FATIGUE TESTS OF GLASS-FABRIC-BASE LAMINATES SUBJECTED TO AXIAL LOADING

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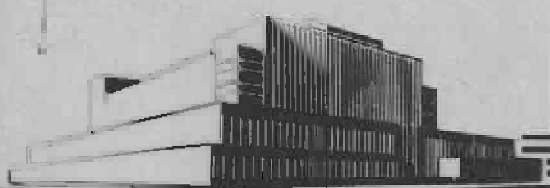

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

FATIGUE TESTS OF GLASS-FABRIC-BASE LAMINATES

SUBJECTED TO AXIAL LOADING[1]

By

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Summary and Conclusions

The fatigue properties of three glass-fabric-base plastic laminates were determined by axial loading. These reinforced plastics conformed to the minimum requirements of USAF specification No. 12051 for laminates and USAF specification No. 12049 for resins, although the ultimate compressive strength of one laminate was higher than is considered typical for these polyester-type laminates.

S-N curves were obtained between 1 thousand and 10 million cycles for determining the fatigue strength and the effect on the fatigue strength of notch, moisture, fan cooling, warp direction, various mean stresses, or a combination of these. Fatigue strength as used in this report is the greatest stress that can be sustained for a given number of cycles without fracture. When the mean stress is zero, the greatest stress is equal to the alternating stress amplitude. In general, the fatigue strength of the control specimens, which is the alternating stress amplitude at 10 million cycles of unnotched specimens at a temperature of 73° F. and at 50 percent relative humidity with a mean stress of zero, was found to be between 22 and 29 percent of the static tensile strength. The presence of a notch in the specimen in the dry condition reduced the strength an additional 3 to 6 percent. Neither the presence of moisture nor absence of the cooling fan affected the fatigue strength at 10 million cycles, although at 10 thousand cycles, moisture or fan cooling did affect the

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[2]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

fatigue strength. At 10 thousand cycles, where the fatigue strength of dry, unnotched specimens was about 50 percent of static tensile strength, the fatigue strength of wet unnotched specimens was 33 percent and that of uncooled, unnotched specimens was 45 percent of the static tensile strength. The fatigue strength of the laminate at 45 degrees to warp was between 14 and 22 percent of the static tensile strength of the laminate at 45 degrees to the warp, depending on the notch or moisture. The S-N curves of the laminates at 45 degrees to warp leveled off after approximately 40 thousand cycles.

Mean stresses of zero, one-half, and one-fifth of the static tensile ultimate stress were used to determine the effect of various mean stresses on the alternating stress amplitude at the dry notched and unnotched condition. Results at 10 million cycles showed that the alternating stress amplitude of specimens with a mean stress of one-half the static tensile stress was about one-tenth of the alternating stress amplitude of specimens having zero mean stress, and about 2 percent of the static tensile stress for both the notched and unnotched conditions. The ratio of the maximum stress (mean stress plus alternating stress) at 10 million cycles to the static tensile strength was found to be 0.22 for mean stress of zero and 0.52 for a mean stress of one-half static tensile strength.

Introduction

Since plastic laminates have been used as structural components in aircraft construction, the need for knowledge of their mechanical properties to contribute to more efficient design and construction has been apparent. Heretofore, some static strengths of plastics with glass-fabric base have been investigated, but few studies of the fatigue strengths have been undertaken. In order to increase the basic knowledge of glass-fabric-base plastic laminates, fatigue data were obtained by axially loading specimens from three laminates. Most of the specimens were loaded with a mean stress of zero, and a few were loaded with mean stresses other than zero.

The fatigue tests in this project were undertaken to provide comparisons of fatigue strength (1) of three glass-fabric-base laminates, (2) on one of these laminates at both 0° and 45° to the warp direction, (3) after exposure to moisture, and (4) as affected by a notch in the specimen. The fatigue tests were designed to provide S-N curves between 1 thousand and 10 million cycles for axially loaded specimens.

Description of Materials

Glass-fabric-base panels, approximately 1/4 by 36 by 36 inches, of 181-114 and 143-114 fabric having 23 plies each, were made by the Laboratory.

The 181-114 fabric in two laminates was parallel-laminated with two types of resin as follows: One laminate was made with a laminating resin (resin 2) of the alkyd-styrene type of polyester. The resin was catalyzed by 1.6 percent by weight with a mixture of tricresyl phosphate and benzoyl peroxide (each 50 percent by weight of the mixture), containing 3.3 percent active oxygen. The lay-up was made between cellophane-covered glass plates. Immediately after impregnation and lay-up, the panels were cured at a pressure of 13 pounds per square inch for 2 hours in a hot press at a temperature gradually increasing from 220° to 250° F.

The second laminate was made with a laminating resin (resin 1) of the diallylphthalate-alkyd polyester type. The sheets of fabric were impregnated separately and rolled up to permit the resin to soak into the fabric. After about 16 hours the sheets were unrolled and laid up in panel form. The panels were cured between cellophane-covered aluminum cauls at a pressure of 14 pounds per square inch for 1 hour and 30 minutes in a press at a temperature of 220° F.

The 143-114 fabric in the third laminate, which had 26 plies, was cross-laminated and impregnated with resin 2. The lay-up and cure of the laminate was the same as mentioned before for the first resin 2 laminate.

It should be noted that the materials tested were polyester laminates that conformed to USAF specification No. 12051 and that the two resins used conformed to USAF specification No. 12049. Specimens cut at random from panels of these three laminates and tested statically in tension and in compression according to standard practice showed the strength properties given in table 1.

It should also be noted that although these three laminates conformed to the minimum requirements of the USAF specifications, the ratios of ultimate strengths, tensile to compressive, were not exactly equal to the ratio of USAF specification No. 12049 or that reportedly usually obtained with other USAF specification No. 12049 polyester resins. In other words, the compressive strength was usually substantially lower than the tensile strength, as shown by strengths of laminates 2 and 3, while the two ultimate strengths of laminate 1 were nearly equal. Also, although the resin content of the laminate is not specified in USAF specification No. 12049, it is considered that between 35 and 45 percent would be necessary to meet the strength requirements. The resin content of laminate 3 was below this range, yet the strength values met the requirements.

Fatigue Specimen

The fatigue specimen was designed to meet one of the requirements of the test, i.e., it was to be loaded axially with equal alternate loads in tension and compression. In order to eliminate lateral support, which is necessary on a long, slender specimen during the compression cycle, the fatigue specimen had an unsupported length of only 2-1/4 inches. The net section in this length was 1/2 inch wide by the thickness. The over-all dimensions were 1-1/2 inches wide by 6 inches long by about 1/4 inch thick. The 1/2-inch-wide net section was between arcs of 4-inch radius (fig. 1).

The specimen was clamped at the ends so that its central portion, about 2-1/4 inches of the length, was axially stressed. During the compression cycle of the fatigue test, the column between clamps had a ratio of free length to least dimension of about 9, which was sufficiently small to prevent buckling during fatigue tests. The theoretical stress at the outside edge of the net section due to the 4-inch radius was about 1.1 times the average stress for an orthotropic laminate, according to calculations.[3] The actual effect of this 4-inch radius, as shown by static tests of unnotched fatigue specimens compared with specimens free of stress concentrations (controls), indicated that when the specimen was stressed in tension at 0 degrees to warp the ratio of control stress to average stress at the net section of the fatigue specimen was from 1.03 to 1.13, and that when stressed in compression at 0 degrees to warp the ratio was from 0.87 to 1.06.

About half of the fatigue specimens had a notch in the net section in the form of a circular hole at the center of the specimen. The hole was 1/8 inch in diameter with its axis perpendicular to the laminations. The theoretical stress at the edge of this centrally located notch is about 3-1/2 times the average stress, according to calculations.[4] The actual effect of the 4-inch radius and this notch, as shown by static tests of notched fatigue specimens, indicated that when the specimen was stressed in tension at 0 degrees to warp the ratio of control stress to average stress in material at the net section of fatigue specimen was from 1.25 to 1.39, and that when stressed in compression at 0 degrees to warp this ratio was from 0.83 to 0.94. Measurements of stress were not made across the width of the specimen to verify the theoretical magnitude of the stress at the edge of the notch.

The test specimens were obtained from their respective panels by a method of random selection. Specimens from laminate 1 were obtained from three panels. Two of these panels provided specimens with the axial direction at 0° to the warp of the fabric, and the remaining panel provided specimens at 45° to the warp. One panel for each of the remaining laminates, laminates 2 and 3, provided all the required specimens. The specimens

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[3] C. B. Smith. Effect of Hyperbolic Notches on the Stress Distribution in a Wood Plate. Quarterly of Applied Mathematics, vol. 6, No. 4.

[4] C. B. Smith. Effect of Elliptic and Circular Holes on the Stress Distribution in Plates of Wood or Plywood Considered as Orthotropic Materials. Forest Products Laboratory Report No. 1510 or A.N.C. Bull. No. 18A, formula 2:14.

were cut from the panels with a carborundum saw and were finished to the desired curvature by the use of an emery wheel mounted on a vertical shaper. The circular hole, which is the notch in the center of the specimen, was drilled carefully to minimize burs on the edges. No further polishing of the notch was undertaken.

Fatigue Tests

The effects of the notch, moisture, fan cooling, direction of load, and magnitude of mean stress were incorporated as variables in the testing conditions. S-N curves were obtained by testing a series of specimens under one condition consisting of one or more of the variables. The series of specimens tested with zero mean stress were as follows:

(1) A series of unnotched specimens from laminate 1, loaded at 0° to warp and tested at a temperature of 75° F. and 50 percent relative humidity with a blast of air directed on the specimen.

(2) A series of notched specimens tested the same as under (1).

(3) A series of unnotched specimens tested as under (1) without the blast of air.

(4) A series of unnotched specimens from laminate 1, loaded at 0° to warp, exposed about 30 days to 100° F. and 100 percent relative humidity atmosphere, then tested in a chamber having continuously moving air at 75° F. and 98 percent relative humidity.

(5) A series of specimens as under (4), except that the specimens were notched.

(6) A series of unnotched specimens from laminate 1, loaded at 45° to warp and tested at 75° F. and 50 percent relative humidity with an air blast for cooling.

(7) A series of notched specimens as under (6).

(8) A series of unnotched specimens from laminate 1, loaded axis at 45° to warp, exposed about 30 days to 100° F. and 100 percent relative humidity, then tested in a chamber having continuously moving air at 75° F. and 98 percent relative humidity.

(9) A series of notched specimens as under (8).

(10) A series of unnotched specimens from laminate 2, loaded at 0° to warp and tested at 75° F. and 50 percent relative humidity with a blast of air directed on the specimen for cooling.

(11) A series the same as (10) without the air-cooling.

(12) A series of notched specimens as under (10).

(13) A series of unnotched specimens from laminate 3, loaded at 0° to warp and tested at 75° F. and 50 percent relative humidity with a blast of air directed on the specimen for cooling.

(14) A series of notched specimens as under (13).

(15) A series of notched specimens from laminate 1, loaded at 0° to warp through a pin in the notch under exposure conditions of 75° F. and 50 percent relative humidity and air-cooled. The notch and pin in this series were 1/4-inch diameter (all others 1/8-inch diameter).

The following series of specimens were tested with mean stress other than zero.

(16) A series of unnotched specimens from laminate 1, loaded at 0° to warp and at 75° F. and 50 percent relative humidity, air-cooled, and with a mean stress of about one-half ultimate tensile strength.

(17) A series of unnotched specimens as under (16), except with a mean stress of about one-fifth ultimate tensile strength.

(18) A series of notched specimens as under (16), except with a mean stress of about one-half notched ultimate tensile strength.

(19) A series of notched specimens as under (16), except with a mean stress of about one-fifth notched ultimate tensile strength.

All of the fatigue specimens were axially loaded alternately in tension and compression, except those under series 16 and 18. The specimens were clamped at their ends by grips bolted to the loading screws of the test machine (fig. 2). Since the axes of the loading screws did not exactly coincide with each other, the upper and lower grips were rotated to bring the stationary faces of both grips into the same plane. The loads were acting axially on the specimen. Tension and compression loads were applied alternately by an eccentric of a direct-stress fatigue machine with a capacity of 10,000 pounds operating at 900 revolutions per minute. The static load that was first applied to the specimen was measured by a dial mounted on a bar that measured with deflection of the horizontal loading bar between 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 increase in dynamic load over the static load was measured by using metalectric strain gages mounted on the lower flexure plate and was recorded by a Wheatstone bridge and cathode-ray oscillograph.

The ratio of the minimum load to the maximum load (stress ratio) was -1.00 for 15 series of fatigue tests. Mean stresses other than zero were used on four series of tests. The stress ratio was kept nearly constant throughout the test by periodic checks and adjustments when necessary. An electronic shut-off mechanism on the machine stopped the test if the load dropped more than 50 pounds. If failure had not occurred when the machine stopped due to a shut-off, load adjustments were made and the test was continued.

The fatigue machine in which the specimens were tested was kept in a room maintained at a temperature of 75° F. and 50 percent relative humidity. Circulation of air around the specimens was insured by a 12-inch fan that forced air on the specimen, except for the tests of uncooled specimens, for which the fan was not used. For specimens designated as tested in the wet condition (75° F. and 98 percent relative humidity), special humidity chambers were provided. For preliminary conditioning, a small metal box having a rack for holding the specimens above water was placed in an oven held at 100° F. and 100 percent relative humidity. The specimens were kept in this exposure for 30 days. After this period they were tested in another chamber fixed to the fatigue machine (fig. 3). This chamber was a cylinder having sides of cellophane and ends of plywood reinforced with tin. This cylinder surrounded the specimen and the clamps that gripped the specimen. The loading screws of the fatigue machine went through the ends of the cylinder that supported an air hose supplying moisture-laden air. Air taken from the Laboratory's air lines was piped to the bottom of a 10-gallon drum filled with water. The air, as it bubbled up through the water, picked up moisture on its way to the cylinder. The air thus supplied to the test chamber was at a temperature of 75° F. and 98 percent relative humidity. It circulated in the cylinder and out through an exhaust port.

Fatigue tests were conducted on one series of specimens in bolt bearing. The fatigue specimen was modified for this loading by increasing the diameter of the notch from 1/8 inch to 1/4 inch, and by removing 2 inches from one end of the regular fatigue specimen, i.e., there remained a 7/8-inch end distance. The alternating load was applied to one end of the specimen through the clamp that was used on the other specimens and to the 1/4-inch-diameter steel pin fastened to a rigid frame (fig. 4). These tests were made at zero mean stress.

Static Tests

Tensile and compressive tests were made statically on the three materials. Tensile properties were obtained from specimens 1-1/2 inches wide by 16 inches long by the thickness of the laminate with a net section 0.8 inch wide by 2-1/2 inches long. The net section was connected to the end sections by arcs of 20-inch radius tangent to the minimum section. Strain measurements were taken over a 2-inch gage length in the minimum section. The specimens were loaded through Templin grips at a no-load head speed of

0.035 inch per minute. Compressive properties were obtained from specimens 1 inch wide by 4 inches long by the thickness of the material. The specimens were tested in a pack jig that gave lateral support to the column during loading. Deformation data were obtained over a 1-inch gage length by a Tuckerman strain gage. The speed of the movable head at no load was 0.012 inch per minute. Tensile and compressive properties were obtained only on specimens conditioned at 75° F. and 50 percent relative humidity.

Maximum tensile and compressive strengths were also obtained statically on specimens shaped the same as the fatigue specimens. These strengths were obtained in a 10,000-pound-capacity testing machine operated at a no-load head speed of 0.036 inch per minute. The ends of the specimens were clamped by the same grips as those used in the fatigue tests. Static tests were made on specimens that had the same exposure as the fatigue specimens.

Results of Tests

The results of static tests on specimens relatively free of stress concentrations (1-1/2- by 16-inch specimens) to determine the tensile and compressive strengths of these materials are presented in table 2. The values of the respective properties are equal to values of similar properties of like material and exceed the minimum values required by U. S. Armed Forces specification No. 12049. For example: The modulus of elasticity in compression of the material made with resin 2 and 181-114 fabric, 0° to warp, is 3,074,000 pounds per square inch compared with a value of 3,162,000 pounds per square inch for the same material as presented in table 1 of Forest Products Laboratory Report No. 1803, "Directional Properties of Glass-fabric-base Plastic Laminate Panels of Sizes that Do Not Buckle." Further, tension and compression maximum stresses are within 5 percent of values shown in Forest Products Laboratory Report No. 1803. Principal minimum requirements of U. S. Armed Forces specification No. 12049 are modulus of elasticity of 2,500,000 pounds per square inch and maximum stress of 25,000 pounds per square inch. Both laminates have values exceeding these. The quality of the material used for fatigue tests was therefore considered adequate.

The nominal maximum strengths on specimens free of stress concentrations are compared in table 3 with the strengths of the fatigue type of specimens tested statically. Average tensile and compression values summarized in this table were taken from table 2 and subsequent tables containing results of static and fatigue tests. The tension and compression specimens, 1-1/2 by 16 inches and 1 by 4 inches, respectively, are relatively free from stress concentrations due to their shape. The fatigue specimens, however, according to the theory, had a 10 percent rise in stress at the outside edge of the midsection. The nominal stress values in table 3 resulting from static tests do not show that the shape of the fatigue type of specimen had a serious effect on the maximum stress because values obtained from these specimens are greater in some cases and less in other cases than values obtained from the specimens free of concentrations. The strength of material with resin 2 and 181-114 fabric at 0° to warp shows that both the tension and the compression fatigue types of specimens tested statically had lower stress values than the specimens free of concentrations, but that at 45° to warp the fatigue type of specimen yielded higher stresses. The fatigue type of specimen made of material with resin 1 and 181-114 fabric, when tested statically had tensile values less than the specimens free of concentrations, while compressive values of the fatigue type of specimen tested statically were greater than those of the specimens free of concentrations.

No explanation is offered for these anomalous results, but the data are presented to illustrate general trends. Two facts, however, are apparent in table 3. (1), that maximum stresses are reduced because of moisture absorbed by the specimen, and (2), that at a given exposure or notched condition the maximum tensile and compressive stresses are not equal. It follows, then, that during the fatigue cycle for a complete reversal of stress, the failure in the fatigue specimen will occur in that portion of the cycle which has the lower maximum value. Both maximum tensile and maximum compressive values, however, are shown as horizontal lines in the vicinity of one cycle on the S-N curves for comparison with the fatigue data.

The results of individual static and fatigue tests are presented in tables 4 through 8. These data are the basis for establishing the individual S-N curves shown in figures 5 through 29. The stresses shown are the results of dividing the dynamic or static test loads by the net cross-sectional area. The dynamic stress shown on tables and curves is the alternating stress amplitude (one-half the range of stress) with a mean stress of zero, unless otherwise stated.

A comparison of the individual static values in a series shows a small difference between the high and low values. In general, the variance between the high and low values is about 5 percent, except for the notched, wet series of material with resin 2 and 181-114 fabric, which has an unusually high difference in compression values. This small scatter of static values is normal for plastics and indicates uniformity of material and test conditions.

The S-N curves, figures 5 through 23, showing the individual test values, are presented to show the scatter of these values from a smooth curve that was drawn as nearly as possible to represent an average of the test points. In general, the S-N curve is fairly well defined by this limited number of tests for each exposure or notch condition. The scatter of values above and below the curve is not large. The scatter is, however, large enough so that the small difference in the ordinates to the smoothed curves in the neighborhood of 10 million cycles should not be given too much weight.

A comparison of all the fatigue tests conducted at zero mean stress is presented in table 9. This table summarizes the data to show the effect of notch, moisture, or a combination of notch and moisture on the strength of these laminates after static tests, and after 10,000 and after 10,000,000 cycles. The strengths shown after 10,000 and after 10,000,000 cycles were picked from the smooth S-N curves at the respective cycles. The strength-reduction factor is the ratio of the strength of unnotched specimens, tested at a temperature of 75° F. and 50 percent relative humidity at a designated number of cycles, to the strength of specimens tested with variables at that specified number of cycles. The value of this ratio is a measure for comparing the effects of variables imposed on different materials at the designated number of cycles. The fatigue ratio, which is also shown, is the ratio of the fatigue strength to the static tensile strength of the unnotched material at 75° F. and 50 percent relative humidity.

The effect of the variables on the fatigue strength is presented graphically in figures 24 through 29 by superimposing various S-N curves on stress-cycle coordinates. These figures show the fatigue strengths at all cycles. They also pointedly show the drop in fatigue strength as the number of cycles increases. The effects that these variables had on the fatigue strength were as follows:

(1) The data show (table 9 or fig. 24) that for laminate 1 at 0° to warp and at 10 million cycles the fatigue strength was about 9,000 pounds per square inch, or 22 percent of the static tensile strength of specimens under like conditions. At 10 thousand cycles the fatigue strength was about 20,600 pounds per square inch, or 51 percent of its static tensile strength.

Tests of the unnotched, uncooled series resulted in a strength-reduction factor of 1.14 at 10 thousand cycles. This indicates that the small amount of heat that was generated in the specimens and not dissipated by forced circulation was somewhat detrimental at the high stresses. This effect was the greatest at 10 thousand cycles and diminished to zero at 10 million cycles, where the strength reduction factor was 1.00. This is to be expected, since the heat generated at the low stresses is less than at the high stresses. Temperature measurements at the 14,500-pounds-per-square-inch level indicated that without fan-cooling a 10-degree rise above ambient temperature occurred during the test, but that just prior to failure the rise was about 70° F. No other temperature measurements were made, inasmuch as the effect of various temperatures on strength was beyond the scope of this study.

The strength-reduction factors for the dry, notched specimens at 10 thousand and 10 million cycles were 1.25 and 1.20, respectively. The bolt-bearing specimens had these same factors (table 9), which indicated that this method of loading had the same effect as the notch alone.

The wet strength of laminate 1, either notched or unnotched, had the highest reduction factors (table 9). In static tests the reduction factor was as high as 1.44. In fatigue tests at 10 thousand cycles it was 1.57, but at 10 million cycles it was only 1.00. This seeming increase in strength is explained by the fact that heat generated at the net section during the fatigue test dries the material in spite of the 98 percent ambient relative humidity, and thus reduces the moisture content and increases the strength."

To summarize these effects (fig. 24 or table 9), it may be noted that the strength-reduction factor was highest at 10 thousand cycles and lowest at 10 million cycles and that, although the fatigue strength at 10 million cycles was not greatly affected by the several variables, the reduction from the static tensile strength was about 80 percent.

(2) The fatigue strength of laminate 1 at 45° to warp was about 4,750 pounds per square inch at 10 million cycles (fig. 25). The S-N curves of this laminate did not follow the pattern set by laminate 1 at 0° to the warp. Specimens tested at 0° to warp did not establish an endurance limit at 10 million cycles, but the specimens tested at 45° to warp did (fig. 26). The S-N curves of the latter became horizontal after about 40,000 cycles. Another difference is shown (fig. 25) by the fact that the moisture affecting the wet fatigue strengths, notched or unnotched, at 45° to warp caused nearly a constant reduction in strength at all cycles. Also, the notched specimens actually had higher fatigue strengths than did unnotched specimens.

(3) It should be noted that the fatigue strength at 10 million cycles of materials made with resin 1 and 181-114 fabric, laminate 2, tested at 0° to warp was about 12,100 pounds per square inch, which is 29 percent of the static tensile strength (table 9 or fig. 27). Comparing the fatigue strength of laminate 2 with that of laminate 1, which was 22 percent of the static tensile strength, the resin 1 in laminate 2 appears to be somewhat more superior in resistance to fatigue than resin 2 in laminate 1 (fig. 29). As pointed out for laminate 1, the fatigue strength of laminate 2 at 10 million cycles was not affected by the lack of fan-cooling due to removal of the fan, but at the high stresses and low number of cycles the fatigue strength was reduced.

(4) The tests of laminate 3 (fig. 28) showed about the same fatigue strengths and characteristics as did laminate 1.

(5) A comparison of the fatigue tests conducted at mean stresses other than zero is presented in table 10. The effect of three mean stresses, zero and one-fifth and one-half of the static tensile strength, on the magnitude of the alternating stress amplitude of laminate 1 (resin 2 + 181-114 fabric) in axial loading is shown. This effect is shown for both the notched and the unnotched specimens at 0° to warp in the dry condition. Alternating stress amplitudes at 1 thousand, 100 thousand, and 10 million cycles were picked from the smoothed S-N curves of the

respective load conditions (figs. 20-23). On these curves both the cooled and uncooled individual test points are shown. Inadvertently, a larger portion of the specimens than planned were tested without cooling, so that an insufficient number of notched specimens were left to be tested as cooled. However, since the two conditions have values that are so nearly equal at the low stresses, the smooth curves were drawn through the cooled-specimen points, wherever possible, with the aid of the uncooled-specimen points wherever needed as a guide. These data are summarized in figures 30 and 31. Increasing the mean stress from zero to the ultimate static tensile value reduces the alternating stress amplitude from a maximum at zero mean stress to zero at the ultimate static tensile stress. The curve of this relationship for laminate 1 concaves upward from zero mean stress to the ultimate static tensile stress.

(6) It should be noted that the fatigue specimen, which, as stated earlier in this report, was designed to meet the requirements of the test, performed satisfactorily. The specimen did not show any visible signs of buckling during test. The bolts and nuts of the clamps provided sufficient support to prevent slipping in the grip. The groups of typical broken specimens, as shown in figures 32 to 35, indicate that failures occurred at the net section. Failures did not commonly occur outside the net section at the edge of the clamp where there was a concentration of stresses; only five specimens in the entire investigation failed at the edge of the clamp. Failures at the net section cannot be described as being either typical tension or compression failures.

Table 1.--Strength properties of specimens of three laminates tested statically in tension and in compression

Properties at standard conditions (73° F. and 50 percent relative humidity)	Laminate Nos. 1 Resin 2 + 181-114	Laminate Nos. 2 Resin 1 + 181-114	Laminate Nos. 3 Resin 2 + 143-114	USAF specification No. 12049
Ultimate strength tensile.......1,000 p.s.i.	42.9	42.5	48.3	35.0
Modulus of elasticity tensile...1,000,000 p.s.i.	2.74	2.54	2.64	2.5
Ultimate strength, compression edgewise..... ....1,000 p.s.i.	43.2	31.8	37.6	25.0
Modulus of elasticity, compression..1,000,000 p.s.i.	3.07	2.74	3.08	2.5
Resin content........percent	39.0	40.6	33.0	....

Table 2.--Tensile and compressive properties of glass-fabric-base laminate resulting from static tests[1]

Specimen No.	Compression					Tension					
	Specific gravity	Modulus of elasticity	Proportional limit	0.2 percent offset stress	Maximum stress	Modulus of elasticity: Initial	Modulus of elasticity: Secondary	Proportional limit stress: Initial	Proportional limit stress: Secondary	0.2 percent offset stress[2]	Maximum stress
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
		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.	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.
Resin 2 + 181-114 at 0° to warp (39 percent resin) -- 69 Barcol hardness											
1	1,740	2,980	32.01	42.50	42.50	2,496	....	15.72	....	....	46.60
2	1,743	3,125	38.75	45.75	45.75	2,692	2,310	10.91	24.25	36.35	44.85
3	1,736	3,075	28.30	43.40	43.40	2,516	2,132	17.10	37.90	41.55	46.40
4	1,750	3,097	29.72	40.40	40.40	2,846	2,388	10.95	31.65	36.50	43.80
5	1,755	3,100	33.20	41.95	41.95	2,968	1,688	8.45	31.40	30.20	39.50
6	1,756	3,070	32.58	45.30	45.30	2,945	2,222	8.40	30.00	28.80	36.50
Av.	1,747	3,074	32.43	43.22	43.22	2,744	2,148	11.92	31.04	34.68	42.94
Resin 2 + 181-114 at 45° to warp (39 percent resin) -- 69 Barcol hardness											
1	1,750	1,896	6.26	12.05	21.51	1,770	950	4.87	7.79	8.52	21.00
2	1,766	1,739	6.26	12.51	21.81	1,852	1,148	4.35	6.78	8.03	19.40
3	1,761	1,826	4.66	11.03	21.60	1,622	1,098	5.35	6.81	9.25	21.87
4	1,741	1,790	3.85	10.78	22.41	1,570	1,066	4.32	6.72	8.44	20.00
5	1,741	1,706	4.53	11.18	22.70	1,590	993	4.37	7.29	8.85	21.88
6	1,745	1,706	4.61	10.94	22.88	1,685	994	4.38	7.30	8.27	20.44
Av.	1,751	1,777	5.03	11.42	22.15	1,681	1,041	4.61	7.12	8.56	20.76

(Sheet 1 of 2)

Table 2.--Tensile and compressive properties of glass-fabric-base laminate resulting from static tests[1] (continued)

Specimen No.	Compression					Tension					
	Specific gravity	Modulus of elasticity	Proportional limit	0.2 percent offset stress	Maximum stress	Modulus of elasticity		Proportional limit stress		0.2 percent offset stress[2]	Maximum stress
						Initial	Secondary	Initial	Secondary		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
		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.	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.
Resin 1 + 181-114 at 0° to warp (40.6 percent resin) -- 71 Barcol hardness											
1	1,796	2,716	33.40	33.40	33.40	2,429	2,060	7.16	26.27	32.25	43.00
2	1,740	3,175	29.50	29.50	29.50	2,381	2,020	11.91	28.59	33.35	41.80
3	1,757	2,679	24.21	31.45	31.45	2,540	2,004	7.11	28.45	24.90	43.05
4	1,780	2,685	26.15	31.00	31.00	2,785	2,122	7.10	24.85	25.10	41.65
5	1,729	2,702	27.71	33.33	33.33	2,681	2,271	6.04	22.95	29.00	43.15
6	1,739	2,505	27.05	32.30	32.30	2,412	2,120	12.20	31.70	39.50	42.65
Av.......	1,757	2,744	28.00	31.83	31.83	2,538	2,100	8.59	27.13	30.68	42.55
Resin 2 + 143-114 at 0° to warp (33.0 percent resin) -- 65 Barcol hardness											
1	1,795	3,060	25.40	40.40	40.40	2,650	2,390	9.82	....	....	48.60
2	1,812	3,340	....	36.00	36.00	2,820	2,365	10.00	38.80	40.80	45.70
3	1,815	3,040	26.10	35.20	35.20	2,380	2,110	26.90	46.40	46.80	46.80
4	1,813	3,060	30.90	38.80	38.80	2,730	2,167	8.20	32.30	28.60	51.00
5	1,815	2,920	25.00	39.50	39.50	2,595	2,195	8.70	33.50	34.70	49.50
Av.......	1,810	3,084	26.85	37.58	37.58	2,635	2,245	12.72	37.75	37.72	48.38

[1] Values shown are for individual specimens.

[2] Offset from initial modulus of elasticity.

(Sheet 2 of 2)

Table 3.--Comparison of nominal maximum stresses of glass-fabric-base laminates resulting from static tests on tension and compression specimens, notched and/or exposed to moisture

Material	Average tensile values					Average compression values				
	Static specimen 1-1/2 by 16 inches	Fatigue specimens 1-1/2 by 6 inches				Static specimen 1 by 4 inches	Fatigue specimens 1-1/2 by 6 inches			
		Unnotched		Notched			Unnotched		Notched	
	75° F., 50 percent relative humidity	75° F., 50 percent relative humidity	75° F., 98 percent relative humidity	75° F., 50 percent relative humidity	75° F., 98 percent relative humidity	75° F., 50 percent relative humidity	75° F., 50 percent relative humidity	75° F., 98 percent relative humidity	75° F., 50 percent relative humidity	75° F., 98 percent relative humidity
	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.	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.
Resin 2 + 181-114 fabric: At 0° to warp	42.94	40.30	35.17	31.07	30.15	43.22	40.71	28.28	46.05	18.25
At 45° to warp	20.76	22.01	13.87	18.96	13.55	22.15	23.06	14.41	24.44	15.56
Resin 1 + 181-114 fabric: At 0° to warp	42.55	41.22	....	31.51	....	31.83	34.22	....	38.59	....
Resin 2 + 143-114 fabric	48.32	42.54	....	38.82	....	37.58	43.05	....	44.88	....

Table 4.--Results of fatigue[1] and static tests of a glass-fabric-base laminate (resin 2 + 181-114) in axial loading

Specimen No.	Static tests: Tension strength	Static tests: Compression strength	Fatigue tests: Maximum and minimum nominal alternating stress	Fatigue tests: Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
Stressed at 0° to warp at 75° F. and 50 percent relative humidity				
1	41.60	41.21	16.00	72,600
2	40.00	40.45	14.50	211,000
3	39.00	39.85	17.50	31,000
4	40.80	42.11	19.00	15,700
5	40.70	38.65	21.00	7,400
6	39.60	42.00	25.00	2,700
7	....	....	13.50	383,000
8	....	....	12.00	1,387,000
[2]9	....	....	32.40	90
10	....	....	11.00	2,070,300
11	....	....	9.00	5,169,300
12	....	....	8.00	11,980,000
Av.........	40.30	40.71	....	....
Stressed at 0° to warp at 75° F. and 50 percent relative humidity with 1/16-inch-radius notch				
1	30.40	45.80	12.00	141,000
2	30.75	48.90	10.00	644,400
3	32.70	41.95	7.00	[3]14,033,000
4	31.50	45.90	9.00	2,511,600
5	30.72	48.15	8.00	2,562,700
6	30.35	45.60	13.50	46,200
7	....	....	11.00	335,000
8	....	....	19.00	3,700
9	....	....	25.00	800
10	....	....	16.00	14,700
11	....	....	7.50	[3]21,209,400
Av.........	31.07	45.05	....	....

Table 4.--Results of fatigue[1] and static tests of a glass-fabric-base laminate (resin 2 + 181-114) in axial loading (continued)

Specimen No.	Static tests: Tension strength	Static tests: Compression strength	Fatigue tests: Maximum and minimum nominal alternating stress	Fatigue tests: Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
	Stressed at 0° to warp at 75° F. and 50 percent relative humidity, uncooled			
1	41.60	41.21	25.00	1,400
2	40.00	40.45	21.00	3,400
3	39.00	39.85	19.00	6,500
4	40.80	42.11	16.00	17,500
5	40.70	38.65	13.50	160,900
6	39.60	42.00	11.00	1,292,700
7			11.00	1,801,700
8			10.00	3,055,100
9			9.00	6,059,500
10			8.00	[3]20,366,300
Av.	40.31	40.71		
	Stressed at 0° to warp at 75° F. and 98 percent relative humidity after 100° F. 100 percent relative humidity conditioning			
1	35.50	27.80	9.50	4,210,900
2	35.40	29.20	10.50	598,500
3	35.00	27.80	9.55	1,087,400
4	34.10	28.60	17.50	1,400
5	35.85	28.00	22.50	100
6			20.00	500
7			9.00	5,211,500
8			13.50	8,100
9			11.00	44,000
10			15.00	3,900
11			12.00	12,300
12			10.00	612,700
Av.	35.17	28.28		

Table 4.--Results of fatigue[1] and static tests of a glass-fabric-base laminate (resin 2 + 181-114) in axial loading (continued)

Specimen No.	Static tests: Tension strength	Static tests: Compression strength	Fatigue tests: Maximum and minimum nominal alternating stress	Fatigue tests: Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
Stressed at 0° to warp at 75° F. and 98 percent relative humidity after 100° F. and 100 percent relative humidity conditioning with 1/16-inch notch				
1	30.15	10.75	8.00	4,461,800
2	29.62	13.05	15.00	8,800
3	31.50	16.10	20.00	600
4	30.60	19.24	9.00	1,899,300
5	28.90	32.10	10.66	566,700
6	...	...	12.50	23,900
7	...	...	17.50	1,400
8	...	...	11.50	257,200
9	...	...	7.50	8,250,500
10	...	...	12.00	36,100
11	...	...	13.75	9,400
Av.	30.15	18.25	...	...
Stressed at 45° to warp at 75° F. and 50 percent relative humidity				
1	22.49	23.28	6.60	4,800
2	23.51	22.90	5.50	25,100
3	22.42	23.28	4.44	[3]14,345,800
4	20.40	22.72	3.30	[3]12,505,000
5	21.21	23.10	7.50	2,500
6	...	...	4.70	2,676,800
[4]7	...	...	17.50	18
[4]8	...	...	12.50	141
9	...	...	4.80	696,000
10	...	...	5.00	36,000
11	...	...	6.00	7,600
Av.	22.01	23.06	...	...

Table 4.--Results of fatigue[1] and static tests of a glass-fabric-base laminate (resin 2 + 181-114) in axial loading (continued)

Specimen No.	Static tests: Tension strength	Static tests: Compression strength	Fatigue tests: Maximum and minimum nominal alternating stress	Fatigue tests: Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
Stressed at 45° to warp at 75° F. and 50 percent relative humidity with 1/16-inch-radius notch				
1	18.52	25.30	9.00	2,300
2	19.03	24.20	7.50	3,600
3	19.30	24.31	6.00	6,600
4	18.89	23.40	5.00	2,530,100
5	19.05	24.98	12.00	200
6			5.50	1,570,300
7			5.25	3,496,300
8			4.75	4,975,600
9			5.75	1,241,700
10			6.75	5,500
11			6.25	62,100
Av.	18.96	24.44		
Stressed at 45° to warp at 75° F. and 98 percent relative humidity after 100° F. and 100 percent relative humidity conditioning				
1			5.00	2,700
2			6.00	1,100
3			7.50	500
4			4.50	3,700
5			4.00	5,900
6			3.00	244,600
7			2.75	3,350,200
8			3.50	53,900
9	14.35			
10	13.39			
11		14.51		
12		14.32		
Av.	13.87	14.41		

Table 4.--Results of fatigue[1] and static tests of a glass-fabric-base laminate (resin 2 + 181-114) in axial loading (continued)

Specimen No.	Static tests		Fatigue tests	
	Tension strength	Compression strength	Maximum and minimum nominal alternating stress	Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
Stressed at 45° to warp at 75° F. and 98 percent relative humidity after 100° F. and 100 percent relative humidity conditioning with 1/16-inch-radius notch				
1	13.55	...	...	...
2	...	15.52	...	...
3	...	15.60	...	...
4	...	...	3.25	467,800
5	...	...	3.50	991,800
6	...	...	3.75	110,900
7	...	...	4.50	4,600
8	...	...	6.25	800
9	...	...	3.00	[3]12,921,300
10	...	...	4.00	11,800
11	...	...	5.00	3,400
12	...	...	7.50	600
Av.	13.55	15.56	...	...

[1]Mean stress of zero.

[2]Tested at 20 revolutions per minute.

[3]Unfailed specimen.

[4]Tested at 40 revolutions per minute.

Table 5.--Results of static and fatigue[1] tests of a glass-fabric laminate (resin 1 + O.C.181-114) in axial loading

Specimen No.	Static tests: Tension strength	Static tests: Compression strength	Fatigue tests: Maximum and minimum nominal alternating stress	Fatigue tests: Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
	Stressed at 0° to warp at 75° F. and 50 percent relative humidity			
[2]1	....	....	....	....
2	42.60	36.60	12.00	7,199,200
3	38.90	33.50	20.00	13,200
4	41.75	34.90	9.00	[3]12,977,200
5	43.30	33.80	14.00	683,500
6	42.85	30.80	13.00	3,008,000
7	....	....	17.50	48,100
8	....	....	26.00	800
9	....	....	23.00	8,700
10	....	....	15.50	133,800
Av.........	41.22	34.22	....	....
	Stressed at 0° to warp at 75° F. and 50 percent relative humidity with 1/16-inch-radius notch			
1	32.15	38.55	22.00	1,900
2	31.70	37.00	20.00	3,800
3	30.45	40.80	17.50	12,800
4	30.80	37.30	15.00	83,100
5	31.75	38.80	12.00	615,600
6	32.20	39.10	13.50	175,300
7	....	....	11.00	1,432,200
8	....	....	16.25	30,900
9	....	....	10.00	4,471,800
10	....	....	9.25	8,902,300
Av.........	31.51	38.59	....	....

Table 5.--Results of static and fatigue[1] tests of a glass-fabric laminate (resin 1 + O.C.181-114) in axial loading (continued)

Specimen No.	Static tests		Fatigue tests	
	Tension strength	Compression strength	Maximum and minimum nominal alternating stress	Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
	Stressed at 0° to warp at 75° F. and 50 percent relative humidity, uncooled			
1	37.90	35.70	23.00	1,600
2	42.60	36.60	20.00	3,400
3	38.90	33.50	17.50	10,200
4	41.75	34.90	15.50	48,500
5	43.30	33.80	14.00	150,900
6	42.85	30.80	13.00	1,112,700
7	....	....	12.00	4,853,600
8	....	....	26.00	500
Av........	41.22	34.22	....	....

[1]Mean stress of zero.

[2]Inadvertently failed.

[3]Unfailed specimen.

Table 6.--Results of fatigue and static tests of a glass-fabric laminate (resin 2 + 181-114) in axial loading at mean stresses other than zero

Specimen No.	Static tests		Fatigue tests	
	Tension strength	Compression strength	Alternating stress	Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
Stressed at 0° to warp at 75° F. and 50 percent relative humidity with a mean stress of 20,150 pounds per square inch (0.5 Sn)				
1	41.60	41.21	15,000	400
2	40.00	40.45	13,000	700
3	39.00	39.85	11,000	1,100
4	40.80	42.11	9,000	1,900
5	40.70	38.55	7,000	3,100
6	39.50	42.00	5,000	6,300
7	....	....	3,000	50,000
8	....	....	1,000	7,360,500
9	....	....	3,000	[1]65,600
10	....	....	7,000	[1]3,000
11	....	....	11,000	[1]1,400
12	....	....	2,000	[1]376,300
Av.........	40.30	40.71	....	....
Stressed at 0° to warp at 75° F. and 50 percent relative humidity with mean stress of 15,535 pounds per square inch (0.5 Sn) with 1/16-inch-radius notch				
1	30.40	45.80	10,000	300
2	30.75	48.90	8,000	700
3	32.70	41.95	4,000	10,600
4	31.50	45.90	2,000	105,200
5	30.72	48.15	6,000	3,200
6	30.35	45.60	....	....
7	....	....	1,000	976,100
8	....	....	....	....
9	....	....	600	[2]20,745,000
10	....	....	6,500	[1]3,100
11	....	....	3,000	[1]25,400
12	....	....	900	[1]3,333,000
Av.........	31.07	45.05	....	....

Table 6.--Results of fatigue and static tests of a glass-fabric laminate (resin 2 + 181-114) in axial loading at mean stresses other than zero (continued)

Specimen No.	Static tests		Fatigue tests	
	Tension strength	Compression strength	Alternating stress	Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
Stressed at 0° to warp at 75° F. and 50 percent relative humidity with a mean stress of 8,060 pounds per square inch (0.2 Sn)				
1	41.60	41.21	19,000	1,200
2	40.00	40.45	2,000	[2]10,403,300
3	39.00	39.85	4,000	3,289,200
4	40.80	42.11	17,000	2,800
5	40.70	38.65	15,000	4,200
6	39.50	42.00	13,000	5,700
7			11,000	15,500
8			9,000	41,100
9			7,000	279,500
10			5,000	2,206,700
11			4,600	7,259,500
12			17,000	[1]3,200
13			13,000	[1]8,900
14			9,000	[1]47,000
15			6,000	[1]353,400
Av.	40.30	40.71		
Stressed at 0° to warp at 75° F., and 50 percent relative humidity with a mean stress of 6,214 pounds per square inch (0.2 Sn) and with 1/16-inch-radius notch				
1	30.40	45.80	13,000	2,900
2	30.75	48.90	2,000	[2]10,401,800
3	32.70	41.95	4,000	1,396,100
4	31.50	45.90	11,000	5,300
5	30.72	48.15	9,000	14,400
6	30.35	45.60	7,000	46,500
7			5,500	224,600
8				
9			12,000	[1]6,400
10			8,000	[1]38,600
11			5,000	[1]193,700
12			3,500	[1]1,387,700
Av.	31.07	45.05		

[1]Fan on specimens, others uncooled.

[2]Unfailed specimens.

Table 7.--Results of fatigue[1] tests of a glass-fabric-base laminate (resin 2 + 181-114 fabric) in axial loading through a 1/4-inch bearing pin

Specimen No.	Fatigue tests	
	Maximum and minimum nominal alternating stress[2]	Cycles to failure
	1,000 p.s.i.	
	Stressed at 0° to warp at 75° F., 50 percent relative humidity	
1	....	....
2	22.00	2,000
3	20.00	3,600
4	18.00	2,600
5	16.00	14,600
6	14.00	25,500
7	12.00	114,100
8	10.00	666,900
9	9.00	1,330,800
10	8.00	4,822,800
11	7.50	9,386,200
12	....	....

[1]Mean stress of zero.

[2]Average stress on net section of specimen outside the limits of the bolt bearing.

Table 8.--Results of fatigue[1] and static tests of a glass-fabric-base laminate (resin 2 + 143-114 fabric) in axial loading

Specimen No.	Static tests: Tension strength	Static tests: Compression strength	Fatigue tests: Maximum and minimum alternating stress	Fatigue tests: Cycles to failure
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	
Stressed at 0° to warp at 75° F. and 50 percent relative humidity				
1	38.10	46.70	29.00	300
2	46.00	41.00	21.00	10,100
3	44.20	43.30	16.00	60,900
4	38.30	40.80	14.00	237,700
5	46.10	43.40	12.00	2,833,400
6	....	....	11.00	2,203,700
7	....	....	11.00	3,608,100
8	....	....	18.00	34,800
9	....	....	24.00	3,600
10	....	....	10.25	7,535,600
Av.	42.54	43.05	....	....
Stressed at 0° to warp at 75° F. and 50 percent relative humidity with 1/16-inch-radius notch				
1	40.60	41.30	25.00	600
2	39.90	46.00	18.00	11,400
3	36.70	45.50	....	....
4	38.00	46.10	13.00	97,900
5	38.90	45.50	11.00	475,100
6	....	....	9.00	1,981,700
7	....	....	10.00	711,200
8	....	....	15.00	34,500
9	....	....	21.00	3,100
10	....	....	7.50	12,212,400
Av.	38.82	44.88	....	....

[1]Mean stress of zero.

Table 9.--Summary of effect of notch and/or moisture on fatigue strength of glass-fabric-base laminates in axial loading with zero mean stress

Variable	Static tests				Fatigue tests					
	Tension		Compression		10,000 cycles			10,000,000 cycles		
	Strength	Reduction factor[1]	Strength	Reduction factor[1]	Strength	Reduction factor[1]	Fatigue ratio[2]	Strength	Reduction factor[1]	Fatigue ratio[2]
	1,000 p.s.i.		1,000 p.s.i.		1,000 p.s.i.			1,000 p.s.i.		
Resin 2 + 181-114 fabric, parallel-laminated at 0° to warp (laminate 1)										
75° F., 50 percent relative humidity, unnotched	40.30	....	40.70	....	20.60	....	0.51	9.00	....	0.22
75° F., 50 percent relative humidity, notched	31.07	1.30	45.05	0.90	16.50	1.25	.41	7.50	1.20	.19
75° F., 98 percent relative humidity, unnotched	35.17	1.15	28.28	1.44	13.10	1.57	.33	9.00	1.00	.22
75° F., 98 percent relative humidity, notched	30.15	1.34	18.25	2.23	14.00	1.47	.35	7.75	1.16	.19
75° F., 50 percent relative humidity, unnotched, uncooled	40.30	1.00	40.70	1.00	18.00	1.14	.45	9.00	1.00	.22
75° F., 50 percent relative humidity, loaded through notch (bolt bearing)	....	......	....	......	16.50	1.25	.41	7.50	1.20	.19

(Sheet 1 of 3)

Table 9.--Summary of effect of notch and/or moisture on fatigue strength of glass-fabric-base laminates in axial loading with zero mean stress (continued)

Variable	Static tests				Fatigue tests					
	Tension		Compression		10,000 cycles			10,000,000 cycles		
	Strength	Reduction factor[1]	Strength	Reduction factor[1]	Strength	Reduction factor[1]	Fatigue ratio[2]	Strength	Reduction factor[1]	Fatigue ratio[2]
	1,000 p.s.i.		1,000 p.s.i.		1,000 p.s.i.			1,000 p.s.i.		
Resin 2 + 181-114 fabric, parallel-laminated at 45° to warp (laminate 1)										
75° F., 50 percent relative humidity, unnotched	22.01	....	23.06	....	5.76	....	0.26	4.75	....	0.22
75° F., 50 percent relative humidity, notched	18.96	1.16	24.44	0.94	6.75	0.85	.31	4.75	1.00	.22
75° F., 98 percent relative humidity, unnotched	13.87	1.59	14.41	1.60	3.87	1.49	.18	2.70	1.76	.12
75° F., 98 percent relative humidity, notched	13.55	1.62	15.56	1.48	4.25	1.35	.19	3.15	1.51	.14
Resin 1 + 181-114 fabric, parallel-laminated at 0° to warp (laminate 2)										
75° F., 50 percent relative humidity, unnotched	41.22	....	34.22	....	21.20	....	.51	12.10	....	.29
75° F., 50 percent relative humidity, notched	31.51	1.31	38.59	.89	18.00	1.18	.44	9.50	1.27	.23
75° F., 50 percent relative humidity, unnotched, uncooled	41.22	1.00	34.22	1.00	18.00	1.18	.44	12.00	1.01	.29

(Sheet 2 of 3)

Table 9.--Summary of effect of notch and/or moisture on fatigue strength of glass-fabric-base laminates in axial loading with zero mean stress (continued)

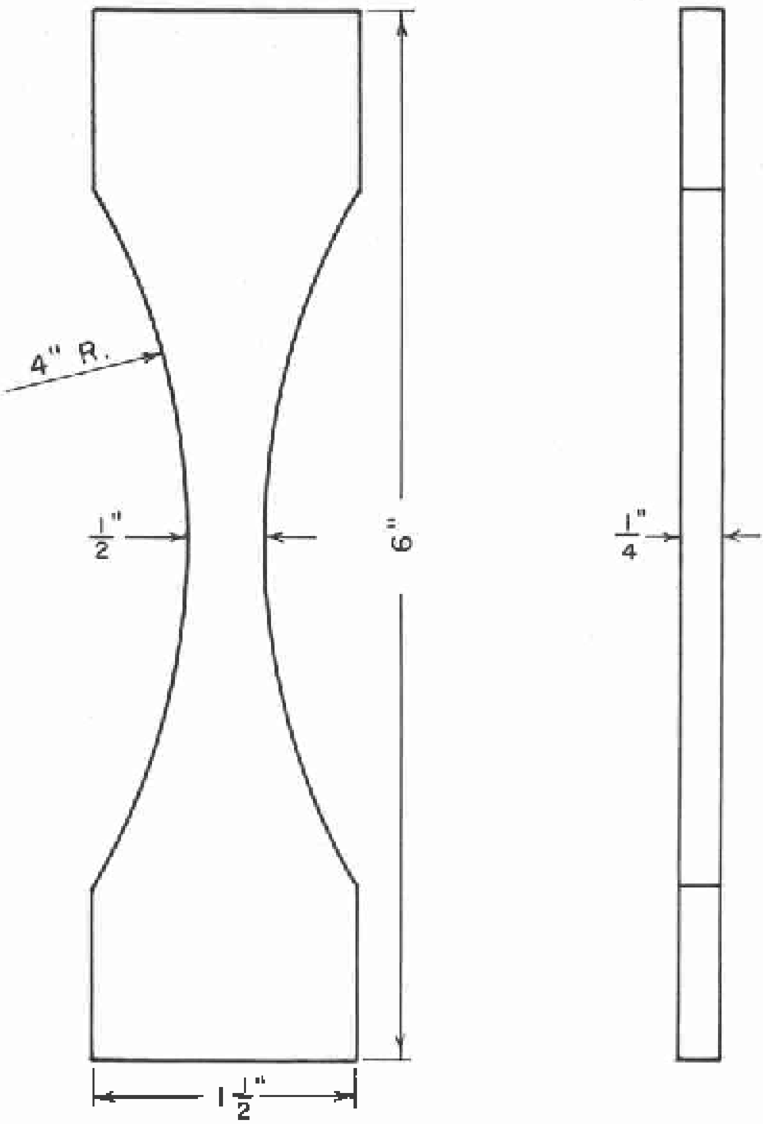
Variable	Static tests				Fatigue tests					
	Tension		Compression		10,000 cycles			10,000,000 cycles		
	Strength	Reduction factor[1]	Strength	Reduction factor[1]	Strength	Reduction factor[1]	Fatigue ratio[2]	Strength	Reduction factor[1]	Fatigue ratio[2]
	1,000 p.s.i.		1,000 p.s.i.		1,000 p.s.i.			1,000 p.s.i.		
Resin 2 + 143-114 fabric, cross-laminated at 0° to warp (laminate 3)										
75° F., 50 percent relative humidity, unnotched	42.54	......	43.05	......	20.70	......	0.49	10.50	......	0.25
75° F., 50 percent relative humidity, notched	38.82	1.10	44.88	0.96	17.80	1.16	.42	7.80	1.34	.18

[1] Reduction factor is the ratio of strength of unnotched material at 75° F., 50 percent relative humidity, to the strength of the affected material at a given number of cycles.

[2] Fatigue ratio is the ratio of the strength of the affected material to the static tensile strength of unnotched material at 75° F., 50 percent relative humidity.

Table 10.--Effect of three mean stresses on fatigue strength of a glass-fabric-base laminate (resin 2 + 181-114 fabric, laminate 1) in axial loading

Variable	Static tension strength	Alternating stress amplitude		
		1,000 cycles	100,000 cycles	10,000,000 cycles
	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.	1,000 p.s.i.
Stressed at 0° to warp at 75° F. and 50 percent relative humidity, unnotched				
Zero mean stress	40.30	27.2	15.5	9.0
8,060 pounds per square inch tensile mean stress	40.30	21.7	7.5	4.2
20,150 pounds per square inch tensile mean stress	40.30	11.5	2.6	.8
Stressed at 0° to warp at 75° F. and 50 percent relative humidity, 1/16-inch-radius notch				
Zero mean stress	31.07	23.3	12.3	7.5
6,214 pounds per square inch tensile mean stress	31.07	17.2	5.8	3.0
15,535 pounds per square inch tensile mean stress	31.07	8.2	2.1	.7



Z M 86440 F

Figure 1.--Sketch of fatigue specimen.

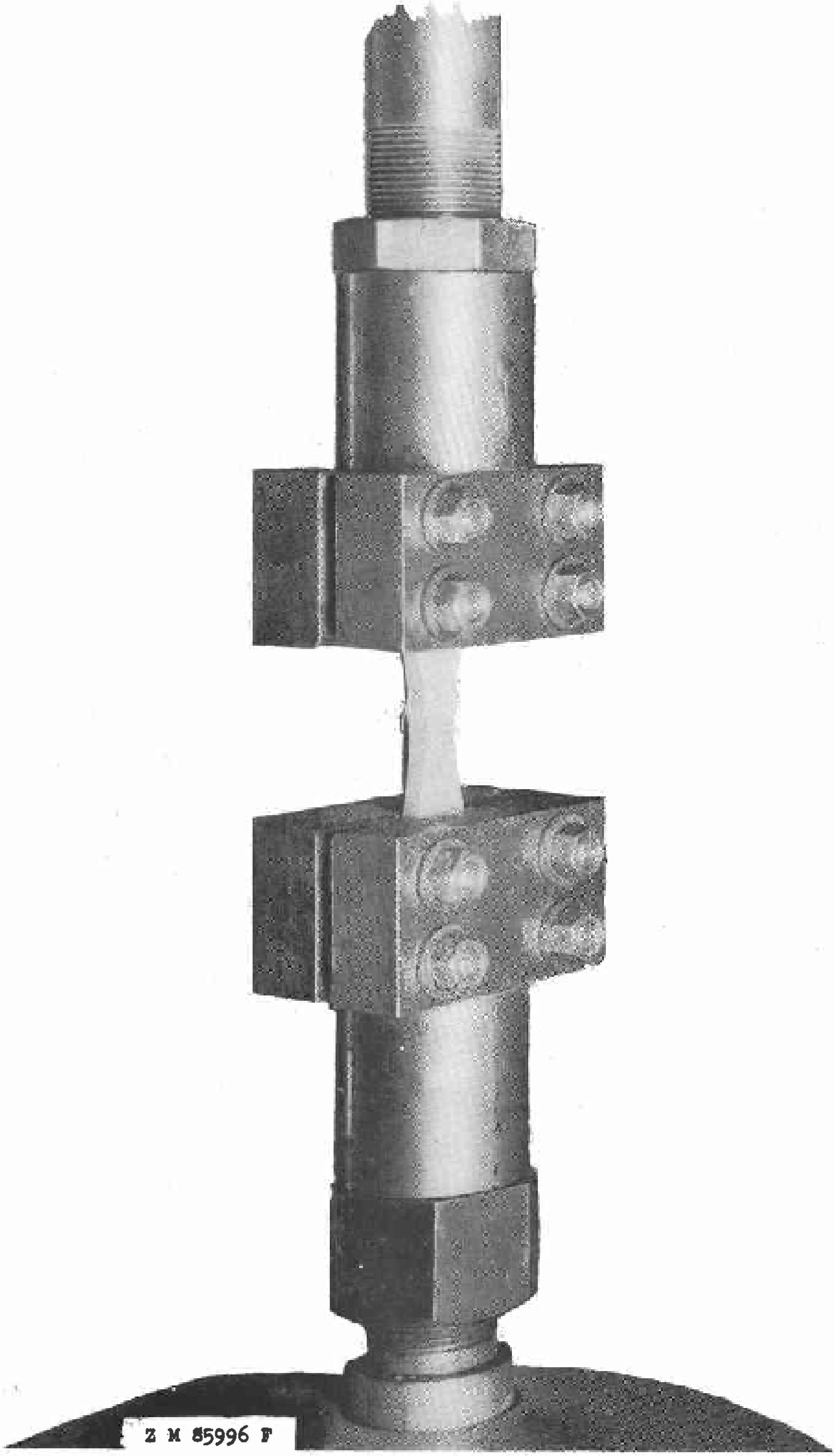
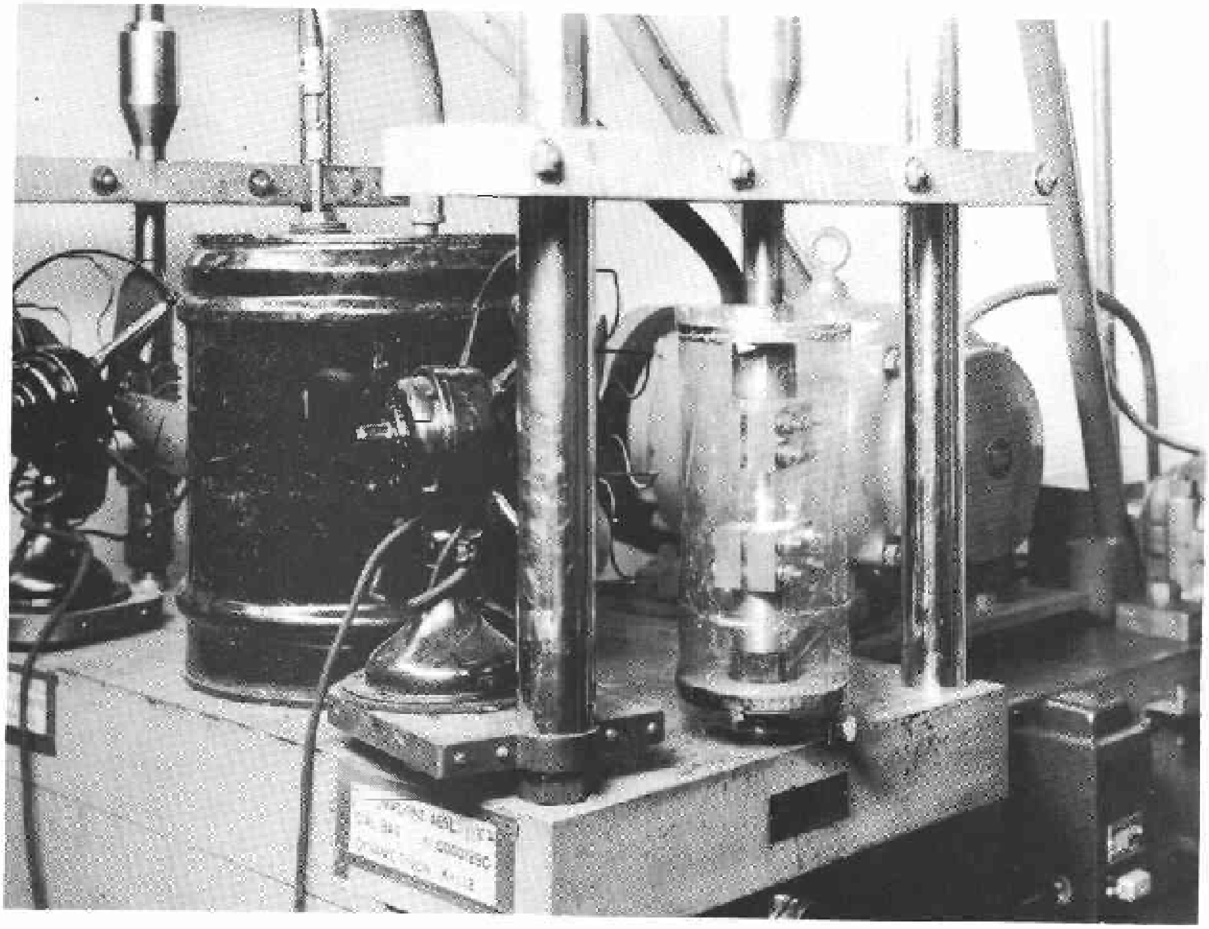
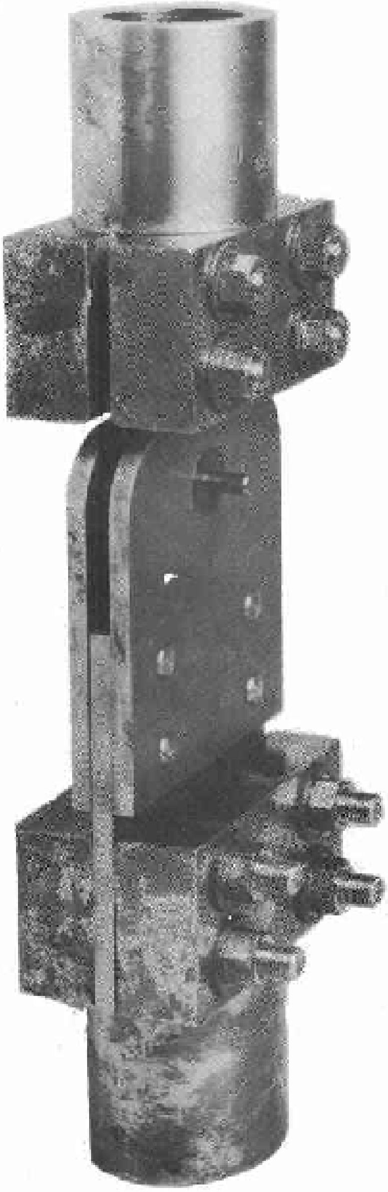


Figure 2.--Grips supporting the fatigue specimen, which is loaded axially in tension and compression in a direct-stress fatigue machine.



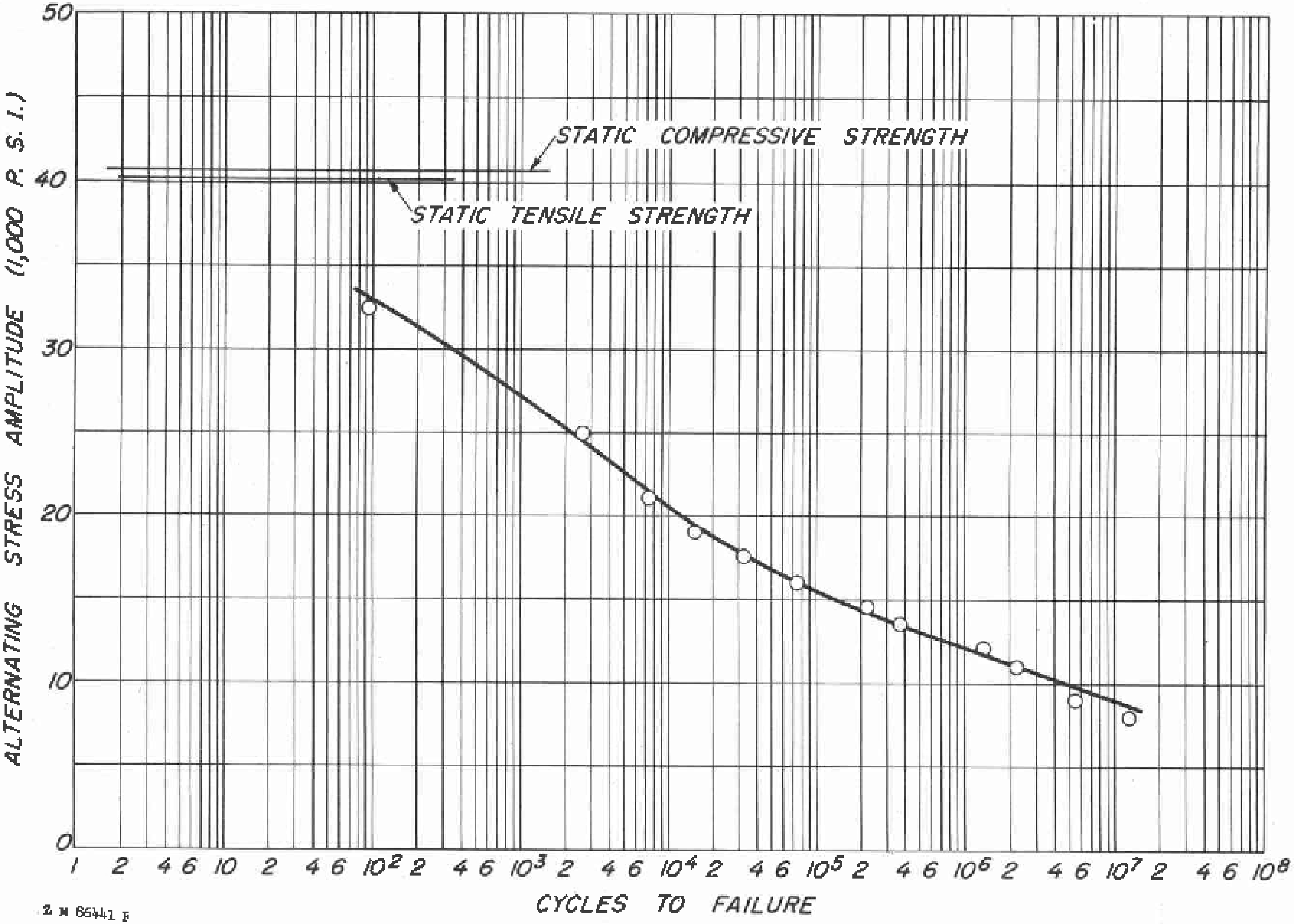
Z M 85997 F

Figure 3.--Humidity chamber surrounding the fatigue specimen and grips in a direct-stress fatigue machine.



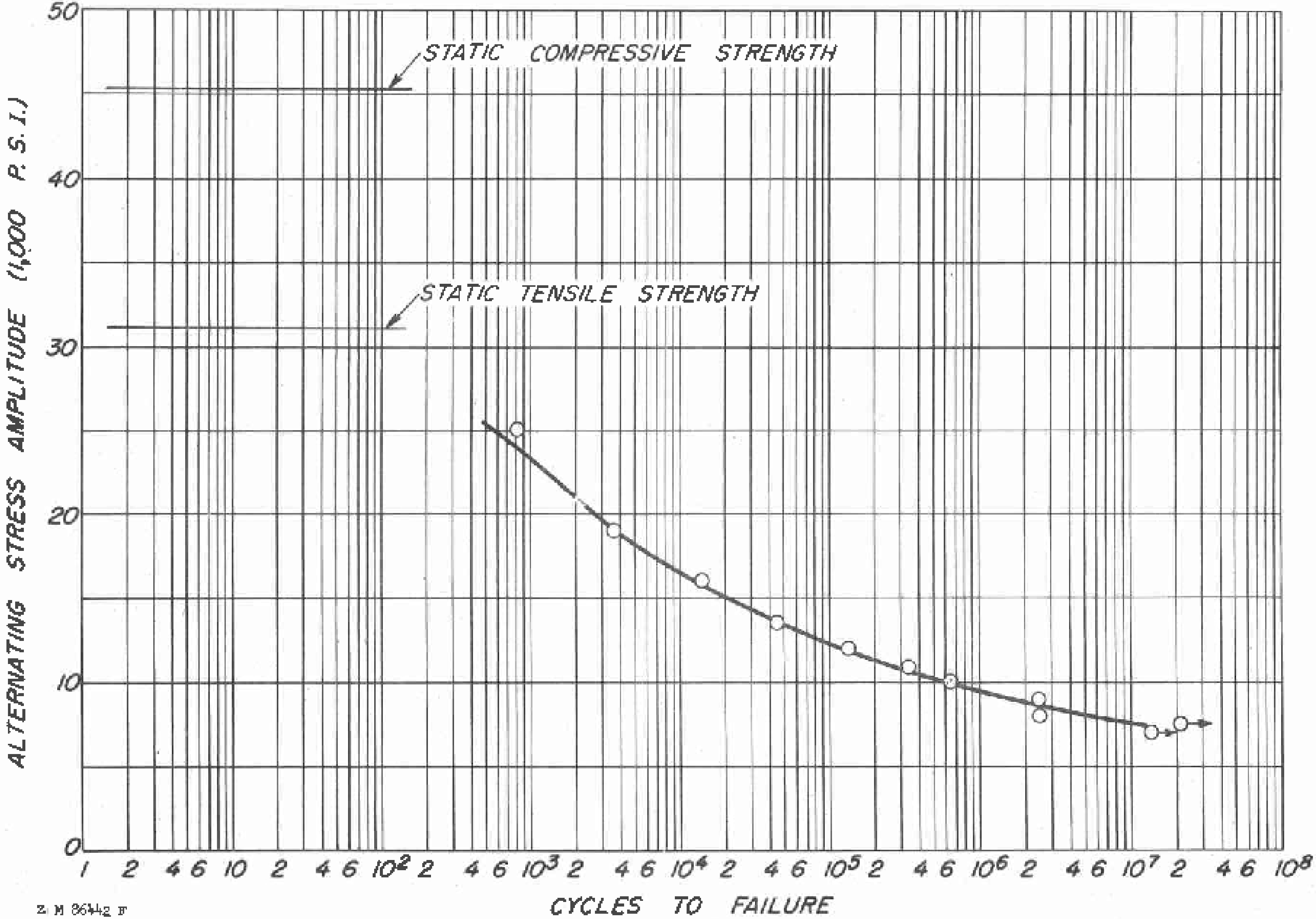
Z M 87900 F

Figure 4.--Clamps for supporting and loading the bolt-bearing fatigue specimen.



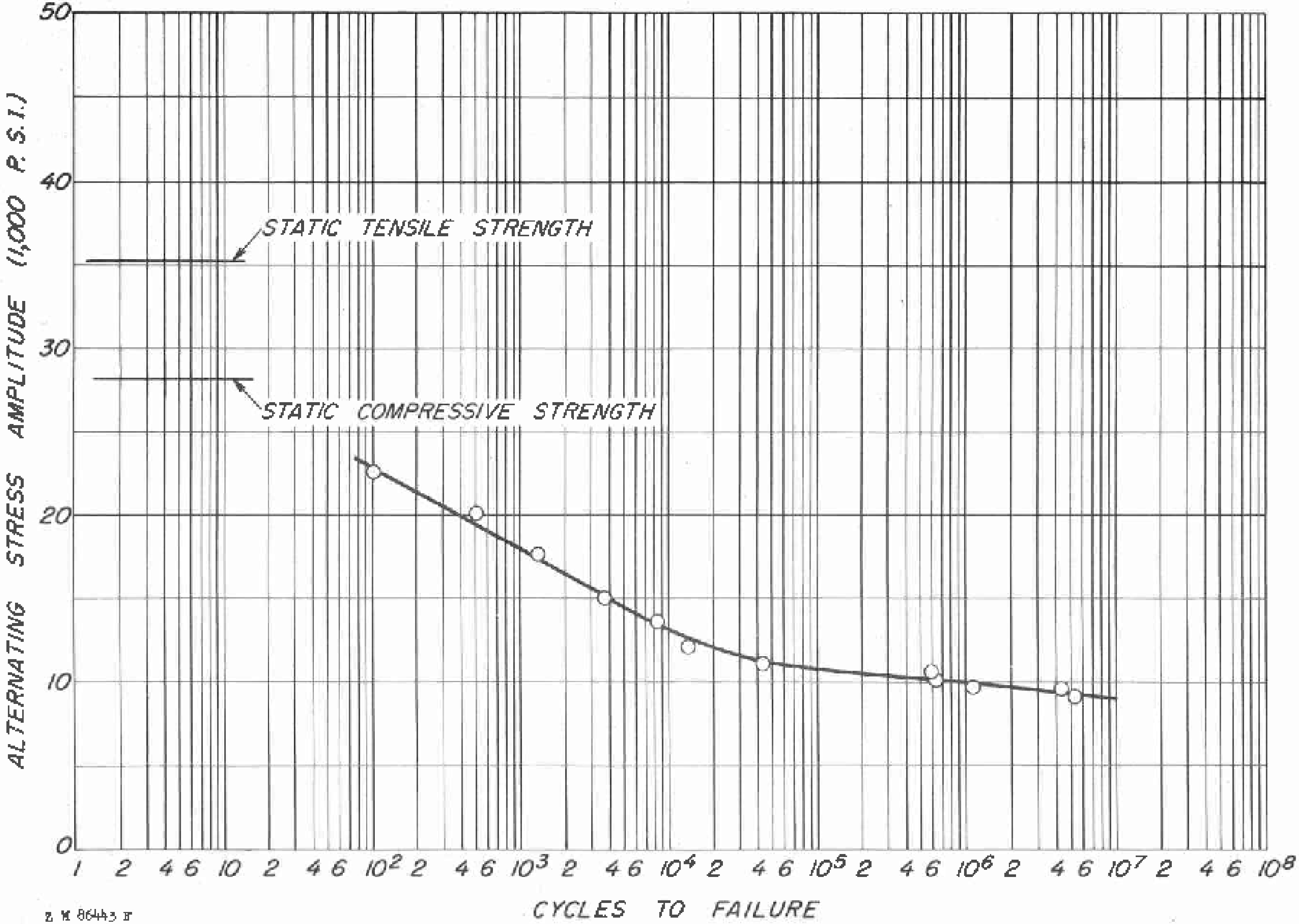
Z M 86441 F

Figure 5.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 2 and 181-114 fabric, tested at 0° to warp at 75° F. and 50 percent relative humidity, with an air blast for cooling. Stress ratio was -1.00.



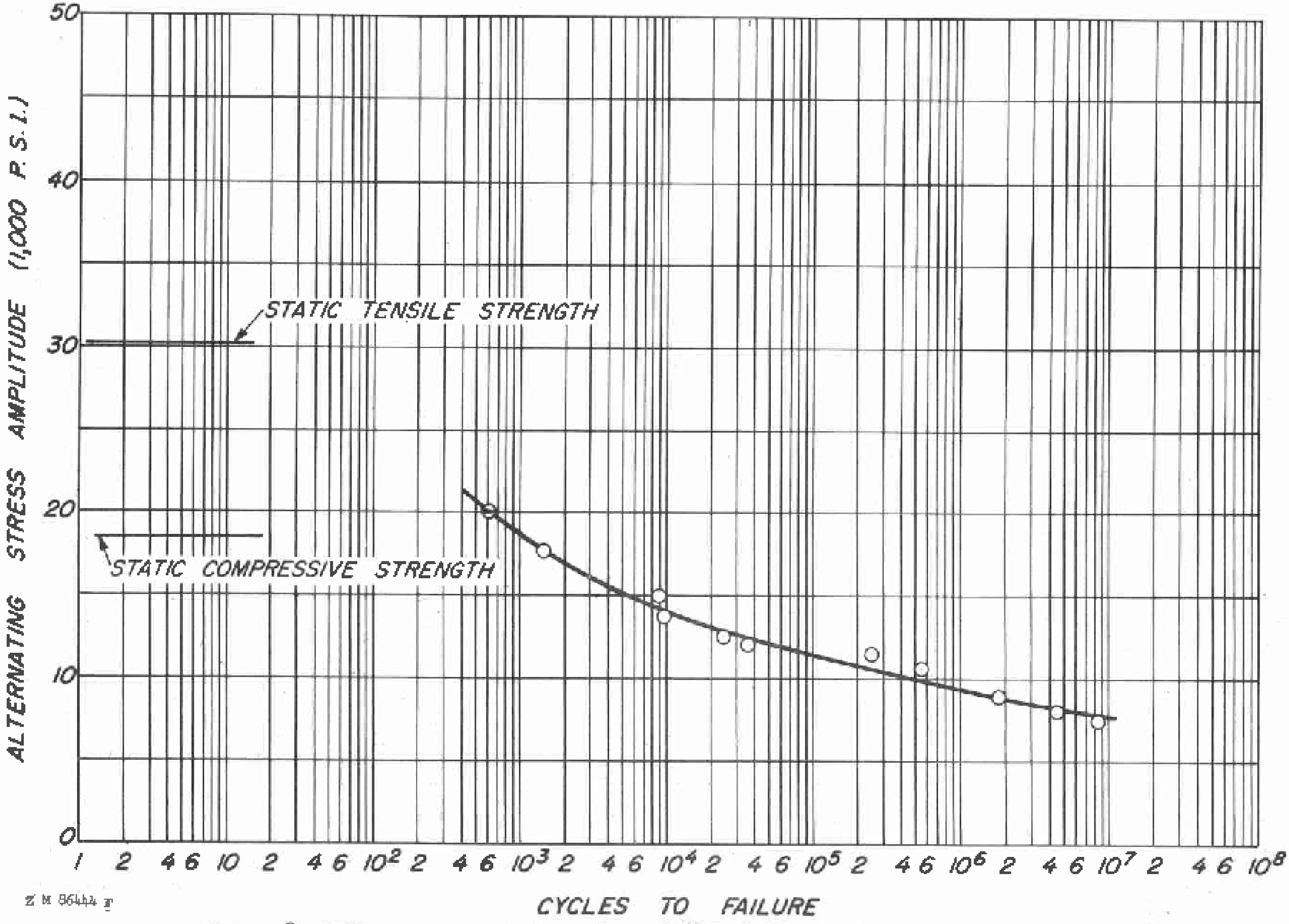
Z M 86442 F

Figure 6.--S-N curve of notched specimens (1/8-inch-diameter hole in center of specimen) of glass-fabric-base laminate, resin 2 and 181-114 fabric, tested at 0° to warp at 75° F. and 50 percent relative humidity, with an air blast for cooling. Stress ratio equal to -1.00.



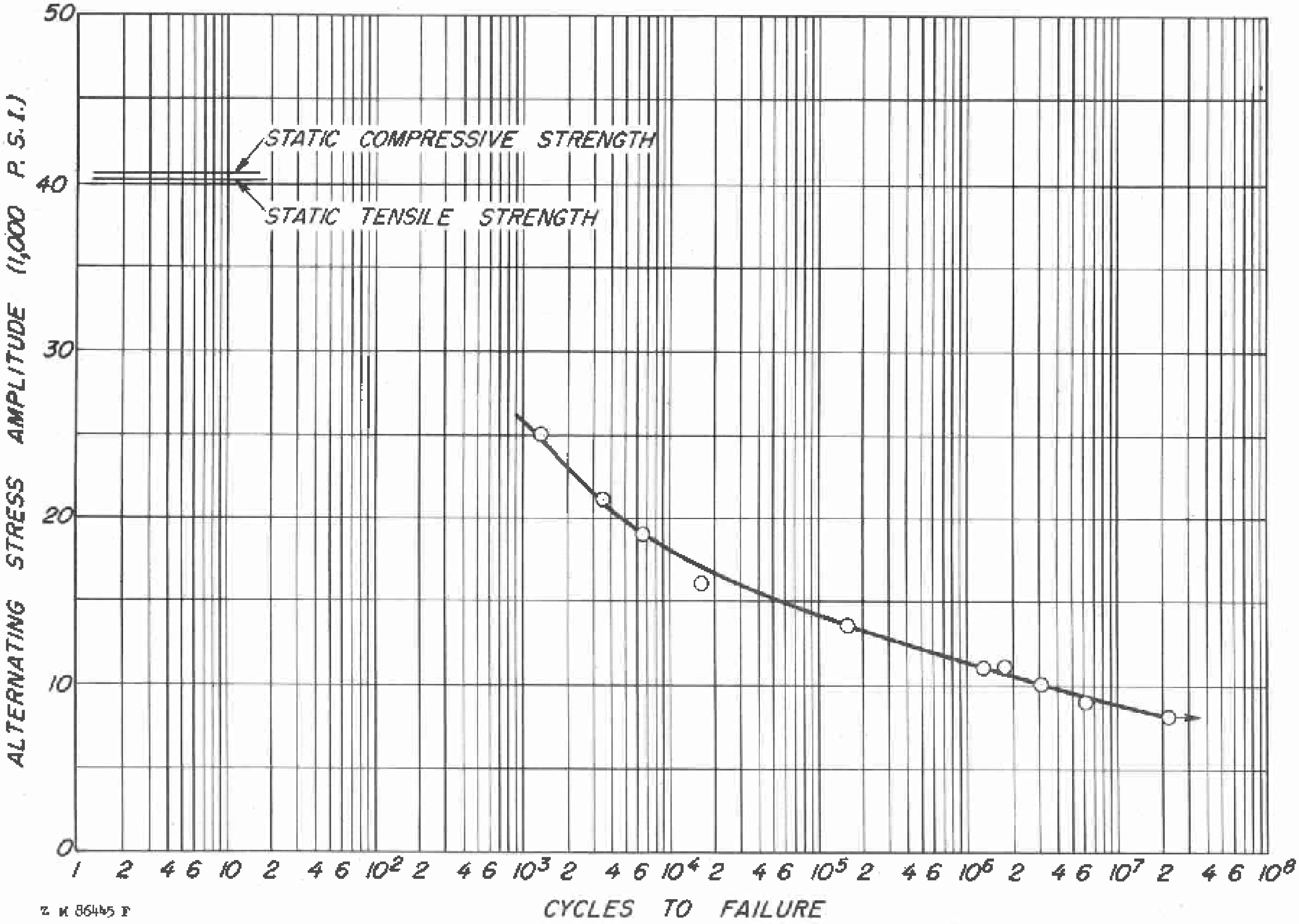
Z M 86443 F

Figure 7.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 2 and 181-114 fabric, tested at 0° to warp, exposed about 30 days to 100° F. and 100 percent relative humidity, then tested at 75° F. and and 98 percent relative humidity. Stress ratio of -1.00.



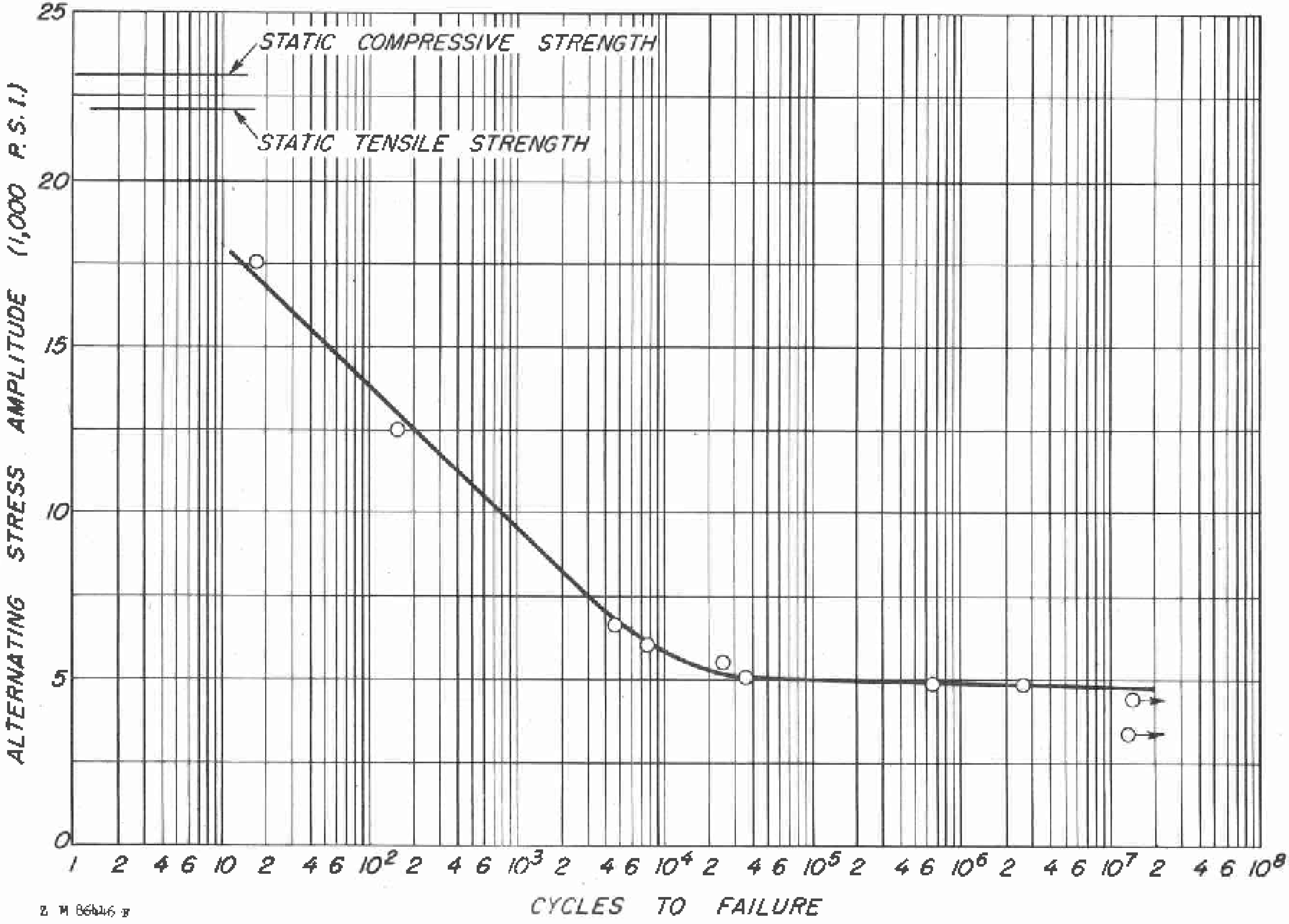
Z M 86444 F

Figure 8.--S-N curve of notched specimens (1/8-inch-diameter hole in center of specimen) of glass-fabric-base laminate, resin 2 and 181-114 fabric, tested at 0° to warp, exposed about 30 days to 100° F. and 100 percent relative humidity, then tested at 75° F. and 98 percent relative humidity. Stress ratio of -1.00.



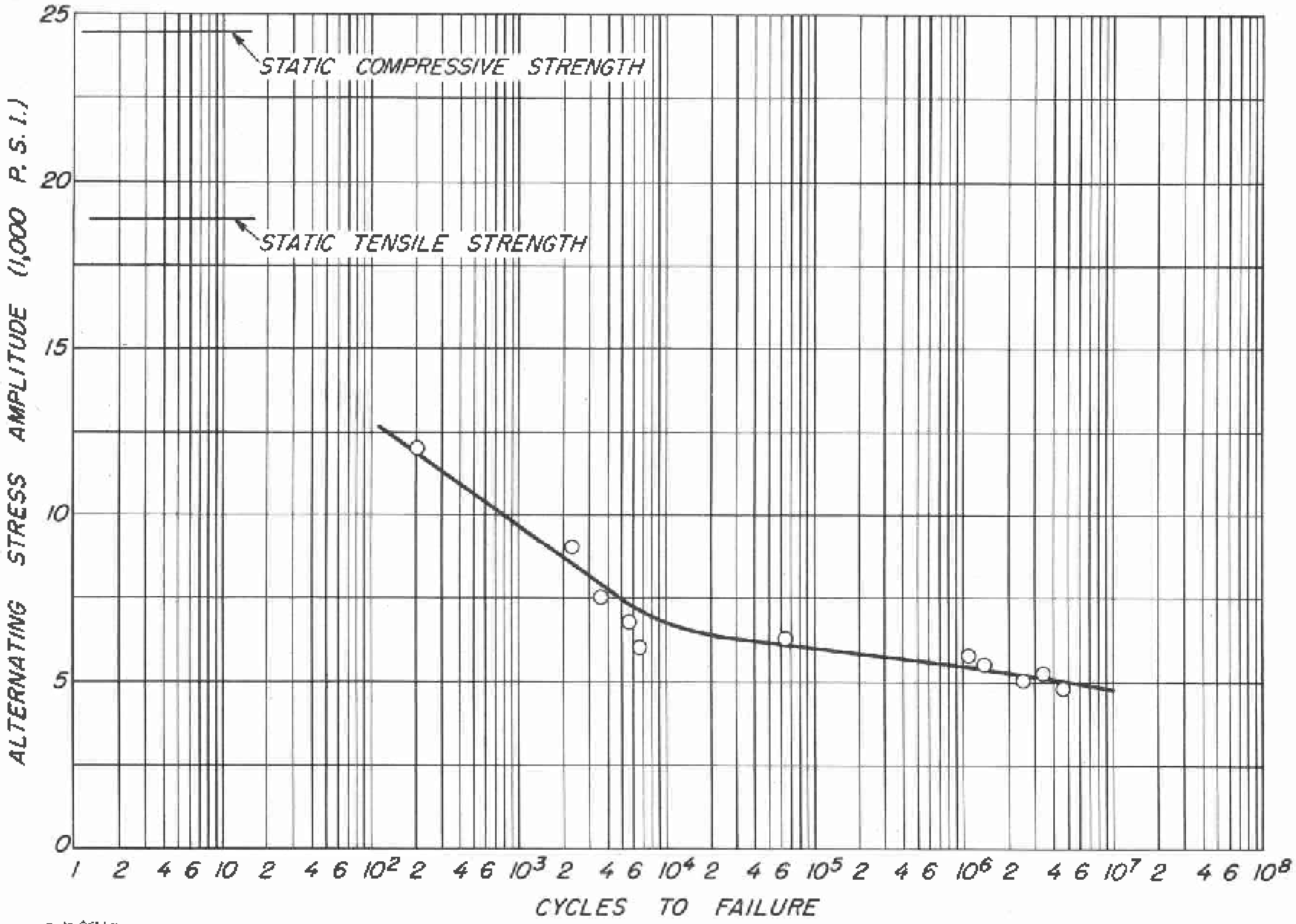
Z M 86445 F

Figure 9.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 2 and 181-114 fabric, tested at 0° to warp at 75° F. and 50 percent relative humidity, without an air blast for cooling. Stress ratio of -1.00.



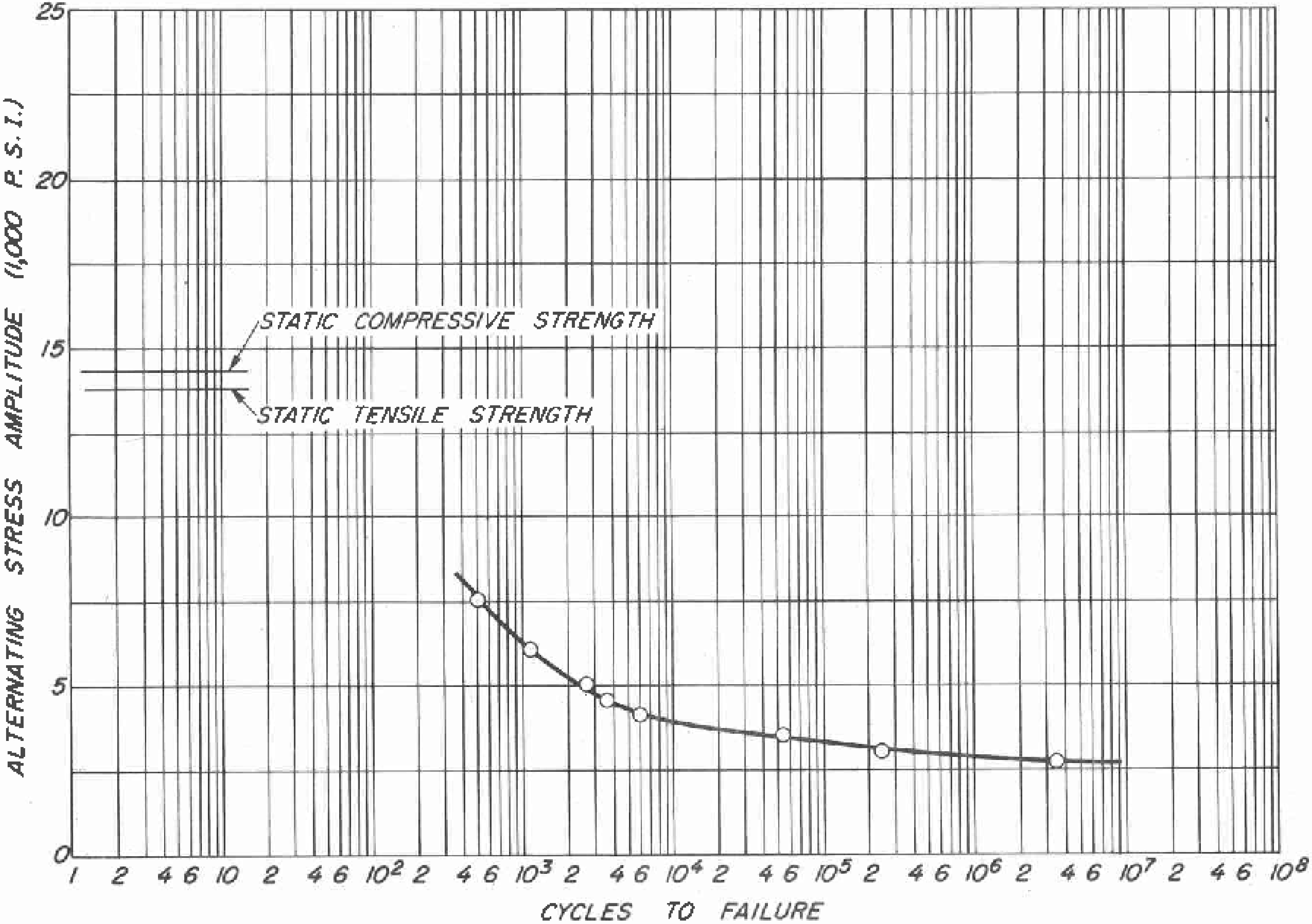
Z M 86446 F

Figure 10.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 2 and 181-114 fabric, tested at 45° to warp at 75° F. and 50 percent relative humidity, with an air blast for cooling. Stress ratio of -1.00.



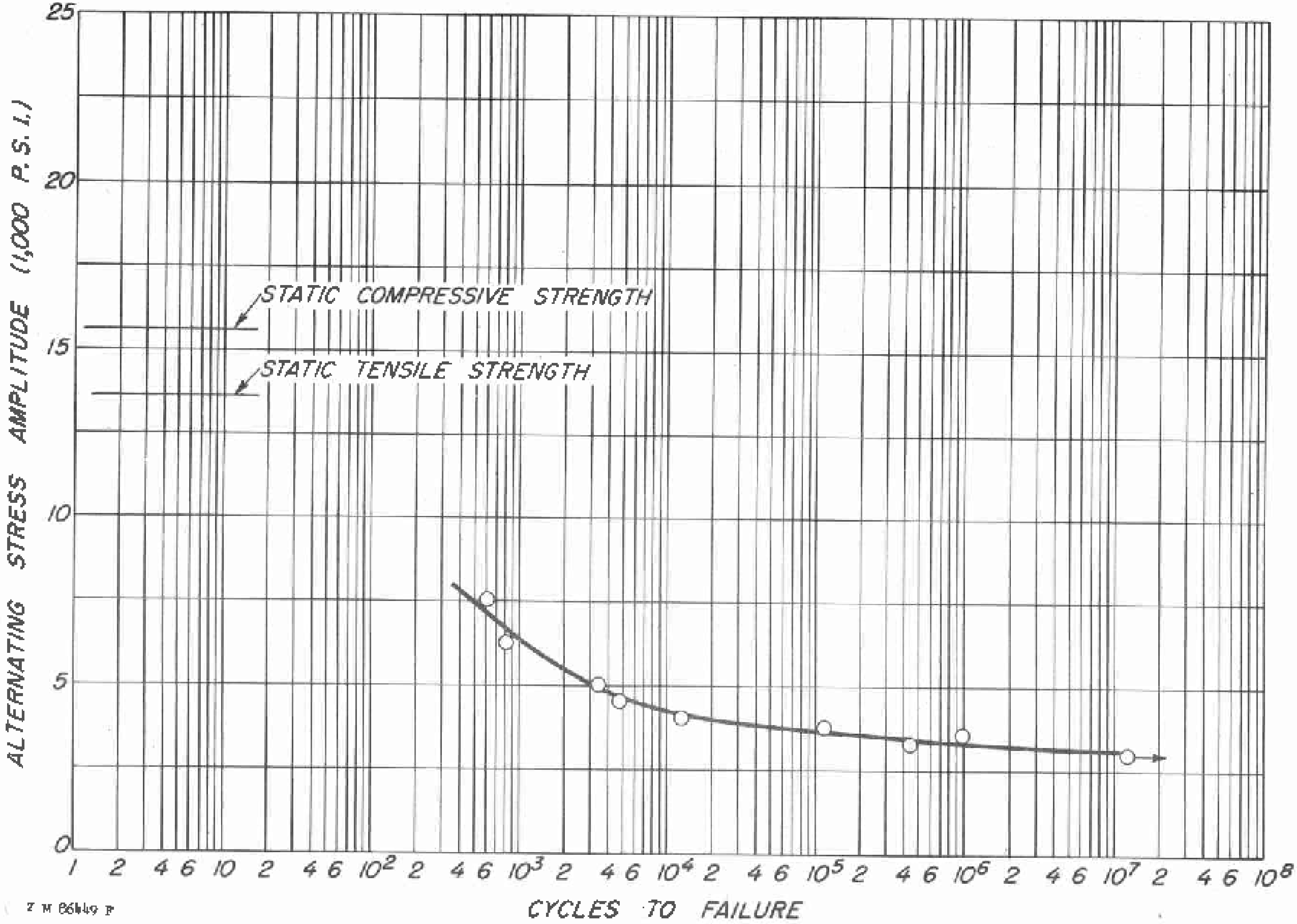
Z M 86447 F

Figure 11.--S-N curve of notched specimens (1/8-inch-diameter hole in center of specimen) of glass-fabric-base laminate, resin 2 and 181-114 fabric, tested at 45° to warp at 75° F. and 50 percent relative humidity, with an air blast for cooling. Stress ratio of -1.00.



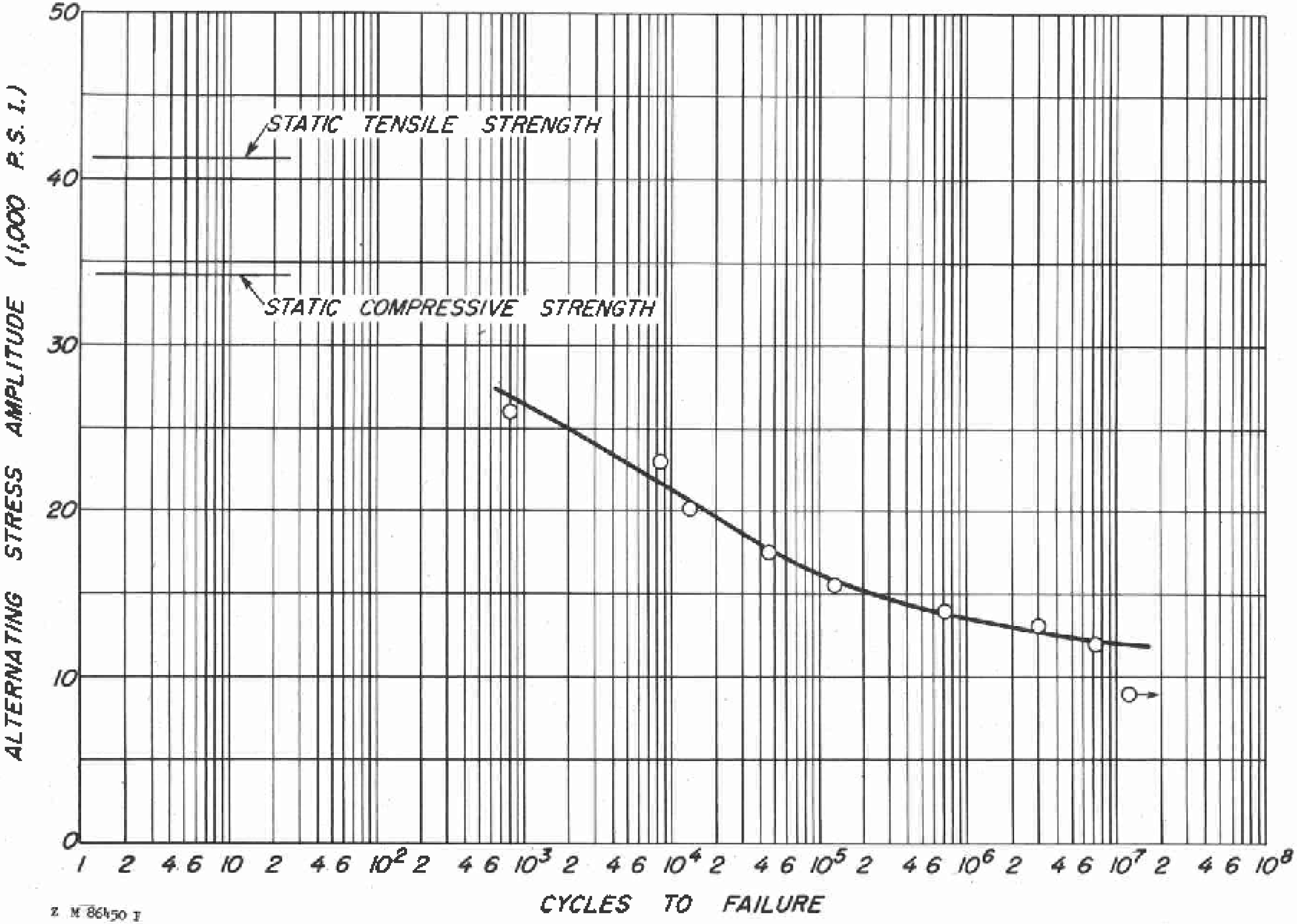
Z M 86448 F

Figure 12.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 2 and 181-114 fabric, tested at 45° to warp, exposed about 30 days to 100° F. and 100 percent relative humidity, then tested at 75° F. and 98 percent relative humidity. Stress ratio of -1.00.



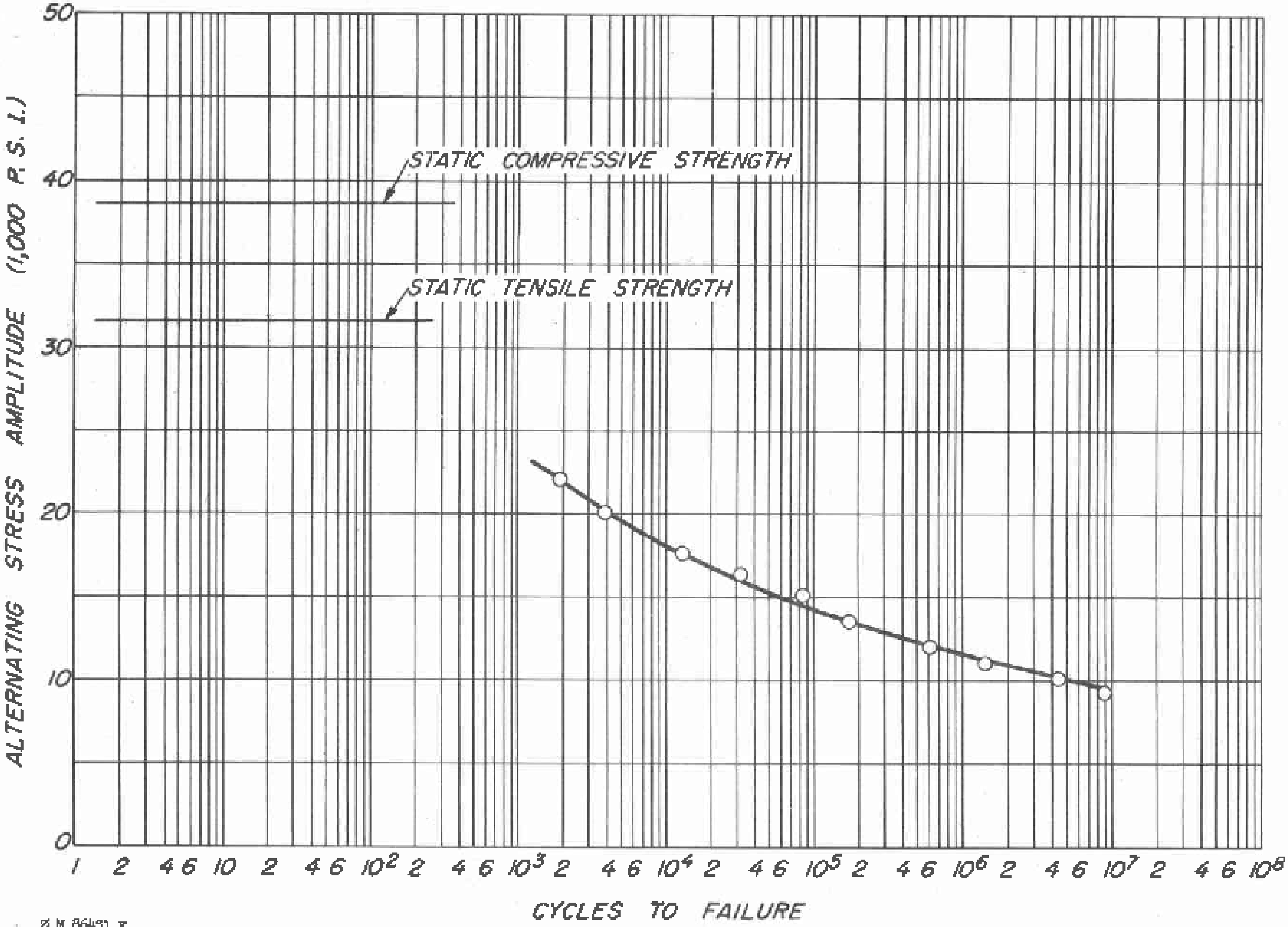
Z M 86449 F

Figure 13.--S-N curve of notched specimens (1/8-inch-diameter hole in center of specimen) of glass-fabric-base laminate, resin 2 and 181-114 fabric, tested at 45° to warp, exposed about 30 days to 100° F. and 100 percent relative humidity, then tested at 75° F. and 98 percent relative humidity. Stress ratio of -1.00.



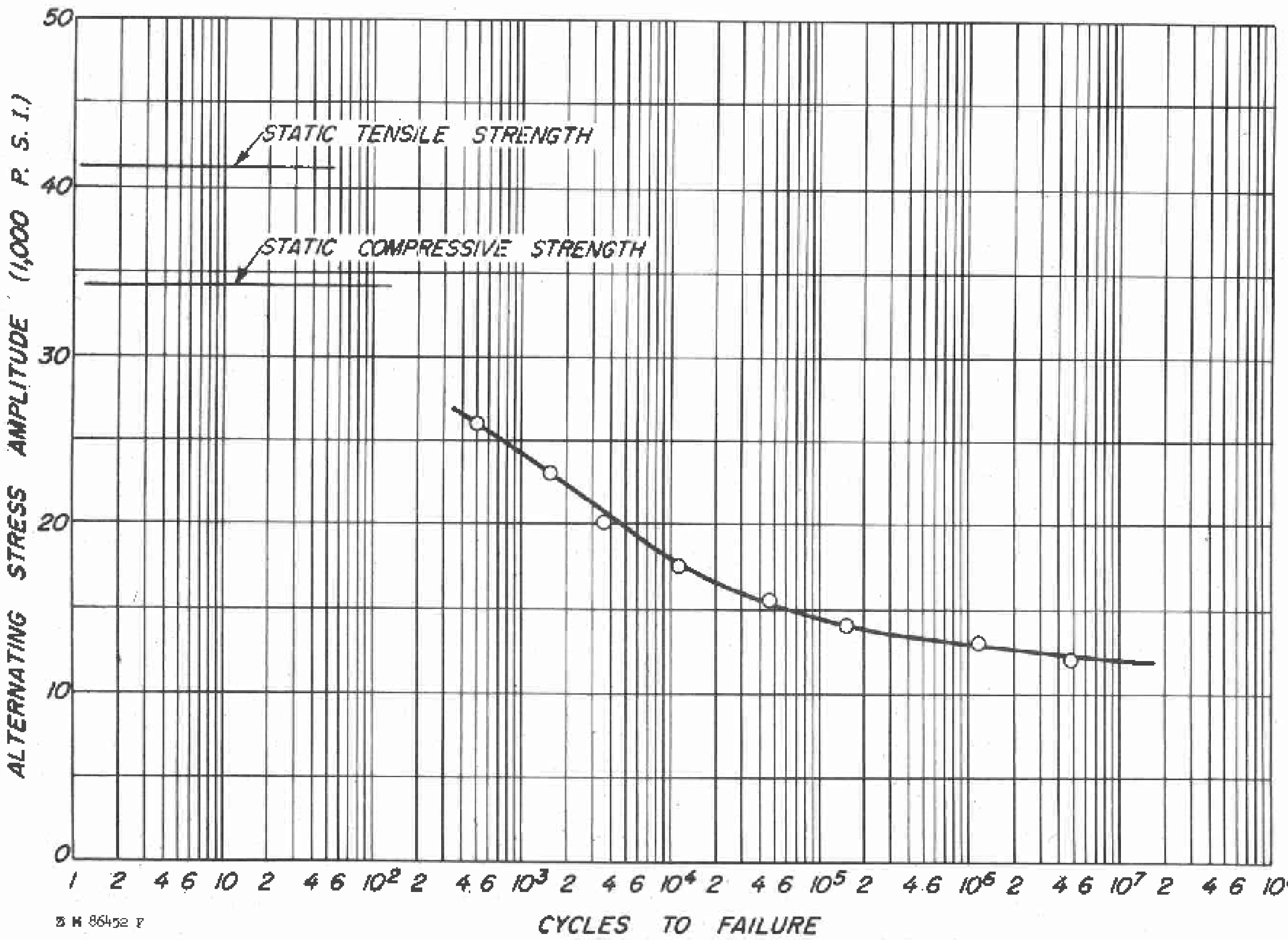
Z M 86450 F

Figure 14.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 1 and 181-114 fabric, tested at 0° to warp at 75° F. and 50 percent relative humidity, with an air blast for cooling. Stress ratio of -1.00.



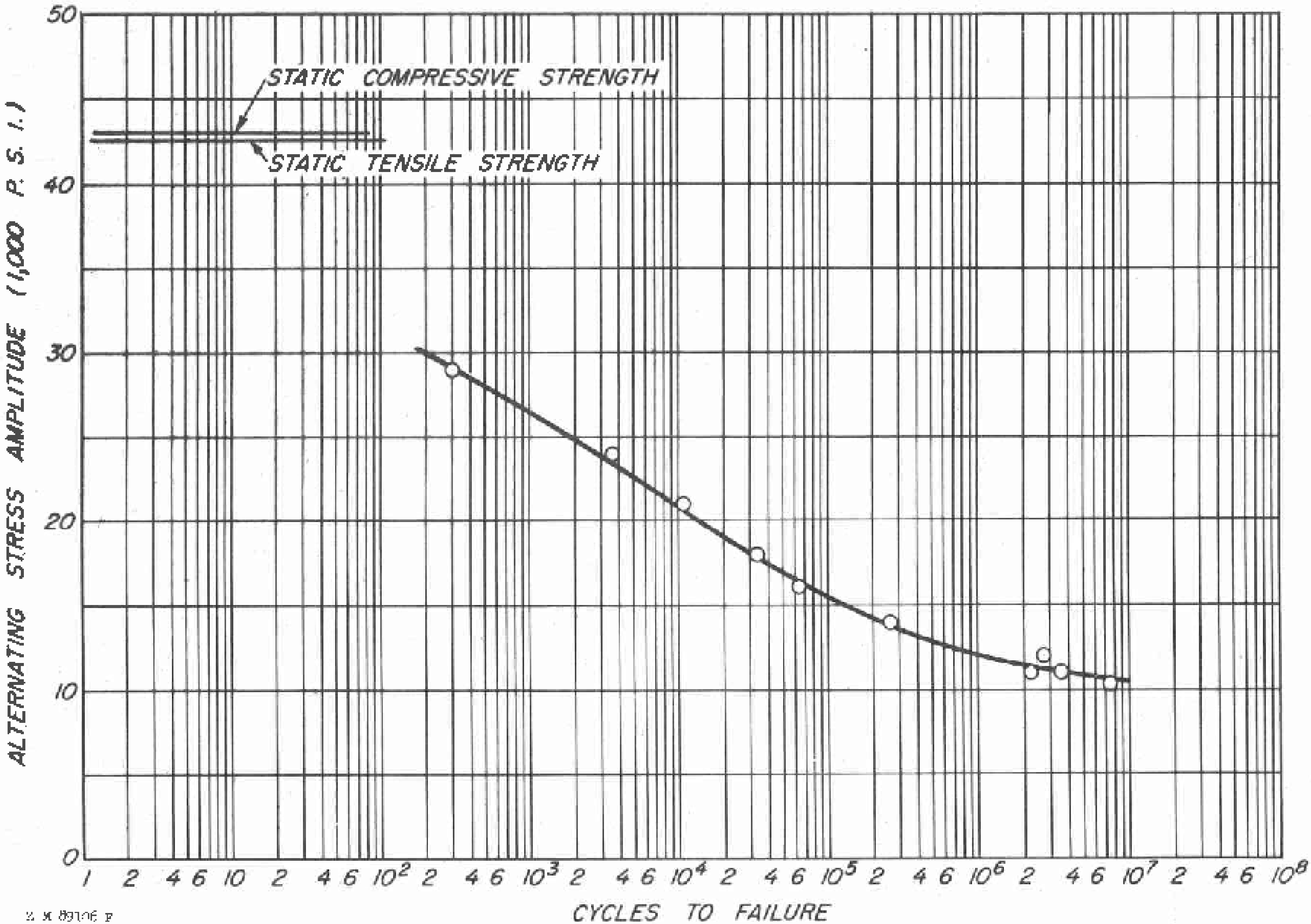
Z M 86451 F

Figure 15.--S-N curve of notched specimen (1/8-inch-diameter hole in center of specimen) of glass-fabric-base laminate, resin 1 and 181-114 fabric, tested at 0° to warp and at 75° F. and 50 percent relative humidity, with an air blast for cooling. Stress ratio of -1.00.



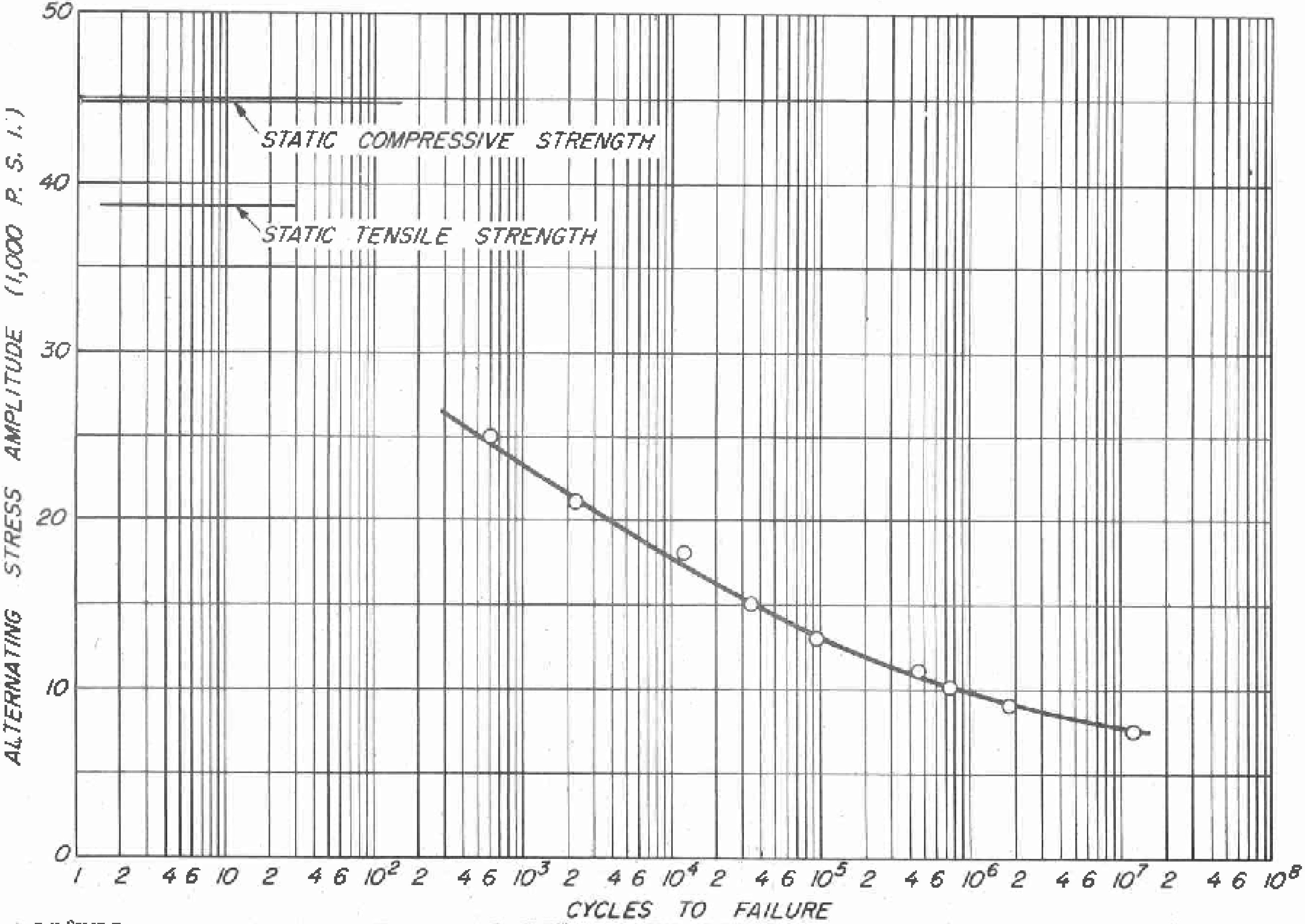
Z M 86452 F

Figure 16.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 1 and 181-114 fabric, tested at 0° to warp and at 75° F. and 50 percent relative humidity, without an air blast for cooling. Stress ratio of -1.00.



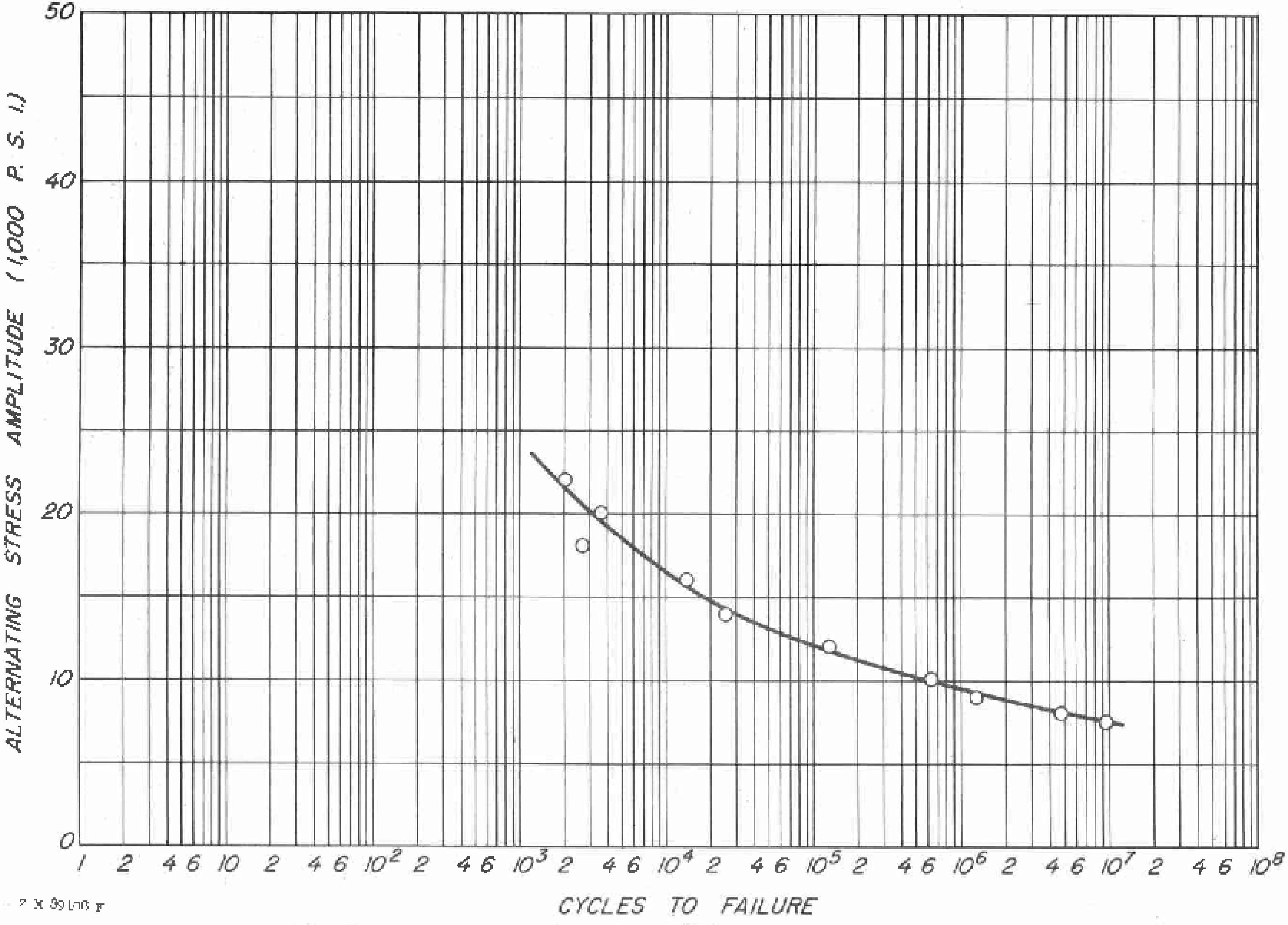
Z M 89106 F

Figure 17.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 2 + 143-114 fabric, tested at 0° to warp, at 75° F. and 50 percent relative humidity, and at stress ratio of -1.00.



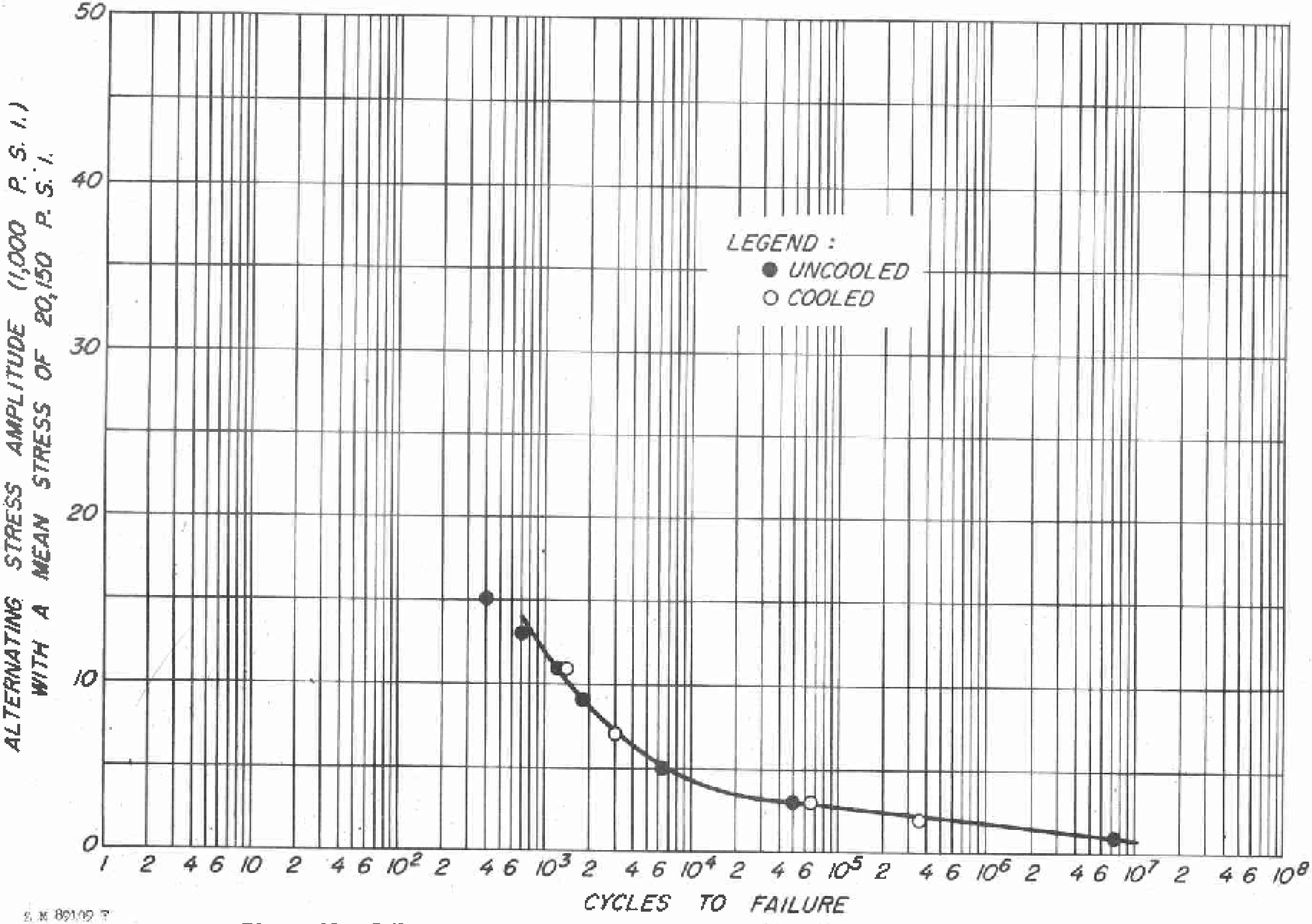
Z M 89107 F

Figure 18.--S-N curve of notched specimens (1/8-inch-diameter hole in center of specimen) of glass-fabric-base laminate, resin 2 + 143-114 fabric, tested at 0° to warp, at 75° F. and 50 percent relative humidity, and at stress ratio of -1.00.



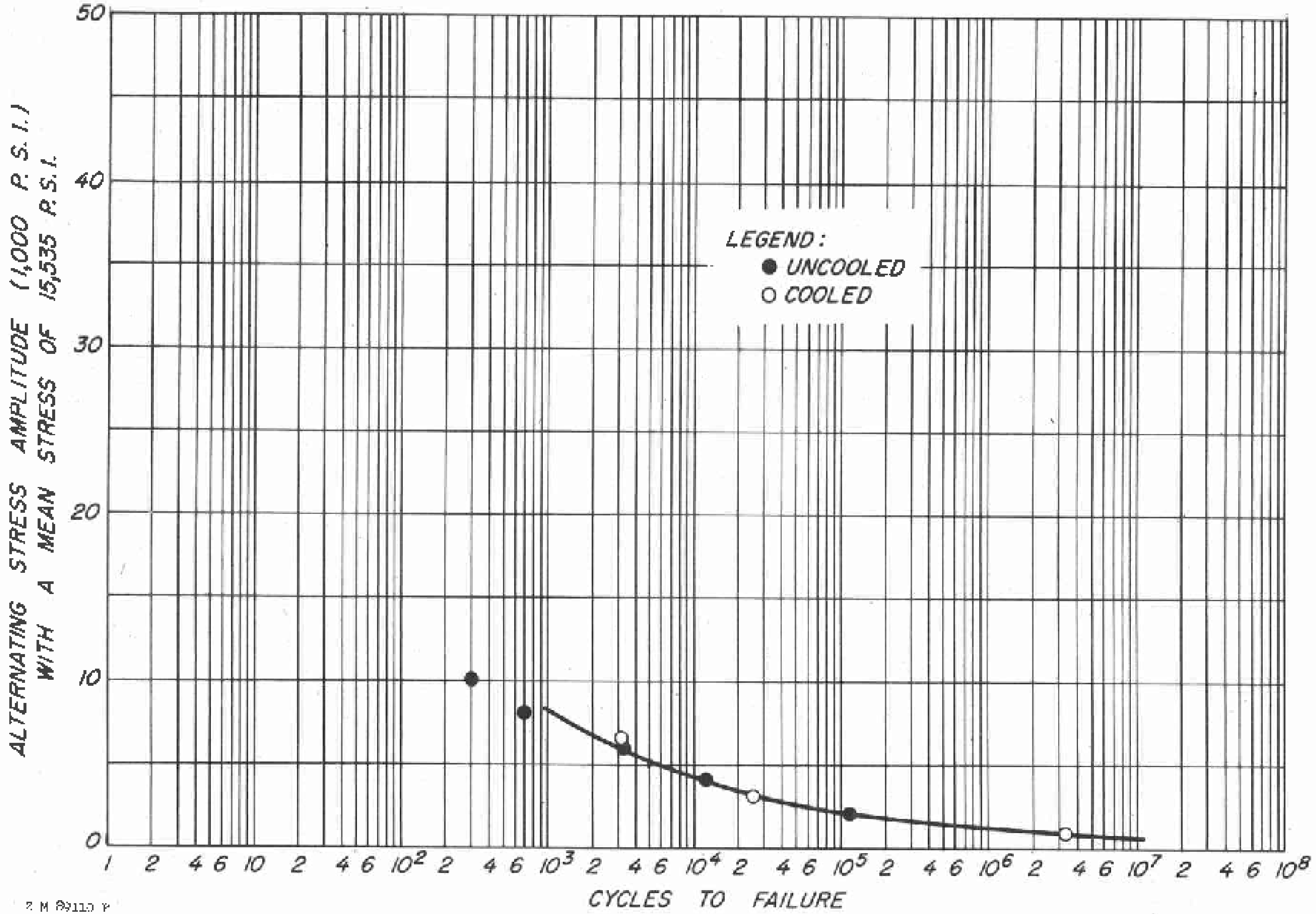
Z M 89178 F

Figure 19.--S-N curve of notched specimens (1/4-inch-diameter hole in center of specimen) of glass-fabric-base laminate, resin 2 + 181-114 fabric, tested at 0° to warp, at 75° F., 50 percent relative humidity, and at zero mean stress with the load applied on a 1/4-inch-diameter pin that was through the hole.



Z M 89109 F

Figure 20.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 2 + 181-114 fabric, tested at 0° to warp, at 75° F. and 50 percent relative humidity, and at a mean stress of 20,150 pounds per square inch (one-half static tensile strength).



Z M 89113 F

Figure 21.--S-N curve of notched specimens (1/8-inch-diameter hole in center of specimens) of glass-fabric-base laminate, resin 2 + 181-114 fabric, tested at 0° to warp, at 75° F. and 50 percent relative humidity, and at a mean stress of 15,535 pounds per square inch (one-half static tensile strength).

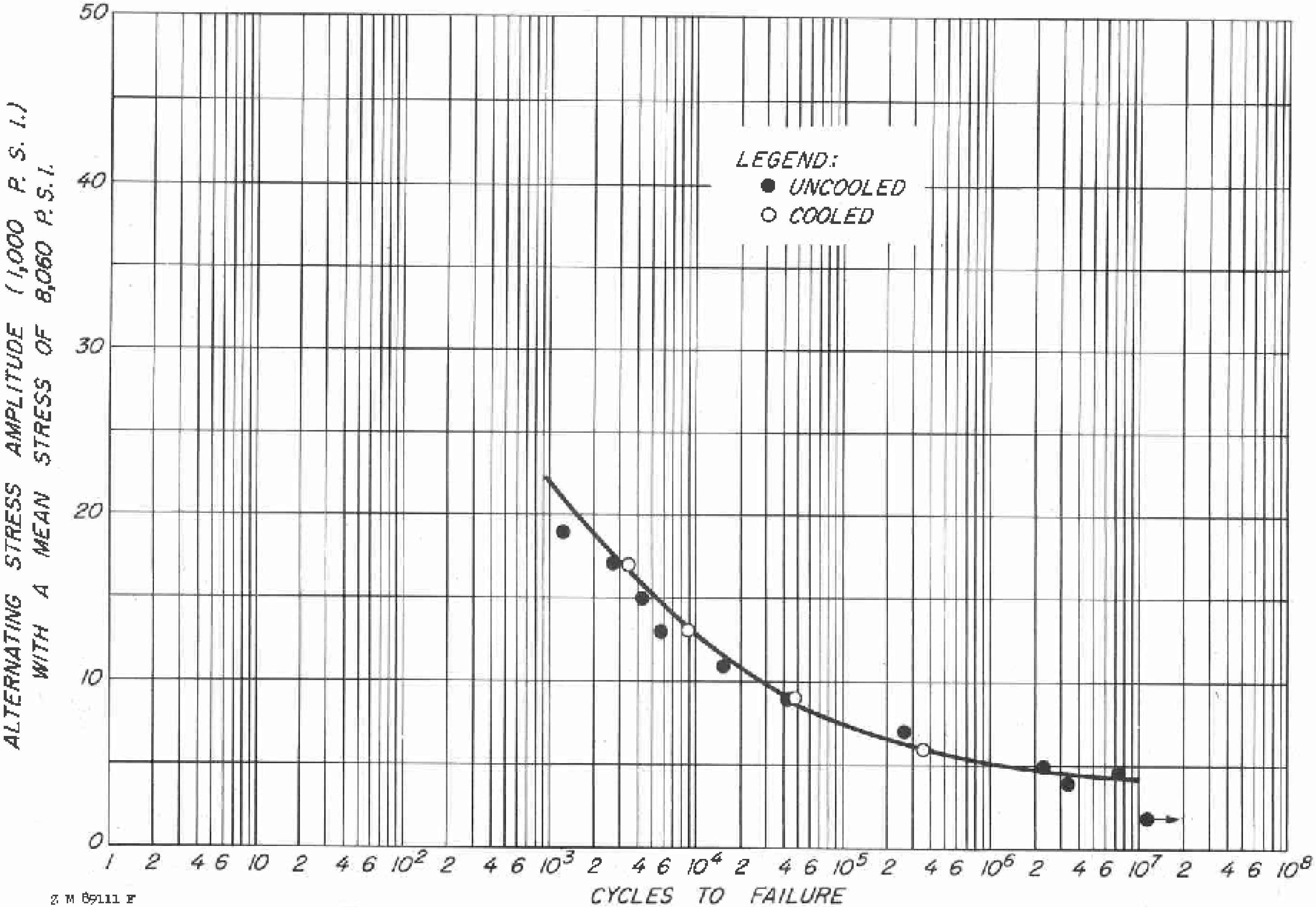
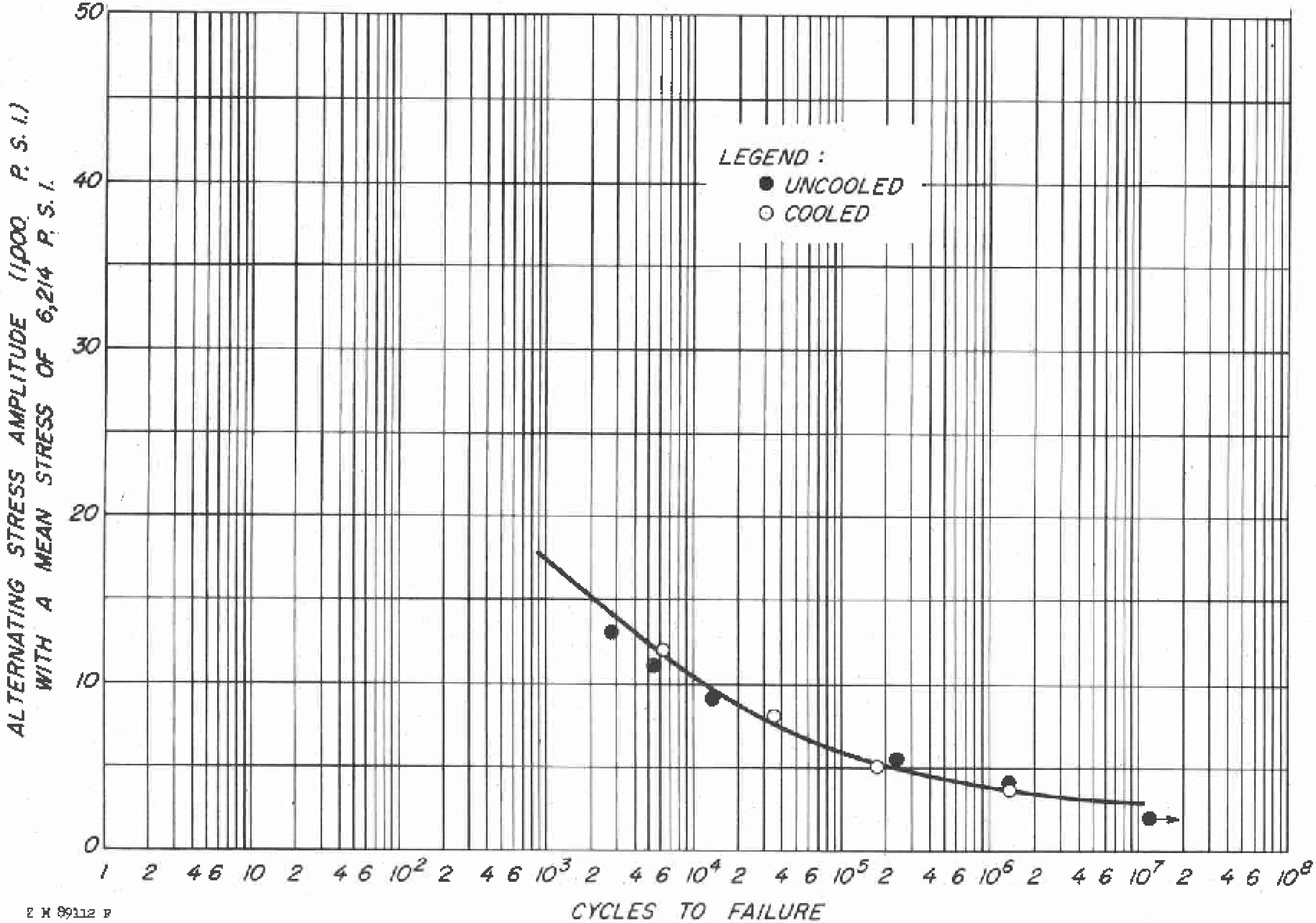
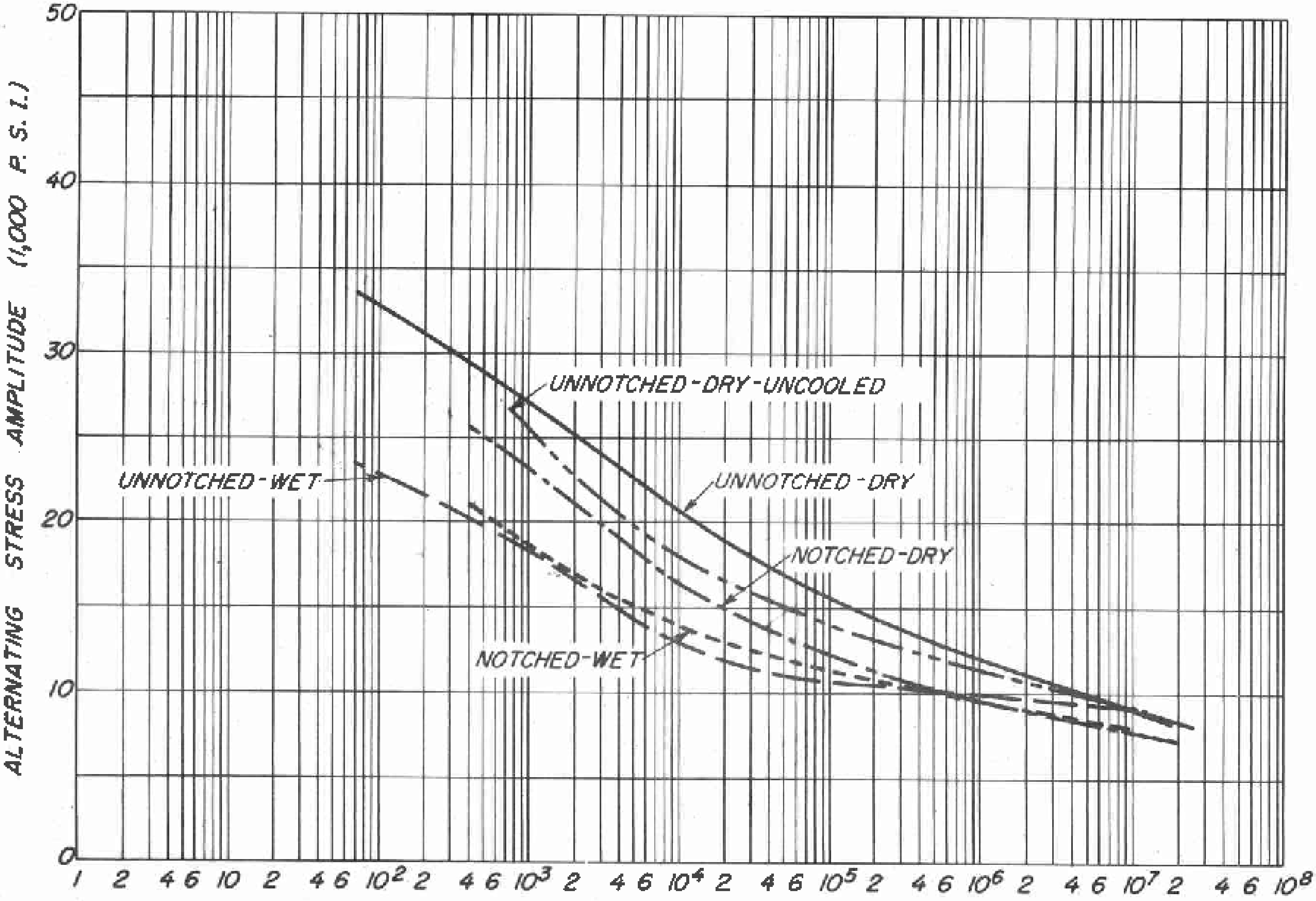


Figure 22.--S-N curve of unnotched specimens of glass-fabric-base laminate, resin 2 + 181-114 fabric, tested at 0° to warp at 75° F. and 50 percent relative humidity, and at a mean stress of 8,060 pounds per square inch (one-fifth static tensile strength).



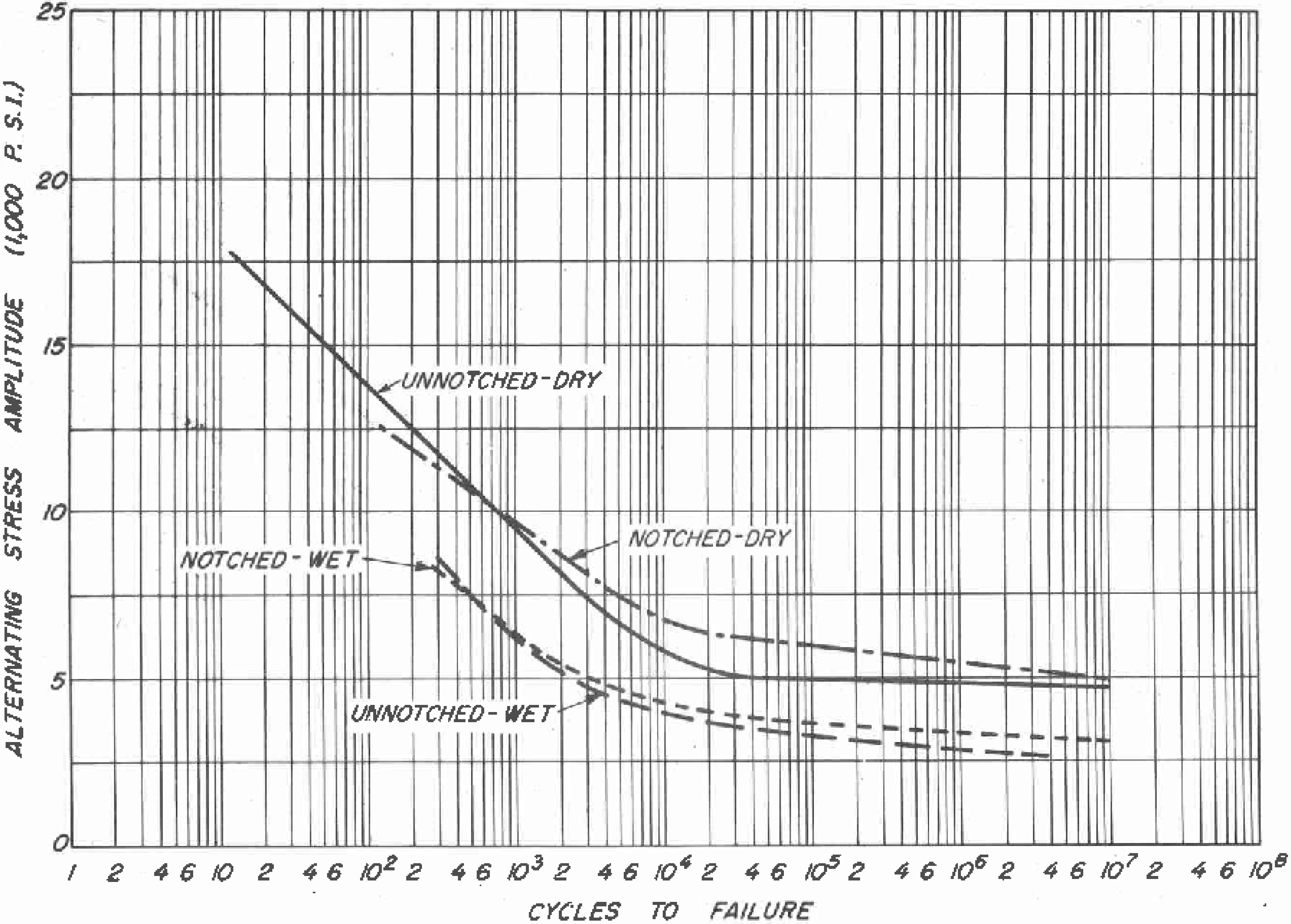
Z M 89112 F

Figure 23.--S-N curve of notched specimens (1/8-inch-diameter hole in center of specimen) of glass-fabric-base laminates, resin 2 + 181-114 fabric, tested at 0° to warp at 75° F. and 50 percent relative humidity, and at a mean stress of 6,214 pounds per square inch (one-fifth static tensile strength).



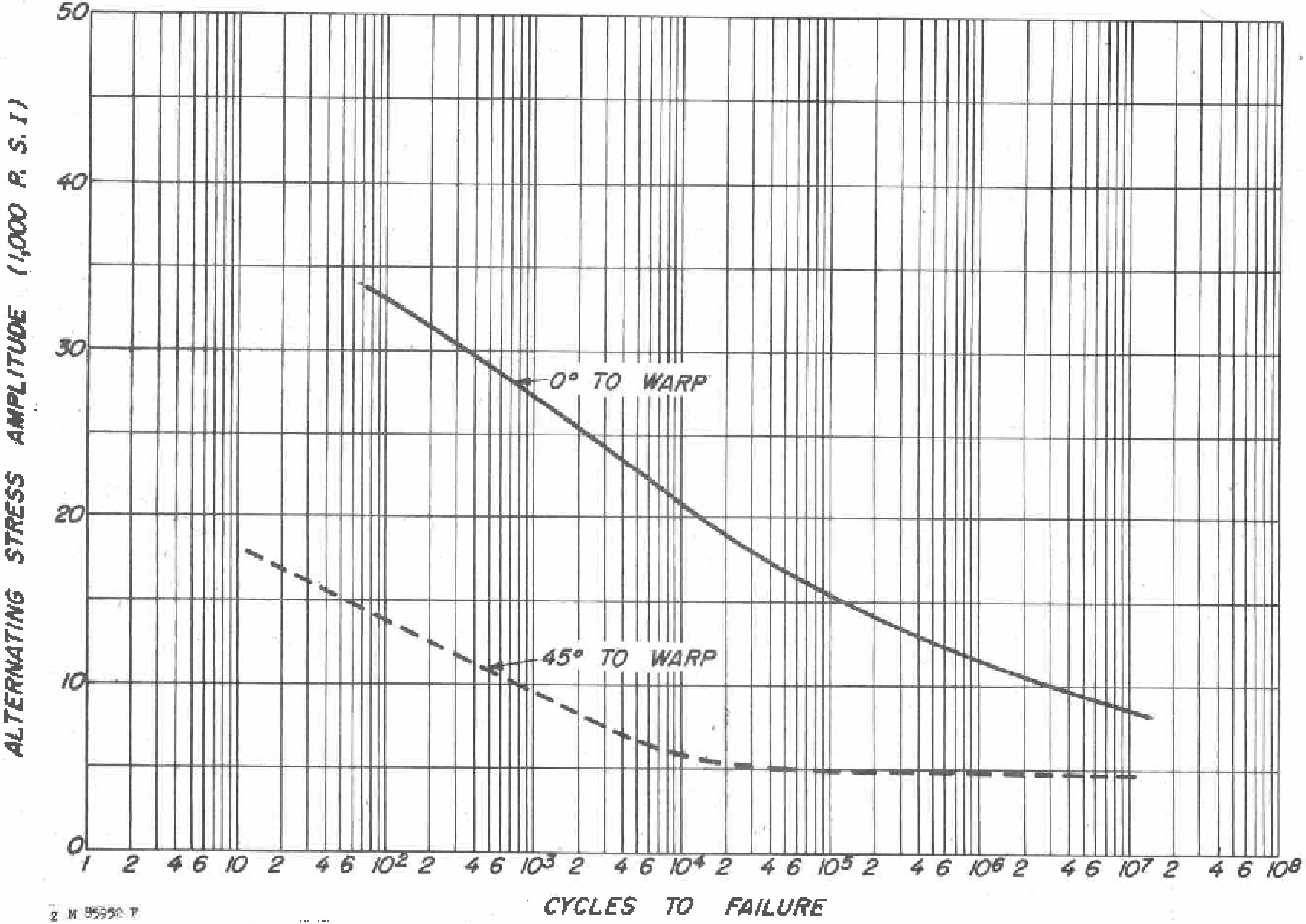
Z M 85950 F

Figure 24.--S-N curves for glass-fabric-base laminate (resin 2 + 181-114 fabric) at 0° to warp. Stress ratio of -1.00.



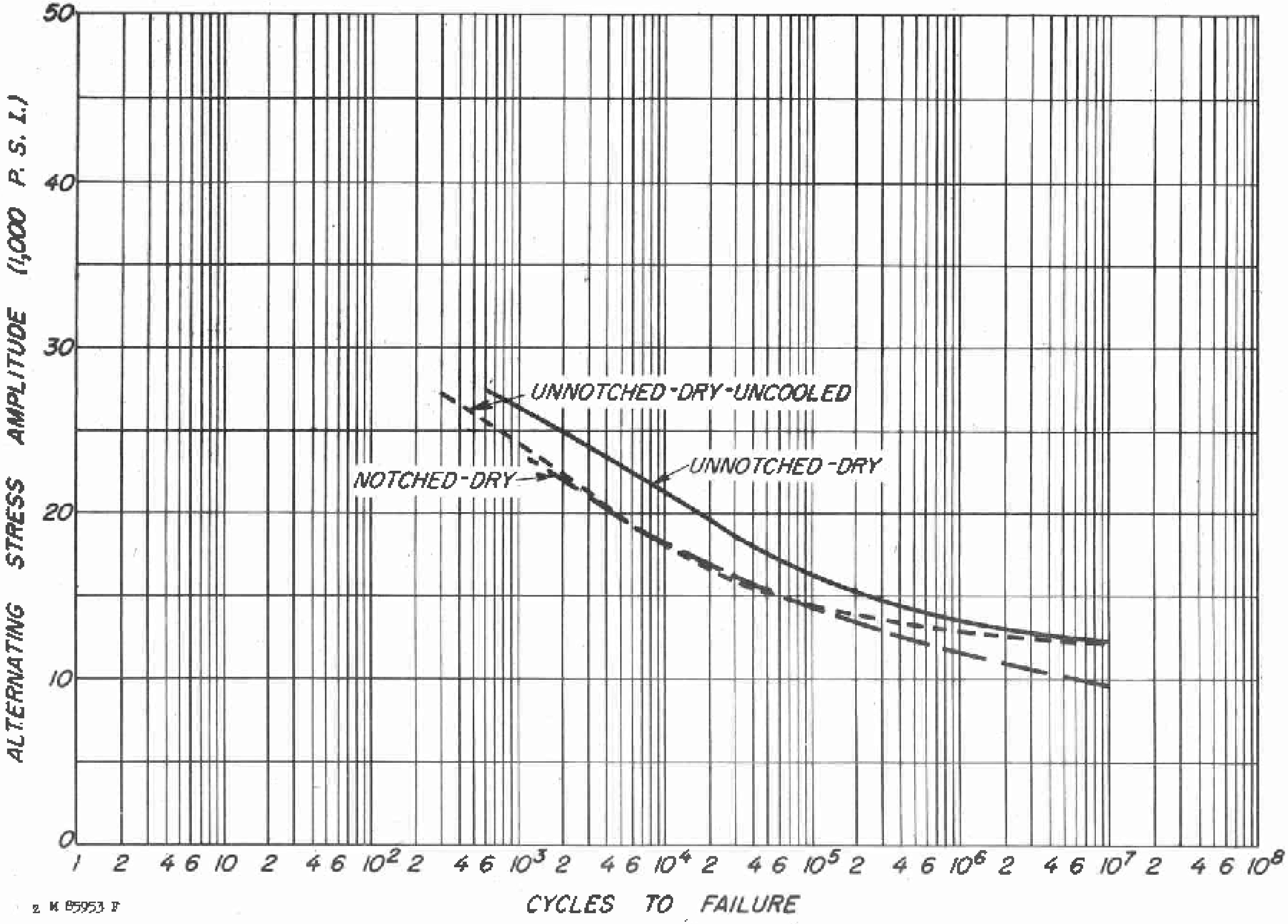
Z M 85951 F

Figure 25.--S-N curves for glass-fabric-base laminate (resin 2 + 181-114 fabric) at 45° to warp. Stress ratio of -1.00.



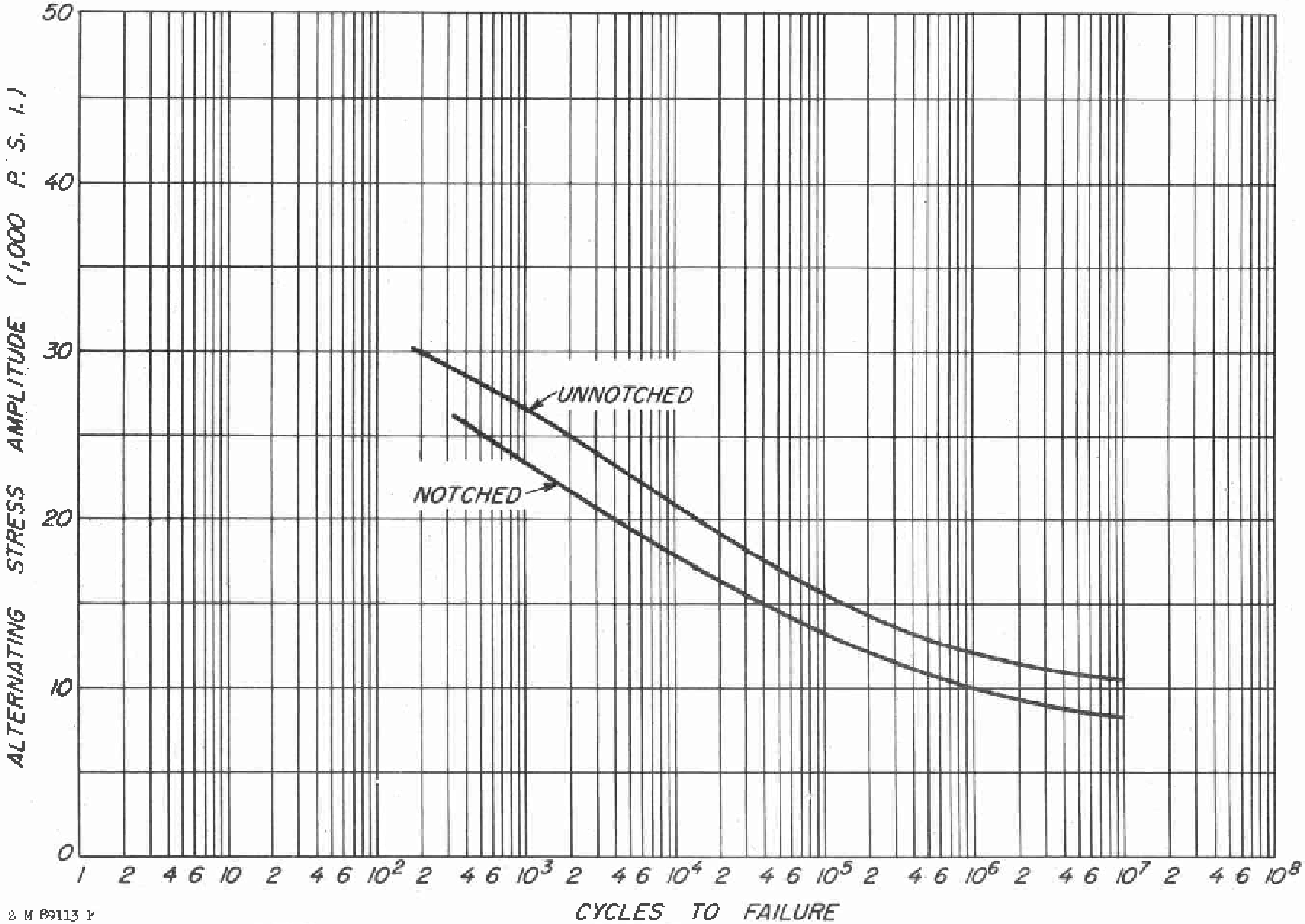
Z M 85950 F

Figure 26.--S-N curves for glass-fabric-base laminate (resin 2 + 181-114 fabric) at 0° and 45° to warp, tested at 75° F. and 50 percent relative humidity. Stress ratio of -1.00.



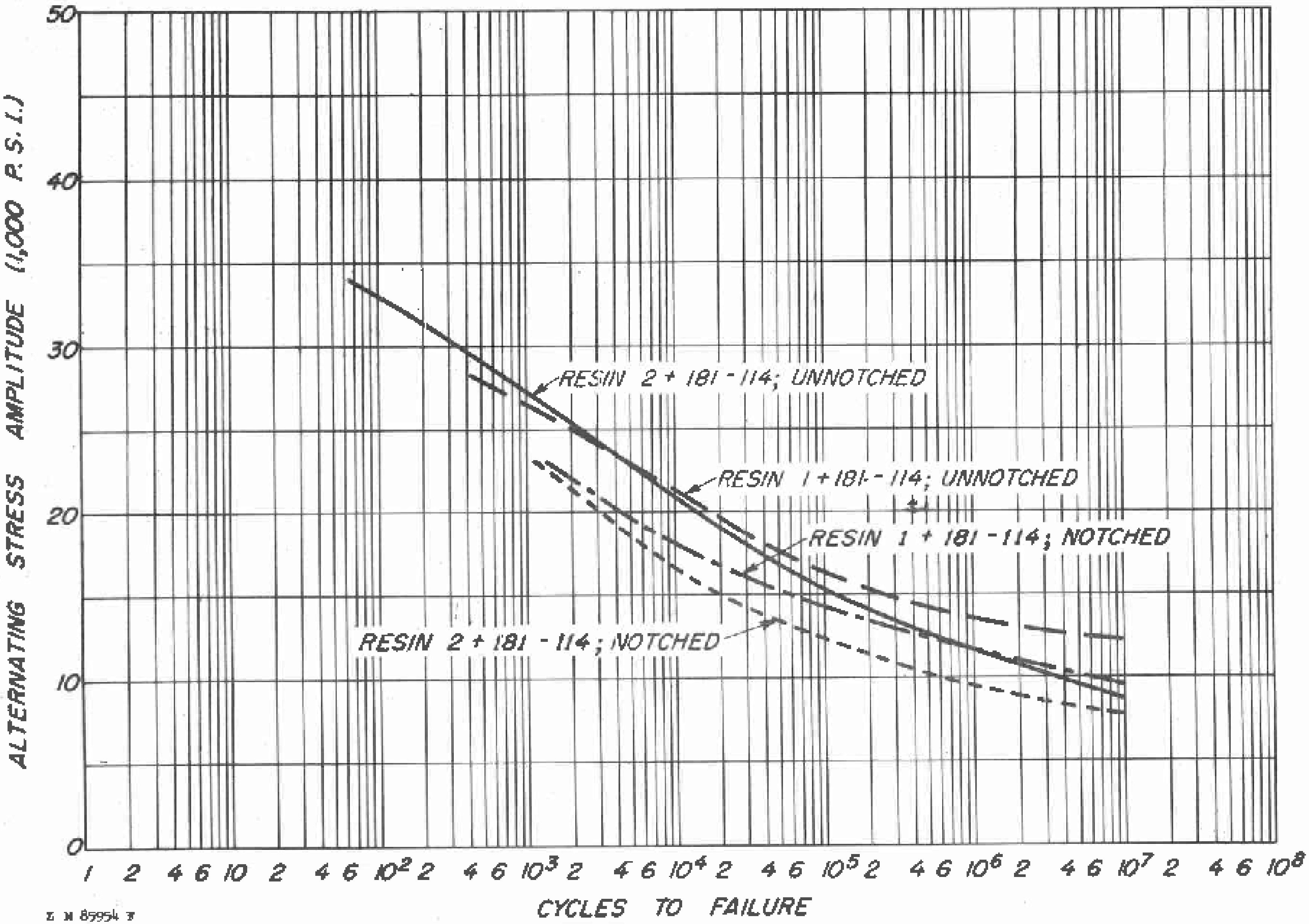
Z M 85953 F

Figure 27.--S-N curves for glass-fabric-base laminate (resin 1 + 181-114 fabric), tested at 0° to warp and at 75° F. and 50 percent relative humidity. Stress ratio of -1.00.



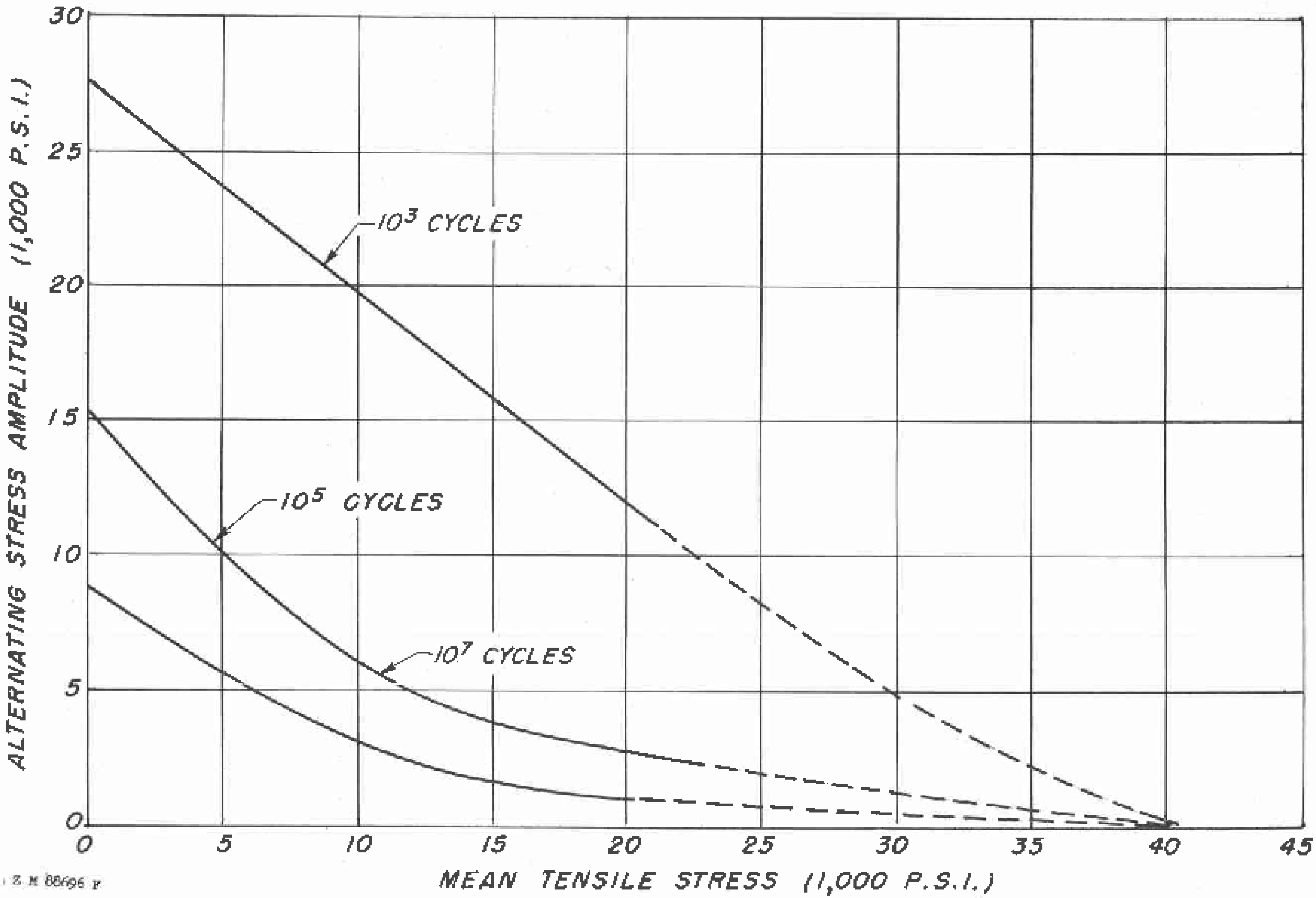
Z M 89113 F

Figure 28.--S-N curves for glass-fabric-base laminate (resin 2 + 143-114 fabric) tested at 0° to warp and at 75° F. and 50 percent relative humidity. Stress ratio of -1.00.



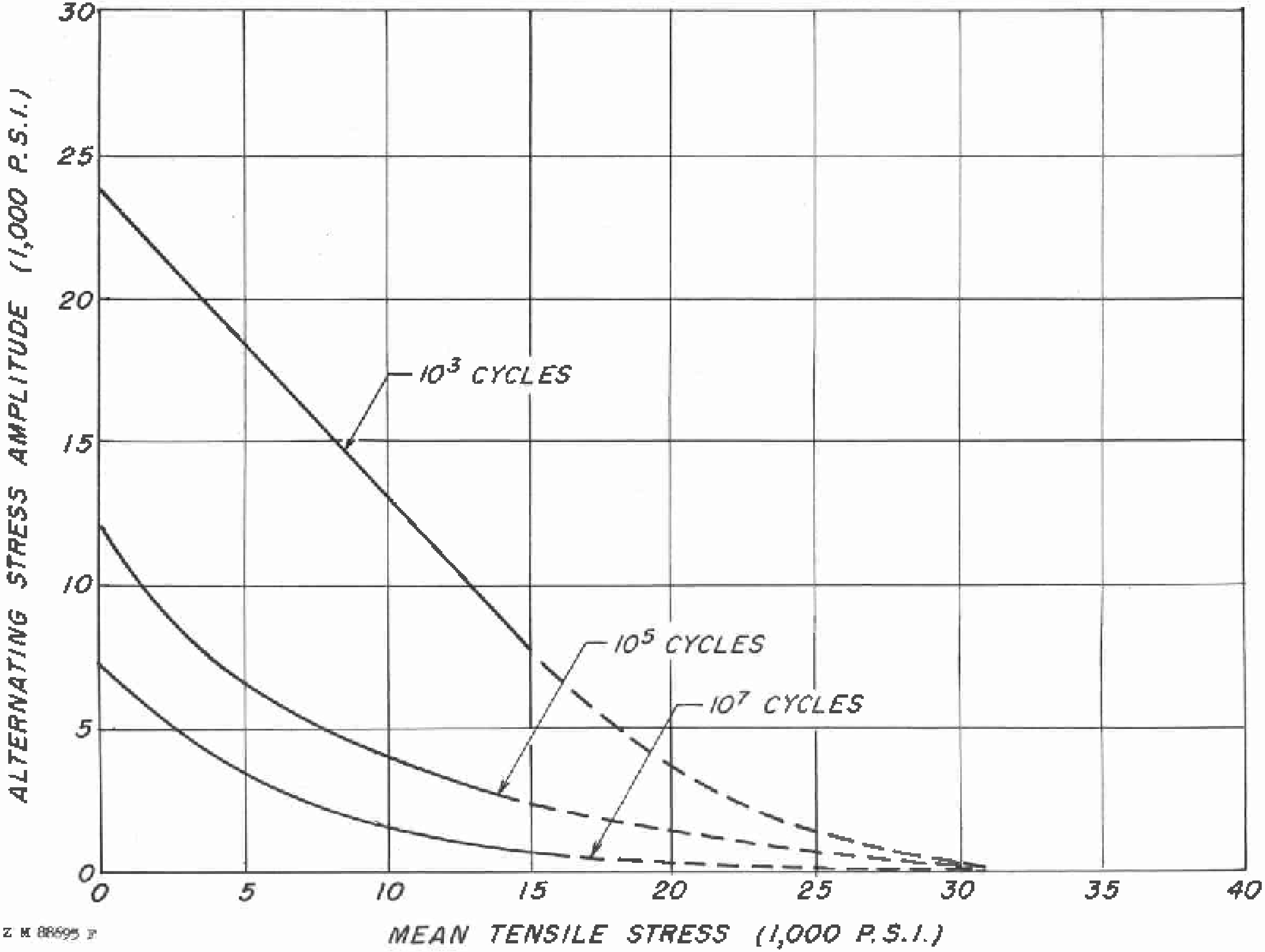
Z M 85954 F

Figure 29.--Comparison of S-N curves of two glass-fabric-base laminates at 0° to warp and at 75° F. and 50 percent relative humidity. Stress ratio of -1.00.



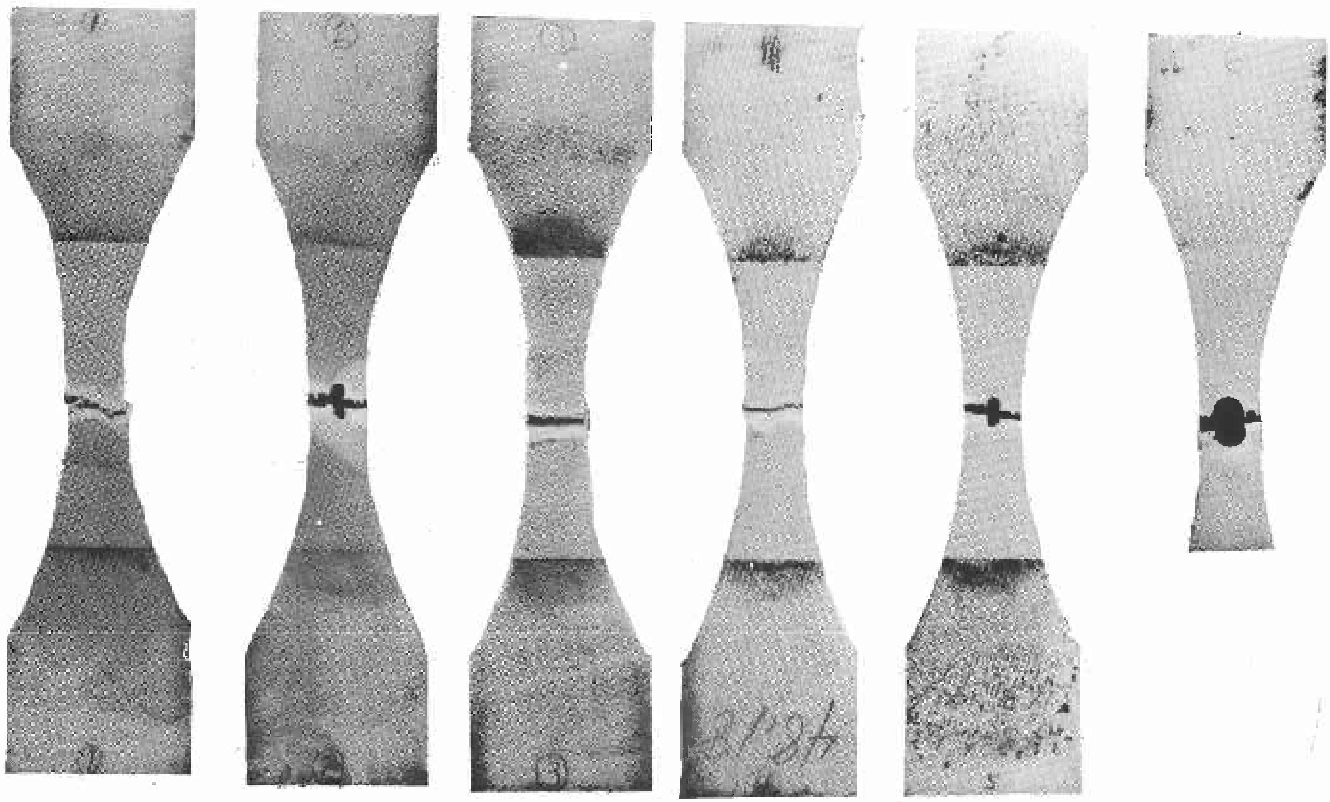
Z M 86696 F

Figure 30.--Effect of three mean stresses on alternating stress amplitude of an unnotched glass-fabric-base laminate (resin 2 + 181-114 fabric) in axial loading.



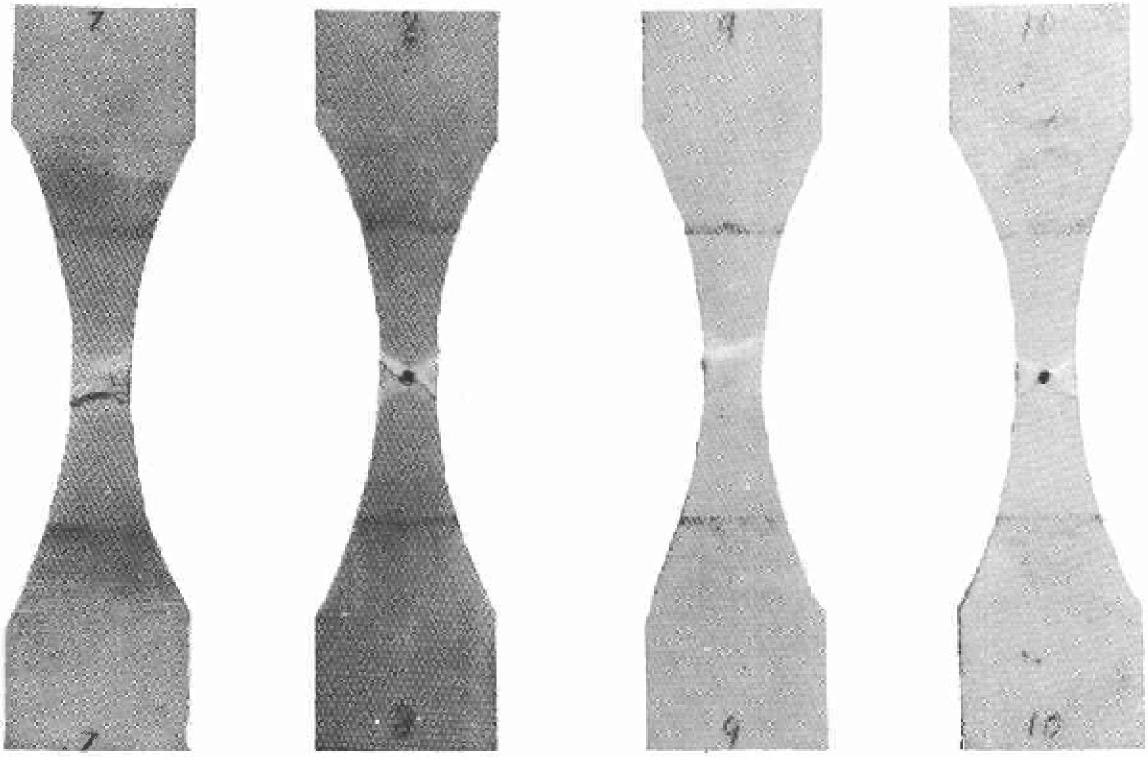
Z M 88695 F

Figure 31.--Effect of three mean stresses on alternating stress amplitude notched glass-fabric-base laminate (resin 2 + 181-114 fabric) in axial loading.



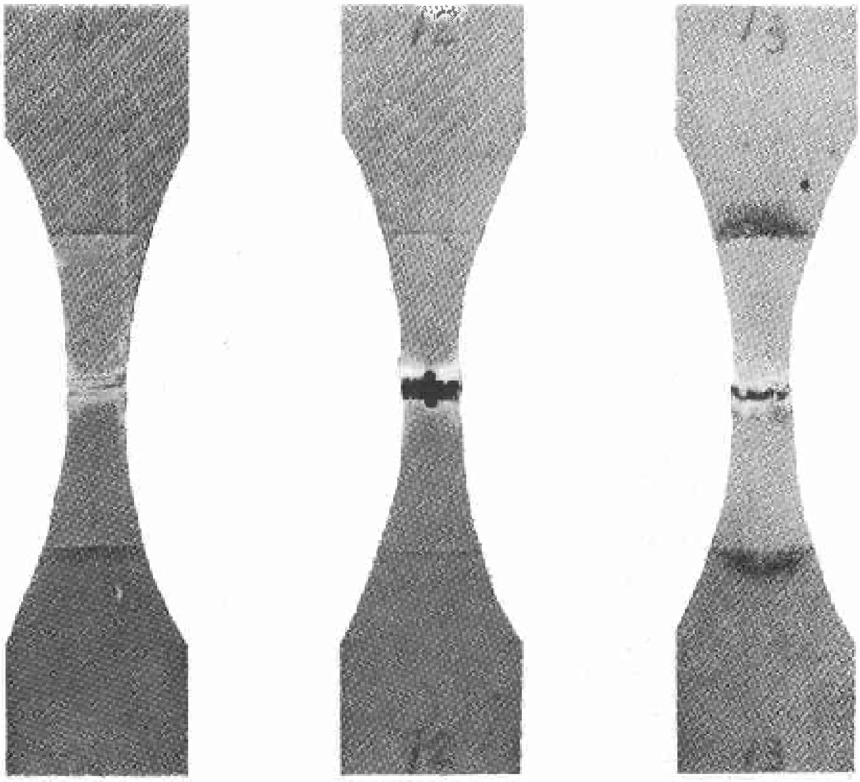
Z M 87896 F

Figure 32.--Typical failures of fatigue specimens made of resin 2 + 181-114 fabric (laminate 1) tested at 0° to warp.



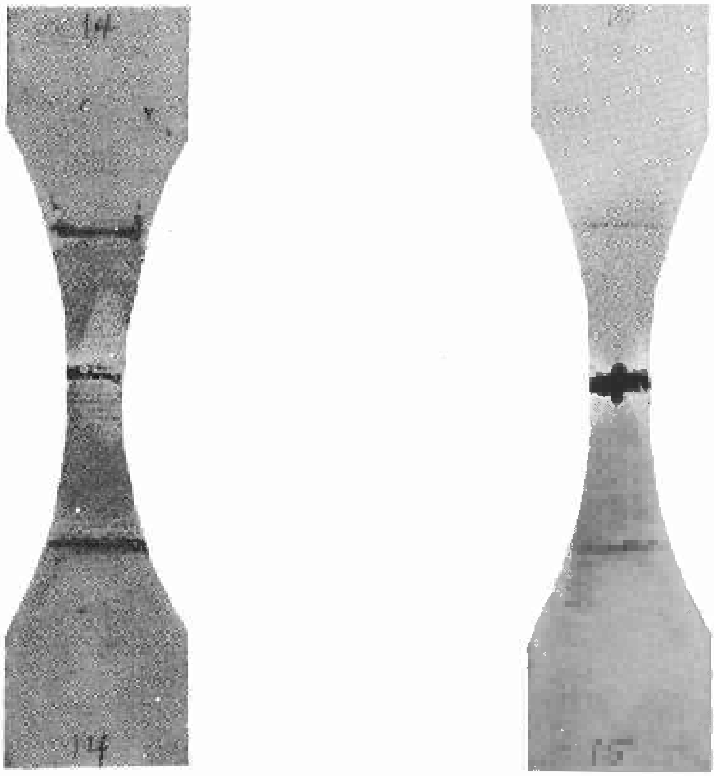
Z M 87897 F

Figure 33.--Typical failures of fatigue specimens made of resin 2 +181-114 fabric (laminate 1) tested at 45° to warp.



Z M 87898 F

Figure 34.--Typical failures of fatigue specimens made of resin 1 + 181-114 fabric (laminate 2) tested at 0° to warp.



Z M 87899 F

Figure 35.--Typical failures of fatigue specimens made of resin 2 + 143-114 fabric (laminate 3) tested at 0° to warp.