TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Fatigue tests were made on some 1.375-inch-diameter and 0.300-inch diameter specimens of a 17S-T aluminum-alloy rod. One test of a large specimen was run continuously to failure at a maximum stress of 22,000 pounds per square inch. In two other tests of large specimens, thin surface layers were removed periodically until failure occurred. The same nominal maximum stress of 22,000 pounds per square inch was used throughout the two tests and the load on the fatigue machine was lowered accordingly after the removal of each surface layer. As each test progressed the stress in the metal of the final surface area therefore was increased after the removal of each surface layer. Because of the stresses used, this metal was overstressed, that is, stressed above its endurance limit. All the remaining specimens were subjected to similar overstressing conditions but no metal was removed and a low initial stress was increased periodically to a final maximum value of 22,000 pounds per square inch as each test progressed.

It was found that the fatigue resistance of 17S-T aluminum alloy can be increased by moderate overstressing. Apparently the increase in fatigue life obtained in the tests of specimens from which layers were removed was the result of overstressing rather than from the removal of damaged surface layers.

INTRODUCTION

The effects of understressing and overstressing in fatigue have been discussed in several published papers. In those papers understressing is defined as the application of repeated stresses of a lower intensity than the endurance limit, and overstressing is defined as the application of repeated stresses of an intensity higher than the endurance limit. Most of the work has been done on ferrous materials although a very small amount has been done on aluminum and other nonferrous metals. It has been generally concluded that understressing strengthens the metal by some type of cold work on a very minute scale and that moderate overstressing does the same sort of thing without damage. The application of higher overstresses, however, causes damage and decreases the fatigue life of the metal (references 1 to 5).

The investigation discussed in this report was originally planned to study a proposed method described by H. W. Gillett, of Battelle Memorial Institute, for increasing the useful life of aluminum-alloy propeller blades. The method consisted of the removal of small thicknesses of surface layers of metal by electrolytic polishing, this polishing to be done periodically after certain lengths of service. This method assumes that, inasmuch as any incipient fatigue cracks should be at the surface because the highest stresses are located at the surface, the suitable removal of such possibly damaged material would extend the fatigue life of the blade beyond its normal value. On the other hand, the fatigue life of the blade might be increased because the fatigue strength of the metal beneath the subsequently removed surface layers might be improved as a result of the overstressing to which it was subjected.

The objects of this investigation were to determine the improvement in fatigue life of an aluminum alloy by moderate overstressing and to learn whether any improvement obtained by the periodic removal of surface layers was the result of the removal of damaged material or the result of overstressing. The alloy used was 17S-T and, for tests in which thin surface layers were removed from the specimen, the metal was removed by machining.

MATERIAL

All specimens were machined from a single 8-foot length of 2.500-inch-diameter rolled rod, which had the following tensile properties and endurance limit:

Tensile strength, pounds per square inch	62,900
Yield strength (offset, 0.2 percent), pounds per square inch	34,900
Elongation in 2 inches, percent	29
Reduction of area, percent	40
Endurance limit, pounds per square inch	18,500

METHOD OF TEST

Fatigue specimens of two sizes, 1.375 and 0.300 inch in diameter, were used. The reduced sections of all specimens had polished smooth surfaces prepared in the usual manner. The large specimens were tested in the 2-inch rotating-simple-beam fatigue machine which is described in reference 6. The speed was 1400 cycles per minute. The two tests of small specimens were made in R. R. Moore machines (reference 7) at speeds of 6250 and 6950 cycles per minute, respectively. The speeds in these two tests were selected in order that the changes in load could be made at convenient times with the tests running continuously.

The tests may be divided into two groups, depending upon whether any surface layers were removed from the specimen during the test. Surface layers were removed by machining with light cuts. Incidentally, machining was used instead of electropolishing because electropolishing, depending upon the alloy and the conditions under which it is used, may in itself have considerable effect upon fatigue strength.

The first group, in which the surface layers were periodically removed, included two tests of large specimens. Each test was made at a nominal maximum stress of 22,000 pounds per square inch throughout the test and the load on the fatigue machine was lowered accordingly after the removal of each surface layer. For example, in the test of the first specimen P-844-L2 the applied load at the beginning of the test was 1502 pounds, whereas after the removal of the fourth layer it was only 1128 pounds, a reduction of 25 percent. In this test layers 0.016 inch thick were removed at intervals of approximately 9 million cycles until failure occurred. The procedure in the test of the second specimen P-844-L3 differed in that thinner layers, 0.008 inch thick, were removed at longer intervals, approximately 20 million cycles. Because a tightening ring became loose during the fourth stress period of the second test and damaged the surface of the specimen, it became necessary to remove the next surface layer after about 600,000 cycles instead of 20 million cycles.

The second group, in which no surface layers were removed, consisted of two tests of specimens of each size. In the test of the first large specimen P-844-L1, a maximum stress of 22,000 pounds per square inch was used continuously until failure. In the test of the first small specimen P-844-11 the stressing procedure was similar to the stress history of the final layer in the test of specimen P-844-L2 of the first group; the initial stress was 20,000 pounds per square inch and was increased 500 pounds per square inch after each period of 9 million cycles until the stress reached 22,000 pounds per square inch. At that stress the test was continued to failure. In the test of the second large specimen P-844-L6 and the second small specimen P-844-12, the stressing procedure was similar to the stress history of the final layer in the test of specimen P-844-L3 of the first group; the initial stress was 20,750 pounds per square inch and was increased 250 pounds per square inch after each period of 20 million cycles until the stress reached 22,000 pounds per square inch. The test was then continued to failure.

DISCUSSION OF RESULTS

The results of the various fatigue tests are summarized in tables I, II, and III and are plotted in figures 1, 2, and 3. The curves included for comparison in each figure are identical with the fatigue curve determined using 0.300-inch-diameter polished specimens of the same material. In each of the tests described in this report the fatigue life was longer than that indicated by the latter fatigue curve.

The results of the two tests in which surface layers were removed are given in figure 1; the fatigue stress history of each surface layer of each specimen is indicated by stress plotted against the total number of cycles to which the surface of the layer had been subjected. In the test of specimen P-844-L2, for example, the original outside surface was subjected to approximately 9 million cycles at a maximum stress of 22,000 pounds per square inch, and a surface layer nominally 0.016 inch thick was then removed. While the metal at the outside surface during the first stress period was subjected to a stress of 22,000 pounds per square inch, the metal that was at the outside surface during the second stress period was subjected to a stress of approximately 21,500 pounds per square inch. The second surface was subsequently subjected to about 9 million cycles at a stress of 22,000 pounds per square inch, and the second layer was then removed. When the specimen finally failed, four layers each approximately 0.016 inch thick had been removed and the specimen diameter was 1.251 inch. The metal at the outer surface had been subjected to periods of about 9 million cycles at stresses of approximately 20,000, 20,500, 21,000, and 21,500 pounds per square inch each, and fracture finally developed after an additional period of almost 5 million cycles at a stress of 22,000 pounds per square inch. Although the total number of cycles in the test was 41,935,200, only a small percentage of this number was at a stress of 22,000 pounds per square inch. The total number of cycles should naturally be greater, therefore, than 29,463,100, the number obtained in the test of specimen P-844-L1 which was run continuously to failure without the removal of any surface layers.

The results of the tests discussed in the preceding paragraph are plotted with the results of the tests of large specimens in which no surface layers were removed in figure 2. The results of the tests of small specimens are plotted in figure 3. In these figures the fatigue stressing history in each test is shown by plotting stress against the total number of cycles. For the tests in which surface layers were removed, the data are plotted for only the final surface area. In the test of specimen P-844-L2, for example, the surface of the fifth and final layer was subjected to periods of about 9 million cycles at stresses of approximately 20,000, 20,500, 21,000, and 21,500 pounds per square inch for each period; fracture finally occurred after an additional period of about 5 million cycles at a stress of 22,000 pounds per square inch.

In the study of the various tests it is of interest to compare the sums of the ratios of applied cycles in the different stress periods to the nominal life at each of the respective stresses. Such ratio totals sometimes are considered an indication of the proportionate effect of fatigue stressing. These ratios are shown in the last column of table II. In the test of a large specimen, which was run continuously at the same stress without the removal of any surface layers, this ratio was 1.23. The fact that it was greater than unity might be ascribed to differences in supposedly identical specimens, to variations in test procedure, and to differences in size of specimens. For the tests in which stresses were periodically increased, the ratio total in a test, regardless of whether any surface layers were removed, was greater for the tests using the smaller stress increments and the longer stress periods. Inasmuch as these ratio totals generally were at least as large for the tests in which surface layers were removed, it appears that the beneficial effects obtained in the former tests were the result of moderate overstressing and not the result of the removal of surface layers that may or may not have contained incipient fatigue damage. This conclusion does not mean, however, that the removal of surface layers would not be beneficial if such layers actually contained incipient damage.

In the tests in which similar stressing procedures were used, it is of interest to compare the results of corresponding tests in which surface layers were or were not removed. In the test of specimen P-844-L3 the stressing history of the sixth and final layer was identical with the stressing procedure in the tests of the large specimen P-844-L6 and of the small specimen P-844-12, both of which were tested without removal of any surface layers. The total number of cycles at failure in the tests of specimens P-844-L6 and P-844-12 agreed closely, that is, within 9 percent, with the number obtained in the test in which surface layers were removed. The stressing history of the fifth and final surface layer of large specimen P-844-L2 was identical with the stressing procedure in the test of the small specimen P-844-11, which was tested without removal of any surface layers. The total number of cycles at failure in the test of specimen P-844-11 was considerably greater than the total number in the test of specimen P-844-L2 and the number of cycles at the highest stress alone was greater than the nominal life at that stress as indicated by the regular fatigue curve. The total number of cycles was less, however, than in any of the tests of specimens P-844-L3, P-844-L6, and P-844-12. Apparently the effects of the overstressing were not so great because of the large stress increments and the small number of cycles in each stress period.

It is of interest also to compare the total number of cycles at various minimum stresses with the expected fatigue life at each minumum stress, as has been done in table III. For example, in the test of large specimen P-844-L6, the total number of cycles at a stress of 20,750 pounds per square inch or larger was 2.32 times as great as would have been expected if the test had been run continuously to failure at a stress of 20,750 pounds per square inch. In the same test, the total number of cycles at a stress of 21,250 pounds per square inch or larger was 1.82 times as great as would have been expected if a continuous stress of 21,250 pounds per square inch had been used. From these comparisons there is no doubt that the overstressing resulted in a definite improvement in fatigue resistance. As shown by the last column of table III, these comparisons also substantiate the statement in the preceding paragraph that the benefits of overstressing were greater in the tests in which the stress increments were smaller and the numbers of cycles in the stress periods were larger.

CONCLUSIONS

From the tests that have been made, the following conclusions seem warranted:

1. The fatigue resistance of 17S-T aluminum-alloy rolled rod can be increased by the use of moderate overstressing in which suitable fatigue stresses above the endurance limit are applied during a sufficient number of cycles.

2. Although a considerable increase in fatigue life was obtained in the tests in which surface layers were periodically removed, the increase appeared to be the result of overstressing and not of the removal of surface metal. It is possible, however, that the removal of surface layers, if they actually contain incipient fatigue damage, might be of additional advantage.

Aluminum Research Laboratories,
Aluminum Company of America,
New Kensington, Pa., June 1, 1942.

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TABLE I

SUMMARY OF FATIGUE TESTS IN WHICH LAYERS WERE PERIODICALLY REMOVED

Surface layer	Outside diameter (in.)	Total applied load (lb)	Maximum stress (lb/sq in.)	Cycles during each stress period	Nominal life (million cycles) (a)	Applied cycles / Nominal life
Specimen P-844-L2. 0.016-in. layers; periods of 9 million cycles						
First	1.3765	1502	22,000	9,143,100		
Second	1.341	1389	21,430	9,143,100		
			22,000	9,299,900		
Third	1.312	1301	20,970	9,143,100		
			21,520	9,299,900		
			22,000	9,295,200		
Fourth	1.2815	1212	20,480	9,143,100		
			21,020	9,299,900		
			21,490	9,295,200		
			22,000	9,412,800		
Fifth	1.251	1128	19,990	9,143,100	65	0.14
			20,520	9,299,900	49	.19
			20,980	9,295,200	38	.24
			21,480	9,412,800	29	.32
			22,000	[b]4,784,200	24	.20
			Total	41,935,200		1.09
Specimen P-844-L3. 0.008-in. layers; periods of 20 million cycles						
First	1.3745	1496	22,000	20,195,300		
Second	1.360	1449	21,770	20,195,300		
			22,000	20,036,700		
Third	1.3446	1400	21,520	20,195,300		
			21,750	20,036,700		
			22,000	19,900,800		
[c]Fourth	1.3290	1352	21,270	20,195,300		
			21,500	20,036,700		
			21,740	19,900,800		
			22,000	590,800		
Fifth	1.313	1304	21,020	20,195,300		
			21,240	20,036,700		
			21,480	19,900,800		
			21,740	590,800		
			22,000	20,000,400		
Sixth	1.297	1257	20,760	20,195,300	43	0.47
			20,980	20,036,700	38	.53
			21,220	19,900,800	33	.60
			21,470	590,800	29	.02
			21,730	20,000,400	26	.77
			22,000	[b]13,082,400	24	.54
			Total	93,806,400		2.93

[a]From regular fatigue curve shown in fig. 1.
[b]Specimen failed.
[c]This layer had to be removed after 590,800 cycles because a tightening ring became loose and scratched the surface of the specimen.

TABLE II

SUMMARY OF RESULTS OF FATIGUE TESTS

Specimen	Surface layers removed	Nominal diameter (in.)	Final diameter (in.)	Maximum stress (lb/sq in.)	Cycles during each stress period	Nominal life (million cycles) (a)	Applied cycles / Nominal life
P-844-L1[b]	No	1.375	1.376	22,000	29,463,100	24	1.23
P-844-L2[c]	Yes	1.375	1.251	19,990	9,143,100	65	0.14
				20,520	9,299,900	49	.19
				20,980	9,295,200	38	.24
				21,480	9,412,800	29	.32
				22,000	4,784,200	24	.20
				Total	41,935,200		1.09
P-844-L3[d]	Yes	1.375	1.297	20,760	20,195,300	43	0.47
				20,980	20,036,700	38	.53
				21,220	19,900,800	33	.60
				21,470	590,800	29	.02
				21,730	20,000,400	26	.77
				22,000	13,082,400	24	.54
				Total	93,806,400		2.93
P-844-L6	No	1.375	1.377	20,760	20,004,700	43	0.47
				21,020	19,900,000	38	.52
				21,270	20,209,800	33	.61
				21,520	590,800	29	.02
				21,770	21,791,700	26	.84
				22,000	17,092,600	24	.71
				Total	99,589,600		3.17
P-844-11	No	0.300	0.2991	19,990	9,228,000	65	0.14
				20,480	9,011,000	49	.18
				20,970	9,292,000	38	.24
				21,430	9,081,000	29	.31
				22,000	31,530,000	24	1.31
				Total	68,142,000		2.18
P-844-12	No	0.300	0.2990	20,760	20,048,000	43	0.47
				21,020	20,012,000	38	.53
				21,270	20,025,000	33	.61
				21,520	589,000	29	.02
				21,770	20,087,000	26	.77
				22,000	4,816,000	24	.20
				Total	85,577,000		2.60

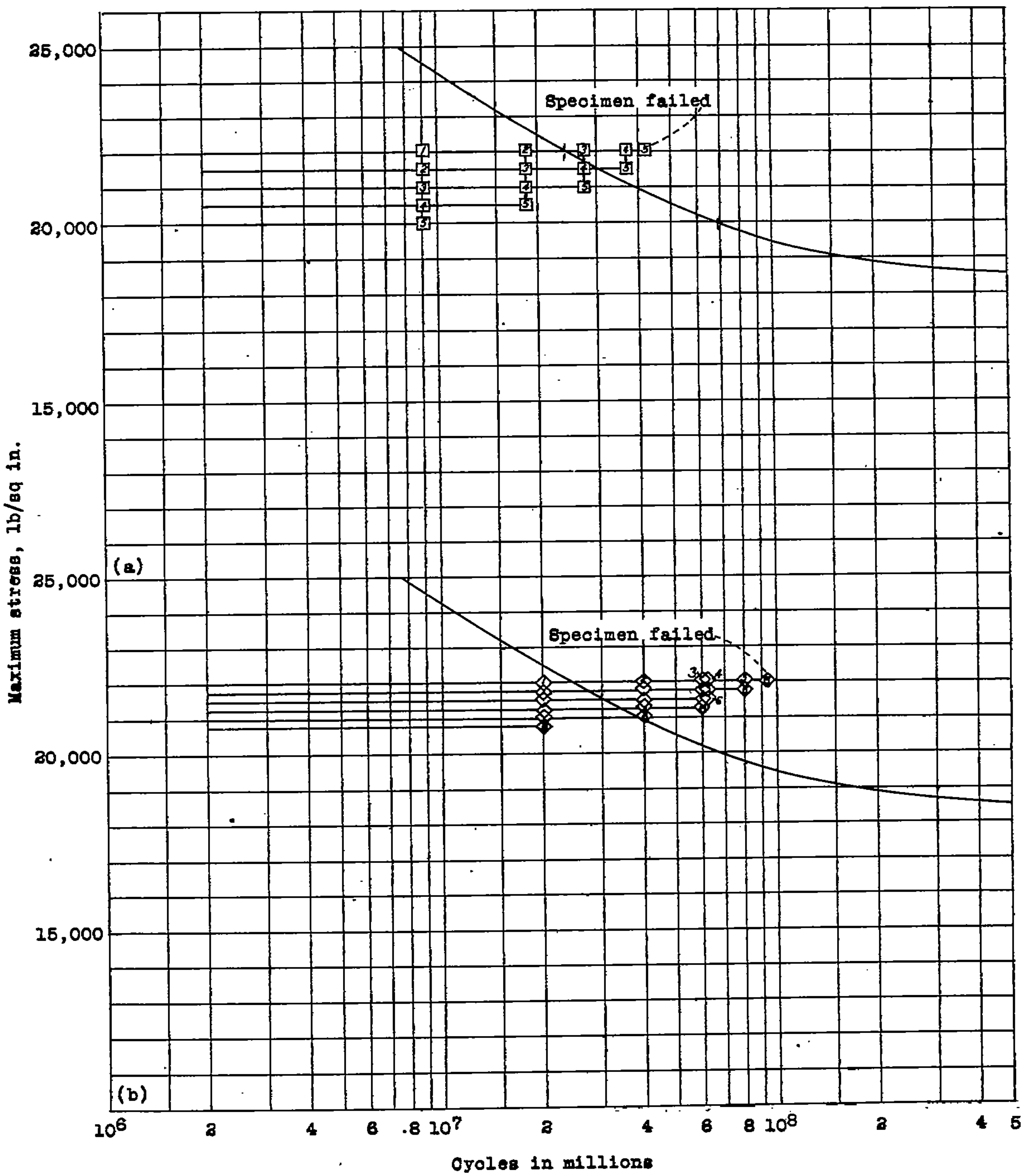
[a]As indicated by the regular fatigue curve determined from tests of 0.300-inch-diameter specimens.
[b]Regular test run at same stress until failure.
[c]Fatigue stressing history given for fifth and final surface layer.
[d]Fatigue stressing history given for sixth and final surface layer.

TABLE III

TOTAL CYCLES OF STRESS IN DIFFERENT STRESS PERIODS

Specimen	Surface layers removed	Nominal diameter (in.)	Final diameter (in.)	Increase in maximum stress at end of each period (lb/sq in.)	Nominal length of each stress period (million cycles)	Stress periods	Maximum stresses used[a] (lb/sq in.)	Total cycles (millions)	Nominal life[b] (million cycles)	Total cycles / Nominal life
P-844-L1	No	1.375	1.376	——	——	1	22,000	29	24	1.21
P-844-L2	Yes	1.375	1.251	500	9	1 to 5 2 to 5 3 to 5 4 and 5 5	20,000 to 22,000 20,500 to 22,000 21,000 to 22,000 21,500 to 22,000 22,000	42 33 23 14 5	65 49 38 29 24	0.65 .67 .61 .48 .21
P-844-L3	Yes	1.375	1.297	250	20	1 to 6 2 to 6 3 to 6 4 to 6 5 and 6 6	20,750 to 22,000 21,000 to 22,000 21,250 to 22,000 21,500 to 22,000 21,750 to 22,000 22,000	94 74 54 34 33 13	43 38 33 29 26 24	2.19 1.95 1.64 1.17 1.27 .54
P-844-L4	No	1.375	1.377	250	20	1 to 6 2 to 6 3 to 6 4 to 6 5 and 6 6	20,750 to 22,000 21,000 to 22,000 21,250 to 22,000 21,500 to 22,000 21,750 to 22,000 22,000	100 80 60 39 39 17	43 38 33 29 26 24	2.32 2.10 1.82 1.34 1.50 .71
P-844-11	No	0.300	0.2991	500	9	1 to 5 2 to 5 3 to 5 4 and 5 5	20,000 to 22,000 20,500 to 22,000 21,000 to 22,000 21,500 to 22,000 22,000	68 59 50 41 32	65 49 38 29 24	1.05 1.20 1.31 1.41 1.33
P-844-12	No	0.300	0.2990	250	20	1 to 6 2 to 6 3 to 6 4 to 6 5 and 6 6	20,750 to 22,000 21,000 to 22,000 21,250 to 22,000 21,500 to 22,000 21,750 to 22,000 22,000	86 66 46 25 25 5	43 38 33 29 26 24	2.00 1.74 1.39 .86 .96 .21

[a]For specimens from which surface layers were removed, the stresses are those at the surface of the final layer.
[b]As indicated by the regular fatigue curve determined from tests of 0.300-inch-diameter specimens.



(a) Specimen P-844-L2. Layers, 0.016 inch; periods of 9 million cycles.

(b) Specimen P-844-L3. Layers, 0.008 inch; periods of 20 million cycles.

Figure 1.- Rotating-beam fatigue tests of specimens of 17S-T aluminum-alloy rod with surface layers removed.

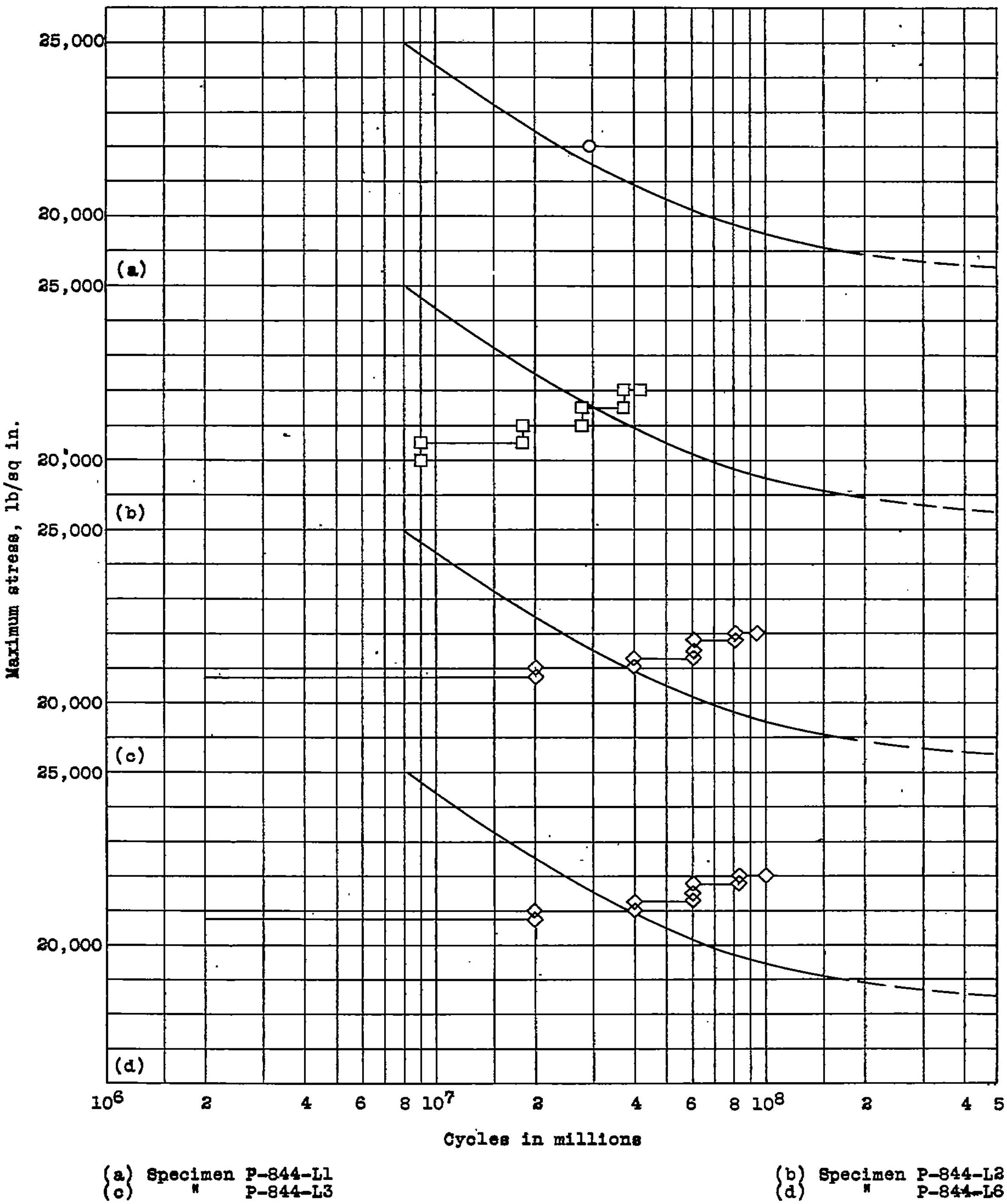
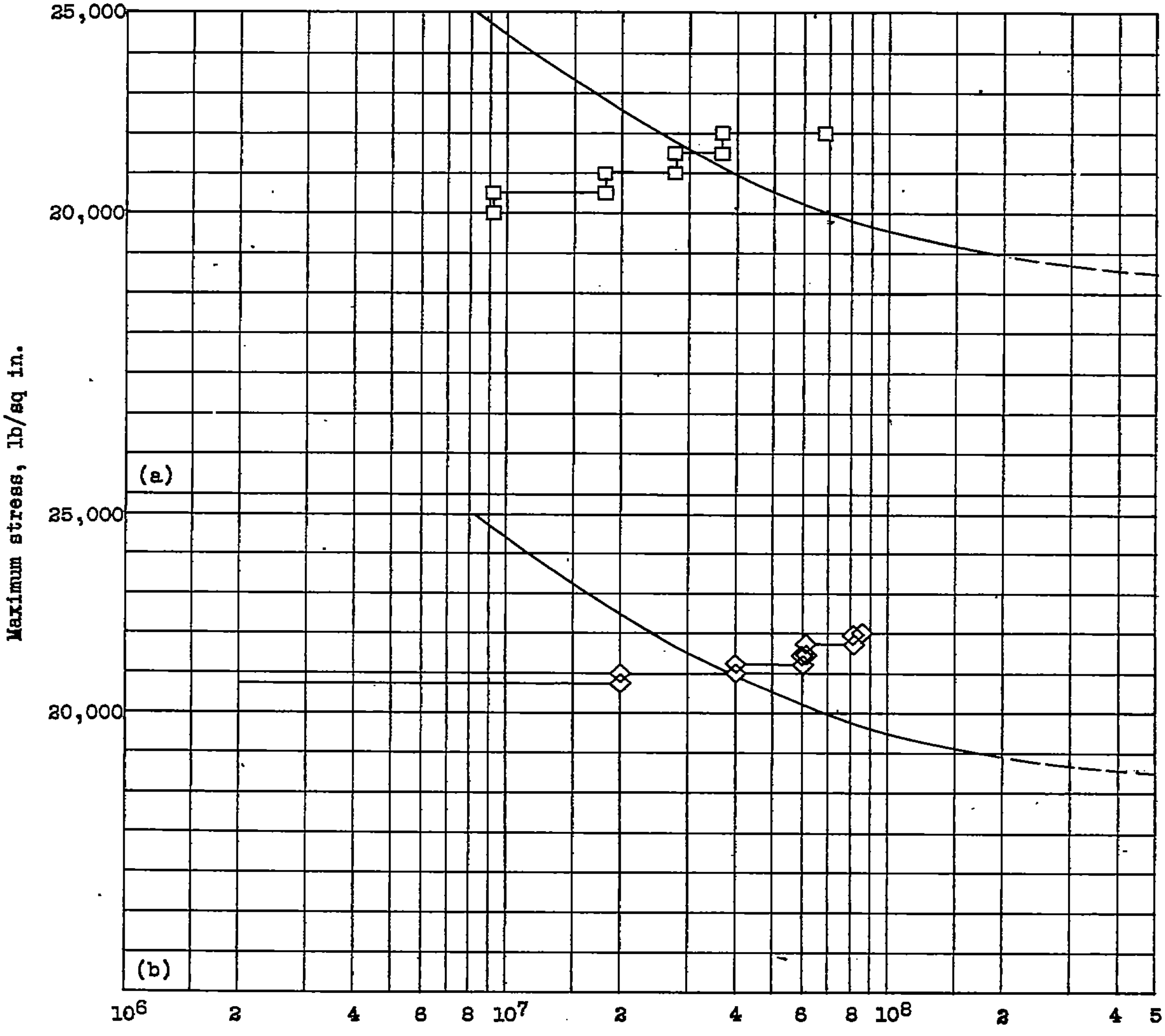


Figure 2.- Rotating-beam fatigue tests of 1.375-inch-diameter specimens of 17S-T aluminum-alloy rod.



(a) Specimen P-844-11 (b) Specimen P-844-12

Figure 3.– Rotating-beam fatigue tests of 0.300-inch-diameter specimens of 17S-T aluminum-alloy rod.