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FRACTURE TOUGHNESS, FATIGUE AND CORROSION CHARACTERISTICS OF HIGH STRENGTH ALUMINUM EXTRUSIONS AND PLATE

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Eighth Quarterly Technical Management Report
December 27, 1968 to March 27, 1969

ALUMINUM COMPANY OF AMERICA
Alcoa Research Laboratories
New Kensington, Pennsylvania

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ABSTRACT

Axial-stress fatigue curves are reported for notched ($K_t = 3$) specimens from the 7075-T6510, 7075-T73510, X7080-T7E42, and 7178-T6510 extruded bars. The fatigue properties generally varied with direction in the same order as the tensile properties. All of the fatigue crack propagation data are reported and analyzed. For both the extruded shapes and the plate, crack propagation was faster for transverse than for longitudinal specimens. Machining to remove the extruded or rolled surfaces, taking specimens from the center of thickness of the thicker extrusions, and varying the thickness of the products, did not consistently affect the crack propagation rates. For extrusions and plate, the four alloys are rated in the following order of decreasing resistance to fatigue crack propagation:

7075-T73-type
X7080-T7-type
7075-T6-type
7178-T6-type

The tests to evaluate stress-corrosion resistance by a fracture-mechanics approach are nearly completed. Test results from bolt-loaded and ring-loaded specimens from the short-transverse direction of the extruded bars generally rated the four samples in the same order as the conventional stress-corrosion tests of smooth tensile specimens. The 7075-T6510 and 7178-T6510 extruded bars were definitely susceptible to stress-corrosion cracking when stressed in the short-transverse direction. The short-transverse direction of the X7080-T7E42 extruded bar showed slight susceptibility to stress-corrosion cracking. The 7075-T73510 extruded bar was apparently immune.

This is the last quarterly report to be issued on this contract. The final report will be completed by July 27, 1969.

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QUARTERLY REPORT

FRACTURE TOUGHNESS, FATIGUE AND CORROSION CHARACTERISTICS OF 7075-T6510, 7075-T73510, X7080-T7510 AND 7178-T6510 EXTRUSIONS AND X7080-T751 AND 7178-T651 PLATE

I. Introduction.

Fracture toughness, fatigue and corrosion characteristics are among the most important properties in determining the suitability of materials for many aerospace applications. The purpose of this contract is to provide data for extrusions and plate of several alloys and tempers which appear potentially suitable for such applications. The data obtained are not design or expected minimum values of the properties involved, but rather the results of tests of representative lots of material. As such, the data should be interpreted as representative values rather than statistically reliable average or minimum values of the properties involved.

The effort during the first twenty-one months on this program was described in seven previous quarterly reports.[1-7] The fourth quarterly report[4] summarized the effort of the program's first year. This report describes the progress during the eighth quarter of the contract, from December 27, 1968 to March 27, 1969. This is the last quarterly report which will be issued. The final report will be submitted by July 27, 1969.

II. Material.

All materials were received before this quarter began; the specific items are listed below.

(1-7) Numbers in parentheses pertain to references.

Product	Alloys and Tempers Received
1/2-in. and 1-3/8-in. thick plate	7178-T651; X7080-W51
11/16x16-in. integrally stiffened extruded panel	7075-T6510; 7075-T73510; 7178-T6510; X7080-W510
3-1/2x7-1/2-in. extruded bar	7075-T6510; 7075-T73510; 7178-T6510; X7080-W511

Following studies to determine proper aging treatments for the X7080 plate and extruded shapes, these products were aged from the W51-type to the T7-type tempers. The samples being used were aged during the second and fourth quarters of the contract.(2,4)

The tensile properties of the contract materials were determined previously,(2,4) and are presented for reference in Table I.

III. Test Programs.

The test specimens and procedures being used are substantially as described in the previous quarterly reports,(1-7) except as noted below.

During the eighth quarter of the contract, stress-corrosion specimens from the plate samples completed one year of exposure to the inland industrial atmosphere at New Kensington, Pennsylvania. During the next quarter, other stress-corrosion specimens which are being exposed to the atmosphere at New Kensington and at Point Judith, Rhode Island (except some long-transverse specimens from the 11/16x16-in. extruded panels), will complete one exposure. The stress-corrosion data which have been obtained thus far from tests in the atmosphere appear to correlate well with the accelerated stress-corrosion test results. Combinations of alloy-temper and stress level which produced specimen failures in accelerated tests also produced specimen failures in the atmosphere. However, longer periods of exposure in the atmosphere are advisable, to develop more reliable correlations with the accelerated stress-corrosion test results. Continuation of the atmospheric tests requires only routine, periodic inspection for failures. Therefore, the stress-corrosion specimens which have survived one year of exposure to the atmosphere at New Kensington or at Point Judith, will be left in test for at least four years, and possibly longer, to obtain information on long-time atmospheric exposure.

IV. Progress During This Quarter.

All test specimens have been machined from the contract materials. All phases of the contract test programs are now either underway or complete.

A. Fracture Toughness

The testing of notch-bend fracture toughness specimens was completed during the fifth quarter. A detailed analysis of the data was included in the Seventh Quarterly Technical Management Report.(7) The four alloy-temper combinations were placed in the following order of decreasing fracture toughness, for each product:

X7080-T7-type
7075-T73-type
7075-T6-type
7178-T6-type

B. Axial-Stress Fatigue

The axial-stress fatigue tests of specimens from the 1/2 and 1-3/8-in. plate samples, and the 11/16x16-in. extruded integrally stiffened panels, were completed during previous quarters. The S-N curves and modified Goodman diagrams were reported in the Fourth and Fifth Quarterly Technical Management Reports.(4,5)

The axial-stress fatigue tests of smooth specimens from the 3-1/2x7-1/2-in. extruded bars were completed last quarter. The results were reported in the Sixth and Seventh Quarterly Technical Management Reports.(6,7)

The axial-stress fatigue tests of the notched specimens from the extruded bars are in progress. The tests of the K_t = 3 notched specimens are nearly completed. The S-N curves and modified Goodman diagrams are shown in Figs. 1 through 24. Specimens from the longitudinal, long-transverse and short-transverse directions, from the center two-thirds of the cross-section of each bar, were tested at three stress ratios, R = +0.5, 0.0, and -1.0 (R = minimum stress/maximum stress). Separate modified Goodman diagrams have been prepared for each direction in each sample.

The fatigue lives of specimens from the three directions of each bar were generally ordered in the same way as the tensile properties. The longitudinal specimens generally had longer lives than the long-transverse specimens, which generally had longer lives than the short-transverse specimens. At higher stress levels, the longitudinal and long-transverse fatigue properties of each sample were quite similar, while the short-transverse fatigue properties were quite dissimilar for all of the materials except the X7080-T7E42 sample. Based on the fatigue strengths of $K_t = 3$ specimens from the extruded bars at 10^7 cycles, the alloys and tempers can be rated in the following order of decreasing fatigue strength:

7075-T6510
X7080-T7E42
7178-T6510
7075-T73510

The order does not hold true for all directions in each product, nor at all individual stress levels or stress ratios; rather, it is an approximate general ranking.

The axial-stress fatigue tests of the $K_t = 12$ notched specimens from the extruded bar samples are in progress. The following numbers of tests have been completed:

7075-T6510	28 of 90
7075-T73510	23 of 90
X7080-T7E42	49 of 90
7178-T6510	18 of 90

C. Fatigue Crack Propagation

The numbers of cycles required to initiate the fatigue cracks in each crack propagation specimen are listed in Table II.

The length of the crack when first observed in each specimen was generally short, but the lengths varied substantially from specimen to specimen. To obtain a common reference for crack growth analysis, each set of data was extrapolated linearly to a zero crack length (notch = 16.7 per cent of gross width) using the first three data points. Fatigue cycles for crack propagation were referred to this calculated initial number of cycles. Fatigue crack propagation curves showing per cent of area cracked on a logarithmic scale versus number of cycles, are plotted in Figs. 25 through 36.

Some of the alloys show considerable scatter for replicate specimens, whereas there is relatively little scatter in the results for others. The data for specimens L2 and T2 in Fig. 29 (7075-T6510, 11/16x16-in. extruded panel) demonstrate the fact that cracking at only one side of the original machined notch can significantly affect its behavior. The total propagation was much slower when there was propagation on only one side of the notch. In the later stages of cracking, however, the eccentricity generally caused faster propagation. Further, final fracture occurred at a shorter total crack length.

Investigations such as that of Ref. 8 have shown that water vapor in the atmosphere can affect the rate of crack propagation. The range of relative humidity which was measured during the crack propagation tests of each specimen is included on Figs. 25 through 36. For specimens where there was a significant variation between the humidities for replicate test specimens having comparable eccentricities, such as specimens T1 and T2 of

Fig. 26 (1-3/8-in. X7080-T7E41 plate), it was observed that the cracks did propagate somewhat faster at the higher humidities.

In Fig. 37, the data for one of the 7075-T7351 specimens from Fig. 32 is replotted using a larger scale for the cycles. As is illustrated, substantial portions of the data can be represented by straight lines. Accordingly, to determine the rates of crack propagation, a computer program was written to determine the slope of the best straight line which could be fit to the logarithms of the crack length versus the number of cycles by the least squares method. To obtain the rate of crack propagation at a certain total crack length (crack length plus machined notch), a straight line was fit to the data for those points which were within 0.30 in. (10 per cent of the gross width) of that total crack length. For example, for a total crack length of 0.90 in. (30 per cent of the gross width), a straight line was fit to the data for total crack lengths from 0.60 in. to 1.20 in. (20 to 40 per cent of gross width).

Log-log plots of the rate of propagation versus ΔK, the range of stress intensity factor, are shown in Figs. 38 through 51 for the various alloys and products. The crack propagation rates are given in terms of da/dN, where a is one-half the total crack length, and N is the number of cycles. The rates shown in the figures were determined by averaging the rates obtained for the multiple specimens of each sample, direction and surface condition. The data were not included in the average if cracks were not visible at all four "corners" of the notch by the time the total crack length equalled 1.0 in. (33-1/3 per cent of the gross area cracked).

In Figs. 38 through 51, curves have been drawn to fit the crack propagation data. For plots such as Fig. 38, a straight line relationship (proposed by Paris and Erdogan[9] and others) provides a good fit. Anderson[10] suggested that there might be a tailing off of the crack propagation curves at both the very low and very high rates. The data for 7178-T6510 extrusions, Figs. 49 and 50, indicate such a relationship.

For X7080-T7E41 plate, Figs. 38 and 39, neither specimen direction, nor light machining to remove the rolled surface of longitudinal specimens, affected the crack propagation behavior of the 1/2-in. thick plate. Similar rates were obtained for specimens from the 1/2-in. thick plate, and from the center of the 1-3/8-in. thick plate.

The 7178-T651 plate (Figs. 40 and 41), especially the 1/2-in. thick sample, was plagued with eccentric cracking. In several cases only one specimen of three had cracks visible at all four corners of the notch by the time the total crack length reached 1.0 in. For this alloy, machining to remove the rolled surface appears to decrease the resistance to crack propagation. In view of the crack eccentricities, there are not enough consistent differences to indicate a directional effect for either plate thickness.

In Fig. 42, the crack propagation curves for the longitudinal specimens from 1-3/8-in. plate are compared with curves previously reported[11] for 7075-T7351 and 7075-T651 specimens from a similar product. The crack propagation rates for 7075-T7351 and X7080-T7E41 plate are consistently lower than those for 7075-T651 and 7178-T651 plate. At medium stress-intensity ranges, the 7075-T651 plate has some advantage over the 7178-T651 plate.

For the 11/16-in. thick 7075-T6510 extrusions, Fig. 43, crack propagation rates were higher for transverse specimens than for longitudinal specimens. However, machining to remove the extruded surface of the longitudinal specimens reduced their resistance to crack propagation to about the same level as that of the transverse specimens. Except at the lowest stress intensities, Fig. 44 does not indicate any effect of specimen location in the 3-1/2-in. thick bar. Also, the curves shown for the 11/16-in. thick extrusion and 1-3/8 in. plate fall within the results shown for the 3-1/2-in. thick extrusion.

It can be seen from Fig. 45 that machining to remove the extruded surface did not affect the propagation rate for the 11/16-in. thick 7075-T73510 extrusion, but that crack propagation rates were somewhat higher for transverse specimens than for longitudinal specimens. In Fig. 46, there is close agreement among the crack propagation rates determined for the longitudinal directions in the various 7075-T73510 products.

Except at the shorter crack lengths, crack propagation was generally faster for transverse X7080-T7E42 specimens than for longitudinal specimens (Fig. 47). Machining to remove the extruded surface of longitudinal specimens did not consistently affect the propagation rate. In Fig. 48, the propagation rate for the X7080-T7E42 specimen from the center of thickness of the extruded bar was somewhat slower than the propagation rates for the surface specimens. Also, the propagation rates for both the 1-3/8 in. X7080-T7E41 plate and the 11/16-in. X7080-T7E42 extruded panel were slower than those of the rates determined with specimens from the surface or the center of thickness of the 3-1/2 in. X7080-T7E42 extruded bar.

The 7178-T6510 extrusions tended to crack eccentrically (as did the 7178-T651 plate), so the data for several specimens were excluded from the average. Neither the specimen direction nor the surface condition consistently affected the propagation rates for the 11/16-in. extrusions (Fig. 49). Fig. 50 shows that the two thicknesses of 7178-T6510 extrusions had comparable crack propagation rates. At the lower stress intensity factors their propagation rates were somewhat slower than the rate for the 7178-T651 plate.

The crack propagation rates for longitudinal specimens from the 3-1/2-in. thick extrusions are compared in Fig. 51. The ranking of the alloys and tempers with respect to rate of fatigue crack propagation is generally the same as for plate: 7075-T73510 has the slowest rate, X7080-T7E42 is next, followed by 7075-T6510 and 7178-T651. The advantage of 7075-T73510 over X7080-T7E42 in the extruded bar is somewhat greater than that which is shown for the corresponding plate samples. The 7178-T6510 curve has an average slope of about 0.25. The lines for the other alloys are less curved, and have slopes of about 0.37.

The fatigue crack propagation characteristics of the materials which have been tested in this contract may be summarized as follows:

1. For both extrusions and plate, crack propagation was faster for transverse specimens than for longitudinal specimens.

2. Neither machining to remove the extruded or rolled surfaces, nor taking specimens from the center of thickness of the thicker extrusions, consistently affected the crack propagation rates.

3. In most cases, similar crack propagation rates were obtained for the extrusions and the plate as well as for the two thicknesses of these products.

4. Except for the shorter cracks (low range of stress intensities) the plate and extrusion alloys would rate in the following order of decreasing resistance to fatigue crack propagation:

7075-T73-type
X7080-T7-type
7075-T6-type
7178-T6-type

5. The relation between ΔK, the range of stress intensity and da/dN, the rate of crack propagation, was close to linear on log-log plots for all except the 7178-T6-type samples. The slopes for the data were about 0.37, instead of 0.25 as suggested by Paris in his relationship $\frac{da}{dN} = \frac{(\Delta K)^4}{C}$.

D. Corrosion Characteristics

1. Exfoliation and Stress Corrosion (Conventional Tests)

a. Status of Tests

All of the accelerated corrosion tests have been completed. All atmospheric tests are in progress, but the results are still too preliminary to be conclusive.

The results of the accelerated exfoliation tests of the plate and extruded shapes were reported in the Fourth and Seventh Quarterly Technical Management Reports, respectively[4,7].

The results of the accelerated stress-corrosion tests of the plate and extruded shapes were reported in the Fifth and Sixth Quarterly Technical Management Reports[5,6]; those for extrusions were contained, for the most part in the Seventh Quarterly Technical Management Report,[7] and are completed in this report.

b. Test Results

The data for the accelerated and the atmospheric tests which were in progress during the seventh quarter were reported in the Seventh Quarterly Technical Management Report.[7] Some additional long-transverse specimens from between the ribs of the 11/16x16-in. extruded panels completed 84 days of exposure to alternate immersion in a 3-1/2 per cent NaCl solution during the eighth quarter, and the results are shown in Table III. The status of the other tests did not change during the eighth quarter, and the other status tables do not need to be reproduced for this report.

The per cent reduction in tensile strength by corrosion in alternate immersion was determined for longitudinal and long-transverse specimens from the extruded shapes during this quarter. These data are reported in Table IV.

c. Discussion of Stress-Corrosion Results

(1) 11/16x16-in. and 3-1/2x7-1/2 in. Extruded Shapes

(a) Longitudinal Direction (3-1/2x7-1/2 in. Extruded Bars Only)

No longitudinal specimen has failed, thereby confirming the high resistance to stress-corrosion cracking which is expected in this direction of all alloys and tempers.

The per cent reduction in tensile strength after 182 days exposure to alternate immersion (Table IV) indicates the relative resistance to general corrosive attack. Alloy X7080-T7E42 was the least affected, followed by 7075-T73510 and then 7075-T6510 and 7178-T6510, which were similar. This general order is in agreement with test results on other items of these alloys-tempers. The reductions in strength of the unstressed and the stressed specimens was generally similar. The most divergent case was the 7178-T6510, for which the stressed specimens showed double the loss in strength of the unstressed specimens. This degree of difference for 7178-T6510, however, is not unusual.

(b) Long-Transverse Direction

For both extruded shapes, failures of the long-transverse specimens in the accelerated and atmospheric tests have occurred only for the 7075-T6510 and 7178-T6510 samples.[7] While these two items are known to be the most susceptible of the four alloy-tempers evaluated, most of these specimens did not contain a true long-transverse grain structure. The 3-1/2x7-1/2 in. bar had a more or less equi-axed grain structure which would more correctly be described as simply transverse (similar to the grain structure in round and square shapes). In the 11/16x16-in. panel, the long-transverse specimens centered under an outstanding rib had a grain structure on an angle to the specimen axis, rather than parallel to it, because of metal movement into the rib during the extrusion process. It is significant that even with these less favorable grain structures, 7075-T73510 and X7080-T7E42 were still resistant to cracking.

The only true long-transverse specimens were the 0.125 in. diameter specimens centered between the outstanding ribs of the 11/16x16-in. panels (Table III). Failure in this case (verified as stress-corrosion cracking by microscopic examination) occurred only for 7178-T6510. Even here a moderately high degree of resistance was indicated, with all three specimens failing in 56 to 67 days, as compared with failures in 10 to 13 days when the same size specimens were positioned directly under a rib.

The four alloy-temper combinations tested in this project are listed below in relative order of decreasing resistance to stress-corrosion cracking of the long-transverse specimens. This order agrees with Alcoa experience with other extruded samples.

<u>11/16x16-in. Extruded Ribbed Panels</u>

7075-T73510 and X7080-T7E42 (very high resistance)
7075-T6510 (high resistance)
7178-T6510 (medium resistance)

<u>3-1/2x7-1/2-in. Extruded Bar (Equi-axed Grain Structure)</u>

7075-T73510 and X7080-T7E42 (very high resistance)
7075-T6510 and 7178-T6510 (low resistance)

The per cent reductions in tensile strength of the various long-transverse specimens exposed to alternate immersion are given in Table IV. The results for unstressed specimens show the same trend as was cited above for longitudinal specimens; X7080-T7E42 is the most resistant to general corrosion, followed by 7075-T73510, then 7075-T6510, with 7178-T6510 the least resistant. The reductions in tensile strength of stressed specimens were not excessively high as compared with the corresponding unstressed specimens, except for the specimens from the 3-1/2x7-1/2-in. X7080-T7E42 bar (Sample No. 340731), where the reductions for stressed specimens were four times the reductions for unstressed specimens. Representative unstressed and stressed specimens of this sample have been submitted for microscopic examination, to determine whether the relatively large reduction in tensile strength of the stressed specimens was merely the result of deeper corrosive attack, or was caused by incipient stress-corrosion cracks.

(c) Short-Transverse Direction (3-1/2x7-1/2-in. Extruded Bars Only)

The results of the tests of the short-transverse specimens were discussed in the Seventh Quarterly Technical Management Report[7] and showed 7075-T73510 to be the most resistant material (no failures at 75 or 50 per cent of the yield strength), followed by X7080-T7E42 (failure at 75 per cent of the yield strength, no failure at 50 per cent of the yield strength and below), and then 7075 and 7178-T6510 (complete failure at 50 and 25 per cent of the yield strength, with 1 of 3 specimens failing at 15 per cent of the yield strength).

Some of the stressed specimens which survived 84 days of exposure to alternate immersion in a 3-1/2 per cent NaCl solution showed high losses in tensile strength. These specimens were examined microscopically. Examination of the 7075-T73510 specimens which had been stressed to 75 per cent of the yield strength showed no evidence of incipient stress-corrosion cracking and verified that these specimens were resistant to stress-corrosion cracking. On the other hand, intergranular cracks were found in both the 7075-T6510 and 7178-T6510 specimens which had been stressed to 15 per cent of the yield stress, confirming the susceptibility to stress-corrosion cracking that had already been shown by a single failure for each of these two samples.

2. Stress Corrosion With A Fracture Mechanics Approach

Tests of bolt-loaded specimens (shown in Fig. 30 of Ref. 6) from each of the 3-1/2x7-1/2 in. extruded bars were completed this quarter. Specimens from each sample were loaded to various stress intensity levels (usually 100, 90 and 80 per cent of the ambient K_{Ic} value) and exposed by either total or alternate immersion in 3-1/2 per cent NaCl solution. At least one specimen from each sample was precracked in direct tension, rather than by fatigue, and since the load was not removed after precracking, the initial K_{Ii} value should have been reasonably close to K_{Ic}. The initial crack lengths for specimens precracked in fatigue were based on measurements made on the surfaces of the specimens. Since the crack fronts through the thicknesses of the specimens were not perfectly straight, the initial crack lengths, loads and K_{Ii} values for the fatigue-cracked specimens are estimated values. Several of these specimens were discontinued after about 1000 hours of exposure, but the majority of the specimens were exposed for 2500 hours.

The results of these tests are summarized in Table V and plots of crack growth versus time are shown in Figs. 52 through 55. As shown in the figures, specimens from alloys 7075 and 7178 in the T6510 temper experienced considerable crack growth; specimens from X7080-T7E42 experienced moderate crack growth and specimens from 7075-T73510 experienced negligible crack growth. For alloys in which cracks grew, the specimens loaded to 100 per cent K_{Ic} experienced more crack growth than those with lower applied K_{Ii} values.

Initially, crack growth in the susceptible alloys seems to have been more rapid in alternate immersion tests than in total immersion tests. After 2500 hours exposure the residual stress intensity factors for the susceptible alloys, shown in Table V, approached the same level regardless of the type of test (alternate or total immersion) or applied stress intensity (K_{Ii}). Except for one specimen, the residual stress intensities for 7075-T6510 range from 13,000 to 13,500 psi$\sqrt{in.}$, and the residual stress intensities for 7178-T6510 range from 8600 to 10,800 psi$\sqrt{in.}$ For both samples, there is little difference between the residual stress intensities after 800 and 2500 hours in the alternate immersion tests, even though the cracks continued to grow (see Figs. 52 and 55) at a slow rate.

Specimens from the 7075-T73510 sample experienced negligible crack growth One must thus conclude that this alloy is not susceptible to stress-corrosion crack growth even though the residual stress intensities are lower than the estimated initial values. This apparent decay in stress intensity could be due to creep or stress relaxation in the screw threads or other highly stressed regions in the specimen, or the actual initial stress intensities may have been lower than the estimated values.

Specimens from the X7080-T7E42 sample experienced some crack growth, but some of the apparent decay in stress intensity may be due to the reasons mentioned above for the 7075-T73510 tests. In any event, there is considerable variability in residual stress intensity values, which may indicate that 2500 hours exposure is not long enough to allow specimens of this particular material to approach a stable condition.

The data for the tests of ring-loaded specimens are summarized in Table VI. (This phase of the testing is still in progress.) It appears that stress-corrosion cracks propagate faster in the alternate immersion test than in the total immersion test. One specimen of 7075-T6510 in alternate immersion failed in about the same time as two other specimens with higher applied stress intensities (K_{Ii}) in total immersion, and one specimen of 7178-T6510 in alternate immersion failed in about one-third the time of an identical specimen (same K_{Ii}) in total immersion.

The data for ring-loaded specimens of 7075-T6510 and 7175-T6510 seem to be approaching the same stable stress intensity level (K_{Iscc}) as the bolt-loaded specimens of the same alloys. The data for the samples of X7080-T7E42 and 7075-T73510 are not as clear-cut, but it appears that both samples are relatively resistant to stress corrosion.

A more thorough analysis of these data will be presented in the final report, when metallographic examinations and the long-time tests of ring-loaded specimens will be complete. It seems evident at this point that the stress-corrosion data which have been developed with a fracture-mechanics approach rate these samples in the same order as stress-corrosion data which have been developed with smooth tensile specimens. The four samples rank as follows, in order of decreasing resistance to stress-corrosion crack growth:

7075-T73510
X7080-T7E41
7075-T6510
7178-T6510

V. Program for Next Quarter.

Planned effort during the next quarter will consist of completing the tests which are in progress, analyzing the data which have been generated, and preparing the final report.

1. The axial-stress fatigue tests of notched ($K_t = 3$) specimens from the 3-1/2x7-1/2-in. extruded bar samples will be completed.

2. The axial-stress fatigue tests of notched ($K_t \geq 12$) specimens from the extruded bar samples will be completed. S-N curves and modified Goodman diagrams will be prepared.

3. The stress-corrosion specimens from the 1/2-in. and 1-3/8-in. thick plate samples will complete one year of exposure

to the seacoast atmosphere at Point Judith, Rhode Island, on March 31, 1969.

4. The stress-corrosion specimens from the 11/16x16-in. extruded panels and the 3-1/2x7-1/2-in. extruded bars will complete one year of exposure to the inland industrial atmosphere at New Kensington, Pennsylvania, on June 14, 1969. Specimens from these samples will complete one year of exposure to the seacoast atmosphere at Point Judith, Rhode Island, on June 2, 1969.

5. The tests to determine stress-corrosion resistance by a fracture-mechanics approach will be concluded. Tests of ring-loaded specimens and metallographic examinations will be finished.

6. The final report will be prepared.

A milestone chart indicating progress on the contract is shown in Fig. 56.

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7. P. E. Schilling, B. W. Lifka, J. W. Coursen, G. E. Nordmark, and J. G. Kaufman, "Fracture Toughness, Fatigue and Corrosion Characteristics of High Strength Aluminum Extrusions and Plate," Contract No. F33615-67-C-1521, Seventh Quarterly Technical Management Report, September 27 to December 27, 1968, dated January 31, 1969.

8. F. J. Bradshaw and C. Wheeler, "The Effect of Environment on Fatigue Crack Propagation, 2. Measurement on Aluminum Alloys at Different Frequencies," Royal Aircraft Establishment TR68041, February, 1968.

9. P. C. Paris and F. Erdogan," A Critical Analysis of Crack Propagation," Journal of Basic Engineering, December 1963.

10. W. E. Anderson, Discussion of Ref. 9.

11. J. G. Kaufman, G. E. Nordmark and B. W. Lifka, "Fracture Toughness, Fatigue and Corrosion Characteristics of 7075-T651, 7075-T7351 and 7079-T651 Aluminum Alloys," Technical Report AFML-TR-65-170, May 1965.

VI. Tables and Figures.

TABLE I

TENSILE PROPERTIES† OF ALUMINUM ALLOY PLATE AND EXTRUDED SHAPES EVALUATED ON F33615-67-C-1521
(Tentative)

Product	Alloy and Temper	Thickness, or Size and Shape, in.	ARL Sample Number	LONGITUDINAL Tensile Strength, psi	LONGITUDINAL Yield Strength,** psi	LONGITUDINAL Elongation in 4D, %	LONG-TRANSVERSE Tensile Strength, psi	LONG-TRANSVERSE Yield Strength,** psi	LONG-TRANSVERSE Elongation in 4D, %	SHORT-TRANSVERSE Tensile Strength, psi	SHORT-TRANSVERSE Yield Strength,** psi	SHORT-TRANSVERSE Elongation in 4D, %
Plate	X7080-T7E41	1/2	343260	68 200	58 900	16.5	67 600	56 800	15.0	--	--	---
		1-3/8	343259	67 900	60 200	14.5	68 300	59 600	12.5	67 100	56 300	7.0
		Minimum‡		NOT ESTABLISHED FOR THIS PRODUCT								
	7178-T651	1/2	340457	88 800	83 400	14.5	88 500	78 800	11.0	--	--	---
		Minimum*		--	--	--	84 000	73 000	6.0	--	--	---
		1-3/8	340450	92 500	81 900	9.0	87 800	77 800	9.0	80 200	68 100	2.2
		Minimum*		--	--	--	84 000	73 000	4.0	--	--	---
Extrusion	7075-T6510	11/16x16 panel	340637	90 400	82 400	12.5	87 000	78 700	13.6	--	--	---
		Minimum*		81 000	72 000	7.0	--	--	--	--	--	---
		3-1/2x7-1/2 bar	340619	85 400	75 700	10.9	77 300	66 700	10.5	75 500	61 400	7.9
		Minimum*		78 000	70 000	6.0	--	--	--	--	--	---
	7075-T73510	11/16x16 panel	340639	75 700	65 000	12.9	73 100	62 400	10.0	--	--	---
		Minimum*		70 000	61 000	7.0	--	--	--	--	--	---
		3-1/2x7-1/2 bar	340620	73 700	63 800	12.6	67 400	56 800	9.5	66 200	54 100	7.1
		Minimum‡		NOT ESTABLISHED FOR THIS THICKNESS								
	X7080-T7E42	11/16x16 panel	340730	72 400	63 800	14.6	70 900	60 200	11.6	--	--	---
		3-1/2x7-1/2 bar	340732	72 000	64 000	13.0	68 000	59 100	11.5	68 100	56 200	8.6
		Minimum‡		NOT ESTABLISHED FOR THIS PRODUCT								
	7178-T6510	11/16x16 panel	340616	94 400	87 200	11.0	91 100	82 900	10.7	--	--	---
		Minimum*		87 000	78 000	5.0	--	--	--	--	--	---
		3-1/2x7-1/2 bar	340635	89 000	80 700	9.2	77 000	67 900	4.5	71 300	62 300	2.0
		Minimum‡		NOT ESTABLISHED FOR THIS THICKNESS								

† At locations corresponding to specification test locations: Plate - t/2, Extruded panel - t/2, W/4 (L); t/2, W/2 (LT), Extruded bar - t/4, W/4 (L); t/2, W/2 (LT, ST) t - thickness, W - width.

‡ Not established at this time.

* Standards for Aluminum Mill Products, Aluminum Association, 1967.

** 0.2 per cent offset.

TABLE II

CYCLES REQUIRED TO INITIATE FATIGUE CRACKS IN CENTER-NOTCHED SPECIMENS

Net Stress = 3300 psi minimum to 9900 psi maximum

F33615-67-C-1521
(Tentative)

Alloy	Temper	Product	ARL Sample Number	Nominal Specimen Thickness, in.	Surface Condition or Location	Direction	No. of Tests	Number of Cycles to Initiate Crack
7075	T6510	Extruded Panel	340637	11/16	Extruded	L	3	82,300, 95,200, 116,700
					Machined[a]	L	2	120,700, 154,400
					Extruded	LT	3	98,100, 113,000, 225,200
	T6510	Extruded Bar	340619	3/4	Surface	L	2	113,500, 128,200
					T/4	L	1	148,000
7075	T73510	Extruded Panel	340639	11/16	Extruded	L	3	62,300, 68,700, 78,200
					Machined[a]	L	2	56,400, 106,500
					Extruded	LT	3	71,100, 82,200, 86,900
	T73510	Extruded Bar	340620	3/4	Surface	L	2	91,100, 139,000
					T/4	L	1	97,100
X7080	T7E42	Extruded Panel	340730	11/16	Extruded	L	3	71,900, 110,600, 116,000
					Machined[a]	L	2	79,000, 85,000
					Extruded	LT	3	55,600, 56,700, 69,400
	T7E42	Extruded Bar	340732	3/4	Surface	L	2	97,700, 111,000
					T/4	L	1	91,400
	T7E41	1/2-in. Plate	343260	1/2	Rolled	L	4	80,700, 105,100, 113,300, 164,000
					Machined[a]	L	2	71,000, 116,400
					Rolled	LT	3	82,200, 90,300, 107,500
	T7E41	1-3/8-in. Plate	343259	3/4	T/2	L	3	51,600, 80,300, 86,600
					T/2	LT	3	72,900, 75,600, 83,700
7178	T6510	Extruded Panel	340616	11/16	Extruded	L	3	95,000, 98,600, 137,600
					Machined[a]	L	2	145,000, 200,100
					Extruded	LT	3	115,900, 124,600, 235,100
	T6510	Extruded Bar	340635	3/4	Surface	L	2	121,700, 155,700
					T/4	L	1	137,800
	T651	1/2-in. Plate	340457	1/2	Rolled	L	3	312,300[d], 3,874,100[d,c], 11,954,900[d]
					Machined[a]	L	2	398,100, 1,570,400[d]
					Rolled	LT	3	450,700, 6,008,600[d], 11,252,000
	T651	1-3/8-in. Plate	340450	3/4	T/2	L	3	107,600, 167,900, 208,800[b]
					T/2	LT	3	147,100, 209,100, 1,149,400

NOTES:
(a) 0.020 machined from surface.
(b) Complete fracture.
(c) Failed in grip end.
(d) Hole oversize.

TABLE III

STATUS OF ADDITIONAL LONG-TRANSVERSE STRESS CORROSION TESTS ON THE 11/16-IN. EXTRUDED PANEL[1]

F33615-67-C-1521
(Tentative)

		Specimen Number and Days to Failure[2]					
	Environment:	3.5% NaCl Alt. Immersion (84 Days)		Pt. Judith Atmos. (4 Years)		New Kensington Atmos (4 Years)	
	Date Started:	October 16, 1968		December 30, 1968		October 25, 1968	
Alloy and Temper	Sample Number	No.	Days	No.	Days	No.	Days
7075-T6510	340637	CT5W	OK 84	CT10W		CT15W	
		CT6W	OK 84	CT11W		CT16W	
		CT7W	OK 84	CT12W		CT17W	
7075-T73510	340639	CT5W	OK 84	CT10W		CT15W	
		CT6W	OK 84	CT11W		CT16W	
		CT7W	OK 84	CT12W		CT17W	
X7080-T7E42	340730	CT5W	OK 84	CT10W		CT15W	
		CT6W	OK 84	CT11W		CT16W	
		CT7W	OK 84	CT12W		CT17W	
7178-T6510	340616	CT5W	67	CT10W		CT15W	
		CT6W	67	CT11W		CT16W	
		CT7W	56	CT12W		CT17W	

NOTES: (1) Specimens from between the ribs. Triplicate tensile specimens stressed in direct tension to 75 per cent of the respective yield strength. Duplicate unstressed specimens also exposed to each environment. Specimens were 0.125 in. in diameter.

(2) No entry in the "days" column means specimen has not failed and is still in test.

TABLE IV

REDUCTION IN TENSILE STRENGTH BY CORROSION OF 3-1/2 AND 11/16 IN. EXTRUSIONS(1)

F33615-67-C-1521
(Tentative)

3-1/2x7-1/2 in. Extruded Bar

Alloy and Temper	Sample Number	Longitudinal 0.437 in. Diameter Unstressed	Longitudinal 0.437 in. Diameter Stressed	Long-Transverse 0.437 in. Diameter Unstressed	Long-Transverse 0.437 in. Diameter Stressed
7075-T6510	340619	8	11	10	*
7075-T73510	340620	3	4	11	9
X7080-T7E42	340731	1	1	3(2)	12(2)
7178-T6510	340635	8	16	17	*

11/16x16 in. Extruded Ribbed Panel

		Long-Transverse					
		Centered Under Outstanding Rib				Between Ribs	
		0.437 in. Diameter		0.125 in. Diameter		0.125 in. Diameter	
Alloy and Temper	Sample Number	Unstressed	Stressed	Unstressed	Stressed	Unstressed	Stressed
7075-T6510	340637	8	*	18	*	6	13
7075-T73510	340639	6	13	6	8	4	6
X7080-T7E42	340730	3	3	2	3	4	3
7178-T6510	340616	9	*	17	*	12	*

* No value since all three specimens failed by stress-corrosion cracking.

NOTES: (1) Duplicate unstressed and triplicate specimens stressed to 75% of the respective yield strength were exposed to alternate immersion in 3.5% NaCl solution. The 0.437 in. diameter specimens were exposed for 182 days, and the 0.125 in. diameter specimens were exposed for 84 days.

(2) These specimens have been submitted for microscopic examination to determine whether the increased loss in stressed specimens was because of deeper corrosive attack or incipient stress-corrosion cracking.

TABLE V

STRESS-CORROSION FRACTURE TOUGHNESS DATA FOR SHORT-TRANSVERSE BOLT-LOADED SPECIMENS OF SOME HIGH STRENGTH ALUMINUM ALLOY 3-1/2x7-1/2 IN. EXTRUDED BARS EXPOSED TO 3-1/2% NaCl SOLUTION

F33615-67-C-1521
(Tentative)

Alloy and Temper	Sample Number	Type of Test	Exposure Period, hrs.	Method of Precracking	Initial Values: Crack Length, in.	Initial Values: Load, lb	Initial Values: K_{TI}, psi $\sqrt{in.}$	Residual Values: Crack Length, in.	Residual Values: Load, lb	Residual Values: K_{TI}, psi $\sqrt{in.}$
7075-T6510	340619	AI	800	Tension	1.015	2760	19 200	1.555	560	13 000
			800	Fatigue	0.975	2340	15 300	1.200	1410	13 500
			2500	Fatigue	0.950	2740	17 300	1.430	792	13 000
		TI	340	Fatigue	1.000	2500	17 500	1.090	2370	17 100
			1000	Fatigue	0.950	2880	18 200	1.090	18[illegible]	14 400
			2500	Tension	1.060	2580	19 200	1.500	410	8 100
			2500	Fatigue	1.005	2530	17 300	1.396	900	13 500
			2500	Fatigue	1.010	2220	15 300	1.420	813	13 000
7075-T73510	340620	AI	2500	Tension	0.965	3200	20 600	0.965	2950	19 000
			2500	Fatigue	0.990	2490	16 600	1.009	2050	14 100
		TI	340	Fatigue	0.940	3180	19 800	0.950	2850	18 000
			1000	Fatigue	0.950	3120	19 700	0.980	2670	17 500
			2500	Fatigue	0.985	2810	18 600	1.004	2400	16 400
X7080-T7E42	340732	AI	800	Fatigue	0.980	2820	18 600	0.975	24[illegible]	16 000
			2500	Tension	1.120	2750	23 200	1.389	1340	20 100
			2500	Fatigue	0.990	3130	20 900	1.082	2300	17 800
		TI	2500	Fatigue	0.975	3190	20 900	1.092	2320	18 200
			2500	Fatigue	0.985	2800	18 600	1.118	1855	15 200
7178-T6510	340635	AI	800	Tension	1.065	1920	14 400	1.485	526	10 000
			800	Fatigue	0.965	1790	11 600	1.125	1177	9 800
			2500	Fatigue	0.975	1990	13 000	1.175	945	8 600
		TI	2500	Tension	1.060	1940	14 400	1.580	350	8 700
			2500	Fatigue	0.995	1930	13 000	1.330	852	10 800

<u>NOTES</u>: (1) Data shown are for single tests.

(2) AI Alternate Immersion; TI - Total Immersion

(3) Alternate immersion cycles were continuous; 10 minutes in and 50 minutes out of solution.

TABLE VI

STRESS CORROSION FRACTURE TOUGHNESS DATA FOR SHORT-TRANSVERSE RING-LOADED SPECIMENS OF SOME HIGH STRENGTH ALUMINUM ALLOY 3-1/2x7-1/2 IN. EXTRUDED BARS EXPOSED IN 3-1/2% NaCl SOLUTION

F33615-67-C-1521
(Tentative)

Alloy and Temper	Sample Number	Type of Test	Number of Cycles	Initial Values: Crack Length, in. Measured	Initial Values: Crack Length, in. Calculated	Initial Values: Load, lb	Initial Values: K_{Ii}, psi in.	Values at Rupture: Crack Length, in. Measured	Values at Rupture: Crack Length, in. Calculated	Values at Rupture: Load, lb	Values at Rupture: K_{If}, psi in.	Time to Rupture, hrs.
7075-T6510	340619	TI	---	0.955	1.041	2700	19 500	--	1.173	2440	22 100	318
			---	0.950	0.977	2800	18 400	1.10	1.128	2550	21 400	260
		AI	43	1.000	0.986	2270	15 100	1.157	1.167	2030	18 200	310
			105	0.9[illegible]5	0.953	2030	12 900	1.219	1.192	1930	18 200	840
7075-T73510	340620	TI	---	0.965	0.977	3010	19 800	0.990	0.981	3010	19 900*	340*
X7080-T7E42	340732	AI	118	0.990	1.033	3110	22 200	1.168	1.233†	2730	24 600†	1010
7178-T6510	340635	TI	---	1.000	0.994	1930	13 000	1.160	1.157	1710	15 160	340
		AI	24	1.000	0.996	1920	13 000	1.122	1.133	1770	14 900	122
			60	1.000	0.990	1720	11 500	1.240	1.254	1430	15 300	264
			62	0.990	0.977	1510	10 000	1.200	1.240	1420	14 700	480

NOTES: (1) AI - Alternate Immersion; TI - Total Immersion

(2) Alternate immersion cycles were accomplished manually during working hours. Specimens were submerged overnight and on weekends.

(3) Crack lengths were measured on the surfaces of the specimens. Calculated crack lengths were obtained with a clip gage and compliance calibration data.

(4) Stress intensities K_{Ii} and K_{If} are based on calculated crack lengths.

* This test was discontinued after 340 hours exposure.

† Calculated crack length may be incorrect because of creep in the specimen. K_{If} is based on measured crack length.

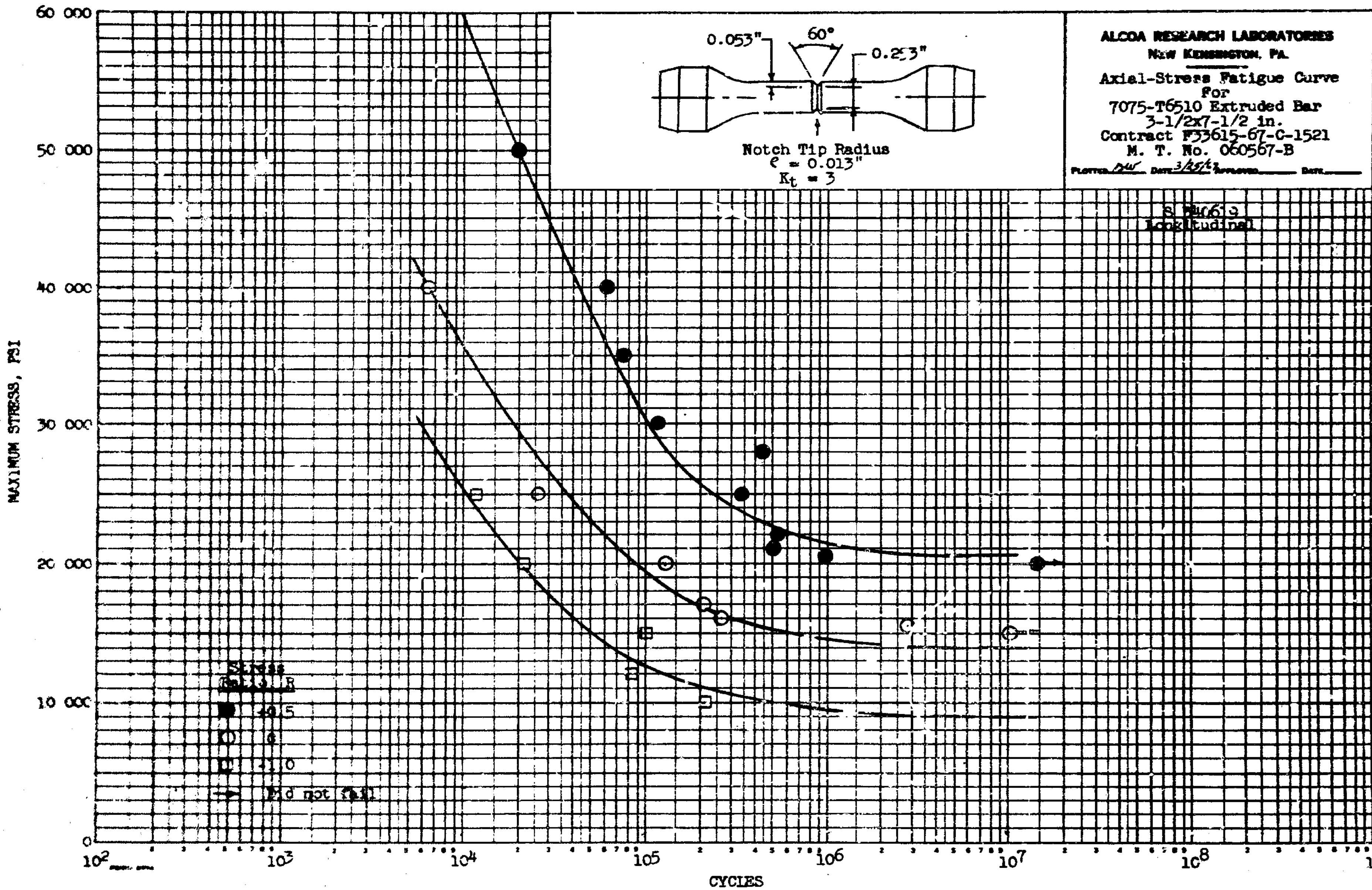
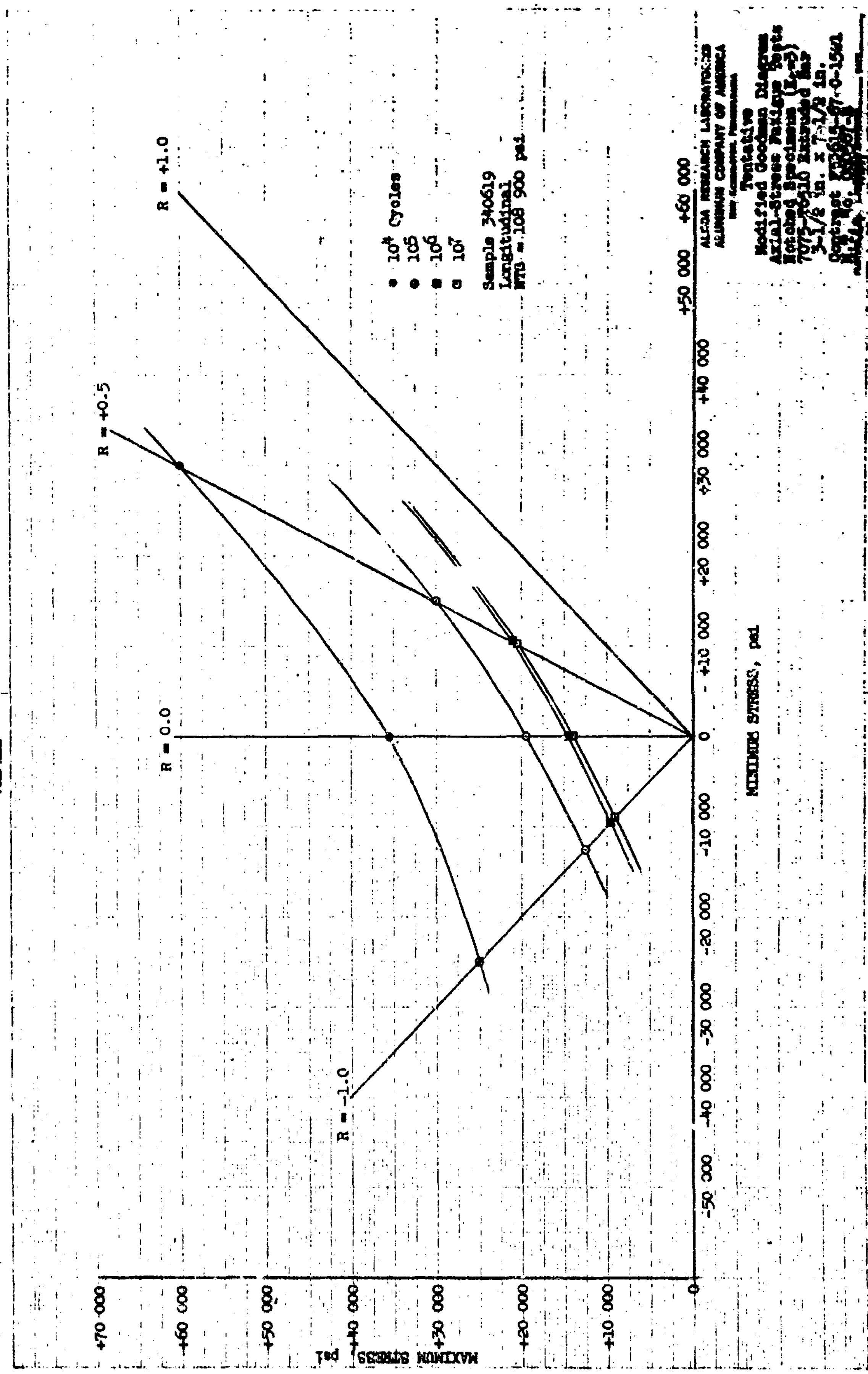

ALCOA RESEARCH LABORATORIES
NEW KENSINGTON, PA.
Axial-Stress Fatigue Curve
For
7075-T6510 Extruded Bar
3-1/2x7-1/2 in.
Contract F33615-67-C-1521
M. T. No. 060567-B
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.013"
K_t = 3
Longitudinal
Stress
R
+0.5
0
-1.0
Did not fail
MAXIMUM STRESS, PSI
60 000
50 000
40 000
30 000
20 000
10 000
0
CYCLES
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Fig. 1



R = +0.5
R = 0.0
R = +1.0
R = -1.0
10^4 Cycles
10^5
10^6
10^7
Sample 340619
Longitudinal
NTS = 108 900 psi
MAXIMUM STRESS, psi
+70 000
+60 000
+50 000
+40 000
+30 000
+20 000
+10 000
0
-50 000 -40 000 -30 000 -20 000 -10 000 0 +10 000 +20 000 +30 000 +40 000 +50 000 +60 000
MINIMUM STRESS, psi
ALCOA RESEARCH LABORATORIES
ALUMINUM COMPANY OF AMERICA
Tentative
Modified Goodman Diagram
Axial-Stress Fatigue Tests
Notched Specimens
7075-T6510 Extruded Bar
3-1/2 in. x 7-1/2 in.
FOLD HERE
FOLD HERE

Fig. 2

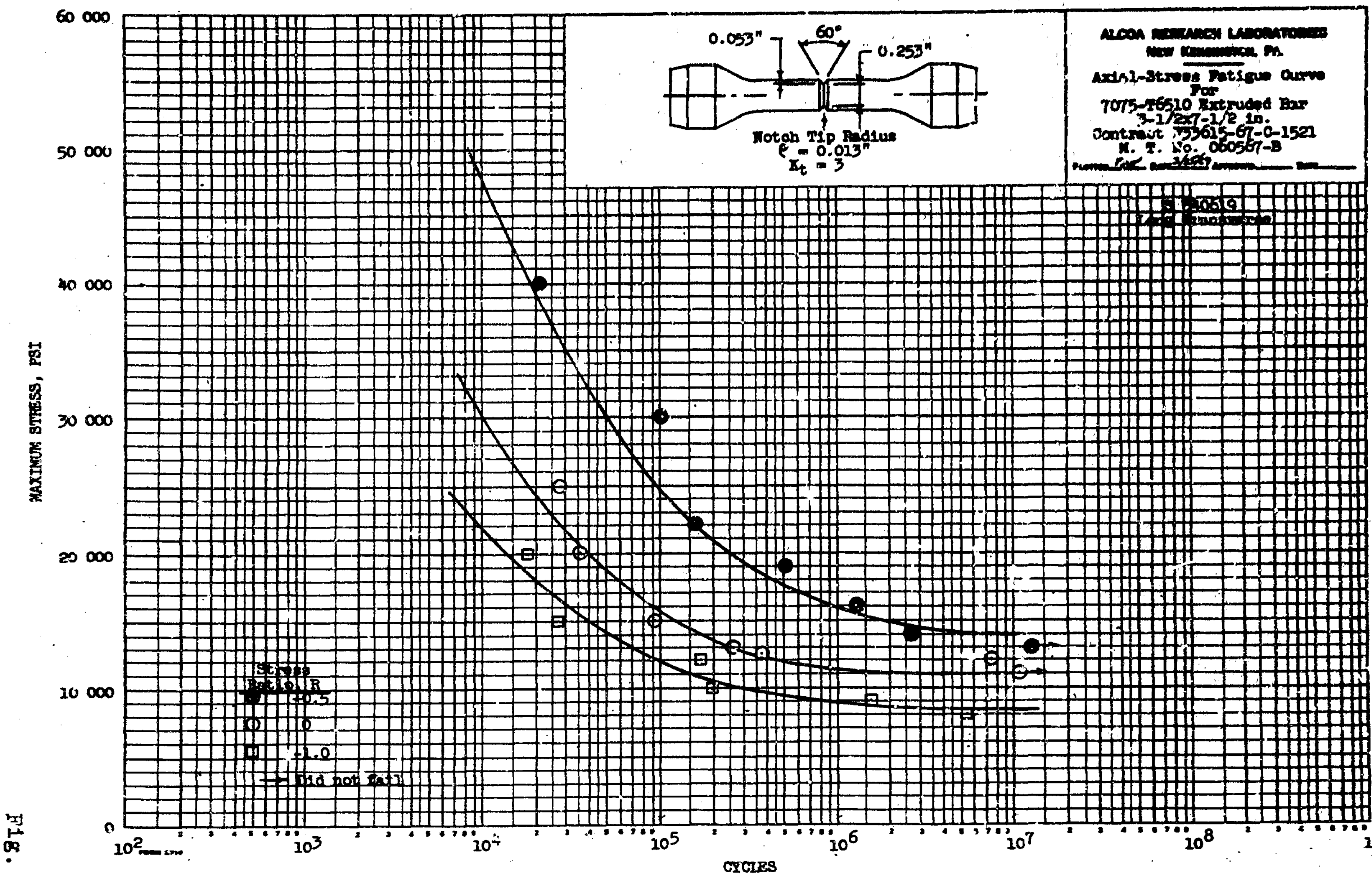
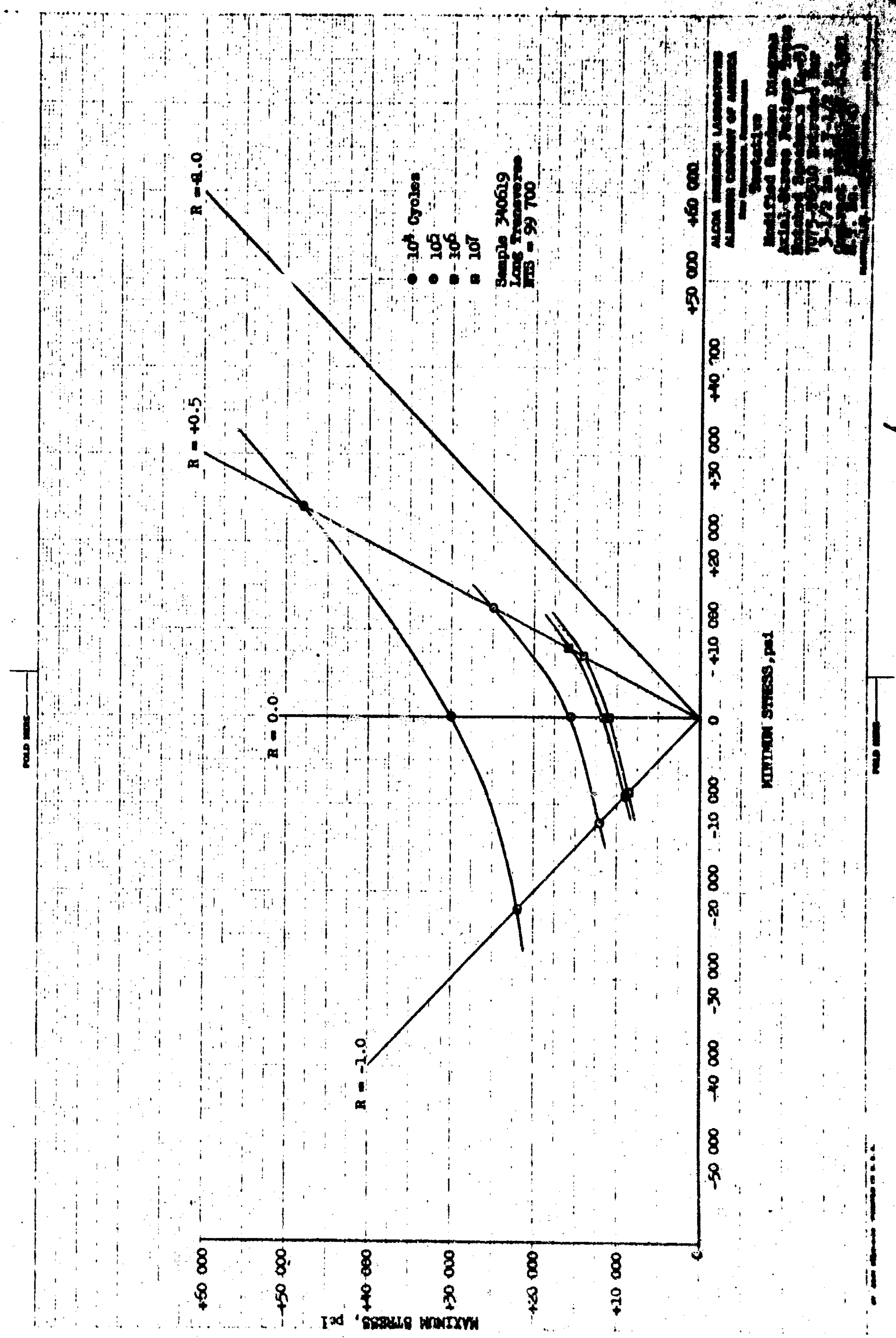
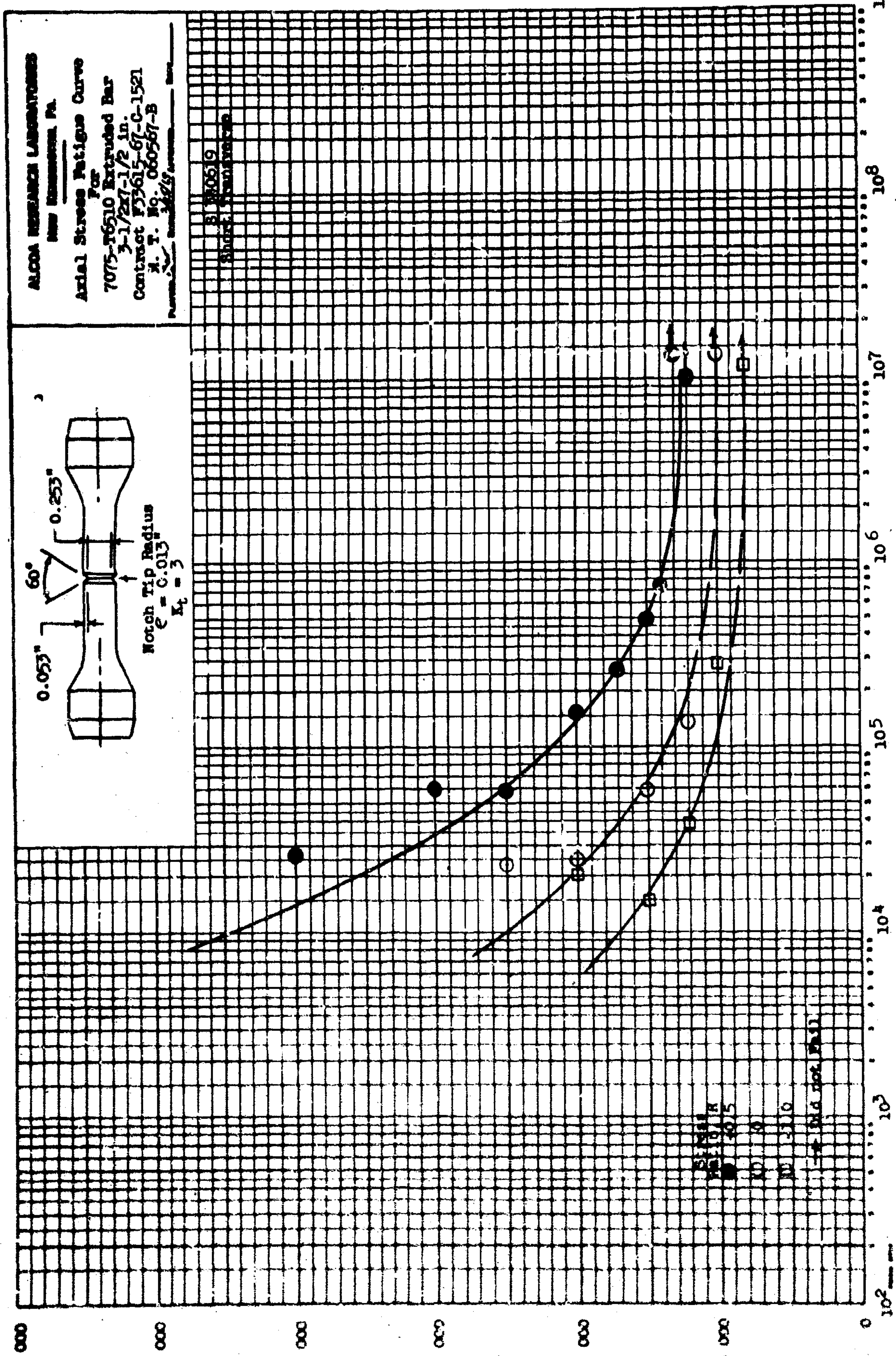

ALCOA RESEARCH LABORATORIES
NEW KENSINGTON, PA.
Axial-Stress Fatigue Curve
For
7075-T6510 Extruded Bar
3-1/2x7-1/2 in.
Contract F33615-67-C-1521
M. T. No. 060567-B
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.013"
K_t = 3
Stress Ratio, R
+0.5
0
-1.0
Did not fail
MAXIMUM STRESS, PSI
60 000
50 000
40 000
30 000
20 000
10 000
0
CYCLES
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Fig. 3



R = -1.0
R = 0.0
R = +0.5
R = +1.0
10^4 Cycles
10^5
10^6
10^7
Sample 340619
Long Transverse
UTS = 99 700
MINIMUM STRESS, psi
MAXIMUM STRESS, psi
-50 000
-40 000
-30 000
-20 000
-10 000
0
+10 000
+20 000
+30 000
+40 000
+50 000
+60 000

Fig. 4



ALCOA RESEARCH LABORATORIES
Axial Stress Fatigue Curve
For
7075-T6510 Extruded Bar
3-1/2x7-1/2 in.
Contract F33615-67-C-1521
W. T. No. 060567-B
0.053"
0.253"
60°
Notch Tip Radius
ρ = 0.013"
K_t = 3
CYCLES
MAXIMUM STRESS, PSI
60 000
50 000
40 000
30 000
20 000
10 000
0
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Fig. 5

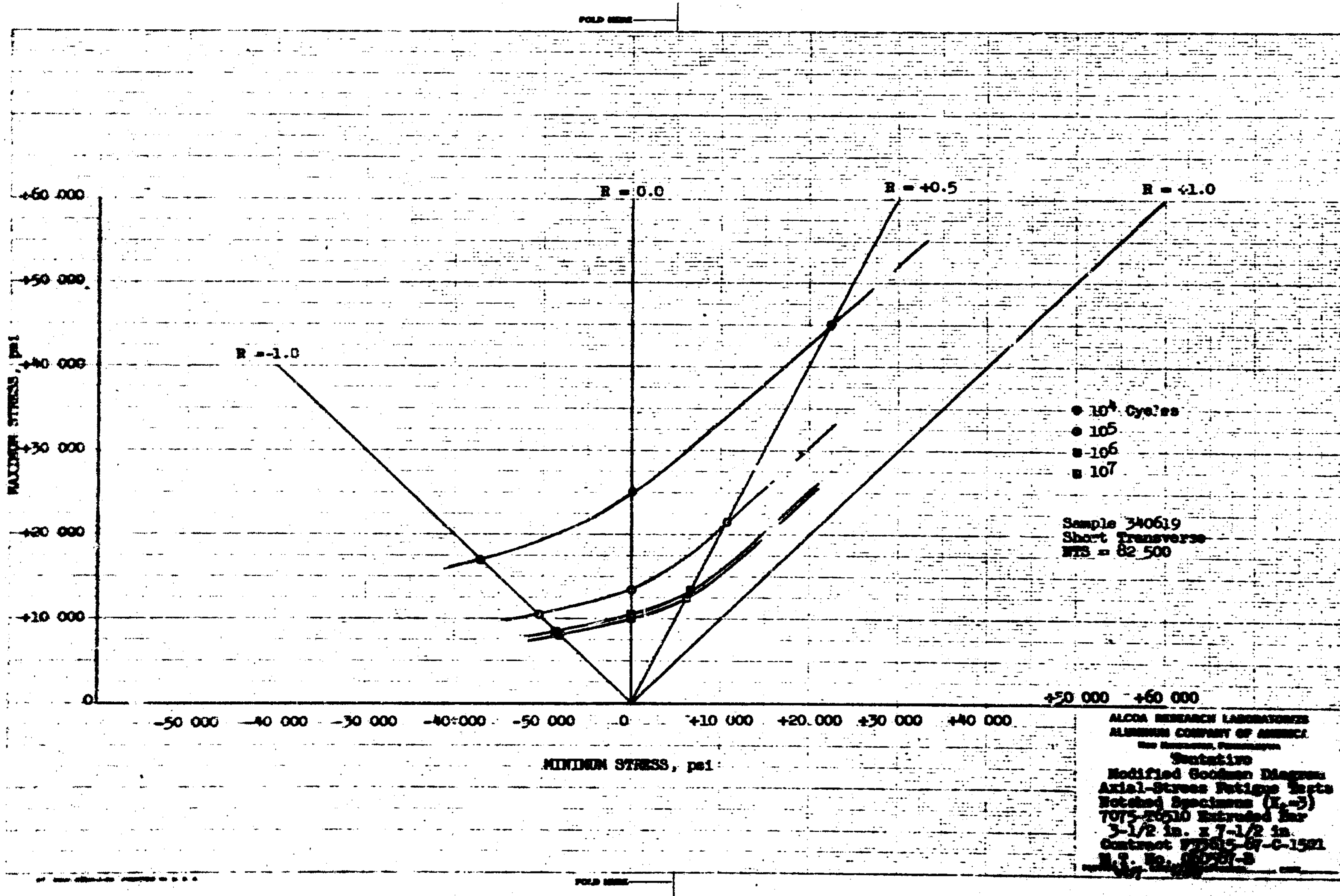

R = 0.0
R = +0.5
R = +1.0
R = -1.0
MAXIMUM STRESS, psi
+60 000
+50 000
+40 000
+30 000
+20 000
+10 000
0
-50 000
-40 000
-30 000
-20 000
-10 000
0
+10 000
+20 000
+30 000
+40 000
+50 000
+60 000
MINIMUM STRESS, psi
10⁴ Cycles
10⁵
10⁶
10⁷
Sample 340619
Short Transverse
NTS = 82 500
ALCOA RESEARCH LABORATORIES
ALUMINUM COMPANY OF AMERICA
Tentative
Modified Goodman Diagram
Axial-Stress Fatigue Tests
Notched Specimens
7075-T6510 Extruded Bar
3-1/2 in. x 7-1/2 in.
FOLD HERE

Fig. 6

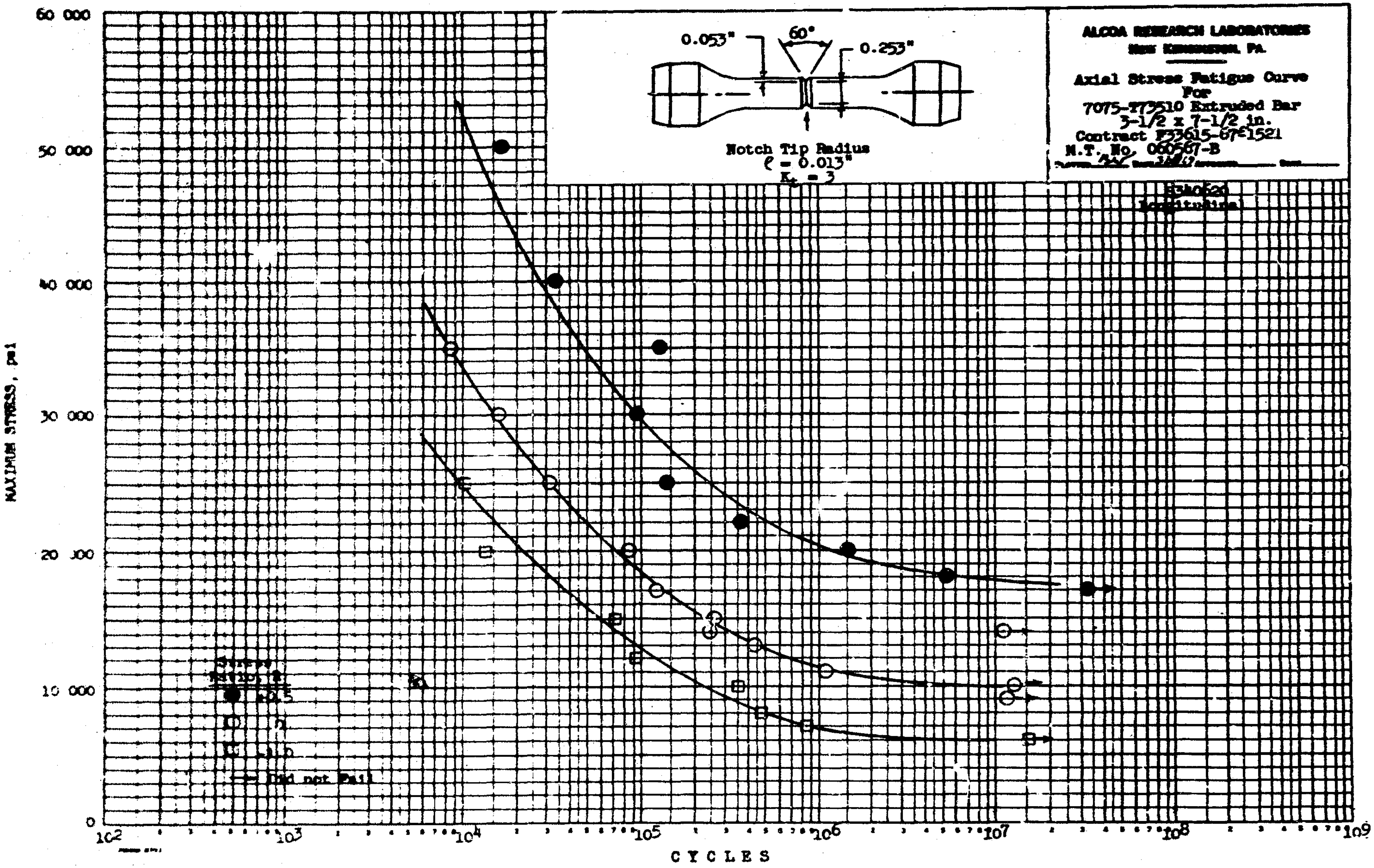
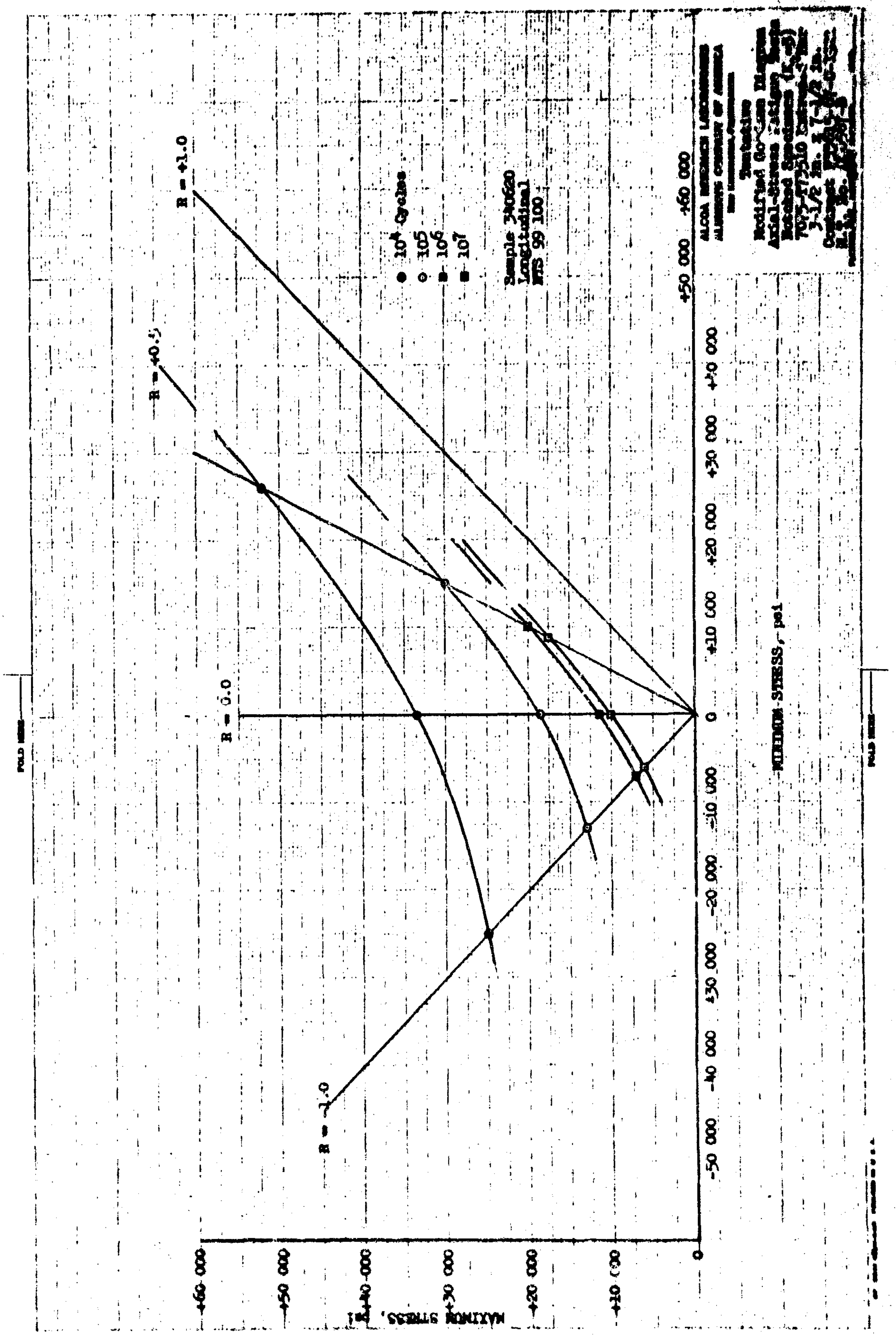
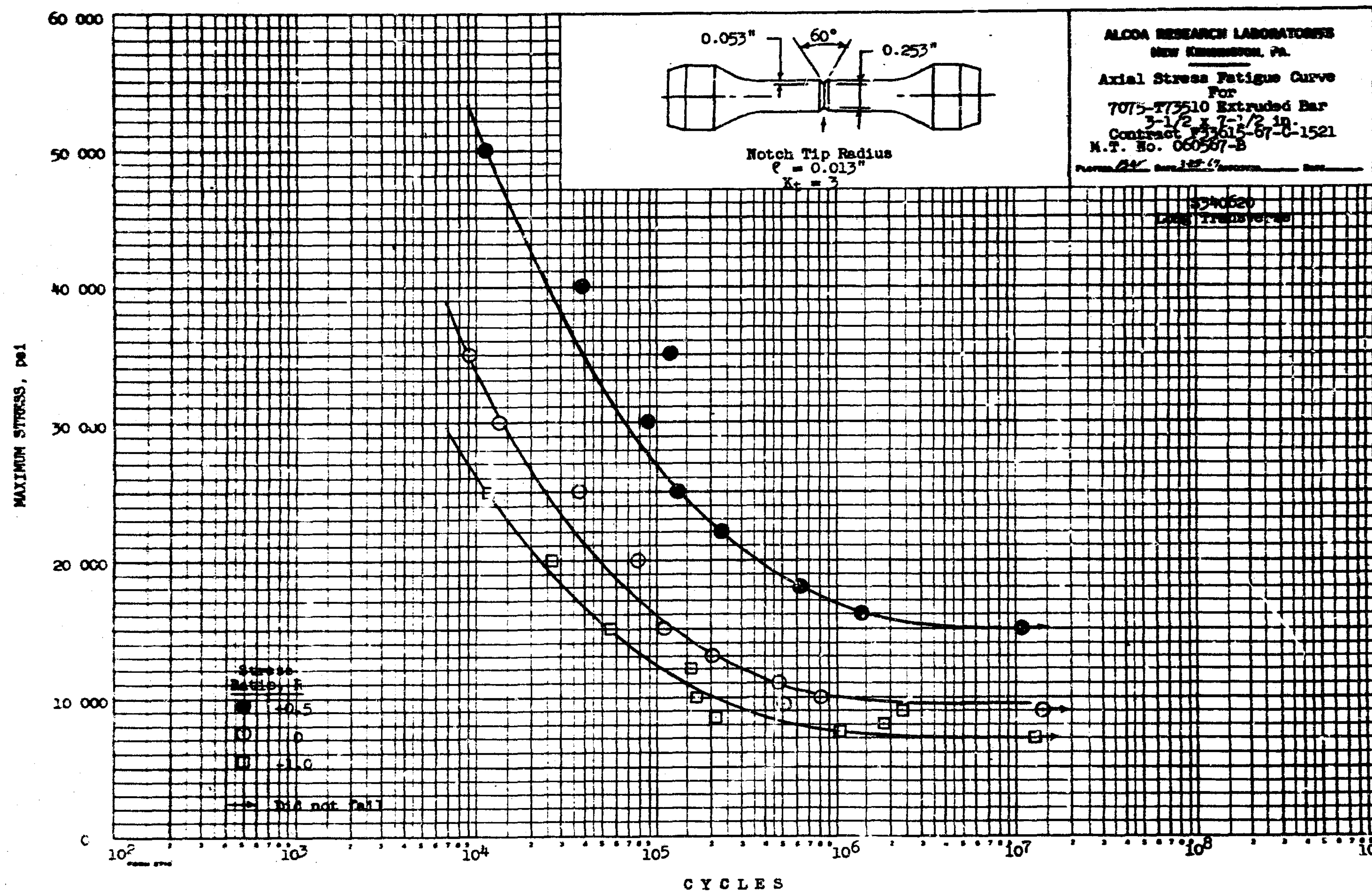

ALCOA RESEARCH LABORATORIES
New Kensington, Pa.
Axial Stress Fatigue Curve
For
7075-T73510 Extruded Bar
3-1/2 x 7-1/2 in.
Contract F33615-67C1521
M.T. No. 060567-B
Longitudinal
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.013"
Kt = 3
Stress Ratio, R
Did not Fail
MAXIMUM STRESS, psi
60 000
50 000
40 000
30 000
20 000
10 000
0
CYCLES
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

Fig. 7



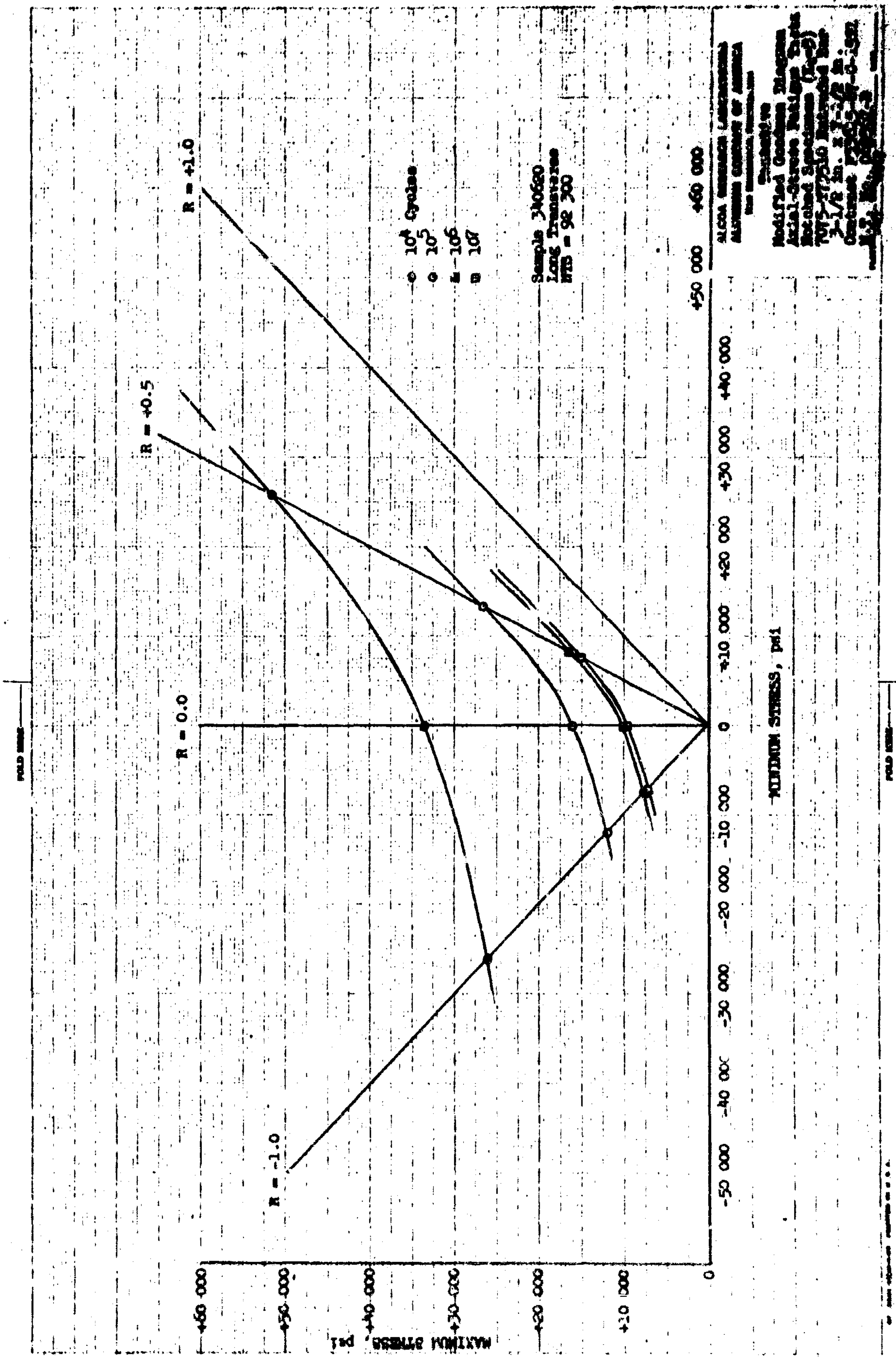
R = +1.0
R = +0.5
R = 0.0
R = -1.0
Sample 340620
Longitudinal
MINIMUM STRESS, psi
MAXIMUM STRESS, psi
-50 000
-40 000
-30 000
-20 000
-10 000
0
+10 000
+20 000
+30 000
+40 000
+50 000
+60 000

Fig. 8



ALCOA RESEARCH LABORATORIES
NEW KENSINGTON, PA.
Axial Stress Fatigue Curve
For
7075-T73510 Extruded Bar
3-1/2 x 7-1/2 in.
Contract F33615-67-C-1521
M.T. No. 060507-B
S340620
Long Transverse
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.013"
Kt = 3
Stress Ratio, R
+0.5
0
+1.0
Did not fail
MAXIMUM STRESS, psi
CYCLES
60 000
50 000
40 000
30 000
20 000
10 000
0
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

Fig. 9



R = +1.0
R = +0.5
R = 0.0
R = -1.0
10⁴ Cycles
10⁵
10⁶
10⁷
Sample 340620
Long Transverse
UTS = 92 300
MAXIMUM STRESS, psi
MINIMUM STRESS, psi
0
+10 000
+20 000
+30 000
+40 000
+50 000
+60 000
-10 000
-20 000
-30 000
-40 000
-50 000
Modified Goodman Diagram
Axial-Stress Fatigue Tests

Fig. 10

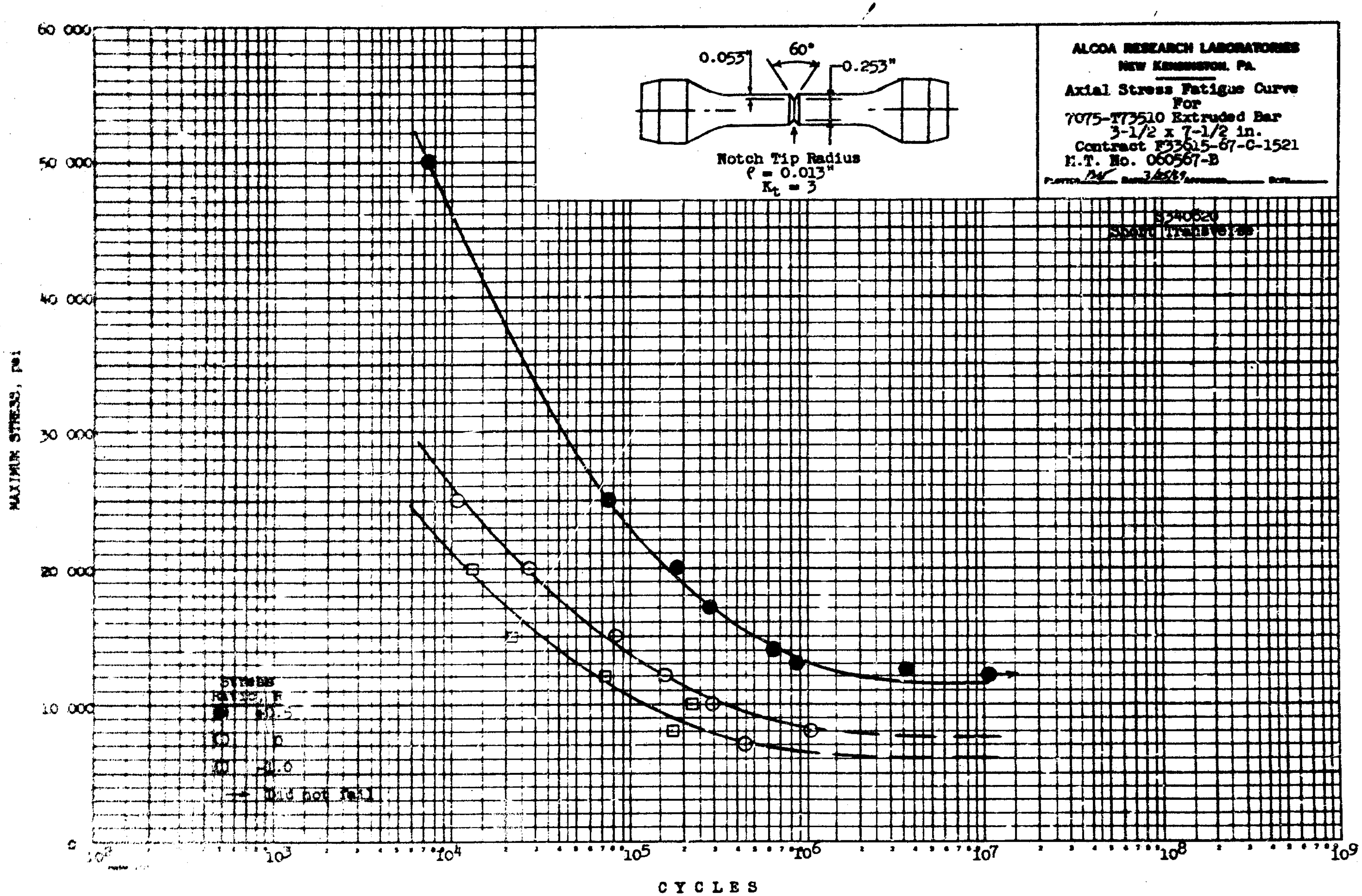

ALCOA RESEARCH LABORATORIES
NEW KENSINGTON, PA.
Axial Stress Fatigue Curve
For
7075-T73510 Extruded Bar
3-1/2 x 7-1/2 in.
Contract F33615-67-C-1521
H.T. No. 060567-B
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.013"
K_t = 3
MAXIMUM STRESS, psi
60 000
50 000
40 000
30 000
20 000
10 000
0
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
CYCLES
Did not fail

Fig. 11

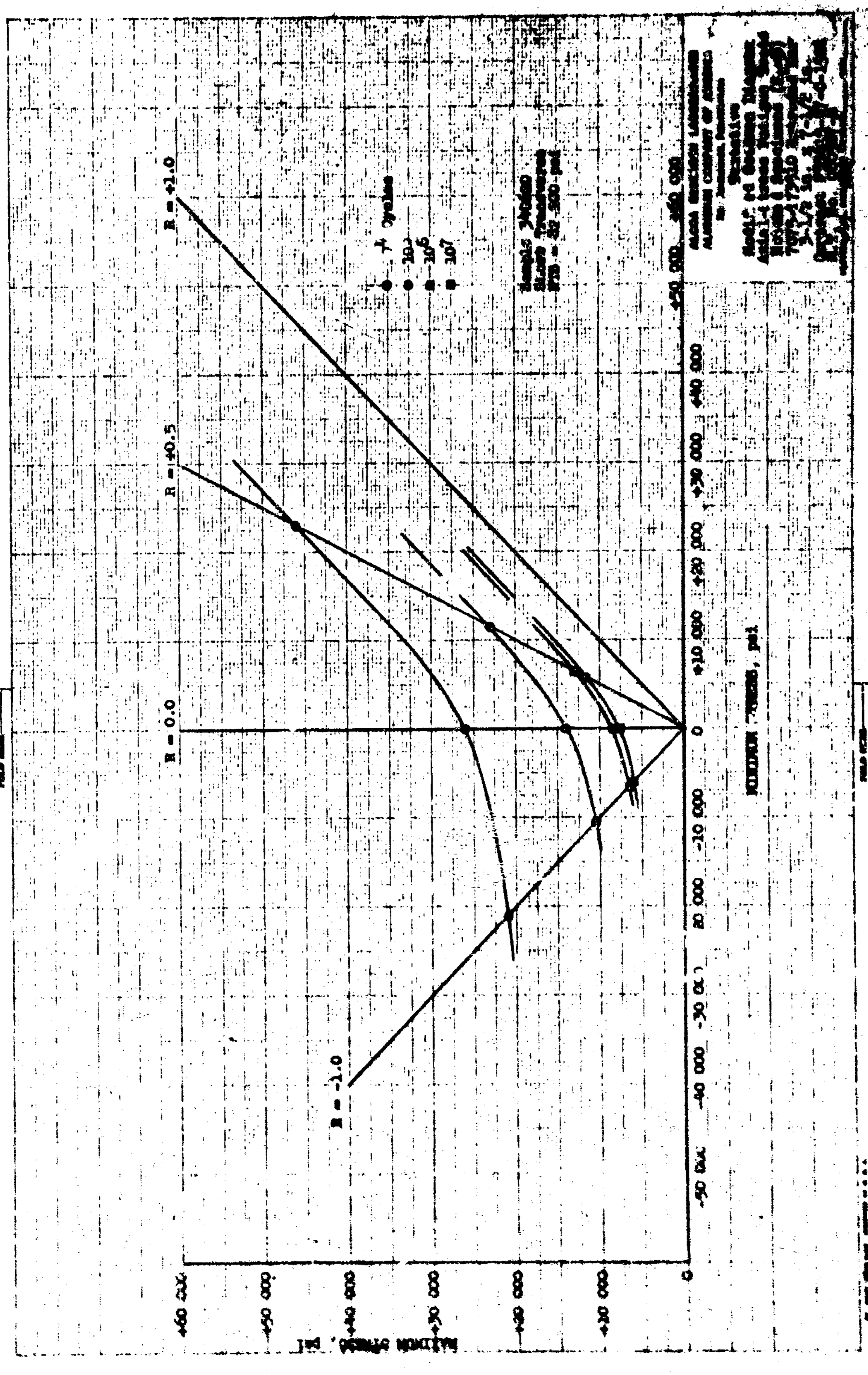


Fig. 12

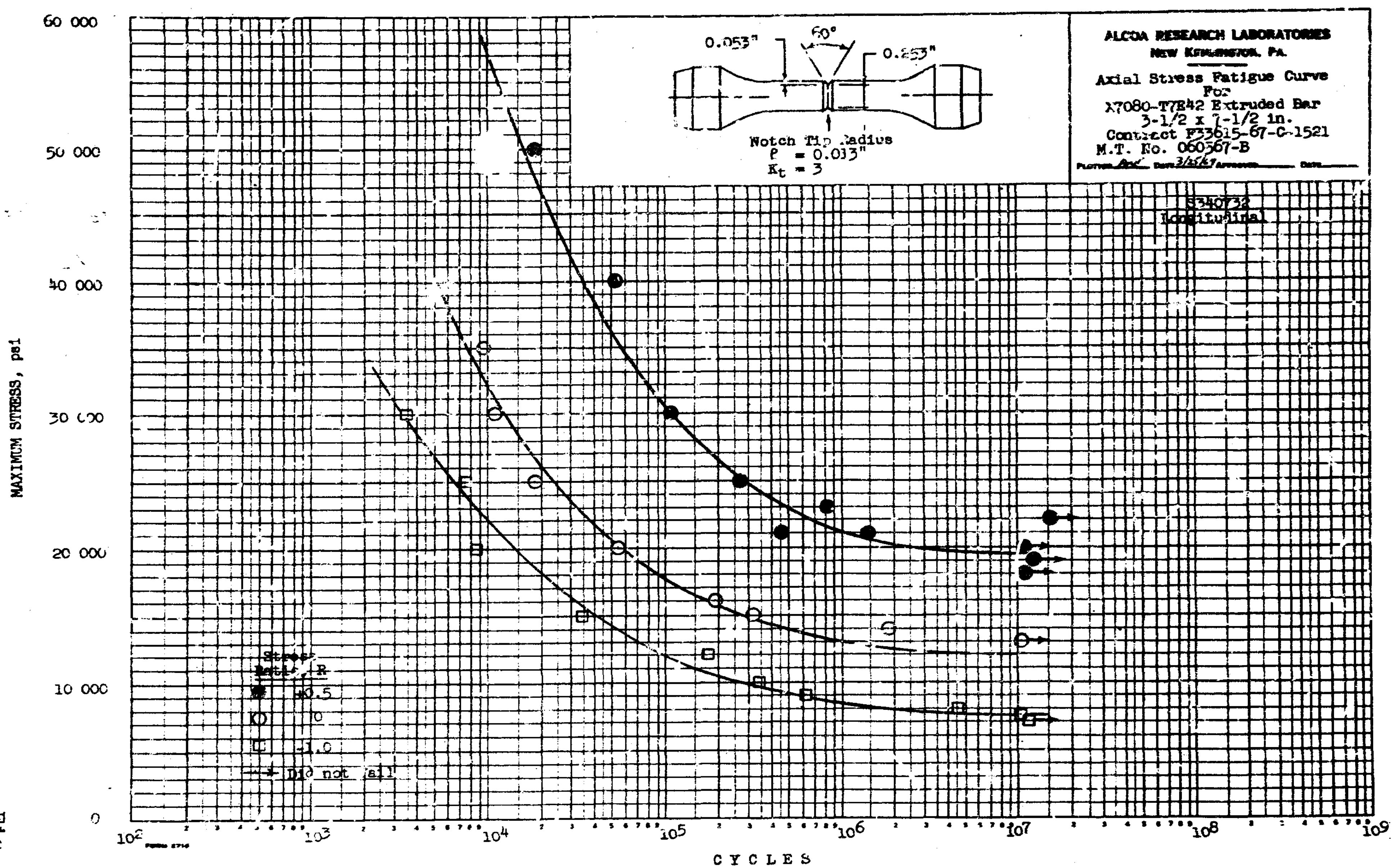
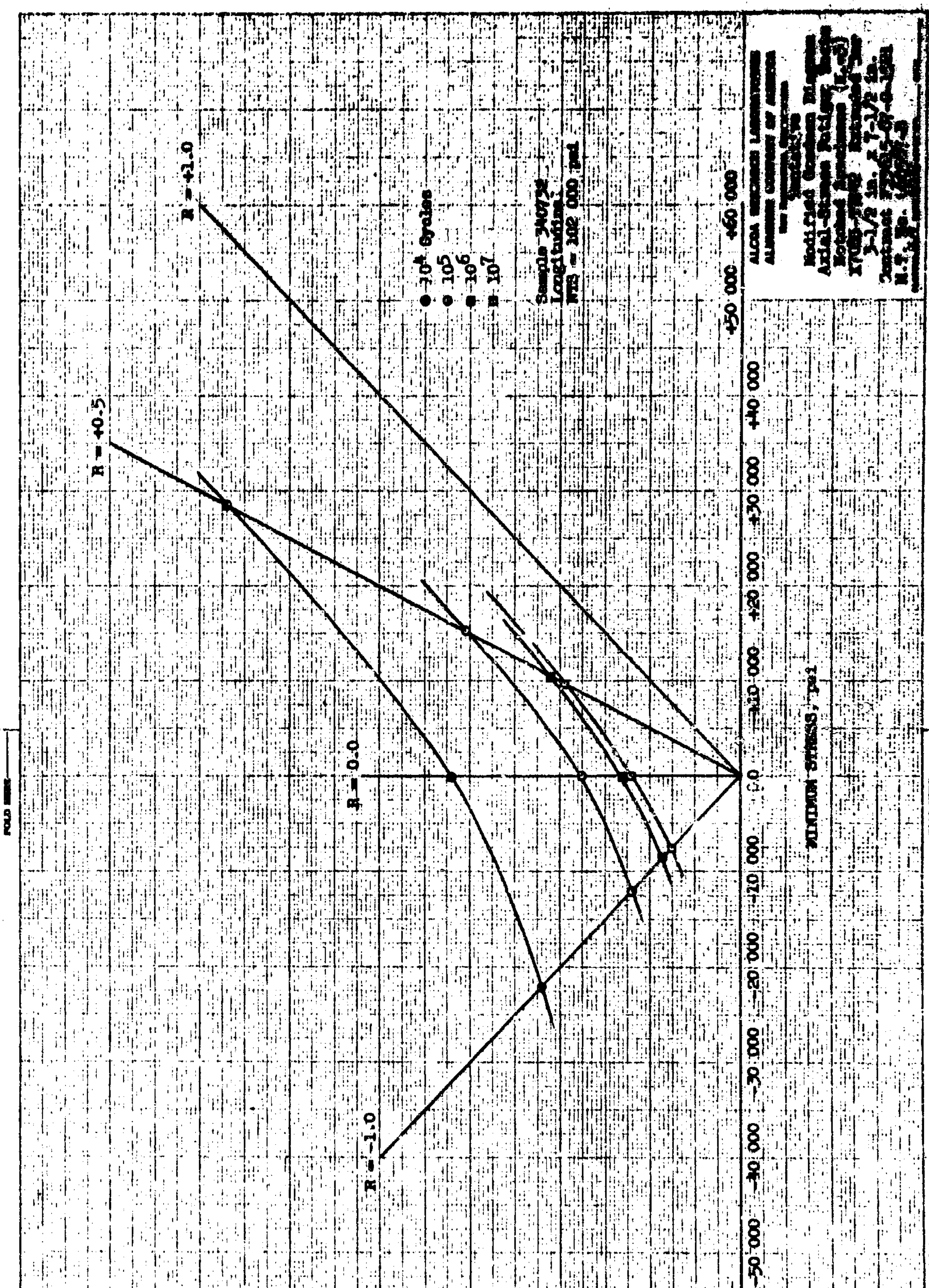
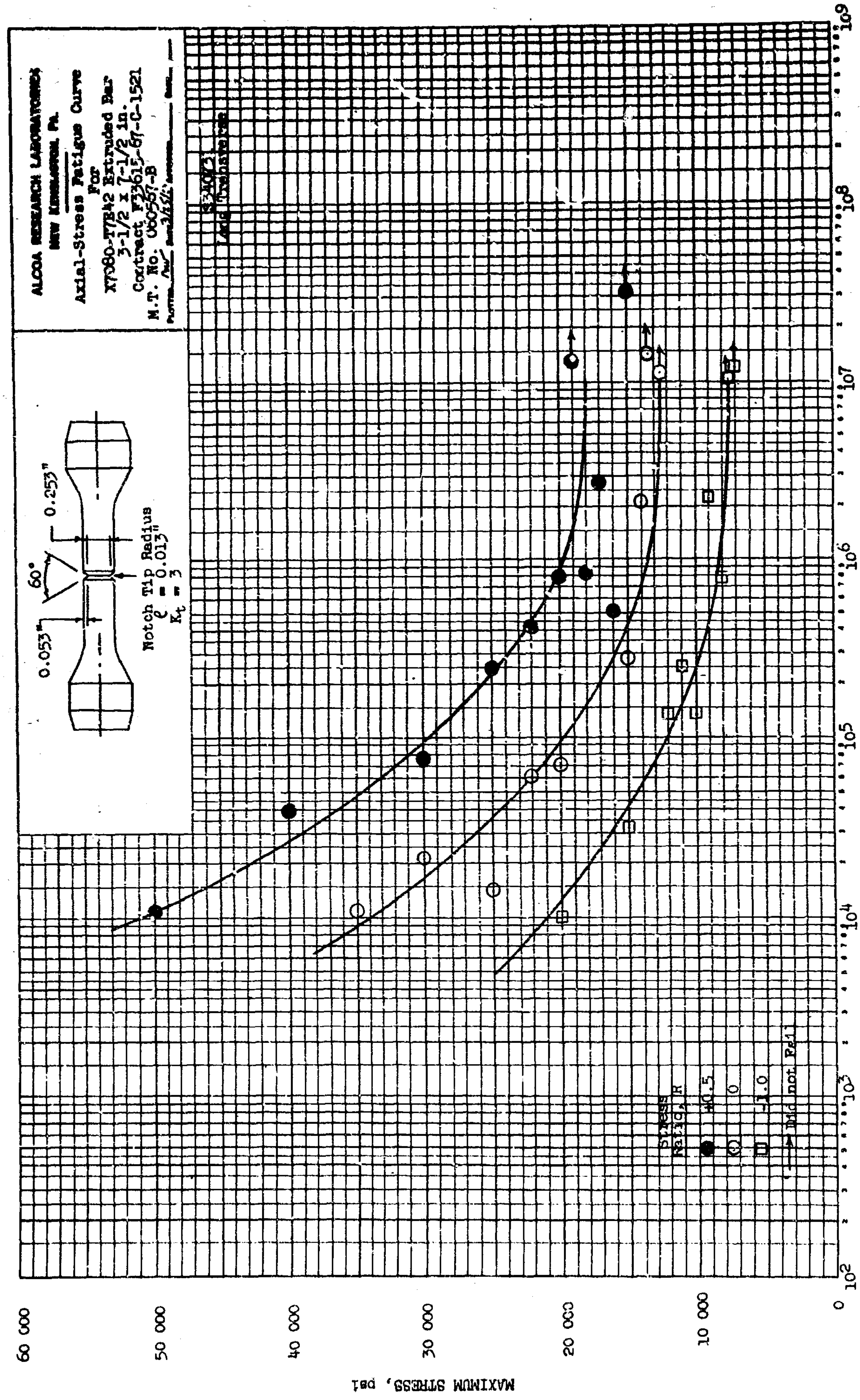

ALCOA RESEARCH LABORATORIES
NEW KENSINGTON, PA.
Axial Stress Fatigue Curve
For
X7080-T7E42 Extruded Bar
3-1/2 x 7-1/2 in.
Contract F33615-67-C-1521
M.T. No. 060567-B
S340732
Longitudinal
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.033"
K_t = 3
Stress Ratio, R
+0.5
0
-1.0
Did not fail
MAXIMUM STRESS, psi
60 000
50 000
40 000
30 000
20 000
10 000
0
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
CYCLES

Fig. 13



R = +1.0
R = +0.5
R = 0.0
R = -1.0
Cycles
Longitudinal
MINIMUM STRESS, psi
MAXIMUM STRESS, psi
+60 000
+50 000
+40 000
+30 000
+20 000
+10 000
0
-10 000
-20 000
-30 000
-40 000
-50 000

Fig. 14



ALCOA RESEARCH LABORATORIES
NEW KENSINGTON, PA.
Axial-Stress Fatigue Curve
For
X7080-T7E42 Extruded Bar
3-1/2 x 7-1/2 in.
Contract F33615-67-C-1521
M.T. No. 060557-B
S340073
Long Transverse
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.013"
Kt = 3
Stress Ratio, R
+0.5
0
-1.0
Did not Fail
MAXIMUM STRESS, psi
60 000
50 000
40 000
30 000
20 000
10 000
0
CYCLES
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Fig. 15

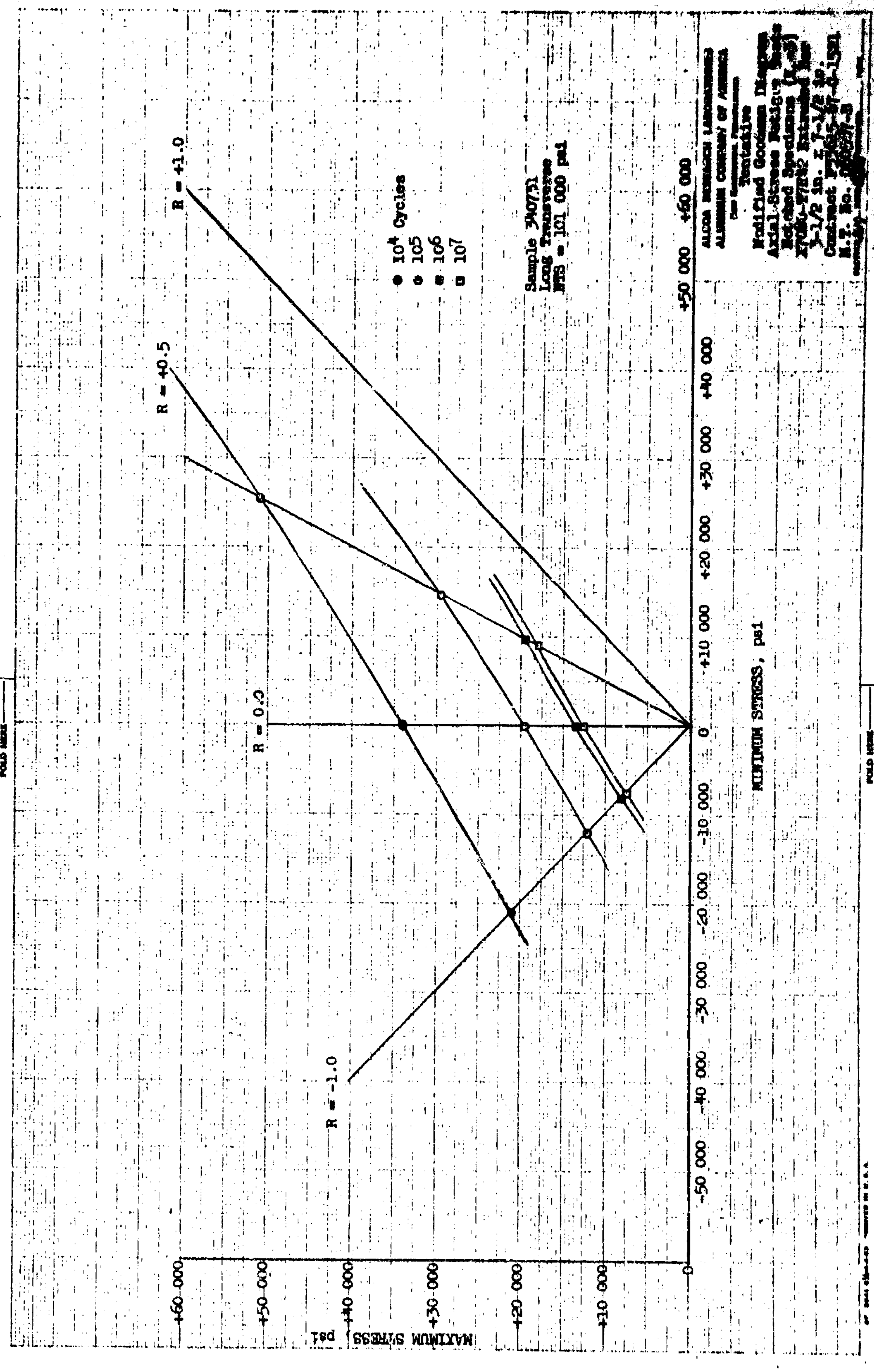
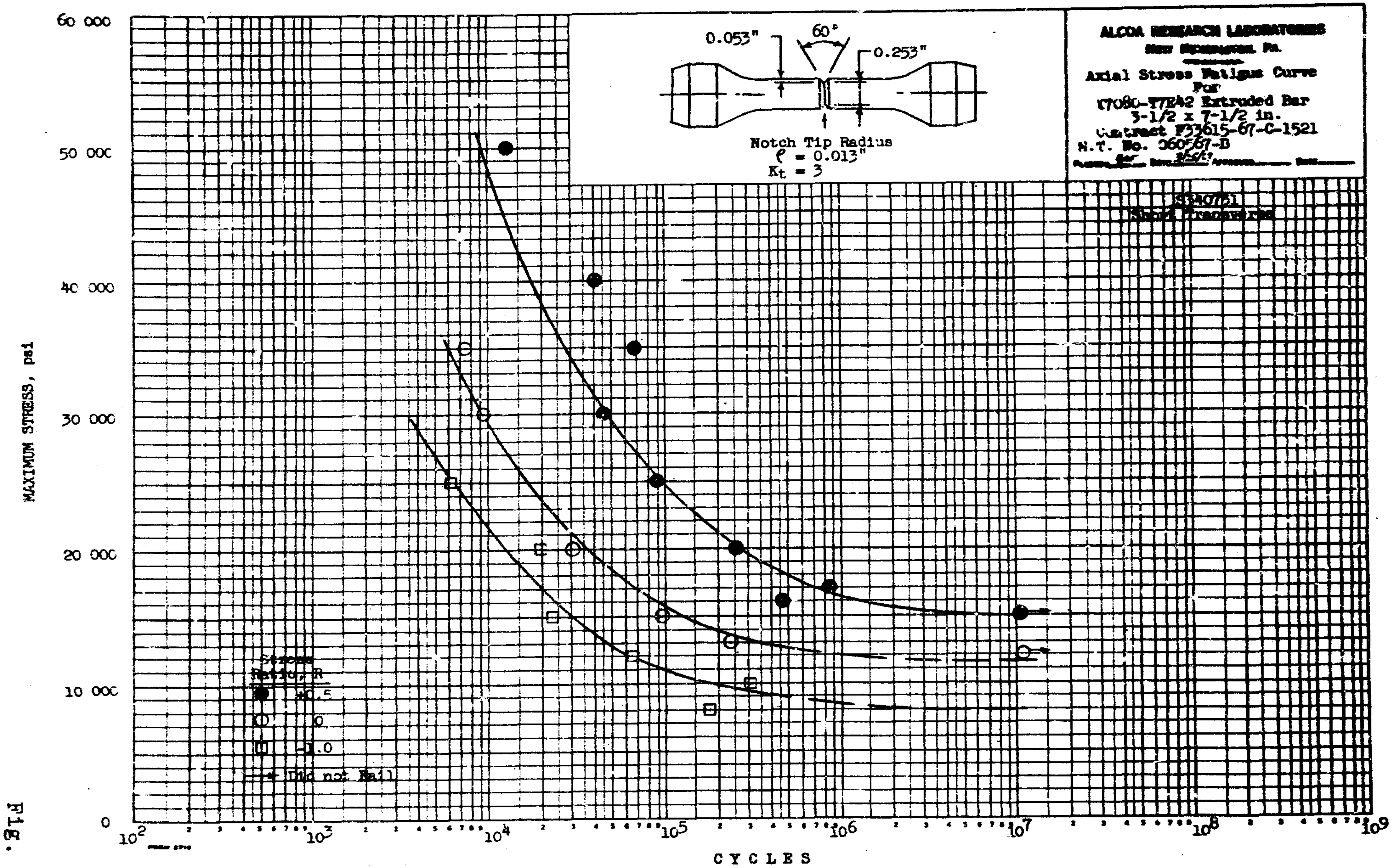
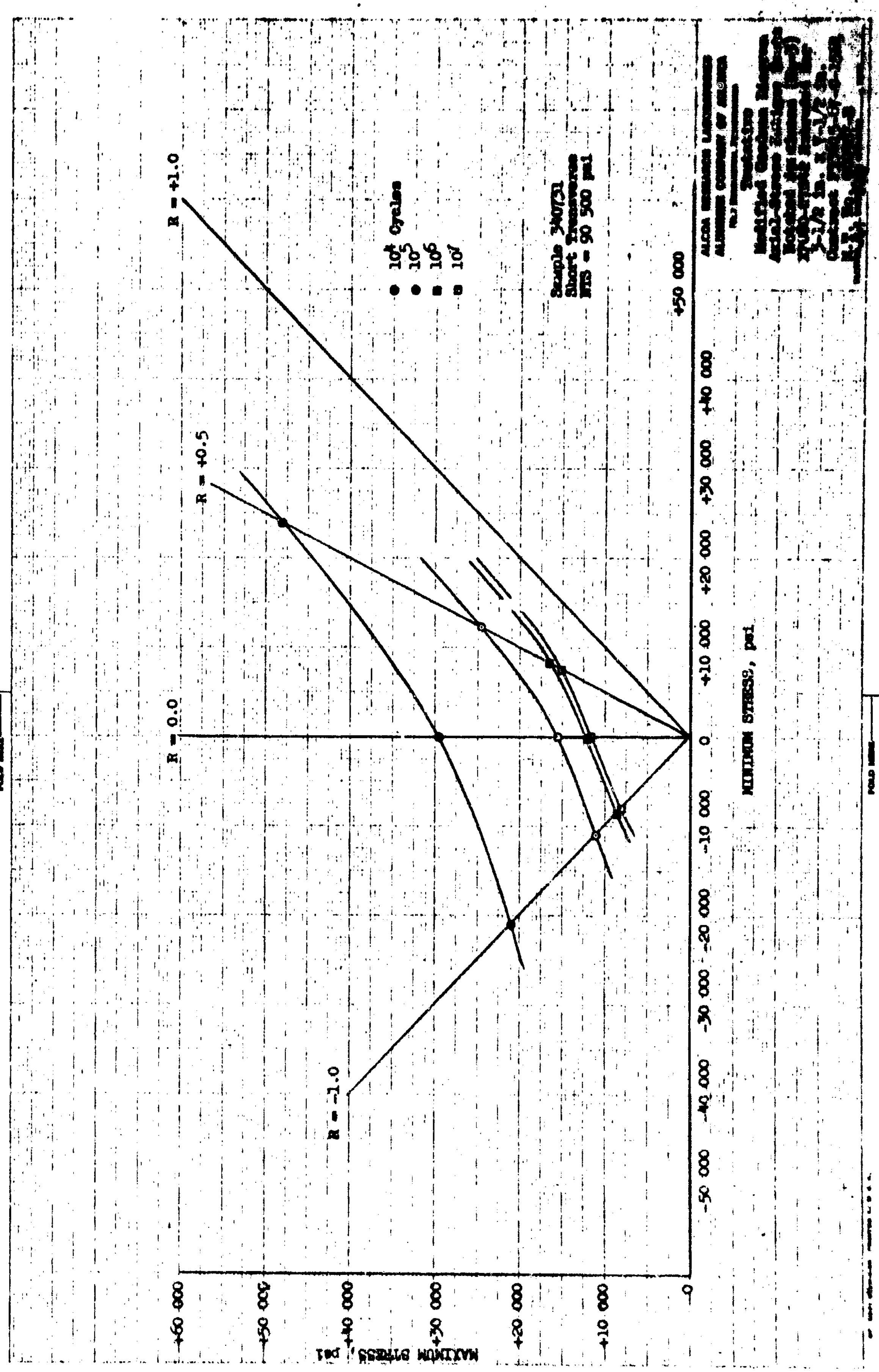

R = +1.0
R = +0.5
R = 0.0
R = -1.0
10^4 Cycles
10^5
10^6
10^7
Sample 340751
Long Transverse
BTS = 101 000 psi
Tentative
Modified Goodman Diagram
Axial-Stress Fatigue
Notched Specimens
MAXIMUM STRESS, psi
MINIMUM STRESS, psi
+60 000
+50 000
+40 000
+30 000
+20 000
+10 000
0
-10 000
-20 000
-30 000
-40 000
-50 000
FOLD HERE

Fig. 16



ALCOA RESEARCH LABORATORIES
New Kensington, Pa.
Axial Stress Fatigue Curve
For
X7080-T7E42 Extruded Bar
3-1/2 x 7-1/2 in.
Contract F33615-67-C-1521
N.T. No. 060567-B
S340751
Short Transverse
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.013"
Kt = 3
Stress Ratio, R
+0.5
0
-1.0
Did not Fail
MAXIMUM STRESS, psi
CYCLES
60 000
50 000
40 000
30 000
20 000
10 000
0
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Fig. 17



R = +1.0
R = +0.5
R = 0.0
R = -1.0
10^4 Cycles
10^5
10^6
10^7
Sample 340731
Short Transverse
UTS = 50 500 psi
MAXIMUM STRESS, psi
MINIMUM STRESS, psi
+60 000
+50 000
+40 000
+30 000
+20 000
+10 000
0
-50 000
-40 000
-30 000
-20 000
-10 000
0
+10 000
+20 000
+30 000
+40 000
+50 000

Fig. 18

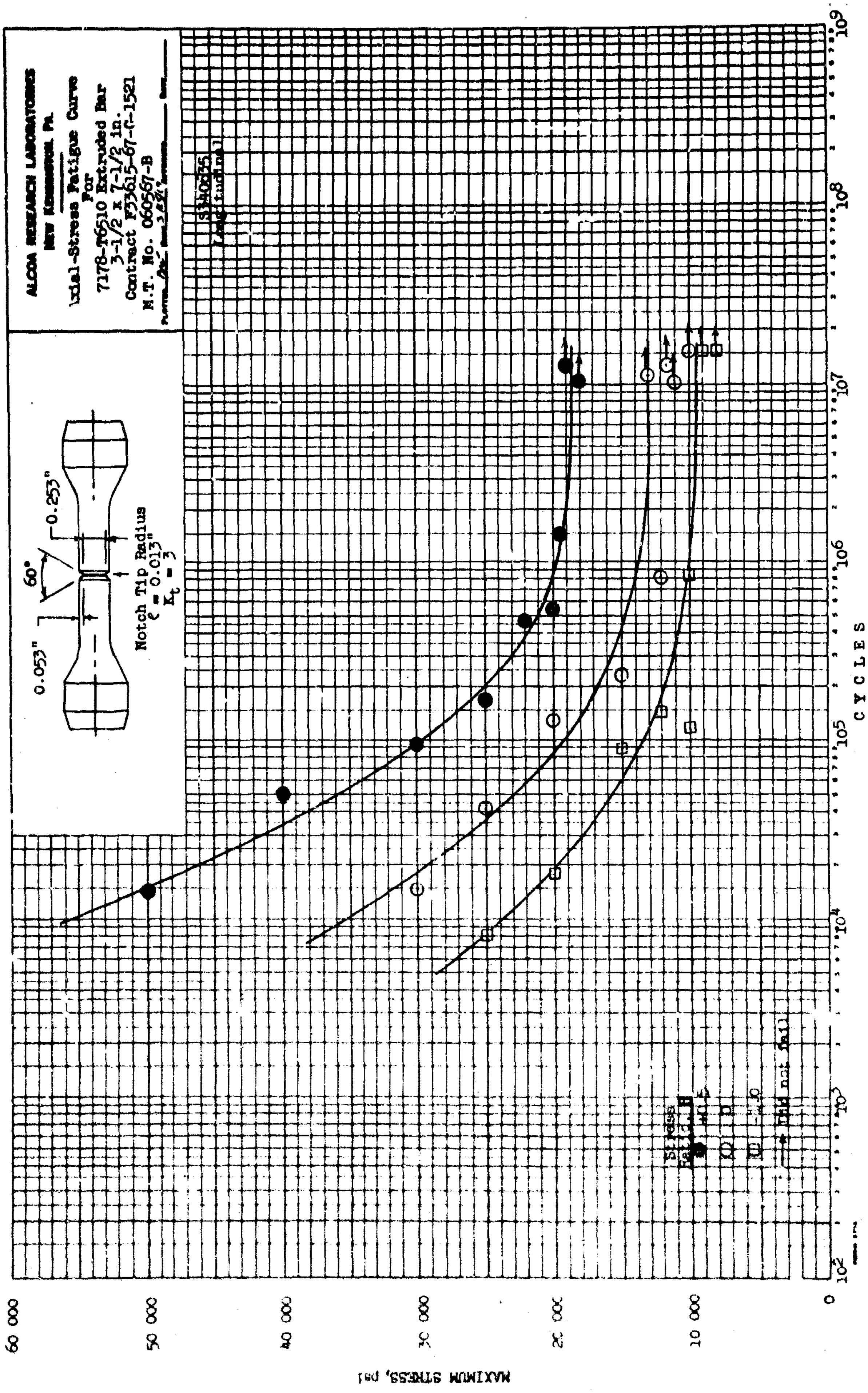
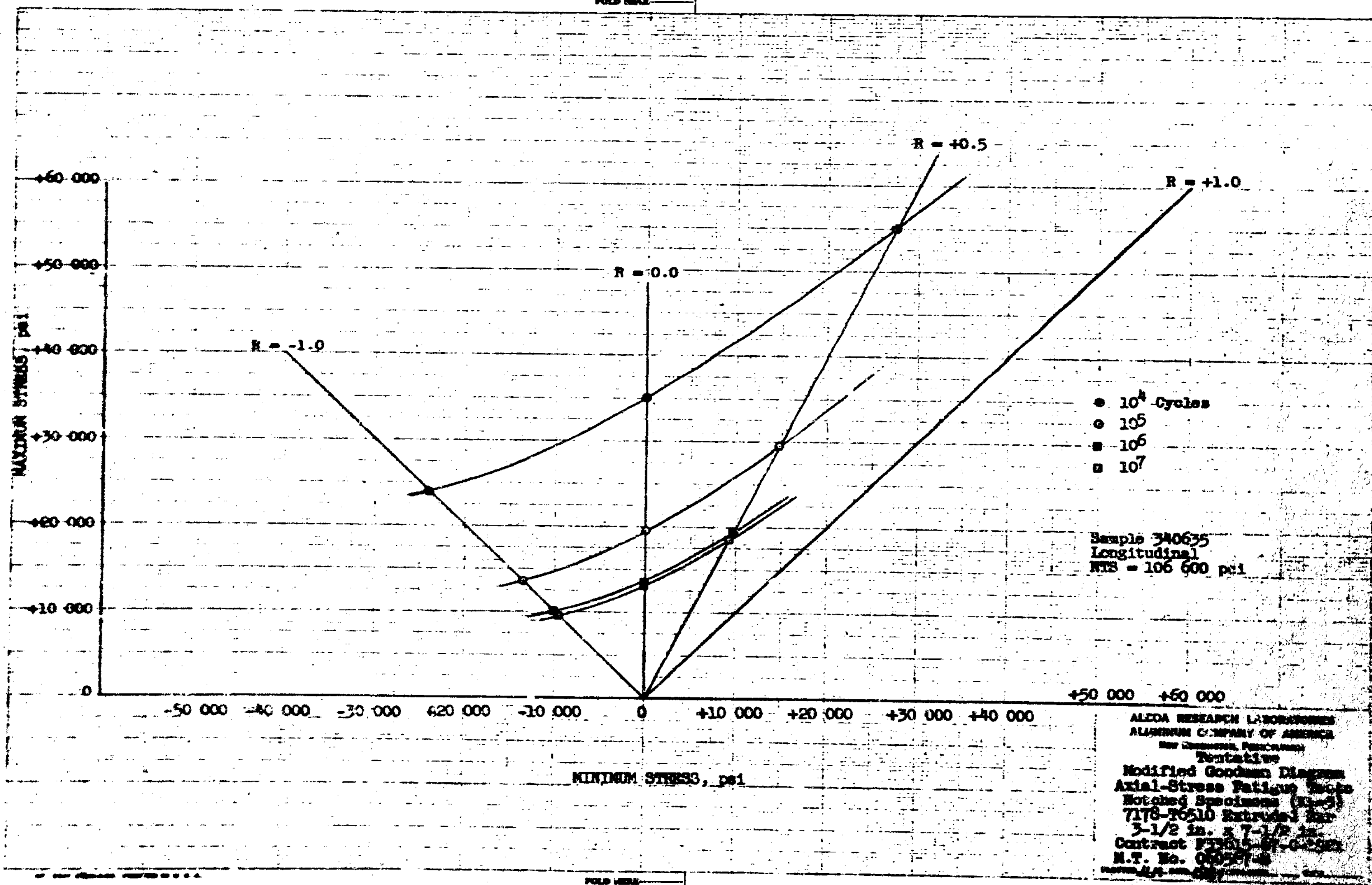
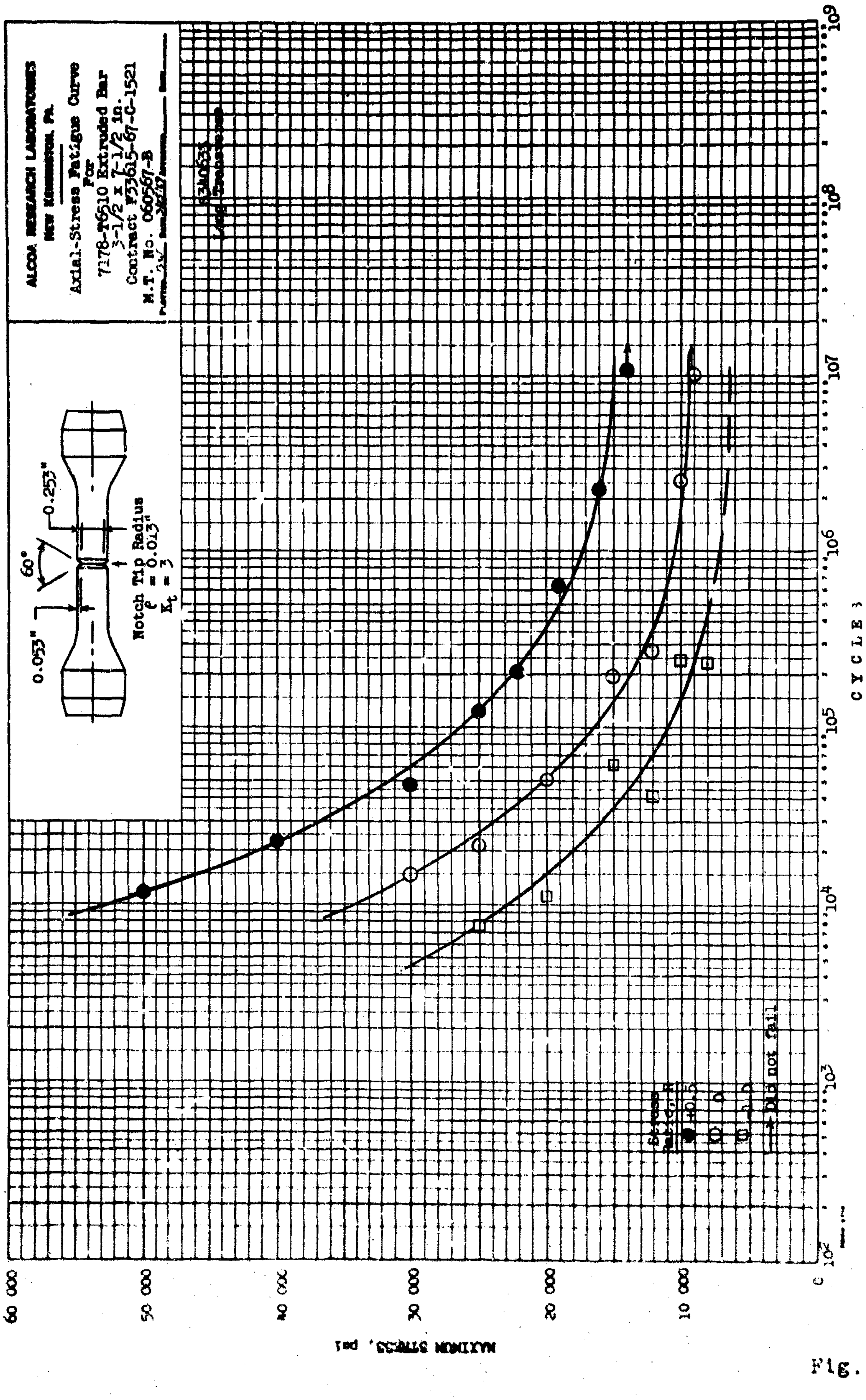

ALCOA RESEARCH LABORATORIES
NEW KENSINGTON, PA.
Axial-Stress Fatigue Curve
For
7178-T6510 Extruded Bar
3-1/2 x 7-1/2 in.
Contract F33615-67-C-1521
M.T. No. 060567-B
S140655
Longitudinal
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.013"
Kt = 3
Stress
Did not fail
60 000
50 000
40 000
30 000
20 000
10 000
0
MAXIMUM STRESS, psi
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
CYCLES

Fig. 19



R = +1.0
R = +0.5
R = 0.0
R = -1.0
10^4 Cycles
10^5
10^6
10^7
Sample 340635
Longitudinal
NTS = 106 600 psi
MAXIMUM STRESS, psi
0
+10 000
+20 000
+30 000
+40 000
+50 000
+60 000
MINIMUM STRESS, psi
-50 000
-40 000
-30 000
-20 000
-10 000
0
+10 000
+20 000
+30 000
+40 000
+50 000
+60 000
ALCOA RESEARCH LABORATORIES
ALUMINUM COMPANY OF AMERICA
Tentative
Modified Goodman Diagram
Axial-Stress Fatigue Tests
Notched Specimens
7178-T6510 Extruded Bar
3-1/2 in. x 7-1/2 in.
Contract
M.T. No.

Fig. 20



ALCOA RESEARCH LABORATORIES
NEW KENSINGTON, PA.
Axial-Stress Fatigue Curve
For
7178-T6510 Extruded Bar
3-1/2 x 7-1/2 in.
Contract F33615-67-C-1521
M.T. No. 060587-B
60°
0.253"
0.053"
Notch Tip Radius
ρ = 0.013"
Kt = 3
Stress Ratio, R
+0.5
0
-1.0
Did not fail
MAXIMUM STRESS, psi
60 000
50 000
40 000
30 000
20 000
10 000
0
CYCLES
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
10⁹

Fig. 21

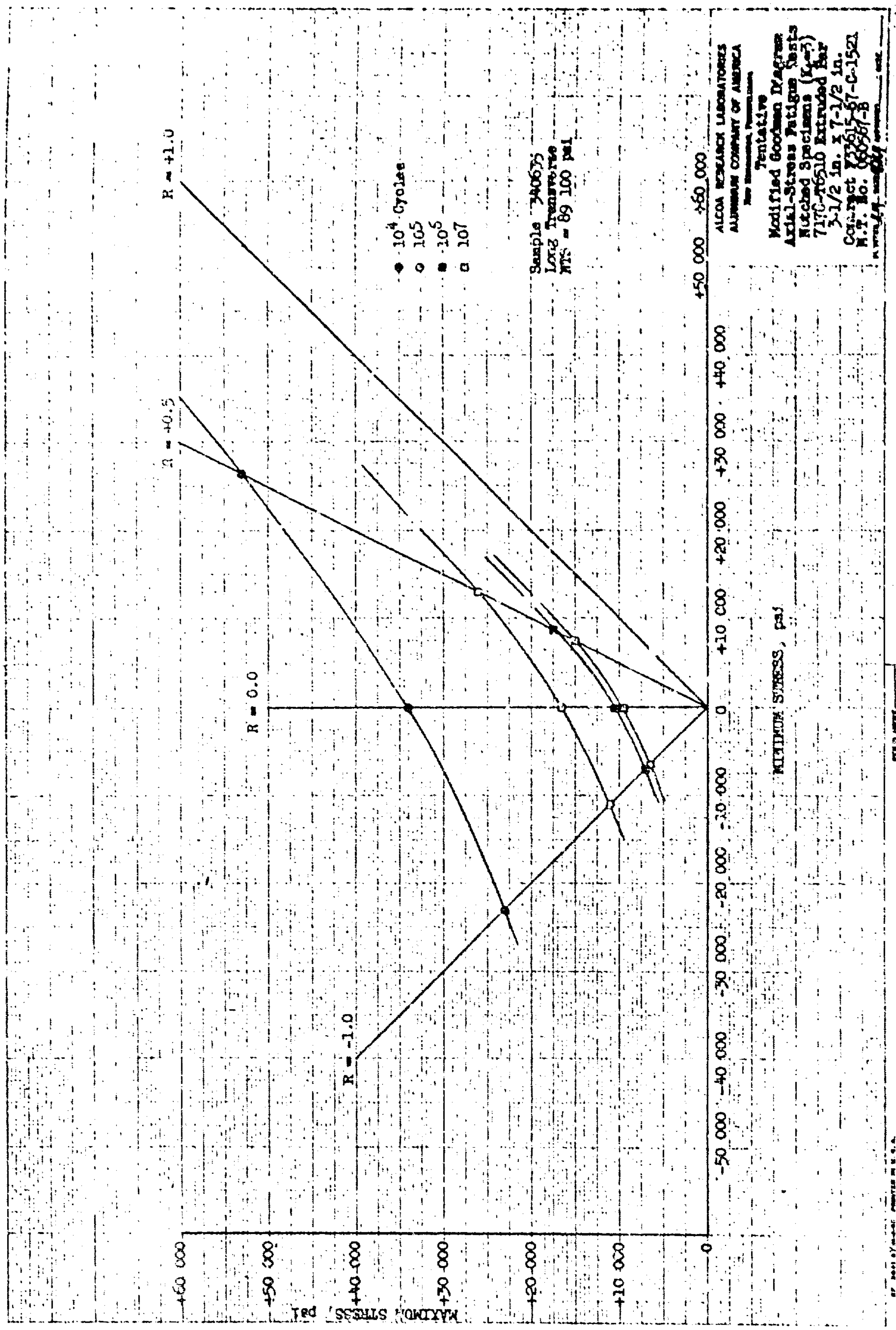

R = +1.0
R = +0.5
R = 0.0
R = -1.0
● 10^4 Cycles
○ 10^5
■ 10^6
□ 10^7
Sample 340675
Long Transverse
NTS = 89 100 psi
MAXIMUM STRESS, psi
MINIMUM STRESS, psi
+60 000
+50 000
+40 000
+30 000
+20 000
+10 000
0
-50 000
-40 000
-30 000
-20 000
-10 000
+10 000
+20 000
+30 000
+40 000
+50 000
+60 000
ALCOA RESEARCH LABORATORIES
ALUMINUM COMPANY OF AMERICA
Tentative
Modified Goodman Diagram
Axial-Stress Fatigue Tests
Notched Specimens (K_t=3)
7175-T6510 Extruded Bar
3-1/2 in. x 7-1/2 in.

Fig. 22

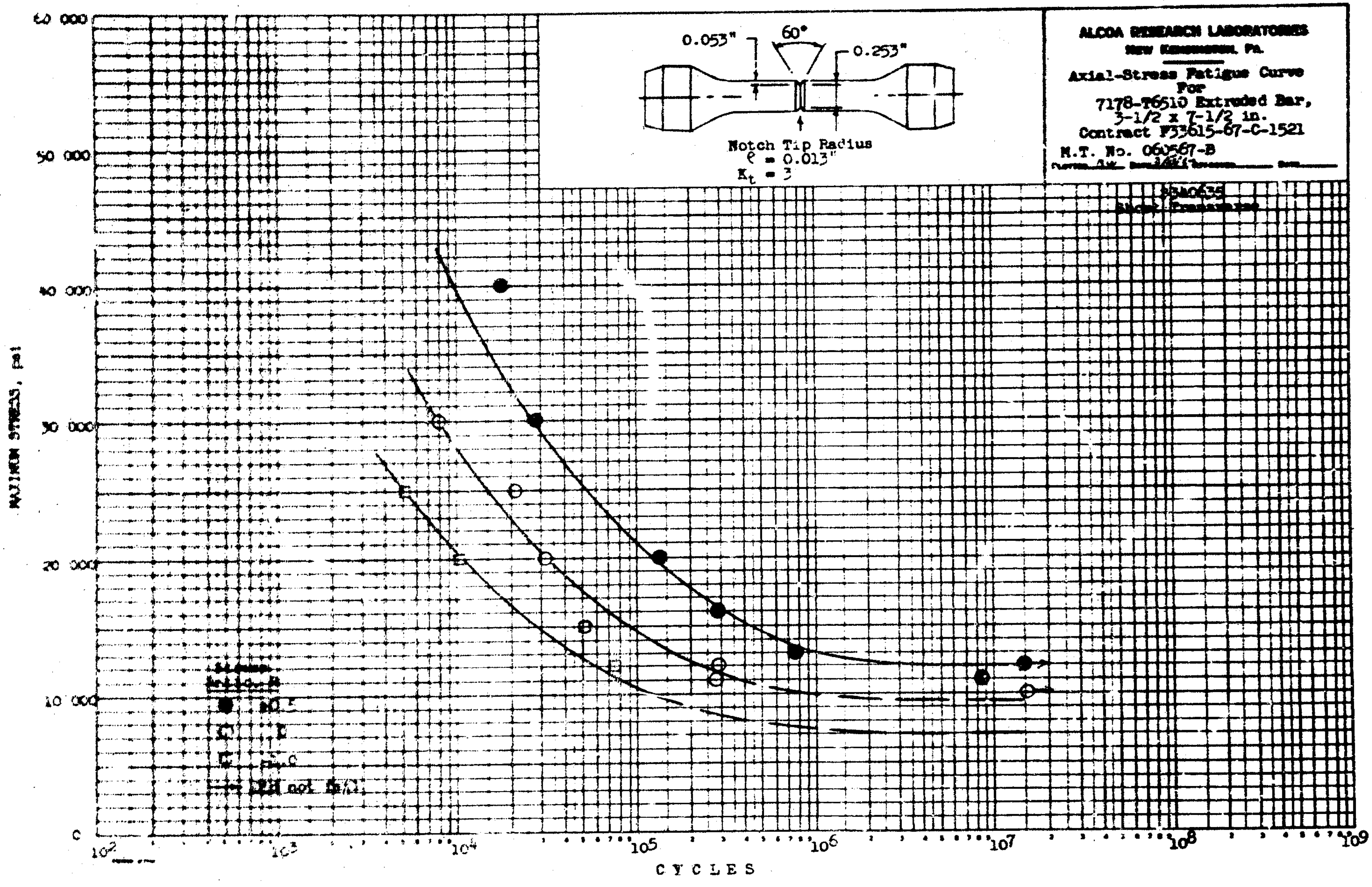
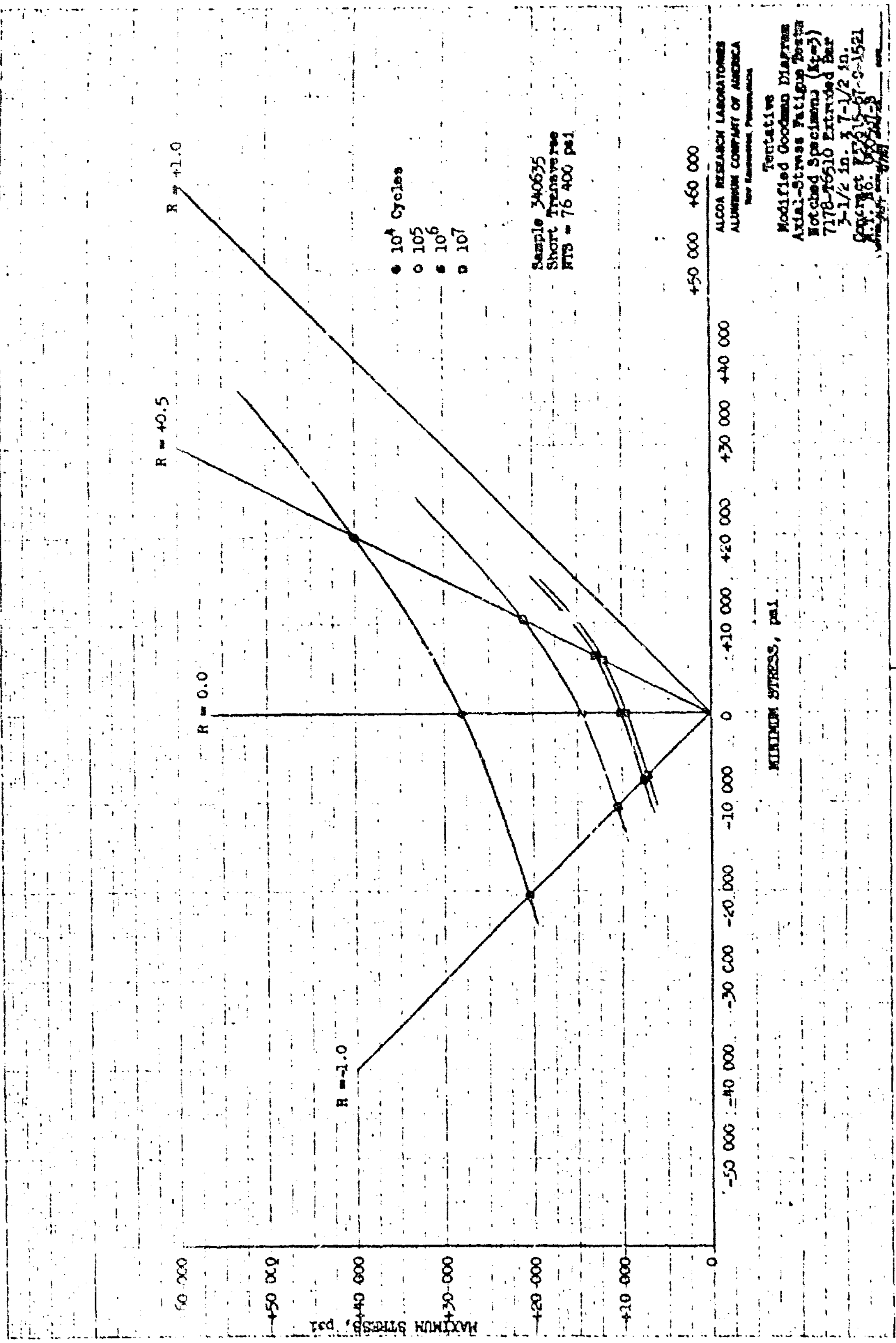
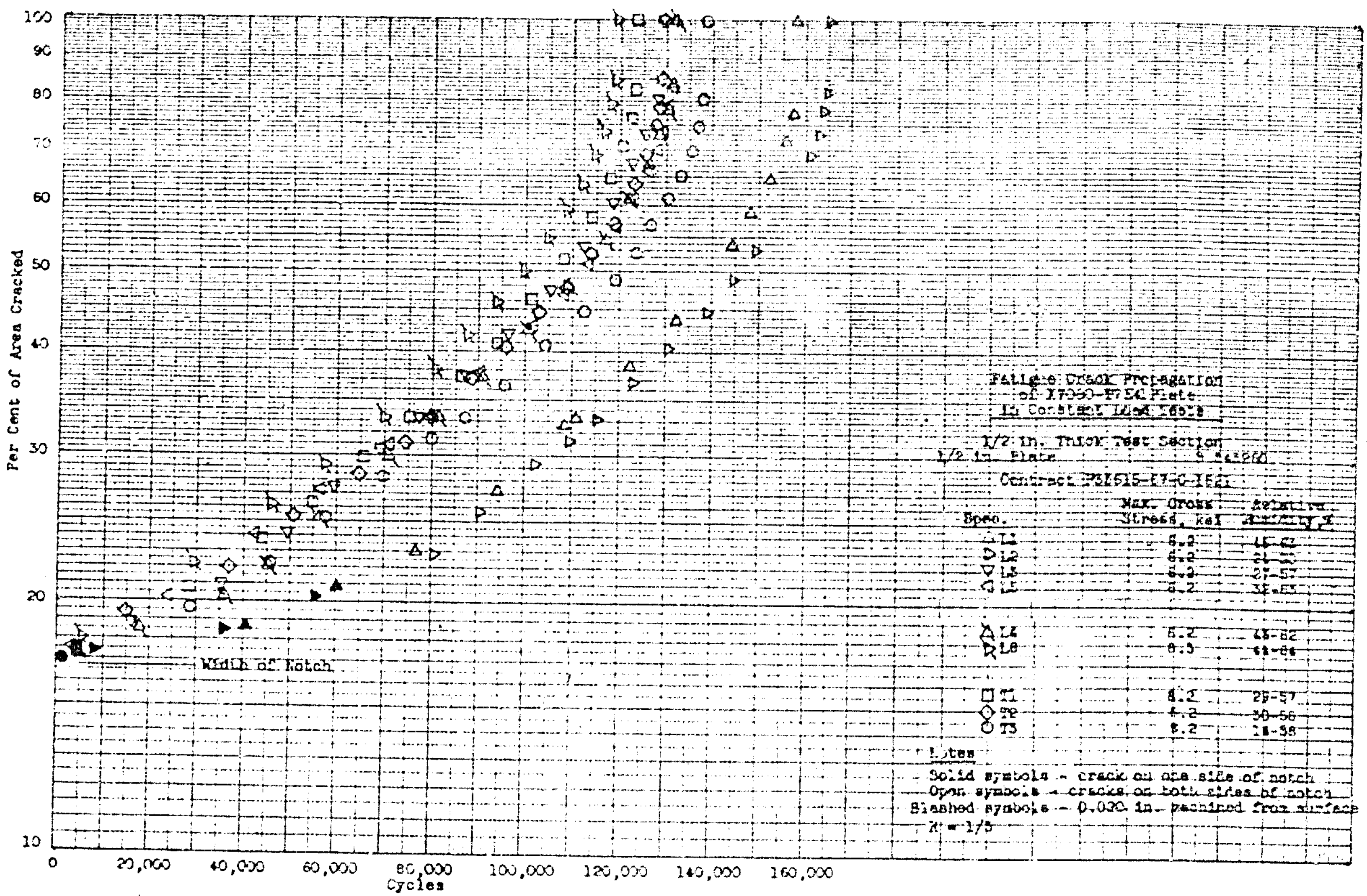

ALCOA RESEARCH LABORATORIES
New Kensington, Pa.
Axial-Stress Fatigue Curve
For
7178-T6510 Extruded Bar,
3-1/2 x 7-1/2 in.
Contract F33615-67-C-1521
M.T. No. 060567-B
0.053"
60°
0.253"
Notch Tip Radius
ρ = 0.013"
K_t = 3
MAXIMUM STRESS, psi
60 000
50 000
40 000
30 000
20 000
10 000
0
CYCLES
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9

Fig. 23



R = +1.0
R = +0.5
R = 0.0
R = -1.0
10^4 Cycles
10^5
10^6
10^7
Sample 340635
Short Transverse
FTS = 76 400 psi
ALCOA RESEARCH LABORATORIES
ALUMINUM COMPANY OF AMERICA
Tentative
Modified Goodman Diagram
Axial-Stress Fatigue Tests
Notched Specimens (Kt=3)
7178-T6510 Extruded Bar
3-1/2 in. X 7-1/2 in.
MINIMUM STRESS, psi
-50 000
-40 000
-30 000
-20 000
-10 000
0
+10 000
+20 000
+30 000
+40 000
+50 000
+60 000
MAXIMUM STRESS, psi
+10 000
+20 000
+30 000
+40 000
+50 000
60 000

Fig. 24



Tentative

Fig. 25

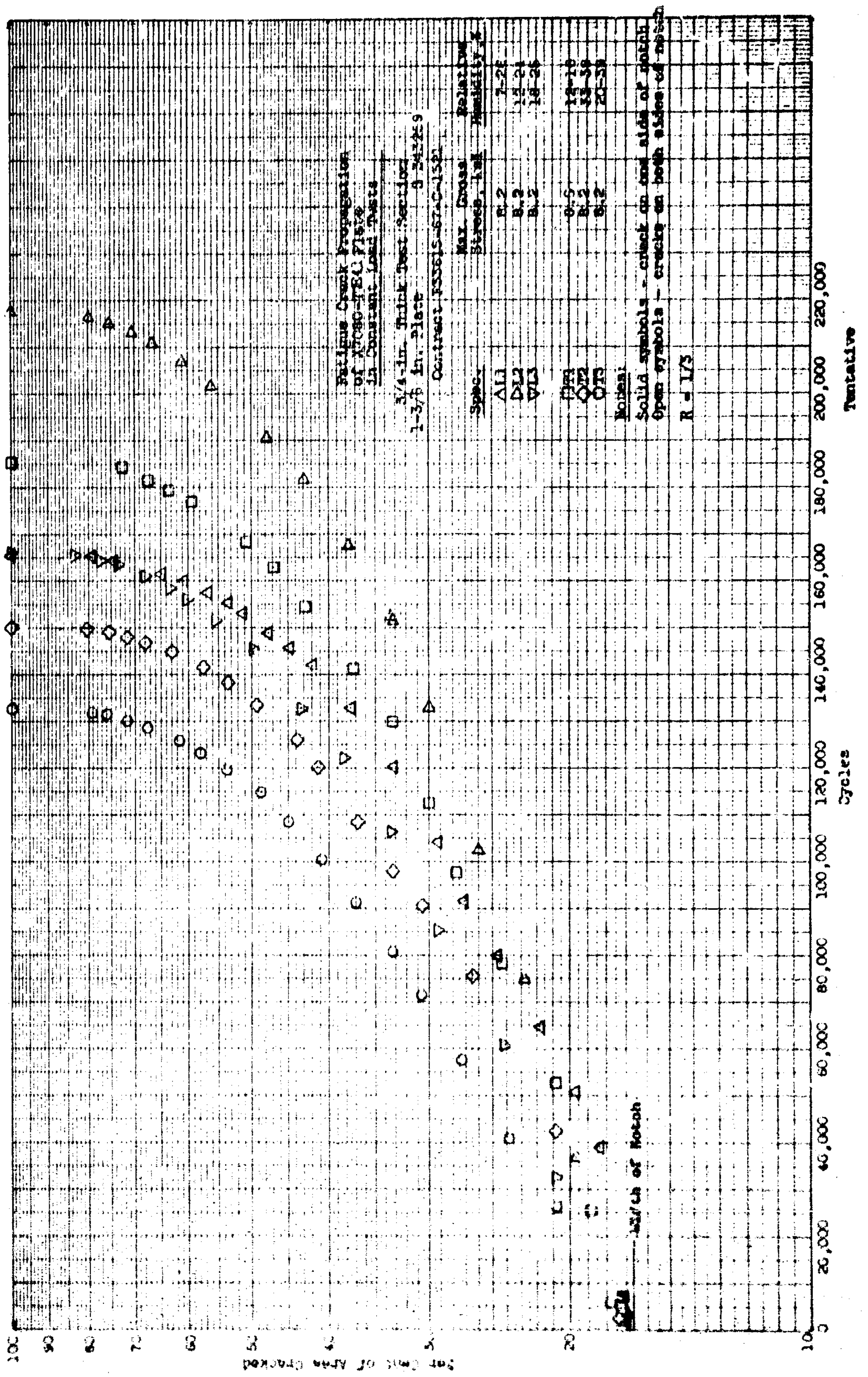
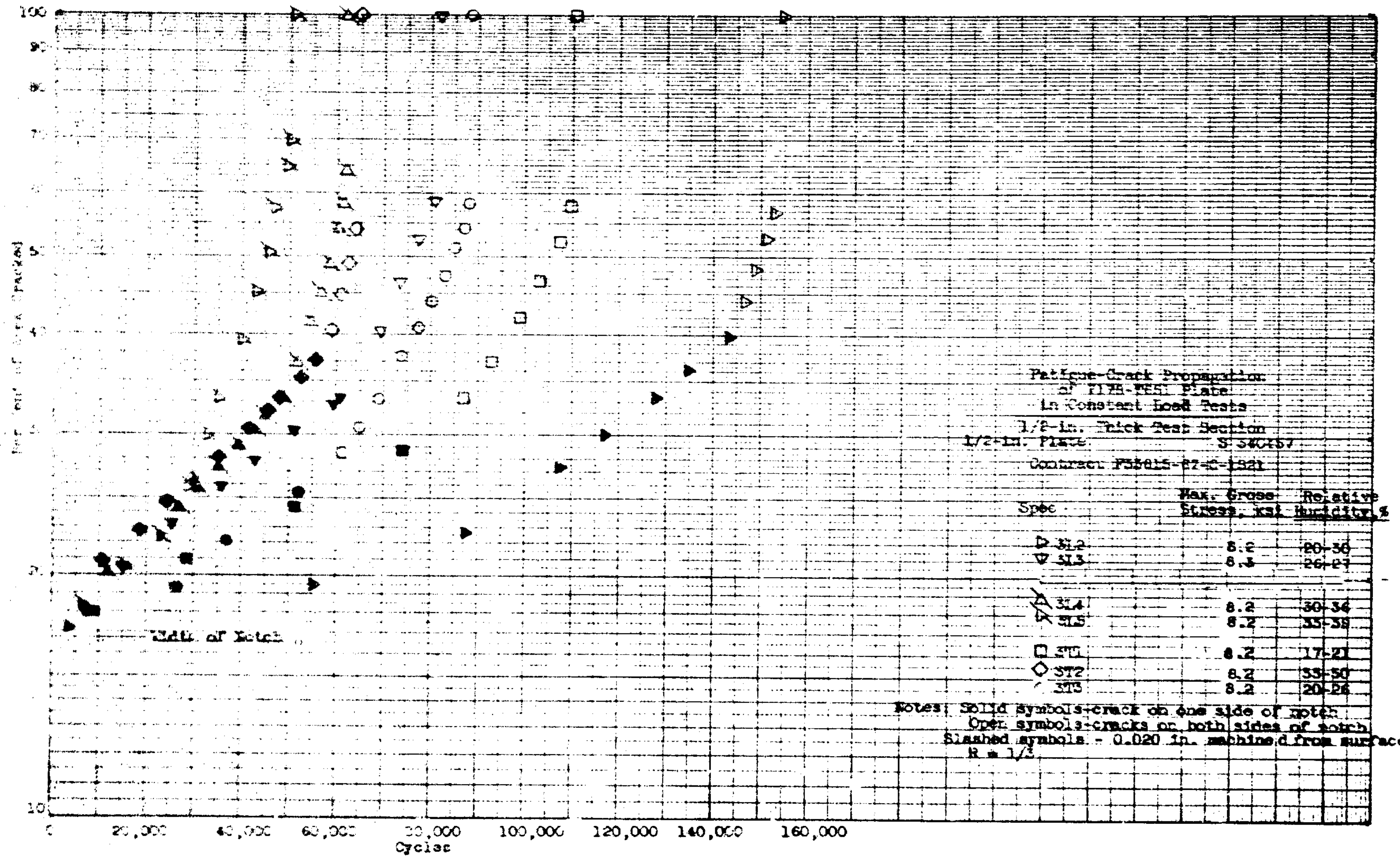
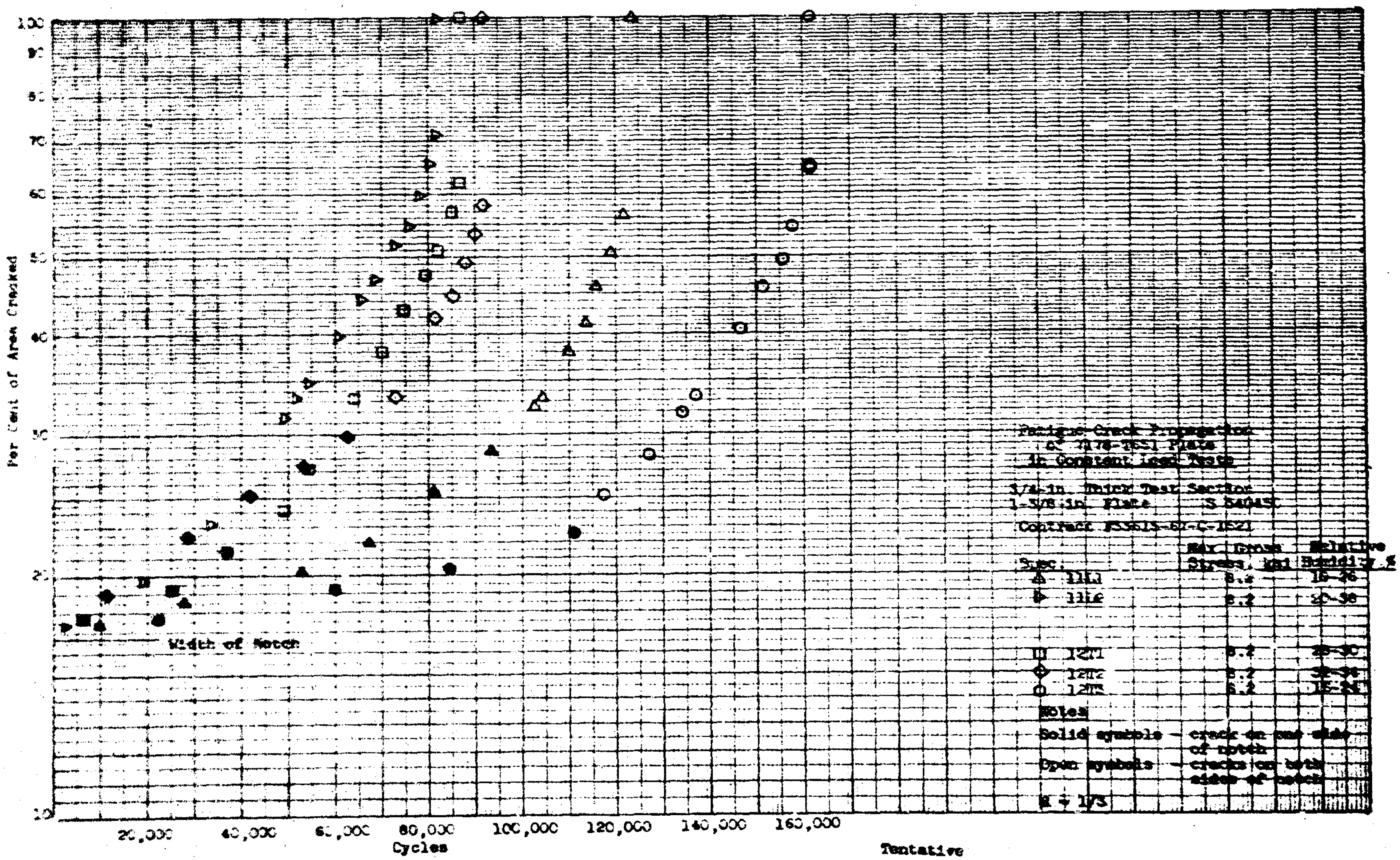

Fatigue Crack Propagation
3/4-in. Thick Test Section
Notes:
Solid symbols - crack on one side of notch
Open symbols - cracks on both sides of notch
R = 1/3
Width of Notch
Per Cent of Area Cracked
Cycles
Tentative
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
180,000
200,000
220,000

Fig. 26



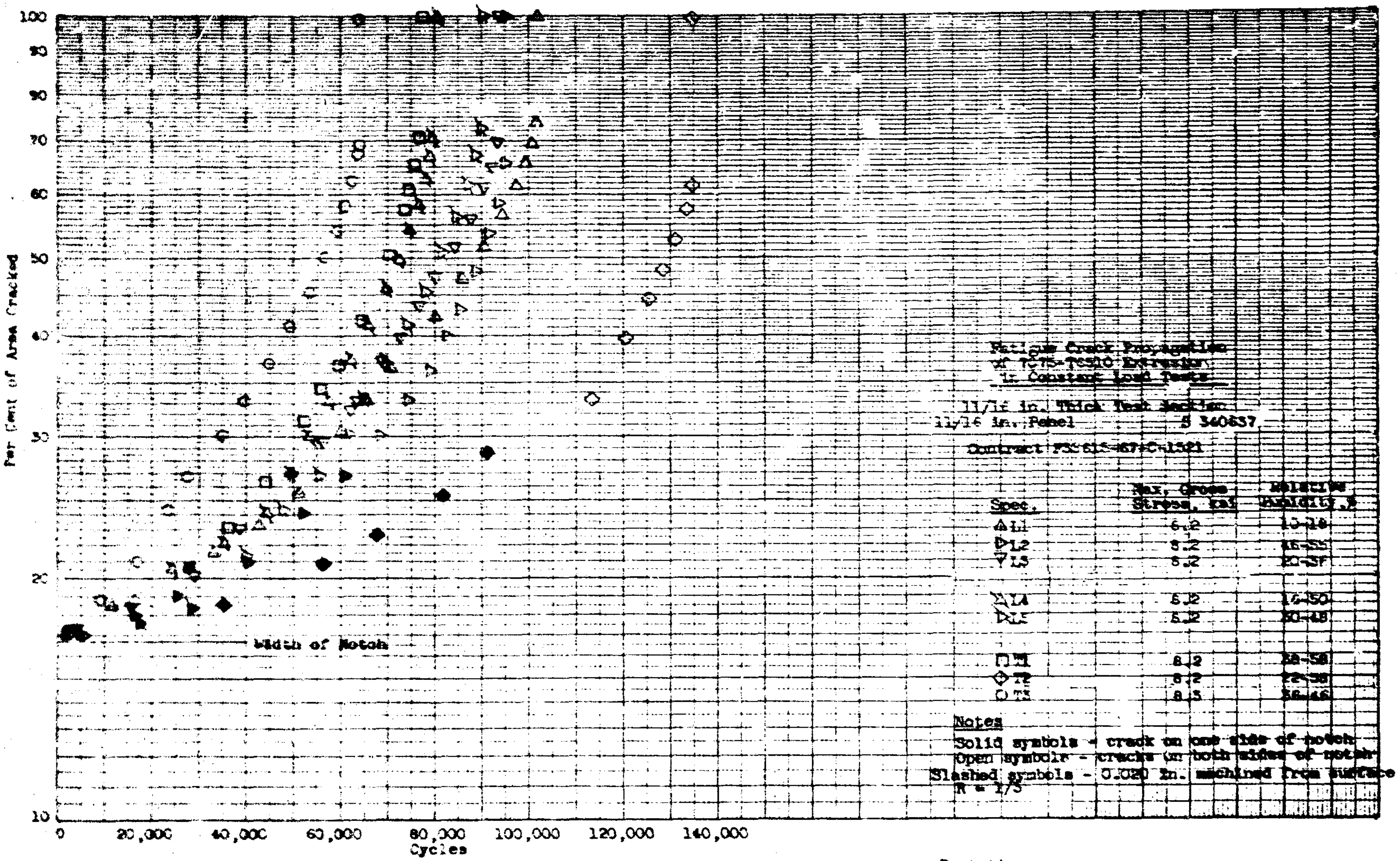
Tentative

Fig. 27



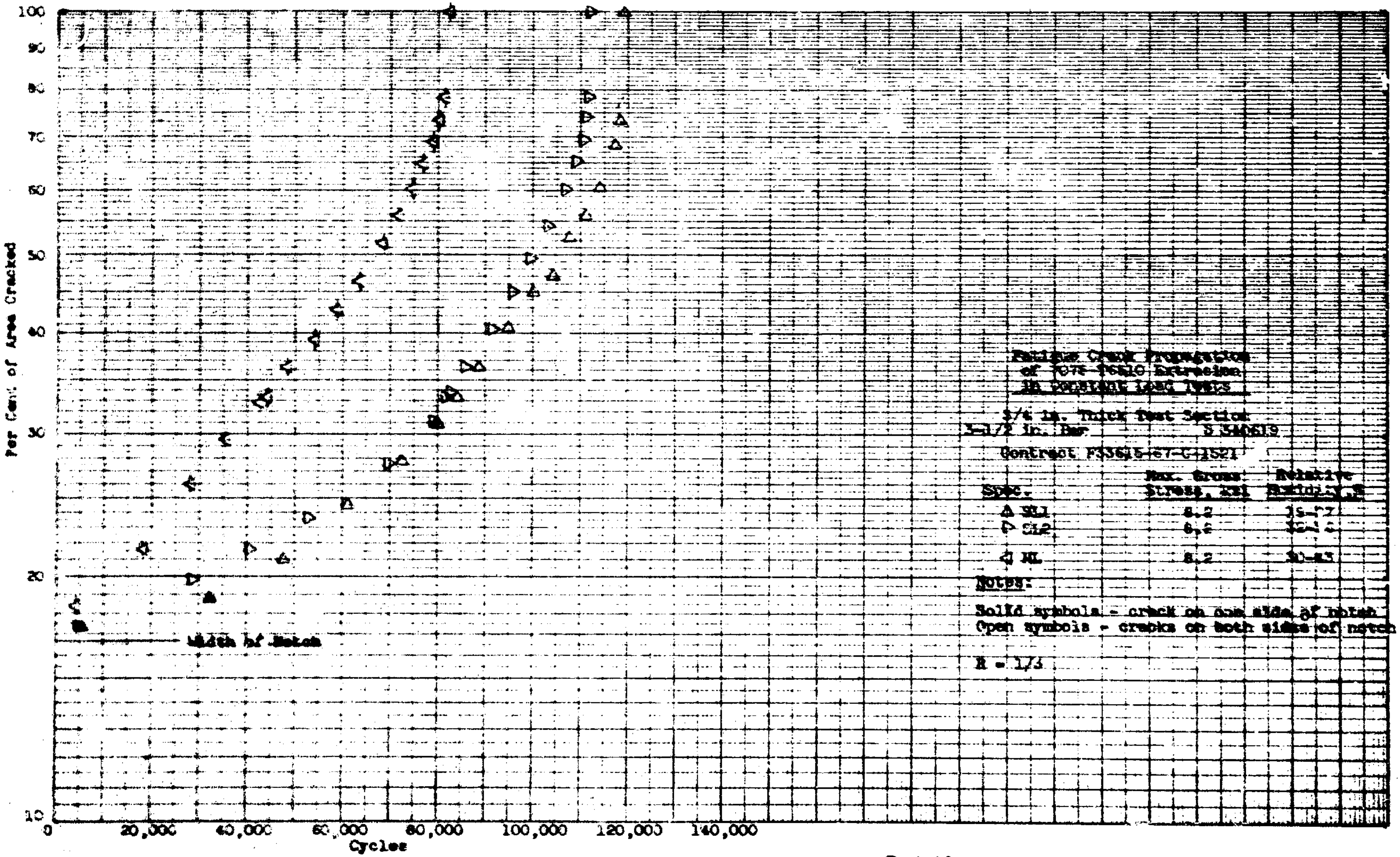
Fatigue Crack Propagation
of 7178-T651 Plate
in Constant Load Tests
3/4-in. Thick Test Section
1-3/8-in. Plate
Contract AF33615-67-C-1621
Max Gross Stress, ksi
Relative Humidity, %
Spec.
Notes
Solid symbols - crack on one side of notch
Open symbols - cracks on both sides of notch
Width of Notch
Per Cent of Area Cracked
Cycles
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000
Tentative

Fig. 28



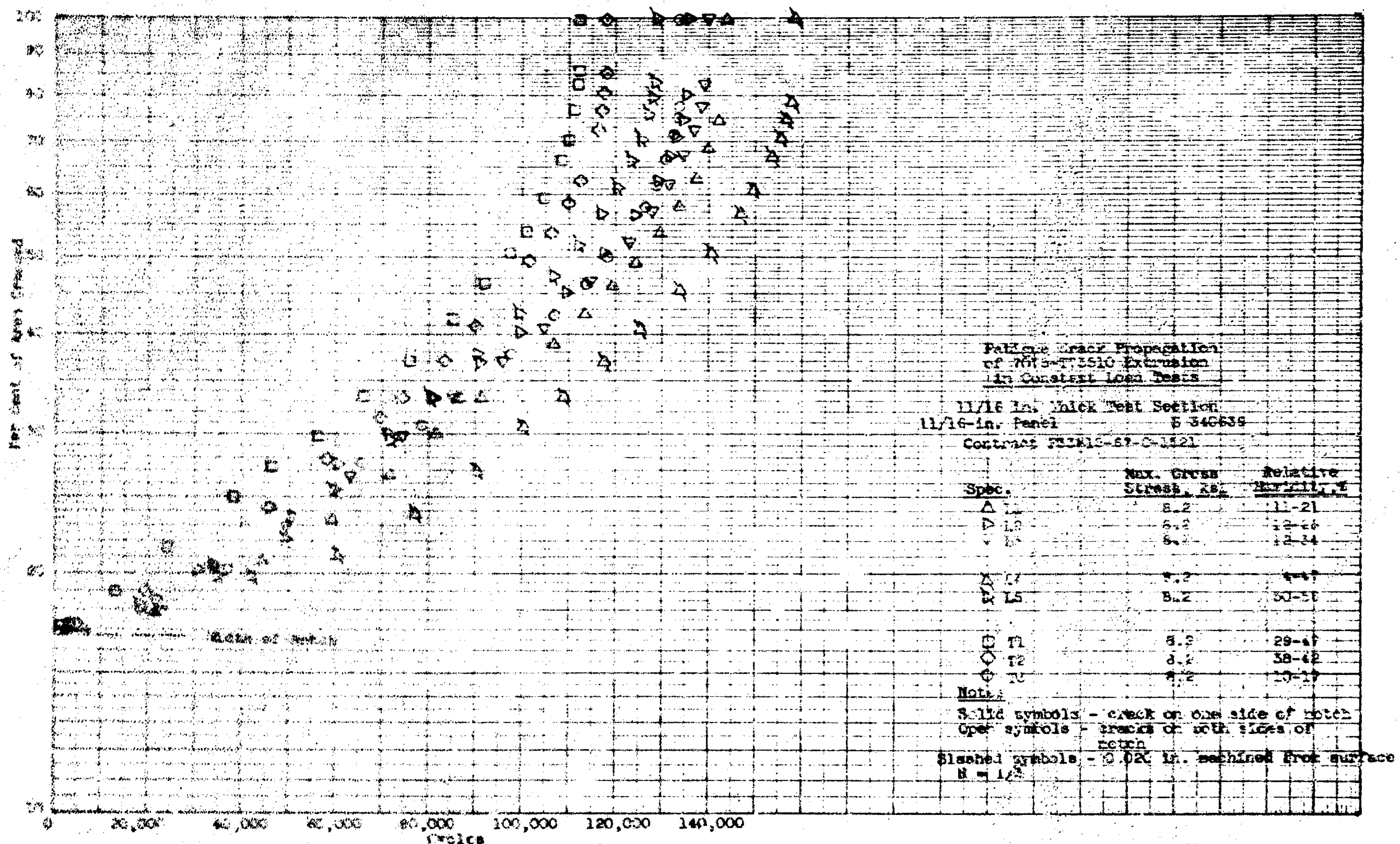
Tentative

Fig. 29



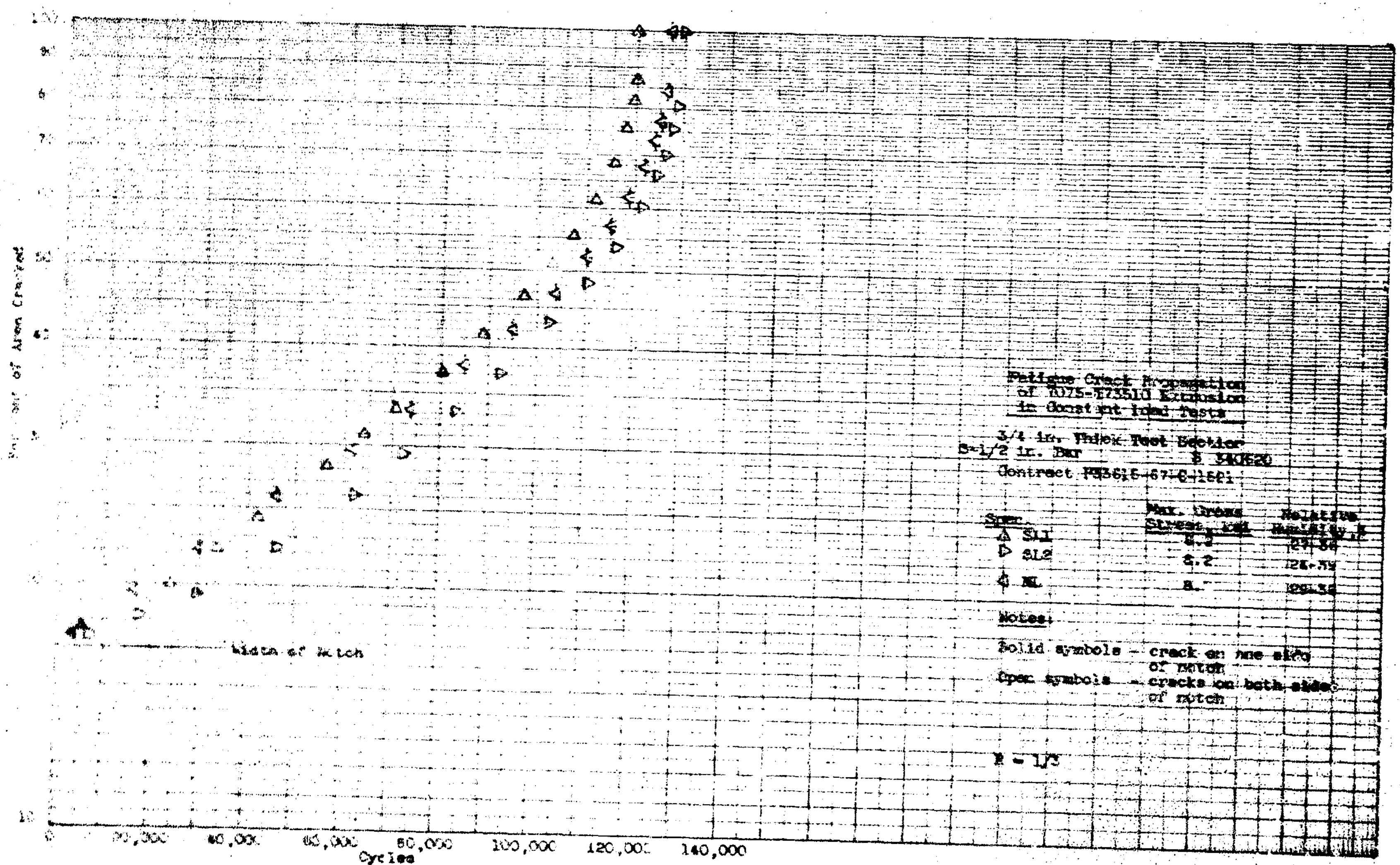
Tentative

Fig. 30



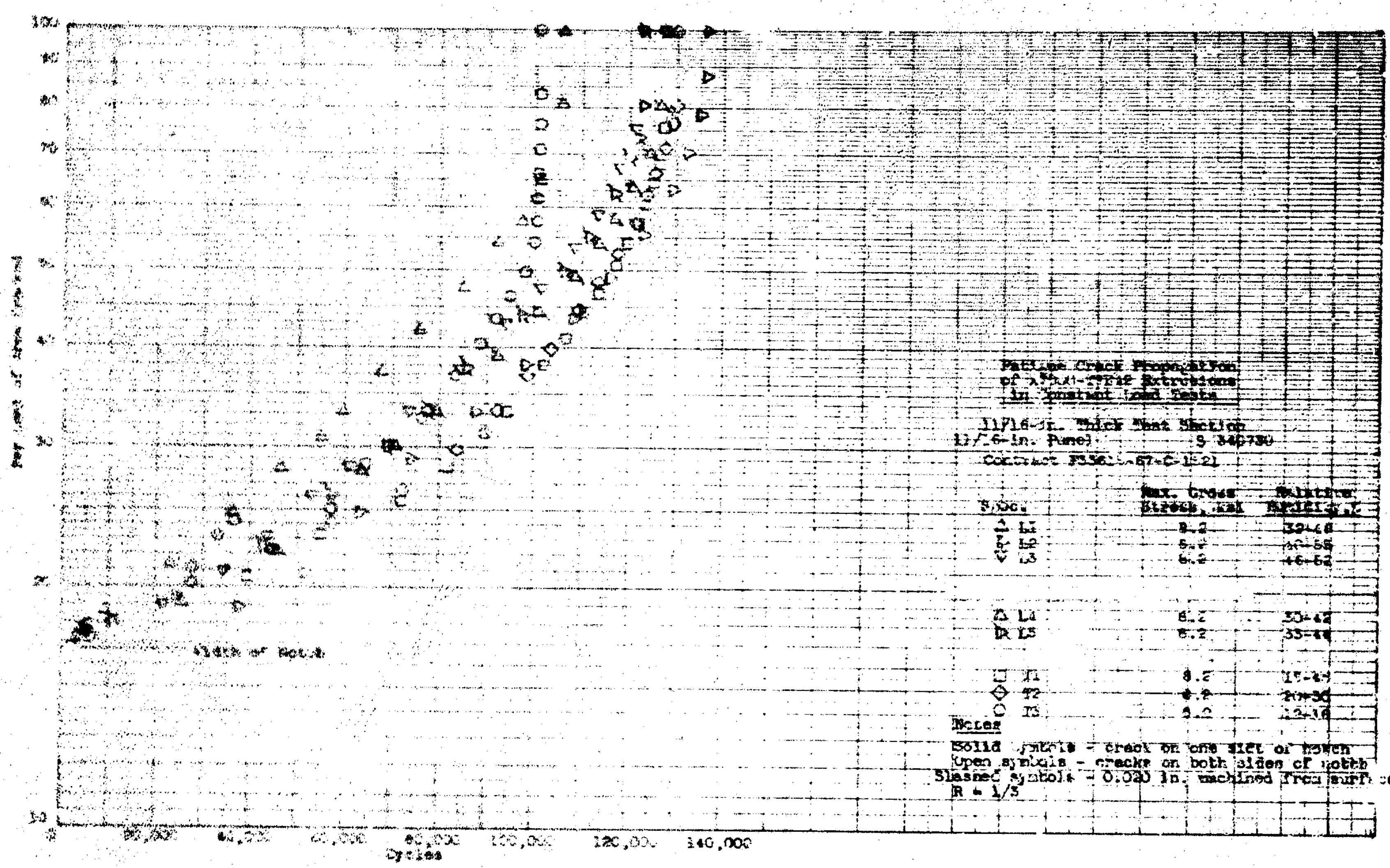
Tentative

Fig. 31



Tentative

Fig. 32



Tentative

Fig. 33

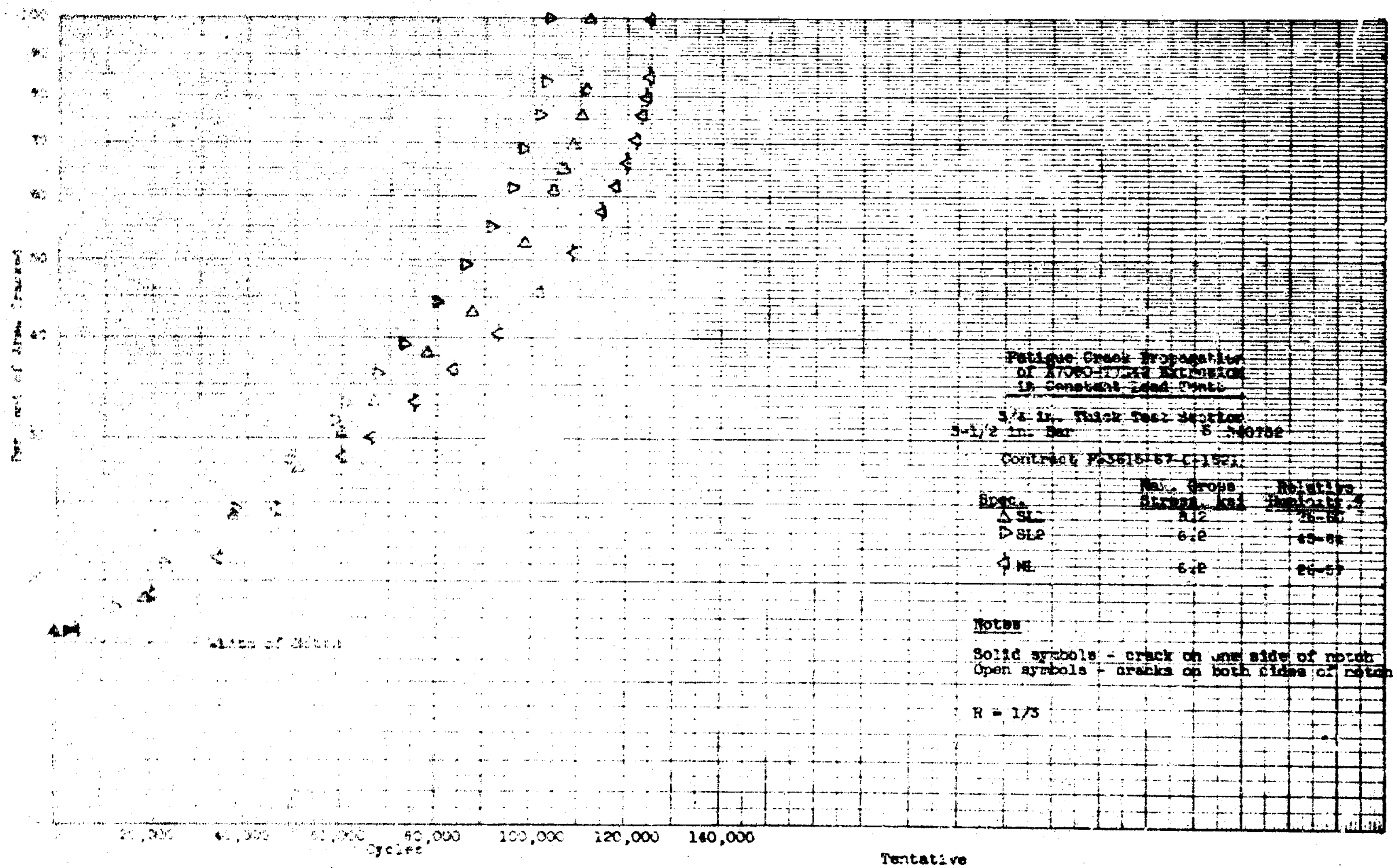
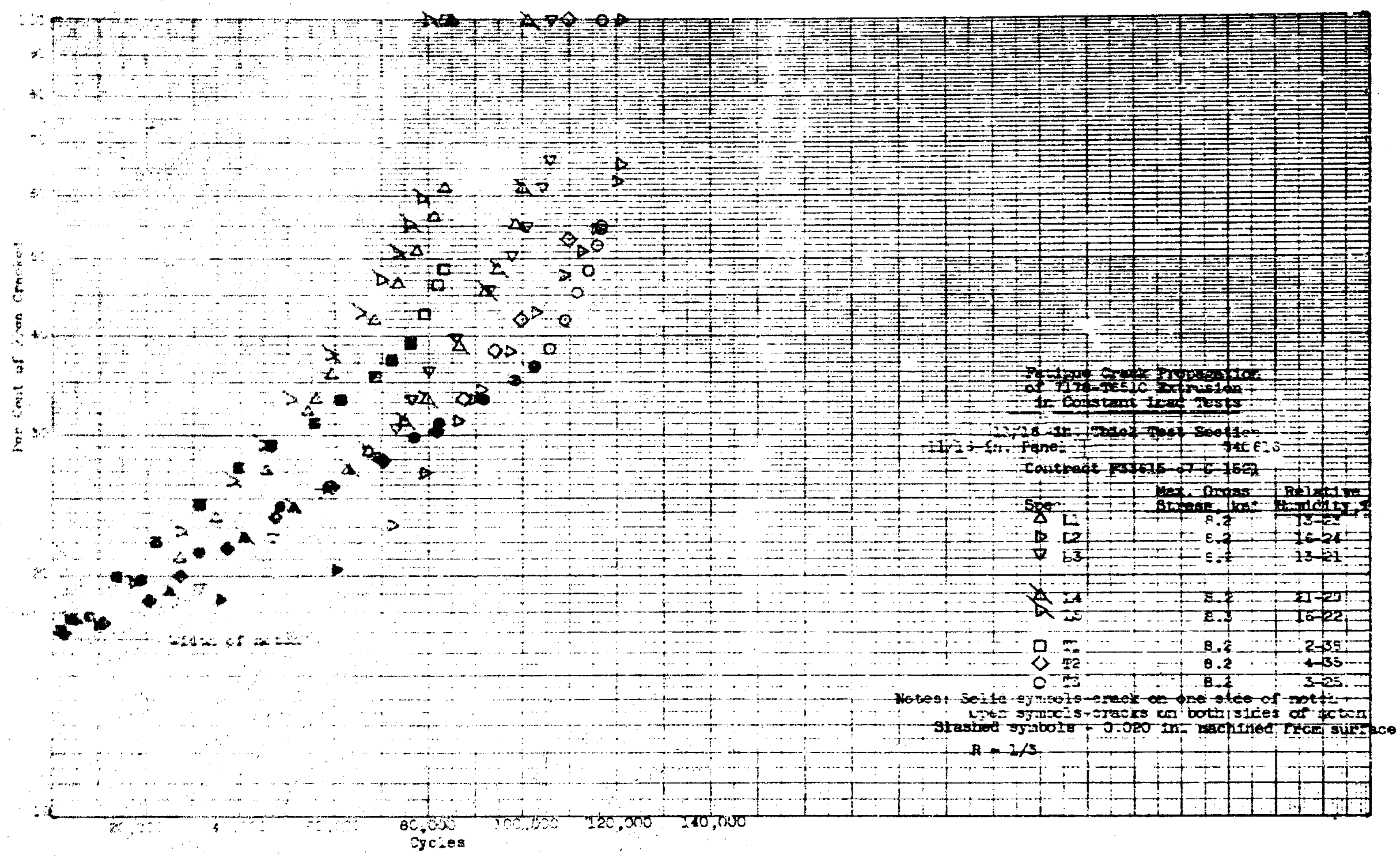
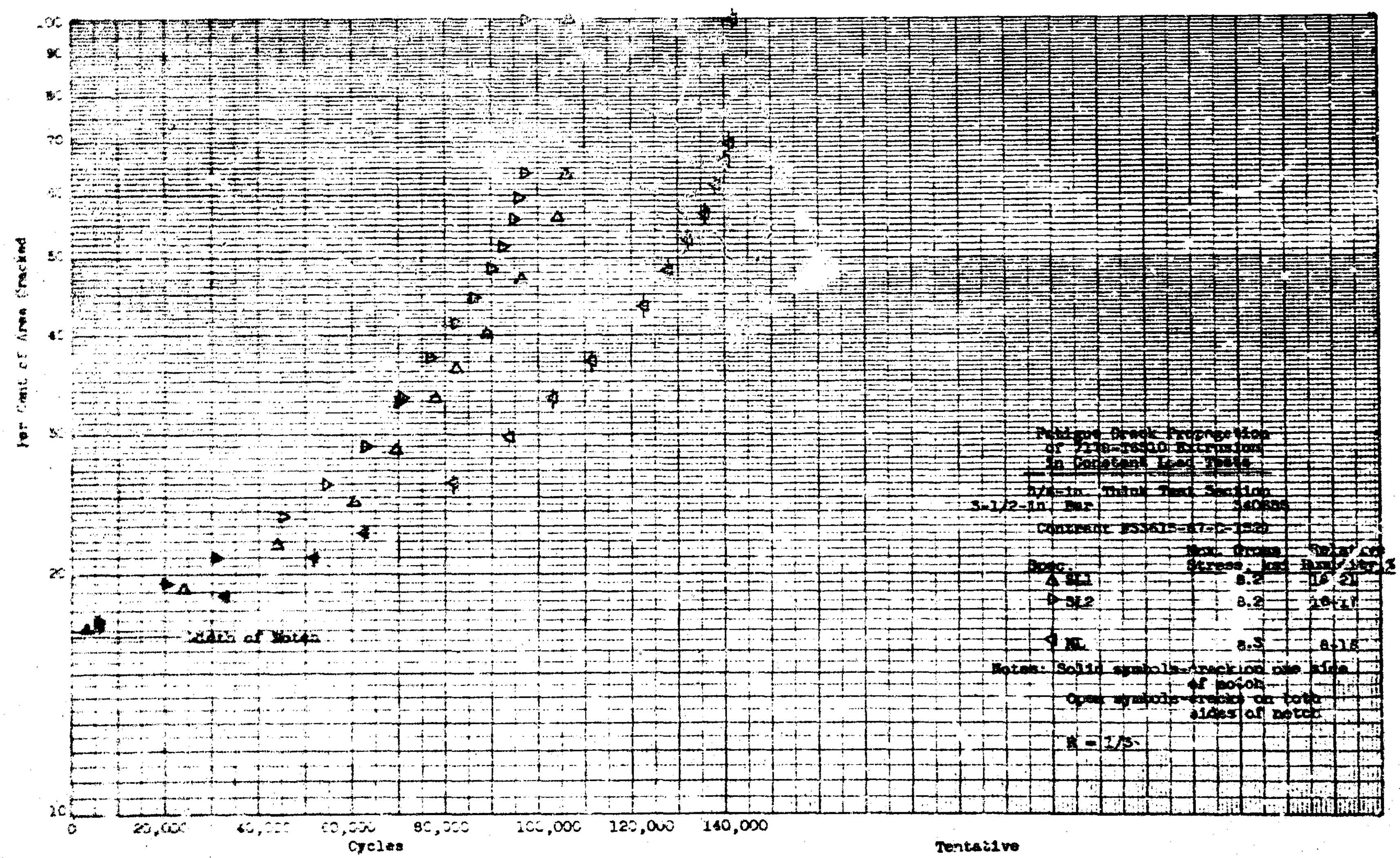

Fatigue Crack Propagation
In Constant Load Tests
Contract
Spec.
SL2
6.2
Notes
Solid symbols - crack on one side of notch
Open symbols - cracks on both sides of notch
R = 1/3
Cycles
140,000
120,000
100,000
Tentative

Fig. 34



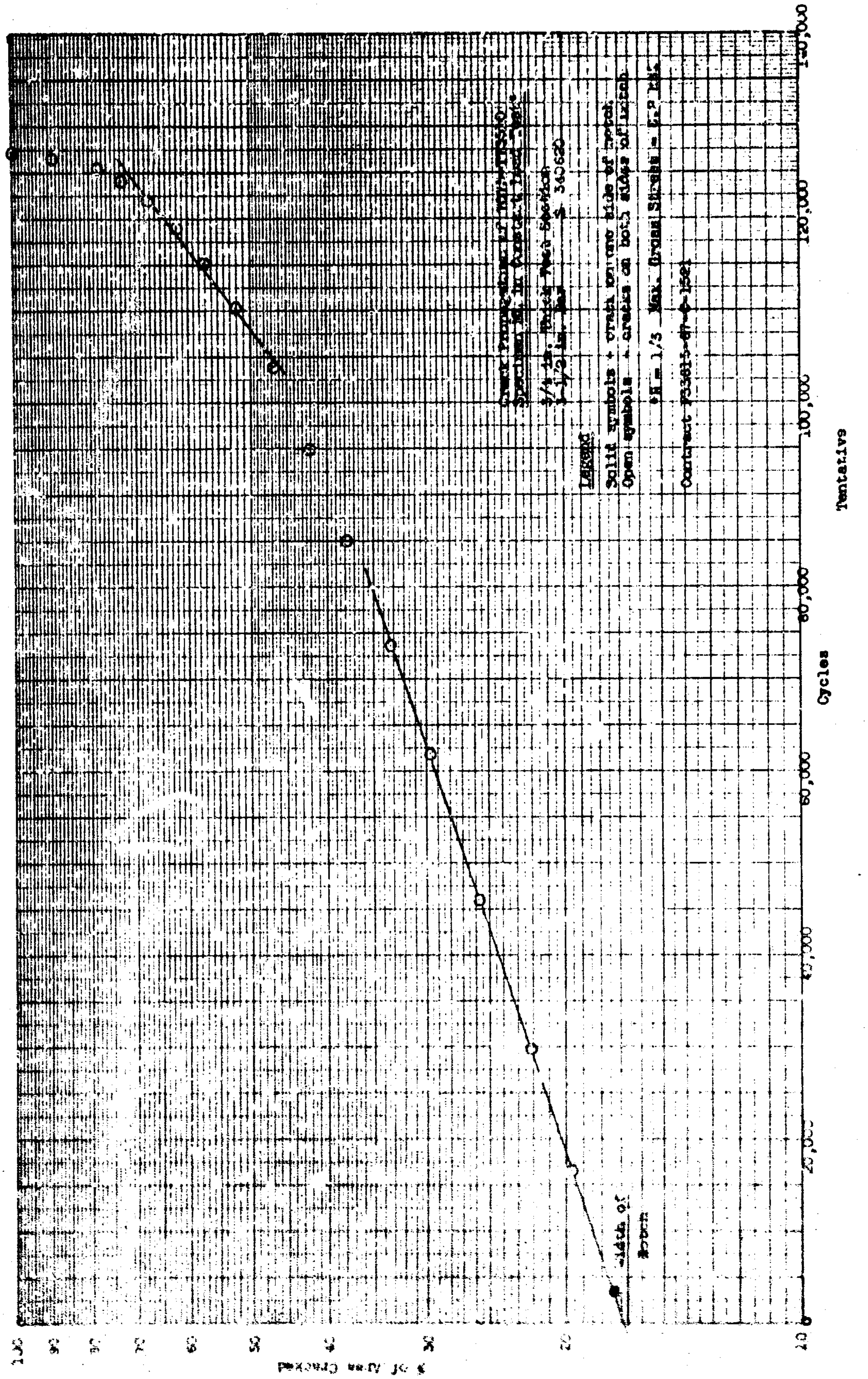
Tentative

Fig. 35



Per Cent of Area Cracked
100
90
80
70
60
50
40
30
20
10
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
Cycles
Tentative
3-1/2-in. Bar
Spec.
SL1
8.2
SL2
8.2
Notes: Solid symbols-cracking one side of notch
Open symbols-cracks on both sides of notch

Fig. 36



% of Area Cracked
Cycles
Tentative
Width of Notch
Legend
Solid symbols + crack on one side of notch
Open symbols + cracks on both sides of notch
Contract F33615-67-C-1521

Fig. 37

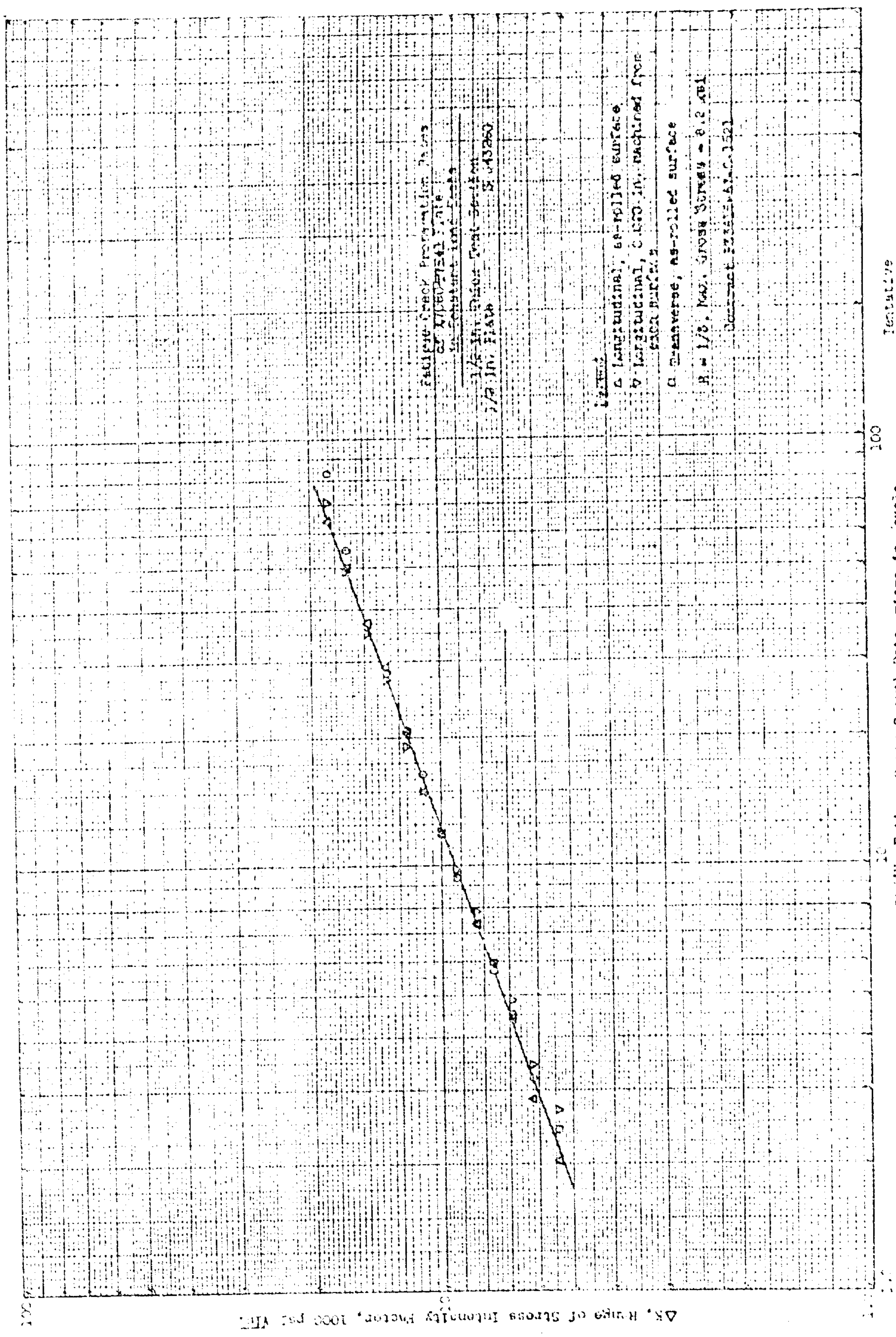
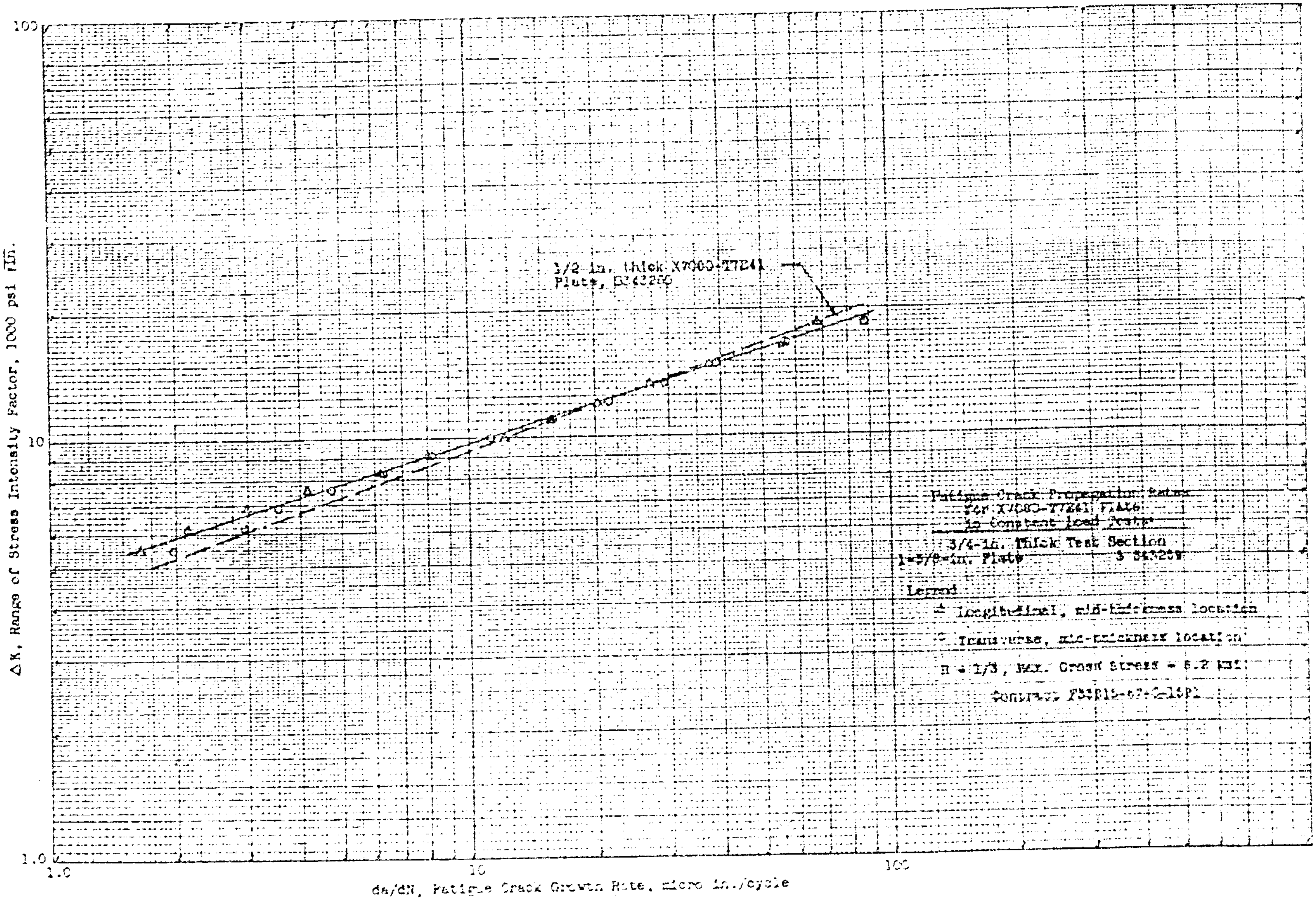

Fatigue Crack Propagation Rates
In Constant Load Tests
Legend
Δ Longitudinal, as-rolled surface
∇ Longitudinal, 0.020 in. machined from each surface
○ Transverse, as-rolled surface
R = 1/3, Max. Gross Stress = 8.2 ksi
10
100
dA/dN, Fatigue Crack Growth Rate, micro in./cycle
Tentative
ΔK, Range of Stress Intensity Factor, 1000 psi √in.
10

Fig. 38



100
10
1.0
1.0
10
100
ΔK, Range of Stress Intensity Factor, 1000 psi √in.
da/dN, Fatigue Crack Growth Rate, micro in./cycle
3/4-In. Thick Test Section
Legend

Fig. 39

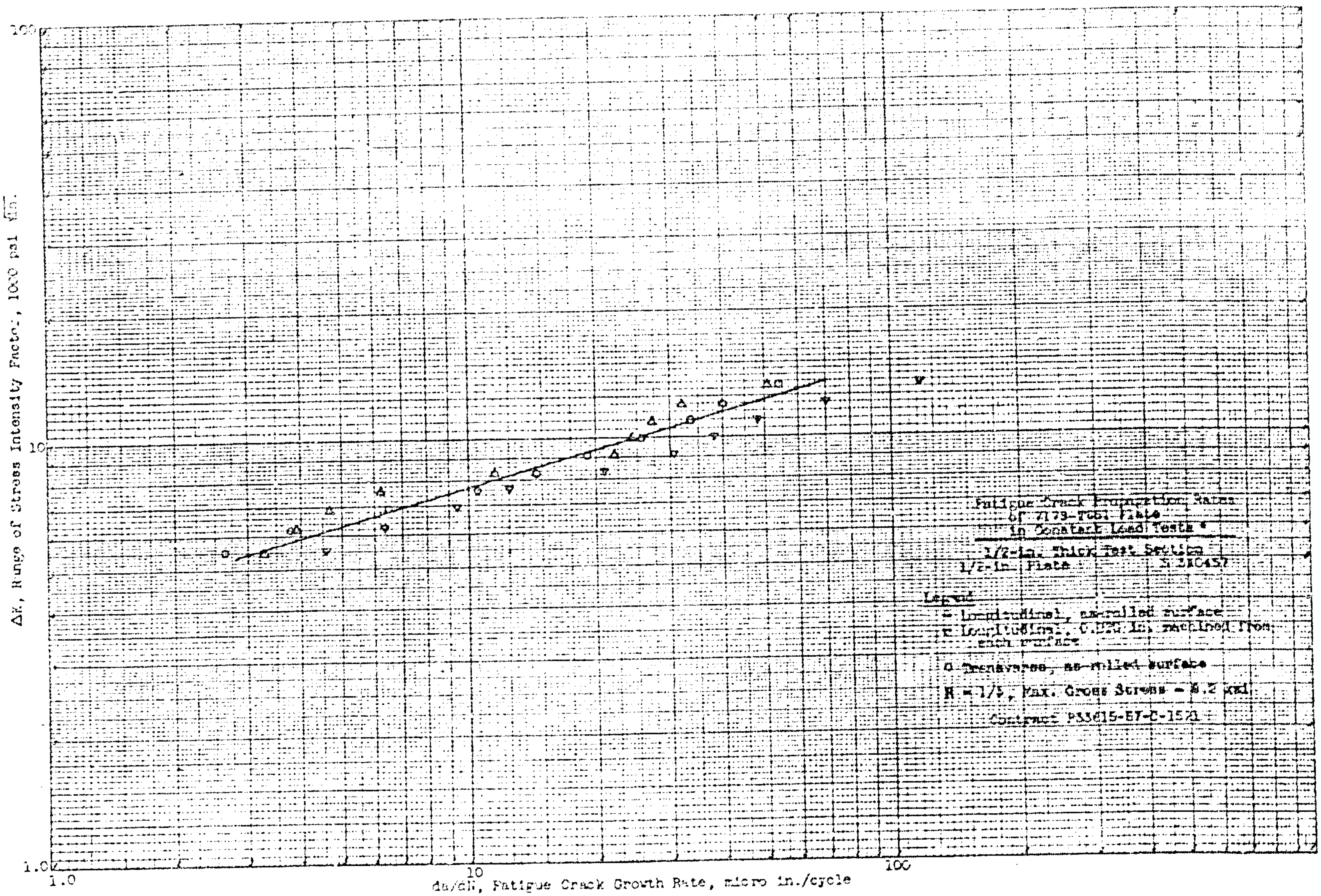
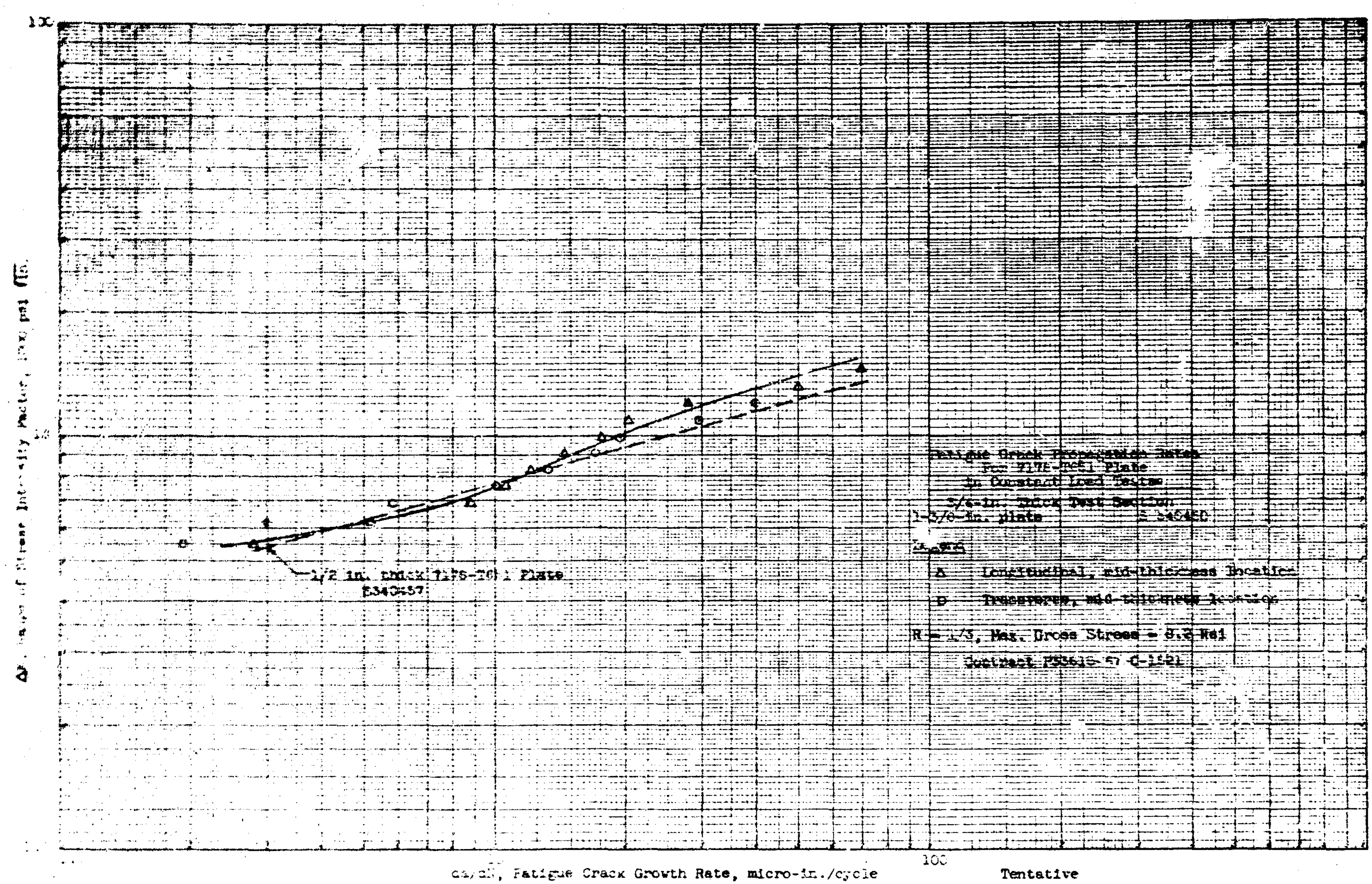
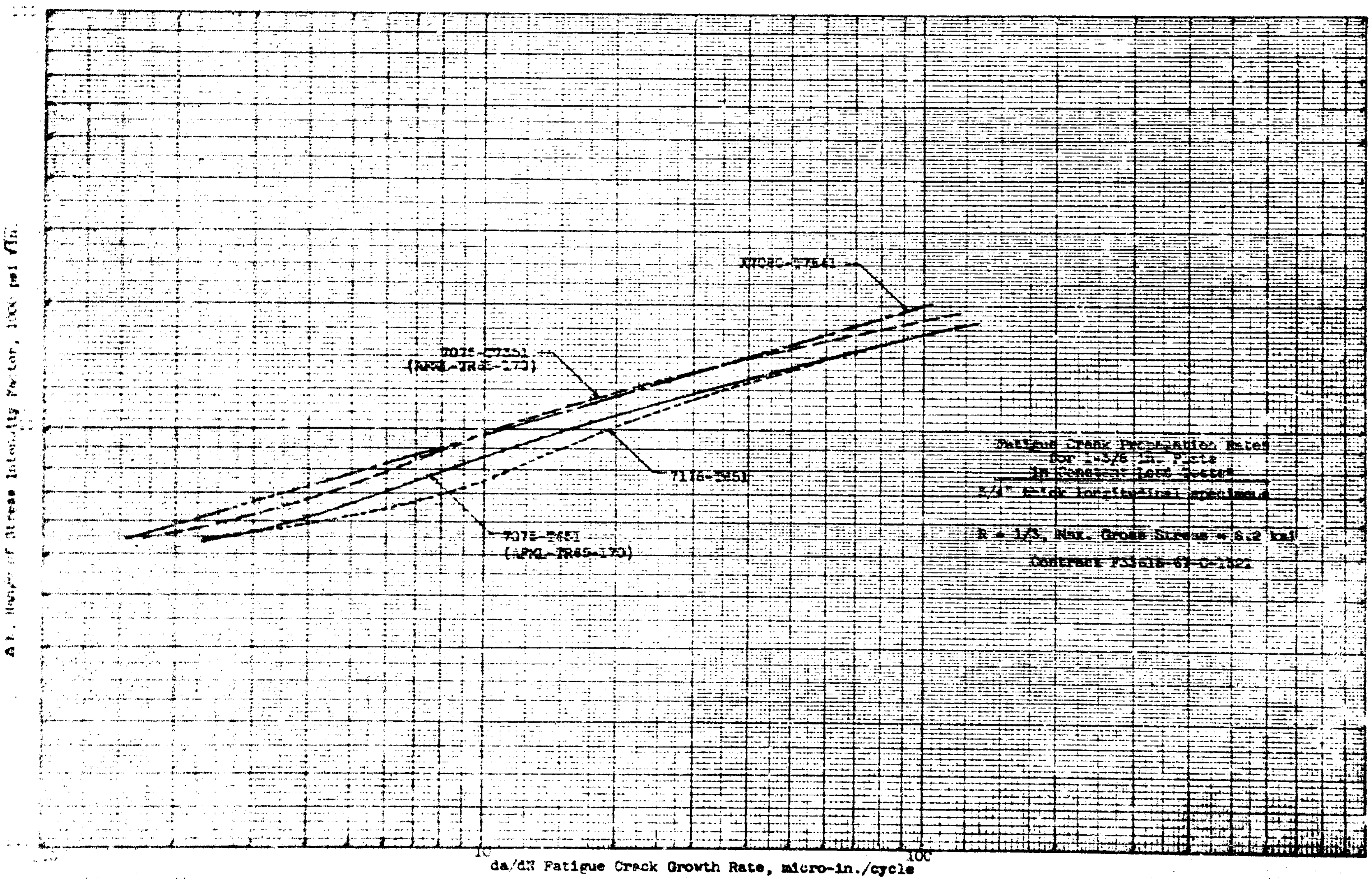

ΔK, Range of Stress Intensity Factor, 1000 psi √in.
da/dN, Fatigue Crack Growth Rate, micro in./cycle
1.0
10
100
1/2-in. Plate
Legend

Fig. 40



100
10
100
ΔK, Range of Stress Intensity Factor, 1000 psi √in.
da/dN, Fatigue Crack Growth Rate, micro-in./cycle
Tentative
1/2 in. thick 7175-T651 Plate
E340457
R = 1/3, Max. Gross Stress

Fig. 41



10
100
da/dN Fatigue Crack Growth Rate, micro-in./cycle
7075-T651
7178-T651

Fig. 42

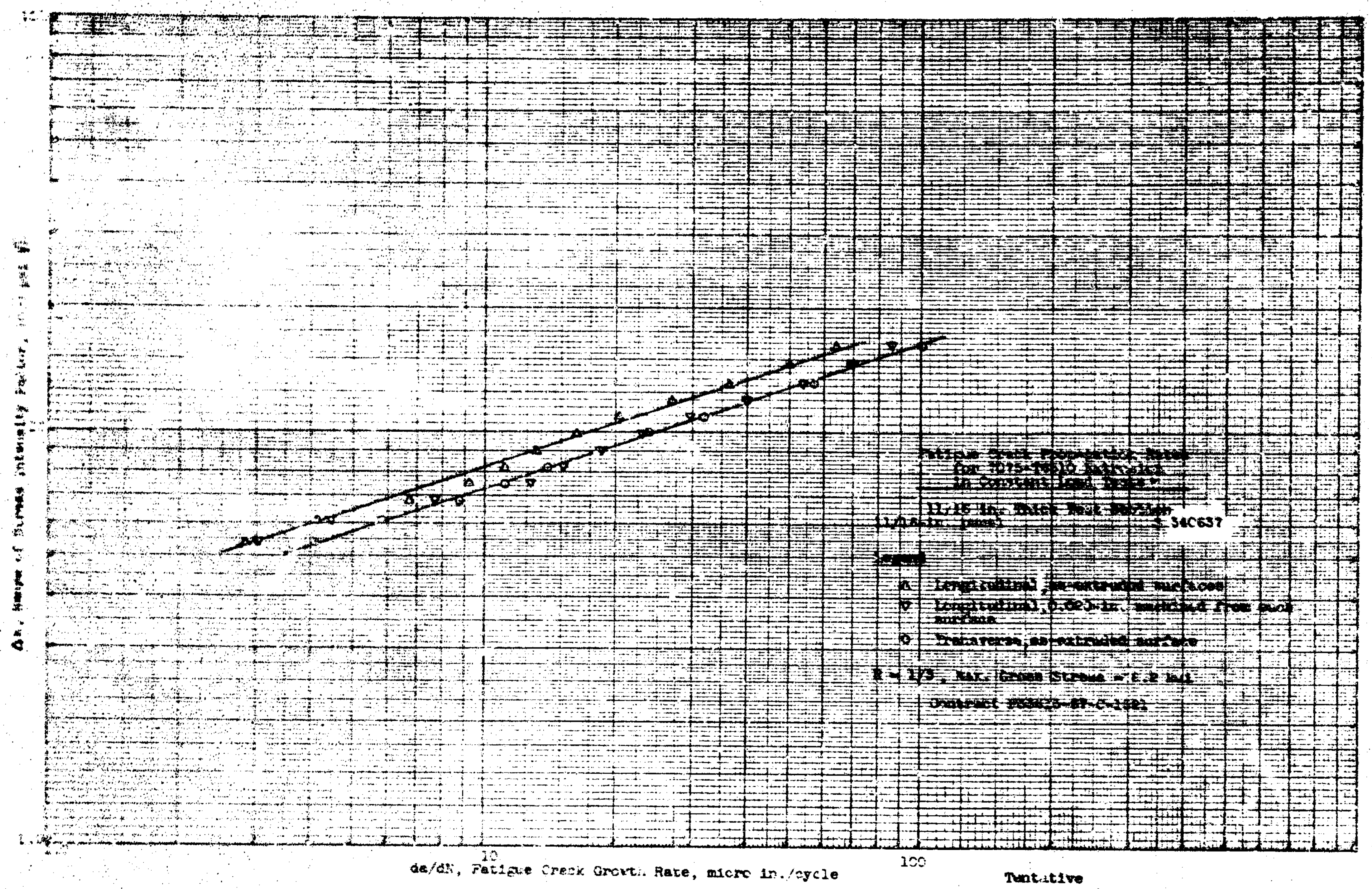
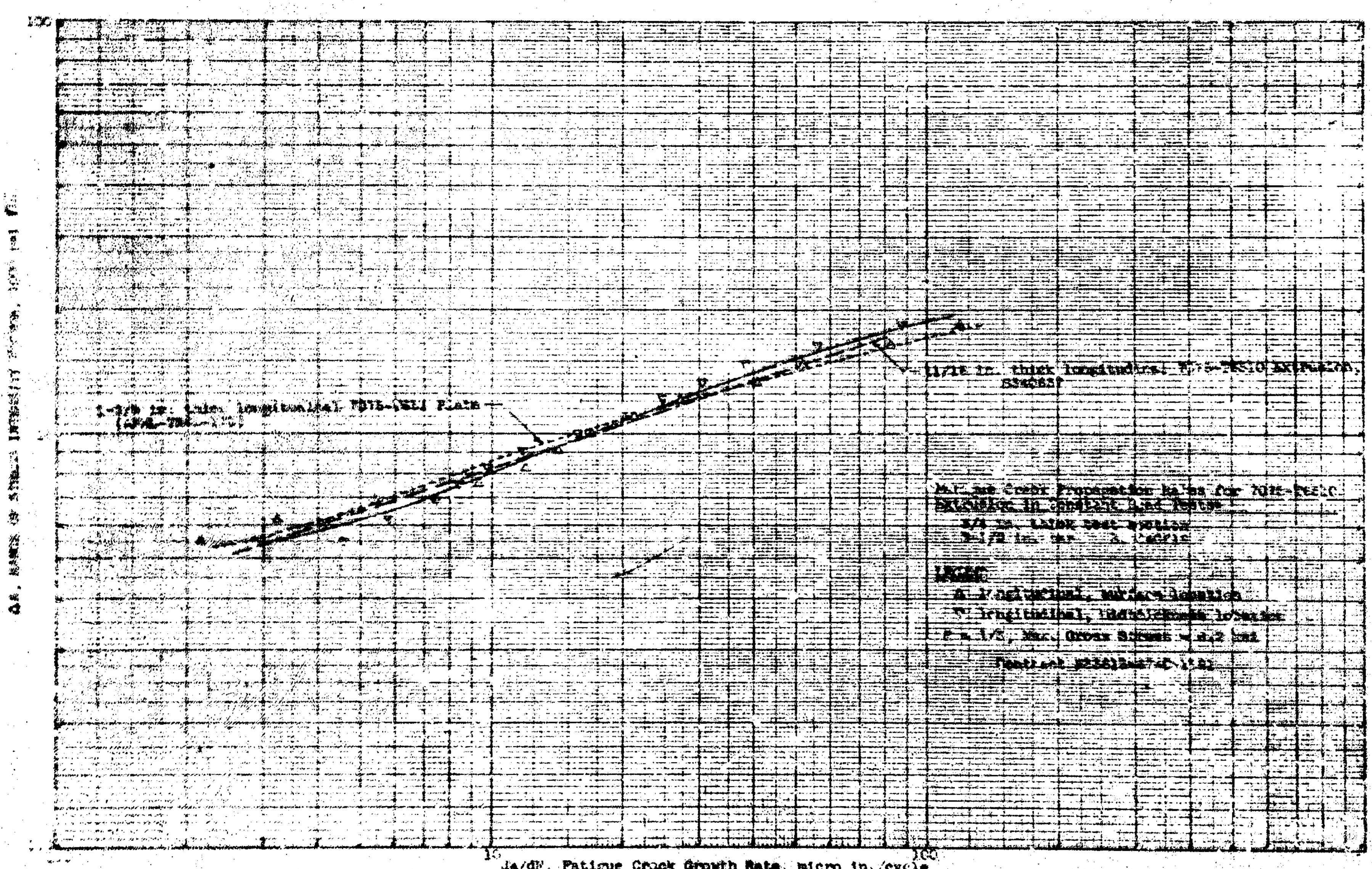

10
100
da/dN, Fatigue Crack Growth Rate, micro in./cycle
Tentative

Fig. 43



Tentative

Fig. 44

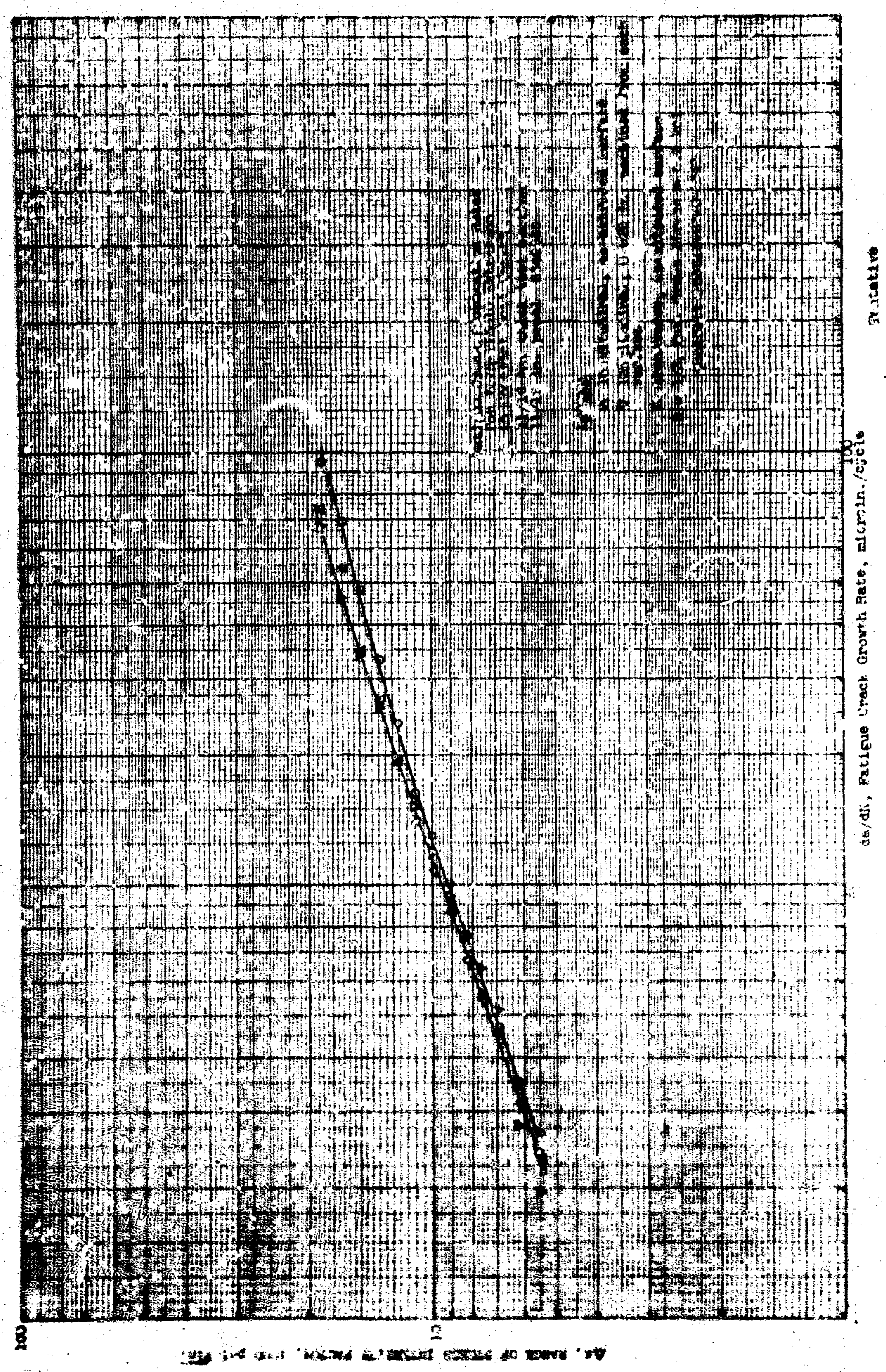


Fig. 45

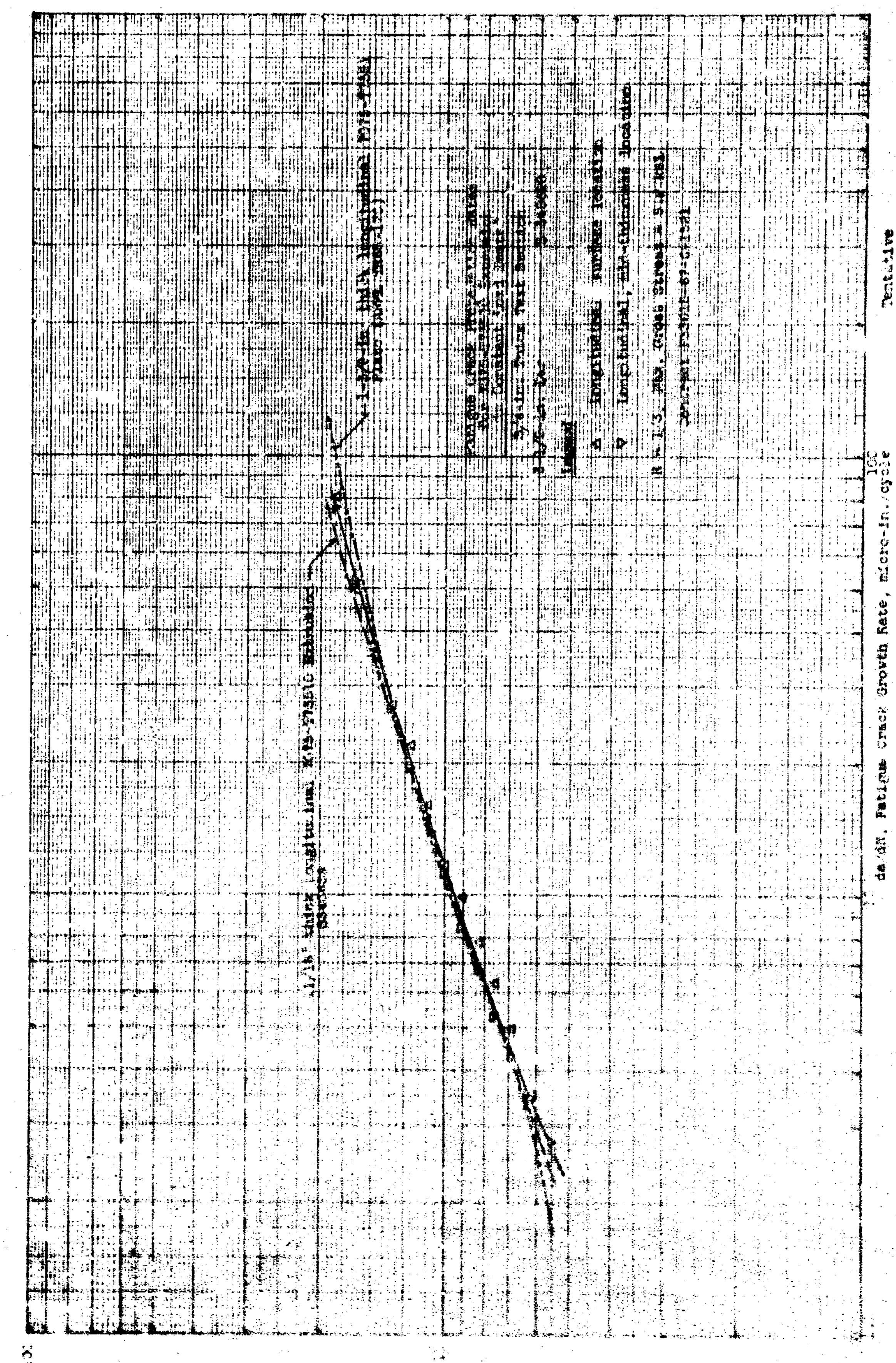

da/dN, Fatigue Crack Growth Rate, micro-in./cycle
100
Tentative

Fig. 40

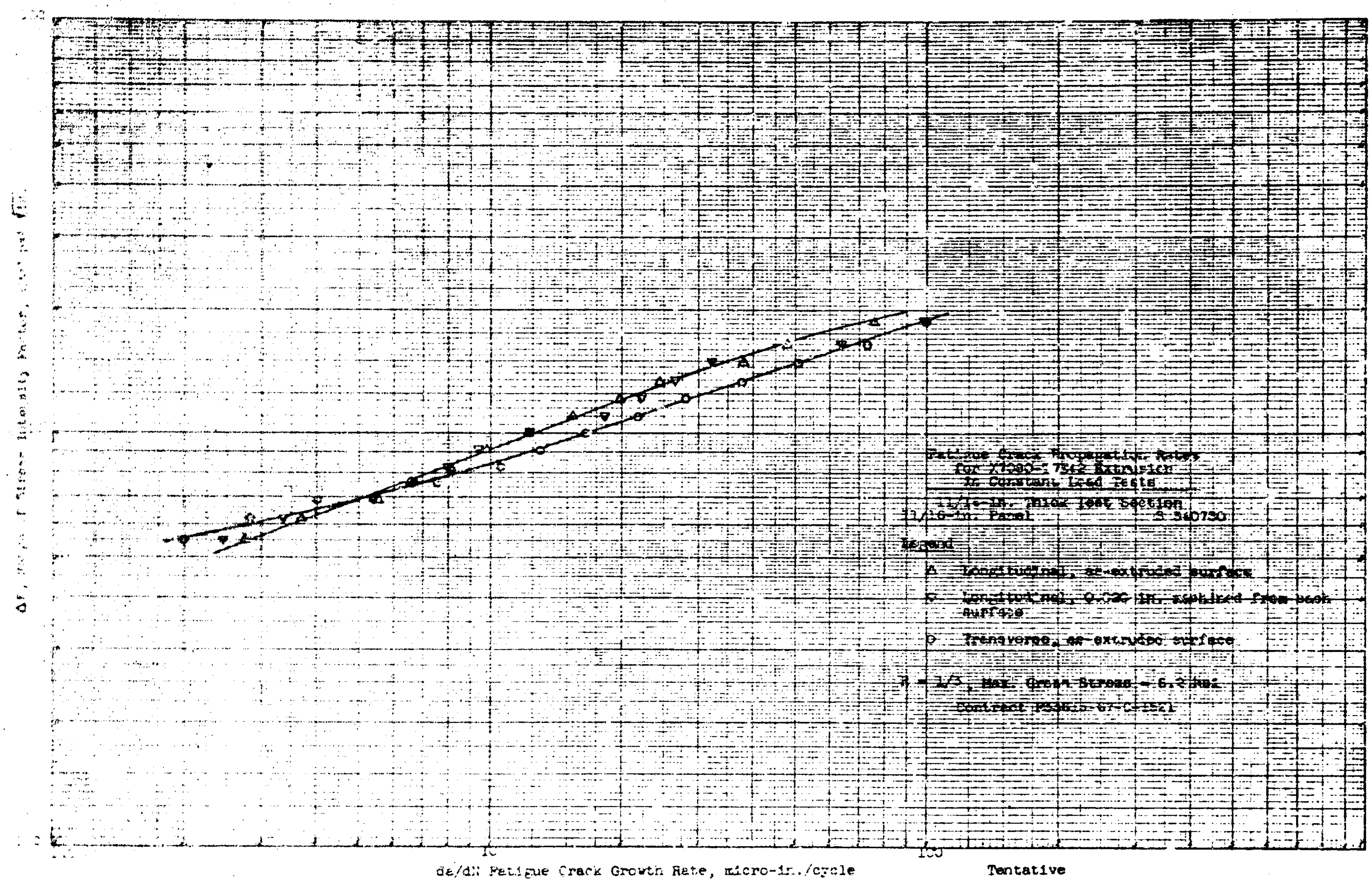
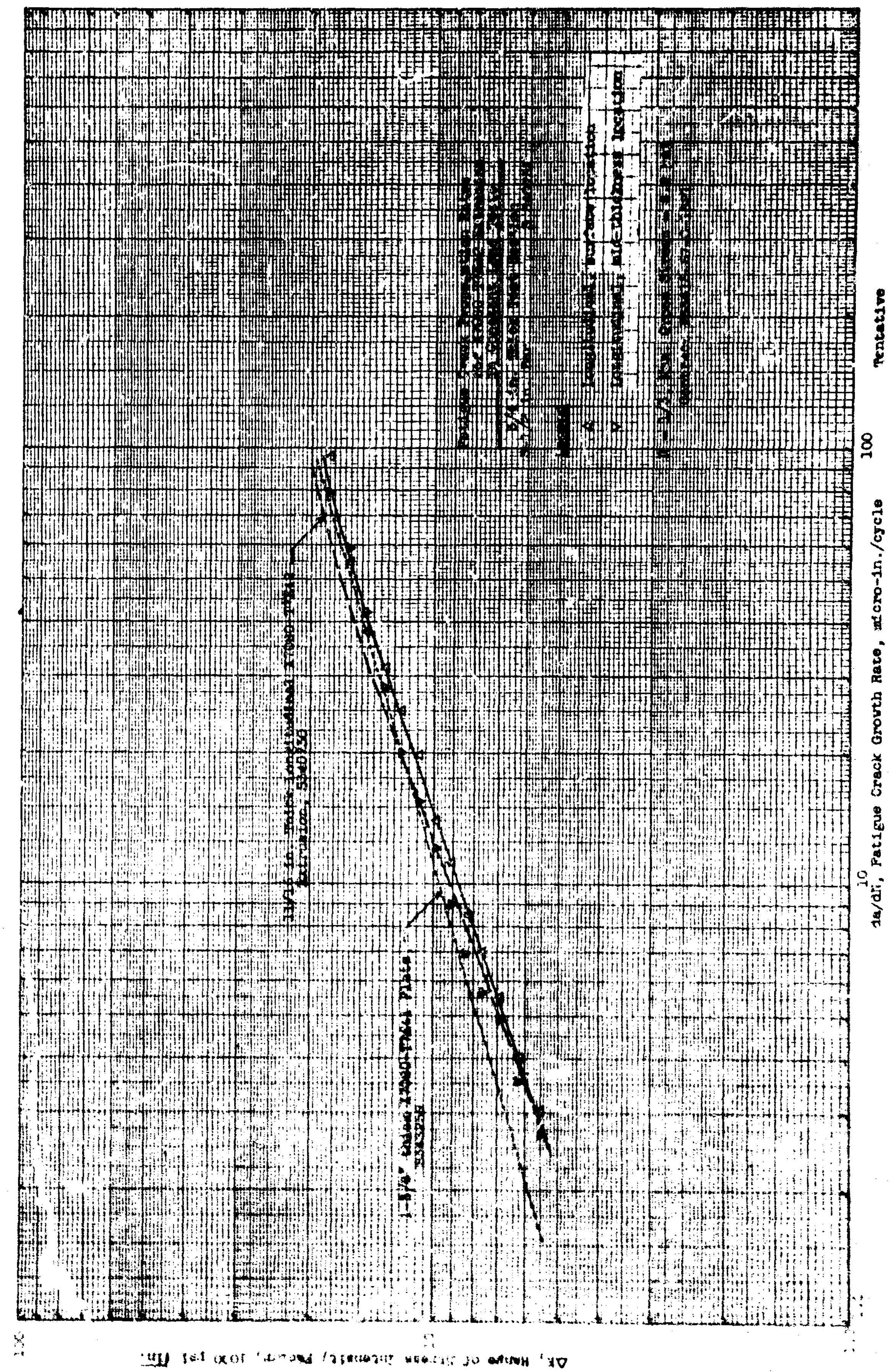
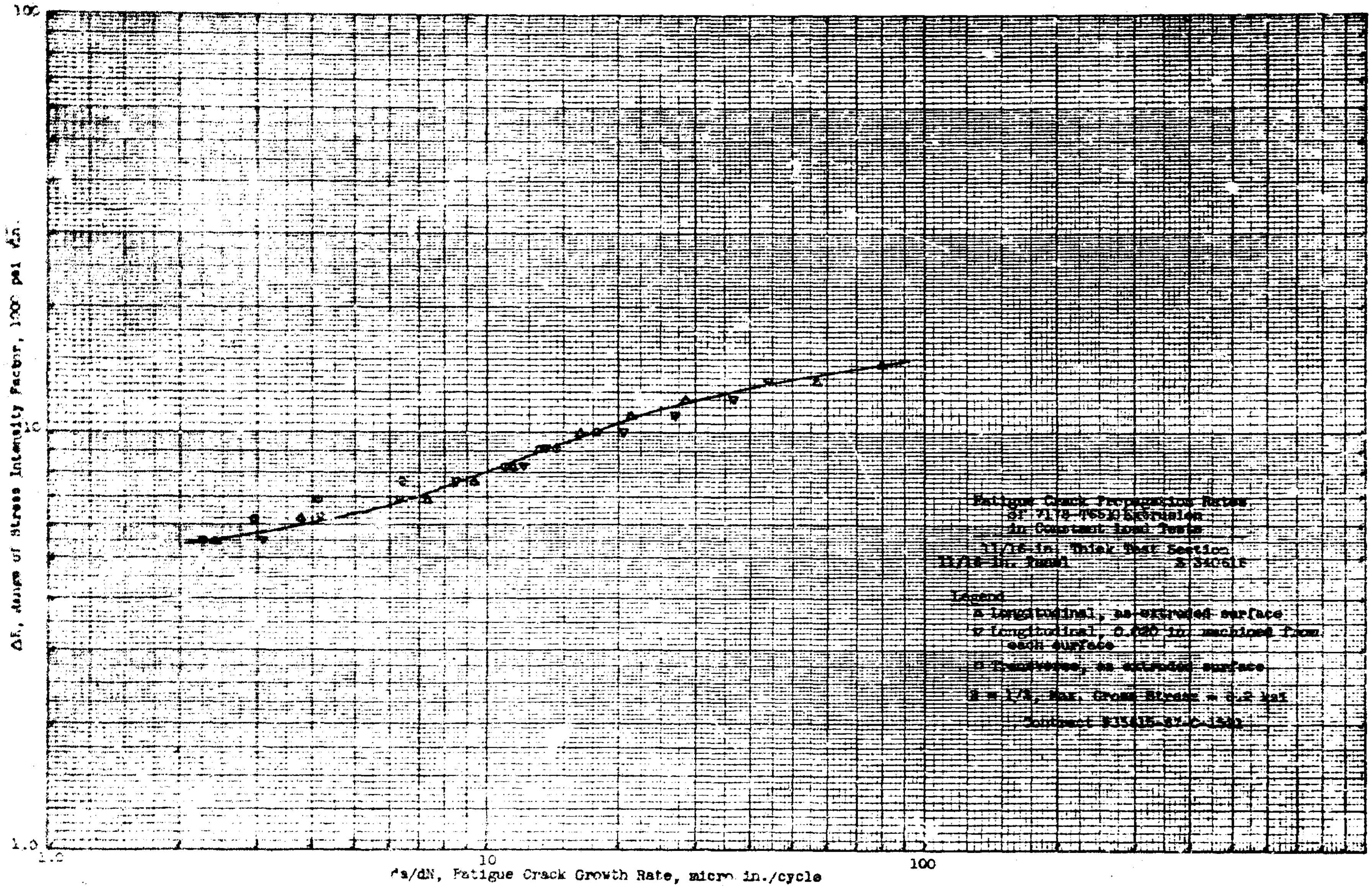

10
100
da/dN Fatigue Crack Growth Rate, micro-in./cycle
Tentative

Fig. 47



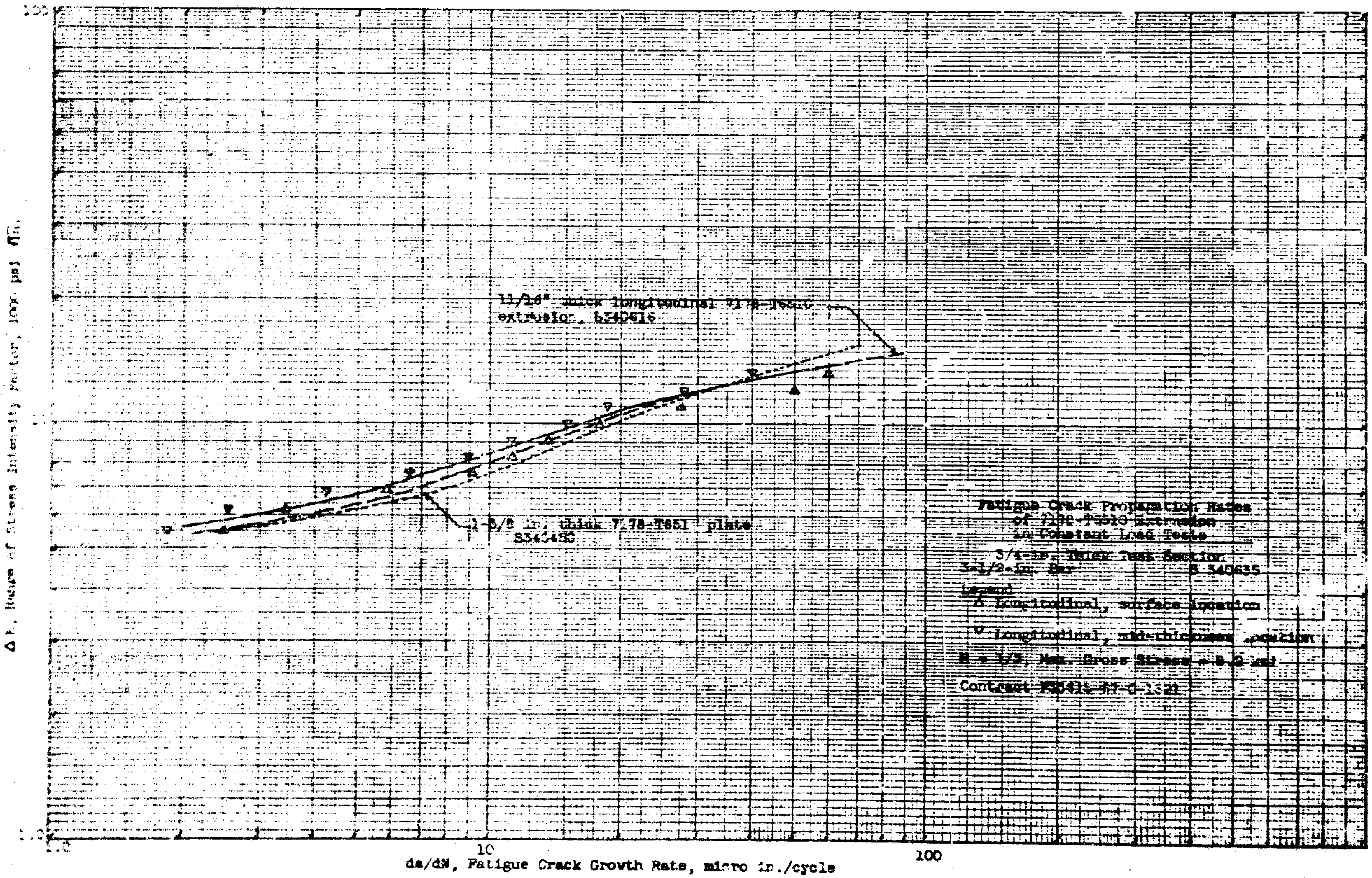
ΔK, Range of Stress Intensity Factor, 1000 psi √in.
da/dN, Fatigue Crack Growth Rate, micro-in./cycle
10
100
Tentative
Longitudinal, surface location
Longitudinal, mid-thickness location

Fig. 48



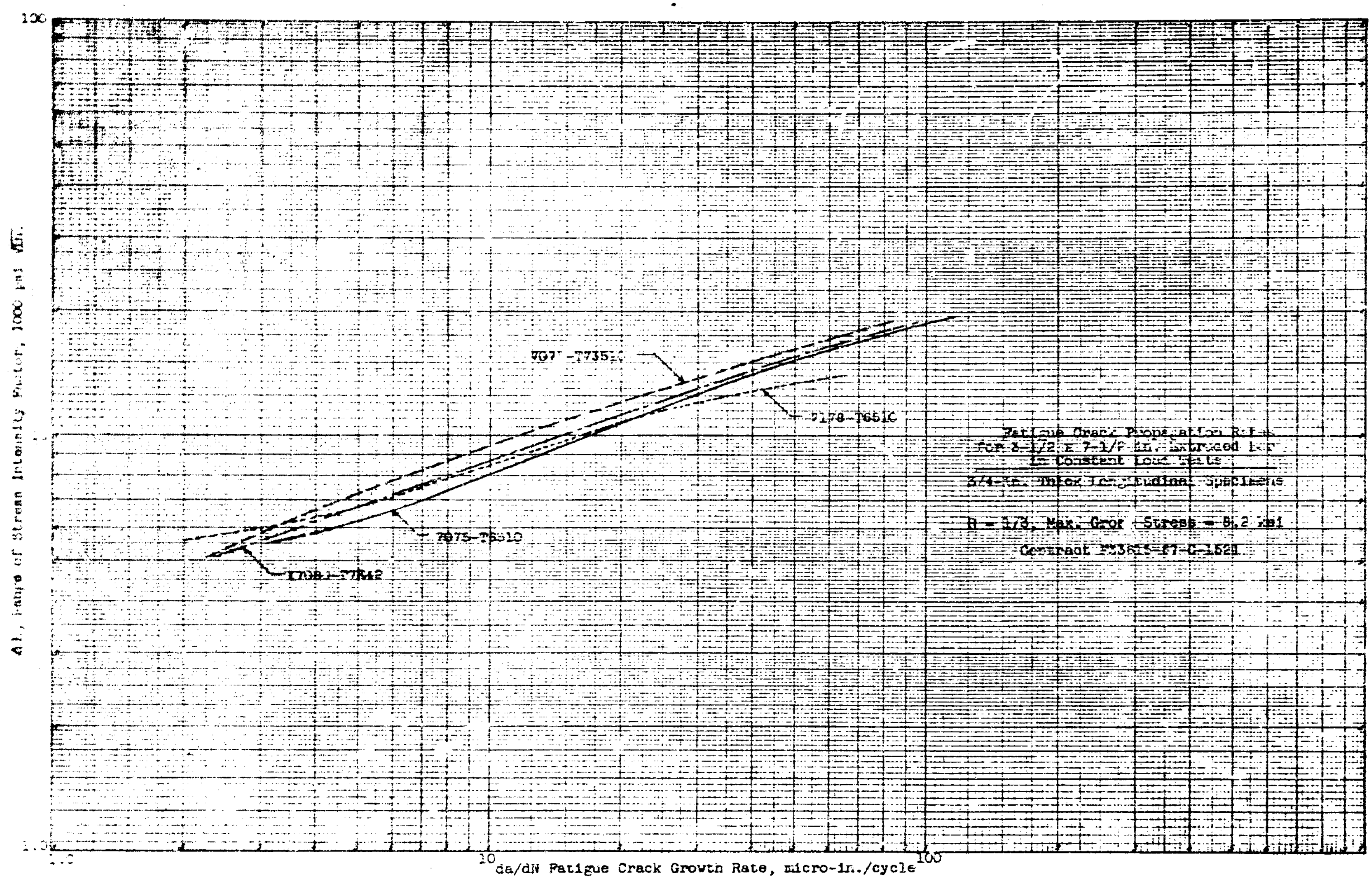
11/16-in. Thick Test Section
Legend
Longitudinal, as-extruded surface
Longitudinal, 0.020 in. machined from each surface
10
100
da/dN, Fatigue Crack Growth Rate, micro in./cycle
1.0
10
100
ΔK, Range of Stress Intensity Factor, 1000 psi √in.

Fig. 49



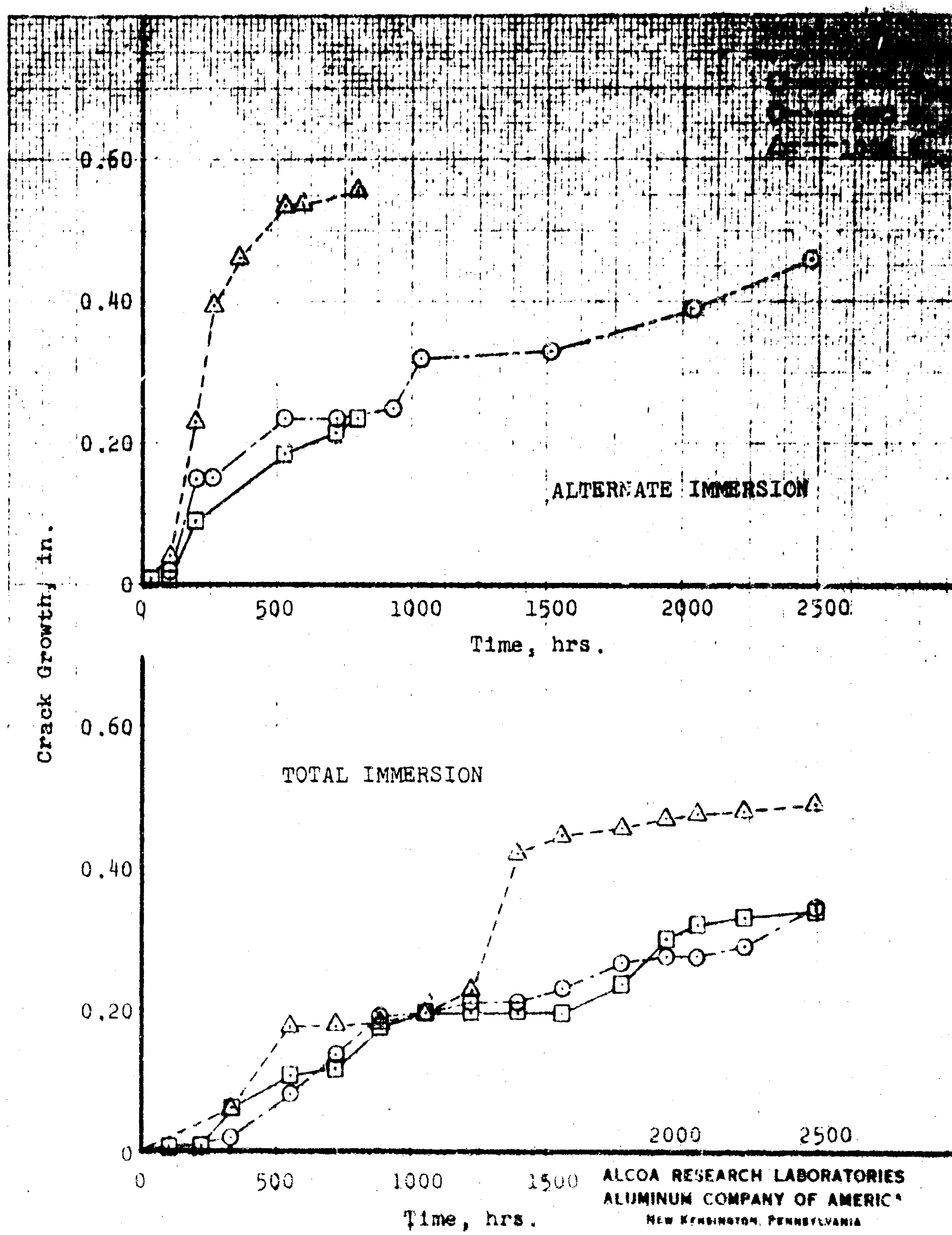
11/16" thick longitudinal 7178-T6510
extrusion, B340616
1-3/8 in. thick 7178-T651 plate
Fatigue Crack Propagation Rates
3-1/2-in. Bar
B 340635
Legend
Δ Longitudinal, surface location
∇ Longitudinal, mid-thickness location
10
100
da/dN, Fatigue Crack Growth Rate, micro in./cycle

Fig. 50



7075-T73510
7178-T6510
7075-T6510
X7080-T7E42
Fatigue Crack Propagation Rate for 3-1/2 x 7-1/2 in. Extruded Bar in Constant Load Tests
3/4-in. Thick Longitudinal Specimens
R = 1/3, Max. Gross Stress = 8.2 ksi
Contract F33615-67-C-1528
da/dN Fatigue Crack Growth Rate, micro-in./cycle
10
100
100

Fig. 51



ALCOA RESEARCH LABORATORIES
ALUMINUM COMPANY OF AMERIC*
NEW KENSINGTON, PENNSYLVANIA

Crack Growth vs Time in 3-1/2% NaCl Solution for Short-Transverse Bolt Loaded Specimens from 7075-T6510 Extruded Bar

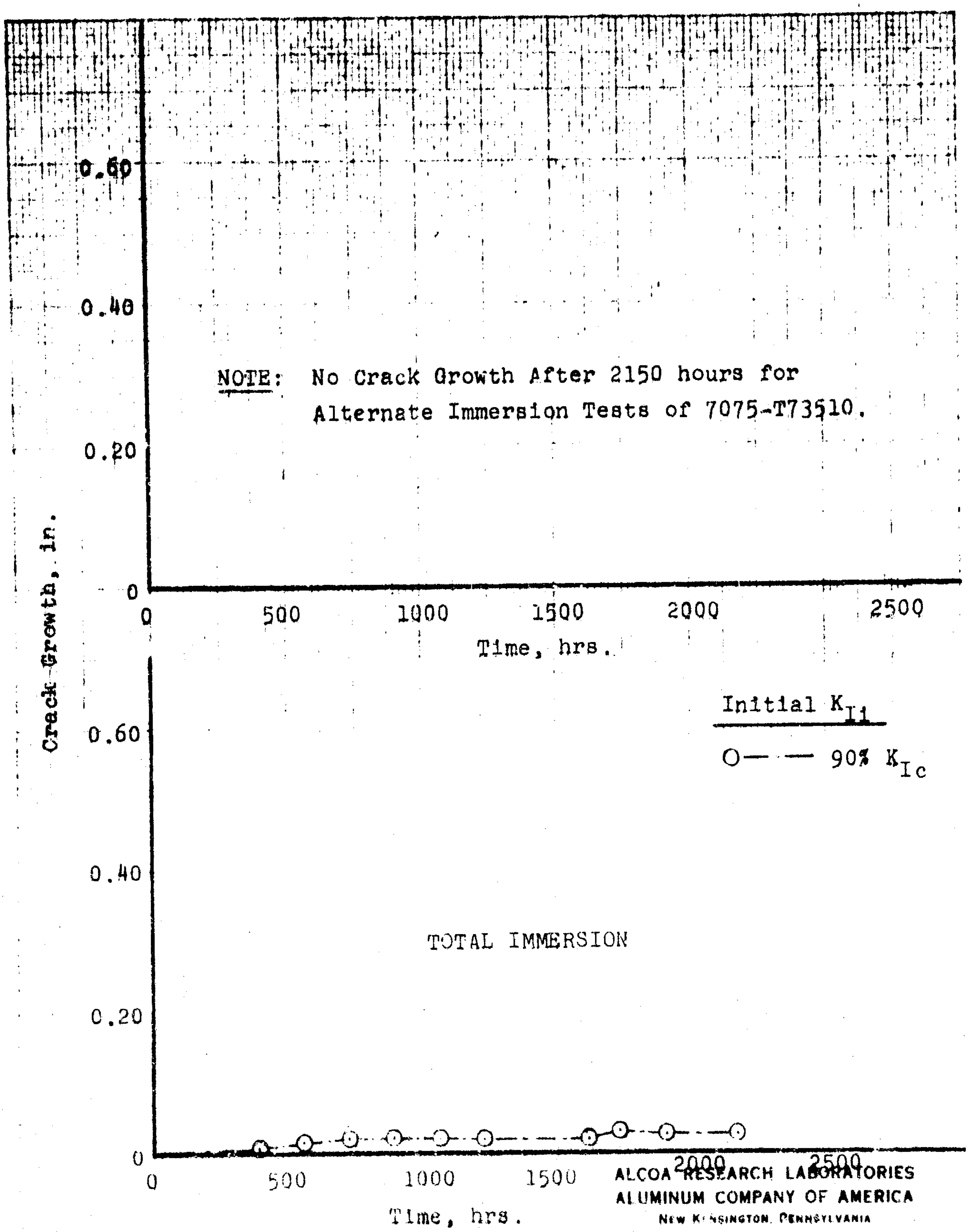
S. No. 340619

PLOTTED ___ DATE ___ APPROVED ___ DATE ___

NOTES: Compact tension specimen
Width = 2.00 in.
Initial crack length = 1.00±0.05 in.
Single specimens were tested at each K_I level

8840-3M-10-65 PRINTED IN U. S. A.

Fig. 52



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ALUMINUM COMPANY OF AMERICA
NEW KENSINGTON, PENNSYLVANIA

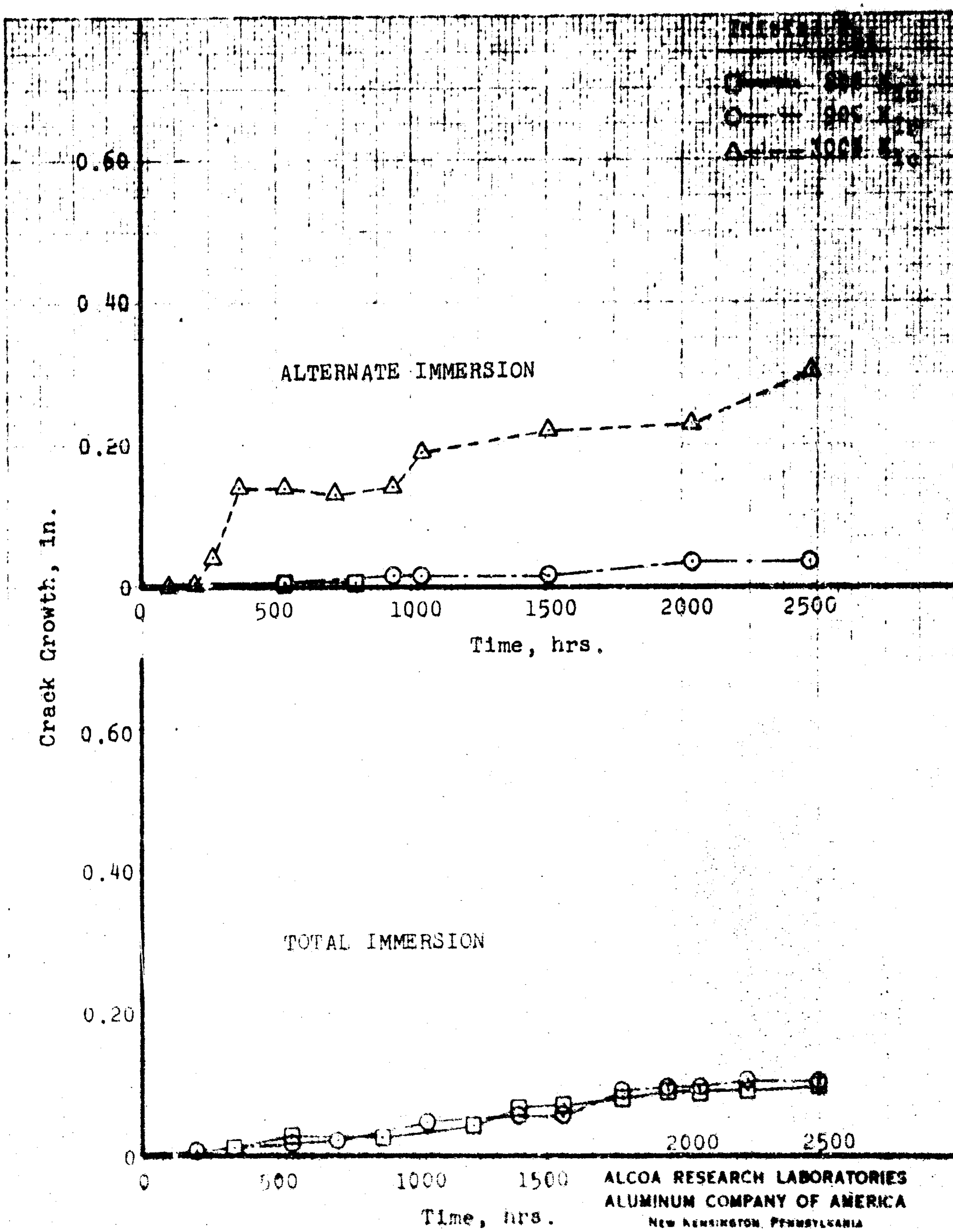
Crack Growth vs Time in 3-1/2% NaCl Solution for Short-Transverse Bolt Loaded Specimens from 7075-T73510 Extruded Bar

S. No. 340620

NOTES: Compact tension specimen
Width = 2.00 in.
Initial crack length = 1.00±0.05 in.
Single specimens were tested at each K_i level

PLOTTED RW DATE 1-1-66 APPROVED ____ DATE ____

Fig. 53



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ALUMINUM COMPANY OF AMERICA
NEW KENSINGTON, PENNSYLVANIA

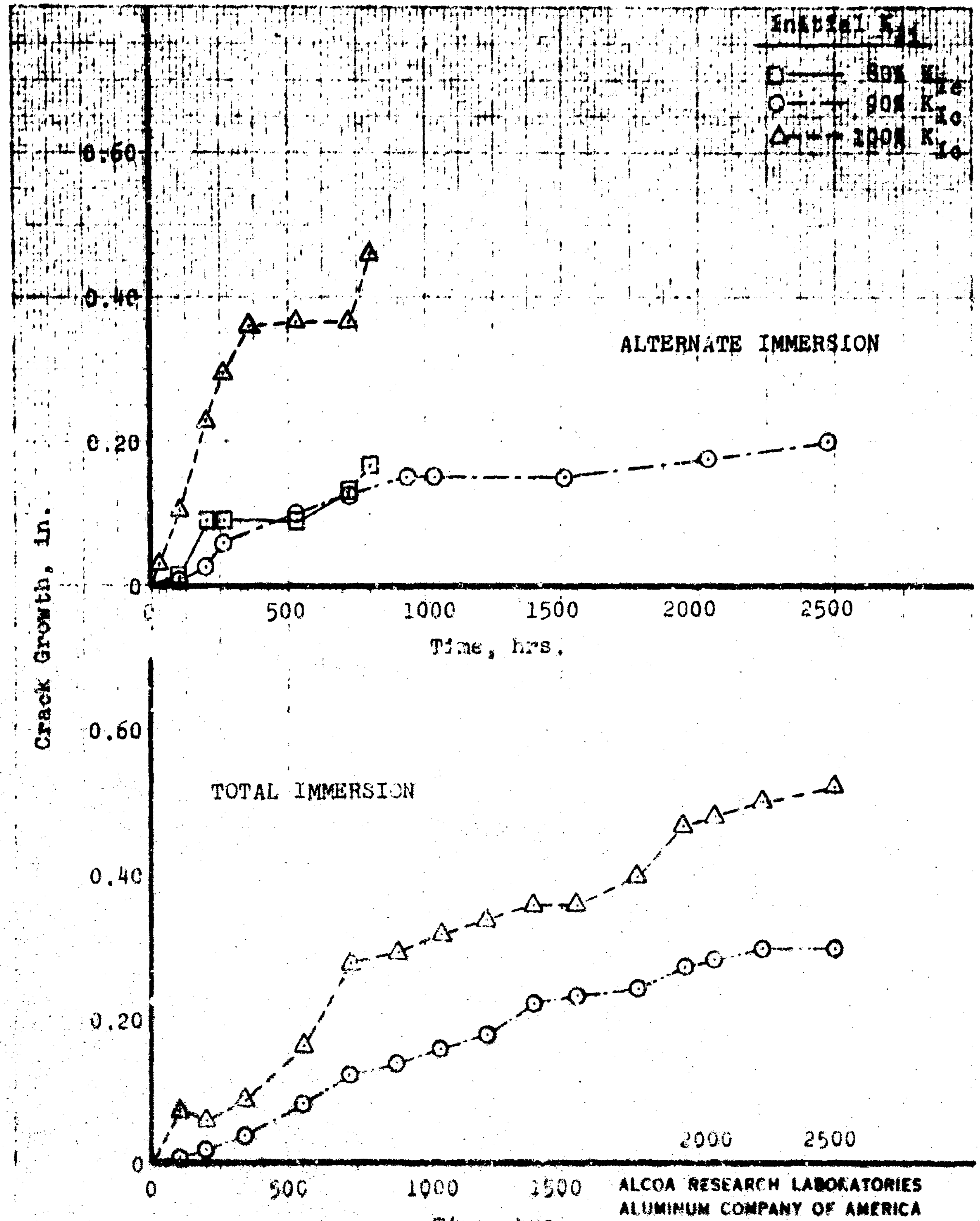
NOTES; Compact tension specimen
Width = 2.00 in.
Initial crack length = 1.00±0.05 in.
Single specimens were tested at each K_I level

Crack Growth vs Time in 3-1/2% NaCl Solution for Short-Transverse Bolt Loaded Specimens from X7080-T7E42 Extruded Bar

S. No. 340732

PLOTTED [illegible] DATE [illegible] APPROVED DATE

Fig. 54



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NEW KENSINGTON, PENNSYLVANIA

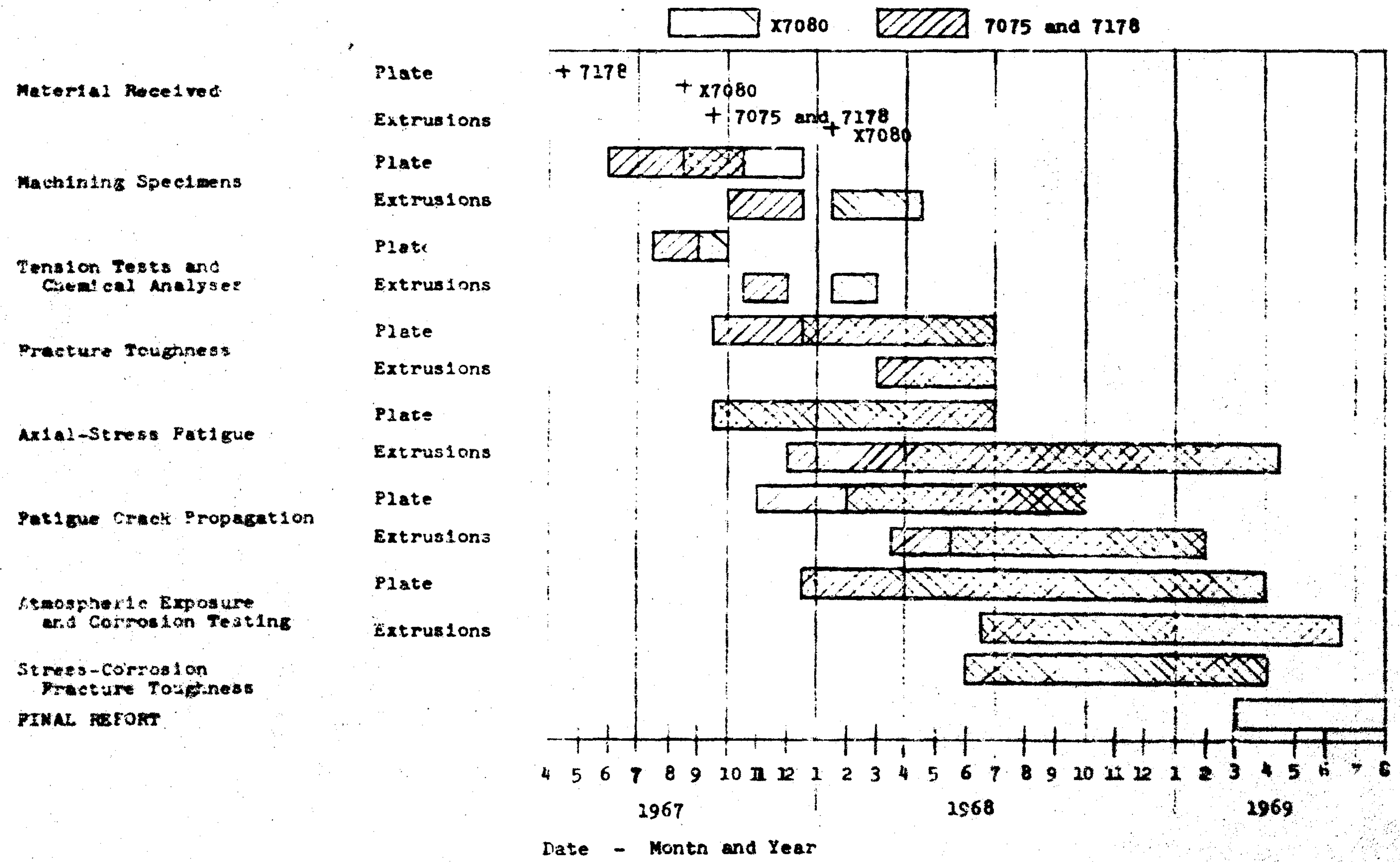
NOTES: Compact tension specimen width = 2.00 in.
Initial crack length = 1.00±0.05 in.
Single specimens were tested at each K_I level

Crack Growth vs Time in 3-1/2% NaCl Solution for Short-Transverse Bolt Loaded Specimens from 7178-T6510 Extruded Bar

S. No. 340635

PLOTTED   DATE   APPROVED   DATE

Fig. 55



Milestone Chart for Program on Fracture Toughness, Fatigue and Corrosion Characteristics of Aluminum Alloy Plate and Extrusions. (Contract F33615-67-C-1521)

Fig. 56