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**MECHANICAL PROPERTIES OF 7049-T73 AND
7049-T76 ALUMINUM ALLOY EXTRUSIONS AT
SEVERAL TEMPERATURES**

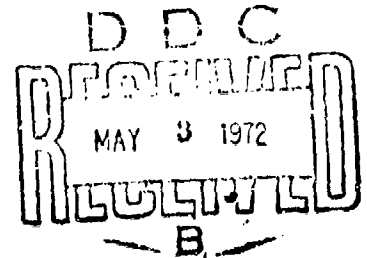
R. E. JONES

*UNIVERSITY OF DAYTON
RESEARCH INSTITUTE*

TECHNICAL REPORT AFML-TR-72-2

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FOREWORD

This report was prepared by the University of Dayton Research Institute, Dayton, Ohio. The work was performed under USAF Contract No. F33615-71-C-1054. The contract was initiated under Project No. 7381, "Materials Applications," Task No. 738106, "Design Information Development," and administered by the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, Mr. David C. Watson (AFML/LAE). Project Engineer.

All (or many) of the items compared in this report were commercial items that were not developed or manufactured to meet Government specifications, to withstand the tests to which they were subjected, or to operate as applied during this study. Any failure to meet the objectives of this study is no reflection on any of the commercial items discussed herein or on any manufacturer.

The author would like to acknowledge that testing performed for this program was accomplished by Messrs. R. J. Marton and W. D. Cambren. Engineering support was provided by Mr. G. J. Petrak.

This report covers work conducted from June 1970 to June 1971. The contractor's report number is UDRI-TR-71-38.

This technical report has been reviewed and is approved.

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ABSTRACT

The mechanical properties of (1) a 7049-T73 bar extrusion, (2) a 7049-T73 integrally stiffened extrusion, and (3) a 7049-T76 bar extrusion were evaluated. The evaluation encompassed tensile, fracture toughness, axial fatigue, stress corrosion, and fatigue crack growth testing at several temperatures from -65°F to 500°F. The tensile properties of the integrally stiffened extrusion were comparable to 7075-T651 extrusion properties in the literature. The fracture toughness properties of the -T73 bar and the -T76 bar were superior to the 7075-T651 properties. The -T73 bar and -T73 integrally stiffened extrusions had superior axial fatigue properties when compared with 7075-T651 extruded panel data in the literature. Failure did not occur in time-to-failure stress corrosion tests using either constant immersion precracked specimen or alternate immersion smooth specimen. The crack growth rate in -T73 bar was similar to that of 7075-T7352 hand forging and 7075-T6 sheet in the literature.

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SECTION I

INTRODUCTION

Extruded aluminum alloys are used extensively by weapon system manufacturers as structural members in Air Force systems. Due to the reduction in machining time and cost to produce complicated structural configurations, extrusions are considered advantageous where they can be used. A newly developed aluminum alloy extrusion in two heat treatment conditions, 7049-T73 and 7049-T76, is being manufactured by the Kaiser Aluminum and Chemical Corporation. Because it is expected to have strength levels comparable to that of 7075, combined with excellent fracture toughness and stress corrosion cracking resistance, the 7049 extrusion is considered a prime candidate for future aircraft structural applications.

Two 7049-T73 extrusions and one 7049-T76 extrusion were procured by AFML for mechanical property evaluation by the University of Dayton Research Institute. Tensile and fracture toughness properties at several temperatures were developed for all three extrusions. In addition, for the two -T73 extrusions, fatigue, corrosion, and crack growth properties were developed as material limitations permitted.

SECTION II

MATERIALS AND SPECIMENS

The three extrusions received from Kaiser Aluminum are shown from right to left in Figure 1: (a) an integrally stiffened 7049-T73 extrusion measuring 18 1/2 inches long x 11 1/4 inches wide x 3 inches high; (b) a 7049-T76 bar extrusion measuring 20 1/4 inches long x 3 1/4 inches wide x 3 1/2 inches high; (c) a 7049-T73 bar extrusion with the same measurements as the 7049-T76 bar extrusion. Tensile properties were generated for the three extrusions with the specimen configuration shown in Figure 2. Specimens were machined from the longitudinal, transverse, and short transverse directions of the extrusions. Compact tension fracture toughness specimens from all three extrusions were tested in the specimen configurations shown in Figure 3. Specimens were again machined from the longitudinal, transverse, and short transverse directions of the extrusions. Axial fatigue properties both smooth and notched ($K_t = 3.0$) were developed for the two extrusions in the -T73 condition. The smooth fatigue specimen configuration and the notched fatigue specimen configuration are shown in Figure 4 and Figure 5 respectively. Only longitudinal fatigue specimens were tested. Stress corrosion properties of the two extrusions in the -T73 condition were studied using longitudinal and short transverse precracked compact tension constant immersion specimen (see Figure 3) and short transverse smooth tensile alternate immersion specimen (see Figure 2). Fatigue crack growth properties were developed for the -T73 extrusions with the rectangular double cantilever beam configuration shown in Figure 6.

SECTION III

TEST PROCEDURES

Tensile and fracture toughness testing was performed on a Wiedemann testing machine according to ASTM standard testing procedures. The -65°F and 0°F test temperatures were reached in a styrofoam chamber using dry ice as a cooling agent, while the 250°F , 350°F and 500°F test temperatures were reached in a split three-zone Marshall furnace. Axial fatigue testing was accomplished on an Amsler Vibrophore testing machine with a loading frequency of 4200 cpm and an "R" ratio (ratio of minimum fatigue stress to maximum fatigue stress) of 0.1. The 250°F and 350°F test temperatures were again reached with a split three-zone Marshall furnace.

Constant immersion stress corrosion testing was performed with pre-cracked specimens in a 3.5 percent sodium chloride solution. The solution was contained in a Plexiglas tank. Static loading was applied to the specimen utilizing a Satec creep frame. Time-to-failure was initially planned to be the output data although failure did not actually occur in the specimens within the testing period.

Alternate immersion stress corrosion testing was accomplished using smooth tensile specimens in a 3.5 percent sodium chloride solution. The specimens were again statically loaded in a creep frame and the time-to-failure monitored. A beaker type immersing system was used to keep the specimen immersed ten minutes and out of solution for fifty minutes during every hour of the test period.

Fatigue crack growth testing was performed in a closed-loop MTS hydraulic testing system. A sinusoidal wave form was used when loading the specimen. Crack growth was monitored optically on the specimen surface with a 30x Gaertner traveling microscope. An "R" ratio of 0.1 was employed for all crack growth testing. Cracks were propagated in the longitudinal and the short transverse directions of the extrusions having the -T73 condition.

SECTION IV

RESULTS AND DISCUSSION

A material's potential usefulness can be ascertained by comparing its properties with those of a material it could possibly replace. It will be shown shortly that the -T651 heat treatment of the 7075 gives it a strength equal to the 7049 strength levels developed in this report. Therefore, when possible, the data developed in this report will be compared to 7075-T651 extrusion data in the literature. In general, a comparison between 7049-T76 or -T73 and the lower strength 7075-T73 would be inappropriate.

The average tensile properties of the three 7049 extrusions are presented in Figures 7 through 12. The properties from each individual specimen are shown in the Appendix. The 7049-T76 bar is the strongest of the three extrusions in the longitudinal direction at all test temperatures with the exception of 500°F (see Figure 7). The 7049-T73 integrally stiffened extrusion is the strongest in the transverse and short transverse directions (see Figures 8 and 9). The best overall average strength was exhibited by the 7049-T73 integrally stiffened extrusion. As can be observed, an acute loss of strength occurred at the 500°F temperature for all materials. The elongation and reduction of area was comparable for all three extrusions (see Figures 10 through 12). The tensile properties of the three extrusions are comparable to 7075-T651 extrusion properties presented by Kaufman, et al⁽¹⁾ (85.4 KSI and 90.4 KSI for the longitudinal ultimate strength of 3-1/2-inch and 11/16-inch extruded shapes, respectively; similar properties for the transverse direction are 77.3 and 87 KSI). These properties are somewhat higher than the same properties for 7075 extrusions in the T7351 condition also reported by Kaufman.

(1) Kaufman, et al, "Fracture Toughness, Fatigue, and Corrosion Characteristics of X7080-T7E41 and 7178-T651 and 7075-T6510, 7075-T7351, X7080-T7E42 and 7178-T6510 Extruded Shapes," AFML-TR-69-255.

Fracture toughness properties are presented in Figures 13 through 15. The -T73 and -T76 bar extrusions exhibited similar longitudinal toughness values that were significantly better than the same properties for the integrally stiffened extrusion. The -T73 and -T76 bar extrusions had longitudinal toughness values significantly better than those for 7075-T6510 extrusion reported in (1), while the toughness for the integrally stiffened extrusion was equal to the 7075-T651 longitudinal toughness. For the transverse direction a somewhat opposite effect is noted. That is, the integrally stiffened extrusion had transverse toughness superior to 7075-T651 extrusions (1) while the -T73 and -T76 bars had toughness equal to or slightly below 7075-T651 extrusion transverse toughness. It is apparent from Figures 13 and 14 that the more homogeneous toughness properties are possessed by the integrally stiffened extrusion. There was a 6 percent loss in longitudinal toughness of the -T73 bar due to a change in temperature from room to -65°F. The -T73 bar was also the tougher of the three extrusions at room temperature in the short transverse direction.

Axial fatigue properties of the 7049-T73 bar and integrally stiffened extrusions are shown in Figures 16 through 21. Composite fatigue curves are presented in Figures 22 and 23. In a smooth condition and at room temperature the -T73 integrally stiffened extrusion had the better fatigue properties of the two extrusions at the higher stress levels. At the lower stress levels the extrusion with the better fatigue properties is dependent on the test temperature. In the notched condition both extrusions had similar fatigue properties. Both extrusions were superior in room temperature smooth axial fatigue to 7075-T6510 extruded panel and 7075-T7351 extruded panel. They were also superior to 7049-T73 forging (see Figure 24). Fatigue limits are presented in Table I. The fatigue limits of both extrusions were similar.

Time-to-failure stress corrosion cracking properties of the -T73 materials are presented in Table II. Precracked compact tension specimens were utilized in this phase of the testing. Neither extrusion was susceptible to cracking in

TABLE I
FATIGUE LIMITS FOR 7049-T73 ALUMINUM
EXTRUSIONS AT 10^7 CYCLES

Test Condition Extrusion Configuration	SMOOTH			NOTCHED		
	RT	250°F	350°F	RT	250°F	350°F
Bar	53.0 KSI	37.5 KSI	31.5 KSI	16.6 KSI	15.0 KSI	10.5 KSI
Integrally Stiffened	49.0 KSI	41.0 KSI	28.0 KSI	15.0 KSI	16.0 KSI	12.0 KSI

TABLE II
TIME-TO-FAILURE STRESS CORROSION PROPERTIES
OF 7049 ALUMINUM EXTRUSIONS IN 3.5%
SODIUM CHLORIDE SOLUTION

Material	Loading Direction	K_I Initial (KSI $\sqrt{\text{in}}$)	Elapsed Test Time (hrs)	Results
7049-T73 Integrally Stiffened	Longitudinal	24.7	265.9	No failure
		26.7	285.5	No failure
	Short Transverse	19.4	0.0	Failed on loading
		19.4	670.6	No failure
7049-T73 Bar	Longitudinal	22.9	0.0	Failed on loading
		19.2	285.5	No failure
		23.9	0.0	Failed on loading
		20.4	353.8	No failure
		21.2	287.3	No failure
	Short Transverse	16.0	330.0	No failure
		20.3	330.0	No failure

a corrosive environment for the indicated elapsed test periods. However, extensive pitting was observed in the precracked region of specimens during post-test examinations.

Alternate immersion stress corrosion results of the 7049-T73 integrally stiffened extrusion in the short transverse direction are presented in Table III. Failure did not occur at a stress level of 61.7 KSI in the 1000-hour elapsed test periods using smooth tensile specimens. Since failure did not occur in either type of stress corrosion test it appears that the materials tested are not susceptible to cracking in a 3.5 percent salt solution within the reported time periods. On first observation these results are somewhat surprising. Initial data from the literature show that while the material has good corrosion resistance it is nevertheless sensitive to corrosive attack above approximately 35 KSI. Because of this discrepancy between the two sets of corrosion tests an examination of the microstructure of the specimens tested in this program was initiated. It was felt that the reason for the apparent insensitivity to corrosion might have been because the specimens were taken from a somewhat complicated shape and the possibility did exist of having specimens with their grain structure oriented other than in the short transverse direction. Since in aluminum alloys the short transverse grain direction is sensitive to corrosive attack, any misorientation of the grain structure would cause the test results to be misleading. Each of the alternate immersion specimens were mounted, polished, etched, and photomicrographed. From these photos it appears the specimens were located with their pull direction parallel to the short transverse direction. Other possibilities for the difference in results are associated with metallurgical differences, such as grain size, and with specimen size effects. The specimens used in this investigation were 1/4 inch in diameter while those in the literature were 1/8 inch in diameter. Since it was not possible to check the grain structure of the specimens tested by the other investigators, no further comparison was made.

Fatigue crack growth rate data are presented in Figure 25. Although crack growth tests were planned for both of the -T73 extrusions, crack growth testing was only possible in the bar extrusion because of the arm break-off problems

TABLE III

ALTERNATE IMMERSION STRESS CORROSION RESULTS
OF 7049-T73 INTEGRALLY STIFFENED EXTRUSION
IN A 3.5% SODIUM CHLORIDE SOLUTION *

Stress Level KSI	Test Period ** (hrs)
30.0	2016
40.0	2016
45.0	2016
54.9 (80% of yield stress)	1000
61.7 (90% of yield stress)	1000

* Specimen Removed from Short Transverse Direction
of Extrusion

** No Failure

in the rectangular DCB specimen from the integrally stiffened extrusion (see Figure 26). This arm break-off problem could be caused by anisotropic material properties in the test sample. Fatigue crack growth rate data similar to the 7049-T73 bar growth data were obtained by Brownhill, et al. (2) for a 7075-T7352 hand forging and by Dubensky for 7075-T6 sheet (see Figure 25). From the limited amount of tests, of which none were duplicates, it appears the 7049 has the same general crack growth rates as the 7075 materials in the literature. Crack growth tests were performed with cracks oriented in the short transverse and the longitudinal directions of the bar extrusions. Little difference was observed in crack growth rates below 10 microinch/cycle. It appears that above this value the curve for the specimen with its crack oriented in the short transverse direction may behave differently than the other specimens. This adds proof to the indication that the crack growth rates are dependent on grain orientation. Crack growth in the -T73 bar extrusion shows loading rate sensitivity in the frequency range of 1200 to 600 cpm. It must be cautioned that these conclusions are drawn from only a limited number of tests.

(2) Brownhill, et al., "Mechanical Properties, Including Fracture Toughness and Fatigue, Corrosion Characteristics and Fatigue-Crack Propagation Rates of Stress-Relieved Aluminum Alloy Hand Forgings," AFML-TR-70-10, February 1970.

SECTION V

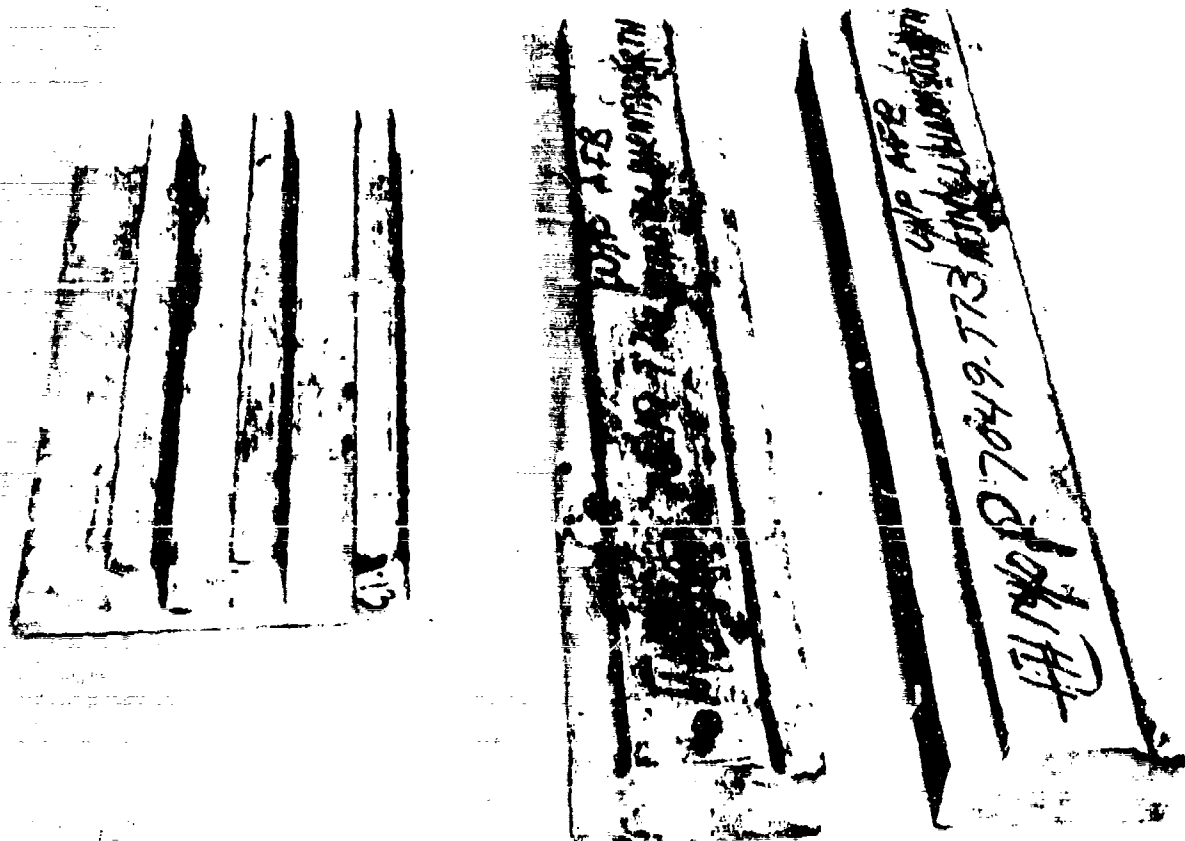
SUMMARY

Three 7049 extrusions of various configurations and heat treatments were evaluated. A synopsis of the observed mechanical properties for each extrusion is presented below.

(a) The 7049-T73 bar extrusion studied in this report was determined to have excellent fatigue, fracture toughness, and corrosion resistance while maintaining the tensile properties of contemporary aluminum alloys. Because of these attributes the 7049-T73 appears to be a likely candidate for future aircraft systems.

(b) The 7049-T73 integrally stiffened extrusion also exhibited excellent fatigue properties while displaying tensile properties on a par with high strength aluminum alloys used in modern aircraft. However, while fracture toughness properties were directionally homogeneous, toughness was low in the longitudinal direction and slightly high in the transverse and short transverse directions as compared to other high strength aluminum alloys. Again, insensitivity to stress corrosion cracking was apparent.

(c) The tensile and fracture toughness properties of 7049-T76 bar were similar to that of the 7049-T73 bar. Further testing is necessary in order to fully evaluate the 7049-T76 bar extrusion.



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Figure 1. 7049 Aluminum Alloy Extrusions as Received

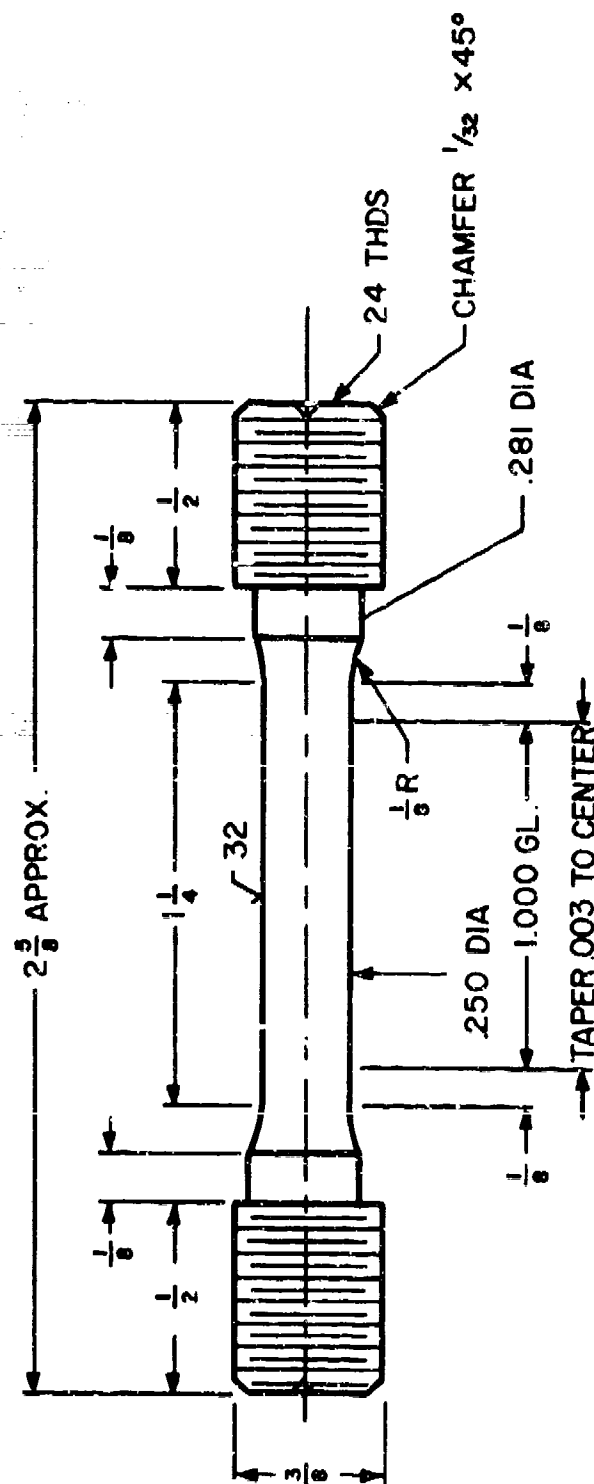
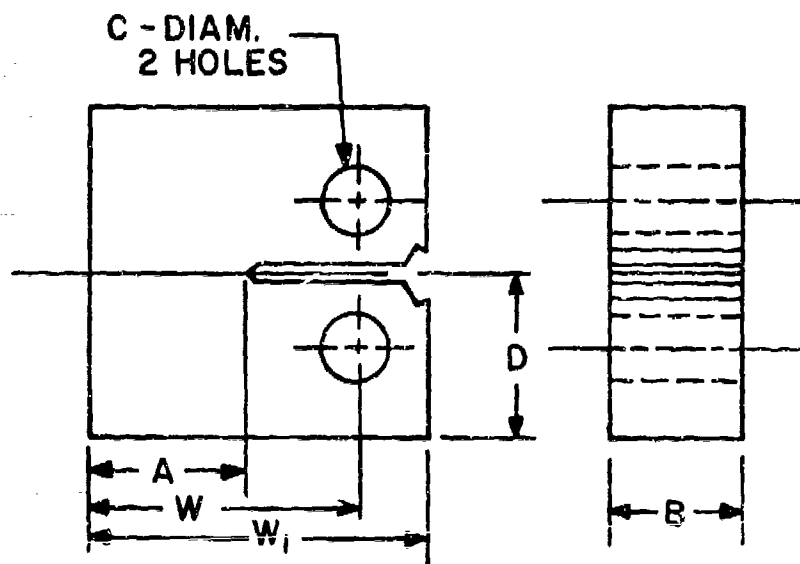


Figure 2. Tensile Specimen Configuration



DIMENSIONS

SPECIMEN THICKNESS (INCHES)	A	B	W	W ₁	D	C
1	1.100	1.000	2.000	2.500	1.200	0.500
3/4	0.835	0.750	1.500	1.875	0.900	0.375
1/2	0.550	0.500	1.000	1.250	0.600	0.250

Figure 3. Compact Tension Specimen Configuration

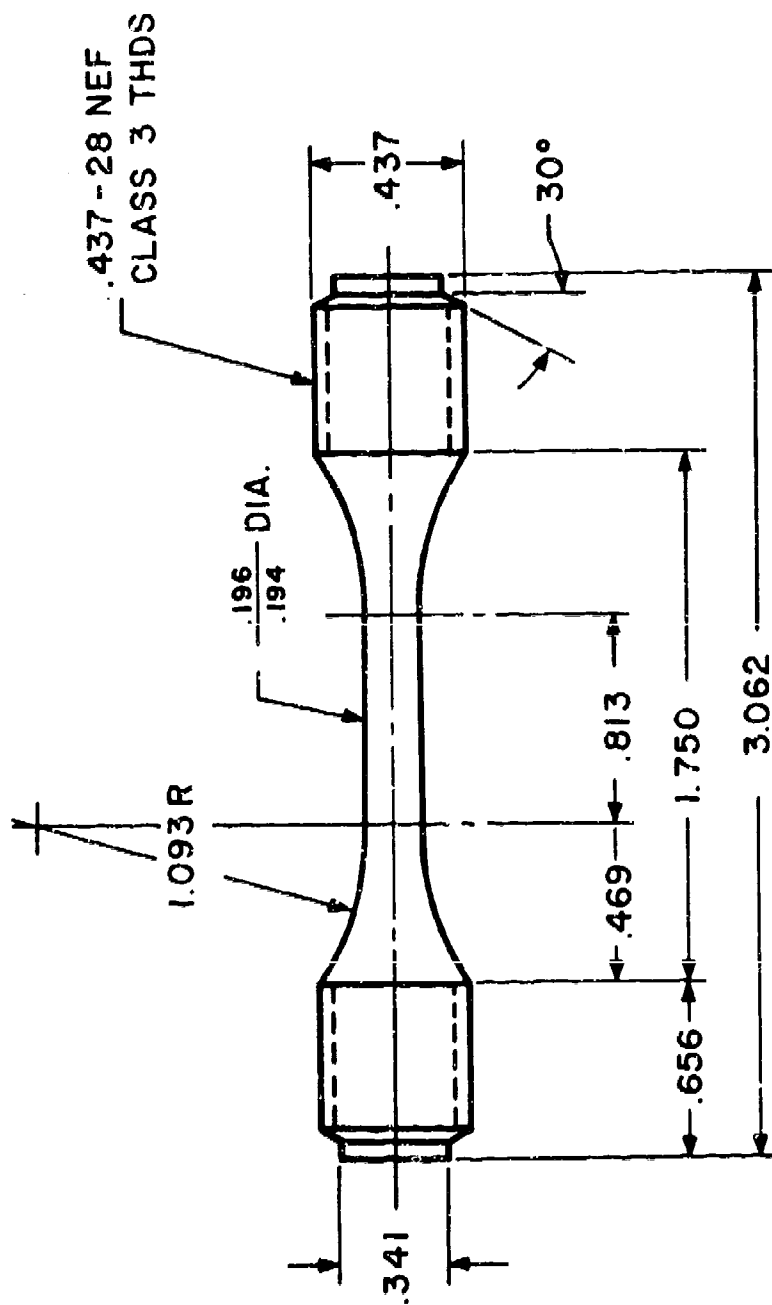


Figure 4. Smooth Axial Fatigue Specimen Configuration

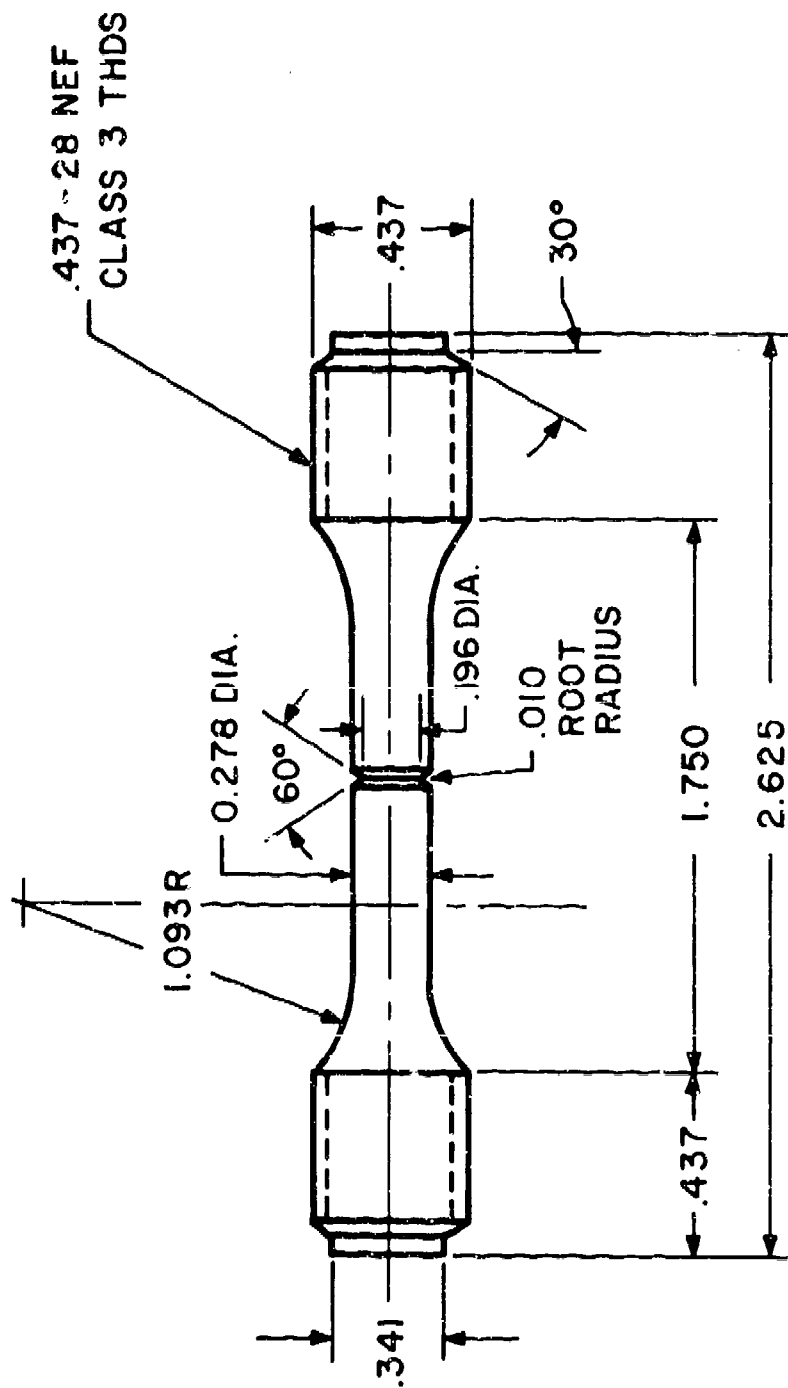


Figure 5. Notched Axial Fatigue Specimen Configuration

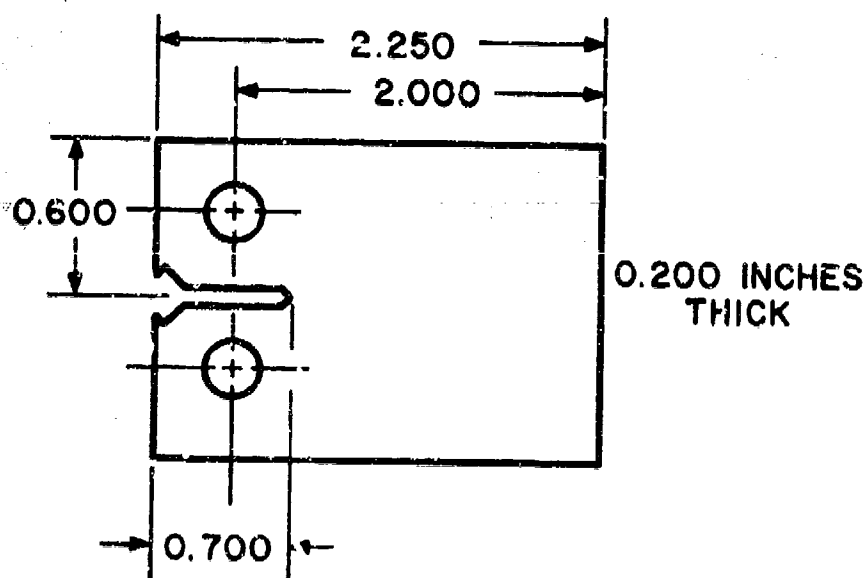


Figure 6. Rectangular Double Cantilever Beam
Crack Growth Specimen Configuration

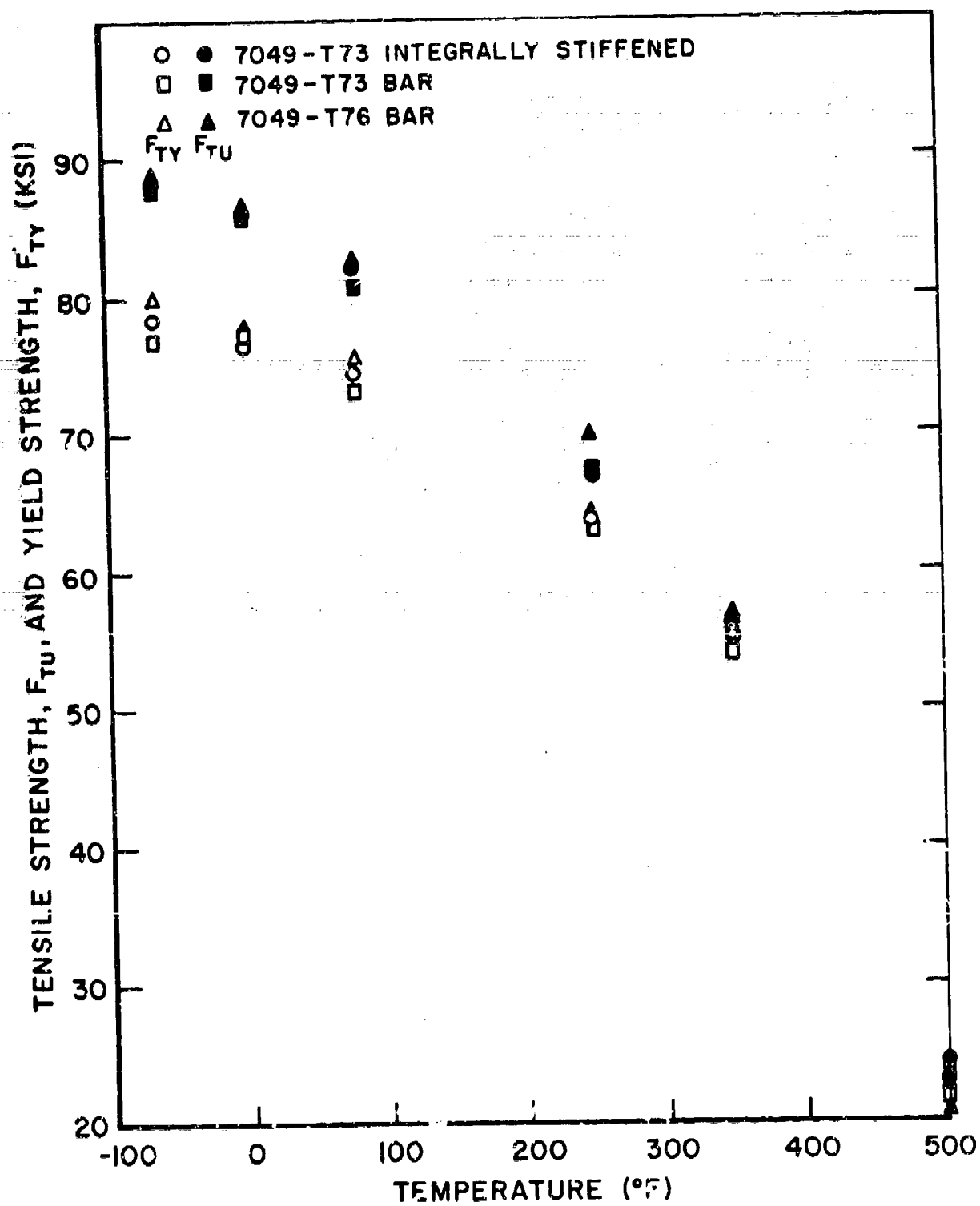


Figure 7. Tensile Property Data for the Longitudinal Direction of Three 7049 Extrusions

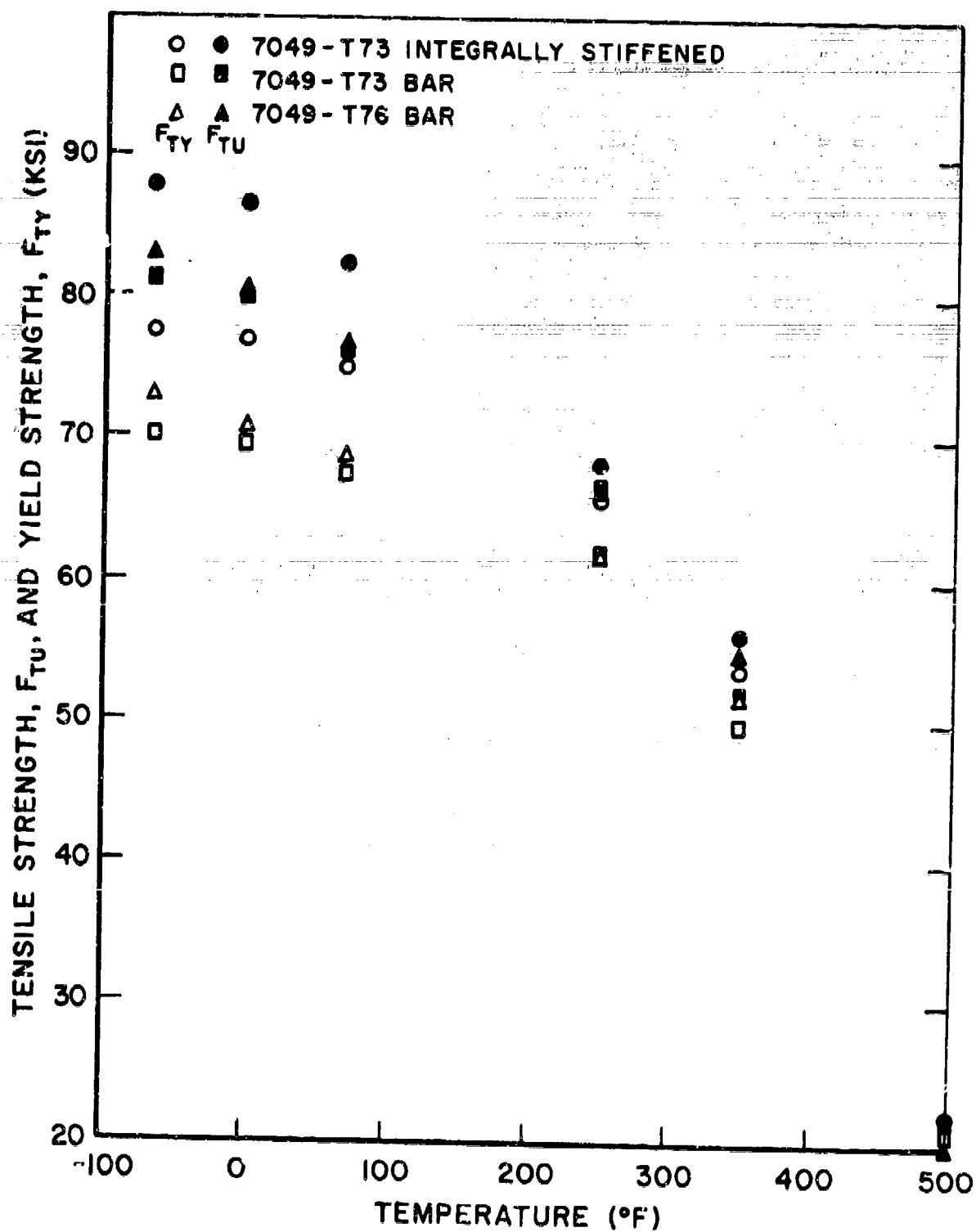


Figure 8. Tensile Property Data for the Transverse Direction of Three 7049 Extrusions

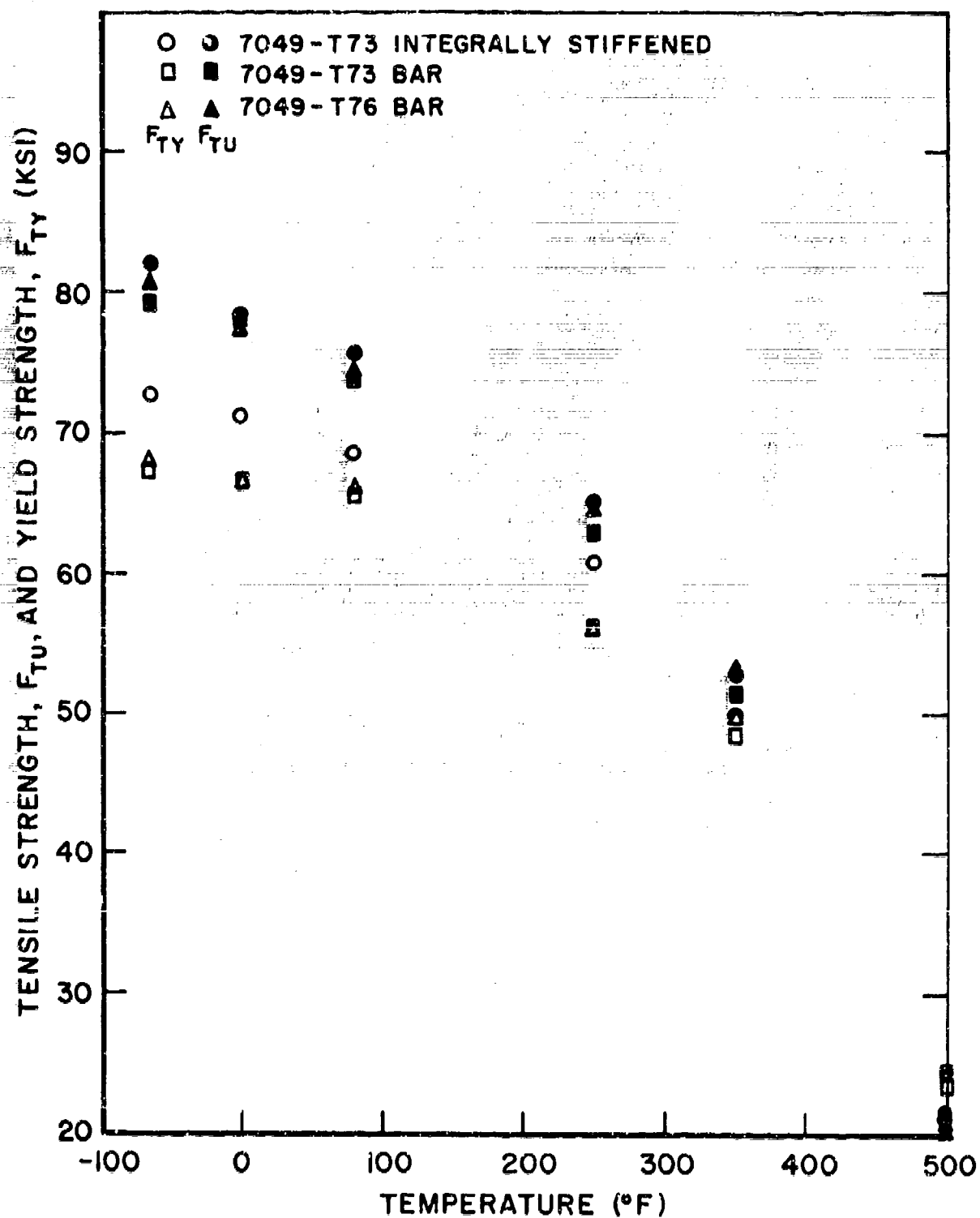


Figure 9. Tensile Property Data for the Short Transverse Direction of Three 7049 Extrusions

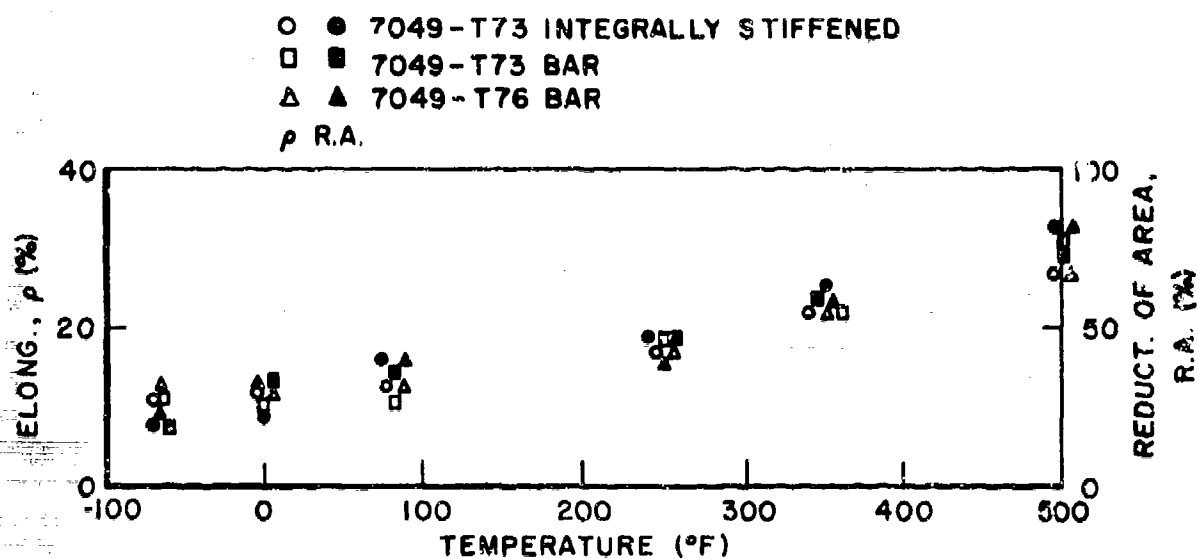


Figure 10. Elongation and Reduction of Area for the Longitudinal Direction of Three 7049 Extrusions

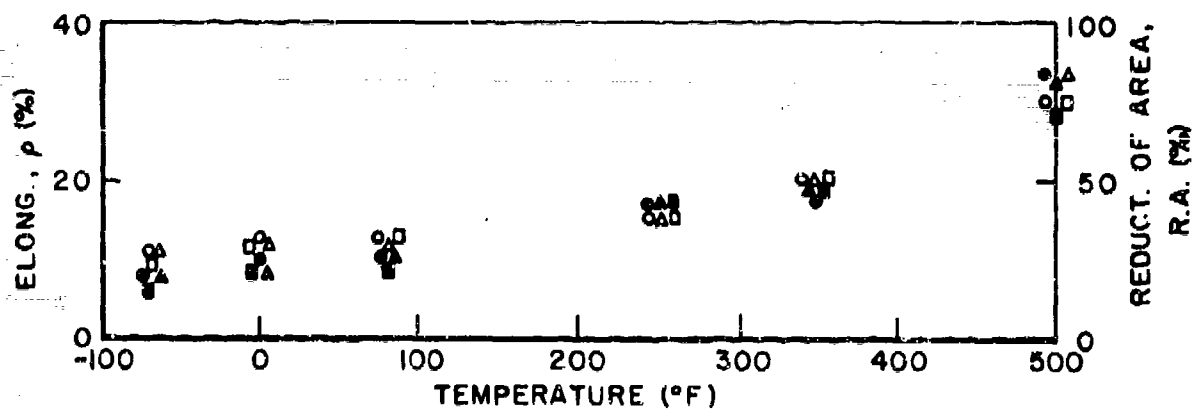


Figure 11. Elongation and Reduction of Area for the Transverse Direction of Three 7049 Extrusions

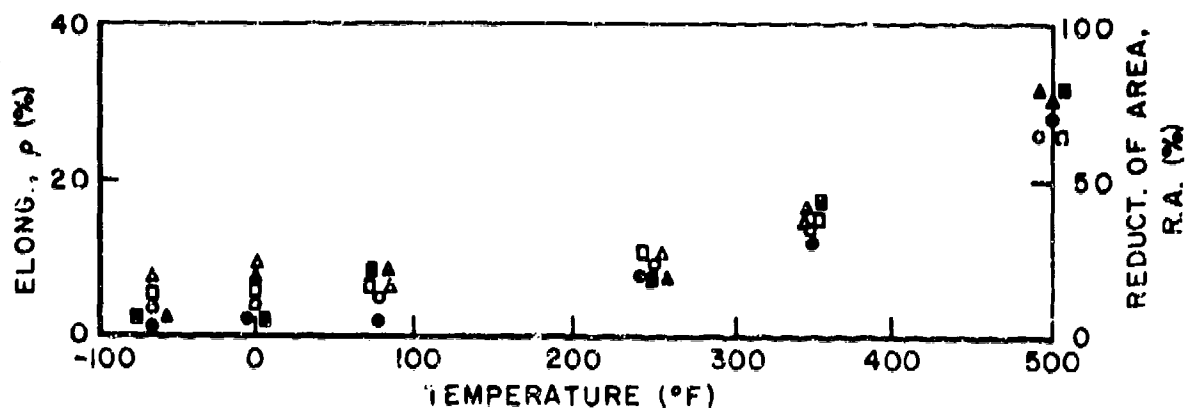


Figure 12. Elongation and Reduction of Area for the Short Transverse Direction of Three 7049 Extrusions

- 7049 - T73 INTEGRALLY STIFFENED
 - 7049 - T73 BAR
 - △ 7049 - T76 BAR
 - 7049 - T73 INTEGRALLY STIFFENED
- [SHORT LONG. (TL) DIRECTION]

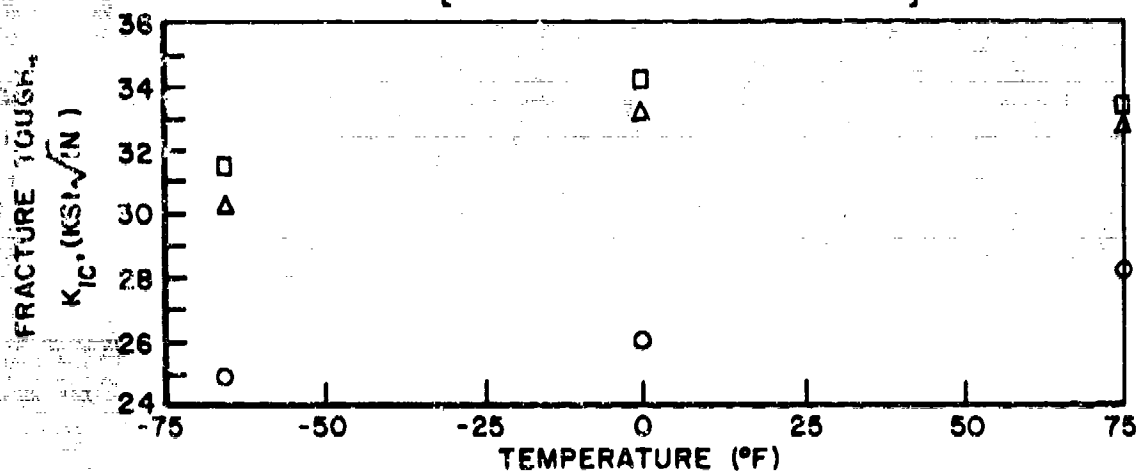


Figure 13. Fracture Toughness, K_{IC} , for the Longitudinal (LW) Orientation in Three 7049 Extrusions

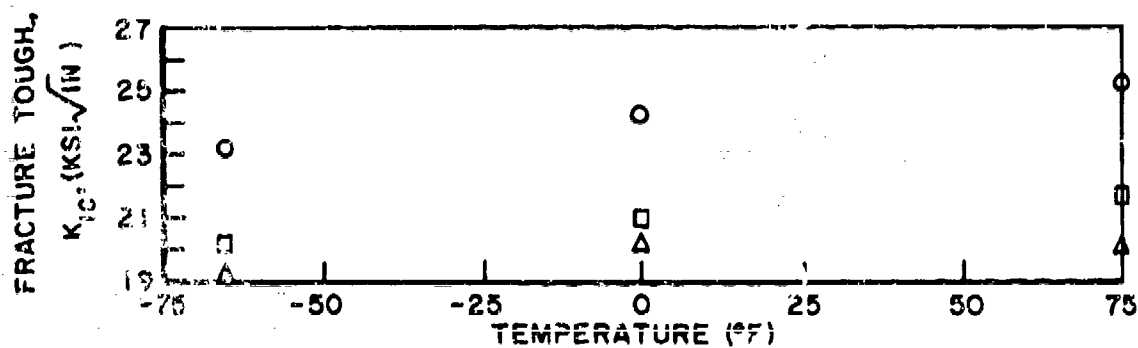


Figure 14. Fracture Toughness, K_{IC} , for the Transverse (WL) Orientation in Three 7049 Extrusions

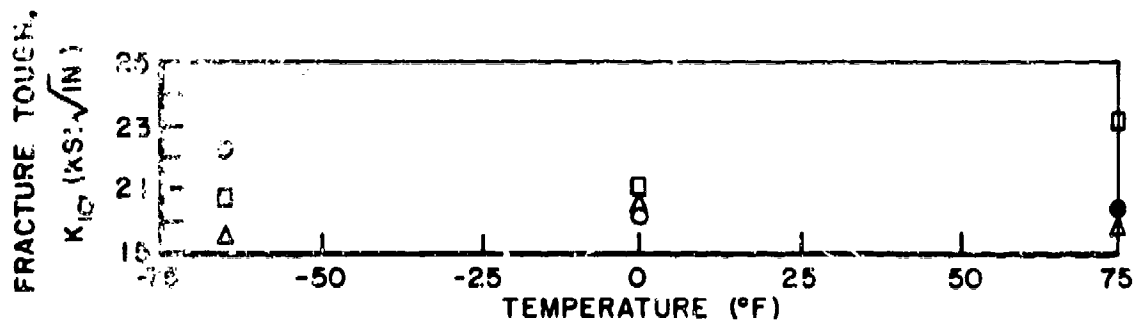


Figure 15. Fracture Toughness, K_{IC} , for the Short Transverse (TW) Orientation in Three 7049 Extrusions

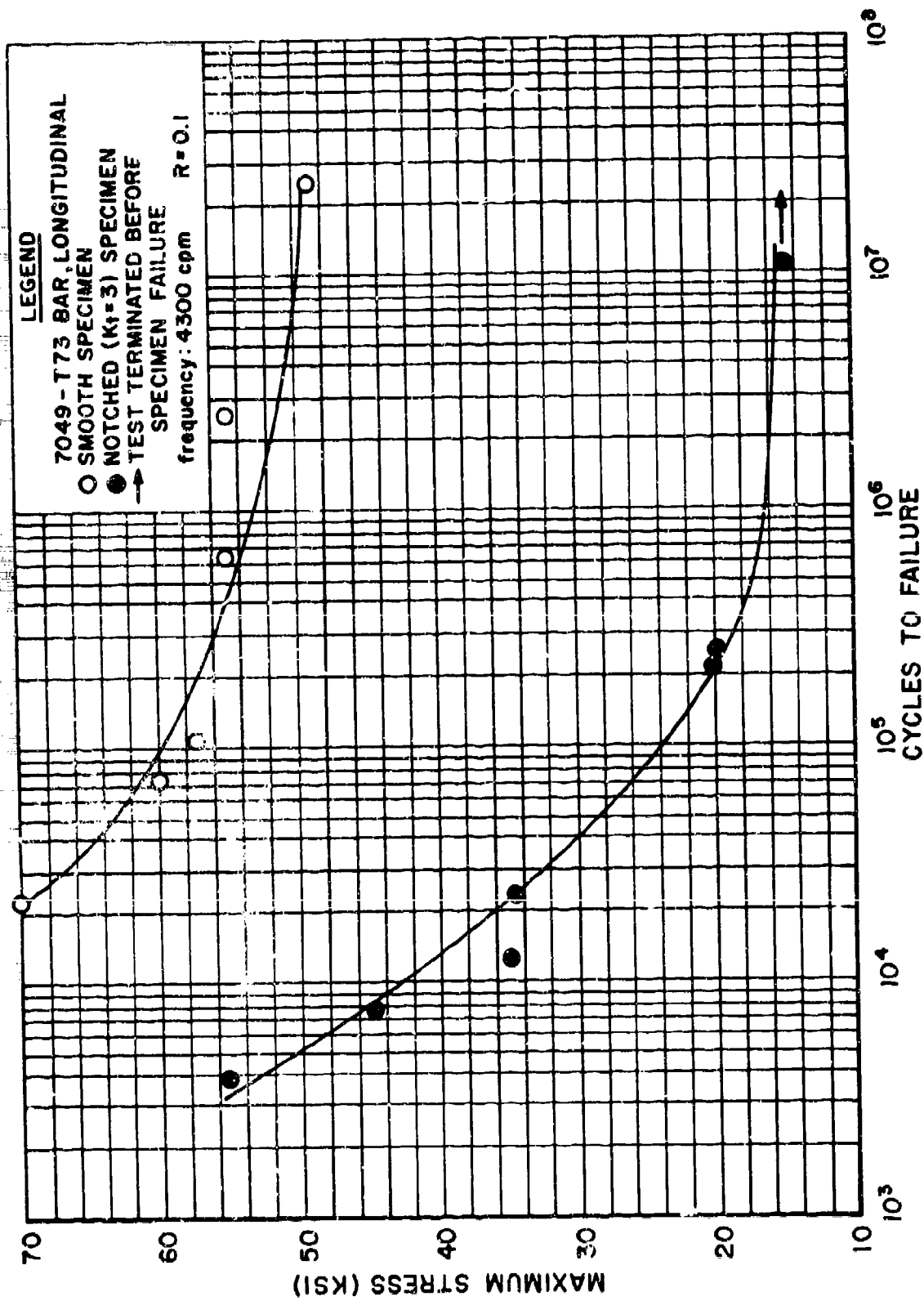


Figure 16. S/N Fatigue Curve at Room Temperature for 7049-T73 Aluminum Bar Extrusion

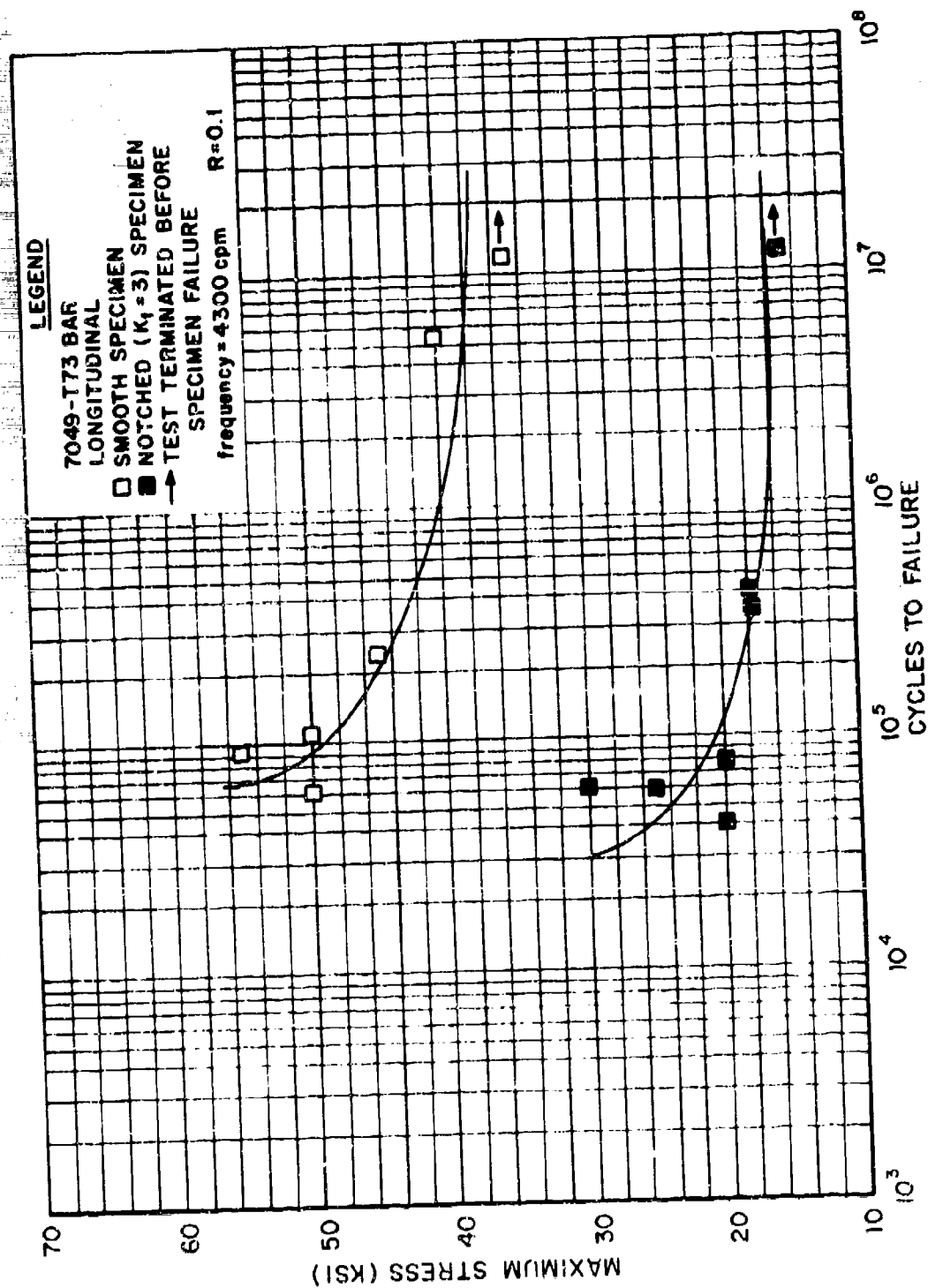


Figure 17. S/N Fatigue Curve at 250°F for 7049-T73 Aluminum Bar Extrusion

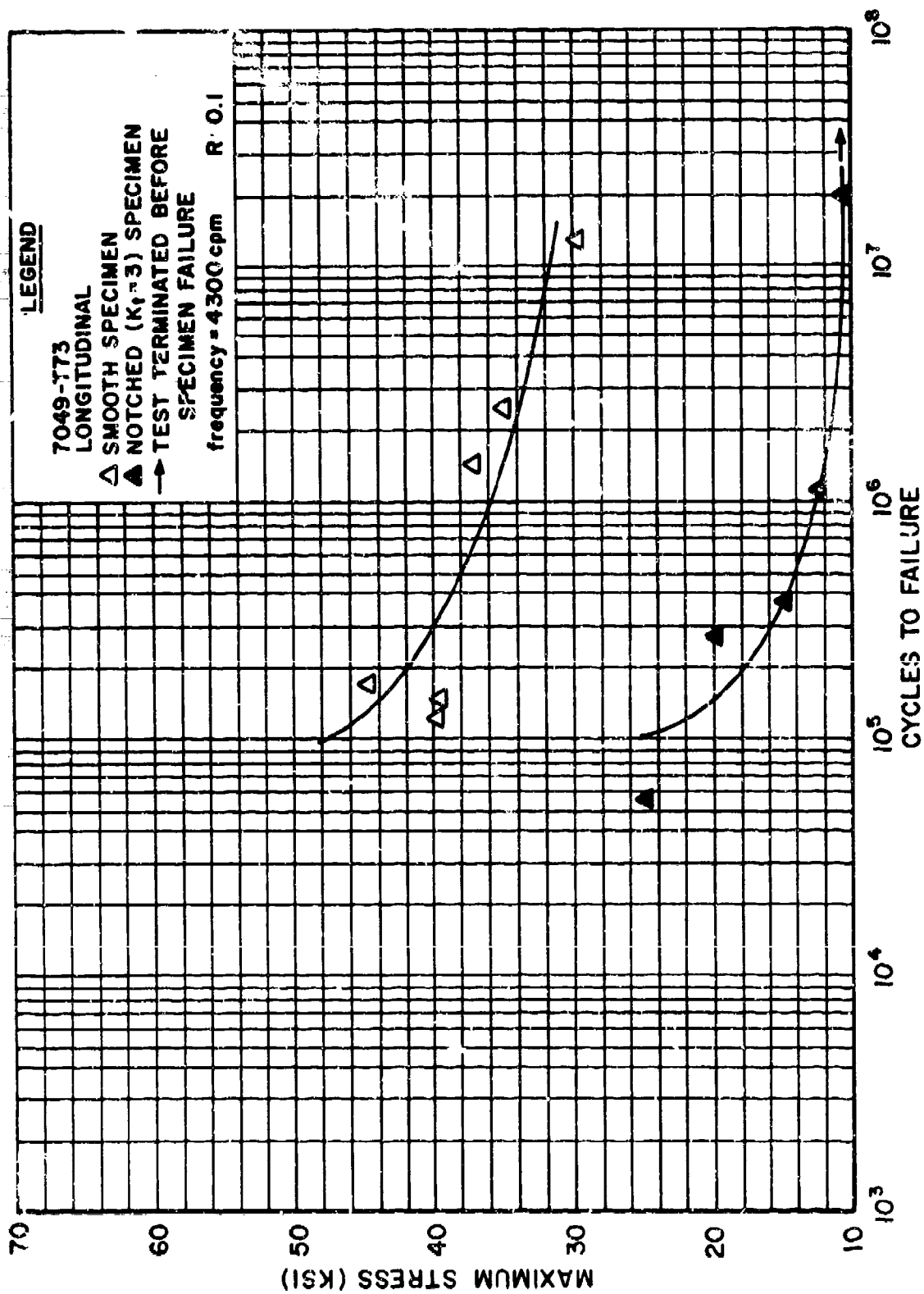


Figure 18. S/N Fatigue Curve at 350°F for 7049-T73 Aluminum Bar Extrusion

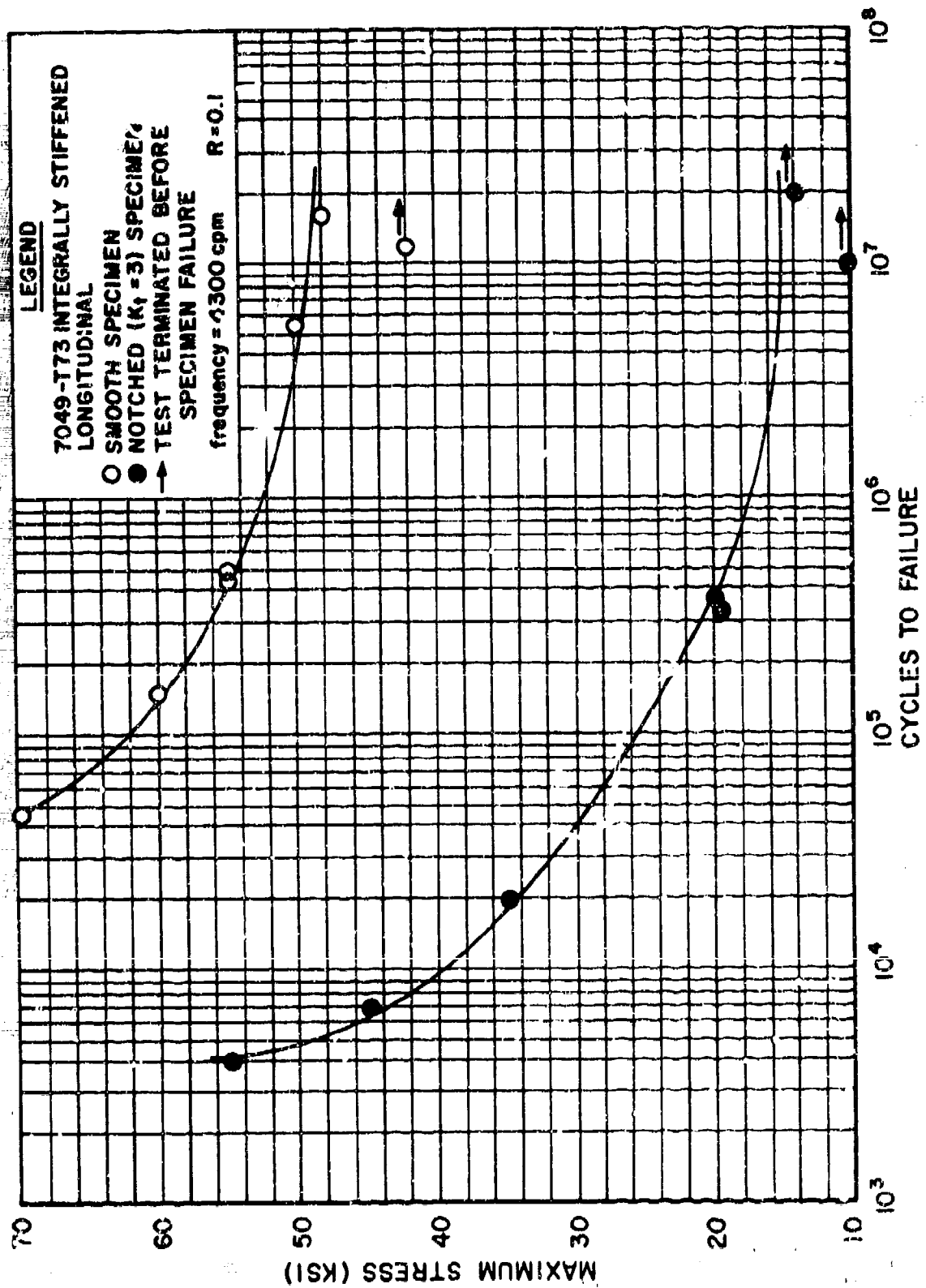


Figure 19. S/N Fatigue Curve at Room Temperature for 7049-T73 Integrally Stiffened Aluminum Extrusion

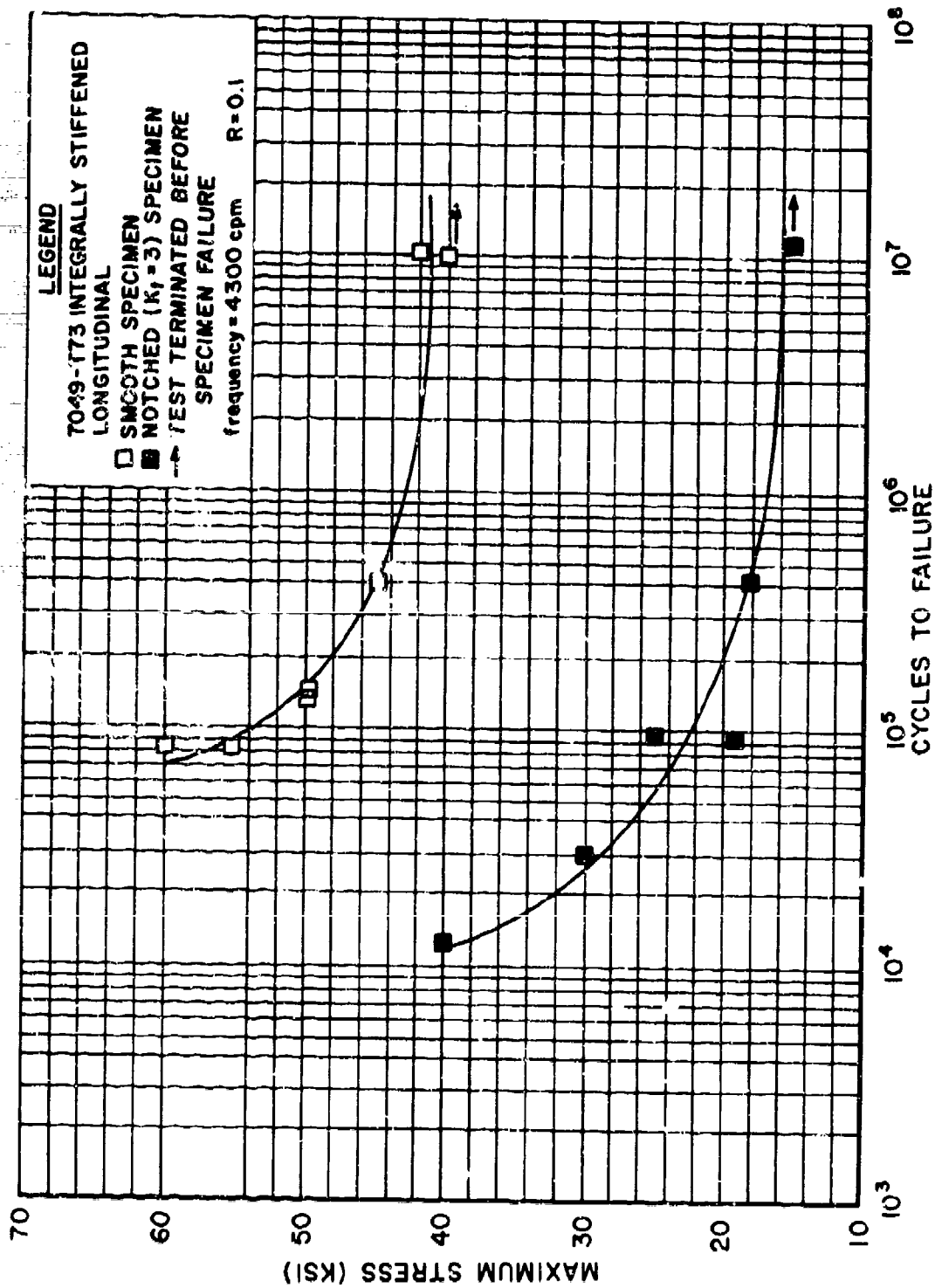


Figure 20. S/N Fatigue Curve at 250°F for 7049-T73 Integrally Stiffened Aluminum Extrusion

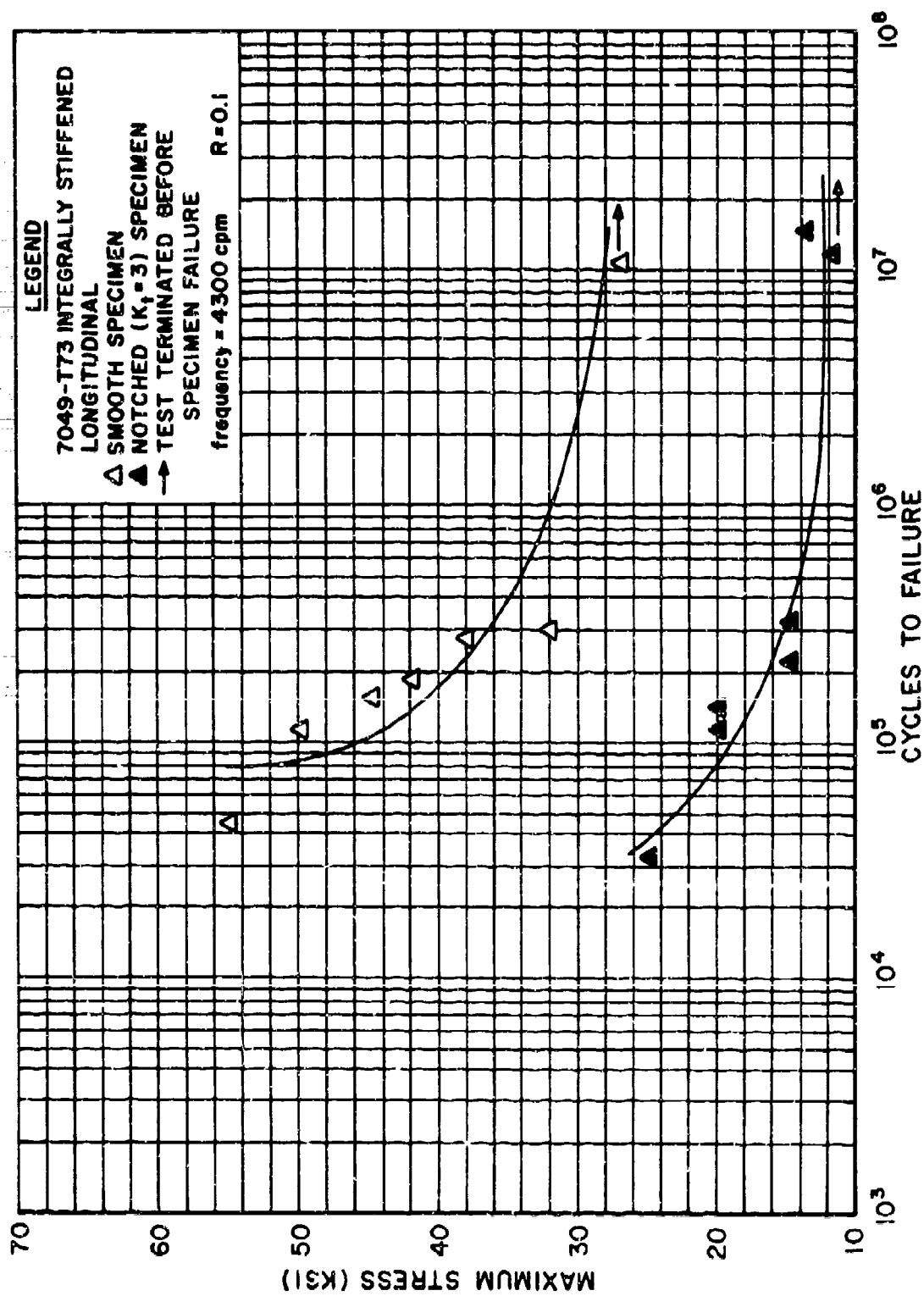


Figure 21. S/N Fatigue Curve at 350°F for 7049-T73 Integrally Stiffened Aluminum Extrusion

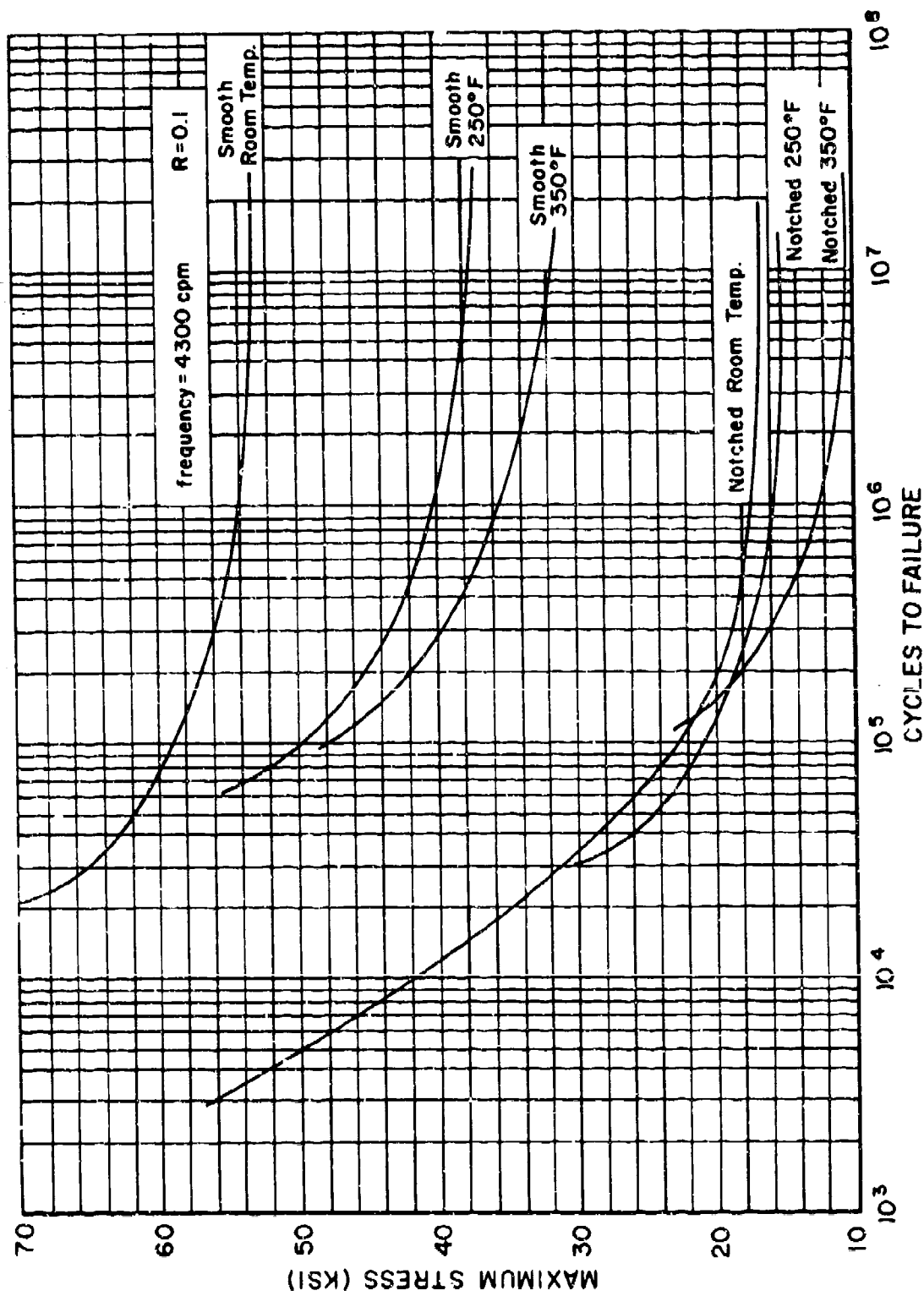


Figure 22. S/N Fatigue Curves for 7049-T73 Aluminum Bar Extrusion

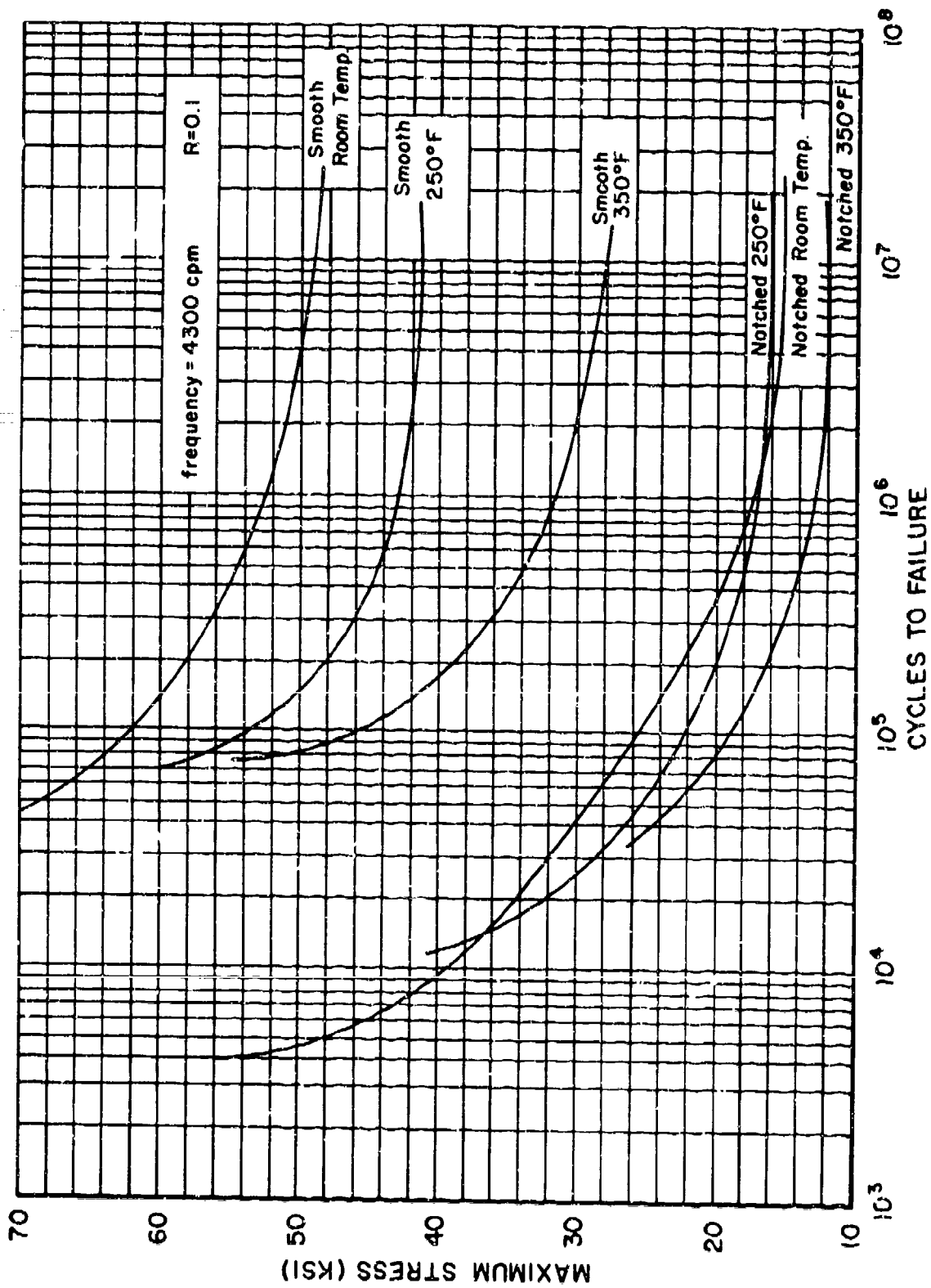


Figure 23. S/N Fatigue Curves for 7049-T73 Integrally Stiffened Aluminum Extrusion

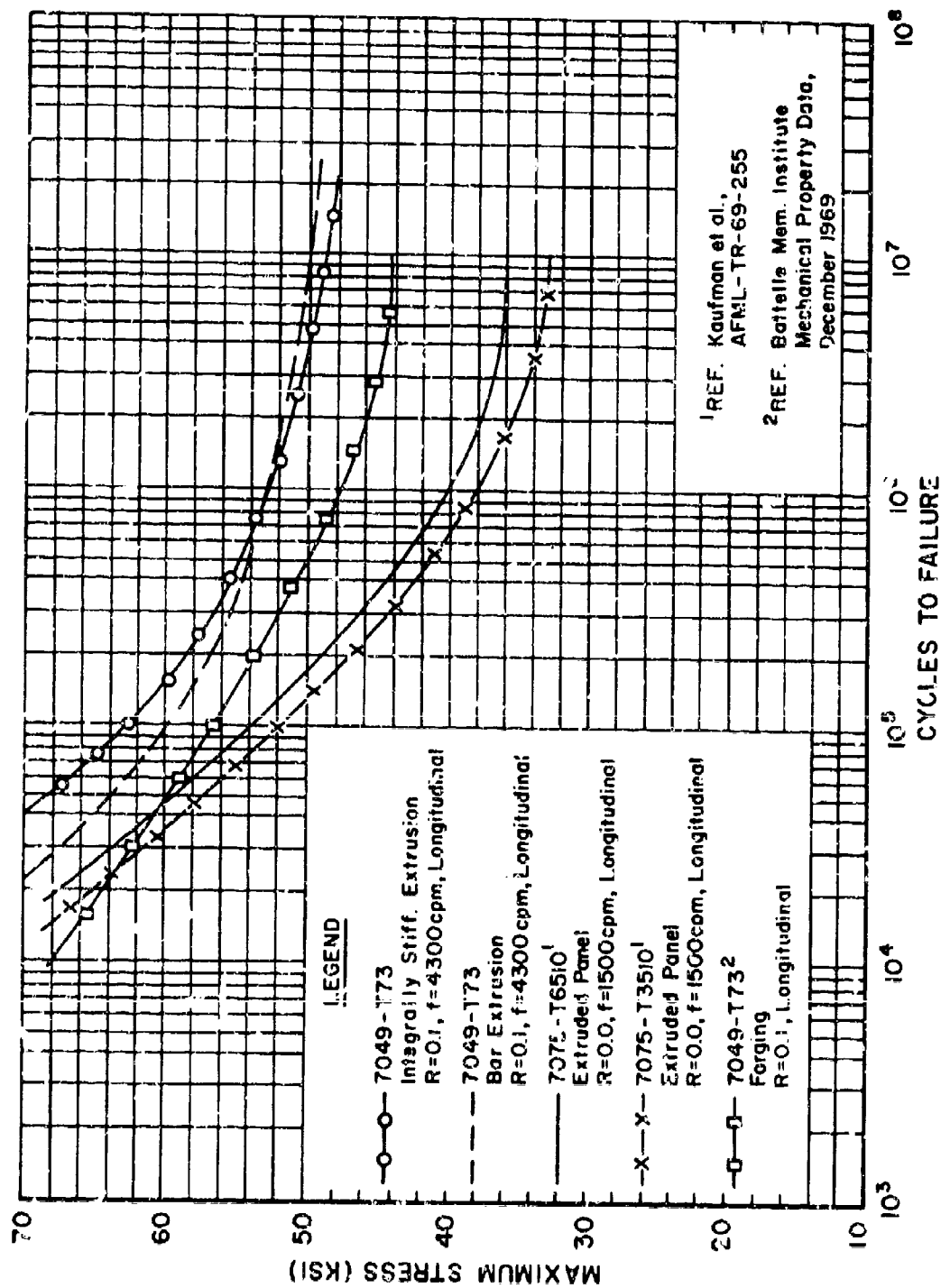


Figure 24. S/N Fatigue Curves for Several Temper of 7049 and 7075 Aluminum Alloys in the Smooth Condition

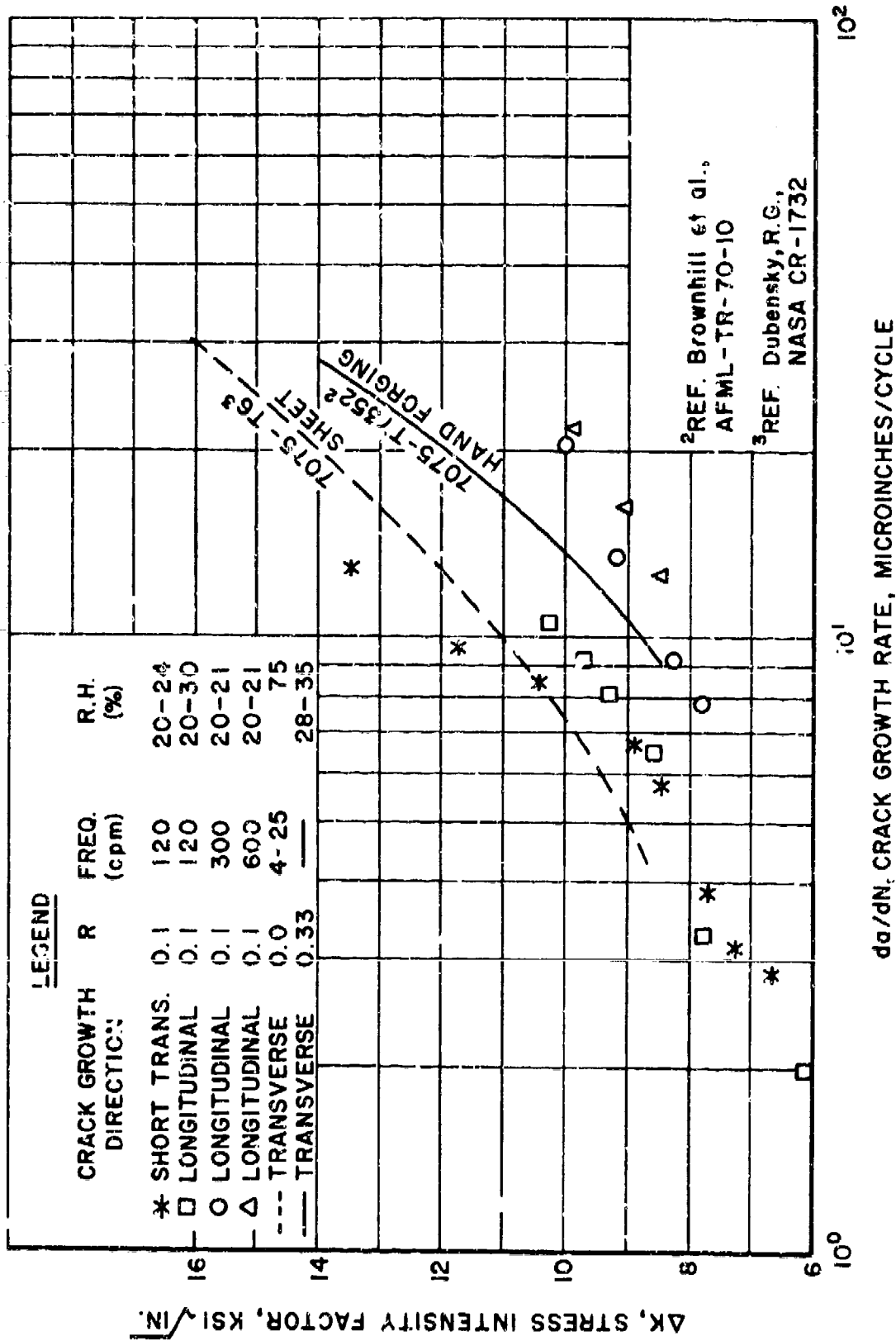


Figure 25. Stress Intensity Factor Range Versus Crack Growth Rate for 7049-T73 Bar Extrusion

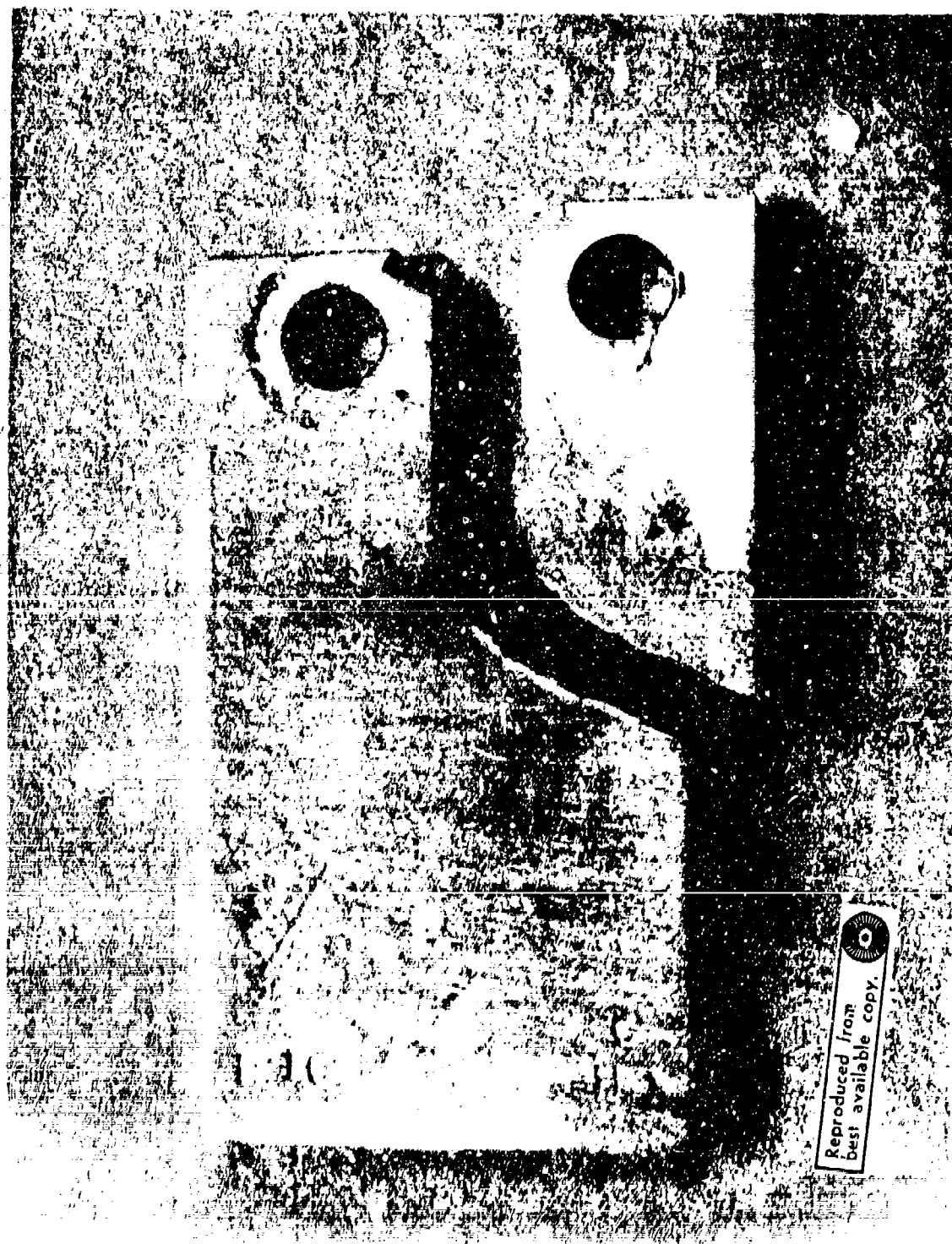


Figure 26. Rectangular DCB Crack Growth Specimen With Arm Break-Off Problem

APPENDIX

MECHANICAL PROPERTY DATA FOR INDIVIDUAL TEST SPECIMENS

TABLE IV
TENSILE PROPERTY DATA FOR INDIVIDUAL SPECIMENS
TESTED AT -65°F

Material	Direction	Ultimate Strength (KSI)	Yield Strength (KSI)	Reduction of Area (%)	Elongation in 1-inch (%)
7049-T73 Integrally Stiffened	Longitudinal	89.4	79.7	18.9	10.4
		87.1	77.8	23.2	10.8
		<u>89.3</u>	<u>78.9</u>	<u>23.2</u>	<u>10.2</u>
		Avg. 88.6	78.9	21.8	10.5
	Transverse	87.8	77.5	23.1	10.4
		87.4	76.9	21.6	10.7
		<u>88.1</u>	<u>78.0</u>	<u>22.0</u>	<u>10.6</u>
		Avg. 87.8	77.5	22.2	10.6
	Short Transverse	81.8	73.6	5.6	3.6
		82.0	72.4	2.4	3.6
		<u>81.9</u>	<u>72.2</u>	<u>3.2</u>	<u>3.3</u>
		Avg. 81.9	72.7	3.7	3.5
7049-T73 Bar	Longitudinal	88.8	77.1	22.6	10.1
		<u>87.5</u>	-	<u>23.7</u>	<u>10.5</u>
		Avg. 88.2	77.1	23.2	10.3
	Transverse	80.4	68.7	7.1	5.0
		<u>82.1</u>	<u>71.9</u>	<u>18.3</u>	<u>9.8</u>
		Avg. 81.3	70.3	12.7	7.4
	Short Transverse	79.6	68.0	7.1	5.4
		<u>79.0</u>	<u>66.3</u>	<u>7.1</u>	<u>3.7</u>
		Avg. 79.3	67.2	7.1	4.6
7049-T76 Bar	Longitudinal	87.9	78.1	11.0	22.4
		<u>90.0</u>	<u>81.2</u>	<u>11.1</u>	<u>26.7</u>
		Avg. 89.0	80.0	11.1	24.6
	Transverse	83.0	73.0	23.2	10.5
		<u>82.5</u>	<u>72.8</u>	<u>23.2</u>	<u>11.1</u>
		Avg. 82.8	72.9	23.2	10.8
	Short Transverse	82.3	-	22.0	11.0
		79.0	66.3	6.3	5.5
		<u>80.7</u>	<u>68.7</u>	<u>7.1</u>	<u>5.5</u>
		Avg. 80.7	67.5	11.8	7.3

TABLE V
TENSILE PROPERTY DATA FOR INDIVIDUAL SPECIMENS
TESTED AT 0°F

Material	Direction	Ultimate Strength (KSI)	Yield Strength (KSI)	Reduction of Area (%)	Elongation in 1-inch (%)
7049-T73 Integrally Stiffened	Longitudinal	87.4	78.3	19.9	10.7
		84.9	75.2	27.5	12.0
		<u>87.5</u>	-	<u>19.1</u>	<u>11.2</u>
	Avg.	86.6	76.8	22.2	11.3
	Transverse	86.6	76.6	23.0	12.7
		86.7	76.2	23.4	11.6
		<u>86.1</u>	<u>76.0</u>	<u>25.3</u>	<u>11.5</u>
	Avg.	86.5	76.3	23.9	11.9
	Short Transverse	79.4	72.7	5.5	3.8
		78.4	70.3	5.4	3.1
		<u>78.0</u>	<u>70.5</u>	<u>4.0</u>	<u>2.4</u>
	Avg.	78.6	71.2	5.0	3.1
7049-T73 Bar	Longitudinal	87.0	77.0	25.5	10.7
		<u>86.2</u>	<u>77.6</u>	<u>27.5</u>	<u>10.9</u>
		Avg.	86.6	77.3	26.5
	Transverse	79.9	68.9	23.2	10.1
		80.3	70.1	23.2	10.2
		<u>80.1</u>	<u>69.7</u>	<u>21.8</u>	<u>10.3</u>
	Avg.	80.1	69.6	22.7	10.2
	Short Transverse	78.6	68.4	7.7	5.6
		76.8	65.2	7.1	4.4
		<u>77.8</u>	<u>65.8</u>	<u>7.7</u>	<u>4.8</u>
	Avg.	77.7	66.5	7.5	4.9
	7049-T76 Bar	Longitudinal	87.6	77.6	28.1
<u>85.6</u>			<u>76.6</u>	<u>27.9</u>	<u>11.4</u>
Avg.			86.6	77.1	28.0
Transverse		80.6	70.7	21.8	9.6
		80.8	70.9	24.0	10.1
		<u>80.0</u>	<u>70.1</u>	<u>21.8</u>	<u>10.0</u>
Avg.		80.5	70.6	22.5	9.9
Short Transverse		78.4	66.4	11.6	6.6
		77.0	65.8	15.3	7.4
		<u>77.0</u>	<u>67.5</u>	<u>30.1</u>	<u>11.4</u>
Avg.		77.5	66.6	19.0	8.5

TABLE VI
TENSILE PROPERTY DATA FOR INDIVIDUAL SPECIMENS
TESTED AT ROOM TEMPERATURE

Material	Direction	Ultimate Strength (KSI)	Yield Strength (KSI)	Reduction of Area (%)	Elongation in 1-inch (%)
7049-T73 Integrally Stiffened	Longitudinal	83.4	75.8	34.0	12.0
		81.0	73.6	31.0	12.0
		<u>82.6</u>	<u>74.9</u>	<u>35.0</u>	<u>12.0</u>
	Avg.	82.3	74.8	33.3	12.0
	Transverse	82.6	75.3	28.0	12.0
		82.9	75.3	28.0	12.0
		<u>82.1</u>	<u>74.4</u>	<u>28.0</u>	<u>12.0</u>
	Avg.	82.5	75.0	28.0	12.0
	Short Transverse	76.8	68.7	5.0	5.0
		76.2	68.4	3.0	4.0
		<u>76.9</u>	<u>68.6</u>	<u>6.0</u>	<u>5.0</u>
	Avg.	76.6	68.6	4.6	4.6
7049-T73 Bar	Longitudinal	81.7	74.5	31.0	11.0
		<u>79.7</u>	<u>72.3</u>	<u>30.0</u>	<u>11.0</u>
		Avg.	80.7	73.4	30.5
	Transverse	75.8	67.1	25.0	11.0
		76.4	68.2	26.0	12.0
		<u>76.4</u>	<u>67.7</u>	<u>28.0</u>	<u>12.0</u>
	Avg.	76.2	67.7	26.3	11.7
	Short Transverse	75.2	67.3	27.0	9.0
		74.1	64.7	10.0	7.0
		<u>74.1</u>	<u>64.1</u>	<u>7.0</u>	<u>6.0</u>
	Avg.	73.9	65.4	14.6	7.3
	7049-T76 Bar	Longitudinal	83.1	76.3	33.0
82.1			74.7	28.0	11.0
<u>82.8</u>			<u>75.6</u>	<u>32.0</u>	<u>12.0</u>
Avg.		82.7	75.5	31.0	11.6
Transverse		76.8	68.6	26.0	11.0
		76.6	68.6	31.0	12.0
		<u>76.8</u>	<u>68.7</u>	<u>30.0</u>	<u>11.0</u>
Avg.		76.7	68.6	29.0	11.3
Short Transverse		76.4	69.1	31.0	11.0
		74.5	64.3	12.0	7.0
		<u>74.5</u>	<u>64.2</u>	<u>11.0</u>	<u>7.0</u>
Avg.		75.1	65.8	18.0	8.3

TABLE VII
TENSILE PROPERTY DATA FOR INDIVIDUAL SPECIMENS
TESTED AT 250°F

Material	Direction	Ultimate Strength (KSI)	Yield Strength (KSI)	Reduction of Area (%)	Elongation in 1-inch (%)
7049-T73 Integrally Stiffened	Longitudinal	67.3	64.6	48.0	16.0
		<u>68.0</u>	<u>65.6</u>	<u>44.0</u>	<u>16.0</u>
	Avg.	67.1	65.1	46.0	16.0
	Transverse	67.8	66.2	42.0	16.0
		<u>68.3</u>	<u>65.6</u>	<u>42.0</u>	<u>16.0</u>
	Avg.	68.1	65.9	42.0	16.0
	Short Transverse	65.0	60.4	22.0	10.0
		<u>64.0</u>	<u>60.4</u>	<u>20.0</u>	<u>8.0</u>
	Avg.	64.5	60.4	21.0	9.0
7049-T73 Bar	Longitudinal	68.1	64.1	46.0	16.0
		<u>66.5</u>	<u>62.2</u>	<u>44.0</u>	<u>14.0</u>
	Avg.	67.3	63.2	45.0	15.0
	Transverse	69.0	64.8	41.0	15.0
		<u>64.6</u>	<u>59.2</u>	<u>40.0</u>	<u>15.0</u>
	Avg.	66.8	62.0	40.5	15.0
	Short Transverse	62.8	56.9	21.0	10.0
		<u>63.1</u>	<u>55.2</u>	<u>23.0</u>	<u>10.0</u>
	Avg.	62.9	56.0	22.0	10.0
7049-T76 Bar	Longitudinal	70.9	64.8	40.0	16.0
		<u>68.9</u>	<u>64.6</u>	<u>45.0</u>	<u>17.0</u>
	Avg.	69.9	64.7	42.5	16.5
	Transverse	66.8	61.7	42.0	15.0
		<u>66.0</u>	<u>61.5</u>	<u>40.0</u>	<u>15.0</u>
	Avg.	66.4	61.6	41.0	15.0
	Short Transverse	63.8	55.6	24.0	11.0
		<u>64.6</u>	<u>56.4</u>	<u>19.0</u>	<u>9.0</u>
	Avg.	64.2	56.0	21.5	10.0

TABLE VIII
TENSILE PROPERTY DATA FOR INDIVIDUAL SPECIMENS
TESTED AT 350°F

Material	Direction	Ultimate Strength (KSI)	Yield Strength (KSI)	Reduction of Area (%)	Elongation in 1-inch (%)
7049-T73 Integrally Stiffened	Longitudinal	54.1	52.6	61.0	20.0
		<u>57.9</u>	<u>57.0</u>	<u>57.0</u>	<u>20.0</u>
	Avg.	56.0	54.8	59.0	20.0
	Transverse	55.7	53.2	49.0	18.0
		<u>56.4</u>	<u>54.0</u>	<u>47.0</u>	<u>18.0</u>
	Avg.	56.1	53.6	48.0	18.0
	Short Transverse	53.5	49.3	30.0	12.0
		<u>52.0</u>	<u>48.5</u>	<u>34.0</u>	<u>12.0</u>
	Avg.	52.8	48.9	32.0	12.0
7049-T73 Bar	Longitudinal	56.6	55.6	55.0	22.0
		55.3	53.8	58.0	21.0
		<u>55.5</u>	<u>54.0</u>	<u>60.0</u>	<u>22.0</u>
	Avg.	55.8	54.5	57.7	21.6
	Transverse	52.3	50.1	52.0	20.0
		<u>51.8</u>	<u>49.5</u>	<u>52.0</u>	<u>20.0</u>
	Avg.	52.1	49.8	52.0	20.0
	Short Transverse	51.4	48.5	40.0	15.0
		<u>51.4</u>	<u>48.5</u>	<u>37.0</u>	<u>14.0</u>
	Avg.	51.4	48.5	38.5	14.5
7049-T76 Bar	Longitudinal	57.6	55.4	55.0	21.0
		<u>56.1</u>	<u>54.5</u>	<u>58.0</u>	<u>21.0</u>
	Avg.	56.9	54.9	56.5	21.0
	Transverse	54.5	51.9	51.0	20.0
		<u>54.9</u>	<u>52.0</u>	<u>49.0</u>	<u>20.0</u>
	Avg.	54.7	51.9	50.5	20.0
	Short Transverse	54.4	50.7	39.0	16.0
		<u>52.2</u>	<u>48.5</u>	<u>35.0</u>	<u>14.0</u>
	Avg.	53.3	49.6	37.0	15.0

TABLE IX
TENSILE PROPERTY DATA FOR INDIVIDUAL SPECIMENS
TESTED AT 500°F

Material	Direction	Ultimate Strength (KSI)	Yield Strength (KSI)	Reduction of Area (%)	Elongation in 1-inch (%)
7049-T73 Integrally Stiffened	Longitudinal	19.9 <u>27.6</u>	19.4 <u>27.4</u>	81.6 <u>77.4</u>	30.7 <u>23.0</u>
	Avg.	23.8	23.4	79.5	26.9
	Transverse	21.8 <u>22.6</u>	21.5 <u>22.4</u>	76.4 <u>83.8</u>	25.9 <u>24.3</u>
	Avg.	22.2	22.0	80.1	25.1
	Short Transverse	21.3	20.4	71.3	26.8
7049-T73 Bar	Longitudinal	20.0	20.2	84.8	32.3
	Transverse	20.8 <u>22.5</u>	20.3 <u>21.7</u>	80.2 <u>74.9</u>	29.1 <u>27.9</u>
	Avg.	21.7	21.0	77.5	28.5
	Short Transverse	26.0 <u>23.2</u>	25.0 <u>22.8</u>	74.1 <u>82.3</u>	25.8 <u>27.1</u>
	Avg.	24.6	23.9	78.2	26.5
7049-T76 Bar	Longitudinal	23.2 <u>23.6</u>	22.8 <u>23.2</u>	82.3 <u>80.7</u>	27.1 <u>28.0</u>
	Avg.	23.4	23.0	81.5	27.5
	Transverse	19.3 <u>20.3</u>	18.9 <u>19.8</u>	82.3 <u>80.6</u>	34.4 <u>32.0</u>
	Avg.	19.8	19.4	81.5	33.2
	Short Transverse	20.7 <u>19.9</u>	20.2 <u>19.5</u>	75.2 <u>80.8</u>	27.8 <u>34.2</u>
	Avg.	20.3	19.9	78.0	31.0

TABLE X
FRACTURE TOUGHNESS DATA FOR INDIVIDUAL SPECIMENS
TESTED AT -65°F

Material	Direction	K_{IC} (KSI $\sqrt{IN}$)
7049-T73 Integrally Stiffened	Longitudinal	25.4
		23.6
		25.2
		24.7 Avg.
	Transverse	22.8
		23.7
		23.2 Avg.
	Short Transverse	23.3
		21.1
		22.2 Avg.
7019-T73 Bar	Longitudinal	32.6
		32.2
		29.4
		31.4 Avg.
	Transverse	20.8
		20.2
		18.9
		20.0 Avg.
	Short Transverse	20.7
7049-T76 Bar	Longitudinal	30.3
		30.5
		30.3
		30.4 Avg.
	Transverse	19.3
		19.0
		19.2 Avg.
	Short Transverse	19.9
		19.3
		19.1
		19.4 Avg.

TABLE XI
FRACTURE TOUGHNESS DATA FOR INDIVIDUAL SPECIMENS
TESTED AT 0°F

Material	Direction	K_{IC} (KSI $\sqrt{IN}$)
7049-T73 Integrally Stiffened	Longitudinal	24.5
		26.8
		26.3
		25.9 Avg.
	Transverse	23.6
		23.8
		24.9
		24.1 Avg.
	Short Transverse	19.8
		22.5
		21.1 Avg.
7049-T73 Bar	Longitudinal	34.7
		34.2
		33.8
		34.2 Avg.
	Transverse	20.4
		20.9
		20.6
		20.6 Avg.
	Short Transverse	21.8
		21.6
		21.0
		21.5 Avg.
7049-T76 Bar	Longitudinal	34.1
		32.3
		32.9
		33.1 Avg.
	Transverse	20.8
		19.6
		20.2 Avg.
	Short Transverse	20.5
		21.2
		20.7
		20.8 Avg.

TABLE XII
FRACTURE TOUGHNESS DATA FOR INDIVIDUAL SPECIMENS
TESTED AT ROOM TEMPERATURE

Material	Direction	K_{IC} (KSI $\sqrt{IN}$)
7049-T73 Integrally Stiffened	Longitudinal	27.3
		28.6
		28.3
		28.1 Avg.
	Transverse	24.7
		25.3
		25.7
		25.2 Avg.
	Short Transverse	20.3
		20.5
		20.1
		20.3 Avg.
7049-T73 Bar	Longitudinal	34.4
		30.1
		35.1
		33.2 Avg.
	Transverse	22.4
		22.1
		21.5
		22.0 Avg.
	Short Transverse	22.5
		23.8
		22.6
		22.0 Avg.
7049-T76 Bar	Longitudinal	34.2
		31.1
		30.8
		32.7 Avg.
	Transverse	20.0
		20.3
		19.7
		20.0 Avg.
	Short Transverse	20.9