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FATIGUE PROPERTIES OF ALUMINUM ALLOYS AT VARIOUS DIRECT-STRESS RATIOS

Part II - Extruded Alloys

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FOREWORD

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ABSTRACT

Axial-stress fatigue tests were performed at various stress ratios on extruded aluminum alloys 14S-T6, 24S-T4, and 75S-T6 using one unnotched and one notched type of round specimen. The data are presented in the form of S-N curves and stress-range diagrams to analyze the effect of: (a) stress ratio, ranging from static tension to reversed axial stress, (b) stress magnitudes which cause failure in the range from 10^3 to 10^7 cycles, and (c) stress concentration resulting from a circumferential V-notch. The notch-sensitivity data are further analyzed by diagrams which display the importance of stress ratio, stress level, and life on fatigue strength reduction. The fatigue properties of the three extruded alloys are compared both with each other and with rolled aluminum alloys.

PUBLICATION REVIEW

Manuscript copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

M. R. WHITMORE
for M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
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FATIGUE PROPERTIES OF ALUMINUM ALLOYS AT VARIOUS DIRECT-STRESS RATIOS PART II - EXTRUDED ALLOYS

I. INTRODUCTION

The justification for additional work in the fatigue and notch sensitivity properties of aluminum alloys was discussed in Part I of this report issued recently. The data on rolled aluminum alloys are presented in Part I and the results of the tests on extruded alloys are given in this, the second part of the report. This extension of the original program to include extruded alloys is justifiable because of the increasing use of extruded parts in aircraft structures as well as other engineering applications.

II. TEST PROGRAM

All fatigue tests in this work were conducted under axial (tensile or compressive) stress at room temperature. In order to study the effect of range of stress and to compare results with those of rolled aluminum, stress ratios A (ratio of alternating stress to mean stress) of 0, 0.15, 0.89, and infinity were used (1).* As the work progressed, it became evident that the extruded alloys exhibited the same trends as the rolled materials and consequently only about four points were needed to establish each S-N curve sufficiently for comparison purposes.

Two of the specimen types used in the rolled-alloys program were employed for notch sensitivity studies included in this report. The first was a single-filleted unnotched specimen and the second was notched having a theoretical stress concentration factor K_t of 3.4. These specimens are described in more detail in Section IV.

*Numbers refer to references in the Bibliography.

III. MATERIALS

3.1 Specifications for Test Materials

The three aluminum alloys used in this program are: 14S-T6 (spec. QQ-A-266), 24S-T4 (spec. QQ-A-268), and 75S-T6 (spec. QQ-A-282), all in extruded bar stock form.

3.2 Processing

Each of the three materials was received in the form of 1 1/4 in. extruded bars 10 ft. long as furnished by the Aluminum Company of America.

All bars of each material were extruded from a single cast ingot, although to facilitate handling the ingot was cut into three pieces. The bars were extruded by standard practice through a 2-hole 1 1/4 in. die. Bars were labeled to indicate the die through which they were extruded and the bar position in the original cast ingot. When the bars were cut into blanks for specimens, the position in the bar was recorded, so that if serious scatter were observed in the data, the effect of possible inhomogeneity of the material with reference to location in the ingot might be evaluated.*

The materials were solution heat treated by Alcoa following extrusion. For 14S-T6 the treatment was 930° F followed by artificial aging at 320° F for 18 hours. The 24S-T4 was solution heat treated at 920° F, while 75S-T6 was treated at 870° F and then artificially aged for 24 hours at 250° F. All bars were slightly stretched after heat treatment.

3.3 Chemical Analysis

Chemical composition (percent) as furnished by Alcoa is as follows:

	Cu	Fe	Si	Mn	Mg	Zn	Cr	Ti
14S-T6	4.46	0.43	0.95	0.80	0.44	0.07	0.00	0.00
24S-T4	4.30	0.22	0.14	0.61	1.54	0.01	0.01	0.01
75S-T6	1.57	0.20	0.12	0.02	2.46	5.63	0.23	0.02

*This attention to location details was later found to be unnecessary since the test data were reasonably uniform and the association of discrepancies in results with bar location was unnecessary.

The composition of the extruded alloys indicated above may be considered equivalent to the composition of the rolled alloys given in Part I.

3.4 Metallographic Structure

The metallographic structure of the three materials is shown in the photomicrographs of Fig. 1. The structure appears to be normal for extruded alloys. The characteristic elongated grains are prominent in the longitudinal sections, while the transverse sections reveal rather uniform grain size.

IV. TEST SPECIMENS

4.1 Design of Specimens

The two types of specimens shown in Fig. 2 were used, one being unnotched while the second was notched to produce a stress concentration. Both specimens have a test-section diameter of 0.400 in. The filleted specimen has insignificant stress concentration and thus K_t is 1.0 for the unnotched specimens. The notched specimen has a 60° V-notch with a root radius of 0.01 in. with a theoretical stress concentration factor determined from Neuber's Charts (2) of 3.4.

Both of these specimen types were also used in the rolled alloy program discussed in Part I.

4.2 Preparation of Specimens

All fatigue specimens were machined and polished by the John Stulen Company of Gibsonia, Pennsylvania. Special procedures were followed to insure uniformity of surfaces, to avoid circumferential scratches, and to reduce to a minimum the residual stresses due to machining. Details on the procedures employed are described in (1).

V. TESTING EQUIPMENT

5.1 Fatigue Testing Machines

All fatigue tests were conducted in axial-stress machines capable of imposing on the specimen any combination of forces up to ± 5000 pounds alternating force and 9000 pounds static tensile force. The alternating force is provided by an eccentric driven by a 3600 rpm synchronous motor. The static force is applied by helical springs, and provision is made to automatically maintain this force if the specimen elongates during a test. Specially designed gripping devices are used to eliminate as far as possible bending stresses due to gripping the specimen. A detailed description of test equipment is given in (1).

5.2 Calibration

Considerable care was taken to insure that the stresses imposed during the tests were accurately controlled. Machines were originally calibrated by three independent methods and spot checks were made throughout the test program. Stresses were thus controlled to within ± 5 percent at all times.

VI. RESULTS AND DISCUSSION

6.1 Static Tensile and Hardness Properties

In order to evaluate the uniformity of each of the three test materials and to compare the properties with accepted values, static tensile tests and hardness tests were performed. Specimens were prepared from blanks taken from one end of each 10 ft bar, and standard ASTM tests were run to determine tensile strength, yield strength, modulus of elasticity, and percent elongation. These values, together with Rockwell A hardness numbers, are given in Tables I, II, and III. These results compare quite favorably with values given by Alcoa (3) for extruded alloys, although the tensile and yield strengths are 5 to 10 percent higher than those found in (4).

The strengths are significantly higher (9 to 20 percent) than for rolled alloys previously tested (1).

Tensile tests were also performed on fatigue type specimens, and these results are included in Tables I, II, and III. As in the case of the rolled alloys, the unnotched specimens exhibited slightly higher tensile strengths than the ASTM straight specimens and the notched specimens of 14S-T6 and 75S-T6 exhibited significantly higher strengths. The notched specimens of 24S-T4 had tensile strengths approximately the same as those of the straight specimen. This behavior corresponds with that observed for rolled 24S-T4.

In addition to the hardness data given in the tables, hardness surveys were made to determine the uniformity of specimens taken from different locations in the ingot. These surveys revealed good uniformity of the materials, and there was no significant variation in either longitudinal or transverse sections of individual specimens.

6.2 Fatigue Properties of 14S-T6

6.2.1 S-N Diagrams. The data obtained on fatigue strength of unnotched and notched specimens of 14S-T6 are given in Table IV and are plotted in the form of S-N curves in Figs. 3 and 4. In these diagrams the logarithm of the crest stress, S_c, is plotted against the logarithm of N, the number of cycles to failure. Three curves are plotted, one for each of the three stress ratios used ($A = 0.15$, 0.89, and ∞), as indicated by the point and line code. Because of the logarithmic scales, a fixed distance represents a constant percentage at any ordinate and for reference a 10 percent spread is indicated at the lower left of the diagram.

As would be expected, the curve for $A = \infty$ is the lowest while that for $A = 0.15$ is highest for both the notched and unnotched specimens. It may be observed, also, that the curves for higher stress ratio have a somewhat steeper slope than those for which the percentage of alternating stress is less. Although the curves become quite flat at the long-life end, there is no certainty that they have a horizontal asymptote. It is therefore not possible with these limited data to establish a definite fatigue limit.

These curves have a pattern quite similar to those for rolled 14S-T6 (1). A comparison of the two materials can better be seen, however, in the diagrams described below.

6.2.2 Stress-Range Diagrams. The data from Figs. 3 and 4 are replotted in Figs. 5 and 6 in a coordinate system of alternating versus mean stress to better reveal the effect of range of stress on fatigue life. The curves show combinations of alternating and mean stress resulting in a given life. In these diagrams, constant-life curves for 10^4, 10^5, and 10^7 cycles are shown, and as the code indicates, the solid curves are for extruded 14S-T6 while the dashed curves are for the rolled alloy (1). The static ultimate strength for extruded 14S-T6 is indicated by the S_u designation on the horizontal axis, and the dashed line extending from this point at a 45° angle indicates the combinations of alternating stress S_a and mean stress S_m whose sum equals the ultimate strength. The radial lines through the origin indicate the stress combinations for a given stress ratio, the vertical axis representing $A = \infty$ while the horizontal axis is $A = 0$.

In Fig. 5, the curves for unnotched specimens of both the extruded and rolled alloys are shown. Here the definite similarity in behavior is evident and the fatigue strengths of the two materials may be readily compared. The fatigue strengths of the extruded alloy, like the static strengths, are slightly higher in all cases. The shape of the curve for 10^7 cycles is quite significant. Because it is quite flat, it is evident that the relative amount of alternating stress is more important in determining fatigue life than is the mean stress.

This observation becomes even more noticeable in the case of notched specimens diagrammed in Fig. 6 where all the curves are very flat. In this case, also, it may be seen that the two materials have very similar behavior and that the extruded fatigue strength is generally somewhat higher than that of the rolled. A comparison of Figs. 5 and 6 shows a marked difference in the fatigue strengths of notched and unnotched specimens due to stress concentration. This effect is further analyzed in the diagrams described below.

6.2.3 Notch Sensitivity. In order to analyze the harmful effect of a notch or stress raiser, the fatigue strength reduction factor, K_f, is defined as the ratio of the stress in an unnotched specimen to the corresponding stress in a notched specimen at a given life.* In Fig. 7 the variation of K_f with stress level and with stress ratio is shown by means of contours of constant K_f plotted on a grid of alternating versus mean stress in the unnotched specimen. These curves were developed by first plotting "profile" curves (not shown) of K_f versus either S_a or S_m, and then the desired K_f values were located on the stress-ratio lines of Fig. 7. These points were joined to form the contour curves shown. Extrapolated portions of the curves are dashed.

A study of Fig. 7 reveals several pertinent facts regarding the strength-reduction factor. It is of course obvious that K_f is not constant, but varies with the stress level and with stress ratio. The largest observed values of K_f occur at $A = \infty$ and the least values are found at $A = 0.15$. At all stress ratios, K_f decreases as the stress is increased. This should be expected, since at high stress (and corresponding short life) the fatigue strengths approach the static ultimate strength which is higher for the notched specimen. In fact, at $A = 0$ (static test) the strength reduction factor $\left(\frac{\text{unnotched } S_u}{\text{notched } S_u}\right)$ reduces to 0.91, a point that is shown on the horizontal axis of the figure. Other features of this type of figure are discussed in Part I.

In order to observe further the stress concentration trends, the variation in K_f is shown in Fig. 8 as a function of life and stress ratio R.** The corresponding values of A are shown in the scale at the right. These contour curves of K_f were plotted by using "profiles" of K_f versus N and K_f versus R. The selected values of K_f were thus located and the contour curves were drawn.

It is evident from Fig. 8 that K_f varies with both life and stress ratio. in the lower half of the diagram (essentially vertical contour lines) K_f if affected more by life and stress ratio is relatively unimportant, whereas in the upper region (essentially horizontal contour lines) stress ratio is the more significant factor. In this figure it is quite clear that the strength reduction factor decreases as the percentage of alternating stress is reduced. This type of plot also shows that the highest value of K_f occurs at $A = \infty$ and at a long life.

*In an analysis based on fixed stress ratios, the ratios of crest stress, alternating stress, and mean stress are all the same.

**R is the ratio of minimum stress in a cycle to the crest stress and is used instead of A since the range in R values from -1 to +1 is easier to diagram than the range of A values from 0 to ∞.

The general pattern and behavior of K_f for extruded 14S-T6 observed in Figs. 7 and 8 is very similar to that of rolled 14S-T6 (1).

6.3 Fatigue Properties of 24S-T4

6.3.1 S-N Diagrams. In Figs. 9 and 10 are shown the S-N curves for unnotched and notched specimens respectively of 24S-T4. The curve for A = 0.15 for unnotched specimens (Fig. 9) is extremely flat. One test run at a crest stress of 90,000 psi lasted only approximately 300 cycles, while another at a stress only 4000 psi less ran for over 5 million cycles. It will be noted that two points appear in the diagram at a stress slightly in excess of the static ultimate strength of the specimen. The significance of this observation, however, is questionable because of the accuracy of imposed stresses.

6.3.2 Stress-Range Diagrams. The stress-range data for unnotched and notched specimens of 24S-T4 are diagramed in Figs. 11 and 12. Here again, it is apparent that the rolled and extruded materials follow generally the same pattern, except that the fatigue strengths of the extruded material are from 7 to 15 percent higher as is the static strength. It should be noted that, as in the case of other materials, the notched stress-range curves are very flat.

6.3.3 Notch Sensitivity. Figure 13 shows the variation in K_f with stress ratio and magnitude. As for 14S-T6, K_f becomes larger as the stress decreases reaching a maximum value of 2.6 at A = 0.89 and ∞. The variation of K_f with stress ratio and life is shown in Fig. 14. Both factors generally affect the value of K_f, but in the lower half of the diagram N seems to be more significant while stress ratio predominates in the upper half.

The behavior of this material as regards notch sensitivity is very similar to that of the rolled 24S-T4 (1).

6.4 Fatigue Properties of 75S-T6

6.4.1 S-N Diagrams. Figures 15 and 16 are the S-N curves for 75S-T6. These curves display practically the same trends as those for 14S-T6 and 24S-T4, the unnotched specimens having flatter curves and, of course, higher fatigue strengths. Here again, there is no conclusive evidence of the existence of an endurance limit; in fact, within the range of data procured, the curves continue to fall after 10 million cycles.

6.4.2 Stress-Range Diagrams. In Figs. 17 and 18 the stress-range curves for unnotched and notched 75S-T6 are shown. It will be noticed that, although the general trends are the same, the fatigue strength of the extruded alloy is in some cases as much as 95 percent higher than that of rolled 75S-T6. This is in line with conclusions reached in the report on rolled alloys (1) that the fatigue strength of the rolled 75S-T6 tested in that program was abnormally low. It is believed that the fatigue strength of this extruded 75S-T6 is more near the average value for this material.

In the case of notched specimens, the difference in fatigue strengths of extruded and rolled materials is not as great, although the strength of the extruded material is significantly higher. The extreme flatness of the curves is again very noticeable.

6.4.3 Notch Sensitivity. The behavior of K_f for 75S-T6 is shown in Figs. 19 and 20. In Fig. 19 the values of K_f are uncertain over much of the area, so the contours are dashed in those regions. The data show a region of maximum K_f at A = 0.89 and at moderate stress. For stresses either greater or less the value of K_f becomes less, and K_f decreases at $A = \infty$ and A = 0.15.

Since the S-N curves from which the K_f values were taken may be in error by approximately $\pm$ 5 percent due to scatter in the data, the values of K_f may be off by 10 percent (quotient of two factors whose reliability is $\pm$ 5 percent). It is therefore quite possible that this diagram does not represent the exact behavior of K_f for this material, although this shape fits the data quite closely. It is also quite similar to the diagram for rolled 75S-T6 (1) except that K_f values are somewhat larger than those for the rolled material.

In Fig. 20 the "peak" region occurs at stress ratio A of about 1.4 and a life of 10^5 cycles. Again, the exact variation of K_f may not be as indicated, but certainly K_f decreases as A is reduced and it is dependent upon life.

VII. COMPARISON OF PROPERTIES OF THE THREE ALLOYS

7.1 Fatigue Strength

A composite stress-range diagram showing the fatigue strengths of the three extruded alloys is given in Fig. 21. In Fig. 21a the curves for unnotched specimens show 75S-T6 to have the highest strength at 10^4 cycles with 24S-T4 next and 14S-T6 having the lowest strength. However, at 10^7 cycles the strength of the three materials is practically the same, although 75S-T6 is somewhat stronger in the low stress-ratio region, while 14S-T6 is a little higher near $A = \infty$.

In the comparison of notched specimens, Fig. 21b, there is relatively little difference in the fatigue strength of the three materials at either 10^4 or 10^7 cycles. The curves for 10^4 cycles again show 75S-T6 to be stronger at low stress ratio, but in this case, 24S-T4 is slightly stronger under reversed stress. These slight differences in strength are not sufficient to indicate a superiority of one material over the other, especially when scatter in the data is considered. However, it seems evident that 75S-T6, because of its higher static strength and higher fatigue strength at low stress ratio, does have significantly higher strength under loads having relatively low alternating stress.

7.2 Notch Sensitivity

A comparison of the notch sensitivity curves for the three materials reveals a very definite similarity between the characteristics of 14S-T6 and 24S-T4 both in magnitude and manner of variation of K_f with stress, stress ratio, and life. The curves for 75S-T6, however, display a different pattern of variation. Where 14S-T6 and 24S-T4 have maximum values at $A = \infty$ and at low stress, 75S-T6 has its maximum at $A = 1.4$ and at a higher stress. Since the differences involved are relatively small, it can not be stated with certainty whether they are due to inherent characteristics of the materials or due to scatter in the data. In general, the range of values of K_f is about the same for the three materials.

VIII. SUMMARY AND CONCLUSIONS

In order to compare the fatigue properties of extruded aluminum alloys 14S-T6, 24S-T4, and 75S-T6 with those of rolled alloys (1), a series of axial stress fatigue tests were performed. To analyze the effect of range of stress, tests were conducted under stress ratios, A, of 0.15, 0.89, and ∞. To study the effect of stress concentration, both unnotched and notched type specimens were used. Static tension and hardness tests were also performed for comparison of the test materials with generally accepted standards.

The results for a given material were presented as S-N curves, one for each stress ratio and specimen type. A comparison of the stress-ratio curves provided data for analysis of the effect of various combinations of alternating and mean stress, while a comparison of the two corresponding curves for specimen types supplied notch-sensitivity data.

These latter analyses were facilitated by the use of stress-range diagrams and notch-sensitivity curves. In the stress-range diagrams, curves of constant life were plotted in a coordinate system of alternating stress versus mean stress. Two types of notch-sensitivity charts were used. In the first type, curves of constant K_f (fatigue strength-reduction factor) were plotted as contours in a field of alternating versus mean stress in the unnotched specimen. The second type showed K_f contours within a stress-ratio versus cycles-to-failure coordinate system.

The following conclusions are based on the results obtained in this work:

(a) The static ultimate strengths of the three extruded alloys are slightly higher than those of rolled materials. As in the case of rolled aluminum, the static tensile strengths of notched extruded 14S-T6 and 75S-T6 are about 10 percent higher than those of unnotched specimens, while the tensile strength of 24S-T4 is about the same for notched and unnotched specimens.

(b) The fatigue strengths of both notched and unnotched specimens of extruded 14S-T6 and 24S-T4 are slightly higher at any life than those of rolled alloys.

(c) The fatigue strength of notched and unnotched extruded 75S-T6 is significantly higher than that found for rolled 75S-T6.

However, this marked difference (as much as 95 percent for unnotched specimens) is undoubtedly due to the fact that the fatigue strengths for rolled 75S-T6 (1) were abnormally low.

(d) The fatigue strengths of unnotched and notched extruded alloys 14S-T6, 24S-T4, and 75S-T6 are practically the same at long life (ten million cycles or more), except that 75S-T6 is slightly stronger at low stress ratios. Unnotched 75S-T6 is somewhat stronger during short-life fatigue.

(e) The notch-sensitivity properties of the three extruded alloys are about the same as those of rolled materials. The strength reduction factor, K_f, varies with stress ratio and stress level (or life) and is maximum for 14S-T6 and 24S-T4 at $A = \infty$ and at low stress. For 75S-T6, K_f is maximum at $A = 1.4$ and at medium stress level. The maximum value of K_f for the three alloys is about 2.8 for a notch whose theoretical stress-concentration factor is 3.4.

(f) The over-all fatigue behavior of extruded 14S-T6, 24S-T4, and 75S-T6 may be considered the same as that of rolled alloys.

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TABLE I. STATIC PROPERTIES OF 14S-T6
EXTRUDED ALUMINUM ALLOY

Specimen No. and Type	Hardness R_A	Mod. E 10^6 PSI	Tensile Strength PSI	.2% Offset Yield Str. PSI	Elong.
Q 1701 AE*	47.7	10.6	79,065	67,400	11%/2"
Q 1702 AE*	47.6	10.3	77,176	70,400	11%/2"
Q 1703 AE*	48.3	11.7	78,270	73,300	11%/2"
Q 1704 AE*	48.1	10.3	78,323	68,200	11%/2"
Q 1705 AE*	48.6	11.2	78,700	73,000	11%/2"
Average*	48.1	10.8	78,307	70,460	11%/2"
Q 1711 V			79,520		.086"
Q 1725 V			78,185		.092"
Average for Type V Specimens (K_t = 1.0)			78,853		.089"
Q 1748 X			87,025		.021"
Q 1762 X			86,032		.017"
Average for Type X Specimens (K_t = 3.4)			86,529		.019"

TABLE II. STATIC PROPERTIES OF 24S-T4
EXTRUDED ALUMIMUM ALLOY

Specimen No. and Type	Hardness R_A	Mod. E 10^6 PSI	Tensile Strength PSI	.2% Offset Yield Str. PSI	Elong.
P 1765 AE*	49.1	9.7	84,604	66,009	11.5%/2"
P 1766 AE*	49.6	10.4	85,213	65,564	11.5%/2"
P 1767 AE*	49.5	10.6	85,032	64,888	11.0%/2"
P 1768 AE*	49.8	10.2	85,832	66,028	11.0%/2"
P 1769 AE*	49.3	10.0	84,873	65,901	10.5%/2"
Average*	49.5	10.2	85,111	65,678	11.1%/2"
P 1783 V			85,692		.076"
P 1785 V			86,874		.072"
P 1791 V			86,783		.080"
P 1798 V			88,019		.089"
Average for Type V Specimens (K_t = 1.0)			86,842		.0793"
P 1806 X			83,540		.028"
P 1813 X			84,270		.026"
P 1819 X			84,494		.029"
P 1825 X			88,019		.027"
Average for Type X Specimens (K_t = 3.4)			84,089		.0275"

*Standard ASTM Specimen and Test.

TABLE III. STATIC PROPERTIES OF 75S-T6 EXTRUDED ALUMINUM ALLOY

Specimen No. and Type	Hardness R_A	Mod. E 10^6 PSI	Tensile Strength PSI	.2% Offset Yield Str. PSI	Elong.
R 1829 AE*	52.4	10.0	93,585	86,166	9.5%/2"
R 1830 AE*	52.6	10.0	93,274	85,740	9.5%/2"
R 1831 AE*	52.9	9.9	92,889	85,927	10.0%/2"
R 1832 AE*	52.8	10.1	92,889	86,900	10.5%/2"
R 1833 AE*	51.7		89,287	81,400	8.5%/2"
Average*	52.5	10.0	92,386	84,226	9.6%/2"
R 1838 V			94,193		.073"
R 1851 V			96,261		.079"
Average for Type V Specimens (K_t = 1.0)			95,227		.076"
R 1875 X			102,853		.016"
R 1887 X			99,446		.020"
Average for Type X Specimens (K_t = 3.4)			101,150		.018"

*Standard ASTM Specimen and Test.

TABLE IV. FATIGUE DATA ON 14S-T6 EXTRUDED ALUMINUM ALLOY

Specimen Number	Stress Ratio A	Crest Stress KSI	Kilocycles to Failure
Type V Specimens (K_t = 1.0)			
Q 1708 V	0.15	70.0	25100. *
Q 1714 V	0.15	77.0	778.
Q 1724 V	0.15	80.0	669.
Q 1718 V	0.15	82.0	0.06
Q 1713 V	0.89	29.0	21600. *
Q 1707 V	0.89	29.0	2290. *
Q 1735 V	0.89	38.0	1910. *
Q 1732 V	0.89	42.0	25200. *
Q 1723 V	0.89	45.0	216.
Q 1706 V	0.89	45.0	101.
Q 1719 V	0.89	60.0	114.
Q 1729 V	0.89	75.0	19.1
Q 1715 V	∞	24.0	14100. *
Q 1722 V	∞	30.0	1080. *
Q 1728 V	∞	32.0	2330. *
Q 1734 V	∞	34.0	832.
Q 1709 V	∞	39.0	108.
Type X Specimens (K_t = 3.4)			
Q 1744 X	0.15	35.0	6570.
Q 1740 X	0.15	45.0	368.
Q 1737 X	0.15	80.0	16.9
Q 1736 X	0.89	16.0	25600. *
Q 1742 X	0.89	20.0	184.
Q 1739 X	0.89	35.0	12.6
Q 1746 X	0.89	55.0	2.16
Q 1738 X	∞	11.0	9640.
Q 1743 X	∞	20.0	23.7
Q 1747 X	∞	39.0	1.8

*Did not fail.

TABLE V. FATIGUE DATA ON 24S-T4 EXTRUDED ALUMINUM ALLOY

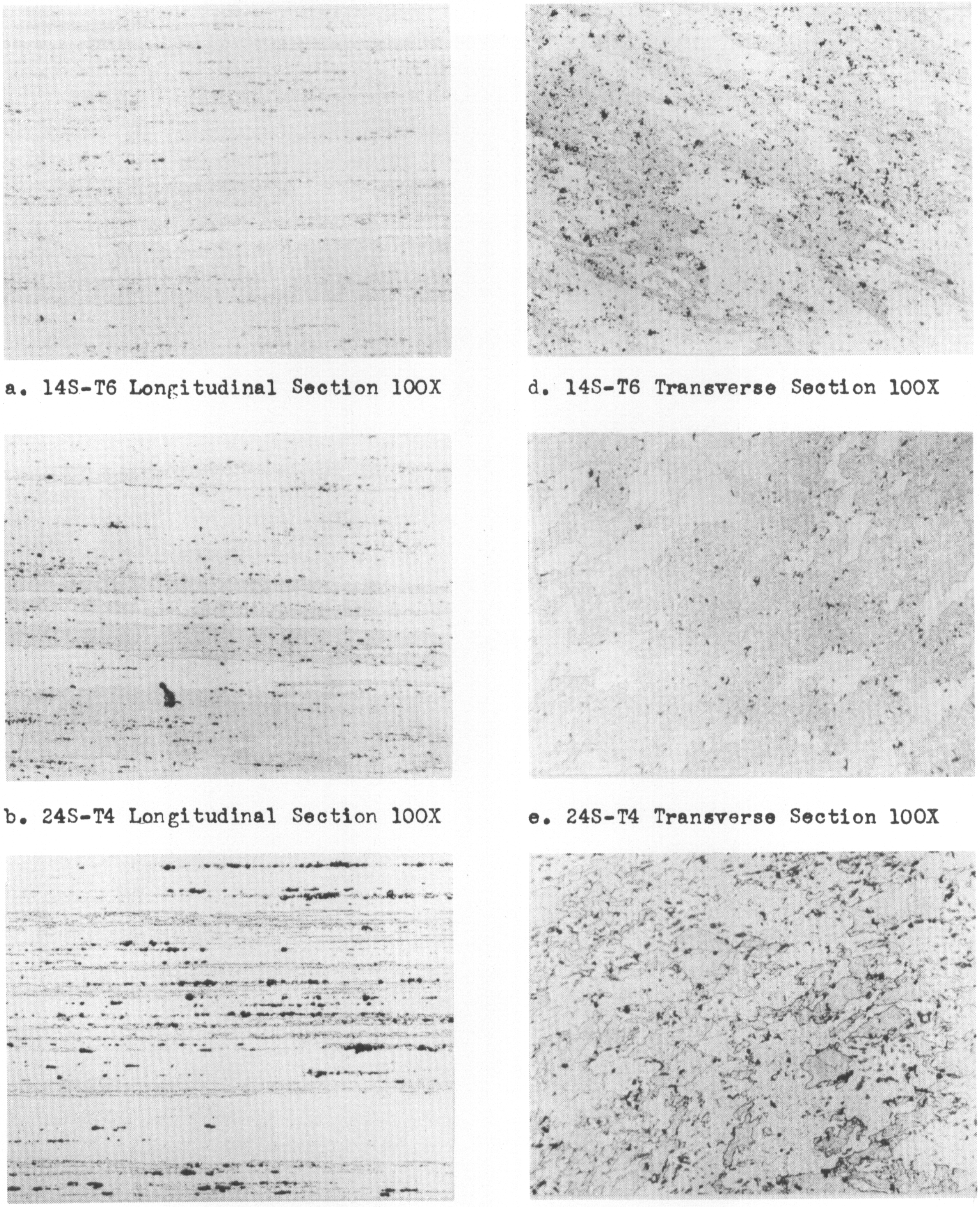
Specimen Number	Stress Ratio A	Crest Stress KSI	Kilocycles to Failure
Type V Specimens (K_t = 1.0)			
P 1776 V	0.15	75.0	24300. *
P 1771 V	0.15	80.0	864.
P 1778 V	0.15	85.0	5600.
P 1781 V	0.15	86.0	318.
P 1773 V	0.15	90.0	0.3
P 1779 V	0.89	42.0	19800.
P 1774 V	0.89	50.0	313.
P 1772 V	0.89	65.0	39.9
P 1775 V	0.89	80.0	9.6
P 1782 V	0.89	84.0	7.6
P 1780 V	∞	26.0	19900. *
P 1777 V	∞	30.0	918. *
P 1784 V	∞	33.0	584.
P 1770 V	∞	39.0	150.
Type X Specimens (K_t = 3.4)			
P 1810 X	0.15	35.0	20500. *
P 1828 X	0.15	40.0	929.
P 1804 X	0.15	45.0	382.
P 1808 X	0.15	60.0	103.
P 1809 X	0.15	75.0	23.8
P 1821 X	0.15	83.0	0.06
P 1815 X	0.89	16.0	19500. *
P 1807 X	0.89	18.0	885.
P 1805 X	0.89	25.0	106.
P 1827 X	0.89	40.0	11.1
P 1800 X	0.89	55.0	3.64
P 1826 X	∞	9.5	24600.
P 1811 X	∞	10.5	4490.
P 1803 X	∞	12.0	2150.
P 1802 X	∞	20.0	170.
P 1812 X	∞	30.0	23.8
P 1801 X	∞	39.0	4.2

*Did not fail.

TABLE VI. FATIGUE DATA ON 75S-T6 EXTRUDED ALUMINUM ALLOY

Specimen Number	Stress Ratio A	Crest Stress KSI	Kilocycles to Failure
Type V Specimens (K_t = 1.0)			
R 1843 V	0.15	80.0	24100. *
R 1835 V	0.15	85.0	454.
R 1839 V	0.15	90.0	356.
R 1860 V	0.89	25.0	19600. *
R 1834 V	0.89	29.0	20500. *
R 1837 V	0.89	40.0	6980. *
R 1853 V	0.89	50.0	292.
R 1840 V	0.89	70.0	55.6
R 1841 V	∞	25.0	26900. *
R 1850 V	∞	29.0	4880.
R 1836 V	∞	39.0	248.
Type X Specimens (K_t = 3.4)			
R 1892 X	0.15	31.0	20200. *
R 1870 X	0.15	34.0	1750.
R 1874 X	0.15	35.0	1400.
R 1866 X	0.15	38.0	1300.
R 1878 X	0.15	60.0	56.4
R 1882 X	0.15	90.0	12.9
R 1868 X	0.89	15.0	21000.
R 1872 X	0.89	20.0	206.
R 1864 X	0.89	40.0	6.12
R 1865 X	∞	10.5	15400.
R 1869 X	∞	15.0	540.
R 1873 X	∞	35.0	5.76

*Did not fail.



a. 14S-T6 Longitudinal Section 100X

d. 14S-T6 Transverse Section 100X

b. 24S-T4 Longitudinal Section 100X

e. 24S-T4 Transverse Section 100X

c. 75S-T6 Longitudinal Section 100X

f. 75S-T6 Transverse Section 100X

Etchant: Keller's Etch

FIG. I. MICROSTRUCTURE OF 14S-T6, 24S-T4, AND 75S-T6 EXTRUDED ALUMINUM ALLOYS IN "AS RECEIVED" CONDITION.

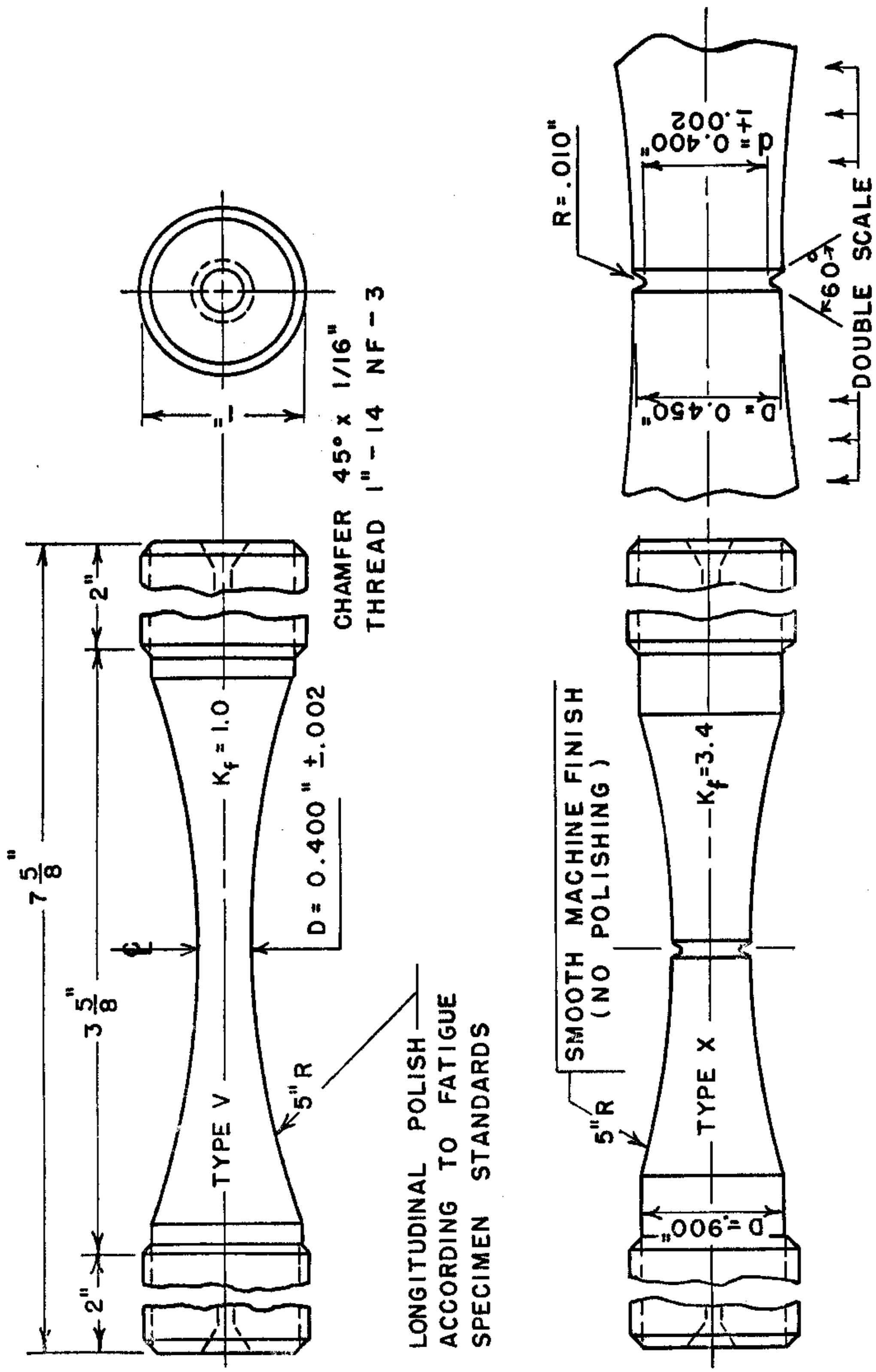


FIG. 2. UNNOTCHED AND NOTCHED FATIGUE SPECIMENS TYPES V AND X

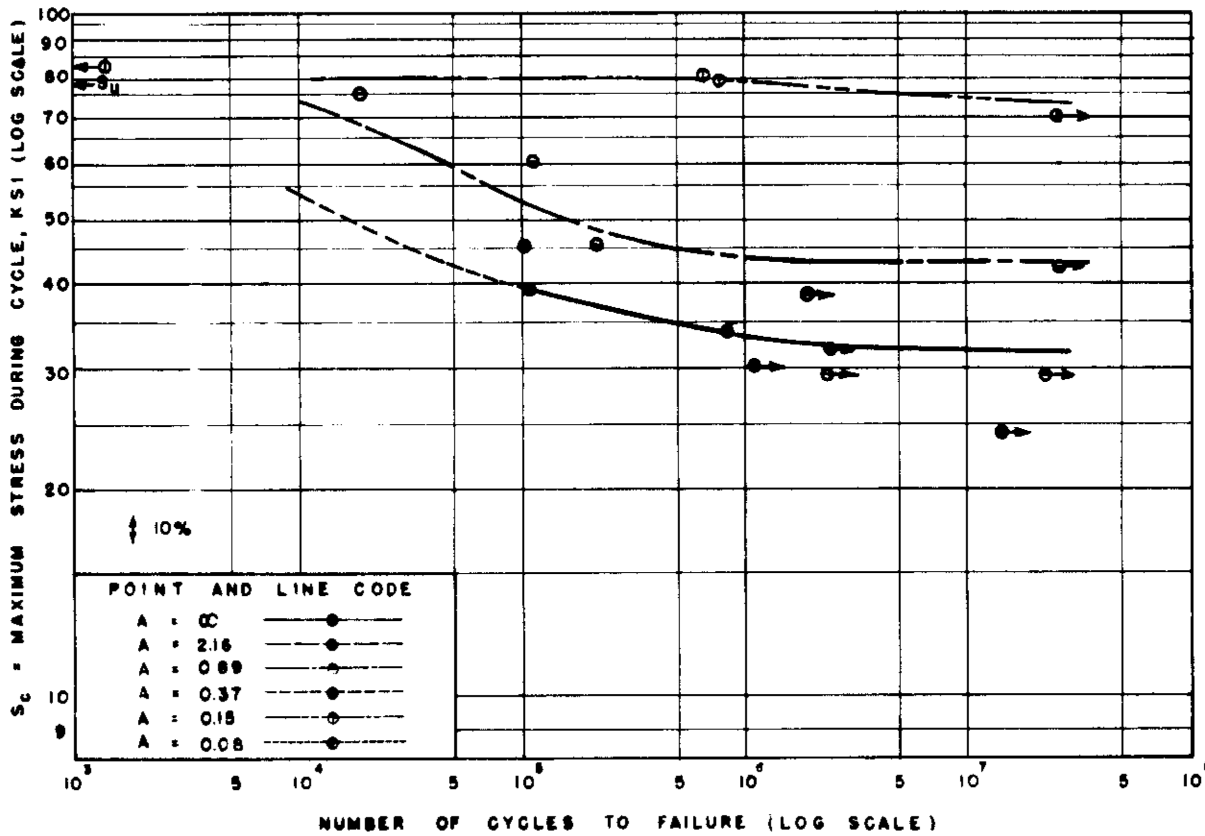


FIG.3. S-N FATIGUE DIAGRAMS AT VARIOUS STRESS RATIOS FOR $K_t = 1.0$ SPECIMENS OF ALUMINUM ALLOY 14S - T6. (EXTRUDED)

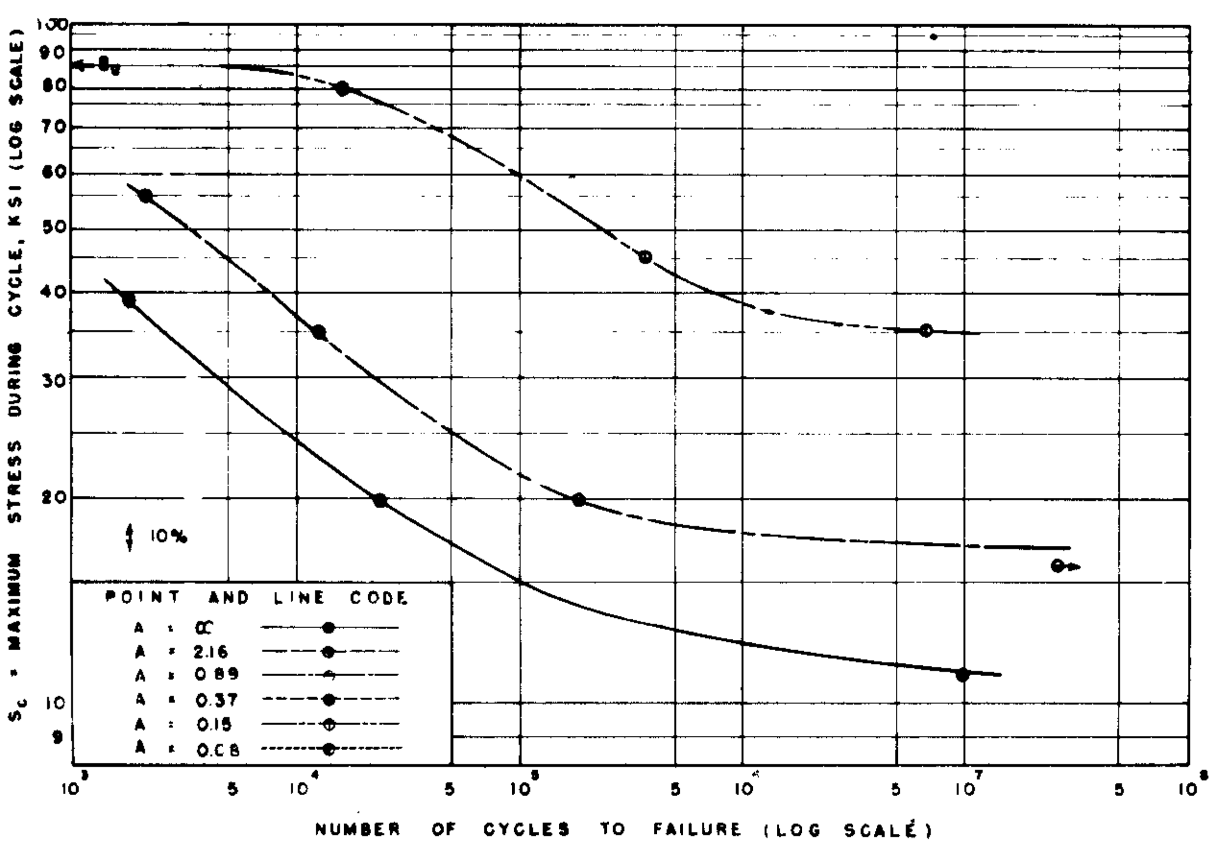


FIG. 4. S-N FATIGUE DIAGRAMS AT VARIOUS STRESS RATIOS FOR $K_t = 3.4$ SPECIMENS OF ALUMINUM ALLOY 14S - T6 (EXTRUDED)

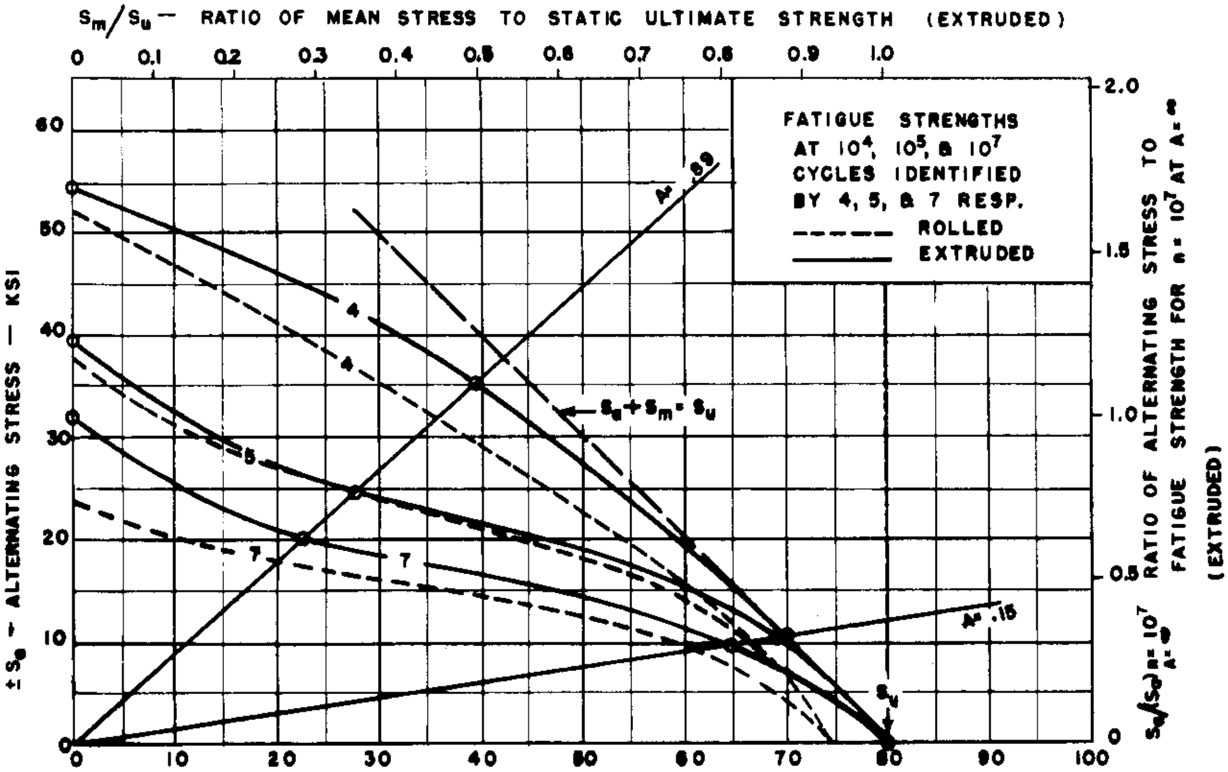


FIG.5. — STRESS RANGE FATIGUE DIAGRAM FOR K_f= 1.0 SPECIMENS OF EXTRUDED ALUMINUM ALLOY 14S-T6

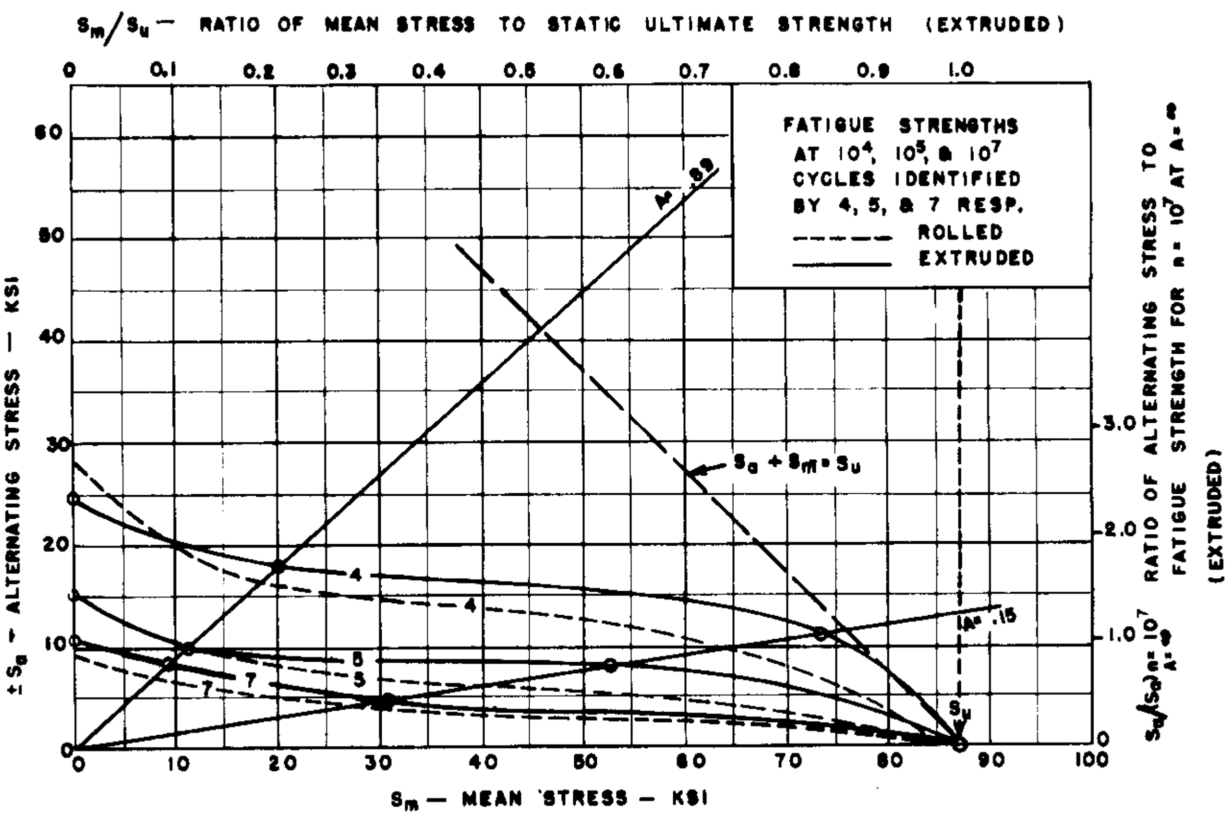


FIG.6. — STRESS RANGE FATIGUE DIAGRAM FOR K_f= 3.4 SPECIMENS OF EXTRUDED ALUMINUM ALLOY 14S-T6

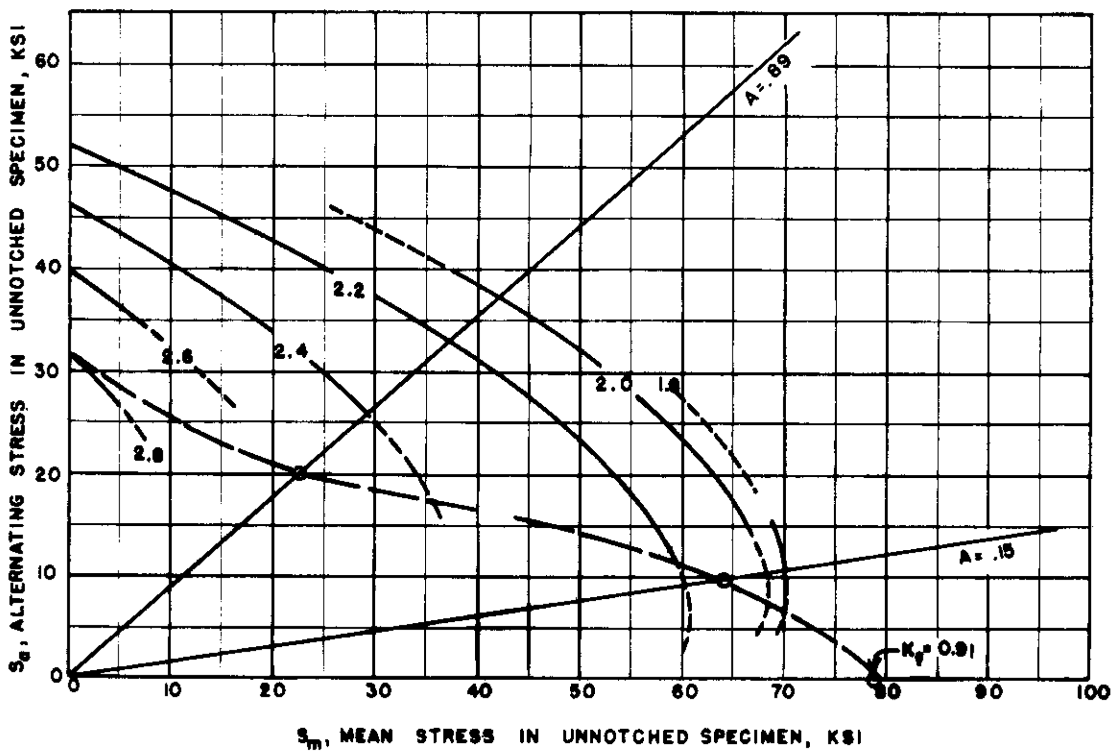


FIG. 7. FATIGUE STRENGTH - REDUCTION "CONTOUR" CURVES FOR K_t = 3.4 SPECIMENS OF EXTRUDED ALUMINUM ALLOY 14S - T6 SHOWING K_f AS A FUNCTION OF S_a AND S_m OF THE UNNOTCHED SPECIMEN

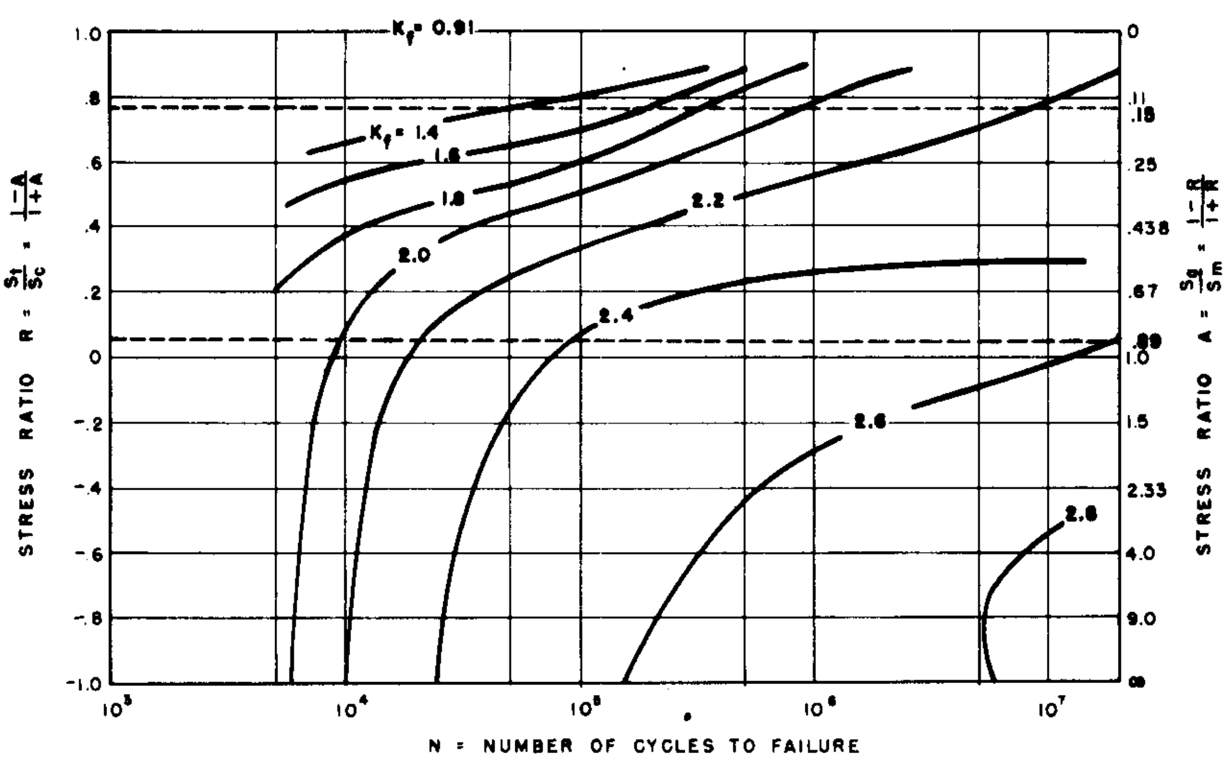


FIG. 8. FATIGUE STRENGTH REDUCTION "CONTOUR" CURVES FOR K_t = 1.0 SPECIMENS OF ALUMINUM ALLOY 14S - T6 (EXTRUDED) SHOWING K_f AS A FUNCTION OF N AND STRESS RATIO R

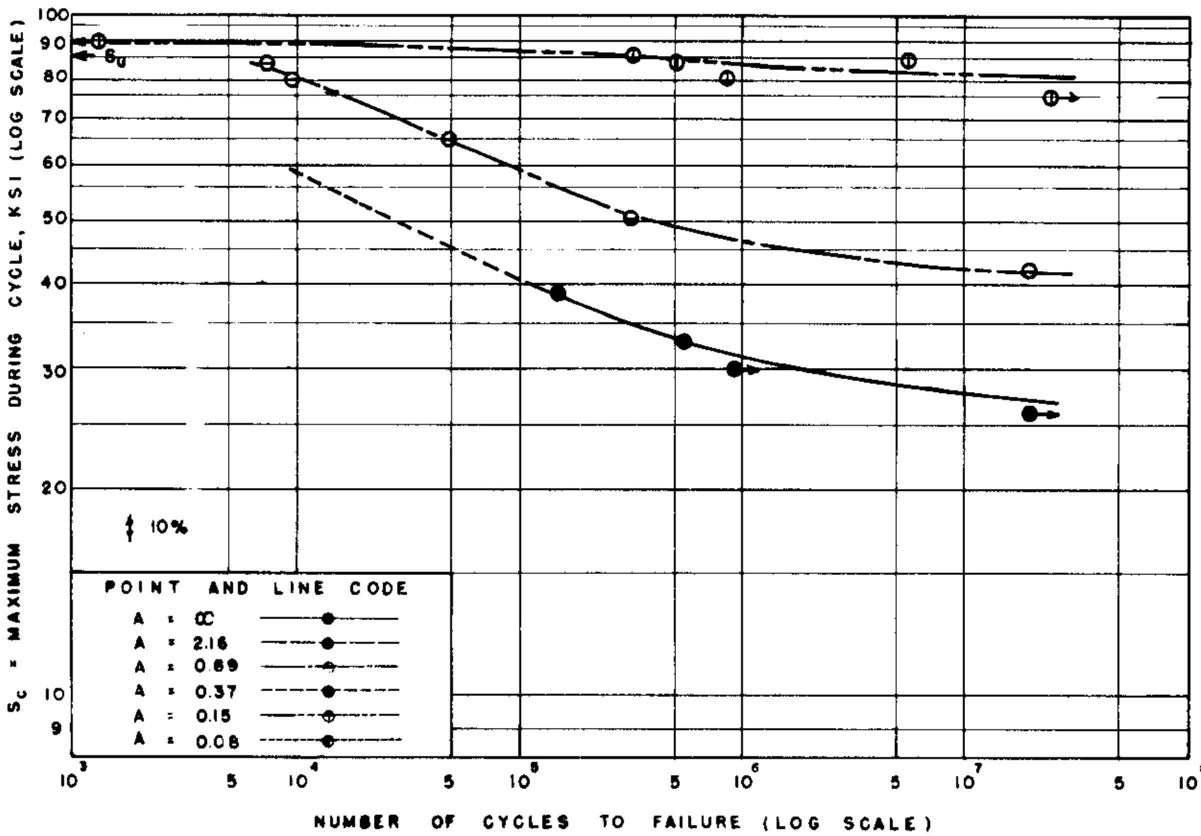


FIG. 9. S-N FATIGUE DIAGRAMS AT VARIOUS STRESS RATIOS FOR $K_t = 1.0$ SPECIMENS OF ALUMINUM ALLOY 24S-T4 (EXTRUDED)

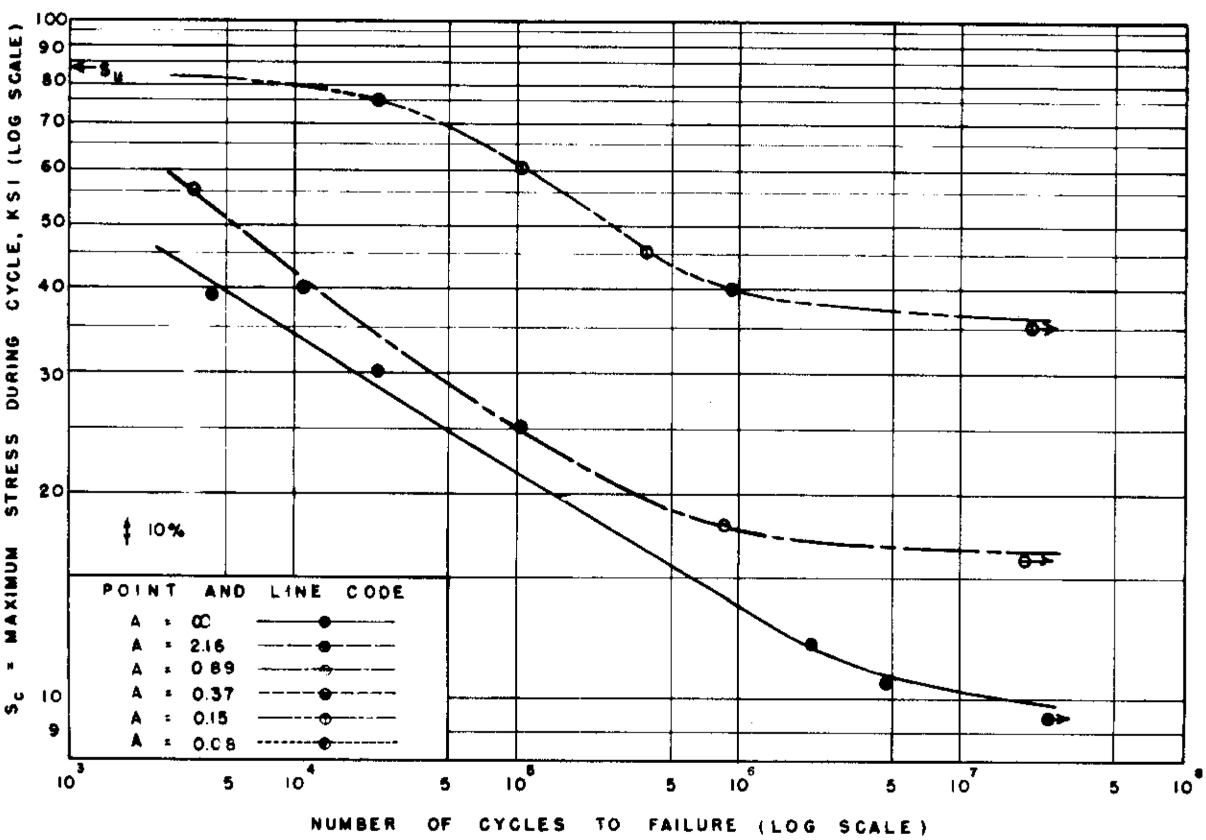


FIG. 10. S-N FATIGUE DIAGRAMS AT VARIOUS STRESS RATIOS FOR $K_t = 3.4$ SPECIMENS OF ALUMINUM ALLOY 24S-T4 (EXTRUDED)

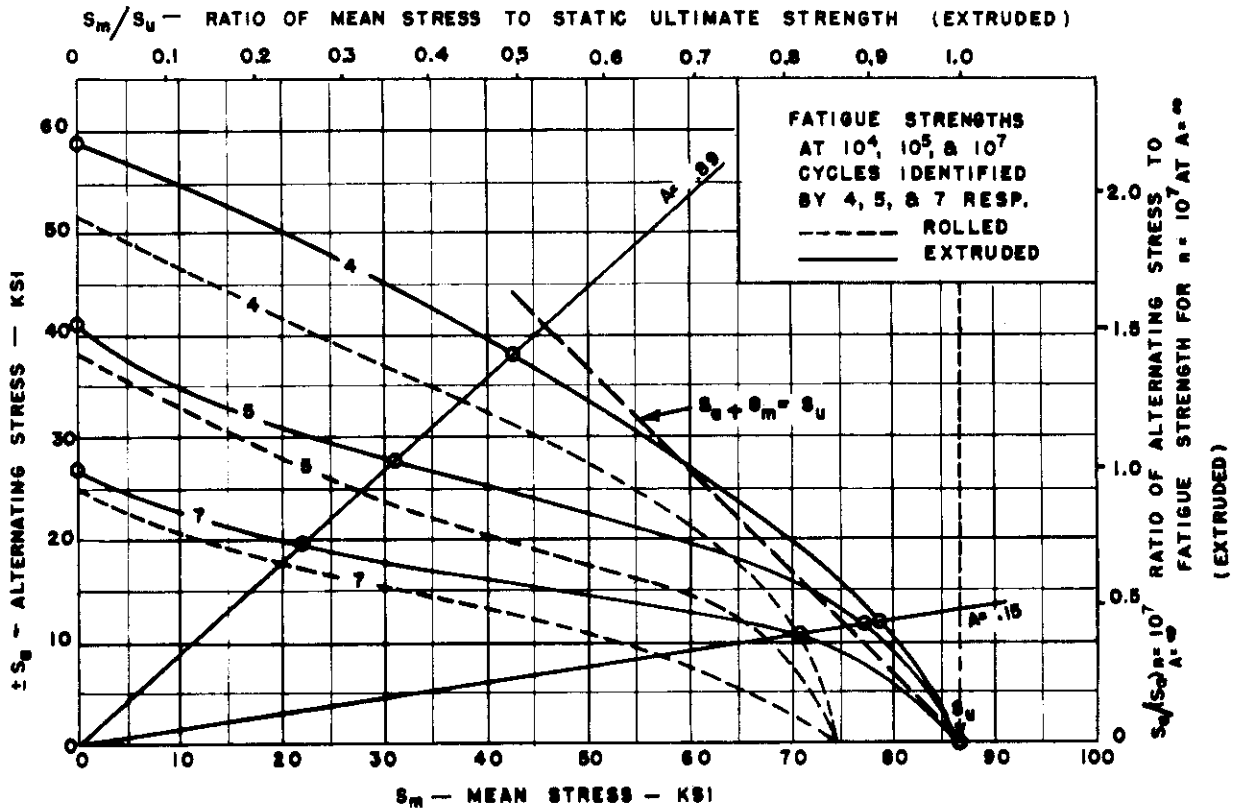


FIG. 11. — STRESS RANGE FATIGUE DIAGRAM FOR $K_f = 1.0$ SPECIMENS OF EXTRUDED ALUMINUM ALLOY 24S-T6

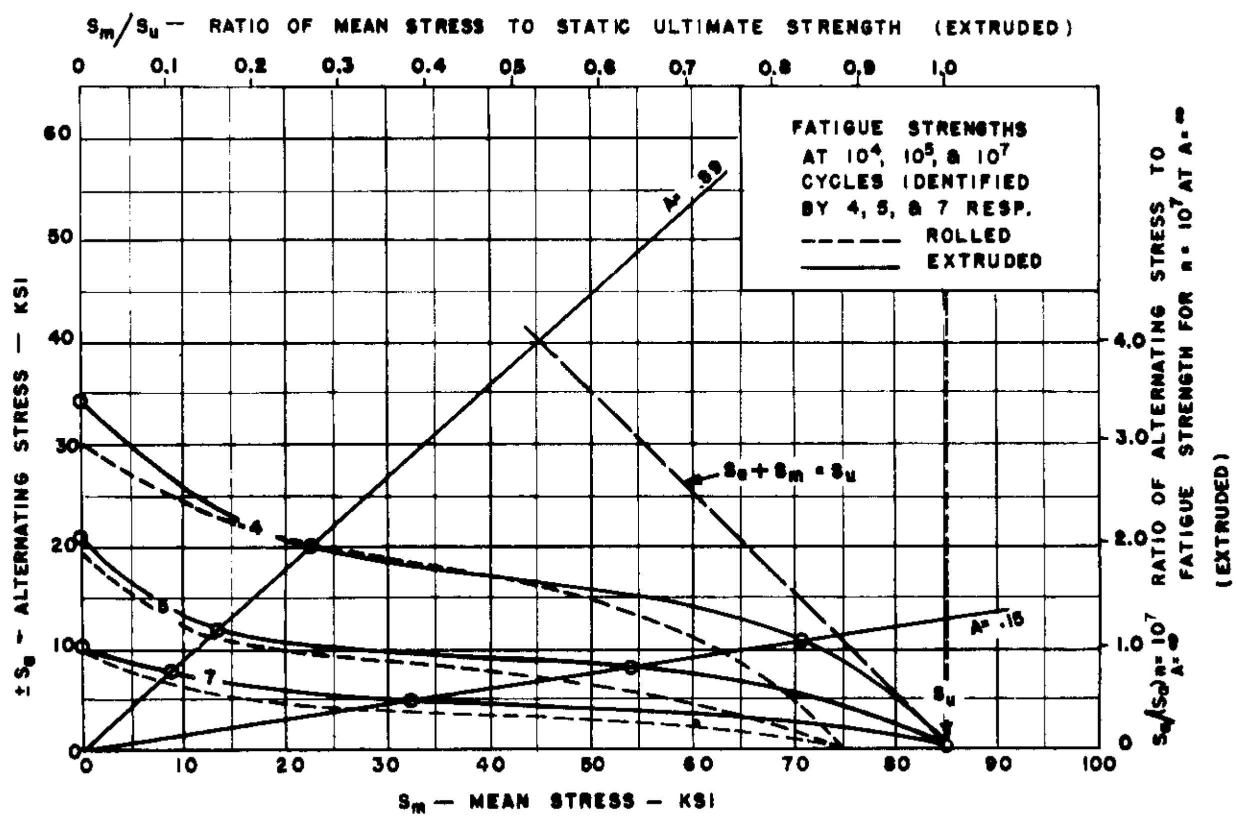


FIG. 12. — STRESS RANGE FATIGUE DIAGRAM FOR $K_f = 3.4$ SPECIMENS OF EXTRUDED ALUMINUM ALLOY 24S-T6

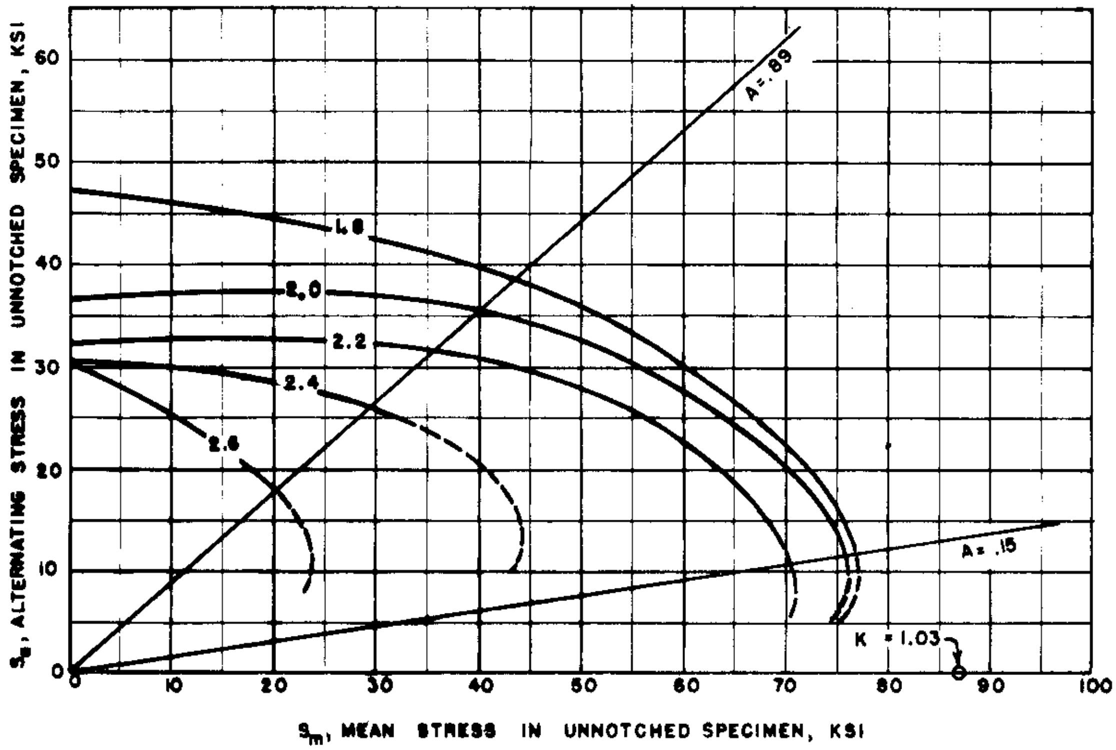


FIG. 13. FATIGUE STRENGTH - REDUCTION "CONTOUR" CURVES FOR $K_t = 3.4$ SPECIMENS OF EXTRUDED ALUMINUM ALLOY 24S-T4 SHOWING K_f AS A FUNCTION OF S_a AND S_m OF THE UNNOTCHED SPECIMEN

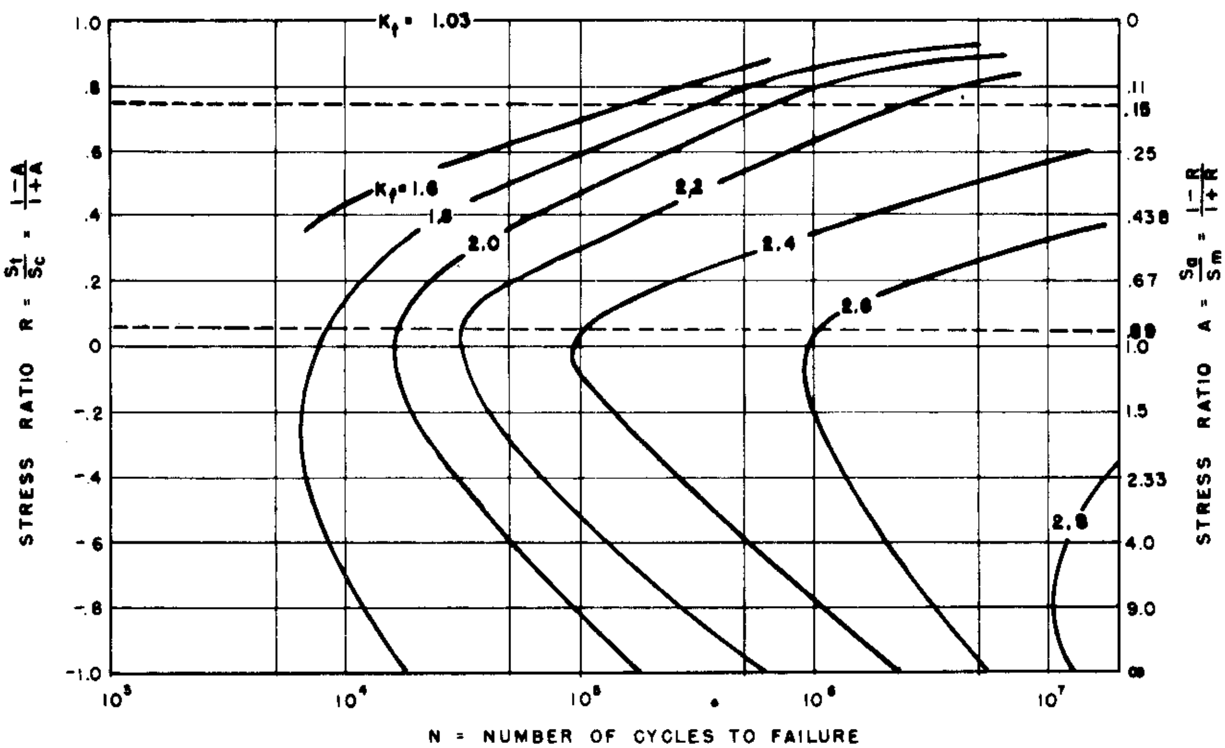


FIG. 14. FATIGUE STRENGTH REDUCTION "CONTOUR" CURVES FOR $K_t = 3.4$ SPECIMENS OF ALUMINUM ALLOY 24S-T4 (EXTRUDED) SHOWING K_f AS A FUNCTION OF N AND STRESS RATIO R

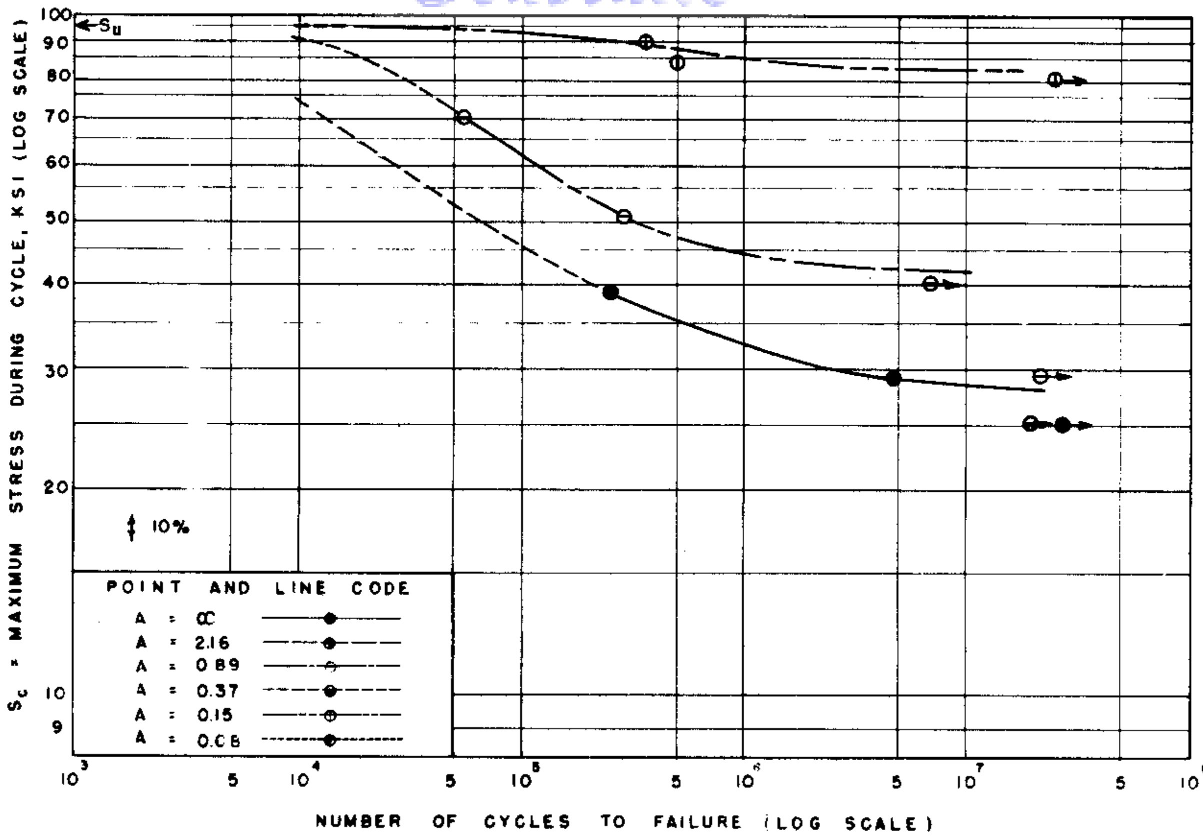


FIG. 15. S-N FATIGUE DIAGRAMS AT VARIOUS STRESS RATIOS FOR $K_t = 1.0$ SPECIMENS OF ALUMINUM ALLOY 75S-T6 (EXTRUDED).

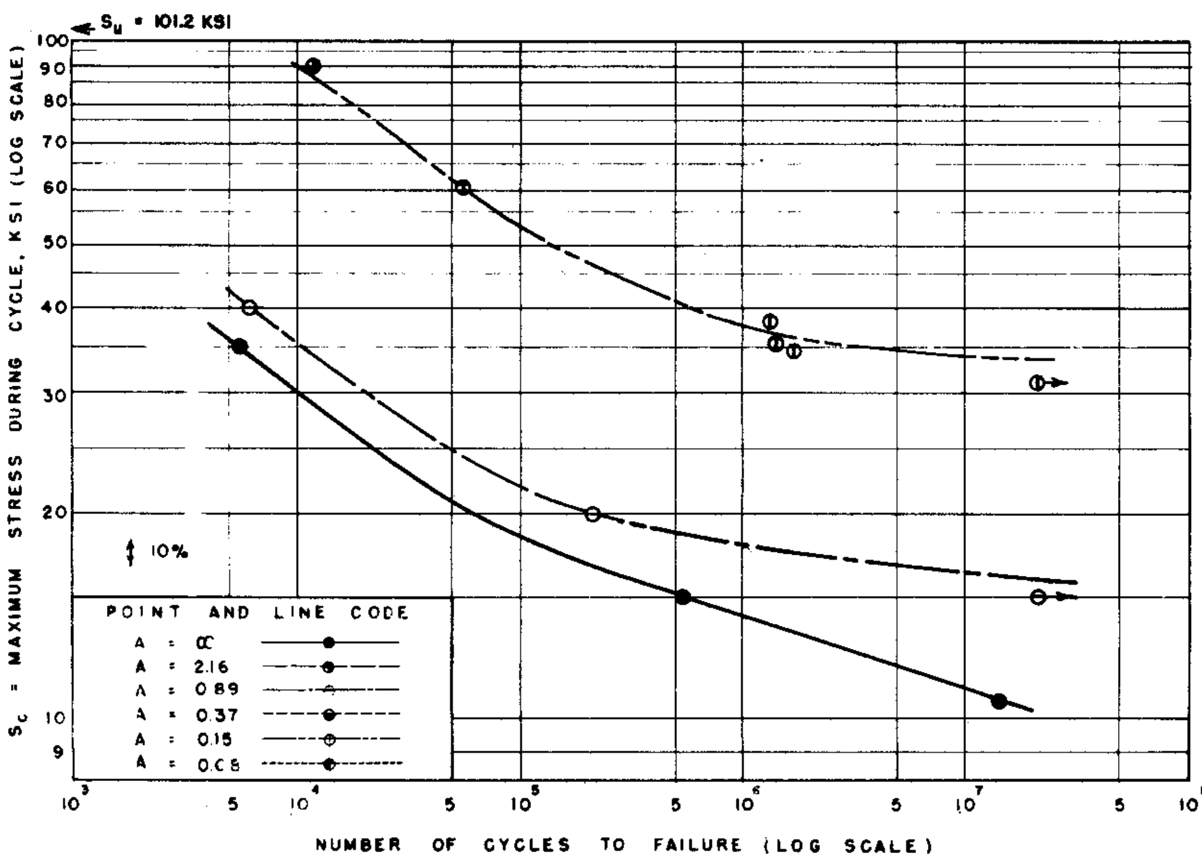


FIG. 16. S-N FATIGUE DIAGRAMS AT VARIOUS STRESS RATIOS FOR $K_t = 3.4$ SPECIMENS OF ALUMINUM ALLOY 75S-T6 (EXTRUDED)

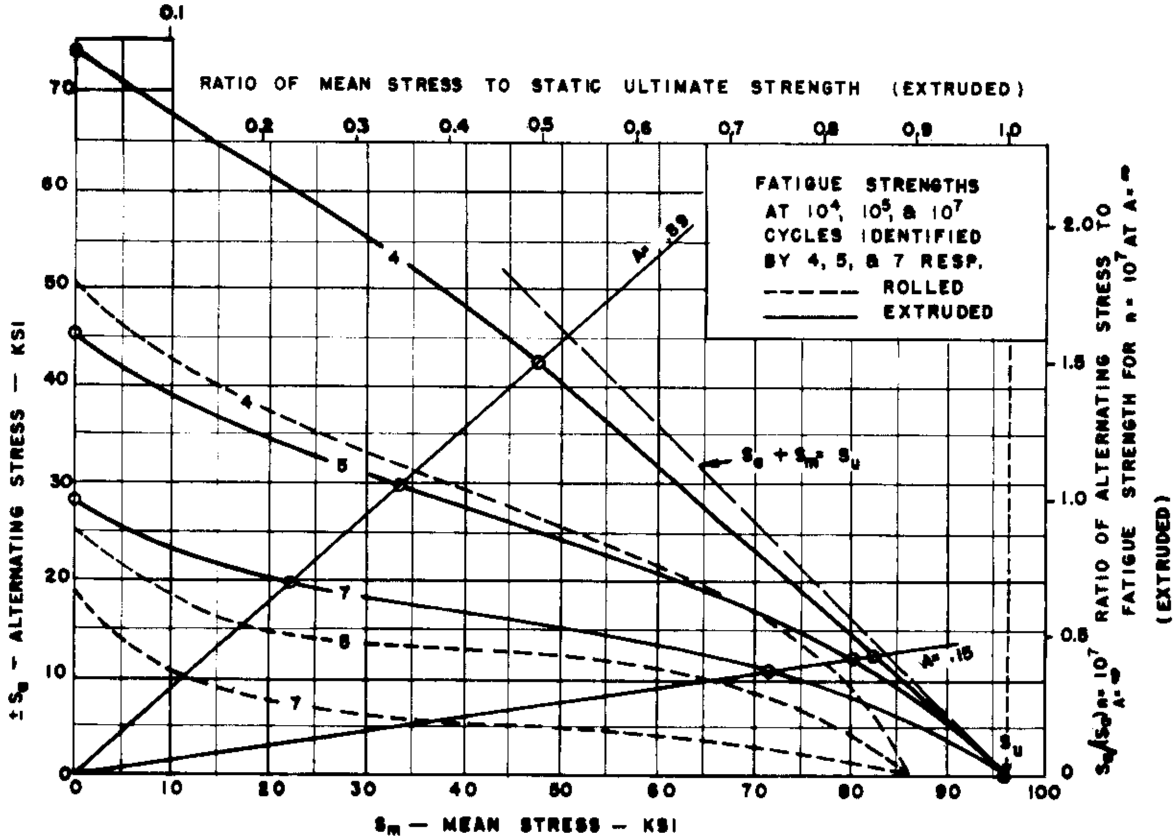


FIG. 17. – STRESS RANGE FATIGUE DIAGRAM FOR K_f = 1.0 SPECIMENS OF EXTRUDED ALUMINUM ALLOY 75S-T6

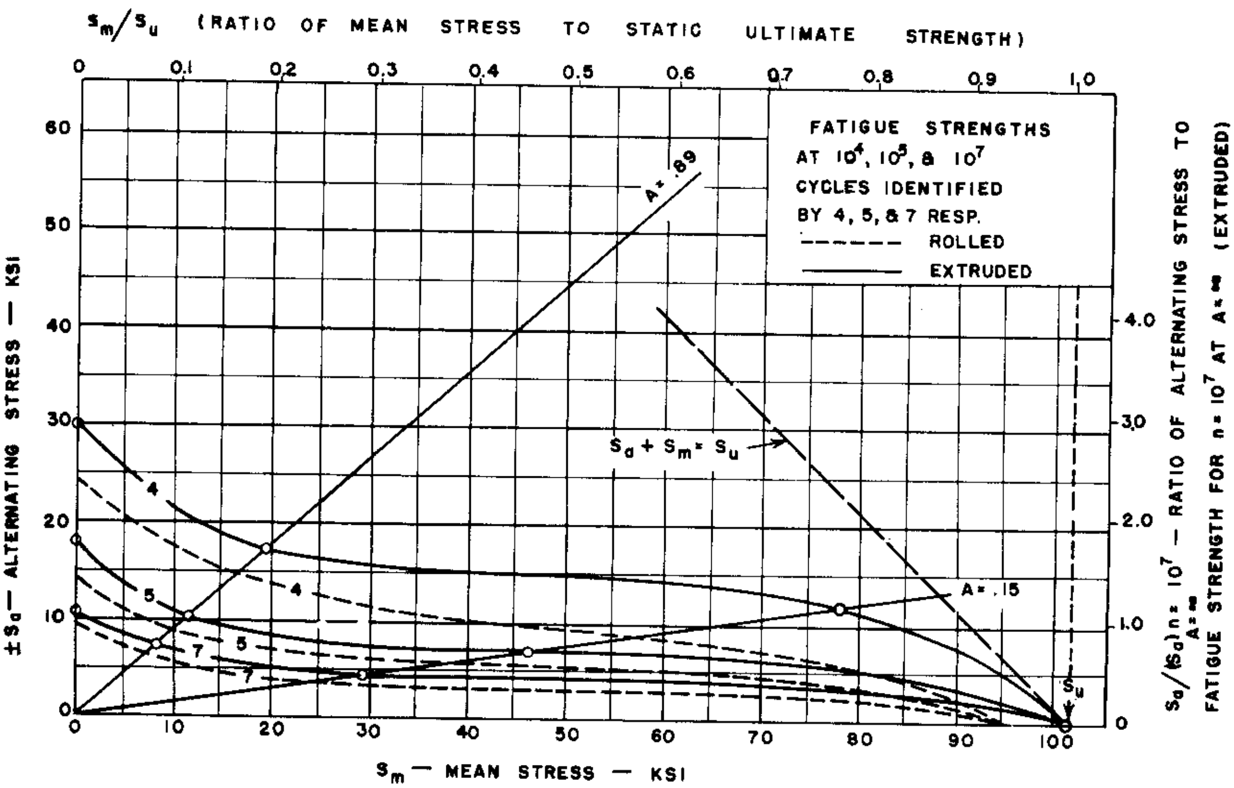


FIG. 18. – STRESS RANGE FATIGUE DIAGRAM FOR K = 3.4 SPECIMENS OF EXTRUDED ALUMINUM ALLOY 75S – T6

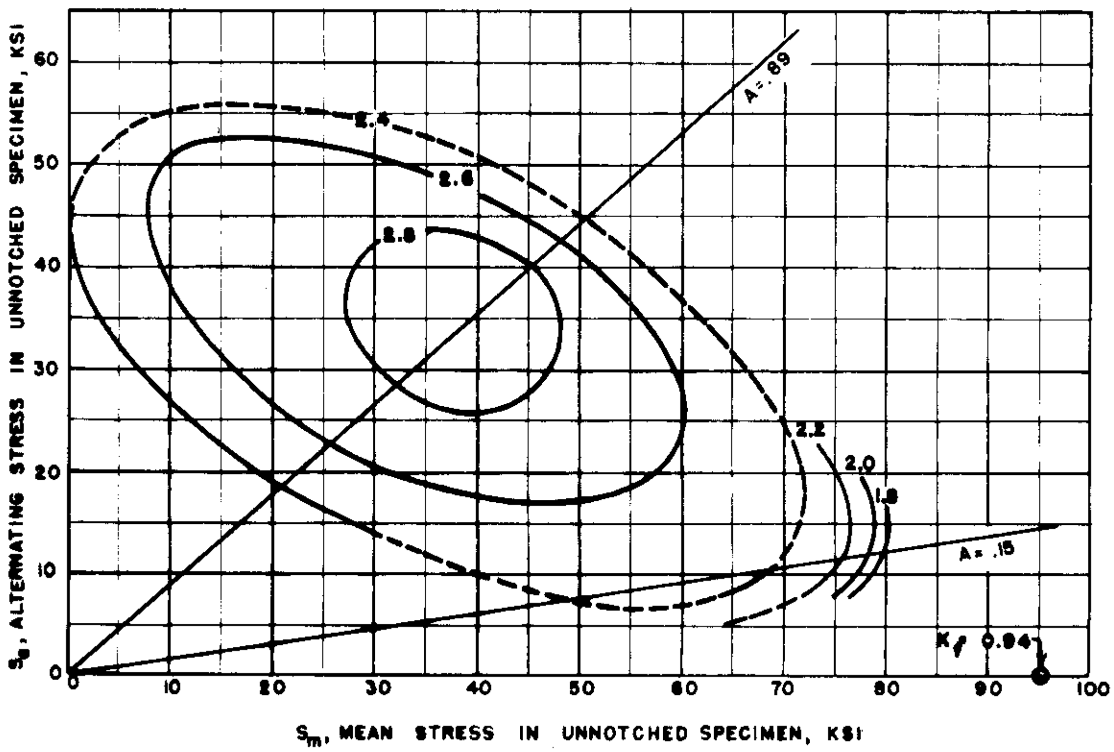


FIG. 19. FATIGUE STRENGTH - REDUCTION "CONTOUR" CURVES FOR $K_t = 3.4$ SPECIMENS OF EXTRUDED ALUMINUM ALLOY 75S - T6 SHOWING K_f AS A FUNCTION OF S_a AND S_m OF THE UNNOTCHED SPECIMEN

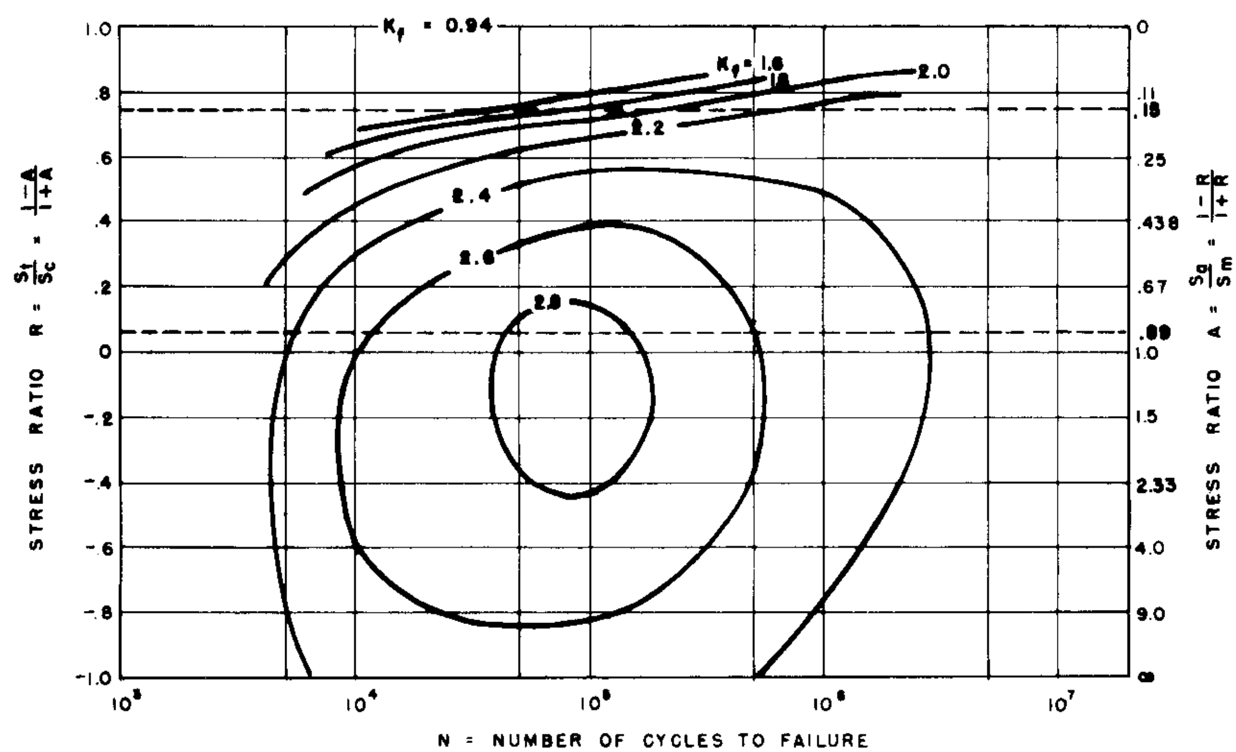


FIG. 20. FATIGUE STRENGTH REDUCTION "CONTOUR" CURVES FOR $K_t = 1.0$ SPECIMENS OF ALUMINUM ALLOY 75S - T6 (EXTRUDED) SHOWING K_f AS A FUNCTION OF N AND STRESS RATIO R

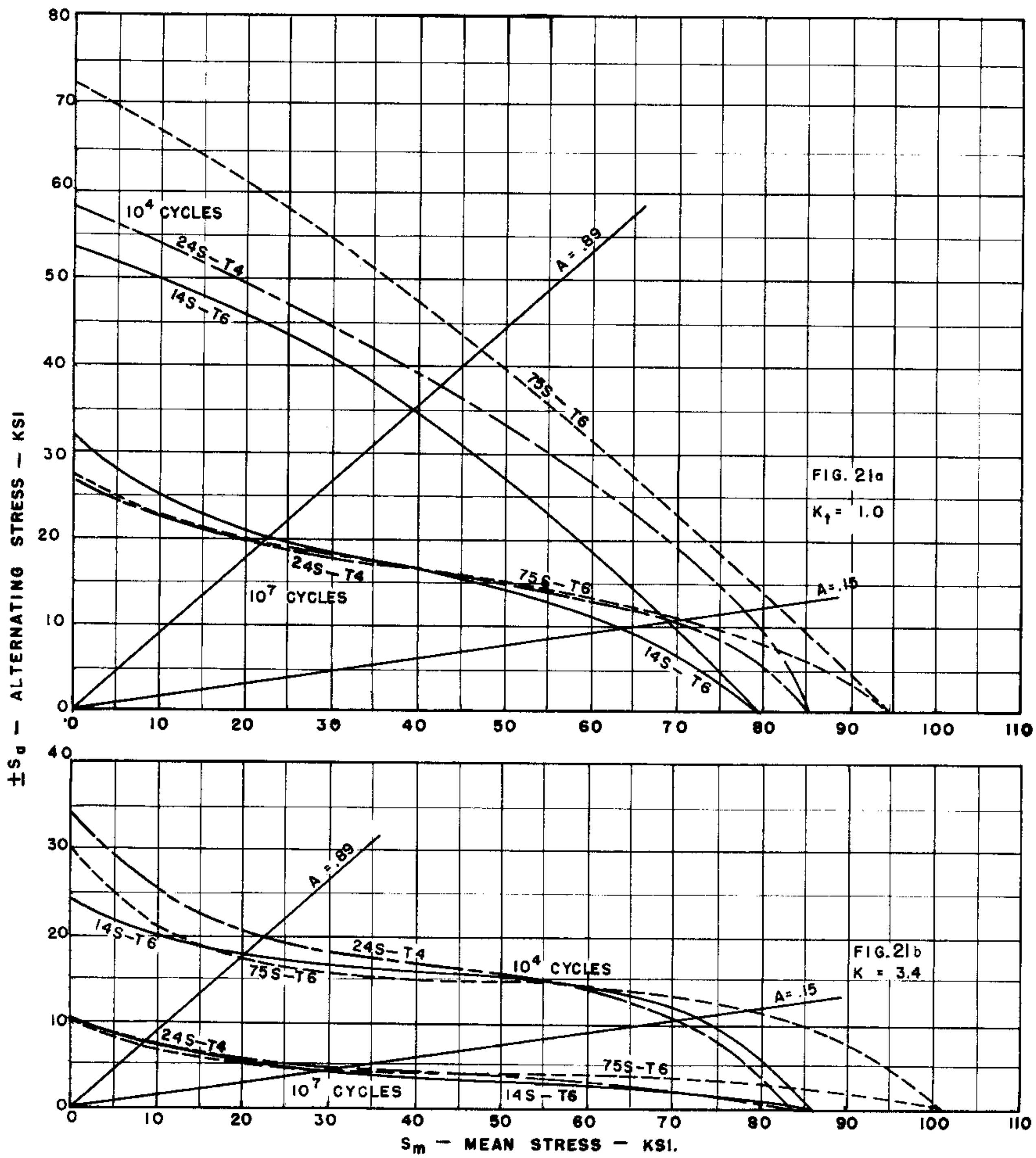


FIG. 21.- STRESS - RANGE DIAGRAMS SHOWING COMPARATIVE FATIGUE STRENGTHS OF EXTRUDED ALUMINUM ALLOYS