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WAPD-T-3194

FRACTURE TOUGHNESS (K_{Ic}) DATA REDUCTION PROGRAM

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U. S. Department of Energy Contract DE-AC11-93PN38195

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ABSTRACT

This report documents the development, verification, and use instructions for an automated K_{IC} data reduction program written in the Hewlett Packard Visual Engineering Environment (HP VEE) programming language. Currently, when the standard test method Plane - Strain Fracture Toughness of Metallic Materials (K_{IC}), is performed, the data is reduced manually. Data reduction includes 15 detailed calculations required by the American Society for Testing and Materials (ASTM) E399 to determine the validity of the computed K_{IC} value. Manual data reduction is both time consuming, tedious, and prone to errors. Since all K_{IC} tests are completed using a data acquisition system to digitally record time, load, and crack opening displacement (COD); automation of K_{IC} data reduction using a computer program to perform all calculations rapidly, enables processing of a large amount of data. The K_{IC} data reduction program reduces any computer American Standard Code for Information Interchange (ASCII) data file. Thus, the K_{IC} data reduction program is also used to over check tests performed at other facilities. The program was qualified based on mechanical properties of commercial alloy specimens.

Key features of the K_{IC} data reduction program are:

1. The program plots load vs. COD on the screen from the digital data.
2. Based on two points, picked by the user encompassing the linear portion of the curve, the program performs a linear regression analysis on the data between these points and plots a 5% secant line.
3. Based on the intersection between the 5% secant line and raw data, the program determines the loads P_5 and P_Q , the maximum load, and the curve type and then the results are displayed on the screen
4. After the user has inputted specimen properties, dimensions, and other pretest information, calculations and validity checks are performed.
5. The results are then displayed to the screen for the user to review; then they can be written to a file, a printer, both, or neither.
6. All user inputs are retained and need not be reentered if additional iterations need to be completed on the same specimen.

Fracture Toughness (K_{IC}) Data Reduction Program

Introduction

Sometimes structures, which were properly designed to avoid excessive elastic deflection and plastic yielding fail in a catastrophic way by, fast fracture. Common to these failures is the preexistence of flaws in the materials that initiate cracks that grow and lead to fracture. This has lead, in a sense, to the need for a determination of fracture toughness (K_{IC}) in order to characterize fracture resistance of low ductility material to support fail-safe design analyses.

The K_{IC} value is a material property just as the yield strength is a material property. But, like any material property, it is influenced by material composition, heat treatment processes, test temperature at which the material will be exposed to during its life, loading rate, etc. A K_{IC} value can be used to quantitatively establish the effects of material composition or heat treatment, or manufacturing operations such as forming or welding, on the fracture performance of new or existing materials. In service evaluations, a K_{IC} value can be used to determine the maximum flaw size that can be allowed in a material in a specific application for a prescribed stress level. Conversely, it can be used to determine an allowable stress level that can be used safely in a specific application for a given flaw size. A K_{IC} value can also be used to establish acceptance specifications and manufacturing quality control.

A K_{IC} value is independent of geometry as long as the specimen meets the size requirements of E 399. The derivation of K is based on a linear elastic solution. The state of stress at the crack tip of the test specimen used to determine K_{IC} should approximate linear elastic conditions. In order to insure that the state of stress is linearly elastic, the specimen's thickness must be such that plane strain conditions exist.

Currently, when a K_{IC} test is performed, the data is reduced manually using a two-page work sheet. The calculations are required to determine if the specimen was precracked properly, if the test itself is valid, and if the specimen is of proper size. In all, 15 calculations and validity checks must be performed. This manual approach is time consuming, tedious, and prone to errors. Currently, all K_{IC} tests are completed using a data acquisition system (DAS) to digitally record time, load, and front- face crack opening displacement (COD). To make the lab more efficient and to better utilize the digital data, a K_{IC} data reduction program was developed to automate the calculations and validity checks and eliminate the manual data reduction.

Manual Method Using an Analog X-Y Chart Recorder

ASTM E 399 requires obtaining a graphical plot of load versus crack opening displacement (COD). One of the initial steps in preparing for a K_{IC} test is properly setting the analog X-Y chart recorder scales. This is directly related to material and specimen geometry, and both the maximum load and maximum COD must be estimated. Therefore, to insure no analog data is lost, these scales must be set greater than the estimated maximum load and maximum COD. This may result in the graphs being so small that reading the load is very difficult (see Fig. 4). One of the validity requirements of E 399 is that the initial slope of the linear portion of the curve must be between 0.7 and 1.5 and a small error in estimating the initial slope can invalidate the results. The combination between the load cell range and X-Y chart recorder scale must be such that the load P_Q can be determined with an accuracy of $\pm 1\%$. Thus, the accuracy of the load P_Q will be greater the larger the scale of the analog X-Y chart recorder. Once the maximum load and maximum COD is determined from the first test, the analog scales can be adjusted accordingly. However, this new adjustment still does not guarantee that the initial slope will lie between 0.7 and 1.5 for the next specimens.

To illustrate some of the problems using an X-Y chart recorder, consider the following: Even though Figures 1 and 2 were obtained from the same aluminum alloy, similar specimens can differ measurably. The load scale for curve #1 was adjusted for the second specimen to record an expected maximum load of approximately 4100 lbs.; this was in error. The second specimen tested (Fig. 2), reached a maximum load which was over 1000 lbs. greater than the first specimen. As seen in Figure 2, the wrong scale was chosen for curve #1. The pen would have reached the maximum travel limit of the X-Y chart recorder before the maximum load had been recorded. Also, if the entire test were recorded using Curve #1, it would have failed to meet the required slope tolerance. So, the test was suspended, the load scale was changed, and the test resumed. Curve #2 is the remainder of the test plotted on a reduced scale. Therefore, the X-Y chart recorder must be carefully and continuously monitored in order that no physical limits on the recorder or scale limits are exceeded.

By recording the data digitally, recording errors are eliminated and recording the data digitally reduces the need for spare specimens of each type/heat. Digital recording also eliminates operator setup of the X-Y chart recorder. This saves the expense of machining spare specimens and potential difficulties the amount of available material.

Manual Data Reduction

Once the recorder has been properly set and a test completed, the user must calculate a conditional value of the fracture toughness value, K_Q , then perform the required calculations and validity checks to determine if a valid K_{IC} , fracture toughness value, was achieved.

The calculation of K_Q begins with determining the load P_Q from the graph. In order to determine the load P_Q , a qualifying load P_s is determined by drawing a line starting at the origin of the graph and through the initial slope of the linear portion of the curve. Note: The origin is defined as the intersection of the line through the initial slope of the linear portion of the curve and the COD axis. A secant line is then drawn through the same origin of the graph with the slope equal to 95% of the initial slope of the linear portion of the curve. P_s is determined from the intersection of the secant line and the data curve. P_Q is determined in the following manner: If the load at every point on the graph which precedes P_s is lower than P_s , then P_Q is equal to P_s (Type I curve, Fig. 4 series); if, however, there is a maximum load preceding P_s which exceeds it, then this maximum load is P_Q (Types II and III, Fig. 1-3 series). It should be noted that the origin of the graph is sometimes not easily discernible. This is due to the fact that some nonlinearity often occurs at the beginning of a test. This nonlinearity is caused in part to crack closure and friction effects. It is important that the initial slope of the linear portion of the curve be determined with a high degree of accuracy.

With a completed test and the specimen now in two pieces, post-test measurements must be performed on the fracture surface. These measurements consist of five crack lengths measured at equally spaced increments across the thickness of the specimen. The three inner crack lengths are then averaged and used with P_Q to calculate K_Q . Once K_Q has been determined, the user must then perform the remaining post-test calculations that will be used to evaluate the validity of K_Q . The sequence of calculations and validity checks may be viewed in the work sheets in Appendix A.

K_{max} is then calculated using the final load at which the specimen was precracked. K_{rate} is then calculated. K_{rate} is directly proportional to the loading rate (lbs./min) of the specimen. K_{IC} tests are controlled to a fixed displacement rate specified in inches/min. One method used to determine the loading rate is to use a stopwatch and while watching the X-Y chart recorder, time the loads in the initial linear region and then calculate a loading rate. In this case, one must make sure not to misjudge the linear region. Other methods exist, but some of these involve knowing the machine stiffness, which further complicates the calculation.

The specimen strength ratio is then calculated. This ratio can be a useful comparative measure of the toughness of materials when the specimens are of the same size and form, and the size is not suitable to provide a valid K_{IC} result. Given the above measurements and calculations, the user will then proceed to perform the validity checks as seen on the second page of the Appendix A work sheet.

If the user wants to refine the results just calculated the lines on the graph would have to be erased replotted, and validity checks depending on the above calculations would have to be performed again. One can see if multiple specimens were being tested, how time consuming, tedious, and prone to errors the process would be.

K_{IC} Data Reduction Program

To help alleviate the problems of the analog X-Y chart recorder, manual calculations, and validity checks, a K_{IC} data reduction program was developed to automate all calculations easily and quickly. By automating the data reduction, all curve fits and line intersections will be well defined and more precise. This eliminates most manual data reduction and associated errors. The only manual data reduction that is the same for both methods is the post-test crack length measurements. The program also allows the data to be reprocessed in order to optimize data reduction. The K_{IC} data reduction program reduces any American Standard Code for Information Interchange (ASCII) data file. Thus, the K_{IC} data reduction program can be used to over check tests performed at other facilities. The K_{IC} data reduction program is configured for compact tension specimens with or without side grooves with either a straight through or chevron fatigue crack starter notch configuration. The program could also be modified for other specimen geometries.

Four specimens and a subcontractor-supplied ASCII data file were used to validate the K_{IC} data reduction program. The specimens tested included: two 7175 Aluminum specimens (Figs. 1 & 2), one 4140 steel (Fig. 3), and one nickel base alloy X-750 (Fig. 4). The aluminum specimens were chosen because this material was known to produce a valid test. The 4140 material cooled to -200°F was predicted to produce a valid test. The X-750 material was known to produce an invalid test due to its superior ductility.

Program Function and Benefits

Automated reduction of the K_{IC} data proceeds according to the following steps:

1. The program reads a time, load, and crack opening displacement (COD) raw data file and then plots load vs. COD on screen.

Benefit

There are no scales for the user to set. The program does this automatically. As a result, the K_{IC} data reduction program eliminates the validity requirement for the initial slope of the linear portion of the curve to lie between 0.7 and 1.5 because the digital data can be scaled with this required slope as seen in Figures 1A - 4A. In these figures, the scales were manually manipulated to produce the slope between 0.7 and 1.5. Also, the program has the potential to reduce the number of specimens that need to be machined and tested; thus, saving total test time and expense.

2. The user picks two points encompassing a linear region on the initial linear slope of the data.

Benefit

This eliminates the need for reliance on the user's graphing skills.

3. The program performs a linear regression analysis on the data between these two points and plots a 5% secant line on screen and determines the intersection between the raw data and the 5% secant line.

Benefit

This eliminates user interpretation of where the lines intersect.

4. Based on the intersection determined by the program, loads P_5 and P_Q , maximum load, and curve type are calculated and the results displayed on the screen

Benefit

This eliminates the user interpretation of the values of the required loads.

It should be noted that a limiting factor with collecting the data digitally is that after the specimen breaks (after maximum load) the data collection rate (4-5 Hz) is not fast enough to collect all of the final test data. This is evident in the Figure 1-3 series graphs. This data is only needed so the program can determine P_5 ; thus, determining P_Q . To fill the gaps in the missing digital data, the K_{IC} data reduction program performs a linear regression on the load-COD data pair bounding the gap and then fills in the missing data every 10 lbs. Then P_5 is determined from this data. It is noted that the missing data is probably not linear between these two points. However, with P_Q being determined as described above, and if the curve is of type III (this problem is not inherent with a type I or types II curve) where the data gap occurs, the exact value of P_5 is unimportant because P_Q and P_{max} precede specimen fracture.

5. A user input screen is then generated, allowing the user to input the specimen dimensions, material properties, specimen serial number, test sponsor's name, and precrack information.

Benefit

This step is the same regardless if the manual method or the program is used. The program offers the user the choice of reviewing the input data as many times as needed to insure everything has been entered correctly.

6. After all supporting information is provided; calculations and validity checks are performed.

Benefit

The time needed to reduce the data for 1 specimen, including the 5 crack length measurements, using the K_{IC} data reduction program is approximately 5 minutes compared to approximately 60 minutes required for the manual method.

The K_{IC} data reduction program eliminates the problem of calculating a loading rate when the loading rate is specified in inches/minute. The program takes the two points that the user selected for encompassing the initial slope of the linear region and selects the time - load pair for each point and calculates a loading rate in lbs./min.

7. The results are then displayed to the screen for the user to review.

Benefit

This eliminates the need to erase and replot the required lines on the test record if the results need to be refined. If while viewing the results on screen and the user wants to refine the results, he or she may elect to rerun the program and select different points encompassing the initial linear region in order to fine tune the results.

8. Once the user acknowledges the results, they can be written to a file, a printer, both, or neither.

Benefit

This has the advantage of easily storing the data for future use. The hard copy of the graph and the work sheet is all that can be stored and copied for future use if using the manual method. For a large number of specimens, archiving could be a problem. Also, digital data can be transferred to the test sponsor electronically.

9. All user inputs are retained and need not be entered if additional iterations need to be completed on the same specimen.

Benefit

This is directly related to step 7. It saves time and the associated errors with reentering data again if the results are to be refined for a given specimen.

Validation

The comparison of the hand calculations versus the computer calculations can be seen in Appendix A and summarized in Table A. The differences between hand calculations and computer calculations are due to round-off error and the accuracy with which the required loads can be read from the analog X-Y chart recorder. Both sets of calculations are identical within the error inherent in the K_{IC} test.

Appendix B compares a subcontractor's data report and calculations to the K_{IC} data reduction program analysis of the subcontractor supplied ASCII data file. Table B is a summary of the calculations. The calculations and validity checks compared exactly except for the K_{rate} and a minimum crack length calculation (i.e., validity check #11 of the subcontractor report and validity check #1 of the K_{IC} data reduction report). The difference in the K_{rate} calculation is due to the interpretation of the initial slope of the linear region of the curve. The difference in the crack length calculation results from the fact that the subcontractor did not supply the length of the machined notch. A length of 0.800 inches was assumed for this specimen.

To further validate the program, one can zoom in with the digital graph and with the use of program generated pointers, confirm these points exactly. Figures 1B - 4B are graphs of the digital data that were analyzed by the program and manually scaled to match the slope of Figures 1A - 4A. The results are printed above the graphs. With the exception of Figure 4A, all manual results are within 1% of the computer-analyzed results. Therefore, if the K_{IC} data reduction program results are ever in question, the digital data may be plotted and the required loads determined with a high degree of confidence.

The manual results of Figure 4A are within 2% of the computer-analyzed results. The reason for the increase and discrepancy is that X-750 is a ductile material. It is virtually impossible to have it fail in a brittle mode in air. Thus, the initial linear portion of the curve is difficult to interpret.

It is noted that the work sheet results are also within 1% of the computer-analyzed results with the exception of the X-750 specimen.

Conclusion

With the data presented here, the K_{IC} data reduction program has been proven to perform satisfactorily.

It is realized that the Standard Test Method for Measurement of Fracture Toughness, E 1820, exists and is intended to replace ASTM Standard E 399 (K_{IC}) among several other fracture toughness standards. E 399 will either be allowed to expire or balloted for withdrawal at some future date. This K_{IC} data reduction program will need to be revised in order to incorporate the requirements of E 1820.

Figures

Series 1- 4

5135N11

Y...mV/cm

X...mV/cm

Name: Figure 1: Alumina 7175

Datum: Mike 2

22

Bibliography

Load vs COD for Specimen S/N m1e1

Figure 1A: Aluminum 7175

Pmax = 4091 lbs Load vs COD PQ = 4091 lbs Specimen S/N: mike1 Type III Curve

— x: 81.07m

y: 2751

— x: 74.36m

y: 1413

Figure 1B: Aluminum 7175

9708056C 1CW Mike 2

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[illegible]

STRENGTH

20

FIGURE 2: ALUMINUM 7175

1044 10 8 10 10 THE CENTERED BS 5114-4

25571
25052

055

751-

7500

500

[illegible]

Load vs COD for Specimen S/N MIKE2

Figure 2A: Aluminum 7175

Pmax = 5266 lbs Load vs COD PQ = 5042 lbs Specimen S/N: MIKE2 Type II Curve

—	x: 94.91m	y: 3506
—	x: 86.83m	y: 2036

Figure 2B: Aluminum 7175

LINSEIS

Y.....mV/cm

X.....mV/cm

Name: *FIGURE 3: 4140 STEEL*

Datum: *MILE 3*

Blatt Nr.

Nr.

Load vs COD for Specimen S/N m1k3

Figure 3A: 4140 Steel

Pmax = 2471 lbs Load vs COD PQ = 2471 lbs Specimen S/N: mike3 Type III Curve

— x: 8.38m

y: 2039

— x: 4.2m

y: 1070

Figure 3B: 4140 Steel

Name: *Fluorid: Incoel X-750* Blat: *1*
 Datum: *M125-1531*
 Y-axis: mV/cm
 X-axis: mV/cm

Figure 1: Incoel X-750

Load vs COD for Specimen S/N M1265-1531

Figure 4A: Inconel X-750

Pmax = 6437 lbs Load vs COD PQ = 4431 lbs Specimen S/N: M1265-1531 Type I Curve

—	x: 8.11m	y: 2811
—	x: 5.37m	y: 1919

Figure 4B: Inconel X-750

Appendix A

Calculations and Validity Checks

Table A: Comparison of Manual Values versus Computer Values							
Specimen ID		P _Q (lbs)	P _{max} (lbs)	K _Q (ksi*in ^{1/2})	K _{rate} (ksi*in ^{1/2})/min	R _{SC}	R=2.5*(K _Q /Y _S) ²
Mike 1	Work Sheet Values	4050	4050	27.7	64.7	0.676	0.5328
	Computer Values	4091	4091	28	64.7	0.683	0.5435
	Figure A Values	4050	4100				
	WS Delta %	1.00	1.00	1.07	0.00	1.02	1.97
	Figure A Delta %	1.00	0.22				
Mike 2	Work Sheet Values	5075	5300	36.6	71.7	0.954	0.9303
	Computer Values	5042	5266	36.4	71.7	0.948	0.9178
	Figure A Values	5060	5250				
	WS Delta %	0.65	0.65	0.55	0.00	0.63	1.36
	Figure A Delta %	0.36	0.30				
Mike 3	Work Sheet Values	2458	2458	50	86.3	0.923	0.4
	Computer Values	2471	2471	50.2	86.3	0.927	0.4035
	Figure A Values	2450	2450				
	WS Delta %	0.53	0.53	0.40	0.00	0.43	0.87
	Figure A Delta %	0.85	0.85				
M1265-1531	Work Sheet Values	4350	6438	93.1	92	2.51	1.302
	Computer Values	4431	6437	94.8	92	2.514	1.351
	Figure A Values	4350	6437				
	WS Delta %	1.83	0.02	1.79	0.00	0.16	3.63
	Figure A Delta %	1.83	0.00				

K_{IC} Work Sheet for C(T) Specimens

Work Request No.: N/A Specimen I.D.: S-L-96DN012A KW (Mike I)

Required Engineer Supplied Information:

Size: 1.0T Material: A1 7175 Heat: N/A Loading Rate (L_R): 100 (inches/min.)
 Modulus (E): 10.4 (10⁶psi) 2% δys: 60 (10³psi) Est. K_{IC}: 36 (10³psi√in) Est. P_{max}: 5300 (lbs)

Specimen Precrack Information:

B: 1 W: 2 Final Precrack Load (P_{f(max)}): 1600 *Precrack a_f: N/A *Precrack a_f/W: .5
 Side 1 Precrack: N/A Side 2 Precrack: N/A Notch Type: ST Cycles for Final 2.5% of a: N/A

Pre-Test Information:

Test Temperature: RT °F Relative Humidity: N/A % X-Y Chart Recorder used: (Y/N) Y If, Yes attach Chart.
 D.A.S. used (Y/N) Y If, Yes: D.A.S. I.D.#: PC#1 File Name: MIKEKIC1.DAT

Post K_{IC} Test Information:

Fracture Appearance: N/A

Type of Curve: III P_s = 3975 P_{max} = 4050 P_q = 4050

Crack Length at Left Surface	Crack Length at Left of Center	Crack Length at Center of Specimen	Crack Length at Right of Center	Crack Length at Right Surface	Average Crack Length (a ₁ + a ₂ + a ₃)/3
a ₁ = <u>1.0004</u>	a ₂ = <u>.9940</u>	a ₃ = <u>1.0065</u>	a ₄ = <u>1.0019</u>	a ₅ = <u>.9914</u>	a _{Avg} = <u>1.0008</u>

a_{avg}: 1.0008 a_{avg}/W: .5004

*NOTE: If unable to obtain all the required measurements to record as (a_{avg}) then use the Precrack a_f measurements per the Precrack Data Work Sheet.

Final K _{IC} Calculations: f = <u>9.67</u>			
f- Refer to the ASTM Conversion Chart that corresponds with the specimens Final calculated a _{avg} /W.			
P _q - Refer to ASTM E399 section 9.1.1	P _{f(max)} - the maximum load for the final 2.5% of crack growth. (See Pre-cracking Data Sheet)	Load Rate (L _R) - actual machine speed (lbs/min) as specified by the Test Sponsor.	Specimen Strength Ratio (R _{sc}):
$K_Q = \frac{P_Q f}{B \sqrt{W}}$	$K_{max} = \frac{P_{f(max)} f}{B \sqrt{W}}$	$K_{Rate} = \frac{L_R f}{B \sqrt{W}}$	$R_{sc} = \frac{2P_{max} (2W + a_{avg})}{B (W - a_{avg})^2 \sigma_{YS}}$
Record K _q here: <u>27.7 ksi√in</u>	Record K _{max} here: <u>10.9 ksi√in</u>	Record K _{Rate} here: <u>64.7 ksi√in/min</u>	Record R _{sc} here: <u>.676</u>

Now Complete all Validity Checks.
(over)

E399 Section	S	C	K _{IC} Test Data Record Sheet for C(T) Type Specimen(s)	Valid / Invalid
7.3.2.2 & 8.2.2	✓	✓	1. Precrack lengths must be $\geq 0.025 \cdot W$ or 0.05 inches. Minimum Length = <u>.1914</u> Inches	1. <u>Valid</u>
7.3.2.1	✓	✓	2. Precrack Must emerge from the chevron on both surfaces of the specimen.	2. <u>N/A</u>
8.2.2	✓	✓	3. a/W must be between 0.45 and 0.55 $a_{avg}/W =$ <u>—</u> - <u>.5004</u> Inches	3. <u>Valid</u>
8.2.2	✓	✓	4. Difference between any Two of (a_2, a_3, a_4) must be $\leq .10 \cdot a_{avg}$ Maximum Difference = <u>.025</u> $0.10 \cdot a_{avg} =$ <u>.10008</u> Inches	4. <u>Valid</u>
8.2.2	✓	✓	5. Difference between a_1 and a_5 must be $\leq .10 \cdot a_{avg}$ $a_1 - a_5 =$ <u>.009</u> $\leq 0.10 \cdot a_{avg} =$ <u>.10008</u> Inches	5. <u>Valid</u>
8.2.2	✓	✓	6. a_1 and a_5 must be between $0.85a_{avg}$ and $1.15a_{avg}$ $.85_{avg} =$ <u>.8507</u> $1.15_{avg} =$ <u>1.1509</u> $a_1 =$ <u>1.0004</u> $a_5 =$ <u>.9914</u>	6. 7. <u>N/A</u>
8.2.2	✓	✓	7. a_1 and a_5 must be between $0.90a_{avg}$ and $1.10a_{avg}$ $.90_{avg} =$ <u>—</u> $1.10_{avg} =$ <u>—</u> $a_1 =$ <u>—</u> $a_5 =$ <u>—</u>	7. 8. <u>Valid</u>
9.1.2	✓	✓	8. P_{max}/P_Q must be ≤ 1.10 $P_{max}/P_Q =$ <u>1</u> (lbs)	8. 9. <u>Valid</u>
A2.3.3	✓	✓	9. $0.60 \cdot K_Q$ must be $\geq K_{max}$ $K_{max} =$ <u>10.9</u> KSI $\sqrt{IN}$ $0.6 \cdot K_Q =$ <u>16.6</u> KSI $\sqrt{IN}$	9. 10. <u>Valid</u>
8.4	✓	✓	10. Test curve initial slope must be between (0.7 and 1.5) Actual Slope = <u>1.4</u>	10. 11. <u>Valid</u>
8.2.4	✓	✓	11. Fatigue precrack plane must be ≤ 10 Deg. Precrack Plane = <u>4.5</u> Deg.	11. 12. <u>Valid</u>
A2.3.3	✓	✓	12. K_{max}/E must be, $\leq 0.002 \sqrt{in}$ $K_{max}/E =$ <u>.0011</u>	12. 13. <u>Valid</u>
8.3	✓	✓	13. K_{Rate} must be between 30 and 150 KSI $\sqrt{IN}/MIN$. $K_{Rate} =$ <u>64.7</u> KSI $\sqrt{IN}/MIN$.	13. 14. <u>Valid</u>
9.1.3	✓	✓	14. B Must be, $\geq R = 2.5 \cdot (K_Q/YS)^{2/3}$ in $B =$ <u>1</u> Inches $R =$ <u>.5328</u>	14. 15. <u>Valid</u>
9.1.3	✓	✓	15. a_{avg} Must be, $\geq R = 2.5 \cdot (K_Q/YS)^{2/3}$ in $a_{avg} =$ <u>1.0008</u> Inches $R =$ <u>.5328</u>	15. <u>N/A</u>

COMMENTS:

$$K_Q = K_Y = 27.7 \text{ ksi } \sqrt{\text{in}}$$

* - C = Chevron Notched Specimen, S = Straight Through Notch Specimen

Prepared By: mk 2/ferriere

Date: 3/98

Checked By: _____

Date: _____

Preliminary Information:

Sponsor: M. R. Helman
Specimen S/N: mike1
Specimen Type & Orientation: 1.0T-C(T)
Notch Type: Straight
Material/Form: Al 7175
Heat: unknown
Relative Humidity (%): 50
Modulus (Msi) = 10.4
Precrack YS (ksi) = 60.0
Testing YS (ksi) = 60.0
Precrack Temperature (°F) = 75.0
Test Temperature (°F) = 75.0

Specimen Measurements:

Thickness, B (inches): 1
Bnet (inches): 1
Width, W (inches): 2

Fracture Test Crack Lengths:

Side 1, A1 = 1.0004 inches
Quarter Point 1, A2 = 0.9940 inches
Center Point, A3 = 1.0065 inches
Quarter Point 2, A4 = 1.0019 inches
Side 2, A5 = 0.9914 inches

Fatigue Precracking:

Precrack Plane = 4.5
Kmax (ksi(sqrt.in.)) = 10.9
Cycles for Final 2.5% of a: 43000
Maximum Fatigue Load (lbs) = 1600.0

Test Results:

KQ (ksi(sqrt.in.)) = 28.0
Pmax Load (lbs) = 4091.1
PQ (lbs) = 4091.1
Specimen Strength Ratio = 0.683
Krate (ksi(sqrt.in.)/min) = 64.7

Validity Checks Per ASTM E399:

1. Precrack lengths must be ≥ 0.0500 or a minimum of 0.05 inches
Minimum Length = 0.1914 inches	VALID
2. a/W must be between 0.45 and 0.55
$a/W = 0.5004$	VALID
3. Difference between any two of (a2, a3, a4) must be ≤ 0.1001
Max difference = 0.0125 inches	VALID
4. Difference between a1 and a5 must be $\leq .1 \cdot a$ avg
difference = 0.009 $\leq .1 \cdot a$ avg = 0.1001 inches	VALID
5. a1 and a5 must be between 0.8507 and 1.1509
a1 = 1.0004 a5 = 0.9914	VALID
6. Pmax / PQ must be ≤ 1.10
Pmax / PQ = 1.00	VALID
7. $0.60 \cdot KQ$ must be $\geq K_{max}$
Kmax = 10.9 ksi(sqrt.in.) $0.6 \cdot KQ = 16.8$ ksi(sqrt.in.)	VALID
8. K_{max} / E must be ≤ 0.002 sqrt.in.
$K_{max} / E = 0.001052$ sqrt.in.	VALID
9. Krate must be between 30 and 150 ksi(sqrt.in.) / min
Krate = 64.7 ksi(sqrt.in.) / min	VALID
10. B must be $\geq R = 2.5 \cdot (KQ/YS)^2$ inches
B = 1 inches R = 0.5435 inches	VALID
11. a must be $\geq R = 2.5 \cdot (KQ/YS)^2$ inches
a avg = 1.001 inches R = 0.5435 inches	VALID
12. The plane of the crack shall be within $\pm 10^\circ$.
Crack plane = 4.5	VALID

*** TEST IS VALID PER ASTM - E399; KIC = 28.0 KSI(SQRT.IN.) ***

K_{IC} Work Sheet for C(T) Specimens

Work Request No.: N/A

Specimen I.D.: 970X056C (CW) (Mike 2)

Required Engineer Supplied Information :

Size : 1.0T Material: A19175 Heat: N/A Loading Rate(L_R): .100 (inches/min.)
 Modulus (E): 10.4 (10³psi) 2% δ_{ys}: 62 (10³psi) Est. K_{IC}: 36 (10³psi√in) Est. P_{max}: 5300 (lbs)

Specimen Precrack Information :

B : 1 W : 2 Final Precrack Load (P_{f(max)}): 1600 * Precrack a_i: N/A * Precrack a_i/W : .5
 Side 1 Precrack : N/A Side 2 Precrack : N/A Notch Type: ST Cycles for Final 2.5% of a : N/A

Pre - Test Information :

Test Temperature: RT °F Relative Humidity: N/A % X - Y Chart Recorder used: (Y/N) Y If, Yes attach Chart.
 D.A.S. used (Y/N) Y If, Yes: D.A.S. I.D.#: PC#1 File Name : Mike K_{IC} 2.dat

Post K_{IC} Test Information :

a_{in} = .8

Fracture Appearance: N/A

Type of Curve: II P_s = 5025 P_{max} = 5300 P_Q = 5075

Crack Length at Left Surface	Crack Length at Left of Center	Crack Length at Center of Specimen	Crack Length at Right of Center	Crack Length at Right Surface	Average Crack Length (a ₁ + a ₂ + a ₃)/3
a ₁ = <u>1.0123</u>	a ₂ = <u>1.0330</u>	a ₃ = <u>1.0406</u>	a ₄ = <u>1.0301</u>	a ₅ = <u>1.0017</u>	a _{avg} = <u>1.0346</u>

a_{avg} : 1.0346 a_{avg}/W : .5173

*NOTE: If unable to obtain all the required measurements to record as (a_{avg}) then use the Precrack a_i measurements per the Precrack Data Work Sheet.

Final K _{IC} Calculations: f = <u>10.20</u>			
f- Refer to the ASTM Conversion Chart that corresponds with the specimens Final calculated a _{avg} /W.			
P _Q - Refer to ASTM E399 section 9.1.1	P _{f(max)} - the maximum load for the final 2.5% of crack growth. (See Precracking Data Sheet)	Load Rate (L _R) - actual machine speed (lbs/min) as specified by the Test Sponsor.	Specimen Strength Ratio (R _{sc}):
$K_Q = \frac{P_Q f}{B \sqrt{W}}$	$K_{max} = \frac{P_{f(max)} f}{B \sqrt{W}}$	$K_{Rate} = \frac{L_R f}{B \sqrt{W}}$	$R_{SC} = \frac{2P_{max} (2W + a_{avg})}{B (W - a_{avg})^2 \sigma_{YS}}$
Record K _Q here: <u>36.6 ksi√in</u>	Record K _{max} here: <u>11.5 ksi√in</u>	Record K _{Rate} here: <u>71.7 ksi√in/min</u>	Record R _{sc} here: <u>.954</u>

Now Complete all Validity Checks.

(over)

Validity Checks per ASTM E399

E399 Section	S	C	K _{IC} Test Data Record Sheet for C(T) Type Specimen(s)	Valid / Invalid
7.3.2.2 & 8.2.2	✓		1. Precrack lengths must be $\geq 0.025 \cdot W$ or 0.05 inches. Minimum Length = <u>.2017</u> Inches	1. Valid
		✓	2. Precrack Must emerge from the chevron on both surfaces of the specimen.	2. N/A
7.3.2.1	✓	✓	3. a/W must be between 0.45 and 0.55 $a_{avg}/W = \underline{\hspace{1cm}}$ - <u>.5773</u> Inches	3. Valid
8.2.2	✓	✓	4. Difference between any Two of (a_2, a_3, a_4) must be $\leq .10 \cdot a_{avg}$ Maximum Difference = <u>.0105</u> $0.10 \cdot a_{avg} = \underline{.10346}$ Inches	4. Valid
8.2.2	✓	✓	5. Difference between a_1 and a_5 must be $\leq .10 \cdot a_{avg}$ $a_1 - a_5 = \underline{.0106} \leq 0.10 \cdot a_{avg} = \underline{.10346}$ Inches	5. Valid
8.2.2	✓		6. a_1 and a_5 must be between $0.85a_{avg}$ and $1.15a_{avg}$ $.85_{avg} = \underline{.8794}$ $1.15_{avg} = \underline{1.1898}$ $a_1 = \underline{1.0123}$ $a_5 = \underline{1.0017}$	6. N/A
8.2.2		✓	7. a_1 and a_5 must be between $0.90a_{avg}$ and $1.10a_{avg}$ $.90_{avg} = \underline{\hspace{1cm}}$ $1.10_{avg} = \underline{\hspace{1cm}}$ $a_1 = \underline{\hspace{1cm}}$ $a_5 = \underline{\hspace{1cm}}$	7. Valid
9.1.2	✓	✓	8. P_{max} / P_Q must be ≤ 1.10 $P_{max} / P_Q = \underline{1.04}$ (lbs)	8. Valid
A2.3.3	✓	✓	9. $0.60 \cdot K_Q$ must be $\geq K_{Max}$ $K_{Max} = \underline{11.5}$ KSI $\sqrt{\text{in}}$ $0.6 \cdot K_Q = \underline{22.0}$ KSI $\sqrt{\text{in}}$	9. Valid
8.4	✓	✓	10. Test curve initial slope must be between (0.7 and 1.5) Actual Slope = <u>1.5</u>	10. Valid
8.2.4	✓	✓	11. Fatigue precrack plane must be ≤ 10 Deg. Precrack Plane = <u>4.5</u> Deg.	11. Valid
A2.3.3	✓	✓	12. K_{max} / E must be, $\leq 0.002 \sqrt{\text{in}}$ $K_{max} / E = \underline{.0011}$	12. Valid
8.3	✓	✓	13. K_{Rate} must be between 30 and 150 KSI $\sqrt{\text{in}}/\text{MIN}$. $K_{Rate} = \underline{13.1}$ KSI $\sqrt{\text{in}}/\text{MIN}$.	13. Valid
9.1.3	✓	✓	14. B Must be, $\geq R = 2.5 \cdot (K_Q/YS)^{2/3}$ in $B = \underline{1}$ Inches $R = \underline{.9303}$	14. Valid
9.1.3	✓	✓	15. a_{avg} Must be, $\geq R = 2.5 \cdot (K_Q/YS)^{2/3}$ in $a_{avg} = \underline{1.0346}$ Inches $R = \underline{.9303}$	15. N/A
COMMENTS:				
$K_Q = K_{IC} = 36.6 \text{ ksi} \sqrt{\text{in}}$				

* - C = Chevron Notched Specimen, S = Straight Through Notch Specimen

rik ifman 3/98
Prepared By: Date

Checked By: Date

Preliminary Information:

Sponsor: M. R. Heiman
Specimen S/N: MIKE2
Specimen Type & Orientation: 1.0T-C(T)
Notch Type: Straight
Material/Form: Al 7175
Heat: unknown
Relative Humidity (%): 50
Modulus (ksi) = 10.4
Precrack YS (ksi) = 60.0
Testing YS (ksi) = 60.0
Precrack Temperature (°F) = 75.0
-Test Temperature (°F) = 75.0

Specimen Measurements:

Thickness, B (inches): 1
Bnet (inches): 1
Width, W (inches): 2

Fracture Test Crack Lengths:

Side 1, A1 = 1.0123 inches
Quarter Point 1, A2 = 1.0330 inches
Center Point, A3 = 1.0406 inches
Quarter Point 2, A4 = 1.0301 inches
Side 2, A5 = 1.0017 inches

Fatigue Precracking:

Precrack Plane = 4.5
Kmax (ksi(sqrt.in.)) = 11.5
Cycles for Final 2.5% of a: 43000
Maximum Fatigue Load (lbs) = 1600.0

Test Results:

KQ (ksi(sqrt.in.)) = 36.4
Pmax Load (lbs) = 5265.8
PQ (lbs) = 5042.0
Specimen Strength Ratio = 0.948
Krate (ksi(sqrt.in.)/min) = 71.7

Validity Checks Per ASTM E399:

1. Precrack lengths must be ≥ 0.0500 or a minimum of 0.05 inches
Minimum Length = 0.2017 inches	VALID
2. a/W must be between 0.45 and 0.55
$a/W = 0.5173$	VALID
3. Difference between any two of (a2, a3, a4) must be ≤ 0.1035
Max difference = 0.0105 inches	VALID
4. Difference between a1 and a5 must be $\leq .1 \cdot a$ avg
difference = 0.0106 $\leq .1 \cdot a$ avg = 0.1035 inches	VALID
5. a1 and a5 must be between 0.8794 and 1.1898
a1 = 1.0123 a5 = 1.0017	VALID
6. P_{max} / PQ must be ≤ 1.10
$P_{max} / PQ = 1.04$	VALID
7. $0.60 \cdot KQ$ must be $\geq K_{max}$
$K_{max} = 11.5$ ksi(sqrt.in.) $0.6 \cdot KQ = 21.8$ ksi(sqrt.in.)	VALID
8. K_{max} / E must be ≤ 0.002 sqrt.in.
$K_{max} / E = 0.001109$ sqrt.in.	VALID
9. Krate must be between 30 and 150 ksi(sqrt.in.) / min
Krate = 71.7 ksi(sqrt.in.) / min	VALID
10. B must be $\geq R = 2.5 \cdot (KQ/YS)^2$ inches
B = 1 inches R = 0.9178 inches	VALID
11. a must be $\geq R = 2.5 \cdot (KQ/YS)^2$ inches
a avg = 1.035 inches R = 0.9178 inches	VALID
12. The plane of the crack shall be within $\pm 10^\circ$.
Crack plane = 4.5	VALID

*** TEST IS VALID PER ASTM - E399; KIC = 36.4 KSI(SQRT.IN.) ***

K_{IC} Work Sheet for C(T) Specimens

Work Request No.: N/A

Specimen I.D.: 415-52R (mke 3)

Required Engineer Supplied Information:

Size: 0.6T Material: 4140 Heat: N/A Loading Rate(L_R): .05 (inches/min.)

Modulus (E): 30 (10⁶psi) 2% δ_{ys}: 125 (10³psi) Est. K_{IC}: — (10³psi√in) Est. P_{max}: 2500 (lbs)

Specimen Precrack Information:

B_{net} = .49

B: .6 W: — Final Precrack Load (P_{f(max)}): 1160 • Precrack a₁: .6965 • Precrack a/W: .5804
Side 1 Precrack: — Side 2 Precrack: — Notch Type: ST Cycles for Final 2.5% of a: —

Pre-Test Information:

Test Temperature: -200 °F Relative Humidity: N/A % X-Y Chart Recorder used: (Y/N) Y If, Yes attach Chart.

D.A.S. used (Y/N) Y If, Yes: D.A.S. I.D.#: R#1 File Name: MIKEKIC3.dot

Post K_{IC} Test Information:

a_u = .54

Fracture Appearance: —

Type of Curve: III P_s = 2393 P_{max} = 2458 P_Q = 2458

Crack Length at Left Surface	Crack Length at Left of Center	Crack Length at Center of Specimen	Crack Length at Right of Center	Crack Length at Right Surface	Average Crack Length (a ₁ + a ₂ + a ₃)/3
a ₁ = <u>.6958</u>	a ₂ = <u>.6902</u>	a ₃ = <u>.6753</u>	a ₄ = <u>.6761</u>	a ₅ = <u>.6972</u>	a _{avg} = <u>.6772</u>

a_{avg}: .6772 a_{avg}/W: .5643

*NOTE: If unable to obtain all the required measurements to record as (a_u) then use the Precrack a₁ measurements per the Precrack Data Work Sheet.

Final K_{IC} Calculations: f = 11.948

f- Refer to the ASTM Conversion Chart that corresponds with the specimens Final calculated a_{avg}/W.

P _Q - Refer to ASTM E399 section 9.1.1	P _{f(max)} - the maximum load for the final 2.5% of crack growth. (See Precracking Data Sheet)	Load Rate (L _R) - actual machine speed (lbs/min) as specified by the Test Sponsor.	Specimen Strength Ratio (R _{sc}):
$K_Q = \frac{P_Q f}{B \sqrt{W}}$ (BB _{min}) ^{1/2}	$K_{max} = \frac{P_{f(max)} f}{B \sqrt{W}}$	$K_{Rate} = \frac{L_R f}{B \sqrt{W}}$	$R_{sc} = \frac{2P_{max} (2W + a_{avg})}{B (W - a_{avg})^2 \sigma_{ys}}$ B _{net}
Record K _Q here: <u>50.0 ksi√in</u>	Record K _{max} here: <u>23.6 ksi√in</u>	Record K _{Rate} here: <u>86.3 ksi√in/min</u>	Record R _{sc} here: <u>.923</u>

Now Complete all Validity Checks.
(over)

E399 Section	S	C	K _{IC} Test Data Record Sheet for C(T) Type Specimen(s)	Valid / Invalid
7.3.2.2 & 8.2.2	✓		1. Precrack lengths must be $\geq 0.025 \cdot W$ or 0.05 inches. Minimum Length = <u>.1353</u> Inches	1. <u>Valid</u>
		✓	2. Precrack Must emerge from the chevron on both surfaces of the specimen.	2. <u>N/A</u>
7.3.2.1	✓	✓	3. a/W must be between 0.45 and 0.55 $a_{avg}/W = \underline{\quad}$ - <u>.5643</u> Inches	3. <u>invalid</u>
8.2.2	✓	✓	4. Difference between any Two of (a_2, a_3, a_4) must be $\leq .10 \cdot a_{avg}$ Maximum Difference = <u>.0099</u> $0.10 \cdot a_{avg} = \underline{.06772}$ Inches	4. <u>Valid</u>
8.2.2	✓	✓	5. Difference between a_1 and a_5 must be $\leq .10 \cdot a_{avg}$ $a_1 - a_5 = \underline{.0014} \leq 0.10 \cdot a_{avg} = \underline{.6772}$ Inches	5. <u>Valid</u>
8.2.2	✓		6. a_1 and a_5 must be between $0.85a_{avg}$ and $1.15a_{avg}$ $.85a_{avg} = \underline{.5756}$ $1.15a_{avg} = \underline{.7786}$ $a_1 = \underline{.6958}$ $a_5 = \underline{.6772}$	6. <u>N/A</u>
8.2.2		✓	7. a_1 and a_5 must be between $0.90a_{avg}$ and $1.10a_{avg}$ $.90a_{avg} = \underline{\quad}$ $1.10a_{avg} = \underline{\quad}$ $a_1 = \underline{\quad}$ $a_5 = \underline{\quad}$	7. <u>Valid</u>
9.1.2	✓	✓	8. P_{max}/P_Q must be ≤ 1.10 $P_{max}/P_Q = \underline{1}$ (lbs)	8. <u>Valid</u>
A2.3.3	✓	✓	9. $0.60 \cdot K_Q$ must be $\geq K_{Max}$ $K_{Max} = \underline{23.6}$ KSI $\sqrt{\text{IN}}$ $0.6 \cdot K_Q = \underline{30.0}$ KSI $\sqrt{\text{IN}}$	9. <u>invalid</u>
8.4	✓	✓	10. Test curve initial slope must be between (0.7 and 1.5) Actual Slope = <u>1.1</u>	10. <u>Valid</u>
8.2.4	✓	✓	11. Fatigue precrack plane must be ≤ 10 Deg. Precrack Plane = <u>4.5</u> Deg.	11. <u>Valid</u>
A2.3.3	✓	✓	12. K_{max}/E must be, $\leq 0.002 \sqrt{\text{in}}$ $K_{max}/E = \underline{.000786}$	12. <u>Valid</u>
8.3	✓	✓	13. K_{Rate} must be between 30 and 150 KSI $\sqrt{\text{IN}}/\text{MIN.}$ $K_{Rate} = \underline{86.3}$ KSI $\sqrt{\text{IN}}/\text{MIN.}$	13. <u>Valid</u>
9.1.3	✓	✓	14. B Must be, $\geq R = 2.5 \cdot (K_Q/YS)^{**2}$ in $B = \underline{.48}$ Inches $R = \underline{.4}$	14. <u>Valid</u>
9.1.3	✓	✓	15. a_{avg} Must be, $\geq R = 2.5 \cdot (K_Q/YS)^{**2}$ in $a_{avg} = \underline{.6772}$ Inches $R = \underline{.4}$	15. <u>N/A</u>

COMMENTS:

$K_Q = 50 \text{ ksi } \sqrt{\text{in}}$ Invalid Test

* - C = Chevron Notched Specimen, S = Straight Through Notch Specimen

mk shuman

3/98

Prepared By:

Date

Checked By:

Date

Preliminary Information:

Sponsor: M. R. Heiman
Specimen S/N: mike3
Specimen Type & Orientation: 0.6T-C(T)
Notch Type: Straight
Material/Form: 4140
Heat: unknown
Relative Humidity (%): 50
Modulus (Msi) = 30.0
Precrack YS (ksi) = 120.0
Testing YS (ksi) = 125.0
Precrack Temperature (°F) = 75.0
Test Temperature (°F) = -200.0

Specimen Measurements:

Thickness, B (Inches): 0.6
Bnet (Inches): 0.48
Width, W (Inches): 1.2

Fracture Test Crack Lengths:

Side 1, A1 = 0.6958 Inches
Quarter Point 1, A2 = 0.6802 Inches
Center Point, A3 = 0.6753 Inches
Quarter Point 2, A4 = 0.6761 Inches
Side 2, A5 = 0.6972 Inches

Fatigue Precracking:

Precrack Plane = 4.5
Kmax (ksi(sqrt.in.)) = 23.6
Cycles for Final 2.5% of a: 43000
Maximum Fatigue Load (lbs) = 1160.0

Test Results:

KQ (ksi(sqrt.in.)) = 50.2
Pmax Load (lbs) = 2470.6
PQ (lbs) = 2470.6
Specimen Strength Ratio = 0.927
Krate (ksi(sqrt.in.)/min) = 86.3

Validity Checks Per ASTM E399:

1. Precrack lengths must be ≥ 0.0300 or a minimum of 0.05 inches
Minimum Length = 0.1353 inches	VALID
2. a/W must be between 0.45 and 0.55
$a/W = 0.5643$	INVALID
3. Difference between any two of (a2, a3, a4) must be ≤ 0.0677
Max difference = 0.0049 inches	VALID
4. Difference between a1 and a5 must be $\leq .1 \cdot a$ avg
difference = 0.0014 $\leq .1 \cdot a$ avg = 0.06772 inches	VALID
5. a1 and a5 must be between 0.5756 and 0.7788
a1 = 0.6958 a5 = 0.6972	VALID
6. P_{max} / PQ must be ≤ 1.10
$P_{max} / PQ = 1.00$	VALID
7. $0.60 \cdot KQ$ must be $\geq K_{max}$
$K_{max} = 23.6$ ksi(sqrt.in.) $0.6 \cdot KQ = 28.9$ ksi(sqrt.in.)	VALID
8. K_{max} / E must be ≤ 0.002 sqrt.in.
$K_{max} / E = 0.000786$ sqrt.in.	VALID
9. Krate must be between 30 and 150 ksi(sqrt.in.) / min
Krate = 86.3 ksi(sqrt.in.) / min	VALID
10. Bnet must be $\geq R = 2.5 \cdot (KQ/YS)^2$ inches
Bnet = 0.48 inches $R = 0.4035$ inches	VALID
11. a must be $\geq R = 2.5 \cdot (KQ/YS)^2$ inches
a avg = 0.6772 inches $R = 0.4035$ inches	VALID
12. The plane of the crack shall be within ± 10 .
Crack plane = 4.5	VALID

*** TEST IS INVALID PER ASTM - E399; KQ = 50.2 KSI(SQRT.IN.) ***

K_{IC} Work Sheet for C(T) Specimens

Work Request No.: N/A Specimen I.D.: M1265-1531 (Mike 5)

Required Engineer Supplied Information :

Size : 0.6T Material: X 750 Heat: N/A Loading Rate(L_R): .05 (inches/min.)
 Modulus (E): 30 (10⁶psi) 2% δys : 129 (10³psi) Est. K_{IC} : — (10³psi√in) Est. P_{MAX} : 4700 (lbs)

Specimen Precrack Information :

B_{net} = .46
 B : .6 W : 1.2 Final Precrack Load (P_{f(max)}): 1160 * Precrack a_f: .6946 * Precrack a_f/W : .5788
 Side 1 Precrack : — Side 2 Precrack : — Notch Type: ST Cycles for Final 2.5% of a : —

Pre - Test Information :

Test Temperature: -200 °F Relative Humidity: 2/4 % X - Y Chart Recorder used: (Y/N) Y If, Yes attach Chart.
 D.A.S. used (Y/N) Y If, Yes: D.A.S. I.D.#: PC #1 File Name : Mike 5. dat

Post K_{IC} Test Information :

Fracture Appearance: —

Type of Curve: I P_s = 4000 P_{max} = 6430 P_a = 4350

Crack Length at Left Surface	Crack Length at Left of Center	Crack Length at Center of Specimen	Crack Length at Right of Center	Crack Length at Right Surface	Average Crack Length (a ₁ + a ₂ + a ₃)/3
a ₁ = .6852	a ₂ = .6999	a ₃ = .6903	a ₄ = .6923	a ₅ = .7040	a _{Avg} = .6942

a_{avg} : .6942 a_{avg}/W : .5785

*NOTE: If unable to obtain all the required measurements to record as (a_{avg}) then use the Precrack a_f measurements per the Precrack Data Work Sheet.

Final K_{IC} Calculations: f = —

f - Refer to the ASTM Conversion Chart that corresponds with the specimens Final calculated a_{avg}/W.

P _a - Refer to ASTM E399 section 9.1.1	P _{f(max)} - the maximum load for the final 2.5% of crack growth. (See Pre-cracking Data Sheet)	Load Rate (L _R) - actual machine speed (lbs/min) as specified by the Test Sponsor.	Specimen Strength Ratio (R _{SC}):
$K_Q = \frac{P_Q f}{B \sqrt{W}}$ (BBN W) ^{1/2}	$K_{max} = \frac{P_{f(max)} f}{B \sqrt{W}}$	$K_{Rate} = \frac{L_R f}{B \sqrt{W}}$	$R_{SC} = \frac{2P_{max} (2W + a_{avg})}{B (W - a_{avg})^2 \sigma_{YS}}$
Record K _Q here:	Record K _{max} here:	Record K _{Rate} here:	Record R _{SC} here:
93.1 ksi√in	24.8 ksi√in	92.0 ksi√in/min	2.57

Now Complete all Validity Checks.
(over)

Preliminary Information:

Sponsor: M. R. Helman
Specimen S/N: M1265-1531
Specimen Type & Orientation: 0.6T-C(T)
Notch Type: Straight
Material/Form: X750
Heat: unknown
Relative Humidity (%): 50
Modulus (Msi) = 30.0
Precrack YS (ksi) = 120.0
Testing YS (ksi) = 129.0
Precrack Temperature (°F) = 75.0
Test Temperature (°F) = -200.0

Specimen Measurements:

Thickness, B (inches): 0.6
Bnet (inches): 0.48
Width, W (inches): 1.2

Fracture Test Crack Lengths:

Side 1, A1 = 0.6852 inches
Quarter Point 1, A2 = 0.6999 inches
Center Point, A3 = 0.6903 inches
Quarter Point 2, A4 = 0.6923 inches
Side 2, A5 = 0.7040 inches

Fatigue Precracking:

Precrack Plane = 4.5
Kmax (ksi(sqrt.in.)) = 24.8
Cycles for Final 2.5% of a: 43000
Maximum Fatigue Load (lbs) = 1160.0

Test Results:

KQ (ksi(sqrt.in.)) = 94.8
Pmax Load (lbs) = 6437.4
PQ (lbs) = 4430.9
Specimen Strength Ratio = 2.514
Krate (ksi(sqrt.in.)/min) = 92.0

Validity Checks Per ASTM E399:

1. Precrack lengths must be ≥ 0.0300 or a minimum of 0.05 inches
Minimum Length = 0.1452 inches	VALID
2. a/W must be between 0.45 and 0.55
$a/W = 0.5785$	INVALID
3. Difference between any two of (a2, a3, a4) must be ≤ 0.0694
Max difference = 0.0096 inches	VALID
4. Difference between a1 and a5 must be $\leq .1 \cdot a$ avg
difference = 0.0188 $\leq .1 \cdot a$ avg = 0.06942 inches	VALID
5. a1 and a5 must be between 0.5900 and 0.7983
a1 = 0.6852 a5 = 0.7040	VALID
6. P_{max} / PQ must be ≤ 1.10
$P_{max} / PQ = 1.45$	INVALID
7. $0.60 \cdot KQ$ must be $\geq K_{max}$
$K_{max} = 24.8$ ksi(sqrt.in.) $0.6 \cdot KQ = 52.9$ ksi(sqrt.in.)	VALID
8. K_{max} / E must be ≤ 0.002 sqrt.in.
$K_{max} / E = 0.000827$ sqrt.in.	VALID
9. Krate must be between 30 and 150 ksi(sqrt.in.) / min
Krate = 92.0 ksi(sqrt.in.) / min	VALID
10. Bnet must be $\geq R = 2.5 \cdot (KQ/YS)^2$ inches
Bnet = 0.48 inches $R = 1.3505$ inches	INVALID
11. a must be $\geq R = 2.5 \cdot (KQ/YS)^2$ inches
a avg = 0.6942 inches $R = 1.3505$ inches	INVALID
12. The plane of the crack shall be within ± 10 .
Crack plane = 4.5	VALID

*** TEST IS INVALID PER ASTM - E399; KQ = 94.8 KSI(SQRT.IN.) ***

Appendix B

Offsite Data

Table B: Comparison of Off Site Values versus Computer Values							
Specimen ID		P _Q (lbs)	P _{max} (lbs)	KQ (ksi*in ^{1/2})	K _{rate} (ksi*in ^{1/2})/min	R _{SC}	R=2.5*(KQ/YS) ²
	Vendor Values	4134	4134	27	80.9	0.601	0.44
Vendor	Computer Values	4134	4134	27	74.4	0.601	0.4397
	Delta %	0.00	0.00	0.00	8.74	0.00	0.07

FRACTURE TOUGHNESS TEST REPORT

PRELIMINARY INFORMATION:

CUSTOMER:
REQ. NO.:
LOT NO.:

P.O. NO.:
P.L. NO.:
MATERIAL SPEC.:
TESTLOG NUMBER:

ALLOY & TEMPER: 7050-T7451
PRODUCT THICKNESS: 3.500
TEST TYPE & ORIENT: 1.000-C(T) S-L
TEST DATE: 041098
PRECRACK YIELD STR.(YS₁): 64.3 KSI
TESTING YIELD STR.(YS₂): 64.3 KSI

PRODUCT: PLATE
Sample No.: S-1
TEST PLANE: T/2
MODULUS: 10.3 MSI
PRECRACK TEMPERATURE(T₁): 75°F
TESTING TEMPERATURE(T₂): 75°F

SPECIMEN MEASUREMENTS:

THICKNESS (B) = 0.995 IN.
WIDTH (W) = 1.997 IN.
AVE. CRACK LENGTH (A) = 0.964 IN.
FRACTURE APPEARANCE = 97 FRACTION OBLIQUE
HEIGHT (2H) = 2.400 IN.
TOTAL WIDTH (W₁) = 2.500 IN.
NOTCH TO HOLE (H₁) = 0.550 IN.

CRACK LENGTHS

SIDE 1 (A1) = 0.953 IN.
QUARTER POINT 1 (A2) = 0.962 IN.
CENTER POINT (A3) = 0.962 IN.
QUARTER POINT (A4) = 0.969 IN.
SIDE 2 (A5) = 0.958 IN.

FATIGUE PRECRACKING SUMMARY:

MAXIMUM FATIGUE LOAD = 1600 LBS
KF (MAX) = 10.4 KSI(SQRT.IN.)

LOAD RATIO = +0.1
CYCLES = 83000

TEST RESULTS:

CANDIDATE LOAD (PQ) = 4134 LBS
KQ = 27.0 KSI(SQRT.IN.)
SPECIMEN STRENGTH RATIO = 0.601

MAXIMUM LOAD (P_{MAX}) = 4134 LBS
K-RATE = 80.9 KSI (SQRT.IN.)/MIN

VALIDITY CHECKS PER ASTM E399 & B645

1. B MUST BE > OR = $R=2.5*(KQ/YS)**2$
B = 0.995 R = 0.440	VALID
2. A MUST BE > OR = $R=2.5*(KQ/YS)**2$
A = 0.964 R = 0.440	VALID
3. P _{MAX} /PQ MUST BE < OR = 1.10
P _{MAX} /PQ = 1.00	VALID
4. A/W MUST BE BETWEEN 0.45 AND 0.55
A/W = 0.48	VALID
5. DIFFERENCE BETWEEN ANY TWO OF A2,A3,A4 MUST BE < OR = .1*A
MAX. DIFF = 0.007 0.10*A = 0.096	VALID
6. A1 AND A5 MUST BE BETWEEN 0.819 AND 1.109
A1 = 0.953 A5 = 0.958	VALID
7. DIFFERENCE BETWEEN A1 AND A5 MUST BE < OR = .1*A
DIFFERENCE = 0.005 0.10*A = 0.096	VALID
8. $0.60*KQ$ MUST BE > OR = KF(MAX)
KF(MAX) = 10.4 KSI(SQRT.IN.) $0.6*KQ = 16.2$ KSI(SQRT.IN.)	VALID
9. KF(MAX)/E MUST BE < OR = 0.002
KF(MAX)/E = 0.001	VALID
10. K-RATE MUST BE BETWEEN 30 AND 150 KSI(SQRT.IN.)/MIN
K-RATE = 81 KSI (SQRT.IN.)/MIN	VALID
11. PRECRACK LENGTHS MUST BE > OR = $0.025*W$ OR 0.05 IN.
$0.025*W$ OR 0.050 = 0.050 IN. MIN. LENGTH = 0.158 IN.	VALID
12. FATIGUE PRECRACK PLANE MUST BE < OR = 10 DEG.	VALID
13. TEST CURVES INITIAL SLOPE MUST BE BETWEEN 0.7 AND 1.5
ACTUAL SLOPE = 1.3	VALID

*** ALL VALIDITY CHECKS ARE VALID ; KIC = 27.0 KSI(SQRT.IN.) ***

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

LOAD vs CRACK OPENING DISPLACEMENT

Preliminary Information:

Sponsor: N/A
Specimen S/N: vendor
Specimen Type & Orientation: 1.0-C(T)
Notch Type: Straight
Material/Form: Al 7050/plate
Heat: T7451
Relative Humidity (%): 16
Modulus (Msi) = 10.3
Precrack YS (ksi) = 64.3
Testing YS (ksi) = 64.3
Precrack Temperature (°F) = 75.0
Test Temperature (°F) = 75.0

Specimen Measurements:

Thickness, B (inches): 0.995
Bnet (inches): 0.995
Width, W (inches): 1.997

Fracture Test Crack Lengths:

Side 1, A1 = 0.9530 inches
Quarter Point 1, A2 = 0.9620 inches
Center Point, A3 = 0.9620 inches
Quarter Point 2, A4 = 0.9690 inches
Side 2, A5 = 0.9580 inches

Fatigue Precracking:

Precrack Plane = 4.5
Kmax (ksi(sqrt.in.)) = 10.4
Cycles for Final 2.5% of a: 83000
Maximum Fatigue Load (lbs) = 1600.0

Test Results:

KQ (ksi(sqrt.in.)) = 27.0
Pmax Load (lbs) = 4134.0
PQ (lbs) = 4134.0
Specimen Strength Ratio = 0.601
Krate (ksi(sqrt.in.)/min) = 74.4

Validity Checks Per ASTM E399:

1. Precrack lengths must be ≥ 0.0499 or a minimum of 0.05 inches
Minimum Length = 0.1530 inches	VALID
2. a/W must be between 0.45 and 0.55
$a/W = 0.4829$	VALID
3. Difference between any two of (a2, a3, a4) must be ≤ 0.0964
Max difference = 0.007 inches	VALID
4. Difference between a1 and a5 must be $\leq .1 \cdot a$ avg
difference = 0.005 $\leq .1 \cdot a$ avg = 0.09643 inches	VALID
5. a1 and a5 must be between 0.8197 and 1.1090
a1 = 0.9530 a5 = 0.9580	VALID
6. P_{max} / P_Q must be ≤ 1.10
$P_{max} / P_Q = 1.00$	VALID
7. $0.60 \cdot K_Q$ must be $\geq K_{max}$
$K_{max} = 10.4$ ksi(sqrt.in.) $0.6 \cdot K_Q = 16.2$ ksi(sqrt.in.)	VALID
8. K_{max} / E must be ≤ 0.002 sqrt.in.
$K_{max} / E = 0.001013$ sqrt.in.	VALID
9. Krate must be between 30 and 150 ksi(sqrt.in.) / min
Krate = 74.4 ksi(sqrt.in.) / min	VALID
10. B must be $\geq R = 2.5 \cdot (K_Q / YS)^2$ inches
B = 0.995 inches R = 0.4397 inches	VALID
11. a must be $\geq R = 2.5 \cdot (K_Q / YS)^2$ inches
a avg = 0.9643 inches R = 0.4397 inches	VALID
12. The plane of the crack shall be within ± 10 .
Crack plane = 4.5	VALID

*** TEST IS VALID PER ASTM - E399; KIC = 27.0 KSI(SQRT.IN.) ***

Pmax = 4134 lbs Load vs COD PQ = 4134 lbs Specimen S/N: vendor Type III Curve

— x: 15.58m

y: 3332

— x: 9.87m

y: 2191

Figure 5A: Aluminum 7050