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PROGRESS REPORT NO. 4

THE INFLUENCE OF SURFACE TREATMENT ON THE FATIGUE PROPERTIES OF TITANIUM AND TITANIUM ALLOYS

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SUMMARY

Four different surface and subsurface treatments have been given Ti-75A, and their effect on the fatigue properties as determined by the R. R. Moore rotating-beam machine has been evaluated.

Of the four treatments given the material only one, the shot-peening, had any appreciable effect. Such a treatment increases the fatigue strength.

Considerable heat is liberated during the testing of titanium, which undoubtedly affects the fatigue strength, particularly in the short cycle-to-failure tests.

A considerable scatter of test results is obtained in testing specimens at any given stress and surface condition. The cause of the scatter is unknown, but it is not believed to be due to variations in surface preparation.

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EXPERIMENTAL RESULTS

The experimental work of the last period has been devoted to the determination of the fatigue properties of stock from a single heat of Ti-75A. The stock under test was supplied by the Titanium Metals Corporation and has the following reported analysis: carbon 0.025%, nitrogen 0.061%, iron 0.19%, balance titanium. As received the material was in the hot-rolled, pickled, and annealed condition. X-ray studies showed that this material had a preferred orientation. Our subsequent heat treatment, heating in argon at a temperature of 1450°F for 1/2 hour, did not break up this orientation and it is possible that this property has an effect on the resulting fatigue properties.

The tensile properties, as determined from specimens from different bars, are shown in Table I below.

TABLE I

TENSILE PROPERTIES OF TI-75A
AS-RECEIVED, ANNEALED 1/2 HOUR AT 1450°F

Specimen No.	Proportional Limit, psi	0.2% Offset Yield, psi	Ultimate Strength, psi	Per Cent Elongation in 2 in.	Per Cent Reduction in Area	Elastic Modulus, psi
1	42,000	68,000	89,700	25.5	50.6	$16x10^6$
2	48,000	68,000	89,900	24.5	51.4	$16x10^6$
3	----	----	92,000	25.0	50.6	----

The six surfaces and subsurfaces to be evaluated in the testing section of the program were prepared according to the following directions:

(1) Machine specimens to within 0.005 inch of final size, anneal at 1450°F for 1/2 hour in argon to relieve surface and subsurface strains, and hand-finish with metallographic papers through 3/0 grade metallographic papers to final size.

(2) Machine specimens to within 0.050 inch of final size, anneal as in (1), machine to 0.005 inch of final size, and hand-finish to final size on metallographic papers.

(3) Machine specimens to 0.050 inch of final size, anneal as in (1), and rough-machine in a uniform fashion to final size.

(4) Machine specimens to 0.025 inch of final size, anneal as in (1), machine to 0.002 inch of final size, re-anneal, hand-polish to final size, and then shot-peen (these specimens were peened to an Almen number of 10 using a 0.010 steel shot in a Wheelabrator unit).

(5) Machine specimens to 0.002 inch of final size, anneal as in (1), and then electropolish to final size.

(6) Machine specimens to 0.025 inch of final diameter, anneal as in (1), then grind in two steps to finish diameter using a Norton 48K8VI wheel and a sample surface speed of 50 for rough grinding and 67 for finish grinding (the surface speeds of the grinding wheel were 3900 and 8900 fpm, respectively).

The surface finish characteristics on the first four of the above treatments are given in Table II.

TABLE II

SURFACE CHARACTERISTICS

Finish No.	Average RMS, Microin.	High RMS, Microin.	Low RMS, Microin.
1	18	28	12
2	13	17	10
3	65	95	54
4	90	104	70

The fatigue data on the first four finishes described above are plotted on the conventional S-N graphs in Figs. 1, 2, 3, and 4. From these data it is apparent that there is a considerable scatter at any given stress level, which makes it difficult to arrive at an average value. Increasing the number of tests to decrease the variance is out of the question due to the cost and difficulty of obtaining stock.

From the graphs there seems to be no essential difference in the properties of the first three surfaces. There is some indication that the rough machining is slightly superior to the hand-finished materials, but this is not marked. On the other hand there is no question but that the shot-peening has very effectively improved the fatigue properties. Data on the remaining two finishes are still being collected at the present time.

On the basis of surface roughness it was believed that the shot-peened samples would be inferior, the rough-machined next, the machined and hand-polished next, and hand-polished the best. In the data gathered to date, however, this trend seems to be completely reversed. This indicates that the subsurface or residual surface stresses are more important than the surface finish.

Heating Effect

During this testing of the first group of specimens it was noted that the specimens heated during the test, due to some form of internal friction. The amount of heat liberated appeared to be directly related to the stress being applied to the specimens, the higher stresses producing more pronounced effects. At the very high stresses, sufficient to cause failure in 10,000-30,000 cycles, this heating was so pronounced that the fracture and the areas adjacent to it actually showed temper colors. This indicates that the temperature had risen to as high as 600-700°F locally. Some of these specimens showed cracked areas adjacent to the fracture, which is indicative of a high-temperature type of failure. Still other specimens simply deformed plastically at the elevated temperature developed and it was necessary to discontinue the tests because of the very large eccentricity that developed in the specimens.

In order to follow the temperature rise during testing, a thermistor-bolometer in a bridge circuit was adapted to measure the temperature rise in the vicinity of the reduced section. The data taken with this instrument indicate that at the start of a test, with the specimen under a high load, the temperature rises continuously and near the fracture time very sharply. Specimens under low stress, such as those which run for 10^6 to 10^7 cycles, showed that the temperature rises to some constant value. At the moment of fracture there is a heat evolution, probably because of the fracture, but some of the effect is probably due to the stopping of the convective cooling that occurs during the running period. Specimens run at intermediate stresses show a variable behavior in regard to the temperature rise. In some cases there is a continual rise until fracture occurs, while in others the temperature remains constant. In all cases, however, there is a heat evolution and in no case does the temperature rise, and then fall.

These data, while only qualitative, show that something is happening internally in the metal to give rise to this heat. It is possible that the scatter observed in data at any given stress level is due to this internal effect.

In order to follow this effect quantitatively, specimens at each stress level for Finishes 3, 4, 5, and 6 have been drilled longitudinally and fitted with thermocouples to measure the actual temperature rise in the specimen and correlate this with the bolometer readings. As a further check a specimen with a heater and with surface thermocouples is being constructed to calibrate the bolometer. In both these cases the presence of a hole will cause premature failure, but the results will be indicative of the order of magnitude of the temperature rise that is occurring. The results of these tests are still fragmentary, since the test machines have been tied up in running the regular specimens.

The occurrence of this heating effect is one of the reasons we have proposed studying the properties of an electropolished surface, since it is possible that the heating effect is due to the presence of submicroscopic cracks in the material. An electropolished surface will permit the use of electron microscopy to examine the test surfaces directly.

While work on the six surfaces described is going forward, it is believed that the presence of this heating effect is definitely an important factor which must be evaluated more accurately. The tests to date have all been made on specimens rotating at a speed of 1720 rpm, but it is apparent that the speed of testing has a marked effect. It is also obvious that the tests to date have not been made under isothermal conditions; possibly some attempt should be made to attain this condition.

FUTURE WORK

The present series of tests on Ti-75A is to be completed. In addition, attempts will be made to determine:

(1) the actual temperature rise

(2) the depth of penetration of the surface treatments given the samples, using x-rays;

(3) the effect of oxidation and nitriding on the fatigue strength of a surface;

(4) the correlation of behavior of specimens with their internal friction; and

(5) the absolute stress in the surface layers of the specimens.

Electron microscope studies of surface and subsurfaces will also be carried out. On the basis of work completed on Ti-75A, certain tests will be carried out on alloy RC-130B, which has just been received.

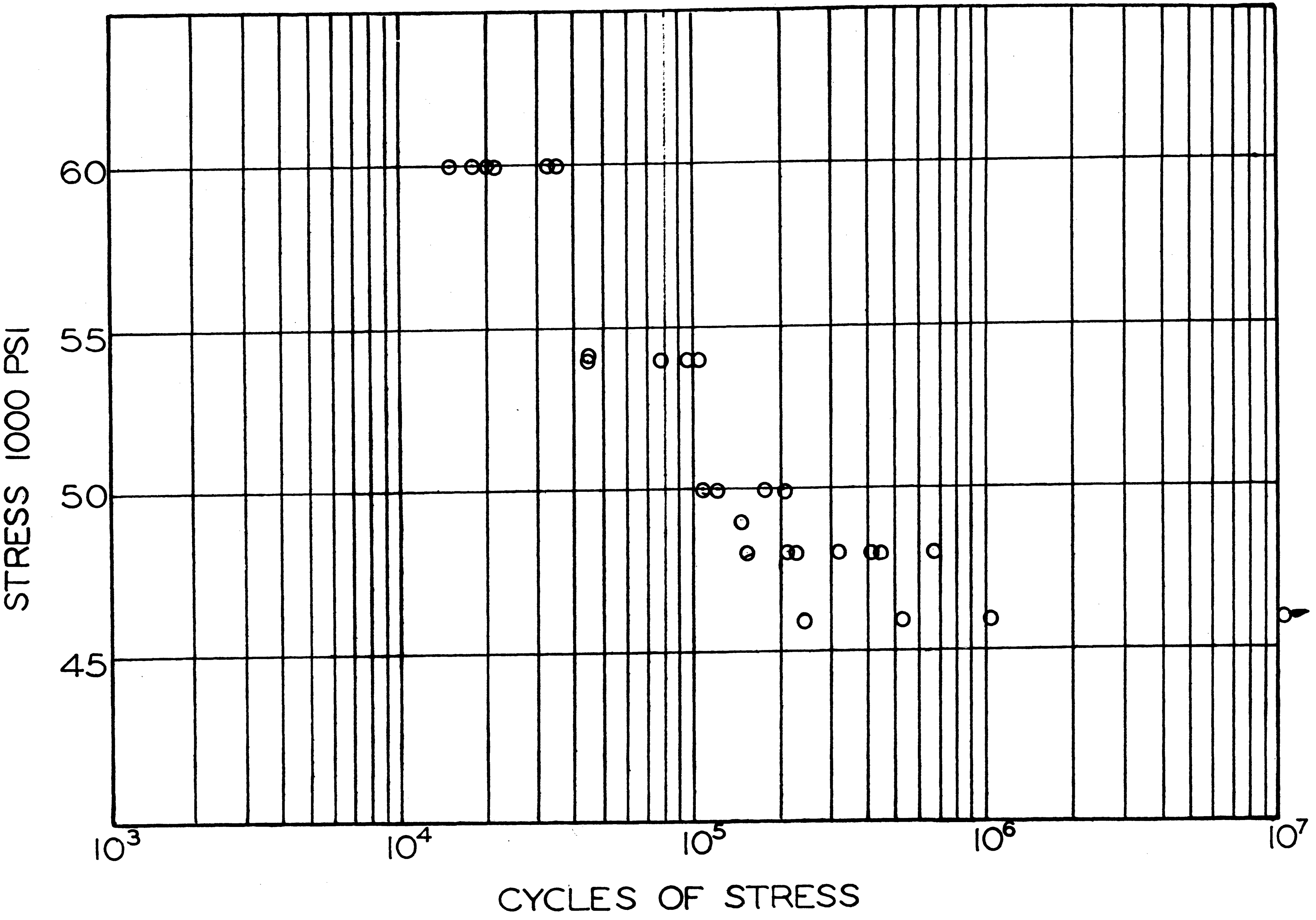

STRESS 1000 PSI
60
55
50
45
10^3
10^4
10^5
10^6
10^7
CYCLES OF STRESS

FIGURE 1

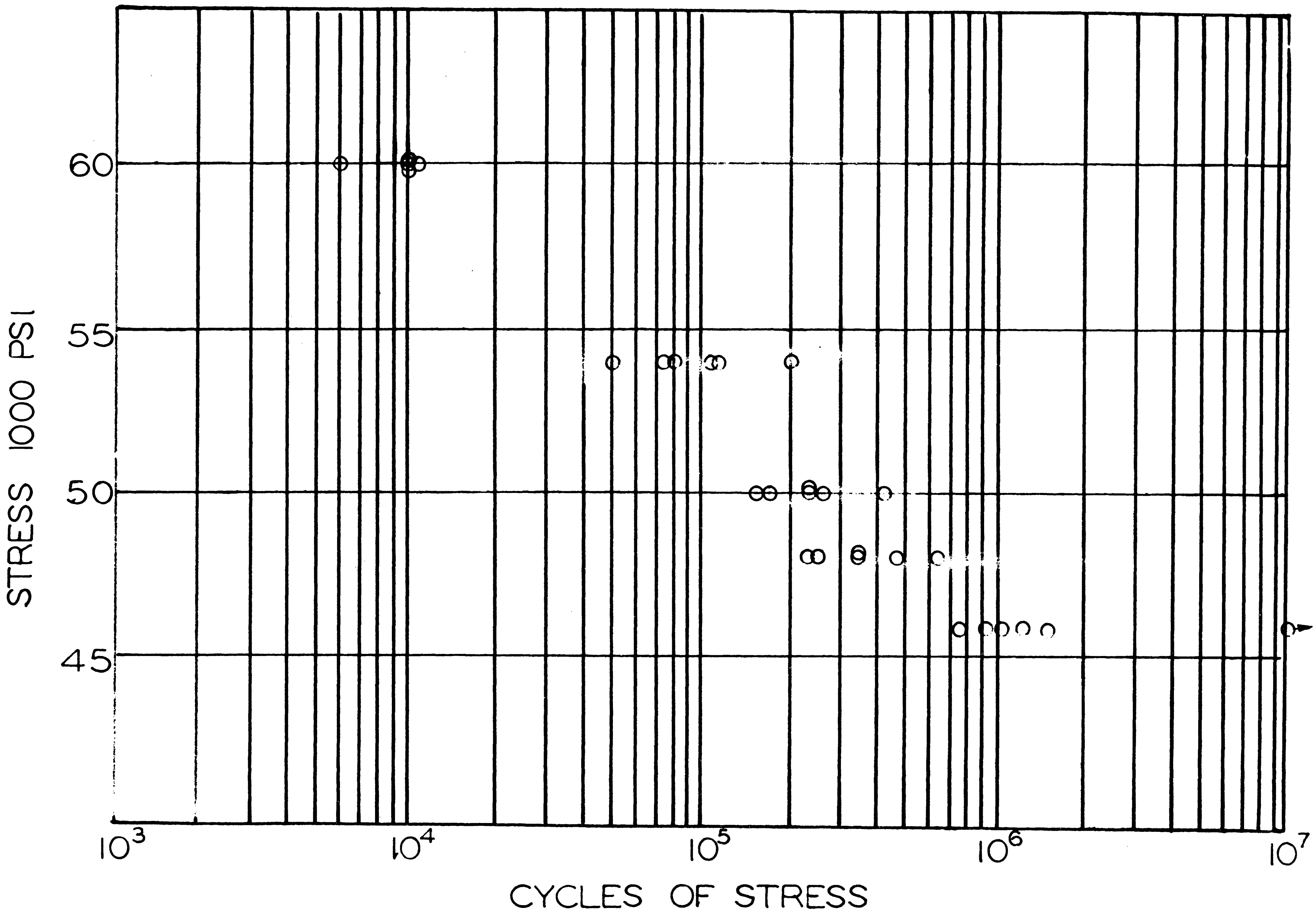
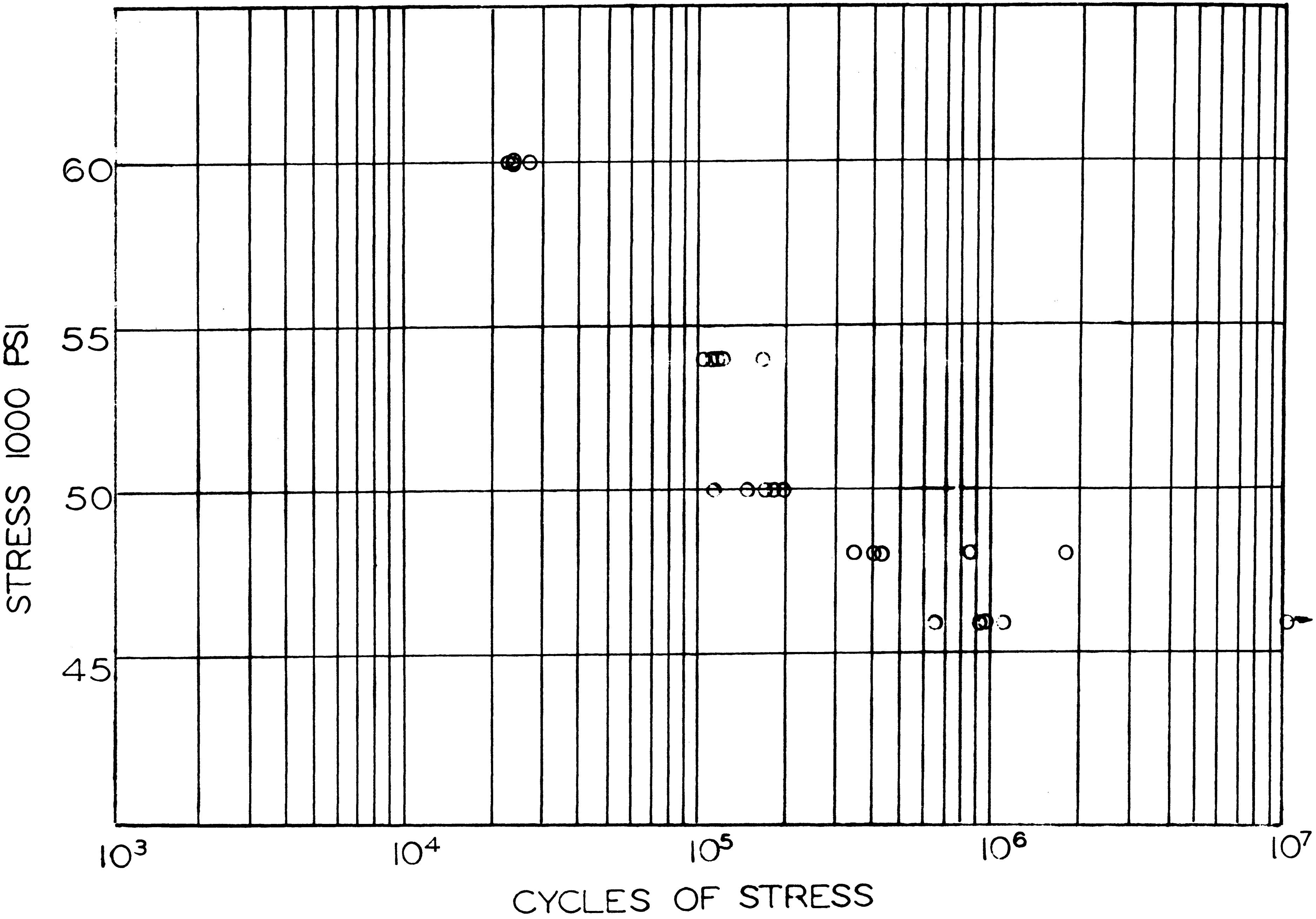

STRESS 1000 PSI
60
55
50
45
10^3
10^4
10^5
10^6
10^7
CYCLES OF STRESS

FIGURE 2


STRESS 1000 PSI
60
55
50
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10^3
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10^6
10^7
CYCLES OF STRESS

FIGURE 3

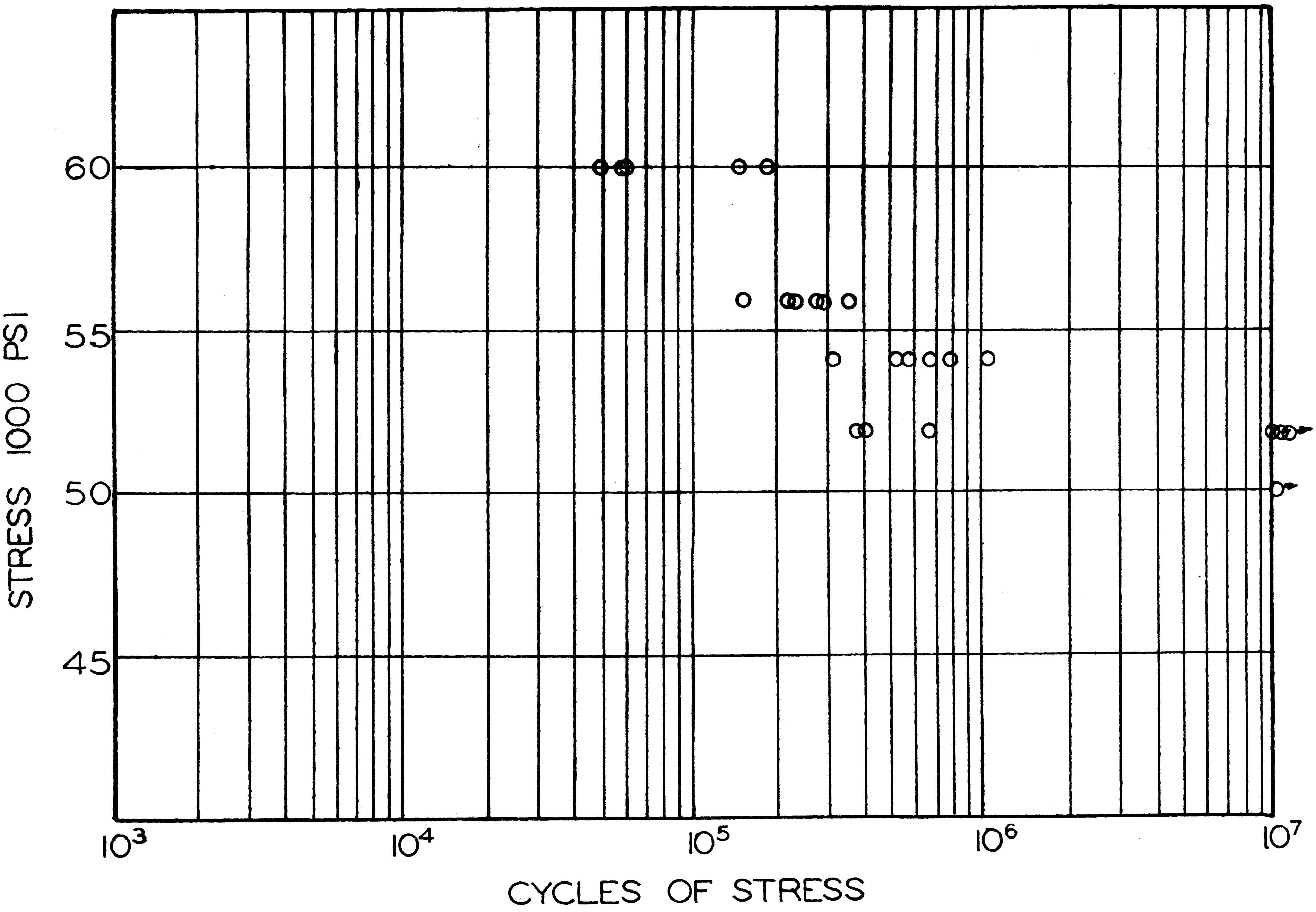
STRESS 1000 PSI
60
55
50
45
10^3
10^4
10^5
10^6
10^7
CYCLES OF STRESS

FIGURE 4