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SPECTRUM FATIGUE CRACK GROWTH RATE CHARACTERISTICS OF PM ALUMINUMS 7090 AND 7091

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7091	Extrusion	Mini-TWIST

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Fatigue crack growth rate testing was performed on powder-metallurgy (PM) produced aluminum 7090 and 7091. Forms examined for each alloy were plate, extrusions, and hand forgings. Crack growth properties for each material were evaluated using both a fighter aircraft-type spectrum (FALSTAFF) and a transport-type aircraft spectrum (Mini-TWIST). All results are compared to ingot-metallurgy (IM) produced aluminum 7050-T76 plate.

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20. Abstract (Concluded)

Results under spectrum loading conditions indicate the PM 7091 alloys are consistently superior to aluminum 7050 in terms of spectrum fatigue crack growth resistance, while the 7090 alloys were clearly inferior. The best PM alloy in terms of crack growth resistance was 7091-T7E69 extrusion; the worst was the 7090-T7E80 forging. Though an improvement in crack growth resistance was observed for the 7091 materials over 7050 under complex loading, constant amplitude crack growth rates for both 7090 and 7091 are considerably greater than that for 7050. These apparent conflicting results are believed to be a result of beneficial load interactions (crack retardation) for the 7091 materials occurring during complex loading.

PREFACE

This interim technical report was submitted by the University of Dayton Research Institute, Dayton, Ohio, under Contract F33615-82-C-5039, "Quick Reaction Evaluation of Materials," with the Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio.

This effort was conducted during the period of July 1982 to January 1983. The author, Mr. John J. Ruschau, was responsible for all the analysis and reporting of the data. Special recognition is given to Mr. Donald Woleslagle of the University of Dayton for performing all fatigue crack growth rate testing.

This report was submitted by the author in February 1983.

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SECTION I
INTRODUCTION

In an effort to assess the state-of-the-art of aluminum powder metallurgy (PM) technology, the Materials Laboratory of the Air Force Wright Aeronautical Laboratories initiated a cooperative testing program to generate mechanical property data on commercially available PM aluminum alloys. The major objective of this effort is to furnish airframers with sufficient design data to perform a cost benefit analysis to determine if a larger scale production of these materials should be pursued. Materials examined were aluminums 7090 and 7091, produced by Alcoa, and aluminum IN-9021, produced by Novamet. These materials were examined in plate, forging (hand), and extruded forms.

Each participant tested or developed a data base on one or more of the materials, following testing guidelines set up by the organizing committee. However, most testing organizations generated spectrum crack growth relationships under conditions best suited for their individual analysis. In an effort to create a common data base, the Materials Laboratory has generated spectrum fatigue crack growth rate data on the majority of PM materials under two widely used load histories. The results of this effort are described herein.

SECTION II
MATERIALS AND SPECIMENS

A list of test materials is provided in Table 1. All the PM alloys investigated were furnished by Alcoa. Originally, the plate thickness to be examined was 0.25 inch (6.4 mm), but because of the inability to use optimum rolling parameters (caused by the fact that laboratory-scaled equipment was used), the surfaces of each plate suffered noticeable recrystallization upon subsequent heat treating. Such differences in through-thickness grain structure for both materials are clearly shown in Figure 1. Therefore, to produce a homogeneous, 0.25 inch (6.4 mm) plate, it was necessary to make the plate thickness 0.4 inch (10 mm). By removing approximately 0.075 inch (1.9 mm) from each surface, it was reported by Alcoa representatives that the remaining plate material would be more representative of the respective test material should either reach a full-scale plate production.

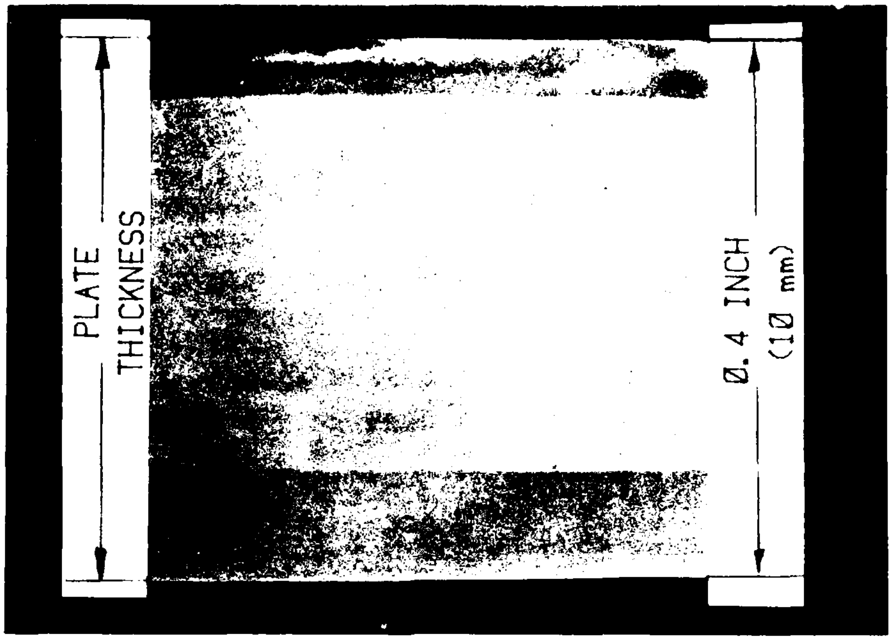
In addition to the 7090 and 7091 PM alloys, a single plate of 7050-T76, 0.197 inch (5 mm) thick was also examined to serve as a baseline for comparison. This particular plate was a remnant from an earlier NATO/AGARD/SMP sponsored test program.

To establish basic strength properties, three tensile specimens were removed from the longitudinal direction of each test material. Tensile specimen geometries are shown in Figure 2 for the forging and extruded materials, and Figure 3 for the plate materials.

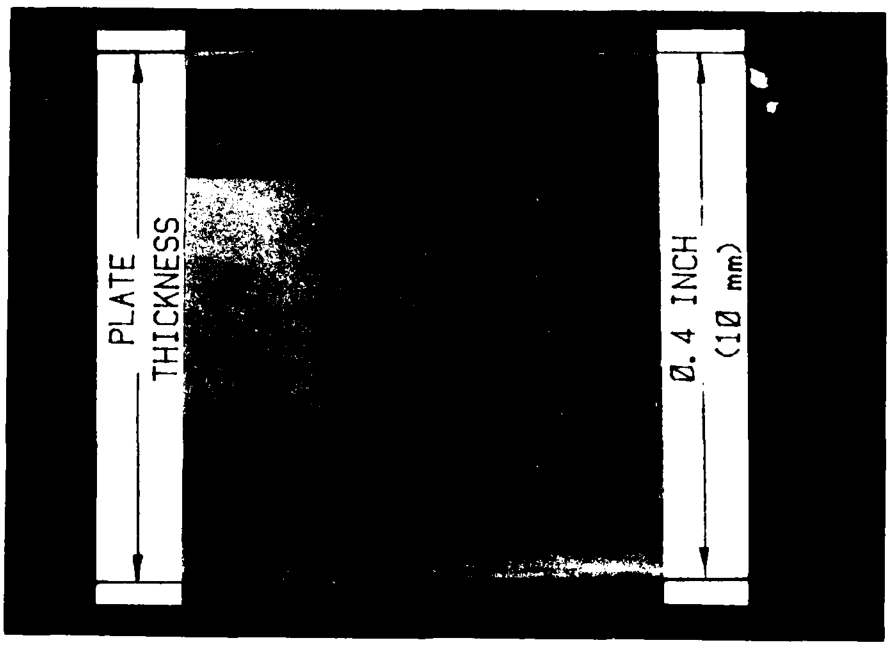
For the spectrum fatigue crack growth rate tests, center-crack panels (CCP) were removed from the longitudinal direction of each material and machined to the configuration shown in Figure 4. The center starting notch was produced using an electric-discharge-machine (EDM), which provided easy crack initiation at relatively low stresses.

TABLE 1
PM ALUMINUM TEST MATERIALS

Material	Form	Dimensions inches	(mm)
7090-T7E71	Plate	0.25 x 16 x 44 long	(6.4 x 406 x 1118)
7091-T7E69	Plate	0.25 x 16 x 20	(6.4 x 406 x 508)
7090-T7E80	Hand Forging	2.5 x 6 x 20	(64 x 152 x 50
7091-T7E78	Hand Forging	2.5 x 6 x 20	(64 x 152 x 5
7090-T7E71	Extrusion	1.5 x 4.5 x 36	(38 x 114 x 9
7091-T7E69	Extrusion	1.5 x 4.5 x 36	(38 x 114 x 9



(a) Aluminum 7090-T7E71 Plate



(b) Aluminum 7091-T7E69 Plate

Figure 1. Through-Thickness Variation in Grain Structure (Concentrated NaOH Etch).

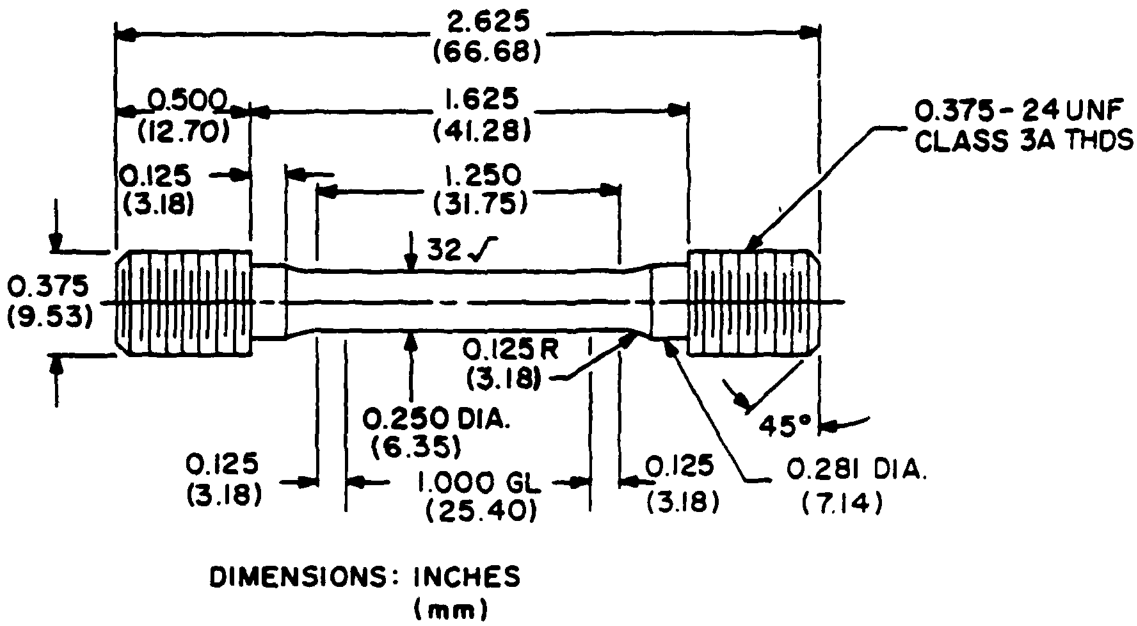


Figure 2. Tensile Specimen Geometry for Forgings and Extruded Materials.

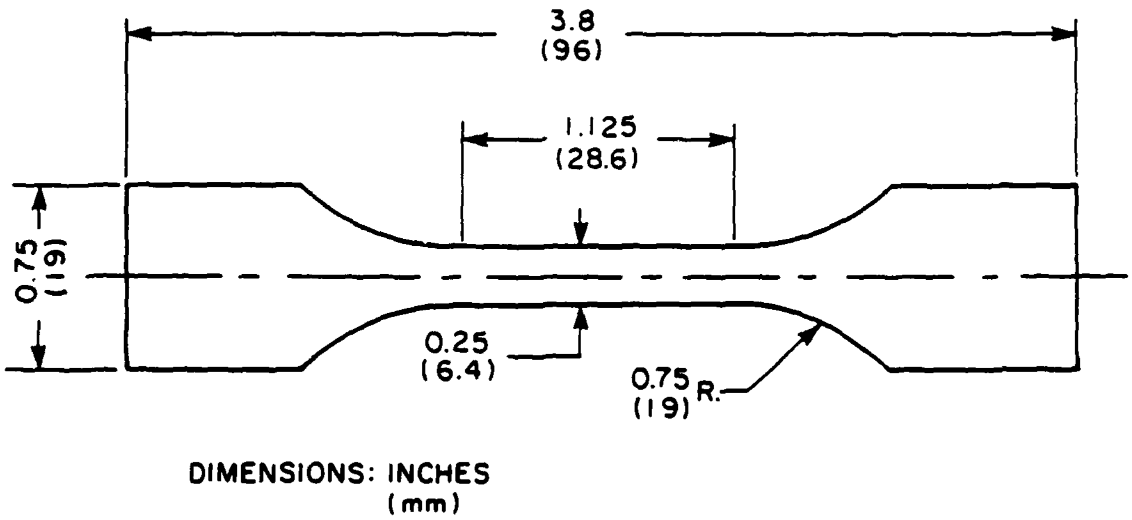


Figure 3. Tensile Specimen Geometry for Plate Material.

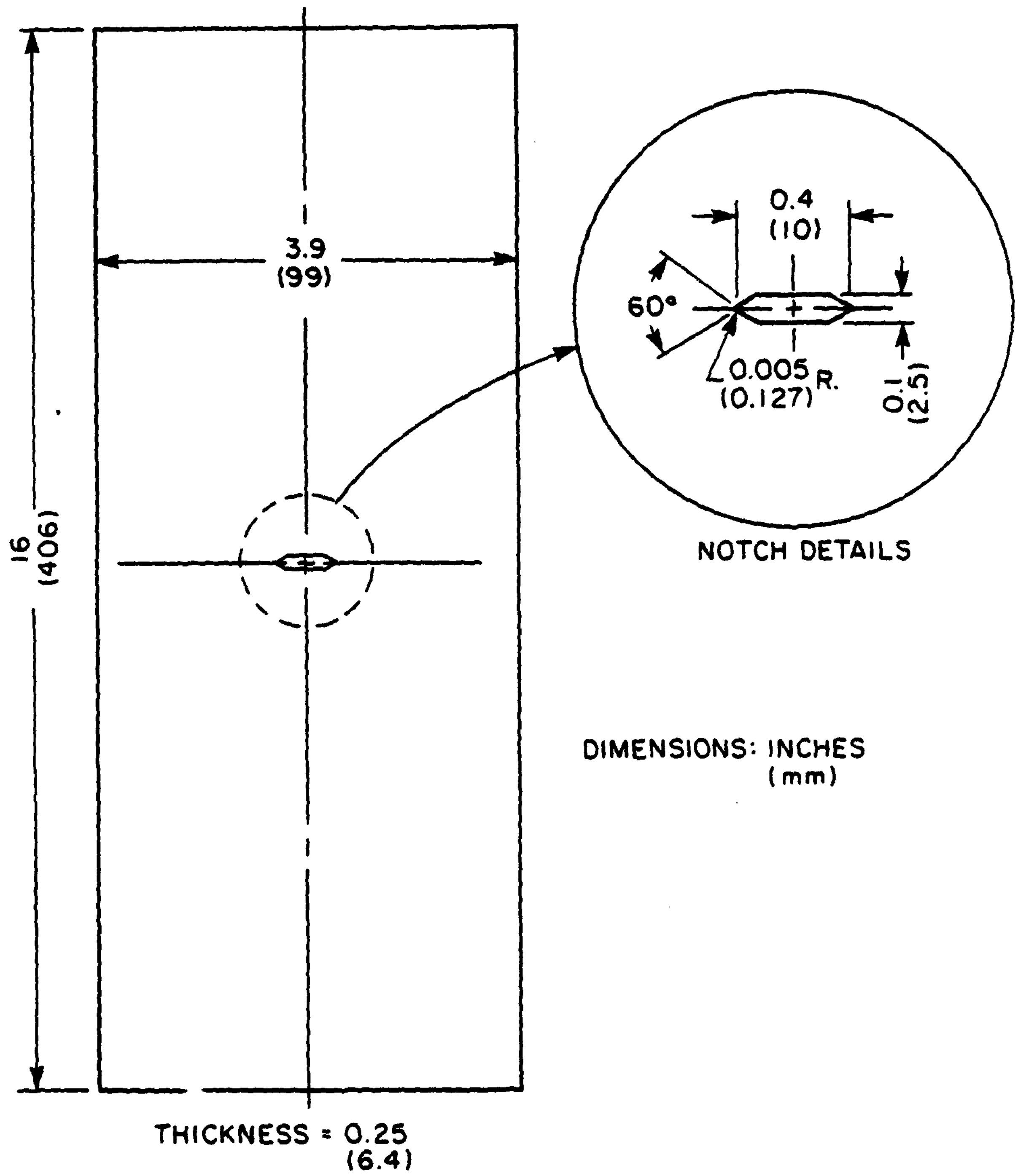


Figure 4. Central-Crack Panel Geometry Used for All Spectrum Crack Growth Tests.

SECTION III
PROCEDURES

Tensile testing was performed on a 10 KIP (44 kN) Instron tensile testing machine. Specimen strain was obtained using a 1.0 inch (25 mm) gage length Instron extensometer. Procedures outlined in ASTM Standard E-8, "Tension Testing of Metallic Materials" were adhered to.

All spectrum fatigue crack growth rate testing was accomplished using a 160 KIP (712 kN) MTS hydraulic fatigue testing machine. A PDP 11-34 computer was interfaced to the test stand to perform both control and feedback functions, providing a closed-loop system. Surface crack length was monitored on one side only using a 30X Gaertner traveling microscope with digital readout.

For the crack growth rate analysis, two standardized load spectra were examined: FALSTAFF, a load-history representative of a fighter type aircraft, and Mini-TWIST, an abbreviated version of TWIST which was developed for a transport-type, lower wing location. Both spectra consist of several flights: 200 for FALSTAFF and 4,000 for Mini-TWIST.

Each specimen was precracked under constant amplitude loading to an initial crack length, 2a, of 0.5 inch (13 mm). Maximum precracking load was kept below the maximum load encountered in the initial flight of each load spectrum. For the crack growth rate tests using FALSTAFF, crack length was measured after each completed spectrum pass of 200 flights, while for Mini-TWIST, crack length was measured after each 1,000 flights. Maximum spectrum stress was chosen to yield a sufficient amount of data in a reasonable time period. Following each test, a comparison of surface crack length versus flights was made, using data developed for the 7050-T76 plate as a baseline for comparison.

SECTION IV
RESULTS

The resuits of the tensile tests are best illustrated in the bar graph shown in Figure 5. The 7050 baseline material has approximately a 84 KSI (579 MPa) ultimate strength, slightly higher ($\sim$5%) than reference data[1,2] found for similar material. For the PM materials, the highest tensile strength material was 7090-T7E71 extrusion, with an average ultimate strength of 93 KSI (641 MPa), while the lowest was the 7091-T7E78 hand-forging at 79 KSI (545 MPa). Only the 7090 extrusion and 7090 plate showed an improvement in strength properties over 7050, while all the 7091 materials displayed noticeably lower yield strength. The most ductile (based on % elongation) PM material was the 7091-T7E78 hand forging at 14%, equal to that of 7050. The least ductile materials were the 7090 products.

1. FALSTAFF

For the FALSTAFF spectrum tests, it was first necessary to generate the 7050 baseline data for subsequent comparisons. The results of a single test are shown in Figure 6 for a maximum spectrum stress of 20 KSI (138 MPa). Crack curvature for this specimen was minimal. Total flights to failure were 3,544.

Using this 7050 data as a baseline, a single specimen from each PM material was tested under identical FALSTAFF loading conditions. Results are shown in Figures 7, 8, and 9, for the 7090 and 7091 plate, forging, and extruded products, respectively. Also presented is the curve for the 7050 material. Results are consistent: in all cases the 7091 materials possess greater resistance to crack propagation, while the 7090 materials were inferior. As evident from the data sets shown, irregularities are seen in several of the crack length versus flight records, most particularly with the 7090 materials. This is a result of an inconsistent, sporadic degree of crack curvature occurring

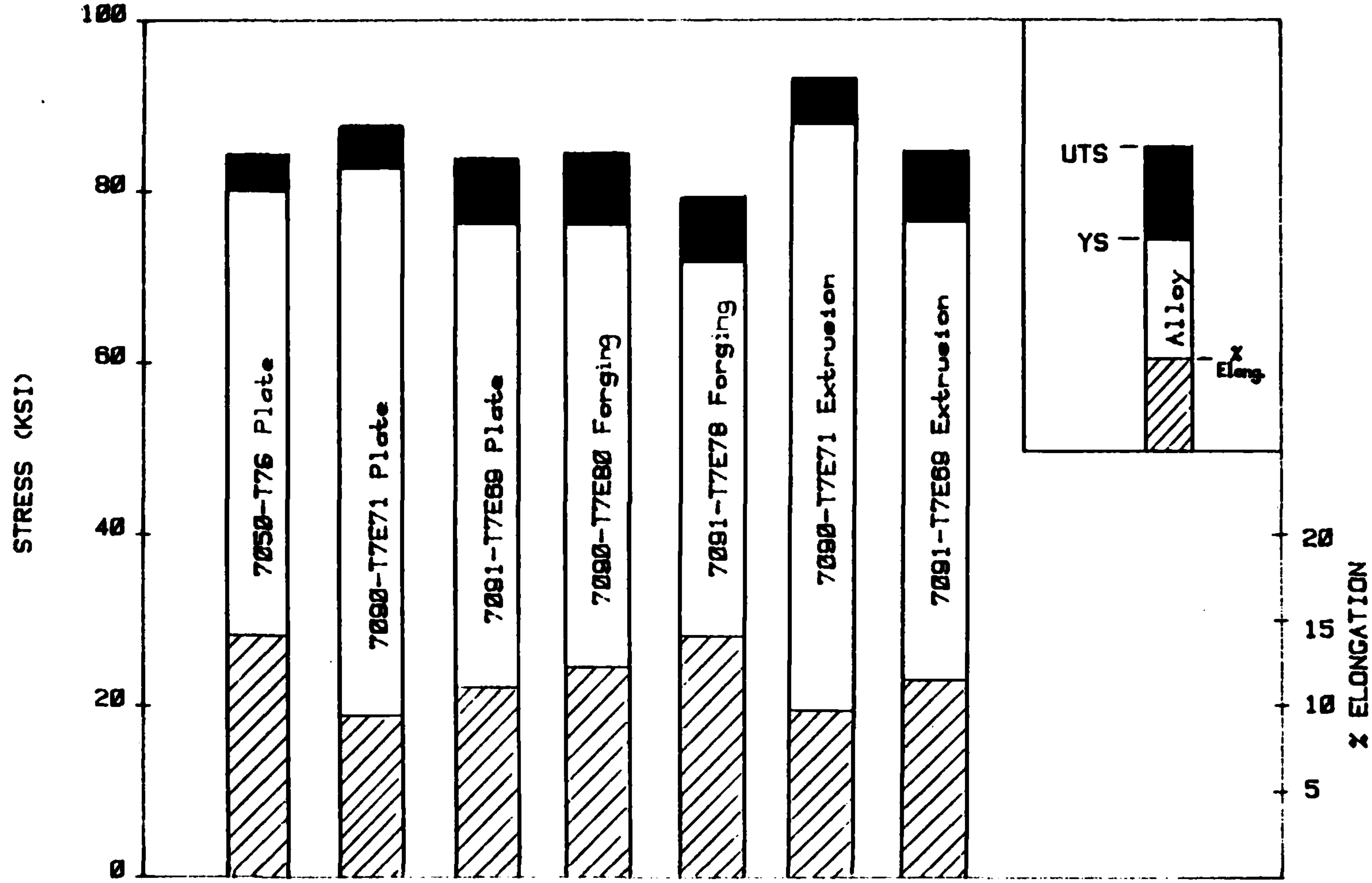


Figure 5. Average Tensile Properties of PM Aluminums Investigated.

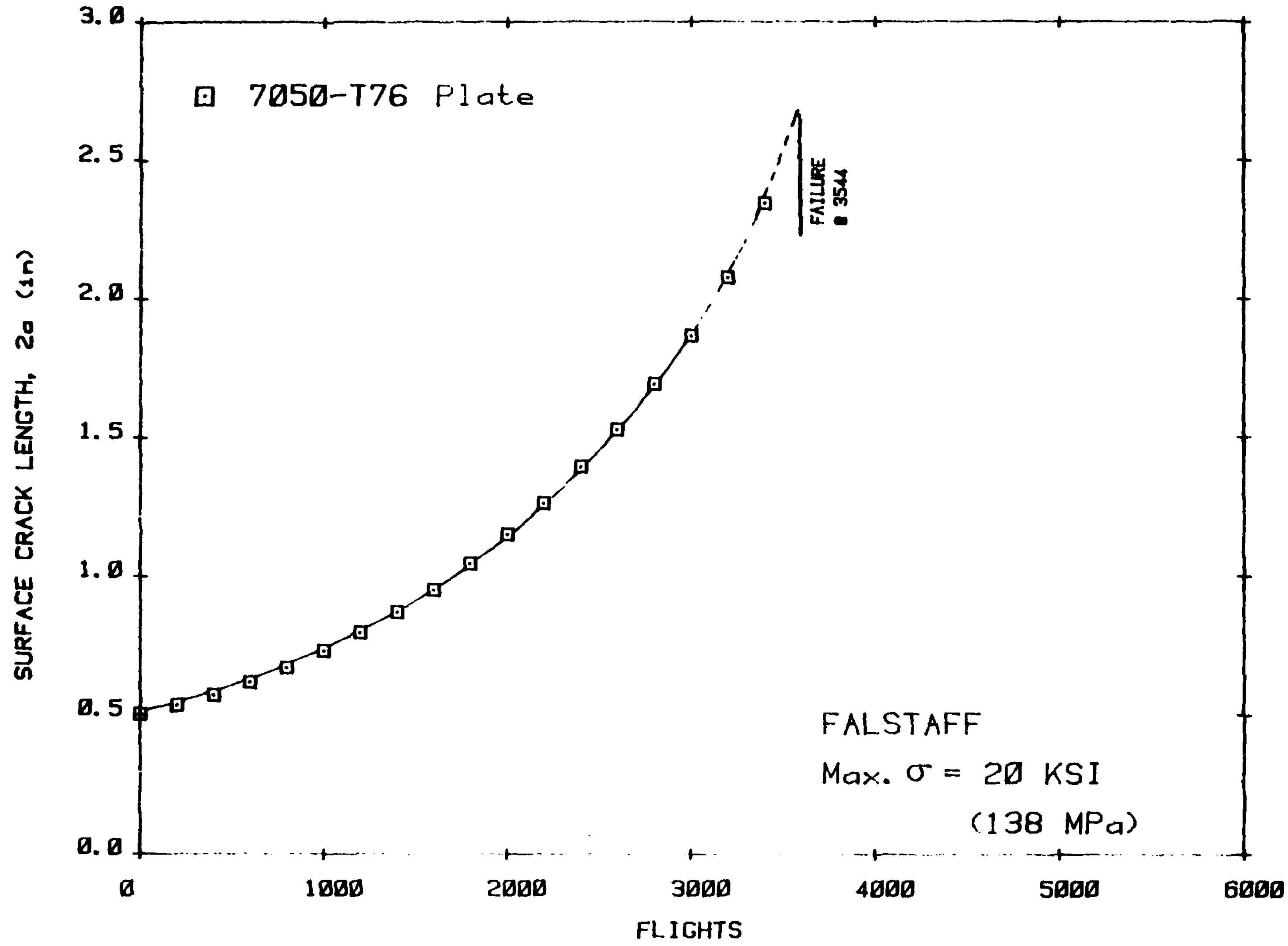


Figure 6. Crack Length Versus Flights Record for 7050 Plate Under FALSTAFF Loading.

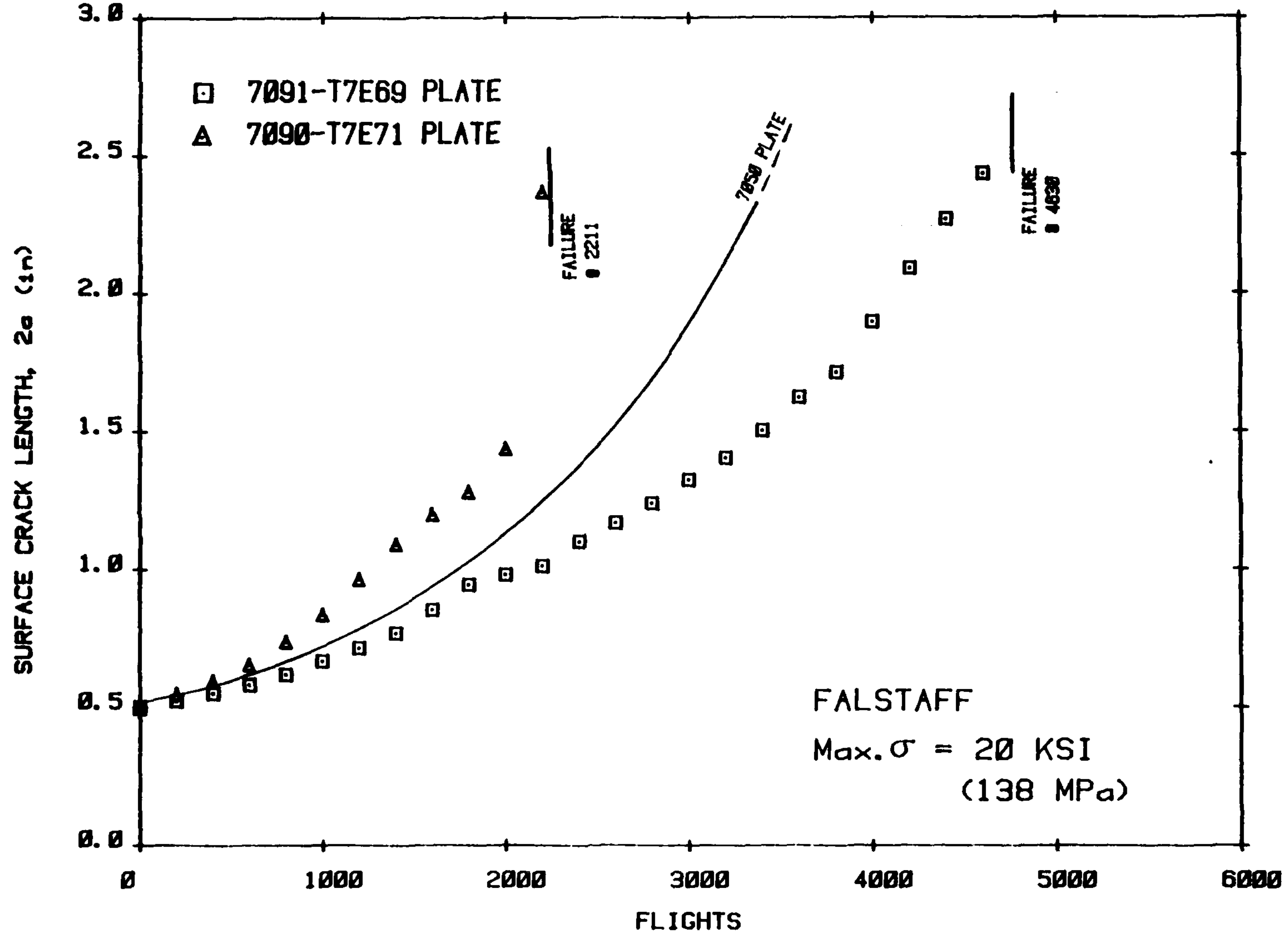


Figure 7. Crack Length Versus Flights Record for PM Aluminum Plates Under FALSTAFF Loading.

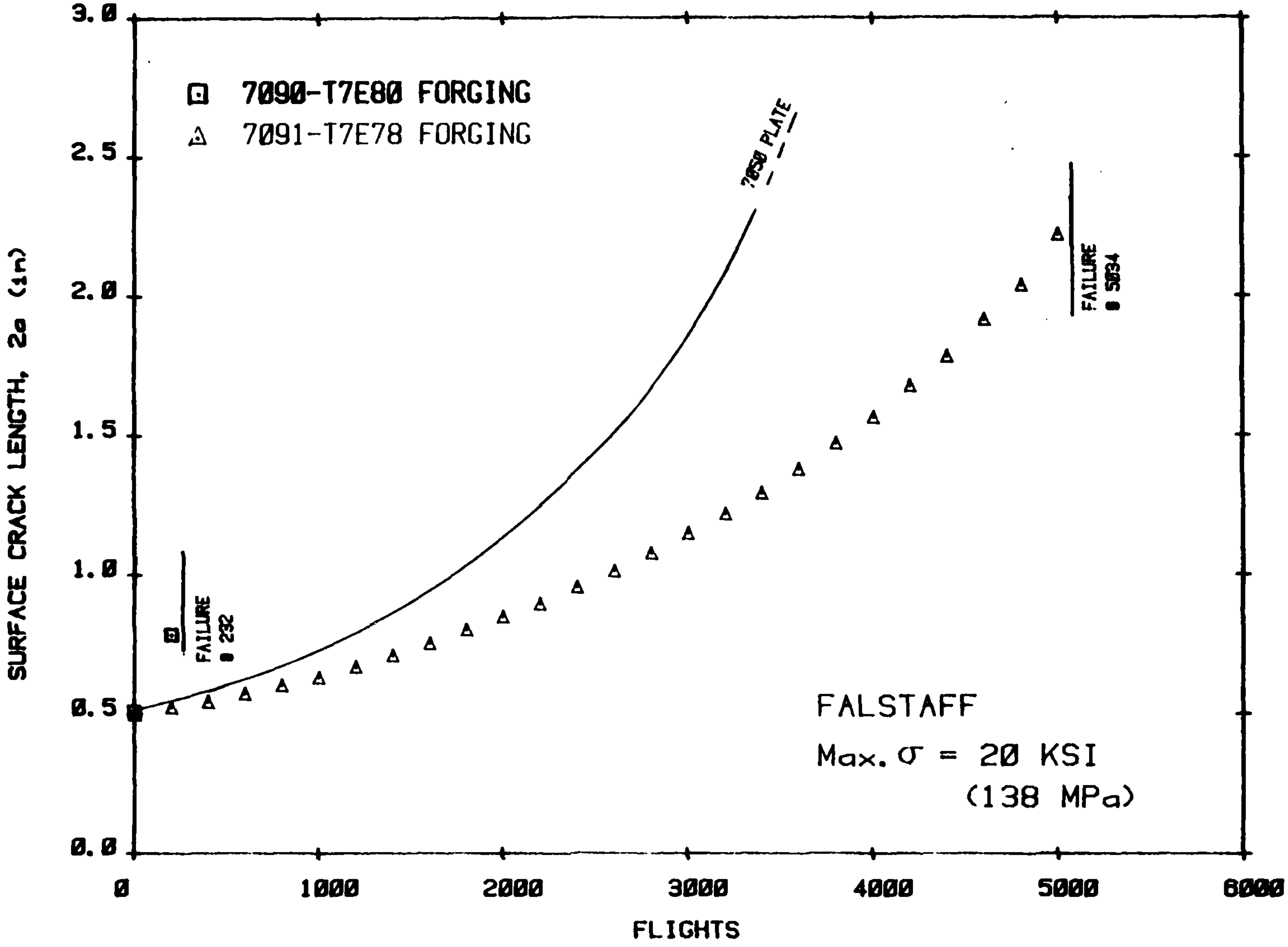


Figure 8. Crack Length Versus Flights Record for PM Aluminum Hand Forging Under FALSTAFF Loading.

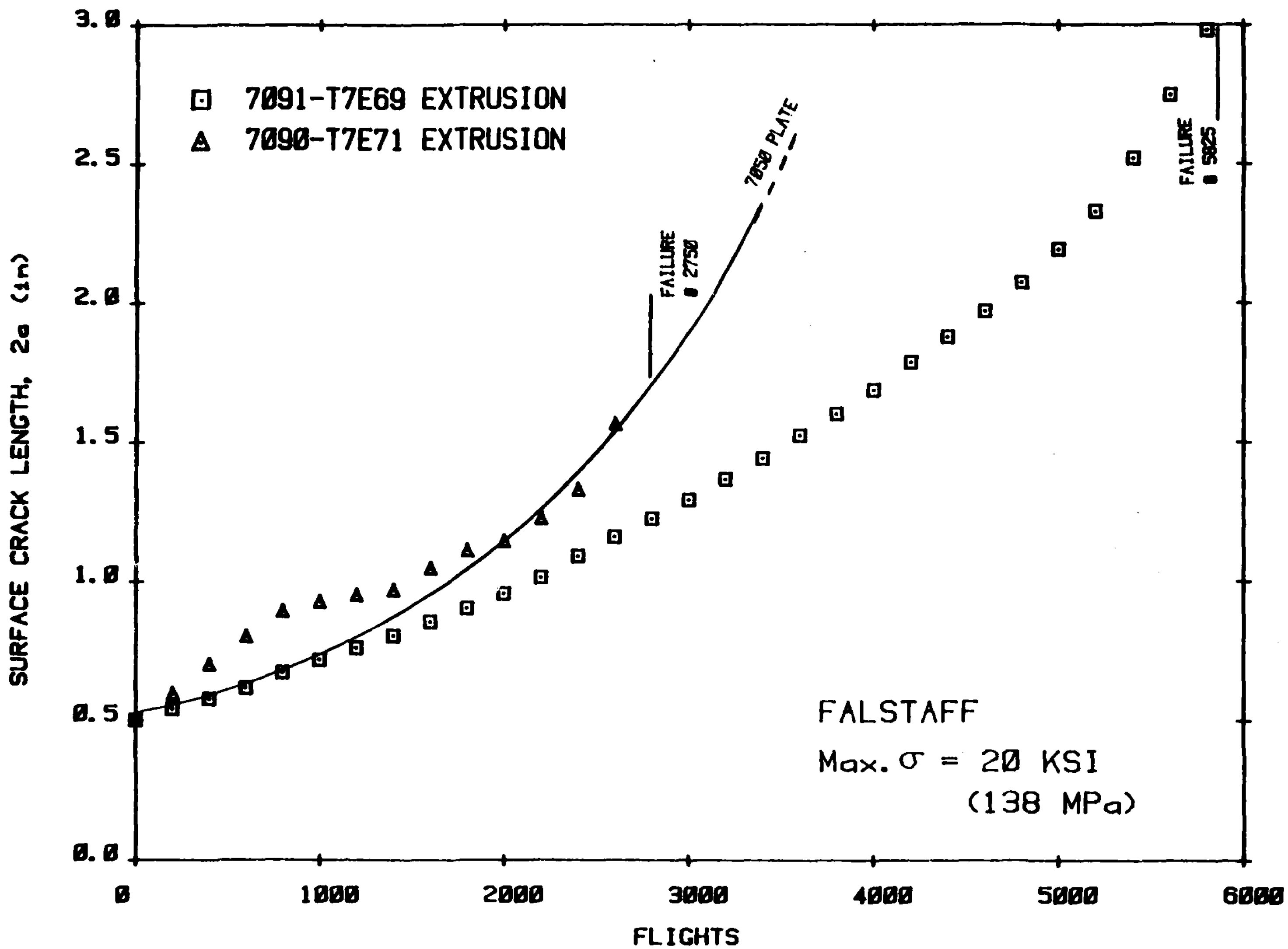


Figure 9. Crack Length Versus Flights for PM Aluminum Extrusions Under FALSTAFF Loading.

throughout the test, most noticeably at the larger crack lengths. Such varying and sometimes obscure curvature made accurate crack length measurements impossible over the entire test duration; consequently, only the surface trace is shown.

The data for each specimen is also shown as visually best fit curves in the composite plot shown in Figure 10, while the total flights to failure for each specimen is furnished in Table 2. Stating again, the 7090 materials were inferior to the 7091 and 7050 materials in terms of spectrum fatigue crack growth resistance, while the 7091 materials showed better resistance over 7050. The most drastic reduction in crack growth resistance was for the 7090 hand-forging, where failure occurred in less than 250 flights. The best material, again in terms of crack growth resistance, was the 7091 extrusion where an increase in life of over 60% is realized over the 7050 material.

In a final attempt at characterizing crack growth rate properties, the test record of crack length versus flights was analyzed to develop crack growth rate versus stress intensity relationships. Fracture faces for each specimen were carefully examined to account for crack curvature in regions where it could be accurately measured, using a five-point, through-thickness averaging technique. For some specimens, several crack length measurements could be accurately accounted for, while for other specimens, in particular the 7090 specimens, only a few initial crack length measurements could be accurately adjusted. The results of this endeavor are illustrated in Figure 11 where crack growth rate ($\Delta a/\Delta$ Flight) is plotted against maximum stress intensity. Again, results are consistent with previous findings: crack growth rates for the 7091 materials are generally lower than for 7050, typically half that of 7050 for both the 7091 extrusion and forging at the higher stress intensities. For the 7090 materials, the crack growth rate is nearly double that of 7050. At lower stress intensities these differences in crack growth rates appear to diminish.

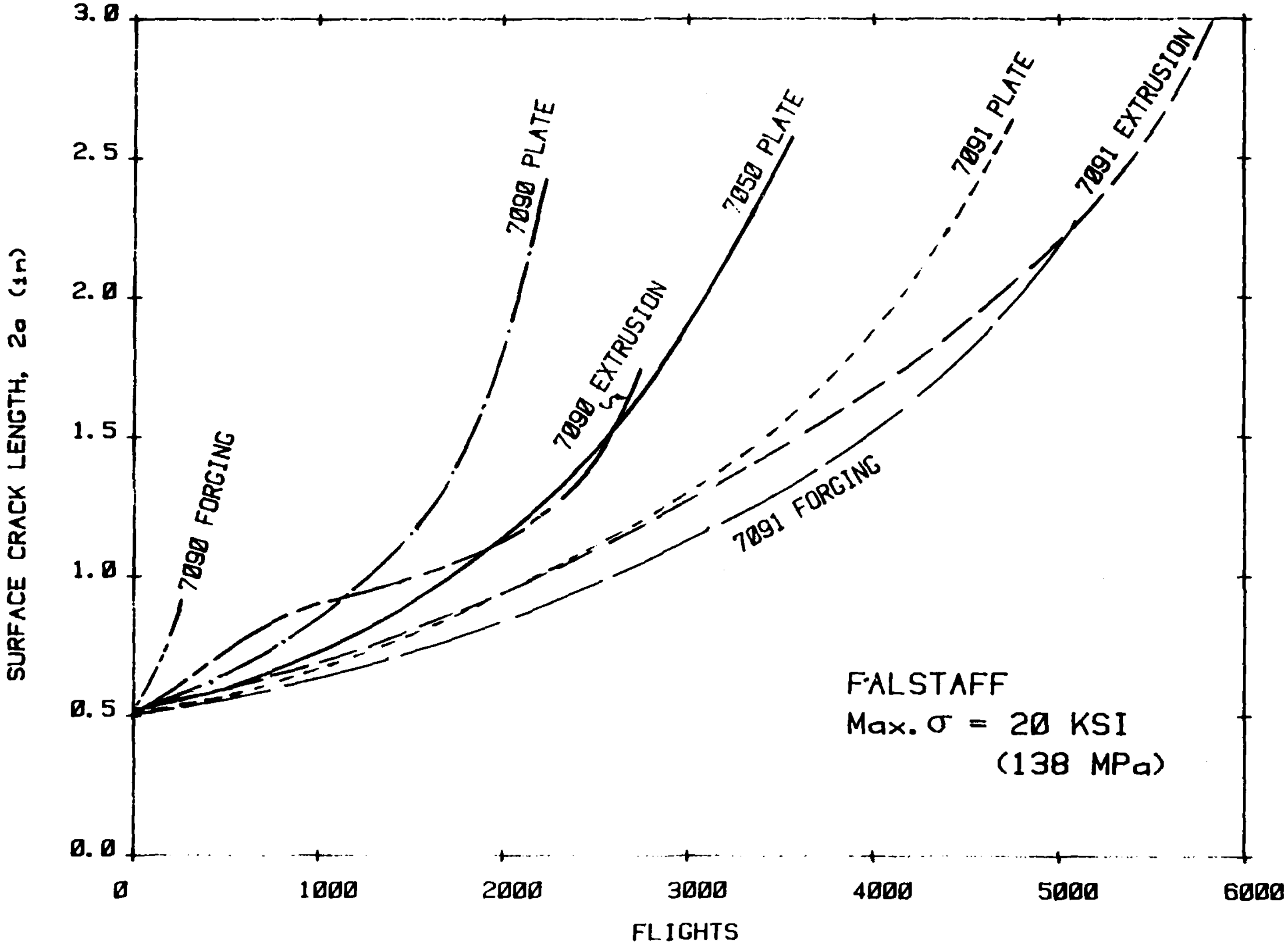


Figure 10. Composite Crack Length Versus Flights Records for All PM Materials Under FALSTAFF Loading.

TABLE 2

TOTAL FLIGHTS TO FAILURE FOR PM ALUMINUM UNDERGOING FALSTAFF LOAD HISTORY

Material	Form	Flights to Failure
7050-T76	Plate	3,544
7090-T7E71	Plate	2,211
7091-T7E69	Plate	4,630
7090-T7E71	Extrusion	2,750
7091-T7E69	Extrusion	5,825
7090-T7E80	Hand Forging	232
7091-T7E78	Hand Forging	5,034

NOTE: Maximum Spectrum Stress = 20 KSI (138 MPa).

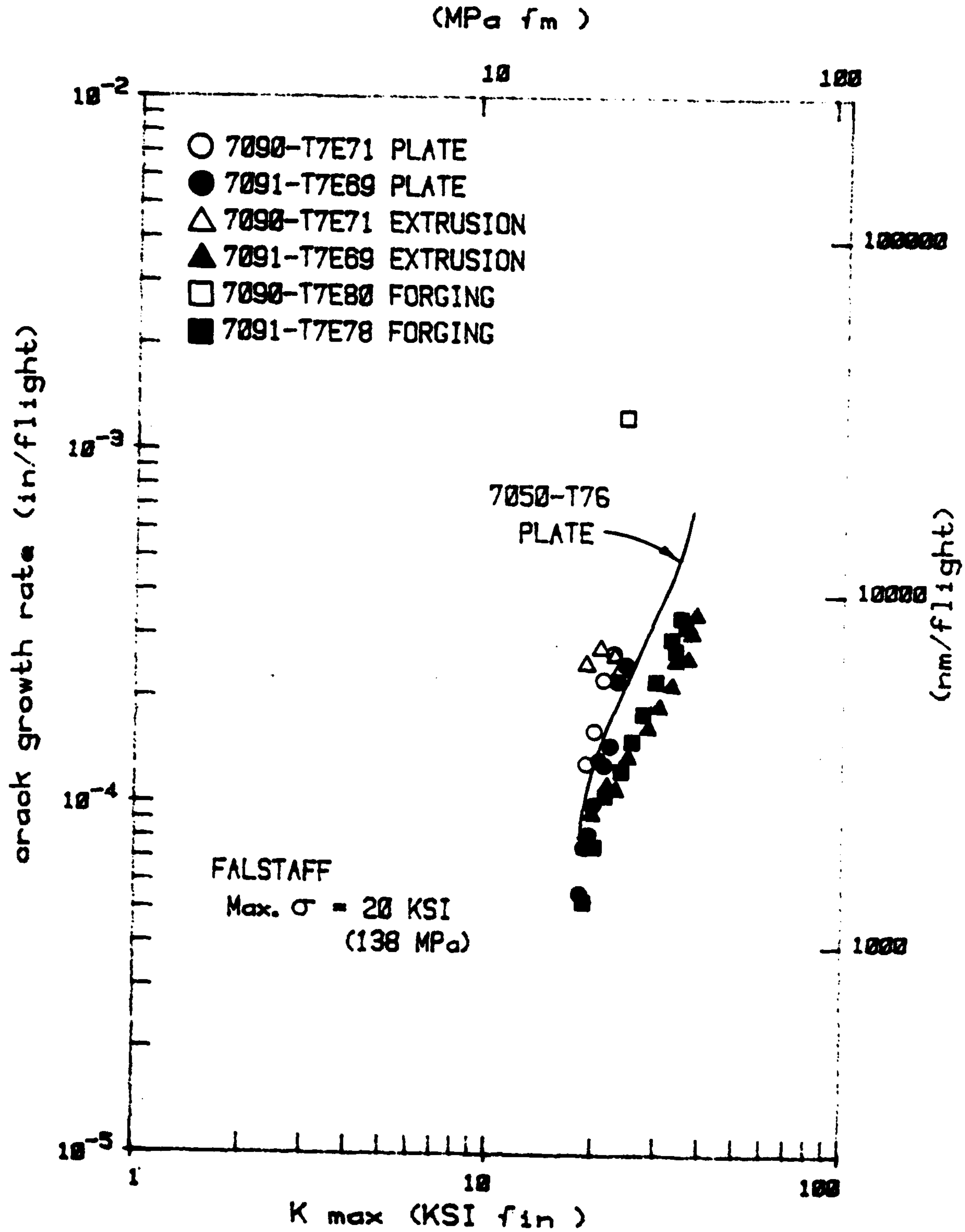


Figure 11. Crack Growth Rate Results of PM Aluminums Under FALSTAFF Loading Conditions.

2. Mini-TWIST

As was done for the FALSTAFF testing, a single 7050 specimen was tested under the Mini-TWIST spectrum to serve as a baseline. Results are illustrated in Figure 12. The stress level corresponding to a 1-g load level was 6.5 KSI (44.8 MPa), resulting in a maximum applied stress of 16.9 KSI (116 MPa). Similar to the FALSTAFF testing, this particular load level was chosen merely to yield a sufficient amount of data in a timely manner. For this 7050 sample, failure occurred after 13,656 flights. Some irregularities are observed in the crack length versus flight record, resulting mostly from the differences in applied flights between readings. (In the FALSTAFF testing, since crack measurements were taken after each completed spectrum pass, the load history between readings was identical. However, under Mini-TWIST testing, readings were taken each 25% of one spectrum pass, i.e. every 1,000 flights. Consequently, the loading conditions between successive crack length readings differ, resulting in different amounts of crack growth for the different portions of the Mini-TWIST spectrum.)

Results of the Mini-TWIST spectrum tests on the 7090 and 7091 PM alloys are shown in Figures 13, 14, and 15, for the plate, extrusion, and forging forms, respectively. A composite plot of all the Mini-TWIST data is also shown in Figure 16, while the total flights to failure are listed in Table 3. Results are consistent with the FALSTAFF test results: the 7090 materials, the higher yield strength PM alloys, were inferior to 7050, while the 7091 alloys, the lower yield strength materials, were clearly superior, in terms of crack growth resistance. Again, the 7090 forging was the least resistant material, with a total crack proportion life less than half that of the 7050 baseline. The 7090 plate performed only slightly better than the forging. The most crack growth resistant material was again the 7091 extrusion, showing an increase in life of over 40% over the 7050 material.

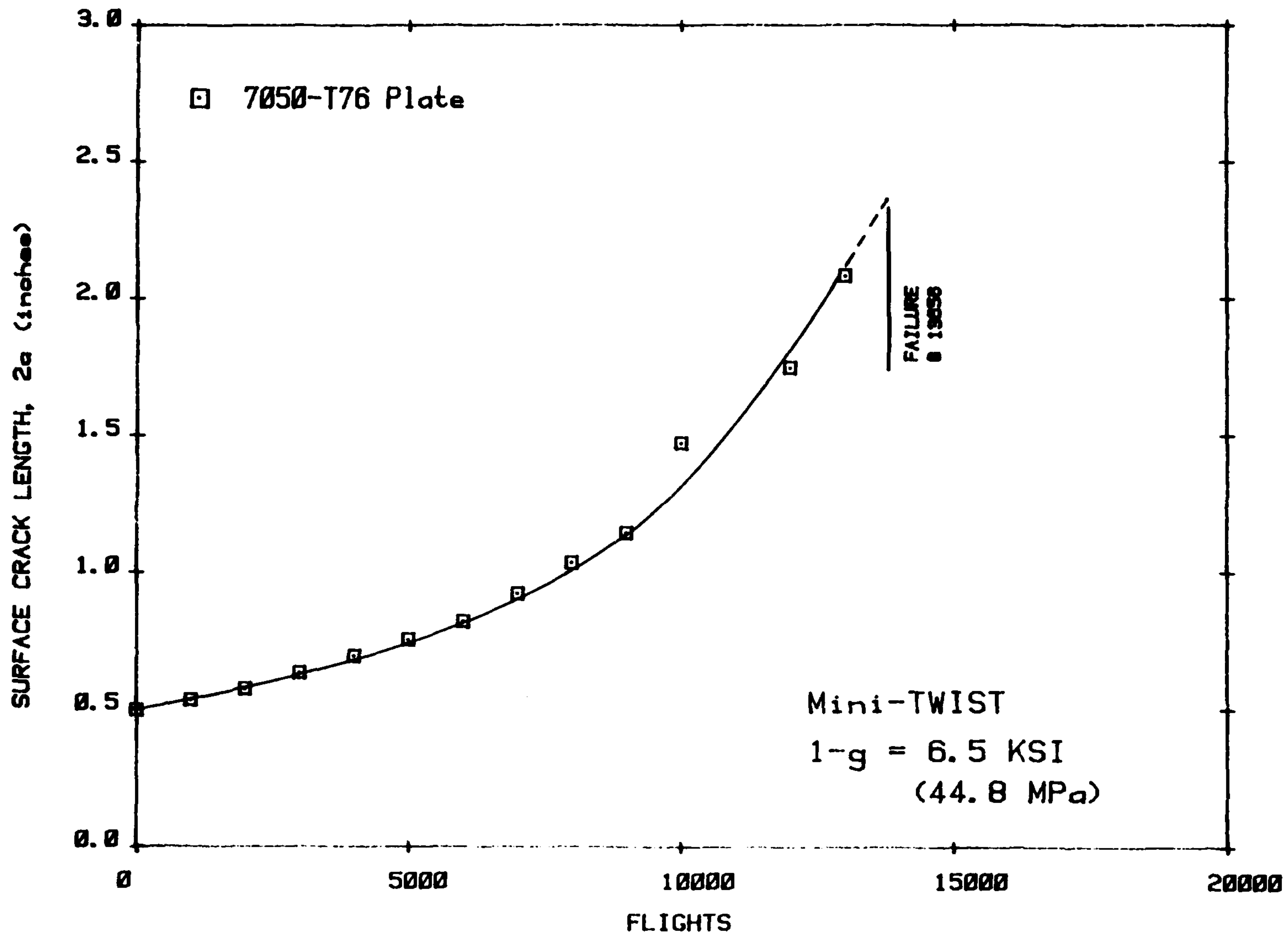


Figure 12. Crack Length Versus Flights Record for 7050 Plate Under Mini-TWIST Spectrum.

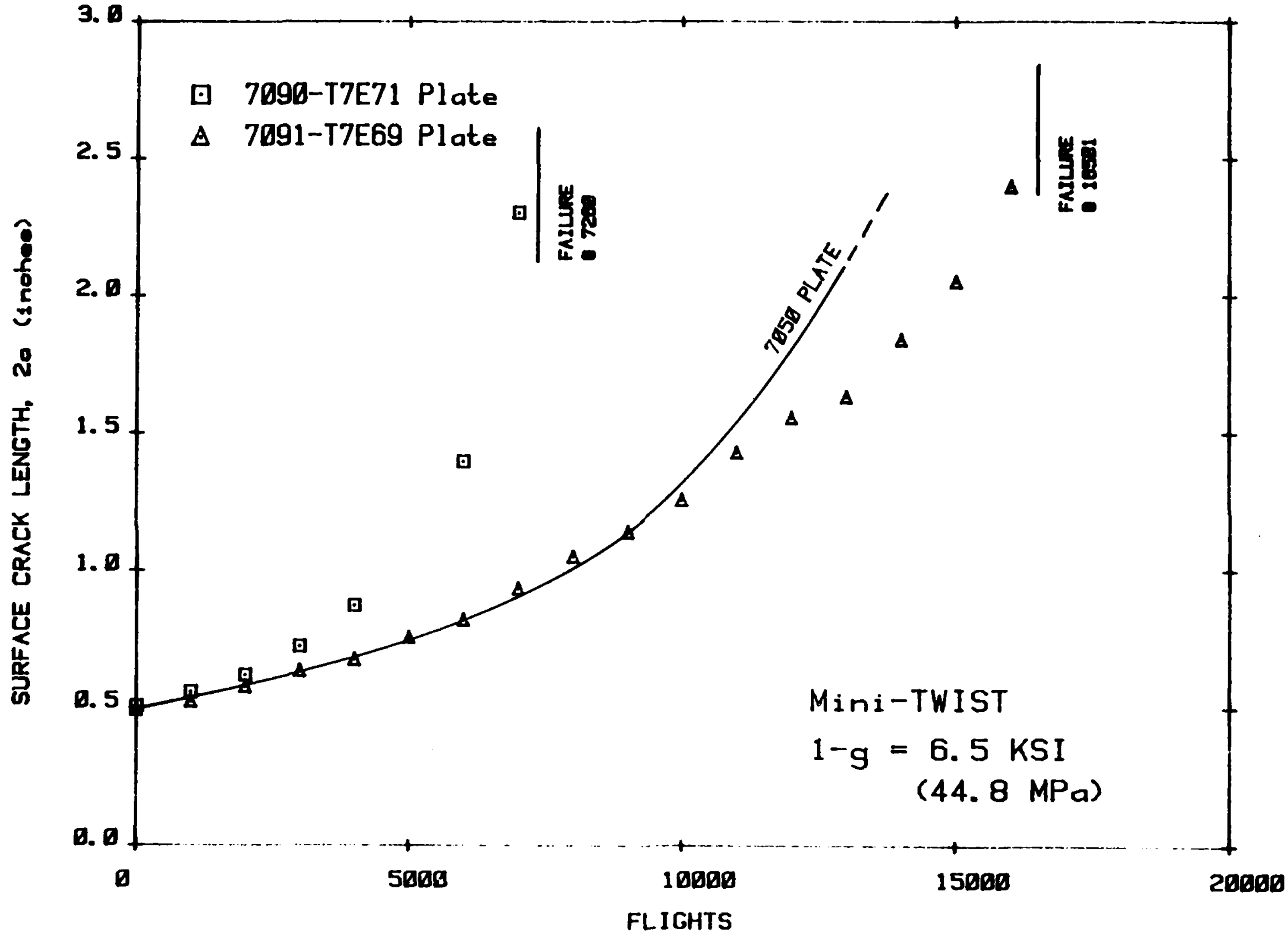


Figure 13. Crack Length Versus Flights Records for PM 7090 and 7091 Plate Under Mini-TWIST Spectrum.

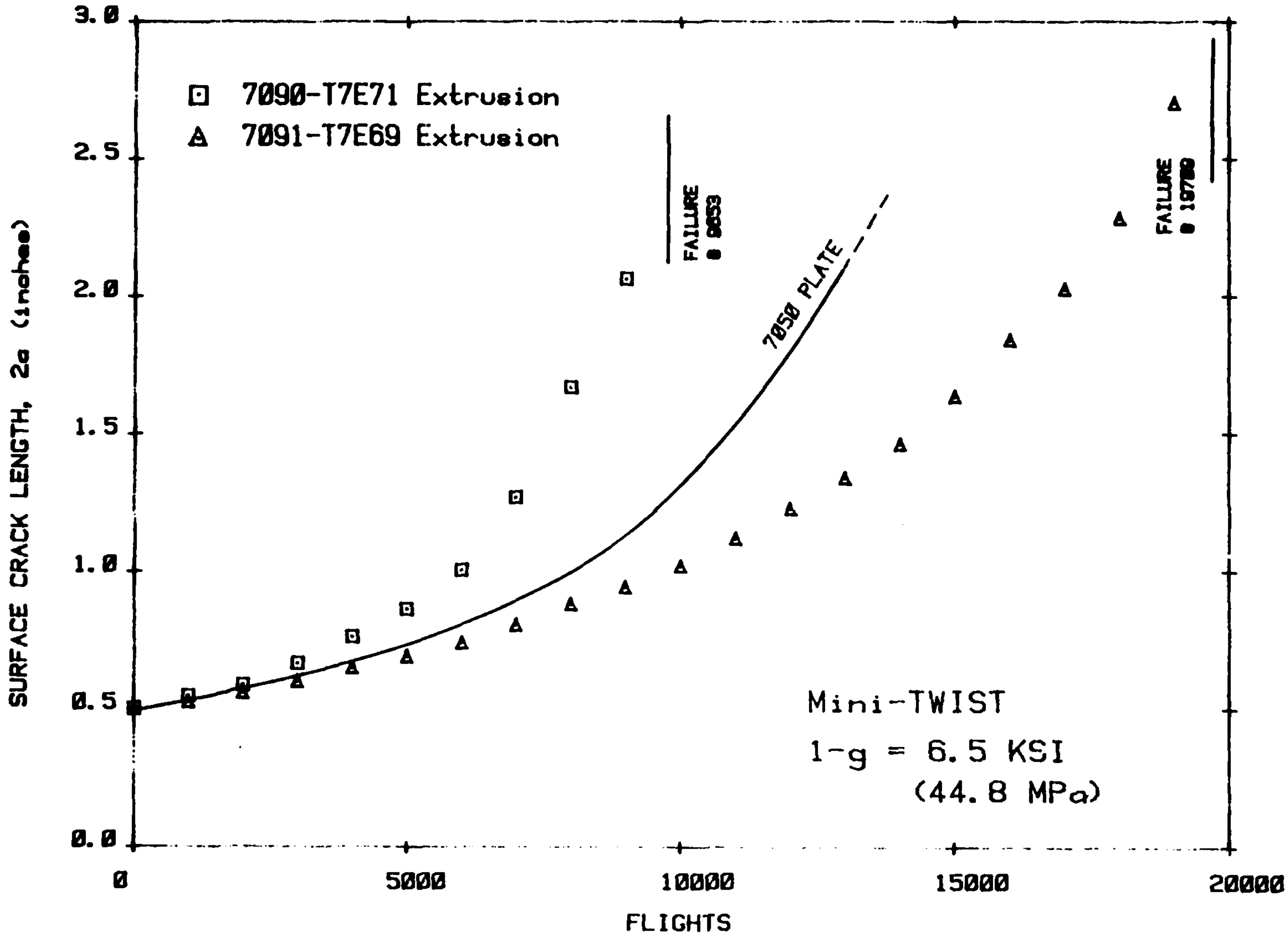


Figure 14. Crack Length Versus Flights Records for PM 7090 and 7091 Extrusion Under Mini-TWIST Spectrum.

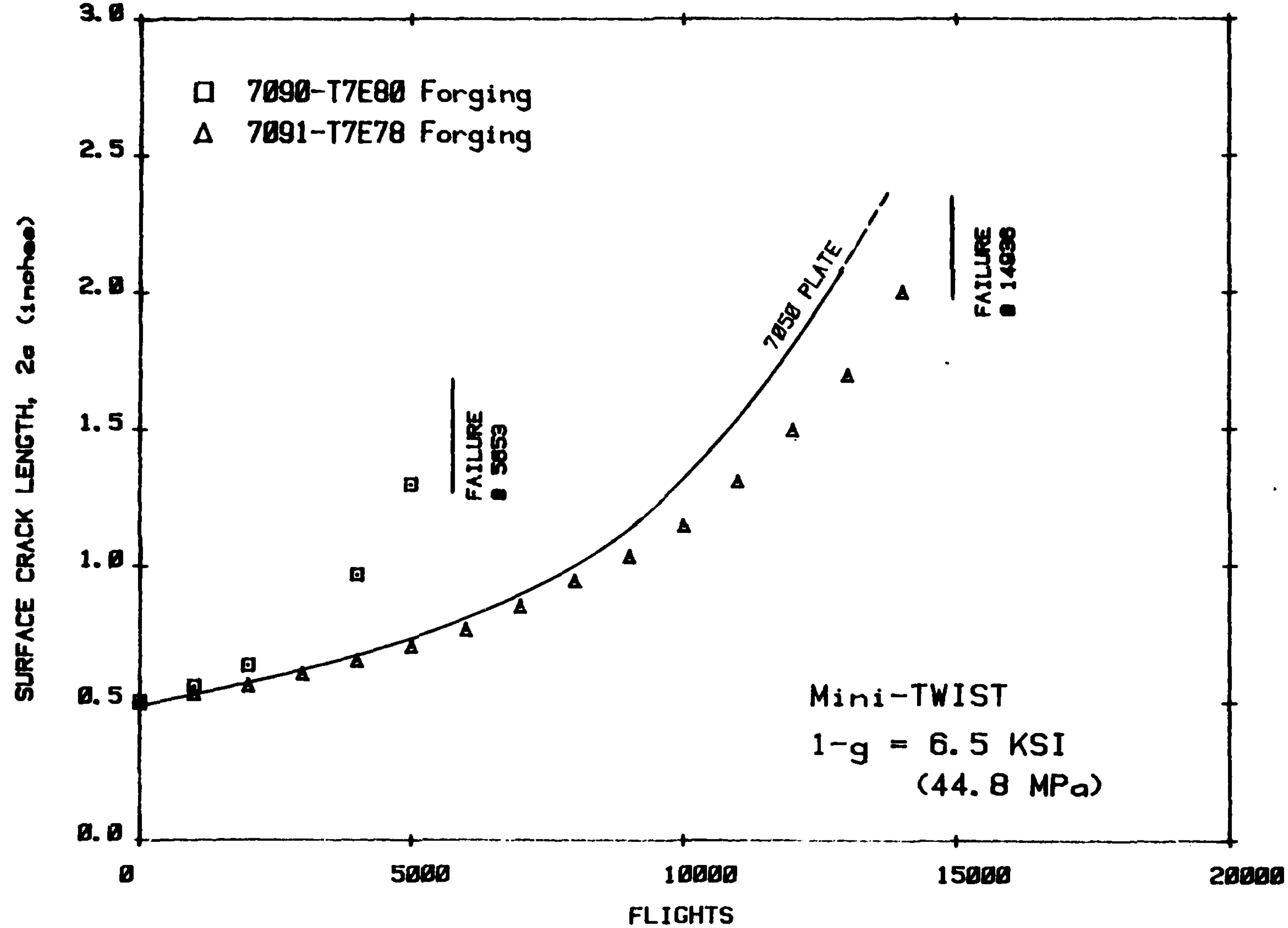


Figure 15. Crack Length Versus Flights Records for PM 7090 and 7091 Forging Under Mini-TWIST Spectrum.

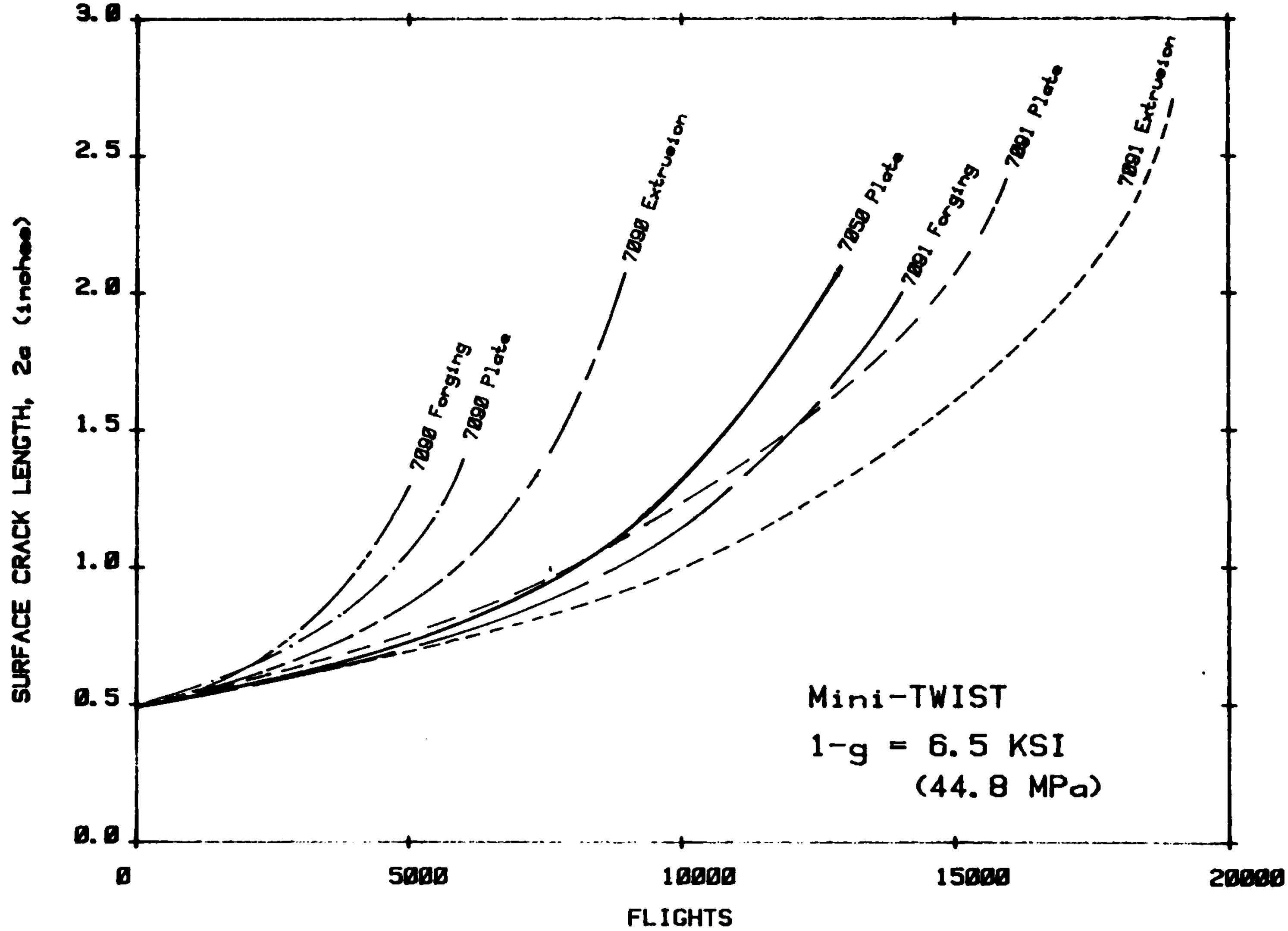


Figure 16. Composite Crack Length Versus Flight Records for All PM Materials Under Mini-TWIST Spectrum.

TABLE 3

TOTAL FLIGHTS TO FAILURE FOR PM ALUMINUM UNDERGOING MINI-TWIST LOAD HISTORY

Material	Form	Flights to Failure
7050-T76	Plate	13,658
7090-T7E71	Plate	7,260
7091-T7E69	Plate	16,501
7090-T7E71	Extrusion	9,653
7091-T7E69	Extrusion	19,709
7090-T7E80	Hand Forging	5,653
7091-T7E78	Hand Forging	14,936

NOTE: 1-g Spectrum Stress = 6.5 KSI (44.8 MPa).

Because of the limited amount of data available, simplified crack growth rate relationships, as were developed with the FALSTAFF data, could not be clearly established. It should be expected, however, that such relationships would be consistent with those previously established from the FALSTAFF test results.

3. CONSTANT AMPLITUDE

Though no constant amplitude testing was performed in this particular effort, reference data on both 7091-T7E69 extrusion[3] and 7090-T7E71 plate[4] are presented in Figure 17, along with similar reference data on aluminum 7050-T7E3511 extrusion[2] and 7050-T73651 plate.[1] Results shown are for lab air conditions and a loading ratio, R, of +0.1. Though the trends of the two PM alloys are consistent with those from the spectrum tests, i.e., the crack growth resistance of 7091 is greater than for 7090, both PM curves lie above the 7050 curve, indicating a lower resistance to constant amplitude fatigue crack propagation. This is in sharp contrast to the results obtained in both the FALSTAFF and Mini-TWIST spectrum testing where all the 7091 materials displayed consistently better crack growth resistance, with the 7091 extrusion possessing nearly double the spectrum fatigue propagation life of 7050. Such seemingly conflicting results clearly show the role that load interaction, i.e. retardation, plays in complex loading situations. Under variable amplitude loading, the lower strength 7091 alloys exhibited greater crack retardation than did the higher strength 7050 and 7090 alloys. Consequently, fatigue propagation lives were greater. However, under constant amplitude, tension-tension loading, crack retardation does not take place and both PM alloys show a lesser resistance to propagation, with the 7090 alloy possessing less resistance than the 7091 alloy.

Consequently, a clear knowledge of the expected load history must exist before the selection of either the 7091 PM alloy or the 7050 IM alloy can be made. If conditions are such

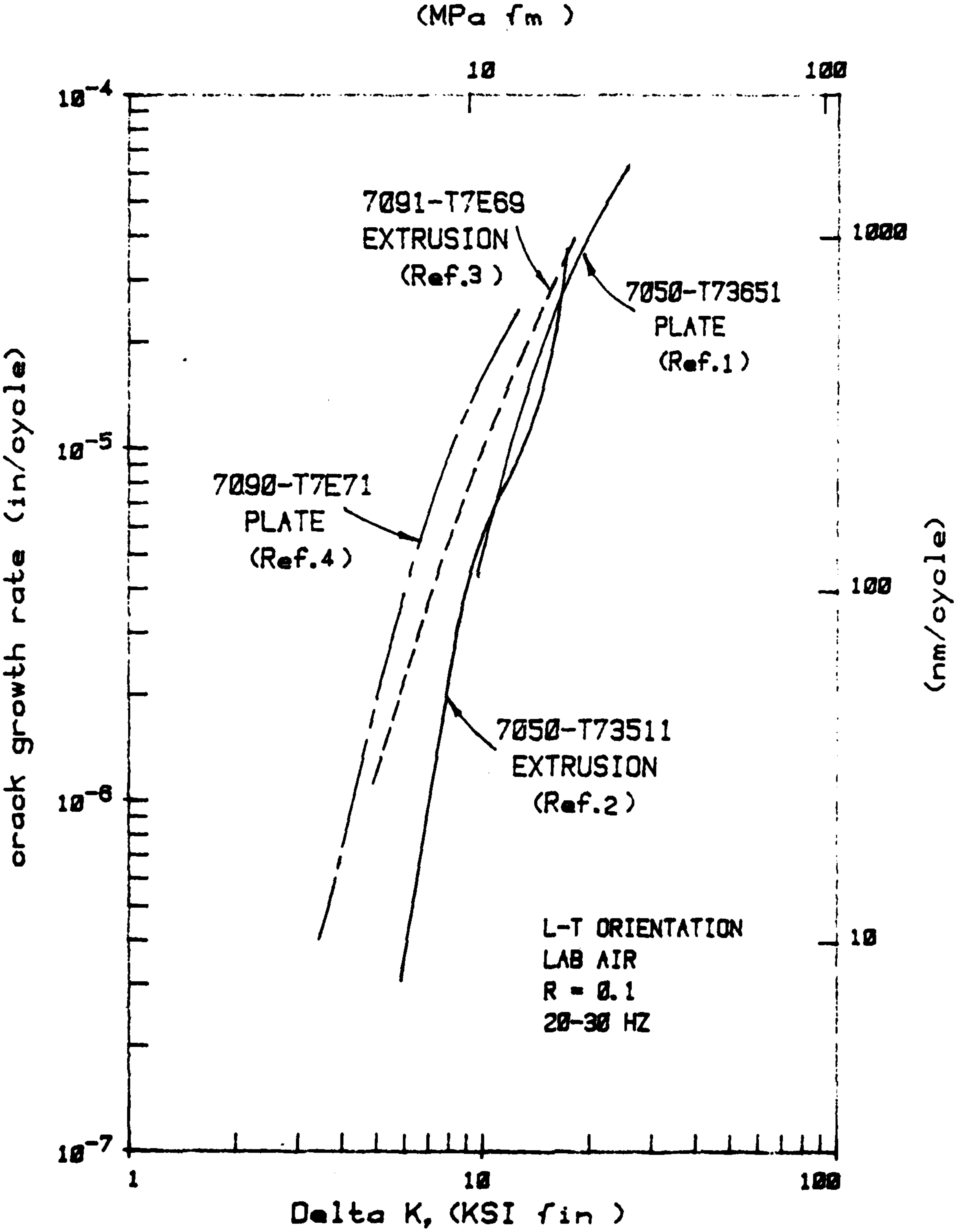


Figure 17. Constant Amplitude Fatigue Crack Growth Rate Data for Aluminums 7090, 7091, and 7050.

that a significant degree of high-low type of load interaction will occur, the 7091 alloy appears to offer a better choice in terms of crack propagation. On the other hand, if the expected usage resembles a constant amplitude loading situation, the choice of the 7091 alloy over the 7050 might prove disastrous.

SECTION V
CONCLUSIONS

The following conclusions are based on results from a single form of each test material investigated. Findings could be altered by an in-depth program which would include multiple specimens taken from several lots of each test material.

1. The 7090 PM materials exhibited higher strength and less ductility than the 7091 materials for a given form. Yield strength of both the 7090 plate and extrusion exceed that for 7050 plate, with the extruded form possessing the highest strength. Yield strengths for all the 7091 material were below that of 7050. Ductility for the 7091-T7E78 forging was equal to that for 7050; ductility for the other materials was less.

2. Under the FALSTAFF load spectrum, crack growth resistance of all the 7091 materials was greater than 7050 plate; the crack growth resistance of all the 7090 materials was less than 7050 plate. The least resistant material was the 7090 forging, while the best was the 7091 extrusion. Crack growth rate properties of all the materials tested, exception being 7090 forging, generally appear similar at lower stress intensities, with the large differences occurring at the higher stress intensities.

3. Results under the Mini-TWIST spectrum were consistent with FALSTAFF results: the 7090 materials were less resistant to crack propagation than the 7050 IM material, while the 7091 materials were superior to the 7050. Again, the 7090 forging possessed the lowest crack propagation life, while the 7091 extrusion possessed the greatest.

4. Though an improvement in fatigue crack propagation was observed in the 7091 materials over the 7050 alloy under complex loading, constant amplitude crack growth rate results indicate the opposite trend. Constant amplitude crack growth rates for both 7090 plate and 7091 extrusion are substantially greater than that for 7050. Consistent with the spectrum results, the 7091 extrusion outperformed the 7090 plate under constant amplitude loading.

REFERENCES

1. Jones, R. E. and Fudge, K. A., "Engineering Design Data for Aluminum Alloy 7050-T73651 Plate," AFML-TR-73-269, November 1973.

2. Petrak, G. J., "Effects of Purity Level on the Mechanical Properties of 7000-Series Aluminums," AFWAL-TR-80-4079, October 1980.

3. Ruschau, J. J., "Mechanical Property Data on P/M Aluminum 7091-T7E69 Extrusion," AFWAL-TR-82-4161, October 1982.

4. Ruschau, J. J., "Mechanical Property Evaluation of P/M Aluminum 7090-T7E71 Plate," (In writing).

*U.S.GPO: 1983-659-062-967