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MECHANICAL PROPERTY DATA ON ALUMINUM ALLOY 7150-T7751 PLATE

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A mechanical properties investigation was performed on aluminum 7150-T7751, a product using a recently developed thermal processing technique. Properties examined were tensile, fracture toughness, fatigue crack growth, spectrum fatigue crack growth, constant amplitude fatigue, stress corrosion cracking, and stress corrosion cracking threshold.

Test results indicate this material possesses high strength with somewhat greater resistance to corrosion and decreased fracture toughness over conventional 7000 series aluminums of similar strength. Fatigue properties were found to be similar to those of other 7000 series aluminums, while fatigue crack growth rates were greater in the lower stress intensity ranges and similar in the higher ranges

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PREFACE

This technical report was submitted by the University of Dayton Research Institute, Dayton, Ohio under Contract F33615-88-C-5437 with the Wright Research and Development Center, Wright-Patterson Air Force Base, Ohio. This work was administered by the Systems Support Division, Materials Laboratory, with administrative direction provided by Ms. Mary Ann Phillips, WRDC/MLSE.

This effort was conducted during the period of June 1988 to June 1989. The author, Patrick W. Ertel, was Project Engineer and would like to extend special recognition to Messrs. John H. Eblin and Donald Woleslagle of the University of Dayton for their technical support.

This report was submitted by the author in December of 1989.

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SECTION 1
INTRODUCTION

Aluminum alloy 7150 has recently attracted renewed attention in the aerospace community because of new heat treatments which improve its corrosion properties with little sacrifice in strength. This alloy is presently heat treatable in a peak temper to over 80 Ksi ultimate strength as a minimum guaranteed value. Using conventional heat treatment at this strength results in a corrosion sensitive product, making its use in aircraft systems undesirable. However, new thermal processing methods are reported that significantly improve the corrosion characteristics of this material at no expense in strength properties. Material suppliers are guaranteeing the product in this condition to have an ultimate strength of over 80 Ksi while possessing the corrosion properties usually associated with material of lower strength. Because of the good strength and corrosion properties. The material is of considerable interest for aerospace applications.

When this product was first introduced to the aerospace community it was still in the development stage. At that time the heat treatment was not registered with the Aluminum Association and was identified by producer specific designations. Since then the Aluminum Association has designated the heat treatment/processing as -T7751.

The purpose of this project is to develop design data for aluminum alloy 7150-T7751 plate. The mechanical properties investigated include tensile, fracture toughness, spectrum fatigue, constant amplitude fatigue, fatigue crack growth, stress corrosion cracking, and stress corrosion cracking threshold.

SECTION 2

MATERIAL, SPECIMENS, AND PROCEDURES

The test material was aluminum 7150-T7751 in 1.75 inch thick plate form procured from ALCOA. Emission spectroscopy was used to determine the test plate's chemical composition listed in Table 1. Absolute values for manganese, chromium, titanium, iron, and zirconium could not be determined with the instrumentation available. These elements may be present in amounts below the weight percent shown. The composition shown is within the ranges specified in AMS 4306 for this alloy.

TABLE 1

CHEMICAL COMPOSITION OF 7150 TEST PLATE

Element	Weight %
Zn	6.00
Mg	2.10
Cu	2.0
Si	0.11
Fe	<0.20
Mn	<0.10
Cr	<0.48
Ti	<0.10
Zr	<0.10
Al	BALANCE

Tensile tests were performed under room temperature conditions in an Instron universal testing machine in accordance with ASTM Standard E8 "Tension Testing of Metallic Materials."[1]

Specimens were removed from the plate in each of the three principal directions (i.e. L, T, and S orientation). The geometry of the L and T orientation specimens is shown in Figure 1.* Specimens removed from the plate in the S orientation are of the same general configuration, but with a 0.5 inch gage length and a 0.160 inch diameter.

Ten smooth fatigue and ten notched fatigue specimens were tested at stress ratio of R=0.1. Their geometries are presented in Figures 2 and 3, respectively. Machining marks were removed

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* Figures are listed at the end of this report.

from smooth fatigue specimens by polishing longitudinally with 600 grit sandpaper prior to testing. Notched fatigue specimens were tested as received. All fatigue testing was done in a Rumul resonant mass fatigue testing machining at 95 Hz.

Two 4-inch wide center crack panels for spectrum fatigue crack growth rate testing were machined from the plate. Figure 4 depicts the center cracked panel geometry. One plate was tested using the FALSTAF load spectrum at a maximum spectrum stress of 20 Ksi and one panel was tested using the Mini-Twist load spectrum at a maximum stress of 17 Ksi. The load histories were applied using a DEC PDP 11-34 computer interfaced to an MTS servohydraulic fatigue machine. Crack length measurements were recorded continuously as a function of elapsed flights with a Fractomat crack monitoring system.

Fatigue crack growth specimens of the compact tension C(t) geometry, two from the L-T orientation and two from the T-L orientation, were removed from the quarter thickness, t/4, position in the plate. These are shown in Figure 5. Testing was accomplished using a 20 KIP (89 kN) maximum MTS servo-hydraulic fatigue machine. A sinusoidal waveform was applied at 25 Hz, using an R ratio of 0.1 for all tests. Crack length was visually monitored using a 10X traveling microscope with digital readout. Procedures were applied and data reduced in accordance with ASTM Standard for E647 "Constant-Load-Amplitude Fatigue Crack Growth Rates Above 10^{-8} m/Cycle."[2]

Precracked C(t) specimens for fracture toughness (16 each) and stress corrosion cracking threshold (four each) determination were machined to the configuration shown in Figure 5. Both sets of specimens were precracked to a crack length to specimen width ratio of approximately 0.5 at a final stress intensity level not exceeding 0.5 K_{IC}. Testing for plane-strain fracture toughness determination was performed following guidelines described in ASTM E399 "Plane-Strain Fracture Toughness of Metallic Materials."[3]

Precracked stress corrosion cracking threshold specimens were loaded at various initial stress intensity levels in a constant load Satec stress rupture testing machine which applied the load to the specimen with dead weights acting through a lever arm. Clevises and pins used to grip the samples were machined from aluminum to minimize any galvanic coupling effects. The specimen was completely submerged before loading in a solution of distilled water with 3.5% by weight NaCl added with air continuously bubbling through the solution to replenish oxygen as well as to assure a uniform test solution. Water lost to evaporation was replaced with demineralized water as needed. Upon failure the specimens were removed and the initial stress intensity and time to failure was recorded. Tests were terminated after 1000 hours if no failure occurred.

Nine stress corrosion cracking tensile bar specimens were removed with their axis oriented in the short rolling direction of the plate. These specimens are similar in geometry to the tensile specimens shown in Figure 1, but with a 1.75 inch overall length, a gage length of 0.50 inch and a diameter of 0.160 inch. All specimens were polished longitudinally with 600 grit sandpaper and cleaned with acetone prior to testing. Specimens were dead weight loaded at various stress levels in a Satec creep rupture test machine and submerged for 10 minutes of every hour in a solution of 3.5% reagent grade NaCl dissolved in Demineralized water, for the remaining 50 minutes the specimens were exposed to lab air at 72°F and 30% relative humidity as recommended in ASTM G44 "Standard Practice for Evaluating Stress Corrosion Cracking Resistance of Metals and Alloys by Alternate Immersion in 3.5% Sodium Chloride Solution."[4] Time to failure was recorded. Tests were terminated after 1000 hours if no failure occurred. After termination of the test, each specimen was examined for evidence of pitting.

SECTION 3

RESULTS AND DISCUSSION

Tensile properties of 7150-T7751 are presented in Table 2. Tensile properties are consistent in the T and L directions with only slightly lower ductility in the transverse direction. Short transverse yield strength is about 10% lower than L orientation yield. Short transverse ductility varied widely between specimens. Tensile properties of the 1.75 inch plate were slightly lower than those of a 1.1 inch thick plate of 7150-T7751 previously reported by this lab.[5]

Tensile properties of the 7150-T7751 1 75-inch plate are compared with 7150-T6151 and 7075-T651 in Table 3. Alloy 7150-T7751 exhibits higher strength than either of the other products, particularly in the short grain direction, with little or no loss in ductility.

Fatigue data for 7150-T7751 plate, for both smooth and notched specimens, are presented in Figure 6. A curve representing smooth specimen fatigue data for 7075-T651 from Air Force Materials Laboratory Report No. AFML-TR-65-1716[6] is also plotted on this graph. Results indicate the smooth fatigue properties of 7050-T7751 and 7075-T651 are similar.

Results from the constant amplitude fatigue crack growth tests are shown in Figure 7 for L-T oriented specimens and in Figure 8 for T-L samples. Figure 7 contains data from three 7150-T7751 L-T specimens tested under like conditions as well as 7075-T651 reference data from the Damage Tolerant Design Handbook[7]. For the stress intensity range below 12 KSI$\sqrt{in}$, 7150-T7751 exhibited a crack growth rate higher than the 7075-T651. Growth rates were similar at higher stress intensity ranges. Results of the 7150-T7751 specimens from the T-L orientation are shown in Figure 8 along with a 7075-T651 reference curve from the Damage Tolerant Design Handbook[8]. Again, the 7150 exhibits a higher growth rate in the lower stress intensity ranges with such differences diminishing at the higher ΔK values.

Results of the stress corrosion cracking tests on smooth tensile bars are presented in Table 4. These results indicate stress corrosion failures would be anticipated at sustained stresses above 30 Ksi. By the ASTM G64[9] criterium, this material would receive a rating of C. In contrast, 7075-T6 received a rating of D, indicating some improvement in stress corrosion cracking properties of 7075-T6.

Test results from the C(T) plane strain fracture toughness (K_{Ic}) specimens are presented in Table 5. These fracture toughness results are compared with two other high strength aluminum alloys, 7075-T651 and 7050-T7351, in Table 6. It can be seen that 7150-T7751 exhibits considerably lower fracture toughness than alloys of similar strength in the L-T and T-L orientations. The L-T fracture toughness fracture toughness of the 1.1-inch plate previously reported[5], while T-L fracture toughness is 94% of the previously reported value. Fracture toughness was consistent between the L-T and T-L specimens. Remarkably, fracture toughness in the S-T orientation was higher than that found in either the L-T or T-L orientations. This result was so surprising that a second set of specimens was machined and tested. Results from these tests verify the original finding.

SECTION 4

CONCLUSIONS

Because of its high strength, 7150-T7751 will inevitably be considered for use where the -T6 temper of 7XXX alloys is now employed. The 7150-T7751 plate exhibits tensile properties slightly superior to those of -T6 tempers. Fatigue properties are similar to 7075-T6 plate material. Constant amplitude fatigue crack growth rates are greater in the lower stress intensity ranges and similar in higher ranges. Fracture toughness in the L-T and T-L directions of -T7751 is considerably lower than that of -T6 temper material, which may be of concern for damage tolerant critical applications. Stress corrosion tests indicate that 7050-T7751 is slightly less susceptible to stress corrosion than 7075-T6 material.

TABLE 2

7150-T7751 TENSILE RESULTS

Specimen Number	Orientation	Ultimate Strength (ksi)	Yield Strength (ksi)	Elongation % (1 inch gage length)
TL1	Longitudinal	86.4	82.8	8.8
TL2	Longitudinal	86.7	82.6	8.9
TL3	Longitudinal	86.2	82.4	8.9
	Average . . .	86.4	82.6	8.9
T1	Transverse	86.7	81.4	8.2
T2	Transverse	84.1	77.4	8.6
T3	Transverse	87.4	82.0	8.0
	Average . . .	86.1	80.3	8.3
TS3	Short Transverse	82.7	74.9	5.7*
TS4	Short Transverse	83.2	75.5	10.4
TS5	Short Transverse	81.8	73.6	6.0
	Average . . .	82.6	74.7	7.4

*Short transverse specimens have 0.5 inch gage length.

TABLE 3

COMPARATIVE 7XXX TENSILE VALUES

Material	Orientation	Ultimate Strength (ksi)	Yield Strength (ksi)	Elongation (%) 1 in gage length
7150-T7751	Longitudinal	86	83	9
7150-T6151[a]	Longitudinal	84	78	9
7075-T651[b]	Longitudinal	78	71	-
7150-T7751	Transverse	86	80	8
7150-T615	Transverse	84	77	9
7175-T651	Transverse	79	69	6
7150-T7751	Short	83	75	7[d]
7075-T651[c]	Short	69	58	-

[a]7150-6151 Plate (1.001-1.500 inch thick) values from MIL-HDBK-5E Table 3.7.7.0 (b), 1 May 1989.

[b]7075-T651 Plate (1.001-2.000 inch thick) values from MIL-HDBK-5E Table 3.7.4.0 (b), 1 June 1987.

[c]7150-T651 Plate (2.000-2.500 inch thick) values from MIL-HDBK-5E Table 3.7.7.0 (b), 1 June 1983.

[d]Short orientation specimens had a 0.5 inch gage length.

TABLE 4

7150-T7751 STRESS CORROSION CRACKING

Specimen Number	Test Stress (ksi)	Test Hours	Failure
TS1	60	116	yes
TS2	65	98	yes
TS3	55	112	yes
TS4	50	170	yes
TS5	45	239	yes
TS6	40	243	yes
TS7	35	459	yes
TS8	30	467	yes
TS11	20	1198	no

TABLE 5

FRACTURE TOUGHNESS RESULTS

7150-T7751 1.75" PLATE

Specimen Number	Orientation	K_{Ic} ksi $\sqrt{in}$
KL1	L-T	20.8
KL2	L-T	20.1
KL3	L-T	20.9
KL2A	L-T	22.1
KL3A	L-T	19.8
	Average	20.7
KT1	T-L	20.2
KT2	T-L	19.2
KT3	T-L	19.4
KT1A	T-L	21.6
KT2A	T-L	22.0
KT3A	T-L	22.7
	Average	20.9
KS2	S-T	22.9
KS3	S-T	21.4
KS1A	S-T	20.4
KS2A	S-T	23.4
KS3A	S-T	23.3
	Average	22.8

TABLE 6

COMPARATIVE 7XXX FRACTURE TOUGHNESS VALUES

Specimen Number	Orientation	K_{Ic} ksi $\sqrt{in}$
7150-T7751	L-T	20.7
7050-T7351[a]	L-T	34.5
7075-T651[b]	L-T	26.5
7150-T7751	T-L	20.8
7050-T7351[a]	T-L	30.0
7075-T651[b]	T-L	22.5
7150-T7751	S-T	22.8
7050-T7351[a]	S-L	28.0
7075-T651[b]	S-L	1.76

[a] 7050-T7351 (1.00-6.00 inch Plate) data from Damage Tolerant Design Handbook, Metals and Ceramics Information Center, MCIC-HB-OIR Volume 3, Table 8.02.

[b] 7075-T651 (0.37-5.00 inch Plate) data from Damage Tolerant Design Handbook, Metals and Ceramics Information Center, MCIC-HB-OIR Volume 3, Table 8.02.

TABLE 7

SHORT TRANSVERSE K_{Iscc} RESULTS

Specimen Number	Hours to Failure	Stress Intensity ksi $\sqrt{in}$
KS 5	868	21.0
KS 3	751	22.8
LSL 5	691	18.6

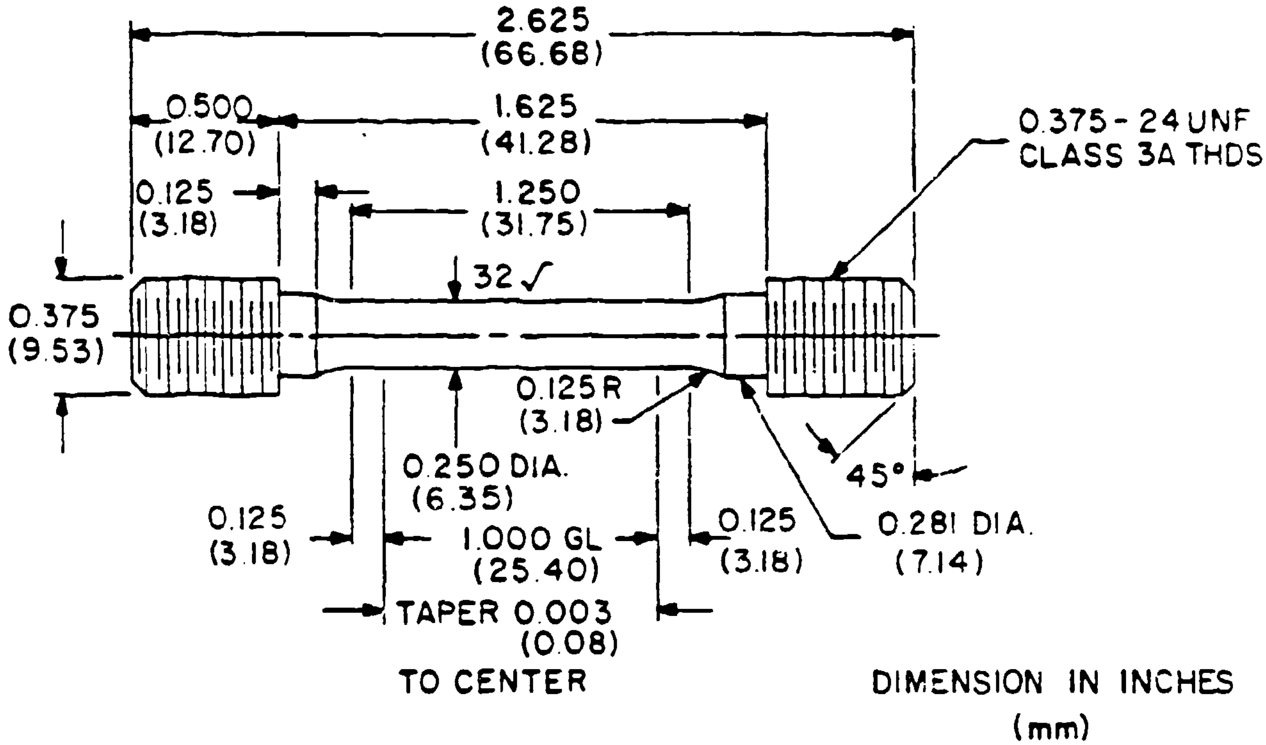


Figure 1. Tensile Specimen Geometry.

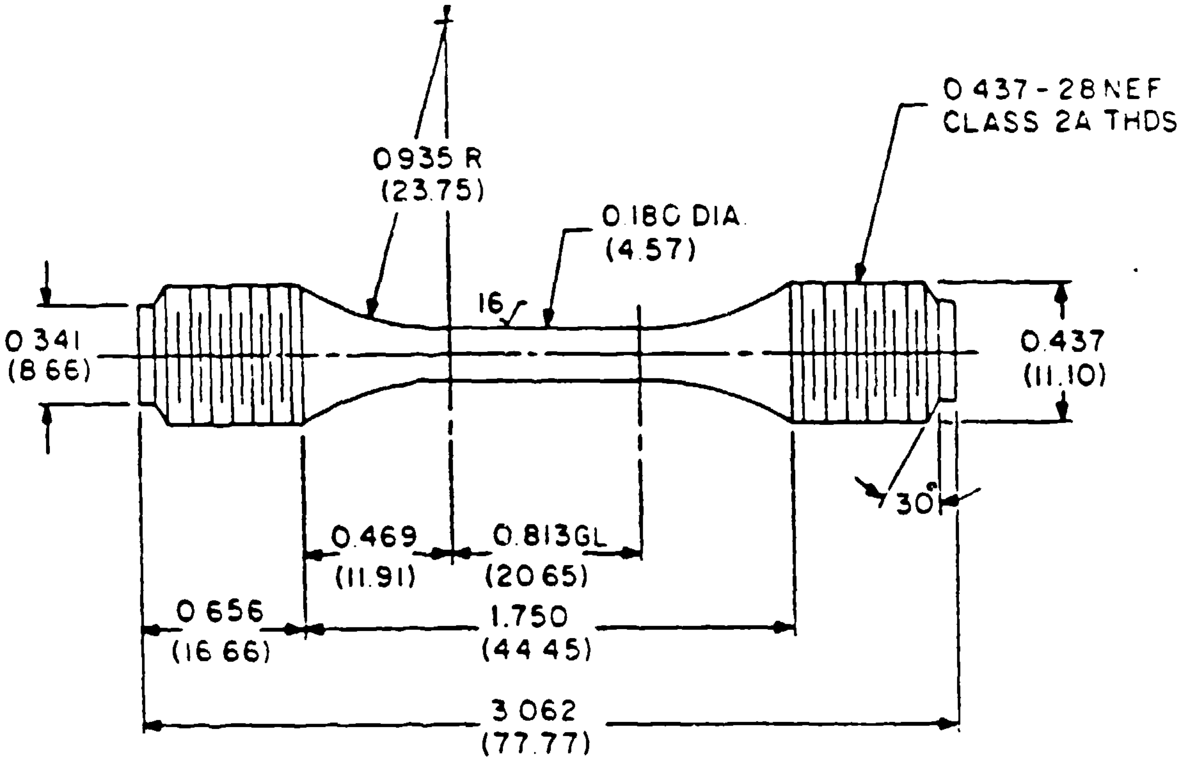


Figure 2. Smooth Fatigue Specimen Geometry.

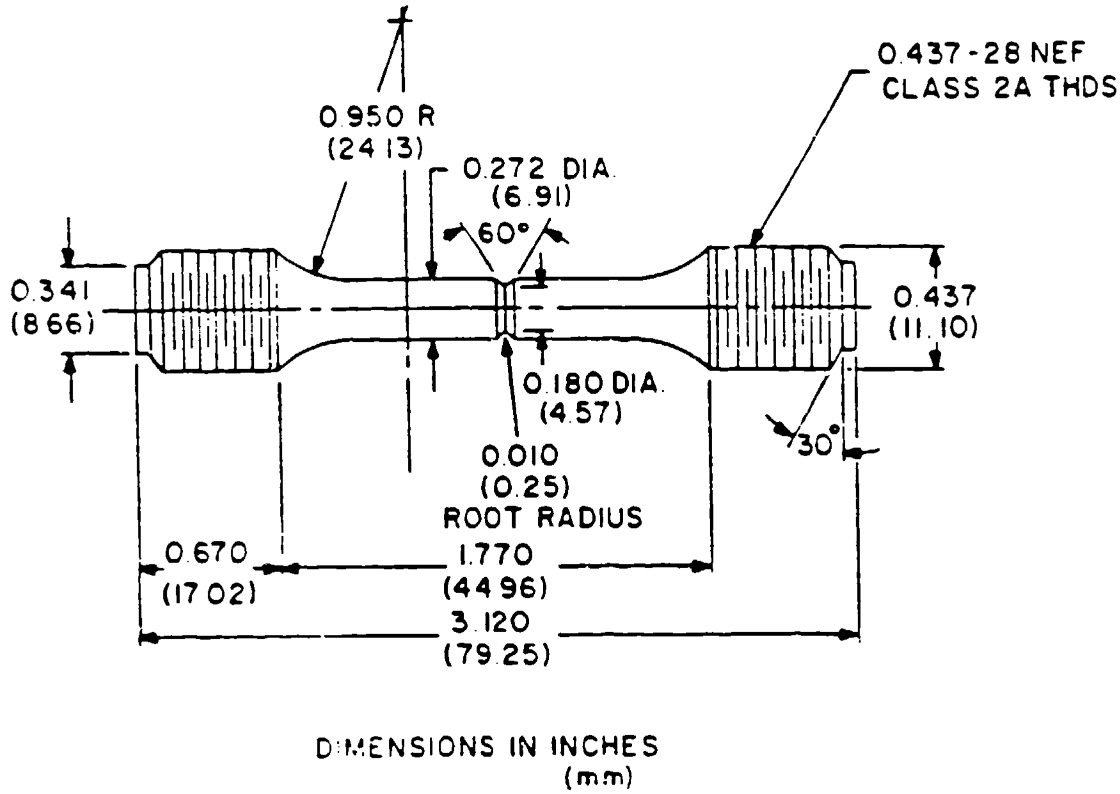


Figure 3. Notched Fatigue ($K_t = 3$) Specimen Geometry.

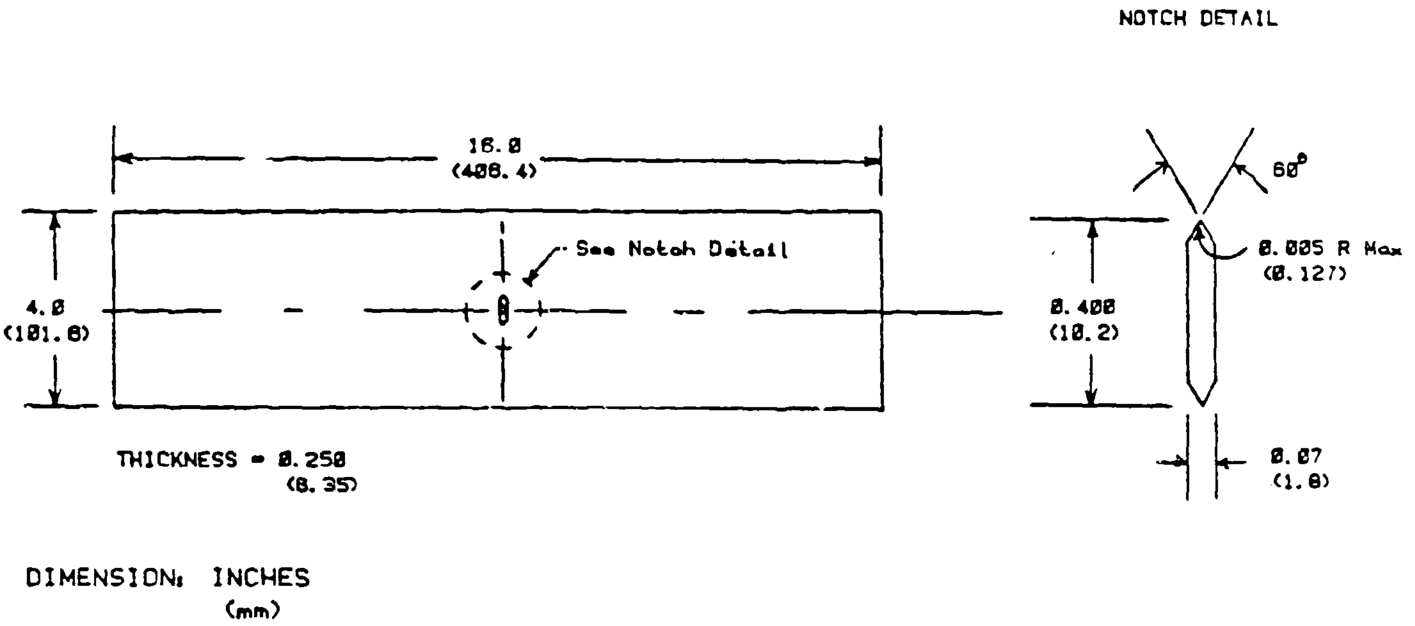
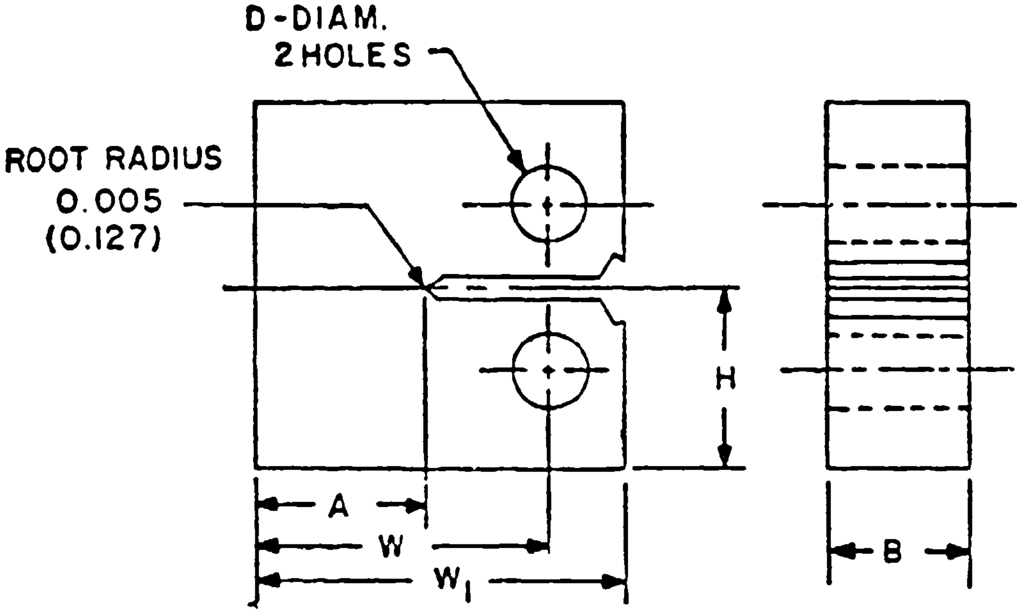


Figure 4. Fatigue Crack Growth Center Crack Panel Specimen Geometry.



DIMENSIONS: INCHES (mm)

SPECIMEN TYPE	A	B	W	W_1	H	D
FRACTURE TOUGHNESS	1.22	1.00	2.00	2.50	1.20	0.50
CRACK GROWTH	2.20	0.425	2.50	3.125	1.50	0.50
CORROSION	1.00	0.625	1.33	1.66	0.80	0.375

Figure 5. Compact Specimen Dimensions Used in Fracture Toughness, Fatigue Crack Growth, and Stress Corrosion Tests.

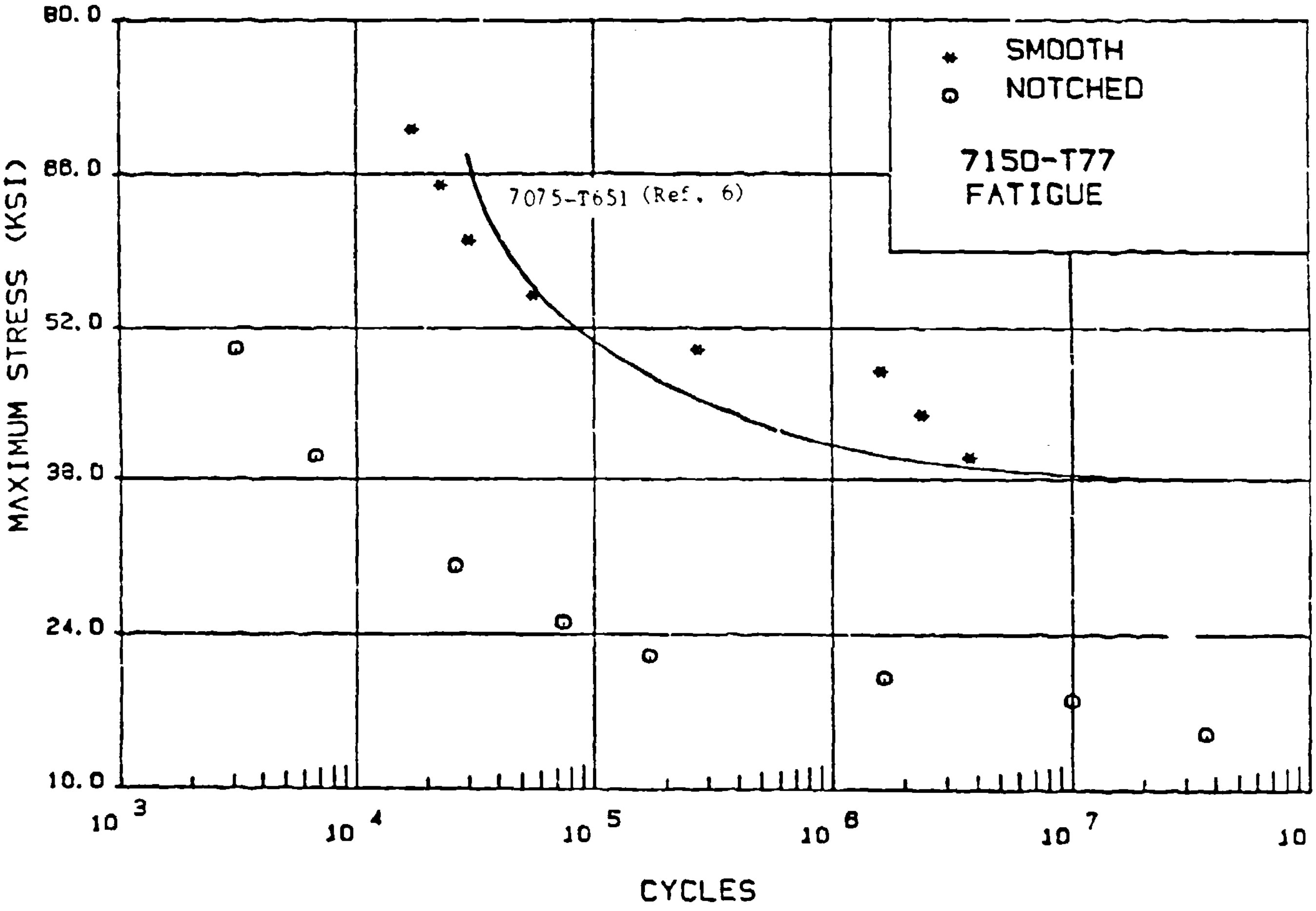


Figure 6. Smooth and Notched Fatigue Data for 7150-T7751 with Smooth 7075-T651 Reference Curve.

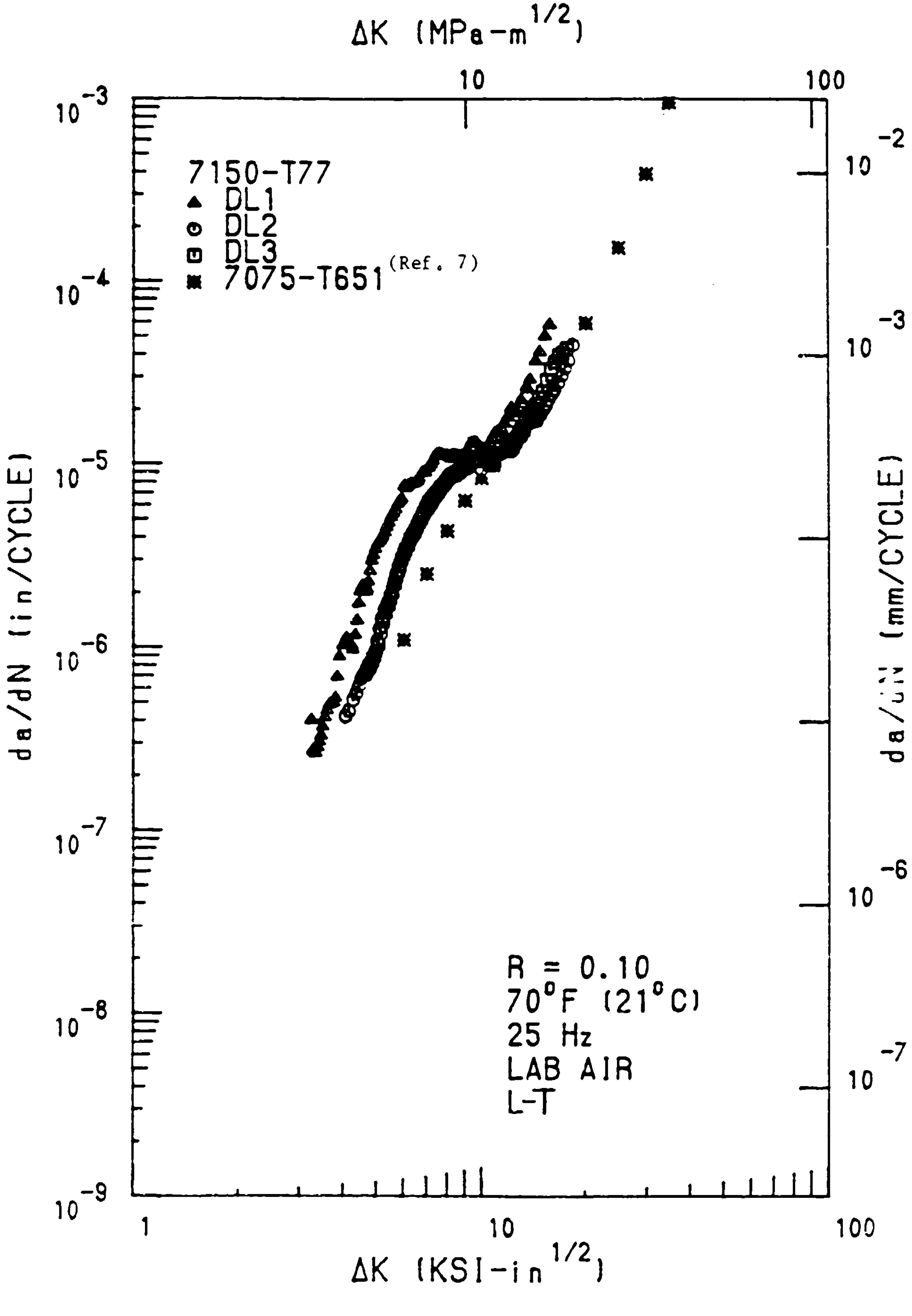


Figure 7. Fatigue Crack Growth Rate Data for 7150-T7751 L-T Orientation.

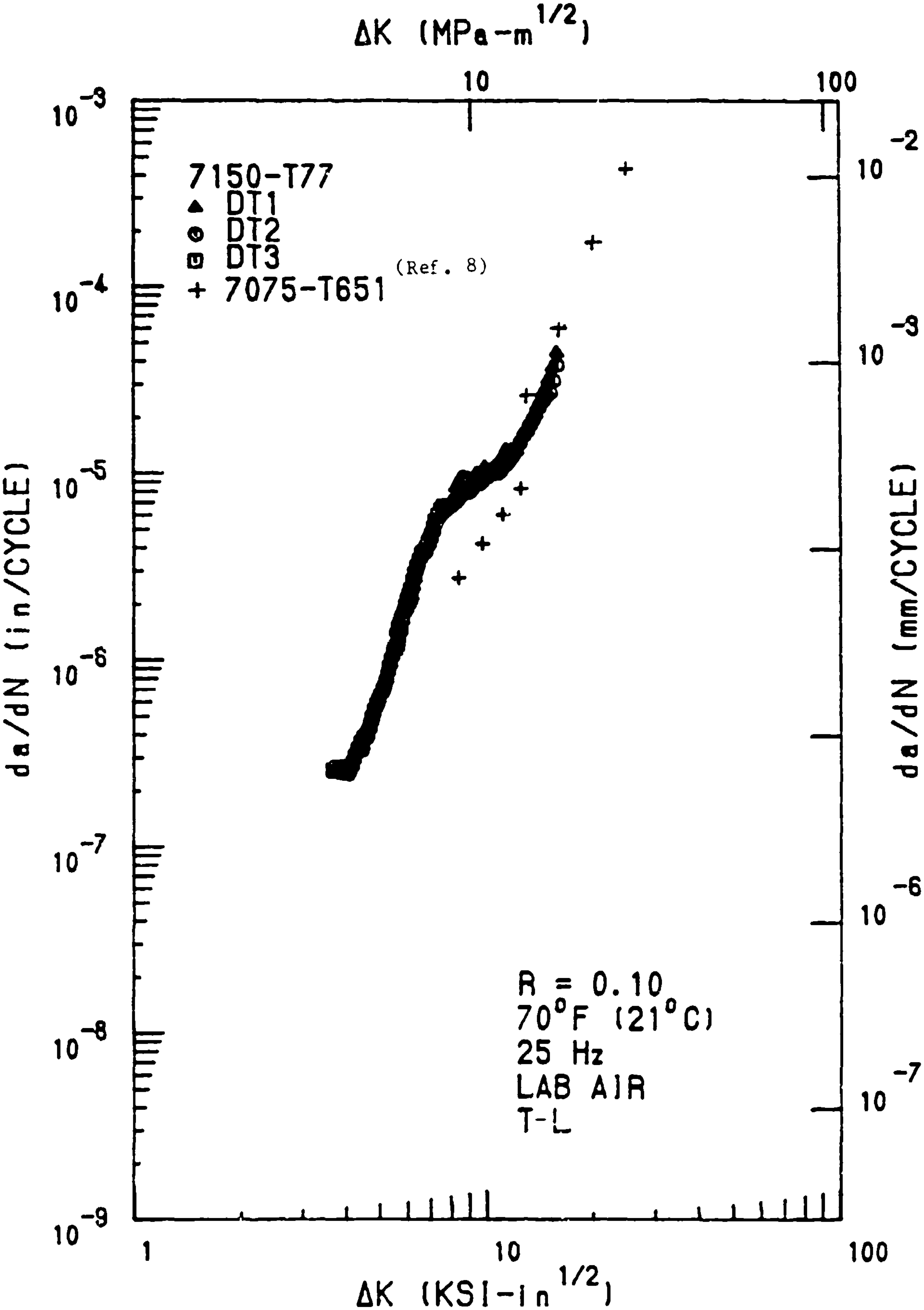


Figure 8. Fatigue Crack Growth Rate Data for 7150-T7751 T-L Orientation.

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