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16. Abstract

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During field testing, the girder from one heat appeared to be more susceptible to fatigue failure than the others, but there were no significant differences in either fracture toughness or laboratory crack growth rates. Crack growth rates decreased with decreasing temperature, and did not appear to be influenced by fracture toughness. The E-399 plain strain fracture toughness test was found to be unsuitable for A-36 steel.

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RELATION OF TOUGHNESS TEST VALUES TO FATIGUE CRACKING IN BRIDGES STUDY 78-2

Prepared for

MISSOURI HIGHWAY AND TRANSPORTATION DEPARTMENT

by

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COLUMBIA, MISSOURI

August 1981

in cooperation with

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

The opinions, findings, and conclusions expressed in this publication are not necessarily those of the Department of Transportation, Federal Highway Administration or the Missouri Highway and Transportation Department. This report does not constitute a standard, specification, or regulation.

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CHAPTER 1 - INTRODUCTION

1.1 BACKGROUND

While the number of catastrophic failures in bridges is low, the fact that they do occur has led to increasing concern within the engineering profession about the potential for fatigue and brittle failure in steel bridges. Relatively recent failures resulting in human loss have been largely responsible for heightening this concern. The fact that some bridges develop cracks under service conditions while others of essentially the same design do not, leads to some speculation that the problem is at least in part related to some property of the material. As a result there has been a recent move towards adoption of fracture toughness acceptance specifications for bridge steels.

Unfortunately, there is a great deal of controversy surrounding the type of acceptance test for such a specification. On the one hand there is the ASTM E-399 test which is theoretically best but is almost prohibitively expensive, while on the other hand there is the Charpy test which is quite economical but is not universally accepted as valid. Between these two are the Dynamic Tear and Bend tests. The problem is complicated by a lack of knowledge concerning threshold values for any of these tests beyond which cracking becomes a problem in actual bridge structures.

During the full scale fatigue test (1)* of a highway bridge in southeast Missouri, it became evident that certain girders, which were identifiable by heat numbers, were more prone to cracking than the others. At midspan, one girder fractured twice through the bottom flange and web, while the other three were loaded to essentially the same stress

---

*Numbers in parenthesis refer to entries in the list of references

load cycles expected during the service life of the member is equal to or less than the number of cycles to failure at the design stress. This is known as "safe-life" design.

Typically, fatigue design data are presented in the form of an S-N curve; a plot of possible stress fluctuations (S) versus the number of cycles to failure (N), as shown in Figure 1 (2). It has long been recognized that the S-N curve is a function of material properties, geometry of the member, and fabrication flaws. As a result, S-N diagrams are determined by conducting fatigue tests on specimens designed with the particular material to be used and to simulate fabrication flaws and details.

Because fabrication flaws are distributed randomly, there is considerable scatter in the data from these tests. As a result of this scatter and uncertainties concerning the magnitude and number of stress cycles during the service life of the structure, it is necessary to apply rather large safety factors in safe-life design to ensure against failure in the worst possible case.

In recent years, it has been recognized that there exist three distinct stages in fatigue failure (See Figure 2) (3). First is an "initiation" stage where an initial flaw develops into a sharp-tipped notch or crack. The number of stress cycles during this stage is a function of material properties, magnitude of repeated load, geometry of the member, and geometry of the flaw.

The second or "growth" stage is the period during which the net cross section of the member is gradually reduced by stable growth of the crack under repeated cyclic loading. In bridges, this growth stage usually spans a period of one or more years during which it is possible to detect and repair the crack. Growth rate is primarily a function of stress amplitude and material properties.

Eventually, the crack reduces the cross section to the critical point where there is either unstable crack growth resulting in sudden failure due to brittle fracture, ductile tearing, or general yielding. This third or "failure"

levels and no cracks developed. In addition, at the ends of the eight cover plates the bottom girder flanges developed cracks at all locations while only two of the eight top flanges developed cracks. Upon completion of the fatigue test, arrangements were made with the U.S. Army Corps of Engineers to salvage material from critical sections as the bridge was demolished.

1.2 OBJECTIVES

The objectives of this work were:

1) To examine the effect of cyclic loading applied to steel specimens made from A-36 steel cut from the Missouri test bridge,
2) To examine the difference in fatigue crack growth rate between three different heats of steel used,
3) To examine the difference in fatigue crack growth rate with varying temperatures,
4) To determine the relative effectiveness of conventional fracture toughness tests in determining the susceptibility of A-36 bridge steel to fatigue cracking, and
5) To determine which fracture toughness test is best as an acceptance test for fatigue design.

1.3 FATIGUE DESIGN

Fatigue is the technical term for failures which are the result of cyclic loads on a structure. Normally the amplitude of the nominal cyclic stress is below the yield strength.

Traditionally fatigue has been treated as a total-life phenomenon. The number of load cycles that will cause failure is determined as a function of the cyclic service stress. The member is designed such that the total number of

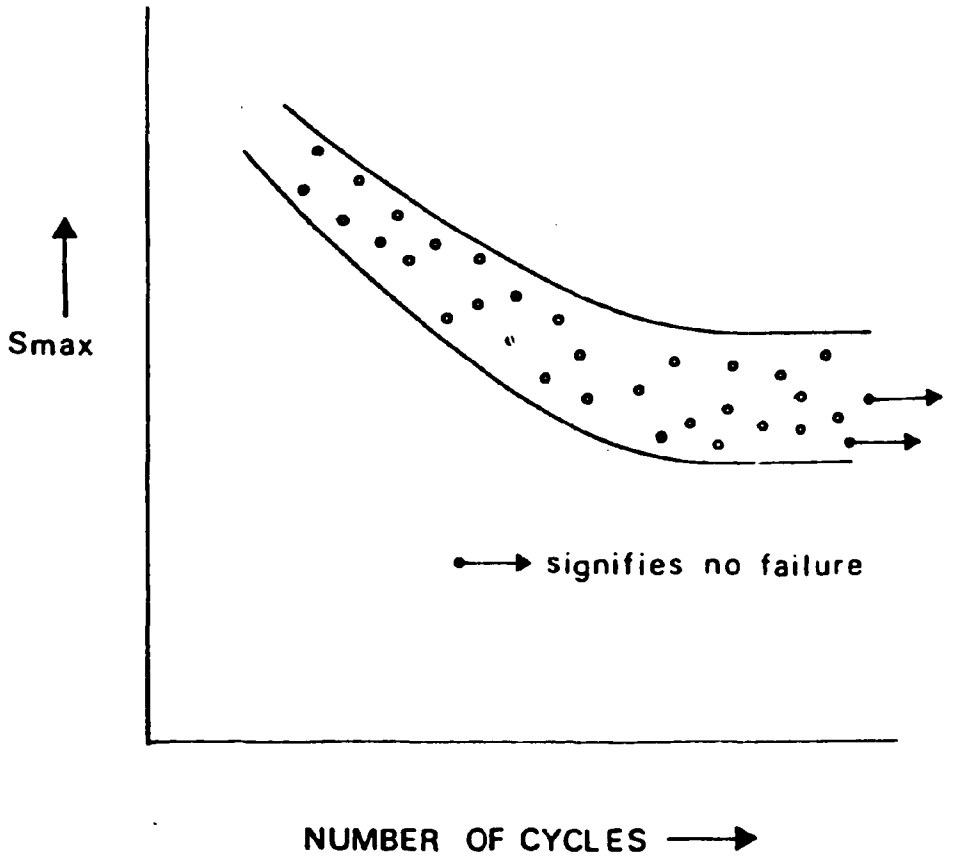


Figure 1 Typical Stress vs. Cycles to Failure

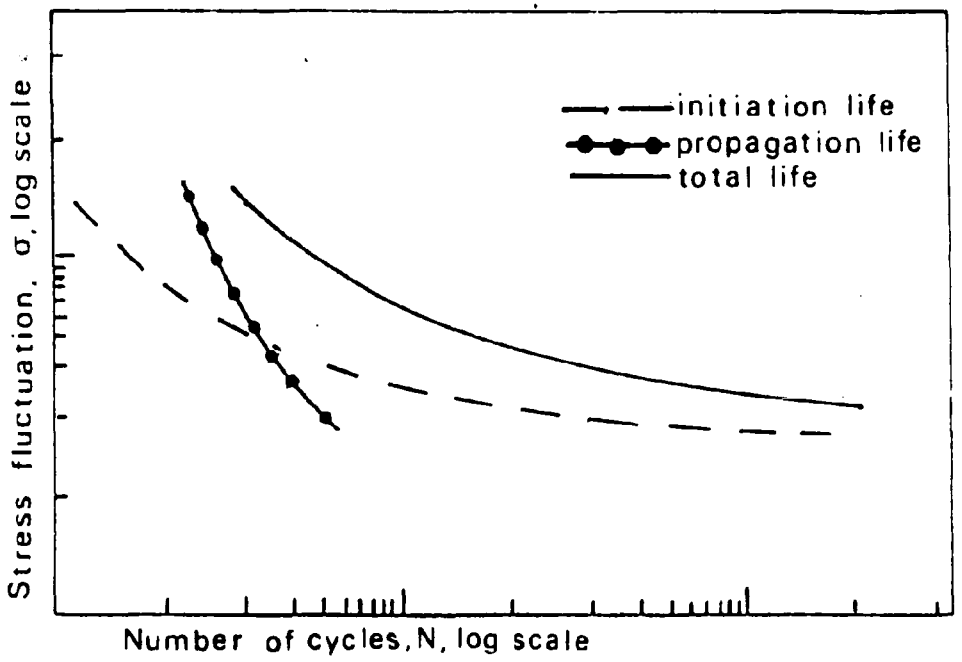


Figure 2 Life Span of a Structure

stage, occurs without warning and occurs over a very short period of time.

The point where unstable crack growth begins is a function of maximum nominal stress, crack geometry, and a property known as fracture toughness. This point can be predicted reasonably well with the aid of modern fracture mechanics analysis. In such an analysis, the effect of crack length and applied nominal stress are combined and expressed as stress intensity, K. The general equation for the calculation of K is:

$$K=f(g)\sigma\sqrt{a} \qquad \text{(Eq. 1)}$$

where,

$f(g)$ = a parameter that depends upon the specimen and crack geometries

σ = maximum nominal stress

a = crack length

The stress intensity value possesses the units ksi $\sqrt{in}$ and may be varied at any crack length by varying the applied stress. There exist three basic types of crack surface displacements known as modes I, II, and III as shown in Figure 3. The opening mode, mode I, is the mode which will be discussed in this work and the stress intensity value associated with this mode will hereafter be called K_I.

Physically, K_I describes the magnitude of the elastic stress field around the crack tip and is a measure of the elastic energy stored in the vicinity of the crack tip. Fracture toughness of the material is expressed as K_{IC}, the critical value of K_I where unstable crack growth occurs under plane strain conditions. A direct test for determination of K_{IC} is specified by ASTM E-399. Tests such as the

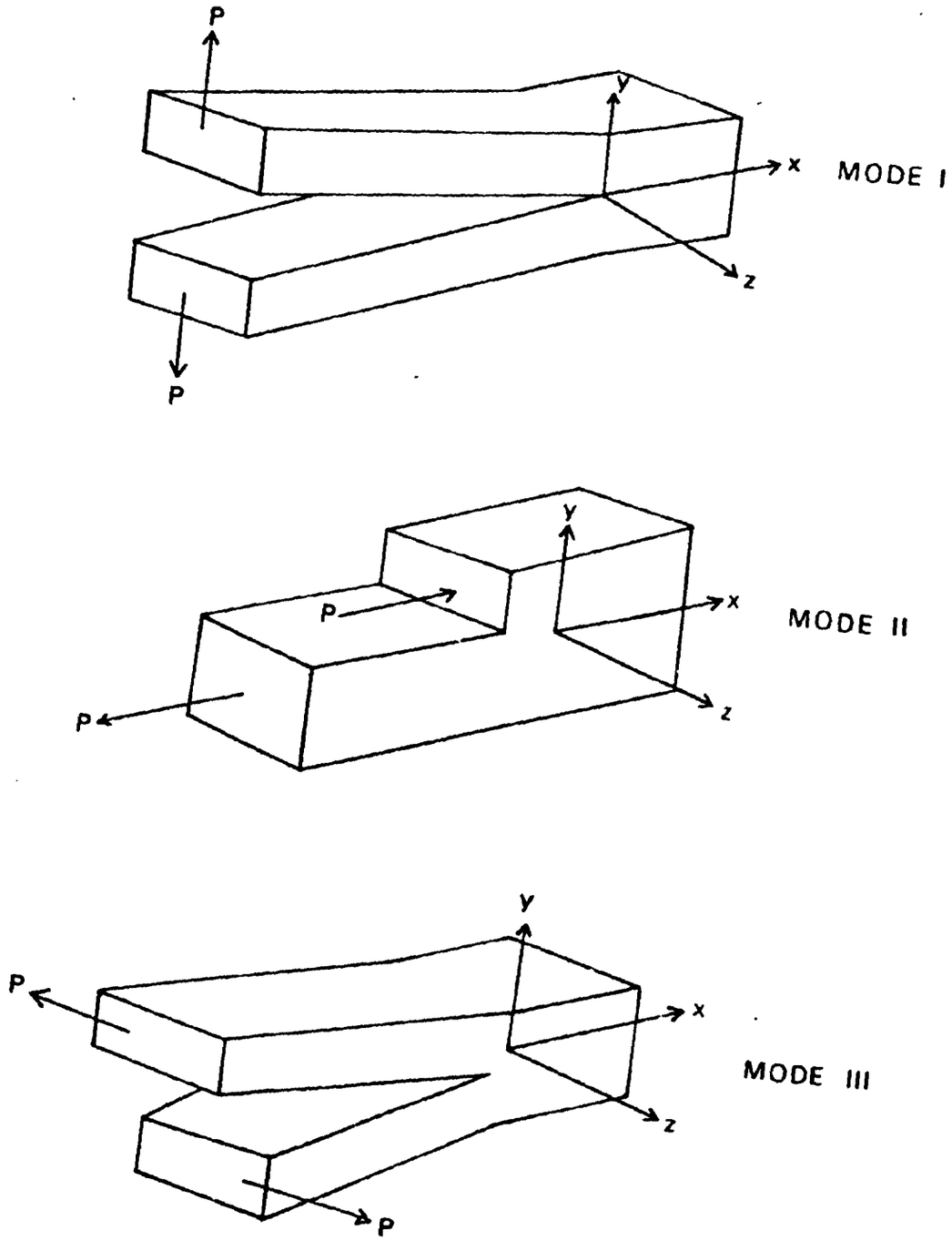


Figure 3 Three Mode Types

Charpy (ASTM E-23) and Dynamic Tear (ASTM E-604) provide for indirect determination of fracture toughness.

Recognition of the fact that fatigue is a progressive failure which occurs in three separate stages paved the way for development by the aircraft industry of a design concept known as "fail-safe" design. The philosophy of this concept is to provide, through a combination of initial design and a regular inspection program, a procedure which will ensure that even though cracks develop, they will be detected and repaired before catastrophic failure occurs. Thus, the frequency of inspection must be such that there is at least one inspection between the time a crack is large enough to be certain of detection and the time a catastrophic failure would occur.

Whether the safe-life or fail-safe design criterion is used, specifications and acceptance tests must ensure that the fatigue crack growth rate in the material of the structure is no greater than that assumed by the designer. In the case of safe-life design, a crack growth rate greater than that assumed during design would shorten the life of the structure, creating the potential for failure before the end of the desired service life. In the case of fail-safe design, a crack growth rate greater than that assumed in determining the inspection interval might result in catastrophic collapse before a crack was detected.

1.4 FATIGUE CRACK GROWTH ANALYSIS

The stress intensity factor, K_I, is not a material property, but merely a function of the applied stress, geometry of the specimen and geometry of the crack (4). The stress intensity varies during cyclic loading from a value K_{Imax} at the maximum applied stress to K_{Imin} at the minimum applied stress. The difference between these is the stress intensity range, ΔK_I, or

$$\Delta K_I = K_{Imax} - K_{Imin} \qquad \text{(Eq. 2)}$$

The stress intensity range can be established for any crack length, a, on the a-N curve (Figure 4). This value is plotted on a log-log scale versus the slope of the a-N curve, da/dN, or the rate of crack growth (Figure 5), at each corresponding value of a.

This plot then takes on the form shown in Figure 6 (5). This curve is easily divided into three regions. Region I is characterized by slow fatigue growth, or no growth at all, as there exists a value of ΔK_I below which no crack growth is seen. Region II is a linear region, which Paris (6) has described by the equation:

$$da/dN = c\ (\Delta K_I)^m \qquad \text{(Eq. 3)}$$

where,

c = intercept on the da/dN axis (log ΔK_I=0, ΔK=1) of a line fitted on the linear portion of the curve.

m = slope of the curve.

This power relationship has been demonstrated by others including Barsom (3). The importance of this is that the coefficients in this equation become material properties which describe the fatigue crack growth properties of the steel.

The curve is not linear in Region III, however. This region is characterized by rapid, unstable crack growth which reaches final fracture quickly. Regions I and III represent limiting values of the crack growth rate. The crack growth rate is almost zero in Region I and almost infinite in Region III. There thus exist two asymptotes at which these limiting values are reached. They are called

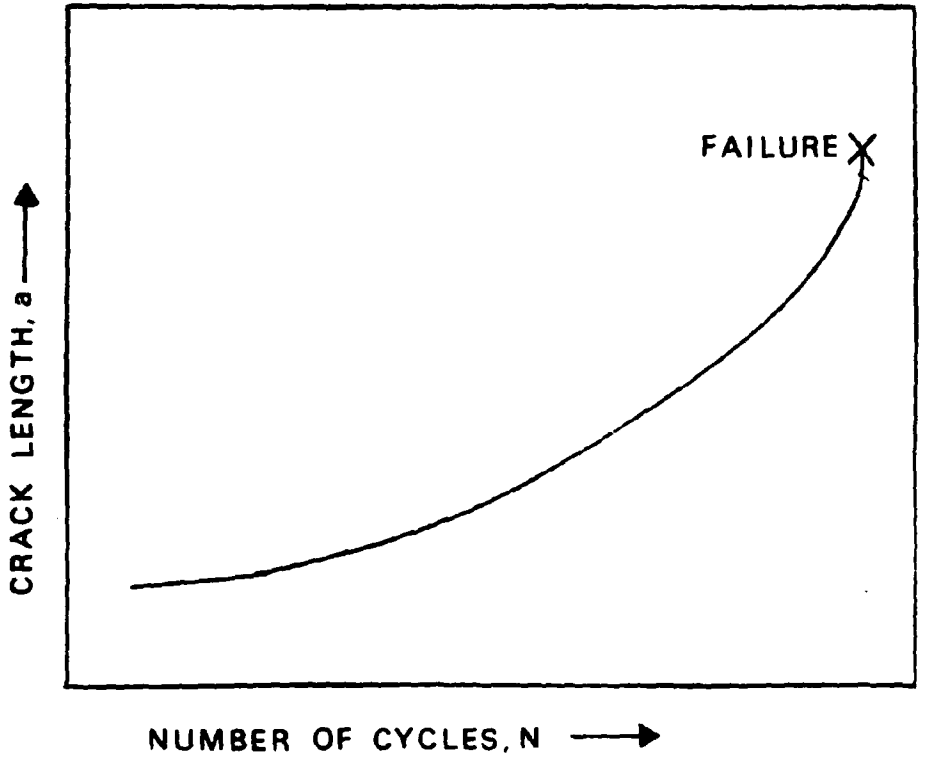


Figure 4 Typical Crack Length Vs. Number of Cycles

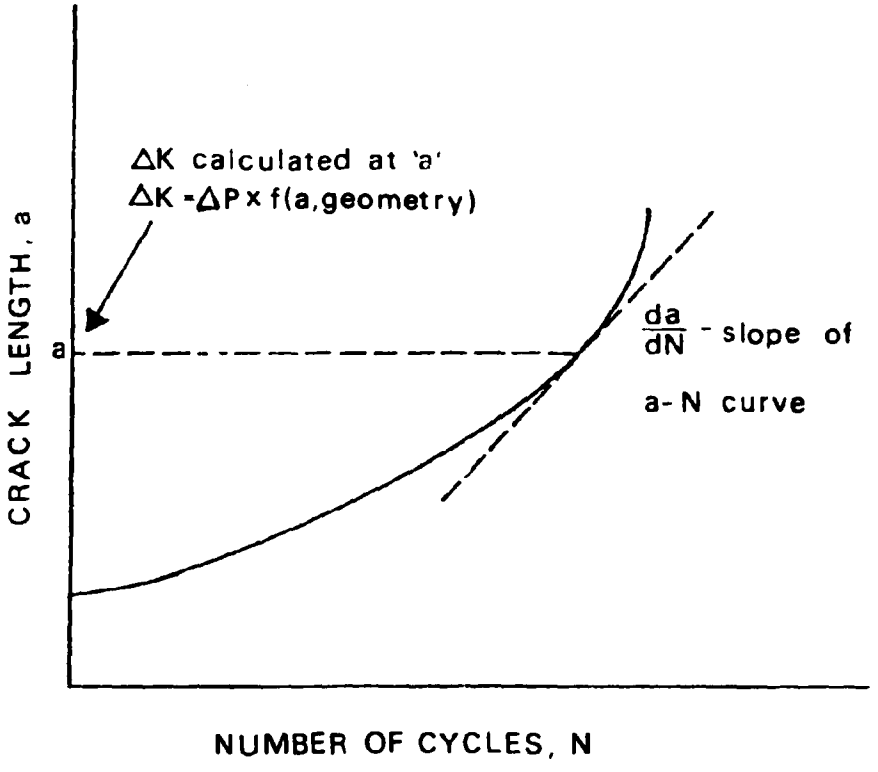


Figure 5 Determining ΔK and da/dN

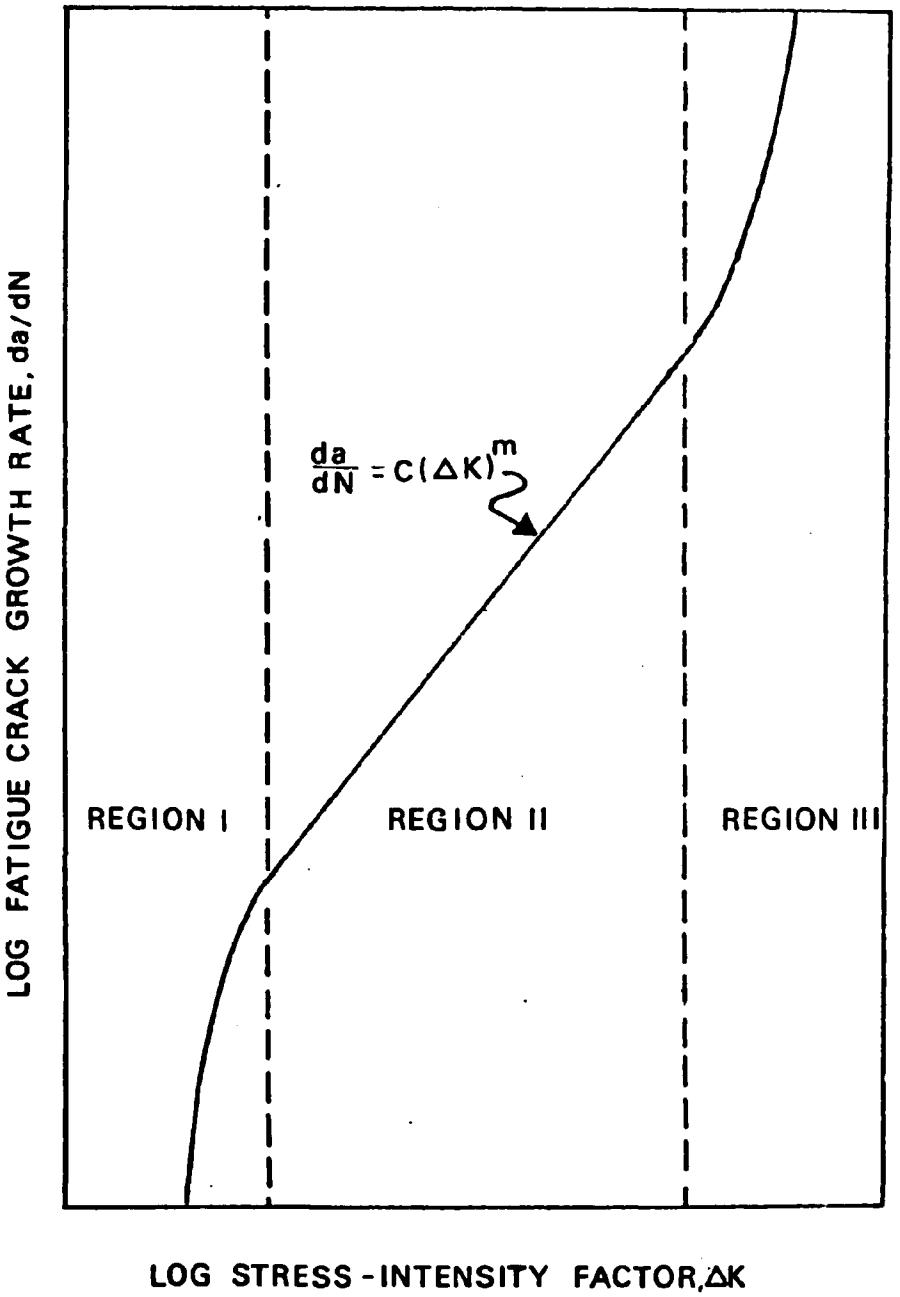


Figure 6 Regions of Fatigue Crack Growth

the threshold asymptote, ΔK_{TH}, and the instability asymptote, ΔK_{INS}, respectively for zero and infinite crack growth.

CHAPTER 2 - SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

2.1 SUMMARY

Fatigue crack-growth rate tests were conducted on 28 compact tension specimens from the three heats of steel recovered from the Missouri test bridge. Tests were conducted at 70° F, 0° F and -50° F with stress intensity ranges varying from 22 to 40 ksi $\sqrt{\text{inches}}$.

Crack growth rate, da/dN, varied sigmoidally with stress-intensity range from approximately 0.9 x 10^{-6} to 0.7 x 10^{-4} inches per cycle. In all cases crack growth was slower at low temperatures than at room temperature.

Material property tests including chemical analyses, ASTM A-370 tension tests, ASTM E-23 Charpy impact tests, ASTM E-604 dynamic tear tests, and ASTM E-399 plane- strain fracture toughness tests were made for each of the three heats of steel. Charpy and dynamic tear tests were conducted at temperatures ranging from -50°F to +80°F while the tension tests and ASTM E-399 fracture toughness tests were conducted at temperatures ranging from -207°F to +80°F.

Because of the high fracture toughness and limited thickness (5/8") of the material, none of the ASTM E-399 fracture toughness tests satisfied the conditions for determination of the plane strain fracture toughness. All of the material property tests indicated essentially the same properties for all three heats of steel.

2.2 CONCLUSIONS

1. Fatigue crack growth rates in steel recovered from the Missouri test bridge are in the same range as those reported by Barsom for ASTM A-36 steel. However, growth rate in the test bridge steel seems to be

considerably more sensitive to stress intensity range, ΔK_I, than those reported by Barsom.

2. There appeared to be no significant differences in either the material properties or the fatigue crack growth behavior of the three heats of steel.
3. Differences in fatigue behavior between girders of the Missouri test bridge were apparently the result of differences in the sharpness of mechanical flaws rather than material properties.
4. Results from fatigue crack growth tests at varying temperatures indicate that fatigue crack growth rate is more likely a function of yield strength than of fracture toughness. Thus , it may be that none of the fracture toughness tests are suitable measures of susceptibility to fatigue cracking.
5. The ASTM E-399 plane strain fracture toughness test is not a suitable test for A-36 and similar low carbon bridge steels.
6. The data reduction method which best serves the fatigue crack growth test is the seven-point polynomial method mentioned in ASTM E-647.

2.3 RECOMMENDATIONS

With the conclusions just mentioned in mind, the following recommendations for further work are suggested.

1. Develop an automated system whereby crack growth rates could be recorded systematically and consistently from test to test. With this a curve fitting method could be employed and more definite statements concerning crack growth rates could be drawn.
2. Additional tests are needed to determine whether fatigue crack initiation, like fatigue-crack-growth rate is unaffected by fracture toughness. If this is in fact the case, then fracture toughness influences only the length of the critical crack at

final fracture and rather large increases in fracture toughness would be required to significantly increase the fatigue life of a structure.

3. Additional work is needed to clarify the effects of reversed stress cycles on fatigue crack growth. In cases where the crack closes during the compressive part of the stress cycle, there is very little if any change in the stress intensity, K_I, during that part of the cycle. Thus, if stress-intensity range is the primary factor in fatigue crack growth, the effects of the negative portion of the stress cycle must be essentially zero.

CHAPTER 3 - MATERIAL DESCRIPTION

3.1 TEST SPECIMENS

The steel used in this investigation was ASTM A-36, the type commonly used in hot-rolled shapes for bridges and other steel structures. It was taken from the girders which supported a highway bridge in southeast Missouri. The girders were rolled from three different heats of steel. A diagram of the heat numbers of the beams is shown in Figure 7. Section numbers shown in this diagram represent locations on the bridge girders which were monitored for cracks during the full scale testing. Beam pieces tested in the lab were cut from sections 2, 4 and 6. A tabular representation relating the beams and their corresponding heat numbers is shown in Table 1. The chemical properties of each heat are listed in Table 2.

Five different tests, as listed in Table 3, were performed on each of the three heats. Each of the test specimens was stamped with a five digit identification code consisting of the section number, the girder number, test type, and specimen number. The specimen locations are shown in Figures 8 - 19.

3.2 TENSION TEST

Tension tests were conducted on ASTM A-370 (7) specimens of the type shown in Figure 20 for each heat of steel. Initial room temperature tests made in a 60,000 pound universal hydraulic testing machine which had been adapted to produce an analog electrical signal proportional to load. Strain was measured with an electro-mechanical extensometer and an automatic stress strain plot was generated. These tests were conducted at a strain rate which produced

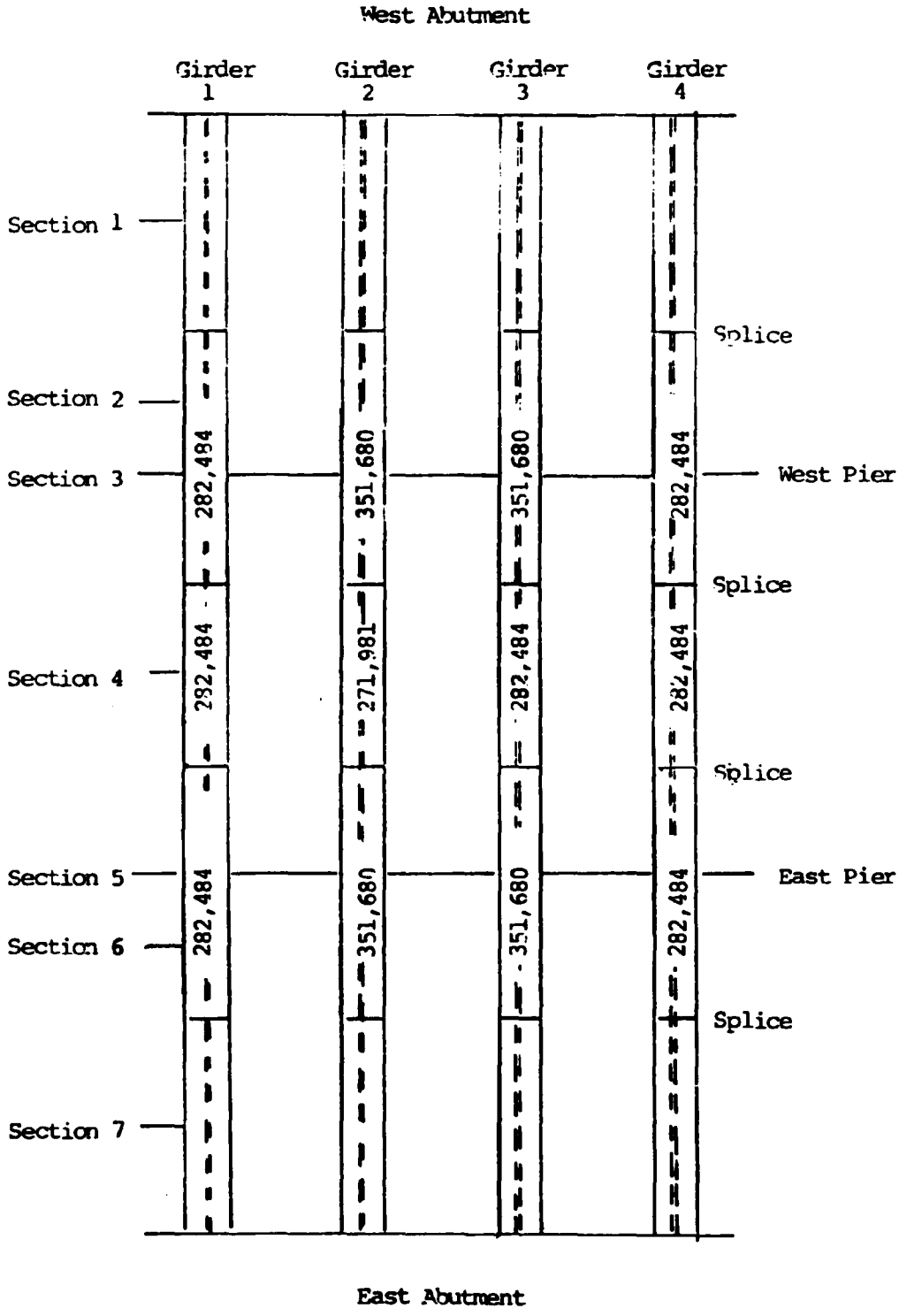


Figure 7 Bridge Layout and Heat Numbers

TABLE 1 HEAT NUMBERS

Section No.	Heat
2,1	282,484
2,2	351,680
2,3	351,680
2,4	282,484
4,1	282,484
4,2	271,981
4,3	282,484
4,4	282,484
6,1	282,484
6,2	351,680
6,3	351,680
6,4	282,484

TABLE 2 CHEMICAL PROPERTIES Percent

Heat No.	351,680	271,981	282,484
Carbon	.22	.23	.23
Aluminum	<.01	<.01	<.01
Titanium	<.01	<.01	<.01
Silicon	.04	.04	.04
Sulfur	.020	.030	.019
Manganese	.64	.66	.60
Phosphorus	.012	.017	.014
Nickel	.05	.02	.02
Chromium	.06	.05	.04
Molybdenum	.01	.01	.01
Copper	.11	.03	.03
Vanadium	<.01	<.01	<.01
Boron	<.0005	<.0005	<.0005

TABLE 3 TEST SCHEDULE

Test Code	Test Type
A	Tensile Test (A-370)
B	Charpy (E-23)
C	Plain-Strain Fracture Toughness (E-399)
E	Fatigue Crack Growth Tests (E-647)
F	Dynamic Tear (E-604)

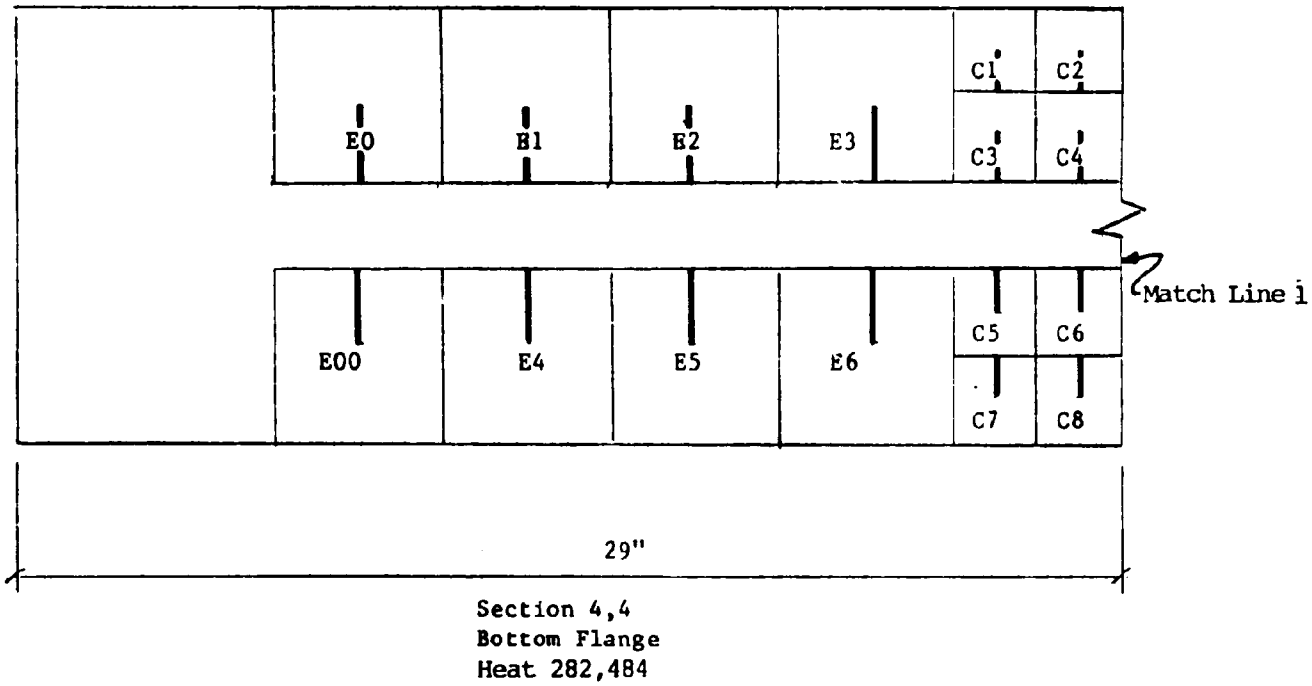
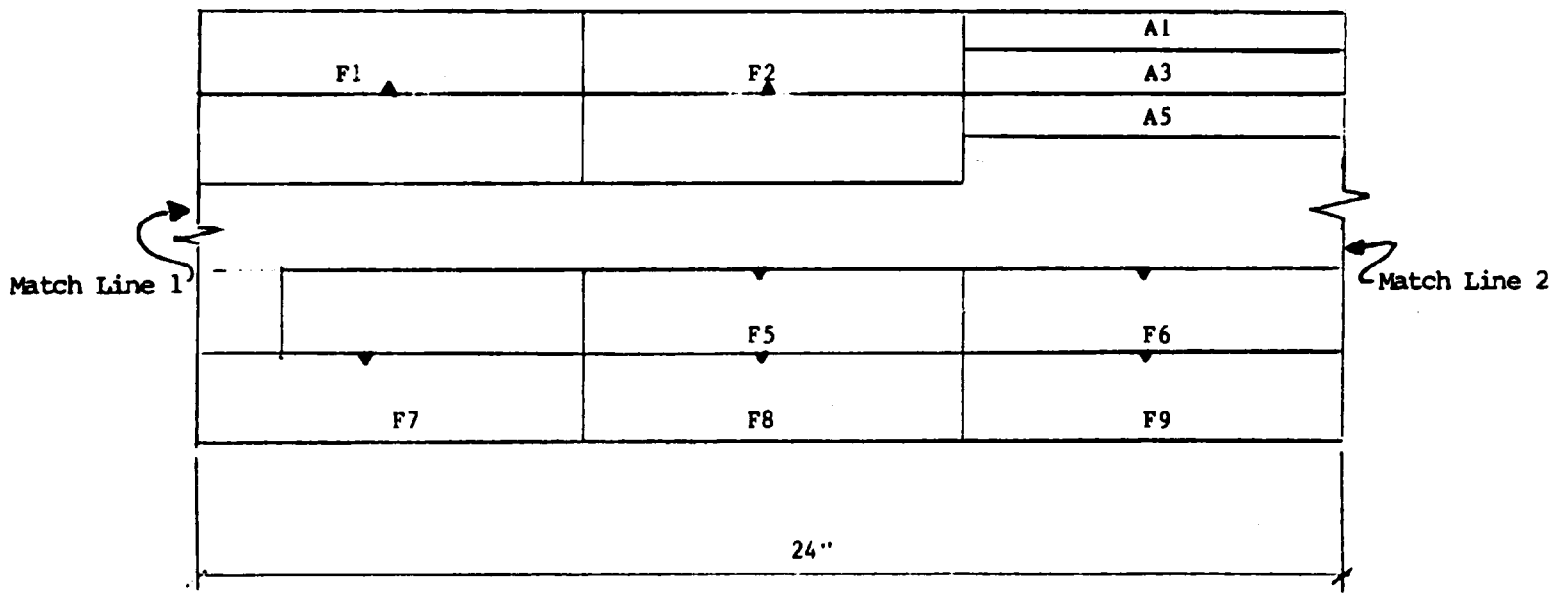
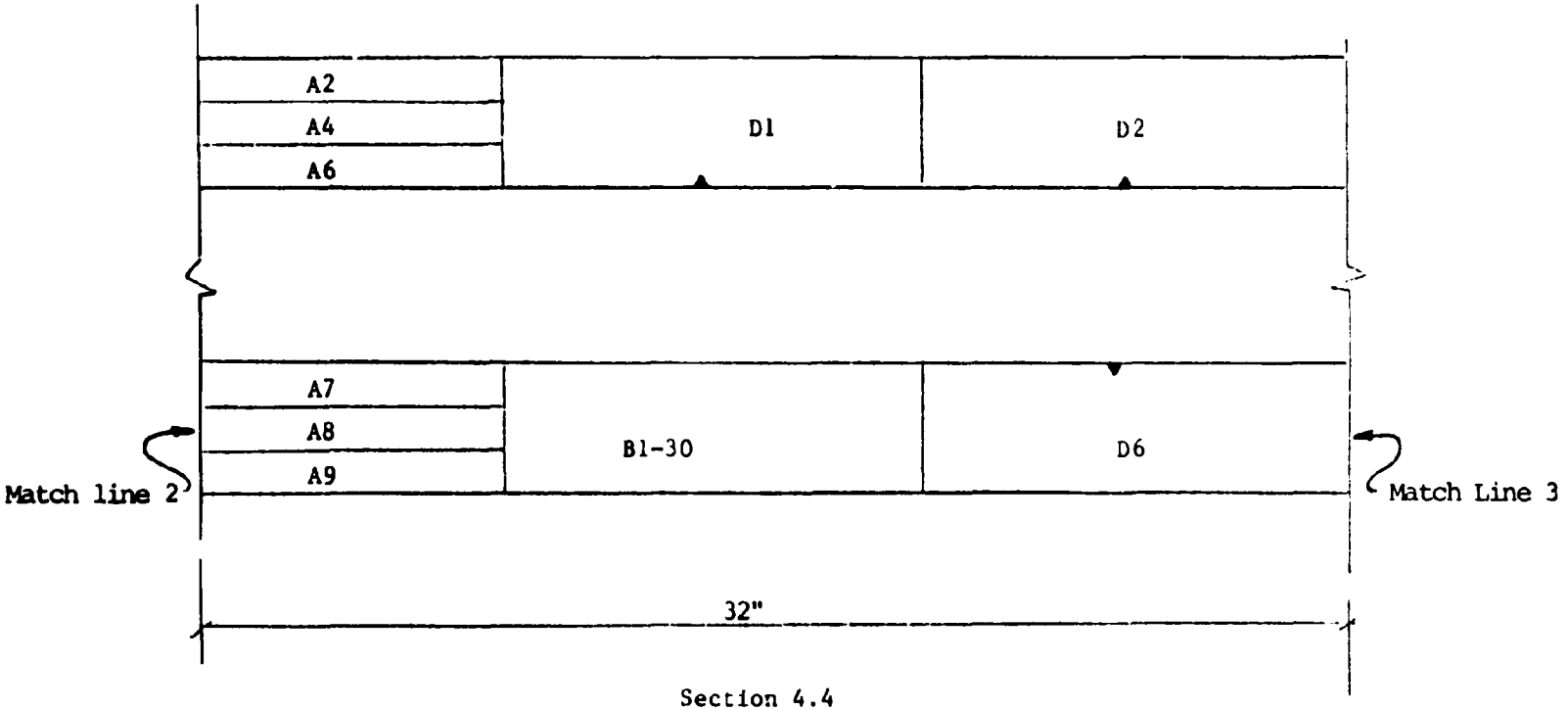


Figure 8 Specimen Locations, 4,4 Bottom 1



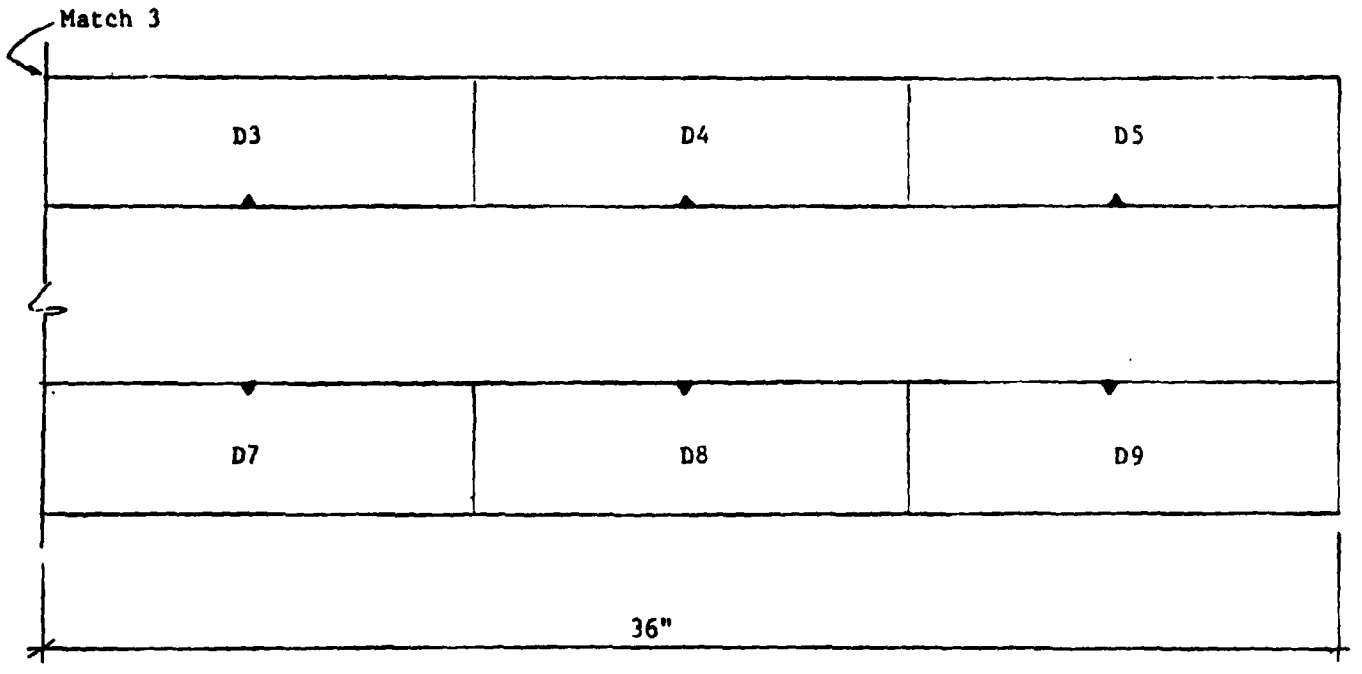
Section 4.4
Bottom Flange
Heat 282,484

Figure 9 Specimen Locations, 4,4 Bottom 2



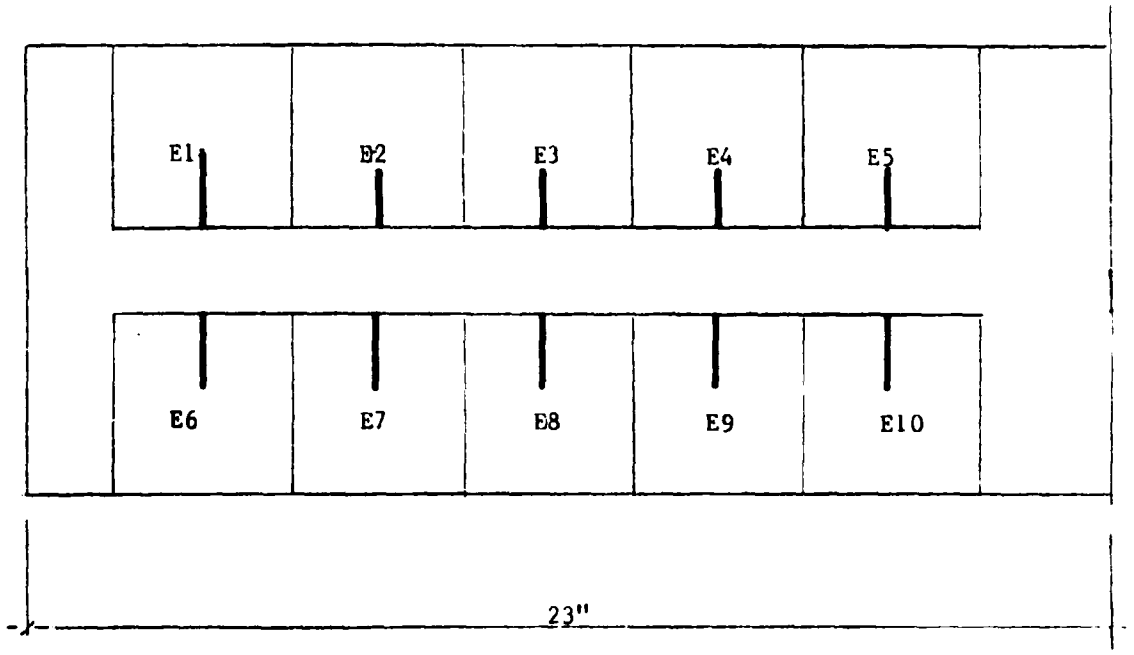
Section 4.4
Bottom Flange
Heat 282,484

Figure 10 Specimen Locations, 4,4 Bottom 3



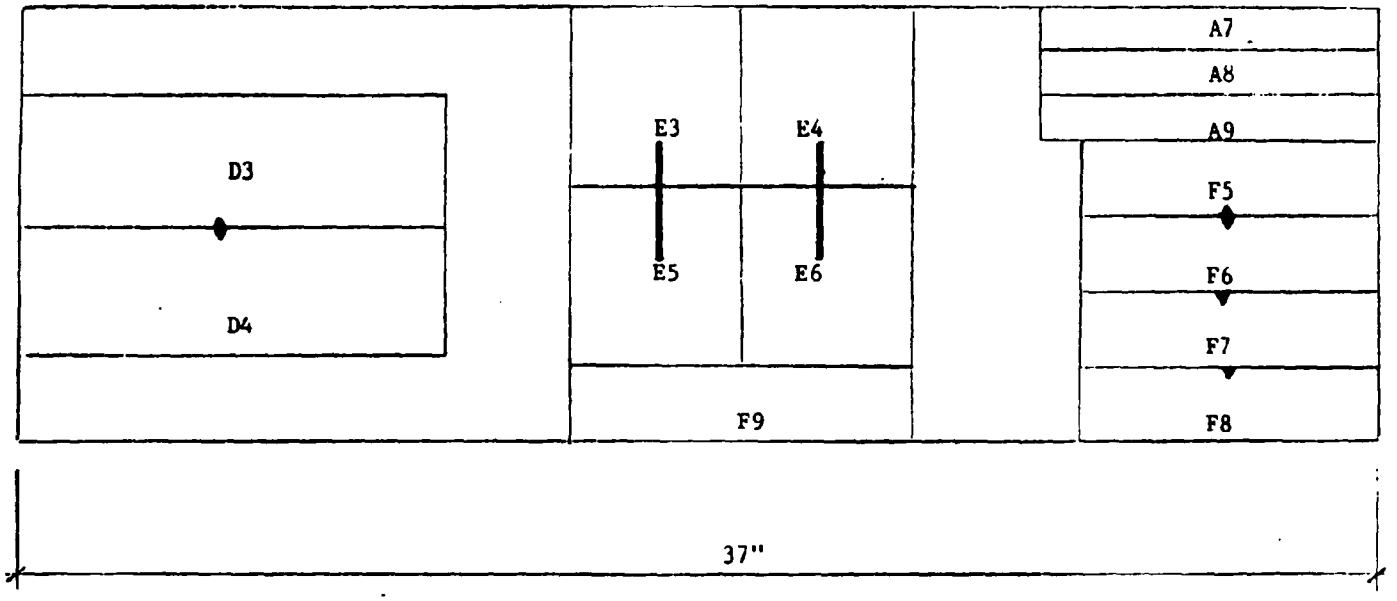
Section 4.4
Bottom Flange
Heat 282,484

Figure 11 Specimen Locations, 4,4 Bottom 4



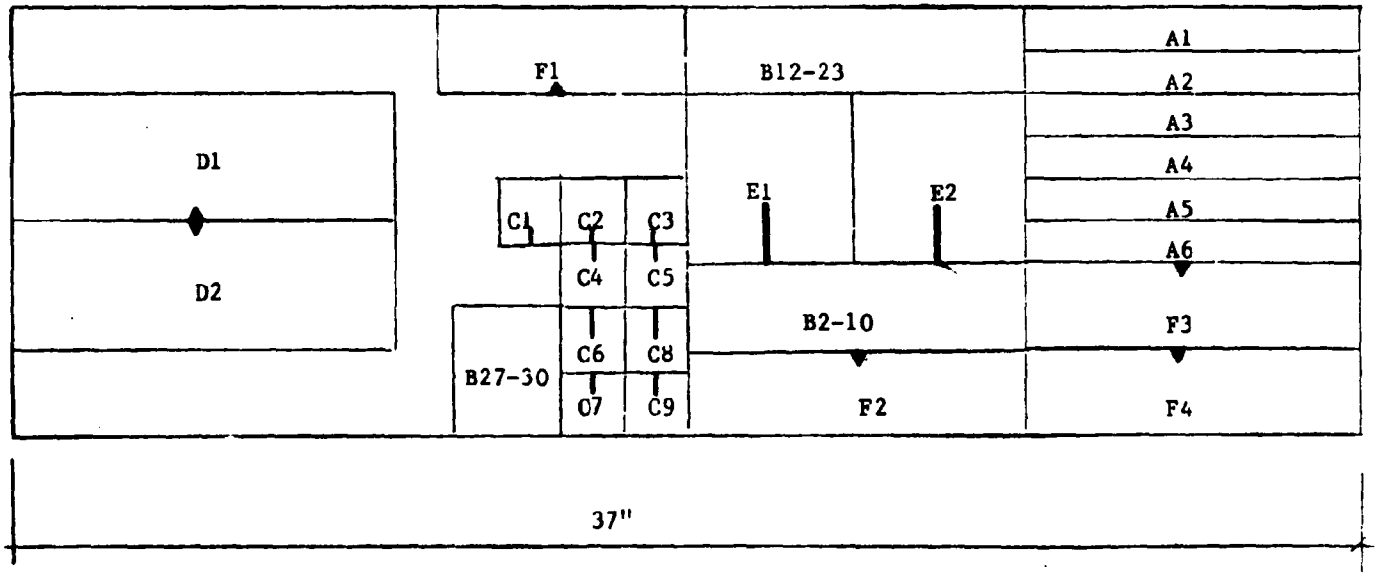
Section 4,1
Bottom Flange
Heat 282,484

Figure 12 Specimen Locations, 4,1 Bottom



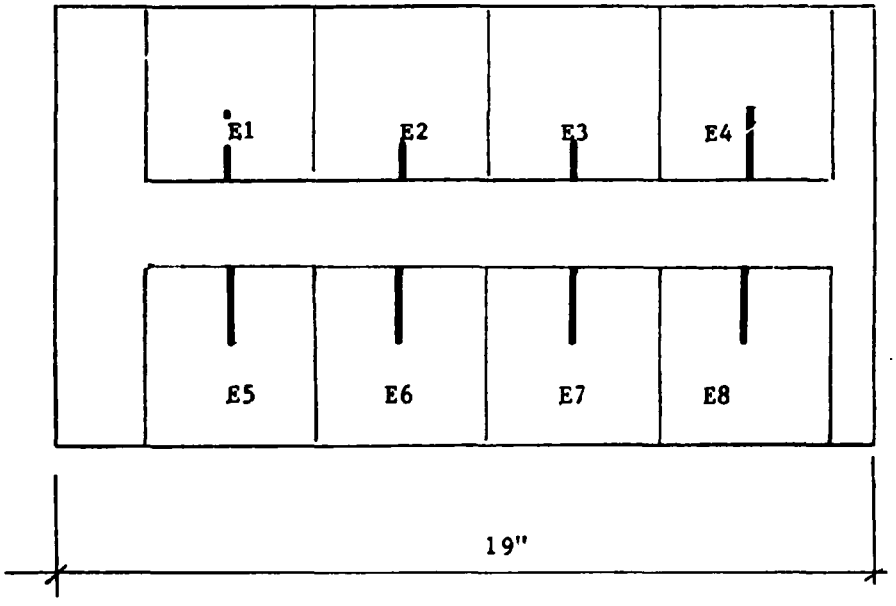
Section 2,3
Top Flange
Heat 351,680

Figure 13 Specimen Locations, 2,3 Top



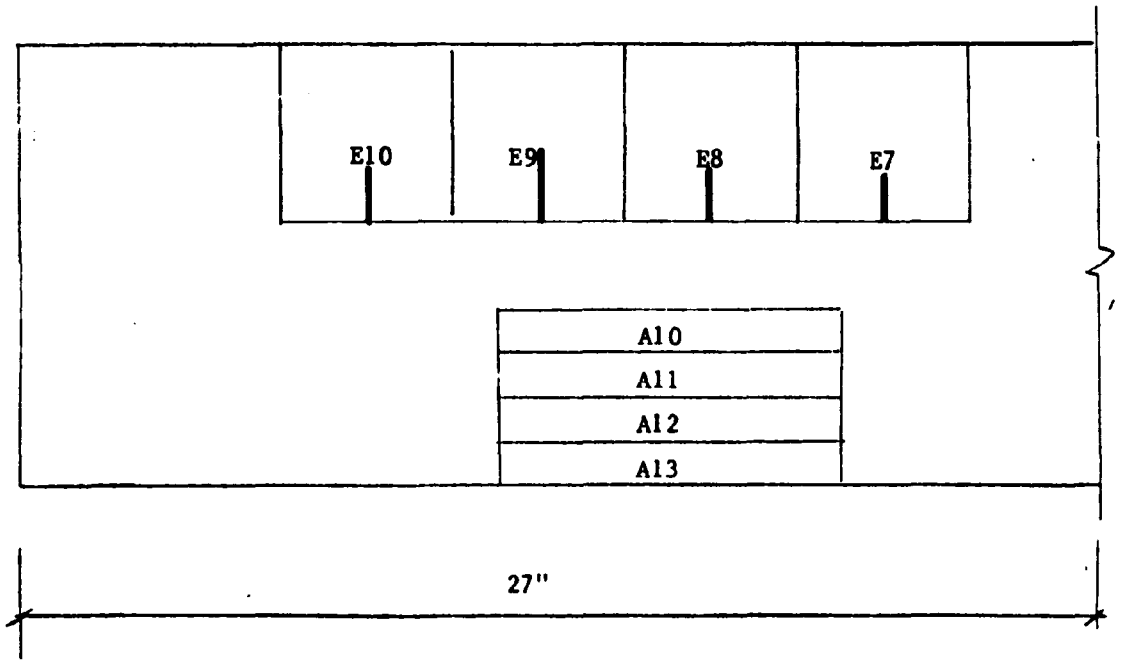
Section 2,3
Bottom Flange
Heat 351,680

Figure 14 Specimen Locations, 2,3 Bottom



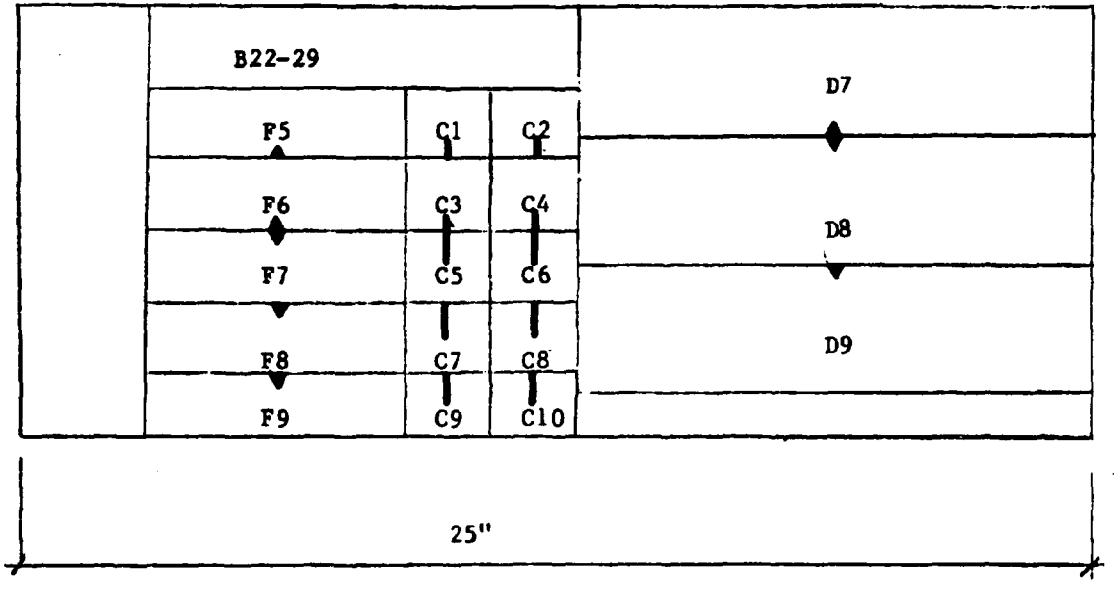
Section 6,2
Bottom Flange
Heat 351,680

Figure 15 Specimen Locations, 6,2 Bottom



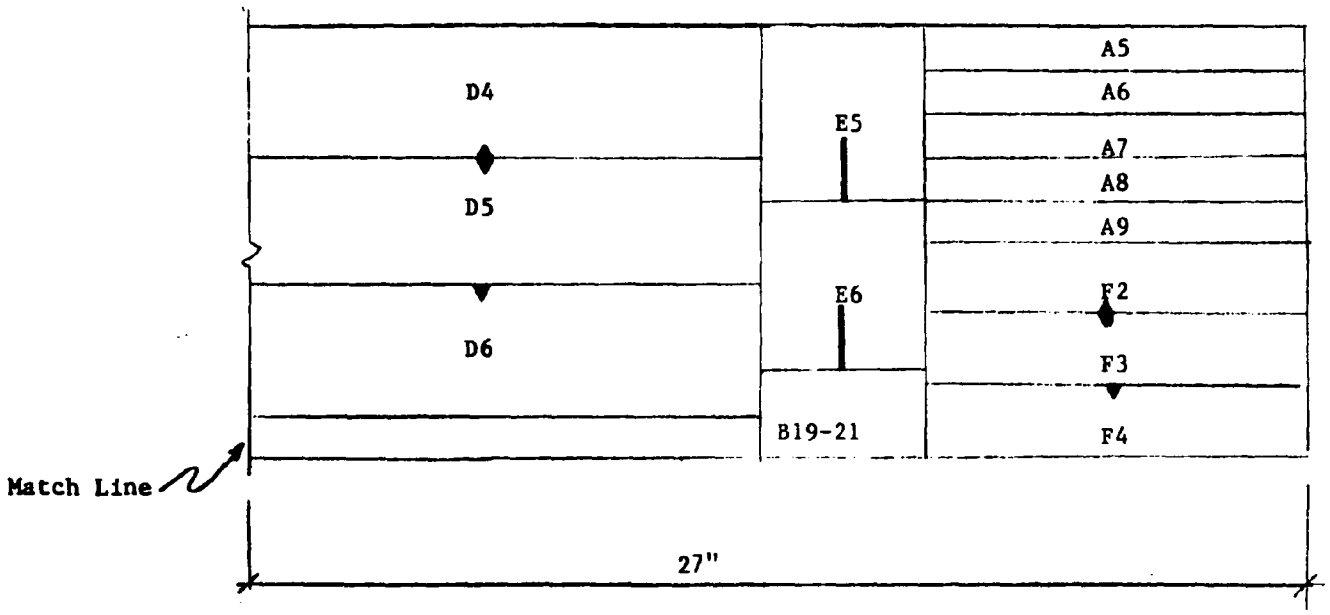
Section 4,2A
Bottom Flange
Heat 271,981

Figure 16 Specimen Locations, 4,2A Bottom



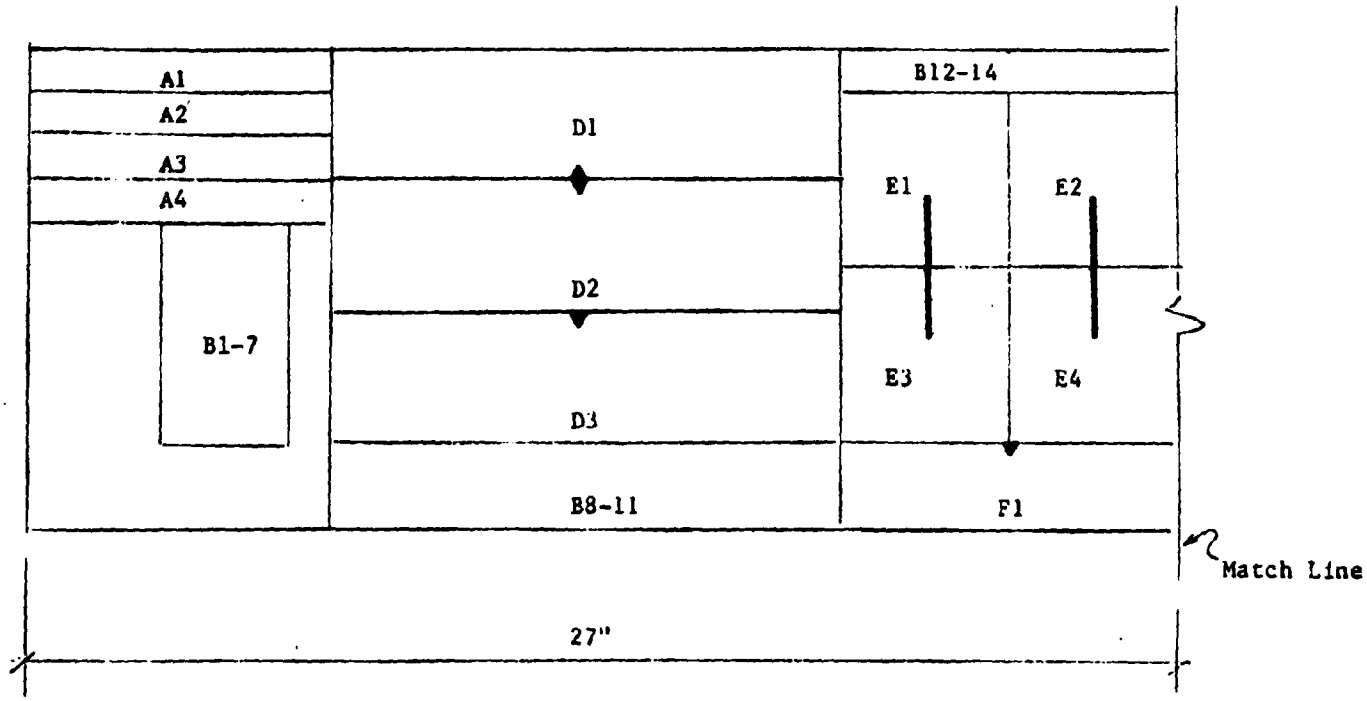
Section 4,2C
Top Flange
Heat 271,981

Figure 17 Specimen Locations, 4,2C Top



Section 4,2B
Top Flange
Heat 271,981

Figure 18 Specimen Locations, 4,2B Top 1



Section 4,2B
Top Flange
Heat 271,981

Figure 19 Specimen Locations, 4,2B Top 2

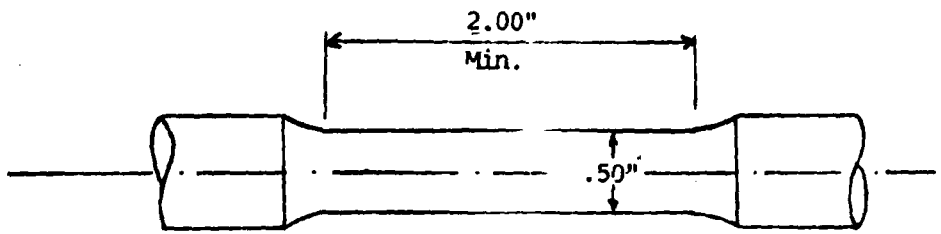


Figure 20 Tensile Test Specimen

a loading rate of approximately 20 ksi per minute in the elastic region.

It was subsequently decided that cold temperature tensile tests would be required and all remaining tests were conducted in the servo-controlled electro-hydraulic testing machine that was used for the da/dN tests. Low temperature environment was provided with the test apparatus described in section 4.2 of this report. Because of space limitations in the cold box, strain was measured with elastic resistance strain gauges and again an automatic stress-strain plot was generated. These tests were conducted under load control at a loading rate of approximately 30 ksi per minute.

Results of these tests are shown in Figure 21. Equation 4 shown in the figure is from Barson and Rolfe and shows the same trend as the test results.

$$\sigma_{yd} = \left(\sigma_{ys} + \frac{174{,}000}{\log\,(2+10^{10}t)(t+459)} - 27.4\right) \quad \text{(Eq.4)}$$

where,

σ_{yd} = .2% offset yield strength at the temperature and load rate indicated by T and t respectively, ksi

σ_{ys} = .2% offset yield strength at room temperature and a load rise time of 100 sec., ksi

T = specimen temperature, °F

t = load rise time from start of load to fracture, sec.

3.3 CHARPY TESTS

Charpy tests were run in accordance with ASTM E-23. The specimens were cut from the flanges of the bridge girders, twenty-seven from each of three heats, at the locations shown in Figures 9-18. They were machined to the dimensions shown in Figure 22.

The specimens were tested in a Tinius Olsen Pendulum Machine which was first calibrated by testing a set of

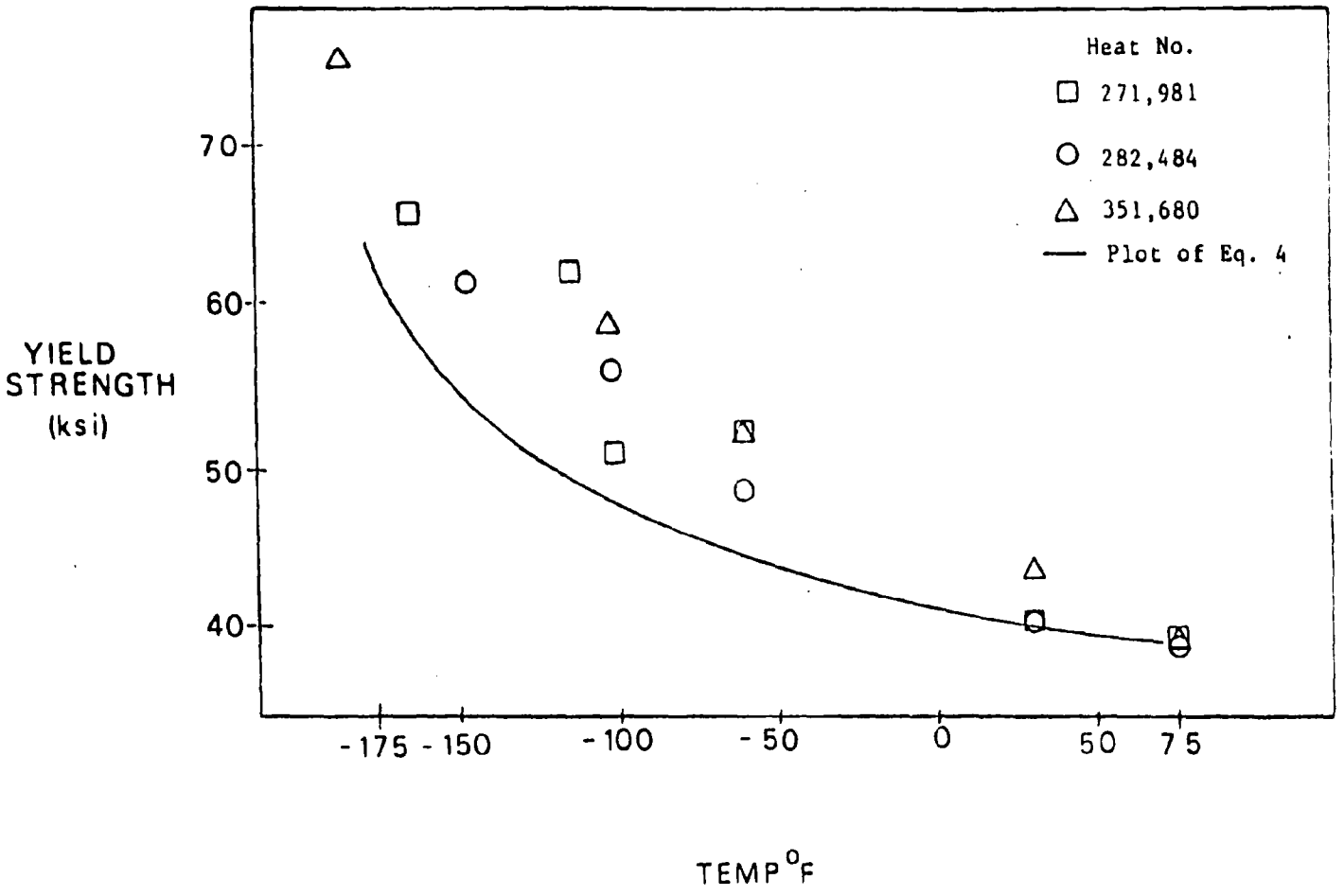


Figure 21 Tensile Test Results

standardized specimens as specified by ASTM E-23. Each heat was tested at temperatures varying from -50° to 70°F. These results are presented in Figure 23.

3.4 DYNAMIC TEAR TESTS

Dynamic Tear tests were run in accordance with ASTM E-604 (9). The specimens were machined to the dimensions shown in Figure 24. They were cut from the flanges of the bridge girders in the locations shown in Figures 9-18.

The specimens were tested on an MTS Vertical Drop Weight Test Machine. Specimens were tested at temperatures varying from -50°F to 70°F. The results are presented in Figure 25.

3.5 E-399 TESTS

Twenty-six ASTM E-399 (10) specimens were cut from the girder flanges as indicated in section 3.1. Specimen thickness was the maximum thickness that could be machined from the girder flanges. The remaining dimensions were made to conform with the specimen thickness and the ASTM E-399 specification for compact tension specimens (Figure 26). Starter slots were milled straight across and the sides of the specimens were surface ground.

Specimens were tested in a 100 kip servo-controlled electro-hydraulic testing machine. However, the 100 kip load cell was replaced with a 10 kip load cell to increase the precision of load measurements. Crack opening was measured with a clip gauge fabricated to ASTM E-399 specifications. Detachable knife edges were positioned with a jig and cemented to the specimens with a cyanocrylate cement.

All specimens except 44C16 were precracked at room temperature while specimen 44C16 and all specimens except specimen 23C1 were tested at temperatures below -58°F.

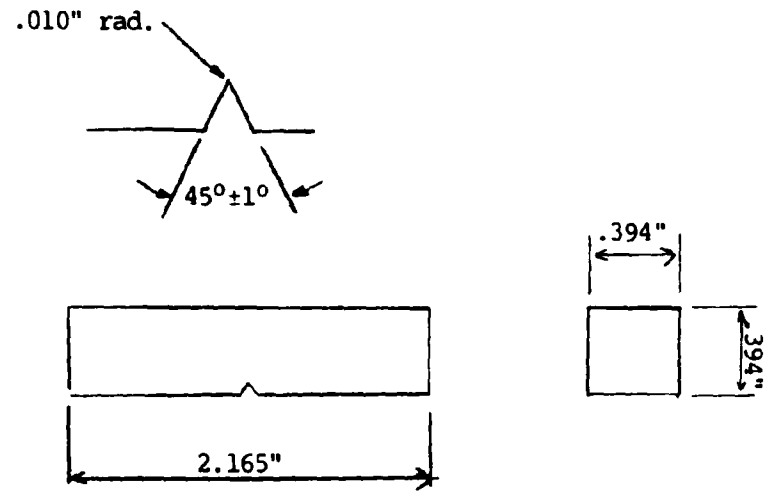


Figure 22 Charpy Test Specimen

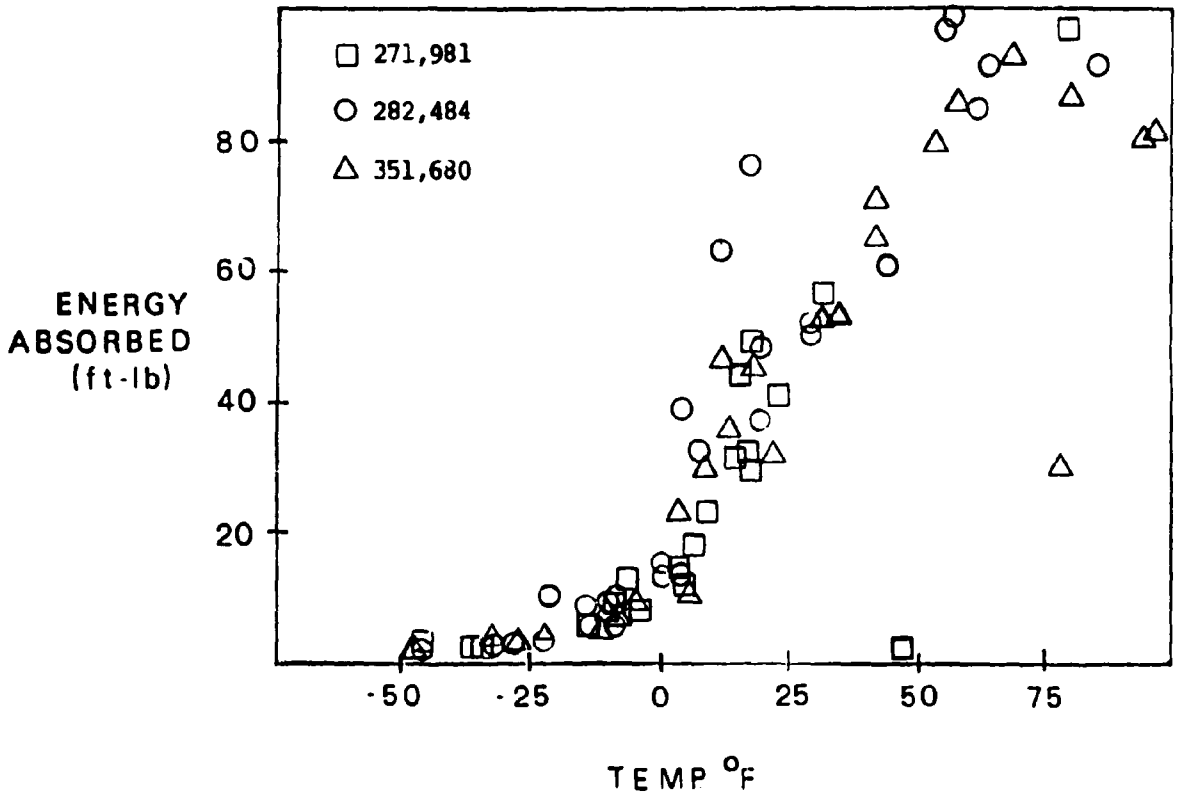


Figure 23 Charpy V-Notch Test Results

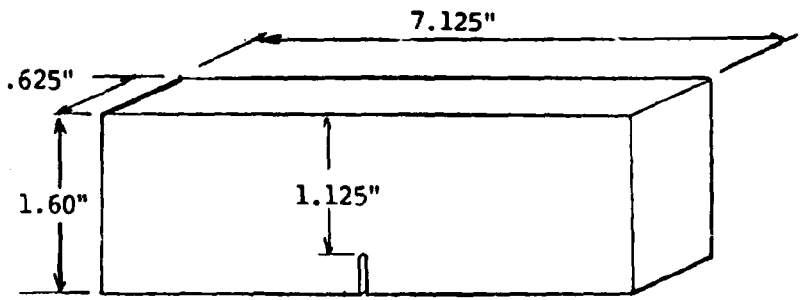


Figure 24 Dynamic Tear Test Specimen

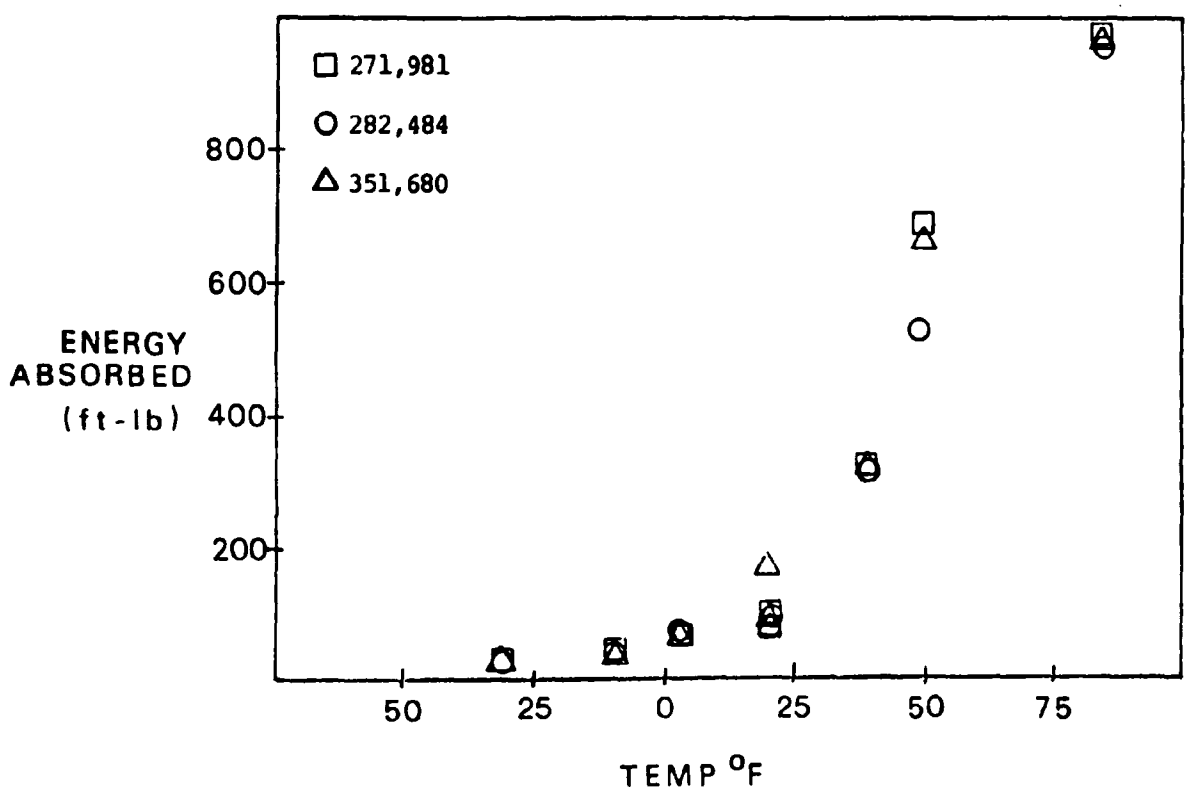


Figure 25 Dynamic Tear Test Results

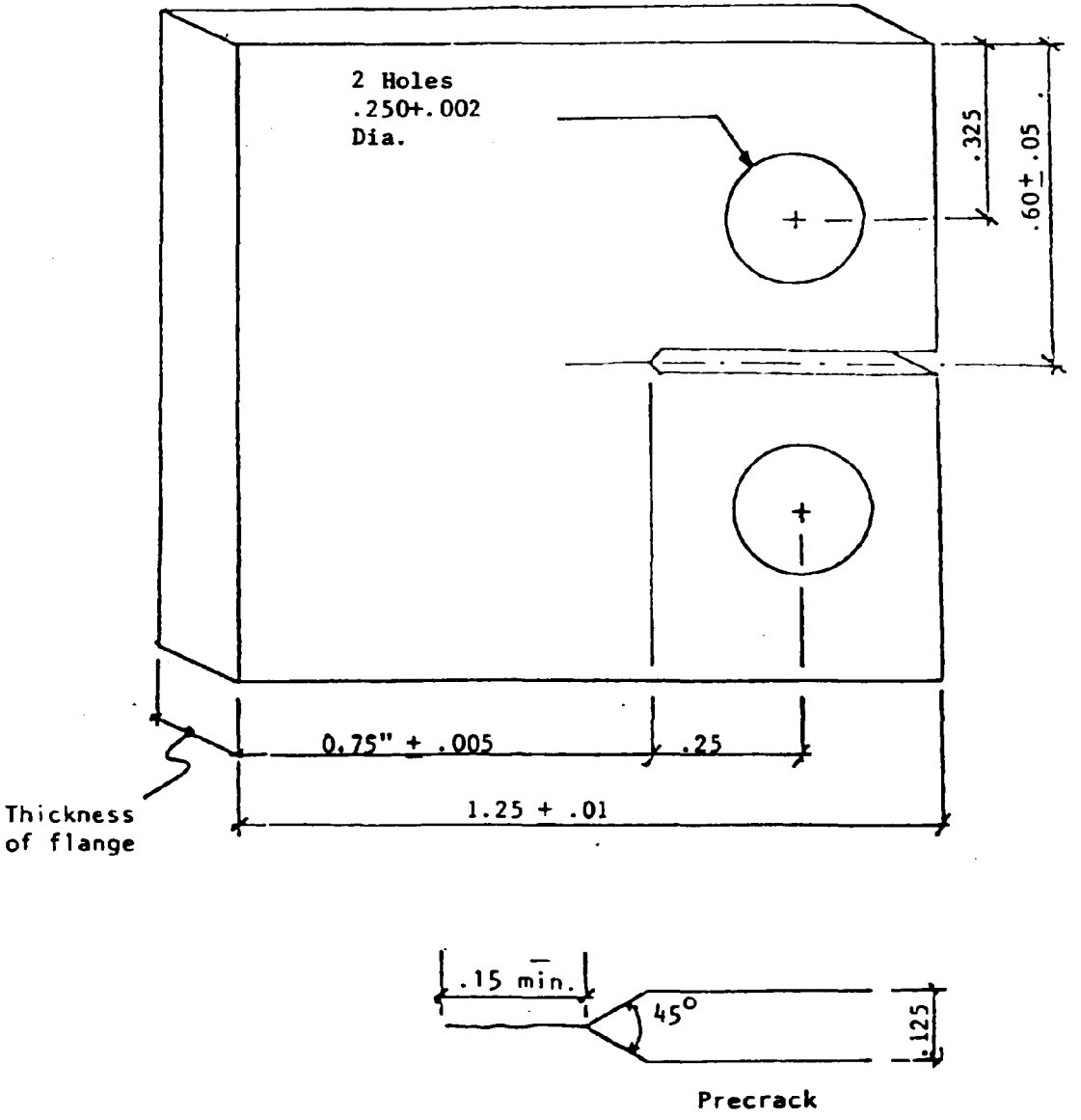


Figure 26 ASTM E-399 Specimen

The low temperature environment was produced in the cold box used for the da/dN tests and described in section 4.2.

Test results are shown in Figure 27 and Table 4. None of the tests satisfied all of the conditions for a valid K_{IC} test. In general, requirements for linear elastic behavior (i.e. $P_{max}/P_Q < 1.1$) was satisfied only by those specimens tested at temperatures below -100°F. Only specimens 44C3, 44C6 and 44C16 tested at temperatures of -186°, 189°F and -207°F, respectively, satisfied the conditions for plain strain i.e., $B>2.5(K_Q/\sigma_{ys})$.

Although these two conditions could apparently be satisfied by testing at sufficiently low temperatures it was virtually impossible to simultaneously satisfy both these requirements and the requirement that the maximum stress intensity during the last 2.5 percent of precracking be less than .6 (σ_{ys} precracking/σ_{ys} test) K_Q. Lowering the testing temperature reduced the value of K_Q and increased the yield strength at the testing temperature. Both of these reduce the permissible maximum stress intensity during the last 2.5 percent of precracking.

Although no formal set of crack growth threshold tests was conducted, observations during precracking indicated that the crack growth threshold at room temperature was approximately 10 ksi$\sqrt{in}$. However from a practical standpoint it was very difficult to precrack at room temperature with manual control and stress intensity less than 14 ksi$\sqrt{in}$. With equipment for programmed automatic continuous load shedding, precracking stress intensity could be reduced to approximately 12 ksi$\sqrt{in}$., but reducing the stress intensity below that level would rapidly increase the required time beyond practical limits. Even 12 ksi$\sqrt{in}$. is significantly higher than the 9 ksi$\sqrt{in}$. which would be the maximum allowable for specimens tested at a temperature of -200°F with a K_Q value of 30 ksi$\sqrt{in}$.

In order to raise the allowable stress intensity during precracking, specimen 44C16 was precracked at a temperature

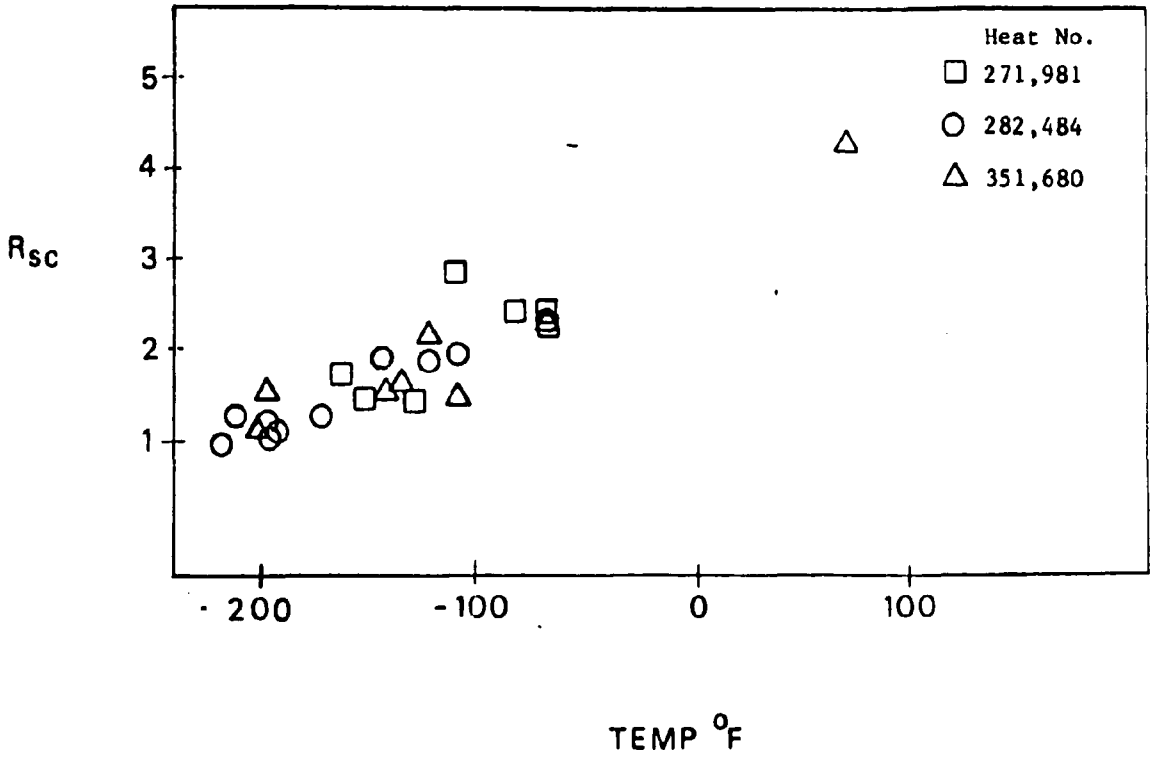


Figure 27 ASTM E-399 Results

TABLE 4 - ASTM E-399 TEST RESULTS

SPEC.	B in.	W in.	PRE-CRACK TEMP. deg F	MAX K_f ksi $\sqrt{in.}$	TEST TEMP. deg F	a in.	P_Q kips	MAX P kips	K_Q ksi $\sqrt{in.}$	R_{sc}	8.2.4*	9.1.2**	7.4.4***	9.1.6****
23C1	0.625	1.249	70	41.2	70	0.853	1.67	2.25	47.11	4.27	F	F	F	F
23C2	0.625	1.254	70	33.0	-58	0.6951	2.30	3.28	37.90	2.07	T	F	F	F
23C4	0.622	1.255	71	19.3	-195	0.7485	2.73	2.73	52.73	1.47	T	T	F	F
23C5	0.623	1.202	70	15.0	-103	0.6422	2.81	2.81	44.33	1.53	T	T	T	F
23C6	0.623	1.258	70	18.5	-135	0.7372	2.62	2.62	48.51	1.58	T	T	F	F
23C7	0.623	1.256	69	14.3	-193	0.6625	2.70	2.70	40.68	1.03	F	T	F	F
23C8	0.623	1.253	73	17.42	-148	0.7311	2.85	2.98	52.37	1.72	T	T	F	F
23C9	0.626	1.257	70	23.0	-112	0.6714	3.10	4.47	47.57	2.11	F	F	F	F
42C2	0.610	1.253	70	30.0	-58	0.6563	3.16	3.67	48.00	2.06	F	F	F	F
42C3	0.609	1.257	78	17.2	-190	0.7207	1.97	1.97	35.37	1.04	T	T	F	F
42C4	0.608	1.252	74	17.9	-160	0.7122	2.26	2.26	40.36	1.28	T	T	F	F
42C5	0.610	1.254	71	36.2	-76	0.7365	2.50	3.00	47.59	2.25	T	F	F	F
42C6	0.608	1.261	67	26.3	-166	0.6883	3.45	3.45	56.61	1.68	T	T	F	F
42C7	0.606	1.255	75	20.1	-103	0.7691	2.83	3.18	59.91	2.70	T	F	T	F
42C8	0.609	1.248	76	15.7	-130	0.6812	2.50	2.50	41.19	1.29	T	T	F	F
42C10	0.592	1.260	71	33.2	-58	0.7008	2.91	3.41	50.85	2.28	T	F	F	F
44C1	0.625	1.252	67	28.5	-58	0.6890	2.81	3.14	45.71	2.11	T	F	F	F
44C2	0.626	1.253	70	32.8	-148	0.7111	2.97	2.97	51.23	1.68	T	T	F	F

TABLE 4 (Continued)

44C3	0.623	1.252	71	18.1	-186	0.7247	1.90	1.90	34.34	0.98	T	T	F	T
44C4	0.625	1.251	71	30.9	-112	0.6880	3.19	3.19	51.85	1.84	F	T	F	F
44C5	0.622	1.253	72	19.5	-197	0.7505	1.98	1.98	38.67	1.11	T	T	F	F
44C6	0.623	1.253	72	18.6	-189	0.7358	1.88	1.88	35.02	1.00	T	T	F	T
44C7	0.622	1.253	73	18.3	-103	0.7421	2.62	2.62	49.86	1.91	T	T	T	F
44C8	0.622	1.256	71	16.8	-177	0.6674	2.95	2.95	45.17	1.18	F	T	F	F
44C9	0.623	1.253	70	17.9	-189	0.7220	2.11	2.11	37.73	1.06	T	T	F	F
44C16	0.601	1.199	-197	20.7	-207	0.6740	1.52	1.52	27.37	0.85	T	T	F	T

* T indicates specification is satisfied, and F indicates it is not satisfied

* Section 8.2.4 of ASTM E-399 defines the shape of the crack front for a valid test.

** Section 9.1.2 of ASTM E-399 requires that $P_{max}/P_Q \leq 1.1$

*** Section 7.4.4 of ASTM E-399 require that K_f during last 2.5% precrack $\leq 0.6(\sigma_{y1}/\sigma_{y2})K_Q$

**** Section 9.1.6 of ASTM E-399 requires that a & $B > 2.5(K_Q/\sigma_y)^2$

of -193°F. This raised the maximum allowable stress intensity during precracking to approximately 13.5 ksi$\sqrt{in}$. However, the low temperature which approximately doubled the yield stress also nearly doubled the crack growth threshold level and the minimum precrack stress intensity attainable was 20 ksi$\sqrt{in}$.

Thus, it was concluded that with a maximum thickness of 0.6 inches it is not possible to conduct a valid K_{IC} test on this material at any temperature. Observations during precracking of these specimens also suggest that fatigue-crack growth is much more closely associated with yield strength than it is with fracture toughness. The plot of $R_{\sigma\sigma}$ shown in Figure 27 reveals no significant difference between these three heats of steel.

CHAPTER 4 - FATIGUE CRACK GROWTH TESTS

The preliminary version of ASTM E-647 used for this work does not in all cases comply with the final version, which was published subsequent to these tests.

4.1 SPECIMEN DESIGN AND PREPARATION

Crack growth tests were conducted using Compact Tension (CT), Wedge-Open-Loading (WOL) specimens. Flanges were flame cut from the web, and rectangular blocks were cut from them with a bandsaw. In Figures 9 - 18 the cutting patterns and specimen orientation are shown for each flange eventually used. No specimen was cut so as to be within 2" of any heat affected zone such as a flame cut or weld. This was to ensure that the micro-structures of all specimens were essentially unaltered. These blocks were then machined and ground to the dimensions shown in Figure 28. Care was taken to ensure that the grinding process did not significantly reduce the thickness of the specimens, but that it did leave a smooth, well polished surface. the grinding process was in the direction perpendicular to the line of crack growth to aid the microscopic viewing of the crack.

The notch opening was cut perpendicular to the direction in which the steel was rolled during fabrication. This was done to most closely approximate the orientation of a crack which could form in a flange and propagate perpendicularly to the axial stress field. The specimens were sprayed with a Krylon lacquer to prevent corrosion before testing.

4.2 TEST EQUIPMENT

A 100 kip Material Testing System (MTS) closed loop

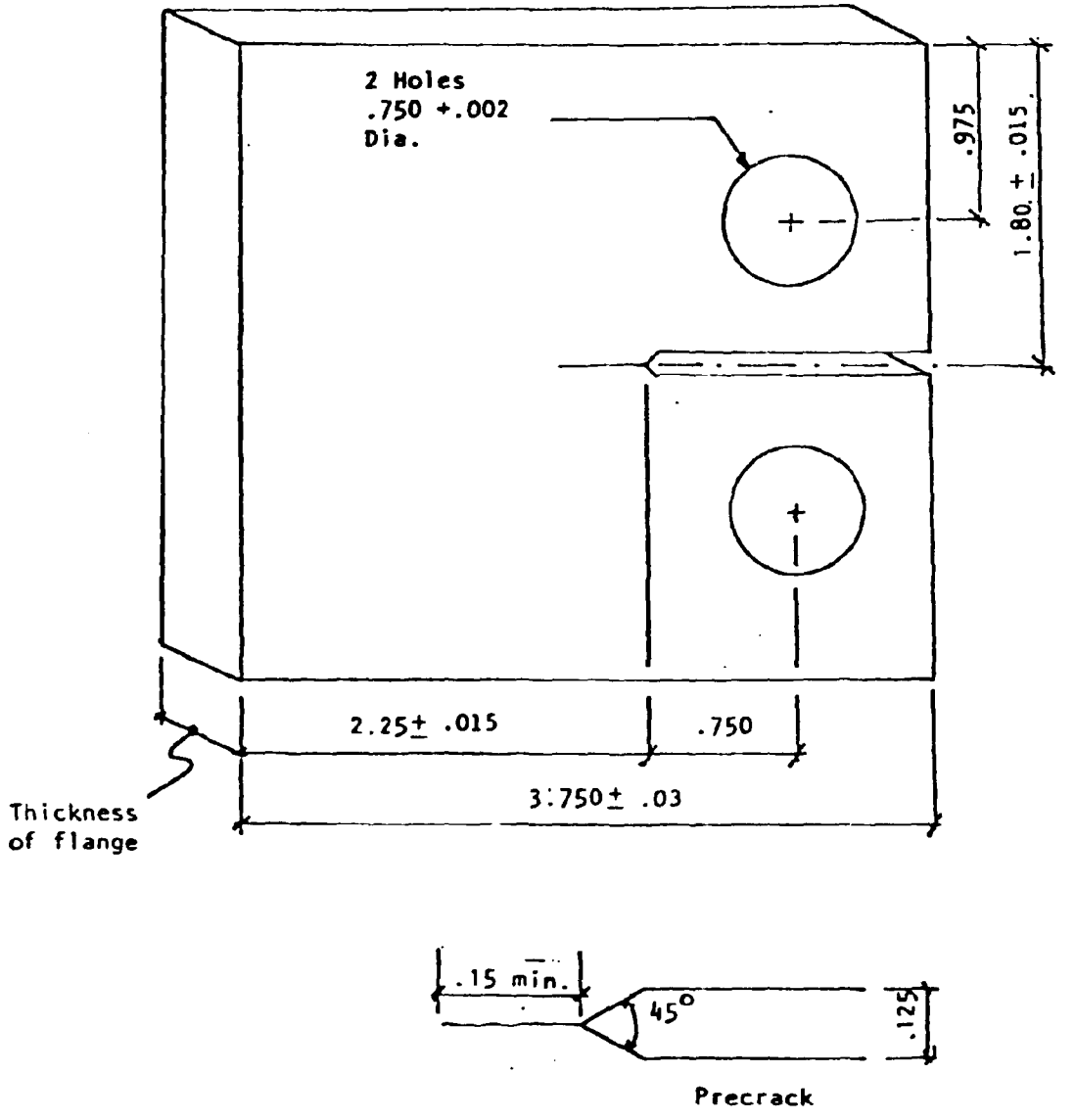


Figure 28 da/dN Specimen Design

electrohydraulic servocontrolled test machine was used to load the fatigue crack growth specimens. Loading was applied to the specimen through clevises designed according to ASTM E-647, Figure 29. The clevises were made of AISI 4340 steel heat treated to a rockwell hardness of C-40. The position of the crack was measured with two Gaertner traveling microscopes mounted on micrometer slides, Figure 30.

To maintain a fixed low temperature a plexiglass box was constructed which would fit around the specimen and clevises, Figures 31 and 32. The specimen was cooled by blowing a temperature regulated gas, primarily nitrogen, through the box.

The gas was blown through 1 1/2" diameter copper piping which was installed with a throttle valve that forced a certain portion of the gas through a dewar containing liquid nitrogen. This kept the gas within a few degrees of the proper temperature. To fine tune the system to the exact temperature, a small heating element made of nichrome wire was installed in the flow and connected to a thermo-controller. A thermocouple relayed the temperature of the gas to the thermo-controller, which cycled the heating element on and off as needed. A second thermocouple was inserted in a hole in the specimen to measure the temperature of the specimen.

At the beginning of the cooling process the system was circulating air, but as the liquid nitrogen boiled off, the test environment became primarily nitrogen. Every effort was made to keep the system airtight, as any moisture entering the system condensed causing ice to collect in the piping.

4.3 TEST PROCEDURES

Since the objective of this experiment was to compare the fatigue crack growth rates of the material in the three heats of steel, the tests were set up with the idea that all

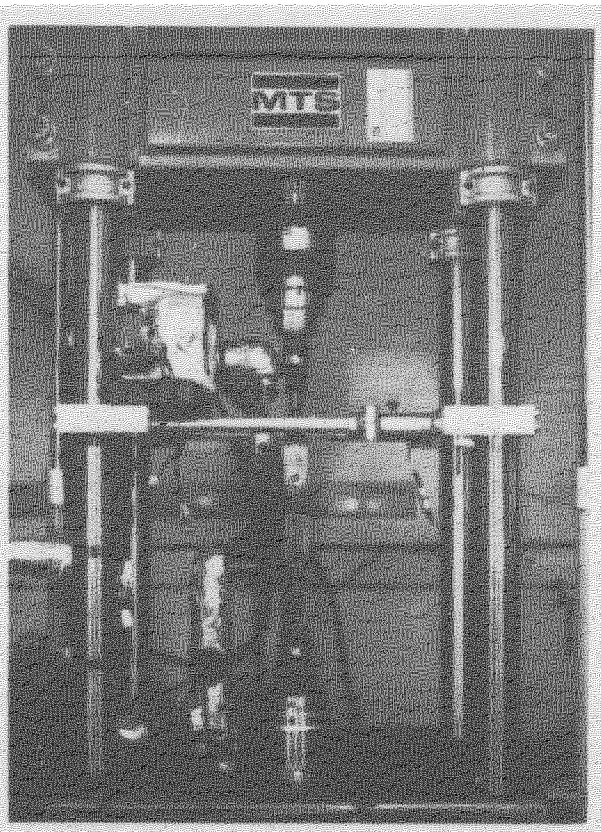


Figure 29 MTS Machine

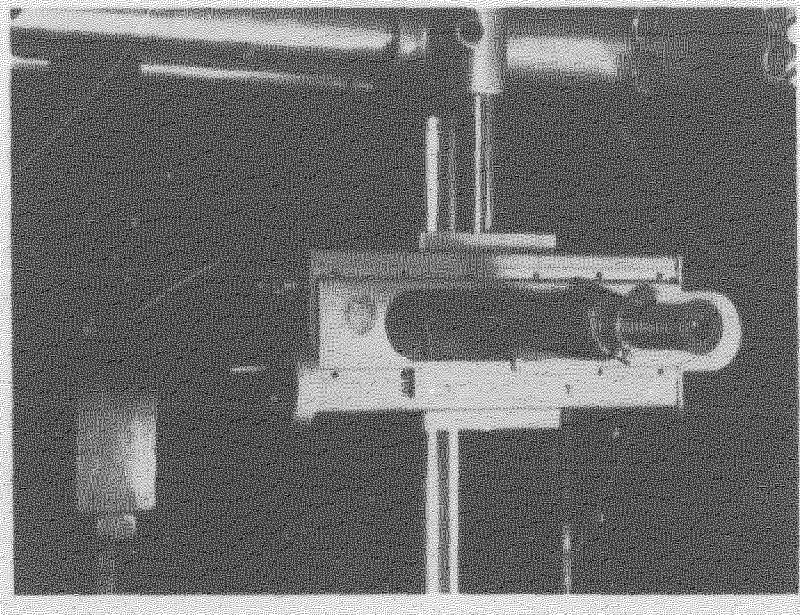


Figure 30 Gaertner Traveling Microscope

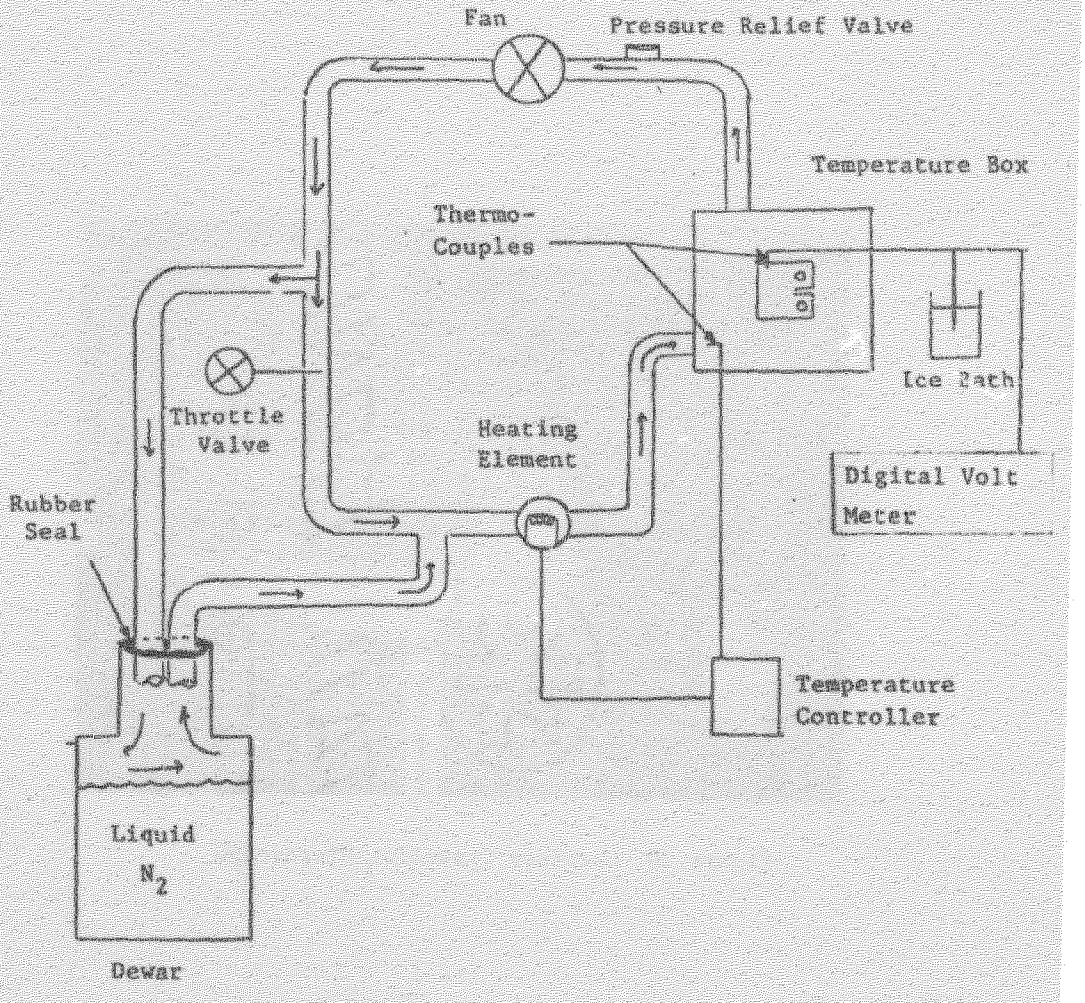


Figure 31 Cold Test Schematic

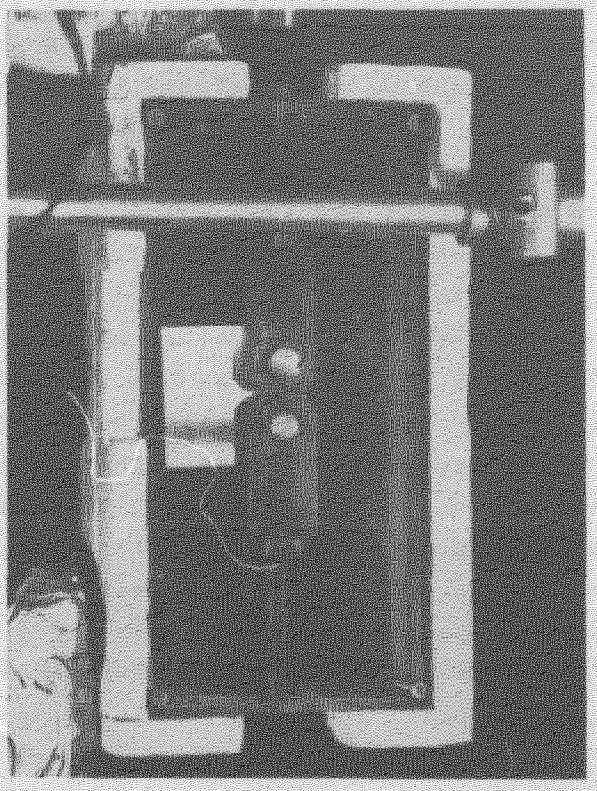


Figure 32 Cold Temperature Box with Specimen Installed

specimens would be tested under identical lab conditions and over the same range of ΔK_I. Nine specimens were tested for each heat at three different temperatures; 70°,0°, and -50°F. The tests were run at each temperature in triplicate to verify the results.

ASTM E-647 (11) requires that the fatigue crack growth procedures be divided into a precracking stage and a fatigue crack growth stage. The purpose of the precracking stage was to establish a sharp, well defined crack tip. While testing specimen 42E04, for example, the maximum precracking load was 6.5 kips and the minimum load was .1 kips. The cyclic frequency throughout the test was 5 Hz. ASTM E-647 requires a minimum precrack length of .15". However, it also suggests that the precrack load be reduced to a starting test load, in this case 4.4 kips, before the precrack stage is completed, so as to minimize the size of the plastic zone in front of the crack just prior to the test. The load was reduced at a precrack length of approximately .13"

The fatigue testing utilized three different maximum loads, beginning with maximum of 4.4 kips, and with a total crack length, a, of .90" which included the depth of the notch to the line of loading. Using different loads was not done to evaluate the effect of R factor, the ratio of minimum to maximum load. In fact, the tests were run so that the ratio of minimum to maximum load was as close to zero as possible. Rather, the loads were changed to comply with the ASTM E-647 specification shown in Equation 5.

$$K_{Imax} < \sigma_y \sqrt{\frac{\pi(w-a)}{4}} \qquad \text{(Eq. 5)}$$

This requirement was to ensure that the region in front of the crack was predominantly elastic. Excessive yielding at the crack tip results in distortion of the crack front and violation of linear elastic fracture mechanics.

With a 4.4 kip maximum load, excessive yielding would have occurred at a crack length of 1.5", consequently the load was shed at a crack length of 1.41" and a maximum stress intensity $K_{I_{max}}$ equal to 37.2 ksi$\sqrt{in}$. The new maximum load was 2.5 kips with a maximum stress intensity of 24.0 ksi$\sqrt{in}$. When the crack length approached 1.80", the load was shed again to 2.1 kips. The resulting maximum stress intensity decreased from 33.5 ksi$\sqrt{in}$. to 29.2 ksi$\sqrt{in}$.

As the specimen approached failure, the crack opening displacement became large enough that at 5 Hz. frequency, the machine was unable to produce the desired maximum load range from 2.1 kips maximum to .1 kips minimum. Instead, the loads drifted towards the mean of the two. Thus, little information of any value could be obtained at failure.

Crack tip readings were taken approximately every .025". The crack required approximately 20000 cycles to grow .025 at the start of a constant load period, but only about 500 cycles near the end.

Specimen compliance was determined during the test by measuring the crack opening with a clip gage (Figure 33) designed according to ASTM E-399. Crack opening displacements (COD) were measured by the voltage readings using a digital peak indicator. Measurements were taken as the test was in progress and while stopped for crack length measurements. Before the cycling was stopped for crack length measurements, COD readings were taken for the maximum and minimum displacements corresponding to the displacemant caused by the maximum and minimum loads. When the cycling was halted, the COD's were taken at zero load and at the load corresponding to the median of the maximum and minimum loads.

Fatigue crack growth measurements were taken until the specimen failed. At room temperature, the final fracture was a slow tearing of the specimen and could be observed. At 0°F and -50°F the fracture was sudden.

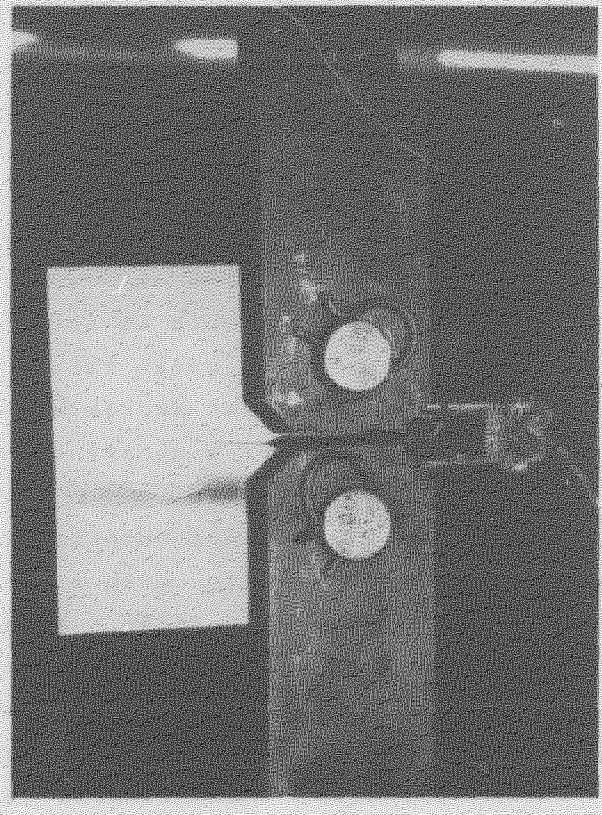


Figure 33 Specimen Installed in Clevises

4.4 DATA REDUCTION METHODS

The values relating the crack tip growth rates, da/dN, and the stress intensity range, ΔK_I, must first be derived from raw a vs. N and load range data taken during the fatigue crack growth tests. ASTM E-647 suggests two methods of reducing the data, the secant method and the seven point polynomial method. For this work, both methods were employed and compared.

For both methods, the alternating stress intensity value ΔK_I was calculated using Equation 6 (3).

$$\Delta K_I = \frac{\Delta P \; f(a/w)}{B\sqrt{a}} \qquad \text{(Eq. 6)}$$

where,

$$f(a/w) = (0.2960(a/w) - 1.855(a/w)^2 + 6.557(a/w)^3 - 10.17(a/w)^4 + 6.389(a/w)^5) \times 100 \qquad \text{(ref. 3)}$$

The fifth order polynomial in Equation 6, found in Barsom and Rolfe, is a function of specimen geometry.

Other compliance functions have been derived for this specimen geometry and can be found in references 6, 11 and 12. Each arrives at approximately the same value of ΔK_I.

The secant method is based on the assumption that the data points lie precisely on the a-N curve. The crack growth rate is derived using Equation 7, which yields the slope of a straight line connecting two consecutive points. If the data points on the a-N curve are numbered $a_1, a_2, \ldots, a_n$, then the value of 'a' is equal to $(a_i + a_{i-1})/2$ is used to calculate ΔK_I.

$$da/dN = \frac{a_{i+1} - a_i}{N_{i+1} - N_i} \qquad \text{(Eq. 7)}$$

Sample calculations are shown in Table 5.

There is a certain amount of scatter that exists in the raw data which the secant method amplifies. The resulting plot does not display the crack growth curve with much clarity. The method does produce one da/dN vs. ΔK_i data point for every a-N data point after the first. Thus, for a short test, this method would be desirable.

The polynomial method utilizes a second order polynomial equation to derive the relationship for da/dN vs. ΔK_I. The method uses seven consecutive data points to approximate the a-N curve with a polynomial, thus effectively smoothing the scatter that exists in the raw data. The original a-N data are fitted to a curve as shown in Figure 34. The value of a used in calculating ΔK_I is arrived at using Equation 8.

$$a = b_0 + b_1(N_i - C_1)/C_2 + b_2(N_i - C_1)^2/C_2 \qquad \text{(Eq. 8)}$$

where,

$$-1 \leq (N_i - C_1)/C_2 \leq +1$$

The values b_0, b_1, and b_2 are the regression parameters determined by the least squares method over the range $a_{i-n} \leq a \leq a_{i+n}$. The value a is the fitted value of crack length at N_i. The parameters $C_1 = 1/2(N_{i-n} + N_{i+n})$ and $C_2 = 1/2(N_{i+n} - N_{i-n})$ are used to scale the input data, thus avoiding numerical difficulties in determining the regression parameters. The rate of crackgrowth at N_i is obtained from the derivative of Equation 7, as shown in Equation 9.

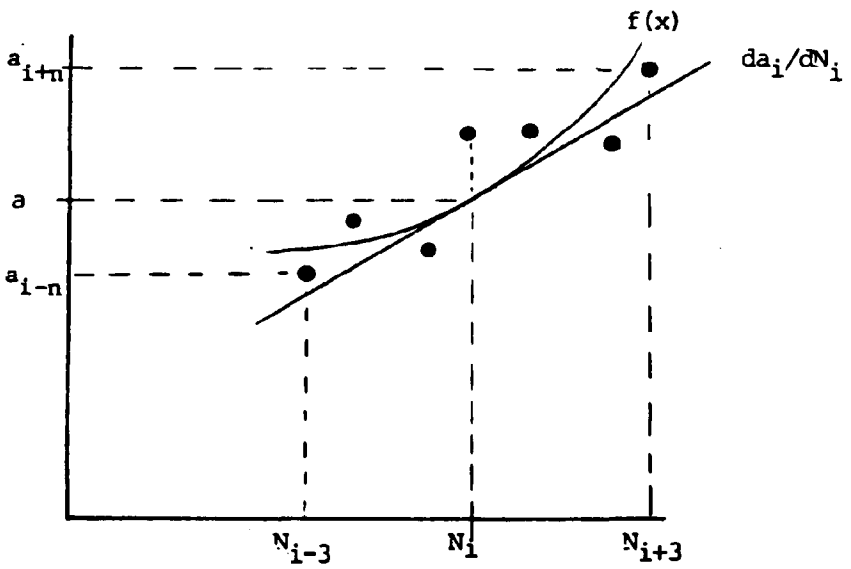


Figure 34 Seven Point Polynomial Method

TABLE 5 SECANT METHOD SAMPLE CALCULATIONS

a	N	da	dN	da/dN
1.00	100,000			
		.10	100,000	1.00×10^{-6}
1.10	200,000			
		.05	40,000	1.25×10^{-6}
1.15	240,000			
		.05	30,000	1.67×10^{-6}
1.20	270,000			
		.05	15,000	3.33×10^{-6}
1.25	285.000			
		.10	20,000	5.00×10^{-6}
1.35	305.000			

$$(da/dN)_i = b_1 C_2 + 2b_2 (N_i - C_1)/C_2^2 \qquad \text{(Eq. 9)}$$

The value of n used was 3, that is, 7 successive data points were utilized.

The data are reduced by moving along the a-N curve until there are only six points left in the curve. Data reduction ends at this point, thus da/dN values are not computed for six of the points in the curve, three at the beginning, three at the end.

The polynomial was found to be far superior to the secant method because it produced results which make the a-N curve appear to have a monotonically increasing first derivative. Because of this, the polynomial method was used to reduce the data for this work. Figures 35 and 36 show the comparison between the two methods using Heat 271,981 at -50°F.

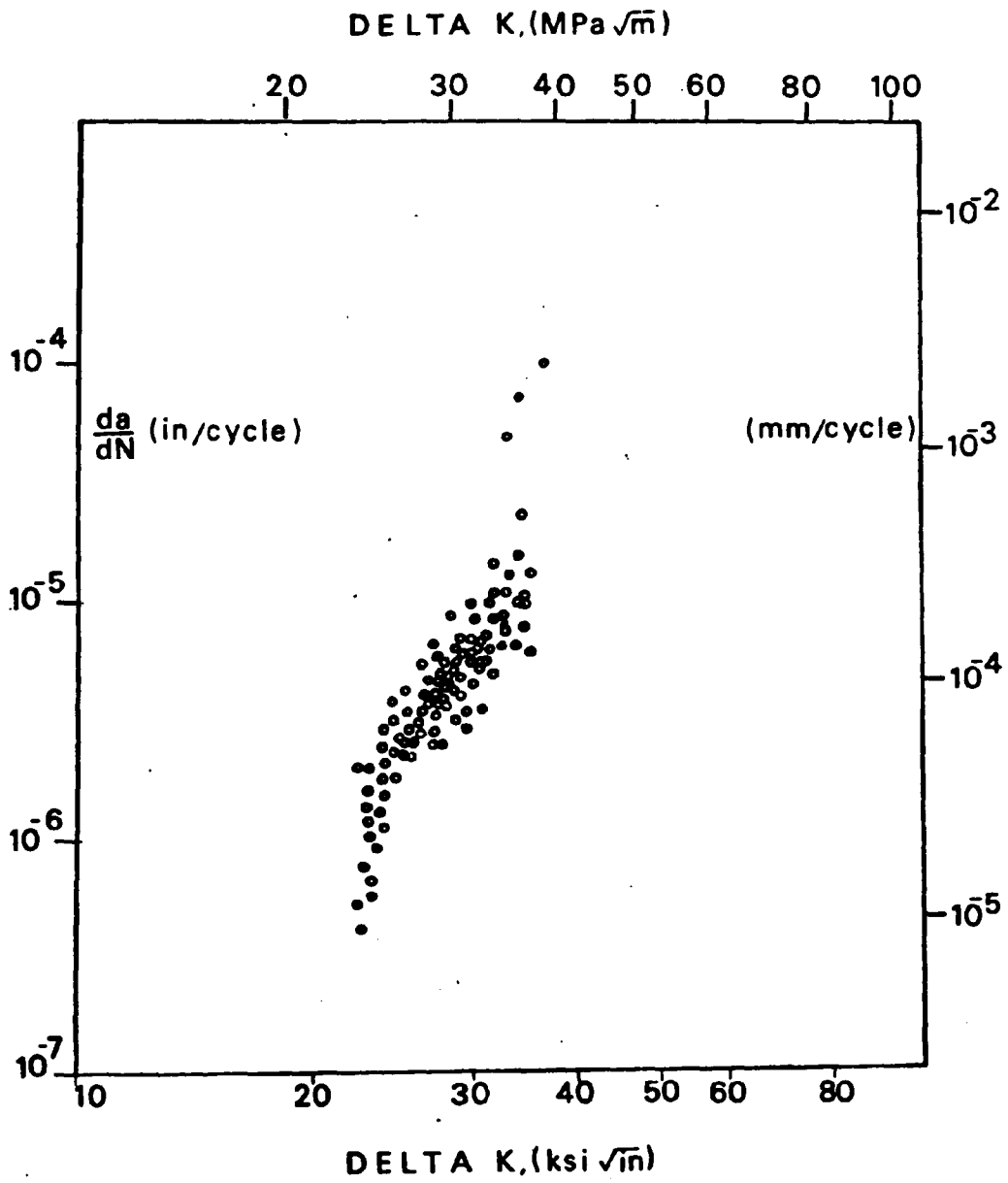


Figure 35 Reduced Data for Heat 271,981 at -50°F
Using the Secant Method

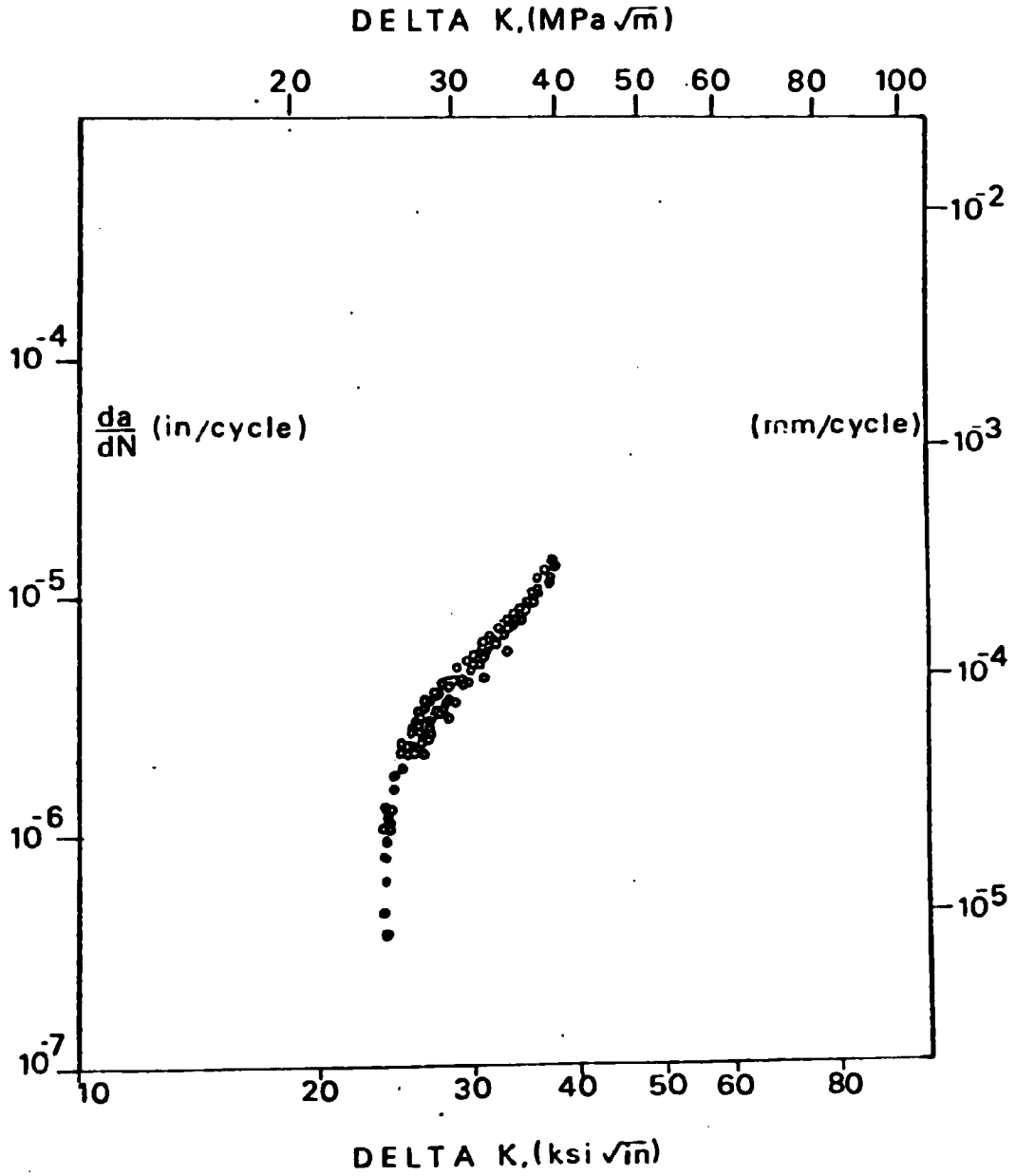


Figure 36 Reduced Data for Heat 271,981 at -50°F

Using the Polynomial Method

CHAPTER 5 - RESULTS AND DISCUSSION

Twenty-eight fatigue crack growth tests were conducted. The raw data were taken as previously described and reduced to a more usable form as da/dN vs. ΔK_I. These results were then plotted on a log-log scale and displayed as shown in Figures 37-45. The original data are given in the Appendix in tabular form.

5.1 GENERAL OBSERVATIONS

It can be observed that the data presented in Figures 37-45 are of the sigmoidal form discussed earlier. It is plainly seen that at low values of ΔK_I the curve rises sharply with increasing ΔK_I. It is also apparent that at certain values of ΔK_I, there is no crack growth. This is the threshold value of ΔK_I, which varied between 22 and 24 ksi$\sqrt{in}$. Beyond this the curve reaches a value of ΔK_I at which the da/dN vs. ΔK_I relationship is linear on a log-log scale. This range was generally between 28 and 38 ksi $\sqrt{in}$.

The third region, where rapid unstable growth occurs as K_{Imax} approaches K_{IC}, is not apparent from the graphs. This is due in part to the fact that the first two loads were shed well before the crack growth reached region III. Only the final constant load period was allowed to enter the third region. However, no data could be taken during this stage, because the machine could not maintain the full load cycle. Thus, it was impossible to determine the value of the instability asymptote. At 70°F, the specimen failed by ductile tearing, which could be observed but not measured. At both -50°F and 0°F, the specimen failed by fracture.

A linear regression model was set up to obtain a least-squares fit of the linear portion of the curves. Since

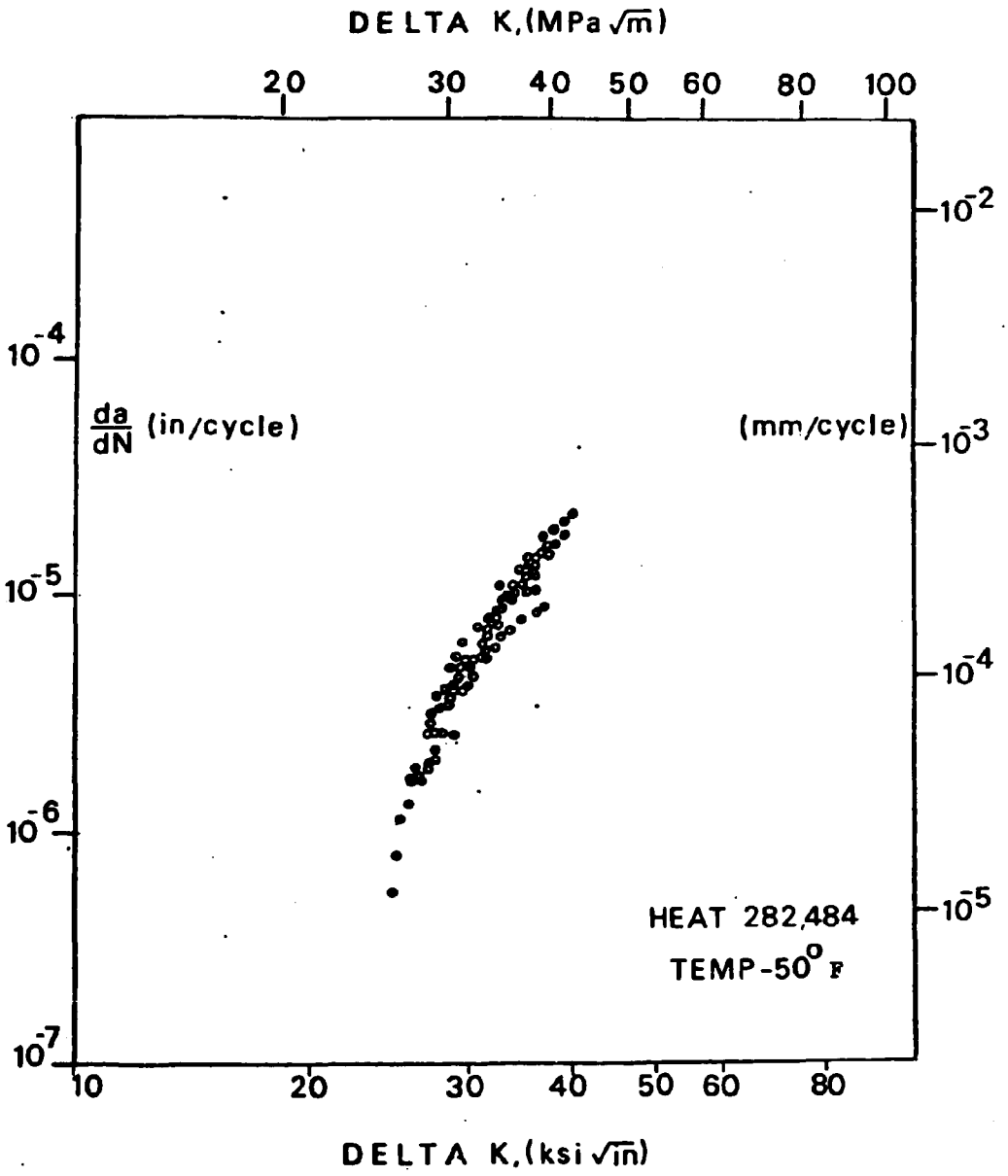


Figure 37 da/dN v. ΔK_I for Heat 282,484 at -50° F

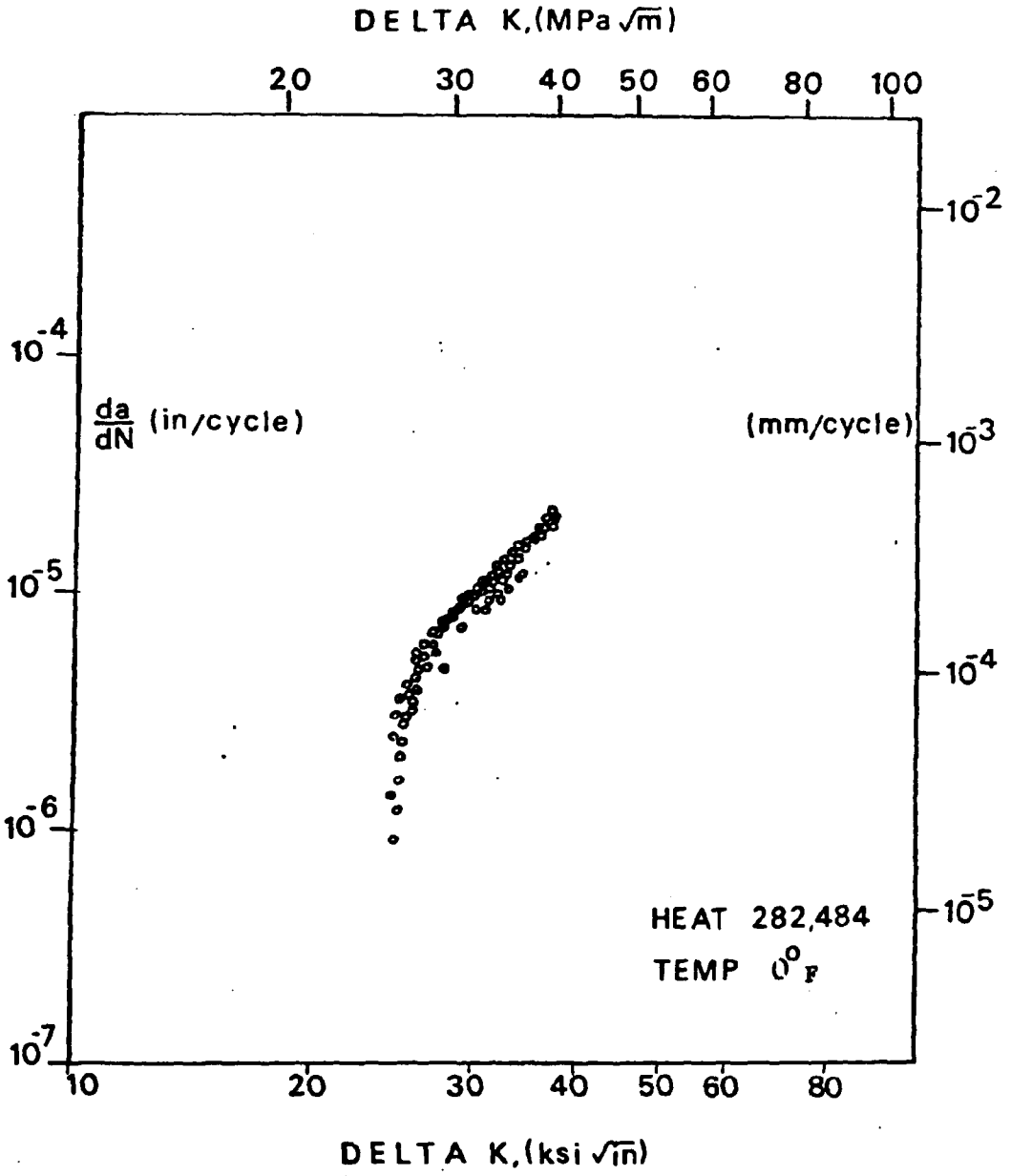


Figure 38 da/dN vs. ΔK_I for Heat 282,484 at 0^oF

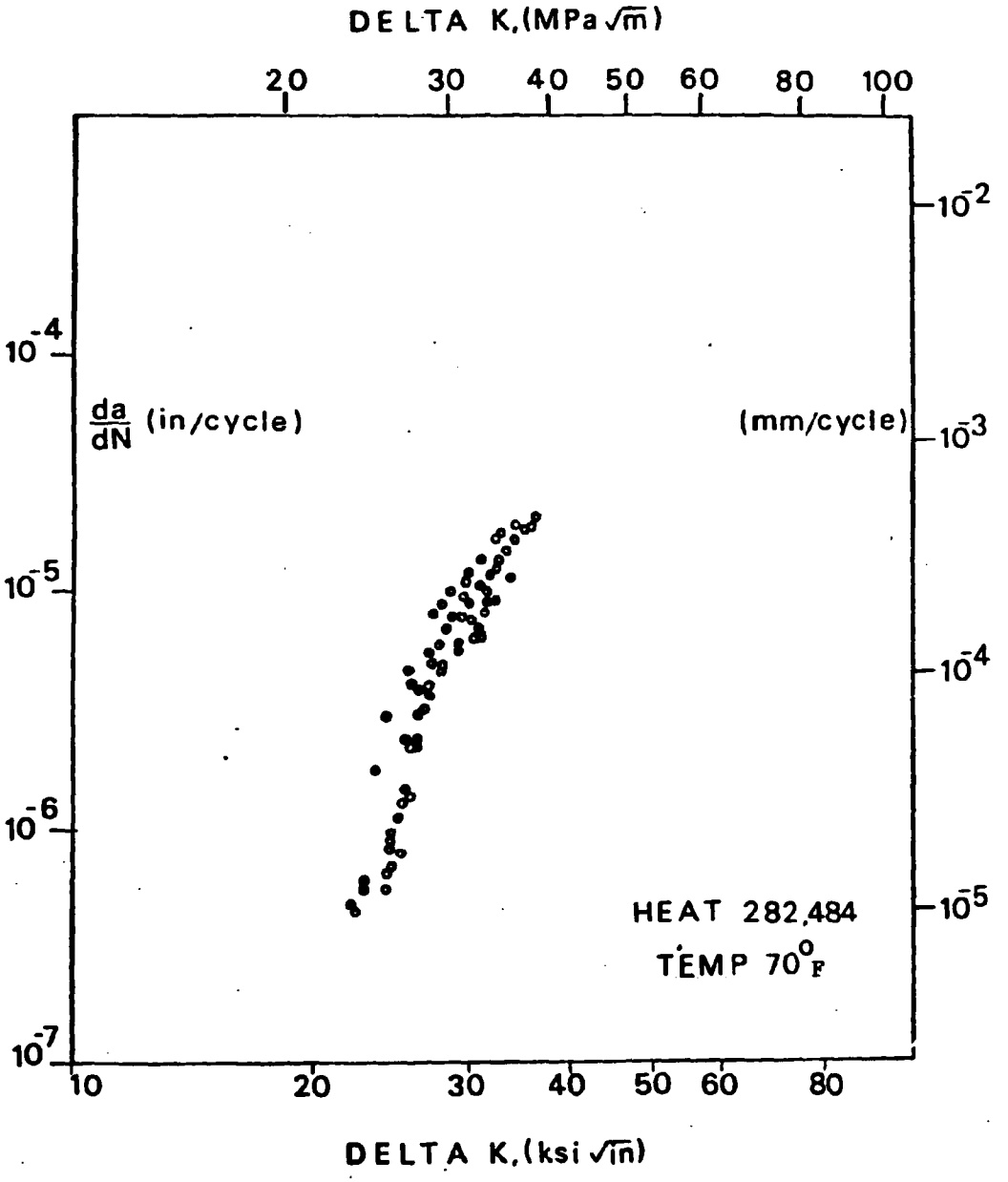


Figure 39 da/dN vs. ΔK_I for Heat 282,484 at 70°F

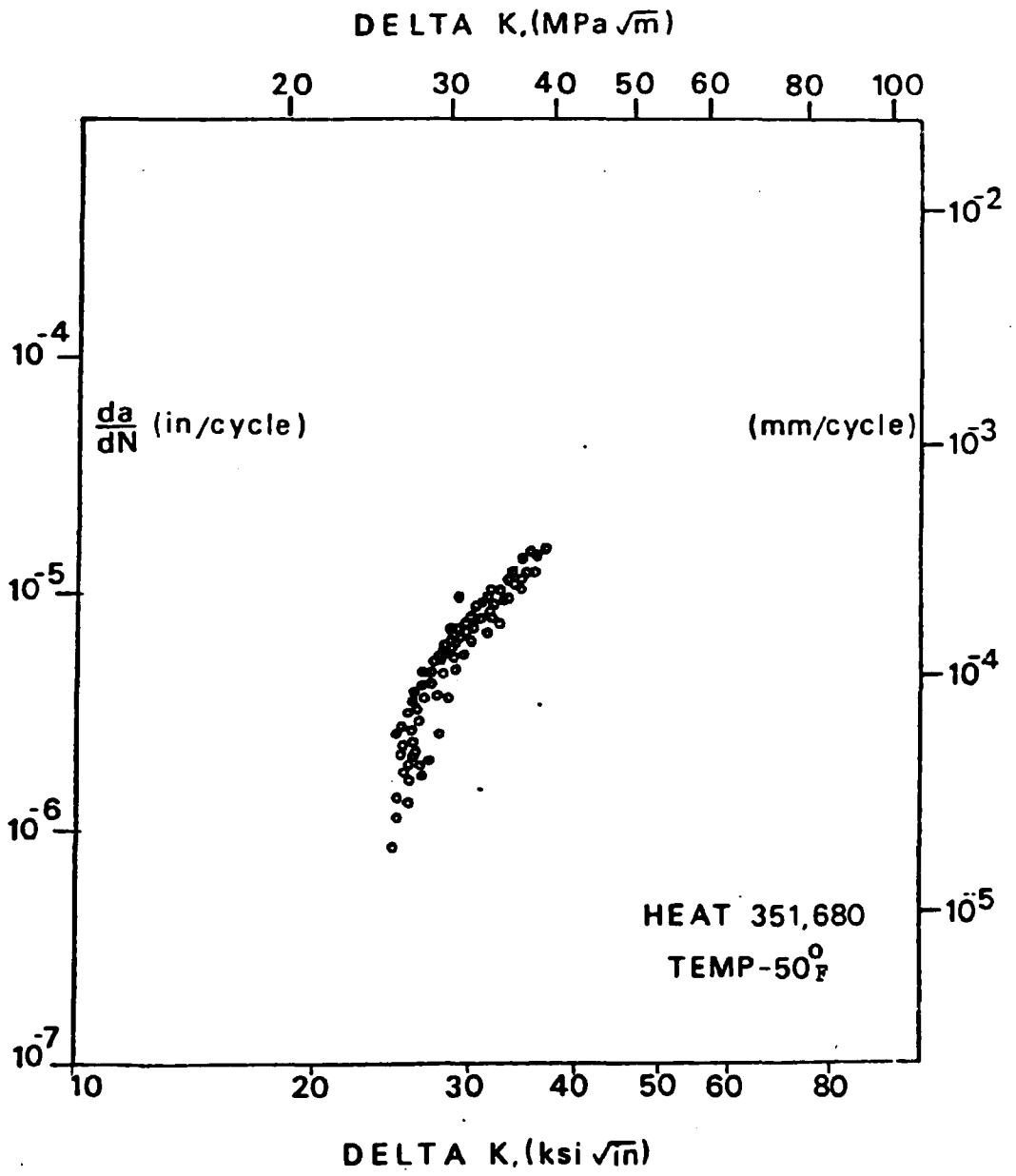


Figure 40 da/dN vs. ΔK_I for Heat 351,680 at -50°F

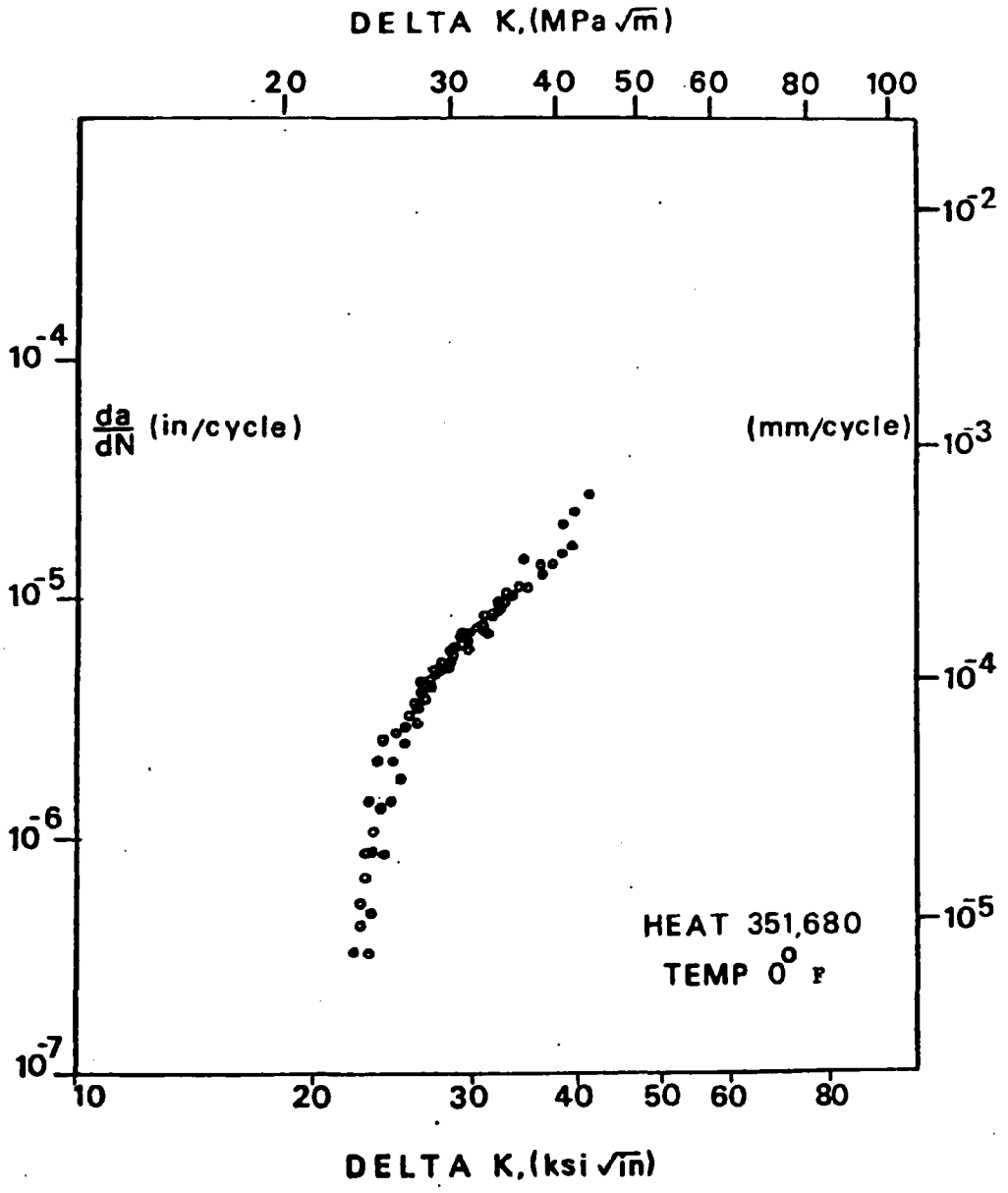


Figure 41 da/dN vs. ΔK_I for Heat 351,680 at 0°F

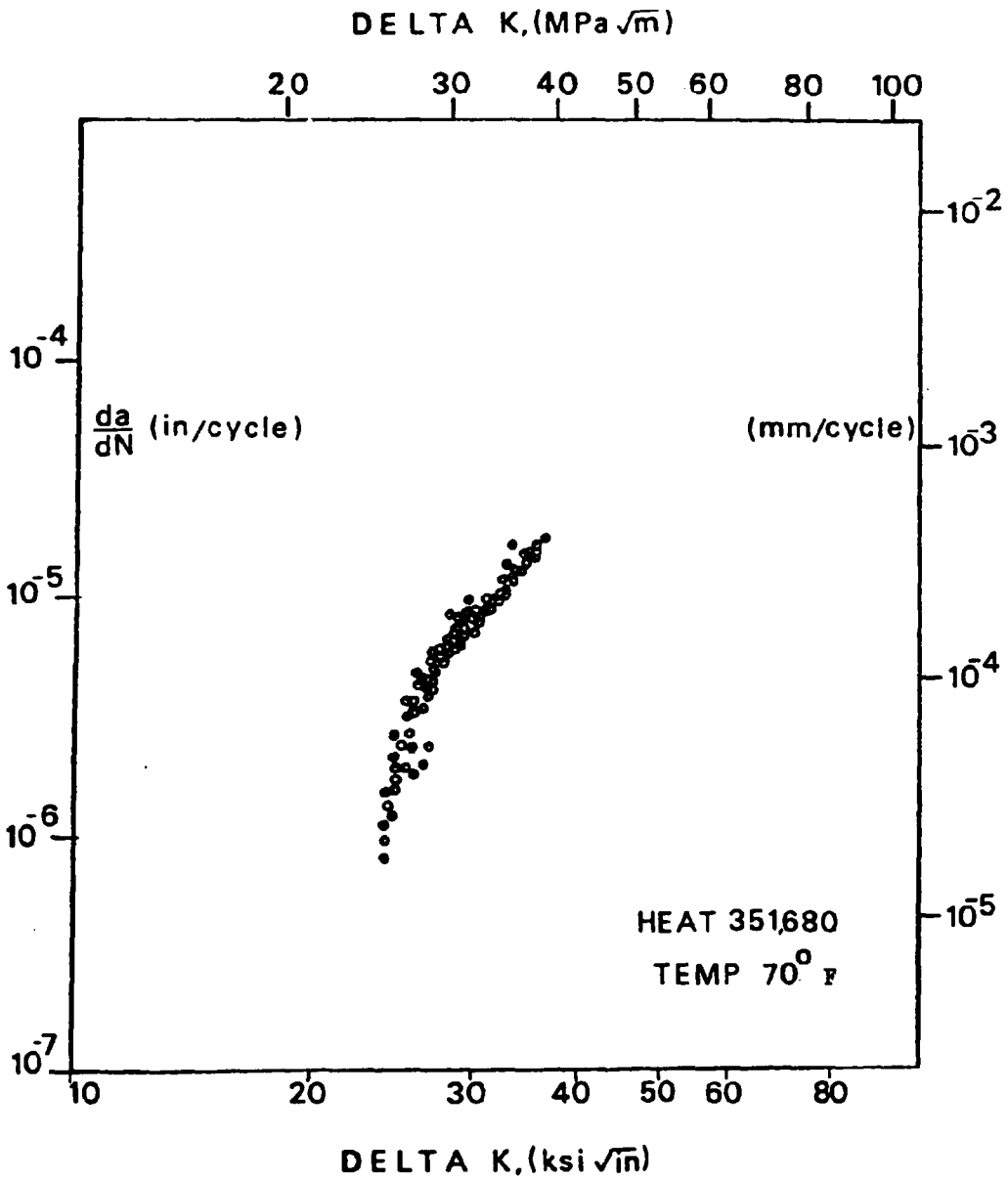


Figure 42 da/dN vs. ΔK_I for Heat 351,680 at 70°F

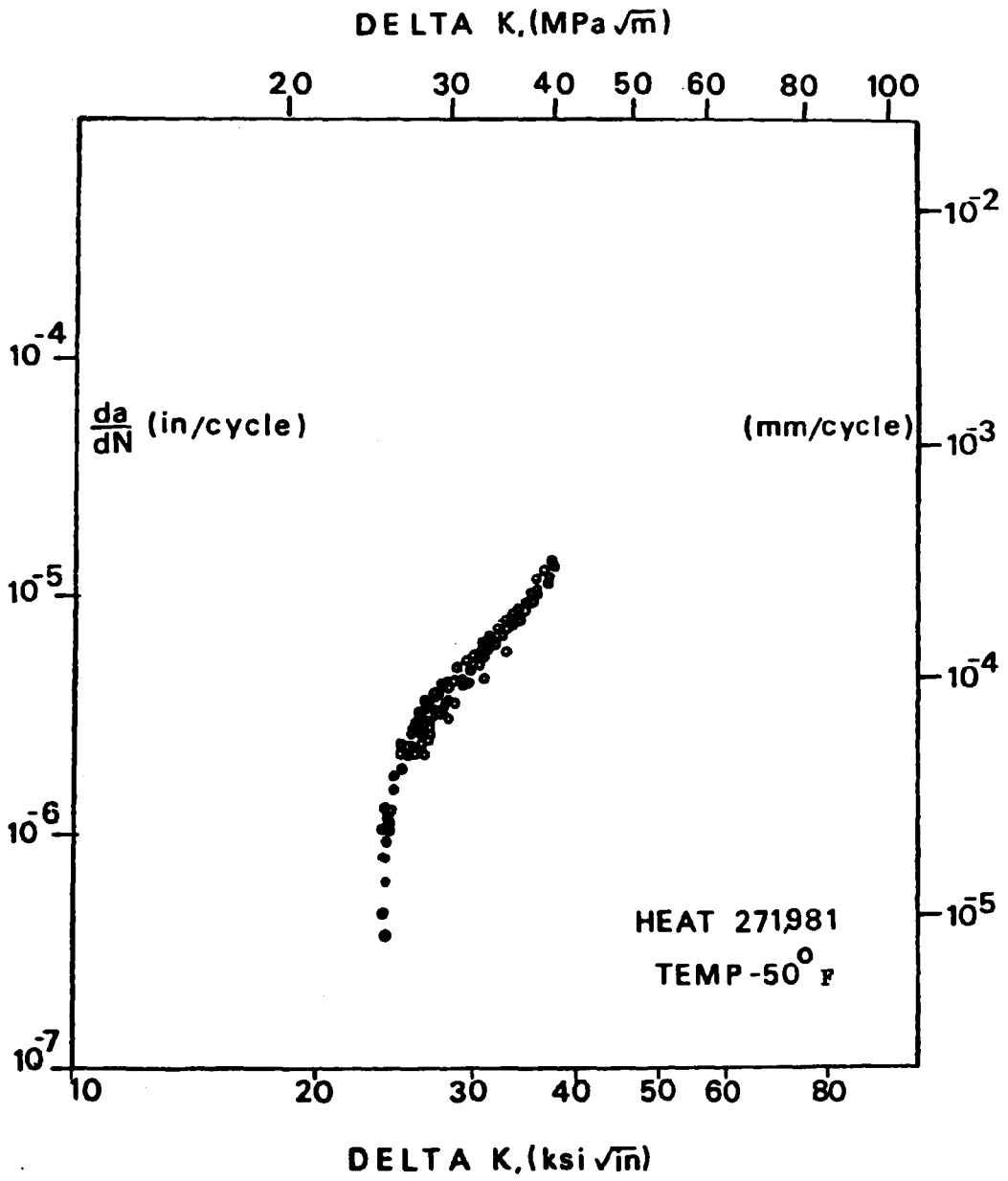


Figure 43 da/dN vs. ΔK_I for Heat 271,981 at -50°F

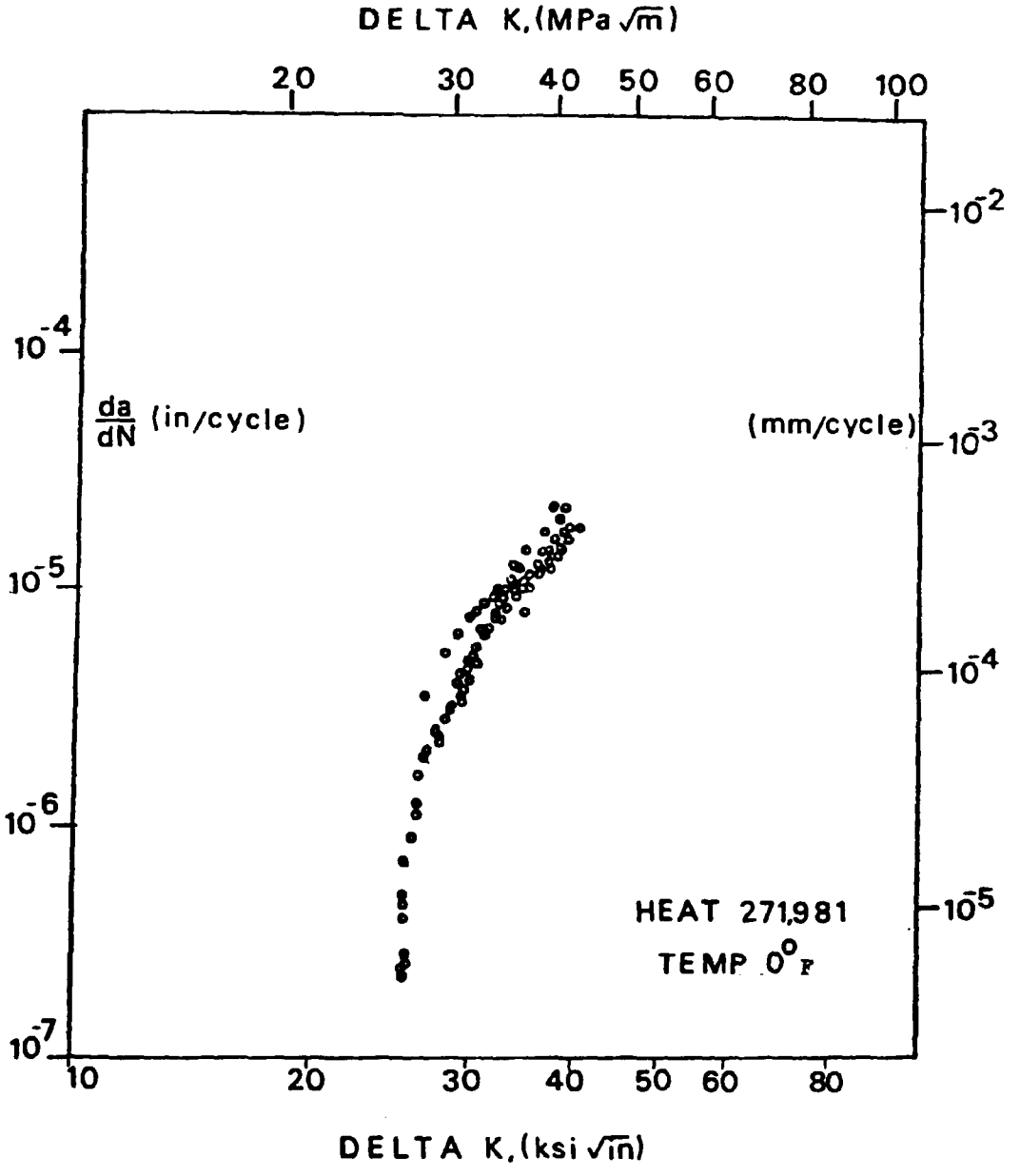


Figure 44 da/dN vs. ΔK_I for Heat 271,981 at 0^oF

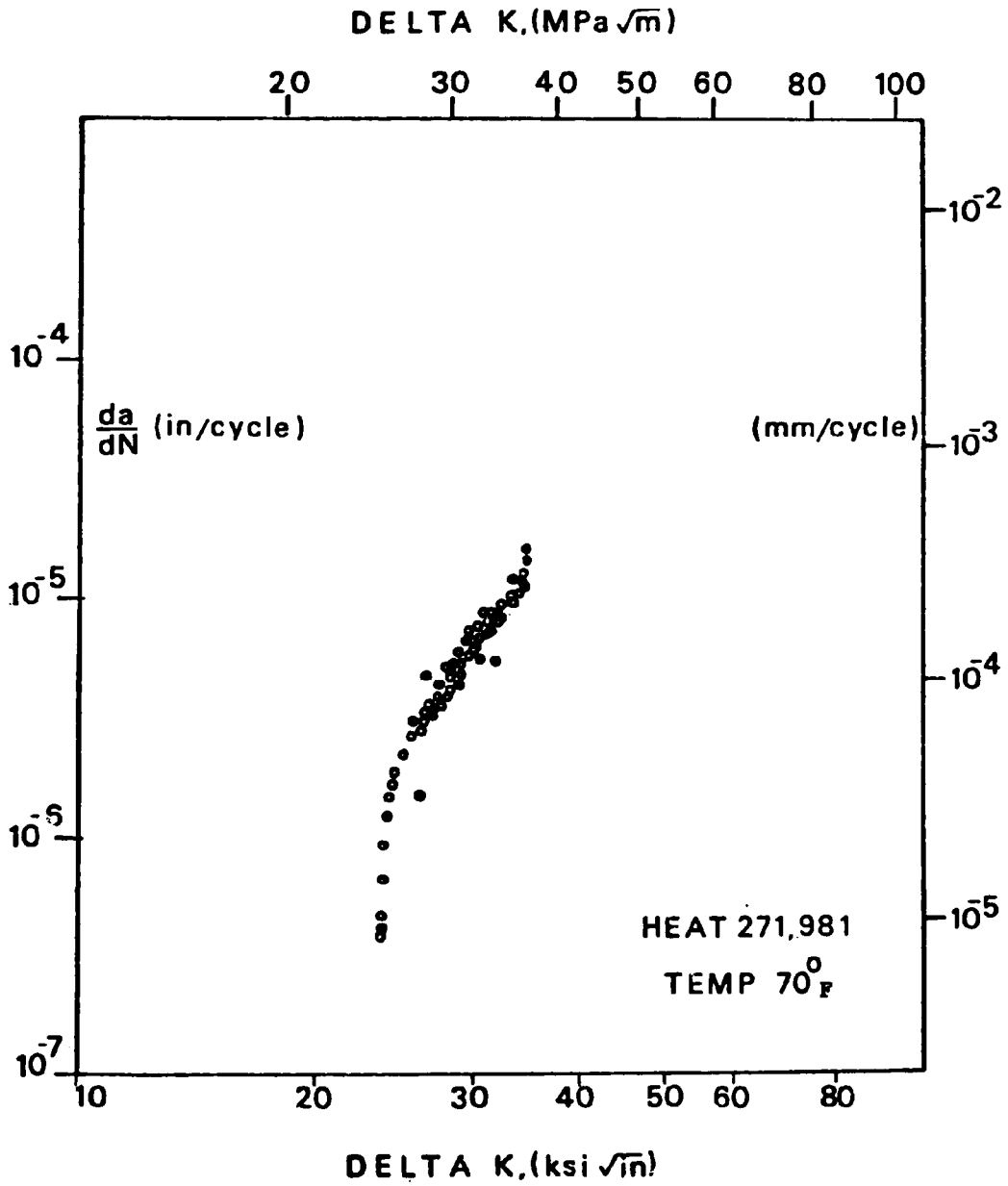


Figure 45 da/dN vs. ΔK_I for Heat 271,981 at 70°F

threshold asymptotes varied somewhat between tests, the curves were evaluated between the ΔK_I values which encompassed the linear portion for each of the nine graphs. From this, an equation of the following form was determined.

$$da/dN = c(\Delta K_I)^m \qquad \text{(Eq. 10)}$$

where,

c = intercept on the da/dN axis (log ΔK_I = 0, ΔK_I = 1) of a line fitted on the linear portion of the curve.

m = slope of the line

These results are shown in Table 6.

5.2 EFFECT OF TEMPERATURE

It is generally accepted fracture mechanics theory that the critical stress intensity value (K_{IC}) describes a material's resistance to fracture, and the higher the value, the tougher the material. In addition, as temperature decreases, the toughness also decreases. Charpy and Dynamic Tear tests conducted for this work verify this, as seen in Figures 23 and 25.

This would lead one to believe that as temperature decreases and toughness also decreases, that the crack growth rate would respond by increasing. However, the results of these tests indicate that the opposite is true, that the crack growth rate actually decreases as temperature decreases.

By plotting the equations, as has been done in Figures 46-48, it can be seen that both the value of the crack growth rate, da/dN, and the slope of the line, or rate of change of the crack growth rate, decrease as temperature

TABLE 6 LINEAR REDUCTION RESULTS

Heat	Temperature	Equation
282,484	-50°F	$da/dN = 3.16\ 10^{-11}\ \Delta K_I^{3.55}$
	0°F	$da/dN = 4.45\ 10^{-12}\ \Delta K_I^{4.22}$
	70°F	$da/dN = 5.03\ 10^{-13}\ \Delta K_I^{4.06}$
351,680	-50°F	$da/dN = 1.62\ 10^{-10}\ \Delta K_I^{3.11}$
	0°F	$da/dN = 7.94\ 10^{-12}\ \Delta K_I^{4.03}$
	70°F	$da/dN = 3.98\ 10^{-12}\ \Delta K_I^{4.25}$
271,981	-50°F	$da/dN = 3.98\ 10^{-11}\ \Delta K_I^{3.49}$
	0°F	$da/dN = 1.74\ 10^{-12}\ \Delta K_I^{4.47}$
	70°F	$da/dN = 3.98\ 10^{-12}\ \Delta K_I^{4.06}$

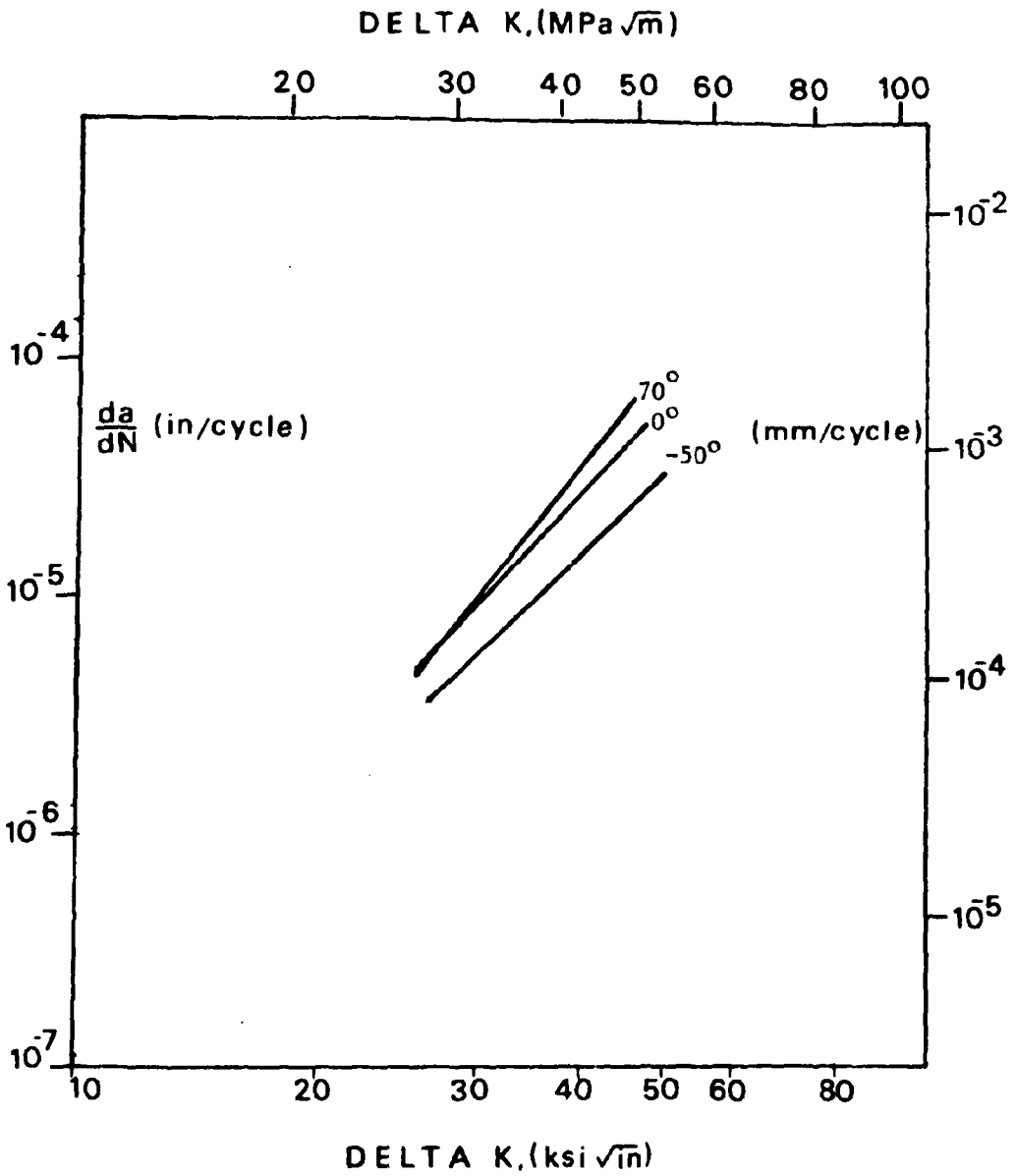


Figure 46. Results for Heat 282,484

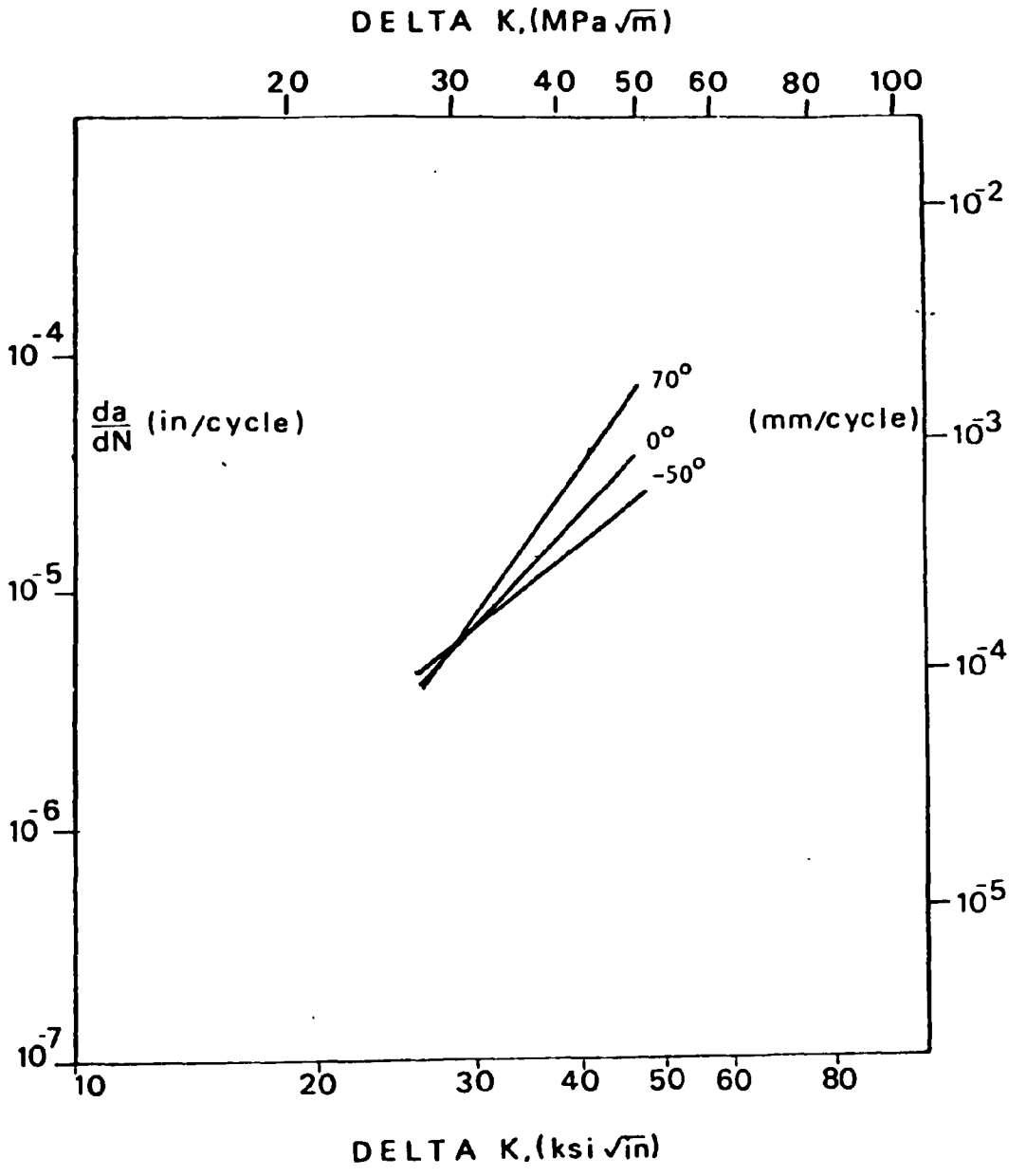


Figure 47 Results for Heat 351,680

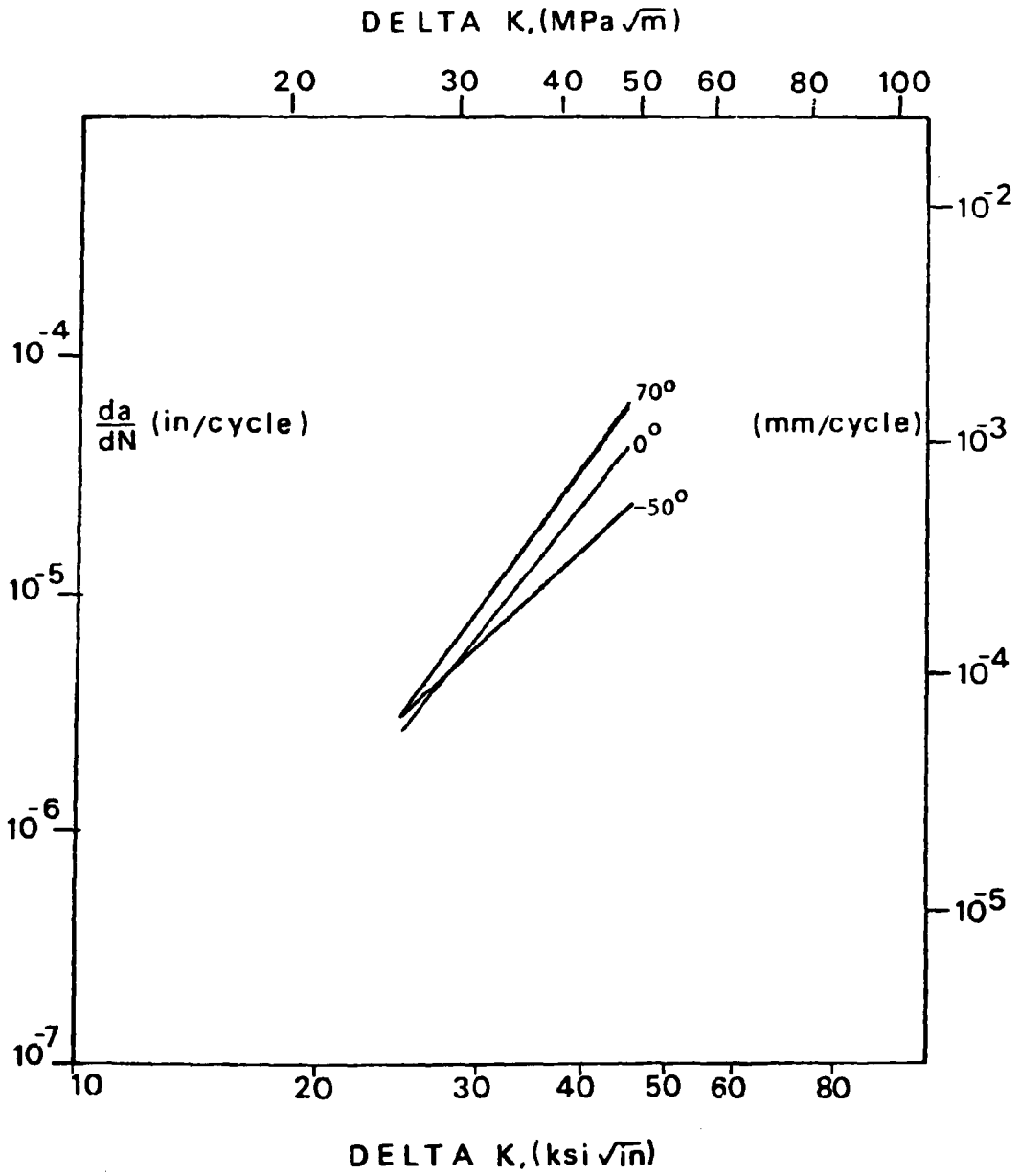


Figure 48 Results for Heat 271,981

decreases. This is true for all three heats. Thus, while failure might occur at a lower stress intensity (K_{IC}) as temperature decreases, the time to failure is significantly longer.

This suggests that crack growth rate is not related to toughness. Clark (13) states that crack growth rate is instead related to the yield strength of the material, as indicated by his statement.

> "Irwin (14) has shown that the size of the localized plastic zone at the tip of a crack is directly dependent upon the applied stress intensity-yield strength ratio quantity squared, $(K_I/\sigma_{ys})^2$. In addition, it has been shown (here) and elsewhere that the fatigue crack growth rate for a given material increases as the stress intensity factor increases (15,16,17,18). Therefore, it is apparent that the fatigue crack growth rate increases as the plastic zone size increases, suggesting that the mechanisms of fatigue crack behavior are related to crack tip plasticity considerations."

Tensile tests conducted on the bridge specimens indicate that yield strength does in fact increase with decreasing temperatures. This concurs with equations shown by Barsom & Rolfe.

$$\sigma_{yd} = \left(\sigma_{ys} + \frac{174{,}000}{\log\,(2+10^{10}t)(T+459)} - 27.4\right) \quad \text{(Eq. 11)}$$

where,

σ_{yd} = 0.2% offset yield strength at the temperature and load rate indicated by T and t respectively, .si

σ_{ys} = 0.2% offset yield strength at room temperature and a load rise time of 100 sec., ksi

T = specimen temperature, °F

t = load rise time from start of load to fracture, sec.

Thus crack growth rate appears to be a function of yield strength and plastic zone rather than fracture toughness.

5.3 EFFECTS OF MATERIAL PROPERTIES

One of the objectives of this work was to determine whether differences in crack growth rates in these three heats of steel could be attributed to differences in other material properties.

Comparing the results shown in Table 5 and plotted in Figures 49-51, it appears that each heat exhibited similar crack growth properties at each temperature. Thus, it appears that material differences were not significant in determining crack growth rates.

The chemical differences in the three heats are minor. From Table 2, the percentage of carbon content in heats 282,484 and 271, 981 is identical: .23%. Heat 351,680's carbon content is slightly lower: .22%. This hardly seems significant, and there appear to be no other differences. Toughness properties as determined by the Charpy tests and Dynamic Tear tests also show no apparent differences.

5.4 EFFECT OF LOAD SHEDDING

During the course of each test, the maximum applied load was reduced to comply with ASTM E-647 and to prevent the stress intensity from becoming so large that it caused excessive yielding at the crack tip. Loads were shed twice per test. This proved significant in analyzing the results.

As the crack grows, K_{Imax} increases, which in turn increases the plastic zone in front of the crack. The size of the plastic zone for plane stress can be determined by Equation 12.

$$r_y = \frac{1}{2\pi}\left(\frac{K_{Imax}}{\sigma_{yd}^2}\right)^2 \qquad \text{(Eq. 12)}$$

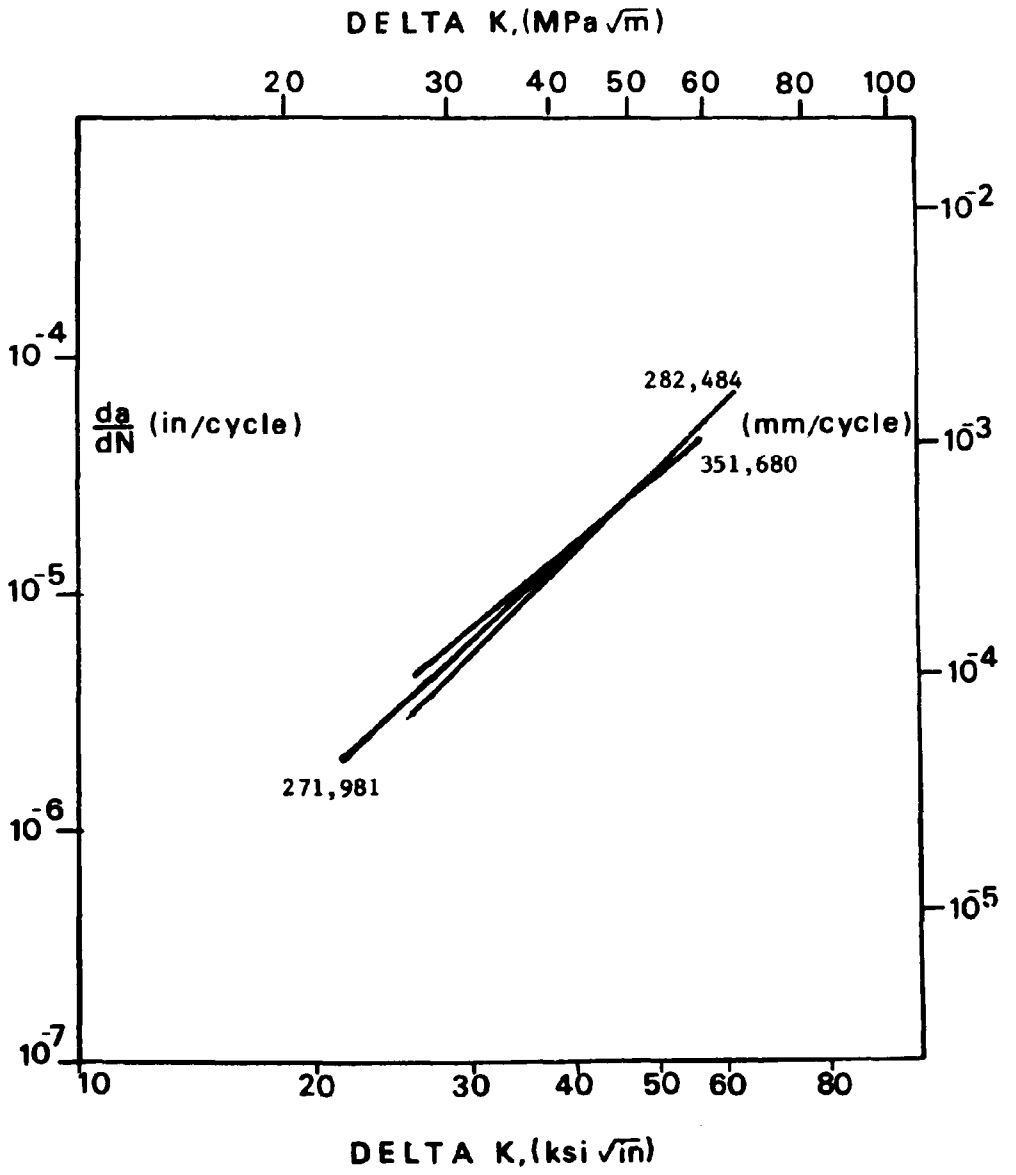


Figure 49. Results at -50°F

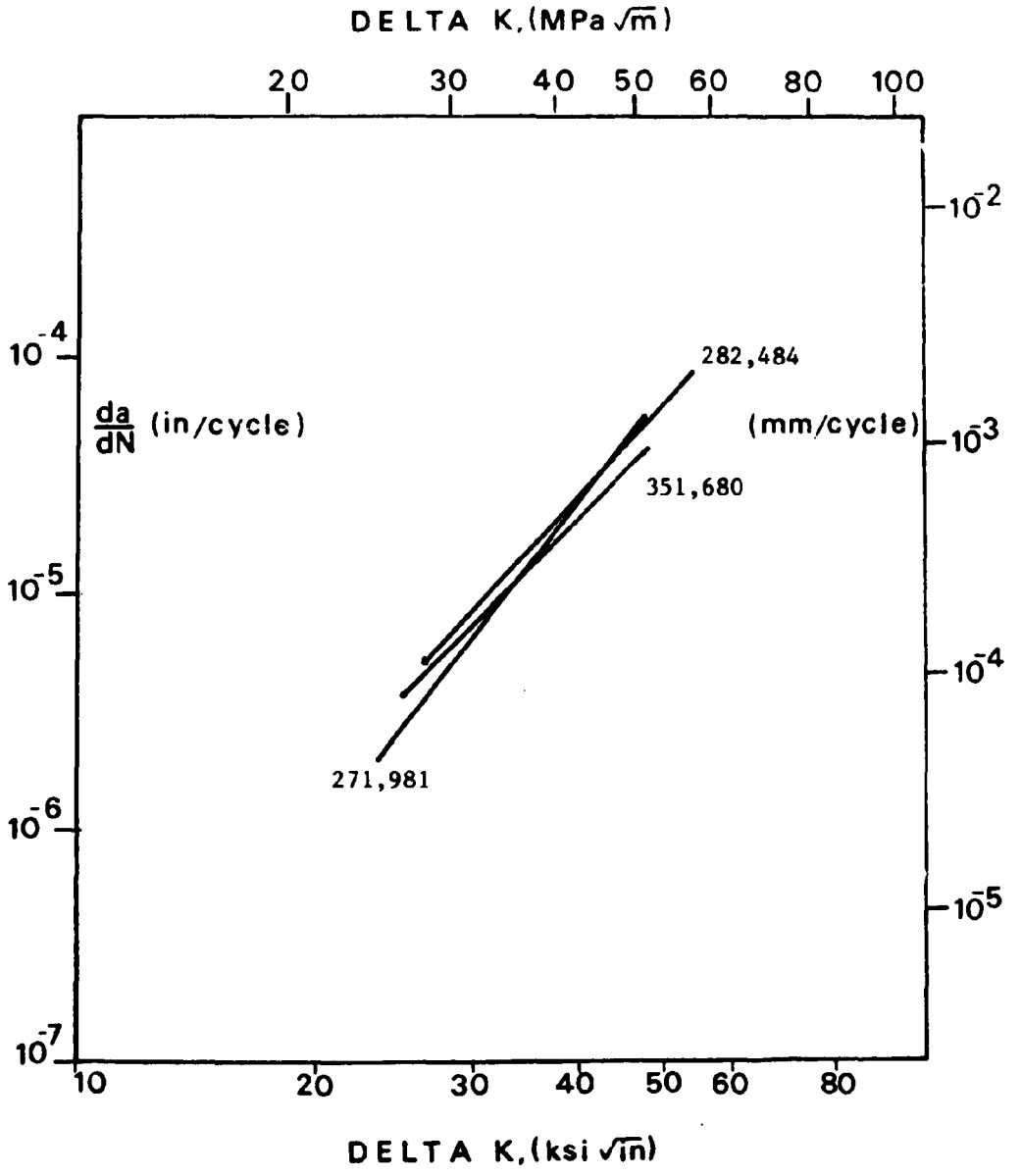


Figure 50. Results at 0°F

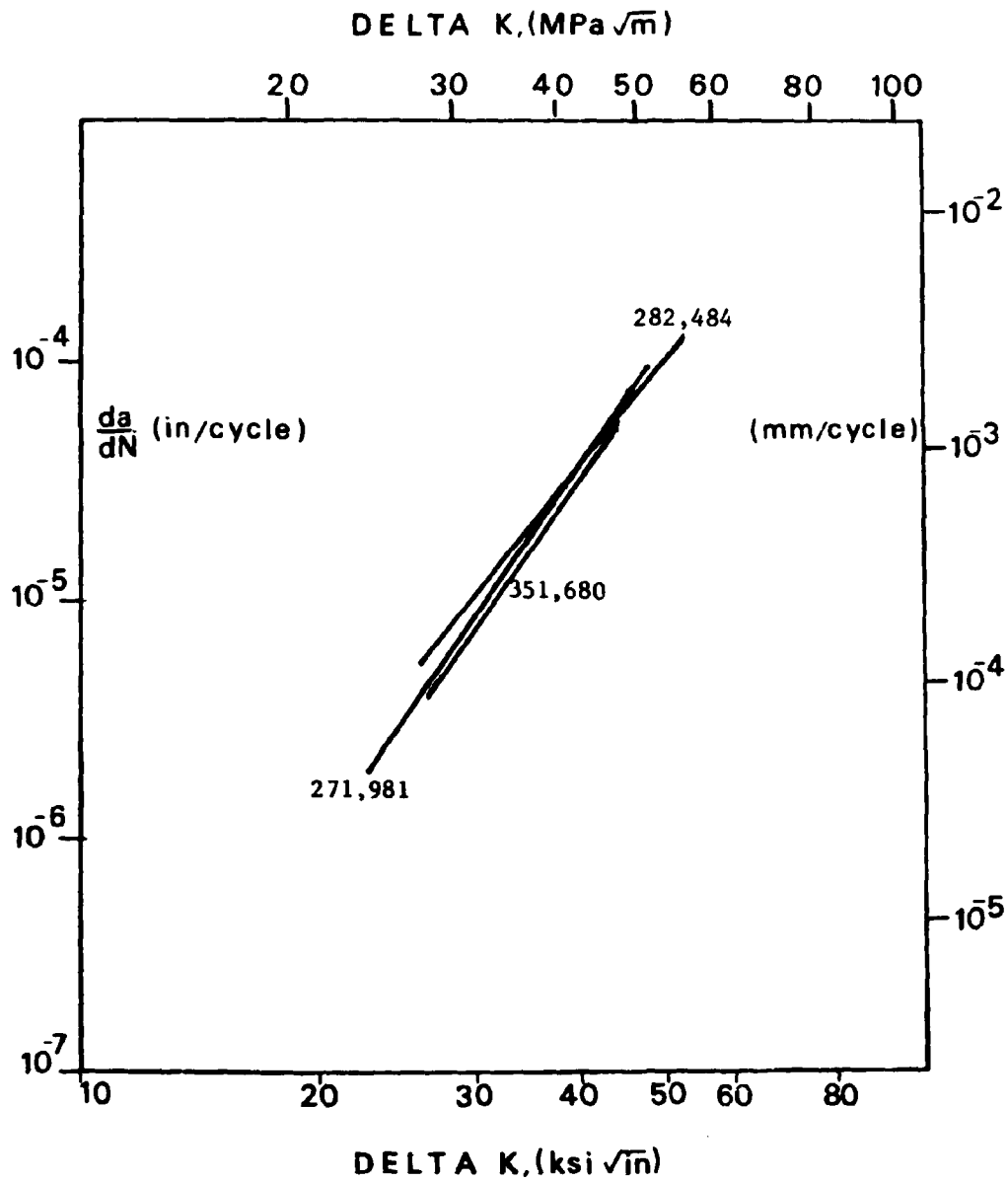


Figure 51. Results at 70°F

In test 44E05, K_{Imax} at the point of load shedding was 39 ksi $\sqrt{in}$, the yield strength was 37 ksi, and the plastic zone, r_y, was .18". After load shedding, K_{Imax} was 26 ksi $\sqrt{in}$. and the plastic zone size should have been .08". At this point large plastic strains around the crack tip just before load shedding probably increased the yield strength in the plastic zone through strain hardening. This in turn reduced the crack growth rate until the outer fringe of the new plastic zone had propagated to the fringe of the plastic zone produced just before load shedding. This did not occur until the crack had grown .08", K_{max} equalled 28.5 ksi $\sqrt{in}$, and r_y equalled .10".

This indicates that crack growth curves may be distorted in the region below 28 ksi $\sqrt{in}$ and the actual crack growth threshold may be lower than the 21 or 22 ksi $\sqrt{in}$ indicated. It was also observed during precracking of the E-399 specimens that the threshold might actually be as low as 10 or 12ksi $\sqrt{in}$ at room temperature.

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APPENDIX

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 42E 3

B=0.588 INCHES W=3.009 INCHES

TEMPERATURE 0 DEGREES F

DA	DN	DA/DN	DK	DP	A	N
0.0315	3000.	8.723	34.400	6.00	0.902	18200.
0.0114	1000.	4.922	34.327	6.00	0.899	19200.
0.0119	4000.	4.259	24.841	4.30	0.914	23200.
0.0139	4000.	1.782	24.974	4.30	0.923	27200.
0.0013	3000.	0.425	25.018	4.30	0.925	30200.
0.0717	40000.	3.524	26.320	4.30	0.999	70200.
0.0016	17850.	5.362	27.852	4.30	1.075	88050.
0.0503	7500.	6.283	28.826	4.30	1.119	95550.
0.0492	7000.	7.923	29.741	4.28	1.164	102550.
0.0260	3270.	8.300	30.426	4.28	1.192	105820.
0.0260	3000.	8.796	31.064	4.28	1.217	108820.
0.0280	3000.	9.482	31.850	4.29	1.243	111820.
0.0275	3000.	10.215	32.647	4.29	1.272	114820.
0.0307	3000.	11.163	33.535	4.29	1.303	117820.
0.0361	3000.	12.692	34.131	4.24	1.337	120820.
0.0368	3000.	12.085	36.431	4.31	1.391	123820.
0.0437	3000.	6.935	36.717	4.31	1.400	126820.
0.0579	3000.	4.084	37.339	4.31	1.418	129820.
0.0032	22000.	1.713	22.795	2.50	1.472	151820.
0.0454	33000.	0.977	23.660	2.49	1.514	184820.
0.0108	26800.	0.665	24.043	2.50	1.526	211620.
0.0440	100000.	1.586	26.139	2.50	1.606	311620.
0.0452	30000.	3.389	27.643	2.50	1.656	341620.
0.0509	12020.	4.875	29.257	2.50	1.705	353640.
0.0775	13000.	7.246	31.466	2.50	1.764	366640.
0.0513	5000.	7.067	32.888	2.48	1.805	371640.
0.0566	4250.	7.940	34.862	2.50	1.842	375890.
0.0539	10000.	6.655	31.593	2.00	1.929	385890.
0.0249	2000.	8.138	32.207	2.00	1.942	387890.
0.0096	1500.	11.146	32.715	2.00	1.952	389390.
0.0159	1500.	13.408	33.537	2.00	1.968	390890.
0.0178	1300.	15.615	34.383	2.00	1.984	392190.
0.0223	1300.	18.903	35.631	2.00	2.007	393490.
0.0284	1300.	22.046	37.204	2.00	2.034	394790.
0.0245	1100.	25.577	38.822	2.00	2.059	395890.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 422 B

B=0.635 INCHES W=3.032 INCHES

TEMPERATURE -50 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0211	3590.	3.463	34.788	6.69	0.881	25010.
0.0121	1920.	1.872	34.775	6.69	0.881	26930.
0.0005	19420.	0.636	23.144	4.40	0.900	46350.
0.0070	18320.	0.390	23.245	4.40	0.907	64670.
0.0063	22030.	0.349	23.375	4.40	0.916	86700.
0.0098	10060.	0.436	23.416	4.40	0.919	96760.
0.0074	22100.	0.591	23.511	4.40	0.926	118860.
0.0046	23680.	0.913	23.716	4.40	0.939	142540.
0.0267	24340.	1.457	24.127	4.40	0.965	166880.
0.0476	25410.	2.152	24.874	4.40	1.008	192290.
0.0247	10600.	2.314	25.336	4.40	1.034	202890.
0.0279	10900.	2.571	25.856	4.40	1.061	213790.
0.0240	9280.	2.777	26.343	4.40	1.086	223070.
0.0338	12850.	3.140	27.105	4.40	1.123	235920.
0.0276	7570.	3.342	27.627	4.40	1.147	243490.
0.0247	7510.	3.627	28.207	4.40	1.173	251000.
0.0323	8110.	4.087	28.911	4.40	1.203	259110.
0.0272	7520.	4.610	29.652	4.40	1.234	266630.
0.0343	7350.	5.069	30.554	4.40	1.269	273980.
0.0340	5500.	5.632	31.307	4.40	1.298	279480.
0.0273	4530.	6.373	32.038	4.40	1.325	284010.
0.0230	4870.	7.350	32.930	4.40	1.356	288880.
0.0328	4000.	8.440	33.760	4.40	1.385	292880.
0.0335	3500.	9.623	34.732	4.40	1.415	296380.
0.0350	3500.	10.891	35.953	4.40	1.452	299880.
0.0291	2570.	11.920	36.944	4.40	1.481	302450.
0.0317	2650.	11.234	38.278	4.40	1.518	305100.
0.0272	2030.	2.800	38.188	4.40	1.515	307130.
0.0242	1560.	1.007	38.600	4.40	1.526	308690.
0.0289	81480.	1.003	24.344	2.60	1.590	390160.
0.0180	25870.	1.366	25.072	2.60	1.618	416030.
0.0265	15600.	1.721	25.719	2.60	1.641	431630.
0.0219	9680.	2.132	26.129	2.60	1.656	441310.
0.0206	11300.	2.607	26.935	2.60	1.683	452610.
0.0310	11320.	3.041	27.913	2.60	1.713	464130.
0.0260	7020.	3.395	28.645	2.60	1.735	471150.
0.0311	8370.	3.944	29.755	2.60	1.766	479520.
0.0230	6890.	4.390	30.028	2.60	1.774	486410.
0.0301	6330.	5.121	31.983	2.60	1.823	492740.
0.0287	3380.	5.602	32.691	2.60	1.839	496120.
0.0293	5880.	7.384	34.404	2.60	1.877	502000.
0.0200	2100.	5.960	35.385	2.60	1.896	504100.
0.0218	2540.	5.843	36.135	2.60	1.911	506640.
0.0231	2170.	5.265	36.614	2.60	1.920	508830.
0.0311	12100.	3.496	38.042	2.00	1.964	520930.
0.0229	9650.	3.465	31.406	2.00	1.993	530580.
0.0249	7100.	4.258	32.686	2.00	2.019	537680.
0.0332	6500.	5.216	34.178	2.00	2.047	544180.
0.0269	5000.	6.557	35.763	2.00	2.074	549180.
0.0293	5100.	8.967	37.974	2.00	2.110	554280.
0.0262	3100.	13.324	39.424	2.00	2.138	557380.

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FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 42E10

B=0.604 INCHES W=3.010 INCHES

TEMPERATURE -50 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0009	670.	4.245	23.953	4.30	0.900	39070.
0.0053	2780.	3.526	24.201	4.30	0.916	41850.
0.0065	3150.	2.083	24.268	4.30	0.920	45000.
0.0079	4000.	2.106	24.396	4.30	0.928	49000.
0.0119	5450.	2.246	24.586	4.30	0.940	54450.
0.0128	5650.	2.445	24.798	4.30	0.953	60100.
0.0141	5600.	2.646	25.044	4.30	0.967	65700.
0.0128	4810.	2.823	25.276	4.30	0.981	70510.
0.0240	7580.	3.091	25.689	4.30	1.003	78090.
0.0229	7410.	3.326	26.142	4.30	1.027	85500.
0.0231	6570.	3.517	26.586	4.30	1.050	92070.
0.0206	5940.	3.683	27.017	4.30	1.071	98010.
0.0198	5120.	3.882	27.423	4.30	1.090	103130.
0.0179	4610.	4.093	27.813	4.30	1.108	107740.
0.0095	2430.	4.229	28.032	4.30	1.118	110170.
0.0220	5000.	4.578	28.514	4.30	1.140	115170.
0.0191	4130.	4.980	28.962	4.30	1.159	119300.
0.0198	4000.	5.422	29.455	4.30	1.180	123300.
0.0191	3270.	5.752	29.981	4.30	1.198	126570.
0.0189	3160.	6.018	30.380	4.30	1.217	129730.
0.0217	3440.	6.237	30.941	4.30	1.239	133170.
0.0218	3380.	6.457	31.498	4.30	1.260	136550.
0.0240	3800.	6.687	32.167	4.30	1.284	140350.
0.0203	3230.	7.496	32.790	4.30	1.306	143580.
0.0211	2620.	8.127	33.361	4.30	1.326	146200.
0.0220	2580.	8.983	34.002	4.30	1.348	148780.
0.0226	2440.	10.468	34.682	4.30	1.370	151220.
0.0287	2960.	12.197	35.701	4.30	1.401	154120.
0.0215	1750.	13.557	36.427	4.30	1.423	155870.
0.0322	1780.	14.987	37.305	4.30	1.448	157650.
0.0152	1350.	13.813	38.144	4.30	1.472	159000.
0.0214	1220.	11.820	38.878	4.30	1.491	160220.
0.0224	1290.	9.281	39.226	4.30	1.500	161510.
0.0024	1330.	5.354	23.840	2.60	1.506	162840.
0.0055	3330.	2.809	24.146	2.60	1.518	166170.
0.0144	6810.	2.295	24.547	2.60	1.535	172980.
0.0211	8400.	2.668	25.070	2.60	1.555	181380.
0.0207	7240.	3.043	25.614	2.60	1.576	188620.
0.0207	6770.	3.427	26.207	2.60	1.597	195390.
0.0220	6110.	3.788	26.828	2.60	1.619	201500.
0.0211	5380.	4.205	27.452	2.60	1.640	206880.
0.0330	7500.	4.931	28.515	2.60	1.673	214380.
0.0230	4800.	5.502	29.337	2.60	1.698	219180.
0.0206	3330.	5.902	30.002	2.60	1.716	222510.
0.0225	3650.	6.489	30.832	2.60	1.739	226160.
0.0246	4060.	7.314	31.894	2.60	1.766	230220.
0.0229	3280.	7.863	32.910	2.60	1.790	233500.
0.0238	3000.	7.686	33.935	2.60	1.814	236500.
0.0181	1290.	7.992	34.414	2.60	1.824	237790.
0.0000	1290.	8.699	34.880	2.60	1.834	239080.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 42E 9

B=0.630 INCHES W=3.015 INCHES

TEMPERATURE -50 DEGREES F

QA	QN	QADN	QK	QC	A	N
0.0220	16000.	1.563	33.576	6.68	0.793	74230.
0.0338	21370.	1.552	38.030	7.40	0.837	95600.
0.0109	6510.	1.754	39.969	7.70	0.855	102110.
0.0600	11310.	1.809	40.470	7.70	0.876	113420.
0.0206	33460.	1.365	24.427	4.50	0.928	146900.
0.0222	22000.	1.495	24.834	4.50	0.953	168900.
0.0150	8370.	1.657	24.968	4.50	0.961	177270.
0.0221	10130.	2.114	25.305	4.50	0.980	187400.
0.0220	8460.	2.318	25.688	4.50	1.001	195860.
0.0231	10220.	2.479	26.147	4.50	1.026	206080.
0.0179	7500.	2.627	26.497	4.50	1.044	213580.
0.0280	10930.	2.915	27.081	4.50	1.073	224510.
0.0302	10000.	3.277	27.726	4.50	1.103	234510.
0.0309	8490.	3.681	28.370	4.50	1.132	243000.
0.0260	6930.	4.088	28.980	4.50	1.159	249930.
0.0280	7170.	4.661	29.703	4.50	1.189	257100.
0.0282	5720.	5.322	30.371	4.50	1.216	262820.
0.0209	3810.	6.093	30.894	4.50	1.236	266630.
0.0229	3650.	6.728	31.501	4.50	1.259	270280.
0.0220	3380.	7.309	32.145	4.50	1.283	273660.
0.0304	3400.	7.796	32.886	4.50	1.309	277060.
0.0216	2930.	8.367	33.575	4.50	1.333	279990.
0.0130	1620.	8.737	33.981	4.50	1.346	281610.
0.0311	3640.	9.518	34.957	4.50	1.378	285250.
0.0271	2570.	10.531	35.771	4.50	1.403	287820.
0.0300	2850.	12.109	36.836	4.50	1.435	290670.
0.0139	1120.	13.024	37.292	4.50	1.448	291790.
0.0277	2150.	12.131	38.602	4.50	1.484	293940.
0.0280	1750.	9.895	39.138	4.50	1.497	295690.
0.0319	1820.	6.100	39.439	4.50	1.506	297510.
0.0306	15370.	3.240	25.186	2.70	1.567	312880.
0.0209	7770.	2.684	25.703	2.70	1.587	320650.
0.0240	10120.	2.591	26.371	2.70	1.611	330670.
0.0238	9370.	2.789	27.105	2.70	1.636	339840.
0.0211	7240.	3.088	27.708	2.70	1.655	347080.
0.0209	6770.	3.482	28.380	2.70	1.677	353850.
0.0240	7500.	4.203	29.274	2.70	1.703	361350.
0.0330	7330.	5.627	30.452	2.70	1.736	368680.
0.0150	2580.	6.501	30.968	2.70	1.749	371260.
0.0240	3750.	7.725	31.974	2.70	1.775	375010.
0.0300	3400.	9.856	33.352	2.70	1.807	378410.
0.0211	2210.	6.607	33.947	2.70	1.822	380620.
0.0218	2200.	6.231	34.536	2.70	1.834	382820.
0.0280	9700.	5.128	27.222	2.00	1.878	392520.
0.0309	5330.	6.081	28.138	2.00	1.903	397820.
0.0231	4700.	7.651	29.462	2.00	1.933	402520.
0.0291	3000.	9.810	30.510	2.00	1.956	405520.
0.0269	3000.	12.662	31.924	2.00	1.986	408520.
0.0285	2500.	16.869	33.677	2.00	2.019	411020.

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FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 23E 3

B=0.702 INCHES W=2.995 INCHES

TEMPERATURE 70 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0571	10000.	11.086	32.325	7.10	0.800	12000.
0.0797	10000.	5.058	33.415	7.10	0.861	22000.
0.0324	3710.	4.565	33.767	7.10	0.879	25710.
0.0053	3000.	4.209	24.130	5.05	0.886	28710.
0.0201	12600.	1.721	24.557	5.05	0.914	41310.
0.0116	14500.	1.265	24.756	5.05	0.926	55810.
0.0160	15500.	1.581	25.090	5.05	0.947	71310.
0.0118	9000.	1.887	25.300	5.05	0.959	80310.
0.0423	18280.	2.967	26.049	5.05	1.000	98590.
0.0173	6000.	3.528	26.387	5.05	1.017	104590.
0.0227	6000.	4.130	26.833	5.05	1.040	110590.
0.0270	6000.	4.705	27.361	5.05	1.065	116590.
0.0288	6000.	5.371	28.017	5.05	1.096	122590.
0.0229	3700.	5.760	28.477	5.05	1.116	126290.
0.0218	4000.	6.226	29.025	5.05	1.140	130290.
0.0333	5000.	6.893	29.804	5.05	1.172	135290.
0.0274	4000.	7.592	30.501	5.05	1.200	139290.
0.0276	3520.	8.334	31.221	5.05	1.228	142810.
0.0279	3300.	9.060	31.976	5.05	1.256	146110.
0.0294	3000.	10.001	32.765	5.05	1.284	149110.
0.0271	2700.	10.903	33.573	5.05	1.312	151810.
0.0259	2400.	11.666	34.389	5.05	1.339	154210.
0.0283	2200.	12.911	35.215	5.05	1.365	156410.
0.0154	1200.	13.384	35.726	5.05	1.381	157610.
0.0143	1200.	14.811	36.338	5.06	1.397	158810.
0.0206	1200.	13.184	37.113	5.06	1.420	160010.
0.0155	1200.	6.093	37.072	5.05	1.421	161210.
0.0242	1200.	0.445	37.402	5.05	1.430	162410.
0.0002	7500.	0.094	22.050	2.95	1.440	169910.
0.0321	123590.	0.756	23.365	2.96	1.496	293500.
0.0406	30190.	0.953	23.791	2.94	1.521	323690.
0.0118	17300.	1.167	24.161	2.93	1.539	340990.
0.0117	16500.	1.509	24.676	2.93	1.560	357490.
0.0288	20000.	2.492	25.394	2.93	1.587	377490.
0.0271	10300.	3.476	26.107	2.93	1.612	387790.
0.0321	8500.	4.582	27.026	2.93	1.643	396290.
0.0403	8000.	5.924	28.265	2.93	1.682	404290.
0.0294	5000.	7.056	29.323	2.93	1.712	409290.
0.0379	5000.	8.632	30.814	2.94	1.750	414290.
0.0271	3000.	8.128	31.856	2.93	1.778	417290.
0.0293	3000.	7.734	33.112	2.93	1.807	420290.
0.0371	3000.	7.361	34.319	2.93	1.834	423290.
0.0210	5000.	4.972	26.887	2.20	1.864	428290.
0.0129	4500.	3.466	27.464	2.20	1.879	432790.
0.0092	3000.	3.230	27.694	2.20	1.885	435790.
0.0057	3000.	3.823	27.880	2.19	1.892	438790.
0.0117	3000.	4.831	28.446	2.20	1.903	441790.
0.0111	2250.	6.183	28.865	2.20	1.913	444040.
0.0206	3000.	6.455	29.759	2.20	1.933	447040.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 23E 5

B=0.705 INCHES W=3.005 INCHES

TEMPERATURE 0 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0132	11000.	3.033	23.963	5.05	0.888	36780.
0.0229	25000.	1.719	24.544	5.05	0.925	61780.
0.0203	17220.	2.049	24.846	5.05	0.944	79000.
0.0322	15000.	2.844	25.412	5.05	0.977	94000.
0.0338	11300.	3.418	26.013	5.05	1.009	105300.
0.0527	12800.	4.231	26.988	5.05	1.059	118100.
0.0724	15000.	5.339	28.505	5.05	1.129	133100.
0.0484	10000.	6.230	29.829	5.05	1.185	143100.
0.0639	10000.	7.366	31.478	5.05	1.249	153100.
0.0809	10000.	8.514	34.001	5.05	1.337	163100.
0.0462	5000.	5.647	35.007	5.05	1.370	168100.
0.0515	5000.	3.449	35.004	5.05	1.370	173100.
0.0127	30000.	1.195	21.436	2.93	1.428	203100.
0.0040	11910.	0.574	21.505	2.93	1.432	215010.
0.0113	42920.	0.248	21.737	2.93	1.443	257930.
0.0043	31500.	0.328	21.863	2.93	1.449	289430.
0.0142	27020.	0.558	22.072	2.93	1.459	316450.
0.0039	26450.	0.844	22.366	2.93	1.473	342900.
0.0184	21180.	1.502	22.775	2.93	1.492	364080.
0.0298	15000.	2.034	23.262	2.93	1.513	379080.
0.0155	13000.	2.442	23.948	2.93	1.542	392080.
0.0524	11380.	2.567	24.742	2.93	1.573	403460.
0.0209	10200.	1.871	25.479	2.93	1.600	413660.
0.0076	4380.	2.166	25.747	2.93	1.610	418040.

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FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 23E 4

B=0.787 INCHES W=2.988 INCHES

TEMPERATURE 0 DEGREES F

DA	DN	DADN	DK	DC	A	N
0.0233	2220.	4.091	33.487	7.10	0.873	29220.
0.0276	29250.	2.141	24.863	5.05	0.940	58470.
0.0353	21830.	2.507	25.327	5.04	0.969	80300.
0.0257	11480.	3.184	25.905	5.04	1.001	92180.
0.0436	11500.	4.141	26.633	5.04	1.038	103680.
0.0445	10000.	4.478	27.605	5.05	1.082	113680.
0.0277	5000.	5.112	28.191	5.05	1.108	118680.
0.0295	5000.	5.708	28.792	5.05	1.135	123680.
0.0218	5000.	6.445	29.448	5.05	1.162	128680.
0.0304	5000.	7.141	30.260	5.05	1.195	133680.
0.0432	5000.	7.961	31.236	5.05	1.233	138680.
0.0388	4000.	8.477	32.132	5.04	1.268	142680.
0.0194	3000.	9.159	32.938	5.05	1.294	145680.
0.0324	3500.	9.839	33.830	5.05	1.324	149180.
0.0368	4000.	11.385	35.034	5.05	1.363	153180.
0.0482	3850.	13.076	36.540	5.04	1.411	157030.
0.0314	2150.	10.346	37.785	5.04	1.446	159180.
0.0242	1540.	6.530	37.860	5.05	1.446	160720.
0.0230	1370.	2.485	38.231	5.05	1.456	162090.
0.0184	24500.	0.496	23.327	2.96	1.497	186590.
0.0040	19550.	0.579	23.637	2.96	1.510	206140.
0.0054	26810.	0.461	23.896	2.96	1.521	232950.
0.0169	25170.	0.653	24.028	2.96	1.526	258120.
0.0079	20000.	1.403	24.296	2.94	1.543	278120.
0.0112	11590.	1.714	24.783	2.96	1.556	289710.
0.0876	40000.	4.089	27.596	2.96	1.654	329710.
0.0597	10000.	5.985	29.050	2.96	1.697	339710.
0.0157	5000.	7.086	29.769	2.92	1.728	344710.
0.0421	4000.	8.418	30.877	2.92	1.757	348710.
0.0221	2000.	9.484	31.490	2.92	1.772	350710.
0.0197	2000.	9.537	32.564	2.92	1.798	352710.
0.0329	3000.	9.012	33.768	2.92	1.824	355710.
0.0278	2000.	8.607	34.541	2.92	1.841	357710.
0.0607	10000.	6.259	32.501	2.44	1.922	367710.
0.0336	3150.	11.284	33.770	2.44	1.947	370860.
0.0126	1000.	13.235	34.353	2.44	1.958	371860.
0.0140	1000.	14.821	35.071	2.44	1.972	372860.
0.0150	1000.	15.700	35.910	2.44	1.986	373860.
0.0168	1000.	17.195	36.852	2.44	2.003	374860.
0.0179	1000.	19.001	37.923	2.44	2.020	375860.
0.0189	1000.	21.085	39.178	2.44	2.040	376860.
0.0223	1000.	23.470	40.647	2.44	2.062	377860.
0.0249	1000.	26.948	42.333	2.44	2.086	378860.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 62E 1

B=0.725 INCHES W=3.000 INCHES

TEMPERATURE -50 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0043	11120.	3.008	23.962	5.23	0.873	49140.
0.0238	22270.	2.023	24.598	5.23	0.915	71410.
0.0301	18290.	2.102	24.934	5.23	0.936	89700.
0.0389	12340.	2.388	25.451	5.23	0.966	102040.
0.0215	8000.	2.430	25.856	5.23	0.988	110040.
0.0238	10000.	2.318	26.397	5.23	1.017	120040.
0.0217	10000.	1.991	26.824	5.23	1.038	130040.
0.0185	7850.	1.796	27.104	5.23	1.052	137890.
0.0143	12000.	1.633	27.450	5.23	1.069	149890.
0.0150	12030.	1.727	27.767	5.23	1.084	161890.
0.0200	15320.	2.436	28.344	5.23	1.110	177210.
0.0323	11020.	3.349	28.974	5.23	1.137	188230.
0.0340	10280.	4.495	29.870	5.23	1.175	198510.
0.0385	7500.	5.420	30.783	5.23	1.211	206010.
0.0284	4720.	5.758	31.472	5.23	1.237	210730.
0.0308	4820.	6.818	32.293	5.23	1.267	215550.
0.0150	2390.	7.352	32.709	5.23	1.282	217940.
0.0281	5000.	8.909	33.806	5.23	1.320	222940.
0.0486	4030.	11.043	34.934	5.23	1.357	226970.
0.0279	2720.	11.668	35.964	5.23	1.389	229690.
0.0231	1770.	13.901	36.735	5.23	1.412	231460.
0.0256	1780.	13.229	37.849	5.23	1.443	233240.
0.0225	2330.	4.729	38.089	5.23	1.450	235570.
0.0523	1680.	2.349	38.478	5.23	1.460	237250.
0.0244	40000.	1.481	23.796	3.03	1.526	277250.
0.0167	25000.	1.724	24.641	3.03	1.561	302250.
0.0412	20000.	2.362	25.609	3.03	1.597	322250.
0.0538	23960.	3.990	27.542	3.03	1.662	346210.
0.0377	8070.	5.542	28.750	3.03	1.698	354880.
0.0398	5000.	6.989	29.632	3.03	1.723	359880.
0.0340	5000.	8.062	31.013	3.03	1.760	364880.
0.0435	5000.	7.332	32.804	3.03	1.803	369880.
0.0177	2000.	6.332	33.501	3.03	1.819	371880.
0.0101	1000.	6.279	33.539	3.03	1.820	372880.
0.0085	3000.	4.094	28.487	2.53	1.832	375880.
0.0371	9250.	8.387	30.450	2.53	1.880	385130.
0.0854	7600.	13.710	34.410	2.53	1.961	392730.
0.0242	2000.	15.949	36.012	2.53	1.991	394730.
0.0425	2000.	18.050	38.018	2.53	2.024	396730.

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FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 23E 6

B=0.705 INCHES W=3.004 INCHES

TEMPERATURE 0 DEGREES F

DA	DN	DADN	DK	DR	A	N
0.0736	10260.	2.866	32.804	7.09	0.844	30760.
0.0102	18800.	2.109	23.903	5.05	0.883	49560.
0.0116	18000.	1.725	24.249	5.05	0.906	67560.
0.0397	20100.	1.902	24.725	5.07	0.930	87660.
0.0302	18660.	2.404	25.420	5.07	0.971	106320.
0.0407	12870.	2.864	26.054	5.07	1.005	119190.
0.0332	10000.	3.802	26.517	5.05	1.035	129190.
0.0186	9000.	4.717	27.305	5.06	1.071	138190.
0.0291	5000.	5.327	27.764	5.06	1.092	143190.
0.0445	5000.	6.003	28.377	5.06	1.120	148190.
0.0226	5000.	6.838	29.155	5.05	1.156	153190.
0.0317	5000.	7.200	29.977	5.05	1.190	158190.
0.0405	5000.	7.799	30.901	5.06	1.224	163190.
0.0399	5000.	8.654	32.035	5.06	1.266	168190.
0.0223	2500.	9.127	32.659	5.06	1.289	170690.
0.0225	2500.	9.718	33.243	5.05	1.311	173190.
0.0248	2500.	10.466	33.970	5.05	1.336	175690.
0.0267	2500.	11.436	34.792	5.05	1.363	178190.
0.0294	2500.	11.119	35.910	5.05	1.397	180690.
0.0335	2580.	4.416	36.099	5.05	1.403	183270.
0.0183	1200.	2.238	36.366	5.05	1.411	184470.
0.0371	58210.	0.522	22.779	2.96	1.481	242680.
0.0045	20000.	0.322	22.866	2.96	1.485	262680.
0.0009	19230.	0.300	22.960	2.96	1.488	281880.
0.0005	18810.	0.311	22.952	2.96	1.488	300690.
0.0090	20300.	0.487	23.087	2.96	1.494	320690.
0.0124	20000.	0.853	23.290	2.96	1.503	340690.
0.0147	20000.	1.341	23.732	2.96	1.522	360690.
0.0240	20000.	2.046	24.403	2.96	1.549	380690.
0.0636	26000.	3.411	26.137	2.96	1.614	406690.
0.0365	10000.	4.082	27.171	2.96	1.649	416690.
0.0487	10000.	4.766	28.306	2.90	1.693	426690.
0.0109	1680.	5.066	28.583	2.93	1.701	428370.
0.0387	8960.	6.228	30.535	2.95	1.749	437330.
0.0252	4000.	7.667	31.350	2.95	1.770	441330.
0.0337	4000.	9.675	32.753	2.95	1.804	445330.
0.0282	3000.	9.302	33.030	2.85	1.836	448330.
0.0255	2000.	9.046	34.353	2.87	1.859	450330.
0.0298	2000.	9.285	35.343	2.87	1.879	452330.
0.0348	5300.	7.104	31.791	2.44	1.918	457630.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 44E 6

B=0.896 INCHES W=2.998 INCHES

TEMPERATURE 70 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0551	5000.	5.331	34.904	6.00	0.939	28020.
0.0148	8300.	4.284	25.376	4.30	0.960	36320.
0.0308	20000.	2.304	26.215	4.30	1.006	56320.
0.0264	20000.	2.846	26.919	4.30	1.042	76320.
0.0820	24600.	4.893	28.906	4.31	1.130	100920.
0.0221	3600.	5.947	29.190	4.31	1.142	104520.
0.0446	10000.	7.839	30.584	4.28	1.207	114520.
0.0408	5000.	9.087	31.758	4.30	1.246	119520.
0.0474	5000.	10.750	33.101	4.30	1.294	124520.
0.0406	3600.	12.290	34.249	4.30	1.333	128120.
0.0478	4000.	11.004	35.879	4.27	1.392	132120.
0.0500	3150.	10.790	36.975	4.25	1.429	135270.
0.0561	3300.	5.570	37.302	4.25	1.439	138570.
0.0093	6100.	3.013	22.571	2.50	1.468	144670.
0.0144	30000.	0.926	23.500	2.51	1.505	174670.
0.0187	31000.	0.593	23.840	2.50	1.523	205670.
0.0081	12000.	0.675	23.506	2.49	1.513	217670.
0.1248	158550.	4.035	30.004	2.50	1.729	376220.
0.1157	20000.	7.500	32.879	2.49	1.804	396220.
0.1221	10000.	8.618	36.830	2.50	1.882	406220.
0.0442	7250.	9.921	32.461	2.00	1.948	413470.
0.0183	2000.	7.830	33.654	2.00	1.971	415470.
0.0115	1000.	12.109	33.923	2.00	1.976	416470.
0.0147	1000.	13.245	34.585	2.00	1.988	417470.
0.0137	1000.	14.811	35.370	2.00	2.002	418470.
0.0129	1000.	16.950	36.237	2.00	2.017	419470.
0.0173	1000.	19.684	37.273	2.00	2.034	420470.
0.0114	500.	20.098	37.496	2.00	2.044	420970.
0.0126	500.	20.474	38.607	2.00	2.056	421470.
0.0098	500.	20.971	39.327	2.00	2.067	421970.
0.0085	500.	20.086	37.591	1.88	2.077	422470.
0.0210	1000.	19.417	38.189	1.85	2.095	423470.
0.0180	1000.	******	58.047	1.80	2.338	424470.

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FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 44E 4

B=0.597 INCHES W=2.993 INCHES

TEMPERATURE 70 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0281	5000.	5.685	32.020	6.00	0.792	11000.
0.0344	5700.	7.282	32.495	6.00	0.821	16000.
0.0074	1470.	5.712	32.857	6.00	0.841	17470.
0.0433	5000.	5.703	33.335	6.00	0.867	22470.
0.0415	4500.	4.093	33.703	6.00	0.885	26970.
0.0177	15000.	2.292	24.739	4.30	0.922	41970.
0.0421	31000.	1.389	25.580	4.30	0.971	72970.
0.0158	20000.	1.467	25.879	4.30	0.988	92970.
0.0350	30000.	2.311	26.811	4.30	1.036	122970.
0.0245	11350.	2.996	27.156	4.30	1.053	134320.
0.0641	20000.	4.444	28.063	4.30	1.122	154320.
0.0648	12600.	5.763	30.152	4.31	1.181	166920.
0.0499	8000.	6.775	31.496	4.32	1.230	174920.
0.0335	5000.	7.811	32.146	4.28	1.265	179920.
0.0356	4650.	8.942	33.309	4.30	1.300	184570.
0.0442	5300.	10.937	34.796	4.32	1.344	189570.
0.0574	5000.	10.587	37.095	4.31	1.417	194570.
0.0470	3500.	3.832	37.027	4.31	1.415	198070.
0.0004	3100.	2.646	37.708	4.31	1.434	201170.
0.0536	130000.	0.722	24.633	2.50	1.553	331170.
0.0110	40000.	0.977	25.296	2.50	1.578	371170.
0.0090	20000.	1.533	25.644	2.50	1.594	391170.
0.0517	40000.	2.959	27.380	2.50	1.650	431170.
0.0549	20000.	4.607	29.191	2.50	1.704	451170.
0.1131	20000.	5.776	33.292	2.51	1.805	471170.
0.0521	5000.	5.699	34.940	2.52	1.837	476170.
0.0506	8100.	6.288	36.419	2.03	1.892	484270.
0.0163	8000.	7.918	32.535	2.03	1.937	492270.
0.0486	6000.	3.681	33.732	1.97	1.979	498270.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 23E 1

B=0.735 INCHES W=2.997 INCHES

TEMPERATURE 70 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0810	10000.	9.398	33.319	7.37	0.872	25800.
0.0148	10000.	3.164	24.312	5.29	0.899	35800.
0.0292	30000.	1.842	25.187	5.29	0.952	65800.
0.0183	13800.	1.991	25.367	5.29	0.963	79600.
0.0460	22040.	3.000	26.319	5.29	1.014	101640.
0.0331	10750.	3.894	26.934	5.29	1.045	112390.
0.0463	10000.	4.939	27.628	5.29	1.088	122390.
0.0257	5000.	5.608	28.377	5.29	1.112	127390.
0.0210	4110.	6.176	28.922	5.29	1.136	131500.
0.0469	7000.	7.258	29.935	5.28	1.181	138500.
0.0466	6100.	8.678	31.130	5.28	1.227	144600.
0.0431	5000.	10.141	32.383	5.28	1.274	149600.
0.0369	3400.	11.577	33.380	5.28	1.308	153000.
0.0379	3140.	13.171	34.503	5.28	1.346	156140.
0.0392	3000.	14.852	35.890	5.29	1.387	159140.
0.0332	2000.	16.369	36.859	5.28	1.418	161140.
0.0219	1300.	17.454	37.550	5.27	1.439	162440.
0.0160	1000.	12.675	38.199	5.27	1.457	163440.
0.0070	300.	4.980	38.135	5.29	1.452	163740.
0.0048	300.	1.592	38.421	5.29	1.459	164040.
0.0143	9050.	0.907	22.686	3.08	1.474	173090.
0.0219	36650.	0.556	23.098	3.06	1.499	209740.
0.0139	35740.	0.421	23.521	3.08	1.510	245480.
0.0092	100000.	0.767	24.576	3.08	1.553	345480.
0.0388	17040.	1.264	24.543	3.05	1.561	362520.
0.0182	18000.	2.090	25.407	3.08	1.585	380520.
0.0323	20870.	3.117	26.578	3.08	1.626	401390.
0.0291	10010.	3.986	27.346	3.08	1.651	411400.
0.0939	20000.	5.814	30.717	3.09	1.745	431400.
0.0442	5000.	5.126	31.830	3.08	1.776	436400.
0.0112	1000.	4.586	32.176	3.08	1.784	437400.
0.0231	7000.	3.747	27.934	2.46	1.822	444400.
0.0126	4000.	3.443	27.310	2.46	1.838	448400.
0.0068	3000.	3.679	27.665	2.46	1.839	451400.
0.0091	3000.	4.316	27.995	2.46	1.847	454400.
0.0202	4150.	5.207	28.718	2.46	1.864	458550.
0.0162	3000.	6.140	29.439	2.45	1.886	461550.
0.0280	3000.	9.670	30.504	2.44	1.913	464550.
0.0258	2000.	11.188	31.357	2.43	1.934	466550.
0.0231	2000.	13.042	32.941	2.46	1.958	468550.
0.0178	1750.	14.855	33.709	2.43	1.981	470300.
0.0313	2000.	68.297	36.413	2.49	2.014	472300.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 23E 2

B=0.724 INCHES W=3.000 INCHES

TEMPERATURE 70 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0159	18870.	2.503	24.735	5.20	0.930	46370.
0.0303	17000.	1.625	25.077	5.20	0.951	63370.
0.0046	8100.	1.225	25.010	5.20	0.947	71470.
0.0084	17000.	1.535	25.335	5.20	0.966	88470.
0.0292	20000.	2.499	25.654	5.20	0.995	108470.
0.0359	10000.	3.232	26.380	5.20	1.022	118470.
0.0260	8000.	3.814	26.939	5.20	1.050	126470.
0.0229	6000.	4.222	27.472	5.20	1.075	132470.
0.0270	6000.	4.447	28.016	5.20	1.101	138470.
0.0189	4000.	5.495	28.484	5.20	1.120	142470.
0.0219	4000.	5.817	28.991	5.20	1.143	146470.
0.0262	4000.	6.243	29.582	5.20	1.168	150470.
0.0307	4000.	6.685	30.226	5.20	1.194	154470.
0.0200	4000.	7.272	30.919	5.20	1.221	158470.
0.0232	3000.	7.877	31.473	5.20	1.242	161470.
0.0315	4000.	9.149	32.278	5.19	1.274	165470.
0.0249	2400.	10.050	32.944	5.19	1.298	167870.
0.0229	2250.	10.997	33.686	5.20	1.321	170120.
0.0304	2650.	12.167	34.355	5.16	1.352	172770.
0.0240	2000.	12.858	35.411	5.20	1.376	174770.
0.0321	2250.	14.312	36.409	5.20	1.407	177020.
0.0196	1100.	15.391	36.663	5.16	1.422	178120.
0.0174	1350.	12.757	37.836	5.20	1.447	179470.
0.0208	1030.	4.884	37.771	5.20	1.446	180470.
0.0184	1000.	1.328	38.145	5.20	1.456	181470.
0.0036	10300.	0.328	22.469	3.03	1.468	191470.
0.0409	140000.	0.696	23.854	3.03	1.528	331470.
0.0188	20000.	0.823	23.965	3.00	1.542	351470.
0.0135	14750.	0.934	24.242	3.00	1.554	366220.
0.0145	18150.	1.135	24.972	3.03	1.572	384370.
0.0122	11150.	1.286	25.239	3.03	1.582	395520.
0.0327	25750.	2.235	26.286	3.03	1.619	421270.
0.0299	12600.	3.308	27.114	3.03	1.647	433870.
0.0267	9700.	4.450	28.226	3.03	1.682	443570.
0.0481	9200.	6.425	29.717	3.03	1.725	452770.
0.0353	5000.	8.139	30.949	3.03	1.757	457770.
0.0253	3600.	9.421	31.946	3.03	1.783	460770.
0.0312	3000.	11.231	33.272	3.03	1.813	463770.
0.0095	1000.	13.686	33.907	3.04	1.824	464770.
0.0147	1000.	16.209	34.314	3.02	1.838	465770.
0.0131	1000.	13.177	35.453	3.04	1.856	466770.
0.0176	500.	13.223	35.252	3.00	1.862	467270.
0.0041	500.	10.583	35.704	3.02	1.866	467770.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 42E 6

B=0.605 INCHES W=3.010 INCHES

TEMPERATURE 0 DEGREES F

DA	DN	DA/DN	DK	DP	A	N
0.0054	18560.	0.319	24.836	4.30	0.958	63580.
0.0080	35790.	0.226	25.002	4.30	0.967	99370.
0.0084	31300.	0.224	25.089	4.30	0.972	130670.
0.0023	17260.	0.250	25.148	4.30	0.976	147930.
0.0000	17260.	0.266	25.202	4.30	0.979	165190.
0.0149	45250.	0.524	25.420	4.30	0.991	210440.
0.0097	15260.	0.777	25.582	4.30	0.998	225700.
0.0143	29280.	1.280	26.047	4.30	1.027	254980.
0.0273	15900.	1.907	26.465	4.30	1.046	270880.
0.0215	5640.	1.984	26.679	4.30	1.057	276520.
0.0212	13790.	2.506	27.362	4.30	1.090	290310.
0.0326	9860.	2.776	27.903	4.30	1.115	300170.
0.0181	9630.	3.195	28.503	4.30	1.141	309800.
0.0348	7860.	3.212	29.182	4.30	1.170	317660.
0.0329	10330.	4.094	29.994	4.30	1.204	327990.
0.0301	5660.	5.075	30.601	4.30	1.228	333650.
0.0015	5660.	6.472	31.324	4.30	1.255	339310.
0.0363	4220.	7.907	32.021	4.30	1.281	343530.
0.0269	3680.	9.516	32.862	4.30	1.311	347210.
0.0291	3180.	9.798	33.988	4.30	1.349	350390.
0.0271	2630.	10.723	34.700	4.30	1.372	353020.
0.0110	840.	10.314	35.031	4.30	1.383	353860.
0.0300	2960.	12.955	36.033	4.30	1.413	356820.
0.0240	1600.	16.700	36.668	4.30	1.432	358420.
0.0007	1160.	23.190	37.464	4.30	1.455	359580.
0.0468	1290.	21.756	38.597	4.30	1.486	360870.
0.0260	360.	22.383	39.080	4.30	1.498	361230.
0.0260	1150.	9.192	39.348	4.30	1.505	362380.
0.0000	1150.	2.777	40.067	4.30	1.523	363530.
0.0386	10310.	1.601	47.913	5.00	1.551	373840.
0.0193	35710.	1.159	26.980	2.70	1.591	409550.
0.0290	34090.	1.338	27.194	2.60	1.633	443640.
0.0248	13000.	1.784	27.687	2.60	1.649	456640.
0.0304	9660.	2.532	28.261	2.60	1.667	466300.

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FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 42E S

B=0.603 INCHES W=3.004 INCHES

TEMPERATURE 70 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0116	26260.	2.512	24.812	4.30	0.948	45930.
0.0177	12130.	1.515	24.960	4.30	0.957	58060.
0.0204	8400.	0.947	25.042	4.30	0.964	66460.
0.0201	24580.	0.921	25.571	4.30	0.991	91040.
0.0106	17810.	0.752	25.771	4.30	1.002	108850.
0.0187	24210.	0.735	26.038	4.30	1.016	133060.
0.0037	14530.	0.873	26.195	4.30	1.024	147590.
0.0188	17200.	1.207	26.479	4.30	1.039	164790.
0.0194	18300.	1.781	26.924	4.30	1.061	183090.
0.0249	13410.	2.476	27.447	4.30	1.087	196500.
0.0327	11940.	3.308	28.131	4.30	1.117	208440.
0.0324	9780.	4.110	28.912	4.30	1.151	218220.
0.0460	10260.	5.206	30.018	4.30	1.197	228480.
0.0419	7140.	6.198	31.011	4.30	1.236	235620.
0.0350	6080.	7.475	32.091	4.30	1.276	241700.
0.0379	4710.	8.878	33.113	4.30	1.312	246410.
0.0218	2470.	9.928	33.732	4.30	1.333	248880.
0.0341	3010.	11.139	34.701	4.30	1.365	251890.
0.0430	3950.	12.518	36.236	4.30	1.412	255840.
0.0339	2220.	13.121	37.235	4.30	1.441	258060.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 42E 7

B=0.637 INCHES W=3.012 INCHES

TEMPERATURE 0 DEGREES F

QA	QN	QADN	QK	QP	A	N
0.0278	4920.	3.699	28.621	5.50	0.876	26990.
0.0050	17520.	1.344	24.985	4.70	0.911	44510.
0.0045	24020.	0.362	25.135	4.70	0.920	68530.
0.0042	27570.	0.206	25.193	4.70	0.924	96100.
0.0027	17610.	0.226	25.244	4.70	0.927	113710.
0.0048	24030.	0.299	25.323	4.70	0.932	137740.
0.0089	23560.	0.435	25.412	4.70	0.937	161300.
0.0054	27190.	0.696	25.629	4.70	0.950	188490.
0.0228	32320.	1.154	26.088	4.70	0.976	220810.
0.0490	28160.	1.844	26.792	4.70	1.013	248990.
0.0292	15770.	2.376	27.412	4.70	1.044	264760.
0.0249	10000.	2.931	27.923	4.70	1.069	274760.
0.0367	10700.	3.812	28.647	4.70	1.102	285460.
0.0084	2960.	4.188	28.879	4.70	1.112	288420.
0.0309	7040.	5.053	29.633	4.70	1.143	295460.
0.0421	5810.	5.901	30.331	4.70	1.173	301270.
0.0319	5170.	6.462	31.166	4.70	1.206	306440.
0.0331	4530.	7.854	32.026	4.70	1.238	310970.
0.0387	3920.	8.872	32.901	4.70	1.270	314890.
0.0331	3630.	10.345	33.864	4.70	1.304	318520.
0.0231	2050.	11.057	34.500	4.70	1.325	320570.
0.0309	2870.	11.994	35.553	4.70	1.359	323440.
0.0330	2200.	12.705	36.462	4.70	1.387	325640.
0.0260	2200.	13.366	37.427	4.70	1.415	327840.
0.0330	2530.	14.325	38.663	4.70	1.450	330370.
0.0350	2410.	15.859	39.941	4.70	1.484	332780.
0.0300	1870.	17.437	41.164	4.70	1.514	334650.
0.0222	1220.	18.300	42.366	4.70	1.543	335870.
0.0324	1630.	12.080	43.013	4.70	1.558	337500.
0.0297	1470.	8.669	43.614	4.70	1.571	338970.
0.0346	9880.	6.065	29.829	3.00	1.635	348850.
0.0513	9270.	6.984	31.592	3.00	1.686	358120.
0.0316	4570.	8.485	32.823	3.00	1.718	362690.
0.0283	3290.	9.995	33.965	3.00	1.746	365980.
0.0400	3790.	11.718	35.680	3.00	1.785	369770.
0.0344	2690.	13.014	37.267	3.00	1.818	372460.
0.0442	3140.	14.383	39.581	3.00	1.862	375600.
0.0311	2130.	15.171	41.643	3.00	1.898	377730.
0.0291	1870.	15.027	43.196	3.00	1.923	379600.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 41E 2

B=0.610 INCHES W=3.009 INCHES

TEMPERATURE 0 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0132	7460.	3.943	24.525	4.30	0.951	30790.
0.0403	31260.	2.315	25.764	4.30	1.020	62050.
0.0423	21440.	3.396	26.709	4.30	1.068	83490.
0.0492	12400.	4.797	27.768	4.30	1.118	95890.
0.0247	5210.	6.642	28.299	4.30	1.142	101100.
0.0335	4050.	7.991	28.904	4.30	1.168	105150.
0.0318	3020.	8.781	29.509	4.30	1.193	108170.
0.0215	3000.	9.867	30.226	4.30	1.222	111170.
0.0309	3060.	10.748	31.001	4.30	1.252	114230.
0.0401	3660.	12.343	32.089	4.30	1.292	117890.
0.0282	1940.	13.219	32.810	4.30	1.318	119830.
0.0249	1930.	13.789	33.592	4.30	1.344	121760.
0.0250	1740.	14.592	34.356	4.30	1.369	123500.
0.0333	2180.	15.343	35.364	4.30	1.401	125680.
0.0323	2260.	16.099	36.547	4.30	1.437	127940.
0.0294	1610.	16.997	37.519	4.30	1.464	129550.
0.0263	1490.	21.075	38.572	4.30	1.493	131040.
0.0301	1250.	20.280	39.830	4.30	1.525	132290.
0.0298	1240.	4.273	39.781	4.30	1.524	133530.
0.0225	900.	2.402	40.295	4.30	1.536	134430.
0.0469	39420.	2.196	26.513	2.60	1.617	173850.
0.0434	21420.	2.650	28.080	2.60	1.668	195270.
0.0306	10300.	2.901	28.975	2.60	1.695	205270.
0.0415	10300.	3.404	30.149	2.60	1.728	215770.
0.0243	10000.	2.959	31.699	2.60	1.768	225770.
0.0248	7030.	2.823	32.534	2.60	1.788	232770.
0.0291	4000.	2.495	32.851	2.60	1.796	236770.
0.0313	25130.	1.964	26.992	2.00	1.845	261900.
0.0313	20010.	2.094	28.305	2.00	1.879	281910.
0.0315	15130.	2.684	29.648	2.00	1.911	297040.
0.0324	12000.	3.391	31.220	2.00	1.946	309040.
0.0274	8000.	32.407	27.533	2.00	1.850	317040.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 41E 4

B=0.610 INCHES W=3.012 INCHES

TEMPERATURE 0 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0154	21470.	2.104	25.077	4.30	0.985	52410.
0.0172	20580.	1.654	25.089	4.30	0.985	72990.
0.0154	11180.	2.374	25.389	4.30	1.002	84170.
0.0280	12720.	3.486	25.952	4.30	1.032	96890.
0.0475	12870.	5.173	26.922	4.30	1.080	109760.
0.0495	7670.	6.646	27.846	4.30	1.123	117430.
0.0257	3310.	7.322	28.350	4.30	1.146	120740.
0.0027	1000.	7.408	28.545	4.30	1.154	121740.
0.0257	3180.	7.827	29.099	4.30	1.178	124920.
0.0345	4130.	8.452	29.906	4.30	1.211	129050.
0.0224	2720.	9.418	30.531	4.30	1.236	131770.
0.0219	2200.	10.034	31.061	4.30	1.256	133970.
0.0473	4530.	11.535	32.376	4.30	1.304	138500.
0.0226	1910.	12.416	33.019	4.30	1.327	140410.
0.0389	2920.	14.351	34.143	4.30	1.364	143330.
0.0404	3000.	16.485	35.528	4.30	1.408	146330.
0.0273	1570.	17.702	36.413	4.30	1.435	147900.
0.0278	1400.	19.135	37.292	4.30	1.460	149300.
0.0260	1250.	19.122	38.386	4.30	1.490	150550.
0.0284	1530.	5.702	38.570	4.30	1.495	152080.
0.0306	1260.	2.963	39.036	4.30	1.507	153340.
0.0263	32120.	1.460	25.175	2.60	1.570	185460.
0.0174	16990.	1.439	25.681	2.60	1.589	202450.
0.0174	13400.	1.639	26.169	2.60	1.607	215910.
0.0238	17060.	2.808	27.025	2.60	1.636	232970.
0.0430	15930.	4.694	28.616	2.60	1.686	248900.
0.0496	8930.	6.964	30.279	2.60	1.733	257830.
0.0322	3100.	8.362	31.027	2.60	1.753	260930.
0.0196	2200.	8.728	31.790	2.60	1.772	263130.
0.0222	2100.	9.184	32.672	2.60	1.794	265230.
0.0093	2100.	9.528	33.435	2.60	1.811	267330.
0.0246	2100.	10.418	34.323	2.60	1.831	269430.

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FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 42E 4

B=0.404 INCHES W=2.999 INCHES

TEMPERATURE 70 DEGREES F

QA	QN	QADb	QK	QE	A	N
0.0284	3500.	3.997	33.957	6.02	0.913	29500.
0.0140	7100.	3.510	24.531	4.31	0.927	36600.
0.0148	13800.	1.333	24.952	4.32	0.949	50400.
0.0086	6700.	0.659	24.940	4.32	0.948	57100.
0.0385	47750.	2.132	25.662	4.28	1.002	104850.
0.0591	27350.	3.605	27.153	4.30	1.071	132200.
0.0871	20000.	5.041	29.061	4.30	1.157	152200.
0.0446	7400.	6.592	30.047	4.31	1.194	159600.
0.0304	5000.	7.769	30.962	4.32	1.227	164600.
0.0410	5000.	8.969	31.830	4.30	1.265	169600.
0.0476	5000.	10.457	33.150	4.30	1.312	174600.
0.0447	4000.	12.048	34.415	4.29	1.357	178600.
0.0443	3600.	11.214	36.218	4.31	1.407	182200.
0.0405	3000.	2.401	35.951	4.30	1.402	185200.
0.0207	1000.	0.482	36.408	4.30	1.415	186200.
0.0409	147000.	1.099	23.001	2.48	1.510	333200.
0.0476	28040.	1.597	23.860	2.49	1.542	361240.
0.0224	23100.	2.083	25.058	2.50	1.585	384340.
0.0282	15000.	2.943	25.773	2.50	1.611	399340.
0.0641	20000.	4.828	27.686	2.50	1.674	419340.
0.0329	6300.	5.993	28.603	2.50	1.702	425640.
0.0639	10000.	5.978	30.887	2.50	1.764	435640.
0.0412	4000.	5.290	32.109	2.49	1.796	439640.
0.0082	1000.	5.796	32.179	2.49	1.798	440640.
0.0347	10000.	5.265	27.426	2.03	1.842	450640.
0.0210	8000.	7.238	29.397	2.03	1.880	458640.
0.0654	6000.	9.780	30.538	1.96	1.930	464640.
0.0295	3100.	12.016	31.287	1.92	1.960	467740.
0.0343	3000.	13.617	32.513	1.87	2.001	470740.
0.0294	2000.	15.615	34.408	1.90	2.026	472740.
0.0298	1800.	17.833	35.735	1.88	2.055	474540.
0.0299	1650.	******	33.364	1.87	2.017	476190.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 42E 2

B=0.630 INCHES W=3.009 INCHES

TEMPERATURE 70 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.4292	2000.	35.927	29.823	6.30	0.534	4600.
0.0028	1100.	18.870	29.845	6.30	0.563	5700.
0.1592	21500.	7.745	32.254	6.30	0.826	27200.
0.0271	19100.	2.923	24.254	4.50	0.914	46300.
0.0219	32250.	2.143	25.432	4.51	0.981	78550.
0.0514	32550.	2.793	26.135	4.51	1.019	111100.
0.0645	20000.	3.987	27.353	4.51	1.079	131100.
0.0484	10000.	4.992	28.178	4.50	1.120	141100.
0.0442	8000.	5.805	29.137	4.50	1.162	149100.
0.0293	6000.	6.560	30.004	4.50	1.197	155100.
0.0444	6000.	7.517	31.001	4.50	1.237	161100.
0.0448	6000.	8.969	32.223	4.50	1.282	167100.
0.0543	6000.	8.700	34.337	4.50	1.354	173100.
0.0564	5000.	7.492	34.904	4.44	1.387	178100.
0.0585	4000.	2.656	35.205	4.50	1.[illegible]82	182100.
0.0353	110970.	0.531	22.995	2.62	1.503	293070.
0.0238	11600.	0.541	22.847	2.60	1.504	304670.
0.0100	25000.	0.473	23.104	2.60	1.516	329670.
0.0033	12610.	0.498	23.302	2.60	1.524	342280.
0.0050	17000.	0.416	23.481	2.61	1.528	359280.
0.0063	17150.	0.473	23.505	2.61	1.529	376430.
0.0154	34500.	1.211	24.031	2.61	1.551	410930.
0.0319	27500.	2.300	25.029	2.61	1.590	438430.
0.0545	20610.	3.690	26.694	2.62	1.645	459040.
0.0457	12500.	5.268	28.064	2.61	1.692	471540.
0.0556	10000.	6.699	30.282	2.64	1.745	481540.
0.0415	8030.	6.781	32.139	2.61	1.801	489540.
0.0480	4500.	6.579	33.745	2.61	1.837	494040.
0.0226	3750.	6.825	28.230	2.10	1.865	497790.
0.0312	7300.	7.093	30.603	2.14	1.908	505090.
0.0297	4500.	9.221	31.771	2.14	1.934	509590.
0.0345	3750.	12.098	33.076	2.16	1.970	513340.
0.0407	3220.	15.546	34.723	2.08	2.009	516560.
0.0588	3490.	20.901	38.712	2.10	2.070	520050.
0.0265	1000.	******	30.826	2.10	1.926	521050.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 41E 1

B=0.615 INCHES W=3.000 INCHES

TEMPERATURE 0 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0181	24740.	1.671	24.864	4.30	0.977	54270.
0.0273	32390.	1.440	25.251	4.30	0.999	86660.
0.0092	12030.	2.043	25.626	4.31	1.016	98690.
0.0339	14940.	3.206	26.261	4.31	1.049	113630.
0.0293	8510.	4.439	26.743	4.31	1.072	122140.
0.0332	6420.	5.391	27.383	4.31	1.103	128560.
0.0475	8910.	7.044	28.565	4.31	1.155	137470.
0.0412	4660.	8.072	29.305	4.30	1.189	142130.
0.0419	5610.	9.593	30.504	4.30	1.237	147740.
0.0419	3770.	10.462	31.521	4.30	1.276	151510.
0.0419	4020.	11.246	32.739	4.30	1.319	155530.
0.0469	3520.	12.029	34.016	4.30	1.362	159050.
0.0289	2700.	11.863	35.065	4.30	1.395	161750.
0.0328	2700.	12.203	36.162	4.3[illegible]	1.428	164450.
0.0328	2250.	13.165	37.087	4.30	1.455	166700.
0.0150	2000.	11.280	38.167	4.30	1.484	168700.
0.0269	1500.	5.126	38.156	4.30	1.484	170200.
0.0139	500.	2.915	38.512	4.30	1.493	170700.
0.0467	21630.	1.524	24.285	2.60	1.535	192330.
0.0473	53420.	2.009	26.387	2.60	1.614	245750.
0.0387	21130.	2.708	27.771	2.60	1.659	266880.
0.0600	20060.	3.969	29.836	2.60	1.720	286940.
0.0569	13830.	6.616	32.458	2.60	1.786	300770.
0.0301	3010.	9.456	33.439	2.60	1.809	303780.
0.0295	2510.	6.396	34.352	2.60	1.829	306290.
0.0404	1900.	9.819	35.631	2.60	1.855	308190.
0.0130	900.	8.628	35.837	2.60	1.859	309090.
0.0246	11090.	5.972	29.461	2.00	1.905	320180.
0.0177	4350.	11.265	30.516	2.03	1.929	324530.
0.0225	2000.	74.208	27.562	2.00	1.959	326530.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 41E 5

B=0.610 INCHES W=3.011 INCHES

TEMPERATURE -50 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0264	20430.	1.094	25.255	4.30	0.994	90350.
0.0158	18140.	1.345	25.664	4.30	1.016	104490.
0.0227	15220.	1.530	26.143	4.30	1.041	123710.
0.0455	21540.	1.642	27.047	4.33	1.077	145250.
0.0159	11300.	1.765	27.295	4.30	1.098	156550.
0.0184	12870.	1.946	27.770	4.30	1.119	169420.
0.0284	18420.	2.572	28.370	4.30	1.146	185840.
0.0278	11070.	3.507	29.030	4.30	1.175	196910.
0.0308	9000.	4.446	29.807	4.30	1.207	205910.
0.0583	12000.	6.126	31.314	4.30	1.266	217910.
0.0662	9680.	8.108	33.086	4.29	1.331	227590.
0.0269	3000.	9.070	33.900	4.30	1.356	230590.
0.0273	3000.	10.165	34.752	4.30	1.383	233590.
0.0322	3060.	11.337	35.776	4.30	1.415	236650.
0.0319	2780.	12.758	36.878	4.30	1.447	239430.
0.0400	3000.	14.875	38.342	4.30	1.488	242430.
0.0266	1750.	16.517	39.302	4.30	1.514	244180.
0.0177	1000.	17.723	40.028	4.30	1.531	245180.
0.0188	1000.	17.222	40.882	4.30	1.552	246188.
0.0180	1000.	2.550	40.443	4.30	1.552	247180.
0.0215	1000.	1.004	41.244	4.30	1.580	248180.
0.0323	47250.	1.866	27.667	2.70	1.622	295430.
0.0320	15530.	2.296	28.672	2.70	1.654	310960.
0.0284	11000.	2.458	29.592	2.70	1.682	321960.
0.0307	10000.	3.851	30.696	2.70	1.713	331960.
0.0207	6000.	5.463	31.921	2.70	1.745	339960.
0.0310	5000.	7.621	33.046	2.70	1.773	344960.
0.0321	3000.	10.535	34.002	2.70	1.795	347960.
0.0204	2030.	12.685	35.001	2.70	1.817	349960.
0.0201	2000.	14.896	36.261	2.70	1.843	351960.
0.0377	2120.	17.992	37.930	2.70	1.875	354080.
0.0236	1090.	19.631	39.059	2.70	1.896	355170.
0.0132	760.	21.174	39.992	2.70	1.912	355930.
0.0186	960.	20.911	41.166	2.68	1.936	356890.
0.0217	910.	14.141	41.553	2.67	1.945	357800.

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FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 41E 3

B=0.612 INCHES W=3.00: INCHES

TEMPERATURE -50 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0141	16440.	2.339	25.852	4.30	1.025	49900.
0.0172	22790.	1.241	26.196	4.30	1.043	72690.
0.0255	21390.	1.904	26.787	4.30	1.072	94080.
0.0334	18100.	2.814	27.595	4.30	1.110	112180.
0.0345	9740.	3.693	28.208	4.30	1.137	121920.
0.0375	10410.	4.817	29.167	4.30	1.178	132330.
0.0304	6030.	5.719	29.908	4.30	1.209	138360.
0.0304	4310.	6.413	30.534	4.30	1.233	142670.
0.0281	3420.	6.781	31.159	4.30	1.257	146090.
0.0247	3230.	7.306	31.771	4.30	1.280	149320.
0.0240	3380.	7.674	32.454	4.30	1.304	152700.
0.0336	4530.	8.512	33.516	4.30	1.340	157230.
0.0420	4430.	9.599	34.706	4.30	1.379	161660.
0.0279	3000.	10.714	35.670	4.30	1.409	164660.
0.0315	3000.	11.994	36.807	4.30	1.442	167660.
0.0318	2500.	13.596	37.015	4.20	1.473	170160.
0.0166	1030.	16.882	38.581	4.30	1.491	171180.
0.0244	1810.	13.576	38.406	4.28	1.491	172970.
0.0092	530.	1.498	38.988	4.30	1.501	173500.
0.0107	17320.	0.905	24.123	2.60	1.524	190820.
0.0817	74950.	1.623	26.540	2.60	1.615	267770.
0.0414	24130.	2.259	27.642	2.60	1.658	291900.
0.0410	19060.	3.030	29.588	2.60	1.709	310960.
0.0299	12550.	5.053	31.175	2.60	1.752	323510.
0.0446	5120.	8.174	32.303	2.60	1.780	328630.
0.0286	3210.	11.414	33.295	2.60	1.803	331840.
0.0312	2620.	8.532	35.044	2.60	1.840	334460.
0.0377	2200.	6.960	36.062	2.60	1.861	336660.
0.0144	950.	8.178	36.334	2.60	1.866	337610.
0.0230	12100.	5.403	29.758	2.00	1.910	349710.
0.0202	4600.	68.817	26.470	2.80	1.927	354310.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 41E 6

B=0.625 INCHES W=3.015 INCHES

TEMPERATURE -50 DEGREES F

DA	DN	DADN	DK	DC	A	N
0.0109	43470.	0.578	24.537	4.30	0.990	127420.
0.0211	41080.	0.793	24.949	4.30	1.013	169100.
0.0384	40550.	1.219	25.568	4.30	1.046	209650.
0.0205	22400.	1.647	26.123	4.30	1.075	232050.
0.0418	21200.	2.181	26.876	4.30	1.111	253250.
0.0347	16010.	2.734	27.634	4.30	1.146	269260.
0.0338	10000.	2.966	28.311	4.30	1.176	279260.
0.0367	12030.	3.367	29.208	4.30	1.214	291290.
0.0345	9210.	3.845	30.017	4.30	1.246	300500.
0.0325	10430.	4.564	31.085	4.30	1.287	310930.
0.0316	6110.	5.327	31.844	4.30	1.315	317040.
0.0292	4420.	5.961	32.503	4.30	1.338	321460.
0.0190	3550.	6.331	33.192	4.30	1.362	325010.
0.0230	3440.	6.813	33.847	4.30	1.384	328450.
0.0240	3490.	7.222	34.578	4.30	1.407	331940.
0.0338	4810.	8.019	35.807	4.30	1.445	336750.
0.0428	4620.	7.996	37.192	4.30	1.484	341370.
0.0283	3100.	8.632	38.122	4.30	1.509	344470.
0.0265	3140.	8.094	39.314	4.30	1.540	347610.
0.0101	2580.	7.516	39.331	4.30	1.541	350190.
0.0416	2840.	[illegible].158	39.764	4.30	1.551	353030.
0.0150	60000.	1.292	25.547	2.60	1.609	413030.
0.0404	26140.	1.881	26.634	2.60	1.647	439170.
0.0169	10410.	2.260	27.239	2.60	1.667	449580.
0.0299	11250.	2.847	28.094	2.60	1.693	460830.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 41E 7

B=0.615 INCHES W=3.010 INCHES

TEMPERATURE 70 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0000	5450.	0.783	24.108	4.30	0.938	41640.
0.0079	19330.	0.623	24.297	4.30	0.949	60970.
0.0094	8580.	0.614	24.403	4.30	0.956	69550.
0.0110	7980.	0.640	24.494	4.30	0.961	77530.
0.0089	19870.	0.678	24.698	4.30	0.973	97400.
0.0014	9600.	0.700	24.784	4.30	0.978	107000.
0.0070	9080.	0.789	24.867	4.30	0.983	116080.
0.0183	19000.	1.299	25.131	4.30	0.998	135080.
0.0179	16520.	2.150	25.598	4.30	1.023	151600.
0.0241	10520.	2.879	26.064	4.30	1.047	162120.
0.0309	9000.	3.729	26.589	4.30	1.074	171120.
0.0307	7580.	4.643	27.232	4.30	1.104	178700.
0.0309	7000.	5.805	27.993	4.30	1.139	185700.
0.0273	4440.	6.717	28.540	4.30	1.165	190140.
0.0298	4080.	7.766	29.247	4.30	1.193	194220.
0.0312	3600.	8.654	29.940	4.30	1.223	197820.
0.0264	3240.	9.963	30.740	4.30	1.252	201060.
0.0432	4060.	11.597	31.848	4.30	1.295	205120.
0.0231	1840.	12.826	32.486	4.30	1.316	206960.
0.0268	2040.	14.284	33.287	4.30	1.344	209000.
0.0142	1070.	15.246	33.741	4.30	1.359	210070.
0.0180	1070.	16.400	34.240	4.30	1.375	211140.
0.0263	1570.	17.699	35.105	4.30	1.403	212710.
0.0186	1000.	18.557	35.712	4.30	1.421	213710.
0.0204	960.	19.907	36.316	4.30	1.439	214670.
0.0132	860.	19.643	36.939	4.30	1.459	215530.
0.0186	840.	2.305	36.974	4.30	1.458	216370.
0.0219	850.	1.252	37.306	4.30	1.467	217220.
0.0214	40000.	0.982	23.645	2.60	1.515	257220.
0.0236	31110.	0.922	24.328	2.60	1.544	288330.
0.0339	26210.	1.059	24.932	2.60	1.567	314540.
0.0106	19420.	1.289	25.513	2.60	1.589	333960.
0.0226	17310.	2.174	26.164	2.60	1.613	351270.
0.0229	12510.	3.398	26.827	2.60	1.635	363780.
0.0244	11120.	4.682	28.040	2.60	1.674	374900.
0.0066	6500.	5.564	29.035	2.60	1.704	381400.
0.0289	5500.	6.354	30.268	2.60	1.738	386900.
0.0072	3000.	6.391	31.223	2.60	1.763	389900.
0.0105	2030.	9.218	31.549	2.60	1.771	391900.
0.0255	2000.	12.658	32.226	2.60	1.788	393900.
0.0179	1300.	14.920	33.001	2.60	1.806	395200.
0.0200	1300.	17.088	33.974	2.60	1.828	396500.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 44E 3

B=0.598 INCHES W=3.001 INCHES

TEMPERATURE 70 DEGREES F

DA	DN	WADN	DK	DP	A	N
0.0269	10500.	5.109	25.637	4.30	0.981	35500.
0.0399	14000.	4.593	26.169	4.30	1.010	47500.
0.0555	10000.	6.388	27.218	4.30	1.062	57500.
0.0300	6000.	8.111	27.946	4.28	1.102	63500.
0.0455	4000.	9.183	28.824	4.30	1.135	67500.
0.0281	3000.	10.048	29.350	4.28	1.163	70500.
0.0323	3000.	11.114	30.324	4.30	1.197	73500.
0.0289	3000.	11.797	31.075	4.29	1.229	76500.
0.0388	3000.	13.363	32.049	4.29	1.266	79500.
0.0349	2500.	15.163	33.083	4.30	1.300	82000.
0.0279	2000.	16.748	34.180	4.32	1.331	84000.
0.0373	2000.	18.472	35.080	4.30	1.365	86000.
0.0395	2000.	12.180	36.350	4.30	1.404	88000.
0.0096	500.	11.993	36.328	4.30	1.404	88500.
0.0093	500.	4.633	36.633	4.32	1.408	89000.
0.0109	5000.	2.072	21.711	2.51	1.429	94000.
0.0206	14500.	1.108	22.226	2.52	1.449	108500.
0.0096	20000.	0.646	22.534	2.52	1.464	128500.
0.0040	20000.	0.452	22.455	2.49	1.472	148500.
0.0085	20000.	0.428	22.654	2.50	1.477	168500.
0.0069	20000.	0.545	22.833	2.50	1.484	188500.
0.0063	9000.	0.570	22.775	2.50	1.483	197500.
0.0307	50010.	1.758	23.310	2.50	1.527	247510.
0.0395	20000.	2.802	24.696	2.50	1.563	267510.
0.0601	20000.	4.004	26.540	2.50	1.630	287510.
0.0410	10000.	5.431	27.783	2.50	1.670	297510.
0.0604	10000.	7.598	29.872	2.50	1.730	307510.
0.0174	2000.	9.536	30.291	2.50	1.742	309510.
0.0399	4000.	10.703	31.828	2.50	1.781	313510.
0.0419	4000.	11.120	34.034	2.50	1.831	317510.
0.0565	3000.	11.228	35.698	2.50	1.865	320510.
0.0226	3000.	11.312	30.037	2.00	1.900	323510.
0.0226	3000.	11.700	31.538	2.00	1.933	326510.
0.0409	3000.	14.198	33.047	2.00	1.964	329510.
0.0204	1500.	16.729	33.848	1.98	1.985	331010.
0.0254	1500.	21.537	33.381	1.87	2.012	332510.

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FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 62E 3

B=0.726 INCHES W=2.990 INCHES

TEMPERATURE -50 DEGREES F

DA	DN	DA/DN	DK	DP	A	N
0.0109	11400.	2.921	24.707	5.23	0.918	52220.
0.0140	15060.	2.175	25.203	5.25	0.943	67280.
0.0633	28100.	3.115	26.269	5.25	1.001	95380.
0.0309	7420.	3.618	26.730	5.25	1.025	102800.
0.0350	10000.	4.424	27.542	5.25	1.064	112800.
0.0355	8260.	5.042	28.344	5.25	1.101	121060.
0.0606	11370.	6.145	29.787	5.25	1.162	132430.
0.0506	6720.	6.930	30.088	5.25	1.206	139150.
0.0359	5680.	7.779	31.990	5.25	1.247	144830.
0.0355	4540.	8.632	33.000	5.25	1.283	149370.
0.0378	4320.	9.433	34.080	5.25	1.320	153690.
0.0449	4360.	10.800	35.461	5.25	1.364	158070.
0.0394	3450.	12.206	36.749	5.25	1.403	161520.
0.0258	2500.	15.196	37.861	5.25	1.434	164020.
0.0239	1350.	13.357	38.926	5.25	1.463	165370.
0.0339	2350.	3.434	39.032	5.25	1.466	167720.
0.0461	1470.	1.778	39.536	5.25	1.479	169190.
0.0074	40650.	1.108	24.114	3.03	1.534	209840.
0.0323	40210.	1.491	25.187	3.03	1.576	250050.
0.0390	25000.	2.337	26.338	3.03	1.617	275050.
0.0396	20000.	3.696	27.901	3.03	1.667	295050.
0.0553	15070.	5.098	29.790	3.03	1.722	310120.
0.0601	8100.	5.513	31.378	3.03	1.763	318220.
0.0721	10100.	6.041	34.271	3.03	1.829	328320.
0.0600	10000.	5.785	37.896	3.03	1.899	338320.
0.0402	8000.	5.572	40.478	3.03	1.943	346320.

FATIGUE-CRACK GROWTH TEST DATA

SPECIMEN NO. 62E 8

B=0.730 INCHES W=3.001 INCHES

TEMPERATURE -50 DEGREES F

DA	DN	DADN	DK	DP	A	N
0.0197	15550.	2.467	25.632	5.25	0.961	92200.
0.0405	14100.	3.298	26.255	5.25	1.014	106300.
0.0579	14260.	4.452	27.193	5.23	1.066	120560.
0.0349	7740.	4.962	28.001	5.23	1.104	128300.
0.0297	6440.	5.705	28.755	5.23	1.137	134740.
0.0384	5030.	6.526	29.502	5.23	1.169	140370.
0.0188	3850.	7.119	30.123	5.23	1.194	144220.
0.0543	6740.	8.517	31.470	5.23	1.246	150960.
0.0376	3990.	9.723	32.414	5.23	1.280	154950.
0.0260	3020.	10.608	33.311	5.23	1.312	157970.
0.0241	2000.	11.457	33.935	5.23	1.333	159970.
0.0239	2000.	12.349	34.641	5.23	1.356	161970.
0.0244	2000.	13.599	35.465	5.23	1.381	163970.
0.0282	2000.	14.824	36.375	5.23	1.409	165970.
0.0300	2000.	14.549	37.651	5.23	1.446	167970.
0.0348	2000.	3.414	37.641	5.23	1.445	169970.
0.0253	1340.	1.852	38.124	5.23	1.459	171310.
0.0367	47820.	1.394	23.677	3.03	1.529	219130.
0.0388	35610.	1.911	24.990	3.03	1.581	254740.
0.0419	20030.	2.814	26.237	3.03	1.626	275370.
0.0420	15640.	3.900	27.590	3.03	1.670	291010.
0.0319	6470.	5.216	28.407	3.03	1.695	297480.
0.0313	5110.	7.060	29.346	3.03	1.722	302590.
0.0246	4000.	9.374	30.418	3.03	1.751	306590.
0.0256	3000.	6.702	31.779	3.03	1.785	309590.
0.0310	2030.	6.941	32.278	3.03	1.797	311590.
0.0322	2030.	5.085	32.590	3.03	1.804	313620.
0.0113	14150.	2.549	22.743	2.03	1.834	327770.
0.0104	12480.	4.432	23.711	2.03	1.864	340250.
0.0231	7070.	6.166	30.994	2.53	1.897	347320.
0.0636	6890.	9.210	33.373	2.55	1.942	354210.
0.0442	3500.	11.561	35.209	2.55	1.976	357710.

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