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MECHANICAL PROPERTY DATA FOR ALUMINUM ALLOY 2419-T851 PLATE

*UNIVERSITY OF DAYTON
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This final report was submitted by the University of Dayton Research Institute, Dayton, Ohio, under contract F33615-74-C-5024, Job Order 73810678, with the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. Mr. David C. Watson, AFML/MXE, was the Laboratory Project Monitor.

This report has been reviewed by the Information Office (IO) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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20. Abstract (Continued)

Material property comparisons indicate the two alloys possess very similar tensile properties, comparable fatigue crack growth rate properties, and similar fracture toughness properties. Notched ($K_t = 3.0$) fatigue results for alloy 2419 coincide with those found for alloy 2219, while smooth fatigue results for 2419 were superior to 2219. Aluminum alloy 2419-T851 also demonstrated excellent resistance to stress corrosion cracking.

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FOREWORD

This final report was submitted by the University of Dayton Research Institute, Dayton, Ohio, under contract F33615-74-C-5024, Job Order 73810678, with the Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio. Mr. David C. Watson, AFML/MXE, was the Laboratory Project Monitor.

The author, Mr. John J. Ruschau, was responsible for the direction of the program, and would like to extend recognition to Messers. Woleslagle, Eblin, and Marton of the University of Dayton for their supporting efforts in this program. The author would also like to thank Mr. Charles Houston, AFML/TUA, for obtaining the chemical analysis.

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This report was submitted by the author in September 1975.

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SUMMARY

The following conclusions are based on test results from a single 2-inch plate of aluminum alloy 2419 with the T851 heat treatment. Findings could be altered by an in-depth program that included numerous lots of test material.

1. Tensile properties of alloy 2419-T851 closely parallel those of 2219-T851. The strength levels for each of the principal directions are essentially equal, with the short-transverse orientation demonstrating far less ductility than the longitudinal or transverse orientations.
2. Notched fatigue results for 2419 and 2219 are similar, while 2419 possesses superior smooth fatigue life for "R" ratios of 0.1 and 0.5.
3. Fracture toughness properties for alloy 2419 are similar to those for 2219 for the longitudinal (L-T), transverse (T-L), and short-transverse (S-T) directions.
4. Fatigue crack growth rates for both 2419 and 2219 alloys are comparable; the cracking rates for the longitudinal (L-T) and transverse (T-L) orientations are equal.
5. Alloy 2419-T851 showed excellent resistance to stress corrosion cracking when loaded at 87 percent of K_{IC} in a 3.5-percent-by-weight NaCl solution environment.
6. Material property comparisons of alloys 2419-T851 and 2219-T851, show the properties of the two alloys are comparable with the exception of smooth fatigue resistance where 2419 proved superior.

SECTION I

INTRODUCTION

This program was initiated to develop mechanical property data for the new aluminum alloy/temper 2419-T851 plate. The test material, which was produced by the Aluminum Company of America (ALCOA), was developed to provide the strength, weldability, and stress corrosion resistance of alloy 2219 but with improved fracture toughness.

The mechanical properties investigated were tensile, smooth and notched fatigue, fracture toughness, fatigue crack growth, and stress corrosion cracking. Tensile and fracture toughness testing were performed at elevated temperatures as well as room temperature. The effects of long-term temperature exposure on tensile properties were also investigated.

SECTION II

MATERIALS AND SPECIMENS

The test material, a 2-inch-thick plate of aluminum alloy 2419-T851, was procured from ALCOA. The chemical composition limits of the alloy are shown in the first table below and the chemical composition of the material tested in this program is shown in the second table.

CHEMICAL COMPOSITION LIMITS OF 2419
(Wt. %)

Silicon	Iron	Copper	Manganese	Magnesium	Zinc	Vanadium	Zirconium	Titanium	Others	Aluminum
0.15 max.	0.18 max.	5.8-6.8	0.2-0.40	0.02 max.	0.10 max.	0.05-0.15	0.1-0.25	0.02-0.10	Ea. 0.05 Tot. 0.15	Balance

CHEMICAL COMPOSITION OF TEST PLATE OF 2419-T851
[Lot No. 108-566]
(Wt. %)

Silicon	Iron	Copper	Manganese	Magnesium *	Zinc *	Vanadium	Zirconium	Titanium	Aluminum
0.05	0.08	6.4	0.26	< 0.02	<0.15	0.068	0.12	0.06	Balance

*Values are the lowest resolution limits for the analysis used.

Photomicrographs of the alloy showing the grain orientation with respect to rolling direction are shown in Figure 1.

Tensile specimens in the longitudinal and transverse directions were machined to the configuration shown in Figure 2, while specimens taken from the short transverse direction were machined to the configuration shown in Figure 3. The fracture toughness and stress corrosion specimens, 2-inches and 3/4-inch thick, were machined from the plate to the

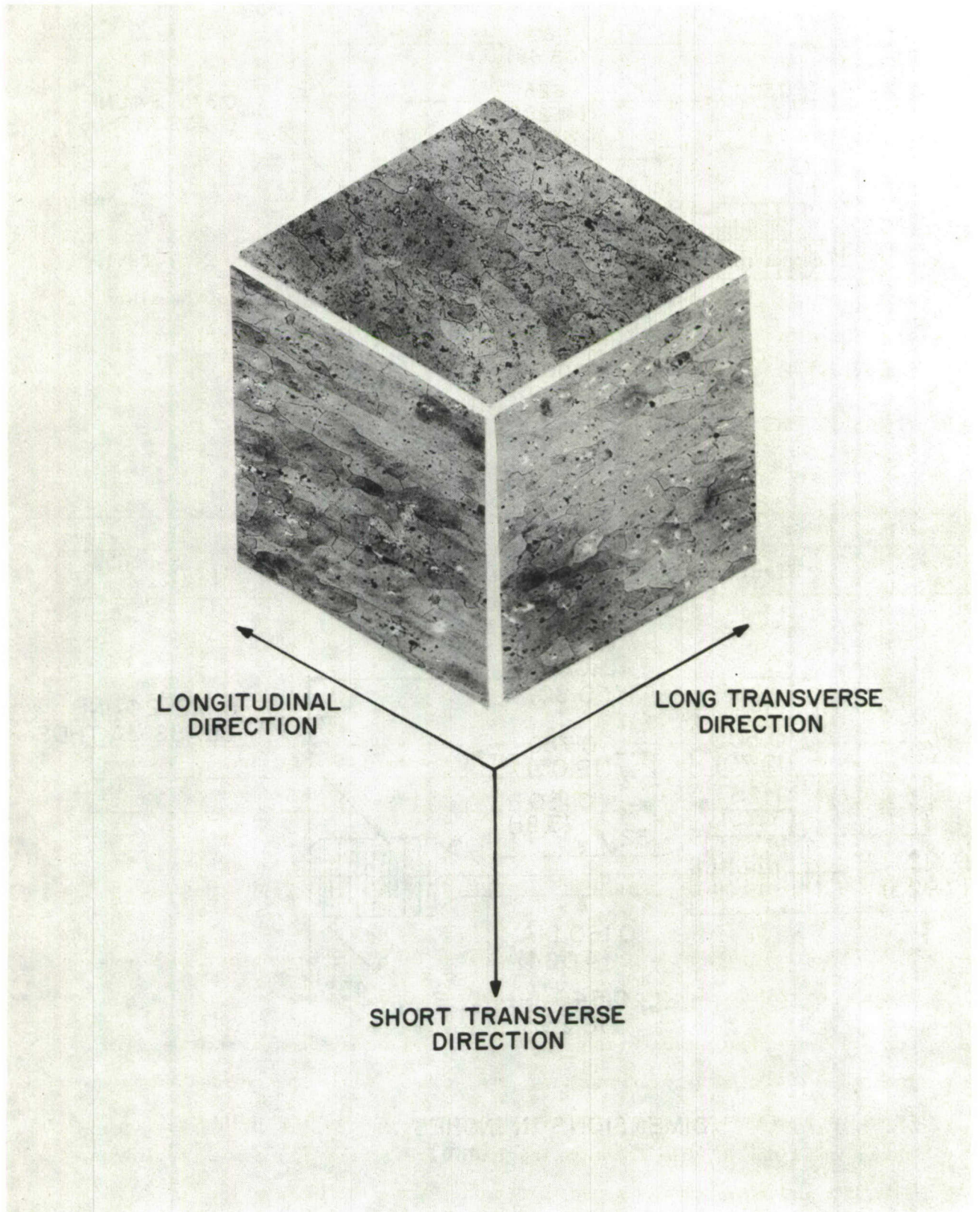


Figure 1. Aluminum Alloy 2419-T851 Microstructure Composite (100X)

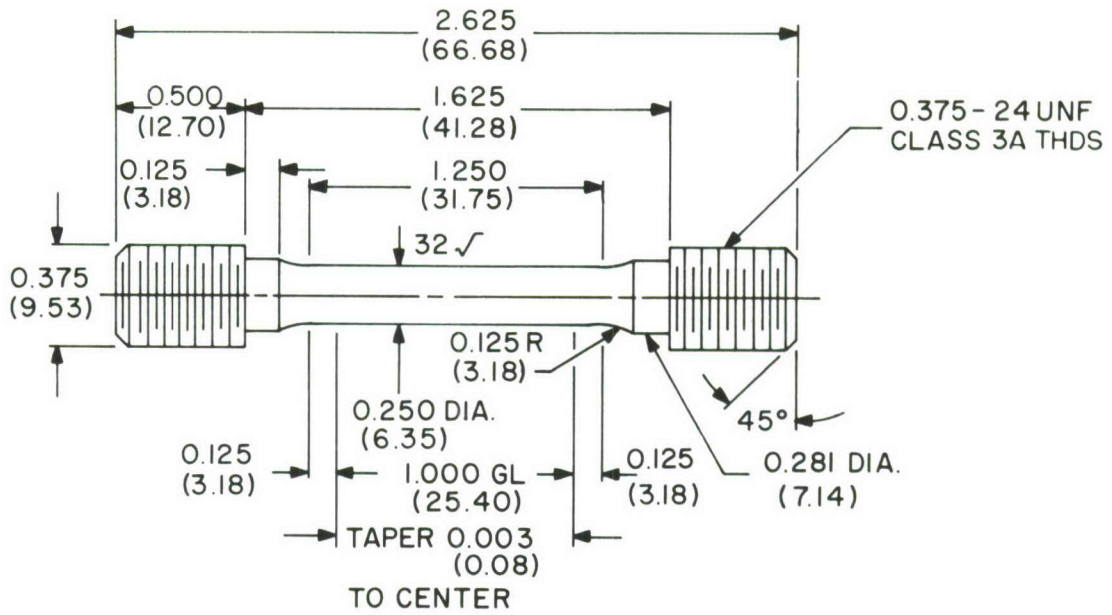
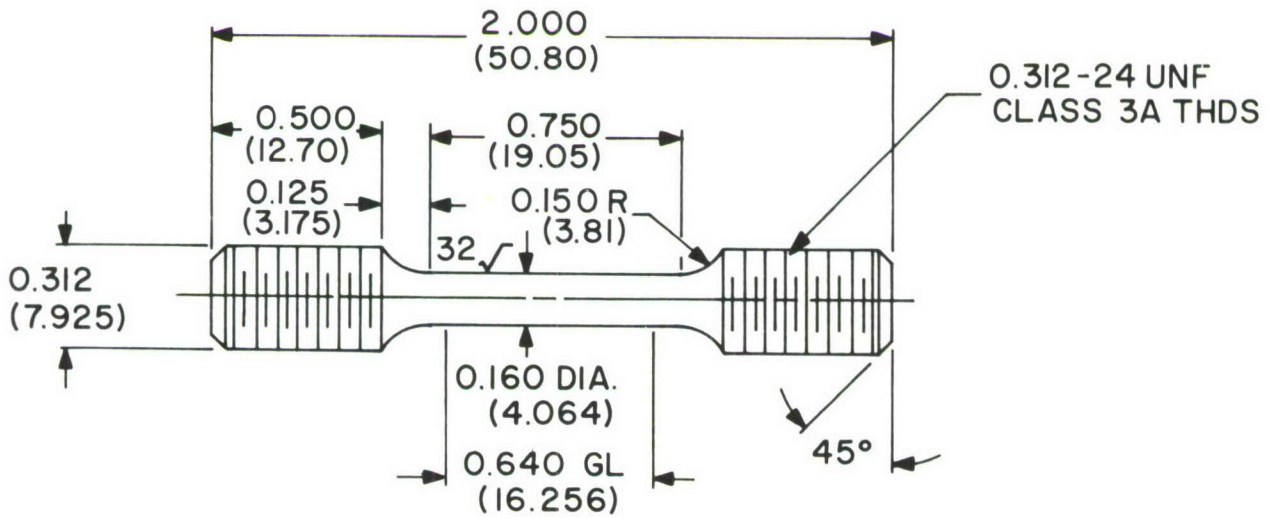


Figure 2. Standard Tensile Specimen



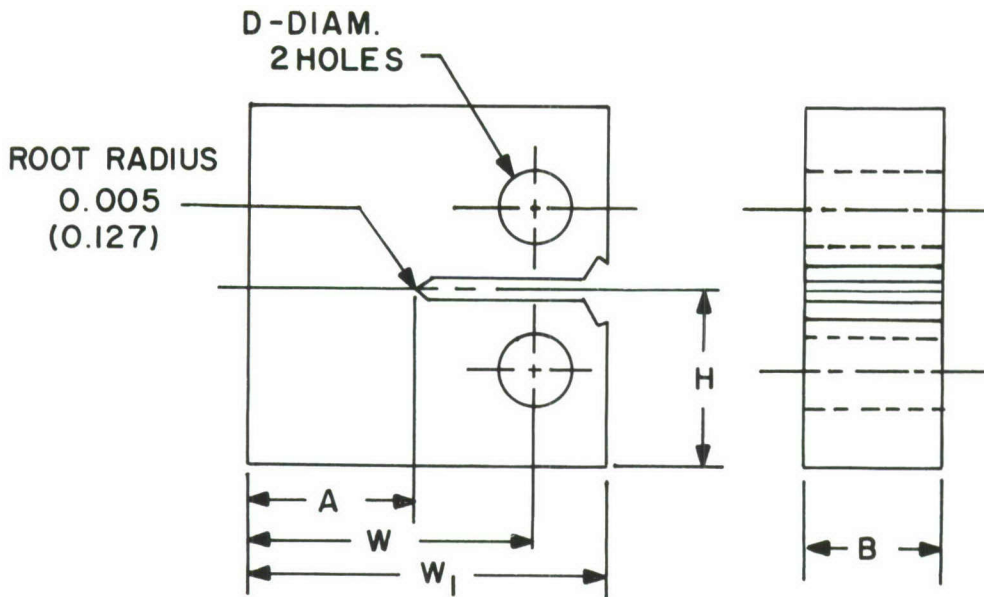
DIMENSIONS IN INCHES
(mm)

Figure 3. Sub-sized Tensile Specimen

configurations shown in Figure 4, along with the 0.5-inch-thick elongated compact specimens used in fatigue crack growth investigation. The L, T, and S designations used to identify the specimen orientation indicate the three principal directions of the plate from which the specimens were taken: longitudinal, transverse, and short transverse, respectively.

The two-letter designations used with the fracture toughness, stress corrosion, and crack growth specimens are used in accordance with the ASTM "two letter code"; the first letter indicating the direction of loading, the second indicating the direction of crack propagation.

Smooth and notched ($K_t = 3.0$) fatigue specimens were machined to the configurations shown in Figure 5 and Figure 6, respectively.



DIMENSIONS

SPECIMEN THICKNESS INCHES	A	B	W	W_1	H	D
a) 2.000 (50.80)	2.250 (57.15)	2.000 (50.80)	4.000 (101.60)	4.625 (117.48)	2.400 (60.96)	0.625 (15.87)
b) 0.750 (19.05)	0.915 (23.24)	0.750 (19.05)	1.500 (38.10)	1.875 (47.62)	0.900 (22.86)	0.375 (9.52)
c) 0.500 * (12.70)	1.450 (36.83)	0.500 (12.70)	1.850 (46.99)	2.315 (58.80)	0.900 (22.86)	0.375 (9.52)

**DIMENSIONS IN INCHES
(mm)**

*** ELONGATED COMPACT SPECIMEN**

Figure 4. Compact Specimen Configurations
 (a) fracture toughness
 (b) fracture toughness and stress corrosion
 (c) fatigue crack growth

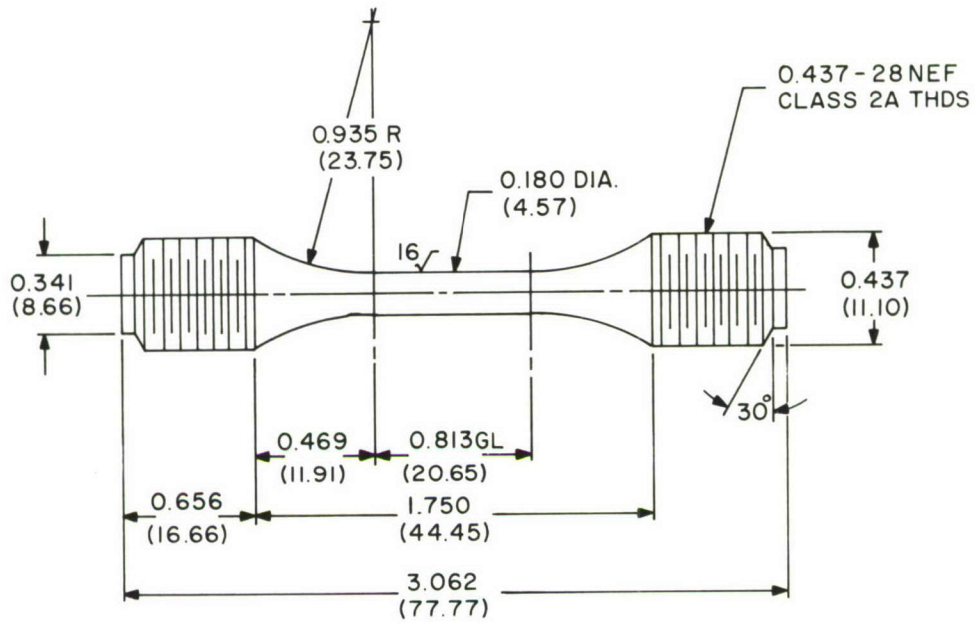
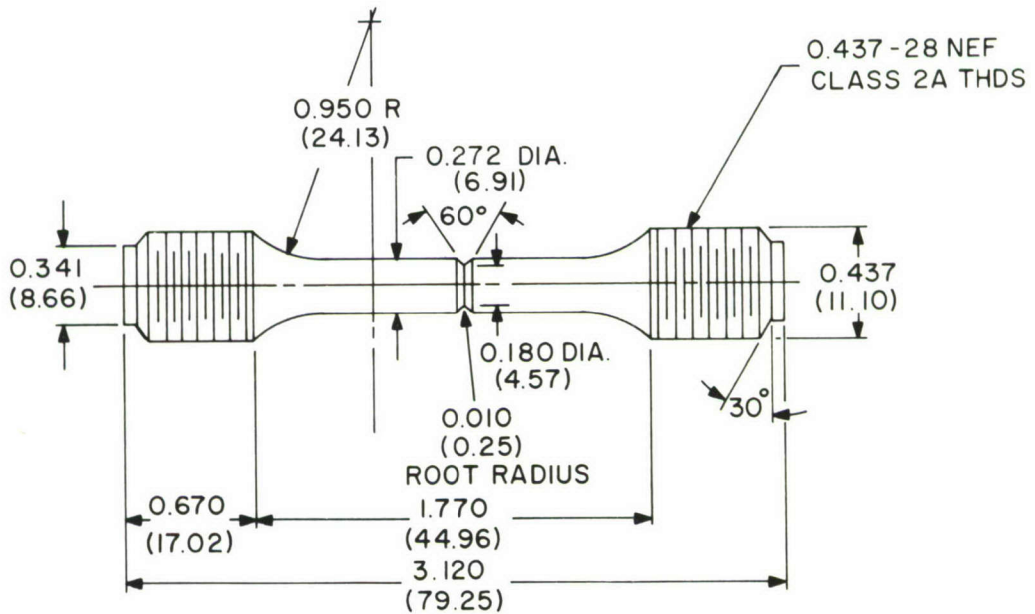


Figure 5. Smooth Fatigue Specimen Configuration



DIMENSIONS IN INCHES
(mm)

Figure 6. Notched Fatigue Specimen Configuration

SECTION III

PROCEDURES

Tensile testing was performed at room temperature, 200°F (93°C), and 300°F (149°C) using an Instron tensile testing machine equipped with an environmental test chamber. Fracture toughness testing was accomplished by using a Weidemann tensile testing machine which also was equipped with an environmental test chamber for the same elevated temperatures. All precracking was accomplished with closed-loop load-controlled MTS hydraulic fatigue testing machines.

Precracked compact specimens used to determine the threshold for stress corrosion cracking were initially loaded at specific stress intensity values, K_{I} , in a 3.5 percent-by-weight NaCl solution using Satec stress-rupture testing machines. If no failure occurred after 1000 hours the test was terminated and the test specimen broken apart to visually examine the precracked surface and to make accurate measurements of the crack length.

Constant amplitude fatigue crack growth rate testing was performed with a closed-loop load-controlled MTS hydraulic testing machine. All crack growth rate testing was carried out in a laboratory air environment with an "R" ratio of 0.1. The frequency was maintained at 30 cps. Crack length was monitored with a 30x traveling microscope. Crack growth data reduction was accomplished with the aid of a computer. Raw data was analyzed by using a least-squares regression method of fitting a straight line, a power function, and an exponential function to an interval of nine raw data points (a, N) to obtain da/dN , the crack growth rate, at the midpoint. Simultaneously the change in stress intensity, ΔK , was calculated at the midpoint of the nine-point subset. When the computation was completed, the first point was dropped, the next sequential data point added, and the calculations were repeated until all data points were analyzed.

Smooth and notched fatigue testing was performed in a laboratory air environment with a Rumul resonant frequency fatigue testing machine. The loading frequency was maintained at 100 Hz for stress ratios (R) of 0.1 and 0.5, where R is equal to the minimum stress divided by the maximum stress.

SECTION IV

RESULTS AND DISCUSSION

The individual tensile results from the room temperature, 200°F (93°C), and 300°F (149°C) tests, as well as the results from the specimens that underwent a 300°F (149°C) exposure for 1000 hours prior to room temperature testing, are presented in Table 1. Typical stress-versus-strain curves for alloy 2419 in each of the three principal orientations are illustrated in Figure 7.

Tensile data presented in Table 2 for the same alloy but a different lot (Ref. 1) confirm the results obtained for the test material. Strength levels for all three orientations are essentially equal. Ductility is greatest for the longitudinal orientation with the transverse orientation being slightly lower. Ductility in the short-transverse orientation was inferior, approximately a third that of the longitudinal. Loss in tensile strength at 300°F (149°C) was roughly 25 percent while the yield strength diminished approximately 16 percent.

The thermal exposure cycle of 300°F (149°C) for 1000 hours diminished the test material's load carrying capability slightly; a decrease of 10 - 15 percent in yield strength while only 6 - 7 percent loss in ultimate strength was observed. Typical room temperature tensile properties for aluminum alloy 2219-T851 (Ref. 2) presented in Table 2 indicate the two alloys exhibit very similar tensile properties.

Smooth and notched ($K_t = 3.0$) fatigue data for alloy 2419 for "R" ratios of 0.1 and 0.5 are shown in Figures 8 and Figure 9. Results for alloy 2219-T851 (Ref. 3) under similar testing conditions are also presented. Fatigue property comparisons indicate the notched fatigue strengths of the two alloys are very similar, but the smooth fatigue strength of alloy 2419 is superior to that of 2219 for both "R" ratios investigated.

TABLE I
TENSILE DATA FOR ALUMINUM ALLOY 2419-T851
(2-INCH-THICK PLATE)

Specimen No.	Specimen Orientation	Test Temp. °F (°C)	Yield Strength KSI (MPa)	Ultimate Strength KSI (MPa)	Elongation %	Reduction of Area (%)
T1	Transverse	R. T.	50.5 (348)	67.5 (465)	10.0	20
T2			51.3 (354)	66.0 (455)	11.1	25
T3			55.8 (385)	66.4 (458)	10.0	18
Average			52.5 (362)	66.6 (459)	10.4	21
L1	Longitudinal	R. T.	52.3 (360)	67.8 (468)	10.5	21
L2			51.3 (354)	66.2 (456)	10.6	23
L3			51.6 (356)	66.8 (461)	11.2	25
Average			51.7 (356)	66.9 (461)	10.8	23
S1	Short Trans.	R. T.	51.8 (357)	63.0 (434)	3.1	6
S2			52.2 (360)	62.6 (432)	2.7	10
S3			51.1 (352)	63.2 (436)	3.0	5
Average			51.7 (356)	62.9 (434)	2.9	7
T4	Transverse	200 (93)	47.1 (325)	59.4 (410)	14.0	26
T5			46.7 (322)	58.5 (403)	12.6	26
T6			47.6 (328)	59.6 (411)	13.0	29
Average			47.1 (325)	59.2 (408)	13.2	27
L4**	Longitudinal	200 (93)	45.4 (313)	62.7 (432)	13.0	30
L5			48.4 (334)	59.5 (410)	16.0	-
L6			46.7 (322)	58.6 (404)	13.6	31
Average			47.6 (328)	59.0 (407)	14.8	31
S4	Short Trans.	200 (93)	50.5 (348)	58.8 (405)	3.3	8
S5			48.5 (334)	58.0 (400)	2.6	10
S6			48.0 (331)	58.5 (403)	2.8	10
Average			49.0 (338)	58.4 (403)	2.9	9

TABLE 1 (Continued)
 TENSILE DATA FOR ALUMINUM ALLOY 2419-T851
 (2-INCH-THICK PLATE)

Specimen No.	Specimen Orientation	Test Temp. °F (°C)	Yield Strength KSI (MPa)	Ultimate Strength KSI (MPa)	Elongation %	Reduction of Area (%)
T7	Transverse	300 (149)	43.1 (297)	49.8 (343)	13.0	44
T8			42.2 (291)	49.4 (341)	13.2	34
T9			44.2 (305)	50.1 (345)	18.0	54
Average			43.2 (298)	49.8 (343)	14.8	44
L7	Longitudinal	300 (149)	43.8 (302)	48.4 (334)	16.1	52
L8			43.7 (301)	49.3 (340)	18.0	50
Average			43.8 (302)	48.8 (337)	17.0	51
S7	Short Trans.	300 (149)	42.3 (292)	49.5 (341)	9.3	22
S8			-	50.0 (345)	6.7	20
S9			42.5 (293)	49.8 (343)	8.2	22
Average			42.4 (292)	49.8 (343)	8.1	21
T10*	Transverse	R. T.	44.9 (310)	62.2 (429)	11.6	21
T11*			44.5 (307)	61.2 (422)	9.0	17
T12**			44.4 (306)	63.6 (438)	11.1	20
Average			44.7 (308)	61.7 (425)	10.3	19
L10*	Longitudinal	R. T.	46.8 (323)	63.6 (438)	11.6	25
L11*			46.1 (318)	62.1 (428)	11.3	26
Average			46.4 (320)	62.8 (433)	11.4	26
S10*	Short Trans.	R. T.	45.8 (316)	58.6 (404)	4.8	8
S11*			45.7 (316)	57.6 (397)	4.7	5
S12*			45.0 (310)	58.3 (402)	5.4	8
Average			45.5 (314)	58.2 (401)	5.0	7

* Specimen underwent thermal cycle of 300°F (270°C) for 1000 hours.

** Loading rate exceeded ASTM maximum allowable rate for tensile testing.
 Not included in average.

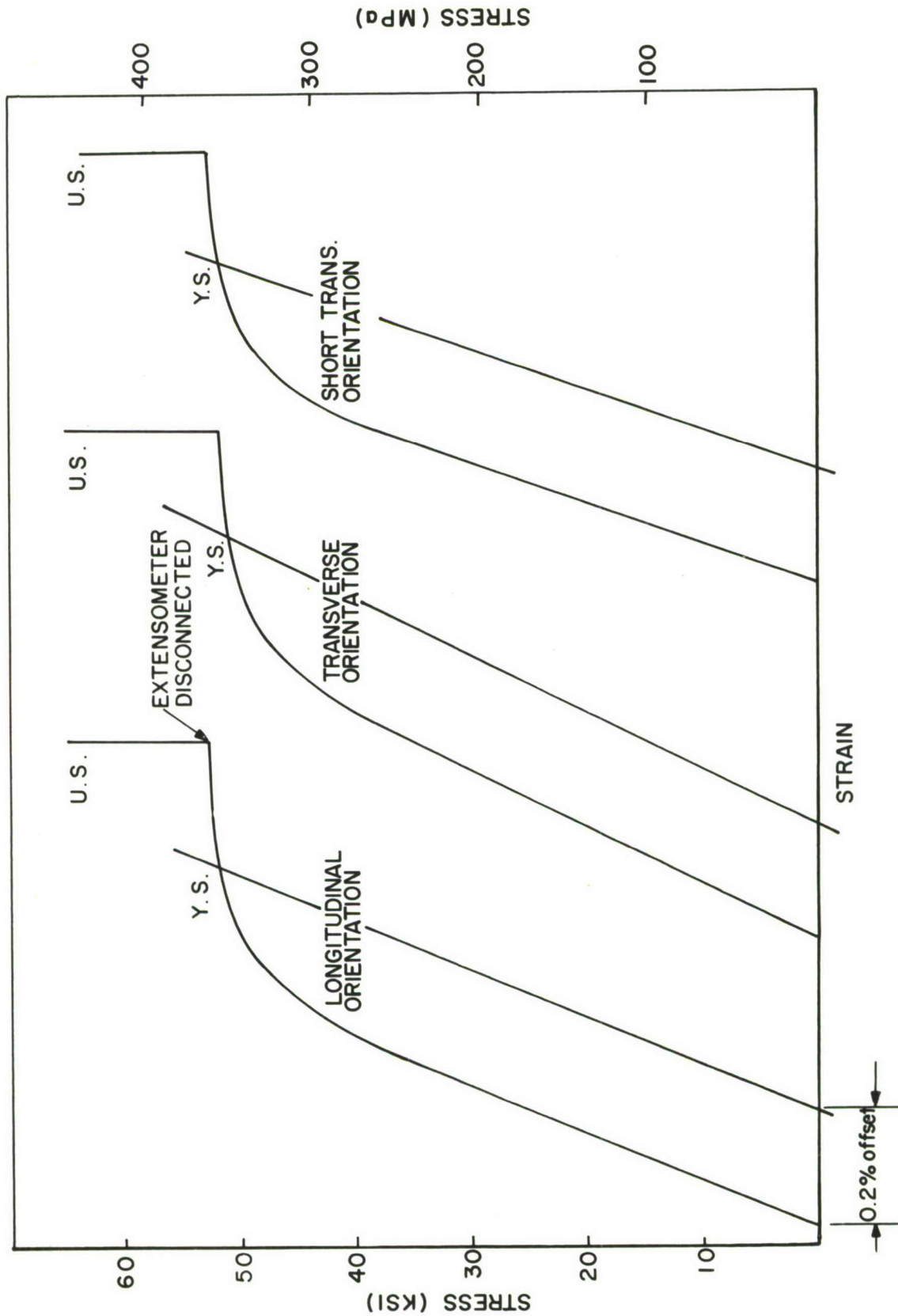


Figure 7. Typical Room Temperature Tensile Stress-Strain Curves for Aluminum Alloy 2419-T851

TABLE 2
 AVERAGE ROOM TEMPERATURE TENSILE PROPERTIES FOR
 ALUMINUM ALLOYS 2419 AND 2219

Alloy	Orientation	Yield Strength		Ultimate Strength		Elongation
		KSI	(MPa)	KSI	(MPa)	in 2-in(50.8mm) G. L. (%)
2419-T851	Longitudinal	51.7	(356)	66.9	(461)	10.8 *
	Transverse	52.5	(362)	66.6	(459)	10.4 *
2219-T851 (2)	Longitudinal	50	(345)	66	(455)	10
	Transverse	50	(345)	66	(455)	10
2419-T851 (1)	Longitudinal	52.4	(361)	66.7	(460)	11.0
	Transverse	52.1	(359)	66.4	(458)	10.7

*Gage Length = 1 inch (25.4 mm)

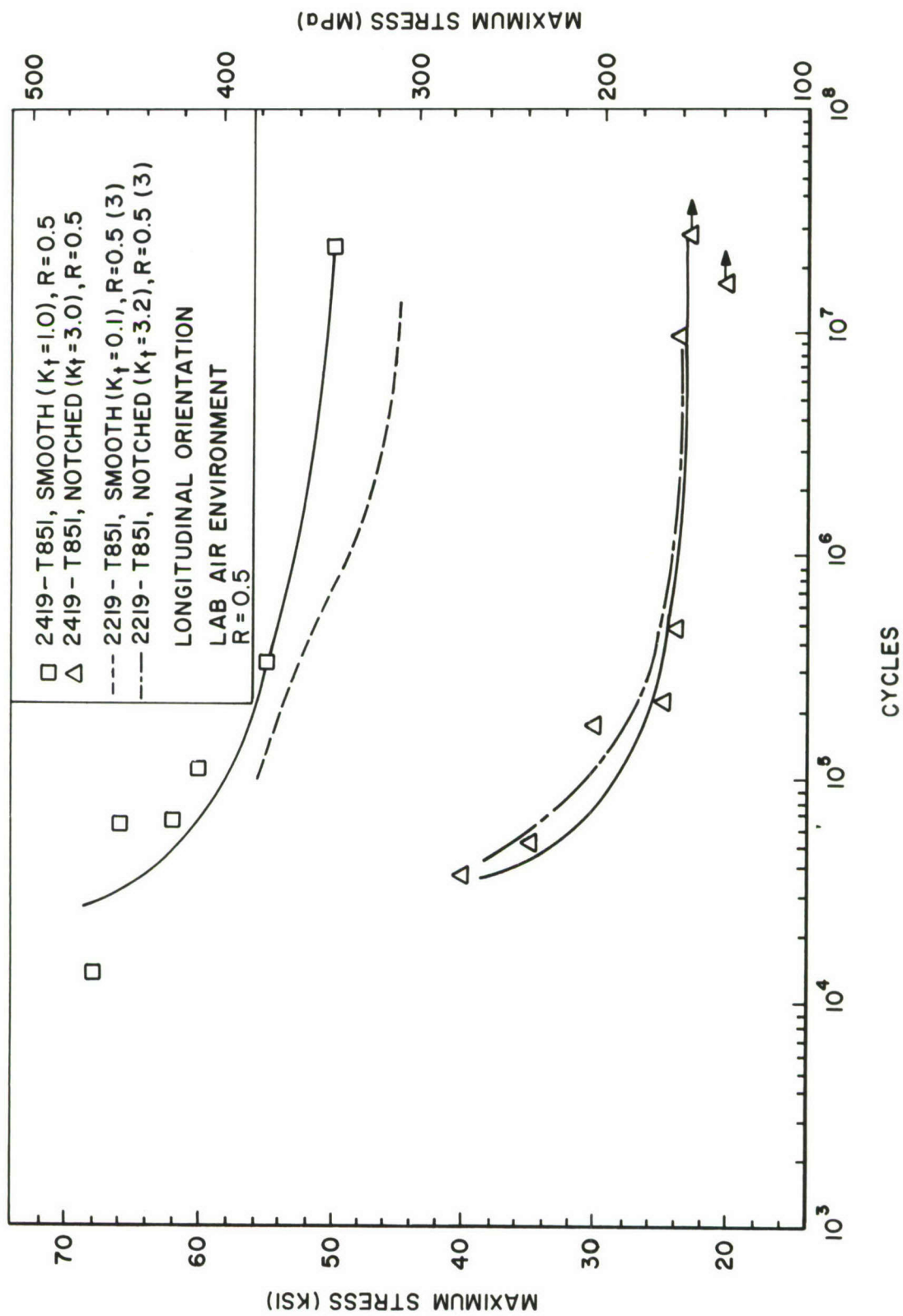


Figure 8. Fatigue Curves for Aluminum Alloy 2419-T851

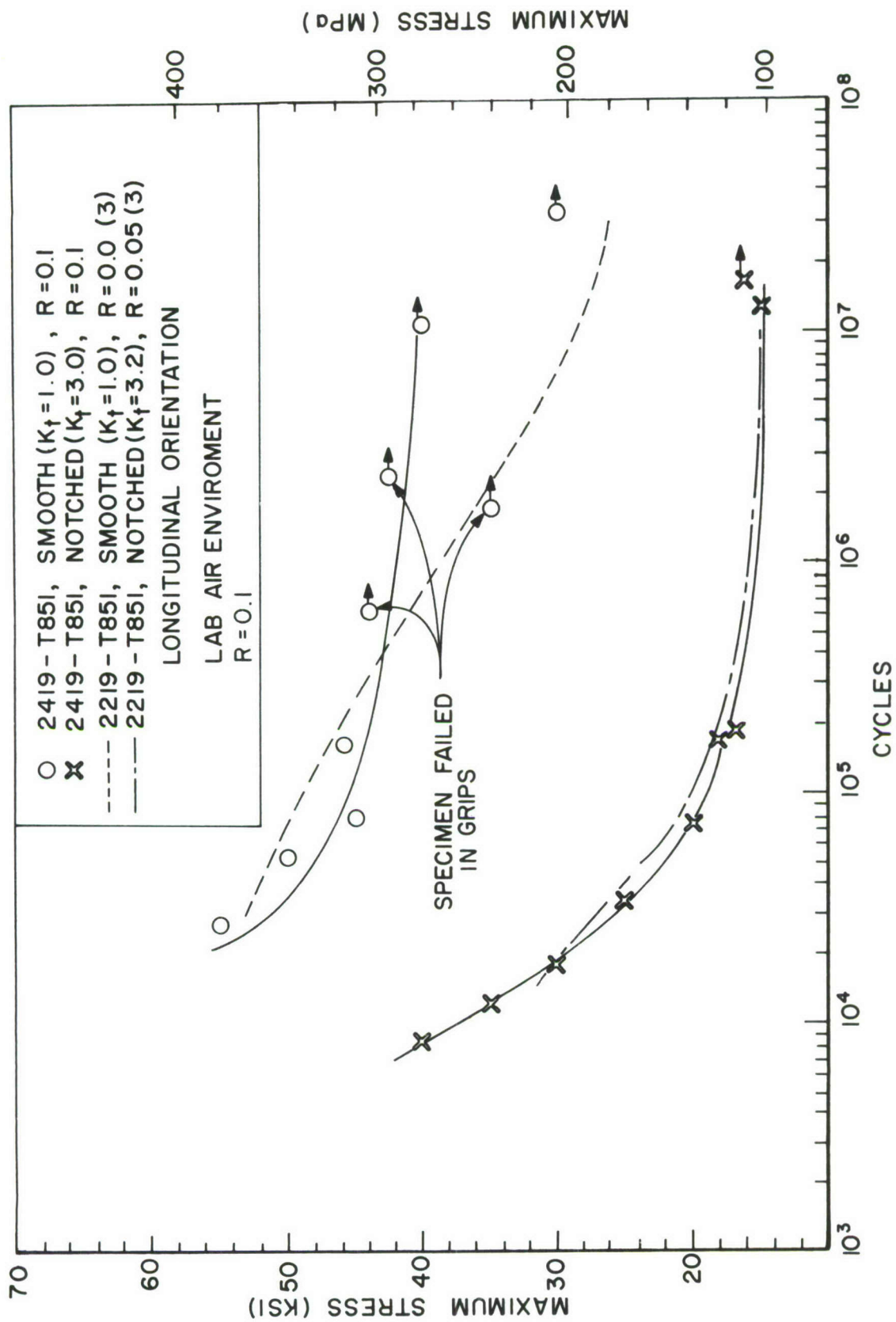


Figure 9. Fatigue Curves for Aluminum Alloy 2419-T851

Fracture toughness values for alloy 2419-T851 for room and elevated temperatures, 200°F (93°C) and 300°F (149°C), are presented in Table 3. All toughness values determined are in accordance with the ASTM E399-74 criteria for validity with the exception of specimen number TL8 which failed the $P_{\max}/P_Q < 1.10$ criterion. However, the deviation from the standard is very small and the value obtained can be assumed accurate for most engineering design considerations. Results indicate greatest toughness in the longitudinal (L-T) orientation, with the short transverse (S-T) orientation being lowest. Toughness values presented in Table 4 for the same alloy (Ref. 1) are comparable to those determined for the test material. Specimens tested at temperatures of 200°F (93°C) and 300°F (149°C) exhibited only a slight decrease in fracture toughness values from those tested at room temperature. Based on results (Ref. 4) presented in Table 4, fracture toughness properties for alloy 2419 are similar to those of alloy 2219 in each of the three principal directions.

Constant amplitude fatigue crack growth rate data for alloy 2419-T851 in a laboratory air environment are presented in Figure 10 along with data from Reference 4 for 2219-T851. Crack growth rates are approximately equal for specimens taken from the test material with longitudinal (L-T) and transverse (T-L) orientation. From the data presented, it is apparent that both alloys 2419 and 2219 have similar crack growth rates.

Precracked compact specimens with short-transverse orientation (S-T) were loaded at various stress intensity levels and immersed in a 3.5 percent by weight NaCl solution at room temperature. Specimens loaded at 87 percent of K_{IC} produced no failures after 1000 hours, although the machined surfaces of the specimens were severely pitted (Figure 11). After 1000 hours the specimens were loaded to failure and the fracture faces examined. There were no signs of stress corrosion cracking in any of the test specimens.

TABLE 3
FRACTURE TOUGHNESS PROPERTIES OF ALUMINUM
ALLOY 2419-T851 PLATE

Specimen No.	Specimen Orientation	Test Temperature °F (°C)		K _{IC}		P _{max}
				KSI√in	(MPa√m)	P _Q
LT1	Longitudinal (L-T)	R. T.	35.3	(38.8)	1.04	
LT2			34.2	(37.6)	1.06	
LT3			34.9	(38.3)	1.06	
Average			34.8	(38.2)		
TL1	Transverse (T-L)	R. T.	31.3	(34.4)	1.05	
TL2			32.3	(35.5)	1.05	
TL3			30.6	(33.6)	1.06	
Average			31.4	(34.5)		
ST1	Short Transverse (S-T)	R. T.	22.9	(25.2)	1.08	
ST2			22.9	(25.2)	1.04	
ST3			23.2	(25.5)	1.08	
Average			23.0	(25.3)		
LT4	Longitudinal (L-T)	200 (93)	32.9	(36.2)	1.07	
LT5			32.6	(35.8)	1.09	
LT6			31.7	(34.8)	1.09	
Average			32.4	(35.6)		
TL4	Transverse (T-L)	200 (93)	29.3	(32.2)	1.07	
TL5			28.9	(31.8)	1.08	
TL6			28.3	(31.1)	1.06	
Average			28.8	(31.6)		
LT7	Longitudinal (L-T)	300 (149)	32.2	(35.4)	1.08	
LT8			31.9	(35.0)	1.08	
LT9			31.8	(34.9)	1.09	
Average			32.0	(35.2)		
TL7	Transverse (T-L)	300 (149)	28.9	(31.8)	1.08	
TL8*			28.2	(31.0)	1.11	
TL9			28.5	(31.3)	1.09	
Average			28.5	(31.3)		

*Invalid due to $P_{\max}/P_Q > 1.10$.

TABLE 4
 AVERAGE ROOM TEMPERATURE FRACTURE TOUGHNESS
 PROPERTIES FOR ALUMINUM ALLOYS 2419 AND 2219

Specimen Orientation	Fracture Toughness (K_{IC})					
	KSI		(MPa \sqrt{m})			
	2419-T851		2219-T851 (4)		2419-T851 (1)	
Longitudinal (L-T)	34.8	(38.2)	36	(39.6)	35.3	(38.8)
Transverse (T-L)	31.4	(34.5)	33	(35.2)	30.2	(33.2)
Short Transverse (S-T)	23.0	(25.3)	23	(25.3)	-	-

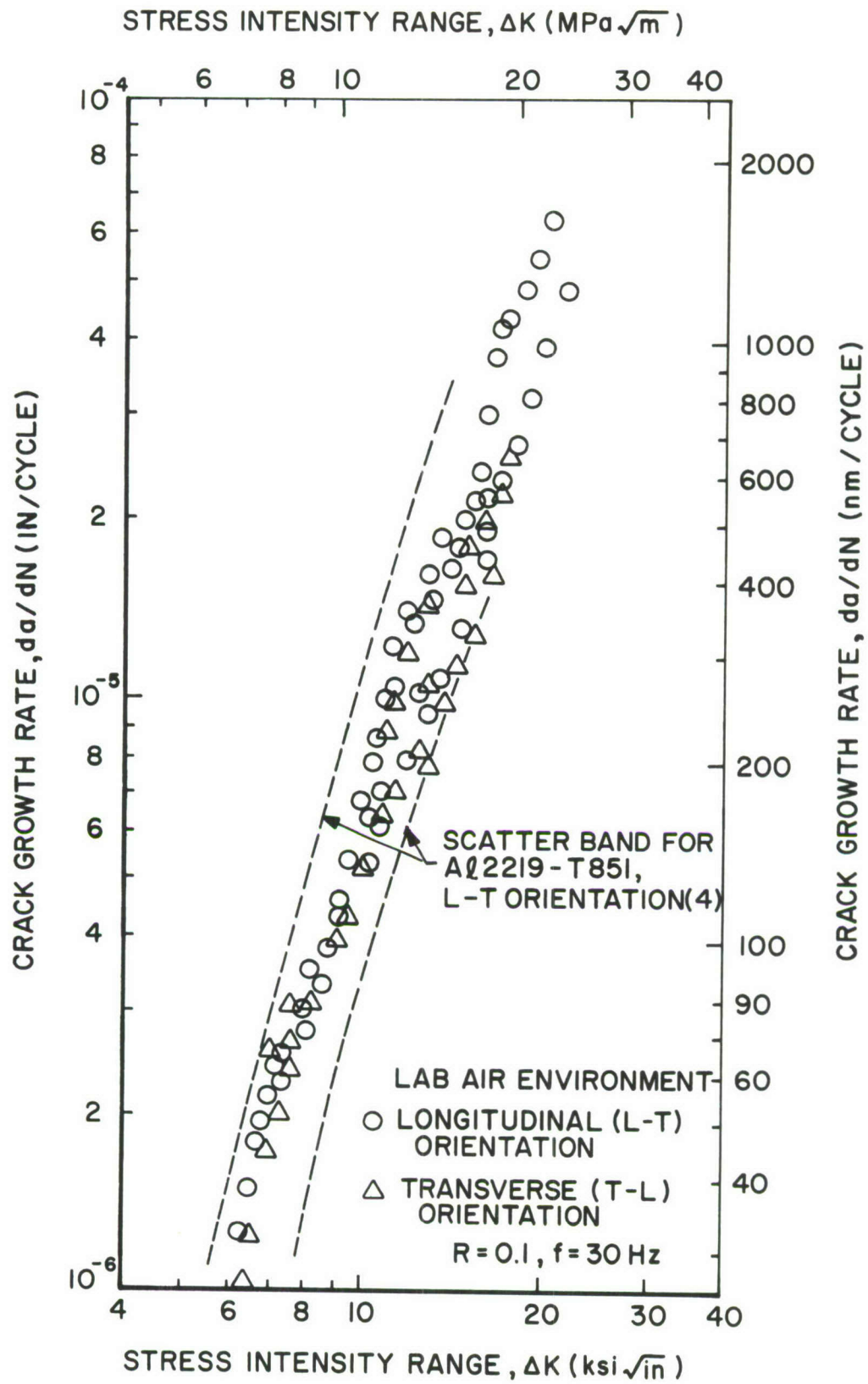


Figure 10. Fatigue Crack Growth Rate Data for Aluminum Alloy 2419-T851

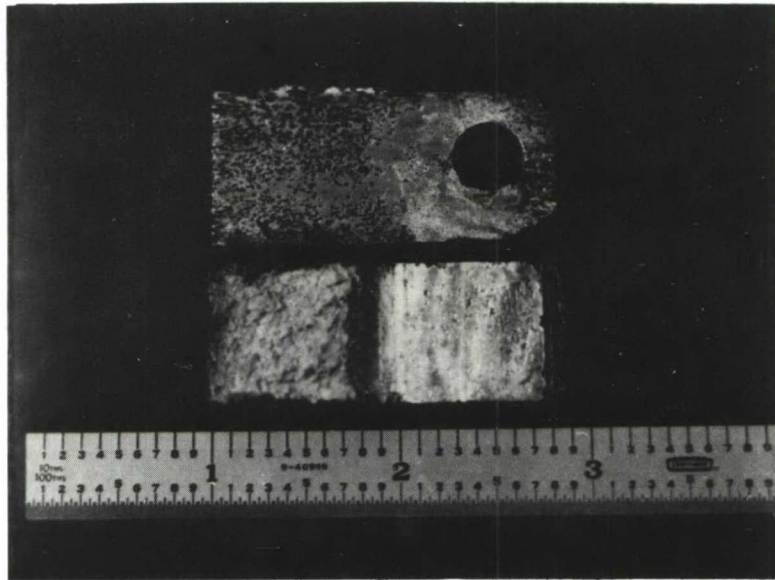


Figure 11. Stress Corrosion Specimen After 1000-Hour Exposure in 3.5 Percent NaCl Environment

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