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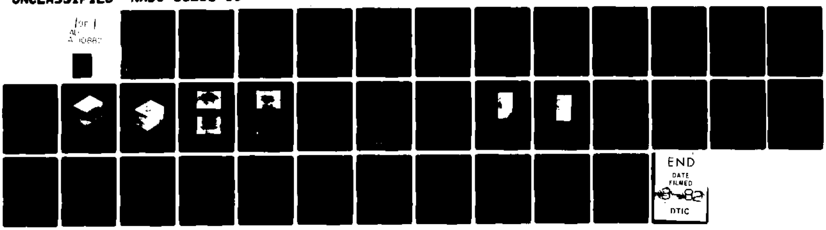

REPORT NO. NADC-81251-60

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PROPERTIES OF SHOCK HARDENED 7050 ALUMINUM ALLOY

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A quantity of 7050-T73651 aluminum alloy plate was shock hardened in an attempt to improve mechanical properties. Test results indicated that shock hardening produced no significant change in tensile or fatigue properties. Exfoliation resistance was unchanged also.

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SUMMARY

INTRODUCTION

Work ~~performed~~ at the University of Denver under the sponsorship of the Naval Air Systems Command (reference ~~(a)~~) has shown that improvements in both strength and ductility of nickel-base alloys can be achieved by shockwave deformation (shock hardening). Such deformation is produced by impact of a driver plate on a flat sample. The driver plate is driven by an explosive pressure pulse. Specifically, the University of Denver work showed shock-aging Udimet 700 sheet at 527 kbar pressure could lead to ductility increases of 200 to 400%, together with substantial increases in strength at both room temperature and 649°C (1200°F). Stress rupture life at 649°C (1200°F) could be increased as high as 50-fold. This report contains the results of an attempt to achieve similar improvements in mechanical properties of 7050 aluminum alloy plate by shock hardening.

RESULTS

Shock hardening produced no significant change in the tensile or fatigue properties of the 7050 plate. Exfoliation resistance was also found to be unchanged.

CONCLUSIONS

Shock hardening of 7050-T73651 aluminum plate produces no significant change in its properties.

FUTURE PLANS

A quantity of solution treated and preconditioned 7050 plate will be shock hardened and evaluated, as material in this condition has greater potential for improvement of mechanical properties by shock hardening than does the material in the T-73651 temper.

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EXPERIMENTAL PROCEDURE

MATERIAL

The material used in this investigation was 1/2 in. (12.7 mm) thick 7050-T73651 aluminum plate obtained from Alcoa by the Naval Air Systems Command (NAVAIRSYSCOM).

SHOCK HARDENING

A 5 in. (12.7 mm) by 8 in. (20.3 mm) piece of plate was pretreated at 121°C (250°F) for 4 hours and shock hardened at the Denver Research Institute with loading conditions and calculated shock wave parameters as follows (reference (b)):

Tooling: 1-1/2 in. wide Al spall rails;
1/2 in. thick Al spall plate;
1 in. thick Al anvil;
Al foil cover to protect impact surface.

Driver Plate: 1/4 in. thick Al;
7.6° inclination angle

Explosive Loading: 4 sheets of Detasheet C-2
(2 g/in^2 areal density;
total of 8 g/in^2);
Oblique detonation

Driver Plate Velocity at Impact: 960 m/s

Particle Velocity: 480 m/sec.

Shock Velocity: 5,730 m/sec.

Peak Pressure: 80 $\pm$ 3 kbar

Peak Pressure Duration: Front face - 2.11 μs
Back face - 1.90 μs
(can be considered a 2 μs pulse).

Transient Strain: $4/3 \ln V/V_o = 8.8\%$
(can be quoted as 9%).

Transient Temperature: 83°C (2 μs duration).

Residual Temperature: 30°C (shot into water and quenched).

Initial Hardness: 143 BHN

As-Shocked Hardness: Front Face - 155 BHN
Back Face - 154 BHN

After the plate was shock hardened a sample was aged at 163°C (325°F) for 4 hours. This treatment resulted in severe overaging with attendant loss of tensile properties. Consequently the balance of the material was aged at 121°C (250°F) for 4 hours.

TEST METHODS

1. Tensile Tests

Tests of 0.252 inch (6.40 mm) diameter tensile specimens (ASTM Standard E-8, Type R-3) were performed on a 10,000 pound (44,500N) capacity Tinius Olsen mechanical universal testing machine equipped with an extensometer.

2. Metallography

Metallographic examinations were performed on longitudinal and transverse sections of the shock hardened plate.

3. Fatigue Tests

R. R. Moore type rotating beam fatigue tests (R=-1) were performed on smooth (unnotched) specimens. The axis of the specimen was parallel to the final roll direction of the plate (longitudinal).

4. Fatigue Crack Growth and Fracture Toughness Tests

Fatigue crack growth rate measurements were made on compact tension specimens (ASTM Standard E-399, W=2 inches (50.8mm)). The specimens were cycled on a 5000 pound (22,200 N) capacity Krouse direct stress fatigue machine between loads of 100 pounds (445 N) minimum and 1500 pounds (6680 N) maximum (R=0.07) until crack initiation was observed. At this point the maximum load was reduced to 1100 pounds (4900 N) (R=0.09), and crack length measurements were made at 1000 cycle intervals until the crack propagated to a point approximately 1 inch (2.5 mm) from the back surface. The specimens were then pulled to destruction for determination of fracture toughness (K_Q on an Instron universal testing machine equipped with a crack opening displacement gage.

5. Exfoliation Tests

Exfoliation tests were performed on broken ends of compact tension specimens machined to expose one-tenth thickness and one-half thickness planes in accordance with ASTM Standard G-34.

RESULTS

TENSILE PROPERTIES

Table I shows results of tensile tests of the 7050 plate as-received and after preconditioning at 121°C (250°F) for 4 hours. The tensile properties were as expected for 7050-T73651 material and were unaffected by the preconditioning treatment.

TABLE I

TENSILE PROPERTIES OF 12.7 mm (1/2 in.) THICK 7050 ALUMINUM ALLOY PLATE

Condition	Orientation		0.2% Offset Yield Strength MPa (ksi)		Tensile Strength MPa (ksi)		Elongation in 25.4 mm (1 in.) (%)		Reduction in area (%)
As rec'd	Longitudinal		448.9 (65.1)		519.9 (75.4)		16		42.7
			444.7 (64.5)		513.0 (74.4)		16		41.0
		Avg.	446.8 (64.8)	Avg.	516.5 (74.9)	Avg.	16	Avg.	41.9
As rec'd	Transverse		454.4 (65.9)		521.2 (75.6)		12		38.0
			445.4 (64.6)		518.5 (75.2)		12		38.3
		Avg.	449.9 (65.3)	Avg.	519.9 (75.4)	Avg.	12	Avg.	38.2
250°F 4-hours	Longitudinal		450.9 (65.4)		518.5 (75.2)		16		45.5
			455.1 (66.0)		522.6 (75.8)		14		42.7
		Avg.	453.0 (65.7)	Avg.	520.6 (75.5)	Avg.	15	Avg.	44.1
250°F 4 hour	Transverse		441.3 (64.0)		512.3 (74.3)		12		35.4
			447.5 (64.9)		518.5 (75.2)		12		39.2
		Avg.	444.4 (64.5)	Avg.	515.4 (74.8)	Avg.	12	Avg.	37.3

Table II shows results of tensile tests on the material after shock hardening and after shock hardening plus aging. The effect of shock hardening was to increase yield strength with a corresponding decrease in elongation and reduction of area. Subsequent aging at 163°C (325°F) caused drastic reduction in yield and tensile strengths; consequently that treatment was eliminated from further evaluation. Aging at 121°C (250°F) restored a portion of the ductility lost in shock hardening while producing a minimal loss in yield strength.

MICROSTRUCTURE

Montages of the three planes of the shock hardened plus 121°C (250°F) four hours material at 100X and 400X are shown in Figures 1a and 1b. Longitudinal sections of the as-shock hardened and shock hardened plus 163°C (325°F) four hours are shown in Figures 2 and 3. All microstructures are similar except that the material aged at 163°C (325°F) showed more precipitate.

FATIGUE PROPERTIES

The results of the rotating beam fatigue tests are shown in Table 3 and plotted in Figure 4. A scatter band for all 7075-T6 products (reference (c)) is shown on Figure 4 for comparison. Note that the 7050 shock hardened data falls in the upper portion of the band in the high cycle region. This is to be expected with the higher degree of cleanliness of 7050 relative to the usual grade of 7075 alloy and is probably not attributable to the shock hardening treatment.

FATIGUE CRACK GROWTH RATE

Fatigue crack growth rate test results are plotted in Figure 5. A scatter band of 7050 data from reference (d) is superimposed on the plot. The shock hardened data fall well within the scatter band except at very low ΔK values.

After the specimens were pulled to distruction in accordance with ASTM Standard E-399, it was determined that the ratio of the maximum load to the 5 per cent secant offset load (P_{max}/P_Q) exceeded 1.10. Thus the tests were not valid for determination of K_{Ic} or K_Q. Accordingly, the specimen strength ratio (R_{SC}) was calculated instead. Its value was 1.235 for the LT oriented specimen and 0.916 for the TL oriented specimen.

EXFOLIATION TEST

After exposure the rating of the one-tenth thickness plane was P (pitting) and the one-half thickness plane EA (superficial) in accordance with ASTM Standard G-34. The exposed specimens are shown in Figures 6 and 7. The ratings are not significantly different from 7050-T73651.

TABLE II

TENSILE PROPERTIES OF 7050 ALUMINUM ALLOY PLATE AFTER SHOCK HARDENING

Condition	Orientation	0.2% Offset Yield Strength MPA (ksi)	Tensile Strength MPa (ksi)	Elongation in 25.4 mm (1 in.) (%)	Reduction in area (%)
Shock Hardened	Longitudinal	477.8 (69.3)	503.2 (73.0)	9.5	17.0
	Transverse	482.6 (70.0)	497.1 (72.1)	5	9.7
S.H.+ 325°F 4-hours	Longitudinal	405.2 (58.8)	450.2 (65.3)	(1)	39.7
	Transverse	411.4 (59.7)	432.9 (62.8)	5	10.8
S.H.+ 250°F 4-hours	Longitudinal	473.2 (68.6)	510.5 (74.0)	9	10.0
	Transverse	446.8 (64.8)	521.2 (75.6)	13	38.5
		475.1 (68.9)	522.6 (75.8)	13	43.4
		481.4 (69.8)	521.4 (75.6)	13	32.4
		Avg. 467.8 (67.8)	Avg. 521.8 (75.7)	Avg. 13	Avg. 38.1

NOTE: (1) Specimen broke outside gage length.

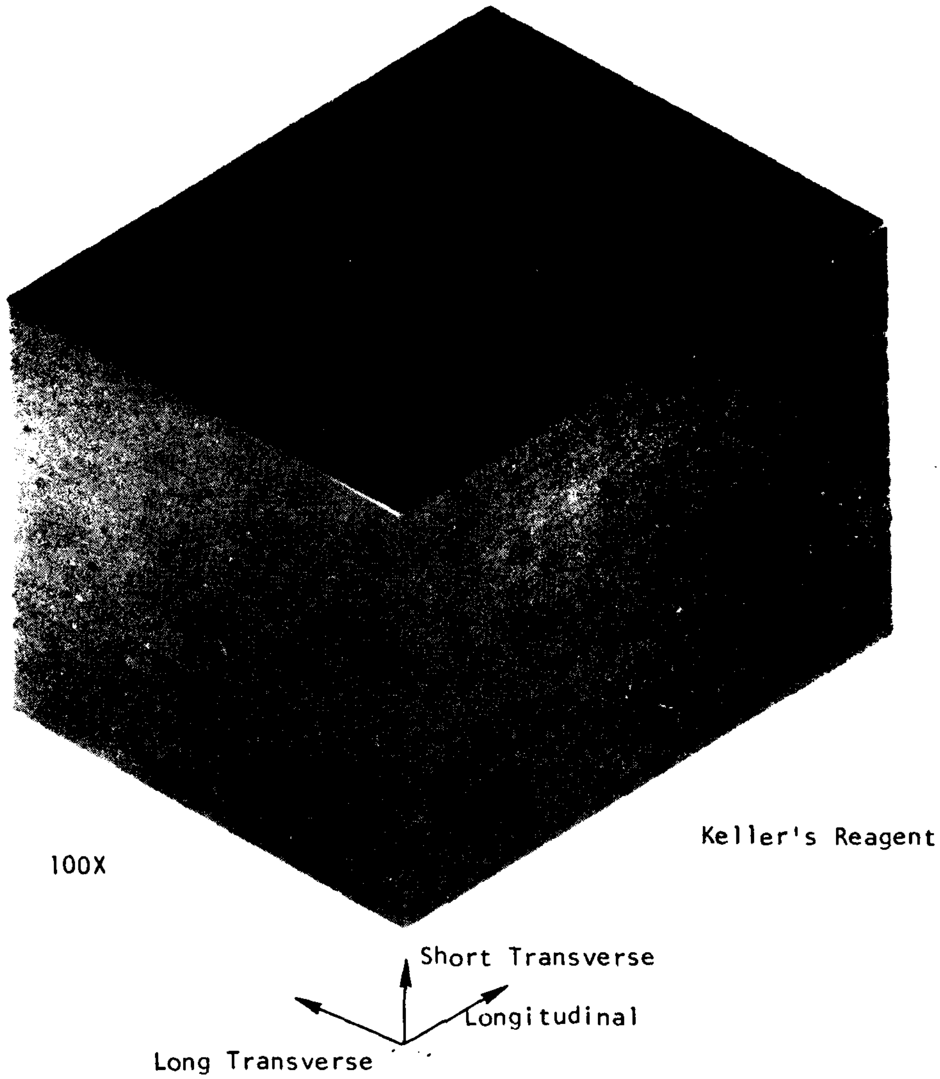


Figure 1a. Microstructural Montage of 7050 Al, Shock Hardened plus 250°F - 4 hour Age

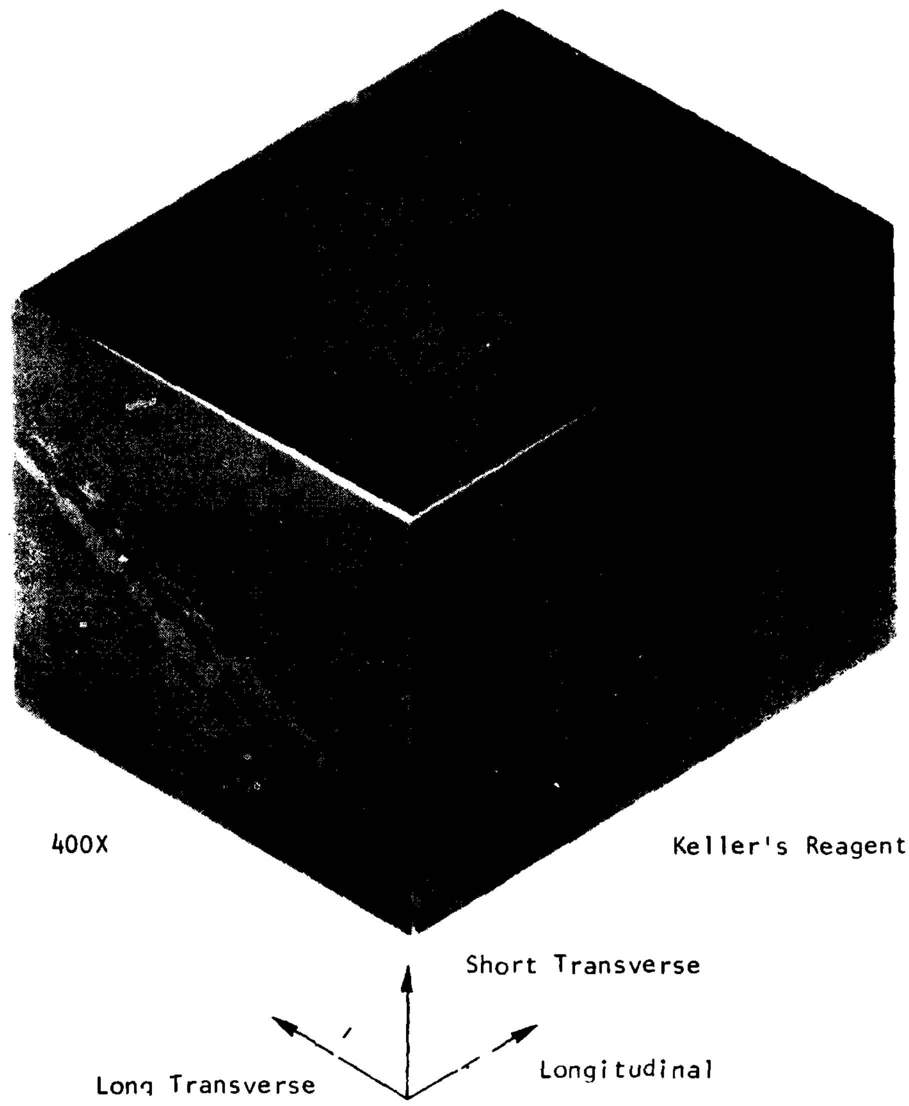
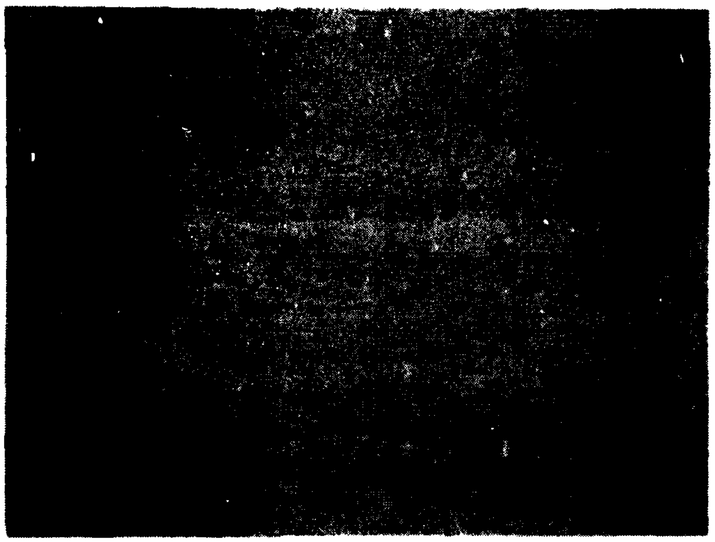


Figure 1b. Microstructural Montage of 7050 Al, Shock Hardened plus 250°F - 4 hour Age

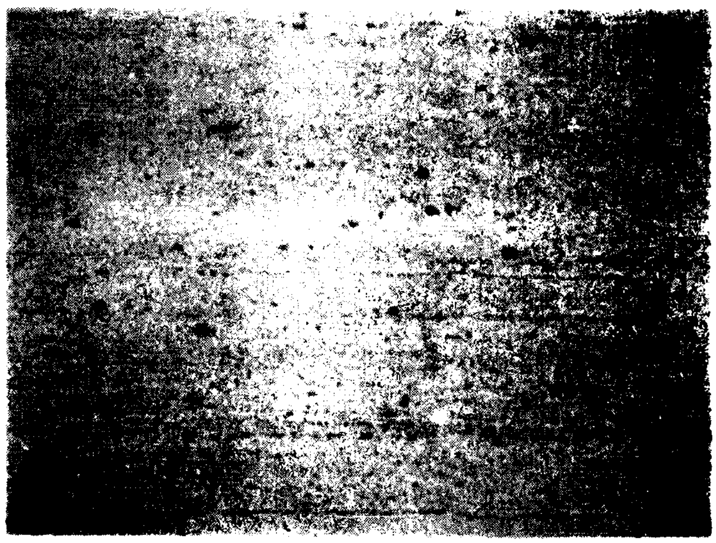
100X Keller's Reagent



400X Keller's Reagent

Figure 2. Microstructure of Shock Hardened 7050 Al

100X Keller's Reagent



400X Keller's Reagent

Figure 3. Microstructure of 7050 Al, Shock Hardened plus 325°F - 4 hour Age

TABLE III

ROTATING BEAM FATIGUE PROPERTIES OF 7050 ALUMINUM ALLOY PLATE
AFTER SHOCK HARDENING PLUS 250°F - 4 HOUR AGE

Specimen No.	Stress MPa	(ksi)	Cycles to Failure
1	287	(40)	143,000
2	207	(30)	3,213,000
3	186	(27)	7,089,000
4	165	(24)	20,156,000 *

* Threaded grip failure

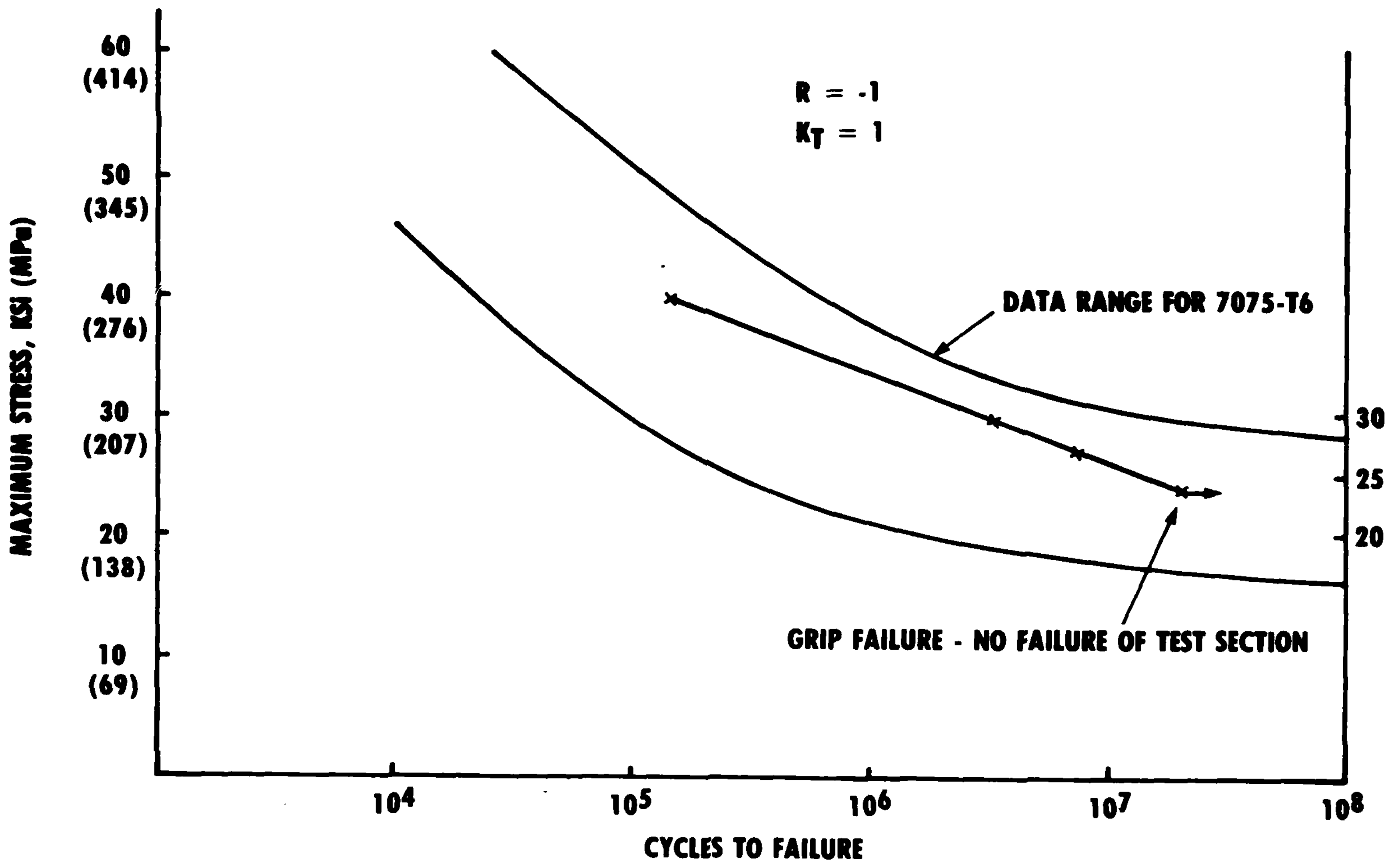


Figure 4. Comparison of Rotating Beam Fatigue Test Results for Shock Hardened 7050 Alloy with Data Range for Non-Shock Hardened 7075-T6 (reference (c)).

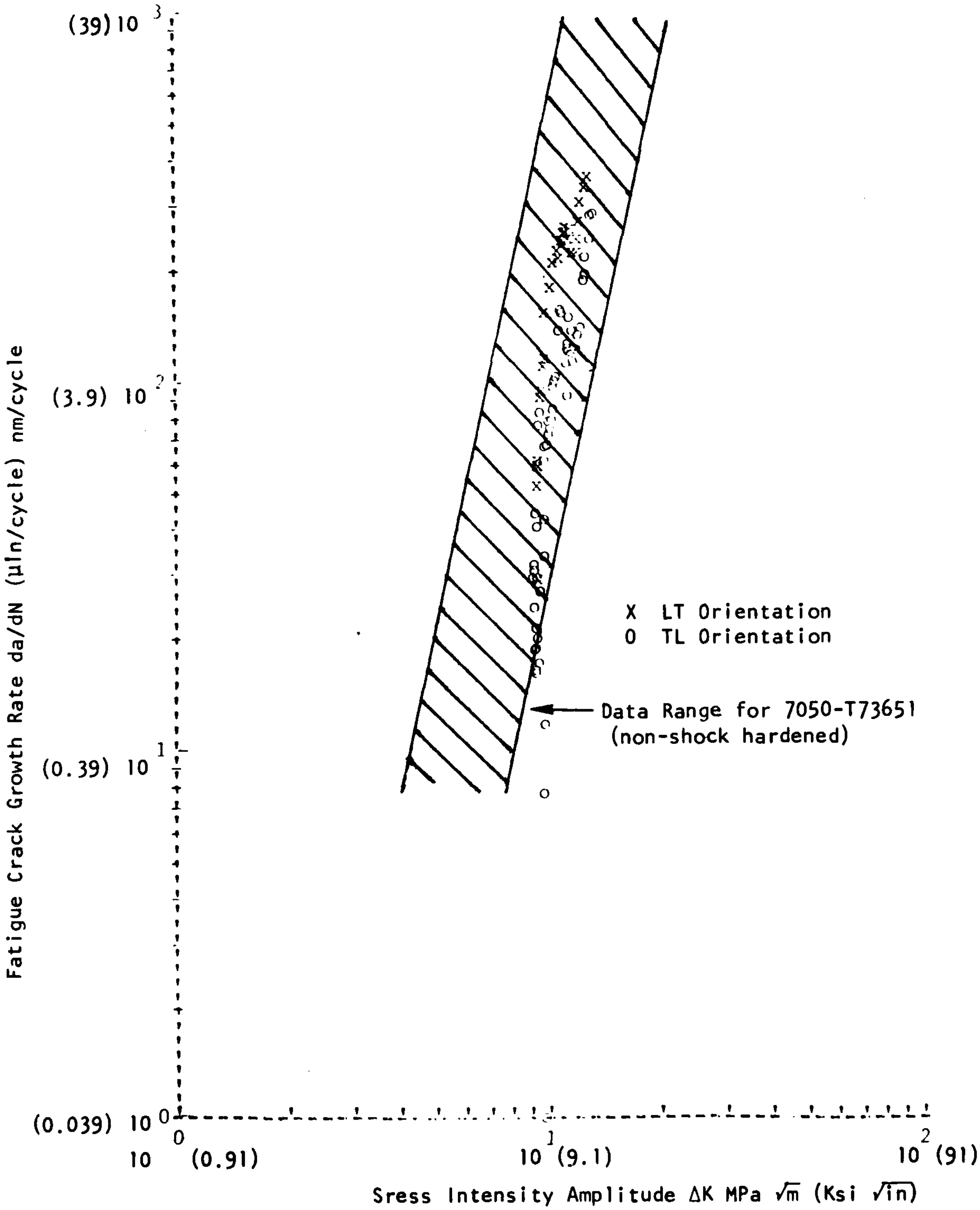
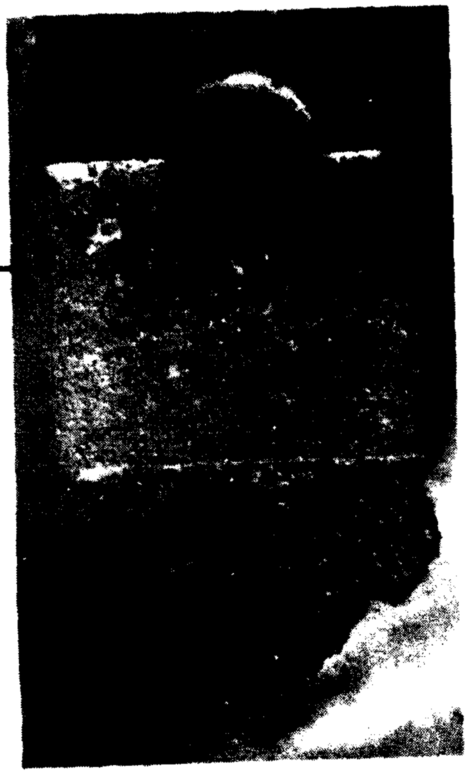


Figure 5. **Comparison of Fatigue Crack Growth Rate Test Results for Shock Hardened 7050 Alloy with Data Range for Non-Shock Hardened 7050-T73651 (reference (d)).**

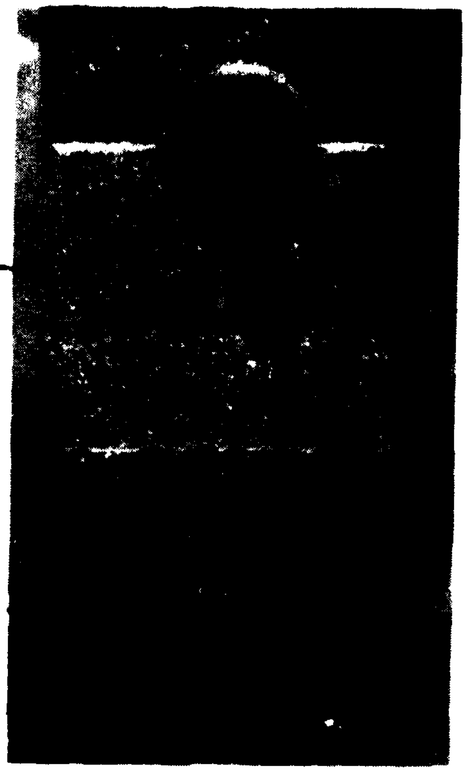
T/10 plane
(rating: pitting)



T/2 plane
(rating: superficial)

Figure 6. Broken End of LT Oriented Compact Tension Specimen after Exfoliation Testing

T/10 plane
(rating: pitting)



T/2 plane
(rating: superficial)

Figure 7. Broken End of TL Oriented Compact Tension Specimen after Exfoliation Testing

DISCUSSION

Of the tests performed in this investigation none showed any evidence of improvement or deterioration in the properties of 7050 aluminum plate as a result of shock hardening. However, it should be noted that the material before shock hardening was already overaged (T73651 condition). Thus, shock hardening and subsequent aging probably had little effect on the morphology and distribution of the precipitate. It is recommended that the shock hardening experiment be repeated on material that is solution-treated, but not aged, as the shock hardening should have a greater effect on material in this condition.

REFERENCES

(a) "Thermomechanical Processing of Nickel-Base Superalloys by Shock Wave Deformation," University of Denver, Denver Research Institute Final Technical Report, contract N00019-72-C-0138, to Naval Air Systems Command, March 1973.

(b) Letter from R. Norman Orava, University of Denver to C. Edwin Neu, Naval Air Development Center, 20 March 1974.

(c) Aerospace Structural Metals Handbook, Vol. 3, Code 3207, Mechanical Properties Data Center, December 1980.

(d) Damage Tolerant Design Handbook, Metals and Ceramics Information Center, Battelle-Columbus Laboratories, MCIC-HB-01, December 1972.

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A P P E N D I X A

COMPARISON OF DATA ANALYSIS METHODS FOR FATIGUE CRACK PROPAGATION TESTS

APPENDIX A

COMPARISON OF DATA ANALYSIS METHODS FOR FATIGUE CRACK PROPAGATION TESTS

The fatigue crack growth rate test data described in the main body of the report and plotted in Figure 5 were reduced by the incremental polynomial method described in ASTM Standard E647-78T, "Tentative Test Method for Constant-Load-Amplitude Fatigue Crack Growth Rates Above 10^{-8} m/cycle." For comparative purposes several other data analysis methods were applied to the same test results.

Figures A-1a and A-1b show crack growth rates calculated from a derived expression of the Paris form:

$$da/dN = C\ (\Delta K)^m$$

where C and m are constants determined by regression.

The incremental polynomial data from Figure 5 are shown for comparison. It is evident from examination of Figures A-1a and A-1b that the Paris expression will yield reasonably good predictions of crack growth rates for this particular material except at very low stress intensity amplitude levels.

Figures A-2a and A-2b are similar to Figures A-1a and A-1b except that the derived expression is of the Foreman form:

$$da/dN = \frac{C\Delta K^m}{(1-R)Kc-\Delta K}$$

where C and m are regression constants, R is the ratio of minimum to maximum load, and Kc is the critical stress intensity factor.

For this test data there is little difference between the Paris and Foreman expressions. Actually, the simpler Paris expression fit the data slightly better than did the Foreman expression. It should be noted, however, that in these tests there were no data points gathered at stress intensity amplitudes close to K_{Ic} It is test data that include high stress intensity values that the Foreman expression is designed to fit best.

Figures A-3a and A-3b show crack growth rates determined by a single fourth degree polynomial curve fit together with those determined by the incremental polynomial method. By comparison the fourth degree polynomial tends to underestimate crack growth rates at high stress intensity levels. It is by nature less sensitive to variations in the data than the incremental method, but is convenient to use.

Figures A-4a and A-4b show a comparison of crack growth rates determined by the secant method described in ASTM E647-78T (actual $\Delta a/\Delta N$) with those determined by the incremental polynomial method. It is evident that the former method allows considerably more data scatter; its chief advantage is that unlike the incremental polynomial method it does not result in the loss of 3 data points from either end of the observed crack length readings.

In spite of the difference in appearance of the growth data determined by the two methods, expressions derived from the data are almost the same. Figures A-5a and A-5b show derived expressions of the Paris form for both data reduction methods.

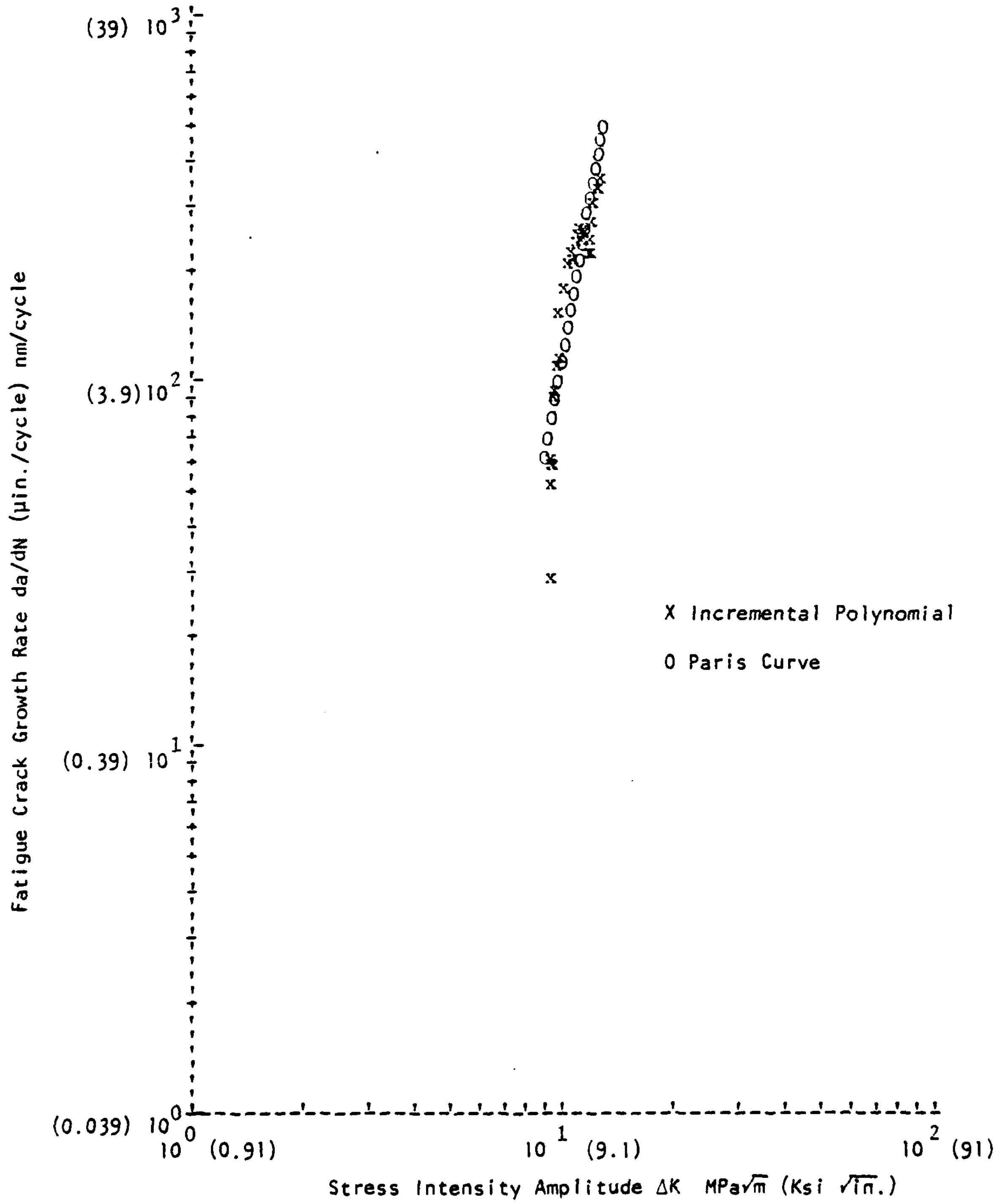

Figure A-1a. Paris Curve Fit, LT Orientation

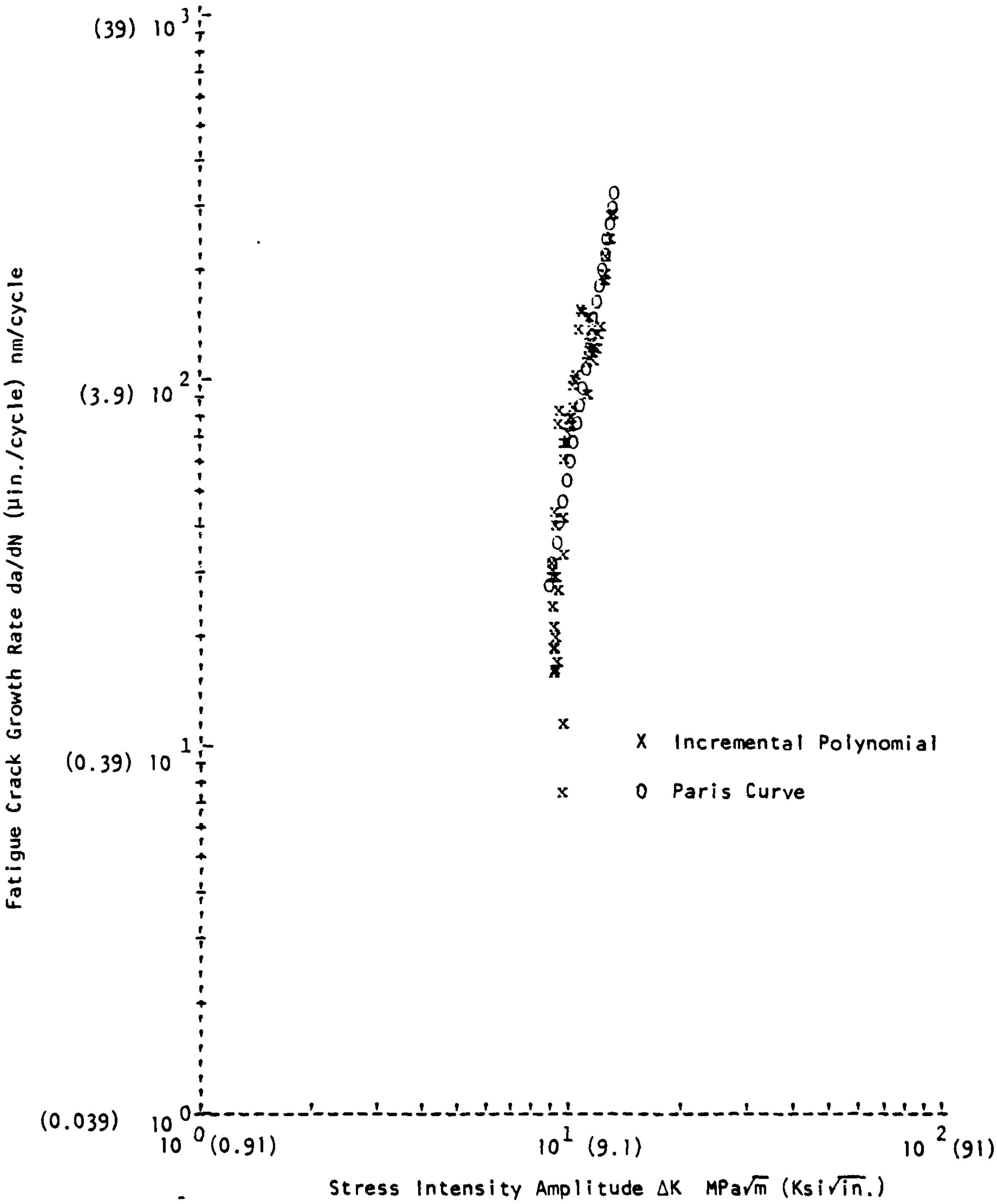

Figure A-1b. Paris Curve Fit, TL Orientation

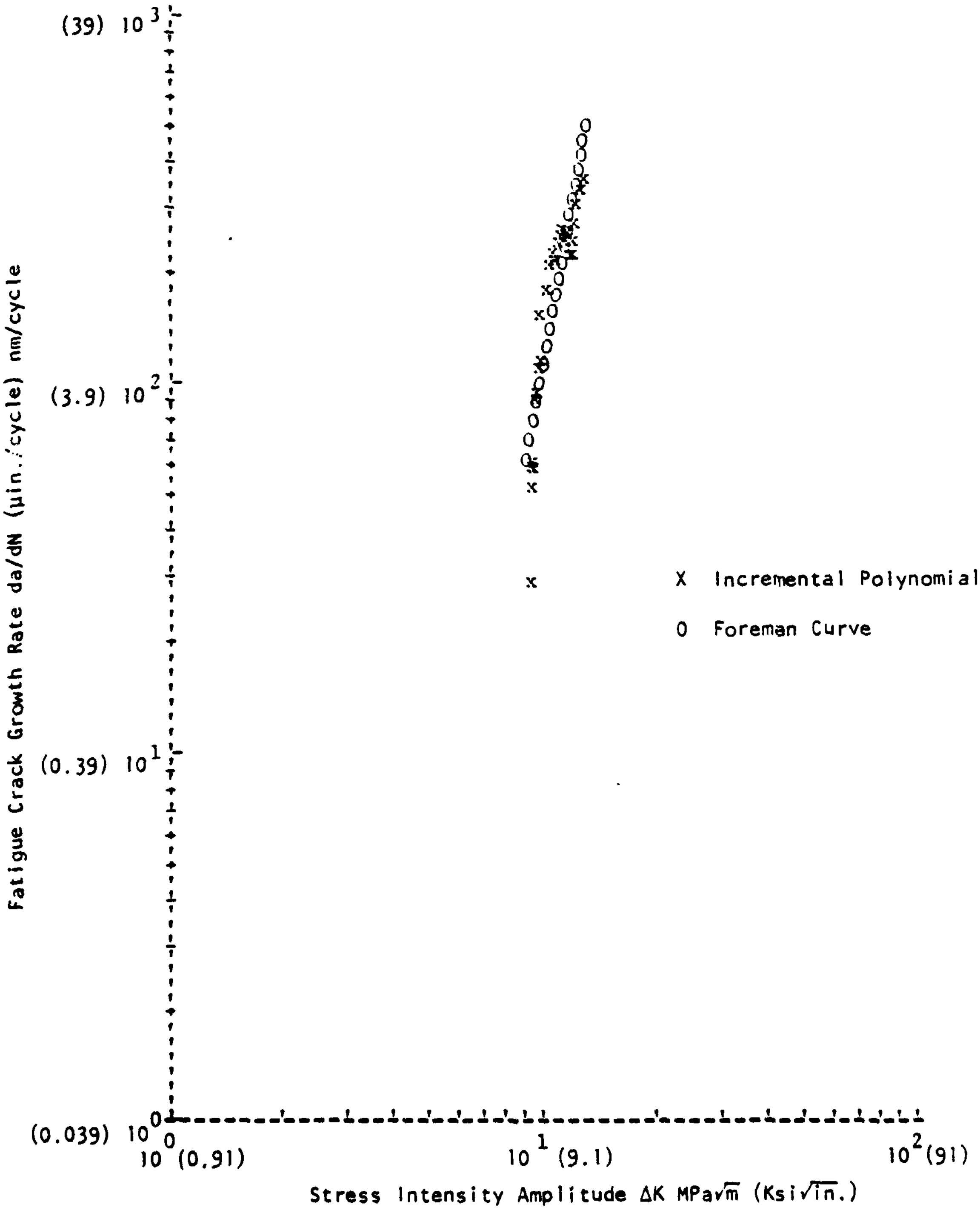

Figure A-2a. Foreman Curve Fit, LT Orientation

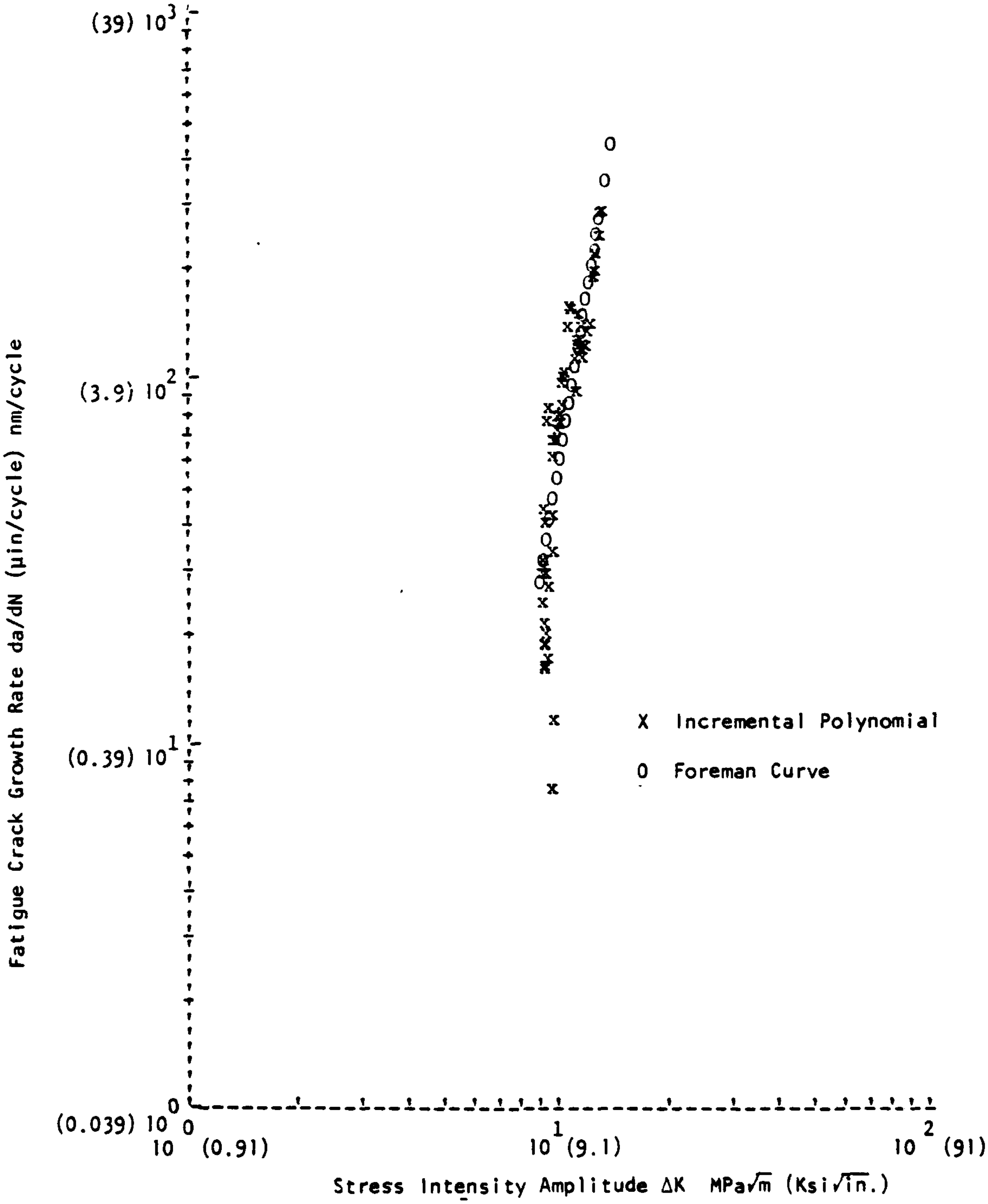

Figure A-2b. Foreman Curve Fit, TL Orientation

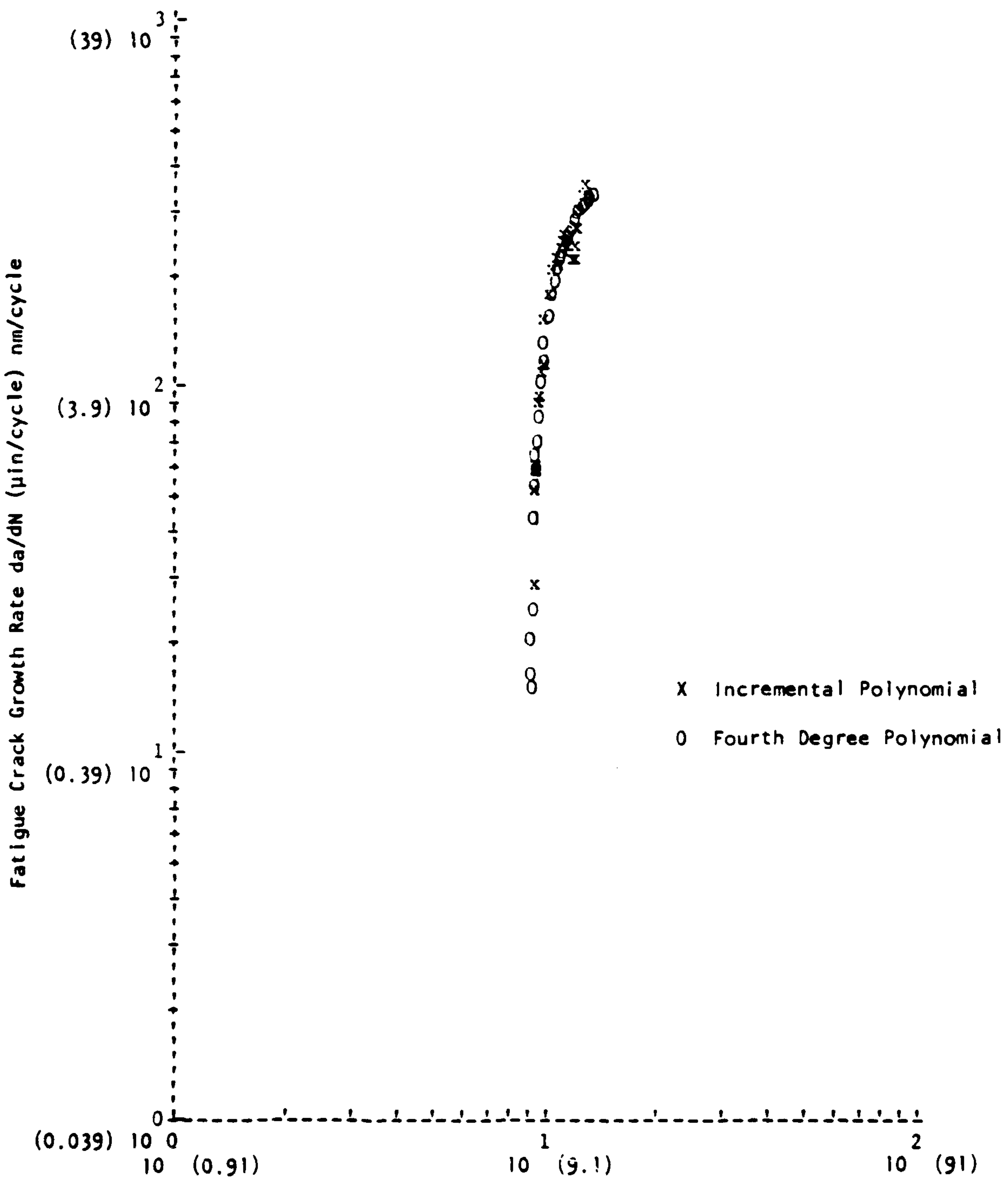

Figure A-3a. Fourth Degree Polynomial Curve Fit, LT Orientation

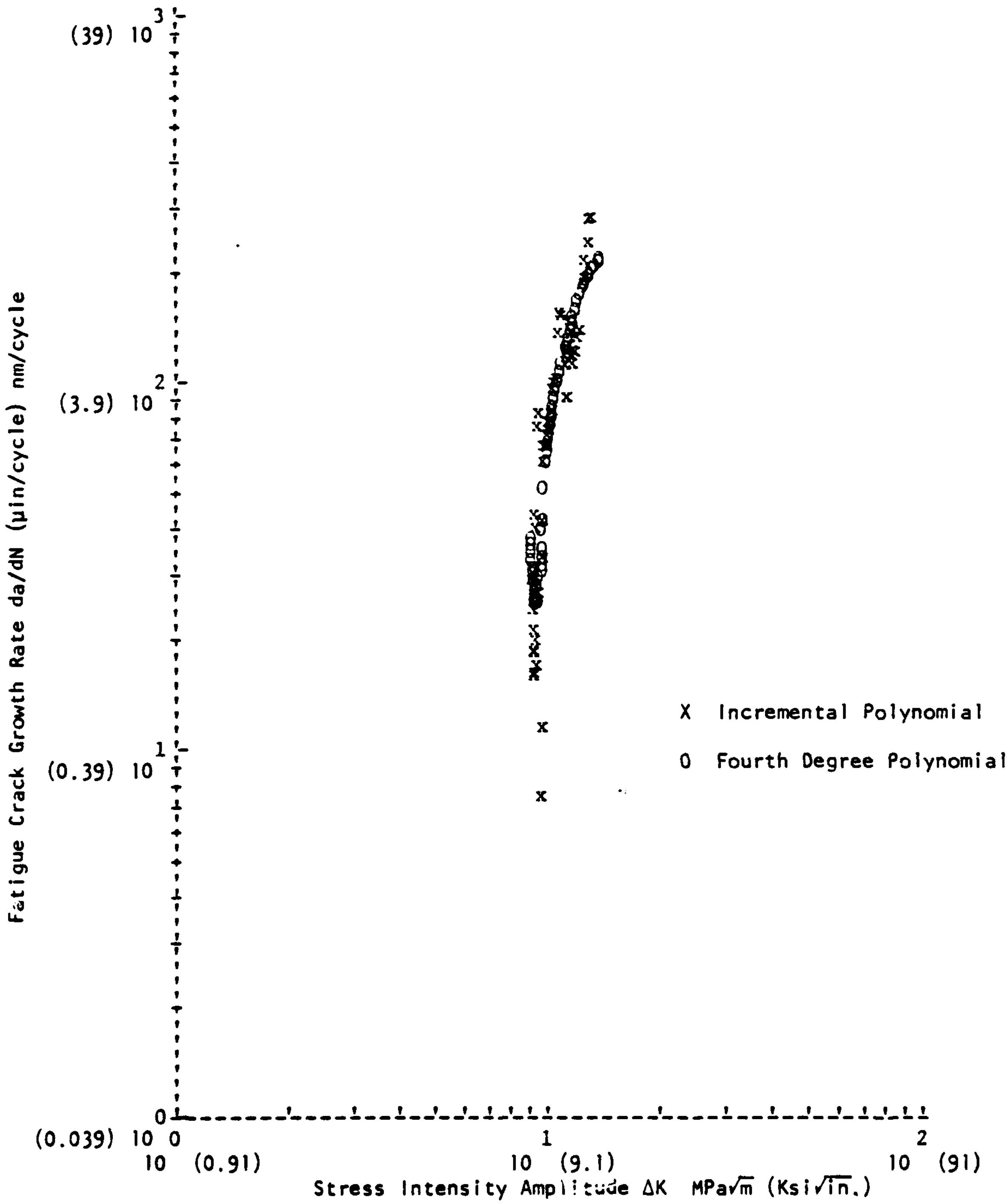

Figure A-3b. Fourth Degree Polynomial Curve Fit, TL Orientation

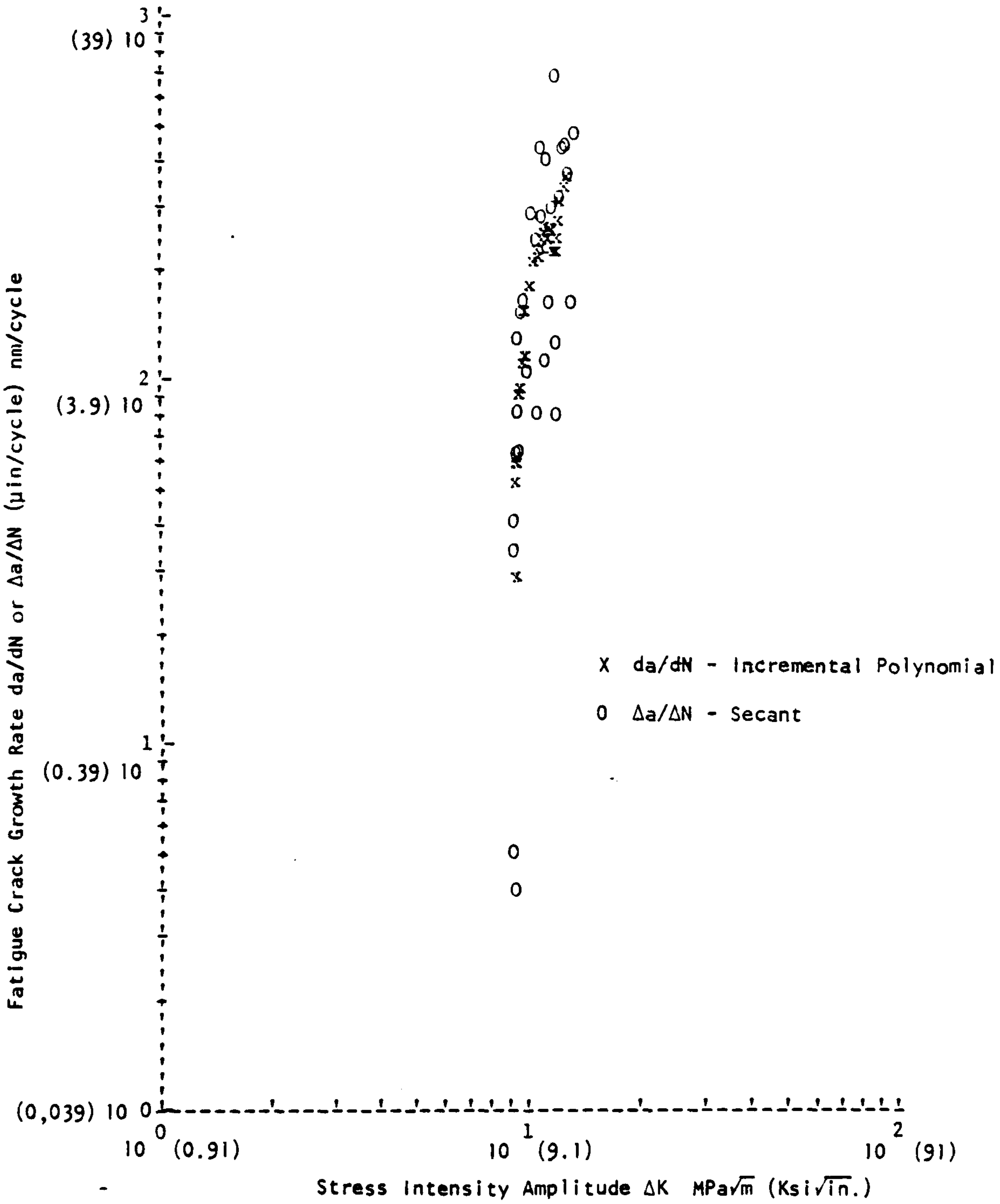

Figure A-4a. Comparison of Secant vs. Incremental Polynomial Methods of Data Reduction, LT Orientation

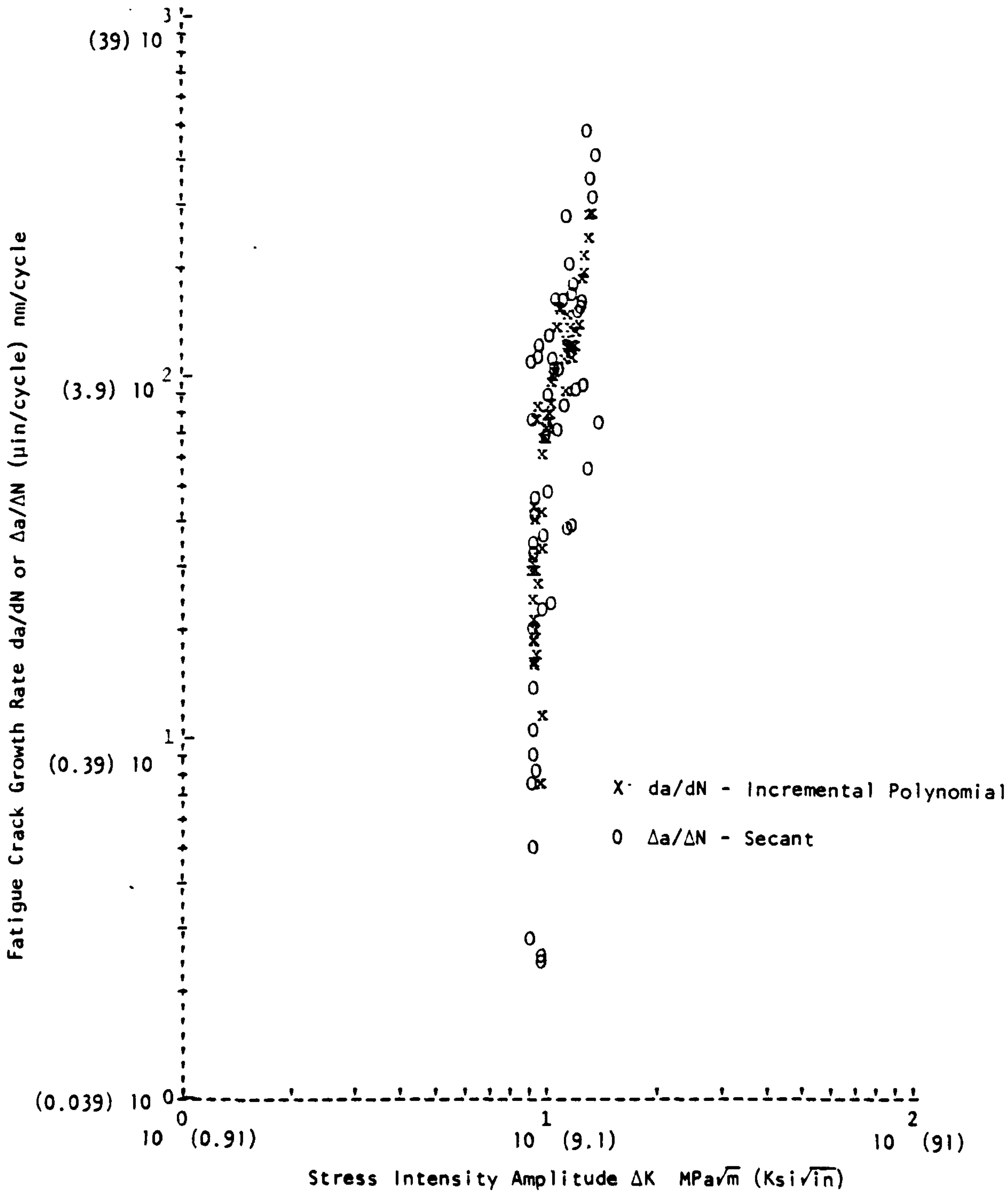

Figure A-4b. Comparison of Secant vs Incremental Polynomial Methods of Data Reduction, TL Orientation

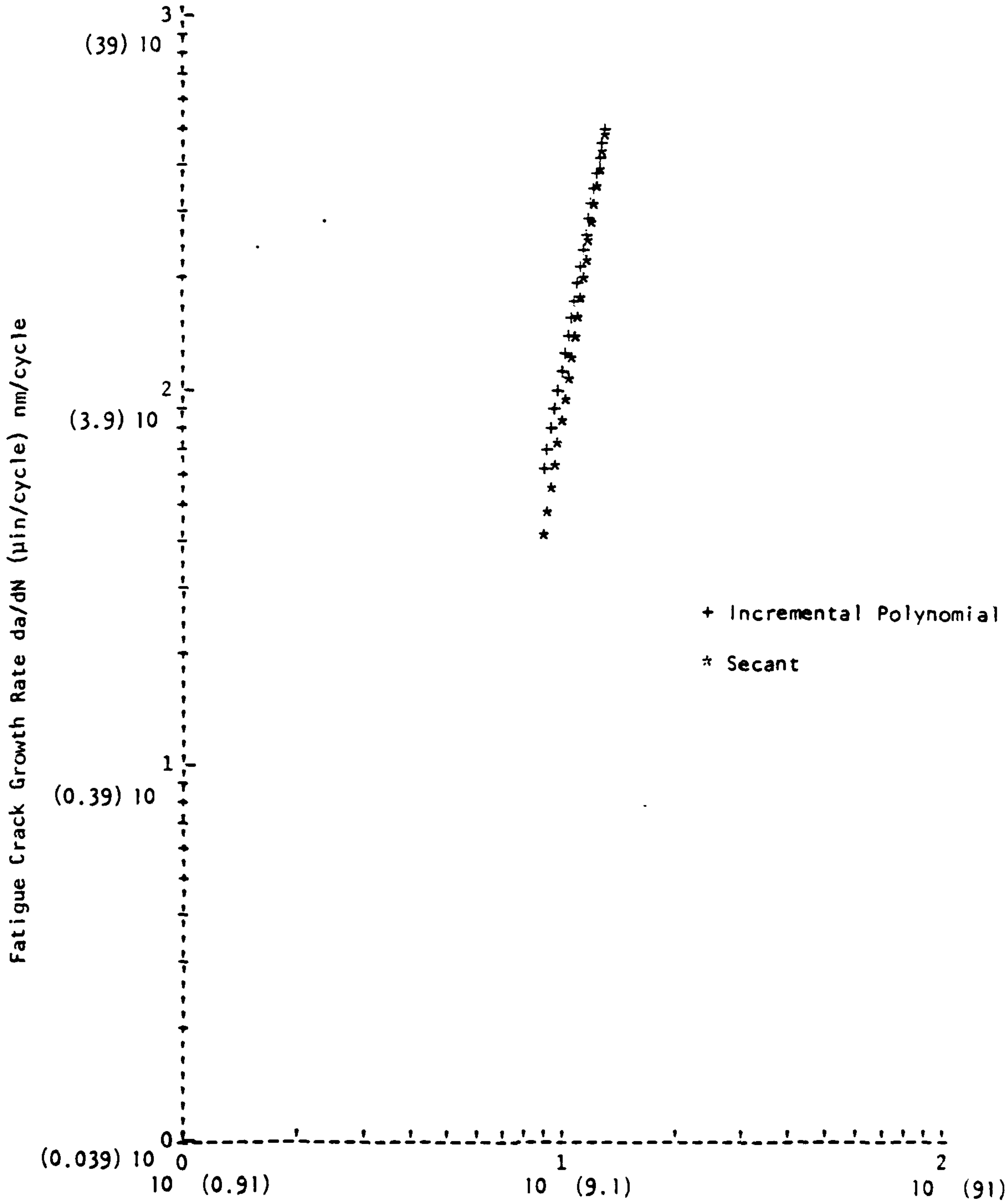

Figure A5a. Comparison of Paris Curves for Incremental Polynomial and Secant Data, LT Orientation

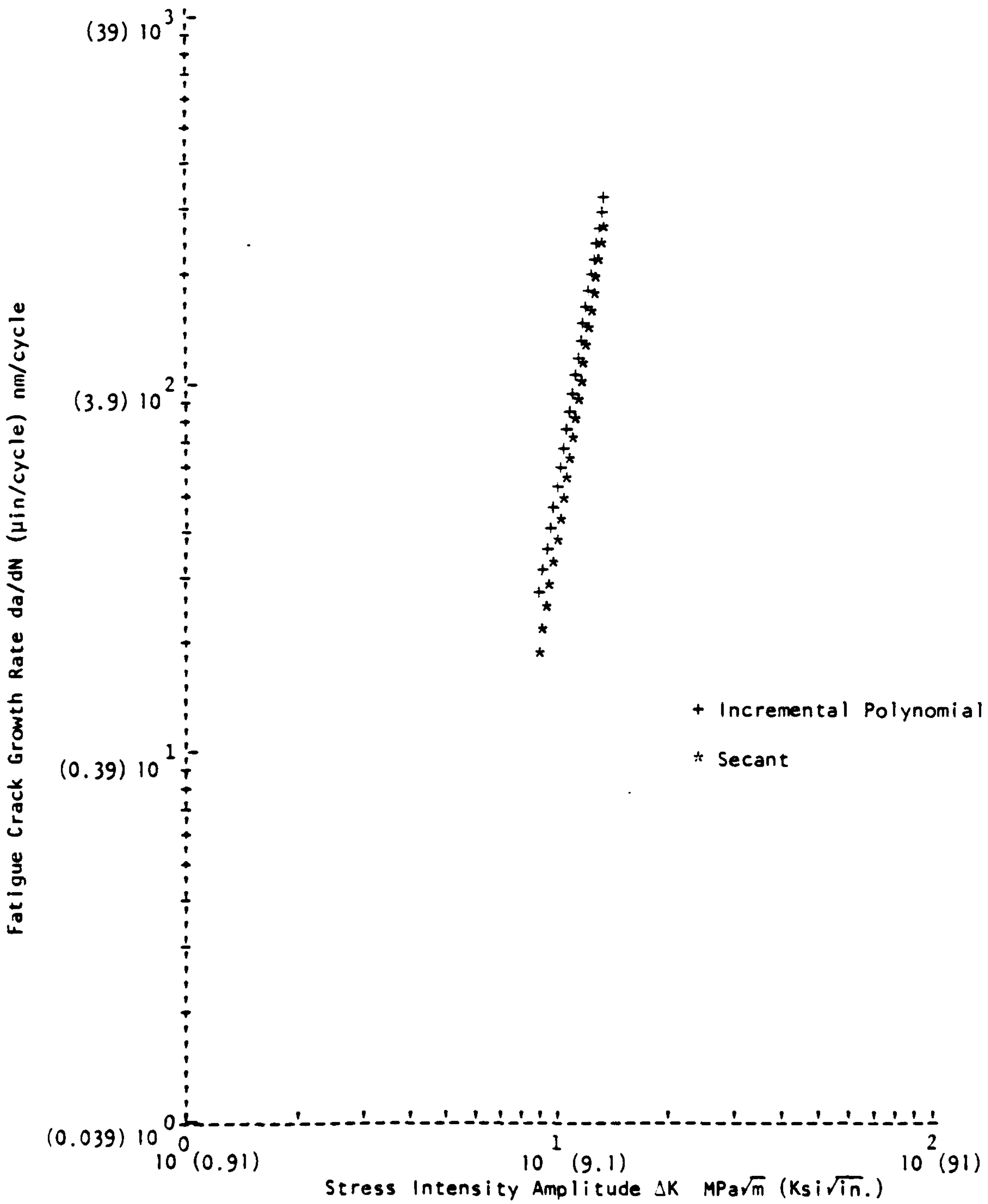

Figure A-5b. Comparison of Paris Curves for Incremental Polynomial and Secant Data, TL Orientation

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