2800	20.37	0.4917	22689	0.0136	5510	2.469E-6	24.188	21.769
2800	20.62	0.4985	25384	0.0137	5413	2.527E-6	24.415	21.974
2800	20.87	0.5054	28102	0.0140	5471	2.564E-6	24.648	22.183
2800	21.14	0.5125	30855	0.0140	5411	2.580E-6	24.877	22.389
2800	21.39	0.5193	33513	0.0134	5221	2.568E-6	25.108	22.598
2800	21.65	0.5259	36076	0.0134	5126	2.624E-6	25.340	22.806

2800	21.91	0.5328	38639	0.0139	5126	2.706E-6	25.571	23.014	
2800	22.19	0.5398	41202	0.0138	5126	2.689E-6	25.804	23.224	
2800	22.46	0.5466	43765	0.0134	5315	2.518E-6	26.038	23.435	
2800	22.73	0.5532	46517	0.0132	5600	2.364E-6	26.270	23.643	
2800	23.01	0.5598	49365	0.0135	5696	2.368E-6	26.504	23.854	
2800	23.29	0.5667	52213	0.0139	5791	2.400E-6	26.743	24.069	
2800	23.59	0.5737	55156	0.0139	5881	2.359E-6	26.984	24.286	
2800	23.89	0.5805	58094	0.0137	5895	2.324E-6	27.231	24.508	
2800	24.19	0.5874	61051	0.0137	5913	2.314E-6	27.474	24.727	
2800	24.49	0.5942	64007	0.0136	5677	2.394E-6	27.719	24.947	
2800	24.80	0.6010	66728	0.0135	5441	2.472E-6	27.962	25.166	
2800	25.10	0.6077	69448	0.0137	5440	2.510E-6	28.213	25.392	
2800	25.43	0.6147	72168	0.0138	5435	2.544E-6	28.461	25.615	
2800	25.75	0.6215	74883	0.0138	5426	2.551E-6	28.719	25.847	
2800	26.09	0.6285	77594	0.0137	5184	2.644E-6	28.971	26.074	
2800	26.42	0.6352	80067	0.0135	4826	2.791E-6	29.229	26.306	
2800	26.75	0.6420	82420	0.0138	4707	2.935E-6	29.489	26.540	
2800	27.11	0.6490	84774	0.0138	4590	3.002E-6	29.746	26.771	
2800	27.45	0.6557	87010	0.0135	4428	3.042E-6	30.011	27.010	
2800	27.80	0.6625	89202	0.0135	4270	3.170E-6	30.272	27.245	
2800	28.16	0.6693	91280	0.0136	4061	3.338E-6	30.536	27.483	
2800	28.52	0.6760	93263	0.0139	4061	3.412E-6	30.810	27.729	
2800	28.91	0.6831	95341	0.0140	4063	3.447E-6	31.082	27.974	
2800	29.29	0.6901	97326	0.0138	3877	3.551E-6	31.362	28.225	
2800	29.67	0.6969	99218	0.0136	3687	3.688E-6	31.638	28.474	
2800	30.06	0.7036	101013	0.0135	3554	3.802E-6	31.917	28.725	
2800	30.45	0.7104	102772	0.0136	3501	3.896E-6	32.198	28.978	
2800	30.85	0.7173	104514	0.0136	3409	3.986E-6	32.479	29.231	
2800	31.25	0.7240	106181	0.0135	3334	4.061E-6	32.768	29.491	
2800	31.67	0.7308	107848	0.0136	3257	4.162E-6	33.053	29.748	
2800	32.08	0.7376	109438	0.0136	3181	4.278E-6	33.348	30.013	
2800	32.52	0.7444	111029	0.0138	3182	4.341E-6	33.645	30.280	
2800	32.96	0.7514	112620	0.0139	3106	4.487E-6	33.950	30.555	
2800	33.41	0.7584	114135	0.0141	2955	4.782E-6	34.262	30.836	
2800	33.88	0.7655	115575	0.0139	2728	5.081E-6	34.571	31.114	
2800	34.34	0.7722	116863	0.0133	2504	5.298E-6	34.881	31.393	
2800	34.78	0.7788	118079	0.0132	2429	5.448E-6	35.190	31.671	
2800	35.25	0.7855	119292	0.0136	2425	5.596E-6	35.501	31.951	
2800	35.73	0.7923	120504	0.0139	2424	5.731E-6	35.824	32.242	
2800	36.24	0.7994	121716	0.0139	2364	5.861E-6	36.150	32.535	
2800	36.73	0.8062	122868	0.0135	2231	6.068E-6	36.481	32.833	
2800	37.23	0.8129	123947	0.0136	2145	6.335E-6	36.816	33.135	
2800	37.75	0.8198	125013	0.0138	2133	6.476E-6	37.153	33.438	
2800	38.28	0.8267	126080	0.0139	2085	6.653E-6	37.499	33.749	
2800	38.83	0.8337	127098	0.0140	1988	7.051E-6	37.855	34.069	
2800	39.39	0.8407	128068	0.0140	1891	7.418E-6	38.212	34.391	
2800	39.96	0.8477	128989	0.0136	1785	7.641E-6	38.571	34.713	
2800	40.51	0.8544	129853	0.0134	1720	7.811E-6	38.932	35.039	
2800	41.08	0.8611	130709	0.0137	1711	8.021E-6	39.298	35.369	
2800	41.67	0.8681	131564	0.0137	1672	8.223E-6	39.666	35.699	
2800	42.26	0.8749	132381	0.0135	1595	8.489E-6	40.044	36.040	
2800	42.86	0.8816	133159	0.0139	1555	8.957E-6	40.434	36.390	
2800	43.51	0.8888	133936	0.0142	1516	9.391E-6	40.826	36.744	
2800	44.16	0.8959	134675	0.0137	1434	9.544E-6	41.222	37.100	
2800	44.79	0.9025	135370	0.0134	1384	9.699E-6	41.628	37.465	
2800	45.44	0.9093	136059	0.0139	1378	1.006E-5	42.034	37.830	
2800	46.13	0.9163	136748	0.0137	1348	1.019E-5	42.440	38.196	
2800	46.79	0.9230	137407	0.0134	1287	1.040E-5	42.860	38.574	
2800	47.47	0.9297	138035	0.0136	1256	1.084E-5	43.283	38.954	
2800	48.18	0.9366	138663	0.0139	1223	1.134E-5	43.713	39.342	
2800	48.92	0.9436	139258	0.0140	1149	1.215E-5	44.160	39.744	
2800	49.67	0.9506	139812	0.0138	1073	1.289E-5	44.608	40.147	
2800	50.42	0.9574	140331	0.0134	1014	1.324E-5	45.059	40.553	
2800	51.16	0.9640	140826	0.0137	990	1.381E-5	45.527	40.974	
2800	51.96	0.9711	141321	0.0142	990	1.435E-5	45.998	41.398	
2800	52.79	0.9782	141816	0.0142	966	1.473E-5	46.491	41.841	
2800	53.64	0.9853	142287	0.0136	895	1.522E-5	46.975	42.278	*
2800	54.43	0.9918	142711	0.0135	848	1.594E-5	47.483	42.734	*
2800	55.30	0.9988	143135	0.0140	849	1.655E-5	47.982	43.184	*
2800	56.19	1.0059	143560	0.0139	829	1.679E-5	48.499	43.649	*
2800	57.08	1.0127	143964	0.0138	787	1.758E-5	49.033	44.130	*

2800	58.00	1.0197	144347	0.0138	743	1.853E-5	49.561	44.605	*
2800	58.92	1.0265	144707	0.0136	716	1.902E-5	50.106	45.095	*
2800	59.86	1.0333	145063	0.0137	711	1.926E-5	50.654	45.589	*
2800	60.83	1.0402	145418	0.0138	695	1.990E-5	51.219	46.097	*
2800	61.83	1.0472	145758	0.0138	647	2.129E-5	51.789	46.609	*
2800	62.83	1.0540	146065	0.0135	604	2.227E-5	52.368	47.131	*
2800	63.83	1.0606	146362	0.0137	587	2.326E-5	52.965	47.668	*
2800	64.91	1.0676	146652	0.0138	568	2.437E-5	53.561	48.204	*
2800	65.99	1.0745	146930	0.0139	556	2.506E-5	54.195	48.775	*
2800	67.13	1.0816	147208	0.0141	543	2.604E-5	54.832	49.348	*
2800	68.30	1.0886	147473	0.0140	517	2.708E-5	55.491	49.941	*
2800	69.47	1.0956	147725	0.0141	492	2.866E-5	56.169	50.551	*
2800	70.71	1.1027	147965	0.0138	455	3.041E-5	56.834	51.151	*
2800	71.90	1.1094	148180	0.0133	397	3.344E-5	57.519	51.765	*
2800	73.09	1.1160	148362	0.0137	351	3.893E-5	58.218	52.395	*
2800	74.41	1.1231	148531	0.0141	339	4.159E-5	58.924	53.030	*
2800	75.75	1.1301	148701	0.0139	332	4.193E-5	59.665	53.697	*
2800	77.10	1.1370	148863	0.0137	316	4.347E-5	60.414	54.371	*
2800	78.46	1.1438	149017	0.0138	295	4.676E-5	61.181	55.062	*
2800	79.89	1.1508	149158	0.0138	272	5.088E-5	61.955	55.757	*
2800	81.34	1.1577	149289	0.0138	262	5.264E-5	62.756	56.480	*
2800	82.84	1.1646	149420	0.0141	263	5.354E-5	63.587	57.225	*
2800	84.42	1.1717	149552	0.0141	250	5.632E-5	64.420	57.976	*
2800	86.00	1.1787	149670	0.0139	226	6.147E-5	65.295	58.762	*
2800	87.63	1.1856	149778	0.0139	208	6.698E-5	66.169	59.549	*
2800	89.30	1.1926	149878	0.0135	190	7.121E-5	67.046	60.337	*
2800	90.92	1.1992	149968	0.0135	162	8.337E-5	67.959	61.158	*
2799	92.68	1.2061	150040	0.0144	129	1.118E-4	68.914	62.014	*

Automated Fatigue Crack
Growth Rate Analysis

Test ID	fcg-7	Geometry	C(T)
Contract	Head	Orientation	T-L
Material	Steel	Yield (ksi)	52.5
Temperature (F)	-20	Modulus (Msi)	28.4
Environment	cold chamber		

Specimen Dimensions (in)

Thickness	0.400	Height	0.000
Net Thickness	0.400	Notch Depth	0.000
Width	2.001	Gage Length	0.700

Precrack Parameters

Pmax (lbs)	1800.0	Stress Ratio	0.10
Final a (in)	0.428	Kmax (ksi sqr[in])	14.16

Test Parameters

EvBP	Freq	Pmax	R	Ai	Kmaxi	C	DKi
18.300	14.32	2800	0.15	0.000	0.00	0.00	0.00

K Coeff	C Coeff
.886	1.001
4.64	-4.6695
-13.32	18.46
14.72	-236.82
-5.6	1214.9
.	-2143.6

Visual Observations

EvB/P	Crack(EvB/P)	Crack(visual)	Error	CAF
18.235	0.428	0.428	0.000	1.015
68.982	1.115	1.115	0.000	1.037

Comments

Date of test: 7/23/2013
Waveform Type Sine

Test ID fcg-7 Page 1

Pmax (lb)	EvB/P	a (in)	N	da (in)	dN	da/dN (in/cyc)	Kmax (ksi[in]^.5)	deltaK
	18.30	0.4302	832					
2800	18.38	0.4328	2015	0.0068	3285	2.075E-6	22.179	18.854
2800	18.50	0.4370	4117	0.0111	5528	2.005E-6	22.356	19.003
2800	18.71	0.4438	7543	0.0140	6935	2.012E-6	22.538	19.157
2800	18.93	0.4509	11052	0.0144	6956	2.068E-6	22.764	19.350
2800	19.16	0.4582	14499	0.0143	6763	2.115E-6	22.992	19.543
2800	19.38	0.4653	17815	0.0146	6657	2.186E-6	23.232	19.747
2800	19.63	0.4728	21156	0.0146	6430	2.273E-6	23.461	19.942
2800	19.86	0.4799	24245	0.0139	5987	2.325E-6	23.695	20.141
2800	20.09	0.4867	27143	0.0142	5916	2.398E-6	23.931	20.342
2800	20.34	0.4941	30161	0.0147	5917	2.487E-6	24.165	20.540
2800	20.59	0.5014	33060	0.0143	5555	2.583E-6	24.402	20.742
2800	20.84	0.5084	35716	0.0142	5312	2.680E-6	24.644	20.948
2800	21.09	0.5156	38372	0.0142	5192	2.736E-6	24.877	21.146
2800	21.34	0.5226	40908	0.0140	4950	2.827E-6	25.117	21.349
2800	21.60	0.5296	43322	0.0142	4829	2.944E-6	25.355	21.552

2800	21.87	0.5368	45737	0.0144	4710	3.059E-6	25.597	21.757	
2800	22.14	0.5440	48032	0.0142	4539	3.132E-6	25.839	21.963	
2800	22.41	0.5510	50276	0.0141	4463	3.155E-6	26.084	22.171	
2800	22.68	0.5581	52495	0.0140	4343	3.229E-6	26.324	22.376	
2800	22.96	0.5651	54619	0.0140	4247	3.307E-6	26.571	22.585	
2800	23.24	0.5722	56742	0.0145	4245	3.420E-6	26.821	22.798	
2800	23.54	0.5796	58864	0.0145	4149	3.501E-6	27.071	23.011	
2800	23.84	0.5867	60891	0.0143	3958	3.613E-6	27.330	23.230	
2800	24.14	0.5939	62822	0.0141	3762	3.742E-6	27.579	23.442	
2800	24.43	0.6008	64653	0.0137	3627	3.788E-6	27.831	23.656	
2800	24.73	0.6076	66449	0.0141	3652	3.852E-6	28.086	23.873	
2800	25.04	0.6148	68305	0.0145	3634	3.998E-6	28.344	24.092	
2800	25.37	0.6221	70083	0.0144	3478	4.150E-6	28.607	24.316	
2800	25.69	0.6293	71783	0.0139	3323	4.186E-6	28.868	24.538	
2800	26.01	0.6361	73406	0.0137	3169	4.338E-6	29.130	24.761	
2800	26.33	0.6430	74952	0.0143	3093	4.620E-6	29.395	24.986	
2800	26.68	0.6503	76499	0.0148	3015	4.902E-6	29.669	25.218	
2800	27.04	0.6578	77967	0.0145	2785	5.205E-6	29.943	25.452	
2800	27.38	0.6648	79284	0.0140	2559	5.453E-6	30.220	25.687	
2800	27.73	0.6718	80526	0.0141	2485	5.691E-6	30.498	25.923	
2800	28.09	0.6790	81769	0.0143	2425	5.891E-6	30.772	26.156	
2800	28.45	0.6860	82951	0.0140	2286	6.116E-6	31.052	26.395	
2800	28.81	0.6930	84055	0.0139	2193	6.316E-6	31.332	26.632	
2800	29.18	0.6999	85144	0.0154	2128	7.235E-6	31.643	26.897	
2800	29.64	0.7084	86183	0.0140	2229	6.265E-6	31.896	27.112	
2800	29.94	0.7139	87373	0.0129	2477	5.193E-6	32.223	27.389	
2800	30.35	0.7212	88660	0.0143	2477	5.788E-6	32.482	27.610	
2800	30.74	0.7282	89850	0.0141	2378	5.940E-6	32.787	27.869	
2800	31.15	0.7353	91038	0.0144	2376	6.051E-6	33.089	28.126	
2800	31.58	0.7426	92226	0.0143	2327	6.150E-6	33.395	28.386	
2800	32.00	0.7497	93365	0.0139	2228	6.259E-6	33.701	28.646	
2800	32.41	0.7565	94454	0.0138	2178	6.348E-6	34.010	28.908	
2800	32.84	0.7635	95543	0.0141	2179	6.477E-6	34.321	29.173	
2800	33.28	0.7706	96633	0.0142	2179	6.539E-6	34.637	29.442	
2800	33.74	0.7777	97722	0.0143	2178	6.559E-6	34.963	29.718	
2800	34.20	0.7849	98811	0.0144	2178	6.602E-6	35.292	29.998	
2800	34.67	0.7921	99900	0.0142	2178	6.517E-6	35.622	30.279	
2800	35.14	0.7991	100989	0.0139	2128	6.521E-6	35.955	30.562	
2800	35.61	0.8060	102028	0.0139	2079	6.705E-6	36.290	30.847	
2800	36.10	0.8130	103068	0.0144	2081	6.917E-6	36.635	31.140	
2800	36.61	0.8204	104109	0.0142	1982	7.178E-6	36.976	31.430	
2800	37.11	0.8273	105050	0.0139	1864	7.458E-6	37.333	31.733	
2800	37.62	0.8343	105973	0.0142	1841	7.739E-6	37.688	32.035	
2800	38.15	0.8415	106891	0.0142	1796	7.919E-6	38.045	32.339	
2800	38.68	0.8485	107769	0.0140	1716	8.139E-6	38.413	32.651	
2800	39.22	0.8555	108607	0.0137	1636	8.371E-6	38.773	32.957	
2800	39.75	0.8622	109405	0.0139	1636	8.523E-6	39.151	33.278	
2800	40.32	0.8694	110243	0.0144	1637	8.824E-6	39.527	33.598	
2800	40.91	0.8766	111042	0.0141	1541	9.121E-6	39.911	33.924	
2800	41.47	0.8835	111784	0.0139	1473	9.405E-6	40.307	34.261	
2800	42.07	0.8905	112515	0.0139	1431	9.724E-6	40.694	34.590	
2800	42.66	0.8974	113215	0.0139	1400	9.935E-6	41.095	34.931	
2800	43.27	0.9044	113915	0.0141	1400	1.005E-5	41.501	35.276	
2800	43.90	0.9115	114615	0.0143	1400	1.023E-5	41.921	35.633	
2800	44.56	0.9187	115315	0.0144	1369	1.052E-5	42.347	35.996	
2800	45.22	0.9259	115984	0.0140	1273	1.099E-5	42.777	36.360	
2800	45.87	0.9327	116588	0.0139	1194	1.164E-5	43.217	36.734	
2800	46.55	0.9398	117178	0.0141	1171	1.201E-5	43.652	37.104	
2800	47.24	0.9468	117759	0.0141	1163	1.216E-5	44.105	37.490	
2800	47.96	0.9539	118341	0.0141	1138	1.238E-5	44.559	37.875	
2800	48.67	0.9609	118897	0.0139	1086	1.281E-5	45.025	38.271	
2800	49.39	0.9678	119427	0.0142	1060	1.343E-5	45.503	38.678	
2800	50.17	0.9751	119957	0.0144	1035	1.388E-5	45.983	39.086	
2800	50.94	0.9822	120462	0.0140	985	1.425E-5	46.479	39.507	
2800	51.71	0.9892	120942	0.0137	930	1.472E-5	46.967	39.922	*
2800	52.47	0.9959	121392	0.0136	894	1.525E-5	47.467	40.347	*
2800	53.27	1.0028	121836	0.0142	889	1.592E-5	47.979	40.782	*
2800	54.13	1.0100	122281	0.0143	869	1.648E-5	48.501	41.226	*
2800	54.98	1.0171	122705	0.0140	808	1.737E-5	49.041	41.685	*
2800	55.84	1.0241	123089	0.0139	759	1.833E-5	49.584	42.147	*
2800	56.71	1.0310	123464	0.0138	747	1.854E-5	50.131	42.611	*

2800	57.60	1.0379	123836	0.0140	744	1.879E-5	50.695	43.090	*
2800	58.53	1.0450	124208	0.0142	744	1.907E-5	51.268	43.578	*
2800	59.49	1.0521	124580	0.0142	711	1.995E-5	51.859	44.080	*

2800	60.46	1.0592	124919	0.0143	664	2.159E-5	52.471	44.600	*
2800	61.48	1.0664	125244	0.0141	633	2.232E-5	53.077	45.115	*
2800	62.47	1.0733	125552	0.0137	598	2.296E-5	53.702	45.646	*
2800	63.48	1.0802	125842	0.0139	566	2.448E-5	54.328	46.178	*
2800	64.54	1.0872	126118	0.0140	552	2.540E-5	54.968	46.723	*
2800	65.62	1.0942	126394	0.0139	552	2.518E-5	55.620	47.276	*
2800	66.71	1.1011	126670	0.0139	538	2.578E-5	56.292	47.848	*

Automated Fatigue Crack
Growth Rate Analysis

Test ID	fcg-6	Geometry	C(T)
Contract	Head	Orientation	T-L
Material	Steel	Yield (ksi)	52.5
Temperature (F)	-20	Modulus (Msi)	27.3
Environment	cold chamber		

Specimen Dimensions (in)

Thickness	0.398	Height	0.000
Net Thickness	0.398	Notch Depth	0.000
Width	2.000	Gage Length	0.700

Precrack Parameters

Pmax (lbs)	4500.0	Stress Ratio	0.10
Final a (in)	0.429	Kmax (ksi sqr[in])	35.65

Test Parameters

EvBP	Freq	Pmax	R	Ai	Kmaxi	C	DKi
18.553	14.32	4500	0.70	0.000	0.00	0.00	0.00

K Coeff	C Coeff
.886	1.001
4.64	-4.6695
-13.32	18.46
14.72	-236.82
-5.6	1214.9
.	-2143.6

Visual Observations

EvB/P	Crack(EvB/P)	Crack(visual)	Error	CAF
18.553	0.429	0.429	0.000	1.000
44.231	0.917	0.917	0.000	1.036

Comments

Date of test: 7/16/2013
Waveform Type Sine

Test ID fcg-6 Page 1

Pmax (lb)	EvB/P	a (in)	N	da (in)	dN	da/dN (in/cyc)	Kmax (ksi[in]^.5)	deltaK
	18.55	0.4290	5					
4500	18.47	0.4262	1414	0.0001	8496	1.161E-8	35.638	19.612
4500	18.56	0.4291	8501	0.0056	12966	4.320E-7	35.653	10.699
4500	18.64	0.4318	14380	0.0059	11892	4.938E-7	35.807	10.742
4500	18.73	0.4350	20393	0.0094	17551	5.369E-7	36.040	10.812
4500	18.92	0.4413	31931	0.0127	22852	5.545E-7	36.286	10.886
4500	19.11	0.4476	43245	0.0127	22422	5.677E-7	36.614	10.984
4500	19.31	0.4540	54353	0.0126	21716	5.816E-7	36.943	11.083
4500	19.50	0.4603	64961	0.0124	20748	6.000E-7	37.269	11.181
4500	19.70	0.4664	75101	0.0125	20337	6.141E-7	37.599	11.280
4500	19.90	0.4728	85298	0.0127	20351	6.251E-7	37.929	11.379
4500	20.11	0.4792	95452	0.0127	19879	6.387E-7	38.262	11.479
4500	20.32	0.4855	105177	0.0126	19275	6.514E-7	38.597	11.579
4500	20.53	0.4917	114727	0.0126	18949	6.663E-7	38.933	11.680
4500	20.74	0.4981	124126	0.0127	18569	6.833E-7	39.269	11.781
4500	20.96	0.5044	133296	0.0127	18365	6.891E-7	39.609	11.883

4500	21.18	0.5107	142491	0.0127	18104	6.993E-7	39.949	11.985	
4500	21.40	0.5171	151400	0.0126	17532	7.164E-7	40.288	12.087	
4500	21.62	0.5233	160023	0.0126	17247	7.278E-7	40.632	12.190	
4500	21.85	0.5296	168647	0.0128	17248	7.400E-7	40.977	12.293	
4500	22.09	0.5361	177271	0.0130	16676	7.787E-7	41.330	12.399	
4500	22.33	0.5426	185323	0.0124	15526	7.999E-7	41.669	12.501	
4500	22.55	0.5485	192797	0.0121	15236	7.925E-7	42.022	12.607	
4500	22.79	0.5547	200559	0.0126	15523	8.105E-7	42.363	12.709	
4500	23.03	0.5611	208320	0.0126	15235	8.254E-7	42.710	12.813	
4500	23.27	0.5673	215794	0.0124	14660	8.442E-7	43.063	12.919	
4500	23.52	0.5734	222980	0.0125	14372	8.731E-7	43.418	13.025	
4500	23.77	0.5798	230166	0.0128	14373	8.896E-7	43.777	13.133	
4500	24.04	0.5862	237353	0.0124	13798	8.986E-7	44.130	13.239	
4500	24.28	0.5922	243964	0.0122	13223	9.223E-7	44.493	13.348	
4500	24.54	0.5984	250576	0.0126	13223	9.521E-7	44.851	13.455	
4500	24.81	0.6048	257187	0.0124	12935	9.619E-7	45.209	13.563	
4500	25.07	0.6109	263511	0.0125	12648	9.850E-7	45.584	13.675	
4500	25.35	0.6173	269835	0.0127	12361	1.024E-6	45.948	13.784	
4500	25.63	0.6235	275872	0.0124	11786	1.055E-6	46.321	13.896	
4500	25.90	0.6297	281621	0.0123	11498	1.069E-6	46.692	14.008	
4500	26.18	0.6358	287370	0.0125	11785	1.065E-6	47.071	14.121	
4500	26.47	0.6422	293406	0.0128	11785	1.087E-6	47.451	14.235	
4500	26.77	0.6486	299155	0.0126	11095	1.132E-6	47.836	14.351	
4500	27.06	0.6548	304501	0.0125	10633	1.177E-6	48.228	14.469	
4500	27.36	0.6611	309788	0.0123	10114	1.220E-6	48.607	14.582	
4500	27.66	0.6671	314615	0.0121	9654	1.254E-6	48.996	14.699	
4500	27.95	0.6732	319442	0.0123	9654	1.272E-6	49.380	14.814	
4500	28.26	0.6794	324269	0.0124	9654	1.287E-6	49.772	14.932	
4500	28.58	0.6857	329096	0.0128	9654	1.321E-6	50.179	15.054	
4500	28.91	0.6922	333923	0.0128	9424	1.361E-6	50.585	15.175	
4500	29.24	0.6985	338520	0.0124	8965	1.387E-6	50.997	15.299	
4500	29.56	0.7046	342888	0.0122	8644	1.415E-6	51.405	15.422	
4500	29.89	0.7107	347164	0.0123	8505	1.452E-6	51.815	15.545	
4500	30.23	0.7170	351393	0.0123	8275	1.483E-6	52.222	15.667	
4500	30.56	0.7230	355439	0.0122	8091	1.504E-6	52.640	15.792	*
4500	30.90	0.7291	359484	0.0123	8091	1.524E-6	53.056	15.917	*
4500	31.25	0.7353	363530	0.0126	8091	1.554E-6	53.487	16.046	*
4500	31.61	0.7417	367575	0.0126	7907	1.596E-6	53.918	16.175	*
4500	31.98	0.7479	371437	0.0124	7724	1.606E-6	54.359	16.308	*
4500	32.34	0.7541	375299	0.0127	7723	1.641E-6	54.809	16.443	*
4500	32.73	0.7606	379160	0.0126	7539	1.677E-6	55.250	16.575	*
4500	33.10	0.7667	382838	0.0122	7172	1.699E-6	55.703	16.711	*
4500	33.47	0.7728	386332	0.0120	6920	1.740E-6	56.147	16.844	*
4500	33.85	0.7788	389758	0.0122	6818	1.784E-6	56.596	16.979	*
4500	34.24	0.7849	393150	0.0124	6786	1.832E-6	57.054	17.116	*
4500	34.64	0.7912	396544	0.0127	6787	1.869E-6	57.528	17.258	*
4500	35.06	0.7976	399937	0.0124	6491	1.905E-6	57.993	17.398	*
4500	35.46	0.8036	403035	0.0122	6196	1.961E-6	58.479	17.544	*
4500	35.88	0.8098	406133	0.0124	6047	2.057E-6	58.953	17.686	*
4500	36.30	0.8160	409082	0.0122	5808	2.107E-6	59.434	17.830	*
4500	36.72	0.8220	411941	0.0123	5801	2.114E-6	59.932	17.980	*
4500	37.16	0.8283	414883	0.0125	5767	2.172E-6	60.426	18.128	*
4500	37.61	0.8345	417708	0.0125	5533	2.254E-6	60.934	18.280	*
4500	38.06	0.8408	420416	0.0123	5297	2.331E-6	61.446	18.434	*
4500	38.51	0.8469	423005	0.0121	5062	2.392E-6	61.954	18.586	*
4500	38.96	0.8529	425478	0.0123	4944	2.482E-6	62.481	18.744	*
4500	39.44	0.8592	427949	0.0127	4943	2.574E-6	63.010	18.903	*
4500	39.94	0.8656	430421	0.0122	4709	2.599E-6	63.536	19.061	*
4500	40.39	0.8714	432658	0.0118	4430	2.669E-6	64.080	19.224	*
4500	40.87	0.8774	434851	0.0124	4460	2.771E-6	64.622	19.387	*
4500	41.39	0.8838	437118	0.0124	4440	2.799E-6	65.164	19.549	*
4500	41.89	0.8898	439291	0.0122	4252	2.865E-6	65.733	19.720	*
4500	42.40	0.8959	441370	0.0124	4156	2.978E-6	66.302	19.891	*
4500	42.93	0.9022	443447	0.0123	3966	3.108E-6	66.873	20.062	*
4500	43.46	0.9083	445336	0.0120	3650	3.275E-6	67.449	20.235	*

Westmoreland Mechanical Testing & Research, Inc.

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-H-H-1
YIELD STRENGTH : 52.5 ksi
MODULUS : 28.8 Msi

TESTLOG NO. : T05250
MATERIAL : Head HAZ
TEST MACHINE : H53

WMT&R REPORT NO. : 3-67089
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 8/1/2013
CRACK PLANE ORIENTATION : T-L

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2486 in
WIDTH (W) : 1.5039 in
NOTCH (An) : 0.3025 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 2877.10 lb
MINIMUM LOAD : 431.6 lb
LOAD RANGE : 2445.5 lb

STRESS RATIO : 0.15
FREQUENCY : 5 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : ROOM
HUMIDITY : 26% - 33%
ANALYSIS METHOD : SECANT

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
2877	0.0488	0.3777	420	0.0088	378	2.3275E-05	39.322	0
2877	0.0498	0.3872	787	0.0095	367	2.6014E-05	39.984	0
2877	0.0508	0.3967	1154	0.0095	367	2.5787E-05	40.656	0
2877	0.0520	0.4077	1521	0.0110	367	3.0028E-05	41.400	0
2877	0.0529	0.4159	1888	0.0082	367	2.2355E-05	42.113	0
2877	0.0538	0.4245	2123	0.0085	235	3.6334E-05	42.739	0
2877	0.0548	0.4332	2373	0.0087	250	3.4985E-05	43.378	0
2877	0.0557	0.4413	2623	0.0080	250	3.2186E-05	44.021	0
2876	0.0568	0.4508	2858	0.0095	235	4.0412E-05	44.685	0
2877	0.0580	0.4614	3108	0.0106	250	4.2377E-05	45.481	1
2877	0.0590	0.4697	3358	0.0083	250	3.3211E-05	46.212	1
2877	0.0603	0.4800	3592	0.0103	234	4.4227E-05	46.956	1
2877	0.0617	0.4918	3842	0.0117	250	4.6962E-05	47.855	1
2877	0.0632	0.5042	4092	0.0124	250	4.9665E-05	48.857	1
2877	0.0648	0.5165	4327	0.0124	235	5.2668E-05	49.902	1
2876	0.0658	0.5244	4459	0.0079	132	5.9544E-05	50.752	1
2877	0.0676	0.5389	4694	0.0145	235	6.1796E-05	51.738	1
2876	0.0687	0.5473	4826	0.0083	132	6.3145E-05	52.756	1
2877	0.0698	0.5553	4944	0.0081	118	6.8278E-05	53.517	1
2877	0.0709	0.5634	5061	0.0081	117	6.9348E-05	54.263	1
2877	0.0723	0.5743	5194	0.0109	133	8.1863E-05	55.149	1
2877	0.0735	0.5830	5311	0.0087	117	7.4515E-05	56.101	1
2877	0.0750	0.5934	5428	0.0103	117	8.834E-05	57.032	1
2876	0.0766	0.6053	5561	0.0119	133	8.9296E-05	58.146	1
2877	0.0784	0.6176	5678	0.0123	117	0.00010544	59.415	1
2877	0.0802	0.6296	5795	0.0120	117	0.00010272	60.719	1
2877	0.0825	0.6453	5928	0.0157	133	0.00011817	62.248	1
2876	0.0847	0.6595	6045	0.0142	117	0.00012109	63.945	1
2877	0.0872	0.6760	6162	0.0166	117	0.00014148	65.788	1
2877	0.0907	0.6976	6295	0.0215	133	0.00016175	68.168	1

Invalid Pts Column

0 - Valid Datapoint
1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)
2 - The crack deviated > 20 degrees from the plane of symmetry
3 - The difference between the front and back crack lengths > 0.25B

Westmoreland Mechanical Testing & Research, Inc.

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-H-H-2
YIELD STRENGTH : 52.5 ksi
MODULUS : 28.8 Msi

TESTLOG NO. : T05251
MATERIAL : Head HAZ
TEST MACHINE : H44

WMT&R REPORT NO. : 3-67089
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 8/13/2013
CRACK PLANE ORIENTATION : T-L

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2498 in
WIDTH (W) : 1.4987 in
NOTCH (An) : 0.2994 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 1170.49 lb
MINIMUM LOAD : 175.6 lb
LOAD RANGE : 994.9 lb

STRESS RATIO : 0.15
FREQUENCY : .5 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : Room
HUMIDITY : 27% - 34%
ANALYSIS METH. : MODIFIED SECANT

Pmax lb	EB(V/P)	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(in^0.5)	Invalid Pts
1171	20.63	0.3696	12723	0.0150	13985	1.0745E-06	15.867	0
1171	21.00	0.3768	20152	0.0143	13913	1.0309E-06	16.087	0
1171	21.37	0.3839	26636	0.0147	12291	1.1992E-06	16.303	0
1171	21.78	0.3916	32443	0.0147	11887	1.2357E-06	16.513	0
1171	22.09	0.3986	38523	0.0141	11489	1.2258E-06	16.729	0
1171	22.47	0.4057	43932	0.0141	10351	1.3579E-06	16.938	0
1170	22.85	0.4127	48874	0.0141	10277	1.3696E-06	17.148	0
1171	23.23	0.4197	54209	0.0141	10081	1.3979E-06	17.360	0
1170	23.59	0.4268	58955	0.0145	9205	1.572E-06	17.582	0
1171	24.00	0.4342	63414	0.0145	9016	1.6077E-06	17.800	0
1170	24.44	0.4413	67971	0.0142	8537	1.6607E-06	18.026	0
1171	24.84	0.4484	71951	0.0141	7781	1.8148E-06	18.250	0
1170	25.25	0.4554	75752	0.0142	7605	1.8704E-06	18.470	0
1171	25.74	0.4626	79556	0.0143	7321	1.9586E-06	18.700	0
1170	26.19	0.4697	83073	0.0143	6848	2.0928E-06	18.932	0
1170	26.64	0.4769	86404	0.0142	6748	2.1077E-06	19.162	0
1171	27.07	0.4839	89821	0.0141	6361	2.2136E-06	19.403	0
1170	27.56	0.4910	92765	0.0142	5893	2.4143E-06	19.633	0
1171	28.07	0.4982	95714	0.0144	5796	2.4775E-06	19.880	0
1170	28.52	0.5054	98561	0.0144	5415	2.6623E-06	20.119	0
1171	29.08	0.5126	101129	0.0146	5329	2.7374E-06	20.381	0
1170	29.58	0.5200	103890	0.0148	5137	2.8907E-06	20.634	0
1171	30.11	0.5274	106266	0.0145	4666	3.1096E-06	20.895	0
1170	30.63	0.5345	108556	0.0141	4480	3.1531E-06	21.155	0
1171	31.27	0.5416	110746	0.0150	4280	3.4985E-06	21.437	0
1170	31.79	0.5494	112836	0.0155	4274	3.6224E-06	21.699	0
1170	32.47	0.5570	115020	0.0150	4270	3.5227E-06	21.996	0
1170	33.09	0.5645	117106	0.0150	3793	3.9544E-06	22.276	0
1170	33.68	0.5720	118813	0.0146	3419	4.2773E-06	22.575	0
1171	34.38	0.5791	120525	0.0145	3519	4.1284E-06	22.857	0
1171	35.01	0.5866	122332	0.0150	3334	4.4865E-06	23.165	0
1171	35.74	0.5941	123859	0.0149	3044	4.8877E-06	23.451	0

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1170	36.34	0.6015	125376	0.0148	2944	5.012E-06	23.767	0
1170	37.15	0.6088	126803	0.0145	2657	5.4492E-06	24.070	0
1170	37.84	0.6159	128033	0.0146	2648	5.5248E-06	24.391	0
1170	38.51	0.6235	129451	0.0154	2845	5.426E-06	24.728	0
1170	39.31	0.6314	130878	0.0149	2568	5.8211E-06	25.038	0
1170	40.12	0.6384	132019	0.0142	2276	6.2448E-06	25.400	0
1171	40.92	0.6456	133154	0.0143	2173	6.5666E-06	25.716	0
1170	41.68	0.6527	134192	0.0147	2075	7.0622E-06	26.067	0
1170	42.67	0.6602	135229	0.0153	2078	7.341E-06	26.427	0
1170	43.41	0.6679	136270	0.0155	2085	7.4107E-06	26.806	0
1170	44.52	0.6757	137314	0.0149	1991	7.4746E-06	27.179	0
1170	45.25	0.6828	138261	0.0145	1800	8.0716E-06	27.583	0
1171	46.23	0.6902	139114	0.0153	1708	8.9305E-06	27.968	0
1171	47.28	0.6981	139969	0.0160	1707	9.3711E-06	28.391	0
1171	48.38	0.7062	140821	0.0157	1610	9.7447E-06	28.820	0
1171	49.44	0.7138	141579	0.0147	1426	1.03E-05	29.255	0
1171	50.45	0.7209	142247	0.0146	1332	1.0993E-05	29.690	0
1171	51.65	0.7284	142911	0.0147	1331	1.106E-05	30.121	0
1170	52.67	0.7356	143578	0.0150	1332	1.1238E-05	30.584	0
1170	53.87	0.7434	144243	0.0152	1235	1.2322E-05	31.036	0
1171	55.01	0.7508	144813	0.0145	1144	1.2672E-05	31.515	0
1170	54.53	0.7579	145387	0.0146	1219	1.1942E-05	31.999	0
1170	55.83	0.7654	146032	0.0158	1245	1.2708E-05	32.519	0
1170	57.06	0.7737	146632	0.0153	1140	1.3453E-05	33.018	0
1170	57.80	0.7807	147172	0.0143	1110	1.2844E-05	33.573	1
1170	59.58	0.7879	147742	0.0145	1110	1.3028E-05	34.092	1
1170	60.81	0.7952	148282	0.0149	1065	1.3947E-05	34.648	1
1170	62.04	0.8028	148807	0.0150	975	1.5358E-05	35.213	1
1170	63.50	0.8102	149257	0.0146	900	1.6241E-05	35.804	1
1170	64.94	0.8174	149707	0.0144	840	1.7165E-05	36.392	1
1170	66.65	0.8246	150097	0.0147	765	1.9163E-05	37.015	1
1170	68.18	0.8321	150472	0.0147	750	1.9655E-05	37.632	1
1170	70.04	0.8393	150847	0.0147	720	2.0412E-05	38.298	1
1170	71.60	0.8468	151192	0.0147	690	2.128E-05	38.958	1
1170	73.14	0.8540	151537	0.0163	720	2.2594E-05	39.739	1
1170	75.47	0.8630	151912	0.0162	705	2.3023E-05	40.441	1
1171	77.54	0.8702	152242	0.0153	646	2.3731E-05	41.312	1
1170	79.22	0.8784	152558	0.0166	570	2.9188E-05	42.128	1
1171	82.50	0.8869	152812	0.0166	509	3.2623E-05	43.008	1
1170	83.81	0.8950	153067	0.0155	555	2.7927E-05	43.895	1
1170	88.10	0.9024	153367	0.0151	510	2.9677E-05	44.810	1
1170	87.80	0.9101	153577	0.0176	525	3.3549E-05	45.852	1
1170	95.43	0.9274	154237	0.0178	510	3.4909E-05	48.117	1
1170	98.55	0.9378	154402	0.0181	435	4.1619E-05	49.133	1
1170	101.21	0.9455	154672	0.0224	570	3.9244E-05	50.923	1
1170	105.02	0.9602	154972	0.0263	465	5.6496E-05	52.357	1
1170	108.49	0.9718	155137	0.0317	330	9.6207E-05	55.159	1
1170	120.44	0.9919	155302	0.0201	165	0.00012211	56.139	1

Invalid Pts Column
- 0 - Valid Datapoint
- 1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)
- 2 - The crack deviated > 20 degrees from the plane of symmetry
- 3 - The difference between the front and back crack lengths > 0.25B

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Westmoreland Mechanical Testing & Research, Inc.

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-H-H-3
YIELD STRENGTH : 52.5 ksi
MODULUS : 30.0 Msi

TESTLOG NO. : T05252
MATERIAL : Head HAZ
TEST MACHINE : H290

WMT&R REPORT NO. : 3-67089
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 8/1/2013
CRACK PLANE ORIENTATION : T-L

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2494 in
WIDTH (W) : 1.5026 in
NOTCH (An) : 0.3012 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 5364.10 lb
MINIMUM LOAD : 3754.9 lb
LOAD RANGE : 1609.2 lb

STRESS RATIO : 0.70
FREQUENCY : 5 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : ROOM
HUMIDITY : 26% - 33%
ANALYSIS METHOD : SECANT

Pmax lb	EPD	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(Sqrt.in)	Invalid Pts
5364	0.0664	0.3552	103	0.0016	81	1.9334E-05	24.951	1
5364	0.0669	0.3569	185	0.0017	82	2.0555E-05	25.012	1
5365	0.0674	0.3585	347	0.0016	162	9.7347E-06	25.089	1
5364	0.0677	0.3595	427	0.0010	80	1.2985E-05	25.171	1
5365	0.0681	0.3606	750	0.0011	323	3.4476E-06	25.214	1
5364	0.0685	0.3619	995	0.0013	245	5.32E-06	25.266	1
5364	0.0689	0.3634	1321	0.0015	326	4.582E-06	25.318	1
5363	0.0694	0.3649	1645	0.0014	324	4.4441E-06	25.383	1
5364	0.0698	0.3662	1886	0.0013	241	5.4283E-06	25.447	1
5364	0.0702	0.3673	2047	0.0012	161	7.1807E-06	25.506	1
5365	0.0707	0.3687	2451	0.0014	404	3.3717E-06	25.574	1
5364	0.0711	0.3699	2777	0.0012	326	3.7258E-06	25.652	1
5364	0.0716	0.3715	2938	0.0016	161	9.663E-06	25.699	1
5365	0.0720	0.3726	3179	0.0011	241	4.5485E-06	25.776	1
5363	0.0726	0.3744	3342	0.0018	163	1.1117E-05	25.802	1
5364	0.0730	0.3754	3507	0.0011	165	6.4778E-06	25.882	1
5364	0.0735	0.3769	3669	0.0014	162	8.7899E-06	25.955	1
5364	0.0740	0.3783	3829	0.0014	160	8.8182E-06	26.004	1
5364	0.0744	0.3794	3910	0.0011	81	1.4098E-05	26.083	1
5364	0.0755	0.3823	4070	0.0029	160	1.8107E-05	26.161	1
5364	0.0760	0.3838	4234	0.0014	164	8.7794E-06	26.271	1
5365	0.0765	0.3850	4314	0.0012	80	1.5322E-05	26.363	1
5364	0.0771	0.3865	4476	0.0016	162	9.6341E-06	26.398	1
5364	0.0775	0.3877	4556	0.0011	80	1.4208E-05	26.472	1
5364	0.0783	0.3899	4719	0.0022	163	1.352E-05	26.539	1
5364	0.0791	0.3919	4881	0.0020	162	1.2283E-05	26.638	1
5364	0.0797	0.3934	4962	0.0015	81	1.8609E-05	26.738	1
5364	0.0813	0.3970	5042	0.0037	80	4.5628E-05	26.874	1
5364	0.0826	0.4003	5122	0.0032	80	4.0377E-05	27.011	1

Invalid Pts Column
0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Westmoreland Mechanical Testing & Research, Inc.

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-H-H-4
YIELD STRENGTH : 52.5 ksi
MODULUS : 29.6 Msi

TESTLOG NO. : T05253
MATERIAL : Head HAZ
TEST MACHINE : H239

WMT&R REPORT NO. : 3-67089
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 8/13/2013
CRACK PLANE ORIENTATION : T-L

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2488 in
WIDTH (W) : 1.5049 in
NOTCH (An) : 0.3034 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 2165.05 lb
MINIMUM LOAD : 1515.5 lb
LOAD RANGE : 649.6 lb

STRESS RATIO : 0.70
FREQUENCY : 5 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : Room
HUMIDITY : 27% - 34%
ANALYSIS METH. : MODIFIED SECANT

Pmax lb	EB(V/P)	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(in^0.5)	Invalid Pts
2165	20.33	0.3641	22296	0.0094	26343	3.5778E-07	10.246	0
2165	20.58	0.3688	36808	0.0096	26213	3.6609E-07	10.341	0
2165	20.80	0.3737	48509	0.0100	23129	4.3366E-07	10.429	0
2165	21.04	0.3789	59937	0.0099	23801	4.1648E-07	10.527	0
2165	21.25	0.3836	72310	0.0101	24805	4.0778E-07	10.627	0
2165	21.51	0.3890	84742	0.0102	23868	4.2573E-07	10.718	0
2165	21.79	0.3938	96178	0.0097	21927	4.4258E-07	10.816	0
2165	22.03	0.3987	106669	0.0100	22390	4.4839E-07	10.909	0
2165	22.28	0.4038	118568	0.0101	22847	4.424E-07	11.001	0
2165	22.55	0.4088	129516	0.0101	21977	4.6039E-07	11.098	0
2165	22.84	0.4140	140545	0.0100	21451	4.6608E-07	11.197	0
2165	23.10	0.4188	150967	0.0100	20424	4.8787E-07	11.302	0
2165	23.33	0.4239	160969	0.0099	20019	4.9325E-07	11.401	0
2165	23.62	0.4287	170986	0.0096	19165	5.0145E-07	11.504	0
2166	23.88	0.4335	180134	0.0099	18159	5.4486E-07	11.610	0
2166	24.20	0.4386	189145	0.0098	17546	5.5651E-07	11.707	0
2166	24.41	0.4433	197680	0.0095	17404	5.4588E-07	11.808	0
2165	24.71	0.4481	206549	0.0095	17191	5.5118E-07	11.895	0
2165	25.03	0.4528	214871	0.0096	16523	5.7876E-07	11.988	0
2165	25.34	0.4576	223072	0.0102	16532	6.1905E-07	12.087	0
2165	25.62	0.4630	231403	0.0103	16950	6.0734E-07	12.192	0
2165	25.95	0.4679	240022	0.0099	15737	6.292E-07	12.305	0
2166	26.21	0.4729	247140	0.0097	14632	6.6562E-07	12.415	0
2165	26.55	0.4777	254654	0.0095	14843	6.3738E-07	12.515	0
2165	26.85	0.4824	261983	0.0096	14125	6.7954E-07	12.618	0
2165	27.18	0.4873	268779	0.0097	13650	7.0962E-07	12.709	0
2165	27.46	0.4921	275633	0.0097	13849	7.0146E-07	12.819	0
2165	27.82	0.4970	282628	0.0099	13247	7.4608E-07	12.927	0
2165	28.13	0.5019	288880	0.0104	13121	7.9101E-07	13.037	0
2165	28.47	0.5074	295749	0.0102	13861	7.3825E-07	13.154	0
2165	28.84	0.5122	302741	0.0096	12769	7.5463E-07	13.261	0
2165	29.19	0.5170	308518	0.0099	11630	8.4893E-07	13.377	0

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2165	29.63	0.5221	314371	0.0102	11567	8.7985E-07	13.491	0
2165	29.94	0.5272	320085	0.0100	10955	9.1578E-07	13.620	0
2165	30.31	0.5321	325326	0.0096	11033	8.7364E-07	13.730	1
2165	30.66	0.5368	331118	0.0098	11241	8.7194E-07	13.848	1
2166	31.05	0.5419	336567	0.0099	10293	9.6174E-07	13.966	1
2165	31.49	0.5467	341411	0.0098	9822	1.0021E-06	14.069	1
2165	31.79	0.5517	346389	0.0100	9885	1.0089E-06	14.196	1
2165	32.25	0.5567	351296	0.0097	9749	9.9939E-07	14.317	1
2165	32.65	0.5615	356138	0.0098	9215	1.0639E-06	14.428	1
2165	32.98	0.5665	360511	0.0101	9076	1.1131E-06	14.563	1
2165	33.54	0.5716	365214	0.0100	9266	1.0763E-06	14.686	1
2165	33.96	0.5765	369777	0.0099	8599	1.1517E-06	14.808	1
2166	34.33	0.5815	373813	0.0100	8061	1.2439E-06	14.955	1
2165	34.75	0.5865	377838	0.0098	7997	1.2225E-06	15.073	1
2166	35.21	0.5913	381810	0.0095	7605	1.2477E-06	15.211	1
2166	35.63	0.5960	385443	0.0100	7196	1.3955E-06	15.346	1
2165	36.13	0.6013	389006	0.0102	7461	1.365E-06	15.470	1
2165	36.60	0.6062	392904	0.0097	7130	1.3627E-06	15.605	1
2165	37.12	0.6110	396136	0.0101	6529	1.5474E-06	15.749	1
2165	37.59	0.6163	399433	0.0102	6799	1.4988E-06	15.882	1
2166	38.13	0.6212	402935	0.0098	6528	1.4953E-06	16.042	1
2165	38.51	0.6260	405961	0.0096	5656	1.6998E-06	16.164	1
2166	39.01	0.6308	408591	0.0099	5791	1.7072E-06	16.326	1
2165	39.51	0.6359	411752	0.0099	6051	1.6384E-06	16.449	1
2165	40.12	0.6407	414642	0.0100	5714	1.745E-06	16.602	1
2166	40.63	0.6459	417466	0.0101	5374	1.8795E-06	16.766	1
2165	41.17	0.6508	420016	0.0097	5107	1.898E-06	16.895	1
2165	41.70	0.6556	422573	0.0097	4906	1.9801E-06	17.060	1
2165	42.24	0.6605	424922	0.0105	4773	2.1898E-06	17.210	1
2165	42.86	0.6660	427346	0.0103	4646	2.2124E-06	17.360	1
2165	43.46	0.6708	429568	0.0096	4163	2.3076E-06	17.526	1
2165	44.00	0.6756	431509	0.0098	3890	2.5209E-06	17.687	1
2165	44.74	0.6806	433458	0.0106	4043	2.6254E-06	17.872	1
2165	45.34	0.6862	435552	0.0104	3986	2.61E-06	18.037	1
2165	46.07	0.6910	437444	0.0099	3771	2.618E-06	18.221	1
2165	46.61	0.6961	439323	0.0101	3632	2.7912E-06	18.386	1
2165	47.28	0.7012	441076	0.0103	3235	3.1761E-06	18.568	1
2165	48.00	0.7064	442558	0.0102	3238	3.15E-06	18.743	1
2165	48.65	0.7114	444314	0.0098	3172	3.0855E-06	18.931	1
2165	49.34	0.7162	445730	0.0096	2958	3.2463E-06	19.112	1
2165	50.03	0.7210	447272	0.0099	2890	3.4144E-06	19.311	1
2165	50.82	0.7260	448620	0.0099	2756	3.6077E-06	19.477	1
2166	51.45	0.7309	450028	0.0097	2689	3.6008E-06	19.700	1
2165	52.16	0.7357	451309	0.0099	2623	3.761E-06	19.877	1
2165	52.92	0.7408	452651	0.0102	2622	3.8796E-06	20.076	1
2165	53.75	0.7459	453931	0.0099	2426	4.0836E-06	20.276	1
2165	54.51	0.7507	455077	0.0095	2366	4.0268E-06	20.477	1
2165	54.49	0.7554	456297	0.0095	2555	3.7076E-06	20.678	1
2165	55.24	0.7602	457632	0.0095	2285	4.1606E-06	20.885	1
2165	56.06	0.7649	458582	0.0095	1565	6.0582E-06	21.094	1
2164	56.87	0.7696	459197	0.0095	1255	7.5892E-06	21.296	1
2165	57.68	0.7745	459837	0.0098	1347	7.289E-06	21.517	1
2165	58.54	0.7795	460544	0.0097	1119	8.691E-06	21.736	1
2165	59.36	0.7842	460956	0.0047	412	1.1465E-05	21.852	1

Invalid Pts Column

"NOTE: The recording of false, fictitious, or fraudulent statements or entries on this document may be punishable as a felony under Federal Statute."

0 - Valid Datapoint
1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)
2 - The crack deviated > 20 degrees from the plane of symmetry
3 - The difference between the front and back crack lengths > 0.25B

Westmoreland Mechanical Testing & Research, Inc.

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-H-W-1
YIELD STRENGTH : 52.5 ksi
MODULUS : 29.2 Msi

TESTLOG NO. : T05254C
MATERIAL : Head Weld
TEST MACHINE : H239

WMT&R REPORT NO. : 3-67089
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 8/5/2013
CRACK PLANE ORIENTATION : L-C
Vessel

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2488 in
WIDTH (W) : 1.5012 in
NOTCH (An) : 0.3001 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 3033.80 lb
MINIMUM LOAD : 455.1 lb
LOAD RANGE : 2578.7 lb

STRESS RATIO : 0.15
FREQUENCY : .1 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : Room
HUMIDITY : 24% - 34%
ANALYSIS METH. : MODIFIED SECANT

Pmax lb	EB(V/P)	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(in^0.5)	Invalid Pts
3033	20.17	0.3594	571	0.0102	612	1.6719E-05	40.473	0
3033	20.42	0.3646	886	0.0104	639	1.6217E-05	40.856	0
3033	20.66	0.3698	1210	0.0105	639	1.6473E-05	41.249	0
3033	20.92	0.3751	1525	0.0104	639	1.6334E-05	41.639	0
3033	21.17	0.3802	1849	0.0102	612	1.6677E-05	42.030	1
3033	21.40	0.3853	2137	0.0102	576	1.7758E-05	42.420	1
3033	21.66	0.3904	2425	0.0104	576	1.7981E-05	42.812	1
3033	21.91	0.3957	2713	0.0105	576	1.8148E-05	43.209	1
3033	22.18	0.4009	3001	0.0104	567	1.8296E-05	43.609	1
3033	22.46	0.4060	3280	0.0103	549	1.8711E-05	44.011	1
3033	22.72	0.4112	3550	0.0102	513	1.9881E-05	44.409	1
3033	22.98	0.4162	3793	0.0101	486	2.0882E-05	44.810	1
3033	23.26	0.4213	4036	0.0102	486	2.1007E-05	45.212	1
3033	23.54	0.4265	4279	0.0102	486	2.1052E-05	45.616	1
3033	23.83	0.4315	4522	0.0104	468	2.2295E-05	46.036	1
3033	24.13	0.4369	4747	0.0104	441	2.351E-05	46.442	1
3033	24.43	0.4419	4963	0.0101	423	2.3927E-05	46.866	1
3033	24.72	0.4470	5170	0.0104	423	2.453E-05	47.283	1
3033	25.03	0.4523	5386	0.0104	414	2.5074E-05	47.701	1
3033	25.35	0.4574	5584	0.0103	387	2.6584E-05	48.130	1
3033	25.66	0.4626	5773	0.0105	379	2.7667E-05	48.560	1
3033	26.00	0.4679	5963	0.0103	361	2.854E-05	48.987	1
3033	26.31	0.4729	6134	0.0101	342	2.9402E-05	49.423	1
3033	26.63	0.4779	6305	0.0104	342	3.0433E-05	49.866	1
3033	26.98	0.4833	6476	0.0104	306	3.3948E-05	50.299	1
3033	27.32	0.4883	6611	0.0105	270	3.8847E-05	50.766	1
3033	27.68	0.4938	6746	0.0106	252	4.1915E-05	51.212	1
3033	28.03	0.4989	6863	0.0101	225	4.4987E-05	51.668	1
3033	28.37	0.5039	6971	0.0101	216	4.6678E-05	52.123	1
3033	28.73	0.5090	7079	0.0105	225	4.6501E-05	52.589	1
3033	29.11	0.5144	7196	0.0106	234	4.5324E-05	53.048	1
3033	29.48	0.5196	7313	0.0105	243	4.3211E-05	53.539	1

"NOTE: The recording of false, fictitious, or fraudulent statements or entries on this document may be punishable as a felony under Federal Statute."

3033	29.88	0.5249	7439	0.0107	243	4.401E-05	54.024	1
3033	30.28	0.5303	7556	0.0107	234	4.5832E-05	54.516	1
3033	30.69	0.5356	7673	0.0104	225	4.6318E-05	55.012	1
3033	31.08	0.5407	7781	0.0103	216	4.7578E-05	55.509	1
3033	31.49	0.5459	7889	0.0103	207	4.9615E-05	55.997	1
3033	31.88	0.5510	7988	0.0104	198	5.2706E-05	56.507	1
3033	32.33	0.5563	8087	0.0104	189	5.5003E-05	57.002	1
3033	32.74	0.5614	8177	0.0102	180	5.6414E-05	57.516	1
3033	33.17	0.5665	8267	0.0103	180	5.7104E-05	58.030	1
3033	33.60	0.5716	8357	0.0106	189	5.6052E-05	58.556	12
3033	34.09	0.5771	8456	0.0108	189	5.7122E-05	59.096	12
3033	34.55	0.5824	8546	0.0105	180	5.8153E-05	59.638	12
3033	35.01	0.5875	8636	0.0102	180	5.6641E-05	60.187	12
3033	35.48	0.5926	8726	0.0102	162	6.2699E-05	60.725	12
3033	35.94	0.5977	8798	0.0104	162	6.4277E-05	61.288	12
3033	36.44	0.6030	8888	0.0105	171	6.1441E-05	61.838	12
3033	36.94	0.6082	8969	0.0107	162	6.5877E-05	62.440	12
3033	37.48	0.6137	9050	0.0106	153	6.9058E-05	63.002	12
3033	37.98	0.6187	9122	0.0103	153	6.7292E-05	63.610	12
3033	38.51	0.6240	9203	0.0104	153	6.7926E-05	64.193	12
3033	39.05	0.6291	9275	0.0105	135	7.7939E-05	64.804	12
3033	39.60	0.6345	9338	0.0112	135	8.2774E-05	65.448	12
3033	40.22	0.6403	9410	0.0115	135	8.534E-05	66.111	12
3033	40.85	0.6460	9473	0.0110	117	9.3859E-05	66.776	12
3033	41.44	0.6513	9527	0.0111	117	9.4854E-05	67.488	12
3033	42.10	0.6571	9590	0.0111	117	9.5258E-05	68.147	12
3033	42.69	0.6624	9644	0.0106	99	0.00010753	68.849	12
3033	43.32	0.6678	9689	0.0104	90	0.0001154	69.511	12
3033	43.96	0.6728	9734	0.0101	81	0.00012483	70.191	12
3033	44.59	0.6779	9770	0.0113	81	0.00013905	70.930	12
3033	45.33	0.6841	9815	0.0114	90	0.00012689	71.624	12
3033	45.99	0.6893	9860	0.0105	81	0.00012904	72.410	12
3033	46.70	0.6945	9896	0.0111	72	0.00015415	73.172	12
3033	47.45	0.7004	9932	0.0113	72	0.00015642	73.930	12
3033	48.20	0.7058	9968	0.0116	72	0.00016164	74.794	12
3033	49.08	0.7121	10004	0.0117	63	0.00018589	75.592	12
3033	49.84	0.7175	10031	0.0117	54	0.00021697	76.521	12
3033	50.75	0.7238	10058	0.0133	54	0.0002457	77.466	12
3033	51.82	0.7308	10085	0.0125	45	0.00027736	78.381	12
3033	52.67	0.7363	10103	0.0116	36	0.00032194	79.408	12
3033	53.61	0.7424	10121	0.0130	36	0.00035998	80.409	12
3033	54.60	0.7492	10139	0.0068	18	0.00038012	80.904	12

Invalid Pts Column
0 - Valid Datapoint
1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)
2 - The crack deviated > 20 degrees from the plane of symmetry
3 - The difference between the front and back crack lengths > 0.25B

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Westmoreland Mechanical Testing & Research, Inc.

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-H-W-2
YIELD STRENGTH : 52.5 ksi
MODULUS : 29.4 Msi

TESTLOG NO. : T05255
MATERIAL : Head Weld
TEST MACHINE : H177

WMT&R REPORT NO. : 3-67089
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 8/15/2013
CRACK PLANE ORIENTATION : L-C
Vessel

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2483 in
WIDTH (W) : 1.5029 in
NOTCH (An) : 0.3017 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 1116.75 lb
MINIMUM LOAD : 167.5 lb
LOAD RANGE : 949.3 lb

STRESS RATIO : 0.15
FREQUENCY : 5 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : Room
HUMIDITY : 27% - 33%
ANALYSIS METH. : MODIFIED SECANT

Pmax lb	EB(V/P)	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(in^0.5)	Invalid Pts
1116	20.49	0.3670	16522	0.0162	32784	4.9301E-07	15.124	0
1116	20.89	0.3751	33323	0.0161	32719	4.9259E-07	15.338	0
1116	21.27	0.3831	49241	0.0161	30442	5.2874E-07	15.563	0
1117	21.67	0.3912	63765	0.0162	28210	5.7265E-07	15.793	0
1116	22.08	0.3993	77451	0.0161	26428	6.0949E-07	16.011	0
1117	22.50	0.4073	90193	0.0161	25145	6.4121E-07	16.253	0
1117	22.92	0.4154	102596	0.0161	23899	6.7274E-07	16.479	0
1117	23.35	0.4234	114092	0.0161	22334	7.1951E-07	16.714	0
1117	23.80	0.4315	124930	0.0161	20854	7.7388E-07	16.955	0
1116	24.26	0.4395	134946	0.0162	19286	8.4192E-07	17.187	0
1117	24.74	0.4477	144216	0.0164	18332	8.9256E-07	17.434	0
1117	25.23	0.4559	153278	0.0162	17564	9.2503E-07	17.676	0
1116	25.71	0.4640	161780	0.0163	16478	9.8823E-07	17.929	0
1117	26.23	0.4722	169756	0.0163	15666	1.0403E-06	18.177	0
1117	26.73	0.4803	177446	0.0161	14916	1.0784E-06	18.437	0
1117	27.27	0.4883	184672	0.0161	14116	1.1432E-06	18.689	0
1117	27.82	0.4964	191562	0.0162	13356	1.2129E-06	18.953	0
1117	28.36	0.5045	198028	0.0163	12389	1.3119E-06	19.211	0
1117	28.93	0.5126	203951	0.0162	11451	1.418E-06	19.483	0
1116	29.52	0.5207	209479	0.0161	10642	1.5165E-06	19.751	0
1117	30.12	0.5288	214593	0.0161	9957	1.6193E-06	20.028	0
1117	30.73	0.5368	219436	0.0161	9277	1.7372E-06	20.310	0
1116	31.34	0.5449	223870	0.0161	8718	1.8515E-06	20.586	0
1117	31.99	0.5530	228154	0.0162	8106	1.9935E-06	20.880	0
1116	32.65	0.5611	231976	0.0162	7498	2.1569E-06	21.164	0
1117	33.34	0.5692	235652	0.0161	7158	2.248E-06	21.462	0
1116	34.02	0.5772	239134	0.0160	6614	2.4248E-06	21.760	0
1116	34.73	0.5852	242266	0.0161	6059	2.6538E-06	22.067	0
1117	35.45	0.5932	245193	0.0161	5787	2.7761E-06	22.379	0
1116	36.20	0.6013	248053	0.0160	5389	2.9748E-06	22.692	0
1117	36.97	0.6093	250582	0.0162	5041	3.213E-06	23.028	0
1116	37.77	0.6175	253094	0.0163	4889	3.3283E-06	23.354	0

“NOTE: The recording of false, fictitious, or fraudulent statements or entries on this document may be punishable as a felony under Federal Statute.”

1117	38.58	0.6255	255471	0.0163	4554	3.576E-06	23.705	0
1117	39.42	0.6337	257648	0.0162	4291	3.7862E-06	24.049	0
1117	40.28	0.6418	259762	0.0163	4163	3.9188E-06	24.416	0
1116	41.19	0.6500	261811	0.0163	3893	4.1875E-06	24.762	0
1117	42.08	0.6581	263655	0.0163	3614	4.5062E-06	25.151	0
1116	43.05	0.6663	265425	0.0163	3474	4.701E-06	25.516	0
1116	44.02	0.6744	267129	0.0163	3347	4.8601E-06	25.911	0
1117	45.02	0.6826	268772	0.0162	3145	5.1661E-06	26.310	0
1116	46.03	0.6907	270274	0.0161	2992	5.3928E-06	26.717	0
1117	47.07	0.6987	271764	0.0162	2919	5.563E-06	27.136	0
1117	48.19	0.7069	273193	0.0163	2796	5.8393E-06	27.575	0
1116	49.32	0.7151	274560	0.0164	2661	6.1485E-06	28.000	0
1117	50.48	0.7233	275854	0.0163	2517	6.469E-06	28.465	0
1116	51.67	0.7313	277077	0.0163	2379	6.8332E-06	28.915	0
1116	52.93	0.7395	278233	0.0167	2314	7.1955E-06	29.401	0
1117	54.25	0.7480	279391	0.0165	2186	7.5539E-06	29.887	0
1116	55.52	0.7560	280419	0.0161	2120	7.5787E-06	30.396	0
1117	56.86	0.7641	281511	0.0162	2076	7.7818E-06	30.907	0
1116	58.29	0.7722	282495	0.0162	1992	8.1406E-06	31.449	0
1117	59.72	0.7803	283503	0.0162	1980	8.1724E-06	31.979	0
1116	61.22	0.7884	284475	0.0162	1836	8.8129E-06	32.566	0
1117	62.78	0.7965	285339	0.0161	1704	9.4735E-06	33.124	1
1116	64.38	0.8045	286179	0.0162	1668	9.7189E-06	33.730	1
1117	66.07	0.8127	287007	0.0162	1656	9.7999E-06	34.341	1
1116	67.77	0.8207	287835	0.0161	1608	1.0003E-05	34.970	1
1117	69.54	0.8288	288615	0.0160	1512	1.0605E-05	35.617	1
1117	71.38	0.8368	289347	0.0161	1452	1.11E-05	36.287	1
1116	73.32	0.8449	290067	0.0162	1404	1.1525E-05	36.956	1
1117	75.28	0.8530	290751	0.0162	1332	1.2135E-05	37.697	1
1116	77.39	0.8610	291399	0.0161	1272	1.267E-05	38.418	1
1117	79.52	0.8691	292023	0.0160	1224	1.3104E-05	39.205	1
1117	81.73	0.8771	292623	0.0161	1164	1.386E-05	39.999	1
1117	84.06	0.8852	293187	0.0163	1092	1.4888E-05	40.817	1
1117	86.53	0.8933	293715	0.0162	1020	1.588E-05	41.671	1
1116	89.04	0.9014	294207	0.0163	948	1.716E-05	42.546	1
1117	91.72	0.9096	294663	0.0164	876	1.8767E-05	43.477	1
1117	94.51	0.9178	295083	0.0164	840	1.947E-05	44.418	1
1117	97.43	0.9260	295503	0.0163	828	1.9687E-05	45.440	1
1117	100.45	0.9341	295911	0.0163	780	2.093E-05	46.449	1
1117	103.63	0.9423	296283	0.0164	708	2.315E-05	47.542	1
1116	106.98	0.9505	296619	0.0165	660	2.507E-05	48.643	1
1117	110.54	0.9588	296943	0.0164	600	2.7275E-05	49.815	1
1117	114.15	0.9669	297219	0.0164	540	3.0426E-05	51.034	1
1117	118.06	0.9753	297483	0.0168	504	3.33E-05	52.321	1
1117	122.24	0.9837	297723	0.0165	456	3.6228E-05	53.631	1
1116	126.42	0.9918	297939	0.0164	420	3.9027E-05	55.020	1
1117	130.96	1.0001	298143	0.0165	372	4.429E-05	56.456	1
1116	135.66	1.0083	298311	0.0167	324	5.1426E-05	57.970	1
1116	140.81	1.0167	298467	0.0170	300	5.6813E-05	59.578	1
1117	146.28	1.0253	298611	0.0169	264	6.4094E-05	61.267	1
1116	152.01	1.0337	298731	0.0167	228	7.3434E-05	63.022	1
1117	158.08	1.0420	298839	0.0173	204	8.4627E-05	64.955	1
1116	164.87	1.0509	298935	0.0183	168	0.00010889	66.980	1
1117	172.47	1.0603	299007	0.0187	132	0.00014149	69.240	1
1117	180.07	1.0696	299067	0.0093	60	0.00015435	70.417	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

Westmoreland Mechanical Testing & Research, Inc.

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-H-W-3
YIELD STRENGTH : 52.5 ksi
MODULUS : 29.8 Msi

TESTLOG NO. : T05256
MATERIAL : Head Weld
TEST MACHINE : H239

WMT&R REPORT NO. : 3-67089
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 8/9/2013
CRACK PLANE ORIENTATION : L-C
Vessel

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2476 in
WIDTH (W) : 1.5020 in
NOTCH (An) : 0.3018 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 2146.45 lb
MINIMUM LOAD : 1502.5 lb
LOAD RANGE : 644.0 lb

STRESS RATIO : 0.70
FREQUENCY : 5 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : Room
HUMIDITY : 30% - 43%
ANALYSIS METH. : MODIFIED SECANT

Pmax lb	EB(V/P)	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(in^0.5)	Invalid Pts
2146	20.09	0.3578	21211	0.0151	41571	3.6373E-07	10.121	0
2146	20.45	0.3654	41632	0.0151	40556	3.7221E-07	10.259	0
2146	20.78	0.3729	61767	0.0152	39877	3.8194E-07	10.402	0
2147	21.17	0.3806	81509	0.0152	38809	3.9257E-07	10.549	0
2146	21.52	0.3882	100576	0.0151	36732	4.1192E-07	10.689	0
2147	21.90	0.3957	118241	0.0152	34714	4.3716E-07	10.838	0
2147	22.30	0.4033	135290	0.0152	33888	4.4847E-07	10.987	0
2146	22.70	0.4109	152129	0.0151	32601	4.6297E-07	11.129	0
2147	23.10	0.4184	167891	0.0150	30872	4.8656E-07	11.281	0
2146	23.51	0.4259	183001	0.0151	29931	5.0394E-07	11.427	0
2146	23.93	0.4335	197822	0.0151	28951	5.2174E-07	11.577	0
2147	24.38	0.4410	211952	0.0151	27181	5.5394E-07	11.735	0
2146	24.80	0.4486	225003	0.0150	25819	5.8211E-07	11.883	0
2147	25.25	0.4561	237771	0.0152	25493	5.9502E-07	12.048	0
2146	25.73	0.4637	250496	0.0153	24761	6.1739E-07	12.199	0
2146	26.18	0.4714	262532	0.0153	23755	6.4532E-07	12.361	0
2146	26.68	0.4791	274251	0.0153	22745	6.7174E-07	12.527	0
2146	27.18	0.4866	285277	0.0152	21372	7.1073E-07	12.690	0
2146	27.68	0.4943	295623	0.0151	20416	7.409E-07	12.857	0
2146	28.20	0.5018	305693	0.0150	19201	7.8269E-07	13.022	0
2146	28.70	0.5093	314824	0.0151	18273	8.2519E-07	13.191	0
2146	29.26	0.5168	323966	0.0151	17810	8.4608E-07	13.357	0
2147	29.82	0.5243	332634	0.0152	17196	8.8309E-07	13.536	0
2146	30.38	0.5320	341162	0.0152	16794	9.0504E-07	13.711	1
2147	30.96	0.5395	349428	0.0151	15839	9.5192E-07	13.894	1
2146	31.54	0.5471	357001	0.0151	14672	1.0325E-06	14.073	1
2146	32.17	0.5547	364100	0.0152	14136	1.0726E-06	14.255	1
2146	32.78	0.5623	371137	0.0151	13646	1.1066E-06	14.439	1
2146	33.41	0.5698	377746	0.0150	12963	1.1598E-06	14.626	1
2147	34.06	0.5773	384100	0.0151	12361	1.2188E-06	14.824	1
2146	34.73	0.5849	390107	0.0151	11905	1.2683E-06	15.019	1
2147	35.41	0.5924	396005	0.0152	11314	1.3402E-06	15.227	1

2147	36.11	0.6000	401421	0.0152	10569	1.4335E-06	15.428	1
2147	36.83	0.6076	406574	0.0151	10015	1.5061E-06	15.641	1
2147	37.56	0.6151	411436	0.0151	9675	1.561E-06	15.848	1
2147	38.34	0.6227	416249	0.0152	9350	1.6306E-06	16.068	1
2147	39.10	0.6304	420786	0.0154	8873	1.738E-06	16.284	1
2147	39.93	0.6381	425122	0.0152	8468	1.7986E-06	16.509	1
2146	40.73	0.6456	429254	0.0151	7992	1.8956E-06	16.727	1
2146	41.58	0.6532	433114	0.0152	7511	2.025E-06	16.962	1
2146	42.43	0.6608	436765	0.0153	7171	2.1397E-06	17.198	1
2146	43.35	0.6686	440285	0.0153	6898	2.2171E-06	17.443	1
2146	44.26	0.6761	443663	0.0150	6286	2.3911E-06	17.702	1
2146	45.19	0.6836	446571	0.0150	5884	2.553E-06	17.945	1
2146	46.13	0.6911	449547	0.0150	5752	2.6121E-06	18.215	1
2146	47.12	0.6986	452323	0.0152	5418	2.8142E-06	18.470	1
2146	48.16	0.7064	454965	0.0155	5154	3.0006E-06	18.753	1
2146	49.21	0.7141	457477	0.0457	11811	3.8689E-06	19.607	1
2146	54.95	0.7521	466776	0.0455	11268	4.0355E-06	19.915	1
2146	56.20	0.7596	468745	0.0150	4170	3.6086E-06	20.855	1
2146	57.47	0.7671	470946	0.0150	4124	3.6485E-06	21.194	1
2146	58.79	0.7746	472869	0.0151	3772	3.9977E-06	21.517	1
2146	60.17	0.7822	474718	0.0152	3691	4.1096E-06	21.883	1
2146	61.57	0.7898	476560	0.0151	3535	4.2747E-06	22.224	1
2146	63.04	0.7973	478253	0.0150	3386	4.4387E-06	22.607	1
2146	64.53	0.8048	479946	0.0151	3121	4.8238E-06	22.978	1
2146	66.10	0.8123	481374	0.0152	2896	5.2371E-06	23.373	1
2146	67.71	0.8200	482842	0.0152	2788	5.434E-06	23.765	1
2146	69.36	0.8275	484162	0.0151	2756	5.4773E-06	24.189	1
2146	71.10	0.8351	485598	0.0151	2650	5.7074E-06	24.610	1
2146	72.88	0.8426	486812	0.0151	2313	6.5202E-06	25.065	1
2146	74.73	0.8502	487911	0.0151	2169	6.9526E-06	25.522	1
2146	76.64	0.8577	488981	0.0152	2077	7.302E-06	25.978	1
2146	78.63	0.8653	489988	0.0152	1868	8.1278E-06	26.468	1
2146	80.71	0.8729	490849	0.0152	1778	8.5225E-06	26.956	1
2146	82.84	0.8805	491766	0.0151	1658	9.1361E-06	27.474	1
2146	85.07	0.8880	492507	0.0152	1324	1.1476E-05	28.022	1
2146	87.38	0.8957	493090	0.0151	1150	1.3161E-05	28.550	1
2146	89.73	0.9032	493657	0.0151	1031	1.4692E-05	29.142	1
2146	92.24	0.9108	494121	0.0076	464	1.6472E-05	29.412	1

Invalid Pts Column

0 - Valid Datapoint

1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)

2 - The crack deviated > 20 degrees from the plane of symmetry

3 - The difference between the front and back crack lengths > 0.25B

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Westmoreland Mechanical Testing & Research, Inc.

Project Parameters

CUSTOMER : SOUTHWEST RESEARCH
P.O. NO. : F58154BT
SPECIMEN NUMBER : FCG-H-W-4
YIELD STRENGTH : 52.5 ksi
MODULUS : 29.4 Msi

TESTLOG NO. : T05257
MATERIAL : Head Weld
TEST MACHINE : H44

WMT&R REPORT NO. : 3-67089
WMT&R QUOTE : QN121622 Rev.1
TEST DATE : 8/14/2013
CRACK PLANE ORIENTATION : L-C Vessel

SPECIMEN MEASUREMENTS:

SPECIMEN TYPE : C(T)
THICKNESS (B) : 0.2495 in
WIDTH (W) : 1.5030 in
NOTCH (An) : 0.3008 in

Testing Parameters

TEST TYPE : CONSTANT AMPLITUDE
MAXIMUM LOAD : 2171.00 lb
MINIMUM LOAD : 1519.7 lb
LOAD RANGE : 651.3 lb

STRESS RATIO : 0.70
FREQUENCY : 5 Hz
WAVEFORM : SINE
SPECIMEN TYPE : C(T)

ENVIRONMENT : LAB AIR
TEMPERATURE : Room
HUMIDITY : 27% - 33%
ANALYSIS METH. : MODIFIED SECANT

Pmax lb	EB(V/P)	a in	N	da in	dN	da/dN in/cycle	ΔK ksi(in^0.5)	Invalid Pts
2171	19.37	0.3412	21422	0.0117	41520	2.8256E-07	9.835	0
2171	19.62	0.3471	41901	0.0114	40043	2.8496E-07	9.946	0
2171	19.85	0.3527	61465	0.0112	36370	3.0784E-07	10.048	0
2171	20.09	0.3583	78271	0.0112	33720	3.3193E-07	10.154	0
2171	20.35	0.3638	95185	0.0111	32078	3.451E-07	10.257	0
2171	20.62	0.3694	110349	0.0111	31376	3.5526E-07	10.371	0
2171	20.87	0.3750	126561	0.0111	31434	3.5333E-07	10.466	0
2171	21.15	0.3805	141783	0.0111	28979	3.8266E-07	10.582	0
2171	21.43	0.3861	155540	0.0111	28238	3.9482E-07	10.678	0
2171	21.70	0.3917	170021	0.0111	28793	3.8475E-07	10.794	0
2171	21.97	0.3972	184333	0.0111	26998	4.1041E-07	10.895	0
2171	22.26	0.4027	197019	0.0112	25329	4.4066E-07	11.014	0
2171	22.55	0.4083	209662	0.0111	25390	4.3706E-07	11.110	0
2171	22.83	0.4138	222409	0.0111	25084	4.4176E-07	11.229	0
2171	23.15	0.4194	234746	0.0111	23491	4.7299E-07	11.332	0
2171	23.44	0.4249	245900	0.0111	22087	5.0066E-07	11.440	0
2171	23.75	0.4305	256833	0.0111	22854	4.8585E-07	11.553	0
2170	24.07	0.4360	268754	0.0112	22358	5.0039E-07	11.659	0
2171	24.37	0.4417	279191	0.0112	20876	5.3784E-07	11.781	0
2171	24.69	0.4473	289630	0.0112	19893	5.6119E-07	11.897	0
2171	25.05	0.4528	299084	0.0111	19598	5.6403E-07	12.016	0
2171	25.36	0.4583	309228	0.0110	19117	5.7651E-07	12.128	0
2171	25.71	0.4638	318201	0.0111	18342	6.0265E-07	12.242	0
2171	26.01	0.4694	327570	0.0111	17958	6.2086E-07	12.354	0
2171	26.41	0.4750	336159	0.0111	16867	6.598E-07	12.469	0
2171	26.76	0.4805	344437	0.0112	16658	6.707E-07	12.601	0
2171	27.12	0.4862	352817	0.0112	16567	6.7726E-07	12.710	0
2171	27.49	0.4917	361004	0.0111	16387	6.7686E-07	12.843	0
2171	27.85	0.4972	369204	0.0111	16004	6.92E-07	12.958	0
2171	28.28	0.5028	377008	0.0114	15403	7.3746E-07	13.084	0
2171	28.65	0.5086	384607	0.0114	14902	7.6252E-07	13.204	0
2171	29.05	0.5142	391910	0.0111	14411	7.6877E-07	13.333	0

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2171	29.43	0.5197	399018	0.0111	13950	7.989E-07	13.459	0
2171	29.87	0.5253	405860	0.0111	13367	8.3352E-07	13.588	0
2171	30.27	0.5308	412385	0.0111	13152	8.4127E-07	13.718	1
2171	30.70	0.5364	419012	0.0112	12939	8.633E-07	13.846	1
2170	31.12	0.5420	425324	0.0113	12652	8.9106E-07	13.981	1
2171	31.56	0.5476	431664	0.0112	13247	8.4526E-07	14.116	1
2170	32.01	0.5532	438571	0.0112	12722	8.8142E-07	14.252	1
2171	32.49	0.5589	444386	0.0112	12822	8.7237E-07	14.394	1
2171	32.93	0.5644	451393	0.0111	13733	8.0925E-07	14.528	1
2171	33.46	0.5700	458119	0.0112	12256	9.123E-07	14.671	1
2171	33.89	0.5756	463649	0.0112	10662	1.0461E-06	14.813	1
2171	34.36	0.5811	468781	0.0112	9477	1.1858E-06	14.959	1
2171	34.84	0.5868	473126	0.0114	8804	1.2893E-06	15.108	1
2171	35.35	0.5925	477585	0.0113	8523	1.3228E-06	15.258	1
2170	35.89	0.5981	481649	0.0115	8329	1.3756E-06	15.411	1
2171	36.44	0.6039	485914	0.0116	7832	1.4844E-06	15.572	1
2170	37.04	0.6097	489481	0.0113	7328	1.544E-06	15.723	1
2171	37.58	0.6153	493242	0.0112	7327	1.5331E-06	15.895	1
2171	38.10	0.6209	496808	0.0116	6834	1.6929E-06	16.050	1
2171	38.65	0.6268	500076	0.0120	6337	1.8935E-06	16.225	1
2171	39.37	0.6329	503145	0.0118	6127	1.9292E-06	16.395	1
2171	39.93	0.6386	506203	0.0113	5932	1.901E-06	16.568	1
2171	40.52	0.6442	509077	0.0113	6146	1.8338E-06	16.736	1
2171	41.06	0.6499	512349	0.0114	6146	1.8565E-06	16.916	1
2171	41.89	0.6556	515223	0.0116	5255	2.2071E-06	17.089	1
2171	42.54	0.6615	517604	0.0121	4568	2.6569E-06	17.280	1
2171	43.17	0.6678	519791	0.0122	4964	2.45E-06	17.475	1
2171	43.93	0.6737	522568	0.0117	5062	2.3054E-06	17.664	1
2171	44.64	0.6794	524853	0.0114	4360	2.613E-06	17.861	1
2171	45.30	0.6851	526928	0.0112	4052	2.7578E-06	18.047	1
2171	46.02	0.6906	528905	0.0113	3952	2.8533E-06	18.242	1
2171	46.78	0.6963	530880	0.0115	3858	2.9694E-06	18.434	1
2171	47.57	0.7021	532763	0.0119	3760	3.1697E-06	18.659	1
2171	48.31	0.7083	534640	0.0118	3561	3.3054E-06	18.856	1
2171	49.07	0.7138	536324	0.0116	3465	3.3571E-06	19.104	1
2171	50.01	0.7199	538105	0.0120	3366	3.5615E-06	19.301	1
2171	50.92	0.7258	539690	0.0117	2969	3.9267E-06	19.549	1
2171	51.71	0.7316	541074	0.0113	2468	4.5766E-06	19.745	1
2171	52.55	0.7371	542158	0.0113	2275	4.983E-06	19.991	1
2171	53.39	0.7429	543349	0.0114	2279	5.0165E-06	20.201	1
2171	54.33	0.7485	544437	0.0117	2083	5.603E-06	20.451	1
2171	54.95	0.7546	545432	0.0124	2465	5.0206E-06	20.707	1
2171	55.73	0.7609	546902	0.0122	2955	4.1137E-06	20.955	1
2171	56.60	0.7667	548387	0.0117	3120	3.7544E-06	21.237	1
2171	57.83	0.7726	550022	0.0116	2895	3.9914E-06	21.478	1
2171	58.34	0.7783	551282	0.0118	2535	4.6407E-06	21.760	1
2171	59.57	0.7844	552557	0.0117	2295	5.0886E-06	22.021	1
2171	60.63	0.7899	553577	0.0111	1875	5.9405E-06	22.298	1
2171	61.80	0.7955	554432	0.0056	855	6.5352E-06	22.436	1

Invalid Pts Column
0 - Valid Datapoint
1 - The specimen was not predominantly elastic (W-a >= (4/Pi)(Kmax/0.2% Yield Strength)^2)
2 - The crack deviated > 20 degrees from the plane of symmetry
3 - The difference between the front and back crack lengths > 0.25B

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14. ABSTRACT
To provide NASA with a suite of materials strength, fracture toughness and crack growth rate test results for use in remaining life calculations for the vessels described above, Southwest Research Institute® (SwRI®) was contracted in two phases to obtain relevant material property data from a representative vessel. An initial characterization of the strength, fracture and fatigue crack growth properties was performed in Phase 1. Based on the results and recommendations of Phase 1, a more extensive material property characterization effort was developed in this Phase 2 effort. This Phase 2 characterization included additional strength, fracture and fatigue crack growth of the multilayer vessel and head materials. In addition, some more limited characterization of the welds and heat affected zones (HAZs) were performed. This report describes Phase 2 of this effort.

15. SUBJECT TERMS
Modal Acoustic Emission; Crack Growth Rate; Pressure Vessel; Fatigue crack growth; Heat affected zones

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
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