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Development of Fracture Mechanics Data for 6Aℓ-6V-2 Sn Titanium Alloy

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DEVELOPMENT OF FRACTURE MECHANICS DATA FOR 6Aℓ-6V-2Sn TITANIUM ALLOY

By

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FOREWORD

The work described in this report was performed by the Martin Marietta Corporation under Contract NAS9-13599 for the Lyndon B. Johnson Space Center of the National Aeronautics and Space Administration. Mr. J. W. Smith acted as Technical Monitor for the contract at JSC.

This final report is submitted in compliance with the reporting requirements of the contract, DRL Item 2, MA-183T.

ABSTRACT

Fracture mechanics properties of 6Aℓ-6V-2Sn titanium in the annealed, solution-treated, and aged condition are presented.

Tensile, fracture toughness, cyclic flaw growth, and sustained-load threshold tests were conducted in this evaluation. Both surface flaw and compact tension-specimen geometries were employed. Temperatures and/or environments used were -65°F (220°K) air, ambient, 300°F (422°K) air, and room-temperature air containing 10 and 100% relative humidity.

ACKNOWLEDGEMENTS

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I. INTRODUCTION

Implementation of fracture control measures to ensure operational safety of Space Shuttle hardware depends to a considerable extent on the availability of representative mechanical property data that includes static fracture toughness (K_{Ic}), sustained-load threshold (K_{TH}), and cyclic crack growth rates (da/dN). Titanium 6Aℓ-6V-2Sn (6-6-2) is an attractive candidate for Space Shuttle structural applications because it has one of the highest strength/density ratios of any structural material. Its ultimate selection will critically depend on knowing its fracture characteristics.

For this program, titanium 6-6-2 was tested in the annealed and solution-treated and aged condition. The fracture characteristics determined were:

1. Static fracture toughness (FT) as a function of temperature, using compact tension (CT) and surface-flawed (SF) specimens;

2. Sustained-load threshold as a function of relative humidity, using CT specimens;

3. Cyclic crack propagation rates as functions of temperature and relative humidity, using CT and SF specimens.

The test program is outlined in Table 1.

Table 1 Test Program

Test Type*	Sample Type*	No. Samples	Environment	Temperature
Material - Annealed 6-6-2 Titanium				
T	RB	3	Ambient	RT
FT	CT	3	Ambient	-65°F(220°K)
FT	CT	3	Ambient	300°F(422°K)
FT	CT	3	Ambient	RT
FT+	SF	(5)	10RH Air	RT
SL	CT	6	10RH Air	RT
SL	CT	6	100RH Air	RT
Compliance	CT	2	Ambient	RT
CP	CT		Ambient	-65°F(220°K)
CP	CT	6	Ambient	300°F(422°K)
CP	CT	4	10RH Air	RT
CP+	SF	(5)	10RH Air	RT
CP	CT	4	100RH Air	RT
Material - Solution Treated and Aged 6-6-2 Titanium				
T	RB	3	Ambient	RT
FT	CT	3	Ambient	-65°F(220°K)
FT	CT	3	Ambient	300°F(422°K)
FT	CT	3	Ambient	RT
FT+	SF	(4)	10RH Air	RT
SL	CT	5	10RH Air	RT
SL	CT	5	100RH Air	RT
CP	CT		Ambient	-65°F(220°K)
CP	CT	6	Ambient	300°F(422°K)
CP	CT	4	10RH Air	RT
CP+	SF	(4)	10RH Air	RT
CP	CT	4	100RH Air	RT

*Abbreviations:

T - Tensile
FT - Fracture Toughness
SL - Sustained Load
CP - Crack Propagation

CT - Compact Tension
SF - Surface Flaw
RB - Round Bar
RH - Relative Humidity

+ Fracture toughness and crack propagation data obtained from same samples.

II. MATERIAL SPECIFICATIONS

Titanium 6-6-2 in the mill annealed condition was purchased from the Wyman-Gordon Company as forged bar (TMCA Heat No. K4137) approximately 3.8 in. (9.65 cm) square x 15 ft (457 cm) long. A chemical analysis is shown in Table 2. The material is well within the composition specifications set by MIL-T-9047E for this alloy.

Tensile, compact tension, and surface-flaw specimen blanks were cut from the forged bar to the nominal sizes shown in Fig. 1. Samples were longitudinally oriented with respect to grain direction and their locations in the original forging were identified. Half of the material was left in the annealed condition (as received) for evaluation and the other half heat treated to the solution-treated and aged condition (STA) according to the following schedule:

Solution treated at $1600^{\circ}F$ ($1144^{\circ}K$) for 30 minutes;

Water quenched;

Aged at $1000^{\circ}F$ ($801^{\circ}K$) for 6 hours;

Air cooled.

The surface of the material was coated with Turco pretreat before heat treatment to protect against high-temperature oxidation.

Table 2 Chemical Analysis* (% by weight)

Mill	Heat No.	C	Fe	O	H	N	V	Sn	Aℓ	Cu	Ti (wt %)
TMCA	K4137	0.026	0.55	0.188-0.193	0.0043-0.0045	0.015	5.30	2.00	5.40	0.48	Bal
Nominal Composition MIL-T-9047E		0.05 max	0.35-1.00	0.20 max	0.015 max	0.04 max	5.00-6.00	1.50-2.50	5.00-6.00	0.35-1.00	Bal

*Certified by Wyman Gordon Co.

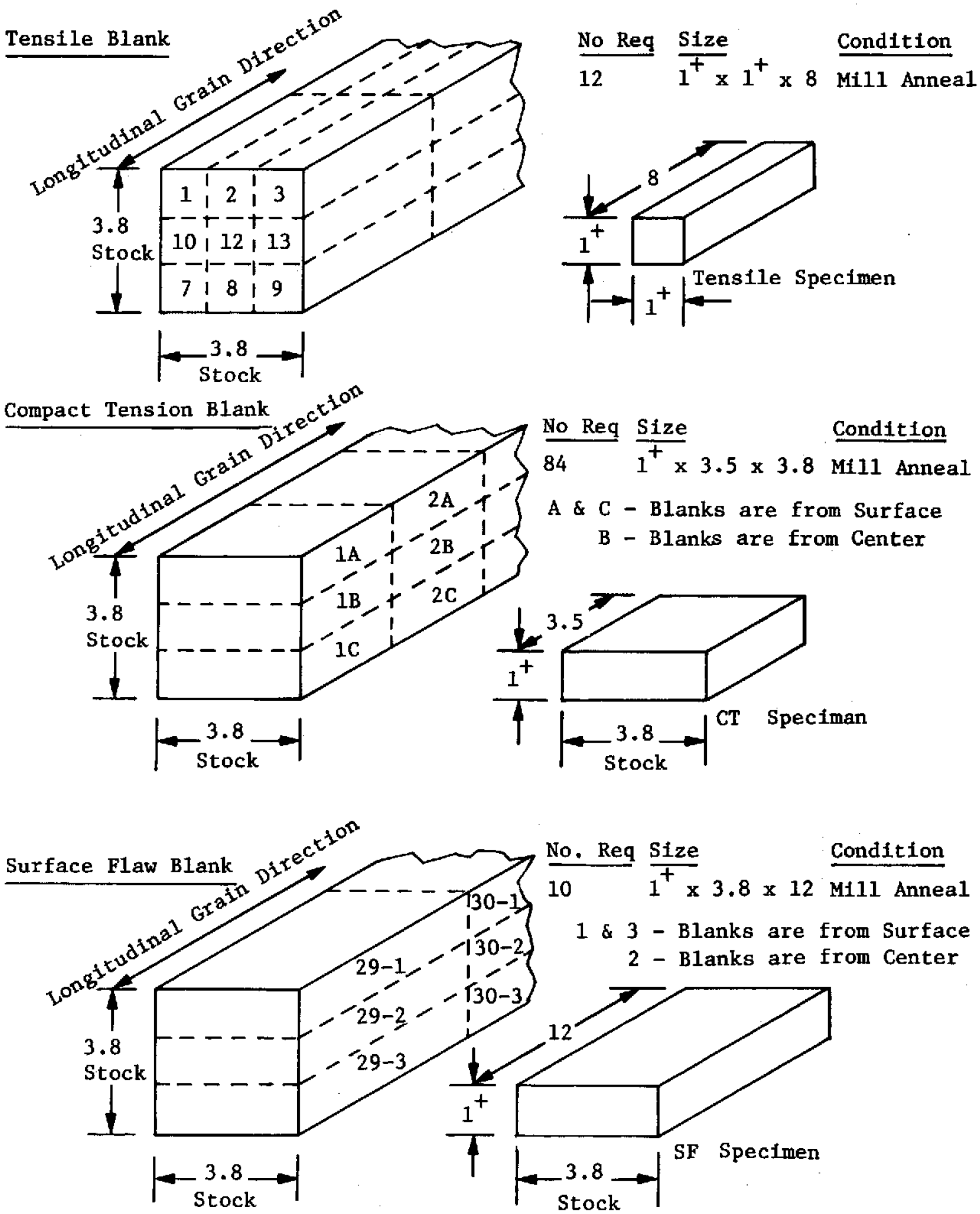


Fig. 1 Sample Locations in Forged Bar

III. SPECIMEN DESIGN

Sample designs for the tensile and surface-flaw specimens are shown in Fig. 2 and 3, respectively. The tensile sample is a standard (ASTM E8) 0.505-in.-diameter (1.282 cm) round bar. The surface-flaw sample was designed with sufficient width and thickness to provide restraint required for plane strain behavior.

The compact tension specimen shown in Fig. 4 has been designed in general accordance with specifications in ASTM E399 for 1-in. (2.54 cm) thickness. The H/W ratio is equal to 0.6, but the W/B ratio was increased to 2.5. This allowed sufficient width for cyclic crack growth data without exceeding an a/W ratio of about 0.65. This same specimen design was used for static fracture toughness and sustained-load threshold data using an a/W ratio of 0.50. The compact tension specimen is oriented in the RW orientation with respect to the original forging. The loading direction is parallel to the longitudinal grain direction and the plane of the flaw is perpendicular to the longitudinal grain direction.

A further consideration was incorporated in the design of this specimen--maximum net section stress is no more than 0.80 S_Y during cyclic crack growth and static fracture toughness testing. All testing conditions met this criterion except annealed material at 300°F (422°K). Because of extremely high fracture toughness ($\approx$100 ksi$\sqrt{\text{in.}}$, 110 MN/$m^{3/2}$) at this temperature, the maximum net section stress was almost equal to S_Y during fracture toughness and cyclic crack growth testing for this single condition.

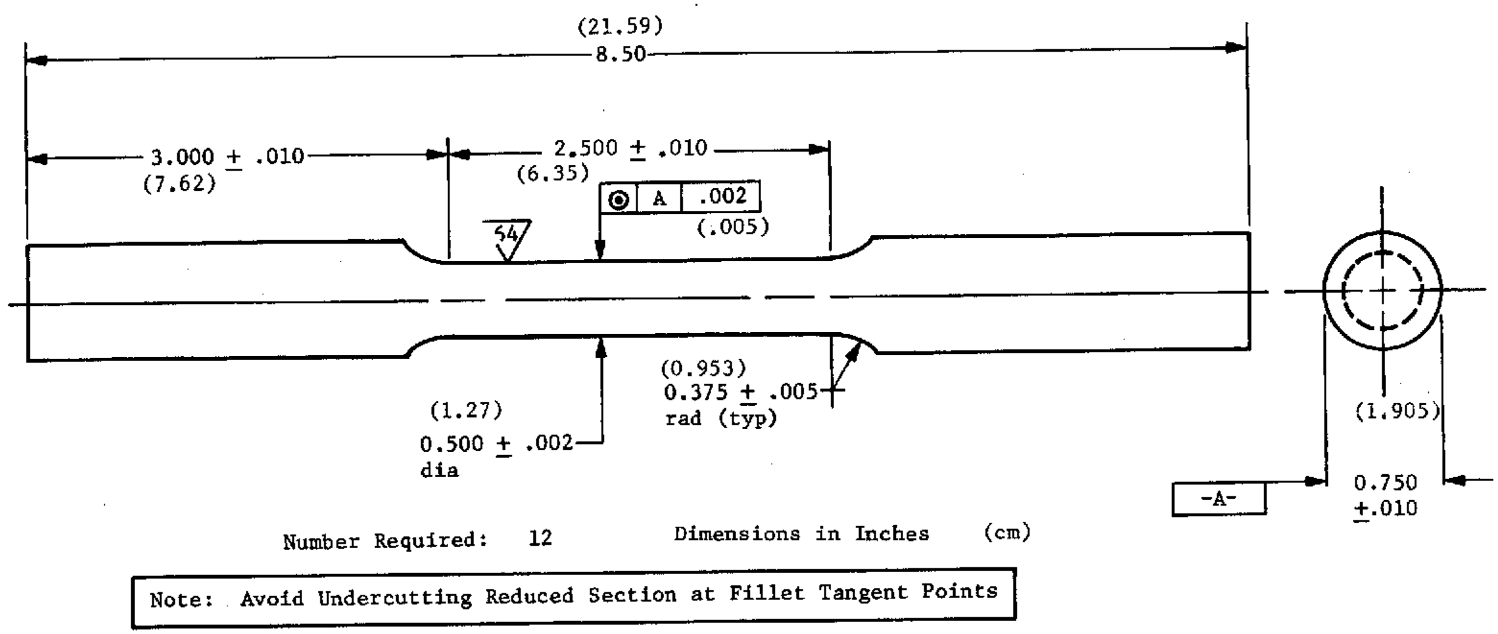
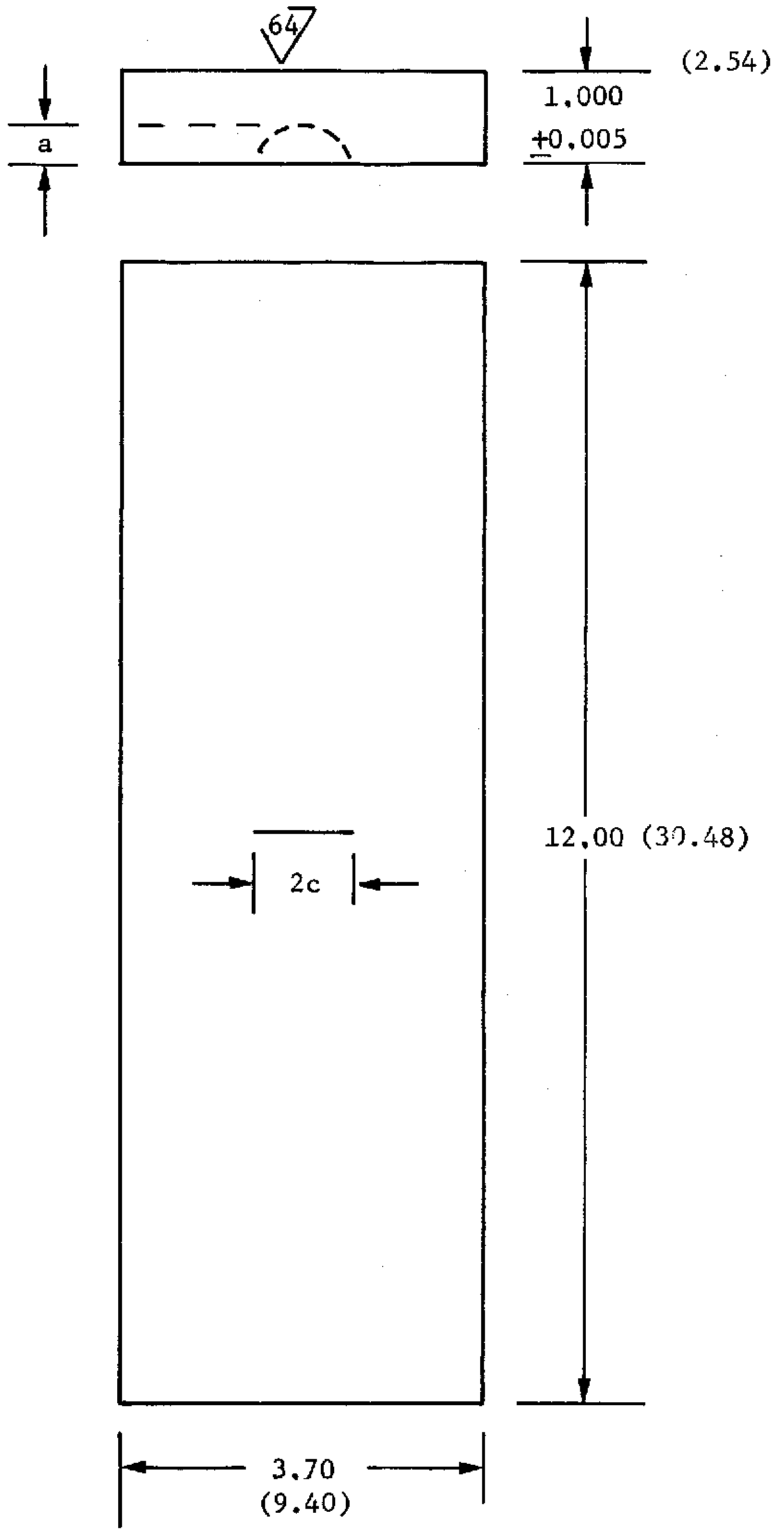
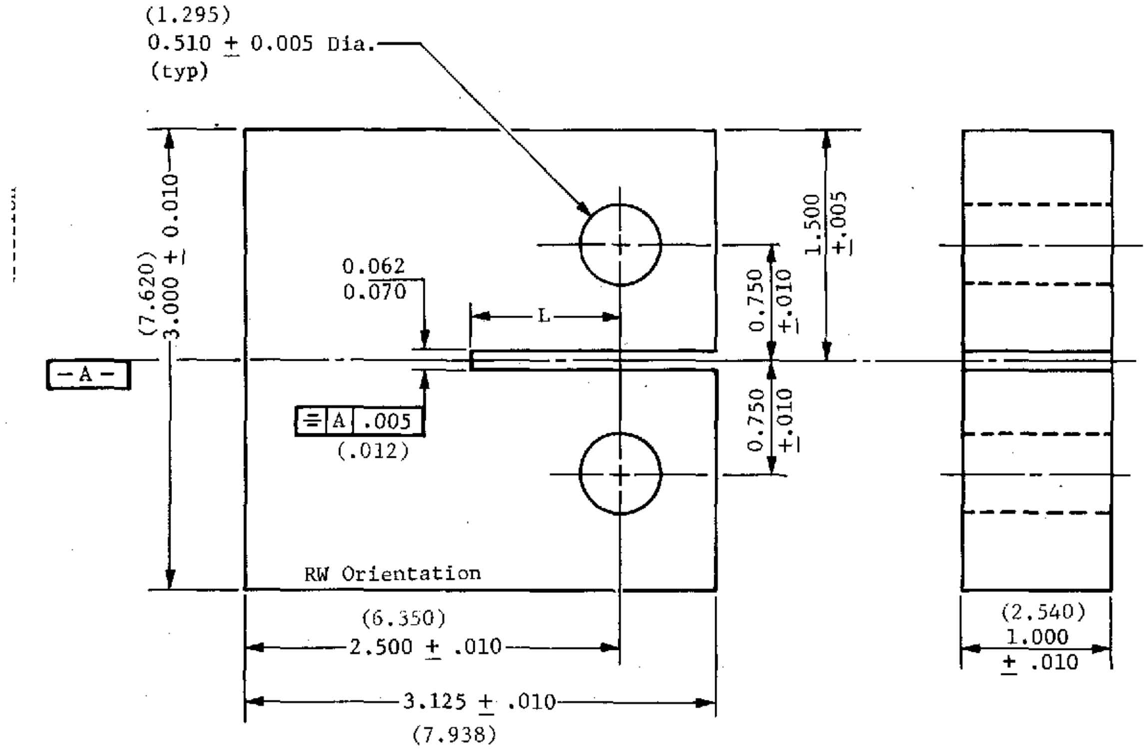


Fig. 2 Tensile Specimen



Number Required; 10 Dimensions in Inches (cm)

Fig. 3 Surface Flaw Specimen



Specimen Type	Dimension "L"	No. Req.
Static Fracture Toughness	1.050 ± .010 (2.667)	42
Sustained Load Threshold	1.050 ± .010 (2.667)	
Cylic Flaw Growth	0.700 ± .010 (1.778)	42

Total Number Required: 84

Dimensions in Inches (cm)

Fig. 4 Compact Tension Specimen

IV. TEST METHODS AND RESULTS

A. Tensile Tests

Tensile properties for ANN and STA 6-6-2 titanium are given in Table 3. These tests were conducted using ASTM E8 procedures. A 2-in. Class B-1 extensometer was placed on each sample to measure strain. Strain versus load was autographically recorded for each sample, thus allowing determination of modulus and yield strength.

B. Fracture Toughness Tests

1. Compact Tension

All compact tension fracture toughness samples shown in Fig. 4 were precracked at room temperature in tension fatigue using an "R" ratio of 0.10. The annealed samples were precracked at a maximum load of 3000 lb ($K_{max} \approx 18$ ksi$\sqrt{in.}$) and the STA samples at a maximum load of 2500 lb ($K_{max} \approx 15$ ksi$\sqrt{in.}$). These stress intensities are 31% and 49% of the room temperature K_{Ic}, respectively. All flaws were precracked to a length of about 1.25 in. (3.18 cm) or a/W equal to 0.5.

Tests at -65 (220°K) and 300°F (422°K) were conducted in a commercial environmental chamber that used LN_2 for cooling and resistance wire elements for heating.

Before tensile testing to failure, samples were instrumented with a COD extensometer, as shown in Fig. 5. With this device, a load-versus-COD autographic plot was obtained from each fracture sample. Each plot was then analyzed using ASTM E399 data reduction procedures to obtain K_Q:

$$K_Q = Y \frac{P_Q \sqrt{a}}{BW}^{*} \qquad (1)$$

*Wessel, E. T., "State of the Art of The WOL Specimen for K_{Ic} Fracture Toughness Testing." Jour. Engr. Fracture Mechanics. Vol. 1, No. 1, June 1968, p 77-103.

Table 3 Tensile Properties for 6Al-6V-2Sn Titanium

Sample No.	Initial Diameter, D_o, in.	Initial Gage Length, L_o, in.	Initial Area, A_{o_2}, in.	Yield Load, P_Y, kips	Ultimate Load, P_U, kips	Final Diameter, D_f, in.	Final Gage Length, L_f, in.	Yield Strength, S_Y, ksi	Ultimate Strength, S_U, ksi	Elongation, El, %	Reduction of Area RA, %	Elastic Modulus, E, ksi x 10^3
Annealed												
7-A	0.501	2.02	0.1970	29.1	30.2	0.378	2.34	147.7	153.3	15.8	43.0	15.9
8-A	0.502	1.97	0.1978	29.5	30.7	0.383	2.29	149.1	155.2	16.2	41.8	15.7
9-A	0.500	1.98	0.1963	29.3	30.5	0.375	2.29	149.3	155.4	15.7	43.8	15.8
Average								148.7	154.6	15.9	42.9	15.8
Solution-Treated and Aged												
10-H	0.500	2.00	0.1963	35.9	37.7	0.471	2.13	182.9	192.1	6.5	11.3	16.0
12-H	0.497	1.99	0.1939	35.7	37.6	0.453	2.13	184.1	193.9	7.0	16.9	15.2
13-H	0.498	1.99	0.1947	35.9	37.2	0.432	2.18	184.4	191.1	9.5	24.8	15.7
Average								183.8	192.4	7.7	17.7	15.6

Table 3 Tensile Properties for 6Aℓ-6V-2Sn Titanium b. International Units (S.I.)

Sample No.	Initial Diameter, D_o, cm	Initial Gage Length, L_o, cm	Initial Area, A_o, cm^2	Yield Load, P_Y, KN	Ultimate Load, P_U, KN	Final Diameter, D_f, cm	Final Gage Length, L_f, cm	Yield Strength, S_Y, MN/m^2	Ultimate Strength, S_U, MN/m^2	Elongation El, %	Reduction of Area RA, %	Elastic Modulus, E, MN/m^2
Annealed												
7-A	1.273	5.13	0.500	129	134	0.960	5.94	1018	1057	15.8	43.0	110
8-A	1.275	5.00	0.502	131	137	0.973	5.82	1028	1070	16.2	41.8	108
9-A	1.27	5.03	0.499	130	136	0.953	5.82	1029	1072	15.7	43.8	109
Average								1019	1065	15.9	42.9	109
Solution-Treated and Aged												
10-H	1.270	5.08	0.499	160	168	1.196	5.41	1261	1324	6.5	11.3	110
12-H	1.262	5.05	0.499	159	167	1.151	5.41	1269	1337	7.0	16.9	104
13-H	1.265	5.05	0.495	160	166	1.098	5.54	1271	1318	9.5	24.8	108
Average								1267	1327	7.7	17.7	108

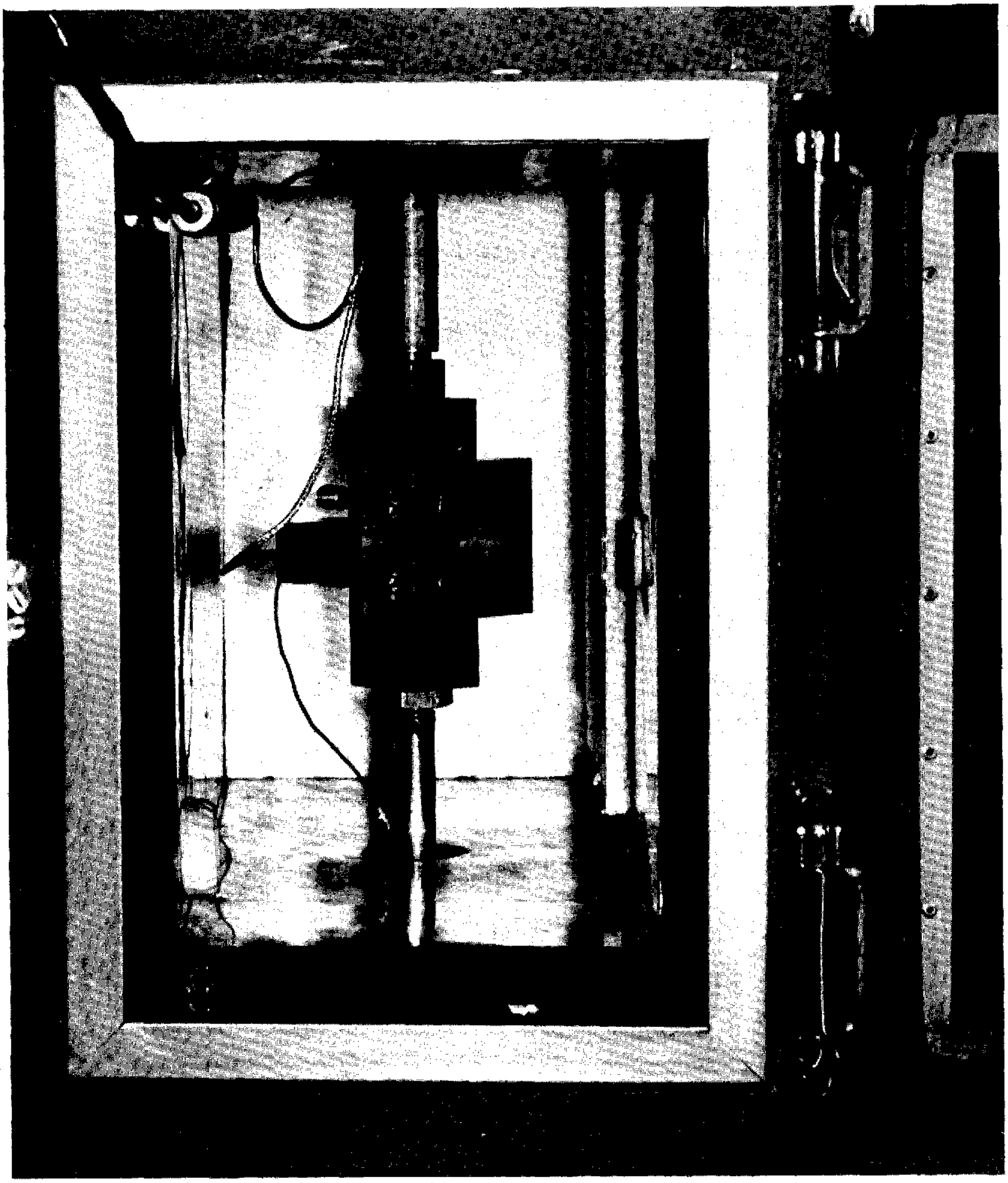


Fig. 5 Compact Tension Sample with Extensometer in Environmental Chamber of Fatigue Test Machine

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where $Y = 29.6 - 185.5\ (\frac{a}{W}) + 655.7\ (\frac{a}{W})^2 - 1017.0\ (\frac{a}{W})^3$

$+ 638.9\ (\frac{a}{W})^4$.

In all cases $\left[P_{max}/P_Q\right]$ ratio for a Type I curve was much less than 1.1, so K_Q was a valid K_{Ic}.

The fracture toughness values from compact tension tests for annealed and STA titanium 6-6-2 are shown in Tables 4 and 5, respectively, and are plotted as a function of temperature in Fig. 6. These values were used as baseline data for selection of load levels for subsequent sustained-load threshold tests.

2. Surface-Flaw Tests

Surface-flaw fracture-toughness samples shown in Fig. 3 were EDM notched and precracked by bending fatigue using an R ratio of 0.10. Both annealed and STA samples were precracked at a maximum load of 9000 lb, corresponding to an outer fiber stress of 22 ksi. This is equivalent to an S/S_Y ratio of 0.15 for the annealed samples and 0.12 for the STA samples. These samples were further cycled in tension fatigue to obtain crack growth rate data. Further description of the test procedure is in Section IV-D. After fatigue cycling, the samples were tested to failure in tension. A load-versus-deflection autographic plot was obtained for each fracture sample. From fracture load, a value of K_{Ic} was calculated using the following stress intensity expression for a surface flaw

$$K = 1.15\sqrt{\pi a/Q}\ ^{*} \qquad (2)$$

where Q = flaw shape parameter

$$= \left[\phi^2 - .212\left(\frac{S}{S_Y}\right)^2\right]$$

and ϕ = complete elliptic integral of the second kind

$$= \int_0^{\pi/2} \sqrt{1 - \left(\frac{c^2 - a^2}{c^2}\right) \sin^2\theta}\quad d\theta \quad .$$

The fracture toughness values from surface flaw tests for annealed and STA titanium 6-6-2 are given in Table 6.

---

*Irwin, G. R., "Crack Extension Force for a Part-Through Crack in a Plate." J. Appl. Mechanics. Transactions ASME. December 1962, p 651-654.

Table 4 Fracture Toughness for Annealed 6Al-6V-2Sn Titanium from Compact Tension Tests

Sample No.	Thickness B in.	Effective Width W in.	Half Height H in.	Crack Length a in.	Half-Height / Eff. Width H/W	Crack Length / Eff. Width a/W	Y*	Fracture Load P_q kip	Fracture Toughness K_{Ic}** ksi $\sqrt{in.}$
-65°F									
7B-A-FT	1.008	2.498	1.503	1.299	0.602	0.520	14.15	7.37	47.2
8C-A-FT	1.007	2.502	1.500	1.312	0.600	0.524	14.29	7.34	47.7
10B-A-FT	1.003	2.503	1.502	1.297	0.600	0.518	14.10	5.88	37.6
							K_{AV} =		44.2
Room Temperature									
3B-A-FT	0.995	2.495	1.503	1.301	0.602	0.521	14.18	8.79	57.3
13B-A-FT	1.006	2.501	1.500	1.300	0.600	0.520	14.15	8.88	56.9
20C-A-FT	0.999	2.499	1.501	1.299	0.601	0.520	14.15	9.55	61.7
							K_{AV} =		58.6
300°F									
1B-A-FT	1.003	2.502	1.502	1.279	0.600	0.511	13.89	16.80	105.2
7C-A-FT	1.004	2.499	1.503	1.288	0.601	0.515	14.01	16.50	104.6
10C-A-FT	1.002	2.495	1.500	1.300	0.601	0.521	14.18	17.70	114.4
							K_{AV} =		108.1

$$^{*}Y = 29.6 - 185.5\left(\frac{a}{W}\right) + 655.7\left(\frac{a}{W}\right)^2 - 1017.0\left(\frac{a}{W}\right)^3 + 638.9\left(\frac{a}{W}\right)^4$$

$$^{**}K = Y \frac{P_q \sqrt{a}}{B\ W}$$

Table 4 Fracture Toughness for Annealed 6Aℓ-6V-2Sn Titanium from Compact Tension Tests b. International Units (S.I.)

Sample No.	Thickness B cm	Effective Width W cm	Half Height H cm	Crack Length a cm	Half-Height / Eff. Width H/W	Crack Length / Eff. Width a/W	Y*	Fracture Load P_q KN	Fracture Toughness K_{Ic}** $MN/m^{\frac{3}{2}}$
220°K									
7B-A-FT	2.560	6.345	3.818	3.300	0.602	0.520	14.15	32.8	51.9
8C-A-FT	2.558	6.355	3.81	3.333	0.600	0.524	14.29	32.7	52.4
10B-A-FT	2.548	6.358	3.815	3.294	0.600	0.518	14.10	26.2	41.3
							K_{AV} =		48.6
Room Temperature									
3B-A-FT	2.527	6.337	3.818	3.305	0.602	0.521	14.18	39.0	63.0
13B-A-FT	2.555	6.353	3.810	3.302	0.600	0.520	14.15	39.5	62.5
20C-A-FT	2.538	6.348	3.813	3.230	0.601	0.520	14.15	42.5	67.8
							K_{AV} =		69.4
422°K									
1B-A-FT	2.548	6.355	3.815	3.249	0.600	0.511	13.89	74.7	115.6
7C-A-FT	2.550	6.348	3.818	3.272	0.601	0.515	14.01	73.4	115.0
10C-A-FT	2.545	6.337	3.810	3.302	0.601	0.521	14.18	78.7	125.7
							K_{AV} =		118.8

$$*Y = 29.6 - 185.5\left(\frac{a}{W}\right) + 655.7\left(\frac{a}{W}\right)^2 - 1017.0\left(\frac{a}{W}\right)^3 + 638.9\left(\frac{a}{W}\right)^4$$

$$**K = Y\,\frac{P_q\sqrt{a}}{B\,W}$$

Table 5 Fracture Toughness for STA 6Al-6V-2Sn Titanium from Compact Tension Tests

Sample No.	Thickness, B, in.	Effective Width, W, in.	Half Height, H, in.	Crack Length, a, in.	Half Weight, Eff Width H/W	Crack Length, Eff Width a/W	Y*	Fracture Load, P_q, kips	Fracture Toughness, K_{Ic}**, ksi $\sqrt{in.}$
-65°F									
2B-H-FT	1.010	2.494	1.501	1.326	0.602	0.532	14.54	4.32	28.7
18C-H-FT	1.005	2.499	1.504	1.267	0.602	0.507	13.77	4.67	28.8
19C-H-FT	1.007	2.496	1.500	1.283	0.601	0.514	13.96	4.42	27.8
							K_{AV} =		28.4
Room Temperature									
4B-H-FT	1.006	2.502	1.499	1.296	0.599	0.518	14.10	4.74	30.2
6C-H-FT	1.007	2.501	1.502	1.278	0.601	0.511	13.89	4.91	30.6
15A-H-FT	1.005	2.498	1.504	1.290	0.602	0.516	14.03	4.97	31.6
							K_{AV} =		30.8
300°F									
5C-H-FT	1.015	2.497	1.501	1.278	0.601	0.512	13.91	8.73	54.2
15C-H-FT	1.001	2.501	1.503	1.292	0.601	0.517	14.07	8.69	55.5
17B-H-FT	1.009	2.499	1.503	1.272	0.601	0.509	13.83	7.99	49.4
							K_{AV} =		53.0

$^{*}Y = 29.6 - 185.5\left(\frac{a}{W}\right) + 655.7\left(\frac{a}{W}\right)^2 - 1017.0\left(\frac{a}{W}\right)^3 + 638.9\left(\frac{a}{W}\right)^4$

$^{**}K = Y \frac{P_q \sqrt{a}}{B\ W}$

Table 5 Fracture Toughness for STA 6Aℓ-6V-2Sn Titanium from Compact Tension Tests b. International Units (S.I.)

Sample No.	Thickness B cm	Effective Width, W cm	Half Height, H cm	Crack Length, a cm	Half Weight, Eff. Width H/W	Crack Length, Eff. Width a/W	Y*	Fracture Load P_q, KN	Fracture Toughness, K_{Ic}** $MN/m^{\frac{3}{2}}$
-65^oF									
2B-H-FT	2.565	6.335	3.813	3.368	0.602	0.532	14.54	19.2	31.5
18C-H-FT	2.553	6.348	3.820	3.218	0.602	0.507	13.77	20.8	31.7
19C-H-FT	2.558	6.340	3.811	3.258	0.601	0.514	13.96	19.6	30.6
							K_{AV} =		31.2
Room Temperature									
4B-H-FT	2.555	6.335	3.808	3.292	0.599	0.518	14.10	21.0	33.2
6C-H-FT	2.558	6.353	3.815	3.246	0.601	0.511	13.89	21.8	33.6
15A-H-FT	2.553	6.345	3.820	3.277	0.602	0.516	14.03	22.1	34.7
							K_{AV} =		33.8
300^oF									
5C-H-FT	2.578	6.342	3.813	3.246	0.601	0.512	13.91	38.8	60.0
15C-H-FT	2.543	6.353	8.598	3.282	0.601	0.517	14.07	38.6	61.0
17B-H-FT	2.563	6.348	3.818	3.231	0.601	0.509	13.83	35.5	54.3
							K_{AV} =		58.2

$*Y = 29.6 - 185.5(\frac{a}{W}) + 655.7(\frac{a}{W})^2 - 1017.0(\frac{a}{W})^3 + 638.9(\frac{a}{W})^4$

$**K = Y\frac{P_q\sqrt{a}}{B\,W}$

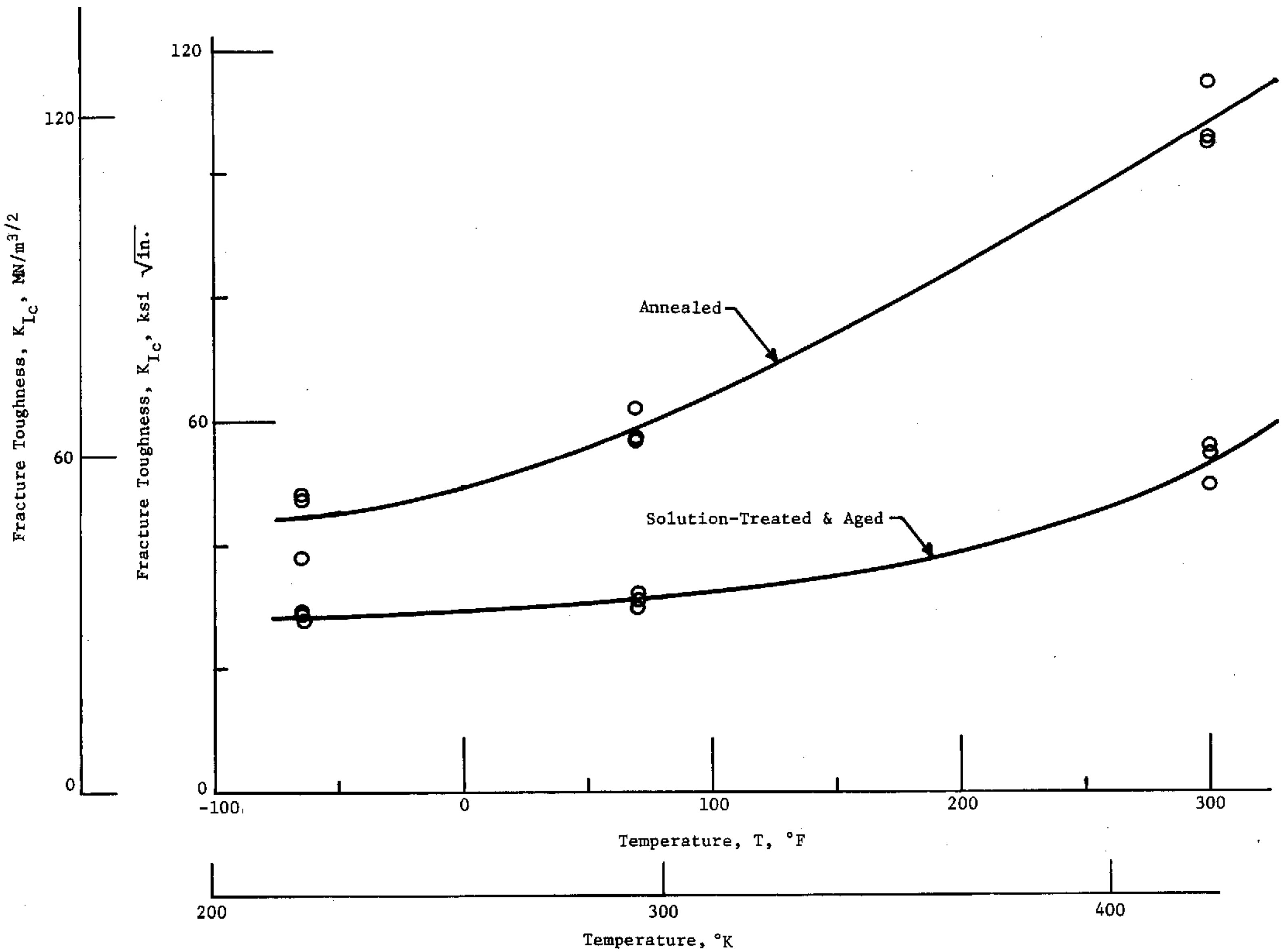

Fig. 6 Fracture Toughness of 6Al-6V-2Sn Titanium (CTS)

Table 6 Fracture Toughness for 6Al-6V-2Sn Titanium from Surface Flaw Tests at Room Temperature

Sample No.	Width W, in.	Thickness, t, in.	Area, A, in.^{2}	Fracture Load, P_f, kips	Fracture Stress, S_f, ksi	Flaw Depth, a, in.	Flaw Length, $2c$, in.	Shape Ratio, $a/2c$	Stress Ratio, S_f/S_Y	Q*	Fracture Toughness K_{Ic}**, ksi $\sqrt{in.}$
Annealed											
32-1-A	3.680	1.010	3.717	326.0	87.7	0.190	0.535	0.355	0.59	1.77	56.1
29-3-A	3.680	1.020	3.754	371.0	98.8	0.235	0.576	0.408	0.66	1.98	66.3
29-1-A	3.630	0.920	3.340	290.0	86.8	0.270	0.680	0.397	0.58	1.93	63.3
29-2-A	3.700	0.979	3.622	327.0	90.3	0.360	0.710	0.507	0.61	2.39	68.2
32-2-A	3.670	0.910	3.340	353.0	105.7	0.200	0.663	0.302	0.71	1.53	74.3
										Average	65.6
Solution-Treated and Aged											
30-1-H	3.701	1.014	3.753	161.0	43.5	0.330	0.671	0.492	0.24	2.42	31.2
33-1-H	3.700	1.014	3.752	164.0	43.7	0.350	0.671	0.522	0.24	2.45	32.1
30-2-H	3.690	0.970	3.579	157.0	43.9	0.335	0.670	0.500	0.24	2.45	31.6
30-3-H	3.670	1.010	3.707	173.0	46.7	0.345	0.668	0.516	0.25	2.45	34.0
										Average	32.2

*$Q = \left[\phi^2 - 0.212 \left(\frac{S}{S_Y}\right)^2\right]$

**$K_{Ic} = 1.1S\sqrt{\pi a/Q}$

$(S_Y)_{ann} = 148.7$ ksi

$(S_T)_{sta} = 183.8$ ksi

Table 6 Fracture Toughness for 6Aℓ-6V-2Sn Titanium from Surface Flaw Tests at Room Temperature
b. International Units (S.I.)

Sample No.	Width W cm	Thickness, t cm	Area, A cm^2	Fracture Load P_f KN	Fracture Stress S_f, MN/m^2	Flaw Depth a, cm	Flaw Length 2c, cm	Shape Ratio a/2c	Stress Ratio S_f/S_Y	Q*	Fracture Toughness K_{Ic}** $MN/m^{\frac{3}{2}}$
Annealed											
32-1-A	9.348	2.565	23.98	1450	665	0.483	0.901	0.355	0.59	1.77	61.6
29-3-A	9.348	2.591	24.22	1650	681.	0.597	1.463	0.408	0.66	1.98	72.9
29-1-A	9.220	2.337	21.55	1290	599	0.686	1.728	0.397	0.58	1.93	69.6
29-2-A	9.398	2.497	23.37	1455	623	0.914	1.803	0.507	0.61	2.39	74.9
32-2-A	9.322	2.311	21.55	1570	730	0.506	1.684	0.302	0.71	1.53	61.6
										Average	72.1
Solution-Treated and Aged											
30-1-H	9.401	2.576	24.21	716	300	0.838	1.704	0.492	0.24	2.42	34.3
33-1-H	9.398	2.576	24.21	729	301	0.889	1.704	0.522	0.24	2.45	35.3
30-2-H	9.373	2.464	24.25	696	302	0.851	1.702	0.500	0.24	2.45	34.7
30-3-H	9.322	2.565	23.92	770	321	0.876	1.697	0.516	0.25	2.45	37.4
										Average	35.4

C. Sustained-Load Threshold Tests

All compact tension sustained-load threshold samples shown in Fig. 4 were precracked by tension fatigue in the same manner as the fracture toughness samples.

Sustained load tests were run for a 100-hr, in deadweight loaded creep racks in a 10 or 100% relative humidity (RH) air environment. Environmental control was achieved with simple well established techniques. For 100% RH, a water-saturated wick completely surrounded the test specimen. For 10% RH, normal laboratory air (approximately 20% RH) was further dried by using a closed container containing a layer of silica gel.

After exposure, the samples were fatigue marked at loads similar to those used for precracking, and broken open. Any evidence of subcritical crack growth was easily detected--appearing as a dark band between the two fatigue zones. Growth was measured using a measuring microscope with a micrometer stage. Sustained-load threshold results for annealed and STA titanium 6-6-2 are given in Tables 7 and 8, respectively.

D. Cyclic Crack Growth Tests

1. Surface-Flaw Tests

Precracking of the surface-flaw crack propagation samples shown in Fig. 3 was described in Section IV-B. After precracking, all samples were cycled at room temperature in tension fatigue using an R ratio of 0.03 and a cyclic frequency of 2-4 cps. Cyclic loads were selected to obtain growth rates of one to 100 μin. per cycle. Each surface flaw was incrementally grown to a Δa of about 0.070 in. (.177 cm) for each increment. Each increment was distinguished by heat tinting at 900^{o}F (755^{o}K) for 10 to 15 minutes. After fracture, the actual growth in each increment was measured on the plane of the fracture surface using a measuring microscope. Figure 7 shows typical multiple cyclic growth increments in a titanium 6-6-2 surface-flaw sample.

Flaw growth rates (da/dN) were determined by dividing the incremental growth (Δa) by the incremental cycles (ΔN). Corresponding cyclic stress intensity ranges were calculated using the stress intensity expression for a surface flaw (Eq. 2). Appendix A). Crack growth rates for annealed and STA titanium 6-6-2 from surface flaw tests are shown as a function of stress intensity range in Fig. 8.

Table 7 Sustained-Load Threshold for Annealed 6Al-6V-2Sn Titanium

Sample No.	Thickness, B, in.	Effective Width, W, in.	Crack Length a, in.	Crack Length / Eff Width a/W	Y^*	Sustained Load, P, kips	Stress Intensity, K^{**} ksi $\sqrt{in.}$	Stress Intensity Ratio, K/K_{Ic}	Crack Growth, Δa, in.	Exposure Time[+] t, hr
10% Relative Humidity Air										
23A-A-SL	1.003	2.500	1.297	0.519	14.13	8.57	55.0	0.94	----	0.25
3C-A-SL	1.008	2.497	1.315	0.527	14.38	7.17	47.0	0.80	0.249	10.5
9B-A-SL	1.009	2.501	1.285	0.514	13.96	5.87	36.8	0.63	0.004	100.0
21B-A-SL	0.987	2.494	1.297	0.520	14.15	5.37	35.2	0.60	0.004	100.0
27A-A-SL	1.006	2.502	1.272	0.508	13.80	4.97	30.6	0.52	0.004	100.3
28C-A-SL	0.991	2.503	1.321	0.528	14.42	4.08	27.3	0.47	0.0005	100.1
							$K_{TH} \approx 0.45$ (26.4 ksi $\sqrt{in.}$)			
100% Relative Humidity Air										
17A-A-SL	1.009	2.497	1.319	0.528	14.42	8.57	56.3	0.96	----	0.01
9A-A-SL	1.005	2.503	1.312	0.524	14.29	6.77	44.0	0.75	0.101	100.0
5B-A-SL	1.003	2.501	1.278	0.511	13.89	5.37	33.6	0.57	0.004	100.0
17C-A-SL	1.005	2.504	1.224	0.489	13.29	4.97	29.0	0.50	0.001	100.0
22A-A-SL	0.980	2.499	1.277	0.511	13.89	4.47	28.6	0.49	0.001	100.4
12A-A-SL	1.006	2.500	1.274	0.510	13.86	3.58	22.3	0.38	None	100.4
							$K_{TH} \approx 0.43$ (25.2 ksi $\sqrt{in.}$)			

$^*Y = 29.6 - 185.5 \left(\frac{a}{W}\right) + 655.7 \left(\frac{a}{W}\right)^2 - 1017.0 \left(\frac{a}{W}\right)^3 + 638.9 \left(\frac{a}{W}\right)^4$

$^{**}K = Y \frac{P\sqrt{a}}{BW}$

$K_{Ic} = 58.6$ ksi $\sqrt{in.}$

+Time less than 100 hrs indicates sample fractured during test.

Table 7 Sustained-Load Threshold for Annealed 6Aℓ-6V-2Sn Titanium b. International Units (S.I.)

Sample No.	Thickness B, cm	Effective Width, W, cm	Crack Length a, cm	Crack Length, Eff Width a/W	Y*	Sustained Load, P, KN	Stress Intensity, K**	Stress Intensity Ratio, K/K_{Ic} $MN/m^{\frac{3}{2}}$	Crack Growth, Δa, cm	Exposure Time + t, hr
10% Relative Humidity Air										
23A-A-SL	2.548	6.350	3.294	0.519	14.13	38.1	60.4	0.94	----	0.25
3C-A-SL•	2.560	6.342	6.509	0.527	14.38	18.5	51.6	0.80	0.632	10.5
9B-A-SL	2.562	6.353	3.264	0.514	13.96	26.1	40.4	0.63	0.010	100.0
21B-A-SL	2.507	6.335	3.294	0.520	14.15	23.9	38.7	0.60	0.010	100.0
27A-A-SL	2.555	6.355	3.231	0.508	13.80	22.1	33.6	0.52	0.010	100.3
28C-A-SL	2.517	6.358	3.355	0.528	14.42	18.1	30.0	0.47	0.001	100.1
100% Relative Humidity Air										
17A-A-SL	2.563	6.342	3.335	0.528	14.42	38.1	61.9	0.96	----	0.01
9A-A-SL	2.553	6.358	3.334	0.524	14.29	30.1	48.4	0.75	0.257	100.0
5B-A-SL	2.548	6.353	3.246	0.511	13.89	23.9	37.0	0.57	0.010	100.0
17C-A-SL	2.552	6.360	3.109	0.489	13.29	22.1	31.9	0.50	0.003	100.0
22A-A-SL	2.489	6.348	3.244	0.511	13.89	22.1	31.4	0.49	0.003	100.4
12A-A-SL	2.555	6.350	3.236	0.510	13.86	15.9	24.5	0.38	None	100.4

K_{TH} 0.43 (27.7 $MN/m^{3/2}$)

*$Y = 29.6 - 185.5 \left(\frac{a}{W}\right) + 655.7 \left(\frac{a}{W}\right)^2 - 1017.0 \left(\frac{a}{W}\right)^3 + 638.9 \left(\frac{a}{W}\right)^4$

**$K = Y \frac{P\sqrt{a}}{BW}$

$K_{Ic} = 64.4\ MN/m^{3/2}$

+ Time less than 100 hours indicates sample procured during test.

Table 8 Sustained-Load Threshold for STA 6Aℓ-6V-2Sn Titanium

Sample No.	Thickness, B, in.	Effective Width, W, in.	Crack Length a, in.	Crack Length, Eff Width a/W	Y*	Sustained Load, P, kips	Stress Intensity, K**, ksi $\sqrt{in.}$	Stress Intensity Ratio, K/K_{Ic}	Crack Growth, Δa, in.	Exposure Time+ t, hr
10% Relative Humidity Air										
26A-H-SL	1.005	2.501	1.274	0.509	13.83	4.18	26.0	0.84	0.0010	112.0
22B-H-SL	1.002	2.499	1.263	0.505	13.72	3.88	23.9	0.78	0.0005	100.2
21C-H-SL	0.998	2.501	1.282	0.513	13.95	3.48	22.0	0.71	<0.0005	100.0
20A-H-SL	1.006	2.502	1.290	0.516	14.04	3.28	20.8	0.68	None	100.8
24B-H-SL	1.008	2.500	1.284	0.514	13.96	2.98	18.7	0.61	None	100.2
							$K_{TH} \approx 0.69$ (21.3 ksi $\sqrt{in.}$)			
100% Relative Humidity Air										
25A-H-SL	1.009	2.502	1.293	0.517	14.07	4.18	26.5	0.86	0.0015	112.0
20B-H-SL	1.004	2.502	1.277	0.510	13.86	3.88	24.2	0.79	0.0010	100.0
23C-H-SL	1.002	2.501	1.291	0.516	14.04	3.48	22.1	0.72	0.0005	100.0
26C-H-SL	1.003	2.498	1.296	0.519	14.13	3.28	21.1	0.68	None	100.8
21A-H-SL	1.006	2.501	1.280	0.512	13.92	2.98	18.6	0.60	None	100.2
							$K_{TH} \approx 0.70$ (21.6 ksi $\sqrt{in.}$)			

*$Y = 29.6 - 185.5 \left(\frac{a}{W}\right) + 655.7 \left(\frac{a}{W}\right)^2 - 1017.0 \left(\frac{a}{W}\right)^3 + 638.9 \left(\frac{a}{W}\right)^4$

**$K = Y \frac{P\sqrt{a}}{BW}$ $\qquad K_{Ic} = 30.8$ ksi $\sqrt{in.}$

Table 8 Sustained-Load Threshold for STA 6Aℓ-6V-2Sn Titanium b. International Units (S.I.)

Sample No.	Thickness B, cm	Effective Width, W, cm	Crack Length a, cm	Crack Length, Eff Width a/W	Y*	Sustained Load, P, KN	Stress Intensity, K** $MN/m^{\frac{3}{2}}$	Stress Intensity Ratio, K/K_{Ic}	Crack Growth, Δa, cm	Exposure Time +, t, hr
10% Relative Humidity Air										
26A-H-SL	2.553	6.353	3.235	0.509	13.83	18.6	28.6	0.84	0.003	112.0
22B-H-SL	2.545	6.348	3.201	0.505	13.72	17.3	26.3	0.78	0.001	100.2
21C-H-SL	2.535	6.353	3.256	0.513	13.95	15.5	24.2	0.71	0.001	100.0
20A-H-SL	2.555	6.355	3.278	0.516	14.04	14.6	22.9	0.68	None	100.8
24B-H-SL	2.560	6.350	3.261	0.514	13.96	13.3	20.6	0.61	None	100.2
							$K_{TH} \approx 0.69$ ($23.4\ MN/m^{3/2}$)			
100% Relative Humidity Air										
25A-H-SL	2.563	6.355	3.284	0.517	14.07	18.6	29.1	0.86	0.004	112.0
20B-H-SL	2.550	6.355	3.244	0.510	13.86	17.3	26.6	0.79	0.003	100.0
23C-H-SL	2.545	6.352	3.279	0.516	14.04	15.5	24.3	0.72	0.001	100.0
26C-H-SL	2.548	6.345	3.292	0.519	14.13	14.6	23.2	0.68	None	100.8
21A-H-SL	2.555	6.353	3.251	0.512	13.92	13.3	20.4	0.60	None	100.2
							$K_{TH} \approx 0.70$ ($23.7\ MN/m^{3/2}$)			

$$*Y = 29.6 - 185.5 \left(\frac{a}{W}\right) + 655.7 \left(\frac{a}{W}\right)^2 - 1017.0 \left(\frac{a}{W}\right)^3 + 638.9 \left(\frac{a}{W}\right)^4$$

$$**K = Y \frac{P\sqrt{a}}{BW} \qquad K_{Ic} = 34.0\ MN/m^{3/2}$$

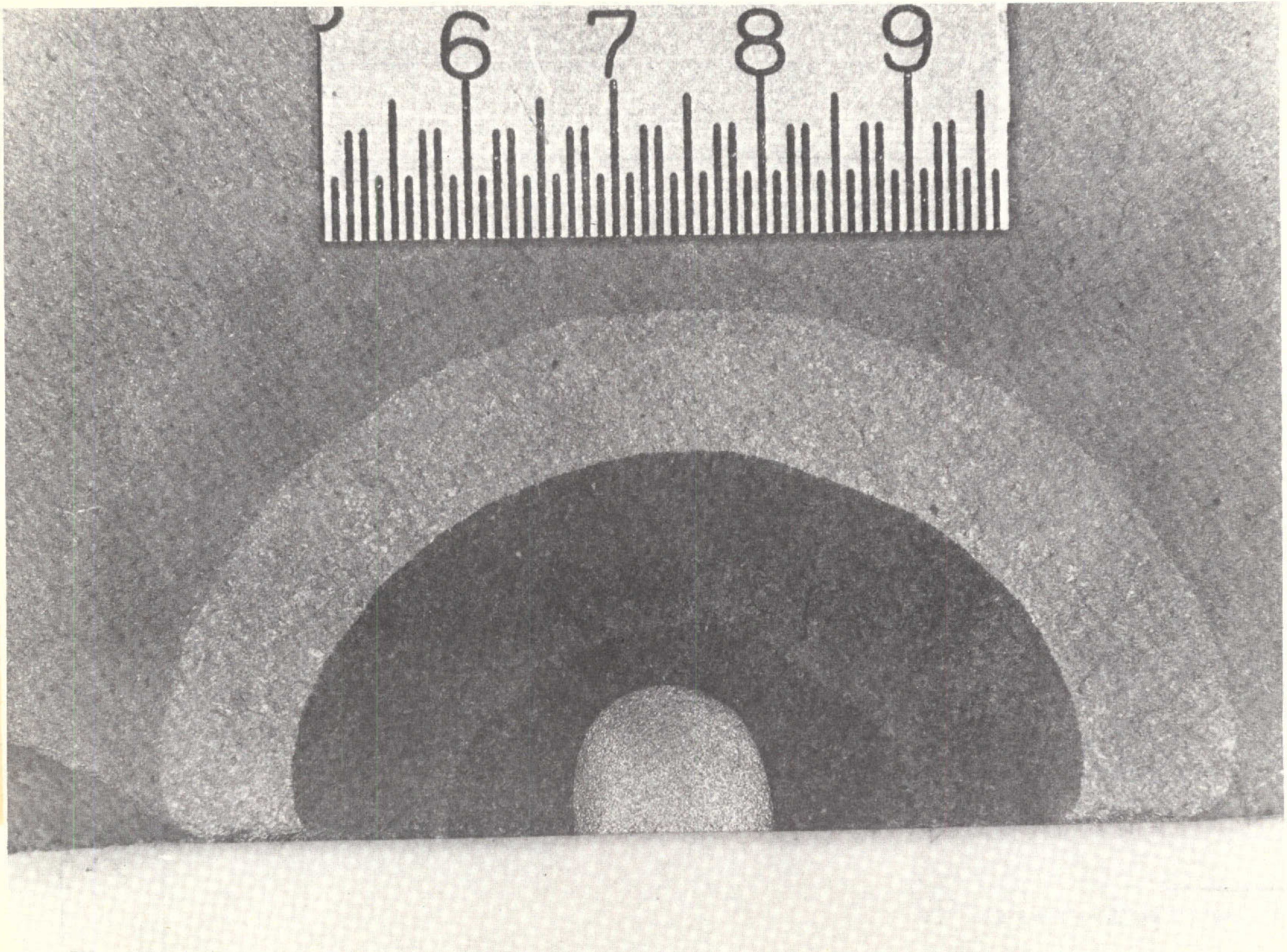

Fig. 7 Fracture Surface of Surface Flaw Specimen Showing Multiple Cycle Growth Increments

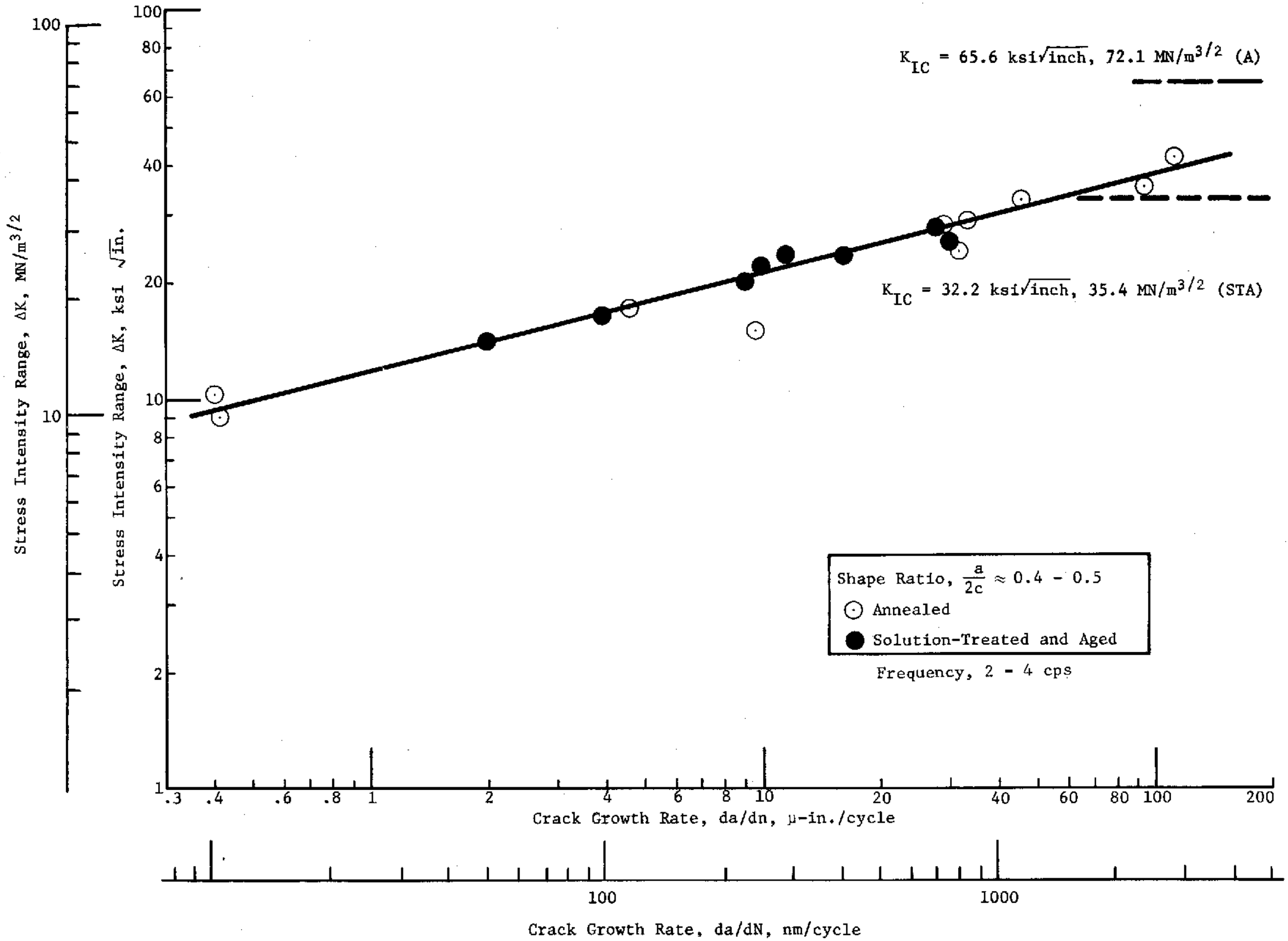

Fig. 8 Crack Growth Rates for 6Al-6V-2Sn Titanium at Room Temperature from Surface-Flaw Tests

2. Compact Tension Tests

All compact tension crack propagation samples shown in Fig. 4 were precracked at room temperature by tension fatigue using an R ratio of 0.10. The annealed samples were precracked at a maximum load of 4000 lb ($K_{max} \approx 17$ ksi$\sqrt{in.}$, 19 $MN/m^{3/2}$) and the STA samples at a maximum load of 3500 lb ($K_{max} \approx 15$ ksi$\sqrt{in.}$, 17 $MN/m^{3/2}$). These stress intensities are 29 and 49% of the room temperature (K_{Ic}) respectively. All flaws were precracked to a length of about 0.87, or a/W equal to 0.35.

Environmental control for testing at $-65^{o}F$ ($220^{o}K$), $300^{o}F$ ($422^{o}K$), 10% RH, and 100% RH was identical to that used for the fracture-toughness and sustained-load threshold samples.

After precracking, all samples were cycled in tension fatigue using an R ratio of about 0.05 and a cyclic frequency of 10 cps. Cyclic loads were selected to obtain growth rates of one to 100 μin. per cycle. Each flawed sample was incrementally grown in the a/W range 0.35 to 0.65 using a Δa of about 0.070 in. (0.175 cm) for each increment. Specimen compliance was measured at room temperature with a COD extensometer after each growth increment. The actual growth in each increment was determined from the experimental compliance calibration curve given in Fig. 9, which shows compliance as a function of relative crack length.

The calibration specimens were incrementally grown at a medium to high level of stress intensity. Growth increments were delineated by fatigue marking at a low level of stress intensity. After fracture, the actual crack length after each increment was measured on the plane of the fracture surface using a measuring microscope. The crack length (a) was taken as the average of three measurements across the crack front per ASTM E399. From these data, the compliance calibration curve shown in Fig. 9 was generated.

Flaw growth rates (da/dN) were determined by dividing the incremental growth (Δa) by the incremental cycles (ΔN). Corresponding cyclic stress intensity ranges were calculated using the stress intensity expression for a compact tension specimen (Eq. 1). An outline of the calculations for each sample is presented in Appendices B, C, D, and E. Crack growth rates for annealed and STA titanium 6-6-2 from compact tension tests are shown as a function of stress intensity range in Fig. 10 (RT-10% RH), 11 (RT-100% RH), 12 ($-65^{o}F$, $220^{o}K$), and 13 ($300^{o}F$, $422^{o}K$).

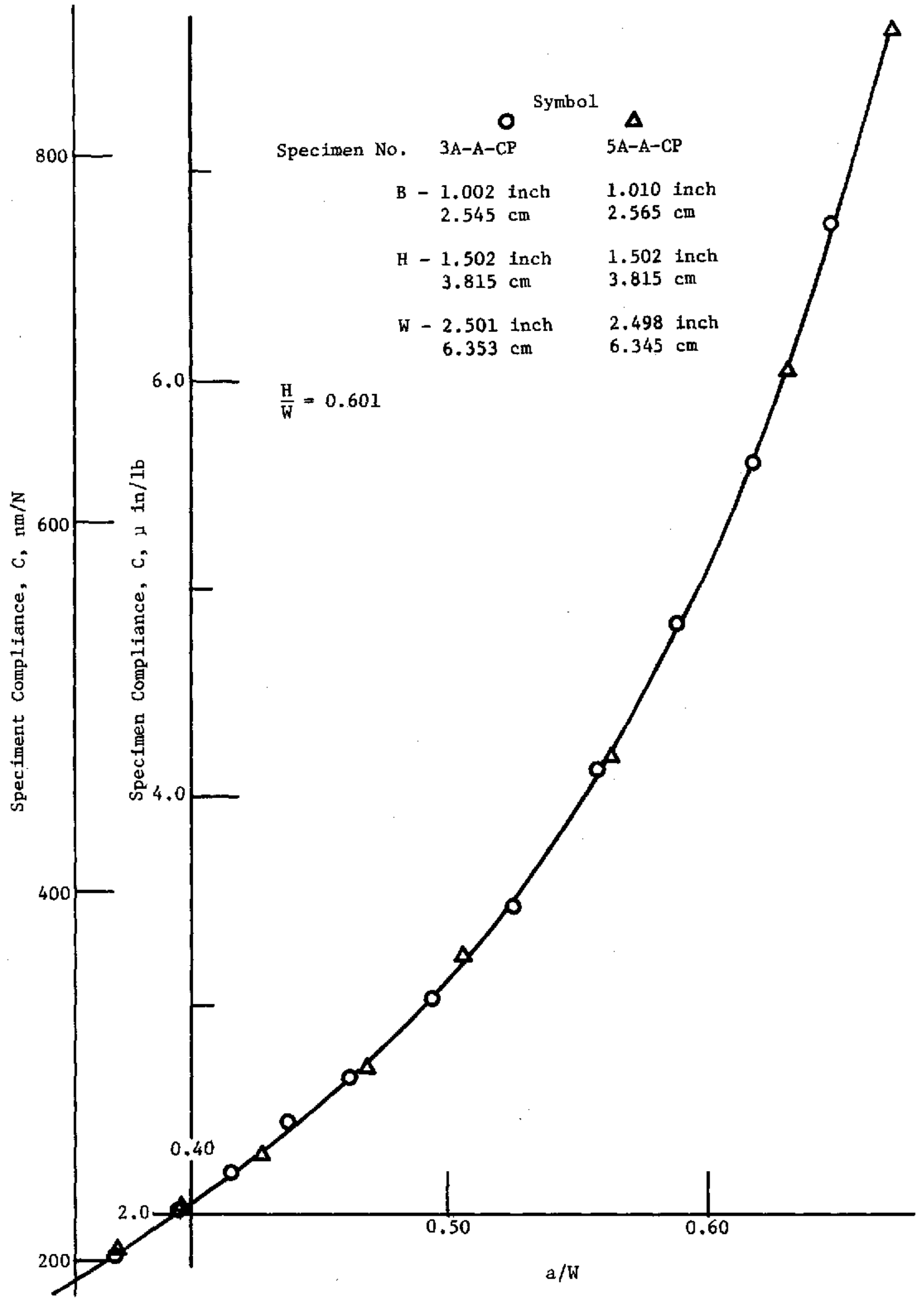

Fig. 9 Compliance Calibration Curve for 6Al-6V-2Sn Titanium Compact Tension Specimens

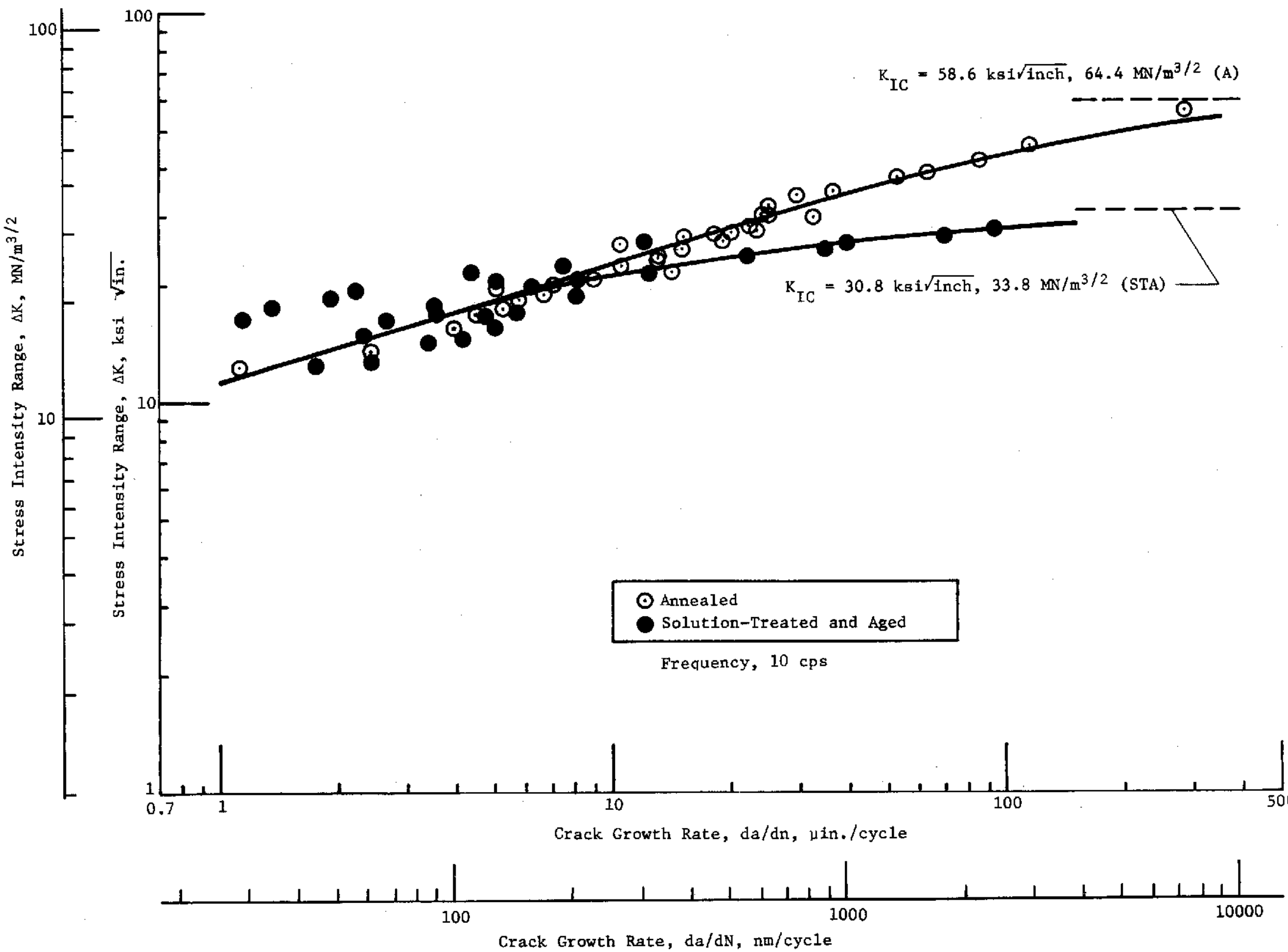

Fig. 10 Crack Growth Rates for 6Aℓ-6V-2Sn Titanium at Room Temperture in 10% Relative Humidity Air

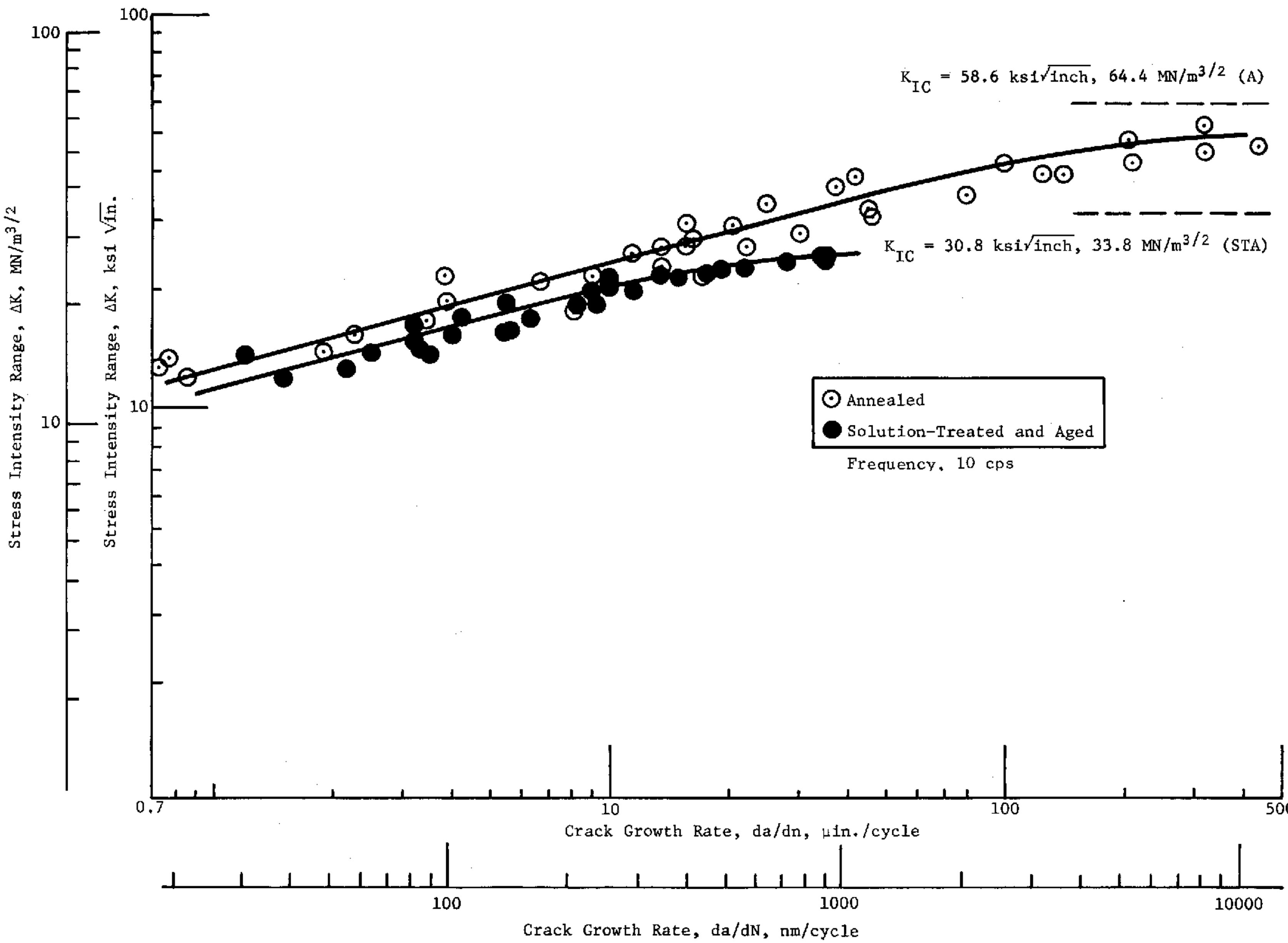

Fig. 11 Crack Growth Rates for 6Al-6V-2Sn Titanium at Room Temperature in 100% Relative Humidity Air

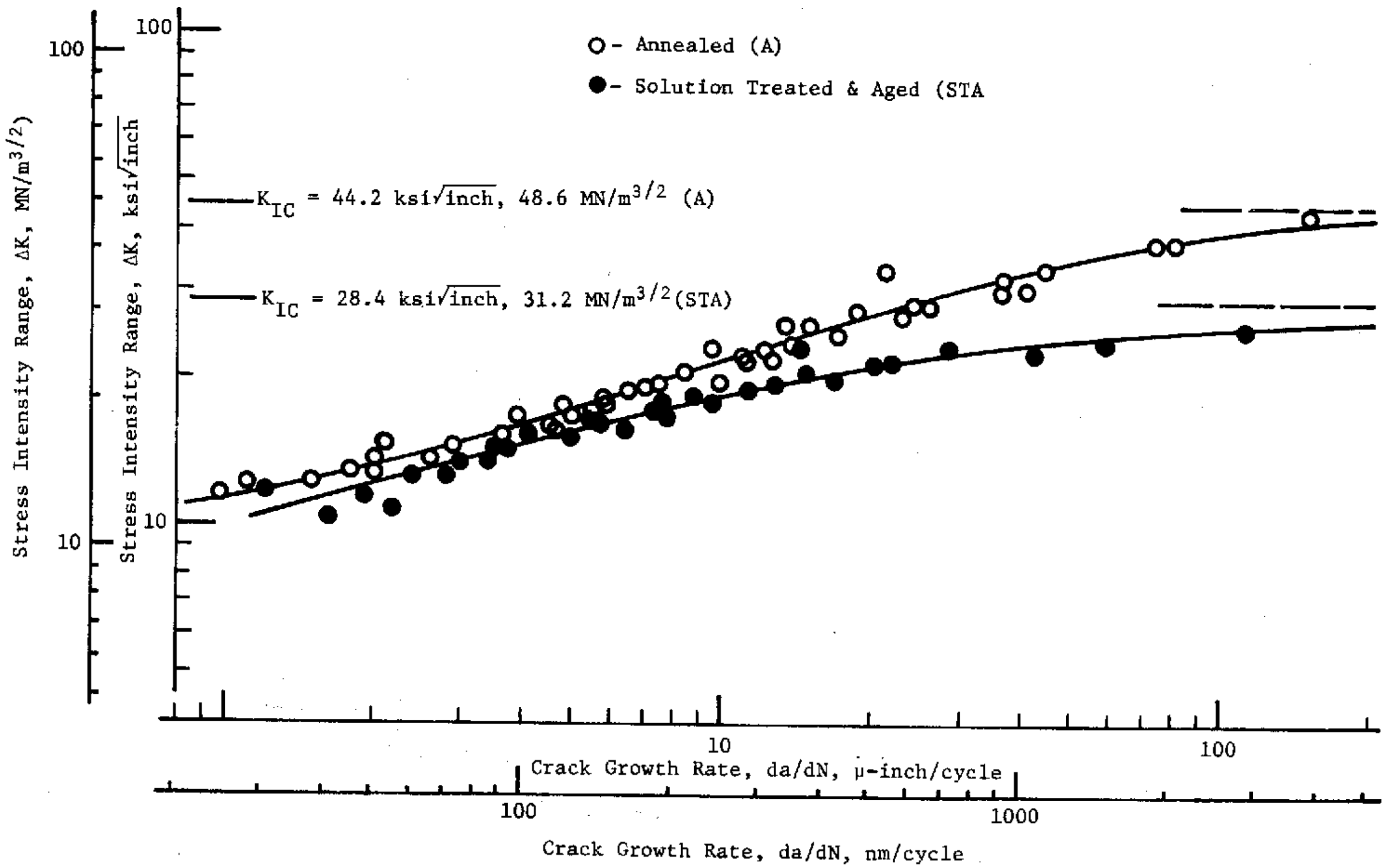

Figure 12 Crack Growth Rates for 6Aℓ-6V-2Sn Titanium at -65°F

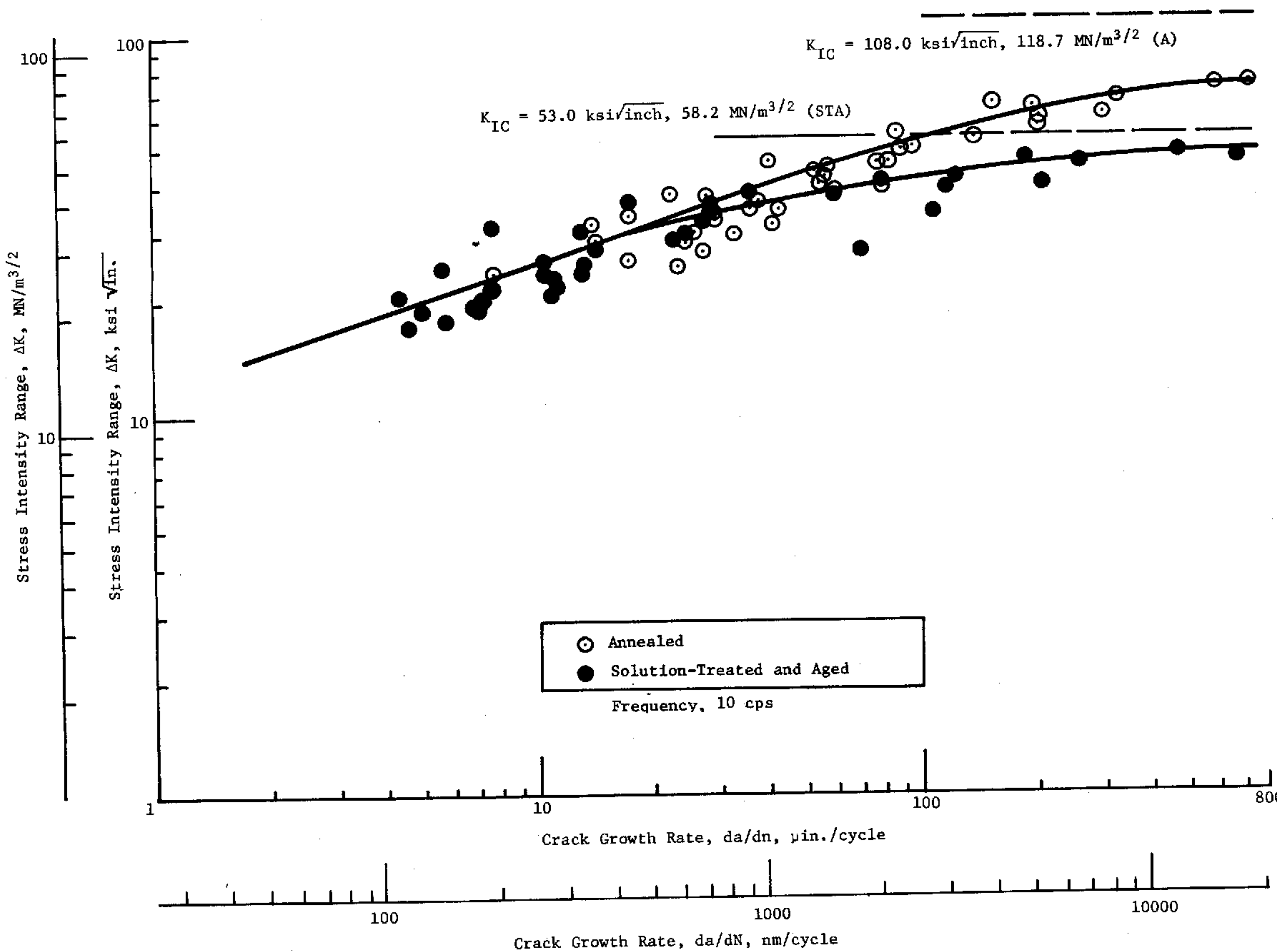

Fig. 13 Crack Growth Rates for 6Al-6V-2Sn Titanium at 300°F

V. DISCUSSION OF RESULTS AND CONCLUSIONS

Tensile property data for annealed and STA titanium 6Aℓ-6V-2Sn exceed minimum properties required by MIL-T-9047E. Yield and ultimate strengths are generally about 10% higher than for the more widely used titanium 6Aℓ-4V alloy.

Over the range from -65 to 300°F (220 to 422°K), the fracture toughness of STA material is less sensitive to temperature than that of annealed material. Room temperature fracture toughness values for the STA condition, from compact tension and surface-flaw tests, are within 4% of each other; however, for the annealed condition, the surface-flaw K_{Ic} was 12% higher. Comparison of surface-flaw results with those for compact tension is often difficult if one is looking for the most appropriate test for design purposes. Provided width and thickness restraint is sufficient, the surface-flaw test is more attractive because it represents typical flaws in aerospace hardware. However, apparent values of K_{Ic} from surface-flaw tests are generally slightly higher than from compact tension tests, which give lower bound values. One reason for this may be that, while the compact tension stress intensity expression is exact, the surface-flaw stress-intensity expression is only approximate, requiring the use of correction factors. The fracture toughness of STA titanium 6-6-2 is generally about 30% lower than for titanium 6Aℓ-4V STA. Annealed toughness values for both alloys are similar.

There appears to be no relative humidity effect on sustained-load threshold stress intensity (K_{TH}) for either annealed or STA titanium 6-6-2. For annealed material, K_{TH} was approximately 43 to 45% of K_{Ic}, or 26 ksi$\sqrt{in.}$ (29 MN/m$^{3/2}$). For the STA condition, K_{TH} was 69 to 70% of K_{Ic}, or 21 ksi$\sqrt{in.}$ (23 MN/m$^{3/2}$). It is interesting that both threshold stress intensities are very close, indicating that crack initiation and propagation behavior might also be the same at low stress intensities. K_{TH} for titanium 6-6-2 appears to be about 45% lower than for STA titanium 6-4, whose K_{TH} is approximately 0.9 K_{Ic}.

Crack growth rates for annealed and STA titanium at room temperature are similar up to a stress intensity of about 20 ksi$\sqrt{in.}$ (22 MN/m$^{3/2}$). At higher stress intensities (20 to 30 ksi$\sqrt{in.}$, 22 to 33 MN/m$^{3/2}$), the growth rate is higher in the STA material because K is approaching K_{Ic}. Relative humidity appears to have no effect on the flaw growth rate. The crack growth rate curves from compact tension tests and surface-flaw tests are identical. Flaw growth rates in titanium 6-6-2 are generally higher than for titanium 6-4.

Crack growth rates for annealed and STA titanium at 300°F (422°K) are similar up to a stress intensity of about 35 ksi in. (39 $MN/m^{3/2}$). At higher stress intensities (35 to 50 ksi$\sqrt{in.}$, 38 to 55 $MN/m^{3/2}$), the growth rate is higher in the STA material because K is approaching K_{Ic}. Crack growth rates at 300°F (422°K) are significantly less than at room temperature. At -65°F (220°K) growth rates are slightly more than at room temperature, with STA material having a faster growth rate than annealed material at all stress intensities.

In general, titanium 6Aℓ-6V-2Sn is a stronger, but more brittle material than titanium 6Aℓ-4V. Sustained load threshold for flaw growth is especially low, being about 21 ksi$\sqrt{in.}$ (23 $MN/m^{3/2}$). Titanium 6Aℓ-6V-2Sn can be used for Space Shuttle application only in areas where low fracture toughness will not be a problem and weight savings can be achieved from the increased strength.

APPENDIX A

Cyclic Crack Growth Data from Surface-Flaw Tests at Room Temperature

Table A-1 Crack Growth Rates for 6A -6V-2Sn Titanium from Surface Flaw Tests at Room Temperature

a. U.S. Customary Units

	Annealed					Solution Treated and Aged			
Specimen No.	32-1-A	29-3-A	29-1-A	29-2-A	32-2-A	30-1-H	33-1-H	30-2-H	30-3-H
W, in.	3.680	3.680	3.630	3.700	3.670	3.701	3.700	3.690	3.670
t, in.	1.010	1.020	0.920	0.979	0.910	1.014	1.014	0.970	1.010
A, $in.^2$	3.717	3.754	3.340	3.622	3.340	3.753	3.752	3.579	3.707
P_{max}, kips	111.0	195.0	140.0	218.0	54.0	131.0	92.0	136.0	152.0
P_{min}, kips	5.0	5.0	4.0	6.0	1.0	4.0	2.0	4.0	6.0
S_{max}, ksi	29.9	51.9	41.9	60.2	16.2	34.9	24.5	38.0	41.0
S_{min}, ksi	1.3	1.3	1.2	1.7	0.3	1.1	0.5	1.1	1.6
Initial Crack Data									
a_o, in.	0.105	0.125	0.125	0.140	0.130	0.175	0.165	0.175	0.170
$(2c)_o$, in.	0.327	0.363	0.385	0.391	0.381	0.381	0.380	0.380	0.380
$(a/2c)_o$	0.321	0.344	0.325	0.358	0.341	0.459	0.434	0.432	0.447
(Q_o)	1.70	1.79	1.72	1.84	1.77	2.27	2.16	2.15	2.21
$(\Delta K)_o$, ksi$\sqrt{in.}$	13.9	26.2	21.6	31.6	8.4	18.2	12.9	20.0	21.2
Crack Growth Data (Band 1)									
a_1, in.	0.158	0.185	0.210	0.260	0.165	0.250	0.250	0.250	0.250
$(2c)_1$, in.	0.408	0.473	0.531	0.526	0.524	0.526	0.519	0.521	0.521
$(a/2c)_1$	0.387	0.391	0.395	0.494	0.315	0.475	0.482	0.480	0.480

Table A-1 (cont)

	Annealed					Solution Treated and Aged			
Specimen No.	32-1-A	29-3-A	29-1-A	29-2-A	32-2-A	30-1-H	33-1-H	30-2-H	30-3-H
(Q_1)	1.95	1.97	1.99	2.44	1.68	2.35	2.39	2.38	2.38
$(\Delta K)_1$, ksi$\sqrt{in.}$	16.0	30.3	25.9	37.5	9.7	21.5	15.1	23.4	25.0
Δa, in.	0.053	0.060	0.085	0.120	0.035	0.075	0.085	0.075	0.080
$(\Delta K)_{0-1,\ avg}$, ksi$\sqrt{in.}$	14.9	28.3	23.7	34.6	9.0	19.9	14.0	21.7	23.1
ΔN_1, cycles	5500	1800	2700	1283	85,000	8372	43,000	7600	7103
$(\Delta a/\Delta N)$, (μin./cycle)	9.6	33.3	31.5	93.5	0.41	9.0	2.0	9.9	11.3
Crack Growth Data (Band 2)									
a_2, in.	0.190	0.235	0.270	0.360	0.200	0.330	0.350	0.335	0.345
$(2c)_2$, in.	0.535	0.408	0.397	0.507	0.302	0.492	0.522	0.500	0.516
$(a/2c)_2$	0.355	0.408	0.397	0.507	0.302	0.492	0.522	0.500	0.516
(Q_2)	1.83	2.04	2.00	2.46	1.63	2.43	2.46	2.46	2.46
$(\Delta K)_2$, ksi$\sqrt{in.}$	18.0	33.7	29.2	43.9	10.8	24.2	17.6	26.5	28.7
Δa, in.	0.032	0.050	0.060	0.100	0.035	0.080	0.100	0.085	0.095
$(\Delta K)_{1-2,\ avg}$, ksi$\sqrt{in.}$	17.0	32.0	27.5	40.7	10.3	22.9	16.3	24.9	26.9
ΔN_2, cycles	7000	1100	2070	900	87,000	4904	25,525	2850	3470
$(\Delta a/\Delta N)$, (μin./cycle)	4.6	45.5	29.0	111.1	0.4	16.3	3.9	29.8	27.4

Table A-1 Crack Growth Rates for 6A -6V-2Sn Titanium from Surface Flaw Tests at Room Temperature

b. International Units (S.I.)

	Annealed					Solution Treated and Aged			
Specimen No.	32-1-A	29-3-A	29-1-A	29-2-A	32-2-A	30-1-H	33-1-H	30-2-H	30-3-H
W, cm	9.347	9.347	9.220	9.398	9.322	9.401	9.398	9.373	9.320
t, cm	2.565	2.591	2.337	2.487	2.311	2.516	2.576	2.464	2.565
A, cm^2	23.98	24.21	21.54	23.36	21.54	24.21	24.20	23.09	23.91
P_{max}, N	493	667	662	969	240	582	409	604	676
P_{min}, N	22	22	17	26	41	17	8	17	26
S_{max}, MN/m^2	206	357	288	415	111	240	168	262	282
S_{min}, MN/m^2	9	9	6	11	2	6	3	6	11
Initial Crack Data									
a_o, cm	0.267	0.318	0.318	0.356	0.330	0.445	0.419	0.445	0.432
$(2c)_o$, cm	0.831	0.922	0.978	0.993	0.968	0.968	0.965	0.965	0.965
$(a/2c)_o$	0.321	0.344	0.325	0.358	0.341	0.459	0.434	0.432	0.447
(Q_o)	1.70	1.79	1.72	1.84	1.77	2.27	2.16	2.15	2.21
$(\Delta K)_o$, $MN/m^{3/2}$	15.2	28.7	23.7	34.7	9.2	20.0	14.1	21.9	23.3
Crack Growth Data (Band 1)									
a_1, cm	0.401	0.470	0.533	0.660	0.419	0.635	0.635	0.635	0.635
$(2c)_1$, cm	1.219	1.201	1.349	1.336	1.331	1.336	1.318	1.323	1.323
$(a/2c)_1$	0.387	0.391	0.395	0.494	0.315	0.475	0.482	0.480	0.480
(Q_1)	1.95	1.97	1.99	2.44	1.68	2.35	2.39	2.38	2.38

Table A-1 (cont)

Specimen No.	Annealed 32-1-A	29-3-A	29-1-A	29-2-A	32-2-A	Solution Treated and Aged 30-1-H	33-1-H	30-2-H	30-3-H
$(\Delta K)_1$, $MN/m^{3/2}$	17.5	33.1	28.4	41.2	10.6	23.6	16.5	25.7	27.4
Δa, cm	0.135	0.152	0.216	0.305	0.085	0.191	0.216	0.191	0.203
$(\Delta K)_{0-1,\ avg}$, $MN/m^{3/2}$	16.3	31.1	28.0	38.0	9.8	21.8	15.3	23.8	25.3
N_1, cycles	5500	1800	2700	1283	85,000	8372	43,000	7600	7103
$(\Delta a/\Delta N)$, (nm/cycle)	243	845	792	2374	10	228	50	251	287
Crack Growth Data (Band 2)									
a_2, cm	0.483	0.597	0.686	0.914	0.508	0.838	0.889	0.851	0.876
$(2c)_2$, cm	1.359	1.037	1.008	1.288	0.767	1.249	1.326	1.270	1.317
$(a/2c)_2$	0.355	0.408	0.397	0.507	0.302	0.492	0.522	0.500	0.516
(Q_2)	1.83	2.04	2.00	2.46	1.63	2.43	2.46	2.46	2.46
$(\Delta K)_2$ $MN/m^{3/2}$	19.7	37.0	32.0	48.2	11.8	26.5	19.0	29.0	31.0
Δa, cm	.0813	.127	.1524	.254	.0889	.203	.254	.2159	.2413
$(\Delta K)_{1-2,\ avg}$, $MN/m^{3/2}$	18.6	35.1	30.2	44.7	11.3	25.1	17.9	27.3	29.5
N_2, cycles	7000	1100	2070	900	87,000	4904	25,525	2850	3470
$(\Delta a/\Delta N)$, (nm/cycle)	116	1155	736	2821	10	414	99	756	695

APPENDIX B

Cyclic Crack Growth Data from Compact Tension Tests in 10% Relative Humidity Air

Table B-1 Specimen 11B-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
11B-A-CP	10% RH-RT	1.008	2.499	3000	200

x	C μin./lb	a/W	a in.	Δa, in.	Y	ΔK ksi$\sqrt{in.}$	ΔK_{AV} ksi$\sqrt{in.}$	ΔN cycles	da/dn μin./cycle
1	1.74	0.364	0.910	0.065	11.12	11.79	12.16	50,000	1.30
2	1.96	0.390	0.975	0.122	11.44	12.54	13.39	50,000	2.44
3	2.42	0.439	1.097	0.135	12.22	14.23	15.38	34,000	3.97
4	3.05	0.493	1.232	0.080	13.40	16.53	17.38	15,000	5.33
5	3.53	0.525	1.312	0.060	14.31	18.22	18.97	9,000	6.67
6	3.97	0.549	1.372	0.072	15.07	19.71	20.78	8,000	9.00
7	4.60	0.578	1.444	0.093	16.36	21.86	23.57	7,000	13.29
8	5.57	0.615	1.537	0.072	18.35	25.28	26.98	4,000	18.00
9	6.59	0.644	1.609	0.050	20.34	28.69	30.08	2,000	25.00
10	7.48	0.664	1.659		21.99	31.48			

Table B-1 **Specimen 11B-A-CP** b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
11B-A-CP	10% RH-RT	2.560	6.348	13,300	890

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.93	0.364	2.31		11.12	12.96			
				0.165			13.36	50,000	33
2	11.19	0.390	2.47		11.44	13.78			
				0.310			14.71	50,000	61
3	13.81	0.439	2.78		12.22	15.64			
				0.343			16.90	34,000	100
4	17.41	0.493	3.12		13.40	18.16			
				0.203			19.10	15,000	135
5	20.15	0.525	3.33		14.31	20.02			
				0.152			20.84	9,000	165
6	22.66	0.549	3.48		15.07	21.66			
				0.183			22.83	8,000	228
7	26.26	0.578	3.66		16.36	24.02			
				0.236			25.90	7,000	337
8	31.80	0.615	3.90		18.35	27.78			
				0.183			29.65	4,000	457
9	37.63	0.644	4.08		20.34	31.52			
				0.127			33.05	2,000	635
10	42.71	0.664	4.21		21.99	34.59			

Table B-2 Specimen 4C-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
4C-A-CP	10% RH-RT	1.007	2.499	4000	200

x	C, μin./lb	a/W	a_i, in.	Δa, in.	Y	ΔK, ksi$\sqrt{in}$	ΔK_{AV}, ksi$\sqrt{in}$	ΔN, cycles	da/dn, μin/cycle
1	1.80	0.371	0.927	0.068	11.20	16.27	16.84	15,000	4.53
2	2.03	0.398	0.995	0.087	11.55	17.40	18.21	15,000	5.80
3	2.36	0.433	1.082	0.085	12.11	19.02	19.93	12,000	7.08
4	2.72	0.467	1.167	0.107	12.78	20.83	22.23	10,000	10.70
5	3.28	0.510	1.274	0.153	13.86	23.63	26.30	10,000	15.30
6	4.45	0.571	1.427		16.05	28.96			

-c B-2 Specimen 4C-A-CP

b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
4C-A-CP	10% RH-RT	2.558	6.348	17,800	890

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.28	0.371	2.35	0.173	11.20	17.88	18.50	15,000	115
2	11.59	0.398	2.52	0.221	11.55	19.12	20.01	15,000	147
3	13.48	0.433	2.74	0.216	12.11	20.90	21.90	12,000	179
4	15.53	0.467	2.95	0.272	12.78	22.89	24.43	10,000	271
5	18.73	0.510	3.23	0.389	13.86	25.97	28.90	10,000	388
6	25.41	0.571	3.62		16.05	31.87			

Table B-3 Specimen 6A-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
6A-A-CP	10% RH-RT	1.009	2.501	5,000	250

x	C, μin./lb	a/W	a_i, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.746	0.364	0.910	0.0304	11.12	19.18	19.86	6,000	5.07
2	1.846	0.376	0.940	0.0854	11.26	20.54	21.44	6,000	14.23
3	2.142	0.410	1.025	0.0654	11.73	22.35	23.13	5,000	13.08
4	2.383	0.436	1.090	0.0755	12.16	23.91	24.92	5,000	15.10
5	2.705	0.466	1.165	0.0930	12.76	25.93	27.38	4,000	23.25
6	3.185	0.503	1.258	0.0725	13.66	28.84	30.21	3,000	24.17
7	3.647	0.532	1.331	0.0746	14.54	31.58	33.26	2,500	29.84
8	4.240	0.562	1.406	0.1270	15.66	34.95	38.72	2,000	63.50
9	5.508	0.613	1.533		18.23	42.49		750	
10	8.136								

Table B-3 Spècimen 6A-A-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
6A-A-CP	10% RH-RT	2.562	6.353	22,200	1100

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.97	0.364	2.31	0.077	11.12	20.08	21.82	6,000	128
2	10.54	0.376	2.39	0.217	11.26	22.57	23.56	6,000	361
3	12.23	0.410	2.60	0.166	11.73	24.57	25.42	5,000	332
4	13.61	0.436	2.77	0.192	12.16	26.27	27.38	5,000	383
5	15.45	0.466	2.96	0.236	12.76	28.49	30.09	4,000	590
6	18.19	0.503	3.20	0.184	13.66	31.69	33.20	3,000	613
7	20.83	0.532	3.38	0.190	14.54	34.70	36.55	2,500	757
8	24.21	0.562	3.57	0.323	15.66	38.40	42.55	2,000	1612
9	31.45	0.613	3.89		18.23	46.69		750	
10	46.46								

Table B-4 Specimen 22C-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
22C-A-CP	10% RH-RT	1.004	2.503	6000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.76	0.367	0.919	0.032	11.16	24.68	25.07	3,000	10.67
2	1.87	0.380	0.951	0.038	11.31	25.46	25.93	2,000	19.00
3	2.00	0.395	0.989	0.040	11.51	26.41	26.95	2,000	20.00
4	2.15	0.411	1.029	0.045	11.74	27.49	28.13	2,000	22.50
5	2.32	0.429	1.074	0.067	12.04	28.78	29.86	2,000	33.50
6	2.59	0.456	1.141	0.050	12.55	30.94	31.82	2,000	25.00
7	2.83	0.476	1.191	0.073	12.98	32.71	34.15	2,000	36.50
8	3.22	0.505	1.264	0.080	13.72	35.60	37.48	1,500	53.33
9	3.73	0.537	1.344	0.078	14.71	39.37	41.58	900	86.67
10	4.36	0.568	1.422	0.070	15.91	43.80	46.23	600	116.67
11	5.03	0.596	1.492	0.145	17.26	48.67	55.54	500	290.00
12	7.04	0.654	1.637		21.13	62.41			

Table B-4 **Specimen 22C-A-CP** b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
22C-A-CP	**10% RH-RT**	2.560	6.360	26,700	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.05	0.367	2.33	0.081	11.16	27.12	27.55	3,000	271
2	10.68	0.380	2.42	0.097	11.31	27.98	28.49	2,000	482
3	11.47	0.395	2.52	0.102	11.51	29.02	29.61	2,000	508
4	12.28	0.411	2.61	0.114	11.74	30.21	30.91	2,000	571
5	13.25	0.429	2.73	0.170	12.04	31.62	32.81	2,000	850
6	14.79	0.456	2.90	0.127	12.55	34.00	34.96	2,000	635
7	16.16	0.476	3.03	0.185	12.98	35.94	37.52	2,000	927
8	13.39	0.505	3.21	0.211	13.72	39.12	41.83	1,500	1,354
9	21.30	0.537	3.41	0.198	14.71	43.26	45.69	900	2,201
10	24.90	0.568	3.61	0.178	15.91	43.80	50.80	600	2,963
11	28.74	0.596	3.79	0.368	17.26	53.48	61.03	500	7,366
12	40.70	0.654	4.16		21.13	68.58			

Table B-5 Specimen 1A-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
1A-H-CP	10% RH-RT	1.003	2.500	3000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi$\sqrt{in.}$	ΔK_{AV}, ksi$\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.77	0.367	0.918	0.037	11.16	11.94	12.16	21,000	1.76
2	1.89	0.382	0.955	0.073	11.33	12.38	12.84	30,000	2.43
3	2.15	0.411	1.028	0.102	11.74	13.30	14.04	30,000	3.40
4	2.56	0.452	1.130	0.080	12.47	14.79	15.48	15,500	5.16
5	2.93	0.484	1.210	0.075	13.17	16.17	16.94	13,000	5.77
6	3.35	0.514	1.285	0.073	13.97	17.70	18.56	9,000	8.11
7	3.85	0.543	1.358		14.92	19.42			

Table B-6 Specimen 6B-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
6B-H-CP	10% RH-RT	1.004	2.497	3500	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi$\sqrt{in.}$	ΔK_{AV}, ksi$\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.76	0.367	0.916	0.050	11.16	14.06	14.40	12,000	4.17
2	1.93	0.387	0.966	0.002	11.40	14.75	14.77	12,000	0.17
3	1.94	0.388	0.968	0.028	11.41	14.79	14.99	12,000	2.33
4	2.04	0.399	0.996	0.048	11.56	15.20	15.57	12,000	4.00
5	2.22	0.418	1.044	0.032	11.85	15.94	16.21	12,000	2.67
6	2.34	0.431	1.076	0.043	12.07	16.49	16.87	12,000	3.58
7	2.52	0.448	1.119	0.042	12.39	17.25	17.66	12,000	3.50
8	2.69	0.465	1.161	0.057	12.74	18.07	18.68	12,000	4.75
9	2.97	0.488	1.219	0.062	13.27	19.28	20.03	12,000	5.17
10	3.33	0.513	1.281	0.090	13.95	20.78	22.06	12,000	7.50
11	3.97	0.549	1.371	0.120	15.15	23.34	25.59	10,000	12.00
12	5.06	0.597	1.491		17.32	27.83			

Table B-5 Specimen 1A-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
1A-H-CP	10% RH-RT	2.545	6.350	13,300	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.11	0.367	2.33	0.094	11.16	13.12	13.36	21,000	44
2	10.79	0.382	2.43	0.185	11.33	13.60	14.11	30,000	61
3	12.28	0.411	2.61	0.259	11.74	14.61	15.43	30,000	66
4	14.62	0.452	2.87	0.203	12.47	16.25	17.01	15,500	131
5	16.73	0.484	3.07	0.191	13.17	17.77	18.61	13,000	146
6	19.13	0.514	3.26	0.185	13.97	19.45	20.39	9,000	205
7	21.98	0.543	3.45		14.92	21.34			

Table B-6 Specimen 6B-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
6B-H-CP	10% RH-RT	2.548	6.344	15,600	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.05	0.367	2.33	0.127	11.16	15.45	15.82	12,000	105
2	11.02	0.387	2.45	0.005	11.40	16.21	16.23	12,000	4
3	11.08	0.388	2.46	0.071	11.41	16.25	16.47	12,000	59
4	11.65	0.399	2.53	0.121	11.56	16.70	17.11	12,000	101
5	12.68	0.418	2.65	0.081	11.85	17.52	17.81	12,000	67
6	13.36	0.431	2.73	0.109	12.07	18.12	18.54	12,000	90
7	14.39	0.448	2.84	0.107	12.39	18.95	19.86	12,000	88
8	15.36	0.465	2.95	0.145	12.74	19.86	20.53	12,000	120
9	16.96	0.488	3.10	0.158	13.27	21.19	22.01	12,000	131
10	19.02	0.513	3.25	0.229	13.95	22.83	24.24	12,000	190
11	22.67	0.549	3.48	0.305	15.15	25.65	28.12	10,000	304
12	28.89	0.597	3.79		17.32	30.58			

Table B-7 Specimen 13A-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
13A-H-CP	10% RH-RT	1.003	2.503	4000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn μin./cycle
1	1.75	0.365	0.914	0.047	11.13	16.12	16.49	41,000	1.15
2	1.91	0.384	0.961	0.055	11.36	16.86	17.33	40,000	1.38
3	2.10	0.406	1.016	0.058	11.67	17.79	18.35	30,000	1.93
4	2.32	0.429	1.074	0.067	12.04	18.90	19.59	30,000	2.23
5	2.60	0.456	1.141	0.105	12.55	20.28	21.58	24,000	4.38
6	3.11	0.498	1.246		13.53	22.87			

Table B-8 Speciment 25C-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
25C-H-CP	10% RH-RT	1.000	2.498	5000	250

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn μin./cycle
1	1.64	0.351	0.877	0.025	10.99	19.56	19.79	4,000	6.25
2	1.72	0.361	0.902	0.032	11.09	20.02	20.33	4,000	8.00
3	1.83	0.374	0.934	0.050	11.24	20.64	21.17	4,000	12.50
4	1.99	0.394	0.984	0.043	11.49	21.70	22.17	3,000	14.33
5	2.15	0.411	1.027	0.055	11.74	22.63	23.29	2,500	22.00
6	2.36	0.433	1.082	0.035	12.11	23.95	24.40	1,000	35.00
7	2.50	0.447	1.117	0.040	12.37	24.85	25.40	1,000	40.00
8	2.68	0.463	1.157	0.035	12.69	25.96	26.48	500	70.00
9	2.84	0.477	1.192	0.047	13.00	26.99	27.76	500	94.00
10	3.09	0.496	1.239		13.47	28.52			

Table B-7 Specimen 13-A-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
13A-H-CP	10% RH-RT	2.548	6.358	17,800	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.99	0.365	2.32	0.119	11.13	17.71	18.12	41,000	29
2	10.91	0.384	2.44	0.140	11.36	18.53	19.04	40,000	35
3	11.99	0.406	2.58	0.148	11.67	19.55	20.16	30,000	49
4	13.32	0.429	2.72	0.170	12.04	20.77	21.53	30,000	56
5	14.85	0.456	2.90	0.267	12.55	22.28	23.71	24,000	111
6	17.76	0.498	3.17		13.53	25.13			

Table B-8 Specimen 25C-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
25C-H-CP	10% RH-RT	2.540	6.345	22,200	1100

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.34	0.351	2.23	0.064	10.99	21.49	21.75	4,000	158
2	9.82	0.361	2.29	0.081	11.09	22.00	22.34	4,000	203
3	10.45	0.374	2.37	0.127	11.24	22.68	23.26	4,000	317
4	11.36	0.394	2.50	0.109	11.49	23.84	24.36	3,000	363
5	12.28	0.411	2.61	0.140	11.74	24.87	25.59	2,500	558
6	13.48	0.433	2.75	0.089	12.11	26.32	26.81	1,000	889
7	14.27	0.447	2.84	0.102	12.37	27.31	27.91	1,000	1,016
8	15.30	0.463	2.94	0.089	12.69	28.53	26.10	500	1,778
9	16.22	0.477	3.03	0.120	13.00	29.66	30.50	500	2,387
10	17.64	0.496	3.15		13.47	31.34			

APPENDIX C

Cyclic Crack Growth Data from Compact Tension Tests in 100% Relative Humidity Air

Table C-1 Specimen 4A-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
4-A-CP	100% RH-RT	1.010	2.475	3000	200

x	C, µin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dN, µin./cycle
1	1.72	0.361	0.893		11.09	11.74			
2	1.86	0.378	0.936	0.043	11.28	12.23	11.98	50,000	0.86
3	2.01	0.396	0.980	0.044	11.52	12.78	12.51	60,000	0.73
6A	2.27	0.424	1.049	0.069	11.95	13.71	13.25	90,000	0.77
7	2.42	0.439	1.087	0.038	12.22	14.22	13.97	20,000	1.90
8	2.83	0.476	1.178	0.091	12.98	15.79	15.01	40,000	2.28
9	3.19	0.504	1.247	0.069	13.69	17.26	16.53	20,000	3.45
10	4.02	0.551	1.364	0.117	15.22	19.92	18.59	30,000	3.90
11	4.88	0.588	1.455	0.091	16.85	22.77	21.35	10,000	9.10
12	6.16	0.632	1.564	0.109	19.47	27.28	25.03	8,000	13.63
13	7.19	0.657	1.626	0.062	21.38	30.54	28.91	3,000	20.67
14	8.40							2,000	

Table C-2 Specimen 10A-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
10A-A-CP	100% RH-RT	1.004	2.475	4000	200

x	C, µin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dN, µin./cycle
1	1.78	0.368	0.911		11.17	16.29			
2	2.20	0.417	1.032	0.121	11.84	18.41	17.35	15,000	8.07
3	3.24	0.507	1.255	0.223	13.77	23.61	21.01	13,000	17.15
4	4.04	0.552	1.366	0.111	15.26	27.28	25.44	7,000	15.86
5	5.93	0.626	1.549	0.183	19.06	36.28	31.78	4,000	45.75
6	7.06	0.654	1.619	0.070	21.13	41.13	38.71	500	140.00

Table C-1 Specimen 4A-A-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
4-A-CP	100% RH-RT	2.565	6.287	13,300	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	$ΔK_{AV}$ $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.82	0.361	2.27	0.109	11.09	12.90	13.16	50,000	21
2	10.62	0.378	2.38	0.112	11.28	13.44	13.75	60,000	18
3	11.48	0.396	2.49	0.175	11.52	14.04	14.56	90,000	19
6A	12.96	0.424	2.65	0.097	11.95	13.71	15.35	20,000	48
7	13.82	0.439	2.76	0.231	12.22	15.63	16.49	40,000	57
8	15.16	0.476	2.99	0.175	12.98	17.35	18.16	20,000	87
9	18.22	0.504	3.16	0.297	13.69	18.97	20.43	30,000	99
10	22.96	0.551	3.47	0.231	15.22	21.89	23.46	10,000	231
11	27.87	0.588	3.70	0.277	16.85	25.02	27.50	8,000	346
12	35.17	0.632	3.97	0.158	19.47	29.98	31.77	3,000	525
13	41.06	0.657	4.13		21.38	33.56		2,000	
14	47.97								

Table C-2 Specimen 10A-A-CP b. International Units (S.I.)

Spec. No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
10A-A-CP	100% RH-RT	2.550	6.287	17,800	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	$ΔK_{AV}$ $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.16	0.368	2.31	0.307	11.17	17.90	19.06	15,000	204
2	12.56	0.417	2.62	0.566	11.84	20.23	23.09	13,000	435
3	18.50	0.507	3.19	0.282	13.77	25.94	27.96	7,000	402
4	23.07	0.552	3.47	0.465	15.26	30.00	34.92	4,000	1,162
5	33.86	0.626	3.93	0.178	19.06	39.87	42.54	500	3,556
6	40.31	0.654	4.11		21.13	45.19			

Table C-3 Specimen 14B-A-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
14B-A-CP	100% RH-RT	1.000	2.499	5000	250

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.072								
								6,000	
2	1.800	0.371	0.927		11.20	20.50			
				0.040			20.91	6,000	6.67
3	1.928	0.387	0.967		11.40	21.31			
				0.023			21.55	6,000	3.83
4	2.090	0.396	0.990		11.52	21.79			
				0.082			22.74	6,000	13.67
5	2.313	0.429	1.072		12.04	23.69			
				0.070			24.61	6,000	11.67
6	2.605	0.457	1.142		12.57	25.53			
				0.082			26.77	5,000	16.40
7	3.000	0.490	1.224		13.32	28.02			
				0.063			29.11	4,000	15.75
8	3.363	0.515	1.287		14.00	30.20			
				0.075			32.61	3,000	25.00
9	3.870	0.545	1.362		15.00	33.27			
				0.075			36.00	2,000	37.50
10	4.524	0.575	1.437		16.22	36.97			
				0.042			38.20	1,000	42.00
11	4.928	0.592	1.479		17.05	39.43			
				0.060			41.43	600	100.00
12	5.608	0.616	1.539		18.41	43.43			
				0.083			46.81	400	207.50
13	6.823	0.649	1.622		20.73	50.19			
				0.032			51.76	100	320.00
14	7.392	0.662	1.654		21.81	53.32			
								50	
15	7.961								
								30	
16	8.421								
								20	
17	8.888								
								20	
18	10.169								

Table C-3 **Specimen 14B-A-CP** b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
14B-A-CP	100% RH-RT	2.540	6.348	22,200	1100

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	6.12								
								6,000	
2	10.28	0.371	2.35		11.20	22.52			
				0.020			22.98	6,000	169
3	11.01	0.387	2.46		11.40	23.41			
				0.058			23.68	6,000	97
4	11.93	0.396	2.52		11.52	23.94			
				0.208			24.99	6,000	347
5	13.21	0.429	2.72		12.04	26.03			
				0.178			27.04	6,000	296
6	14.88	0.457	2.90		12.57	28.05			
				0.208			29.42	5,000	416
7	17.13	0.490	3.11		13.32	30.79			
				0.160			31.99	4,000	400
8	19.20	0.515	3.27		14.00	33.18			
				0.191			35.83	3,000	635
9	22.10	0.545	3.46		15.00	36.56			
				0.191			39.56	2,000	952
10	25.83	0.575	3.65		16.22	40.62			
				0.107			41.98	1,000	1,066
11	28.14	0.592	3.76		17.05	43.33			
				0.152			45.52	600	2,540
12	32.02	0.616	3.91		18.41	47.72			
				0.211			51.43	400	5,270
13	38.96	0.649	4.12		20.73	55.15			
				0.081			56.87	100	8,128
14	42.21	0.662	4.20		21.81	58.59			
								50	
15	45.46								
								30	
16	48.09								
								20	
17	50.75								
								20	
18	58.07								

Table C-4 Specimen 11C-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
11C-A-CP	100% RH-RT	1.009	2.495	6000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.695	0.358	0.893	0.067	11.06	24.08	25.33	3,000	22.33
2	1.916	0.385	0.961	0.092	11.37	24.83	27.38	3,000	30.67
3	2.250	0.422	1.053	0.115	11.92	28.19	30.03	2,500	46.00
4	2.727	0.468	1.168	0.120	12.80	31.88	34.28	1,500	80.00
5	3.388	0.516	1.287	0.075	14.03	36.69	38.56	600	125.00
6	3.906	0.546	1.362	0.042	15.03	40.43	41.65	200	210.00
7	4.253	0.563	1.405	0.032	15.70	42.88	43.91	100	320.00
8	4.549	0.576	1.437	0.022	16.27	44.94	45.72	50	440.00
9	4.772	0.585	1.460	0.040	16.70	46.49	47.98	50	800.00
10	5.153	0.601	1.499	0.072	17.54	49.47	52.66	50	1,440.00
11	6.096	0.630	1.572		19.33	55.84			

Table C-5 Specimen 27B-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
27B-H-CP	100% RH-RT	1.006	2.497	3000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.714	0.361	0.901	0.030	11.09	11.74	11.91	20,000	1.50
2	1.826	0.373	0.931	0.065	11.22	12.07	12.47	30,000	2.17
3	2.035	0.399	0.996	0.105	11.56	12.87	13.60	30,000	3.50
4	2.437	0.441	1.101	0.135	12.26	14.34	15.50	25,000	5.40
5	3.063	0.495	1.236	0.125	13.45	16.67	18.08	15,000	8.33
6	3.894	0.545	1.361	0.122	15.00	19.50	21.40	7,000	17.43
7	4.983	0.594	1.483	0.035	17.16	23.29	23.96	1,000	35.00
8	5.347	0.608	1.518		17.93	24.63			

Table C-4 Specimen 11C-A-CP

b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
11C-A-CP	100% RH-RT	2.563	6.337	27,000	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.68	0.358	2.27	0.170	11.06	26.46	27.83	3,000	567
2	10.94	0.385	2.44	0.234	11.37	27.28	30.09	3,000	779
3	12.85	0.422	2.67	0.292	11.92	30.98	33.00	2,500	1,168
4	15.57	0.468	2.97	0.305	12.80	35.03	37.67	1,500	2,032
5	19.35	0.516	3.27	0.191	14.03	40.31	42.37	600	3,175
6	22.30	0.546	3.46	0.107	15.03	44.43	45.77	200	5,334
7	24.29	0.563	3.57	0.081	15.70	47.12	48.25	100	8,128
8	25.98	0.576	3.65	0.056	16.27	49.38	50.24	50	11,176
9	26.96	0.585	3.71	0.102	16.70	51.08	52.72	50	20,320
10	29.42	0.601	3.81	0.183	17.54	54.36	57.86	50	36,576
11	34.81	0.630	3.99		19.33	61.36			

Table C-5 Specimen 27B-H-CP

b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
27B-H-CP	100% RH-RT	2.555	6.342	13,300	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.79	0.361	2.29	0.076	11.09	12.90	13.09	20,000	38
2	10.43	0.373	2.37	0.165	11.22	13.26	13.70	30,000	55
3	11.62	0.399	2.53	0.267	11.56	14.14	14.94	30,000	89
4	13.92	0.441	2.80	0.343	12.26	15.76	17.03	25,000	137
5	17.49	0.495	3.14	0.318	13.45	18.32	19.87	15,000	212
6	22.24	0.545	3.46	0.310	15.00	21.43	23.51	7,000	443
7	28.45	0.594	3.77	0.089	17.16	25.59	26.33	1,000	889
8	30.53	0.608	3.86		17.93	27.06			

Table C-6 Specimen 19A-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
19A-H-CP	100% RH-RT	1.005	2.500	3500	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.619	0.348	0.870	0.012	10.96	13.50	13.54	10,000	1.20
2	1.666	0.353	0.882	0.025	11.01	13.59	13.75	10,000	2.50
3	1.744	0.363	0.907	0.033	11.11	13.91	14.12	10,000	3.30
4	1.820	0.376	0.940	0.032	12.26	14.34	14.57	10,000	3.20
5	1.953	0.389	0.972	0.040	11.43	14.80	15.10	10,000	4.00
6	2.089	0.405	1.012	0.056	11.65	15.40	15.85	10,000	5.60
7	2.292	0.427	1.068	0.060	12.00	16.29	16.83	9,500	6.32
8	2.541	0.451	1.128	0.070	12.49	17.36	18.06	7,500	9.33
9	2.860	0.479	1.198	0.070	13.06	18.76	19.56	6,000	11.67
10	3.235	0.507	1.268	0.060	13.77	20.36	21.16	4,000	15.00
11	3.616	0.531	1.328	0.022	14.51	21.96	22.28	1,000	22.00
12	3.797	0.540	1.350	0.028	14.82	22.61	23.04	1,000	28.00
13	4.000	0.551	1.378	0.034	15.22	23.46	24.06	1,000	34.00
14	4.304	0.565	1.412		15.79	24.64			

Table C-7 Specimen ZC-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
2C-H-CP	100% RH-RT	1.000	2.503	4000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.648	0.352	0.881	0.048	11.00	15.68	16.03	15,000	3.20
2	1.793	0.371	0.929	0.065	11.20	16.39	16.92	15,000	4.33
3	2.025	0.397	0.994	0.082	11.54	17.46	18.23	15,000	5.47
4	2.333	0.430	1.076	0.203	12.06	18.99	21.42	15,000	13.53
5	3.292	0.511	1.279		13.89	23.85			

Table C-6 Specimen 19A-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
19A-H-CP	100% RH-RT	2.553	6.350	15,600	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.25	0.348	2.21	0.031	10.96	14.83	14.88	10,000	31
2	9.51	0.353	2.24	0.064	11.01	14.93	15.11	10,000	64
3	9.96	0.363	2.30	0.084	11.11	15.28	15.52	10,000	84
4	10.39	0.376	2.41	0.081	12.26	15.76	16.01	10,000	81
5	11.15	0.389	2.47	0.102	11.43	16.26	16.59	10,000	102
6	11.93	0.405	2.57	0.142	11.65	16.92	17.42	10,000	142
7	13.09	0.427	2.71	0.152	12.00	17.90	18.49	9,500	161
8	14.51	0.451	2.86	0.178	12.49	19.08	19.84	7,500	237
9	16.33	0.479	3.04	0.178	13.06	20.61	21.49	6,000	296
10	18.47	0.507	3.22	0.152	13.77	22.37	23.25	4,000	381
11	20.65	0.531	3.37	0.056	14.51	24.13	24.48	1,000	559
12	21.68	0.540	3.43	0.071	14.82	24.84	25.32	1,000	711
13	22.84	0.551	3.50	0.086	15.22	25.78	26.44	1,000	864
14	24.58	0.565	3.61		15.79	27.07			

Table C-7 Specimen ZC-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
2C-H-CP	100% RH-RT	2.540	6.358	17,800	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.41	0.352	2.24	0.122	11.00	17.23	17.61	15,000	81
2	10.24	0.371	2.36	0.166	11.20	18.01	18.59	15,000	110
3	11.56	0.397	2.52	0.208	11.54	19.19	20.03	15,000	139
4	13.32	0.430	2.73	0.516	12.06	20.87	23.54	15,000	344
5	18.80	0.511	3.25		13.89	26.21			

Table C-8 Specimen 1C-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb	
1C-H-CP	100% RH-RT	1.004	2.502	5000	250	

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.617	0.348	0.871	0.027	10.96	19.35	19.59	3,000	9.00
2	1.701	0.359	0.898	0.030	11.07	19.84	20.12	3,000	10.00
3	1.800	0.371	0.928	0.030	11.20	20.41	20.71	3,000	10.00
4	1.905	0.383	0.958	0.030	11.35	21.01	21.32	3,000	10.00
5	2.000	0.395	0.988	0.058	11.51	21.63	22.28	3,000	19.33
6	2.217	0.418	1.046	0.107	11.85	22.93	24.31	3,000	35.67
7	2.658	0.461	1.153		12.65	25.70			

Table C-8 Specimen 1C-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
1C-H-CP	100% RH-RT	2.550	6.355	22,200	1100

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.23	0.348	2.21	0.068	10.96	21.26	21.53	3,000	229
2	9.71	0.359	2.28	0.076	11.07	21.80	22.11	3,000	254
3	10.28	0.371	2.36	0.076	11.20	22.43	22.76	3,000	254
4	10.88	0.383	2.43	0.076	11.35	23.09	23.43	3,000	254
5	11.42	0.395	2.50	0.147	11.51	23.77	24.48	3,000	491
6	12.66	0.418	2.66	0.272	11.85	25.20	26.71	3,000	906
7	15.18	0.461	2.93		12.65	28.24			

APPENDIX D

Cyclic Crack Growth Data from Compact Tension Tests at -65°F (220°K)

Table D-1 Specimen 11A-A-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
11A-A-CP	-65°F	1.009	2.497	2,500	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi$\sqrt{in.}$	ΔK_{AV}, ksi$\sqrt{in.}$	ΔN, cycles	da/dN μin./cycles
1	1.71	0.359	0.898	0.042	11.07	9.57	9.77	120,000	0.35
2	1.84	0.376	0.940	0.025	11.26	9.97	10.08	122,000	0.20
3	1.93	0.386	0.965	0.035	11.39	10.20	10.38	45,000	0.78
4	2.05	0.400	1.000	0.050	11.58	10.56	10.83	78,000	0.64
5	2.23	0.420	1.050	0.058	11.89	11.11	11.46	60,000	0.97
6	2.47	0.443	1.108	0.045	12.29	11.80	12.10	40,000	1.13
7	2.66	0.461	1.153	0.060	12.65	12.39	12.83	30,000	2.00
8	2.94	0.485	1.213	0.050	13.20	13.26	13.66	25,000	2.00
9	3.21	0.505	1.263	0.087	13.72	14.07	14.89	24,000	3.63
10	3.81	0.540	1.350	0.085	14.82	15.71	16.70	15,500	5.48
11	4.51	0.574	1.345	0.085	16.18	17.69	18.93	12,000	7.08
12	5.36	0.608	1.520	0.098	17.93	20.17	22.02	9,000	10.89
13	6.77	0.647	1.618		20.58	23.88			

Table D-1 Specimen 11A-A-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
11A-A-CP	-65°F	2.563	6.342	11,100	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.76	0.359	2.28	0.110	11.07	10.52	10.74	120,000	9
2	10.51	0.376	2.39	0.060	11.26	10.96	11.07	122,00	5
3	11.02	0.386	2.45	0.090	11.39	11.21	11.40	45,000	20
4	11.71	0.400	2.54	0.127	11.58	11.60	11.90	78,000	16
5	12.73	0.420	2.67	0.147	11.89	12.21	12.59	60,000	25
6	14.10	0.443	2.81	0.114	12.29	12.97	13.30	40,000	29
7	15.19	0.461	2.93	0.152	12.65	13.61	14.10	30,000	51
8	16.79	0.485	3.08	0.127	13.20	14.57	15.09	25,000	51
9	18.33	0.505	3.21	0.221	13.72	15.46	16.36	24,000	92
10	21.76	0.540	3.43	0.216	14.82	17.26	18.35	15,500	139
11	25.75	0.574	3.42	0.216	16.18	19.44	20.80	12,000	180
12	30.61	0.608	3.86	0.249	17.93	22.16	24.20	9,000	277
13	38.66	0.647	4.11		20.58	26.24			

Table D-2 Specimen 15B-A-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
15B-A-CP	$-65^{o}F$	1.005	2.498	3,000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi$\sqrt{in.}$	ΔK_{AV}, ksi$\sqrt{in.}$	ΔN, cycles	da/dN μin./cycles
1	1.73	0.362	0.905	0.068	11.10	11.78	12.17	45,000	1.51
2	1.95	0.389	0.973	0.050	11.43	12.57	12.89	27,250	1.83
3	2.13	0.409	1.023	0.065	11.71	13.21	13.67	25,000	2.60
4	2.38	0.435	1.088	0.070	12.15	14.13	14.58	24,000	2.92
5	2.68	0.463	1.158	0.077	12.70	15.23	15.93	17,000	4.53
6	3.07	0.494	1.235	0.088	13.42	16.63	17.57	15,000	5.87
7	3.60	0.529	1.323	0.052	14.44	18.51	19.18	7,000	7.43
8	3.98	0.550	1.375	0.058	15.18	19.85	20.69	7,000	8.29
9	4.48	0.573	1.433	0.097	16.14	21.53	23.30	7,000	13.86
10	5.48	0.612	1.530	0.040	18.17	25.07	25.94	3,000	13.33
11	6.01	0.628	1.570	0.060	19.19	26.82	28.34	2,500	24.00
12	6.96	0.652	1.630		20.97	29.85			
13	7.85								

Table D-2 Specimen 15B-A-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
15B-A-CP	219°K	2.553	2.345	13,300	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.88	0.362	2.299	0.173	11.10	12.94	13.37	45,000	38
2	11.15	0.389	2.471	0.127	11.43	13.81	14.16	27,250	47
3	12.16	0.409	2.598	0.165	11.71	14.52	15.02	25,000	66
4	13.59	0.435	2.764	0.178	12.15	15.53	16.02	24,000	74
5	15.30	0.463	2.941	0.196	12.70	16.74	17.50	17,000	119
6	17.53	0.494	3.137	0.234	13.42	18.27	19.30	15,000	149
7	20.56	0.529	3.360	0.132	14.44	20.34	21.08	7,000	188
8	22.73	0.550	3.493	0.147	15.18	21.81	22.73	7,000	210
9	25.58	0.573	3.640	0.246	16.14	23.66	25.60	7,000	352
10	31.29	0.612	3.886	0.102	18.17	28.65	28.50	3,000	339
11	34.32	0.628	3.988	0.152	19.19	29.47	31.14	2,500	610
12	39.74	0.652	4.140		20.97	32.80			
13	44.82								

Table D-3 Specimen 16C-A-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
16C-A-CP	-65°F	1.003	2.504	3,500	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi$\sqrt{in.}$	ΔK_{AV}, ksi$\sqrt{in.}$	ΔN, cycles	da/dN μin./cycles
1	1.78	0.369	0.924	0.035	11.18	14.12	14.36	12,000	2.92
2	1.91	0.383	0.959	0.025	11.35	14.60	14.78	12,000	2.08
3	1.99	0.393	0.984	0.070	11.48	14.97	15.51	15,000	4.67
4	2.24	0.421	1.054	0.075	11.91	16.05	16.72	15,000	5.00
5	2.55	0.451	1.129	0.060	12.45	17.38	17.98	10,300	5.83
6	2.82	0.475	1.189	0.088	12.96	18.57	19.58	9,000	9.78
7	3.28	0.510	1.277	0.068	13.86	20.59	21.51	6,000	11.33
8	3.75	0.537	1.345	0.077	14.71	22.42	23.68	5,500	14.00
9	4.36	0.568	1.422	0.080	15.92	24.93	26.55	3,500	22.86
10	5.15	0.600	1.502	0.081	17.48	28.16	30.18	2,000	40.50
11	6.15	0.632	1.583	0.032	19.47	32.19	33.15	1,500	21.33
12	6.67	0.645	1.615	---	20.42	34.10	---	1,500	---
13	8.71	---	---		---	---			

Table D-3 Specimen 16C-A-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
16C-A-CP	219°K	2.548	6.360	15,600	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.16	0.369	2.346	0.089	11.18	15.52	15.78	12,000	74
2	10.91	0.383	2.436	0.064	11.35	16.04	16.24	12,000	53
3	11.36	0.393	2.499	0.178	11.48	16.45	17.04	15,000	119
4	12.79	0.421	2.677	0.191	11.91	17.64	18.37	15,000	127
5	14.56	0.451	2.868	0.152	12.45	19.10	19.77	10,300	146
6	16.10	0.475	3.020	0.224	12.96	20.41	21.51	9,000	248
7	18.73	0.510	3.244	0.173	13.86	22.62	23.64	6,000	288
8	21.44	0.537	3.416	0.196	14.71	24.64	26.02	5,500	356
9	24.90	0.568	3.612	0.203	15.92	27.39	29.17	3,500	581
10	29.41	0.600	3.815	0.206	17.48	30.94	33.16	2,000	1,029
11	35.12	0.632	4.021	0.081	19.47	35.37	36.43	1,500	542
12	38.09	0.645	4.102		20.42	37.47		1,500	
13	49.74								

Table D-4 Specimen 18A-A-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
18A-A-CP	-65°F	1.002	2.496	4,000	200

x	C μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dN μin./cycles
1	1.80	0.371	0.926	0.047	11.20	16.37	16.76	12,000	3.92
2	1.96	0.390	0.973	0.048	11.44	17.14	17.56	10,000	4.80
3	2.13	0.409	1.021	0.070	11.71	17.98	18.65	11,000	6.36
4	2.39	0.437	1.091	0.100	12.18	19.32	20.44	12,000	8.33
5	2.84	0.477	1.191	0.097	13.01	21.55	22.87	8,000	12.13
6	3.37	0.516	1.288	0.075	14.04	24.19	25.43	5,000	15.00
7	3.92	0.546	1.363	0.065	15.03	26.67	27.94	2,500	26.00
8	4.47	0.572	1.428	0.092	16.09	29.21	31.46	2,500	36.80
9	5.39	0.609	1.520	0.112	17.99	33.70	37.36	1,525	73.44
10	7.05	0.654	1.632	---	21.14	41.02	---	500	---
11	8.79	---	---		---	---			

Table D-4 Specimen 18A-A-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
18A-A-CP	219°K	2.545	6.342	17,800	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.28	0.371	2.352	0.119	11.20	17.99	18.42	12,000	100
2	11.19	0.390	2.471	0.122	11.44	18.93	19.29	10,000	122
3	12.16	0.409	2.593	0.178	11.71	19.76	20.49	11,000	162
4	13.65	0.437	2.771	0.254	12.18	21.23	22.46	12,000	212
5	16.22	0.477	3.025	0.246	13.01	23.68	25.13	8,000	308
6	19.24	0.516	3.272	0.191	14.04	26.58	27.94	5,000	381
7	22.38	0.546	3.462	0.165	15.03	29.30	30.70	2,500	660
8	25.52	0.572	3.627	0.234	16.09	32.10	34.57	2,500	935
9	30.78	0.609	3.861	0.285	17.99	37.03	41.05	1,525	1,865
10	40.26	0.654	4.145		21.14	45.07		500	
11	50.19								

Table D-5 Specimen 24C-A-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
24C-A-CP	-65°F	1.002	2.498	5,000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK ksi$\sqrt{in.}$	ΔK_{AV}, ksi$\sqrt{in.}$	ΔN cycles	da/dN μin./cycle
1	1.90	0.383	0.957	0.050	11.35	21.28	21.83	4,000	12.50
2	2.07	0.403	1.007	0.047	11.62	22.37	22.92	5,000	9.40
3	2.25	0.422	1.054	0.085	11.92	23.46	24.57	5,000	17.00
4	2.59	0.456	1.139	0.093	12.55	25.67	27.10	5,000	18.60
5	3.05	0.493	1.232	0.072	13.40	28.52	29.83	2,000	36.00
6	3.47	0.522	1.304	0.080	14.22	31.13	32.87	1,800	44.44
7	4.06	0.554	1.384	0.097	15.34	34.61	37.27	1,200	80.83
8	4.95	0.593	1.481	0.090	17.11	39.32	43.12	600	150.00
9	6.04	0.629	1.571		19.26	46.31			

Table D-6 Specimen 8A-H-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
8A-H-CP	-65°F	1.005	2.502	2,500	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK ksi$\sqrt{in.}$	ΔK_{AV}, ksi$\sqrt{in.}$	ΔN cycles	da/dN μin./cycle
1	1.75	0.365	0.913	0.012	11.13	9.73	9.79	37,000	0.32
2	1.79	0.370	0.925	0.060	11.19	9.84	10.14	37,000	1.62
3	2.00	0.394	0.985	0.055	11.49	10.44	10.74	25,000	2.20
4	2.20	0.416	1.040	0.048	11.82	11.03	11.41	25,000	1.92
5	2.38	0.435	1.088	0.035	12.15	11.59	11.81	30,000	1.17
6	2.52	0.449	1.123	0.070	12.41	12.03	12.52	25,000	2.80
7	2.84	0.477	1.193	0.067	13.01	13.00	13.53	20,000	3.35
8	3.20	0.504	1.260	0.043	13.69	14.06	14.43	11,500	3.74
9	3.46	0.521	1.303	0.082	14.19	14.81	15.67	13,000	6.31
10	4.08	0.554	1.385	0.058	15.34	16.52	17.23	8,000	7.25
11	4.58	0.577	1.443	0.067	16.32	17.94	18.92	6,000	11.17
12	5.24	0.604	1.510	---	17.70	19.90	---	4,550	---
13	8.30	---	---		---	---			

Table D-5 Specimen 24C-A-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
24C-A-CP	219°K	2.545	6.345	22,200	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	$ΔK_{AV}$ $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.85	0.383	2.430	0.127	11.35	23.99	23.99	4,000	318
2	11.82	0.403	2.558	0.119	11.62	24.58	25.18	5,000	239
3	12.84	0.422	2.678	0.216	11.92	25.78	27.00	5,000	432
4	14.79	0.456	2.893	0.236	12.55	28.21	29.78	5,000	472
5	17.42	0.493	3.129	0.183	13.40	31.34	32.78	2,000	914
6	19.81	0.522	3.312	0.203	14.22	34.21	36.12	1,800	1,129
7	23.18	0.554	3.515	0.246	15.34	38.03	40.95	1,200	2,053
8	20.27	0.593	3.762	0.229	17.11	43.20	47.38	600	3,810
9	34.49	0.629	3.990		19.26	50.89			

Table D-6 Specimen 8A-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
8A-H-CP	219°K	2.553	6.355	11,100	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	$ΔK_{AV}$ $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.99	0.365	2.431	0.031	11.13	10.69	10.76	37,000	8
2	10.22	0.370	2.350	0.152	11.19	10.81	11.14	37,000	41
3	11.42	0.394	2.502	0.140	11.49	11.47	11.80	25,000	56
4	12.56	0.416	2.642	0.122	11.82	12.12	12.55	25,00	49
5	13.59	0.435	2.764	0.089	12.15	12.74	12.98	30,000	30
6	14.39	0.449	2.852	0.178	12.41	13.22	13.76	25,000	71
7	16.21	0.477	3.030	0.170	13.01	14.28	14.87	20,000	85
8	18.27	0.504	3.200	0.109	13.69	15.45	15.86	11,500	95
9	19.76	0.521	3.310	0.208	14.19	16.27	17.22	13,000	160
10	23.30	0.554	3.518	0.147	15.34	18.15	18.93	8,000	184
11	26.15	0.577	3.640	0.170	16.32	19.71	20.79	6,000	284
12	29.92	0.604	3.835		17.70	21.87		4,550	
13	47.39								

Table D-7 Specimen 12B-H-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
12B-H-CP	-65°F	1.003	2.500	3000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi$\sqrt{in.}$	ΔK_{AV}, ksi$\sqrt{in.}$	ΔN, cycles	da/dN μin./cycle
1	1.87	.379	0.947	0.048	11.30	12.29	12.58	20,000	2.40
2	2.03	.398	0.995	0.060	11.55	12.87	13.27	20,000	3.00
3	2.25	.422	1.055	0.050	11.92	13.67	14.04	13,000	3.85
4	2.45	.442	1.105	0.080	12.28	14.41	15.07	16,000	5.00
5	2.81	.474	1.185	0.100	12.94	15.73	16.71	13,000	7.69
6	3.34	.514	1.285	0.062	13.98	17.69	18.43	7,000	8.86
7	3.77	.539	1.347	0.058	14.78	19.16	19.95	3,500	16.57
8	4.23	.562	1.405	0.085	15.66	20.73	22.14	2,000	42.50
9	5.03	.596	1.490		17.27	23.54			

Table D-8 Specimen 13C-H-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W. in.	P_{max}, lb	P_{min}, lb
13C-H-CP	-65°F	1.008	2.475	3,5000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi$\sqrt{in.}$	ΔK_{AV}, ksi$\sqrt{in.}$	ΔN, cycles	da/dN μin./cycle
1	1.81	0.371	0.918	0.042	11.20	14.20	14.50	12,000	3.50
2	1.94	0.388	0.960	0.062	11.41	14.79	15.27	15,100	4.11
3	2.17	0.413	1.022	0.057	11.78	15.75	16.23	10,000	5.70
4	2.39	0.436	1.079	0.097	12.16	16.71	17.64	10,000	9.70
5	2.82	0.475	1.176	0.084	12.96	18.58	19.56	5,000	16.80
6	3.27	0.509	1.260	0.054	13.83	20.53	21.26	2,500	21.60
7	3.64	0.531	1.314	0.057	14.51	21.99	22.87	2,000	28.50
8	4.08	0.554	1.371	0.112	15.34	23.76	25.91	260	431.00
9	5.11	0.599	1.483		17.43	28.07			

Table D-7 Specimen 12B-H-CP   **b. International Units (S.I.)**

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
12B-H-CP	219°K	2.548	6.350	13,300	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN. cycle	da/dn nm/cycle
1	10.68	0.379	2.405	0.122	11.30	13.50	13.82	20,000	61
2	11.59	0.398	2.527	0.152	11.55	14.14	14.58	20,000	76
3	12.85	0.422	2.680	0.127	11.92	15.02	15.43	13,000	98
4	13.99	0.442	2.807	0.203	12.28	15.83	16.56	16,000	127
5	16.05	0.474	3.010	0.254	12.94	17.28	18.36	13,000	195
6	19.07	0.514	3.264	0.152	13.98	19.44	20.25	7,000	225
7	21.53	0.539	3.421	0.147	14.78	21.05	21.92	3,500	421
8	24.15	0.562	3.569	0.216	15.66	22.78	24.33	2,000	1,080
9	28.72	0.596	3.785		17.27	25.86			

Table D-8 Specimen 13C-H-CP   b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
13C-H-CP	219°K	2.560	6.287	15,600	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.34	0.371	2.332	0.106	11.20	15.60	15.93	12,000	89
2	11.08	0.388	2.405	0.158	11.41	18.25	16.78	15,100	104
3	12.39	0.413	2.596	0.145	11.78	17.31	17.83	10,000	145
4	13.65	0.436	2.741	0.246	12.16	18.36	19.38	10,000	246
5	16.10	0.475	2.987	0.213	12.96	20.42	21.49	5,000	427
6	18.67	0.509	3.200	0.137	13.83	22.56	23.36	2,500	549
7	20.79	0.531	3.338	0.145	14.51	24.16	25.13	2,000	724
8	23.30	0.554	3.483	0.285	15.34	26.11	28.47	260	10,947
9	29.18	0.599	3.767		17.43	30.84			

Table D-9 Specimen 16A-H-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
16A-H-CP	-65°F	0.997	2.498	4,000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dN μin./cycles
1	1.73	0.362	0.905	0.065	11.10	16.11	16.63	12,000	5.42
2	1.94	0.388	0.970	0.085	11.41	17.14	17.91	11,000	7.73
3	2.26	0.422	1.055	0.063	11.92	18.67	19.31	5,000	12.60
4	2.51	0.447	1.118	0.100	12.37	19.94	21.12	5,000	20.00
5	2.97	0.487	1.218	0.050	13.26	22.29	22.97	3,500	14.30
6	3.25	0.507	1.268	0.082	13.77	23.65	24.95	730	112.00
7	3.81	0.540	1.350		14.82	26.26			

Table D-10 Specimen 18B-H-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
18B-H-CP	-65°F	1.003	2.488	4,500	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dN μin./cycles
1	1.70	0.359	0.893	0.045	11.07	18.02	18.42	6,000	7.50
2	1.85	0.377	0.938	0.132	11.27	18.81	20.16	9,000	14.67
3	2.33	0.430	1.070	0.154	12.06	21.50	23.50	2,600	59.23
4	3.03	0.492	1.224		13.37	25.50			

Table D-9 Specimen 16A-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
16-A-H-CP	219°K	2.532	6.345	17,793	890

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.88	0.362	2.299	0.165	11.10	17.70	18.27	12,000	138
2	11.08	0.388	2.464	0.216	11.41	18.83	19.68	11,000	196
3	12.91	0.422	2.680	0.160	11.92	20.52	21.22	5,000	320
4	14.33	0.447	2.840	0.254	12.37	21.91	23.21	5,000	508
5	16.96	0.487	3.094	0.127	13.26	24.49	25.24	3,500	363
6	18.56	0.507	3.221	0.208	13.77	25.99	27.42	730	2,844
7	21.76	0.540	3.429		14.82	28.85			

Table D-10 Specimen 18B-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
18B-H-CP	219°K	2.548	6.320	20,000	200

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.71	0.359	2.268	0.114	11.07	19.80	20.24	6,000	190
2	10.56	0.377	2.383	0.335	11.27	20.67	22.15	9,000	373
3	13.31	0.430	2.718	0.391	12.06	23.62	25.82	2,600	1,504
4	17.30	0.492	3.109		13.37	28.02			

APPENDIX E

Cyclic Crack Growth Data from Compact Tension Tests at 300°F (422°K)

Table E-1 Specimen 28B-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
28B-A-CP	300°F	0.999	2.500	5500	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.85	0.377	0.942	0.031	11.27	23.22	23.6	4,000	7.7
2	1.95	0.389	0.973	0.047	11.43	23.93	24.5	2,000	23.5
3	2.12	0.408	1.020	0.035	11.70	25.06	25.5	2,000	17.5
4	2.25	0.422	1.055	0.055	11.92	25.97	26.7	2,000	27.5
5	2.47	0.444	1.110	0.055	12.31	27.51	28.4	2,250	24.4
6	2.71	0.466	1.165	0.033	12.76	29.23	29.8	1,000	33.0
7	2.86	0.479	1.198	0.062	13.05	30.31	31.5	1,500	41.3
8	3.19	0.504	1.260	0.020	13.69	32.62	33.0	700	28.6
9	3.32	0.512	1.280	0.043	13.92	33.42	34.3	1,000	43.0
10	3.59	0.529	1.323		14.44	35.23			

Table E-2 Specimen 2A-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
2A-A-CP	300°F	1.000	2.505	6000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn μin./cycle
1	2.4	0.410	1.027	0.043	11.73	27.51	28.12	3,000	14.3
2	2.30	0.427	1.070	0.077	12.01	28.73	29.97	3,000	25.7
3	2.14	0.458	1.147	0.028	12.59	31.21	31.69	2,000	14.0
4	2.75	0.469	1.175		12.83	32.17			

Table E-1 Specimen 28B-A-CP   b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
28B-A-CP	422°K	2.538	6.350	24,500	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	$ΔK_{AV}$ $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.56	0.377	2.392	0.079	11.27	25.51	25.93	4,000	196
2	11.13	0.389	2.471	0.119	11.43	26.29	26.92	2,000	597
3	12.11	0.408	2.591	0.089	11.70	27.54	28.02	2,000	445
4	12.85	0.422	2.680	0.140	11.92	28.54	29.34	2,000	699
5	14.10	0.444	2.819	0.140	12.31	30.23	31.21	2,250	620
6	15.48	0.466	2.959	0.084	12.76	32.12	32.74	1,000	838
7	16.33	0.479	3.043	0.158	13.05	33.01	34.61	1,500	1,049
8	18.22	0.504	3.200	0.051	13.69	35.84	36.26	700	726
9	18.96	0.512	3.251	0.109	13.92	36.72	37.69	1,000	1,092
10	20.50	0.529	3.360		14.44	38.71			

Table E-2 Specimen 2A-A-CP   b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	$ΔK_{AV}$ $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	13.70	0.410	2.609	0.109	11.73	30.23	30.90	3,000	363
2	13.33	0.427	2.718	0.156	12.01	31.57	32.93	3,000	652
3	12.22	0.458	2.913	0.071	12.59	34.29	34.82	2,000	356
4	15.70	0.469	2.985		12.83	35.35			

Table E-3 Specimen 9C-A-CP a. U.S. Customary Units

Spec. No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
9C-A-CP	300°F	1.008	2.499	8000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.73	0.362	0.905	0.035	11.10	32.69	33.3	2,000	17.5
2	1.84	0.376	0.940	0.087	11.26	33.82	35.3	3,000	29.0
3	2.15	0.411	1.027	0.045	11.74	36.85	37.7	2,000	22.5
4	2.32	0.429	1.072	0.055	12.04	38.62	39.8	1,000	55.0
5	2.54	0.451	1.127	0.058	12.45	40.92	42.3	1,000	58.0
6	2.80	0.474	1.185	0.074	12.94	43.61	45.6	900	82.2
7	3.20	0.504	1.259	0.045	13.69	47.57	48.9	500	90.0
8	3.48	0.522	1.304	0.063	14.22	50.26	52.4	450	140.0
9	3.93	0.547	1.367	0.057	15.07	54.57	56.8	275	207.3
10	4.42	0.570	1.424	0.038	16.00	59.12	60.8	125	304.0
11	4.77	0.585	1.462	0.015	16.70	62.50	63.2	75	200.0
12	4.90	0.591	1.477	0.052	17.00	63.97	66.8	156	333.3
13	5.48	0.612	1.529	0.060	18.17	69.60	73.3	100	600.0
14	6.29	0.636	1.589		19.75	77.08			

Table E-3 Spècimen 9C-A-CP **b. International Units (S.I.)**

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
9C-A-CP	422^{o}K	2.560	6.348	35,600	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.88	0.362	2.299	0.089	11.10	35.92	36.59	2,000	445
2	10.51	0.376	2.388	0.221	11.26	27.16	38.79	3,000	737
3	12.28	0.411	2.609	0.114	11.74	40.49	41.43	2,000	572
4	13.25	0.429	2.723	0.140	12.04	42.44	43.73	1,000	1,397
5	14.50	0.451	2.862	0.147	12.45	44.96	46.48	1,000	1,473
6	16.00	0.474	3.010	0.188	12.94	47.92	50.11	900	2,088
7	18.27	0.504	3.198	0.144	13.69	52.27	53.73	500	2,286
8	19.87	0.522	3.312	0.160	14.22	55.19	57.57	450	3,556
9	22.44	0.547	3.472	0.145	15.07	59.96	62.41	275	5,265
10	25.24	0.570	3.617	0.096	16.00	64.96	66.81	125	7,722
11	27.24	0.585	3.713	0.038	16.70	68.68	69.44	75	5,080
12	27.98	0.591	3.752	0.132	17.00	70.29	73.40	156	8,466
13	31.29	0.612	3.88	0.152	18.17	76.48	80.54	100	15,240
14	35.92	0.636	4.036		19.75	84.70			

Table E-4 Specimen 14A-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.
14A-A-CP	300°F	1.007	2.471

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn μin./cycle
P_{max} = 10,000 P_{min} = 200									
1	1.98	0.392	0.969	0.061	11.47	44.45	45.9	1,500	40.7
2	2.21	0.417	1.030	0.097	11.84	47.36	49.9	1,000	97.0
3	2.60	0.456	1.127		12.55	52.44			
P_{max} = 4,500 P_{min} = 200									
4	4.11	0.556	1.374	0.044	15.42	31.24	32.3	1,500	29.3
5	4.50	0.574	1.418	0.047	16.18	33.30	34.5	1,300	36.2
6	4.96	0.593	1.465	0.023	17.11	35.78	36.4	600	38.3
7	5.20	0.602	1.488	0.014	17.59	37.08	37.5	500	28.0
8	5.35	0.608	1.502	0.018	17.93	37.97	38.5	300	60.0
9	5.57	0.615	1.520	0.032	18.35	39.09	40.2	400	80.0
10	5.99	0.628	1.552	0.017	19.19	41.32	42.0	300	56.7
11	6.27	0.635	1.569	0.012	19.68	42.59	43.1	225	53.3
12	6.47	0.640	1.581	0.047	20.04	43.57	45.6	600	78.3
13	7.28	0.659	1.628		21.55	47.54		500	
14	8.38								

Table E-4 Specimen 14A-A-CP

b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
14A-A-CP	422°K	2.558	5.514		

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
N_{max} = 44,900		N_{min} = 900							
1	11.31	0.392	2.461	0.158	11.47	48.90	49.98	1,500	1,034
2	12.62	0.417	2.616	0.246	11.84	52.04	55.01	1,000	2,464
3	14.85	0.456	2.862		12.55	57.62			
N_{max} = 20,000		N_{min} = 900							
4	23.47	0.556	3.490	0.112	15.42	34.33	35.49	1,500	744
5	25.70	0.574	3.602	0.119	16.18	36.59	37.91	1,300	920
6	28.32	0.593	3.721	0.058	17.11	39.32	40.00	600	973
7	29.69	0.602	3.280	0.036	17.59	30.74	41.21	500	711
8	30.55	0.608	3.815	0.046	17.93	41.72	42.30	300	1,524
9	31.81	0.615	3.861	0.081	18.35	42.95	44.17	400	2,032
10	34.20	0.628	3.442	0.043	19.19	45.40	46.15	300	1,440
11	35.80	0.635	3.990	0.035	19.68	46.79	47.36	225	1,354
12	36.95	0.640	4.016	0.119	20.04	47.88	50.11	600	1,989
13	41.57	0.659	.135		21.55	52.24			
14	47.85								

Table E-5 Specimen 16B-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
16B-A-CP	300°F	1.004	2.505	12,000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.88	0.381	0.954	0.088	11.32	51.90	54.27	1,000	88.0
2	2.19	0.416	1.042	0.083	11.82	56.65	59.17	400	207.5
3	2.52	0.449	1.125		12.41	61.69			

Table E-6 Specimen 26B-A-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
26B-A-CP	300°F	1.002	2.504	14,000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.97	0.391	0.979	0.078	11.45	62.34	64.86	500	156.0
2	2.26	0.422	1.057	0.145	11.92	67.38	73.13	200	725.0
3	2.87	0.480	1.202		13.08	78.88			

Table E-5 Specimen 16B-A-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
16B-A-CP	422°K	2.550	6.363	53,400	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.74	0.381	2.423		11.32	57.03			
				0.223			59.63	1,000	2,235
2	12.51	0.416	2.647		11.82	62.25			
				0.211			65.01	400	5,270
3	14.39	0.449	2.858		12.41	67.78			

Table E-6 Specimen 26B-A-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
26B-A-CP	422°K	2.545	6.360	62,300	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	11.25	0.391	2.487		11.45	68.50			
				0.198			71.27	500	3,962
2	12.91	0.422	2.685		11.92	74.04			
				0.368			80.36	200	18,415
3	16.39	0.480	3.053		13.08	66.67			

Table E-7 Specimen 23B-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
23B-H-CP	300°F	0.908	2.503	3700	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da,dn, μin./cycle
1	1.85	0.377	0.944	0.032	11.27	16.86	17.1	7,000	4.6
2	1.96	0.390	0.976	0.058	11.44	17.40	17.9	10,000	5.8
3	2.17	0.413	1.034	0.035	11.78	18.45	18.8	5,000	7.0
4	2.30	0.427	1.069	0.035	12.01	19.13	19.5	4,500	7.8
5	2.44	0.441	1.104	0.057	12.26	19.84	20.5	5,200	11.0
6	2.68	0.464	1.161	0.045	12.72	21.10	21.7	4,000	11.3
7	2.89	0.482	1.206	0.028	13.12	22.20	22.6	2,500	11.2
8	3.04	0.493	1.234	0.040	13.40	22.93	23.5	3,000	13.3
9	3.27	0.509	1.274	0.053	13.83	24.05	24.9	4,000	13.3
10	3.61	0.530	1.327		14.48	25.68			

Table E-8 Specimen 7A-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
7A-H-CP	300°F	1.003	2.503	4500	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.81	0.372	0.931	0.045	11.21	18.54	18.94	9,000	5.0
2	1.96	0.390	0.976	0.065	11.44	19.35	20.02	9,000	7.2
3	2.19	0.416	1.041		11.82	20.68			

Table E-7 Specimen 23B-H-CP

b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
23B-H-CP	422°K	2.306	6.358	16,500	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	$ΔK_{AV}$ $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.56	0.377	2.398	0.081	11.27	18.53	18.79	7,000	117
2	11.19	0.390	2.479	0.147	11.44	17.40	19.67	10,000	147
3	12.39	0.413	2.626	0.089	11.78	20.27	20.66	5,000	178
4	13.13	0.427	2.715	0.089	12.01	21.02	21.43	4,500	198
5	13.43	0.441	2.804	0.145	12.26	21.80	22.53	5,200	279
6	15.30	0.464	2.951	0.114	12.72	23.18	23.84	4,000	287
7	16.50	0.482	3.063	0.071	13.12	22.20	24.83	2,500	284
8	17.35	0.493	3.134	0.102	13.40	25.20	25,82	3,000	338
9	18.67	0.509	3.235	0.135	13.83	26.43	27.36	4,000	338
10	20.61	0.530	3.371		14.48	28.72			

Table E-8 Specimen 7A-H-CP

b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
7A-H-CP	422°K	2.548	6.358	20,000	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	$ΔK_{AV}$ $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	10.34	0.372	2.365	0.114	11.21	20.37	20.81	9,000	127
2	11.19	0.390	2.379	0.165	11.44	21.26	22.00	9,000	183
3	12.51	0.416	2.644		11.82	22.72			

Table E-9 Specimen 8B-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
8B-H-CP	300°F	1.006	2.501	5000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.71	0.359	0.898	0.040	11.07	20.0	20.4	9,000	4.4
2	1.83	0.375	0.938	0.077	11.25	20.8	21.6	10,000	7.7
3	2.11	0.406	1.015	0.053	11.67	22.4	23.0	5,000	10.6
4	2.30	0.427	1.068	0.040	12.01	23.7	24.2	7,000	5.7
5	2.46	0.443	1.108	0.107	12.29	24.7	26.3	1,500	71.3
6	2.95	0.486	1.215	0.041	13.22	27.8	28.5	1,800	22.8
7	3.17	0.502	1.256		13.64	29.2			

Table E-10 Specimen 14C-H-CP a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
14C-H-CP	300°F	1.001	2.498	6000	200

x	C, μin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, μin./cycle
1	1.73	0.361	0.902	0.052	11.09	24.4	25.1	5,000	10.4
2	1.89	0.382	0.953	0.100	11.34	25.7	27.0	7,000	14.3
3	2.26	0.422	1.054	0.075	11.92	28.4	29.6	3,000	25.0
4	2.55	0.452	1.129	0.023	12.47	30.7	31.1	3,000	7.7
5	2.65	0.461	1.152	0.109	12.65	31.5	33.6	1,000	109.0
6	3.21	0.505	1.261	0.048	13.72	35.7	36.8	800	60.0
7	3.51	0.524	1.309	0.047	14.28	37.9	39.1	400	117.5
8	3.84	0.543	1.356	0.025	14.92	40.3	41.0	200	125.0
9	4.05	0.553	1.381	0.103	15.30	41.7	45.1	150	686.7
10	4.97	0.594	1.484		17.16	48.4			

Table E-9 Specimen 8B-H-CP | b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
8B-H-CP	422°K	2.555	6.352	22,200	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	5.76	0.359	2.281	0.102	11.07	21.98	22.42	9,000	112
2	10.45	0.375	2.383	0.196	11.25	22.86	23.73	10,000	196
3	12.05	0.406	2.378	0.135	11.67	24.61	25.27	5,000	269
4	13.13	0.427	2.712	0.102	12.01	25.04	26.59	7,000	145
5	14.05	0.443	2.814	0.272	12.29	27.14	28.90	1,500	1,811
6	16.84	0.486	3.086	0.102	13.22	30.55	31.32	1,800	579
7	18.10	0.502	3.086		13.64	32.08			

Table E-10 Specimen 14C-H-CP | b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
14C-H-CP	422°K	2.543	6.345	26,700	900

x	C nm/N	a/W	a, cm	Δa, cm	Y	ΔK $MN/m^{3/2}$	ΔK_{AV} $MN/m^{3/2}$	ΔN cycle	da/dn nm/cycle
1	9.88	0.361	2.291	0.132	11.09	26.81	27.58	5,000	264
2	10.79	0.382	2.321	0.254	11.34	28.24	29.67	7,000	363
3	12.90	0.422	2.678	0.191	11.92	31.21	32.52	3,000	635
4	14.56	0.452	2.868	0.058	12.47	33.73	34.17	3,000	196
5	15.13	0.461	2.926	0.277	12.65	34.61	36.92	1,000	2,769
6	18.33	0.505	3.202	0.122	13.72	39.23	36.92	800	1,524
7	20.04	0.524	3.325	0.199	14.28	41.64	40.44	400	2,985
8	21.93	0.543	3.444	0.064	14.92	44.28	45.05	200	3,175
9	28.84	0.553	3.508	0.262	15.30	45.82	49.56	150	17,442
10	28.38	0.594	3.769		17.16	53.18			

Table E-11 Specimen 19B-H-CP   a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
19B-H-CP	300°F	1.007	2.495	7000	200

x	C, µin./lb	a/W	a, in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, µin./cycle
1	1.82	0.373	0.931	0.052	11.23	29.32	30.1	4,000	13.0
2	1.99	0.394	0.983	0.082	11.49	30.85	32.2	3,000	27.3
3	2.29	0.427	1.065	0.058	12.01	33.55	34.6	2,000	29.0
4	2.53	0.450	1.123	0.035	12.43	35.64	36.3	2,000	17.5
5	2.68	0.464	1.158	0.119	12.72	37.01	39.8	550	216.4
6	3.31	0.512	1.277	0.065	13.92	42.57	44.4	250	260.0
7	3.75	0.538	1.342	0.033	14.75	46.24	47.3	68	485.3
8	4.02	0.551	1.375		15.22	48.30			

Table E-12 Specimen 27C-H-CP   a. U.S. Customary Units

Spec No.	Environment	B, in.	W, in.	P_{max}, lb	P_{min}, lb
27C-H-CP	300°F	0.948	2.499	8000	200

x	C, µin./lb	a/W	a in.	Δa, in.	Y	ΔK, ksi $\sqrt{in.}$	ΔK_{AV}, ksi $\sqrt{in.}$	ΔN, cycles	da/dn, µin./cycle
1	1.88	0.381	0.952	0.073	11.32	36.38	37.73	2,000	36.5
2	2.14	0.410	1.025	0.080	11.73	39.09	40.78	1,000	80.0
3	2.45	0.442	1.105	0.144	12.28	42.47	46.21	750	192.0
4	3.14	0.500	1.249		13.58	49.96			

Table E-11 Specimen 19B-H-CP **b. International Units (S.I.)**

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
19B-H-CP	422°K	2.558	6.338	31,100	900

x	C	a/W	a,	Δa,	Y	ΔK	$ΔK_{AV}$	ΔN	da/dn
	nm/N		cm	cm		$MN/m^{3/2}$	$MN/m^{3/2}$	cycle	nm/cycle
1	10.39	0.373	2.365	0.132	11.23	32.21	33.07	4,000	330
2	11.36	0.394	2.500	0.208	11.49	33.90	35.38	3,000	693
3	13.08	0.427	2.705	0.147	12.01	36.87	38.02	2,000	737
4	14.45	0.450	2.852	0.089	12.43	39.16	39.89	2,000	445
5	15.30	0.464	2.941	0.302	12.72	40.67	43.73	550	5,497
6	18.90	0.512	3.243	0.165	13.92	46.78	48.79	250	6,604
7	21.44	0.538	3.409	0.084	14.75	50.81	51.97	68	12,327
8	22.96	0.551	3.492		15.22	53.07			

Table E-12 Specimen 27C-H-CP b. International Units (S.I.)

Spec No.	Environment	B, cm	W, cm	P_{max}, N	P_{min}, N
27C-H-CP	422°K	2.408	6.348	35,600	900

x	C	a/W	a,	Δa,	Y	ΔK	$ΔK_{AV}$	ΔN	da/dn
	nm/N		cm	cm		$MN/m^{3/2}$	$MN/m^{3/2}$	cycle	nm/cycle
1	10.74	0.381	2.418	0.185	11.32	39.97	41.46	2,000	927
2	12.22	0.410	2.604	0.203	11.73	42.95	44.81	1,000	2,032
3	13.99	0.442	2.807	0.366	12.28	46.67	50.78	750	4,877
4	17.92	0.500	3.173		13.58	54.90			