WADC TECHNICAL REPORT 55-389

FATIGUE PROPERTIES OF VARIOUS GLASS-FIBER-REINFORCED PLASTIC LAMINATES

K. H. BOLLER

FOREST PRODUCTS LABORATORY, FOREST SERVICE

MAY 1956

MATERIALS LABORATORY
USAF CONTRACT No. DO 33(616)-54-14
PROJECT No. 7360

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
600 - July 1956

FOREWORD

This report was prepared by the U. S. Forest Products Laboratory under USAF Contract No. DO 33(616)-54-14, Amendment A1(55-1780). This contract was initiated under Project No. 7360, "Materials Analysis and Evaluation Techniques," Task No. 73604, "Fatigue Properties of Structural Materials," and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. Robert J. Rooney acting as project engineer.

This report covers work conducted from May 1954 to October 1955.

ABSTRACT

Fatigue strength values are presented for 6 standard and 4 heat-resistant resin laminates reinforced with glass fibers. Fifty-three S-N curves, representing fatigue data between 1 thousand and 10 million cycles, show the effect on fatigue strength of a notch, moisture, fabrics, resins, mean stress levels, angles to warp, and temperatures up to 500° F.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (Cont.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

Introduction

Since glass-fiber-reinforced plastic laminates are continually being developed for structural use in aircraft and power plants, it is essential that the factors affecting their strength be evaluated for the designers. There is a considerable amount of data available on the static strength properties of structural plastics under standard conditions, and there are some data available on their fatigue strength at room temperatures, but available fatigue data at elevated temperatures are limited. To fill this gap in the knowledge of factors affecting the strength of reinforced plastics that are being formulated for use under adverse conditions, the fatigue properties of typical heat-resistant plastic laminates were investigated at both room and elevated temperatures at the Forest Products Laboratory in cooperation with Wright Air Development Center.

The fatigue data were obtained on axially loaded specimens from 10 types of laminates that were molded in flat sheets. Each of these 10 types of laminates consisted of one of 6 types of resin and one of 5 types of glass fiber reinforcement. The effects investigated were: (1) effect of stress concentration; (2) moisture effects; (3) temperature effects; (4) effect of direction of loading; (5) effect of various levels of mean stress; and (6) effect of types of fabric reinforcement. The stress concentration was produced by a 1/8-inch diameter hole in the center of the specimen. Moisture effects were produced by conditioning the material at 100° F. and 100 percent relative humidity for not less than 30 days prior to testing at that condition. The effects of temperature were investigated at 73°, 300°, and 500° F. during the test period. Since the test material was in flat sheets, the specimens were loaded axially in the plane of the sheet at 0° and 45° to the warp at a test frequency of 900 cycles per minute. Various alternating stresses were superimposed on various tensile mean stresses. The complete relationship between alternating stress and mean stress with respect to time was clarified by stress-rupture data supplied by Wright Air Development Center on matched material. A total of 53 S-N curves were obtained, each covering a range of 1 thousand to 10 million cycles.

The methods of test and presentation in this report have the same general pattern that was used in presenting fatigue and stress-rupture information in Forest Products Laboratory reports 1823[1] and 1839[2]. These two reports presented 19 S-N curves for 3 materials under various conditions that are comparable to those presented here except that all tests were at room temperature.

[1] Boller, K. H. Fatigue Tests of Glass-Fabric-Base Laminates Subjected to Axial Loading, Forest Products Laboratory Report 1823, May 1952.

[2] Boller, K. H. Stress-Rupture Tests of a Glass-Fabric-Base Plastic Laminate, Forest Products Laboratory Report 1839, June 1953.

Manuscript released by author 1 March 1956 for publication as a WADC Technical Report.

Description of Materials

Flat, glass-fiber-reinforced panels approximately 1/4 inch thick were made or procured by the Forest Products Laboratory. The size and number of panels of each type of laminate varied with the number of tests required for that particular laminate. The specifications for the materials were supplied by Wright Air Development Center.

Of the 10 laminates under investigation, 4 were made with heat-resistant resins: (1) polyester resin (PDL-7-669) (2) epoxide resin (Epon X12100) (3) phenolic resin (BV 17085) and (4) silicone resin (DC 2106). All of these heat-resistant laminates were reinforced with 181 glass fabric, Volan A finish, except the silicone laminates, which was made with heat-cleaned 181 glass fabric. The other six laminates were in the standard class. One of these was made with an epoxide resin (Epon 828 CL), and the remaining 5 were made with a polyester resin (Paraplex P43). The standard epoxide laminate was reinforced with 181 glass fabric and the polyester laminates were reinforced with 181, 112, 120, and 184 glass fabric and a 1-1/2-ounce glass mat. All the woven fabrics had Volan A finish. All of the fabric laminates were parallel laminated.

The methods used to make the panels at the Forest Products Laboratory are shown in table 1. The methods used for the other panels are not specifically known, but the laminates did meet the established strength requirements.

The quality of the laminates, as measured by their physical properties and static strength in tension, compression, and flexure, is shown in table 2. Values reported in this table were obtained in accordance with Federal Specification LP406b. The standard laminates had properties that exceeded the minimum requirements of parallel-laminated, 1/8-inch-thick stock, as stipulated in Specification MIL-P-8013A, except that the maximum tensile stress at room temperature for the polyester laminate with mat reinforcement was below the specification requirement.

The four heat-resistant laminates had some properties that were lower than considered possible to attain with these materials.

Fatigue Tests

Test Specimens - Unnotched

The type of fatigue specimen used in this investigation (fig. 1) is the same as the type used previously.[1] The specimen was gripped by the clamps shown in figure 2 so that it had an unsupported length of 2-1/4 inches. The ratio of this length to the thickness was about 9, which was sufficiently small to prevent buckling during the compression cycle of the fatigue tests.

Test Specimens - Notched

The notched fatigue specimens were the same size and shape as the unnotched specimens. The notch, or stress concentration, was a hole 1/8 inch in diameter at the center of the specimen. Theoretically, the stress at the edge of this centrally located notch was 3-1/2 times the average stress. However, the actual effect of the notch and the 4 inch radius used to reduce the width, as shown by data in the previous report,[1] was a reduction in average stress of 20 to 28 percent in tension, and an increase in average stress of 6 to 20 percent in compression.

Smooth cuts along the edges of the specimens were made with a carborundum saw for the straight cuts or by a small emery wheel mounted in the plane of the sheet for the curved cuts. The 1/8-inch hole was drilled with a steel drill and received no polishing.

Test Specimens - Stress Rupture

Stress-rupture specimens, which were subjected to a steady stress without a superimposed alternating stress, were necked down like the fatigue specimens. These constant load specimens were the same as the fatigue specimens, except that their overall length was 20 inches instead of 6, and their width was 1-1/4 inches instead of 1-1/2 inches. Three quarters of an inch from each end, a hole 3/8 inch in diameter was drilled for use in applying the load to the specimen. The areas around the holes at the ends of the specimens were reinforced with 1-1/4- by 2- by 0.041-inch aluminum plates that were bonded to the specimens with Epon VI metal adhesive. This measure was taken because failures were occurring at these holes in both notched and unnotched specimens at room and elevated temperatures.

Scope of Test Program

The effects of notch, moisture, direction of loading, magnitude of mean stress, and temperature on the fatigue characteristics of the 10 materials were evaluated in this test program. All combinations of variables and materials were not investigated, however. The specific variables that were investigated for each material are shown in table 3. In addition to the S-N curves obtained at the Laboratory, 6 stress-rupture curves were obtained by Wright Air Development Center. They were for notched and unnotched specimens of the heat-resistant polyester laminate tested at 73° and 50 percent relative humidity, 300° and 500° F.

Test Method and Equipment

After the quality of the materials had been determined by standard methods of test, 10 specimens for fatigue tests and 5 specimens for static tests of ultimate tensile strength were cut from each material, to make a total of 15 basic matched specimens for each S-N curve. Some compression control tests were made on heat-resistant laminates. The control specimens were tested in a universal testing machine (fig. 3) under the same conditions of temperature and humidity as were to be maintained during fatigue tests on the same material. After the static ultimate tensile strength had been determined on a fatigue-type specimen of one material, alternating stress amplitudes were assigned to a series of fatigue specimens of that material. The highest alternating stress assigned was about 70 percent of the static tensile strength, and the percentage was decreased on subsequent specimens until a specimen endured 10 million cycles. This procedure provided test data between about 1,000 and 10 million cycles.

All of the fatigue specimens were axially loaded by fatigue machines of the type shown in figure 4. For high-temperature tests, the specimens were enclosed in ovens, as shown in figure 5.

To have the specimen truly axially loaded, without torsion or bending distortion, the upper and lower grips were rotated to bring the stationary faces of both grips into the same plane. Tension and compression loads were applied alternately by an eccentric operating at 900 revolutions per minute. The static load that was first applied to the specimen was measured by a dial mounted on a calibrated dial bar. The dial measured the deflection of the horizontal loading arm between the connecting rod of the eccentric and the loading screws. This static load took into account the inertia effects of the moving parts, so that the desired dynamic load was applied during test. The factors for this increase of dynamic load over static load had been previously measured electronically. The desired dynamic load was kept constant throughout the test by periodic checks, and adjustments when necessary. An electronic shut-off mechanism on the horizontal loading arm stopped the test if the load dropped more than 25 pounds. Then, if failure had not occurred at a shut-off, load adjustments were made and the test was continued.

One testing machine was operated in a room maintained at 73° F. and 50 percent relative humidity. Heat generated in the net section of the specimen was removed by a 12-inch fan that continuously blew air past the specimen. Two machines were equipped with ovens (fig. 5) capable of heating the specimen and its clamps to 1,000° F. and maintaining the desired temperature to ± 5° F. The ovens were split in the center in a vertical plane, and each half could be rotated on a hinge at the vertical post of the fatigue machine, so that the fatigue specimens were accessible. The heating elements in the ovens were divided into 3 zones, each of which was regulated by a rheostat, which was in turn regulated by a thermocouple. The thermocouple was taped to the specimen at the net section, so that the temperature rise due to the heat generated in the specimen during the test was considered as part of the total temperature upon which control of oven temperature was based. The temperature of the air between the heating coils and the specimen was thus somewhat less than the established test temperature. Each fatigue specimen to be tested at 300° or 500° F. was installed in a comparatively cool oven. After installation, it required about an hour for the specimen, its fittings, and the loading screws to reach temperature equilibrium. The specimen was then loaded and tested.

A wet condition of 100° F. and 100 percent relative humidity was provided by special humidity chambers. For preliminary conditioning, a small metal box with a rack for holding the specimens above water was placed in an oven at 100° F. The fatigue specimens were exposed in this manner for at least 30 days before they were tested. In the fatigue machine, they were tested in another chamber attached to the loading screws (fig. 6). This chamber was a cylinder with rubber sides and tin ends. A rubber hose carried moisture-laden air from a generator (fig. 7) to the specimen. The generator, which was a tank filled with water that was heated by thermostatically controlled electric elements, combined air and water so that air at the fatigue specimen would be at 100° F. and 100 percent relative humidity. Compressed air bubbled up through the warm water, and picked up moisture and heat. Heat losses through the rubber hose were taken into account, so that the air delivered to the specimen was at the desired conditions.

Stress-rupture test specimens of the size and shape indicated earlier were supplied to the Wright Air Development Center, where stress-rupture tests were made in tension on apparatus at the Materials Laboratory at Wright-Patterson Air Force Base, Ohio. They used the creep testing machines and ovens normally used for testing metals to test the modified fatigue specimens. The bearing holes at the ends of these modified specimens were reinforced with aluminum plates, as mentioned earlier, to prevent premature failure during load application.

Test Data

The results of individual fatigue and stress-rupture tests are shown in tables 4 through 15 and in figures 8 through 38.

The individual static control strength values, shown in tables 4 through 14, have been averaged and their variation is shown by the coefficient of variation, Cov, which equals 100 times the standard deviation divided by the average. Only 3 tensile values of the coefficient of variation are greater than 10 percent, and the average Cov is 5.30 percent. The individual fatigue test values, as shown by their location on the stress-cycle coordinates, do not scatter a great deal on either side of the smooth curve that has been drawn through them. The scatter is small for all S-N curves except those for heat-resistant phenolic and epoxide resin laminates at

500° F. The amount of scatter at 500° F. probably results from the combined effects of exposure to high temperature and to fatigue loading. Both cause a reduction in strength. The test results are a combination of these, and the time of exposure to high temperature is not proportional to the time (cycles) to failure, because of pre-test conditioning and shut-off periods. The smooth curves drawn through the test data represent the data well enough to make comparisons with other fatigue data, however.

Summaries of fatigue and stress-rupture data are shown in tables 16 through 19 and in figures 39 through 53. These figures and tables present the smooth curves and the fatigue strength values that have been picked from the smooth curves at a specific number of cycles. The percentage values in the tables are the respective strength values times 100 divided by the static tensile strength of an unnotched specimen of similar material at room temperature. In this manner, the effect of all variables can be related to a common base.

Values for stress at rupture (table 19) were picked from stress-rupture curves (figs. 36 to 38) at a number of hours equivalent to the duration of the indicated number of cycles. The conversion factor is 900 cycles per minute.

Discussion of Results

It has been well established that the continual application of stresses, either alternating, steady, or a combination of both, causes the failure of plastic laminates, even though the stress is less than the short-time static ultimate strength. It is also well known that notches, water, and temperature affect the strength, but the magnitude of the effect of combinations of these factors has not been known.

The effect of these variables on the fatigue strength is shown in the summary figures (figs. 39 to 53), where various individual S-N curves have been superimposed to permit comparison. The effects that these variables had on the fatigue strength are as follows:

Effect of Repetition of Stress at Room Temperature

Tables 16 and 17 show a considerable range in fatigue strength values of unnotched material with different reinforcements and resins. However, the standard laminates made with polyester resin and fabric reinforcements have essentially the same fatigue strength above 10^4 cycles to failure, regardless of the fabric type (table 16, fig. 39). The mat-reinforced laminate has a fatigue strength considerably below those for the fabric-reinforced laminates (table 16, fig. 39). When expressed as a percentage of static tensile strength, most fatigue strength values at 10^7 cycles ranged from 20 to 25 percent, except for the strength of the epoxide laminate, which was considerably higher.

The heat-resistant laminates, when tested at room temperature, show characteristics similar to those discussed above (table 17, fig. 41). The silicone laminate shows the lowest fatigue strength at 10^7 cycles.

Effect of Moisture

Normally, the amount of moisture that is absorbed by glass-reinforced plastic laminates is on the order of 1/2 to 2 percent. However, these small amounts of moisture cause reductions in static short-time strength and in fatigue strength. For example, the short-time tensile strength of the standard polyester resin laminate was reduced from 46,000 to 42,330 pounds per square inch (table 4) due to the absorption of moisture, and the fatigue strength (table 16, fig. 42) was reduced from 32,300 to 20,000 pounds per square inch at 10^3 cycles and from 10,400 to 9,400 pounds per square inch at 10^7 cycles. This phenomenon of smaller reductions in fatigue strength as the number of cycles increases was observed in the previous study at 73° F. and 100 percent relative humidity.[1] It was believed at that time that some drying was taking place. However, in this experiment at 100° F. and 100 percent relative humidity, the specimens were thoroughly wet at all times. Current data, therefore, show that the fatigue strength of standard polyester resin laminates is reduced only 2 percent of the static tensile strength at 10^7 cycles because of moisture.

Fatigue data obtained on epoxide resin laminates show the effect of moisture absorption to be insignificant (fig. 42).

Effect of Stress Concentration (Notch of 1/16-inch Radius)

Almost every S-N curve that was experimentally obtained for unnotched specimens has a companion curve for notched specimens. Data for notched and unnotched specimens of standard polyester resin reinforced with 181 glass fabric are given in Forest Products Laboratory Report 1823.[1] The S-N curves for notched specimens are in almost every instance lower than those for unnotched specimens. Exceptions exist at elevated temperature where either the degree of scatter of data is greater than the effect of the notch, or where the low compressive strength disrupts the usual trend.

S-N and stress-rupture curves that compare strength values of notched and unnotched specimens are shown in figures 18, 19, 27 through 38, and 43. Fatigue data for the heat-resistant polyester resin laminate at 3 temperatures and various stress levels are shown in table 18. It should be noted that the S-N curves for notched specimens of the standard polyester laminate reinforced with various fabrics are approximately parallel to each other (fig. 43). Parallelism of the S-N curves of notched and unnotched material is illustrated for the laminate with 184 fabric. This parallelism between companion curves of notched and unnotched material exists in general throughout the entire study. The degree of difference between the two curves varies for each material.

The average fatigue strength for notched material at room temperature after 10^7 cycles at zero mean stress is about 23 percent of the room-temperature ultimate tensile strength (tables 16 and 17). However, the average difference in fatigue strength between notched and unnotched material at room temperature after 10^7 cycles at zero mean stress is only about 4.5 percent of the room-temperature ultimate tensile strength (tables 16 and 17). Those materials with the highest percentage of reduction would be considered the most sensitive to stress concentration. In this respect, the standard polyester laminate reinforced with 112 fabric shows the greatest sensitivity.

At high temperature, particularly at 500° F., the difference between the strength values of notched and unnotched specimens at 10^7 cycles is generally smaller than at room temperature (table 17). Two of the materials show progressively decreasing differences with increasing temperature. At high temperature, the failure was commonly in compression, and showed as a shear failure at an angle to the plane of the specimen. In a compression failure, the notch would be expected to have a lesser effect than in the case of a tensile failure through the notch. Fatigue data at elevated temperatures, then, probably should not be used as an indication of the sensitivity of the material to a notch.

Another effect of notching, which is not so readily noticeable, is the apparent reduction of the degree of scatter. It may be seen in the individual figures that the data points of unnotched material have more scatter than data from the notched material.

Effect of Direction of Loading

The laminates used in this fatigue study were 1/4-inch-thick flat plates made of parallel laminations of individual layers of glass fabric. The majority of the specimens were cut from the laminates so that their lengthwise direction (axial direction) was parallel to the warp direction of the fabric. A few specimens of heat-resistant polyester resin laminate, however, were cut from the flat plates with their lengthwise direction at 45° to the warp direction. These specimens were unnotched and were tested at room temperature, 300°, and 500° F. The results of these tests are shown in tables 11 and 17, and in figures 26 and 44. In figure 44, these results are compared with fatigue strengths at 0° to warp. The static tensile strength at 45° to warp is usually lower than that at 0° to warp, and so the fatigue strength would also be lower. The data show that at room temperature an endurance limit is reached at about 40,000 cycles and a stress level of 6,500 pounds per square inch. Fatigue data on specimens tested at room temperature and 0° to warp do not show an endurance limit at 10^7 cycles. Time and high temperature cause S-N curves to continue their decline, so that it is not certain whether or not an endurance limit was reached at 10^7 cycles at elevated temperatures (fig. 26). The endurance limit at 40,000 cycles and 6,500 pounds per square inch agrees with Forest Products Laboratory Report 1823,[1] which shows an endurance limit at 40,000 cycles and 5,000 pounds per square inch for a similar laminate.

Effect of Elevated Temperature

As is true for other properties, exposure to elevated temperature results in a reduction of fatigue strength. The fatigue data for 4 heat-resistant laminates (table 17 and figs. 44 through 47) show this effect at 300° and 500° F. While each of the laminates shows a decrease in fatigue strength with an increase in temperature, the magnitude of the decrease varies with the type of laminating resin. The effect appears to be related to the strength retention of the laminate with increasing periods of high-temperature exposure. For example, although the epoxide and silicone laminates had the lowest static properties at 500° F. (tables 8 through 14), their fatigue strength at 10^7 cycles was somewhat higher than that of the polyester and phenolic laminates. The lower initial strength of the epoxide and silicone laminates is reflected in the lower fatigue strength at the shorter periods (smaller numbers of cycles).

Stress-rupture data (table 19) do not indicate a large effect for extended periods of exposure of the polyester laminate to elevated temperatures. It appears, therefore, that this laminate is more sensitive to time at temperature when subjected to fatigue loading.

The effect of temperature on the endurance limit of laminates loaded at 45° to warp is pointed out above. The weakening effect of temperature is not confined to 0° and 45° to the warp, however. It also affects the strength perpendicular to the laminations. The clamps holding the fatigue specimen in the machine had to be tightened during the course of the test to prevent slippage which indicated that some crushing perpendicular to the plane of the specimen was occurring.

The weakness in compression in the plane of the specimen at elevated temperatures is demonstrated quantitatively by the static compression tests on the heat-resistant resin laminates (tables 9, 10, 12, 13, 14).

The scatter of the fatigue data at 500° F. for the heat-resistant epoxide laminate (fig. 29) was partially due to erratic failures. The majority of the failures were in compression although some were in tension.

As was indicated earlier, all tests, including those at elevated temperature, were made at a frequency of 900 cycles per minute. Somewhat different effects of elevated temperature on fatigue properties might have been expected had the tests been made at a different frequency. That is, the test frequency determines the time of exposure to elevated temperature for any given number of cycles. Thus, a lower test frequency would increase the time of exposure and, particularly for those laminates more effected by extended high-temperature exposure, might be expected to lead to lower fatigue strength, particularly at the larger number of cycles. Conversely, a higher test frequency might be expected to lead to higher fatigue strength because of the reduced time of exposure.

Effect of Various Mean Stress Levels

In all of the previous discussion, the alternating stresses have been equal tensile and compressive stresses that alternated about a zero mean stress. In practice, this condition is only one of the many mean stress conditions that may be encountered. The alternating stress amplitude, at zero mean stress, may vary from zero to the ultimate strength of the material, and the mean stress level may vary from zero to the ultimate strength of the material when time, temperature, and other factors are considered. Data in table 18 and in figures 48 through 53 show graphically the relation between mean stress, alternating stress, and time when other factors remain constant. These figures show the alternating stress amplitude as ordinates that may be either compressive or tensile stress, and the mean stress levels are shown as abscissas that may also be either compressive or tensile stress. The data plotted on these coordinates are the alternating stress amplitudes, at various numbers of cycles, that were picked from the S-N curves of the respective mean stress conditions (figs. 20 to 25). When the alternating stress amplitude is zero, the abscissa intercepts are equal to the steady stress (from stress-rupture data) that can be supported for a period equivalent to the number of cycles shown.

Laminated plastics at elevated temperatures do not always have equal tensile and compressive strength values, as discussed earlier. If they are not equal, the alternating stress amplitude that can be sustained for a given number of cycles depends in part on the compressive strength. Thus when tensile mean stresses are applied, somewhat higher alternating stress amplitudes can be sustained at low levels of mean stress than at zero mean stress. Examples of this effect are shown in figures 52 and 53.

The alternating stress-mean stress diagram, if modified to non-dimensional coordinates to show the effect of temperature at a specified time period, changes to the form shown in figure 54. In that figure, the ordinate is the alternating stress amplitude S_a for a specified lifetime or number of cycles divided by the experimental fatigue strength S_e at the same lifetime for a completely reversed stress. The abscissa is the specified mean stress S_m divided by the experimental static stress-rupture strength S_c for a specified lifetime converted to the same period as fatigue life. The straight line (modified Goodman line) is then expressed as $\frac{S_a}{S_e} = 1 - \frac{S_m}{S_c}$.[3] Nearly all of the data are below the straight line and show that allowable stresses obtained by the modified Goodman line would be too high.

Summary

Data presented in this report show the fatigue characteristics at a frequency of 900 cycles per minute of a number of typical laminates and the effect on these characteristics of a number of factors that may affect design. Not all the trends are clearly defined, but a few generalizations are indicated by the data.

1. Differences in reinforcements have less effect on fatigue strength, particularly after many cycles, than they have on static strength.

2. The effect of moisture absorption on fatigue strength is less than on static strength. Moisture effects appear to vary with resin type.

3. A stress concentration, such as the hole used in this study, generally reduces fatigue strength. The magnitude of the reduction, however, varies considerably with the material and with the conditions of test.

4. The materials tested do not appear to have reached an endurance limit at 10 million cycles, except for specimens tested at 45° to the warp direction. They reached an endurance limit at about 40,000 cycles at room temperature. Thus, the fatigue strength values at 0° and at 45° to warp tend to be similar after many cycles.

5. Elevated temperatures tend to reduce fatigue strength, even that of laminates made with heat-resistant resins. The effect of elevated temperature tends to decrease with an increasing number of cycles.

6. An increase in the mean stress applied decreases the amplitude of the alternating stress that can be sustained for a given number of cycles. Where the compressive strength of the material is low compared with the tensile strength, the amplitude of the alternating stress may be further reduced, particularly for small mean tensile stresses.

---

[3] Trapp, W. J. Elevated Temperature Fatigue Properties of SAE 4340 Steel, WADC Technical Report 52-325, Part 1.

Table 1.--Fabrication data for glass-reinforced plastic laminates

Type of resin	Reinforcement Type	Reinforcement Finish	Number of plies	Pressure	Temperature	Time of cure	Manufacturer
				P.s.i.	°F.	Min.	
Polyester (Paraplex P43)	181	Volan A	23	14	220 - 250	90	Forest Products Laboratory
Polyester (Paraplex P43)	112	...do...	84	14	220 - 250	90	Do.
Polyester (Paraplex P43)	120	...do...	64	14	220 - 250	90	Do.
Polyester (Paraplex P43)	184	...do...	10	14	220 - 250	90	Do.
Polyester (Paraplex P43)	Mat	....	7	14	220 - 250	90	Do.
Epoxide (Epon 828 - 14% CL)	181	Volan A	24	0 50 0	212 212 400	10 25 120	Shell Development Co.
Polyester (PDL 7-669)	181	...do...	23	14 0	220 500	45 180	Forest Products Laboratory
Epoxide (Epon X12100 - 4% E)	181	...do...	24	0 200 0	310 310 400	3 42 1440	Shell Development Co.
Phenolic (BV 17085)	181	...do...					Swedlow
Silicone (DC 2106)	181	Heat cleaned	28				Dow-Corning

Table 2.--Physical properties of glass-reinforced plastic laminates.

Property	Polyester + 181 fabric	Polyester + 112 fabric	Polyester + 120 fabric	Polyester + 184 fabric	Polyester + mat	Epoxide + 181 fabric	TAC polyester + 181 fabric	Heat-resistant epoxide + 181 fabric	Heat-resistant phenolic + 181 fabric	Silicone + 181 fabric
	Composition of laminates[1]									
Resin content....Percent	34.3	37.8	38.6	29.5	58.3	37.7	35.3	35.0	28.0	31.0
Specific gravity....	1.87	1.74	1.79	1.88	1.44	1.80	1.90	1.87	1.92	1.85
Average thickness....In.	0.233	0.223	0.246	0.261	0.234	0.247	0.222	0.221	0.257	0.261
Barcol hardness....	70	73	72	70	59	71	74	74	81	63
Moisture absorption[2]....Percent	0.09	0.06	0.08	0.14	0.28	0.11	2.81	0.10	0.32	0.21
Tensile strength (73° F.-50 percent R.H.)										
Modulus of elasticity....P.s.i. x 10^{-6}	3.23	2.87	2.94	3.18	1.10	3.04	2.65	2.81	3.46	2.64
Proportional limit stress....P.s.i. x 10^{-3}	9.45	11.67	12.98	9.85	5.17	16.28	18.05	13.84	12.77	20.95
Maximum stress....P.s.i. x 10^{-3}	52.22	46.26	45.66	50.26	11.95	48.95	46.19	42.58	47.88	37.70
Maximum stress required....P.s.i. x 10^{-3}	40.00	40.00	40.00	43.00	20.00	40.00	32.00	38.00	40.00	20.00
Compressive strength (73° F.-50 percent R.H.)										
Modulus of elasticity....P.s.i. x 10^{-6}	3.57	3.19	3.29	3.56	1.24	3.22	3.08	3.54	3.93	2.80
Proportional limit stress....P.s.i. x 10^{-3}	23.15	24.52	26.90	15.99	10.54	27.82	26.66	22.57	24.23	13.35
Maximum stress....P.s.i. x 10^{-3}	43.48	45.18	43.48	32.28	23.18	58.47	37.72	49.33	54.65	22.80
Maximum stress required....P.s.i. x 10^{-3}	35.00	33.00	33.00	26.00	20.00	35.00	37.00	50.00	22.00	18.00
Flexural strength (73° F.-50 percent R.H.)										
Modulus of elasticity....P.s.i. x 10^{-6}	3.45	3.08	3.23	3.32	1.33	3.02	3.16	3.08	3.63	2.92
Fiber stress at proportional limit....P.s.i. x 10^{-3}	23.05	24.56	26.76	23.23	9.16	27.17	38.60	27.54	38.48	16.59
Modulus of rupture....P.s.i. x 10^{-3}	66.92	63.52	62.18	56.32	23.60	65.63	51.30	61.57	71.01	32.66
Modulus of rupture required....P.s.i. x 10^{-3}	50.00	50.00	50.00	45.00	25.00	50.00	35.00	60.00	50.00	25.00
Flexural strength (73° F.-wet, after 2-hr. boil)										
Modulus of elasticity....P.s.i. x 10^{-6}	3.07	2.78	2.78	3.00	1.02	2.92	2.78	3.00	3.60	2.91
Fiber stress at proportional limit....P.s.i. x 10^{-3}	23.60	25.56	26.26	21.48	7.25	32.93	33.90	33.55	32.19	13.49
Modulus of rupture....P.s.i. x 10^{-3}	54.80	51.86	52.92	47.74	21.76	64.00	41.80	61.27	66.93	23.66
Modulus of rupture required....P.s.i. x 10^{-3}	45.00	45.00	45.00	40.00	20.00	45.00	--	--	--	--
Flexural strength (at 500° F. after 1/2 hr.)	These laminates are not heat resistant									
Modulus of elasticity....P.s.i. x 10^{-6}	do.						2.39	2.35	2.42	2.13
Fiber stress at proportional limit....P.s.i. x 10^{-3}	do.						19.30	15.04	17.88	6.05
Modulus of rupture....P.s.i. x 10^{-3}	do.						27.30	18.71	29.36	11.53
Modulus of rupture required....P.s.i. x 10^{-3}	do.						30.00	40.00	40.00	12.00
Flexural strength (at 500° F. after 200 hr.)										
Modulus of elasticity....P.s.i. x 10^{-6}	do.						2.04	2.13	1.28	2.38
Fiber stress at proportional limit....P.s.i. x 10^{-3}	do.						4.46	9.79	1.88	6.52
Modulus of rupture....P.s.i. x 10^{-3}	do.						5.98	16.81	3.56	15.45
Modulus of rupture required....P.s.i. x 10^{-3}	do.						10.00	5.00	5.00	12.00

[1] All fabrics with Volan A finish.

[2] After 24 hours in water.

Table 3.--Scope of test program for fatigue studies of glass-reinforced plastic laminates

Laminates: Resin	Laminates: Fabric	Mean stress level	Room temperature: 73° F., 50 percent relative humidity: 0° to warp: Un-notched	Room temperature: 73° F., 50 percent relative humidity: 0° to warp: Notched	Room temperature: 73° F., 50 percent relative humidity: 45° to warp: Un-notched	Elevated temperature: 100°F., 100 percent relative humidity: 0° to warp: Un-notched	Elevated temperature: 100°F., 100 percent relative humidity: 0° to warp: Notched	Elevated temperature: 300° F.: 0° to warp: Un-notched	Elevated temperature: 300° F.: 0° to warp: Notched	Elevated temperature: 300° F.: 45° to warp: Un-notched	Elevated temperature: 500° F.: 0° to warp: Un-notched	Elevated temperature: 500° F.: 0° to warp: Notched	Elevated temperature: 500° F.: 45° to warp: Un-notched
Room-Temperature Laminates													
Polyester	181	0	X			X							
Polyester	112	0	X	X									
Polyester	120	0	X	X									
Polyester	184	0	X	X									
Polyester	mat	0	X	X									
Epoxide	181	0	X	X		X	X						
Heat-Resistant Laminates													
Polyester	181	0	X	X	X			X	X	X	X	X	X
Polyester	181	1/5	X	X				X	X		X	X	
Polyester	181	1/2	X	X				X	X		X	X	
Epoxide	181	0	X	X				X	X		X	X	
Phenolic	181	0	X	X				X	X		X	X	
Silicone	181	0	X	X				X	X		X	X	

Table 4.--Results of control and fatigue tests on unnotched specimens of polyester resin reinforced with 181 glass fabric, Volan A finish. Test conditions: 73° F. - 50 percent relative humidity and 100° F. - 100 percent relative humidity, axially loaded at zero mean stress

Control specimens		Fatigue specimens		
No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure
	1,000 P.s.i.		1,000 P.s.i.	
		73° F., 50 Percent Relative Humidity		
1	45.2	70	32.20	1,000
2	48.6	60	27.60	2,300
3	48.6	55	25.30	3,200
4	42.5	50	23.00	5,700
5	45.0	45	20.70	13,400
Ave.	46.0	40	18.40	24,200
Cov[1]	5.68%	30	13.80	417,400
		25	11.50	2,185,200
		20	9.20	[2]11,970,000
		100° F., 100 Percent Relative Humidity		
1	42.10	60	25.40	100
2	42.05	50	21.15	1,300
3	42.90	40	16.93	3,200
4	42.00	37	15.66	13,700
5	42.70	30	12.70	181,200
Ave.	42.33	27	11.43	600,300
Cov[1]	.98%	24	10.16	3,455,900
		20	8.47	[2]11,700,000

[1]Coefficient of variation.

[2]Discontinued -- no failure.

Table 5.--Results of control and fatigue tests on notched and unnotched specimens of polyester resin reinforced with 1-1/2 ounce glass mat and 120 glass fabric, Volan A finish. Test conditions: 73° F.-50 percent relative humidity, axially loaded at zero mean stress

Unnotched specimens					Notched specimens[1]				
Control specimens		Fatigue specimens			Control specimens		Fatigue specimens		
No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure	No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure
	1,000 P.s.i.		1,000 P.s.i.			1,000 P.s.i.		1,000 P.s.i.	
1-1/2-Ounce Glass Mat									
1	12.69	70	9.72	900	1	12.15	70	9.84	300
2	15.96	60	8.33	2,100	2	14.95	60	8.34	700
3	14.14	50	6.94	7,700	3	13.94	50	7.03	7,600
4	12.04	45	6.25	41,100	4	13.94	45	6.32	10,000
5	14.55	40	5.55	91,800	5	15.29	40	5.62	220,800
Ave.	13.88	35	4.86	1,100,600	Ave.	14.05	35	4.92	462,800
Cov[2]	11.6%	30	4.16	3,770,900	Cov[2]	8.7%	32-1/2	4.57	9,958,200
		26	3.61	1,462,400			30	4.22	[3]10,887,700
		26	3.61	8,896,300					
120 Glass Fabric, Volan A Finish									
1	45.0	60	25.08	cull	1	30.5	60	19.26	4,400
2	42.4	55	22.99	5,500	2	33.6	55	17.65	7,000
3	40.0	50	20.90	30,400	3	30.8	50	16.05	11,100
4	36.6	45	18.81	25,700	4	33.6	45	14.44	32,600
5	44.9	40	16.72	133,100	5	31.9	40	12.85	53,700
Ave.	41.8	35	14.63	630,800	Ave.	32.1	35	11.24	191,900
Cov[2]	8.50%	30	12.54	2,632,000	Cov[2]	4.67%	30	9.63	1,340,700
		26	10.87	5,995,900			28	8.99	2,662,900
							25	8.03	[3]11,235,900

[1]Notch was a 1/8-inch-diameter hole in the center of the specimen.

[2]Coefficient of variation.

[3]Discontinued - no failure.

Table 6.--Results of control and fatigue tests on notched and unnotched specimens of polyester resin reinforced with 112 and 184 glass fabric, Volan A finish. Test conditions: 73° F. - 50 percent relative humidity, axially loaded at zero mean stress

Unnotched specimens					Notched specimens[1]				
Control specimens		Fatigue specimens			Control specimens		Fatigue specimens		
No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure	No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure
	1,000 P.s.i.		1,000 P.s.i.			1,000 P.s.i.		1,000 P.s.i.	
112 Glass Fabric, Volan A Finish									
1	47.0	60	24.8	3,800	1	32.9	60	18.84	4,200
2	46.9	55	22.7	3,000	2	32.2	40	12.56	48,300
3	40.1	50	20.7	7,500	3	28.8	30	9.42	408,500
4	34.6	45	18.6	9,600	4	32.8			
5	37.9	40	16.5	34,700	5	30.3	55	17.27	7,300
Ave.	41.3	35	14.5	327,000	Ave.	31.4	50	15.70	15,400
Cov[2]	13.35%	30	12.4	1,517,100	Cov[2]	5.71%	45	14.13	31,700
		25	10.3	9,938,600			35	10.99	309,500
							25	7.85	5,033,800
							73	23.00	800
184 Glass Fabric, Volan A Finish									
1	50.4	70	36.12	100	1	40.9	70	29.47	800
2	49.1	60	30.96	500	2	42.8	60	25.26	1,600
3	55.2	50	25.80	1,800	3	34.4	50	21.05	4,500
4	52.3	40	20.64	10,000	4	43.7	40	16.84	27,500
5	50.8	30	15.48	157,900	5	48.6	35	14.74	48,200
Ave.	51.6	25	12.90	549,800	Ave.	42.1	30	12.63	323,200
Cov[2]	4.55%	35	18.06	29,200	Cov[2]	12.17%	25	10.53	746,700
		20	10.32	[3]11,376,000			20	8.42	15,176,000
		22	11.35	3,152,200			22	9.26	2,761,900

[1] Notch was a 1/8-inch-diameter hole in the center of the specimen.

[2] Coefficient of variation.

[3] Discontinued - no failure.

Table 7.--Results of control and fatigue tests on notched and unnotched specimens of epoxide resin reinforced with 181 glass fabric, Volan A finish. Test conditions: 73° F. - 50 percent relative humidity and 100° F. - 100 percent relative humidity, axially loaded at zero mean stress.

Unnotched specimens					Notched specimens[1]				
Control specimens		Fatigue specimens			Control specimens		Fatigue specimens		
No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure	No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure
	1,000 P.s.i.		1,000 P.s.i.			1,000 P.s.i.		1,000 P.s.i.	
73° F., 50 Percent Relative Humidity									
1	38.90	70	28.84	2,000	1	30.40	70	22.69	2,200
2	43.60	60	24.72	5,300	2	32.70	60	19.45	19,100
3	41.50	50	20.60	217,700	3	34.80	80	25.94	3,800
4	40.50	55	22.66	220,200	4	31.80	55	17.83	260,000
5	41.50	45	18.54	2,458,200	5	32.40	50	16.21	788,500
Ave.	41.20	40	16.48	4,560,400	Ave.	32.42	48	15.56	1,980,400
Cov[2]	4.16%	38	15.66	13,055,300	Cov[2]	4.81%	46	14.91	5,711,000
		58	23.90	190,600					
100° F., 100 Percent Relative Humidity									
1	42.50	60	26.77	3,200	1	32.10	70	22.32	5,100
2	45.60	50	22.31	11,200	2	31.00	60	19.13	52,600
3	47.60	45	20.08	1,370,100	3	30.50	50	15.94	340,000
4	44.40	40	17.85	4,606,800	4	31.30	40	12.75	2,337,200
5	43.00	47-1/2	21.19	109,400	5	34.50	55	17.53	265,200
Ave.	44.62	35	15.62	19,268,300	Ave.	31.88	80	25.50	2,000
Cov[2]	4.61%	55	24.54	5,000	Cov[2]	4.94%	35	11.16	11,272,800
							45	14.35	1,586,900

[1] Notch was a 1/8-inch-diameter hole in the center of the specimen.

[2] Coefficient of variation.

Table 8.--Results of control and fatigue tests on notched and unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish. Test conditions: 73° F. - 50 percent relative humidity, axially loaded at 3 mean stress levels.

Unnotched specimens					Notched specimens[1]				
Control specimens		Fatigue specimens			Control specimens		Fatigue specimens		
No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure	No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure
	1,000 P.s.i.		1,000 P.s.i.			1,000 P.s.i.		1,000 P.s.i.	
Zero Mean Stress					Zero Mean Stress				
1	41.50	50	22.99	5,900	1	34.20	50	17.60	14,000
2	46.10	60	27.59	1,500	2	35.20	60	21.12	3,400
3	43.50	70	32.19	200	3	33.40	70	24.64	900
4	51.00	40	18.39	80,400	4	37.40	40	14.08	114,100
5	47.80	30	13.79	530,100	5	35.80	30	10.56	651,500
Ave.	45.98	25	11.50	2,626,200	Ave.	35.20	25	8.80	2,882,300
Cov[2]	8.00%	20	9.20	[3]10,008,200	Cov[2]	4.35%	20	7.04	[3]10,024,400
		22-1/2	10.34	8,826,100			22-1/2	7.92	10,461,700
9,193 P.s.i. Mean Stress					7,040 P.s.i. Mean Stress				
			23.00	1,000				17.00	1,700
			19.00	4,400				14.00	6,200
			14.00	22,200				11.00	30,300
			11.00	48,600				8.00	116,500
			9.00	146,200				6.00	539,800
			7.00	1,490,100				5.00	947,000
			6.00	6,931,900				3.50	11,916,900
			5.50	5,841,200					
			4.00	3,104,100					
22,990 P.s.i. Mean Stress					17,600 P.s.i. Mean Stress				
			9.00	2,900				7.00	4,000
			11.00	1,300				6.00	7,300
			7.00	9,000				5.00	34,000
			5.00	15,500				4.50	33,300
			3.00	51,300				4.00	56,600
			2.00	[3]10,445,500				3.00	167,000
			4.00	127,400				2.00	1,194,600
			3.00	1,540,400				1.60	13,354,100

[1] Notch was a 1/8-inch-diameter hole in the center of the specimen.

[2] Coefficient of variation.

[3] Discontinued - no failure.

Table 9.--Results of control and fatigue tests on notched and unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish. Test conditions: 300° F., axially loaded at 3 mean stress levels.

	Unnotched specimens					Notched specimens[1]				
	Control strength		Fatigue specimens			Control strength		Fatigue specimens		
	Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure	Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure
	1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.		1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.	
	Zero Mean Stress					Zero Mean Stress				
	40.00	27.70	60	24.39	1,600	31.60	34.60	60	19.43	4,500
	38.30	26.10	55	22.36	2,600	33.20	33.90	55	17.81	8,300
	41.40	23.80	50	20.33	4,300	31.80	33.30	50	16.19	15,600
	41.30	27.90	45	18.29	8,000	32.40	30.20	45	14.57	45,500
	42.20	27.20	40	16.26	45,800	32.90	33.70	40	12.95	82,500
Ave.	40.65	26.54	35	14.23	68,100	32.38	33.14	35	11.33	197,700
Cov[3]	3.77%	5.60%	30	12.19	375,000	0.63%	5.18%	30	9.71	860,600
			25	10.16	3,071,800			25	8.09	3,115,500
			23	9.49	2,314,000			20	6.48	8,279,000
				9.00	2,430,800			71	23.00	1,200
	7,280 P.s.i. Mean Stress					5,800 P.s.i. Mean Stress				
				7.27	661,500				12.95	5,800
				9.27	79,200				11.00	11,500
				6.75	556,800				7.50	154,300
				7.27	203,800				9.00	80,500
				12.27	10,200				6.00	315,400
				4.50	6,180,300				4.50	620,000
				17.50	2,900				15.00	4,400
									3.00	[2]15,442,900
									4.00	2,743,600
									17.50	2,700
	18,200 P.s.i. Mean Stress					14,540 P.s.i. Mean Stress				
				2.75	2,954,500				4.00	36,300
				3.50	618,900				8.00	2,600
				1.00	[2]14,321,700				2.00	1,795,800
				2.00	[2]11,547,300				10.00	1,500
				4.00	92,000				6.50	8,300
				6.00	9,700				5.50	15,700
				5.00	28,200				3.00	331,400
				7.00	7,200				1.00	[2]15,928,000
				8.00	5,600				1.50	[2]12,172,000
				10.00	2,100					

[1] Notch was a 1/8-inch-diameter hole in the center of the specimen.

[2] Discontinued - no failure.

[3] Coefficient of variation.

Table 10.--Results of control and fatigue tests on notched and unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish. Test conditions: 500° F., axially loaded at 3 mean stress levels.

Unnotched specimens					Notched specimens[1]				
Control strength		Fatigue specimens			Control strength		Fatigue specimens		
Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure	Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure
1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.		1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.	
		Zero Mean Stress					Zero Mean Stress		
36.50	12.70	30.0	11.43	29,900	30.80	13.74	35.5	11.01	6,100
38.75	13.50	15.0	5.72	2,201,600	29.00	18.30	16.5	5.12	7,636,000
37.50	16.26	24.9	9.50	299,800	30.95	19.05	27.5	8.53	1,063,500
38.90		18.6	7.09	1,674,900	32.30		13.5	4.19	6,026,000
38.90		11.1	4.23	7,110,900	32.10		22.0	6.83	2,649,800
Ave. 38.11	14.15	9.3	3.55	10,842,000	31.03	17.03	32.2	10.00	472,700
Cov[3] 2.82%	13.2%	20.5	7.81	1,167,300	4.27%	17.0%	41.8	13.00	10,000
		32.8	12.50	13,800				15.00	8,300
		24.9	9.50	163,600					
		7,622 P.s.i. Mean Stress					6,206 P.s.i. Mean Stress		
			13.00	7,000				15.00	2,900
			16.00	3,500				12.00	12,100
			18.50	500				10.00	31,200
			9.00	36,200				7.50	62,900
			6.00	87,700				5.00	172,700
			4.00	1,328,200				2.50	3,340,500
			2.50	[2]12,884,700				3.75	558,200
								2.00	8,813,500
		19,050 P.s.i. Mean Stress					15,515 P.s.i. Mean Stress		
			2.00	205,300				5.00	4,600
			3.00	16,800				3.00	23,500
			6.00	2,600				2.00	131,500
			1.50	1,680,700				7.00	1,700
			2.50	147,700				1.00	[2]10,871,000
			4.50	7,200				1.70	273,000
			1.20	[2]10,920,000				1.30	1,547,100
			1.35	[2]14,951,200				1.15	4,018,900
								1.30	1,160,800

[1] Notch was a 1/8-inch-diameter hole in the center of the specimen.

[2] Discontinued - no failure.

[3] Coefficient of variation.

Table 11.--Results of control and fatigue tests on unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish. Test conditions: axially loaded at 45° to warp and zero mean stress, at 3 temperatures

Control specimens		Fatigue specimens		
No.	Tensile strength	Percentage of control strength	Alternating stress	Cycles to failure
	1,000 P.s.i.		1,000 P.s.i.	
73° F. - 50 Percent Relative Humidity				
1	23.45	70	16.48	300
2	22.91	60	14.12	400
3	24.10	50	11.77	1,000
4	23.68	40	9.42	2,300
5	23.56	30	7.06	12,100
Ave.	23.54	20	4.71	[1]13,036,700
Cov[2]	1.83%	23	5.41	[1]17,138,200
		27	6.36	[1]17,140,000
300° F.				
1	18.05	70	12.74	100
2	18.40	50	9.10	900
3	18.65	27.5	5.01	139,500
4	18.45	40	7.28	3,100
5	17.45	25	4.55	978,600
Ave.	18.20	20	3.64	[1]12,084,700
Cov[2]	3.29%	30	5.46	14,800
500° F.				
1	8.86	50	4.60	7,000
2	9.02	60	5.53	2,700
3	9.38	70	6.45	800
4	9.25	30	2.76	260,400
5	9.52	40	3.68	25,900
Ave.	9.21	25	2.30	1,931,000
Cov[2]	2.88%	35	3.22	105,200
		20	1.84	3,572,600
		15	1.38	10,954,600

[1]Discontinued - no failure.

[2]Coefficient of variation.

Table 12.--Results of control and fatigue tests on notched and unnotched specimens of heat-resistant epoxide resin reinforced with 181 glass fabric, Volan A finish. Test conditions: axially loaded and zero mean stress, at 3 temperatures.

Unnotched specimens					Notched specimens[1]				
Control strength		Fatigue specimens			Control strength		Fatigue specimens		
Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure	Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure
1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.		1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.	
				73° F. - 50 Percent Relative Humidity					
38.80		70	30.16	3,700	35.30		70	25.19	4,400
43.40		60	25.85	11,100	35.90		60	21.59	11,000
44.50		50	21.54	47,900	36.00		55	19.79	79,800
46.70		40	17.23	289,600	36.30		50	17.79	261,100
42.10		30	12.92	3,176,600	36.10		45	16.19	1,416,600
43.00		27	11.63	4,963,100	36.30		43	15.47	859,500
Ave. 43.08		35	15.08	1,595,300	35.98		40	14.39	1,506,900
Cov[2] 6.08%		45	19.39	236,900	0.09%		30	10.79	6,293,600
				300° F.					
37.35	24.90	40	15.42	183,400	29.70	31.70	70	21.86	4,400
40.80	29.70	50	19.28	32,500	31.30	28.10	60	18.74	18,000
36.30	26.30	30	11.57	10,080,900	32.85	28.20	50	15.62	71,300
	28.80	60	23.13	3,500	32.70	31.40	40	12.49	156,300
39.10	30.00	20	6.25	[3]12,581,000	30.40	25.50	30	9.37	2,382,500
39.20	32.20	70	26.99	1,000	30.45	25.20	45	14.05	282,100
Ave. 38.55	28.65	45	17.35	173,600	31.23	28.35	35	10.93	1,186,100
Cov[2] 4.55%	9.28%	37	14.26	952,200	4.15%	9.82%	27	8.43	[3]11,515,100
		35	13.49	4,703,100			28	8.75	[3]16,613,900
		55	21.20	27,100					
				500° F.					
32.96	9.40	50	16.08	10	32.00	14.00	70	21.94	10
31.40	13.60	40	12.86	1,800	31.45	14.70	60	18.80	50
31.17	11.15	37	11.90	3,000	31.35	10.30	50	15.67	500
32.70	10.70	33	10.61	4,000	32.75	11.80	40	12.54	4,000
33.87	8.60	31	10.13	1,721,700	29.90	11.10	35	10.97	733,600
30.82	12.40	30	9.65	1,495,600	30.60	9.00	30	9.40	483,100
Ave. 32.15	10.98	25	8.04	2,421,100	31.34	11.82	20	6.27	[4]2,969,000
Cov[2] 3.60%	19.41%	35	11.25	1,484,000	3.19%	18.33%	35	10.97	593,200
		23	7.39	5,307,400			35	10.97	400,000
		43	16.38	3,500			25	7.83	3,514,500
		20	7.10	4,593,200			18	5.62	9,464,600
		36	13.88	2,00			20	6.27	6,231,900
		40	12.86	677,500			40	12.53	8,500
		50	16.08	1,800					
		45	14.47	3,900					

[1] Notch was a 1/8-inch-diameter hole in the center of the specimen.

[2] Coefficient of variation.

[3] Discontinued - no failure.

[4] Tension failure; all others in this group at 500° F. had compression failures.

Table 13.--Results of control and fatigue tests on notched and unnotched specimens of heat-resistant phenolic resin reinforced with 181 glass fabric, Volan A finish. Test conditions: axially loaded and zero mean stress, at 3 temperatures.

Unnotched specimens					Notched specimens[1]				
Control strength		Fatigue specimens			Control strength		Fatigue specimens		
Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure	Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure
1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.		1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.	
73° F. - 50 Percent Relative Humidity									
43.60		70	31.54	8,300	30.20		70	22.33	14,000
50.00		60	27.04	25,500	33.80		60	19.14	77,000
43.90		40	18.02	390,000	32.00		50	15.95	312,500
40.80		35	15.77	1,746,800	30.10		40	12.76	2,571,100
47.00		30	13.52	4,003,200	33.40		35	11.17	3,698,800
Ave. 45.06		50	22.53	99,200	31.90		30	9.57	13,615,300
Cov[2] 7.86%		27	12.17	[3]13,266,200	5.42%		80	25.52	1,400
300° F.									
36.00	33.50	70	23.87	700	29.00	40.20	70	18.70	18,600
32.70	34.40	60	20.46	18,900	25.50	38.00	60	16.03	262,300
33.40	28.30	55	18.76	37,700	26.60	35.90	40	10.69	2,508,600
32.80	29.20	50	17.05	445,100	24.50	35.60	50	13.36	926,000
35.60	35.20	45	15.35	573,700	28.00	36.80	65	17.37	64,000
Ave. 34.10	32.12	40	13.64	[3]6,688,500	26.72	37.30	75	20.04	17,800
Cov[2] 4.63%	9.82%	30	10.23	[3]10,044,800	6.81%	5.00%	30	8.02	9,938,000
		20	6.82	[3]12,130,800			80	21.38	4,600
500° F.									
30.60	17.00	70	23.43	100	23.10	18.30	80	19.97	1,600
30.75	18.30	60	20.08	700	23.90	20.30	70	17.47	21,000
35.50	13.00	50	16.74	4,400	25.90	19.40	60	14.98	84,900
34.70	14.80	35	11.71	1,285,700	25.60	22.10	50	12.48	66,900
35.80	12.70	30	10.04	1,949,600	26.30	22.00	40	9.98	321,900
Ave. 33.47	15.16	25	8.36	1,634,600	24.96	20.42	30	7.49	1,530,400
Cov[2] 7.71%	16.10%	25	8.36	1,459,200	5.50%	8.08%	10	2.50	8,649,900
		20	6.69	2,953,200					
		10	3.35	4,263,900					

[1]Notch was a 1/8-inch-diameter hole in the center of the specimen.

[2]Coefficient of variation.

[3]Discontinued - no failure.

Table 14.--Results of control and fatigue tests on notched and unnotched specimens of heat-resistant silicone resin reinforced with 181 glass fabric, heat-cleaned. Test conditions: axially loaded and zero mean stress, at 3 temperatures.

Unnotched specimens					Notched specimens[1]				
Control strength		Fatigue specimens			Control strength		Fatigue specimens		
Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure	Tension	Compression	Percentage of tension control	Alternating stress	Cycles to failure
1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.		1,000 P.s.i.	1,000 P.s.i.		1,000 P.s.i.	
73° F. - 50 Percent Relative Humidity									
37.00		60	21.17	0	30.20		60	18.23	500
32.80		50	17.64	900	32.30		50	15.19	2,500
38.20		45	15.88	4,000	32.70		45	13.67	12,800
33.70		40	14.11	5,500	26.50		40	12.15	41,000
34.70		35	12.35	54,500	30.20		35	10.63	283,100
Ave. 35.28		30	10.58	620,400	30.38		30	9.11	1,219,600
Cov[2] 6.41%		27	9.52	878,800	8.10%		27	8.20	1,705,300
		24	8.47	[3]9,324,000			24	7.29	8,278,700
300° F.									
30.40	10.72	33.1	10.00	2,000	31.40	12.75	16.7	5.00	[3]13,785,000
30.40	10.76	23.1	7.00	[3]12,803,200	21.10	9.93	20.1	6.00	[3]11,125,400
29.00	10.00	25.5	7.70	59,000	32.10	12.28	23.4	7.00	207,700
32.00	10.40	29.7	9.00	3,800	31.60	11.61	26.7	8.00	38,600
29.60	12.20	26.5	8.00	9,900	33.40	10.90	33.4	10.00	800
Ave. 30.28	10.82	16.5	5.00	[3]13,785,700	29.92	11.60	30.1	9.00	2,400
Cov[2] 3.60%	7.61%	24.1	7.30	[3]9,702,900	16.66%	10.56%	22.4	6.70	[3]10,910,000
500° F.									
32.80	4.35	26.1	8.50	3,200	32.30	7.47	23.4	7.50	2,900
32.10	7.72	23.0	7.50	6,500	32.30	7.85	20.9	6.70	40,600
34.30	7.57	19.9	6.50	22,000	34.50	7.82	20.3	6.50	73,600
34.50	8.25	16.9	5.50	[3]9,037,000	29.60	5.48	18.7	6.00	28,500
29.40	5.66	19.1	6.25	122,600	31.80	7.69	17.7	5.70	49,100
Ave. 32.62	6.71	18.4	6.00	748,100	32.10	7.26	15.6	5.00	[3]10,010,400
Cov[2] 6.23%	24.40%				5.41%	13.85%	21.8	7.00	5,600
							16.5	5.30	4,001,900

[1] Notch was a 1/8-inch-diameter hole in the center of the specimen.

[2] Coefficient of variation.

[3] Discontinued - no failure.

Table 15.--Tensile stress-rupture data[1] for notched and unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish

Unnotched specimens		Notched specimens	
Stress level	Rupture time	Stress level	Rupture time
1,000 P.s.i.	Hours	1,000 P.s.i.	Hours
73° F. - 50 Percent Relative Humidity			
43.80	0.2	20.79	[2]406
41.58	[3]0	25.00	1,314
36.96	1.2	26.00	141
34.65	51.1	27.00	11.0
33.00	11.3	26.50	12.2
35.50	3.9	25.50	7.4
32.34	[4]2.3	32.34	[3]0
31.00	87.3	27.72	0.1
300° F.			
30.00	[2]526	27.00	103.5
33.00	4.7	28.00	16.6
35.00	0.1	29.00	0.3
33.00	406.2	26.50	[2]604.1
32.50	292.4	28.50	0.4
34.00	5.3	26.50	[2]425.0
32.00	[2]212.0	26.70	10.7
30.00	(4)	26.00	[4]90.0
500° F.			
32.00	0.5	27.00	154.1
31.00	13.3	28.00	153.8
30.40	19.5	29.00	[2]0
27.00	91.9	28.50	0.2
28.00	74.5	28.25	0.3
31.50	0.1	26.50	130.8
28.00	14.4	26.40	42.4
29.50	51.4	27.00	[4]20.9

[1]Furnished by Wright Air Development Center.

[2]Test discontinued - no failure.

[3]Failed during application of load.

[4]Failure at loading joint.

Table 16.--Summary of fatigue strength values of standard laminates at zero mean stress and loaded at 0° to warp.

Glass reinforcement	Temperature	Relative humidity	Stress concentration	Alternating stress amplitude at - 10³ cycles		10⁴ cycles		10⁵ cycles		10⁶ cycles		10⁷ cycles	
	°F.	Percent		1,000 P.s.i.	Percent[1]	1,000 P.s.i.	Percent[1]	1,000 P.s.i.	Percent[1]	1,000 P.s.i.	Percent[1]	1,000 P.s.i.	Percent[1]
				Polyester Resin									
181	73	50	Unnotched	32.3	70.2	21.0	45.6	15.6	33.9	12.4	27.0	10.4	22.6
181	100	100	....do...	20.0	43.5	15.8	34.3	13.0	28.3	11.1	24.1	9.4	20.4
Mat	73	50	....do...	9.5	68.5	6.7	48.3	5.6	40.3	4.6	33.1	3.5	25.2
Mat	73	50	Notched	8.5	61.2	6.6	47.5	5.4	38.9	4.8	34.6	4.5	32.4
120	73	50	Unnotched	27.6	66.0	21.6	51.6	17.4	41.6	14.0	33.5	11.0	26.3
120	73	50	Notched	24.7	59.1	16.7	40.0	12.0	28.7	9.7	23.2	8.7	20.8
112	73	50	Unnotched	27.2	65.8	19.8	48.0	15.3	37.0	12.4	30.0	10.4	25.2
112	73	50	Notched	23.1	55.9	16.5	40.0	11.8	28.5	9.1	22.0	7.6	18.4
184	73	50	Unnotched	28.1	54.4	20.8	40.3	15.5	30.1	12.5	24.2	10.9	21.1
184	73	50	Notched	28.0	54.2	18.5	35.9	13.5	26.2	10.5	20.3	8.6	16.7
				Epoxide Resin									
181	73	50	Unnotched	29.3	71.1	26.0	63.1	22.6	54.9	19.4	47.1	16.1	39.1
181	73	50	Notched	26.2	63.6	21.0	51.0	17.8	43.2	15.7	38.1	14.2	34.4
181	100	100	Unnotched	28.7	69.6	23.2	56.3	21.5	52.2	20.0	48.5	16.7	40.5
181	100	100	Notched	25.9	63.0	22.1	53.6	18.5	45.0	14.9	36.2	11.3	27.4

[1] Stress expressed as percentage of ultimate static tensile strength of unnotched specimens at room temperature.

Table 17 --Summary of fatigue strength values of heat-resistant laminates at zero mean stress.

Temperature	Direction of load	Stress concentration	10 cycles		10^4 cycles		10^5 cycles		10^6 cycles		10^7 cycles	
°F.	Degrees		1,000 P.s.i.	Percent[1]	1,000 P.s.i.	Percent[1]	1,000 P.s.i.	Percent[1]	1,000 P.s.i.	Percent[1]	1,000 P.s.i.	Percent[1]
			Polyester Resin - 181 Glass Fabric									
73	0	Unnotched	28.4	61.3	22.4	48.7	17.0	37.0	12.9	28.1	10.3	22.4
300	0	...do....	25.8	56.1	18.5	40.5	13.9	30.2	10.6	23.1	9.0	19.6
500	0	...do....	13.6	29.6	12.6	27.4	10.4	22.6	7.2	15.7	4.2	9.1
73	0	Notched	24.5	53.2	18.8	40.9	13.7	29.8	10.0	21.8	8.0	17.4
300	0	...do....	23.6	51.3	17.5	38.1	12.6	27.4	9.1	19.8	7.0	15.2
500	0	...do....	15.6	33.9	14.3	31.1	12.1	26.3	8.7	18.9	3.8	8.3
73	45	Unnotched	11.5	25.0	7.4	16.1	6.5	14.4	6.5	14.1	6.4	13.9
300	45	...do....	8.8	19.1	6.1	13.3	4.8	10.4	4.4	9.6	4.4	9.6
500	45	...do....	6.3	13.7	4.4	9.6	3.2	7.0	2.4	5.2	1.8	3.9
			Epoxide Resin - 181 Glass Fabric									
73	0	Unnotched	35.0	81.3	26.3	61.0	19.8	46.0	15.2	35.3	10.9	25.3
73	0	Notched	27.8	64.5	23.4	54.3	19.1	44.2	15.0	34.8	10.7	24.8
300	0	Unnotched	27.0	62.7	21.5	49.9	17.1	39.6	13.9	32.2	11.9	27.6
300	0	Notched	25.0	58.0	19.6	45.5	14.6	33.9	11.0	25.5	9.0	20.9
500	0	Unnotched	13.2	30.6	11.8	27.4	10.4	24.1	9.0	20.9	7.5	17.4
500	0	Notched	15.0	34.8	13.0	30.1	10.8	25.0	8.8	20.4	6.6	15.3
			Phenolic Resin - 181 Glass Fabric									
73	0	Unnotched	40.0	89.0	30.6	68.0	21.8	48.5	16.3	36.2	12.5	27.8
73	0	Notched	24.6	54.6	22.6	50.2	18.5	41.1	14.2	31.5	10.0	22.2
300	0	Unnotched	23.8	52.8	21.0	46.6	18.2	40.4	15.4	34.2	12.7	28.2
300	0	Notched	22.7	50.4	19.8	43.9	17.0	37.7	13.5	30.0	8.0	17.7
500	0	Unnotched	19.2	42.6	16.0	35.5	13.5	30.0	10.0	22.2	3.2	7.1
500	0	Notched	20.2	44.7	17.4	38.6	14.0	31.1	9.3	20.6	2.6	5.8
			Silicone Resin - 181 Glass Fabric									
73	0	Unnotched	17.2	48.7	14.8	42.0	12.5	35.4	10.2	28.9	7.9	22.4
73	0	Notched	16.1	45.6	13.7	38.8	11.5	32.6	9.2	26.1	6.9	19.6
300	0	Unnotched	9.0	25.6	8.1	23.0	7.6	21.6	7.4	21.0	7.3	20.7
300	0	Notched	9.0	25.6	7.5	21.3	7.0	19.9	6.8	19.3	6.7	19.0
500	0	Unnotched	7.0	19.9	6.6	18.7	6.3	17.9	6.0	17.0	5.6	15.9
500	0	Notched	6.6	18.7	6.3	17.9	6.0	17.0	5.6	15.9	5.3	15.0

[1] Stress expressed as percentage of ultimate static tensile strength of unnotched specimens at room temperature.

Table 18.--Effect of 3 mean stress levels on fatigue strength of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish.

Stress concentration	Temperature	Mean tensile stress level	Static tensile strength	Alternating stress amplitude at - 10^3 cycles	10^4 cycles	10^5 cycles	10^6 cycles	10^7 cycles
	°F.	1,000 P.s.i.	1,000 P.s.i.	1,000 P.s.i.	1,000 P.s.i.	1,000 P.s.i.	1,000 P.s.i.	1,000 P.s.i.
Unnotched	73	0	45.98	28.4	22.4	17.0	12.9	10.3
		9.19	45.98	22.6	15.7	10.2	6.5	5.0
		22.99	45.98	11.4	6.2	4.0	2.7	2.4
Notched	73	0	35.20	24.5	18.8	13.7	10.0	8.0
		7.04	35.20	18.1	13.0	8.4	5.3	3.5
		17.60	35.20	9.4	5.7	3.4	2.1	1.5
Unnotched	300	0	40.65	25.8	18.6	13.9	10.6	9.0
		7.28	40.65	19.8	13.4	9.0	6.0	4.5
		18.20	40.65	11.7	6.6	4.0	2.8	2.5
Notched	300	0	32.38	23.6	17.5	12.6	9.1	7.0
		5.80	32.38	17.2	12.2	7.8	4.7	3.3
		14.54	32.38	9.4	6.3	3.7	2.2	1.7
Unnotched	500	0	38.11	13.6	12.6	10.4	7.2	4.2
		7.62	38.11	18.0	12.7	6.6	4.0	3.1
		19.05	38.11	7.7	4.2	2.4	1.6	1.4
Notched	500	0	31.03	15.6	14.3	12.1	8.7	3.8
		6.21	31.03	17.3	12.5	6.9	3.3	1.9
		15.52	31.03	8.3	4.2	2.1	1.3	1.1

Table 19.--Stress-rupture properties of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, at periods corresponding to various number of fatigue cycles.

Fatigue period		Stress at rupture			
		Unnotched specimens		Notched specimens	
Cycles	Hours	1,000 P.s.i.	Percent[1]	1,000 P.s.i.	Percent[1]
73° F. - 50 Percent Relative Humidity					
10^3	.0185	43.7	95.0	30.2	65.6
10^4	.185	38.5	83.8	28.2	61.3
10^5	1.85	35.0	76.1	27.2	59.2
10^6	18.5	33.5	72.9	26.4	57.4
10^7	185	32.5	70.7	25.6	55.7
300° F.					
10^3	.0185	36.4	79.5	30.4	66.4
10^4	.185	34.6	75.5	29.0	63.3
10^5	1.85	33.8	73.6	28.3	61.6
10^6	18.5	33.2	72.5	27.6	60.2
10^7	185	32.6	71.0	26.9	58.7
500° F.					
10^3	.0185	33.4	72.9	29.1	63.5
10^4	.185	32.0	69.8	28.6	62.4
10^5	1.85	30.7	67.0	28.1	61.3
10^6	18.5	29.3	63.9	27.6	60.3
10^7	185	28.0	61.0	27.1	59.1

[1]Stress expressed as percentage of ultimate static tensile strength (45,980 p.s.i.) of unnotched specimens at room temperature.

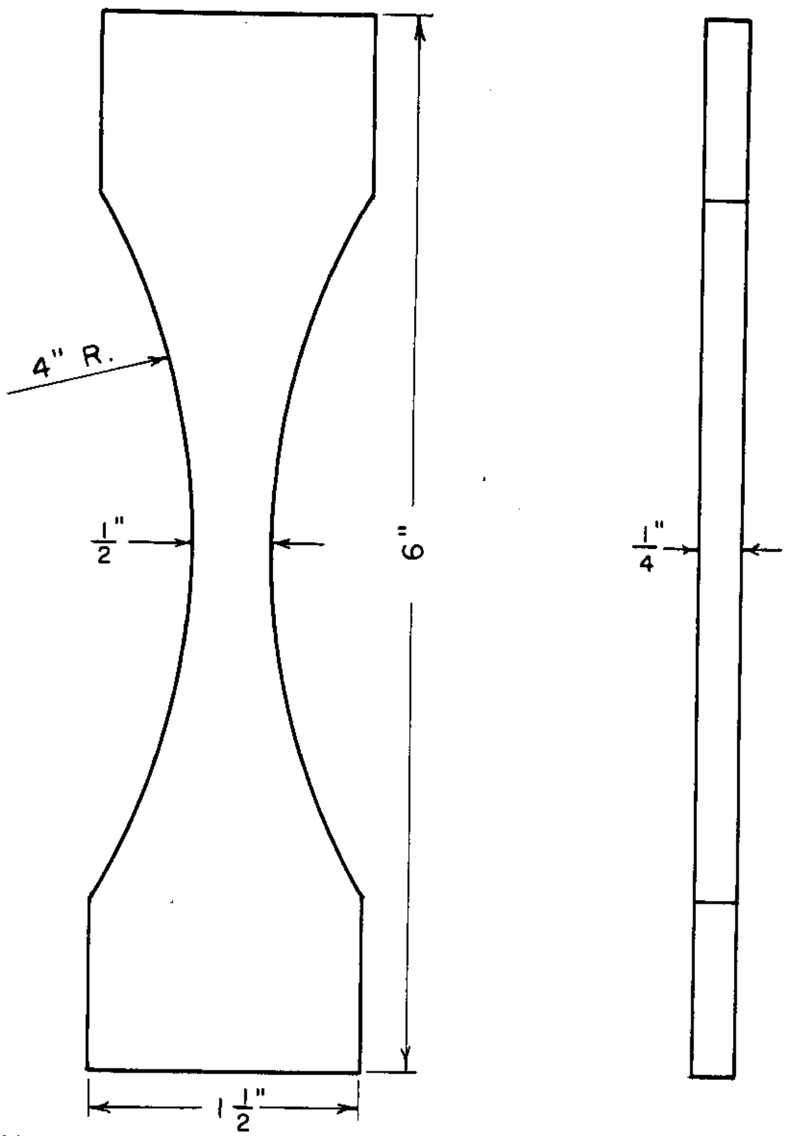

Figure 1.--Sketch of fatigue specimen.

ZM 86440 F

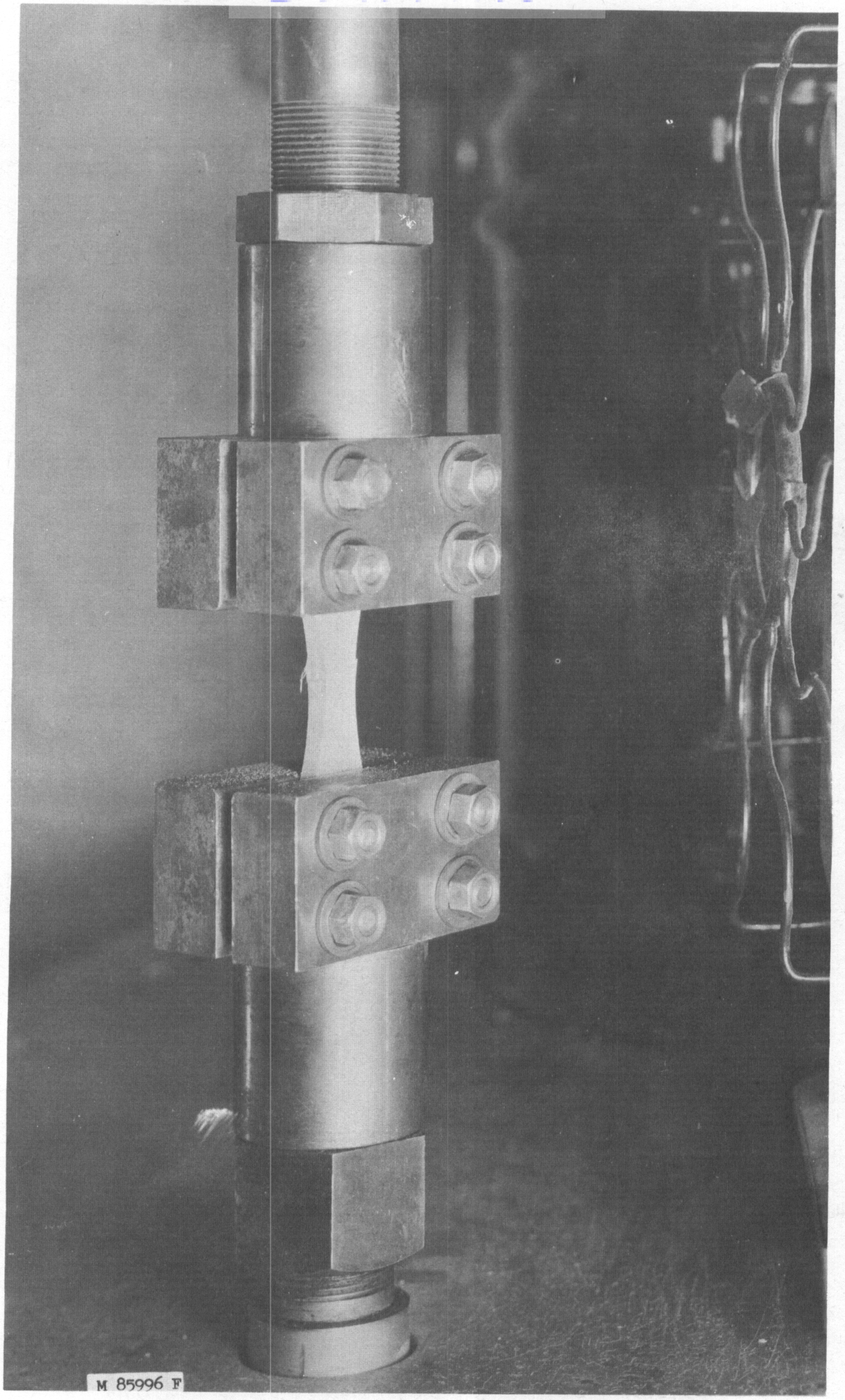

Figure 2.--Grips supporting the fatigue specimen, which is loaded axially in tension and compression in a direct-stress fatigue machine.

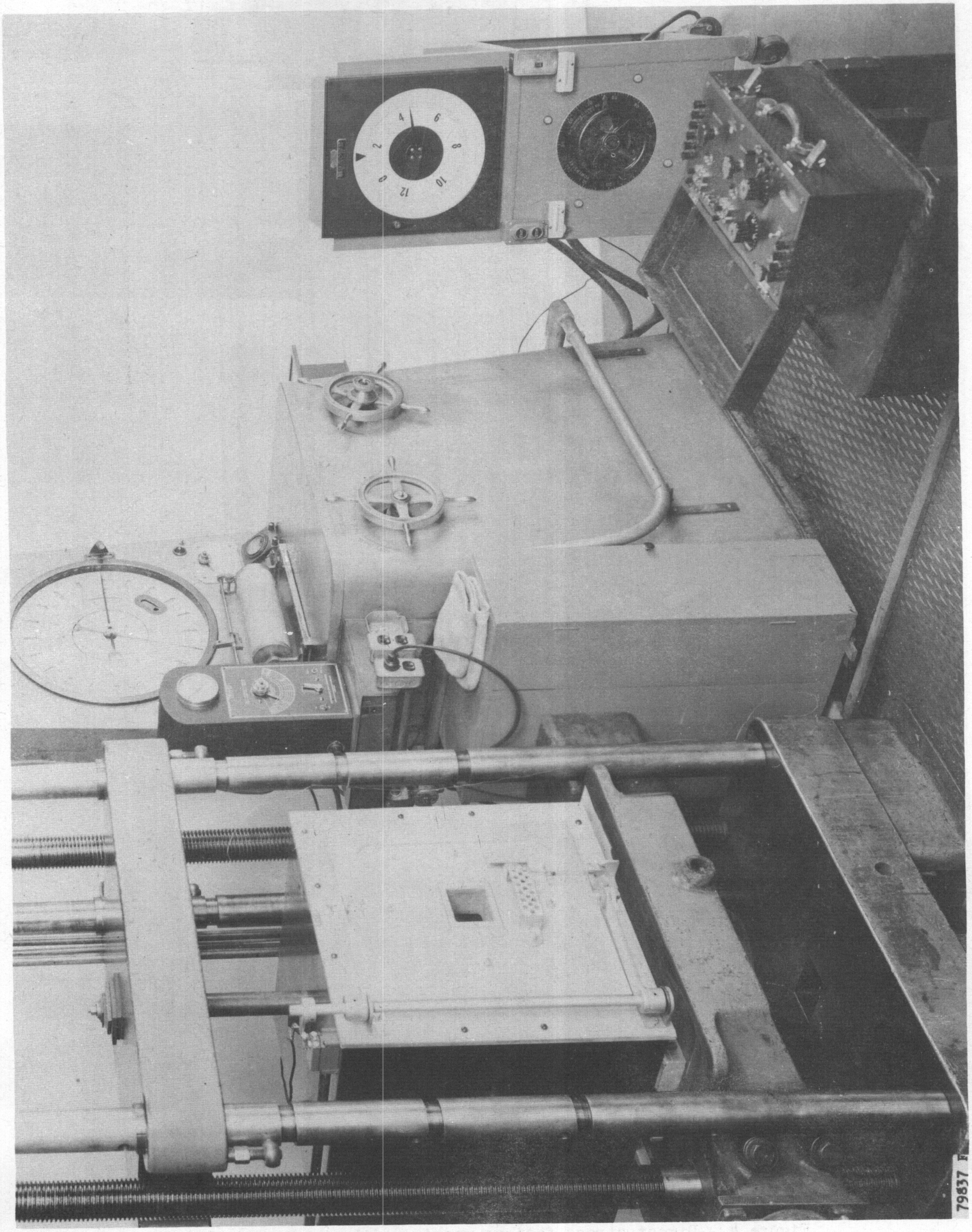

Figure 3.--General view of universal testing machine and oven for static testing at elevated temperatures.

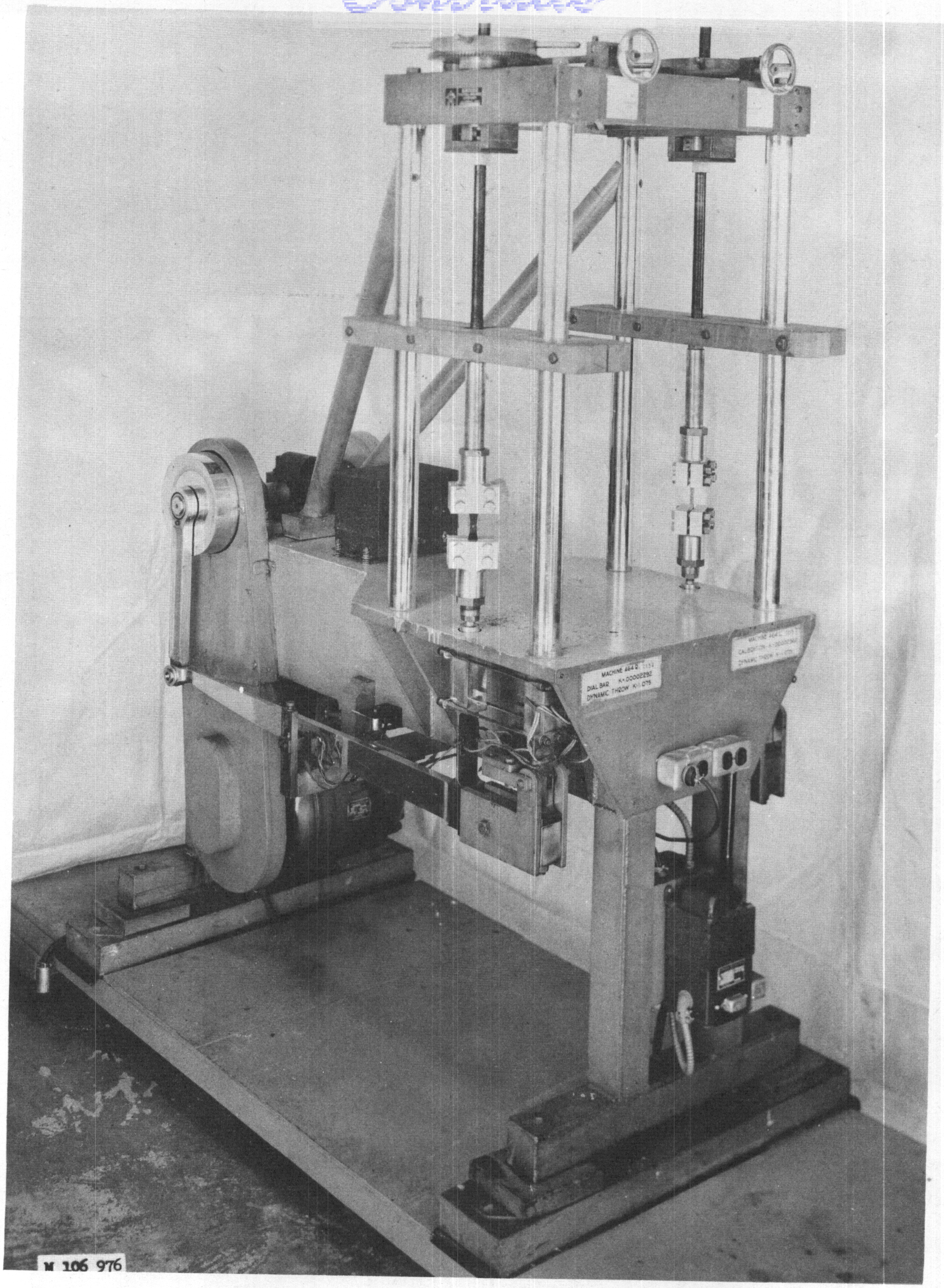

Figure 4.--Direct-stress fatigue machine with specimens under test. Specimens are held in special grips to permit both tensile and compressive loading.

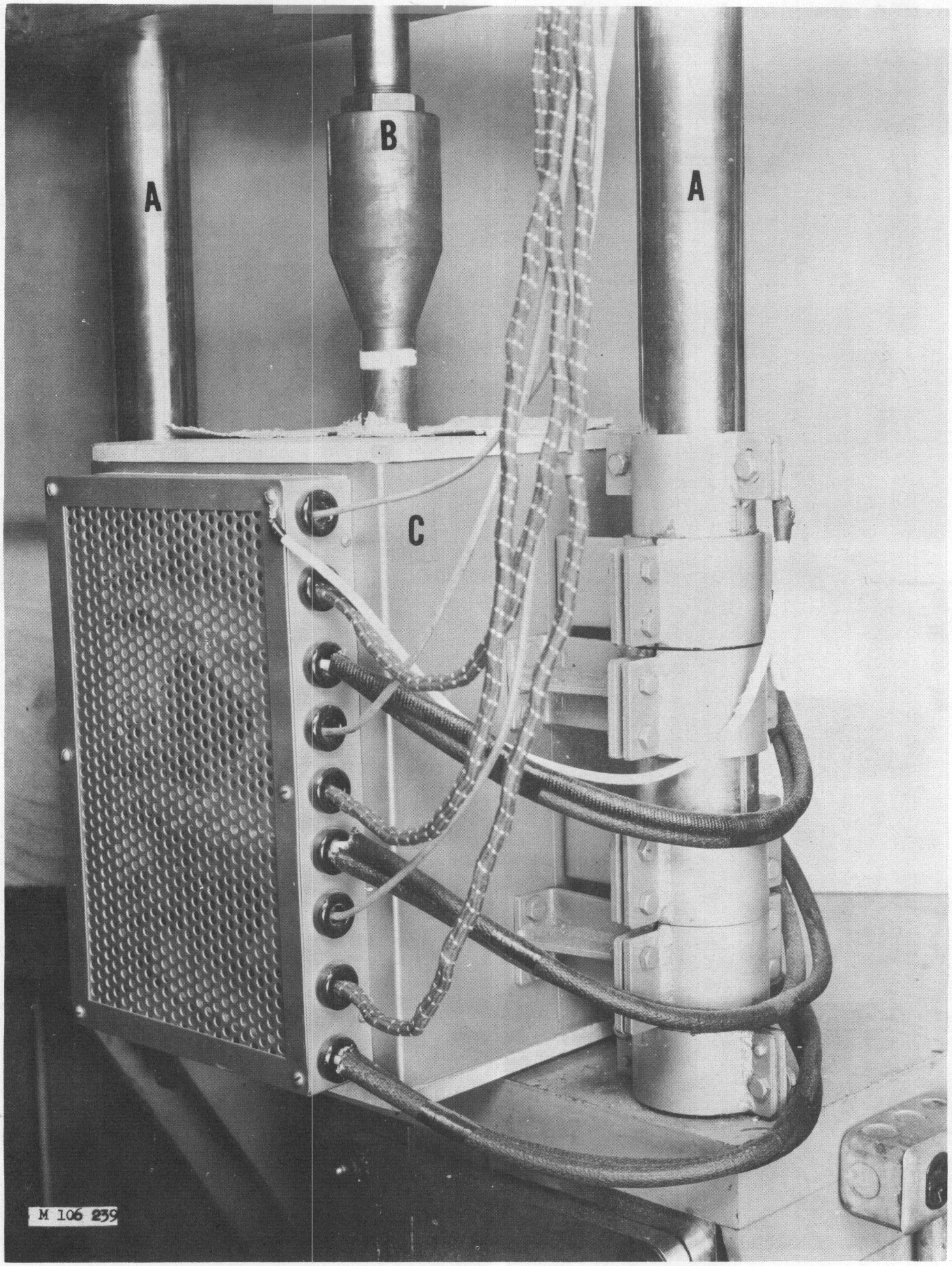

Figure 5.--View of fatigue machine and electric oven for tests at elevated temperatures showing: A columns of fatigue machine, B upper loading screw, and C electric oven.

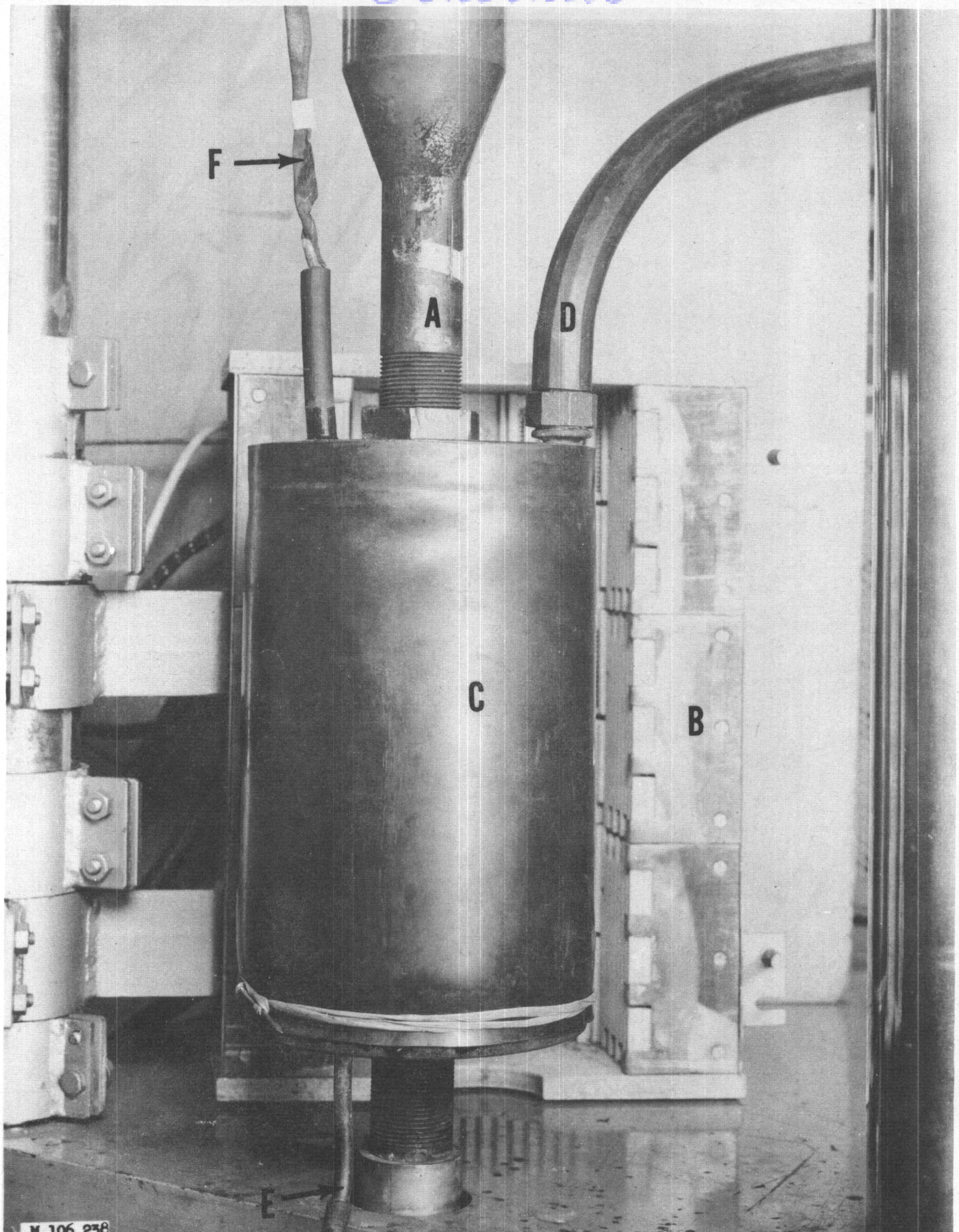

Figure 6.--View of fatigue machine with humidity chamber showing:
A upper loading screw of fatigue machine, B oven, swung free of test area, C rubber sheet surrounding specimen and its clamps, D air hose supplying 100° F. - 100 percent relative humidity air, E air hose for discharge of air and condensate, and F insulated thermocouple lead wires for temperature control.

Figure 7.--View of tank for generating 100° F. - 100 percent relative humidity atmosphere at the test specimen showing: A tank, B air inlet pipe, C electric heating elements, D water supply valve, E discharge hose for air-water mixture, and F temperature controller.

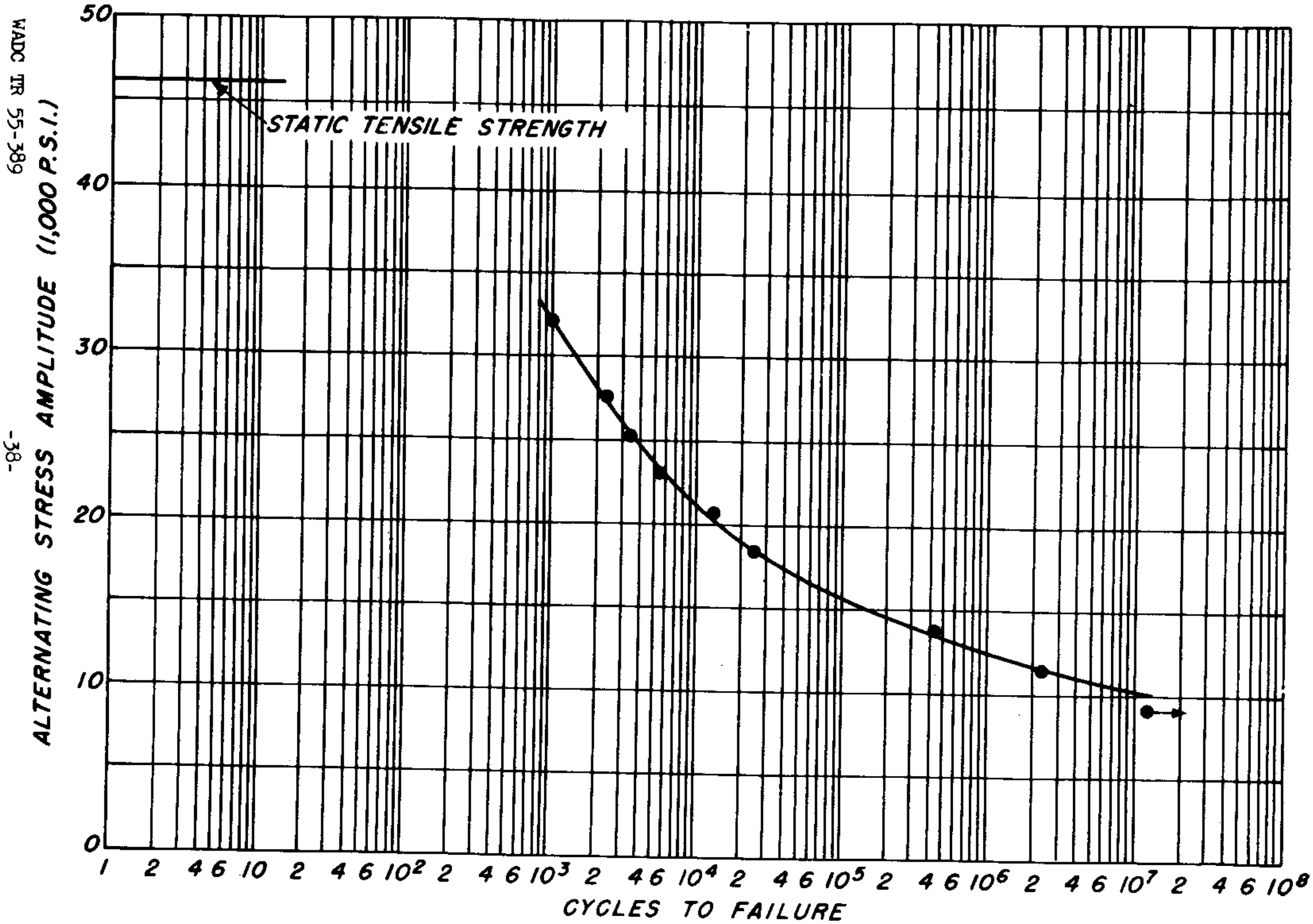

Figure 8.--S-N curve of unnotched specimens of polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

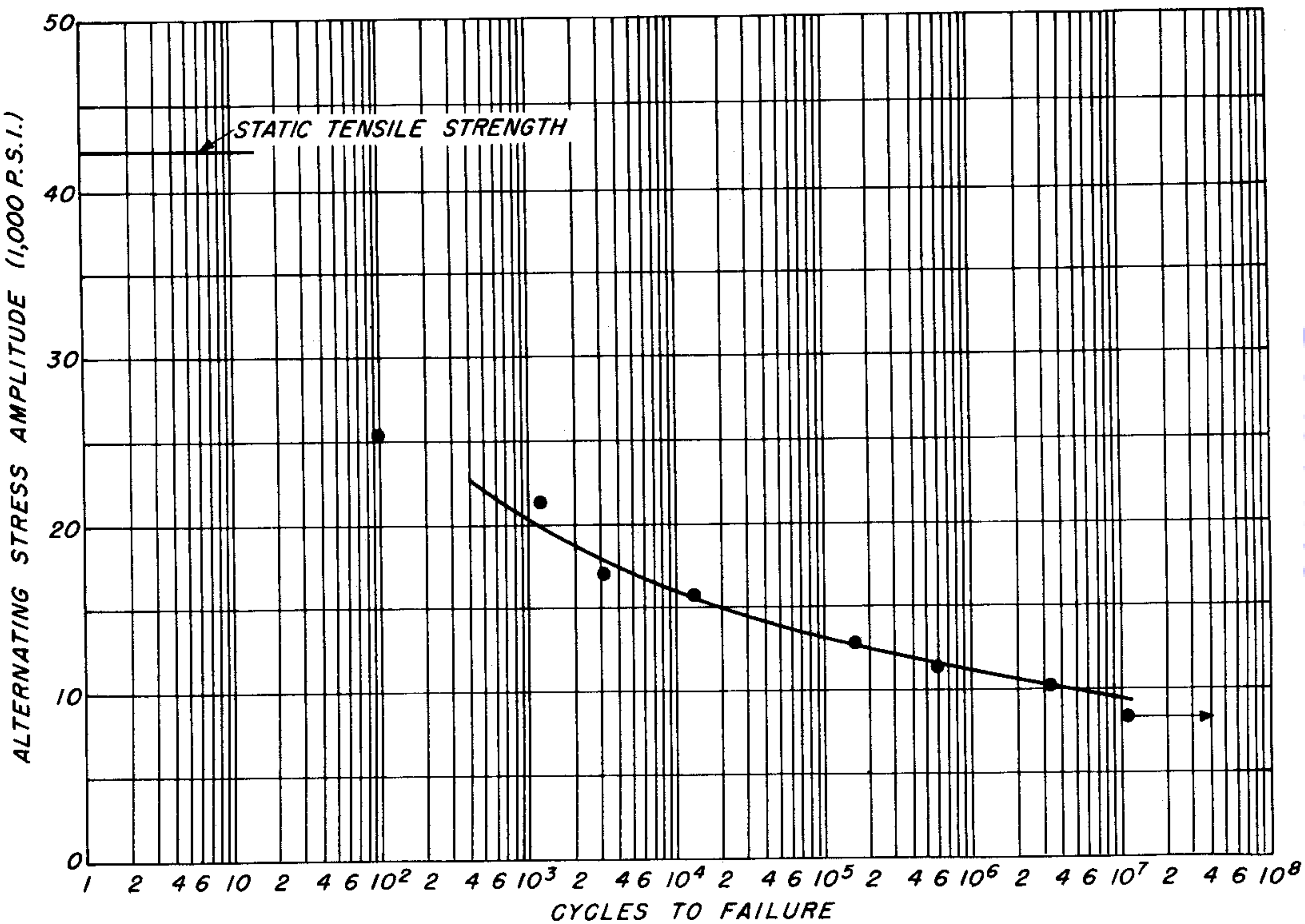

Figure 9.--S-N curve of unnotched specimens of polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp, 100° F. and 100 percent relative humidity, and zero mean stress.

Z M 107 287

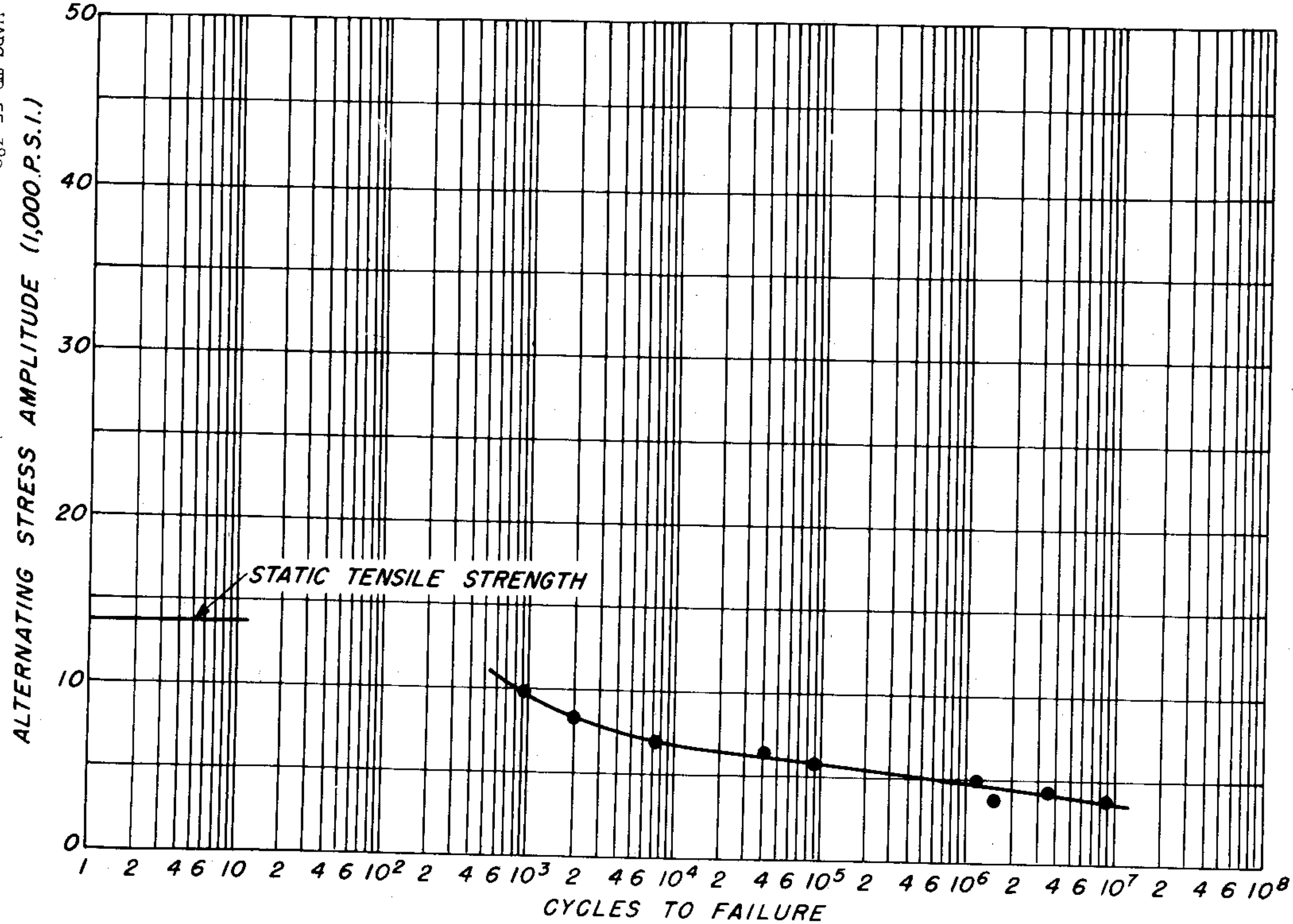

Figure 10.--S-N curve of unnotched specimens of polyester resin reinforced with 1-1/2 ounce glass mat and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 288

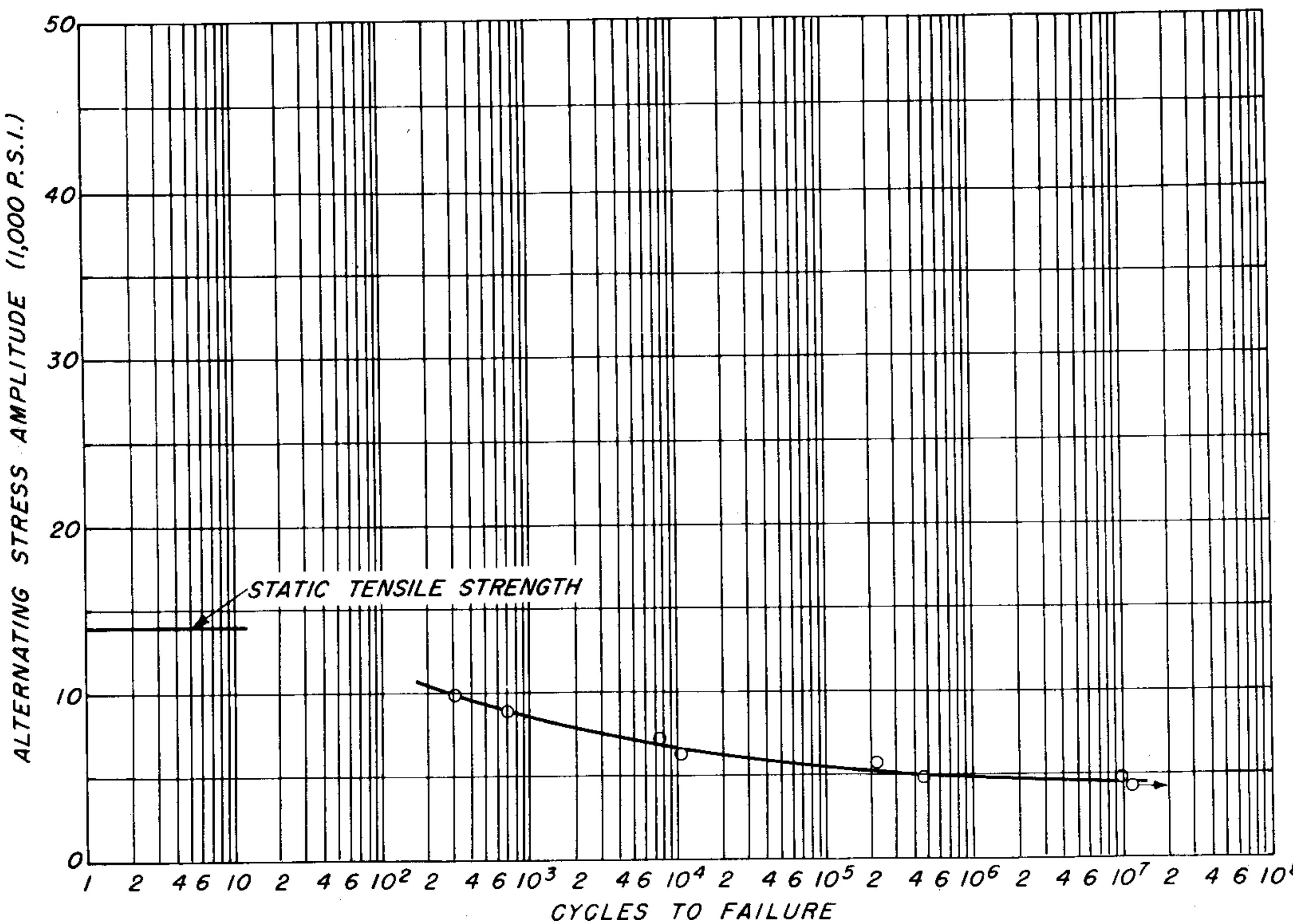

Figure 11.--S-N curve of notched specimens of polyester resin reinforced with 1-1/2 ounce glass mat, and tested at 0° to warp, 73° F. and 50 percent relative humidity and zero mean stress.

Z M 107 289

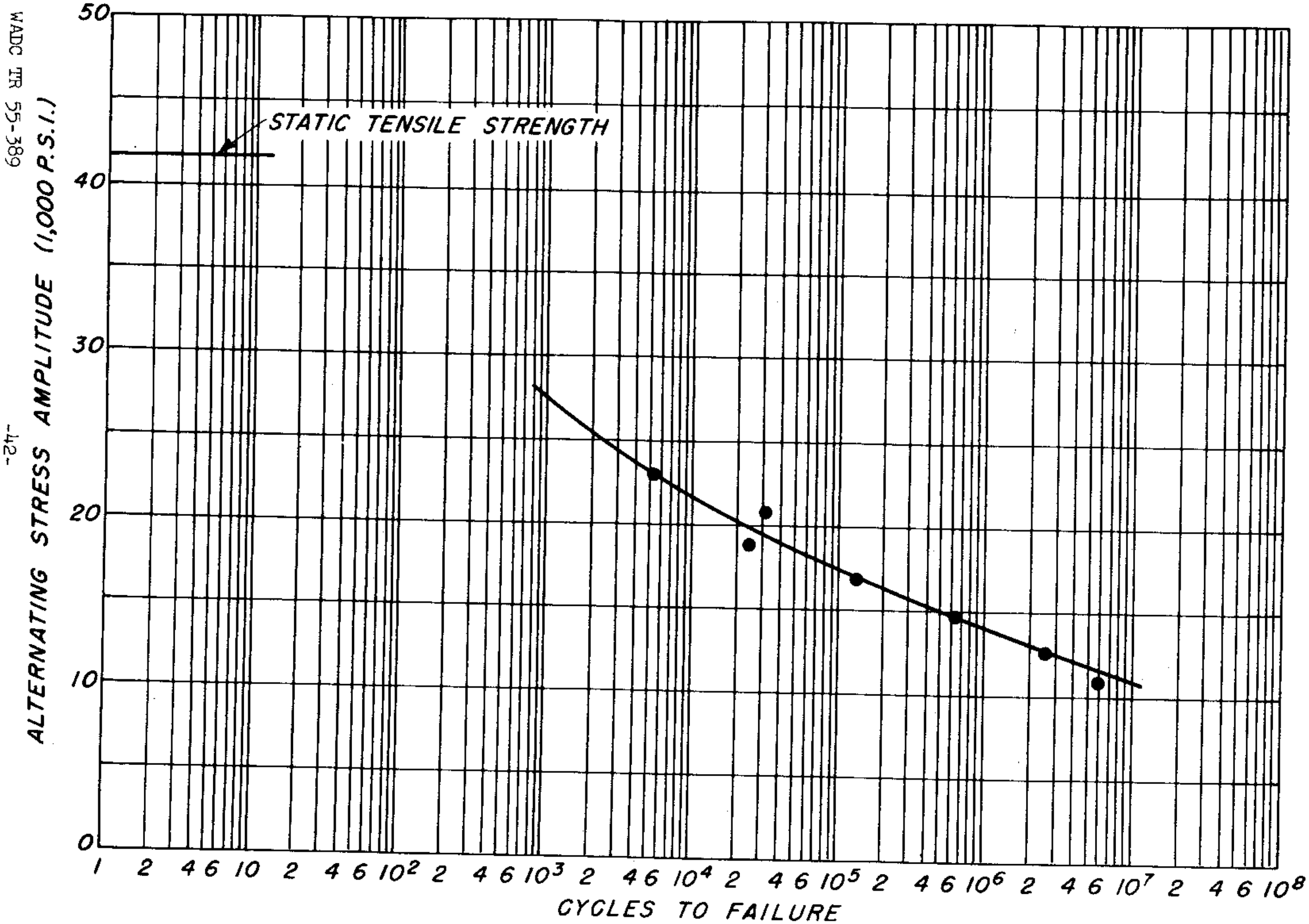

Figure 12.--S-N curve of unnotched specimens of polyester resin reinforced with 120 glass fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 290

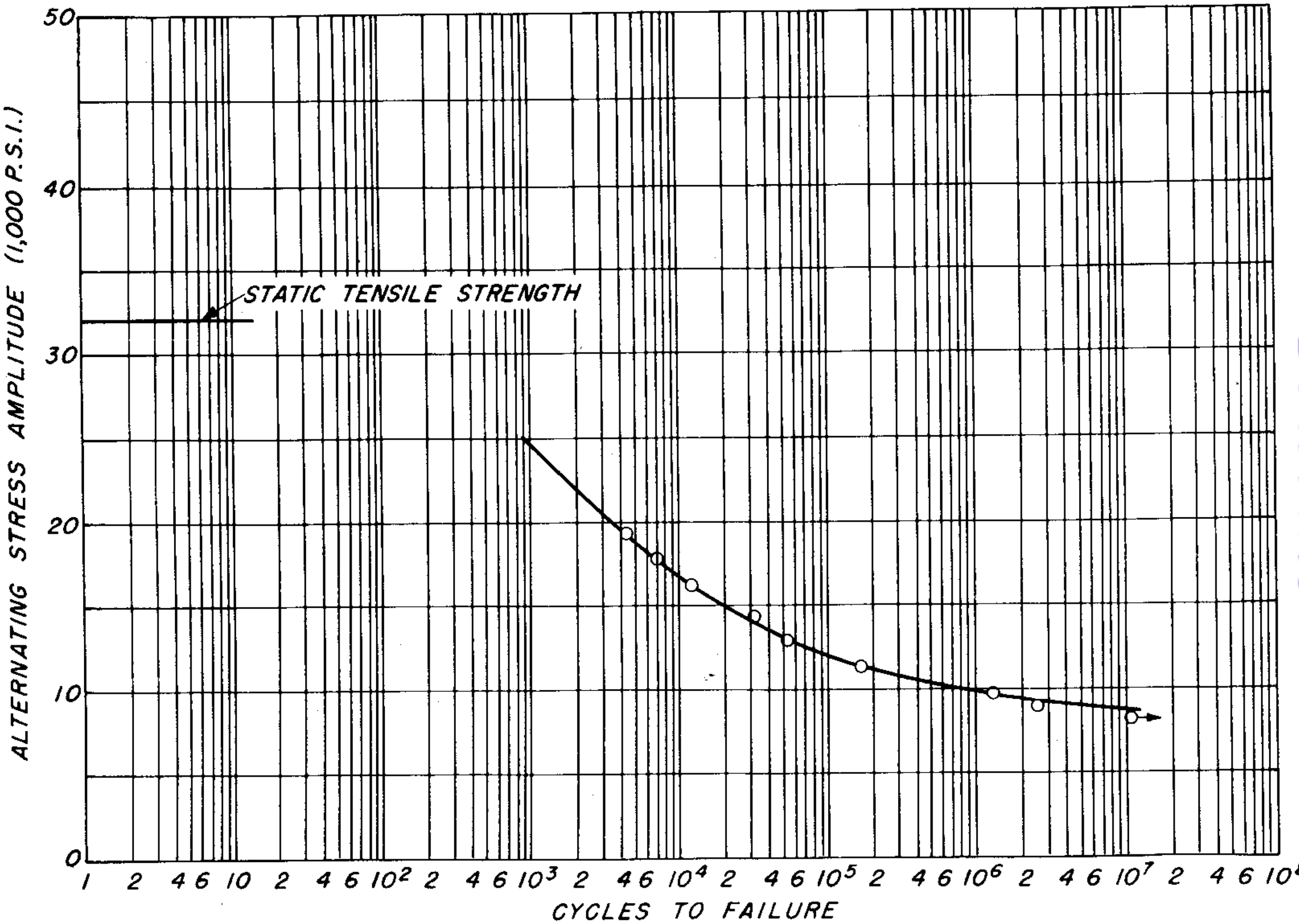

Figure 13.--S-N curve of notched specimens of polyester resin reinforced with 120 glass fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 291

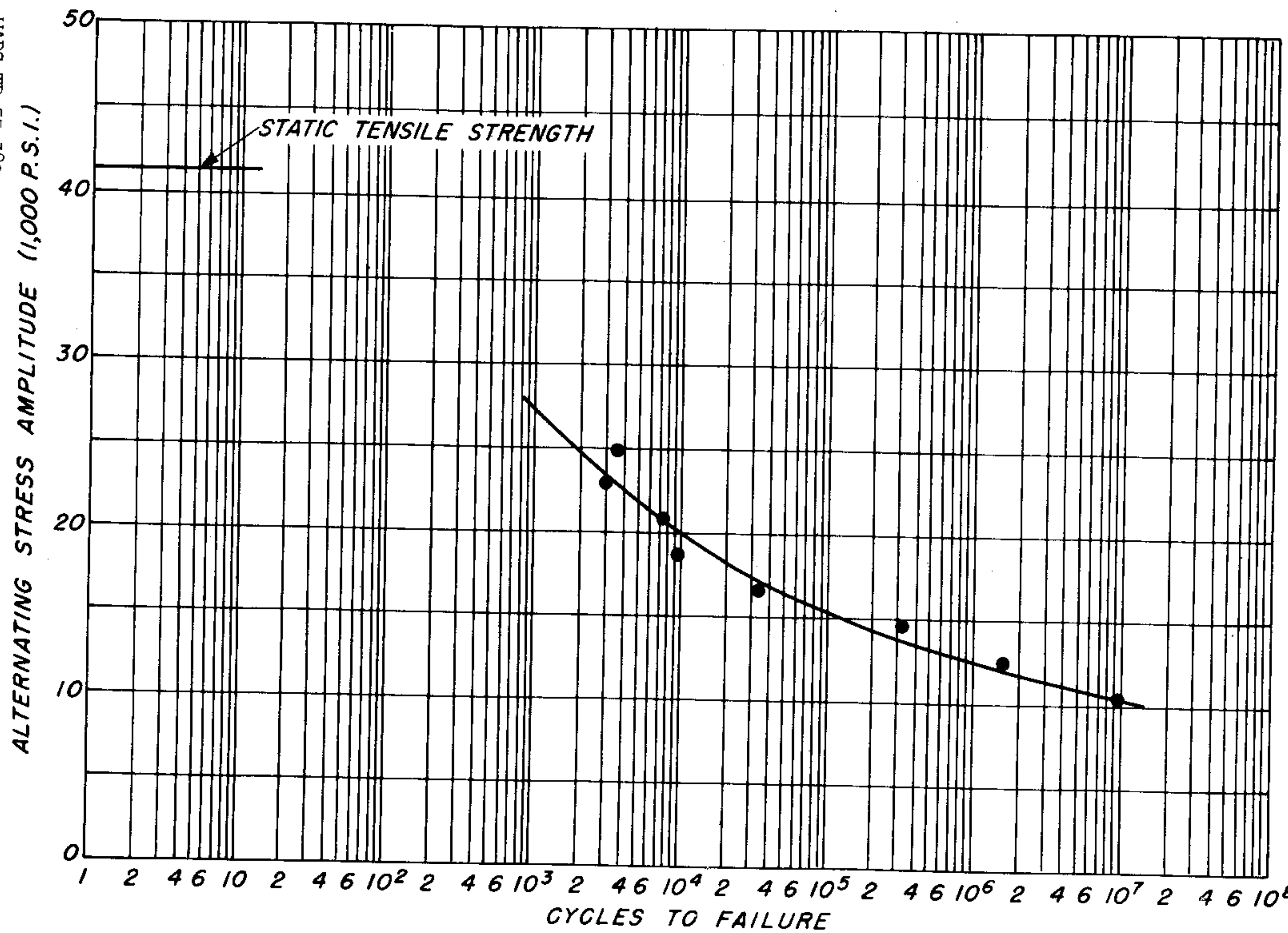

Figure 14.--S-N curve of unnotched specimens of polyester resin reinforced with 112 glas fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 292

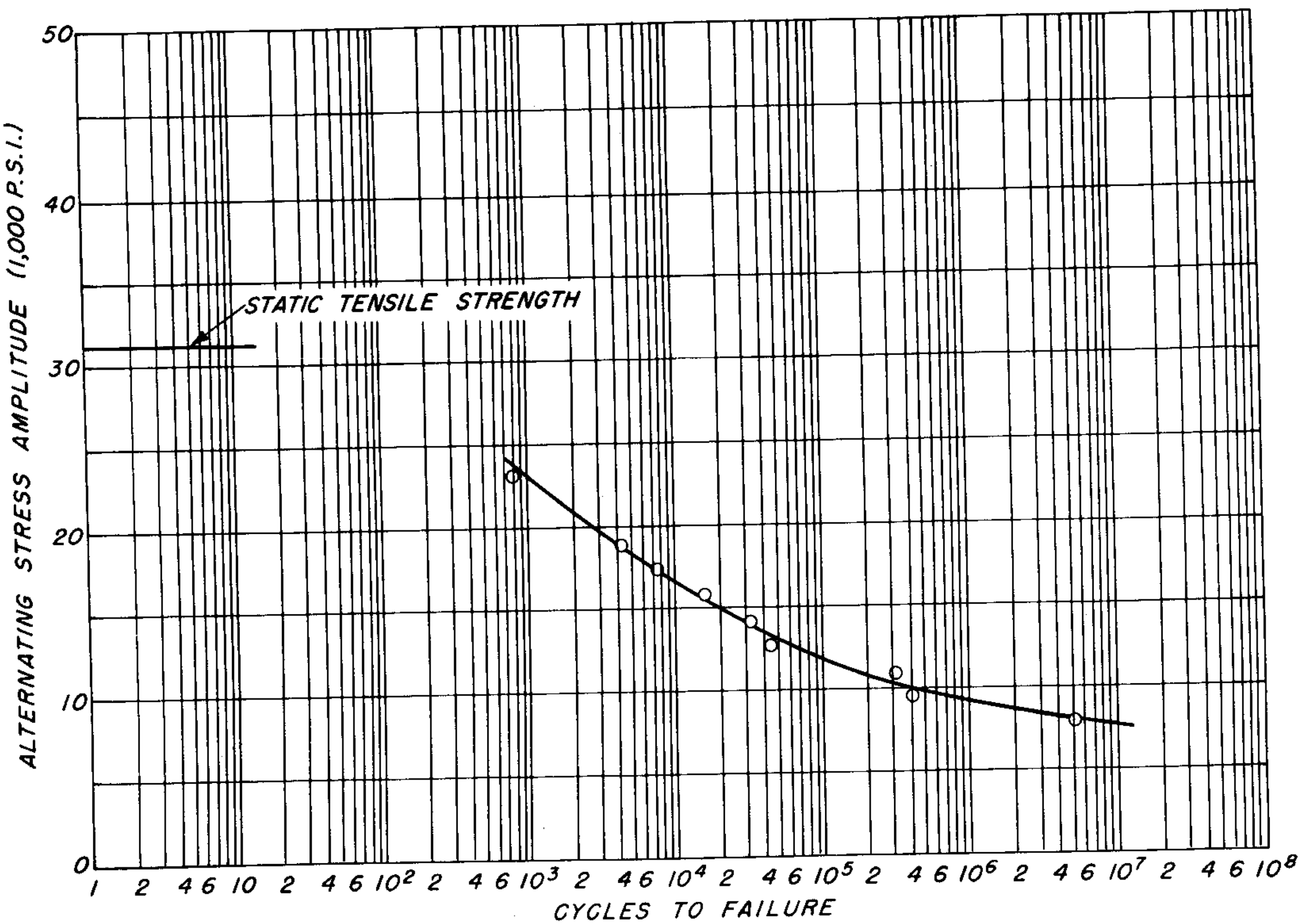

Figure 15.--S-N curve of notched specimens of polyester resin reinforced with 112 glass fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 293

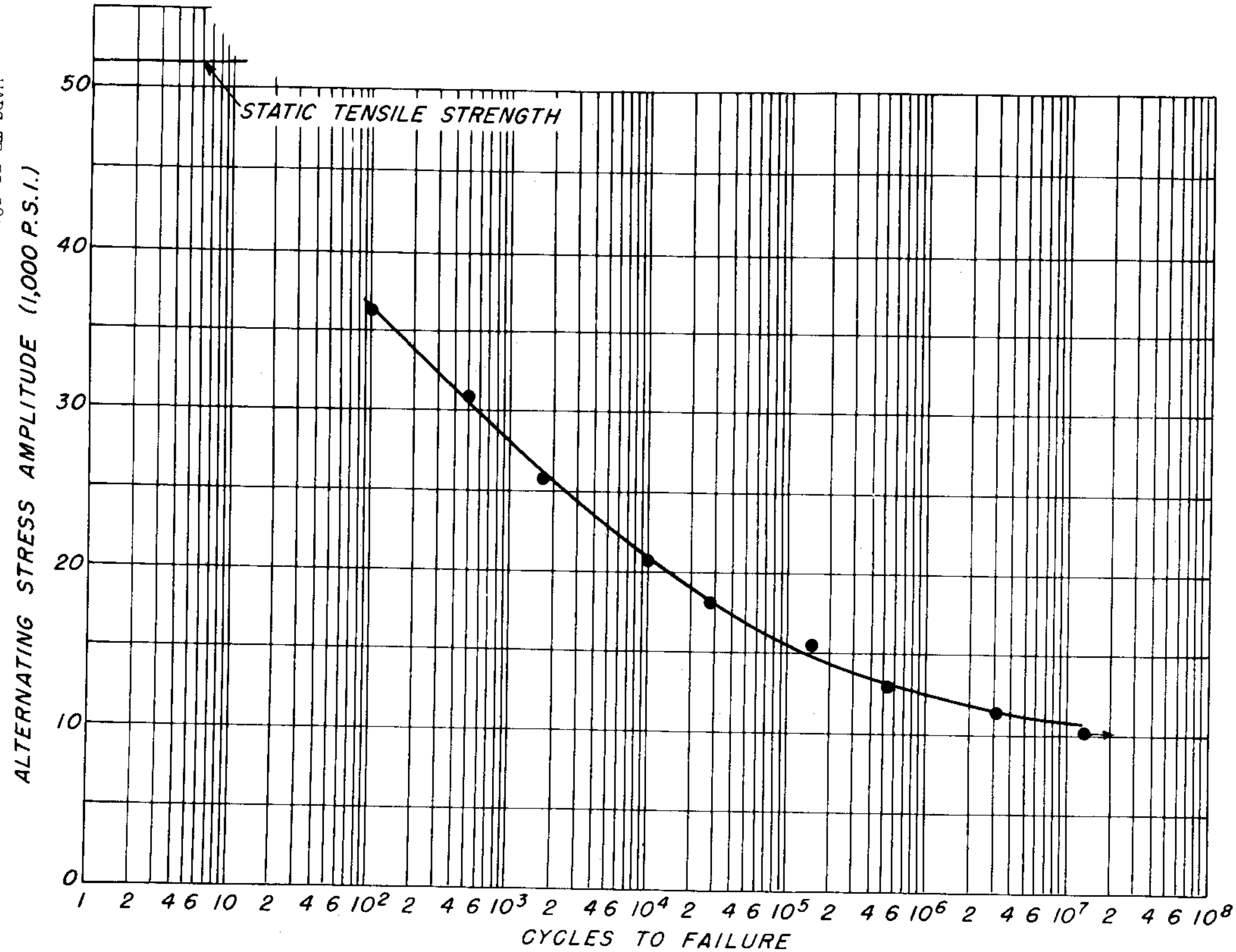

Figure 16.--S-N curve of unnotched specimens of polyester resin reinforced with 184 glass fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 294

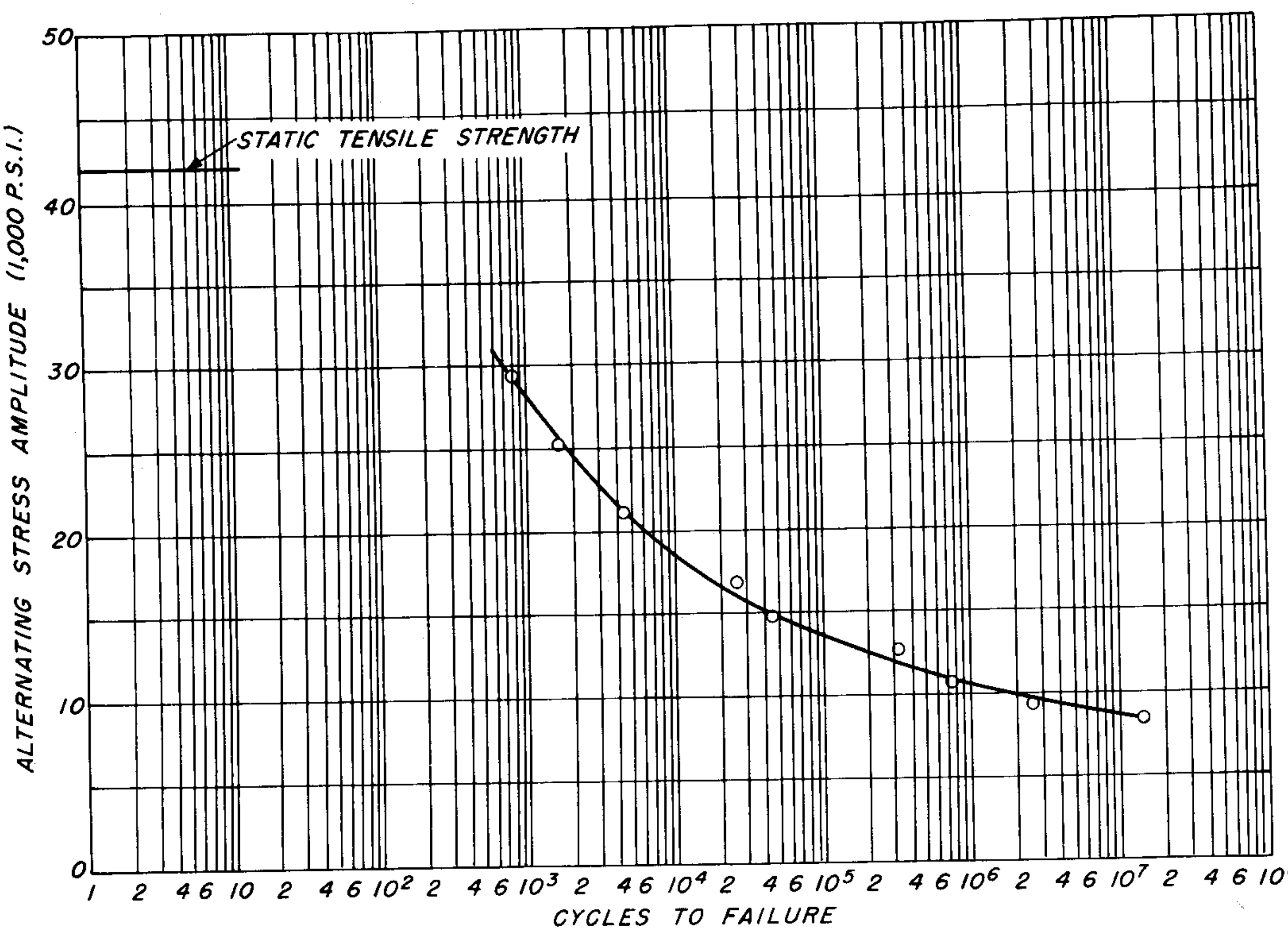

Figure 17.--S-N curve of notched specimens of polyester resin reinforced with 184 glass fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 295

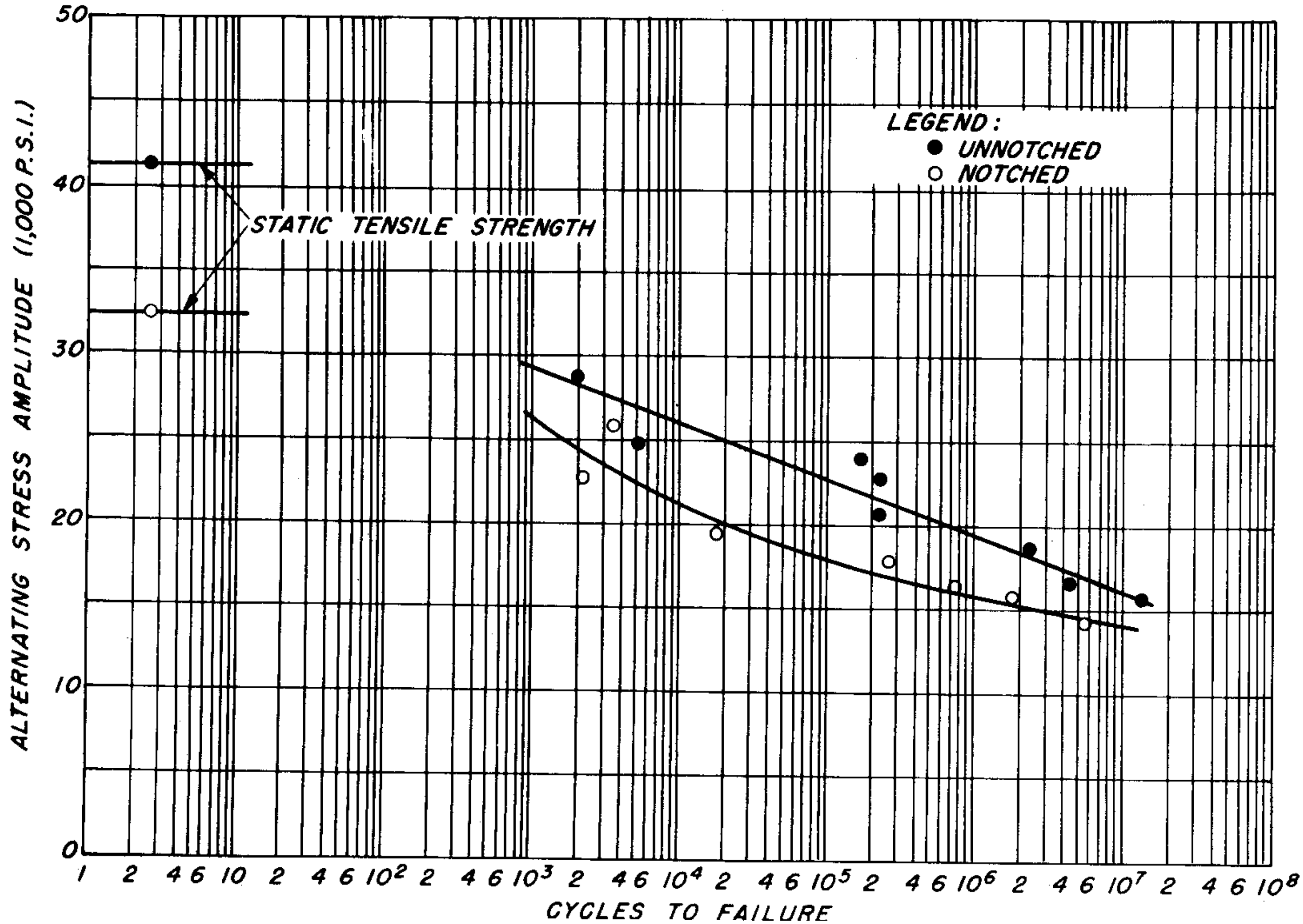

Figure 18.--S-N curves of notched and unnotched specimens of epoxide resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 296

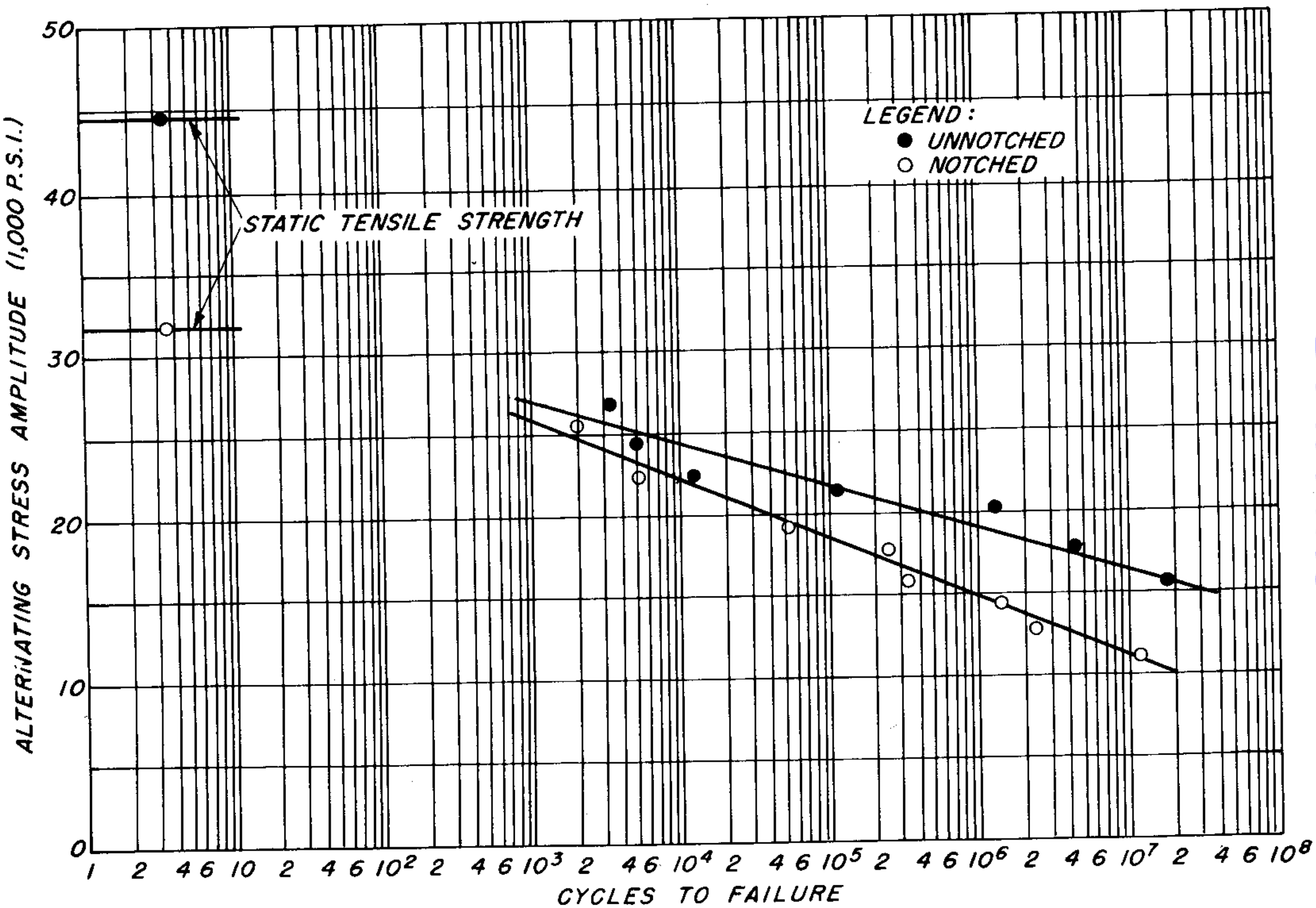

Figure 19.--S-N curves of notched and unnotched specimens of epoxide resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp, 100° F. and 100 percent relative humidity, and zero mean stress.

Z M 107 297

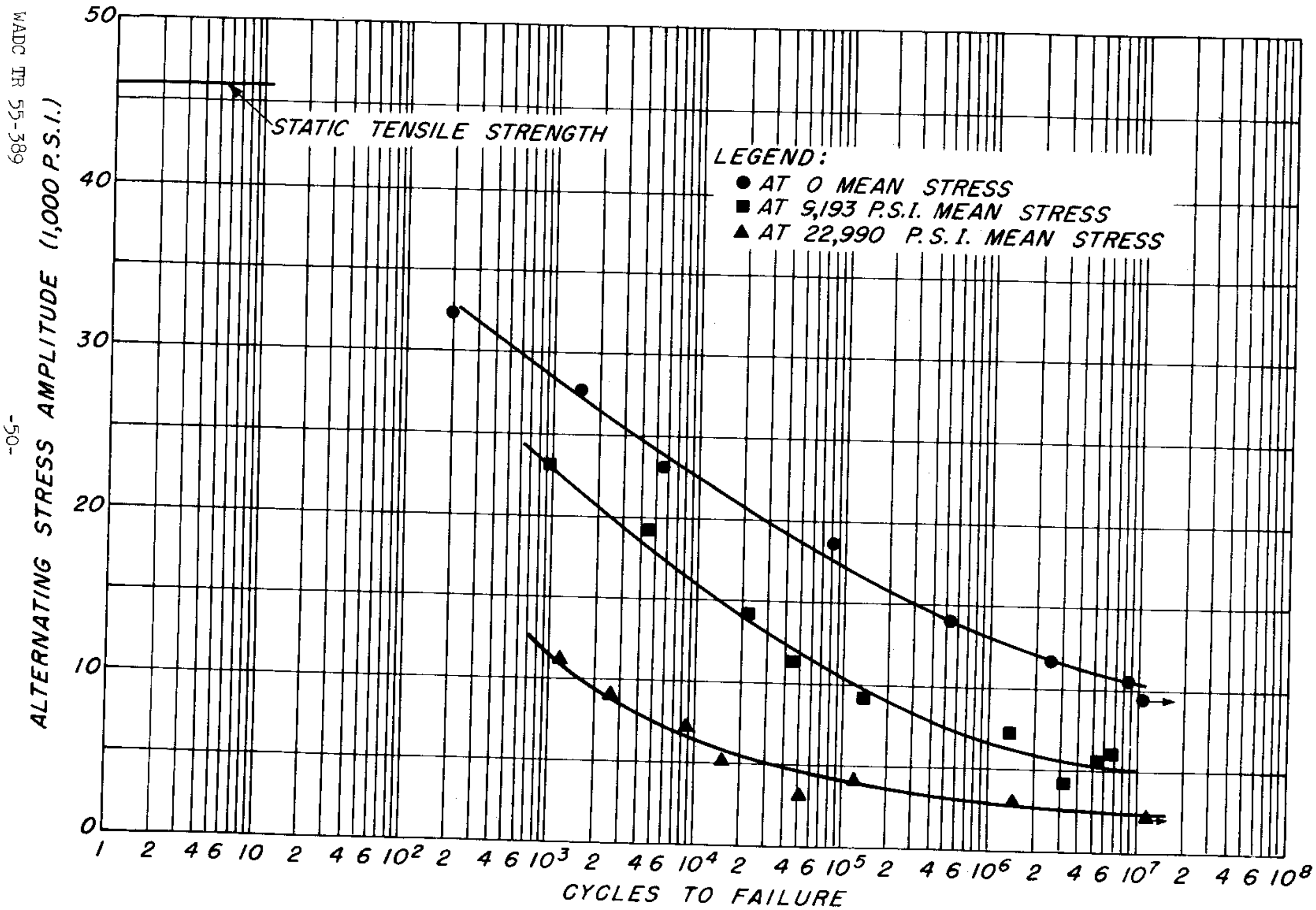

Figure 20.--S-N curves of unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp, and 73° F. and 50 percent relative humidity at 3 mean stress levels.

Z M 107 298

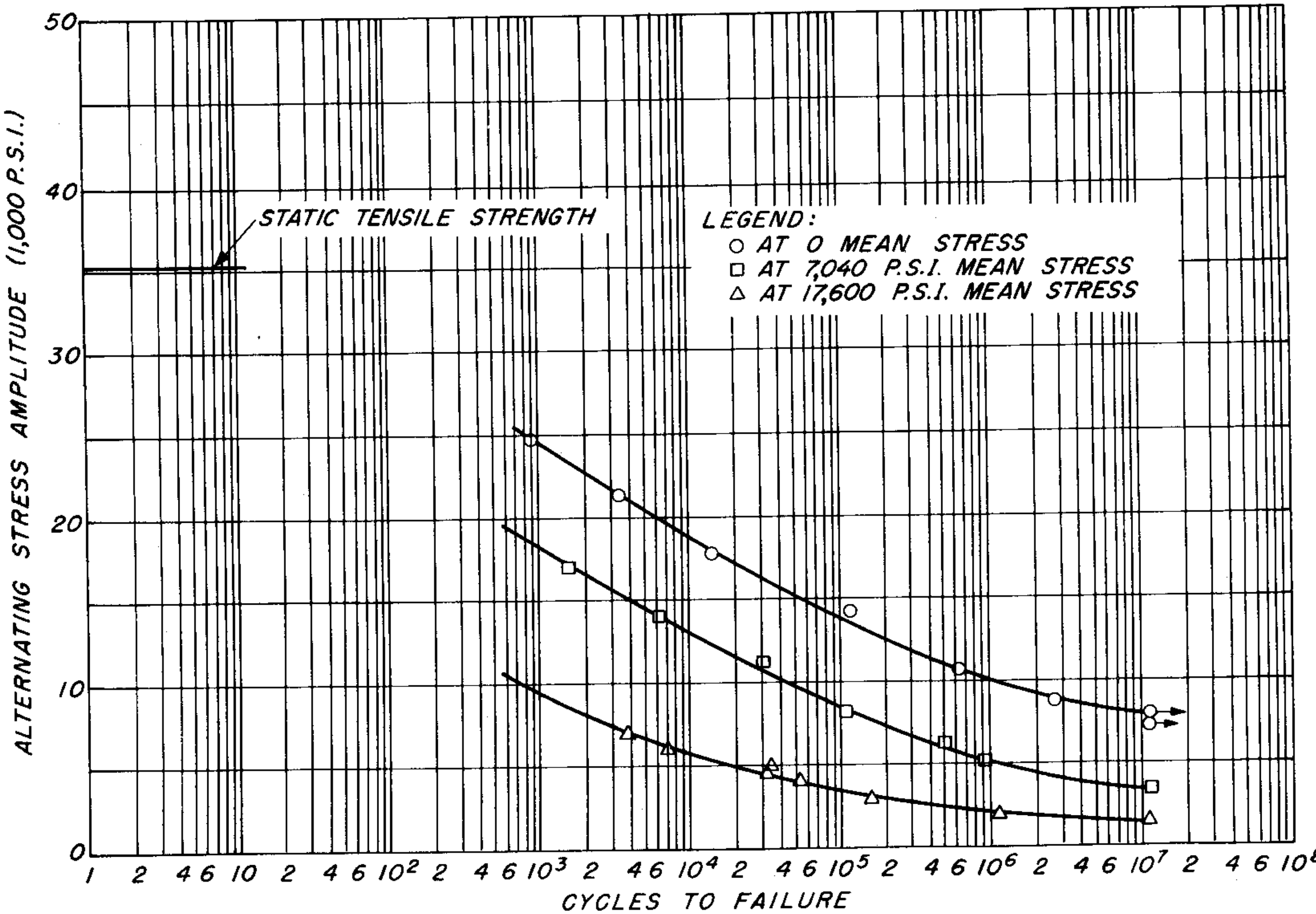

Figure 21.--S-N curves of notched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp and 73° F. and 50 percent relative humidity at 3 mean stress levels.

Z M 107 299

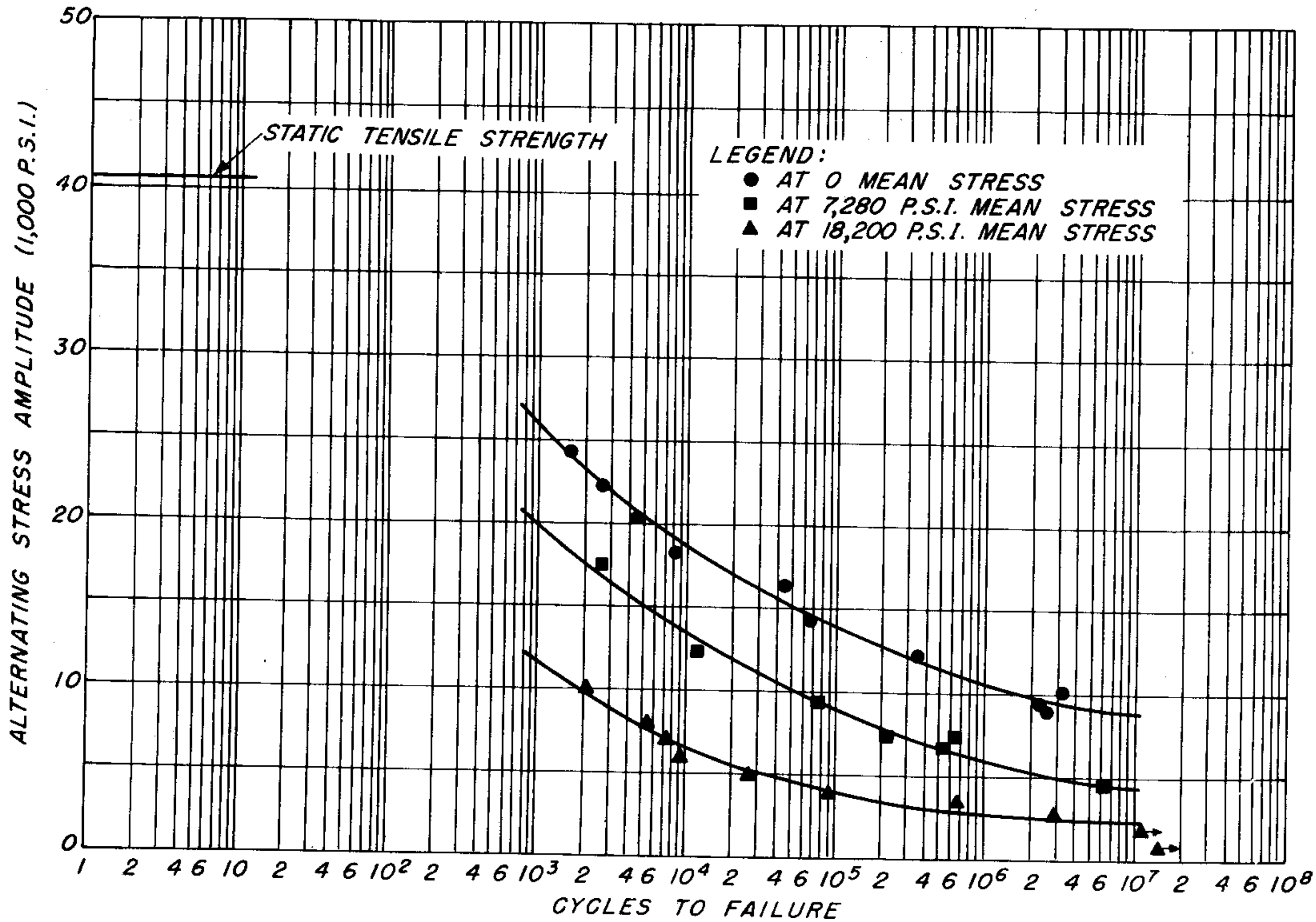

Figure 22.--S-N curves of unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp and 300° F. at 3 mean stress levels.

2 M 107 300

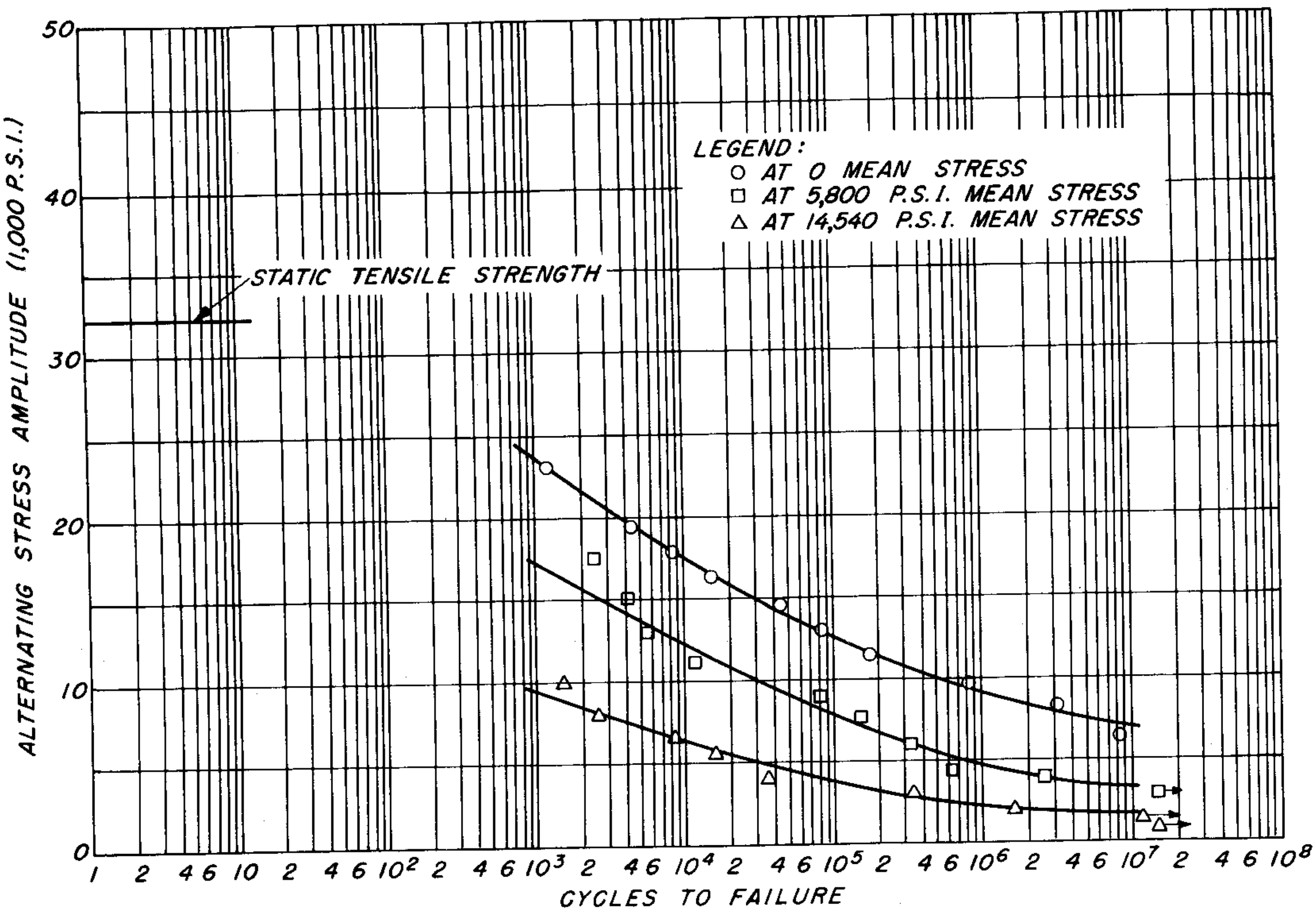

Figure 23.--S-N curves of notched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp and 300° F. at 3 mean stress levels.

Z M 107 301

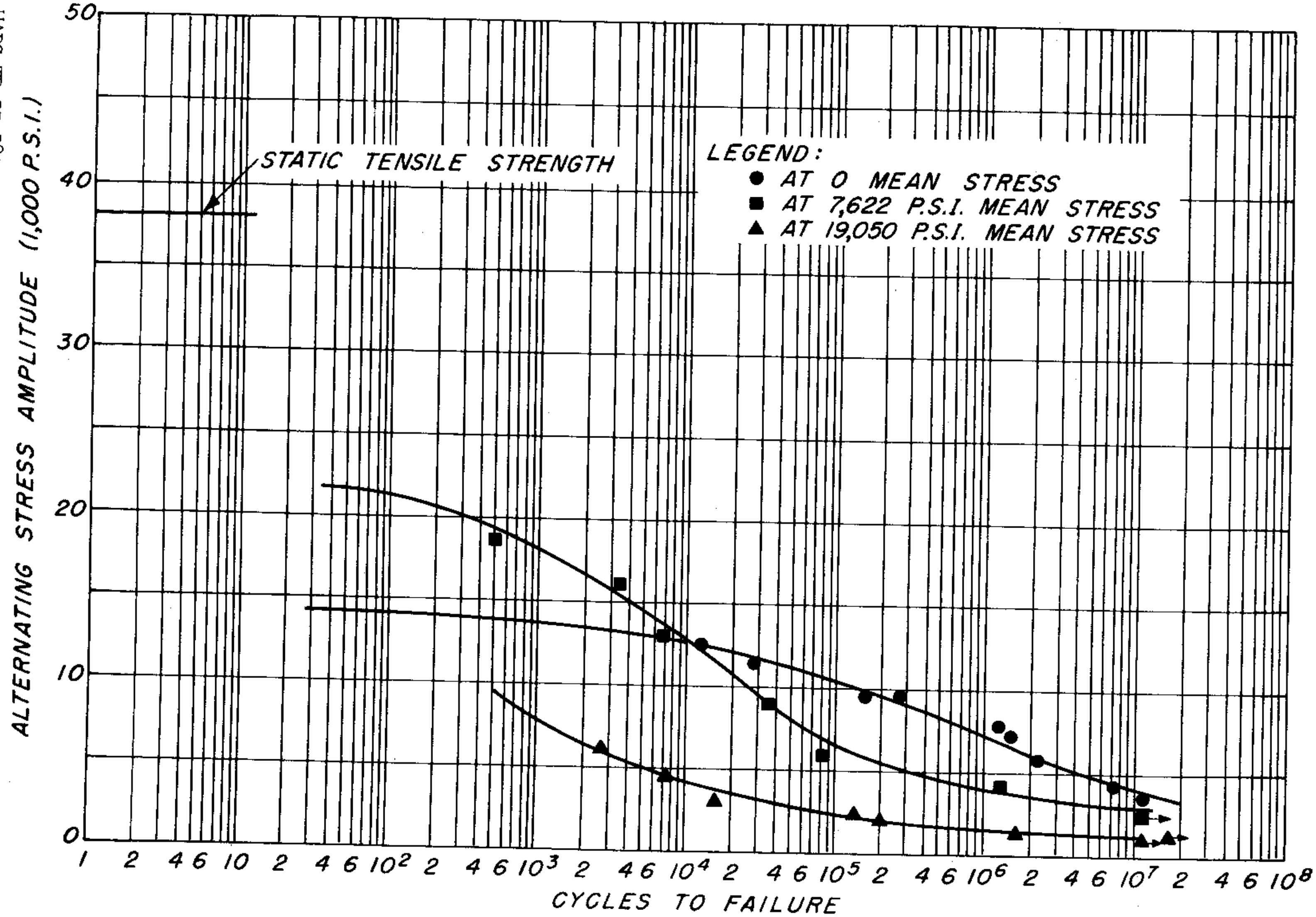

Figure 24.--S-N curves of unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp and 500° F. at 3 mean stress levels.

Z M 107 302

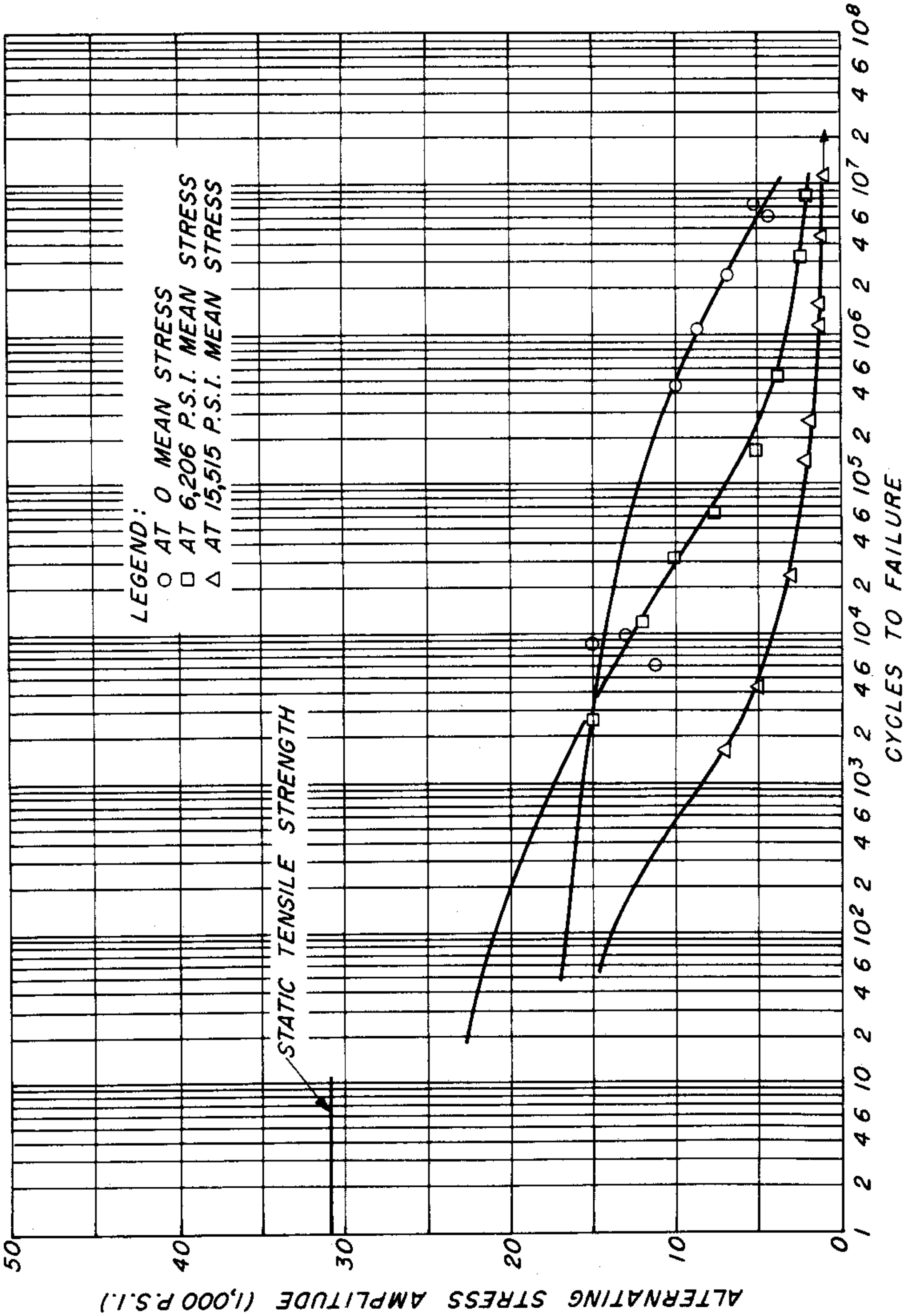

Figure 25.--S-N curves of notched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp and 500° F. at 3 mean stress levels.

Z M 107 303

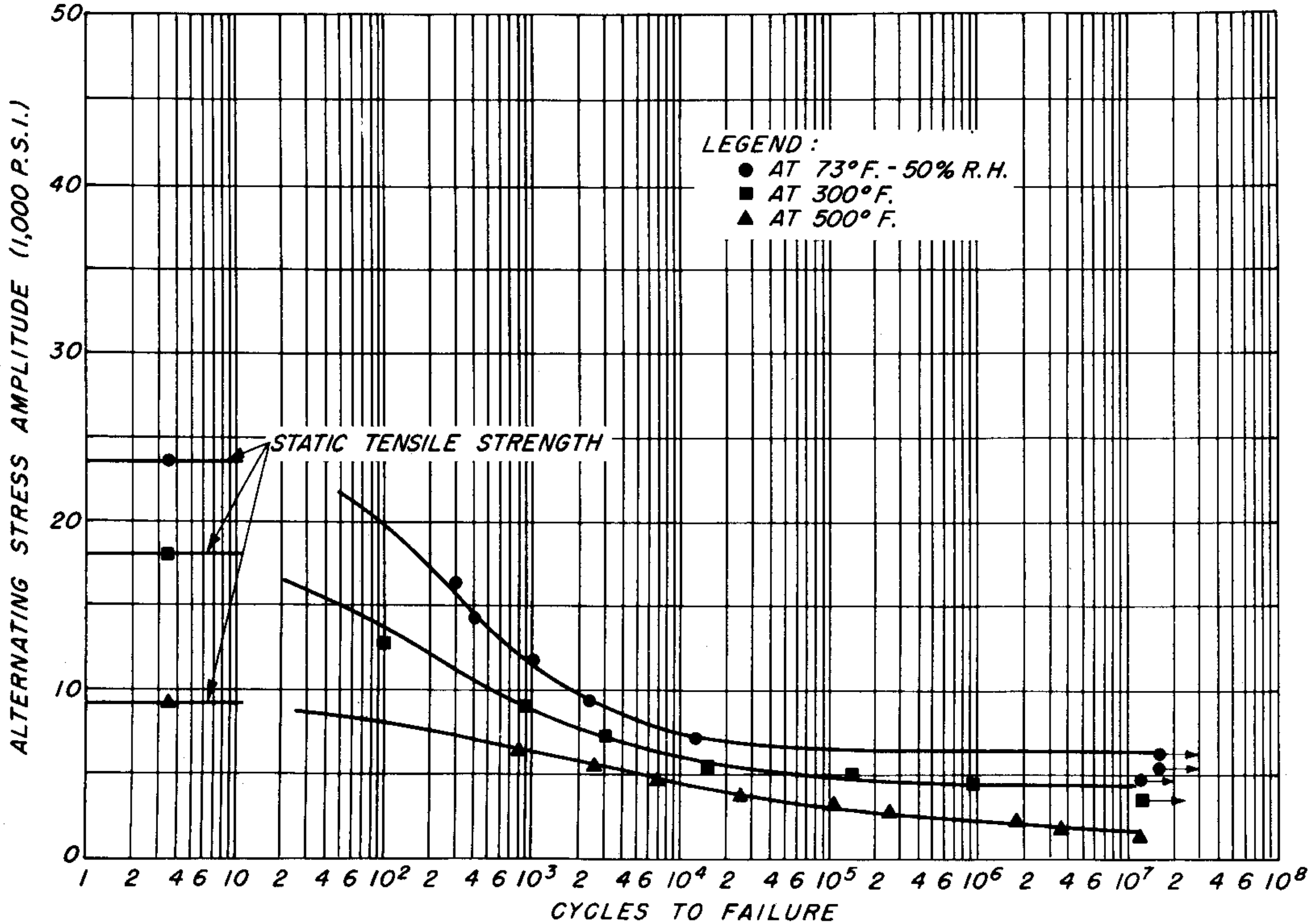

Figure 26.--S-N curves of unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 45° to warp and zero mean stress at 3 temperatures.

Z M 107 304

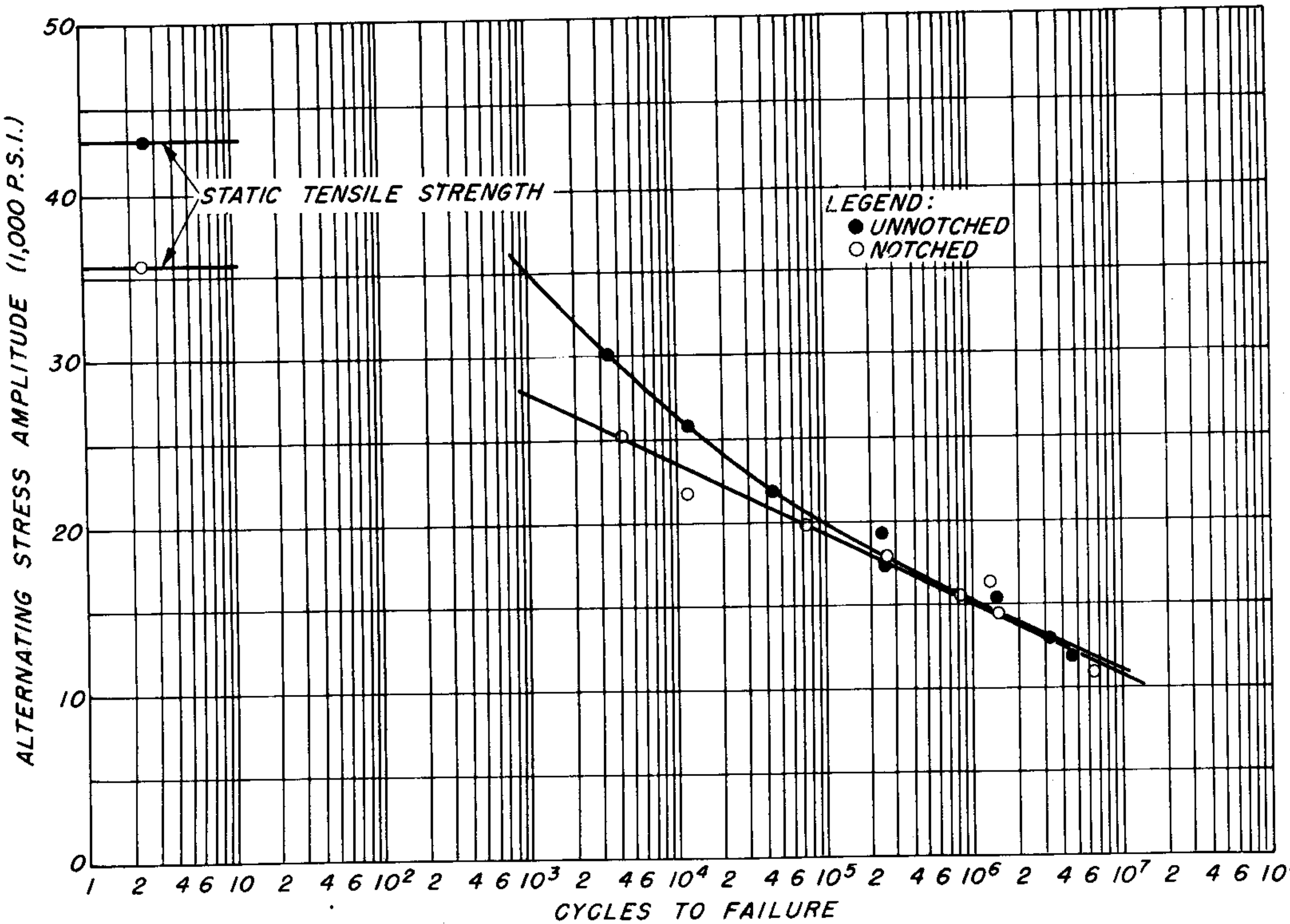

Figure 27.--S-N curves of notched and unnotched specimens of heat-resistant epoxide resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp at 73° F. and 50 percent relative humidity and zero mean stress.

Z M 107 305

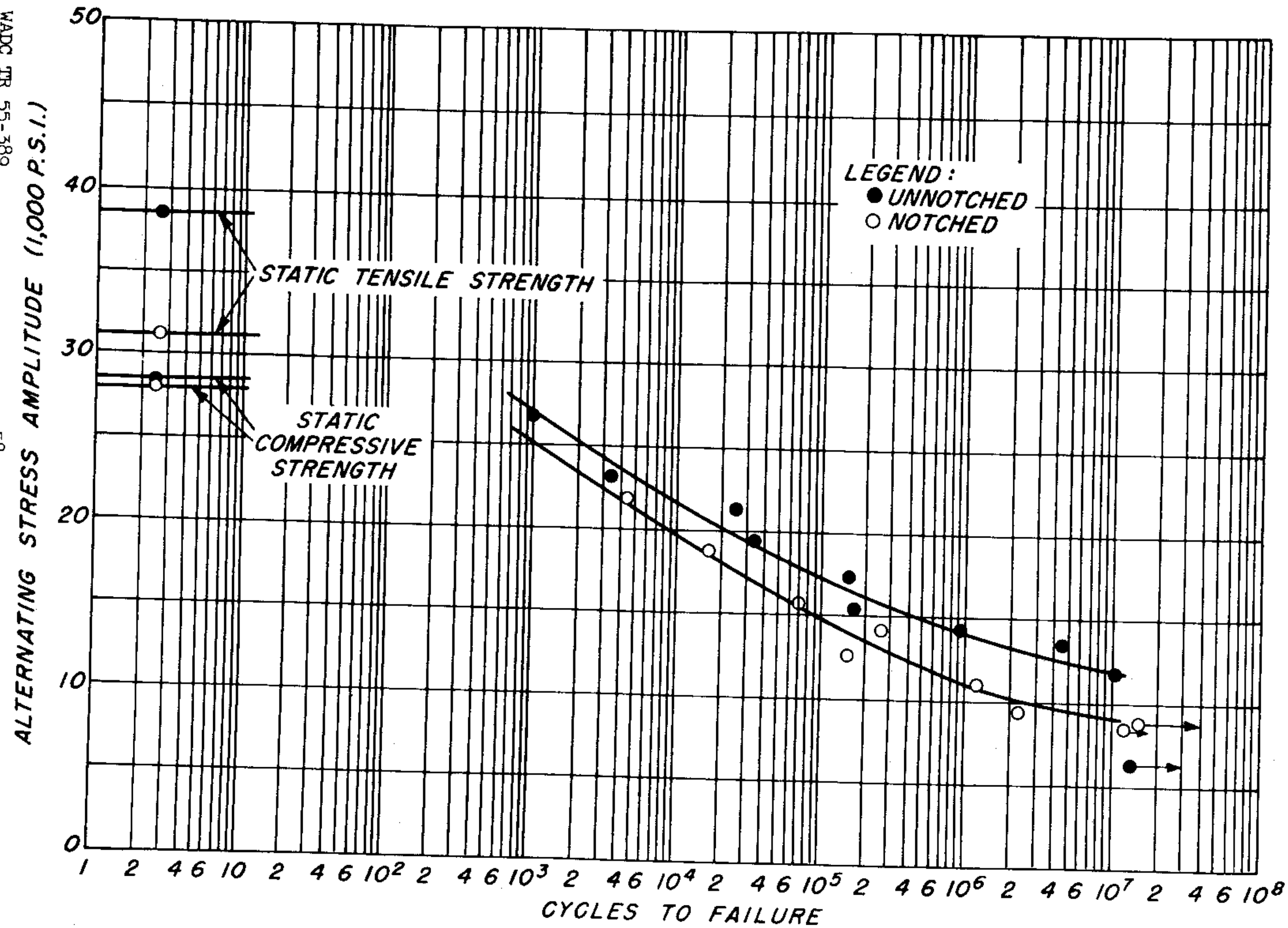

Figure 28.--S-N curves of notched and unnotched specimens of heat-resistant epoxide resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp at 300° F. and zero mean stress.

Z M 107 306

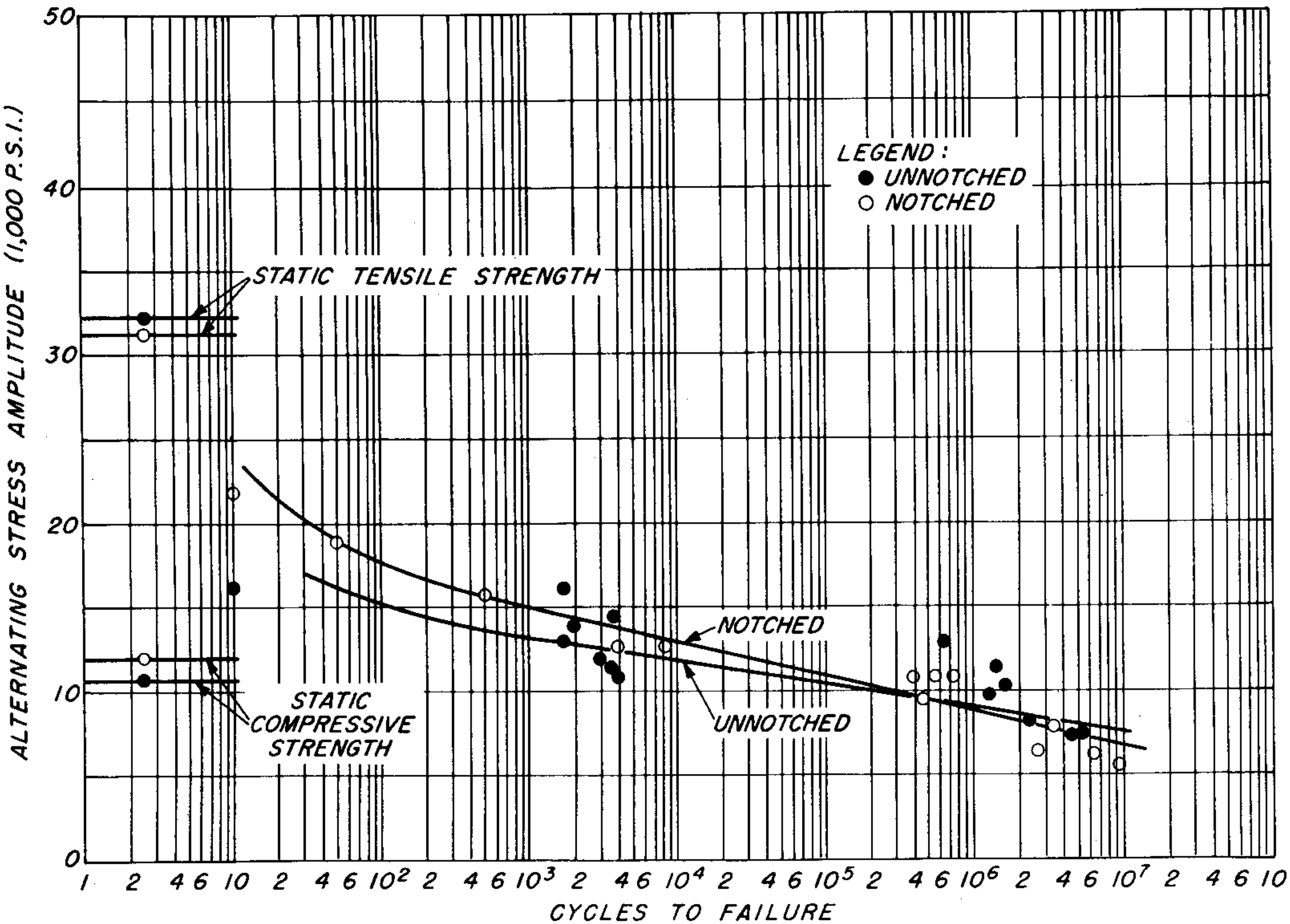

Figure 29.--S-N curves of notched and unnotched specimens of heat-resistant epoxide resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp at 500° F. and zero mean stress.

7 M 107 307

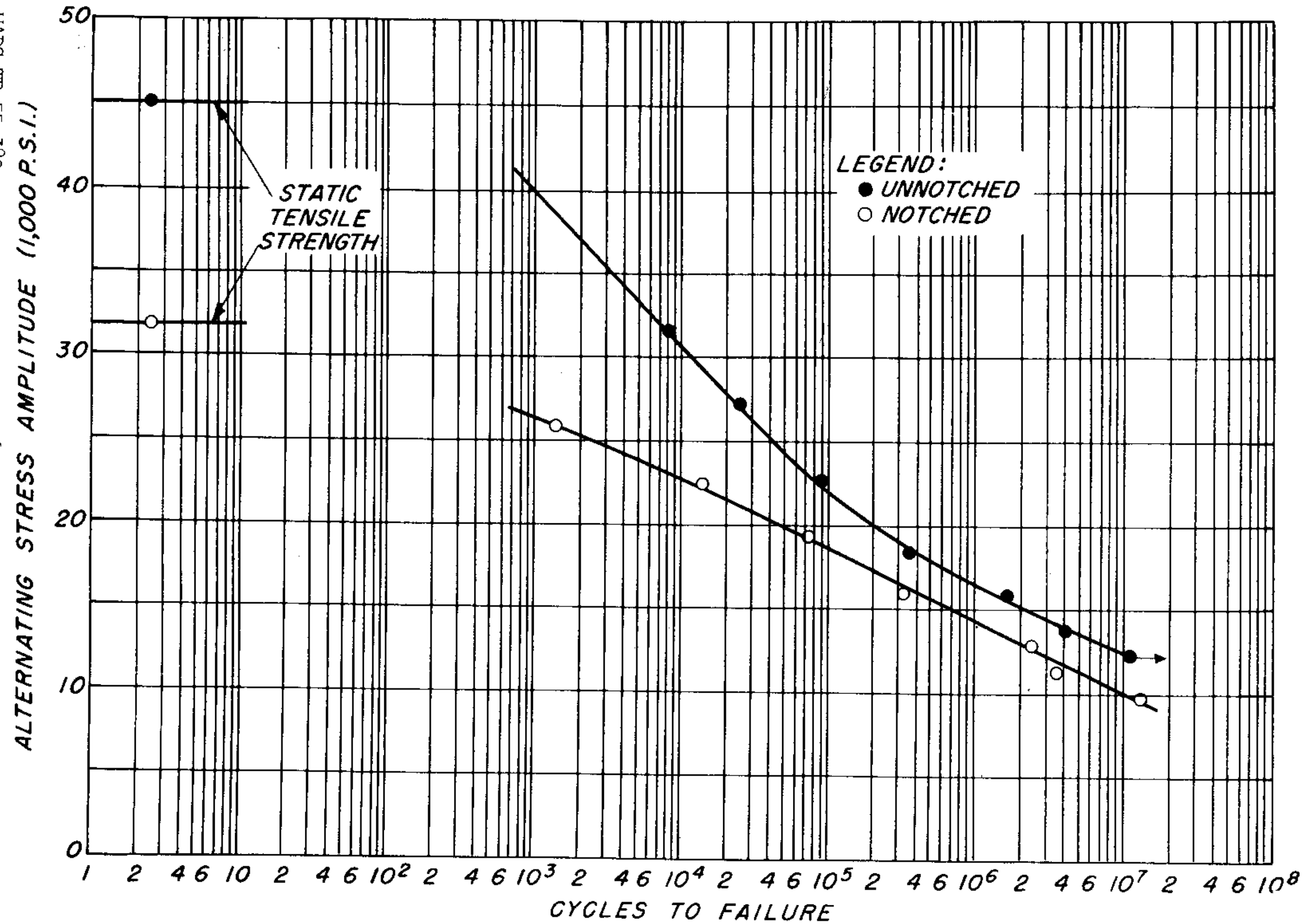

Figure 30.--S-N curves of notched and unnotched specimens of heat-resistant phenolic resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 308

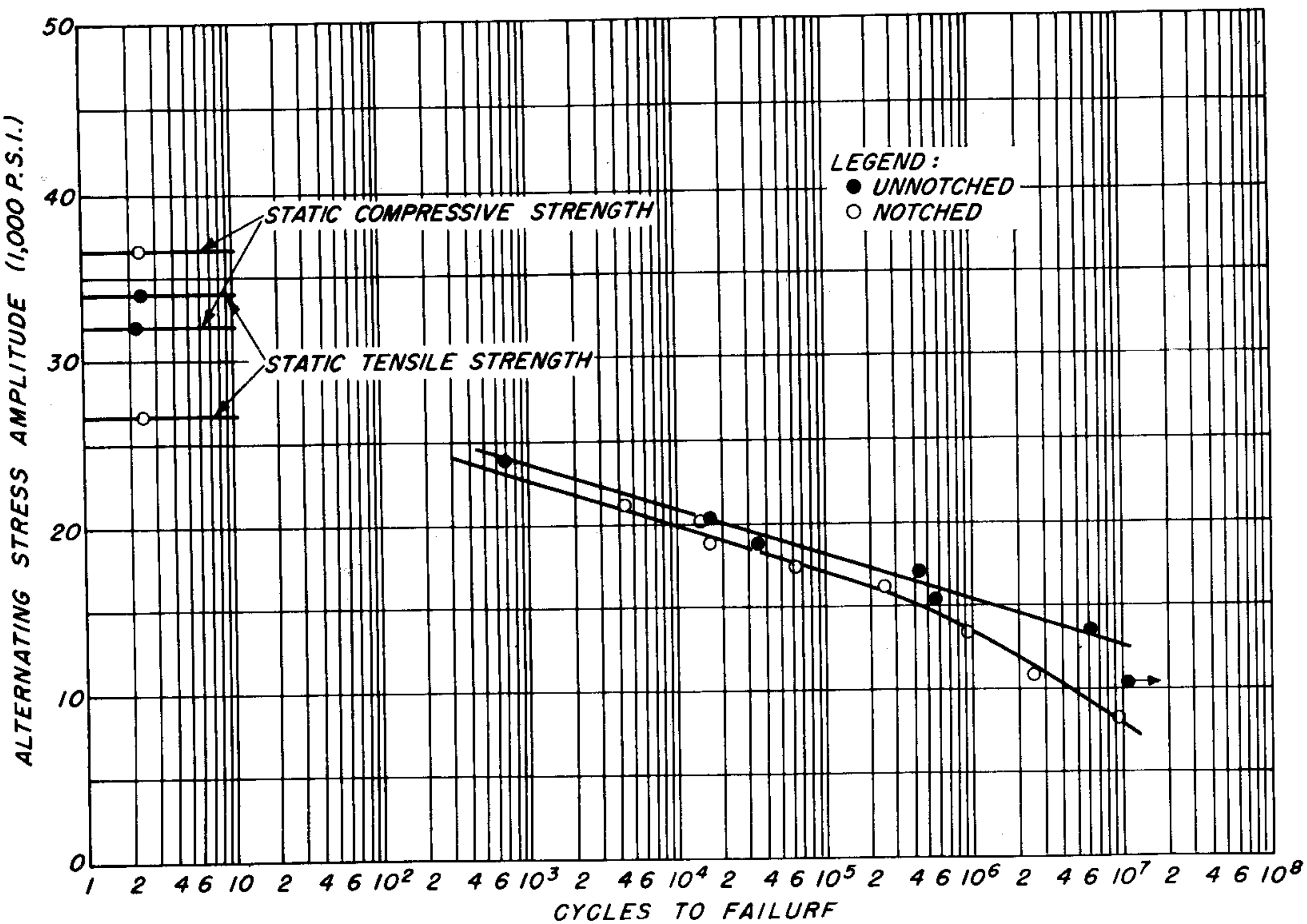

Figure 31.--S-N curves of notched and unnotched specimens of heat-resistant phenolic resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp, 300° F., and zero mean stress.

Z M 107 309

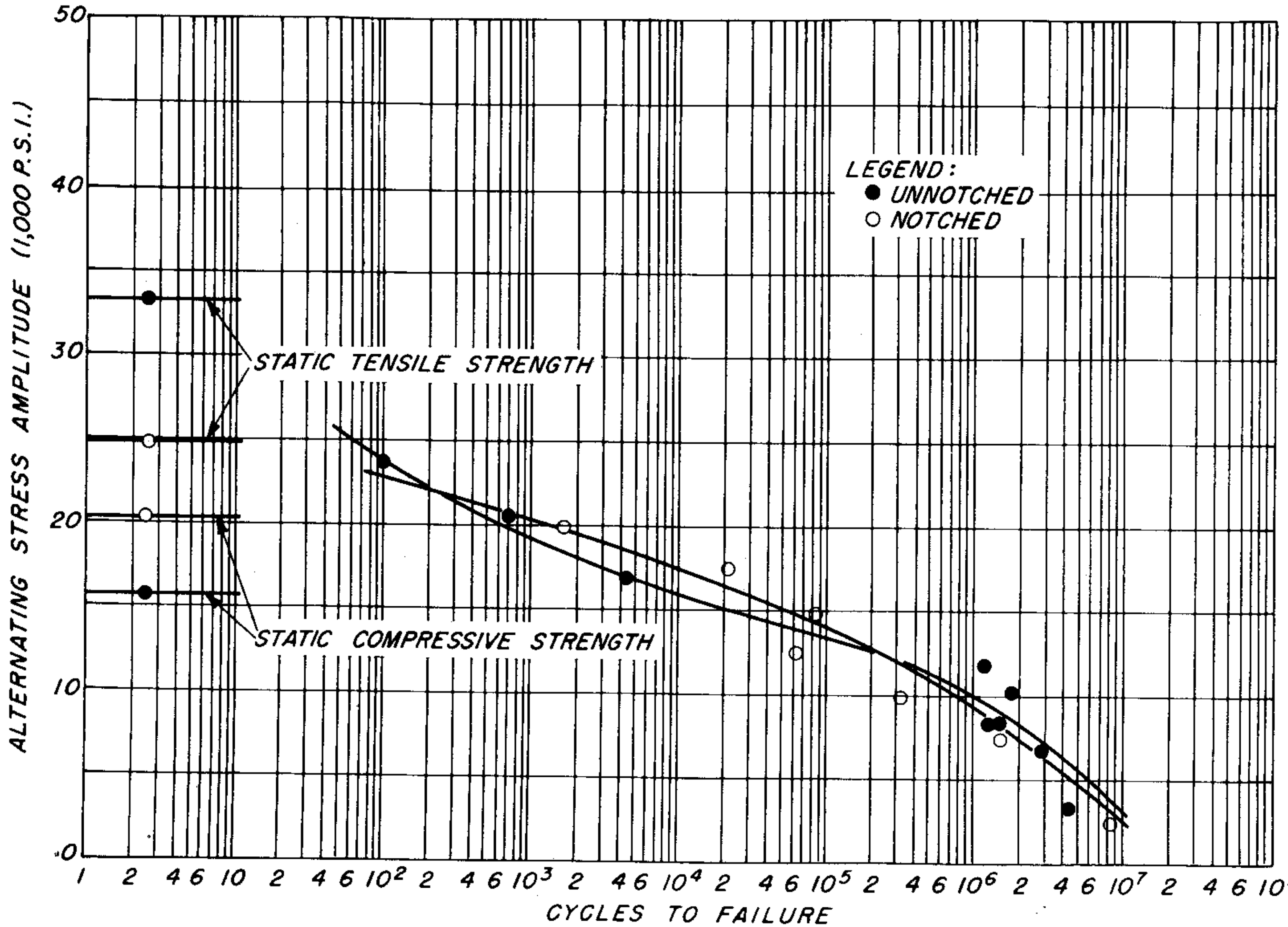

Figure 32.--S-N curves of notched and unnotched specimens of heat-resistant phenolic resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp, 500° F., and zero mean stress.

Z M 107 310

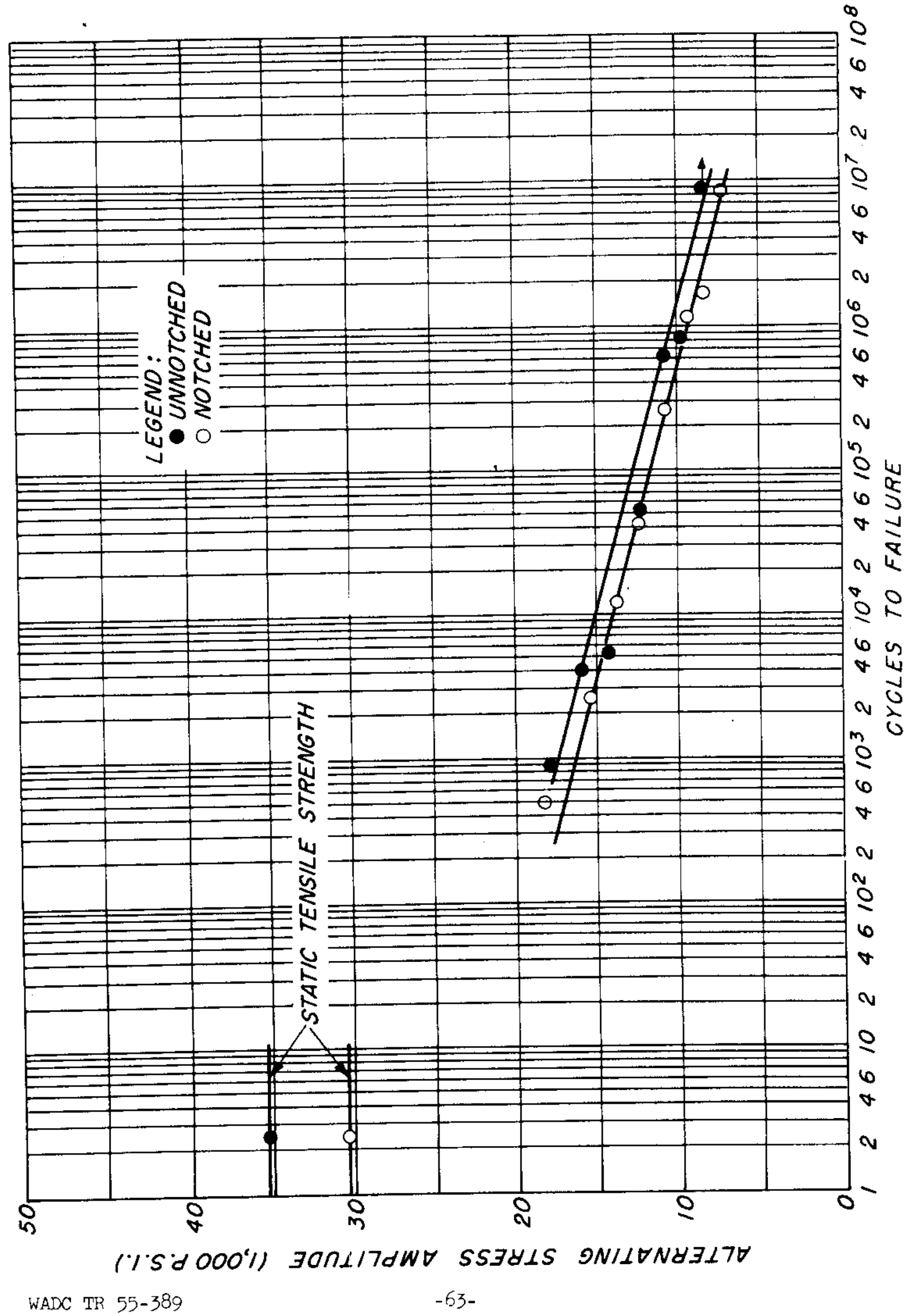

Figure 33.--S-N curves of notched and unnotched specimens of heat-resistant silicone resin reinforced with 181 glass fabric, heat cleaned, and tested at 0° to warp, 73° F, and 50 percent relative humidity, and zero mean stress.

Z M 107 311

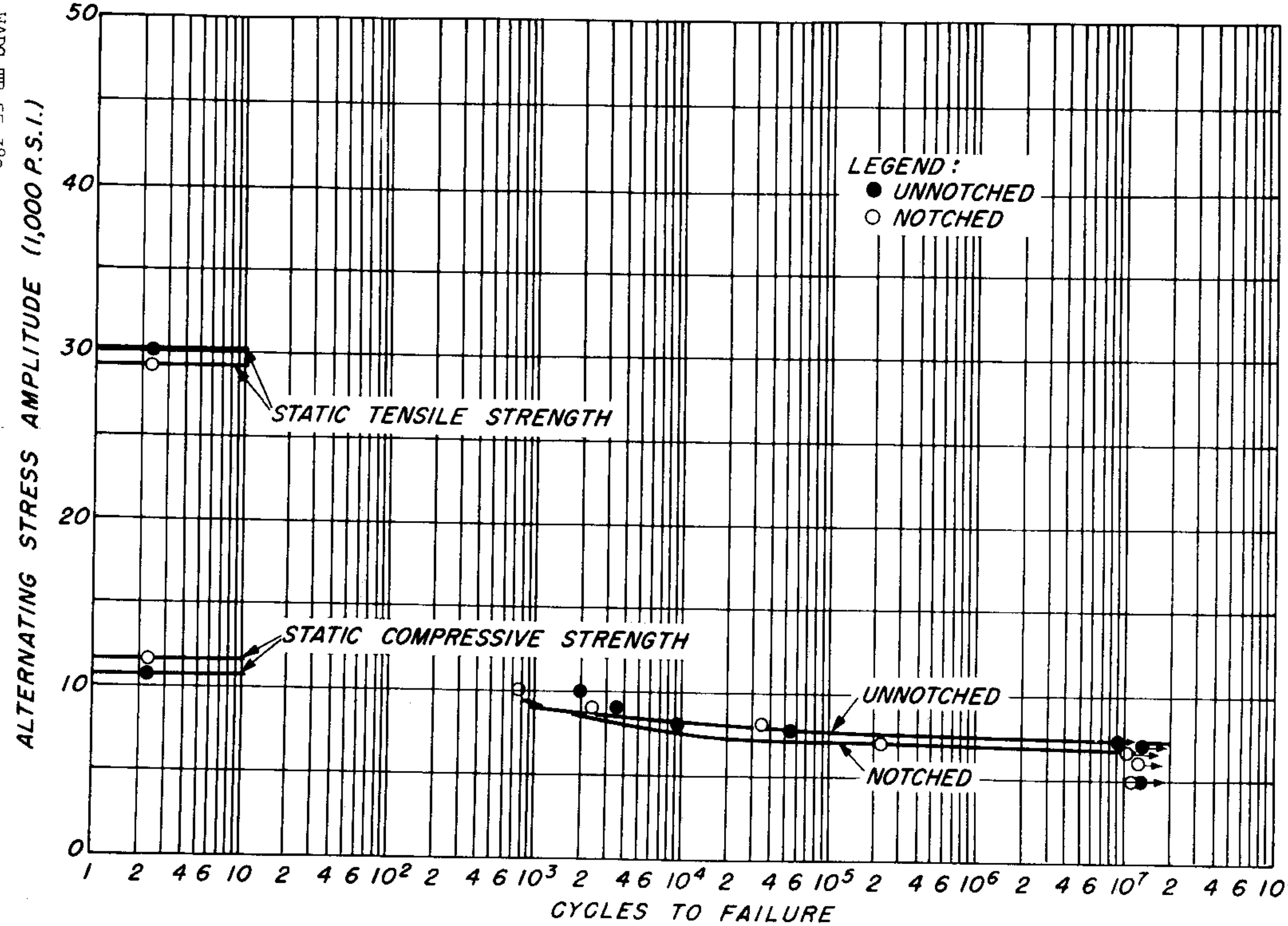

Figure 34.--S-N curves of notched and unnotched specimens of heat-resistant silicone resin reinforced with 181 glass fabric, heat cleaned, and tested at 0° to warp, 300° F., and zero mean stress.

Z M 107 312

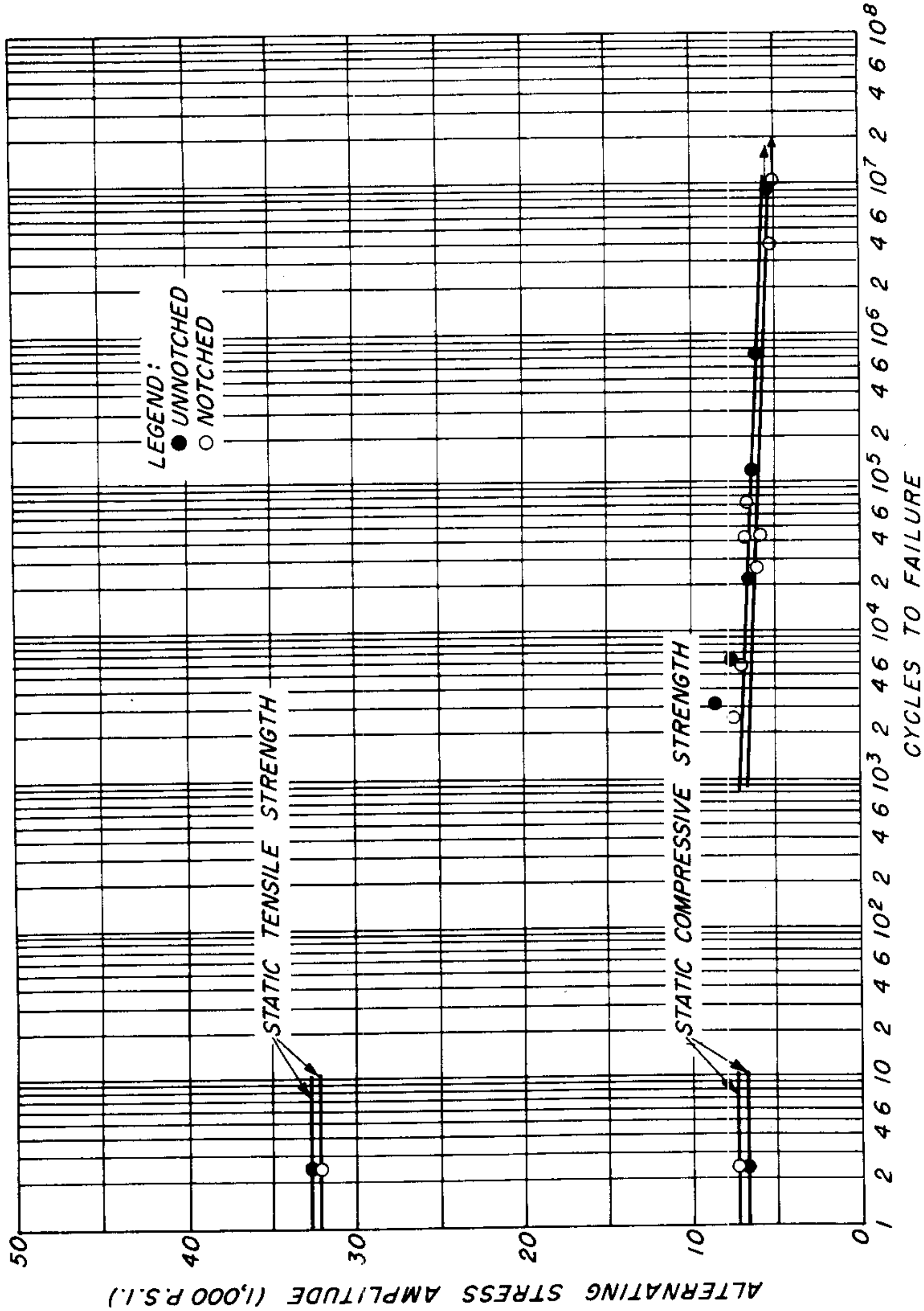

Figure 35.--S-N curves of notched and unnotched specimens of heat-resistant silicone resin reinforced with 181 glass fabric, heat cleaned, and tested at 0° to warp, 500° F., and zero mean stress.

Z M 107 313

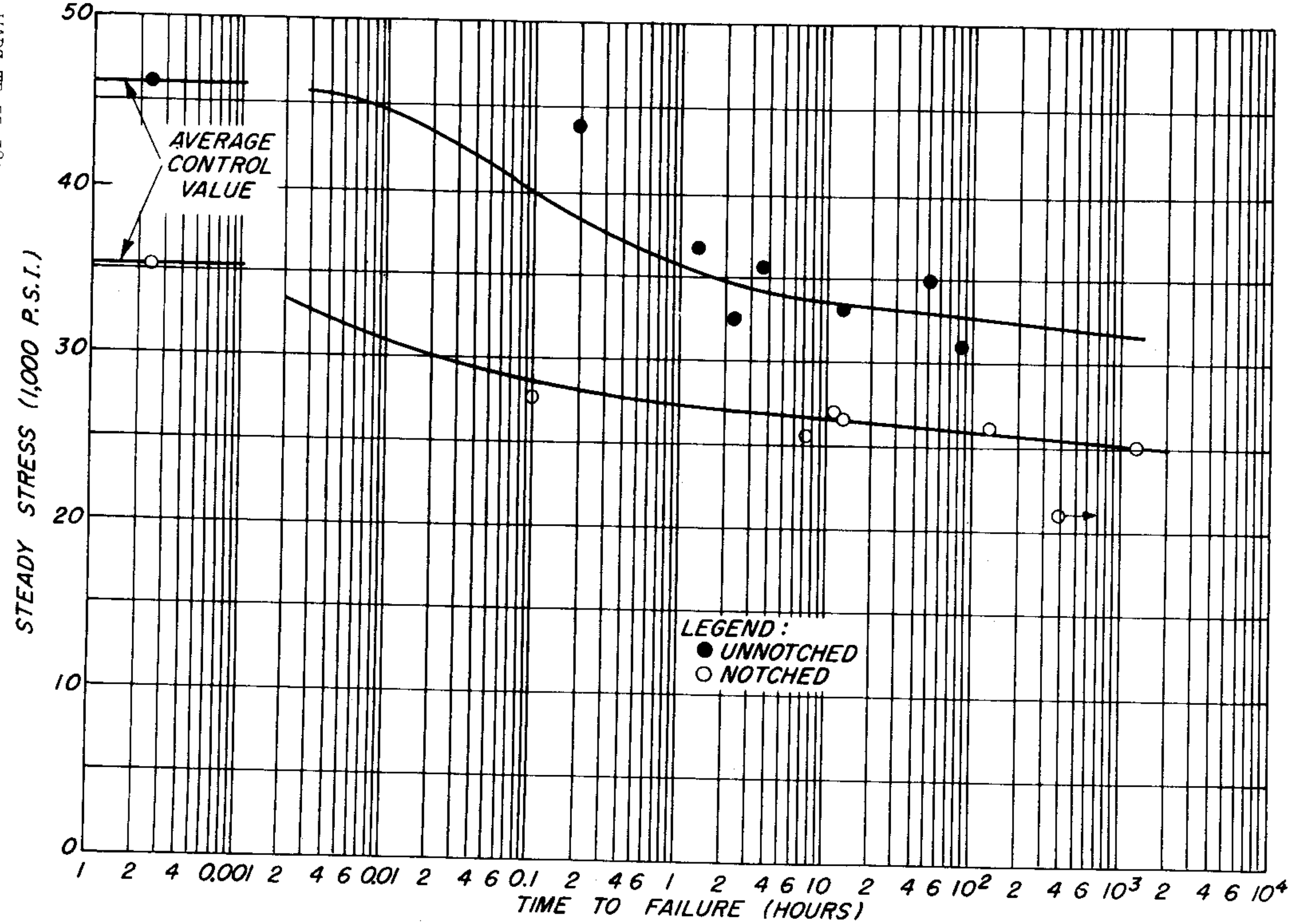

Figure 36.--Tensile stress-rupture curves of notched and unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp at 73° F. and 50 percent relative humidity.

Z M 107 314

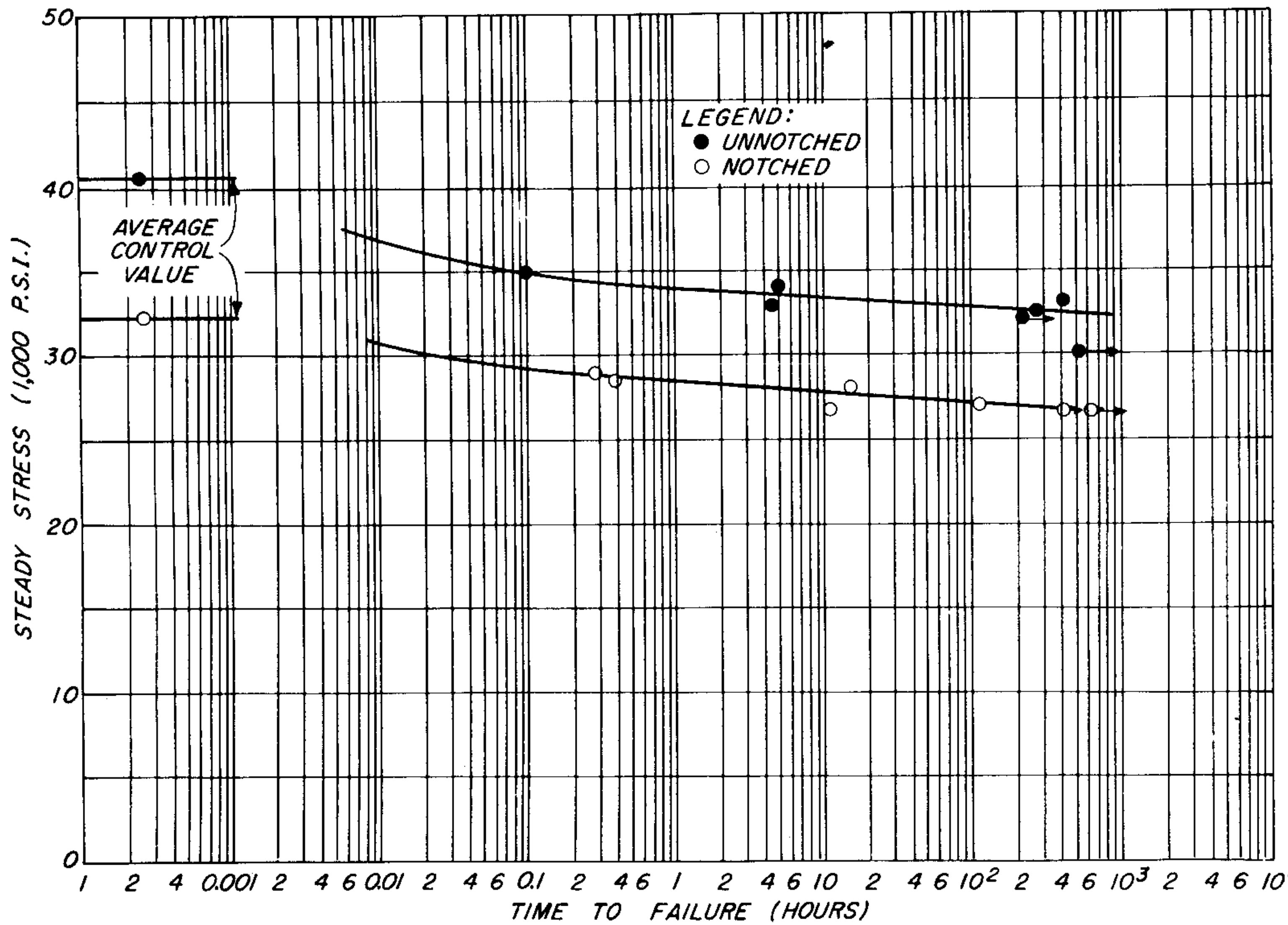

Figure 37.--Tensile stress-rupture curves of notched and unnotched specimens of heat resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp at 300° F.

Z M 107 315

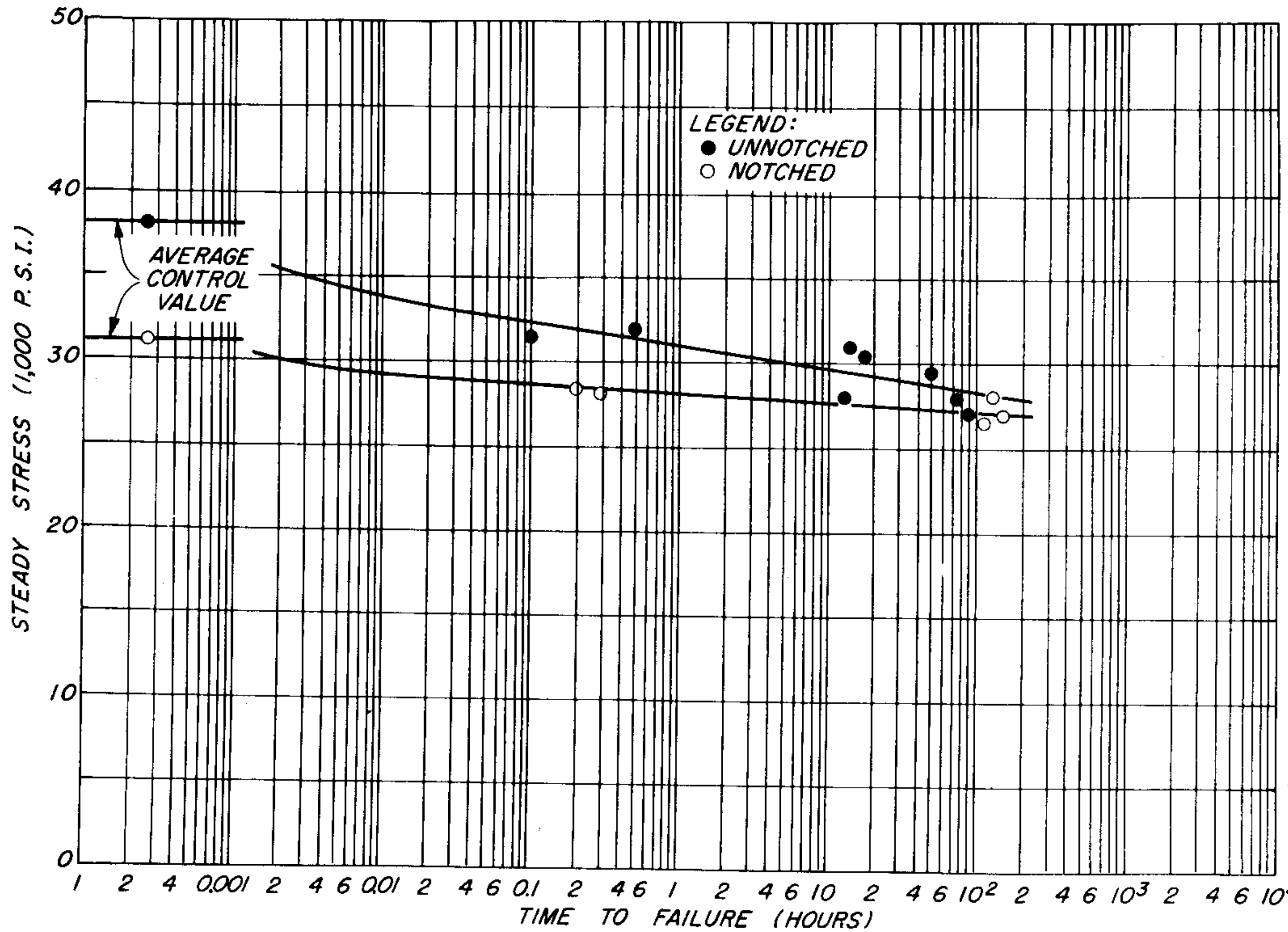

Figure 38.--Tensile stress-rupture curves of notched and unnotched specimens of heat resistant polyester resin reinforced with 181 glass fabric, Volan A finish. and tested at 0° to warp at 500° F.

Z M 107 316

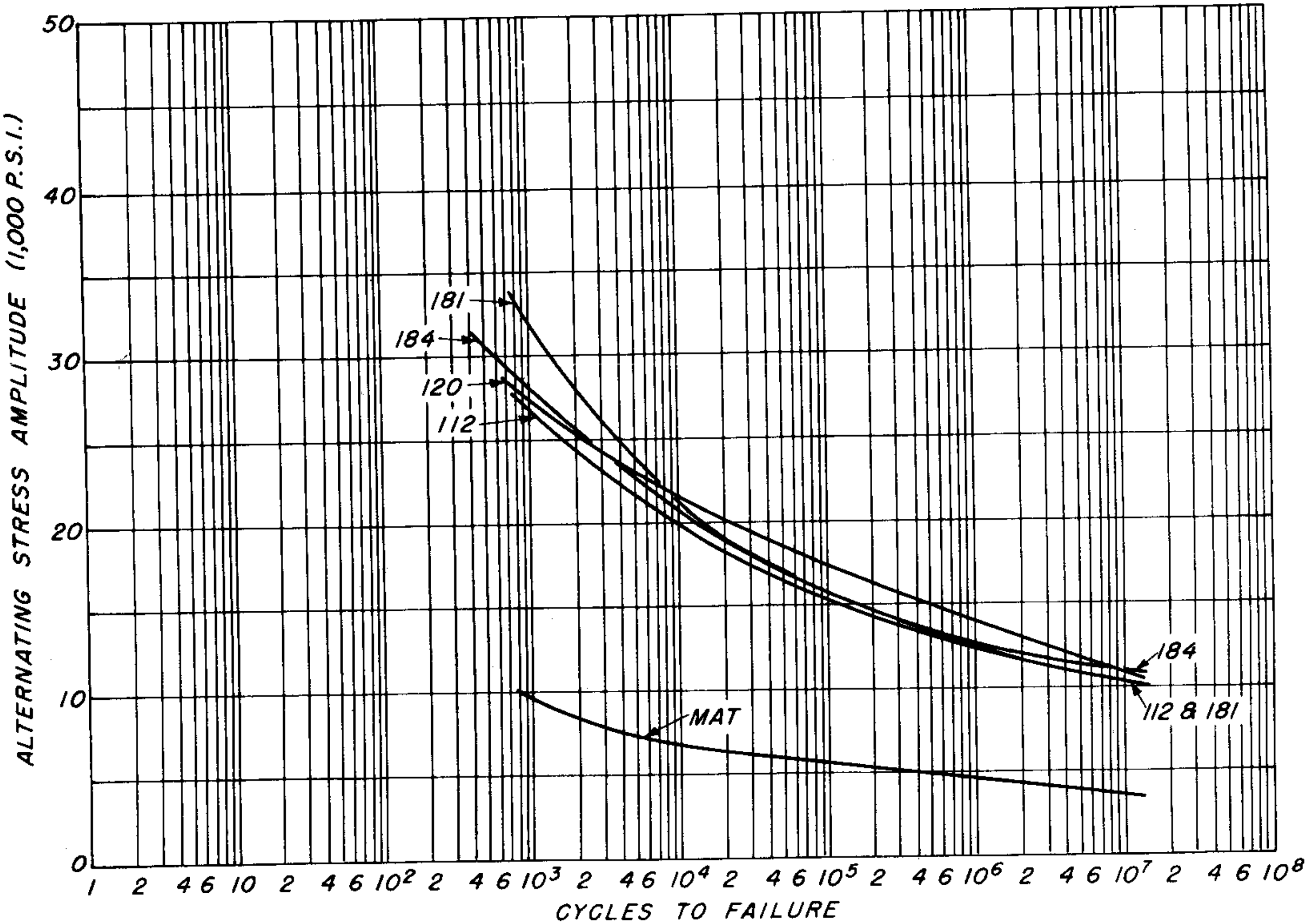

Figure 39.--S-N curves of unnotched specimens of polyester resin reinforced with various glass fabrics and a glass mat, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 317

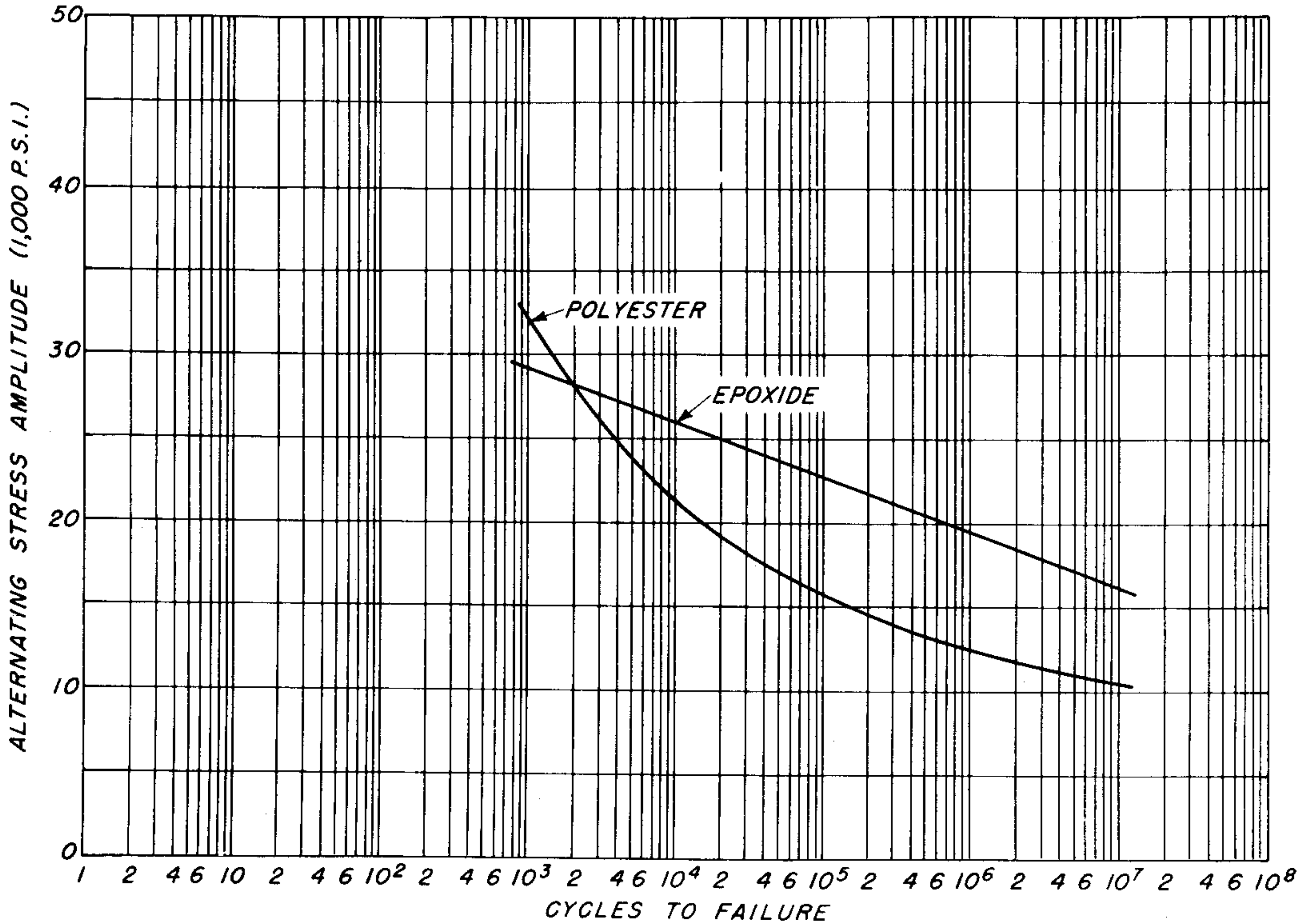

Figure 40.--S-N curves of unnotched specimens of polyester and epoxide resins reinforced with 181 glass fabric, Volan A finish, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 318

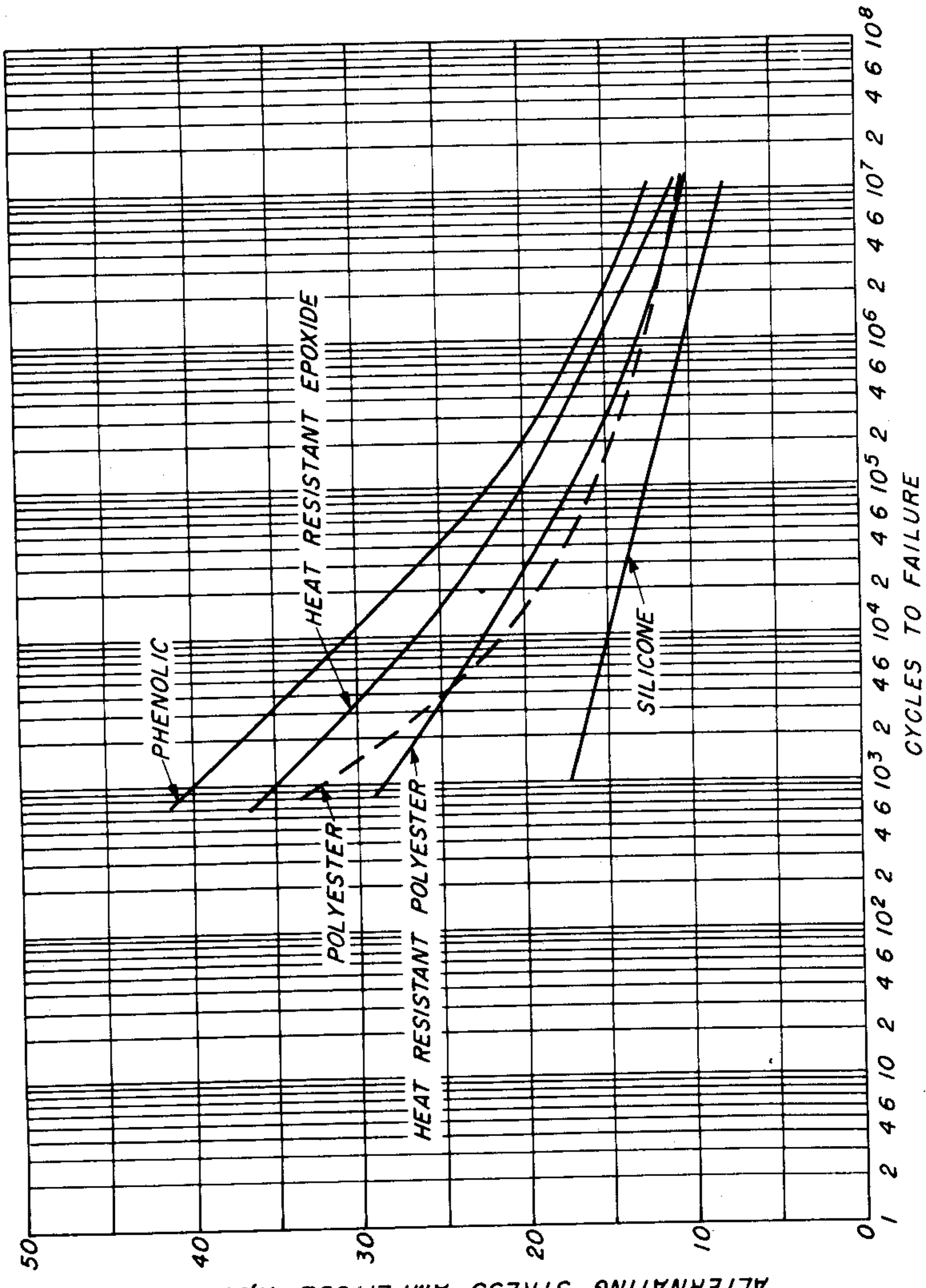

Figure 41.--S-N curves of unnotched specimens of heat-resistant resins reinforced with 181 glass fabric, and tested at 0° to warp, 73° F. and 50 percent relative humidity, and zero mean stress.

Z M 107 319

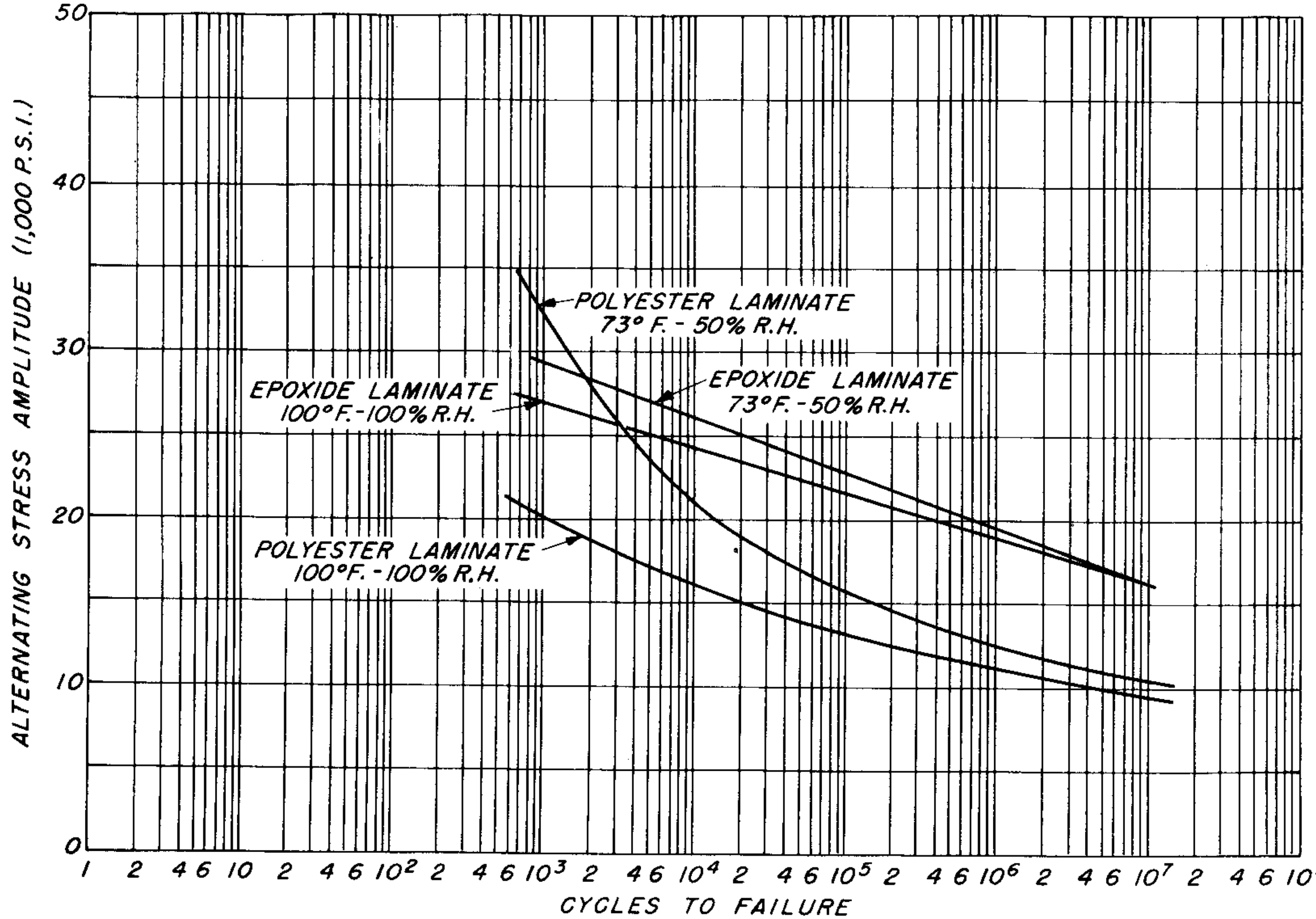

Figure 42.--S-N curves of unnotched specimens of polyester and epoxide resins reinforced with 181 glass fabric, Volan A finish, showing effect of moisture. Test conditions: 0° to warp, zero mean stress.

Z M 107 320

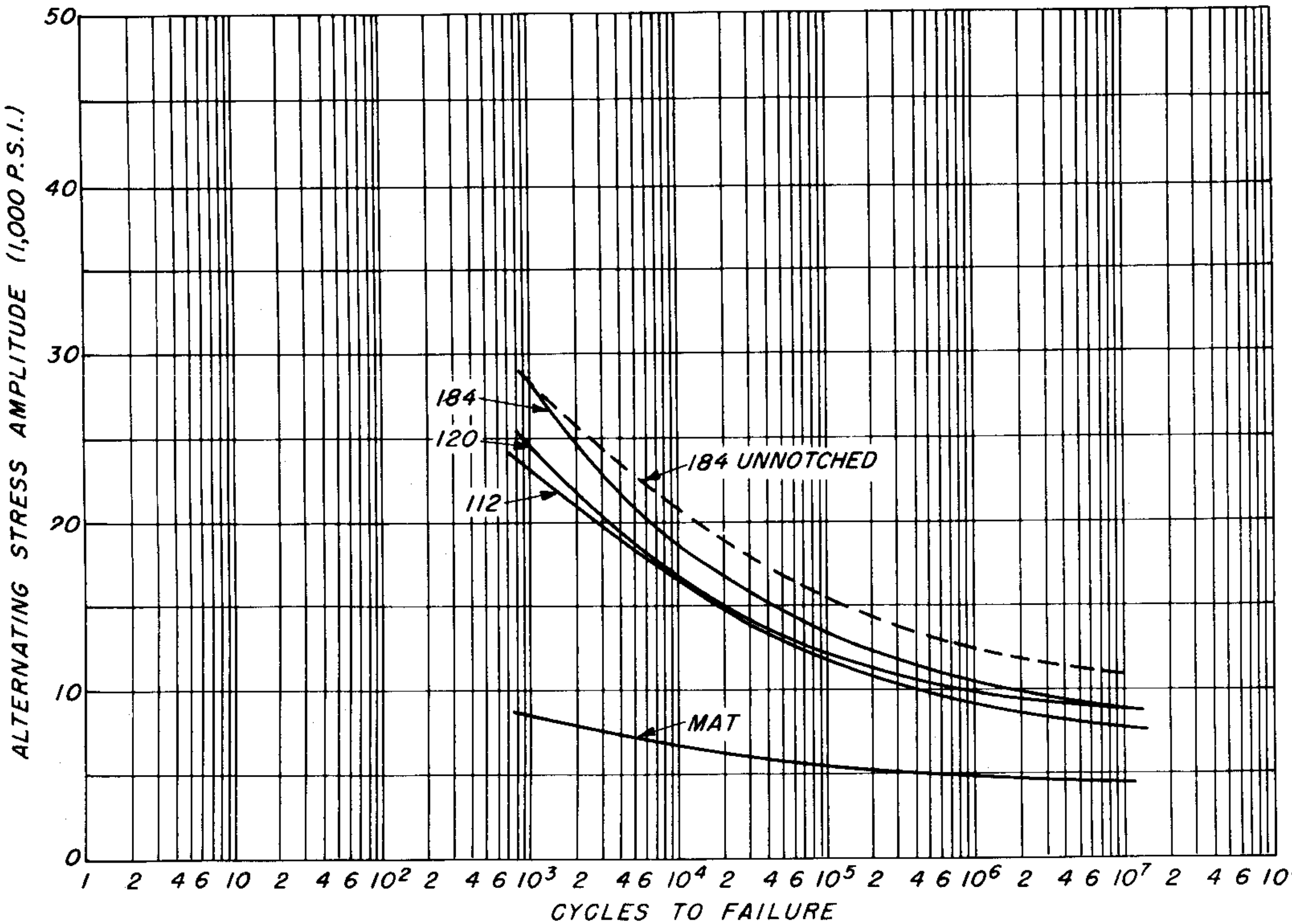

Figure 43.--S-N curves of notched specimens of polyester resin reinforced with various glass fabrics and a glass mat, showing effect of notch. Test conditions: 0° to warp, 73° F. and 50 percent relative humidity, zero mean stress.

Z M 107 321

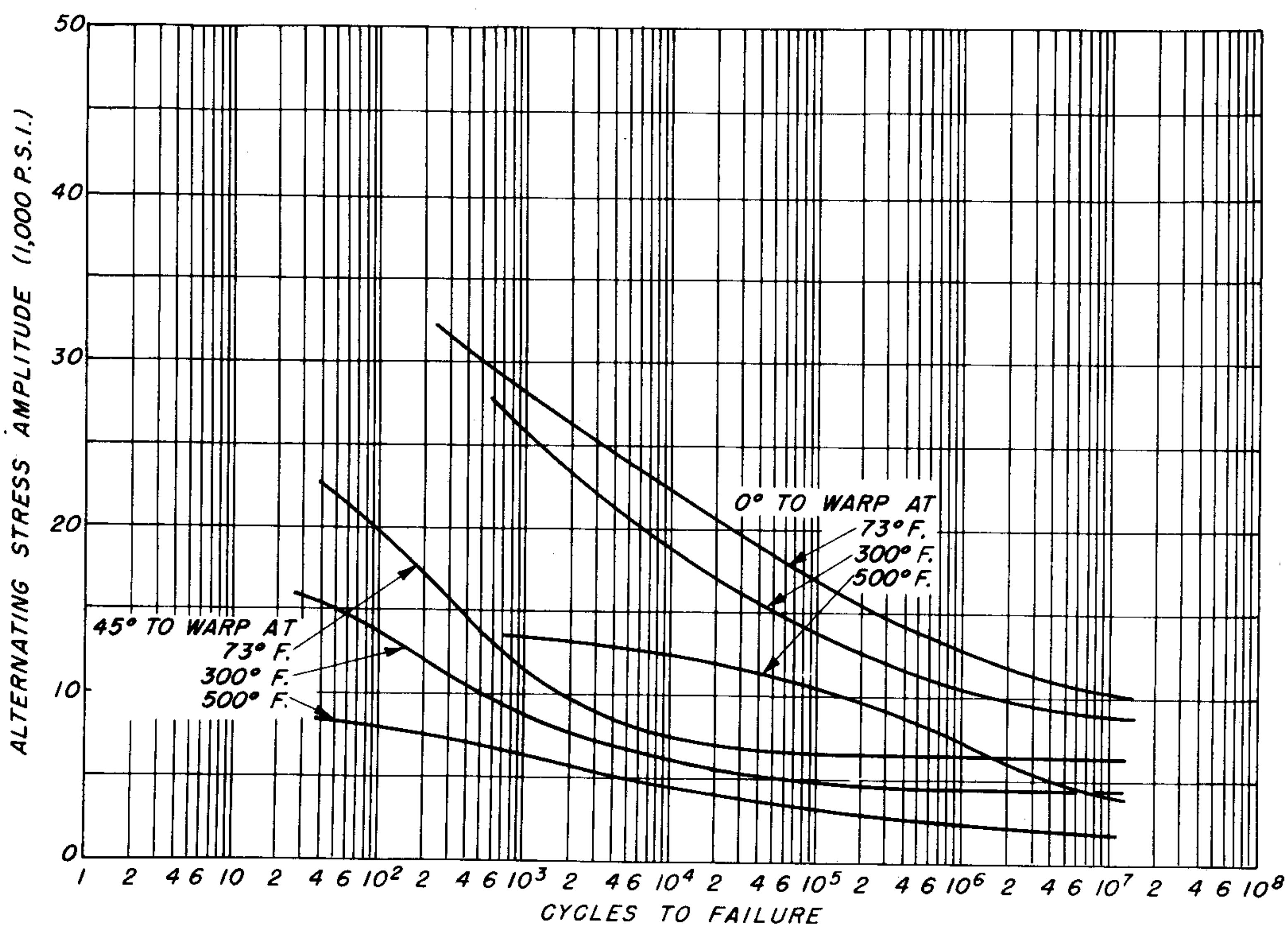

Figure 44.--S-N curves of unnotched specimens of heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, showing effect of temperature and direction of loading. Test condition: zero mean stress.

Z M 107 322

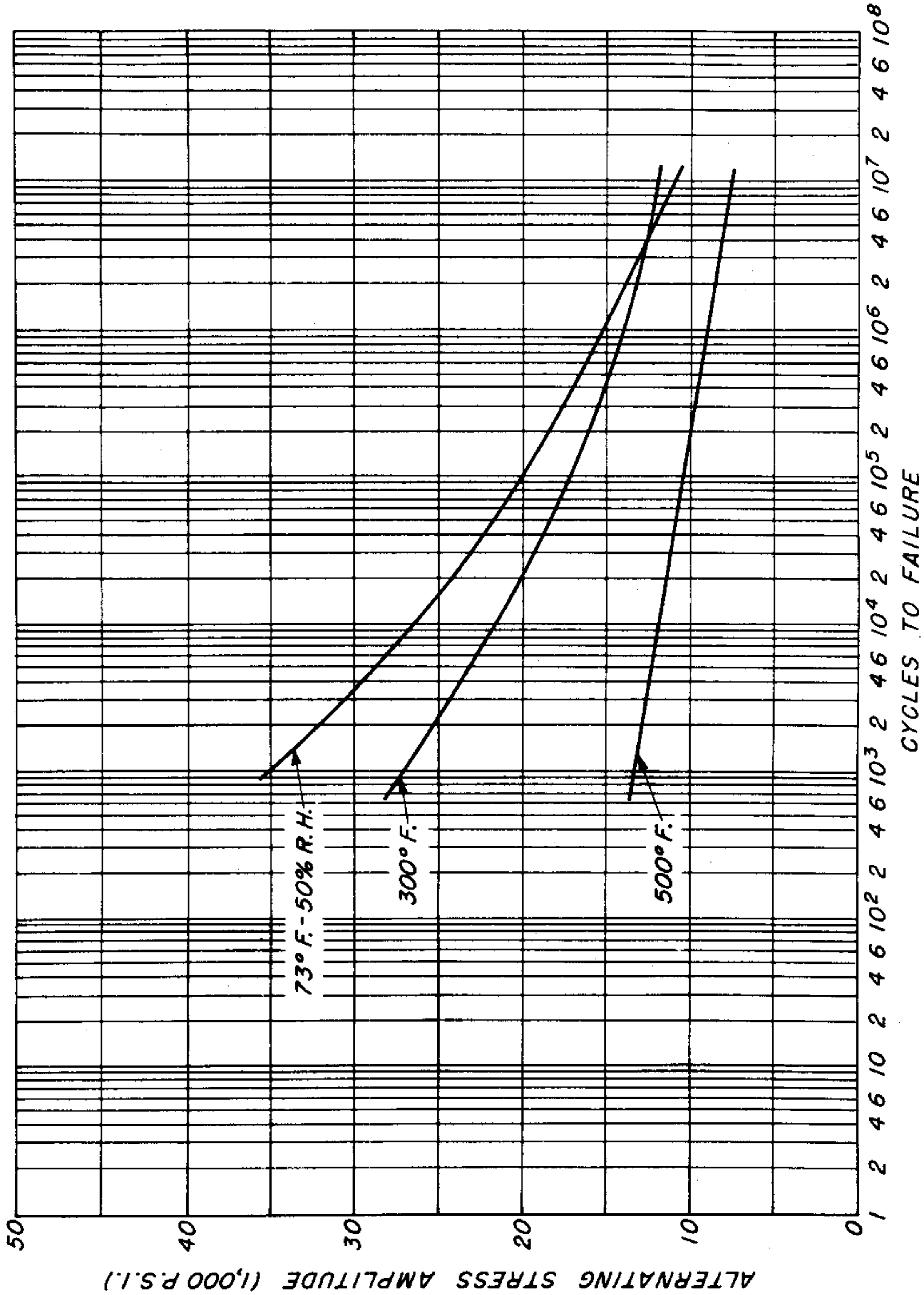

Figure 45.--S-N curves of unnotched specimens of heat-resistant epoxide resin reinforced with 181 glass fabric, Volan A finish, showing effect of temperature. Test conditions: 0° to warp, zero mean stress.

Z M 107 323

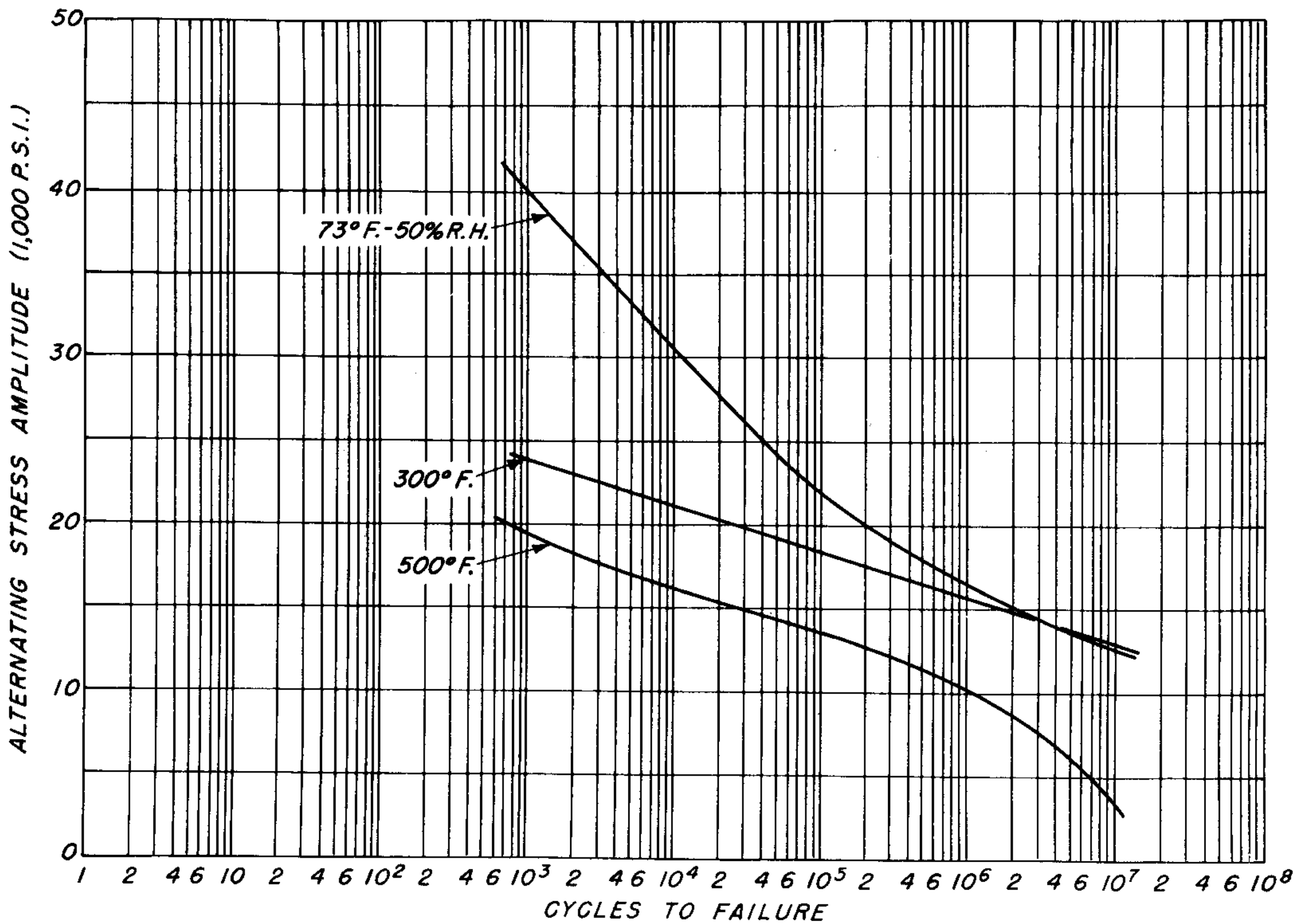

Figure 46.--S-N curves of unnotched specimens of heat-resistant phenolic resin reinforced with 181 glass fabric, Volan A finish, showing effect of temperature. Test conditions: 0° to warp, zero mean stress.

Z M 107 324

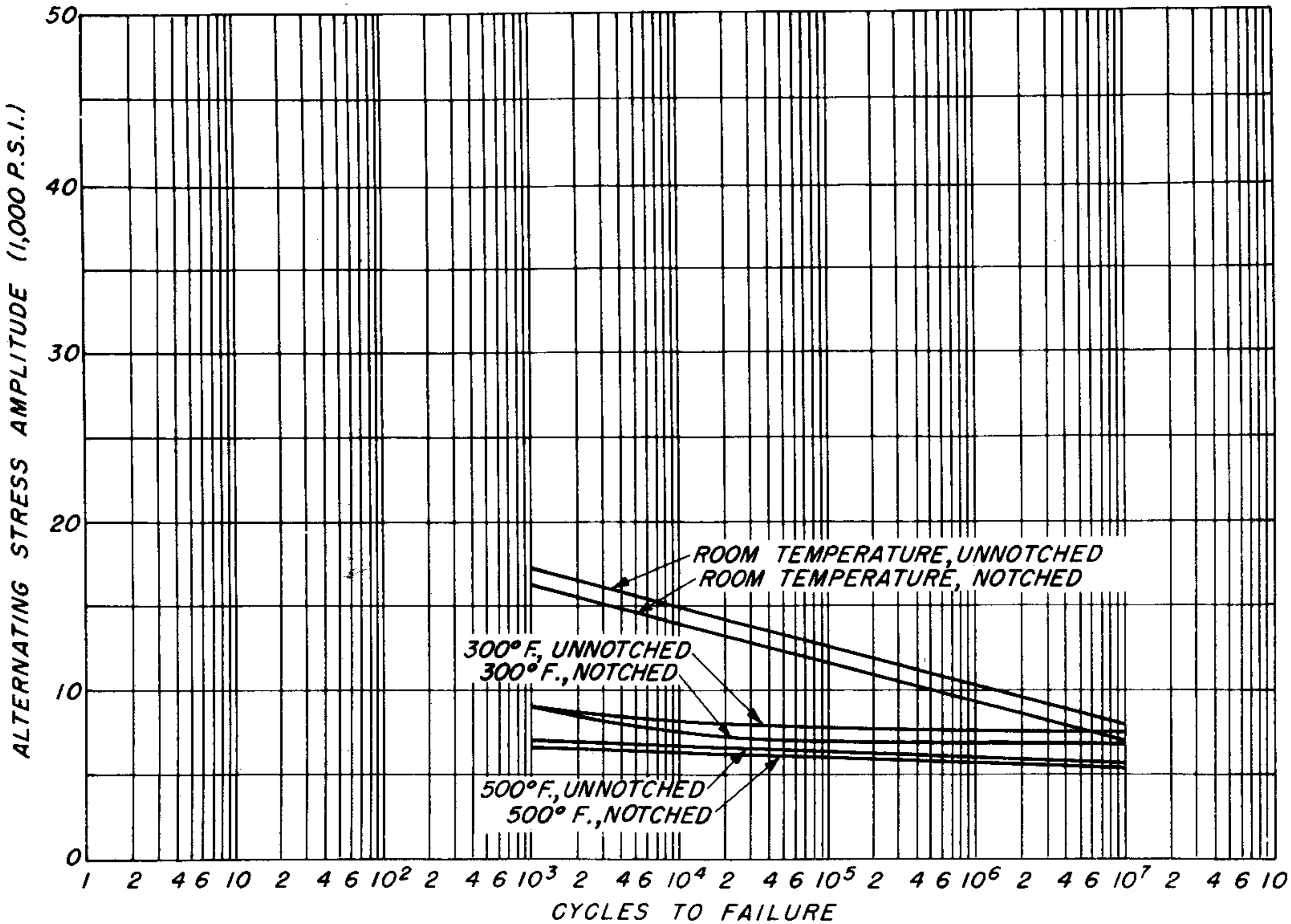

Figure 47.--S-N curves of notched and unnotched specimens of heat-resistant silicone resin reinforced with 181 glass fabric, heat cleaned, showing effects of temperature and notching. Test conditions: 0° to warp, zero mean stress.

Z M 107 325

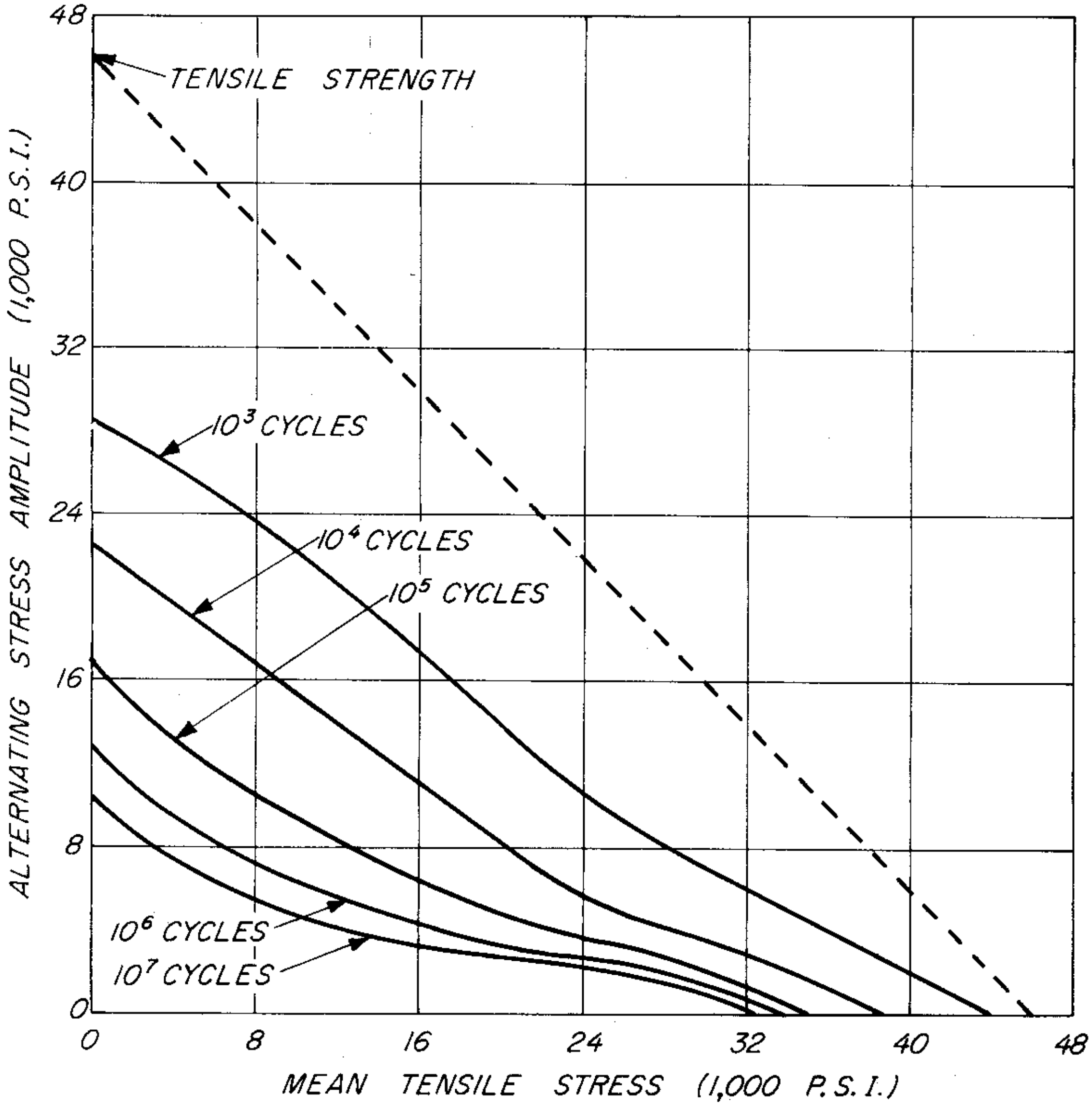

Figure 48.--Effect of mean stress on alternating stress amplitude of unnotched, heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, tested at 73° F. and 50 percent relative humidity.

Z M 107 326

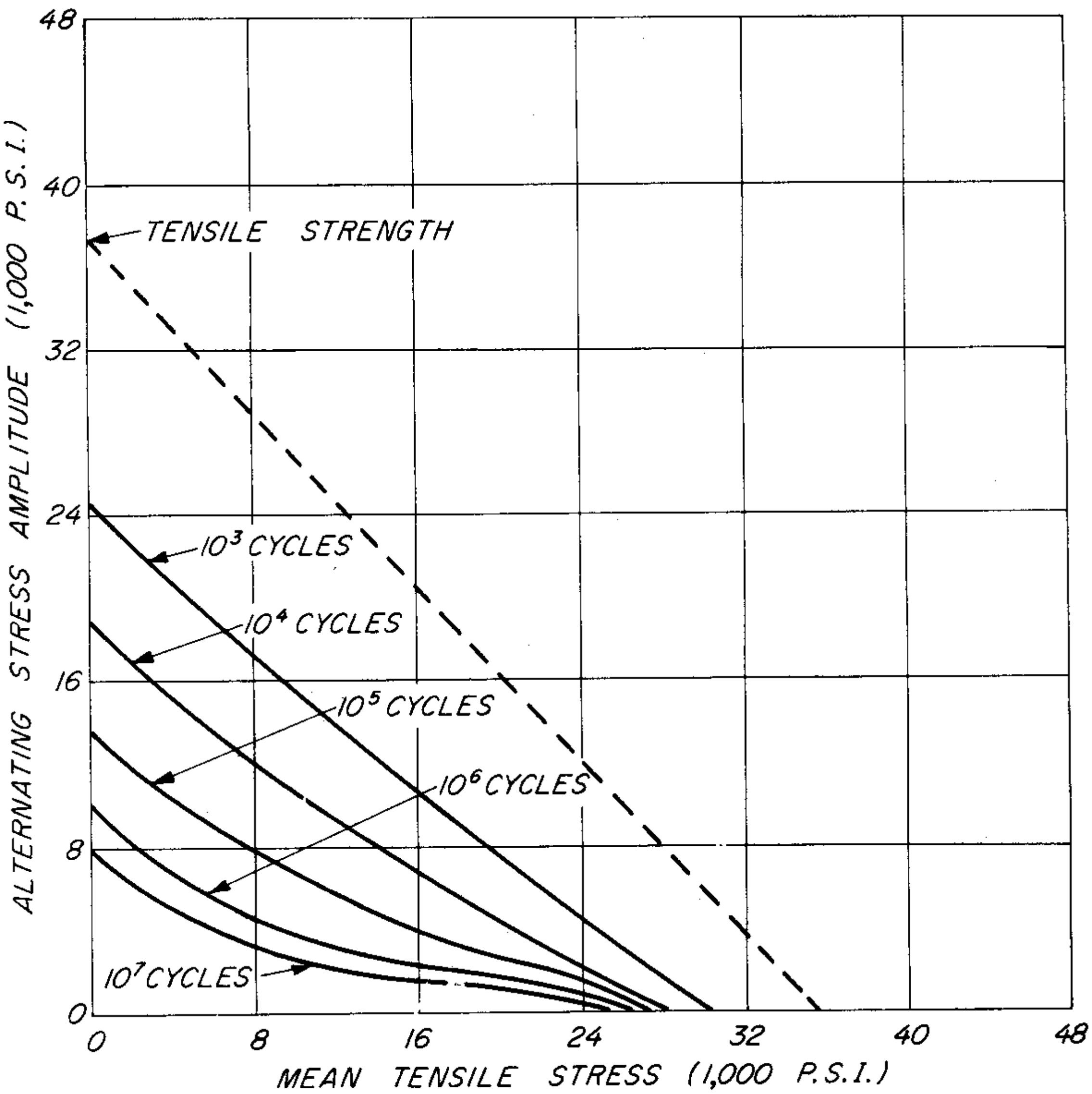

Figure 49.--Effect of mean stress on alternating stress amplitude of notched, heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, and tested at 73° F. and 50 percent relative humidity.

Z M 107 327

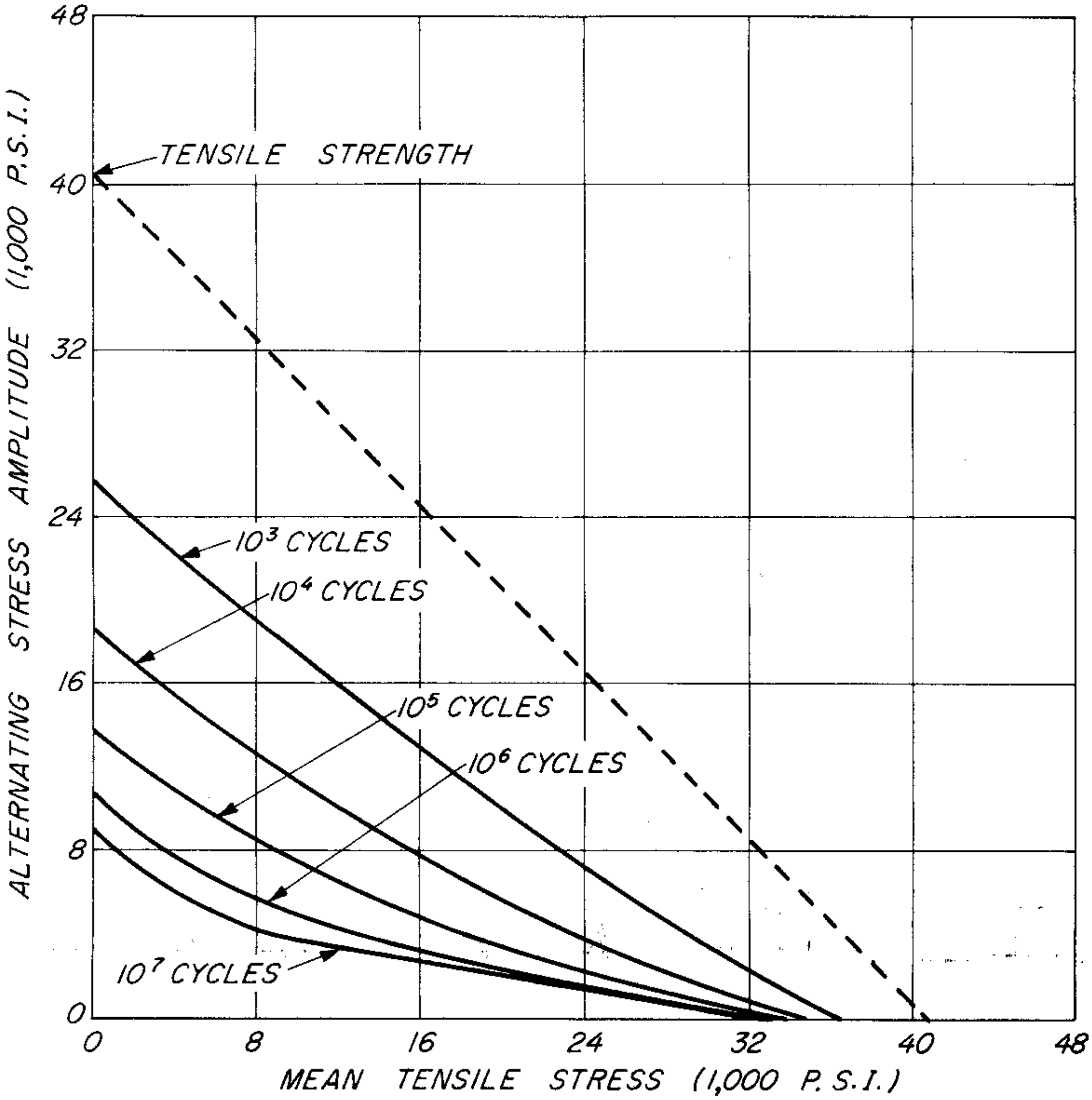

Figure 50.--Effect of mean stress on alternating stress amplitude of unnotched heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, tested at 300° F.

Z M 107 328

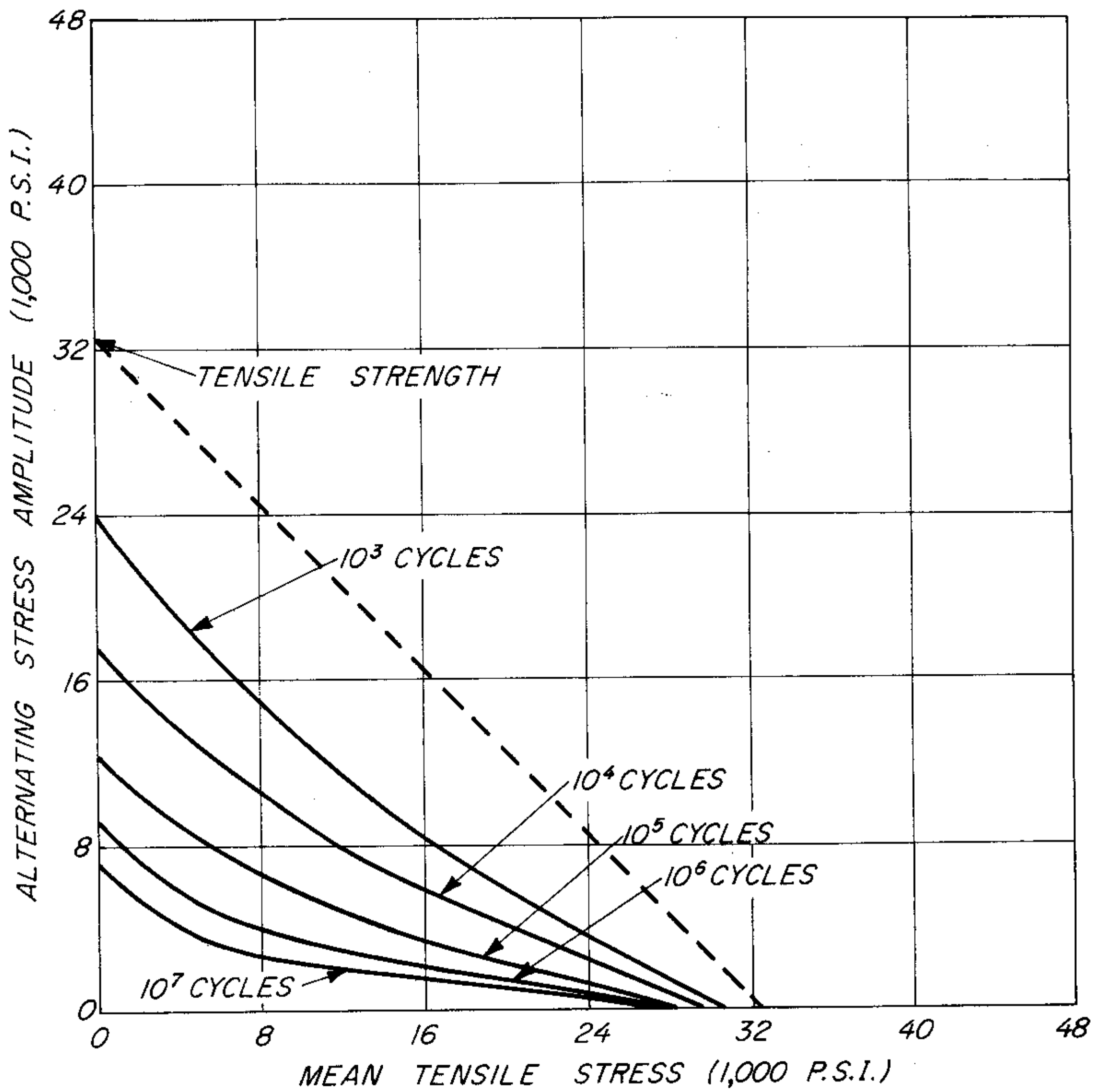

Figure 51.--Effect of mean stress on alternating stress amplitude of notched, heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, tested at 300° F.

Z M 107 329

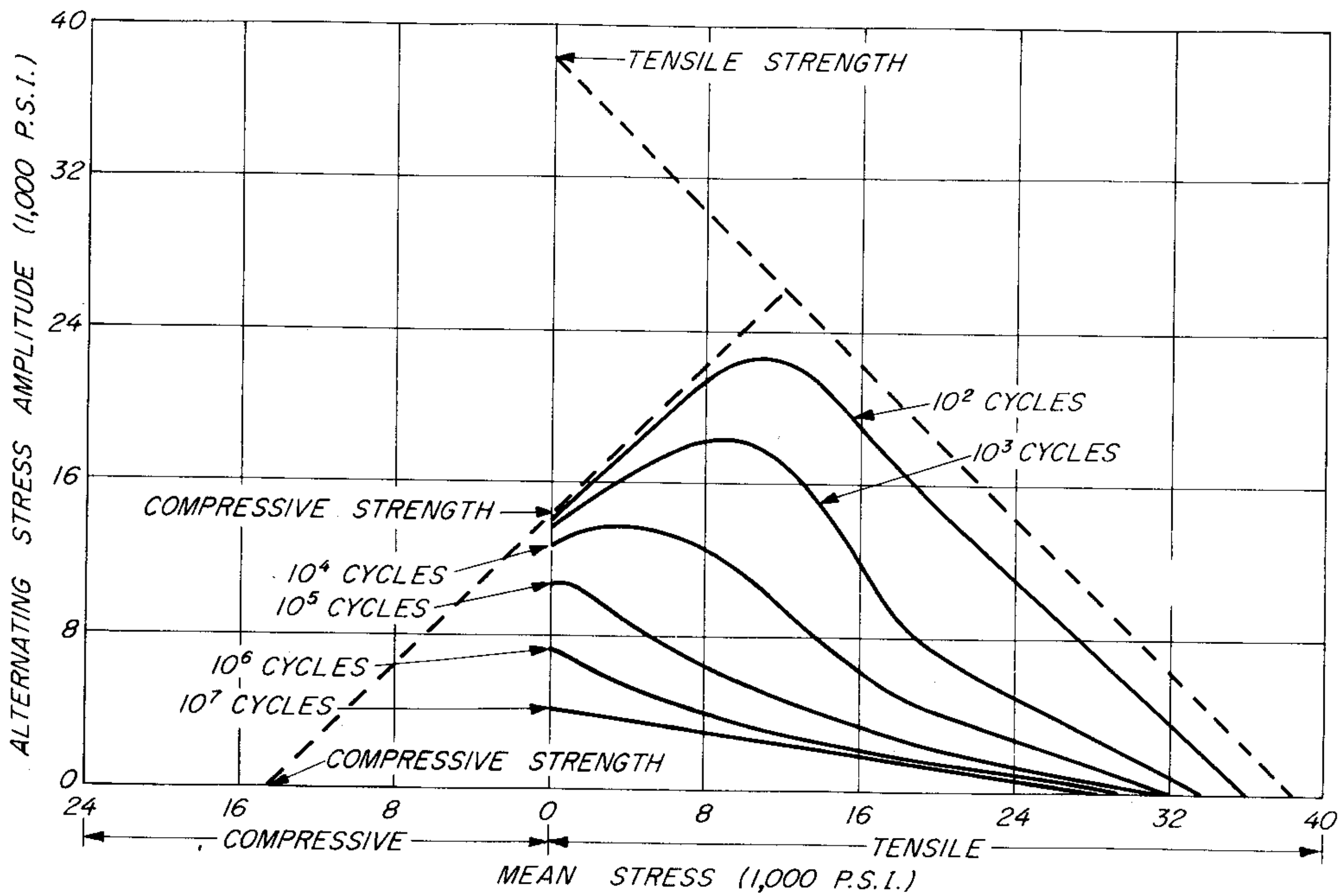

Figure 52.--Effect of mean stress on alternating stress amplitude of unnotched heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, tested at 500° F.

Z M 107 330

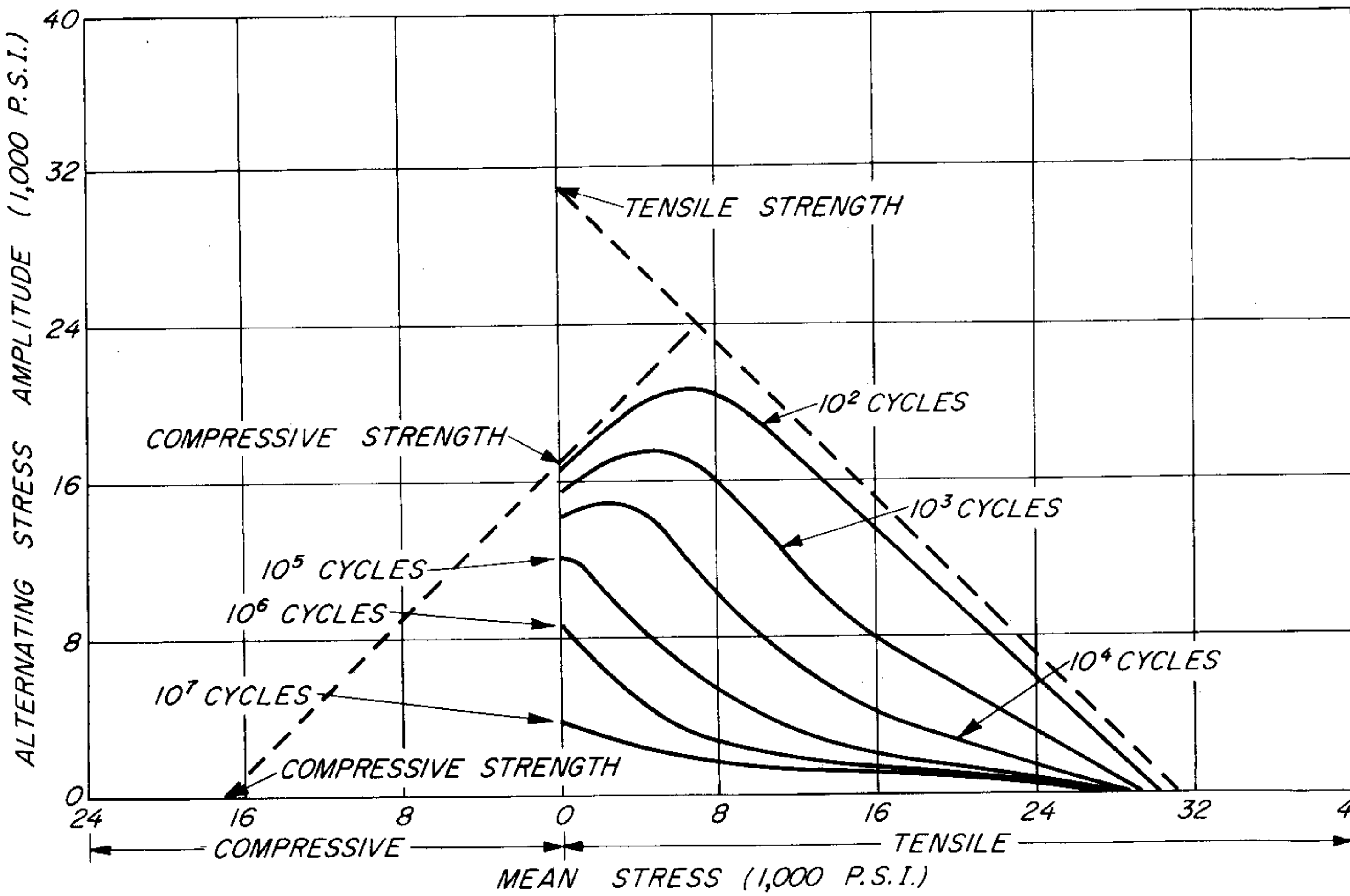

Figure 53.--Effect of mean stress on alternating stress amplitude of notched, heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, tested at 500° F.

Z M 107 331

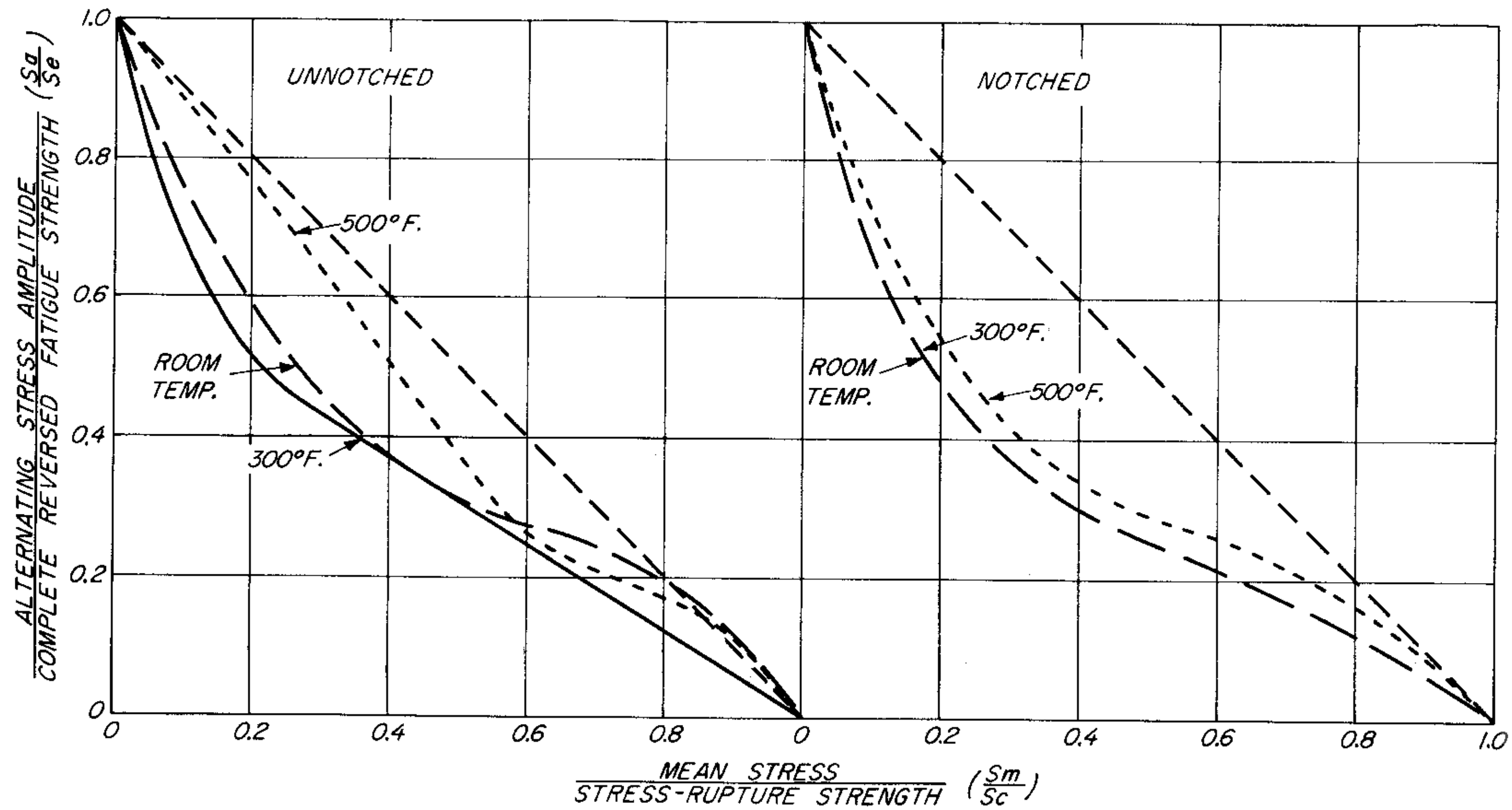

Figure 54.--Non-dimensional modified Goodman diagrams for notched and unnotched, heat-resistant polyester resin reinforced with 181 glass fabric, Volan A finish, for room and elevated temperature at 10 million cycles.

Z M 107 332