WADC TECHNICAL REPORT 56-320
ASTIA DOCUMENT No. AD 118228

RESEARCH ON STRUCTURAL ADHESIVE PROPERTIES OVER A WIDE TEMPERATURE RANGE

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APRIL 1957

MATERIALS LABORATORY
CONTRACT No. AF 33(616)-2620
PROJECT No. 7340

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.
400 - May 1957

FOREWORD

This report has been prepared by The Glenn L. Martin Company, Materials Engineering, covering the work conducted under Air Force Contract No. AF33(616)-2620. This contract was initiated under Project No. 7340, "Rubber, Plastics, and Composite Materials", Task No. 73401, "Structural Adhesives". It was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. Floyd Bair acting as project engineer. The assistance of Mr. R. J. Rooney, Materials Laboratory, Directorate of Research, WADC, for conducting fatigue tests is appreciated.

This report covers work conducted from July 1954 to April 1956.

ABSTRACT

The widespread increased use of adhesive bonded construction in military aircraft requires that the mechanical properties of adhesives be determined over a wide temperature range in order to determine the useful operating temperature range.

The mechanical properties of adhesive bonded aluminum joints were determined using standard test procedures over a range of temperatures from -100° F to +800° F. The effect of exposure at test temperature for various periods of time was also determined. The effect on the properties of using a different adherend was determined by duplication of some of the test conditions on stainless steel lap joint specimens. Nine general purpose adhesives, AF-6, PA-101, Plastilock 608, Metlbond 4021, FM-47 Liquid, FM-47 Film, Redux E (Type R), Cycleweld 55-20 and Epon VIII; and two high temperature adhesives, Shell 422 **and HT-20, were tested.**

The program was confined to the testing of standard specimens, bonded in accordance with exact procedure specified at the beginning of the contract by the adhesive manufacturers to obtain the optimum properties over a wide temperature range. Tensile shear, creep rupture, tensile, impact, bend, cleavage, fatigue and peel tests were conducted.

Lap specimens of general purpose adhesive decreased in strength after 1/2 hour exposure at test temperature compared to test values obtained immediately after reaching test temperatures. Further exposure in general produced increased strength over the initial values obtained for the bonded joints.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

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

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SUMMARY

The mechanical properties of adhesive bonded aluminum joints were determined (See NOTE*) using nine general purpose and two high temperature structural adhesives and standard test procedures over a range of temperatures from -100° to +800° F. The effect on these properties of using a different adherend was determined by duplication of some of the test conditions on stainless steel lap joint specimens.

Shear tests were conducted over the range of temperatures to determine ultimate strength at temperature and strength retention at temperature after various periods of exposure at the test temperature. Shear tests conducted over a range of temperatures (without long time exposure) show that all general purpose adhesives drop in strength at -100° F. The nitrile-phenolic types reach maximum strength at 76° F and suffer a marked loss in properties at 180° F. Three resinous adhesives increased in strength at 180° F as compared to room temperature data. Further increase in testing temperature up to 350° F resulted in decreasing strengths for all general purpose adhesives.

The strength-temperature curves for the high temperature adhesives show comparatively very little change in strength as a function of temperature up to 500° F.

Several phenomena are apparent from the data obtained after heat exposure tests:

1. Joint strengths of the general purpose adhesives decreased initially after one-half hour exposure at test temperature compared to values obtained upon testing at stabilization of temperature.

2. Further exposure beyond one-half hour at elevated temperatures of 180°, 250°, and 350° F in general produced a curing effect and resulted in increased strengths over the initial values for aluminum joints bonded with the general purpose adhesives.

3. Long time exposure at 350° F of steel joints bonded with the high temperature adhesives resulted in a greater loss in strength than was found after the same exposure period for aluminum joints.

4. After exposure for 1000 hours, the difference in strength at 350° F between the high temperature and most of the general purpose adhesives was slight.

Creep-rupture tests were performed and stress versus time to rupture curves developed for each adhesive at three elevated temperatures for a life of one to 200 hours. Tests on steel joints were performed only on the two high temperature adhesives. Since

the creep characteristic of structural adhesives is an important property for consideration in selecting materials for aircraft applications of bonding, further tests should be run to relate stress-rupture life to various curing cycles; to determine accurate creep time/deformation curves; and to establish design criteria.

Impact tests conducted at 76° F and -100° F show that a marked reduction in impact strength occurs at the lower temperature, the relative loss in strength being greater for nitrile-phenolic type adhesives. The impact specimen and test method specified by WADC gave more reproducible results than the test formerly specified in USAF Specification No. 14164 (now superseded by MIL-A-5090B with impact test deleted).

Impact strength is a measure of energy required to fracture a given material and is roughly indicative of the ability of the material to withstand shock loading or sudden blows. However, it is not a fundamental material property; it represents a complex of interrelated factors such as tensile strength, shear strength, elongation, plasticity and testing conditions. It may not be used quantitatively in design (11).

Cleavage tests were run on all adhesives at 76° F. Results obtained from this test show considerable scatter in spite of tests repeated in an effort to obtain more reproducible values. Efforts to relate these data to values obtained from other tests were of slight success; no relation between cleavage and peel strength was found. The data, however, show a rough relationship when plotted against the values obtained from the tensile tests (Fig. 67).

Tension tests were performed at 76° F only. The data obtained from this test do not represent the true tensile strength of the adhesives since a peeling force was present during the loading of the specimen. However, the tensile data may be compared roughly with tensile shear data on lap joints since peeling forces are present in both of these tests. For the resinous types of adhesives the tensile data are equivalent to the tensile shear data on lap joints. For the nitrile-phenolic class the tensile data are lower than the tensile shear test data, with the ratio of the two test values at approximately 70 per cent. The data for both types of adhesives plot as straight line ratios (Fig. 68). Specimens for the determination of the tensile strength property should consist of straight cylinders threaded for attachment to pull rods (or equivalent) rather than the specimen configuration used in this investigation (12).

Bend strength values were obtained on lap joints by loading the specimens as a simple beam. The three adhesives which failed to pass the MIL-A-5090B specification requirement of 150 pounds also have low peel strength; however, a direct correlation of bend strength with peel strength can not be made.

Peel tests were run on all adhesives at 76° F. Attempts to relate the peel strength of an adhesive to bend strength were unsuccessful. Peel strength is not a fundamental material property but, similar to impact strength, represents a complex of interrelated factors such as notch tensile strength, modulus of elasticity of the adhesive, flexural rigidity of the adherend, thickness, the surface preparation method used on the adherend, and testing conditions (13). However, empirical peel tests are useful as quality control tools for production cleaning systems, studies of the effects of contaminants on metal, and evaluation of new cleaning methods. Peel test values will vary as a function of changes in surface condition of the adherend more than any other test parameter.

Fatigue tests were conducted on lap joints at three temperatures. Stress levels were selected in order to establish S-N curves in the range of 10^3 to 10^7 cycles for each adhesive at the various test temperatures. Multiple-curve graphs were prepared for comparative evaluation of fatigue life of the adhesives at the various test temperatures. In considering fatigue properties of bonded joints in general, it should be pointed out that in normal practice the ratio of depth of lap to the thickness of the metal is considerably greater than was used in these test joints. Therefore, the primary concern is often the fatigue characteristics of the metal rather than of the adhesive (6)(14).

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* NOTE: Test data presented in this report are not to be construed as design criteria.

I. INTRODUCTION*

The expanding application of adhesive bonded construction in aircraft wings, fuselage, and empennage requires that mechanical properties be acceptable and consistent over a wide temperature range. It is necessary that the mechanical properties of adhesives be determined over a wide temperature range in order to evaluate the adhesives comparatively and determine their useful temperature range. The following adhesives were investigated over a temperature range from -100° F to +800° F:

Type I Nitrile rubber - phenolic

Scotchweld AF-6	Minnesota Mining and Mfg. Co.
PA-101	Bloomingdale Rubber Co.
Plastilock 608	B. F. Goodrich Co.
Metlbond 4021	Narmco, Inc.

Type II Vinyl - phenolic

FM-47 Liquid	Bloomingdale Rubber Co.
FM-47 Film	Bloomingdale Rubber Co.
Redux E - Type R	Ciba Company, Inc.
Cycleweld 55-20	Cycleweld Cement Products

Type III Epoxide

Epon VIII	Shell Chemical Corp.

Type IV Epoxide - phenolic

422 (Formulation 607-317)	Shell Development Co.

Type V Acrylate

262-A	Bjorksten Laboratories

Type VI Modified phenolic

HT-20	Bloomingdale Rubber Co.

This program did not involve the development of new or improved structural adhesives, or bonding procedures. It was confined primarily to the testing of standard lap-joint specimens, bonded in accordance with one exact procedure specified at the beginning of the contract by the adhesive manufacturers to obtain the optimum properties over a wide temperature range. Creep-rupture, tensile, impact, bend, cleavage, fatigue and peel tests were also conducted. Due to the scope of the work involved, no changes were made in the composition of the adhesives or the processes used throughout the duration of the investigation.

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* Manuscript released by the author 1 March 1957 for publication as a WADC Technical Report.

The co-operation of the adhesive manufacturers was solicited to obtain the preferred bonding procedure for each material in order to ensure optimum properties over the widest possible range of operating temperatures. The manufacturers and The Glenn L. Martin Company each bonded two similar standard-lap shear panels using the specified bonding technique for each of the adhesives. The cleaning procedure used was specified by WADC. Comparative shear tests on these panels were made at room temperature to ensure that the properties of the contractor's specimens duplicated those of the manufacturer at this temperature. It was then assumed that the contractor's bonding procedures were in accordance with the manufacturer's recommendations.

Type V adhesive, acrylate 262-A, Bjorksten Laboratories, was not evaluated under this program since the material was still undergoing further improvement under a separate development program involving formulation changes.

All of the adhesives evaluated under this program are not approved adhesives under MIL-A-5090B specification. The fact that these materials have been tested and reported under an Air Force contract does not imply endorsement for Air Force use. However some of the adhesives are approved for use under MIL-A-5090B specification.

II. TEST METHODS

A. SPECIMEN PREPARATION

The metals used for this investigation were 0.064 inch 2024-T3 alclad aluminum and 0.064 inch type 301, 1/2-hard, 2D finish stainless steel conforming to specification MIL-S-5059(ASG). The aluminum was cleaned according to specification MIL-A-9067 using sodium dichromate-sulfuric acid, except the aluminum for Epon VIII adhesive **which** was cleaned with an acid etch consisting of 109 parts by weight sulfuric acid, 30 parts by weight sodium dichromate, 261 parts by weight distilled water.

The steel was first cleaned by vapor degreasing and then alkaline cleaned in Sprex AN-9. It was then etched for ten minutes at 150° F in a solution of:

H_2SO_4 (95%)(Fed. Spec. OA-115)	10% By Volume
Activol 57X*	0.5% By Volume
H_2O	89.5% By Volume

The parts were then rinsed in cold water and immersed for ten minutes at room temperature in a solution of:

HNO_3 (70%)(Fed. Spec. OA-88)	10% By Volume
HF (48%)(Fed. Spec. 0-H-795)	2% By Volume
H_2O	88% By Volume

The parts were rinsed in cold water and allowed to air dry at room temperature.

The adhesive was applied and the panels were bonded according to the manufacturer's recommendations. The details of the bonding process used for each of the adhesives tested are shown in Table 1.

B. TENSILE SHEAR TESTS

The shear and creep-rupture tests were conducted in accordance with specification MIL-A-8331 (USAF), which was subsequently superseded by MIL-A-5090B. Accurate glue-line temperatures were measured for every

* Manufactured by Haas Miller Corporation.

specimen at the time of testing by means of a shielded thermocouple attached to the specimen at the flash line of the joint. A Brown Instrument Company potentiometer was used with the thermocouple.

The shear-tests were conducted on a Baldwin-Southwark Universal testing machine with the loads being read to the nearest five pounds. The rate of loading was 500 lb/min. Elevated temperature tests were conducted in a Marshall furnace equipped with a Foxboro temperature controller. Figure 1 shows the elevated temperature tensile shear test set-up.

Low temperature tensile shear tests were performed in a Baldwin Universal elevated and reduced temperature cabinet with sublimator for testing at -100° F. Figure 2 shows a test specimen mounted in the low temperature cabinet.

The effect of long time exposures at various temperatures of -100° F to 800° F upon the shear strength of the adhesives was determined. The exposure periods to elevated temperatures were carried out in a Lydon oven. The exposure to -100° F was conducted in a low temperature cabinet. All specimens were tested at the temperature to which they had been exposed for 1/2 to 1000 hours.

C. CREEP RUPTURE

The creep-rupture tests were conducted in Baldwin lever-arm creep machines using Marshall furnaces. Temperatures were controlled to ∓2° F with a Leeds and Northrup automatic temperature controlling and recording instrument. Glue line temperatures were measured by shielded thermocouples on the specimens. Maximum glue line temperature variation was ∓5° F. See Fig. 3 for creep fixture and test set-up. The specimens were stressed by applying dead weight loads using a cantilever loading apparatus capable of applying loads within 1 per cent accuracy. The specimens were suspended by means of pins passed through the ends of the long pull rods and through 0.250-inch holes in the ends of the specimens. Specimens stressed above 1800 psi required doublers at the ends in order to prevent bearing failures in the metal. After installation of the specimen in the test fixture, the load was applied in increments.

Time to rupture curves were developed for each adhesive at three temperatures. Stress levels were selected in order to produce failures with regular spacing over a range of at least 200 hours to less than one hour.

Each specimen was brought to the desired temperature and the load applied after the glue line temperature was stable. An automatic time recorder measured the time under load and the hours to rupture.

For those specimens which did not fail in 200 hours, measurements were made of the total deformation (including that due to initial loading) at regular intervals throughout the test. Measurements were made using 2-inch gage length O.S. Peters extensometers spanning the bonded joint. Control tests were also run on the metals used in order to determine the amount of deformation due to the metal as distinct from that of the adhesive.

D. IMPACT

The impact tests were conducted at room temperature and -100° F at a speed of 12.75 feet per second in a Riehle impact tester having a capacity of 110 and 220 foot-pounds. Tests were conducted on shear lap joints loaded in tension. Specimens consisted of 0.125-inch alclad 2024-T3 bonded with an overlap of 0.75-inch. Figure 4 shows the impact test machine. Figure 5 shows a test specimen and an exploded view of the loading grips. Figure 6 shows the test specimen in the test machine at the simulated moment of impact.

E. CLEAVAGE

The cleavage tests were conducted in accordance with ASTM tentative standard D1062-49T. Specimens consisted of 5/8 x 1-1/4 x 1-inch pieces of 2024-T3 bonded to give a one square inch bond area. Figure 7 shows the specimen in the test machine. Figure 8 shows a sketch of the test specimen. The load was applied at 700 pounds per minute. Tests were conducted at room temperature.

F. TENSILE

The tensile tests were conducted in accordance with Method 1011 of Federal Specification MMM-A-175. The specimens consisted of two 1.129-inch diameter aluminum discs bonded together to produce a one square-inch bond area for the tensile test. Figure 9 shows the specimen and loading mechanisms in the test machine. Tests were conducted at room temperature.

G. BEND

The bend tests were conducted on 1/2-inch lap joint specimens loaded at the center as a simple beam with a 1-1/2-inch span. The specimens were tested at a loading rate of 200 pounds per minute. Figure 10 shows the bend specimen in the test machine.

H. PEEL

The peel tests were conducted on specimens prepared by bonding a 1 x 14-inch piece of 0.020-inch 2024-T3 to a 1-1/2 x 12-inch piece of 0.064-inch 2024-T3 alclad aluminum as shown in Fig. 14.

The peel tests were conducted at room temperature in a climbing peel test apparatus developed by the Forest Products Laboratory, Madison, Wisconsin, and in accordance with the following method as disclosed by Forest Products Laboratory Report "Preliminary Observations from Tests with Climbing Peel Apparatus". This peel test apparatus consists essentially of a drum having two end collars with larger diameters than the center section of the spool. See Figs. 11, 12, and 13. One end of the over-hanging 0.020-inch 2024-T3 alclad metal is clamped to the drum so that the clamped part is tangent to the drum. The other end of the 0.020-inch strip is fastened to the top head of the testing machine. A thin stainless steel strap is attached to each collar. The other ends of the straps are pin-connected to a loading bar to assure uniform tension in each strap when load is applied. The specimen and peeling apparatus are placed in the testing machine which is then readjusted to indicate zero load. A tensile load is applied to the 0.020-inch strip and steel straps. The load P_1 (Fig. 11) produces a clockwise torque, $P_1 r_i$, on the drum; the strap load, P_2, results in a counterclockwise torque. At some loads, the torque, $P_2 r_o$, will be large enough to overcome both the clockwise torque and the peeling resistance of the panel, and the drum will rotate counterclockwise. As it does, the drum will peel the 0.020-inch part from the 0.064-inch part of the specimen and progressively climb upward. If load and head travel are recorded autographically, a relatively uniform curve will result, once peeling has started. Peeling torque observed from this method will include that required to bend the 0.020-inch strip as well as to peel the two pieces of metal apart.

The torque required to overcome the weight of the drum must be considered in the calculations. If the drum is balanced (that is, if the center of gravity is at the center of the circle as shown in Fig. 11), P_c, the load in the straps required to counteract the weight of the drum, will be equal to $\frac{Wr_i}{(r_o - r_i)}$. The load required to cause peeling, P_p, will be equal to $P_2 - P_c$; also $P_1 = P_2$, since the machine was set at zero with drum and specimen in place.

The peeling torque, T, equals the peeling load times the moment arm, or

$$\begin{aligned} T &= P_p (r_o - r_i) \\ &= (P_2 - P_c)(r_o - r_i) \\ &= P_2(r_o - r_i) - Wr_i \end{aligned}$$

The torque, T, as given above includes the torque required to bend the metal strip.

Weight of drum, $W = 6.1$ lb

$r_o = 2\text{-}1/2$ in.

$r_i = 2$ in.

$r_o - r_i = 0.5$ in.

$Wr_i = 12.2$ in.-lb

I. FATIGUE TESTS

The fatigue tests were conducted in accordance with specification MIL-A-5090B. In order to provide maximum correlation with data presently available from qualification tests for the above specification, all fatigue tests were performed using Schenck constant deflection fatigue machines at the WADC Materials Laboratory, Wright-Patterson Air Force Base, Ohio. All specimens were bonded at 3/8-inch depth of lap with the exception of PA-101 adhesive which was bonded at 5/16-inch depth of lap. Fatigue tests were made in shear by applying alternating tensile loads to the shear lap joint. The ratio of minimum to maximum tensile load was 0.1. Stress versus number of cycles to failure curves were established from 10^3 to 10^7 cycles at three temperatures. Cyclic axial loads were applied at a frequency of approximately 3600 cycles per minute.

III. RESULTS

The mechanical properties of adhesive bonded aluminum alloy lap joints, made with a number of available structural adhesives, using standard test procedures over a range of temperatures from -100° F to +800° F, have been determined. The effects of using a different adherend (stainless steel) on these properties also have been determined. The differences in initial bond strength, as well as the differences in elevated temperature properties of the metals and adhesives involved are comparatively evaluated in the following discussion of test results.

Quantities of adhesive and bonded control test panels were received from each of the adhesive manufacturers. Control test panels of the adhesives were prepared and comparative shear tests conducted at room temperature on both sets of panels to ensure that the bonding procedures used were in accordance with manufacturer recommendations. The computed results of this phase of the work are given in Table 2. In all cases data obtained from tests on control specimens were equal to or slightly above those obtained from tests on panels bonded by the adhesive manufacturers. Thus, the bonding procedures used were considered satisfactory.

Nine of the adhesives tested are grouped as general purpose adhesives. These are: AF-6, PA-101, Plastilock 608, Metlbond 4021, FM-47 Liquid, FM-47 Film, Redux E (Type R), Cycleweld 55-20, and Epon VIII. The remaining two adhesives tested, Shell 422 and HT-20, are high temperature adhesives.

A. SHEAR STRENGTH VS TESTING TEMPERATURE - ALUMINUM JOINTS

Table 3 presents tensile shear data at 76° F, 180° F, 250° F, 350° F, 500° F, 650° F, and 800° F. Figure 18 presents graphically the five specimen average values plotted for tensile shear at the various test temperatures. These tests on 2024-T3 alclad aluminum joints were performed when the thermocouple at the glue line had stabilized at the desired temperature without further exposure or aging at the test temperature (conveniently called "0-exposure").

Tests conducted at -67° F and -100° F differ from the remaining data in the table in that the specimens were exposed for 1/2-hour at the test temperature before the application of load (Table 4). All general purpose adhesives tested exhibit a loss in strength at -67° F and -100° F, compared to their strengths at room temperature, with average strengths of 1500 to 3100 psi obtained at the low temperatures. However, all adhesives tested, except PA-101 exceed the MIL-A-5090B specification requirement of 2500 psi at -67° F.

All general purpose adhesives tested exceed the specification strength requirement at room temperature. Average strengths at 76° F range from 3100 to 4600 psi.

At 180° F, six of the nine general purpose adhesives exhibit a marked loss of shear strength as compared to the values obtained at room temperature. However, three adhesives show an increase in strength at 180° F, as follows: Epon VIII, 104 per cent; FM-47 Liquid, 104.5 per cent; and FM-47 Film, 106 per cent of room temperature values.

At 250° F, the average strength of seven adhesives fell in the range of 500 to 1750 psi. The remaining two adhesives, FM-47 Liquid and FM-47 Film, exhibit good strength retention at this temperature, giving 3570 psi and 2940 psi respectively.

At 350° F, none of the general purpose adhesives display substantial shear strength. Average strengths vary from 250 psi to 1000 psi with Metlbond 4021 retaining the highest shear strength at this temperature. No tests were conducted on these adhesives above 350° F on 2024-T3 aluminum joints.

In general the shear strength-temperature curves for the two high temperature adhesives show less variation in strength for a given change in temperature than do the general purpose adhesives. The initial portion of both curves, from -100° F to 180° F, is essentially independent of temperature. At 180° F, Shell 422 exhibits considerably higher strength than HT-20 adhesive. At 180° F the curve for HT-20 increases slightly in strength and Shell 422 begins to decrease. The strengths of the two adhesives are the same at 250° F and, thereafter, maintain essentially the same strength retention with a gradual decrease to an average of 1750 psi at 500° F. The primary difference in the strength of the two adhesives occurs at 76° F where Shell 422 had an average strength of 3240 psi, compared to 2160 psi for HT-20.

If the data are considered from the standpoint of design requirements, an interesting contrast can be shown. All structures, particularly aircraft, are required to operate at two extremes in temperature; for this discussion, assume that the lower limit is -100° F. With the inevitable growth of a particular aircraft, the low temperature requirement will probably continue to the maximum capabilities of the material - the adhesive, in this case. Let the trends shown here for the 1/2-inch laps be indictative of the behavior of lap lengths designed to carry structural loads. Then the following chart indicates the strength at -100° F and the temperature span over which the adhesive shear strength is greater than its value at -100° F.

SHEAR STRENGTH AT -100° F AND RANGE OVER WHICH STRENGTH IS EQUAL TO OR GREATER THAN -100° F STRENGTH

Adhesive	Shear Stress (psi), at -100° F	Elevated Temperature at Which Strength Equals Strength at -100° F
PA-101	1500	240
Metlbond 4021	2000	225
Plastilock 608	2200	150
AF-6	2500	110
Epon VIII	2750	205
Redux E, Type R	2970	110
Cycleweld 55-20	2960	108
FM-47 Film	3080	245
FM-47 Liquid	3100	262

The designer might expect to compromise his selection of a particular adhesive so that, to get high strength, there would necessarily be a sacrifice of latitude for operation at the upper temperature. This trend is evident in the first four adhesives in the tabulation (PA-101, Metlbond 4021, Plastilock 608 and AF-6, all the same chemical type-nitrile phenolic). For example, to use a design strength of 2200 psi shear stress in the adhesive, the maximum operating temperature is 150° F. However, if the design is such that a 1500 psi adhesive can be used, the upper temperature limit is 240° F.

The trend of the first four adhesives is not continued in the remaining adhesives; Redux E and Cycleweld 55-20 appear as one type with relatively high strength and a small temperature range. The trend of Epon VIII, FM-47 Film and FM-47 Liquid is the reverse of the first four adhesives; with an increase in shear strength of the adhesive, there is an increasing temperature range. This feature, of course, makes it unnecessary for the designer to compromise his requirements for high strength and a broad temperature range.

B. SHEAR STRENGTH AT TEMPERATURE AS A FUNCTION OF AGING TIME AT TEMPERATURE - ALUMINUM JOINTS

The effect of aging at various temperatures upon the strength retention of the adhesives at the same test temperatures was determined. Tensile shear test data obtained after one-half hour exposure time at -100° F to 800° F are listed in Table 4 for aluminum joints. Table 5 gives the data obtained after 18 hours exposure at 500° F to 800° F on aluminum joints. All specimens exposed at 650° F and 800° F fell apart during the exposure period. Table 6 lists the data obtained after 192 hours exposure at 350° F to 650° F. All specimens exposed at 650° F delaminated. Table 7 contains the data obtained after 1000 hours exposure at 180° to 500° F. All specimens exposed at 500° F delaminated during exposure. Table 8 presents a summary of the averages of all data contained in Tables 4 through 7 for all exposure tests at 180° F, 250° F, and 350° F. Table 9 lists the per cent strength retention after exposures of up to 1000 hours at various temperatures, using the room temperature values as a reference point. Figures 20 through 23 show semilog plots of the aluminum joint exposure data. It may be seen (Fig. 20) that although slight decreases occurred in some of the adhesives after one-half hour exposure at 180° F, continued exposure up to 1000 hours results in increased shear strength at 180° F, with the exception of Epon VIII, Shell 422, HT-20, and PA-101 which remain substantially unchanged.

Figure 21, a plot of exposure data at 250° F shows that a loss in strength occurs after one-half hour exposure at 250° F for the general purpose adhesives; however, after 1000 hours exposure, the shear strengths exceeded those obtained from the tests at 250° F on unaged specimens. Shell 422 and HT-20 remained substantially unchanged by exposure at 250° F.

Figure 22 is a plot of the data obtained after exposure at 350° F. After one-half hour exposure, seven adhesives show a strength loss. Continued exposure of up to 192 hours at 350° F resulted in increased shear strengths, compared to the original strength at 350° without aging. After 1000 hours of exposure, the strength of four adhesives decreases slightly, compared to the strength obtained after 192-hour exposure. Before exposure, none of the general purpose adhesives exceeded 1050 psi. After 1000 hours exposure, five adhesives exceeded 1050 psi with the highest average value being 1820 psi. This increase in strength of the general purpose adhesives with long time exposure probably is due to increased curing effects.

Figure 23 shows the data from exposure tests on Shell 422J and HT-20 at 500° F for aluminum joints. A marked loss in strength occurred during the period between 18 and 192 hours.

C. SHEAR STRENGTH VS TESTING TEMPERATURE - STEEL JOINTS

An interesting comparison of the shear strength of aluminum bonded joints with type 301, 1/2-hard stainless steel joints for the same adhesives now may be made from the data presented in Table 10 and Figure 19. In general, the elastomeric adhesives result in decreased joint strength for steel bonds as compared to aluminum bonds. The strength of

PA-101 steel joints was 52 per cent of the aluminum joints; with Metlbond 4021, 56 per cent. The maximum efficiency for the nitrile-phenolic class was Plastilock 608 at 85 per cent. The epoxide and especially the vinyl-phenolic type adhesives exhibited improved efficiencies, ranging from 99 per cent for Epon VIII to 178 per cent for FM-47. The following chart presents comparative joint strength data for aluminum and steel joints at 76° F:

COMPARATIVE JOINT STRENGTH DATA (ALUMINUM AND STEEL) AT 76° F

Adhesive	2024-T3 Aluminum Tensile Shear (psi)	Type 301, 1/2-Hard Stainless Steel Tensile Shear (psi)	Per Cent of Aluminum Strength
PA-101	3606	1865	51.7
Metlbond 4021	4130	2298	55.7
Cycleweld 55-20	3820	2744	72.0
AF-6	3240	2576	79.5
Plastilock 608	3705	3130	84.5
Epon VIII	3712	3326	89.9
Redux E, Type R	4080	3734	91.5
Shell 422	3240	3214	99.2
HT-20	2165	2356	108.5
FM-47 Film	4560	5606	123.0
FM-47 Liquid	4526	8056	178.0

Theoretically, all other factors remaining constant, the joint strength increases as a function of the strength characteristics of the adherends. Therefore, one or more variables other than the alloy are probably present in the bonding of steel with nitrile-phenolic adhesives since the joint strength of steel bonds did not increase as compared to aluminum bonds.

None of the general purpose adhesives retained sufficient strength at 350° F to be of significant value.

The general shape of the curves of Shell 422 and HT-20 as tested from -100° F to 500° F show that the same relationship exists between the two adhesives as was found on the aluminum specimens tested. The slopes of the curves are nearly identical throughout the temperature range. The joint strength of steel bonds decreases steadily above 500° F and reaches a low of 1000 psi at 650° F. However, the aging characteristics of the adhesives as presented later show that 500° F probably constitutes the maximum temperature that may be considered for the present formulations of Shell 422 and HT-20.

D. SHEAR STRENGTH AT TEMPERATURE AS A FUNCTION OF AGING TIME AT TEMPERATURE - STEEL JOINTS

Tables 11 through 15 contain the data on exposure tests conducted on bonded steel specimens. Shell 422 and HT-20 exposed at 180° F show no change in strength up to 1000 hours (Fig. 24). Figure 25 shows that the same adhesives increase in strength slightly after exposure of 1000 hours at 250° F. Figure 26 is a plot of the data obtained from steel specimens tested at 350° F after exposure at 350° F. Values obtained from the general purpose adhesives are of little significance. Shell 422 and HT-20 show a loss in strength at some exposure time between 192 and 1000 hours.

E. CREEP-RUPTURE

Data for the creep-rupture tests on aluminum joints are given in Table 16 and are presented graphically in Fig. 27 through 36. This program did not include creep-rupture tests on Epon VIII. Stress-rupture curves were prepared showing the relationship between stress applied to the joint in pounds per square inch and time to rupture. Tests were conducted at 180° F, 200° F, and 250° F, except for one curve on Redux E at 225° F; therefore, direct comparisons may be made by referring to the figures. In general, a similarity is seen in the behavior of certain adhesives under long-time loading conditions as noted previously between the same adhesives under other test conditions. Cycleweld 55-20 and AF-6 have the lowest strength-rupture curves. Plastilock 608 and Redux E, rated next highest, show very similar characteristics. A similarity exists between the next two adhesives rated in order, PA-101 and Metlbond 4021, with the latter material slightly better. FM-47 Liquid and FM-47 Film have comparatively high stress-rupture strengths at 180° F and 200° F. Since the transition point in the static strength versus temperature curve occurs between 180° F and 250° F for the latter two materials, the lower creep-rupture curves obtained at 250° F can be anticipated. The two high temperature adhesives show the same relationship in creep-rupture testing as was noted previously under static tests for the long-time loading conditions at the same temperatures.

The curves are comparatively flat. Shell 422 at 200° F has a higher time-fracture strength than HT-20 at 180° F; at 250° F and 350° F, the data are substantially the same.

Creep-rupture tests were run on steel specimens at 180° F, 250° F, and 350° F for Shell 422 and HT-20 adhesives. Table 17 lists the data which are presented graphically in Figs. 37 and 38. There is no noticeable difference in the data on HT-20 steel joints compared to the tests on aluminum joints. However, the data on Shell 422 steel joints are uniformly higher than those obtained on aluminum specimens - roughly 20 to 30 per cent.

The creep-rupture characteristics of spot-welded and riveted joints of 2024-T3 alclad aluminum and type 301, 1/2-hard stainless steel may be studied for comparison in NACA Technical Note 3412(5).

Measurements were made, as required by this program, to determine the amount of deformation occurring in the specimens used to obtain rupture data in the 100- to 200-hour range. O.S. Peters extensometers of 2-inch gage length spanning the joints were used. Upon study of the creep-deformation curves, it became evident that some uncontrolled variables were present in the system. The anomalies found in the data were discussed with instrumentation representatives, metallurgists and others conducting creep phenomena studies in allied fields. The problem was presented to WADC Materials Laboratory personnel and an alternate method of measuring the deformation of adhesive lap joints was proposed for future investigations. Consequently, creep-deformation curves are not presented at this time.

The evaluation of the method used for measuring the deformation of adhesive joints is, nevertheless, believed to be a constructive contribution to the general field of standardization of test methods for adhesives.

F. IMPACT STRENGTH

Impact tests were conducted at 76° F and -100° F. Results of this test are presented in Table 18. Metlbond 4021 has the highest impact strength at room temperature, averaging approximately 27 foot-pounds. As expected, a significant drop in the impact data occurs at -100° F. However, the greatest loss in strength is evident in the nitrile-phenolic class of adhesives. A similar loss of peel strength at -100° F has been noted by other test facilities for this class of adhesives.

G. CLEAVAGE TESTS

Cleavage tests were conducted at room temperature only. Table 19 lists the detail data. Note that these data exhibit more scatter than was found in some of the other tests reported. In some instances, repeat tests were conducted and the degree of scatter was reduced. However, it is difficult to relate the results of this test to the quality of the glue line due to the configuration of test specimens and the resultant peak stresses occurring in the glue line at the line of cleavage. A small flaw in the adhesive at the line of cleavage affects the results, whereas voids in the area of the bond away from the cleavage line has no effect on the results obtained.

H. TENSILE STRENGTH

Tension tests were conducted on all adhesives at room temperature (Table 20). The design of the test specimen and the method of loading cause an unequal stress distribution through the area of the joint. Peak stresses are induced at the periphery of the test cylinder on a portion of the circumference. Therefore, these values do not represent the true tensile strength of the adhesives, since a peeling force is present. The true tensile strength of some of the adhesives is considerably higher than the test results obtained by this method indicate. Figure 9 shows the specimen mounted in the grips.

I. BEND STRENGTH

Bend test data obtained at 76° F are presented in Table 21. PA-101 adhesive exhibits the highest bend strength with an average of 250 pounds. The lowest values are obtained with HT-20, Shell 422 and Epon VIII; however in view of their low peel strengths, the results are higher than might be expected.

The value of this empirical test will remain uncertain until a thorough analysis of the forces involved throughout the loading period has been made. An application of load at the exact center of the lap is necessary to obtain reproducible results. At an applied load of 154 pounds, the stress in the metal in bending is 60,000 psi. Any load in excess of this results in continual yielding of the metal and beam theories are no longer valid. It is nearly impossible to apply loads beyond 265 pounds due to excessive bending of the metal.

J. PEEL TESTS

Peel tests were conducted on all adhesives using the Climbing Peel Test Method previously described. All tests were conducted at room temperature. The results of these tests are reported in Table 22. A typical curve for each adhesive is shown in Fig. 39 through 49. The average load, P_2, was determined by measuring the area under the last two-thirds of the curve with a planimeter and dividing by the length.

The peel strength was calculated from the formula: $T = P_2 (r_o - r_i) - Wr_i$, where T represents the torque or peel strength in in.-lb. As expected, the nitrile-phenolic type adhesives have the highest peel strength. Shell 422, HT-20, and Epon VIII have the lowest resistance to peeling forces.

It should be noted that the peel strength obtained is a function of the surface preparation method equally as much as it is a function of the adhesive being tested. Therefore, comparisons of peel strength of various adhesives may be made only when a highly controlled surface preparation method is used for all test specimens. Note also that peel strength represents the load required to continue failure, but does not necessarily represent the load required to initiate failure. The peel strength of an adhesive may be roughly defined as its resistance to further failure. This implies that some failure has already occurred. Thus, the load required to initiate failure in an adhesive will not necessarily be in ratio to its peel resistance.

K. FATIGUE STRENGTH

Individual test data obtained in fatigue tests for aluminum joints are given in Table 23. The data obtained from tests on stainless steel joints are presented in Table 24. Each adhesive was tested at 76°, 180° F, and either 200° F, 250° F, or 350° F, depending upon the elevated temperature strength of the particular adhesive. Cycleweld 55-20 was not tested beyond 180° F because of the relatively low results obtained at that temperature. These test data are presented graphically in Figs. 50 through 62 as S-N curves showing the maximum repeated stress, psi vs the number of cycles to failure. The ratio of minimum to maximum loads was 0.1. One specimen was tested for each stress level at each temperature.

In studying the data for general trends or patterns of behavior of adhesives under fatigue loading, a number of interesting observations can be made. These generalizations may require modifications in the future because relatively few specimens were tested for each set of parameters, however general trends, as presented, have been indicated by similar tests conducted at other agencies such as FPL(6), WADC(7), and private aircraft companies(8)(9). More thorough investigation will be necessary to verify the trends.

The fatigue data are subject to certain limiting factors frequently found in such data. Under the test conditions described in this report, doubt exists as to the actual stress in the joint due to the yielding of the adhesive layer and in some cases the metal under load. It is likely that some reduction in preload occurred during testing, particularly on the low modulus adhesives(6)(10). This uncertainty is magnified with elastomeric adhesives, especially at elevated temperatures.

The fatigue strength of all adhesives, except FM-47 Liquid and FM-47 Film, decreases at elevated temperatures when compared to strength at 76° F. It has been previously observed by many investigators that the fatigue strength of adhesives, in general, is greater at -70° F than at room temperature.

PA-101 and Metlbond 4021 have the highest fatigue strength at 76° F, approximately 1300 psi for 10 million cycles. The data for both curves at 76° F are for all purposes identical; however, note that PA-101 was tested at a shorter depth of lap than the remaining adhesives. This same relationship exists for the elevated temperature data.

The fatigue strength of Plastilock 608 at 76° F is somewhat less than that of Metlbond 4021, but is considerably higher than that obtained for AF-6. At 180° F and 250° F, the curves for Plastilock 608 are higher than those for AF-6.

Of the resinous type adhesives, Epon VIII has the highest curve at 76° F; the fatigue properties generally are higher than Plastilock 608 and compare favorably with those of PA-101, especially at elevated temperatures.

Figures 63 through 66 show the same data replotted for the adhesives at the four testing temperatures. The fatigue life at high stress levels, as well as endurance limits for the various bonding systems, are easily determined on a comparative basis at 76° F, 180° F, 200° F, and 250° F. At room temperature, PA-101 and Metlbond 4021 have the best fatigue properties throughout the range of stress levels tested. At 180° F, the selection of an adhesive is based on a consideration of the number of cycles as well as the stress level requirements, since several curves cross at approximately four million cycles. At 200° F, FM-47 Liquid displays the best fatigue properties of the five adhesives tested at that temperature. Shell 422 has the highest curve at 250° F, with HT-20 and Metlbond 4021 also exhibiting good properties.

The fatigue test data for Shell 422 and HT-20 bonded joints are surprisingly high at all testing temperatures. HT-20 data are slightly higher than Shell 422 at 76° F; however, for all practical purposes, the data are identical for both adhesives at all three test temperatures. Only Metlbond 4021 exceeded either adhesive at 76° F.

A very significant comparison may now be made by examining the data obtained for Shell 422 and HT-20 on stainless steel joints. A marked increase is apparent in the fatigue life of stainless steel joints as compared to aluminum joints for both adhesives when tested at 76° F and 180° F. Curves obtained from steel joints tested at 350° F are higher than those for aluminum joints tested at 250° F. Fatigue data obtained from these two adhesives on both aluminum and steel bonds, as well as data from Epon VIII joints, do not verify the commonly held opinion that fatigue strength of an adhesive is related to its peel resistance. Data obtained at -70° F on a number of adhesives also contradicts this theory. Studying fatigue data from a vinyl-phenolic type adhesive, it is found that fatigue life increases at -70°Fcompared to 76° F; it increases with degree of cure (300° F cure compared to 350° F cure); and it increases with formulation changes which increase the modulus of rigidity.

These general trends shown by the data are not consistent with commonly held theories regarding fatigue characteristics of materials. This points out the need for more precisely controlled tests and more thorough investigation before adequate theories relating chemical type and fundamental strength properties to fatigue life of adhesives may be developed.

IV. ILLUSTRATIONS

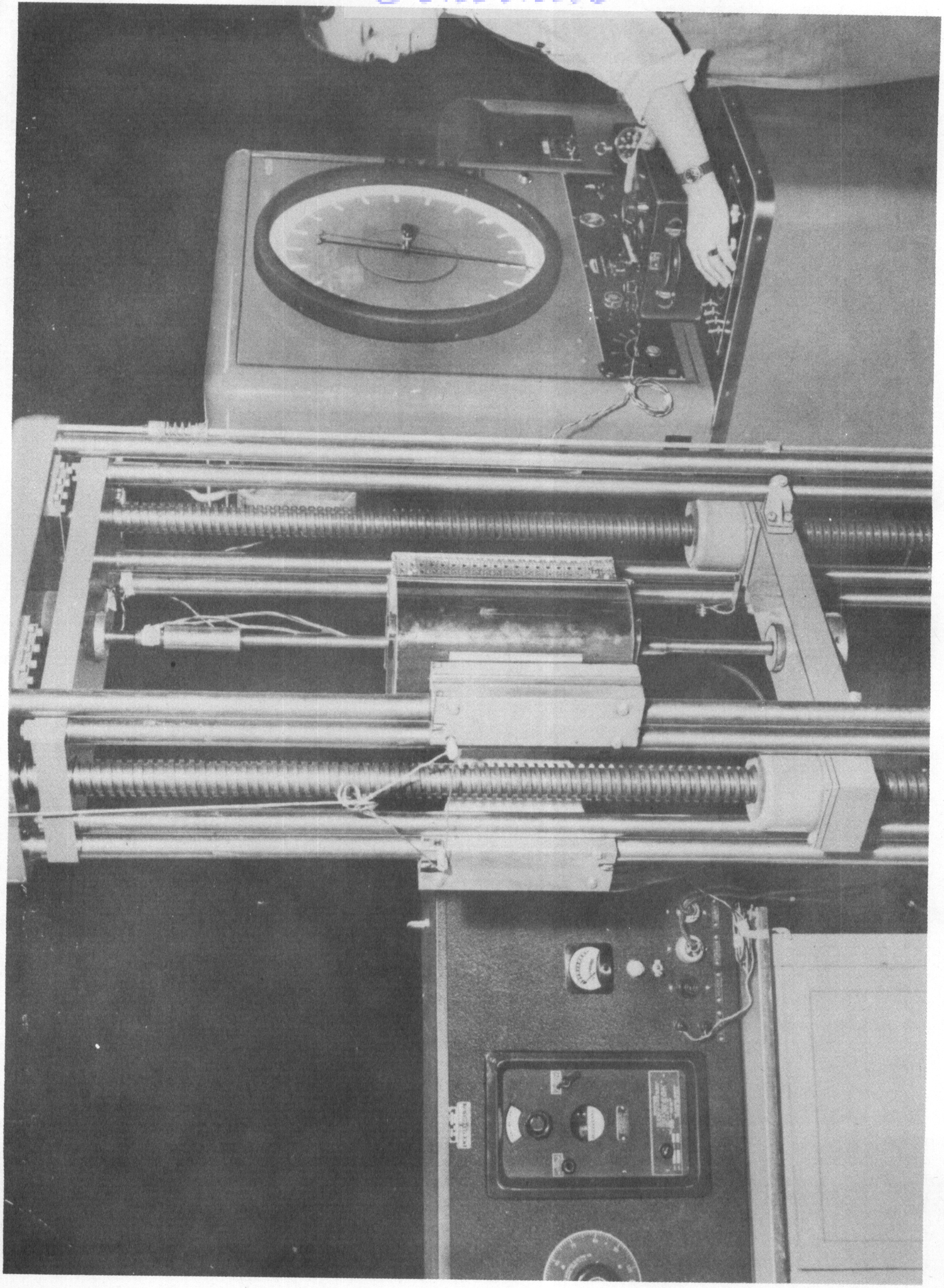


Fig. 1. High Temperature Shear Test Set-Up

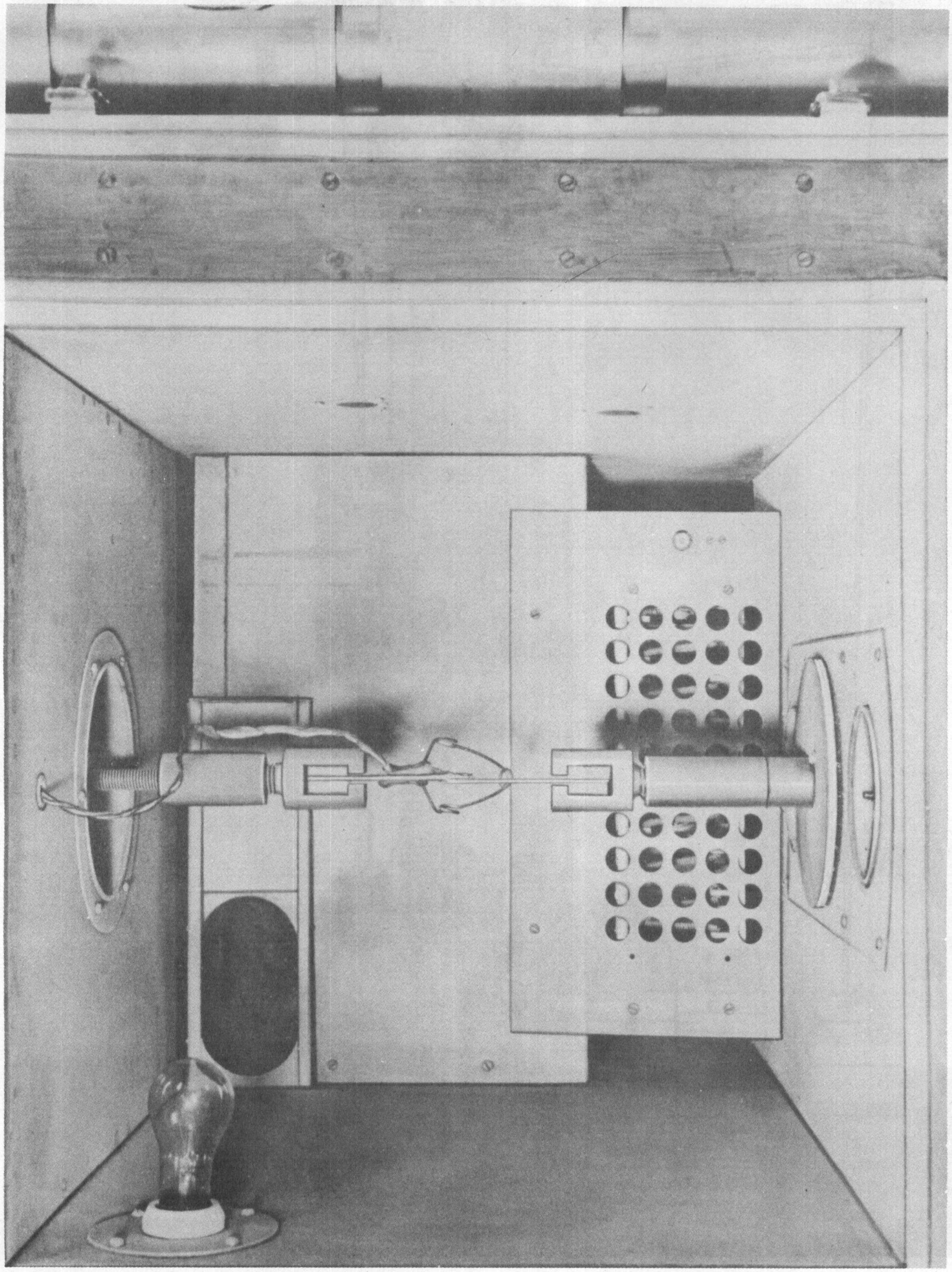


Fig. 2. Low Temperature Shear Test Set-Up

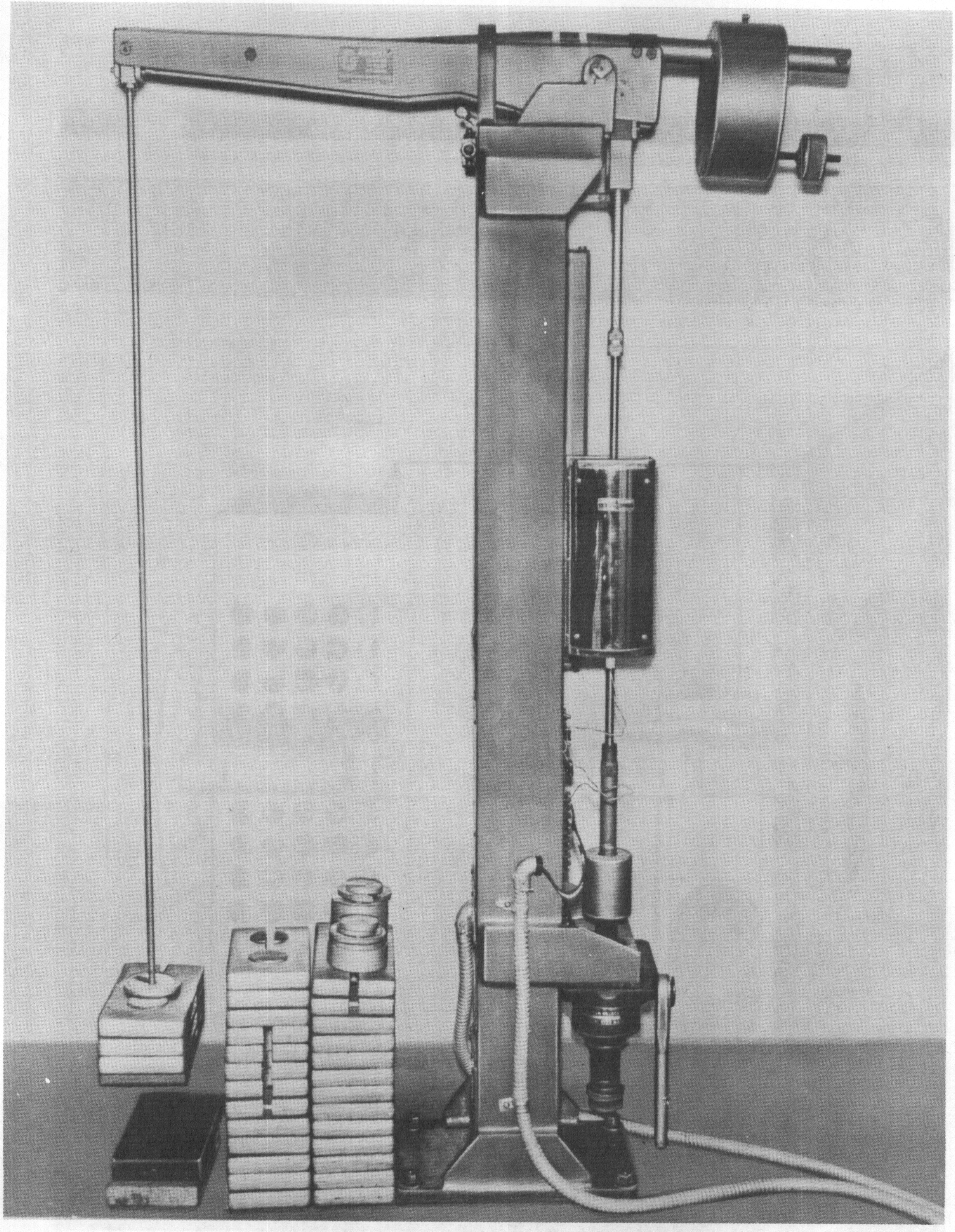


Fig. 3. Creep-Rupture Test Set-Up

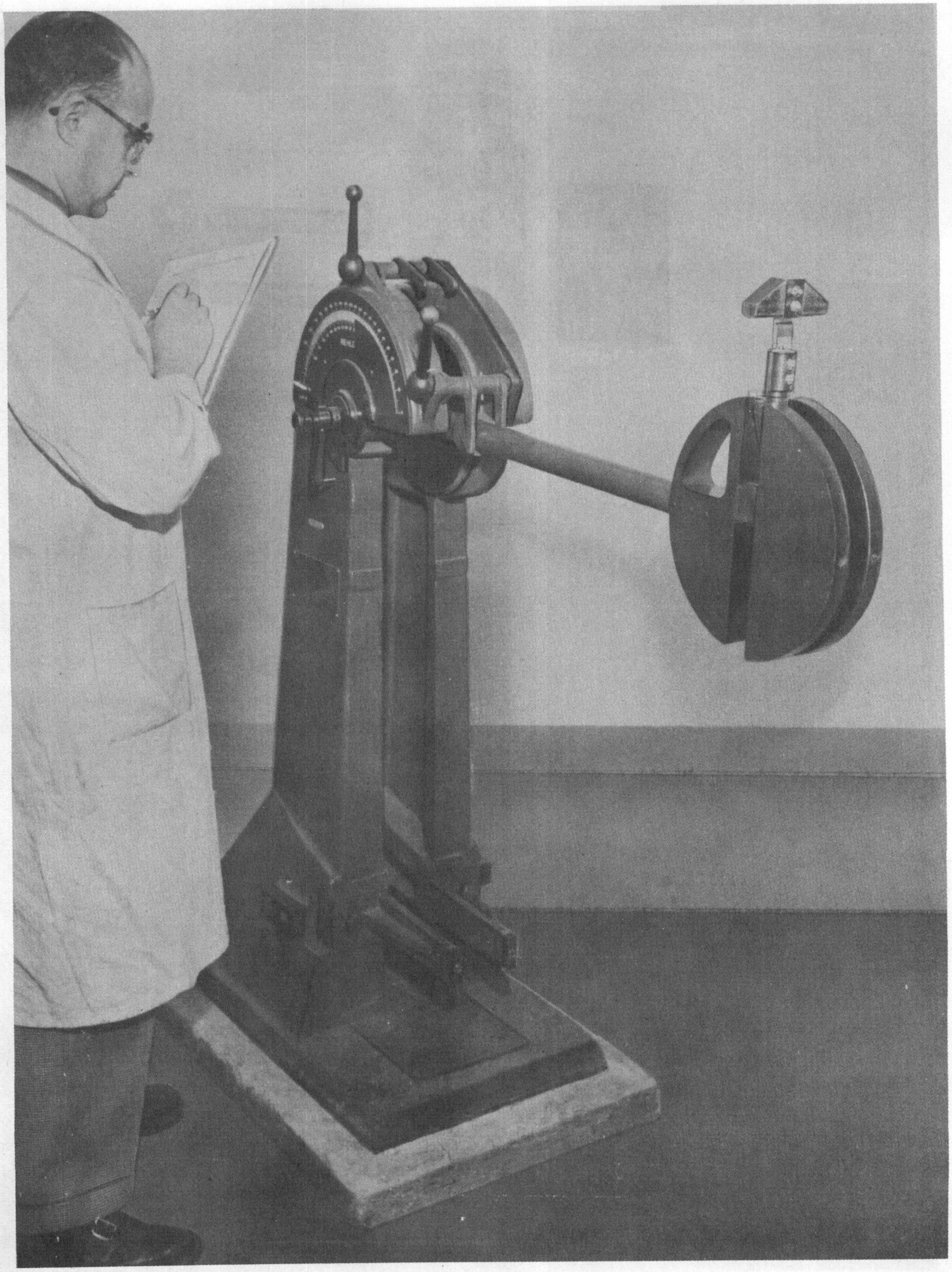


Fig. 4. Riehle Impact Test Machine

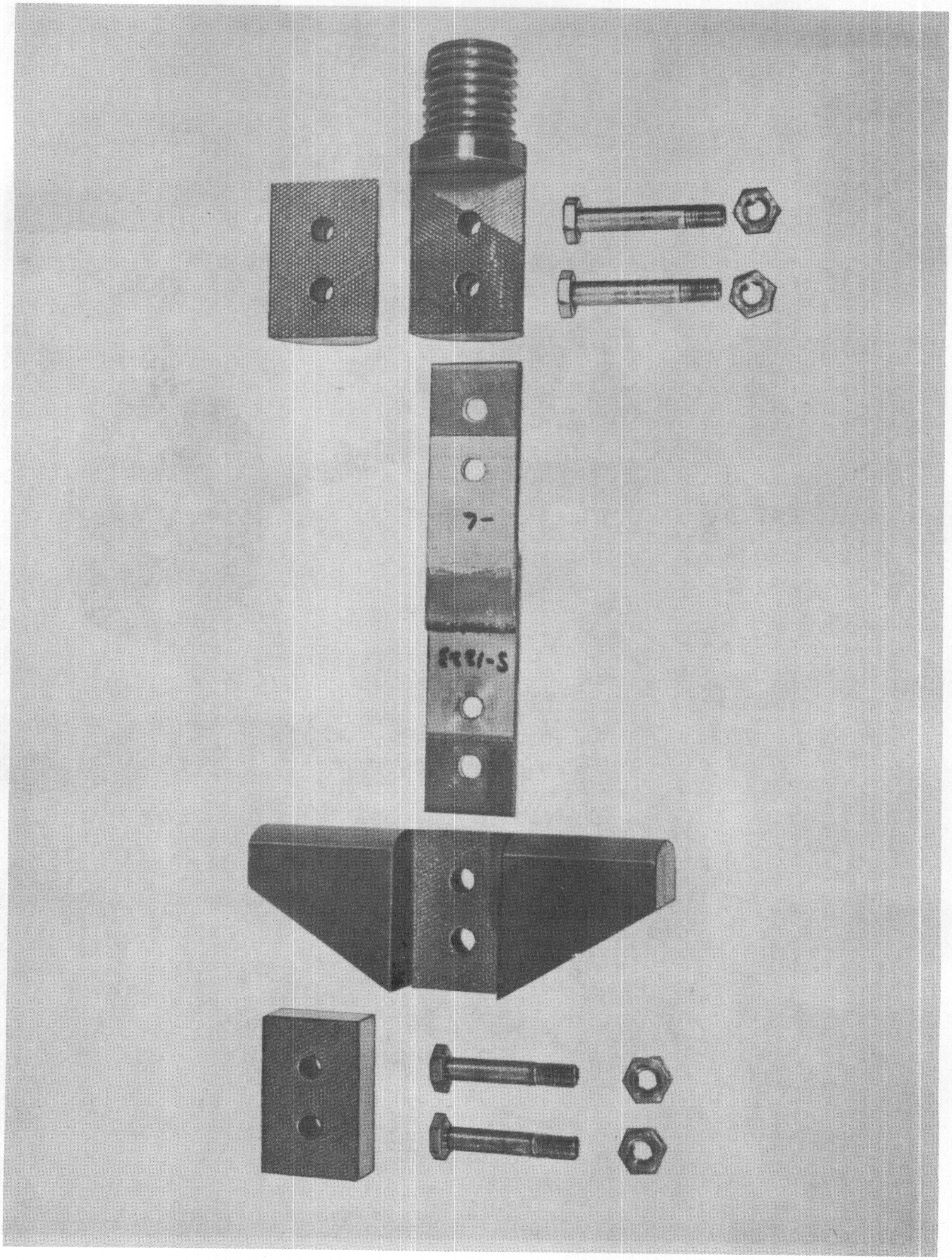


Fig. 5. Impact Test Specimen and Exploded View of Loading Grips

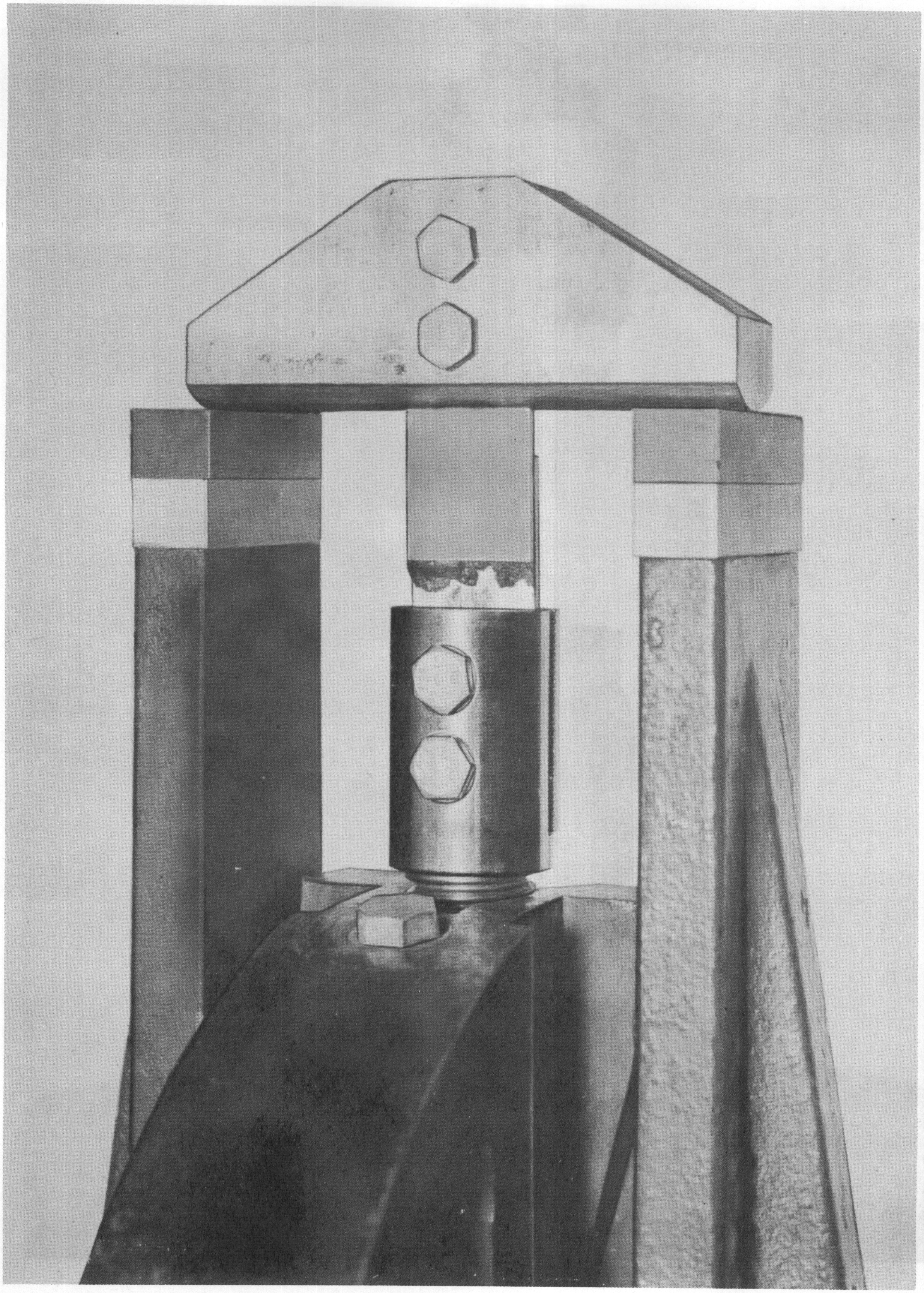


Fig. 6. Impact Test Specimen Mounted in Riehle Testing Machine

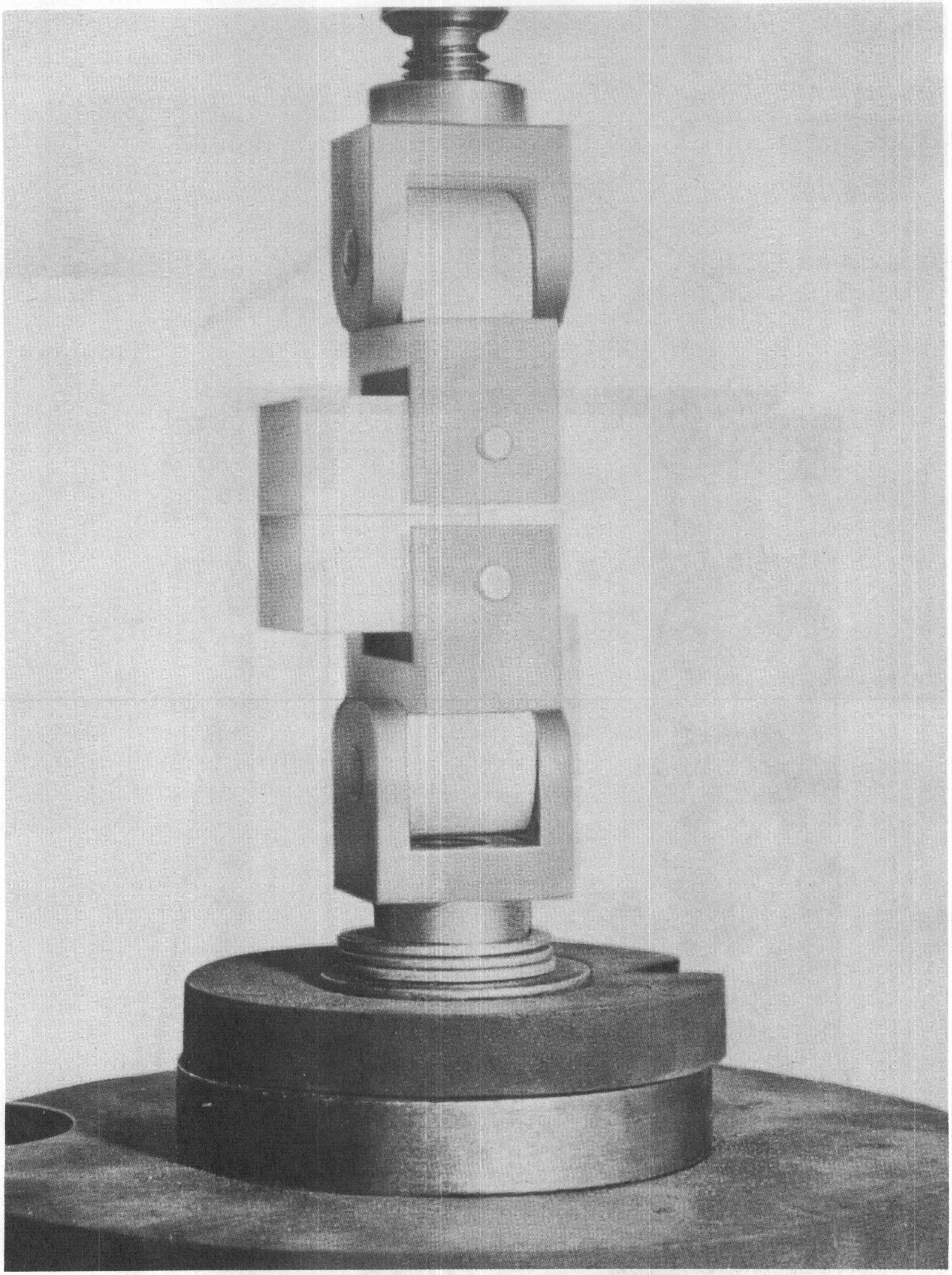
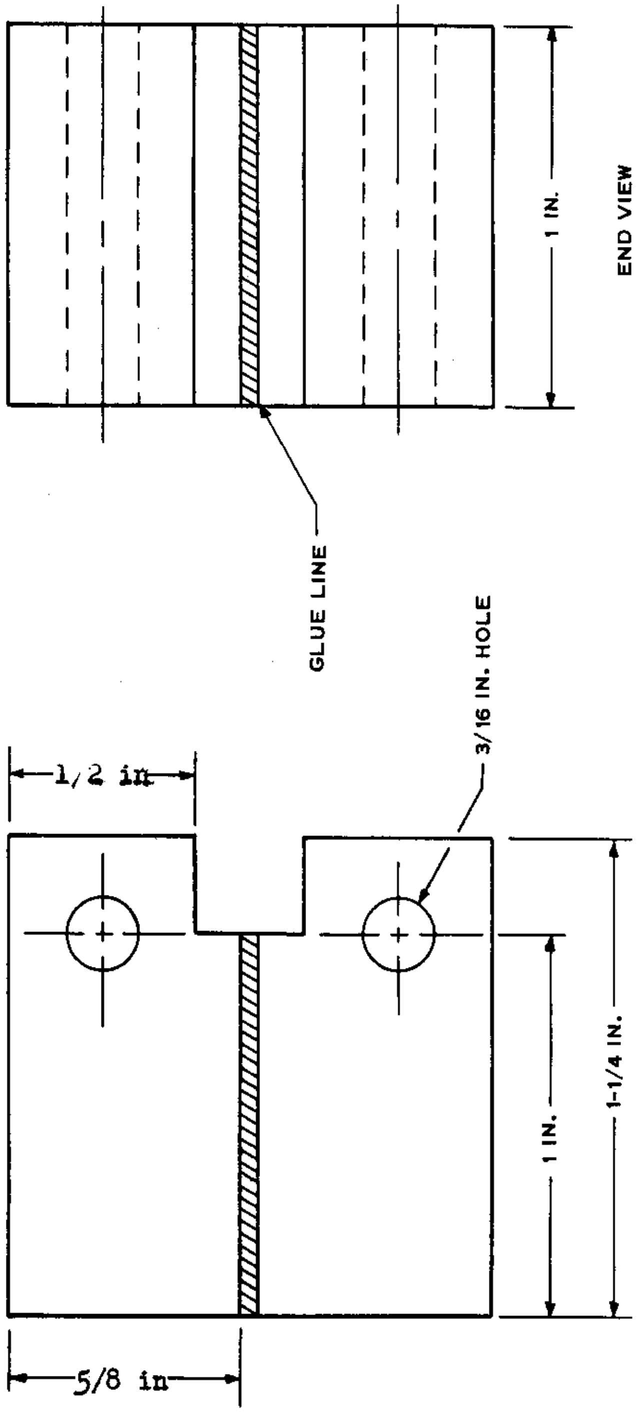


Fig. 7. Cleavage Test Specimen Mounted in Test Fixture


1 IN.
END VIEW
GLUE LINE
3/16 IN. HOLE
1/2 in
1 IN.
1-1/4 IN.
5/8 in

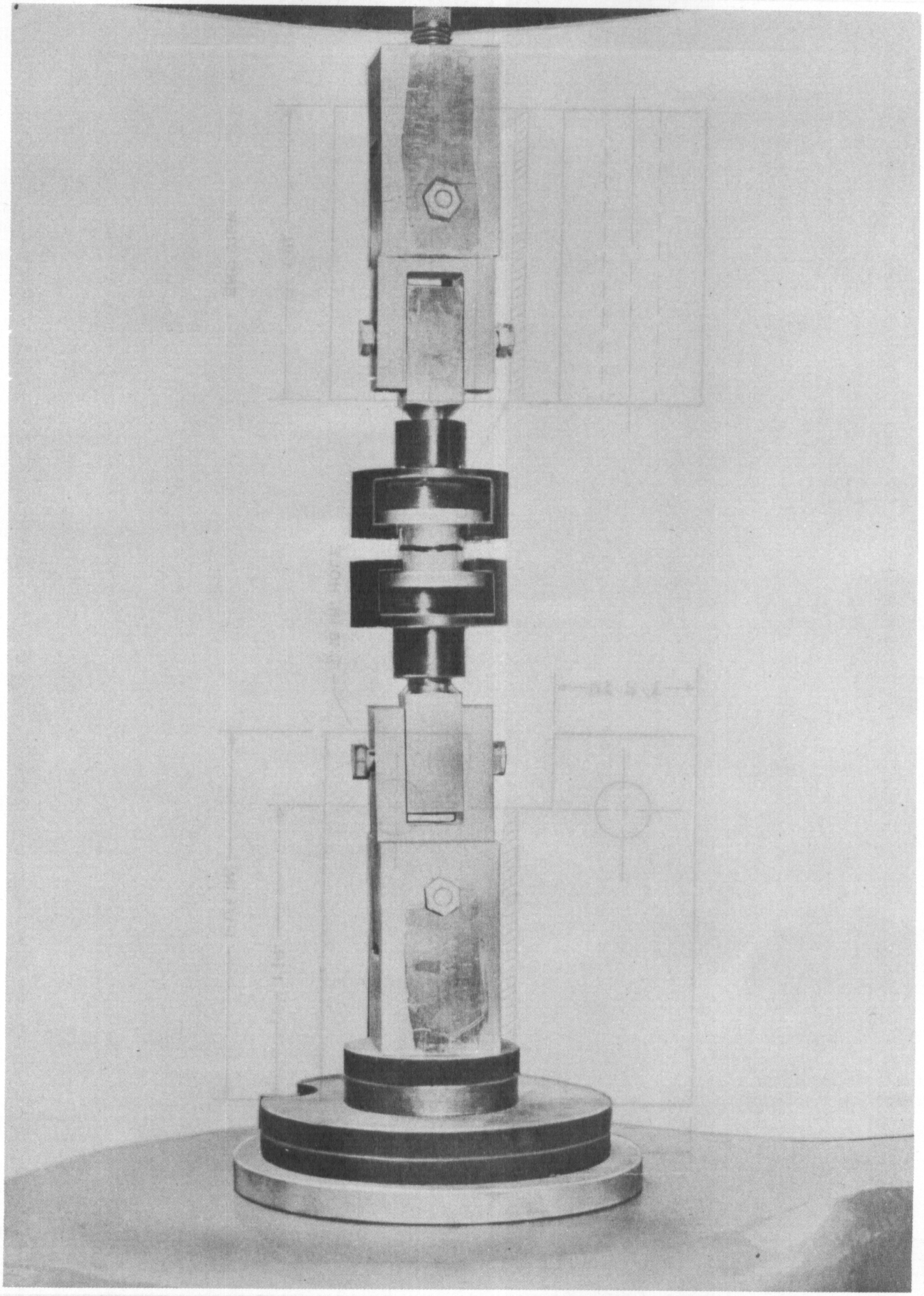


Fig. 9. Tensile Specimen Mounted in Test Fixture

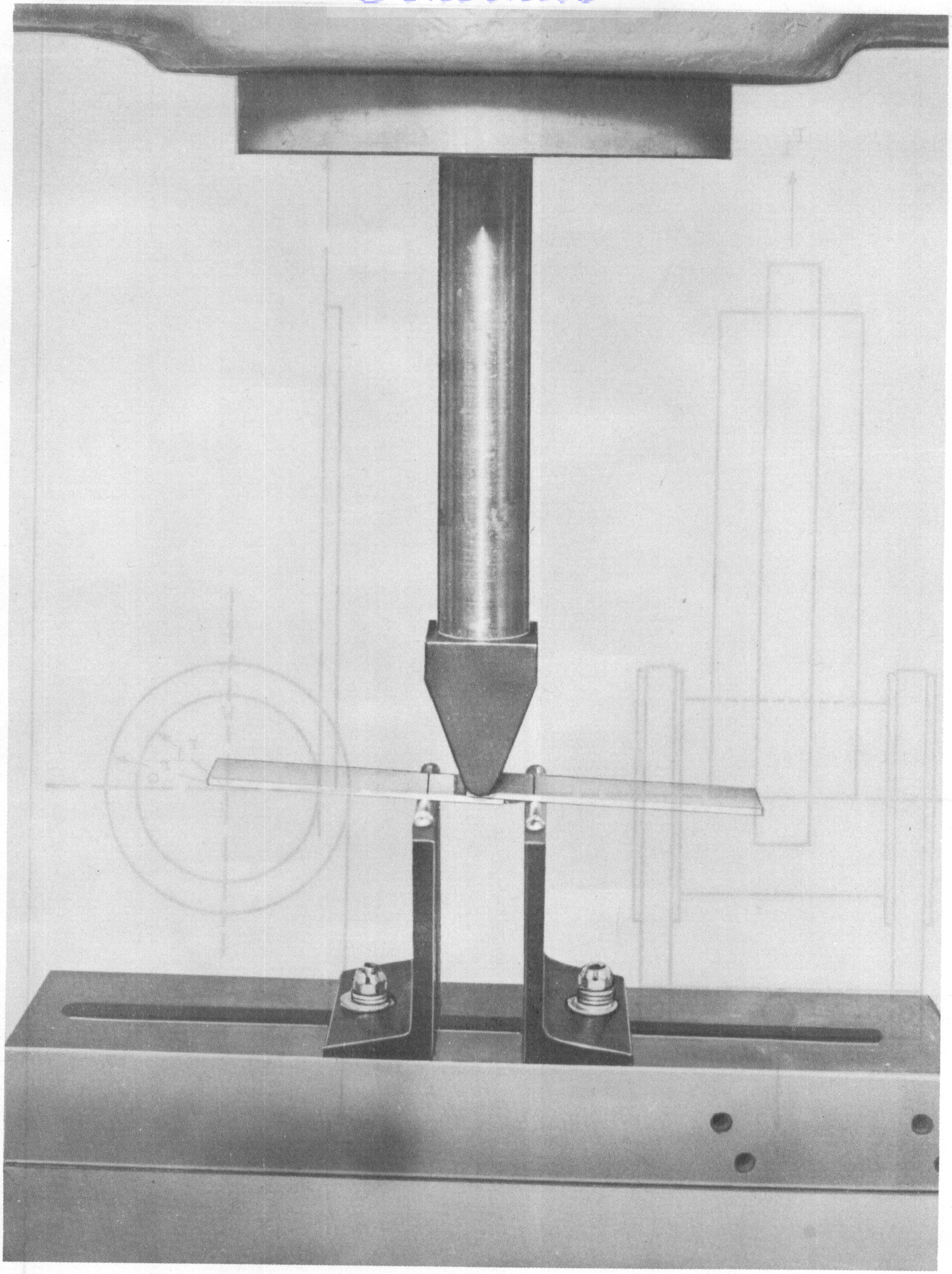


Fig. 10. Bend Test Specimen in Test Machine

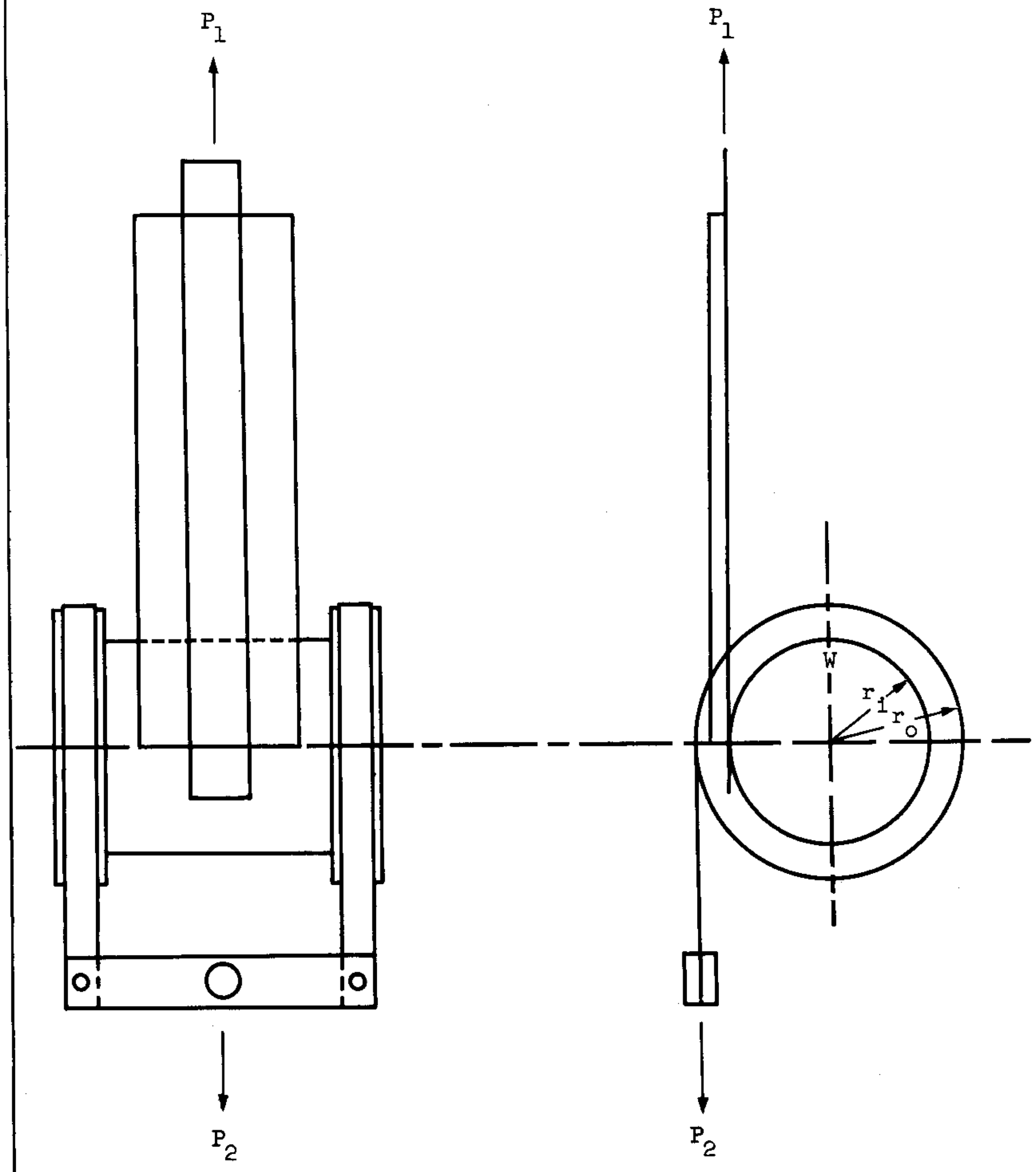


Fig. 11. Sketch of Climbing Peel Test Apparatus

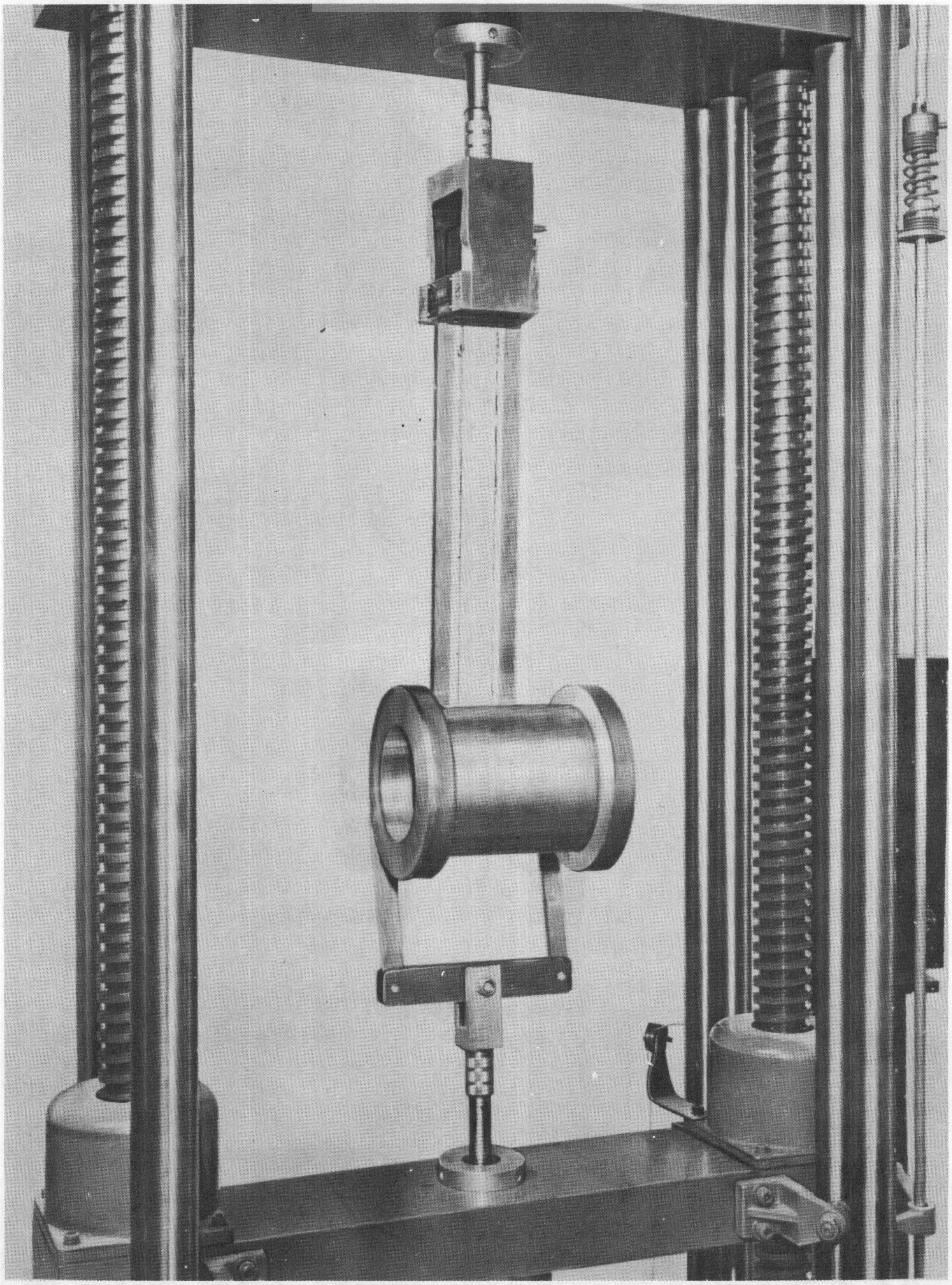


Fig. 12. Peel Test Specimen Mounted in Test Fixture (Front View)

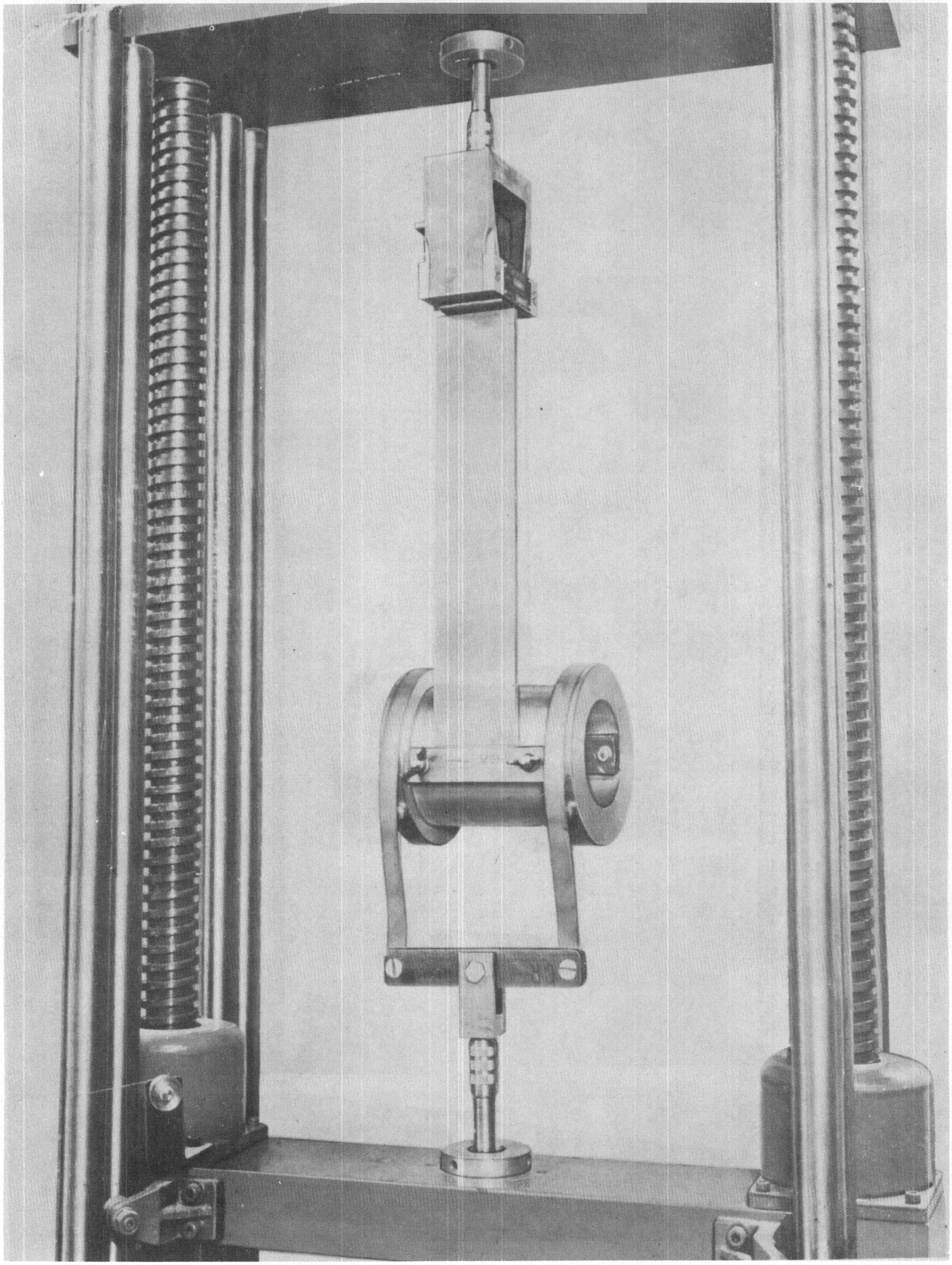


Fig. 13. Peel Test Specimen Mounted in Test Fixture (Rear View)

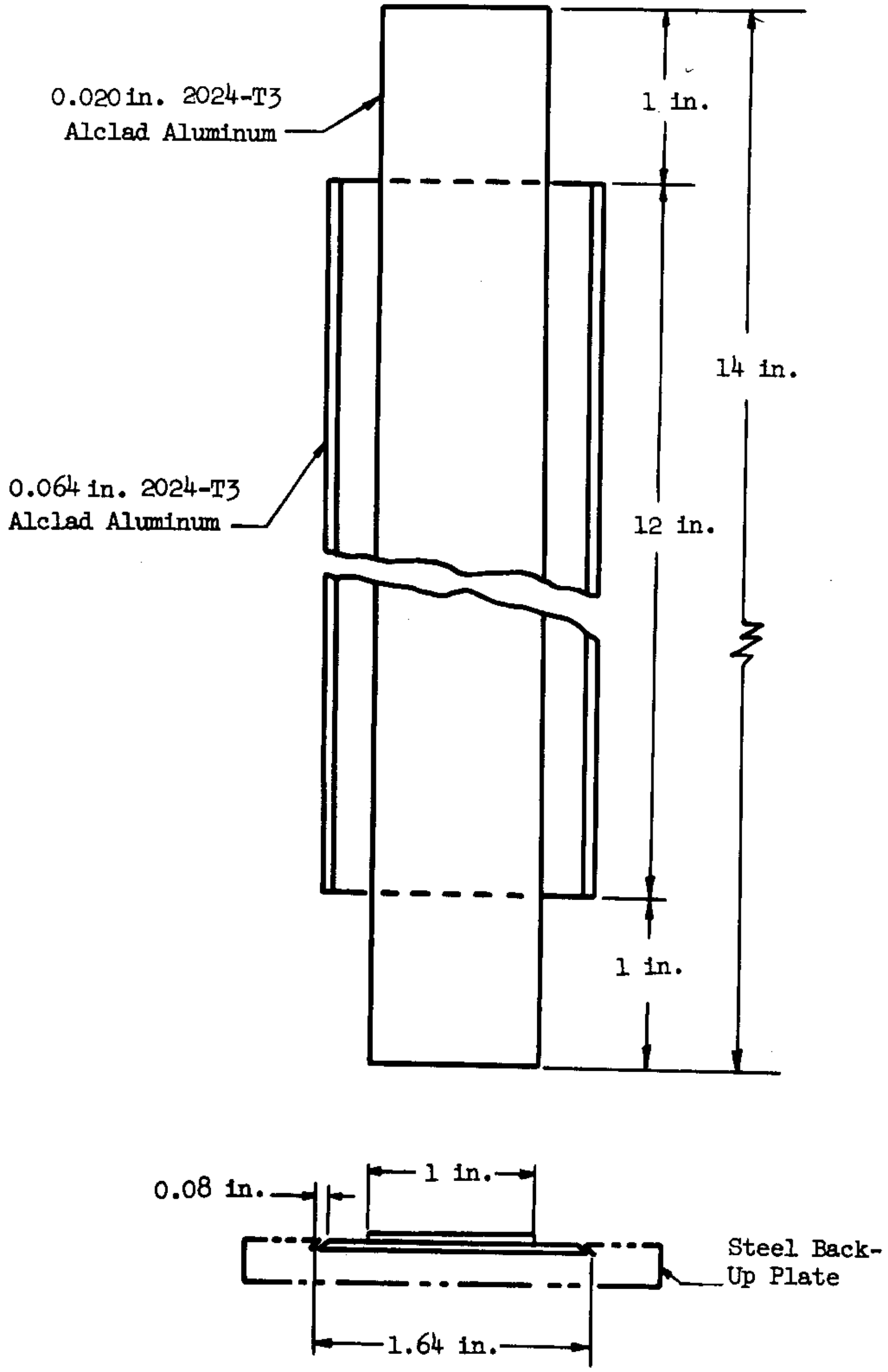


Fig. 14. Sketch of Peel Test Specimen

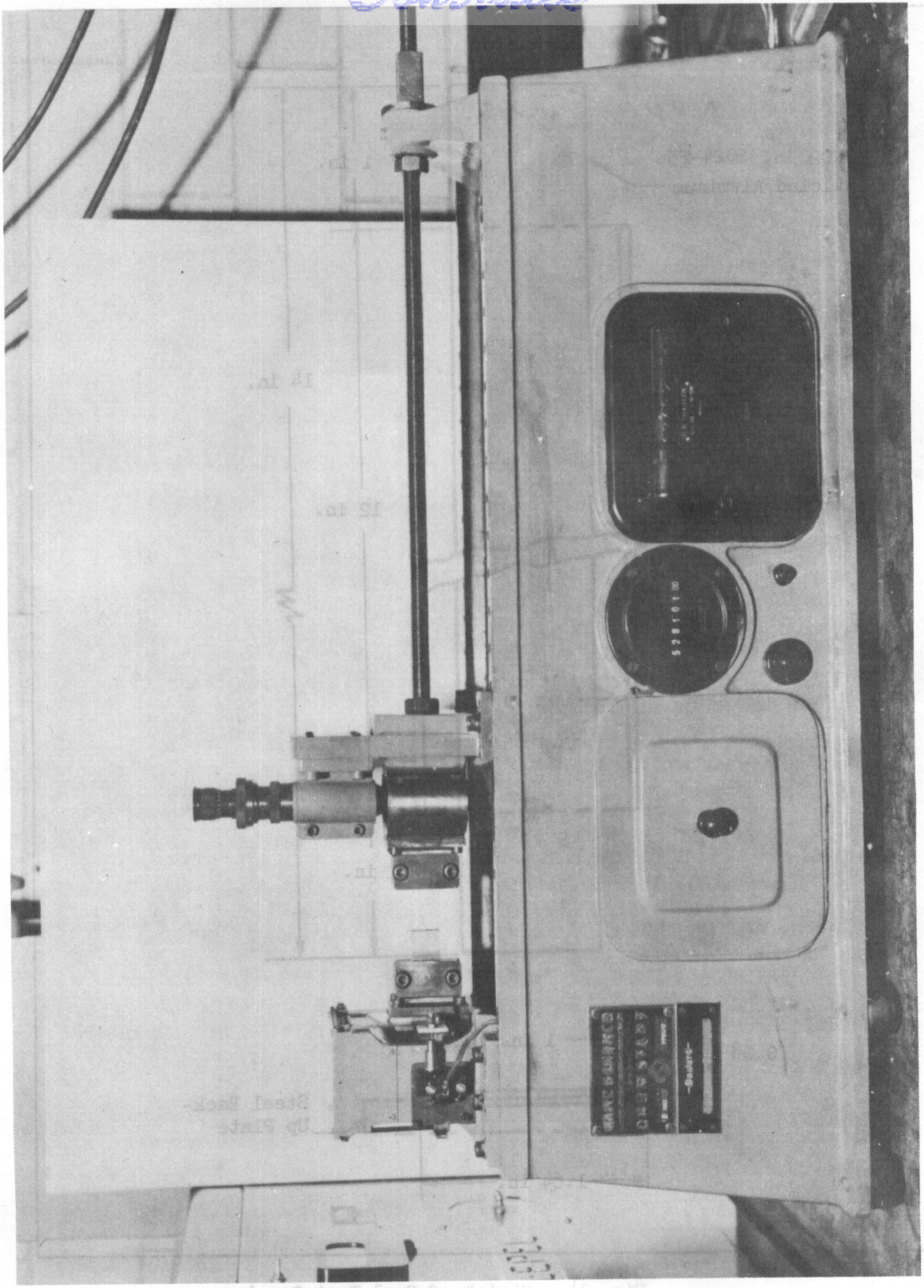


Fig. 15. Schenck Fatigue Test Machine with Specimen Mounted for Room Temperature Test.

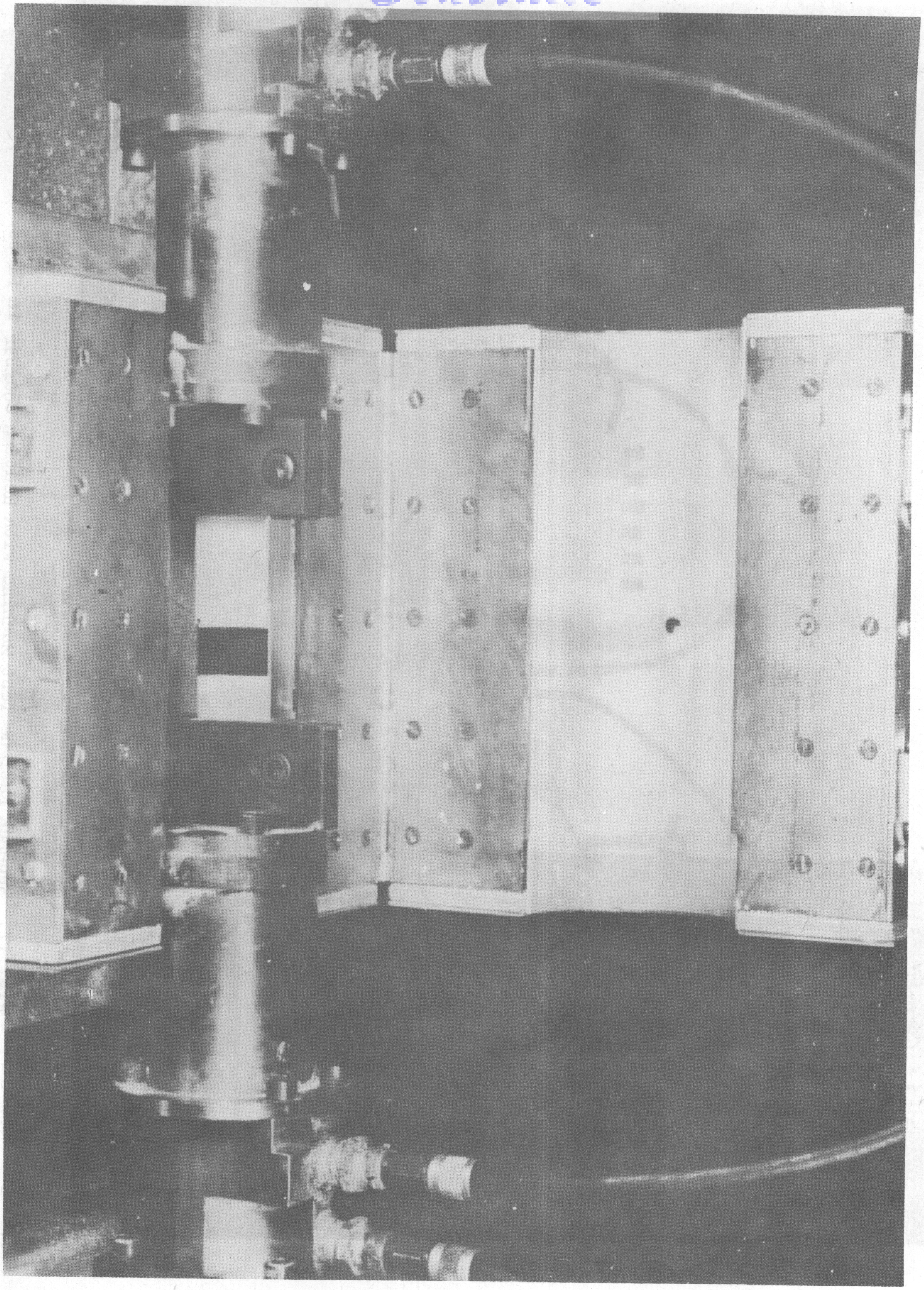


Fig. 16. Fatigue Test Specimen Mounted in Heating Chamber for Elevated Temperature Tests.

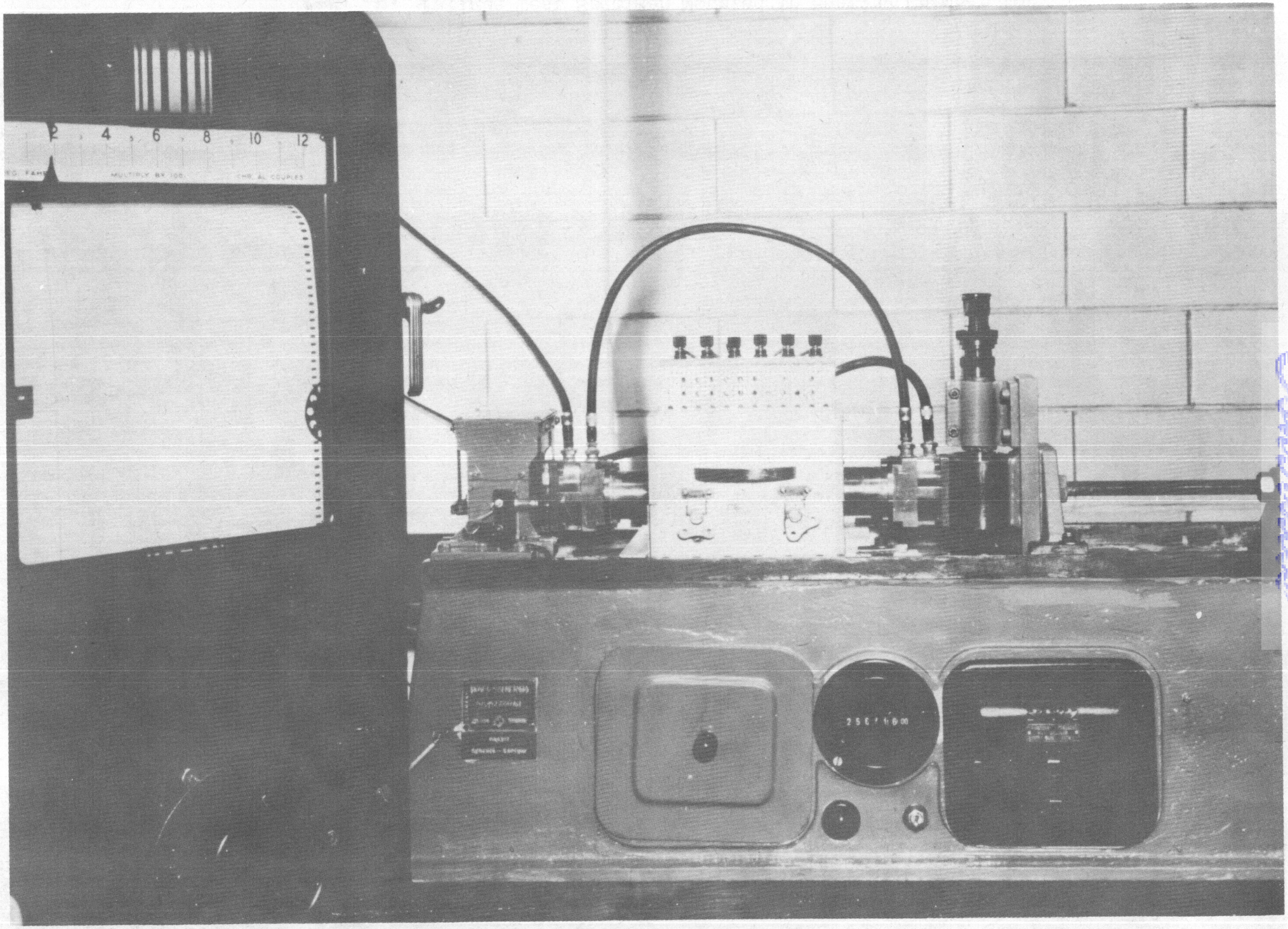


Fig. 17. Schenck Fatigue Test Machine with Heating Chamber in Place

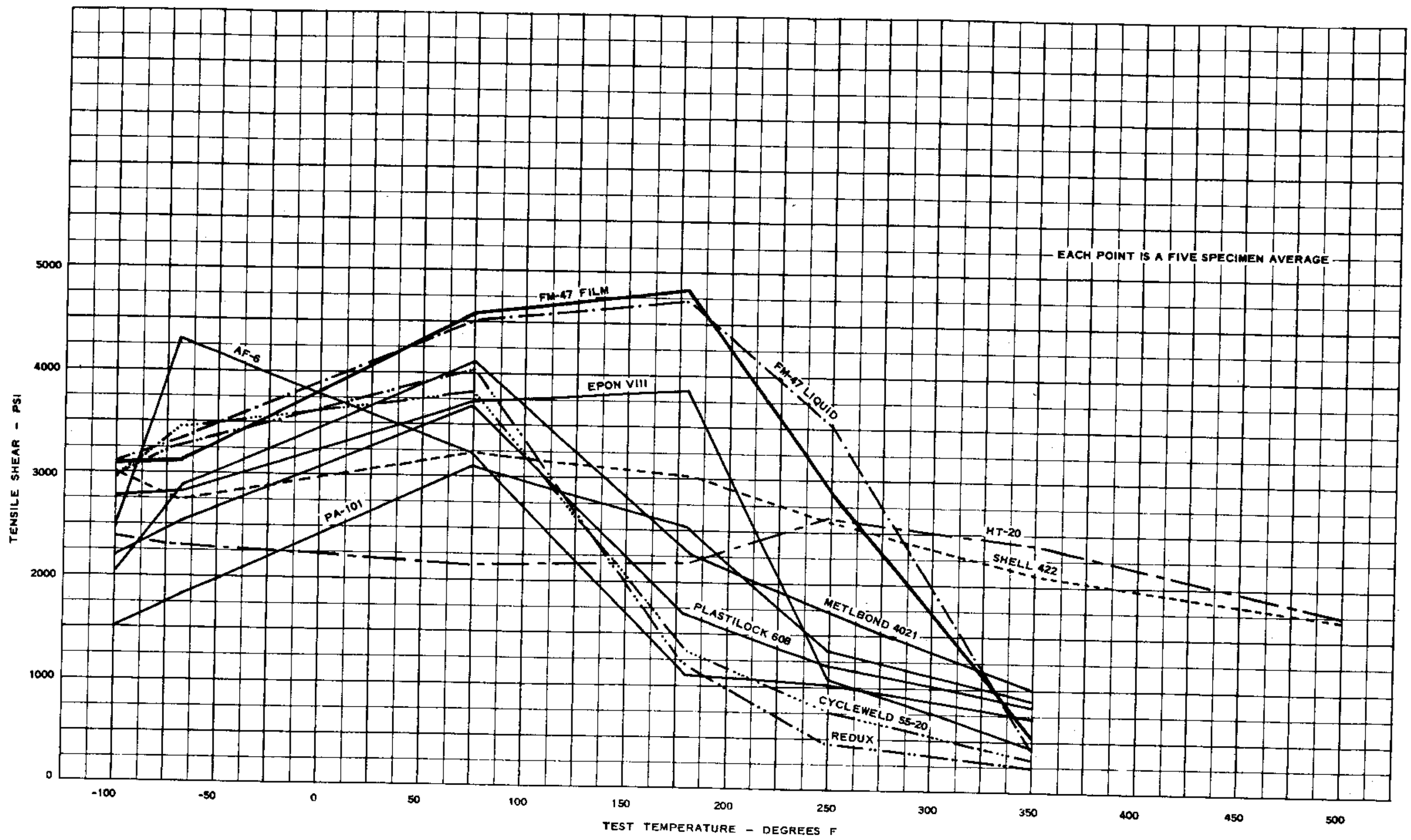


Fig. 18. Tensile Shear Strength vs Testing Temperature for 2024-T3 Alclad Aluminum Joints.

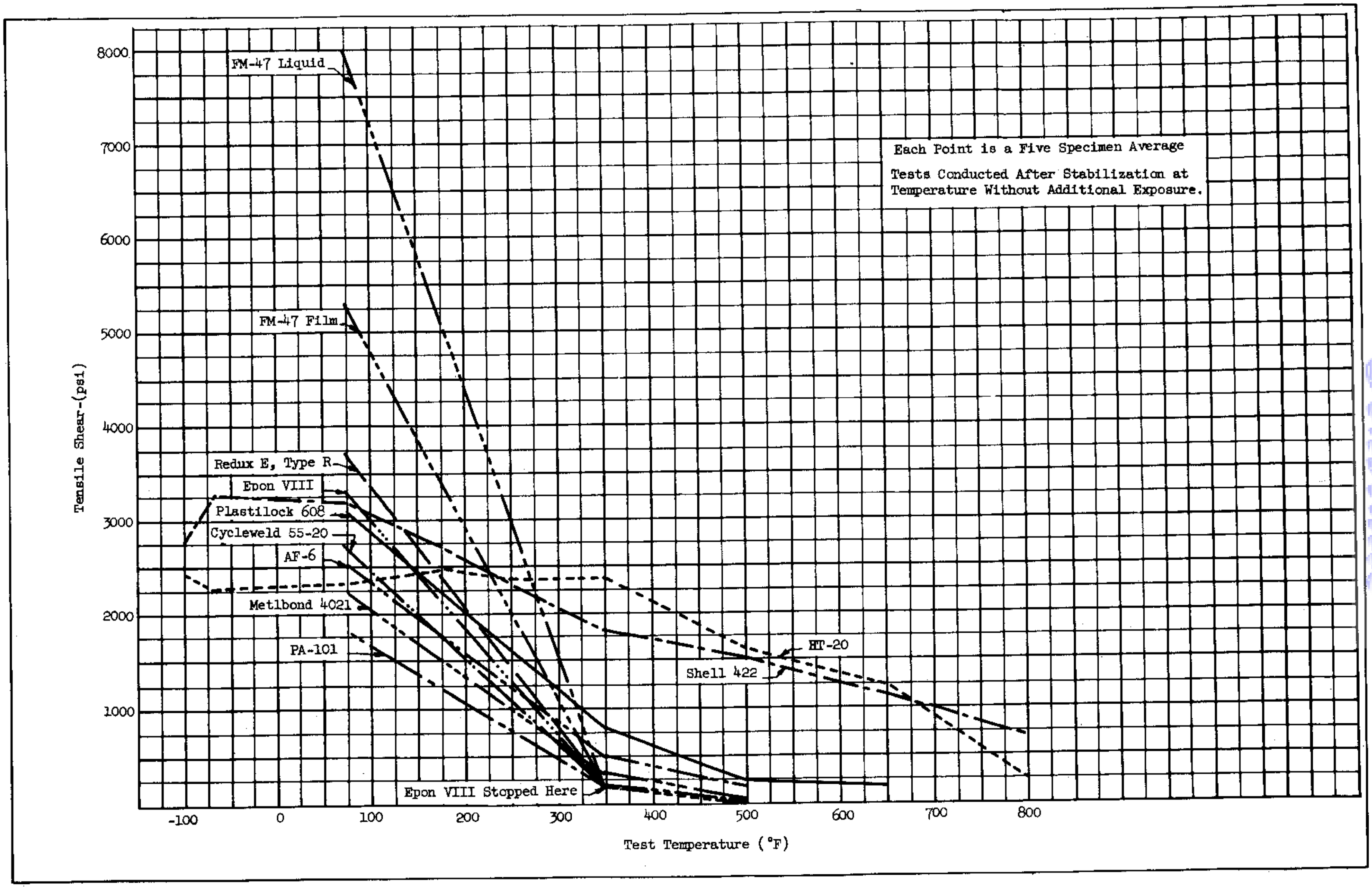


Fig. 19. Tensile Shear Strength vs Testing Temperature for Type 301, 1/2-Hard Stainless Steel Joints

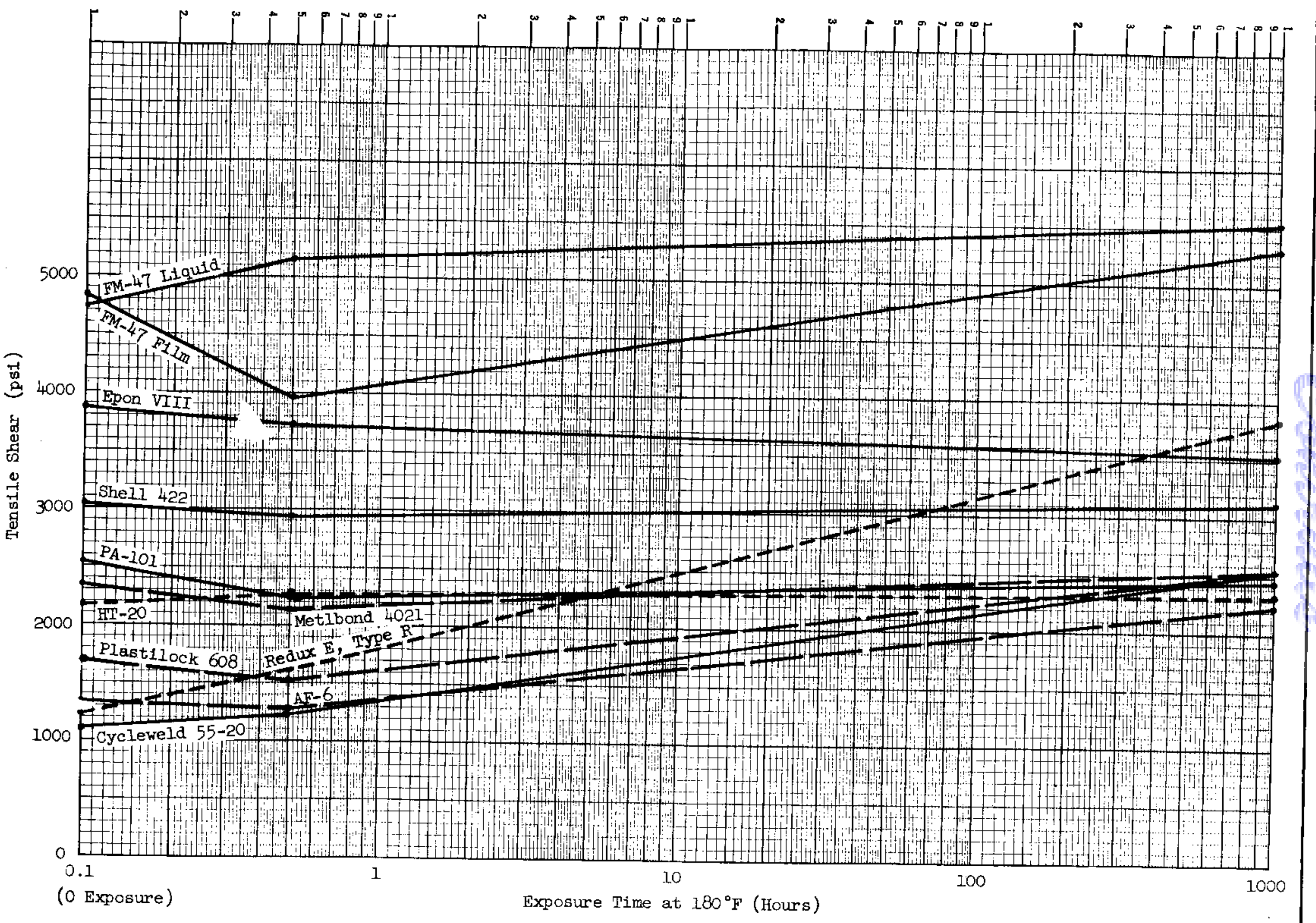


Fig. 20. Tensile Shear Strength at 180° F vs Exposure Time at 180° F for 2024-T3 Alclad Aluminum Joints

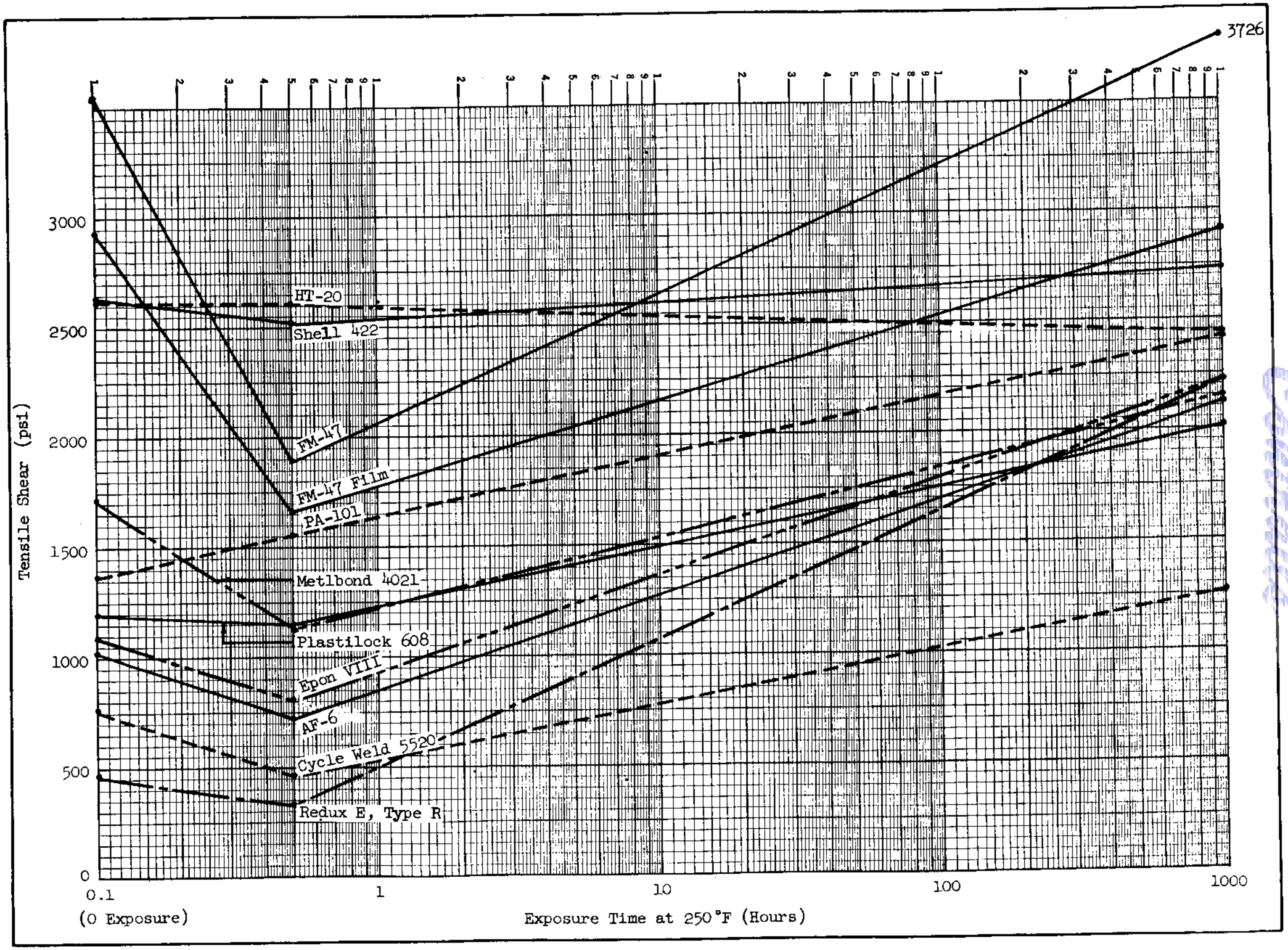


Fig. 21. Tensile Shear Strength at 250° F vs Exposure Time at 250° F for 2024-T3 Alclad Aluminum Joints

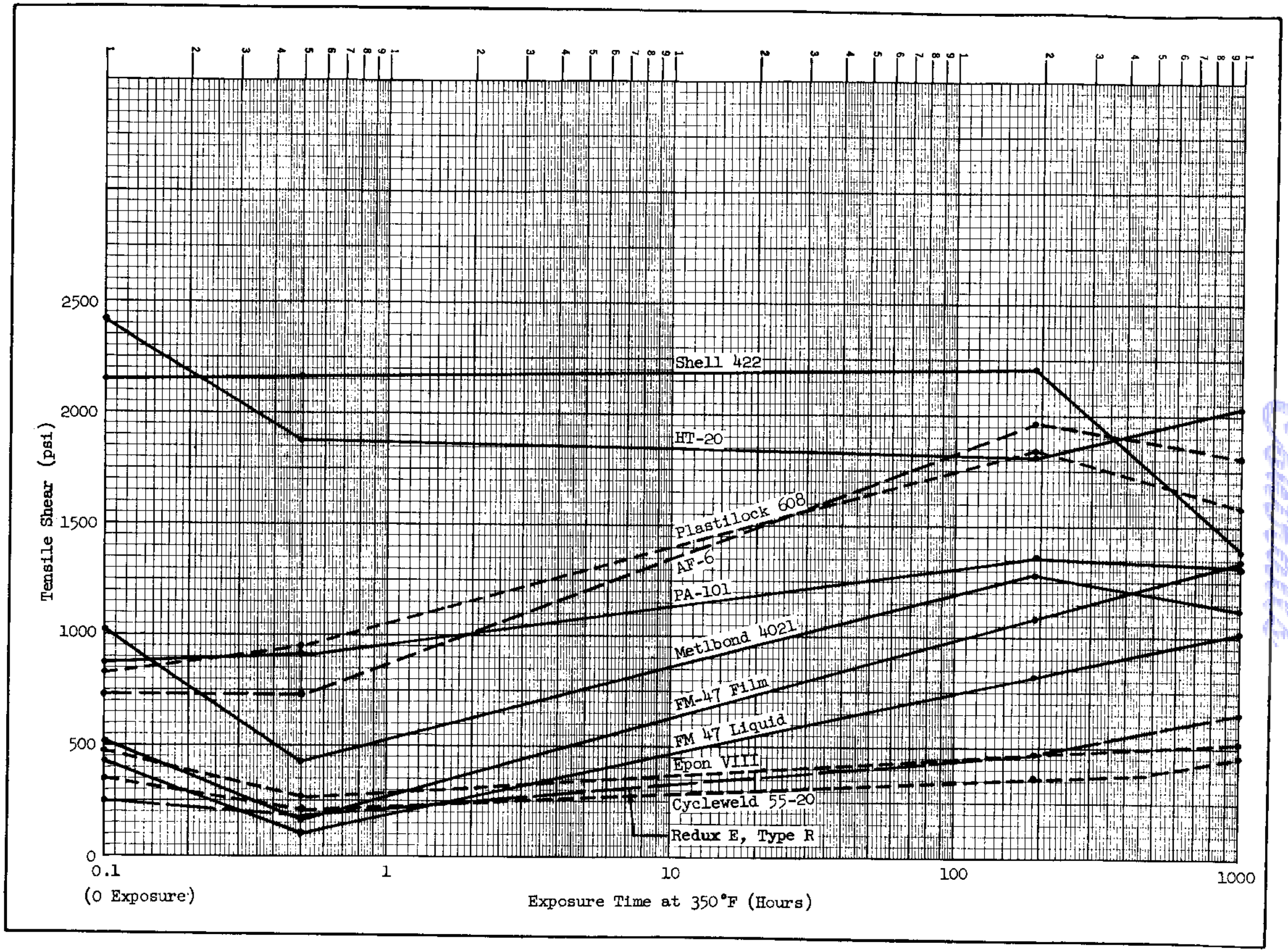


Fig. 22. Tensile Shear Strength at 350° F vs Exposure Time at 350° F for 2024-T3 Alclad Aluminum Joints

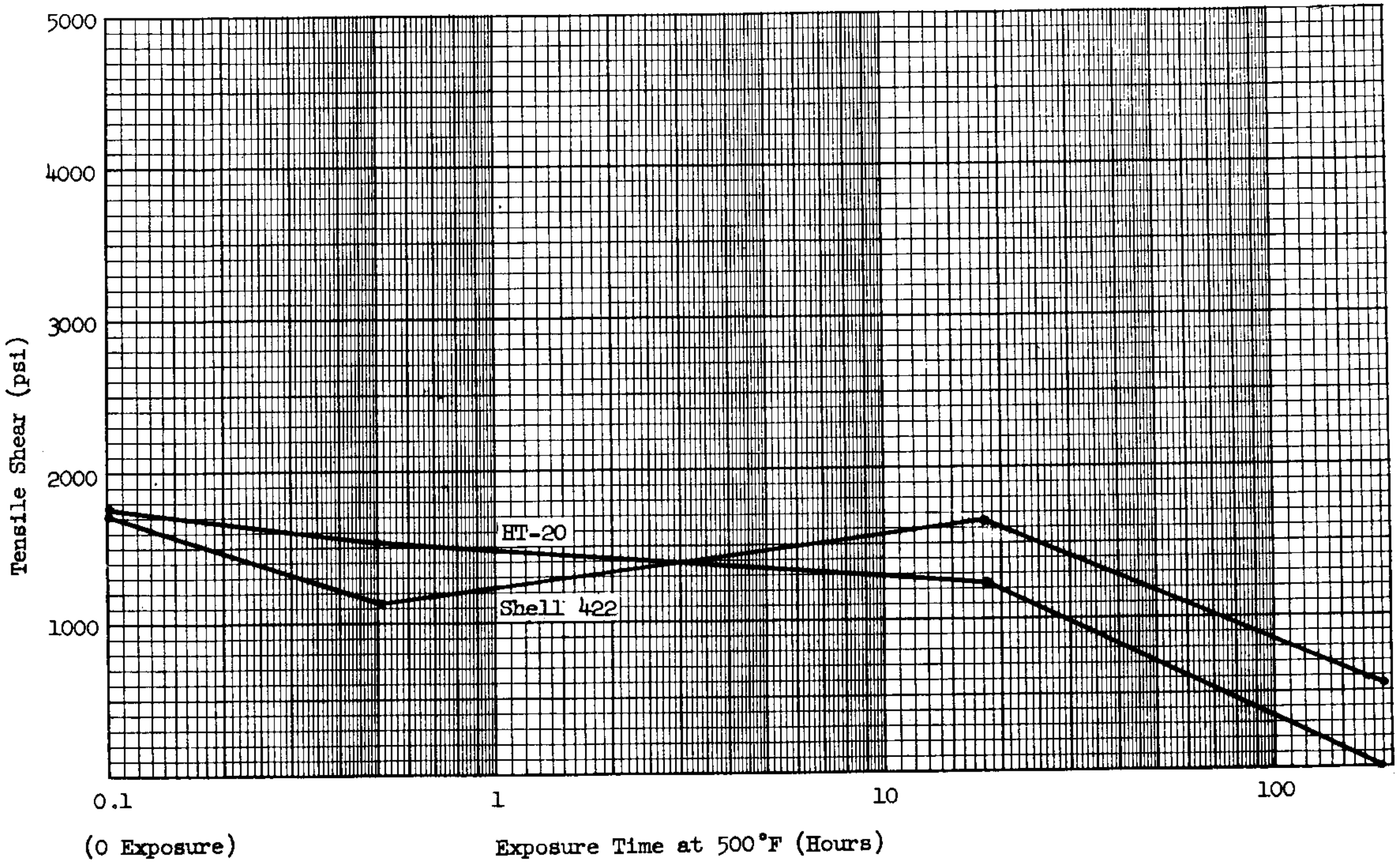


Fig. 23. Tensile Shear Strength at 500° F vs Exposure Time at 500° F for 2024-T3 Alclad Aluminum Joints

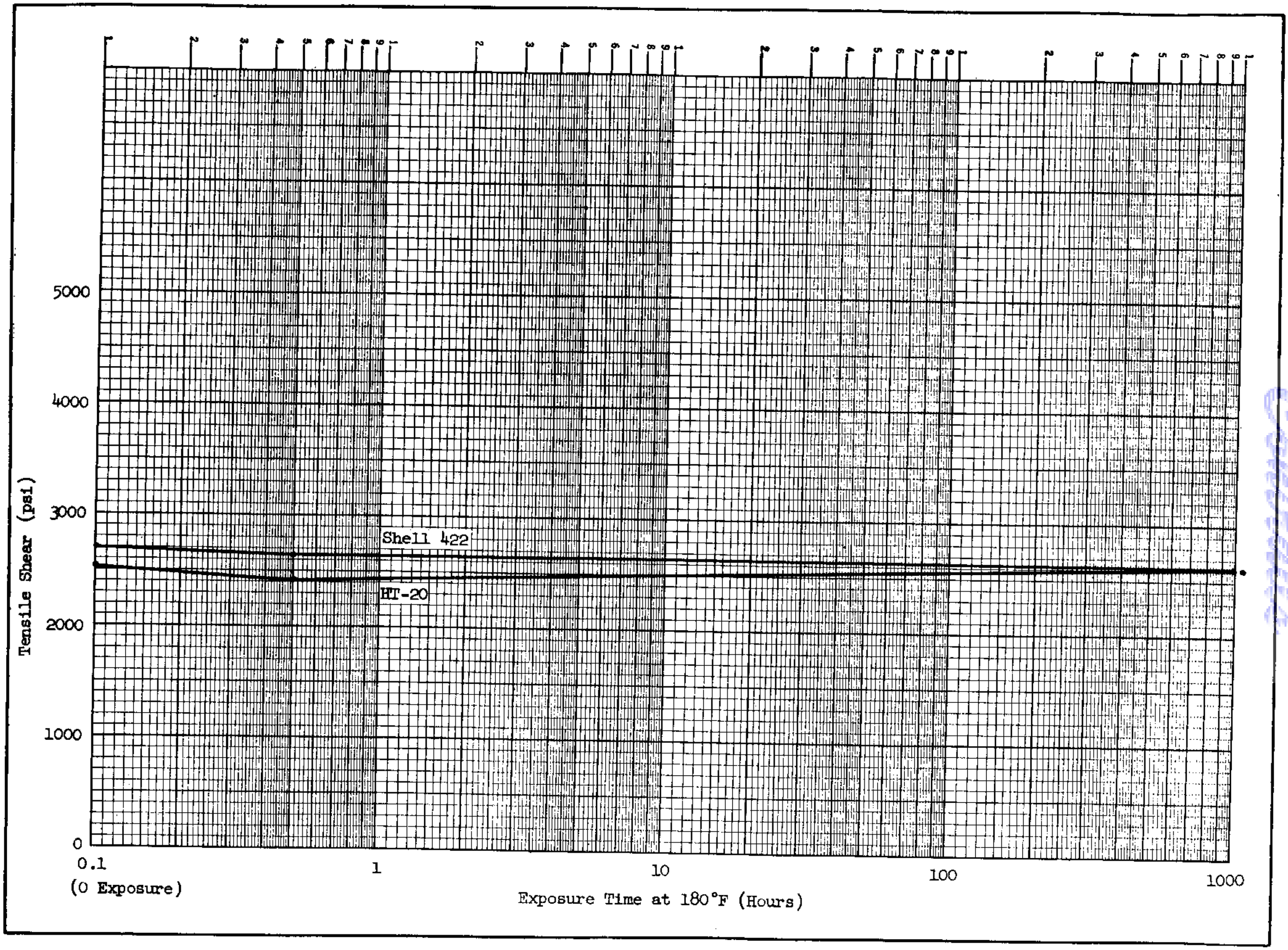


Fig. 24. Tensile Shear Strength at 180° F vs Exposure Time at 180° F for Type 301, 1/2-Hard Stainless Steel Joints

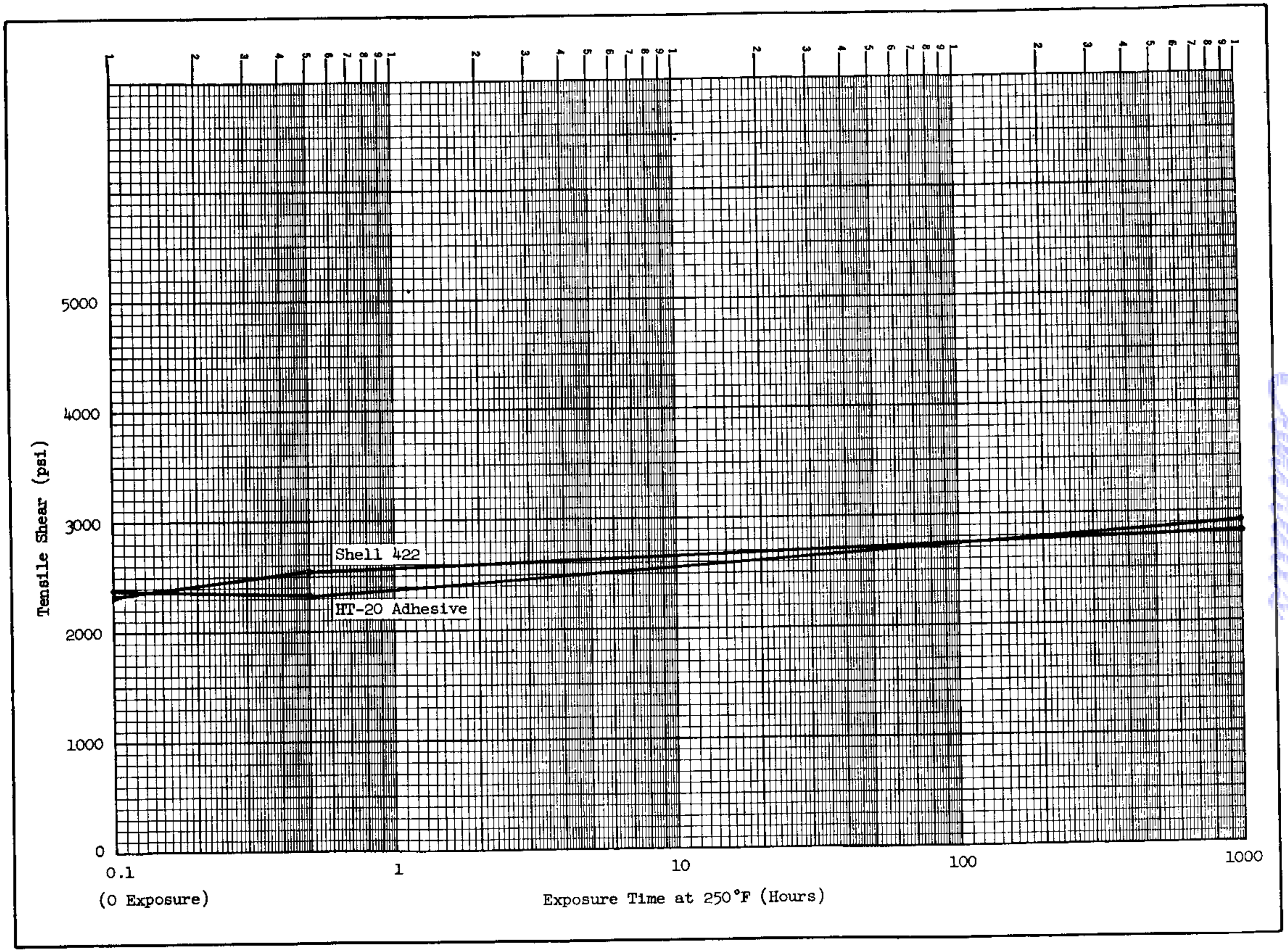


Fig. 25. Tensile Shear Strength at 250° F vs Exposure Time at 250° F for Type 301, 1/2-Hard Stainless Steel Joints

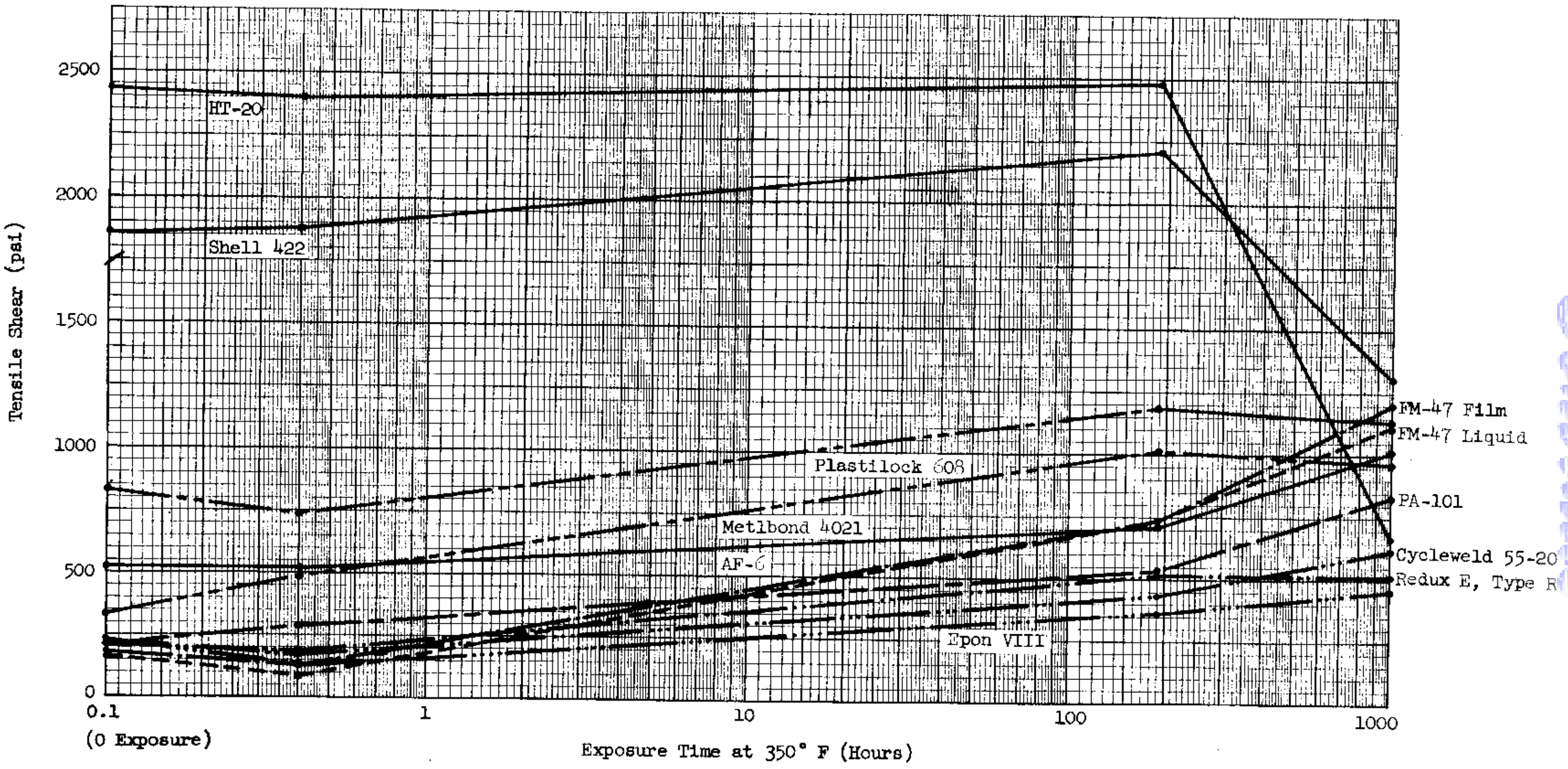


Fig. 26. Tensile Shear Strength at 350° F vs Exposure Time at 350° F for Type 301, 1/2-Hard Stainless Steel Joints

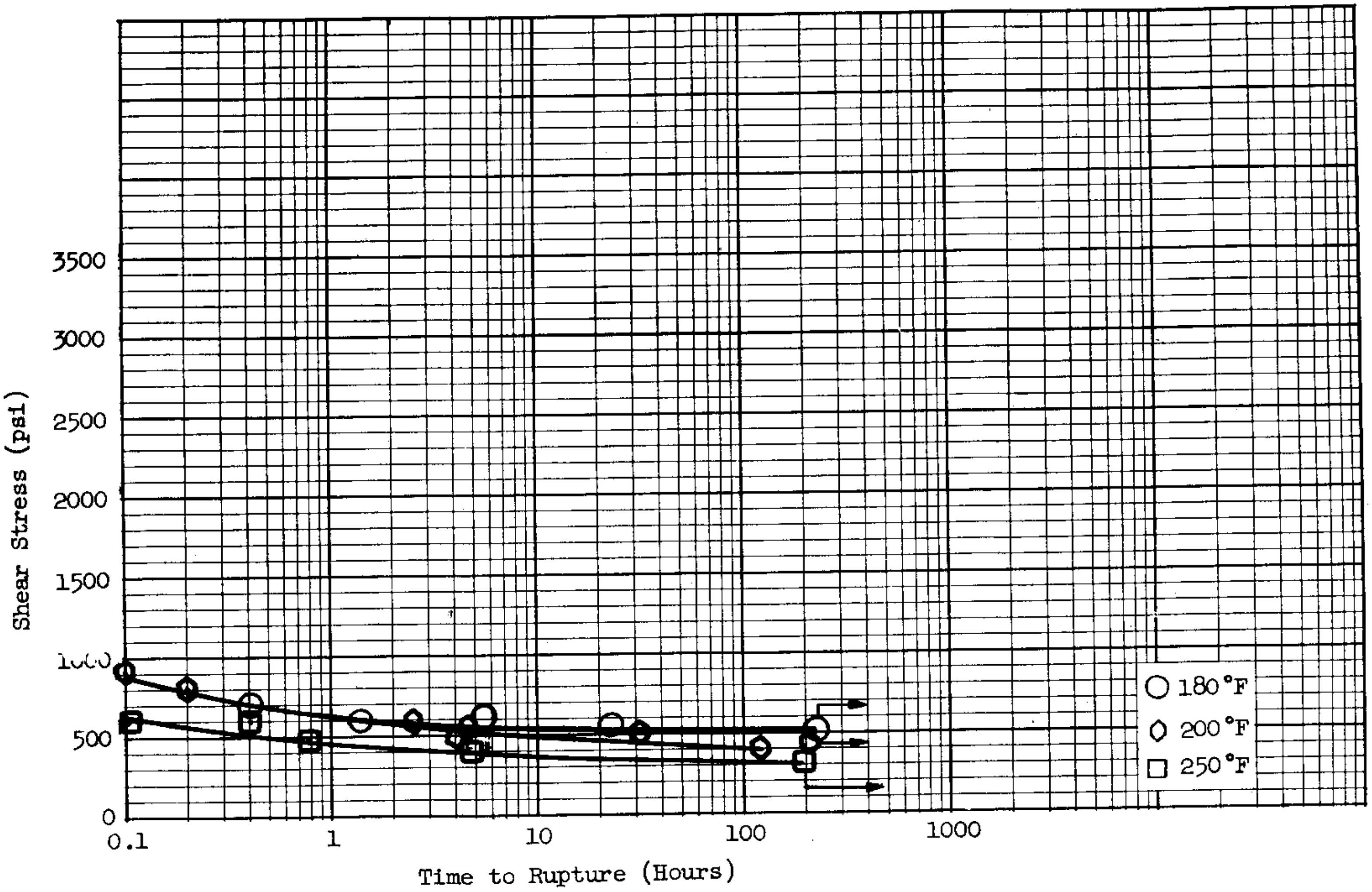


Fig. 27. Semilog Shear Stress-Time Rupture Curves for AF-6 Adhesive at 180° F, 200° F, and 250° F; 2024-T3 Alclad Aluminum.

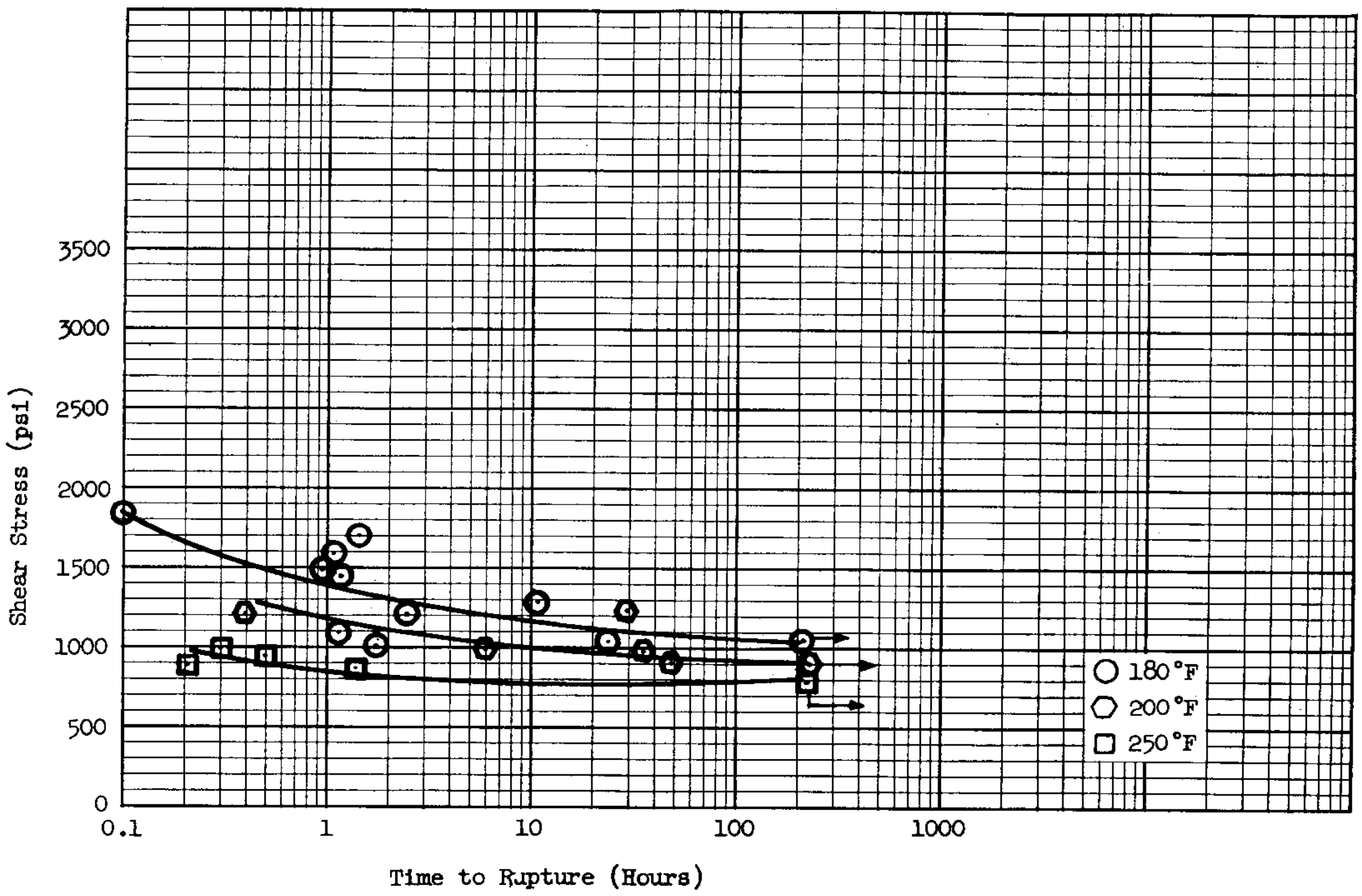


Fig. 28. Semilog Shear Stress-Time Rupture Curves for PA-101 Adhesive at 180° F, 200, F and 250° F; 2024-T3 Alclad Aluminum.

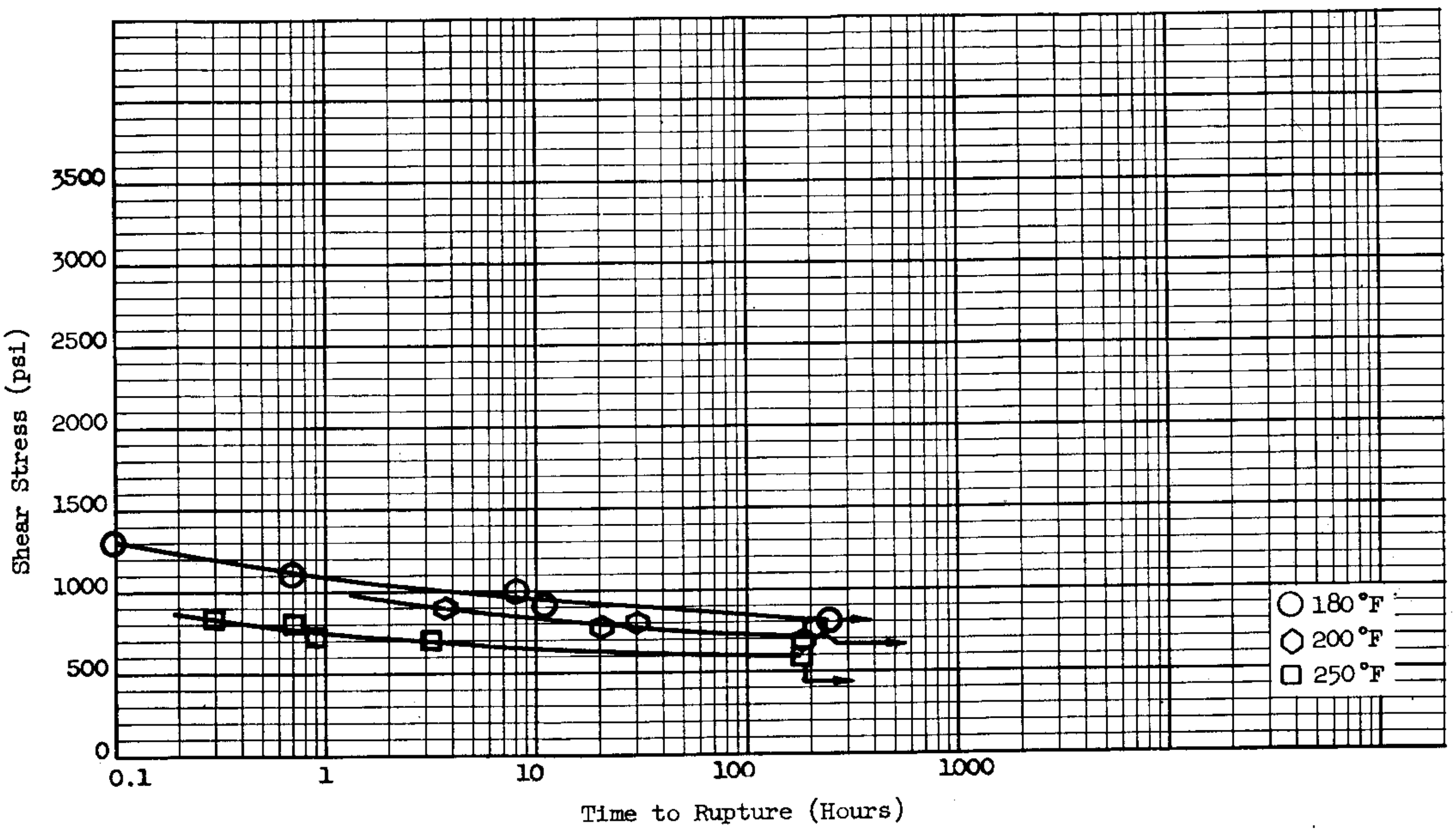


Fig. 29. Semilog Shear Stress-Time Rupture Curves for Plastilock 608 Adhesive at 180° F, 200° F and 250° F; 2024-T3 Alclad Aluminum.

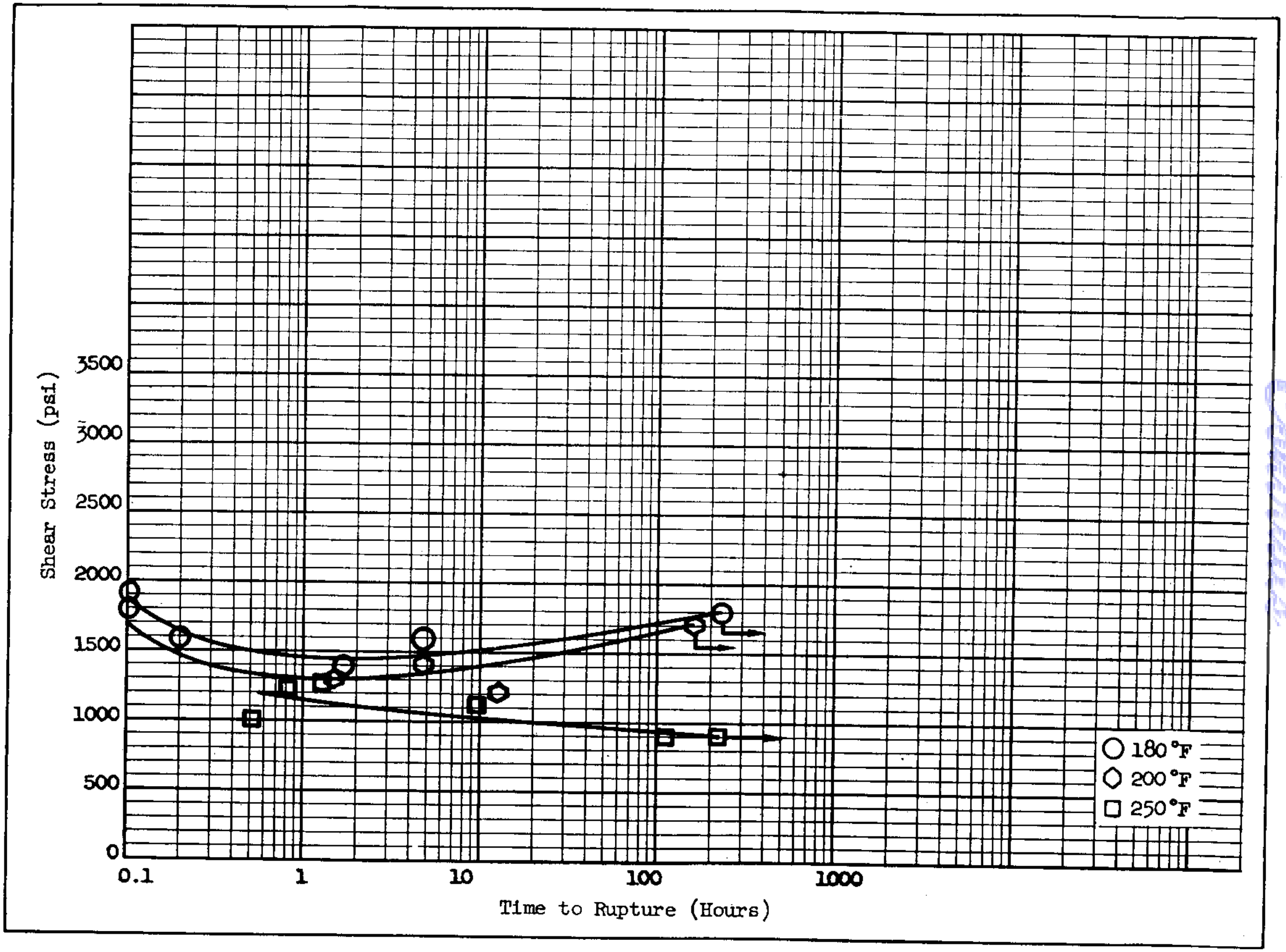


Fig. 30. Semilog Shear Stress-Time Rupture Curves for Metlbond 4021 Adhesive at 180° F, 200° F and 250° F; 2024-T3 Alclad Aluminum.

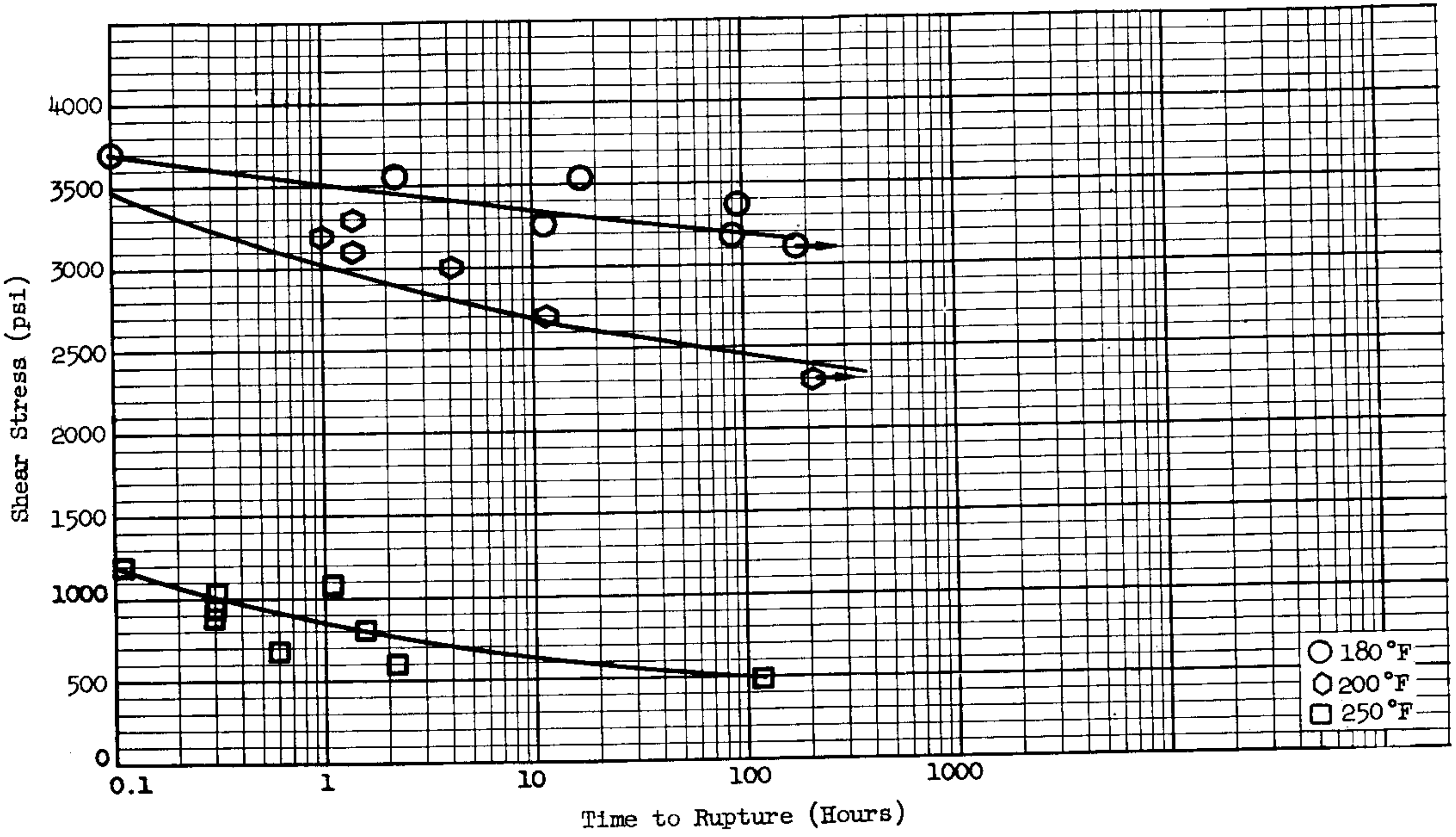


Fig. 31. Semilog Shear Stress-Time Rupture Curves for FM-47 Liquid Adhesive at 180° F, 200° F and 250° F; 2024-T3 Alclad Aluminum.

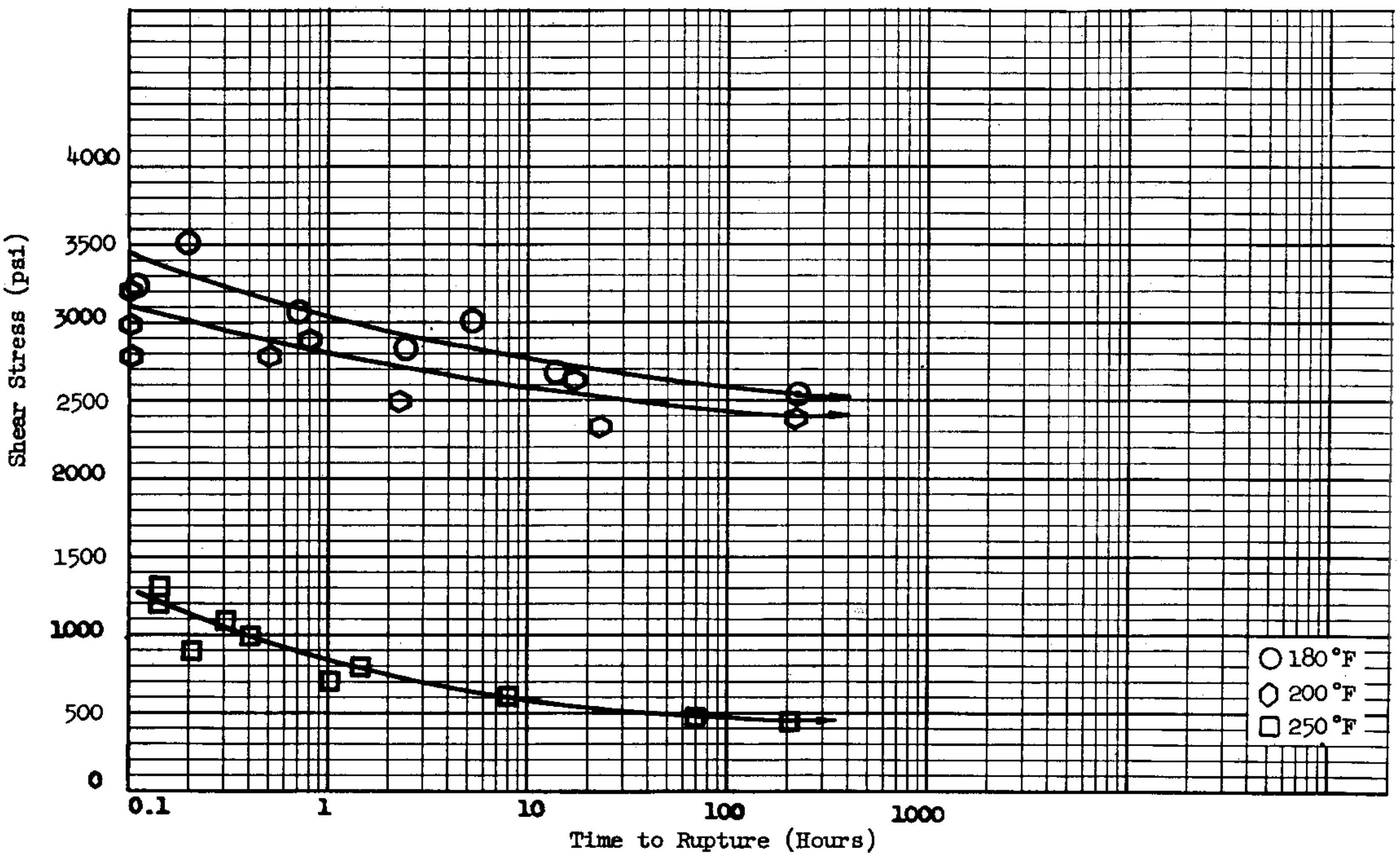


Fig. 32. Semilog Shear Stress-Time Rupture Curves for FM-47 Film Adhesive at 180° F, 200° F and 250° F; 2024-T3 Alclad Aluminum.

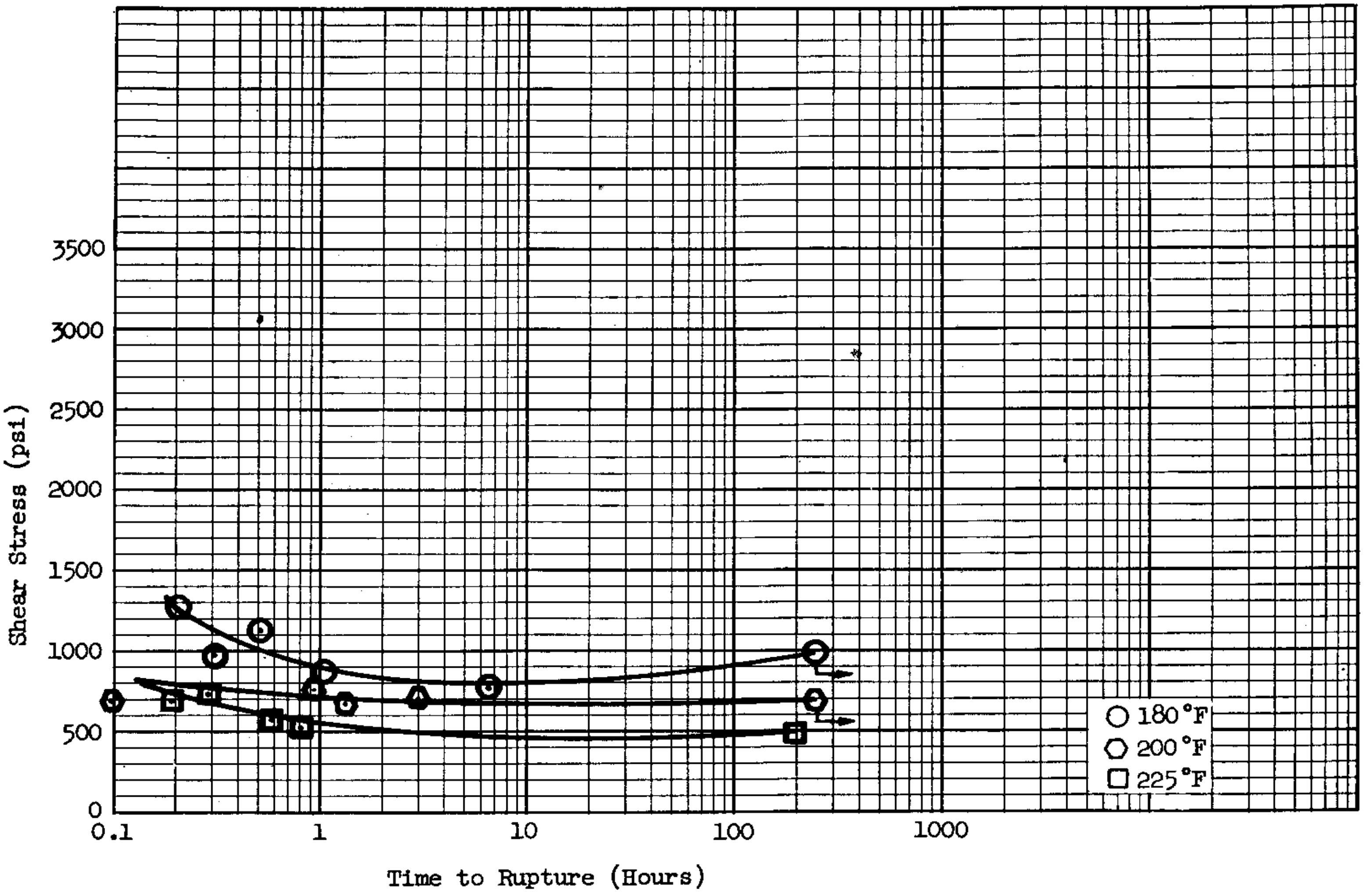


Fig. 33. Semilog Shear Stress-Time Rupture Curves for Redux E, Type R Adhesive at 180° F, 200° F and 225° F; 2024-T3 Alclad Aluminum.

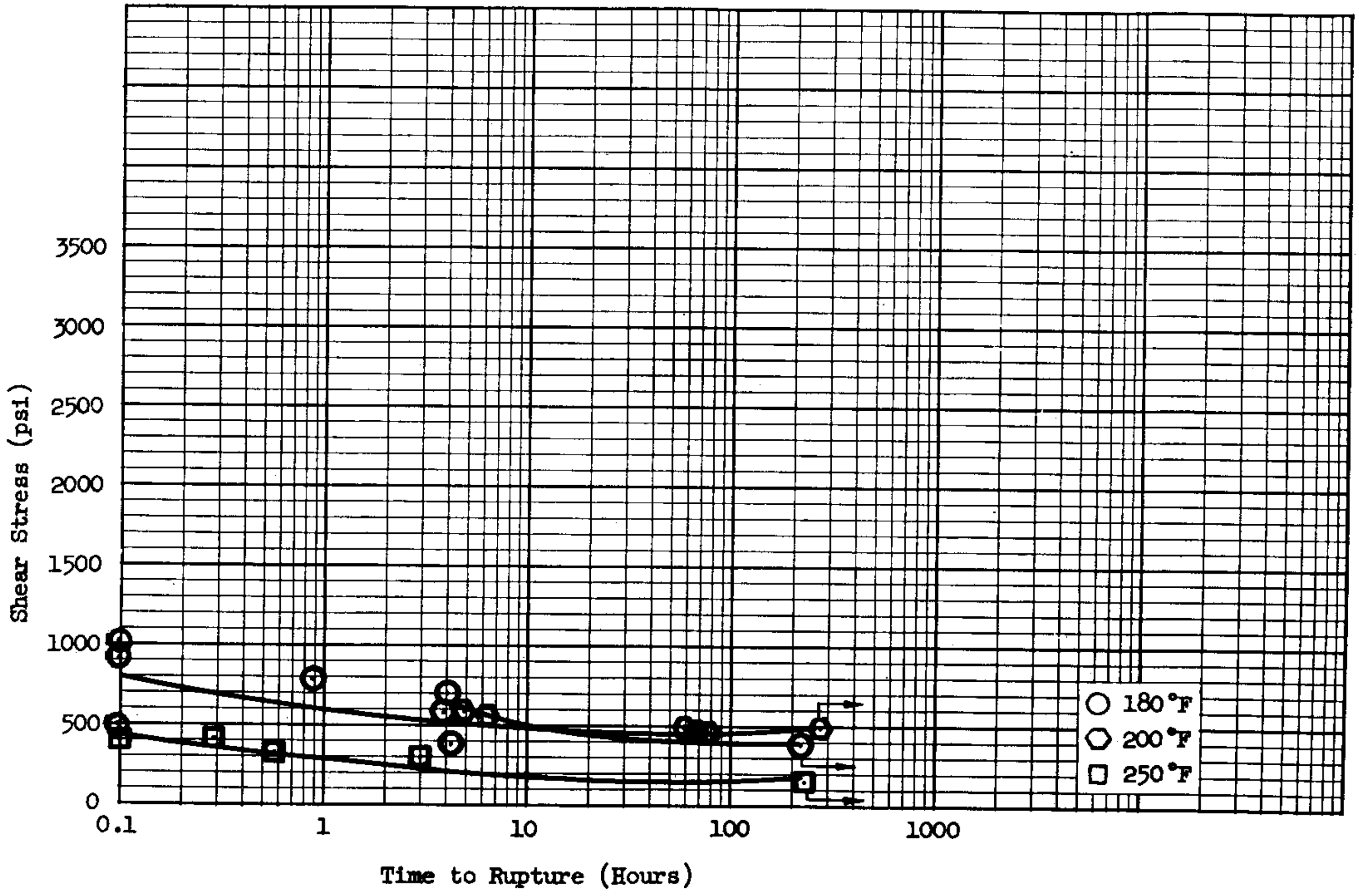


Fig. 34. Semilog Shear Stress-Time Rupture Curves for Cycleweld 55-20 Adhesive at 180° F, 200° F and 250° F; 2024-T3 Alclad Aluminum.

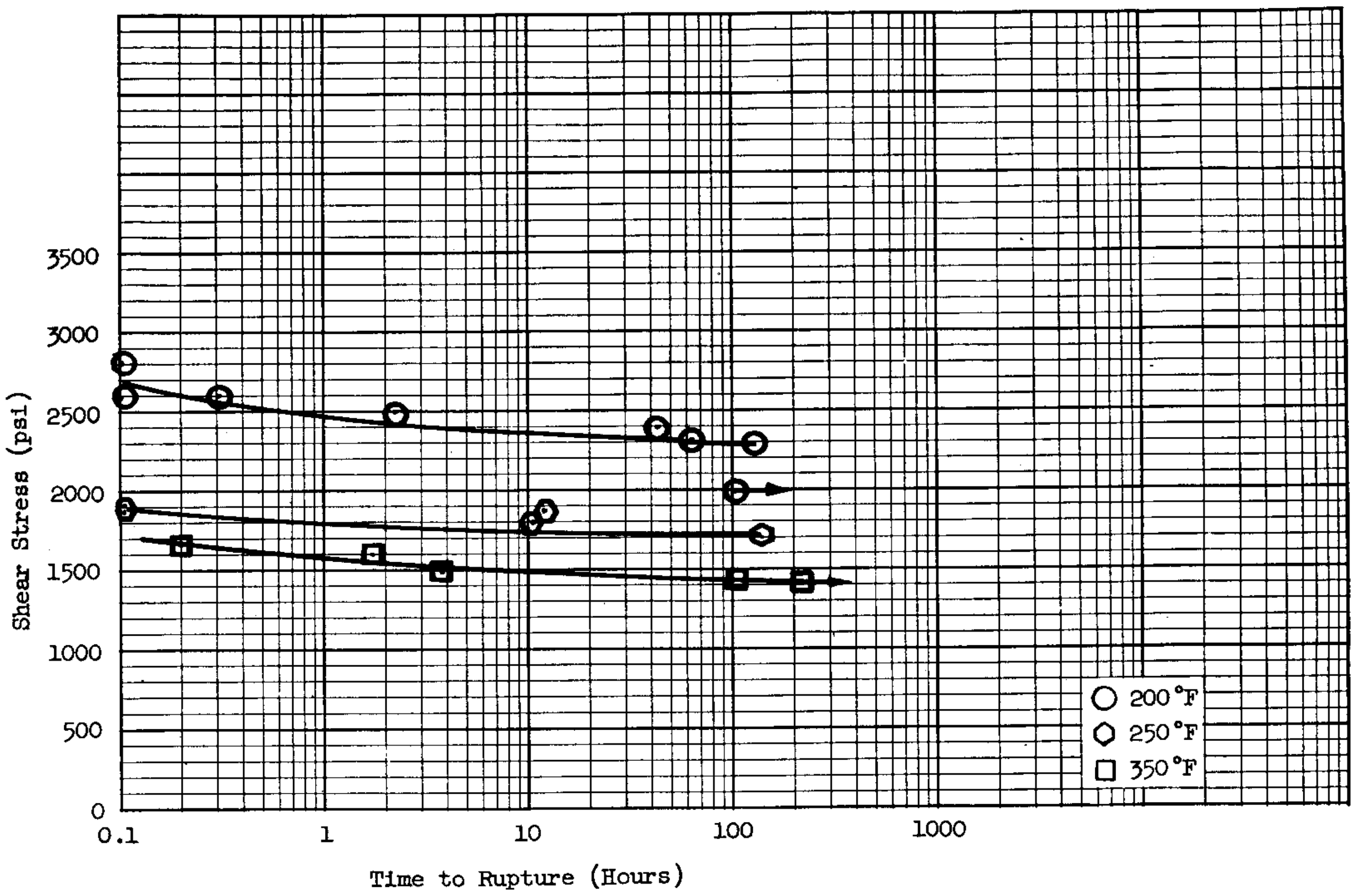


Fig. 35. Semilog Shear Stress-Time Rupture Curves for Shell 422 Adhesive at 200° F, 250° F and 350° F; 2024-T3 Alclad Aluminum.

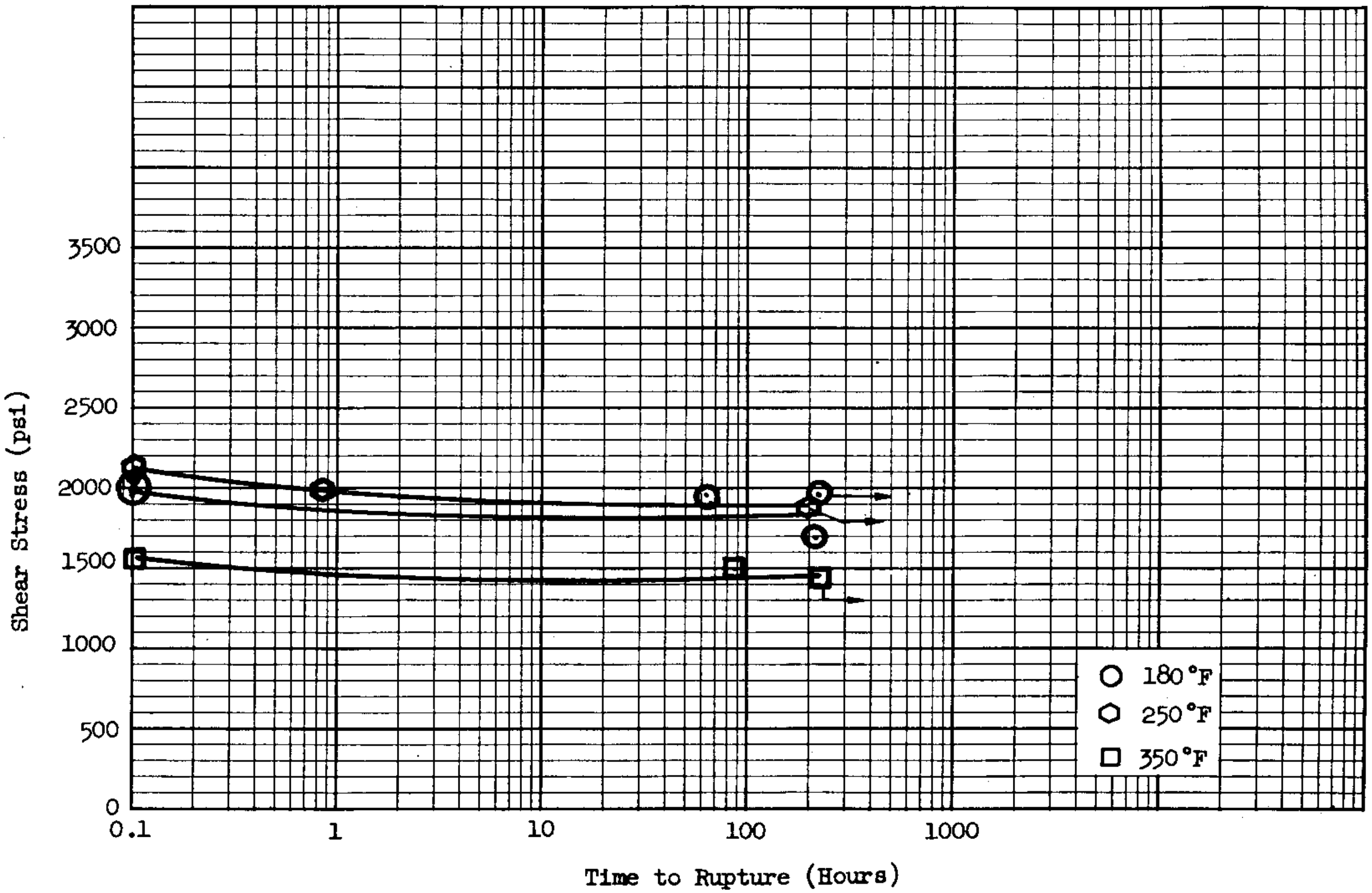


Fig. 36. Semilog Shear Stress-Time Rupture Curves for HT-20 Adhesive at 180° F, 250° F and 350° F; 2024-T3 Alclad Aluminum.

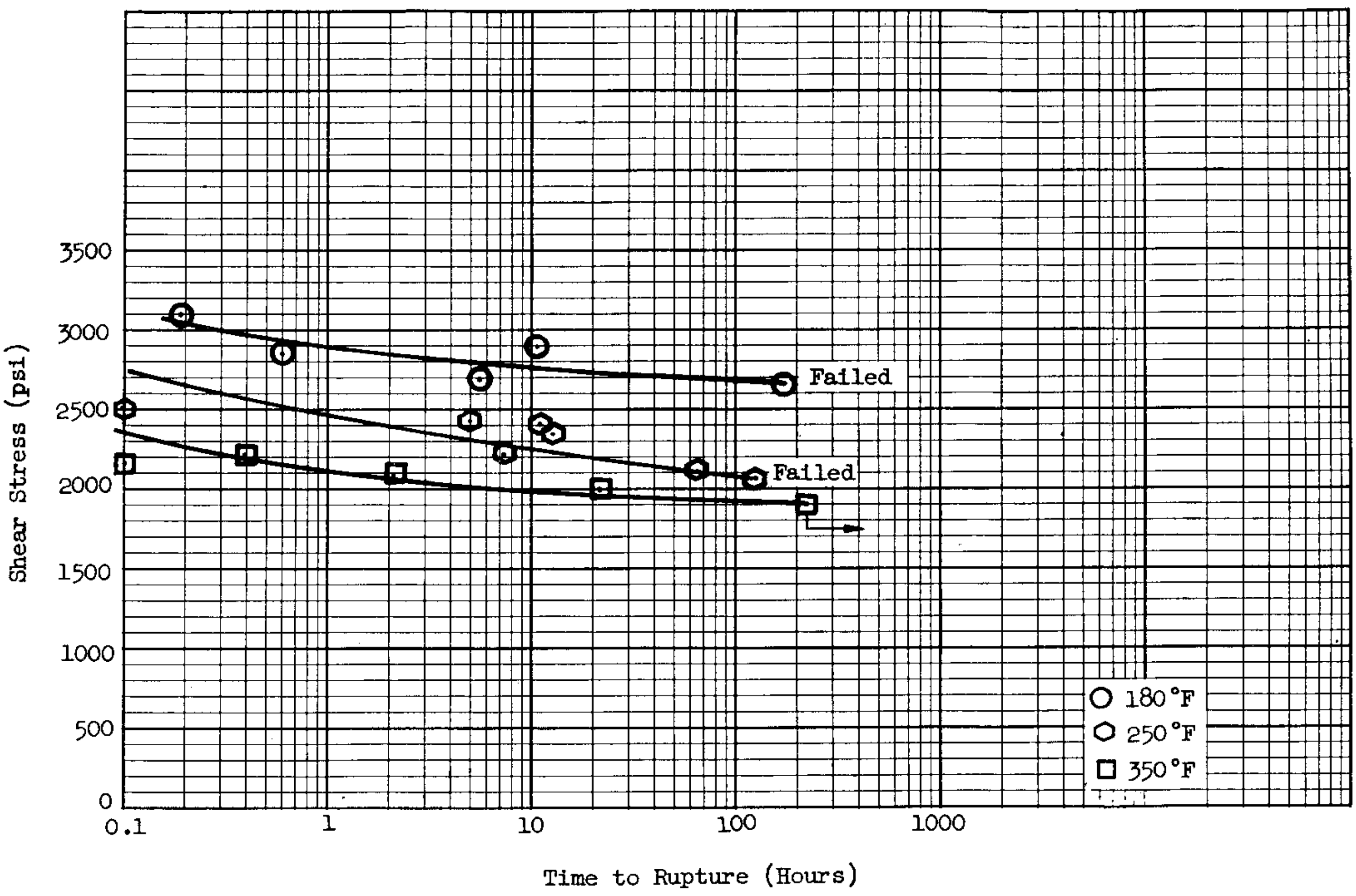


Fig. 37. Semilog Shear Stress-Time Rupture Curves for Shell 422 Adhesive at 180° F, 250° F and 350° F; Type 301, 1/2-Hard Stainless Steel.

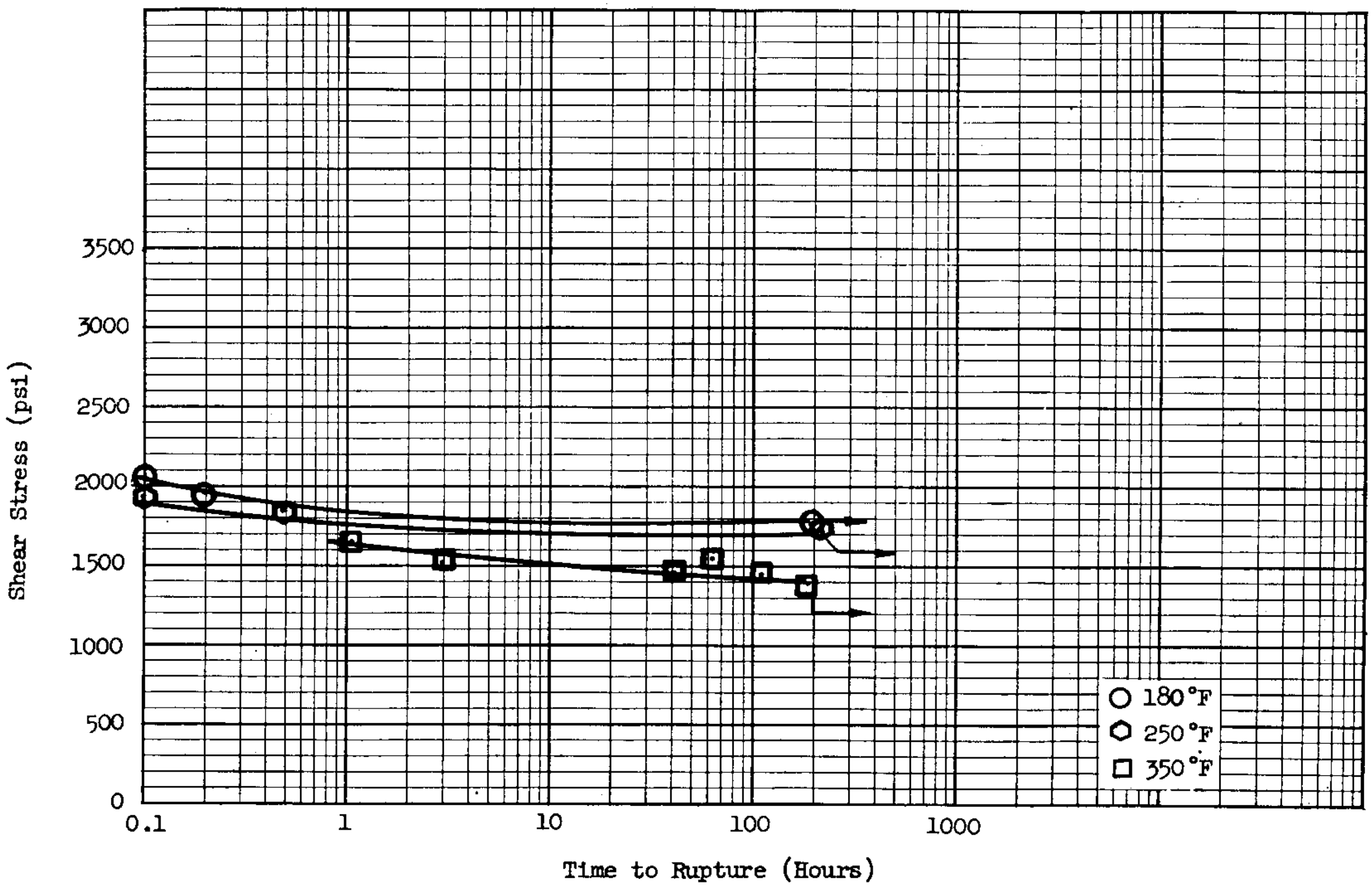


Fig. 38. Semilog Shear Stress-Time Rupture Curves for HT-20 Adhesive at 180° F, 250° F and 350° F; Type 301, 1/2-Hard Stainless Steel.

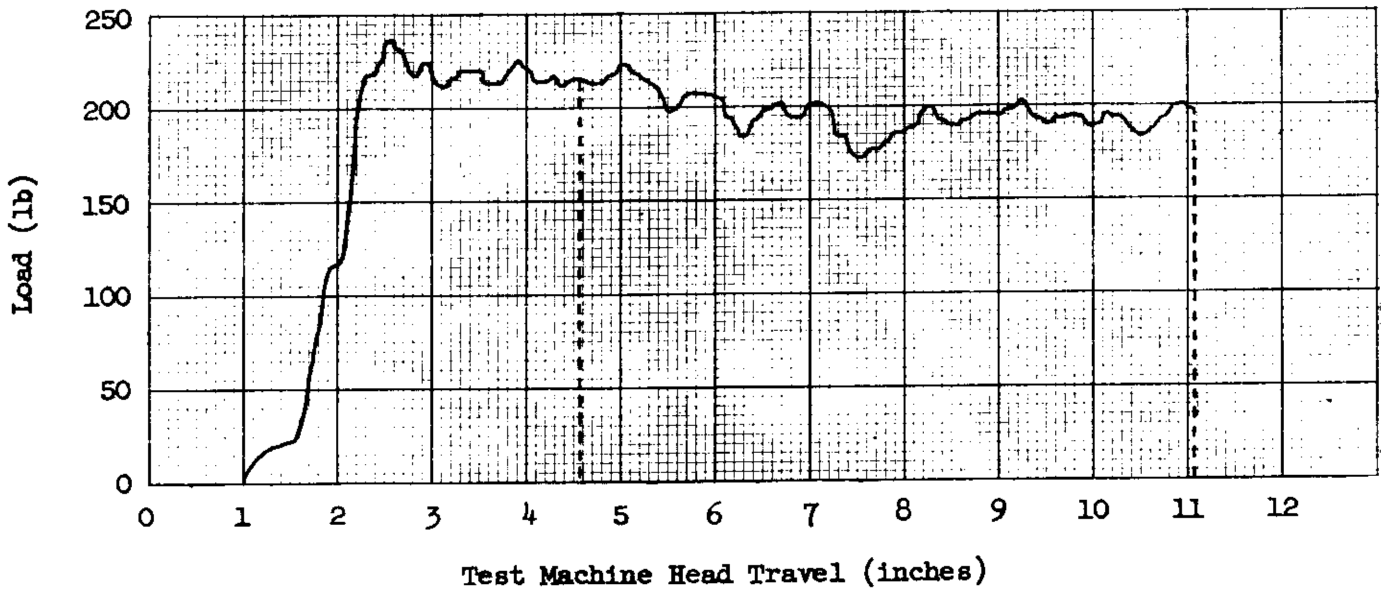


Fig. 39. Peel Test Curve for AF-6

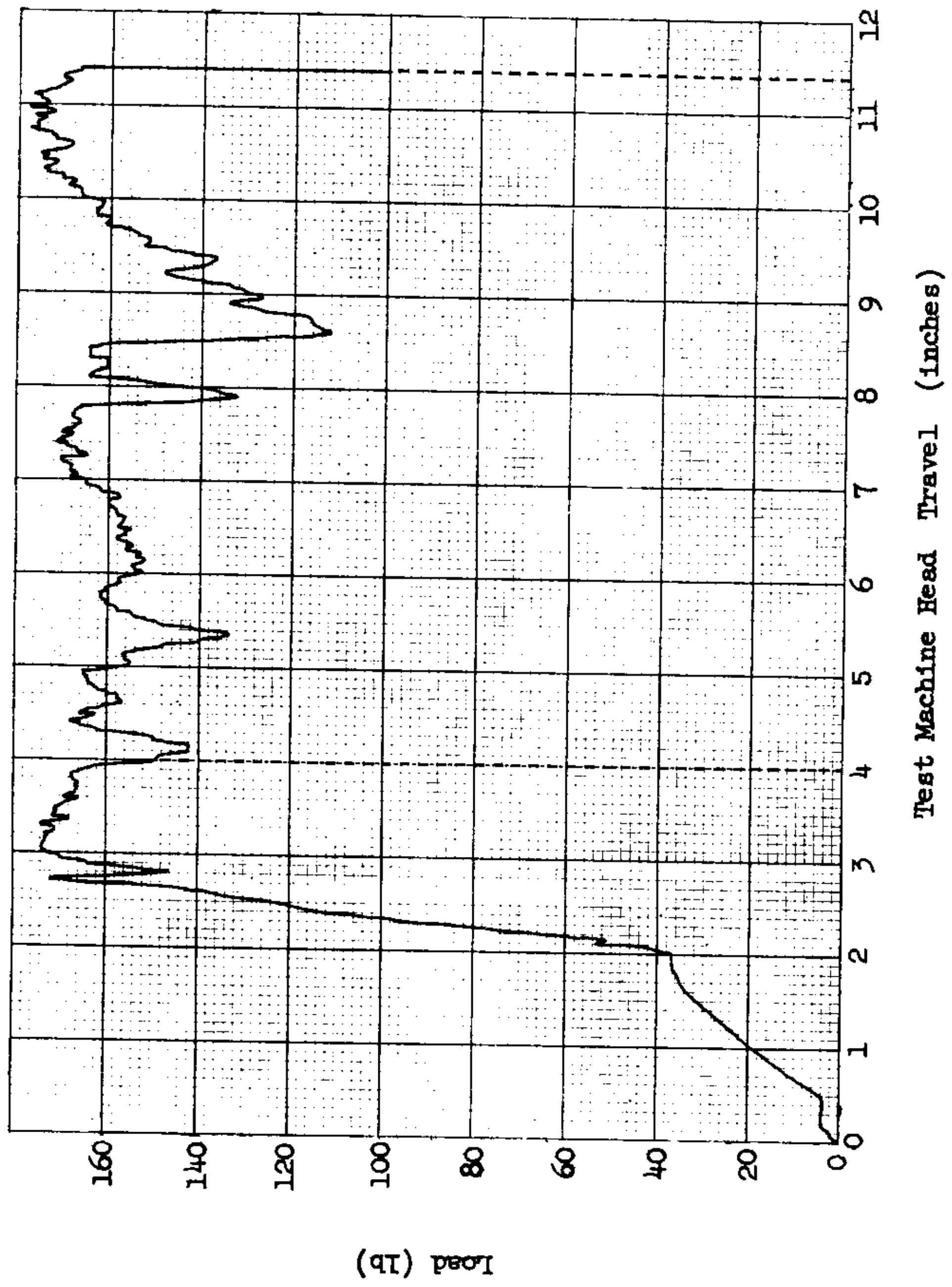


Fig. 40. Peel Test Curve for PA-101

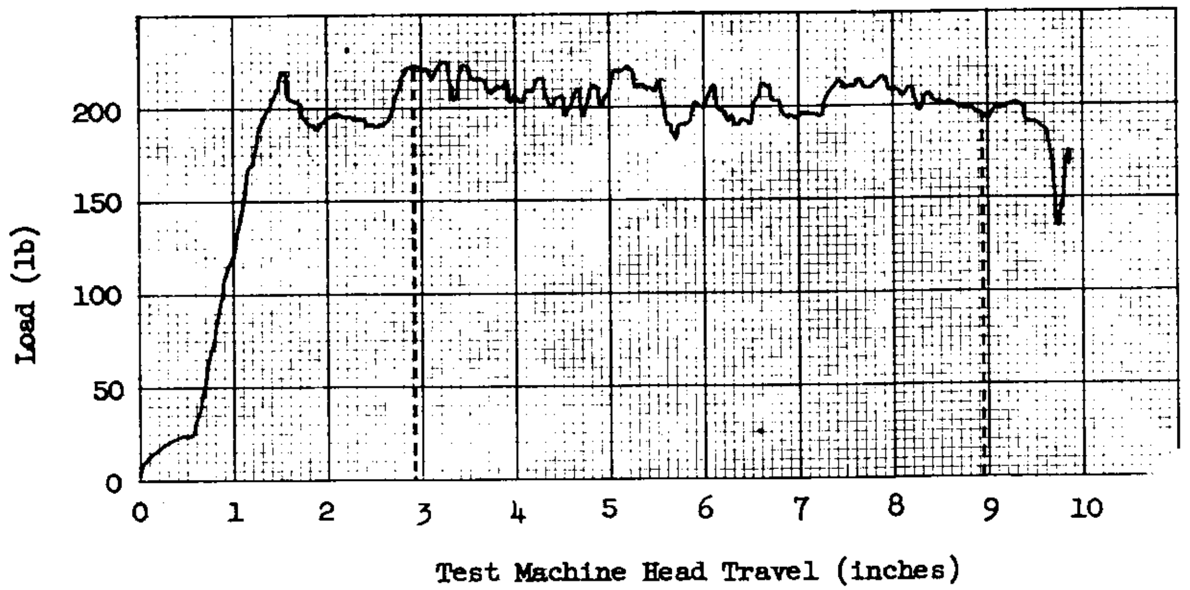


Fig. 41. Peel Test Curve for Plastilock 608

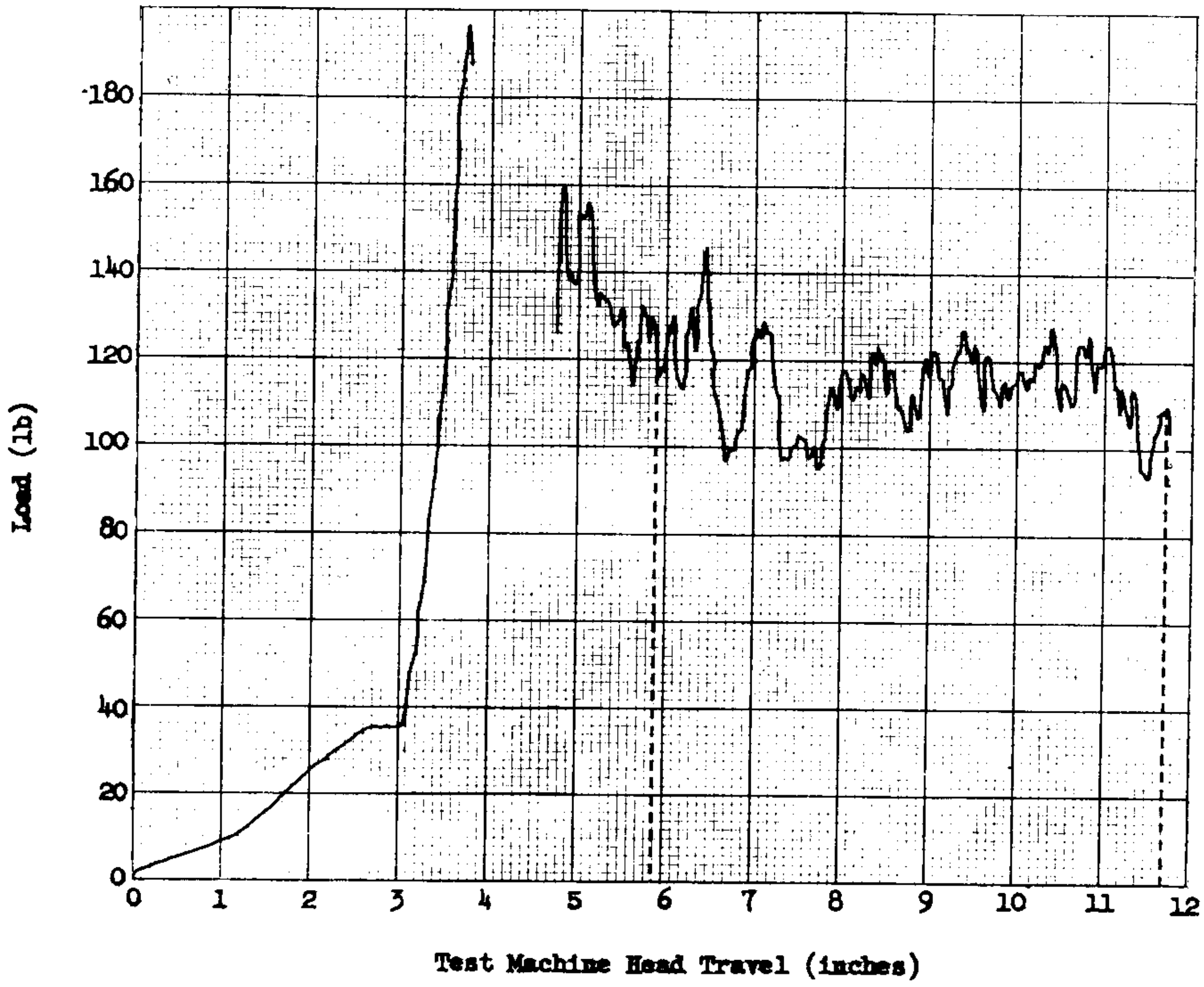


Fig. 42. Peel Test Curve for Metlbond 4021

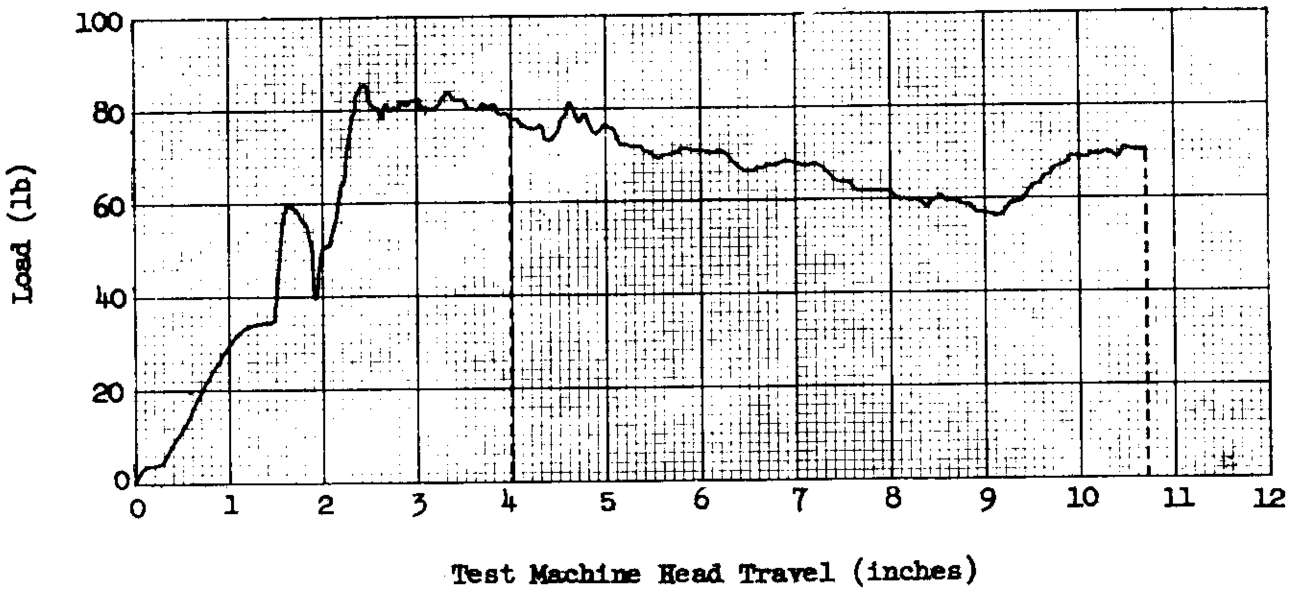


Fig. 43. Peel Test Curve for FM-47 Liquid

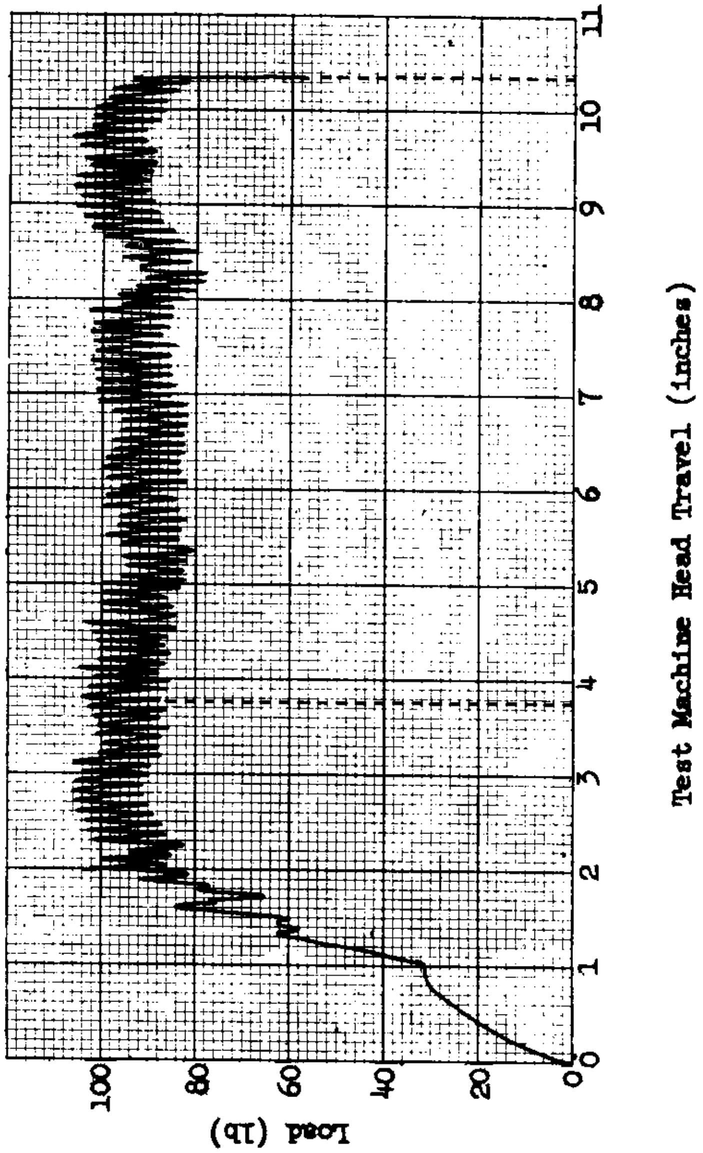


Fig. 44. Peel Test Curve for FM-47 Film

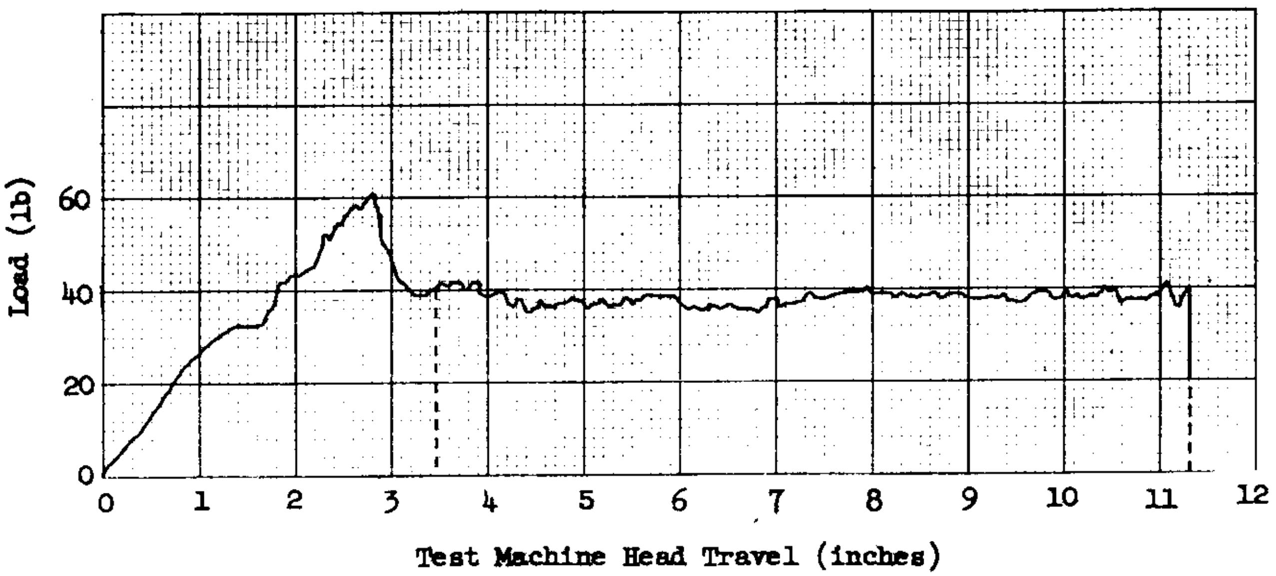


Fig. 45. Peel Test Curve for Redux E, Type R

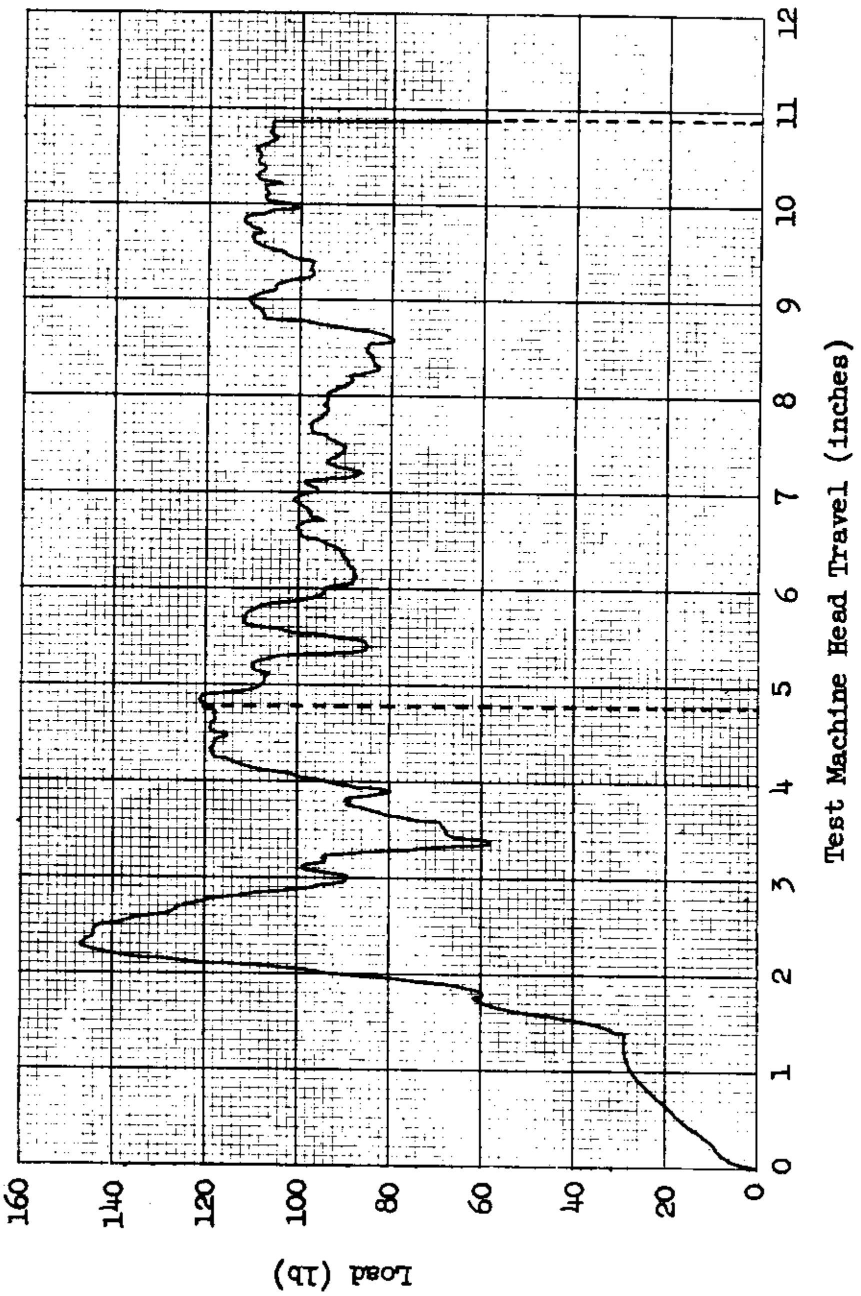


Fig. 46. Peel Test Curve for Cycleweld 55-20

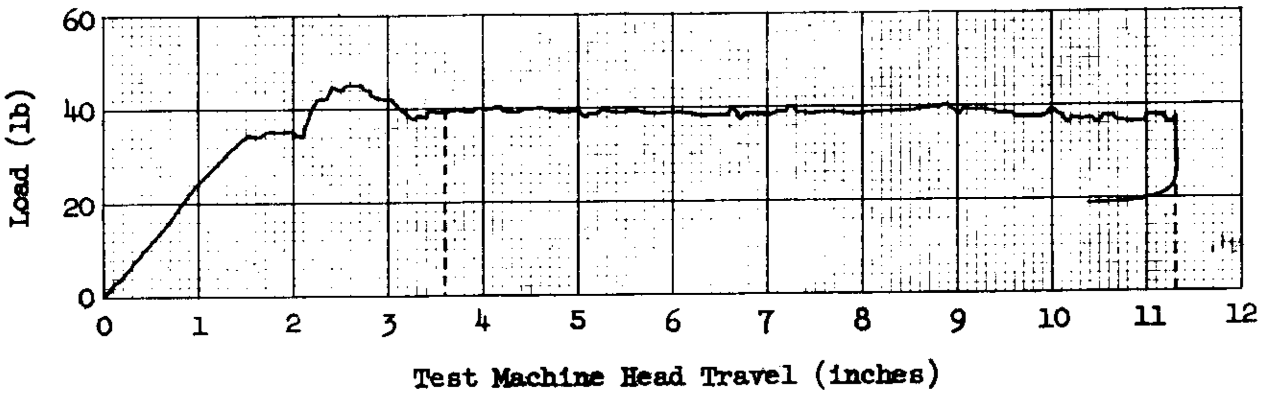


Fig. 47. Peel Test Curve for Epon VIII

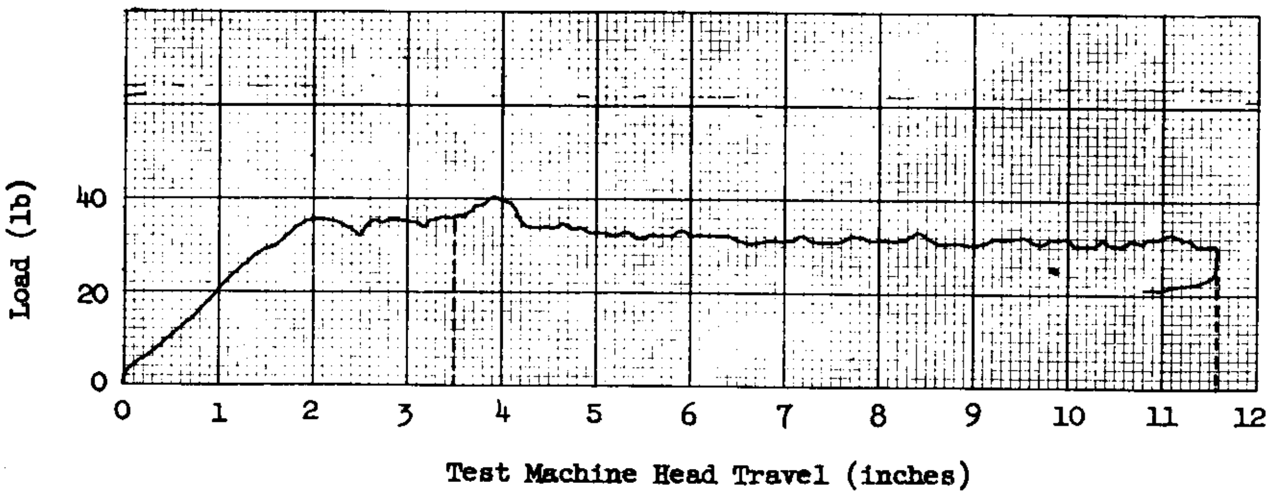


Fig. 48. Peel Test Curve for Shell 422

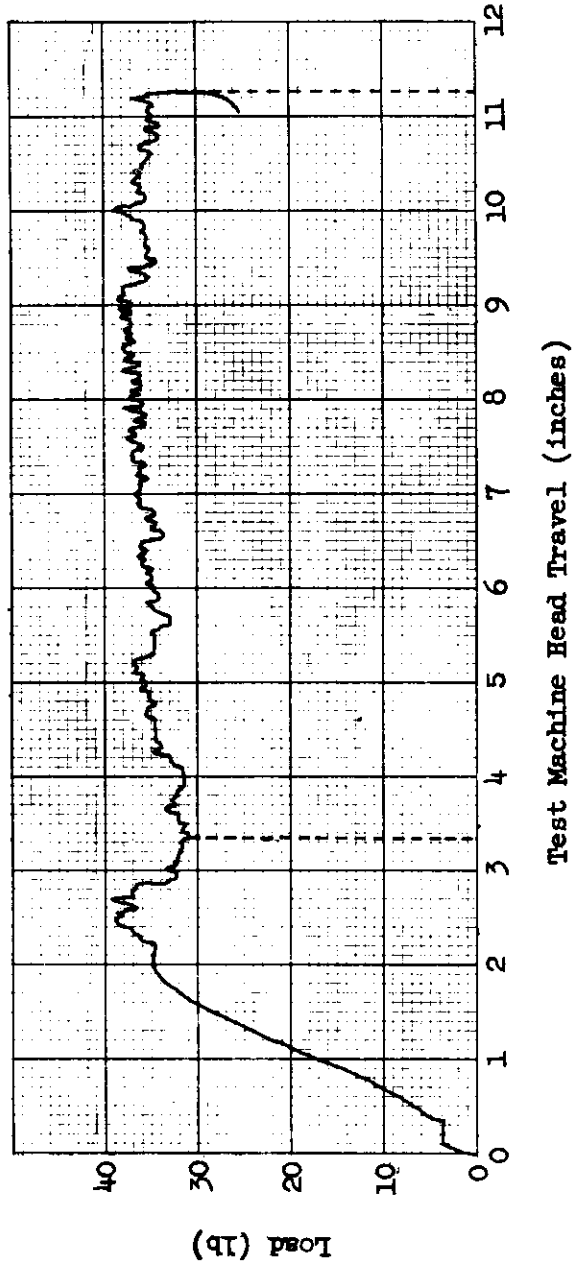


Fig. 49. Peel Test Curve for HT-20

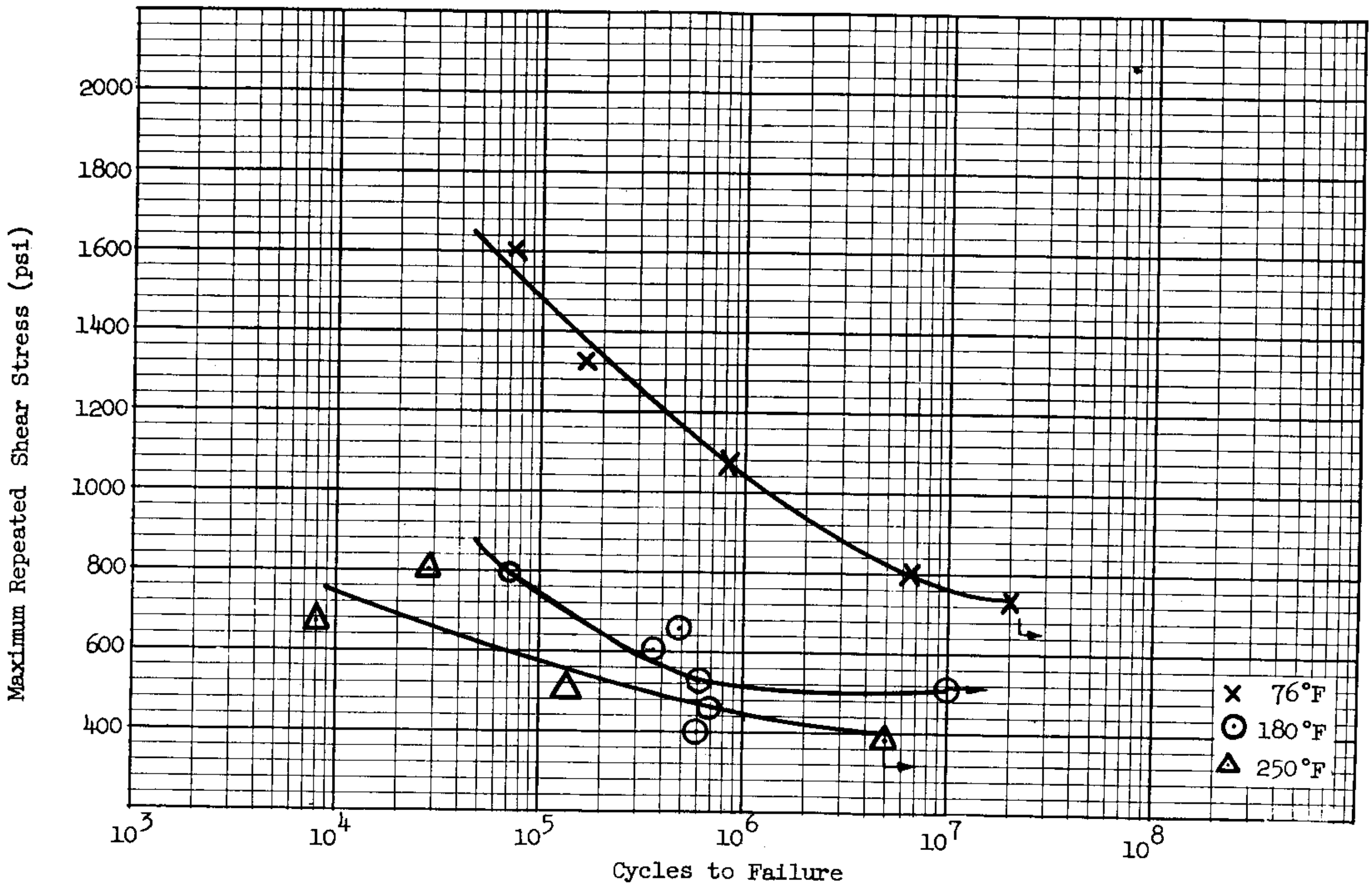


Fig. 50. S-N Fatigue Curves of AF-6 Adhesive at 76° F, 180° F and 250° F for R = 0.10; 2024-T3 Alclad Aluminum.

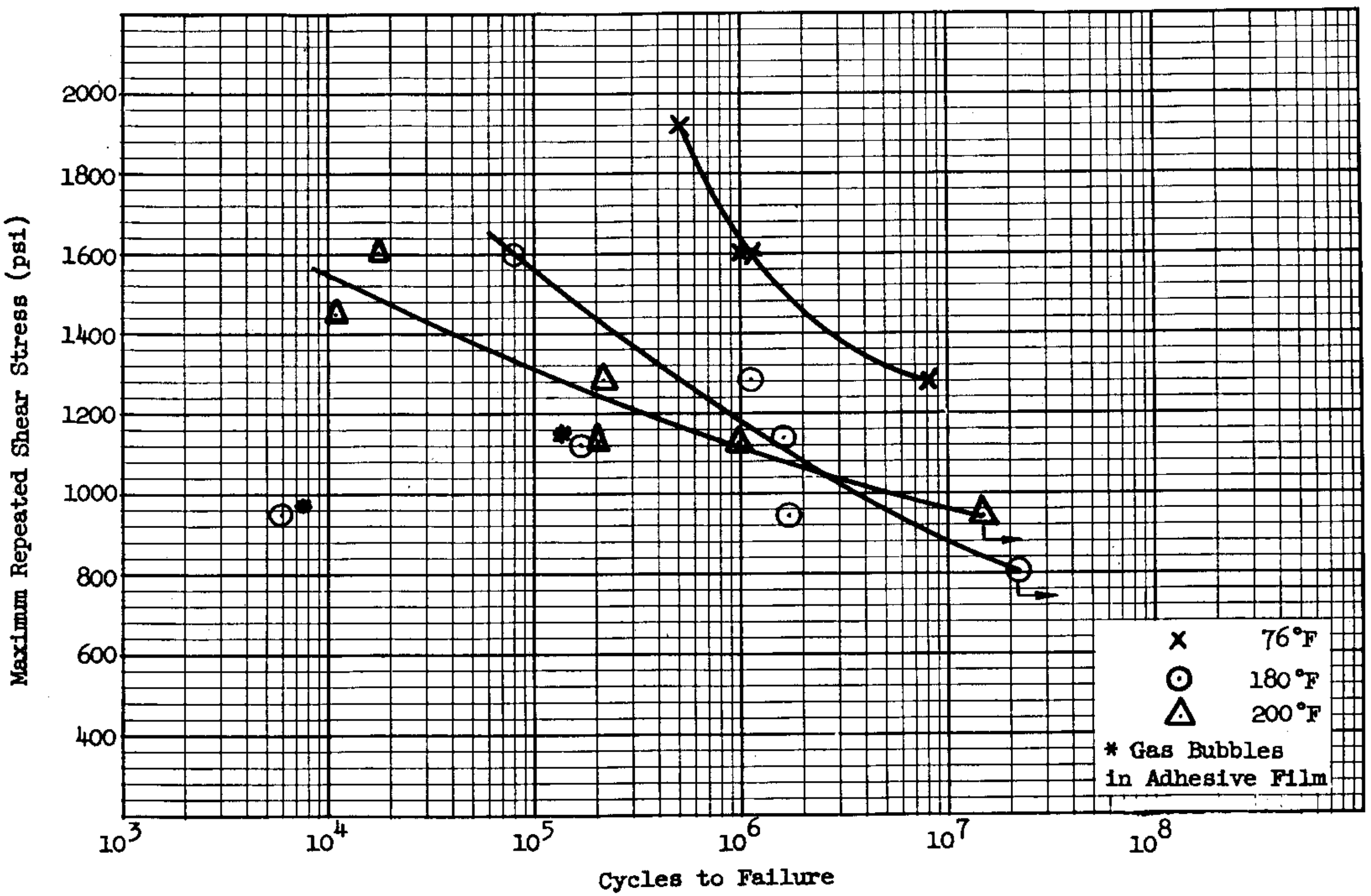


Fig. 51. S-N Fatigue Curves of PA 101 Adhesive at 76° F, 180° F and 200° F for R = 0.10; 2024-T3 Alclad Aluminum.

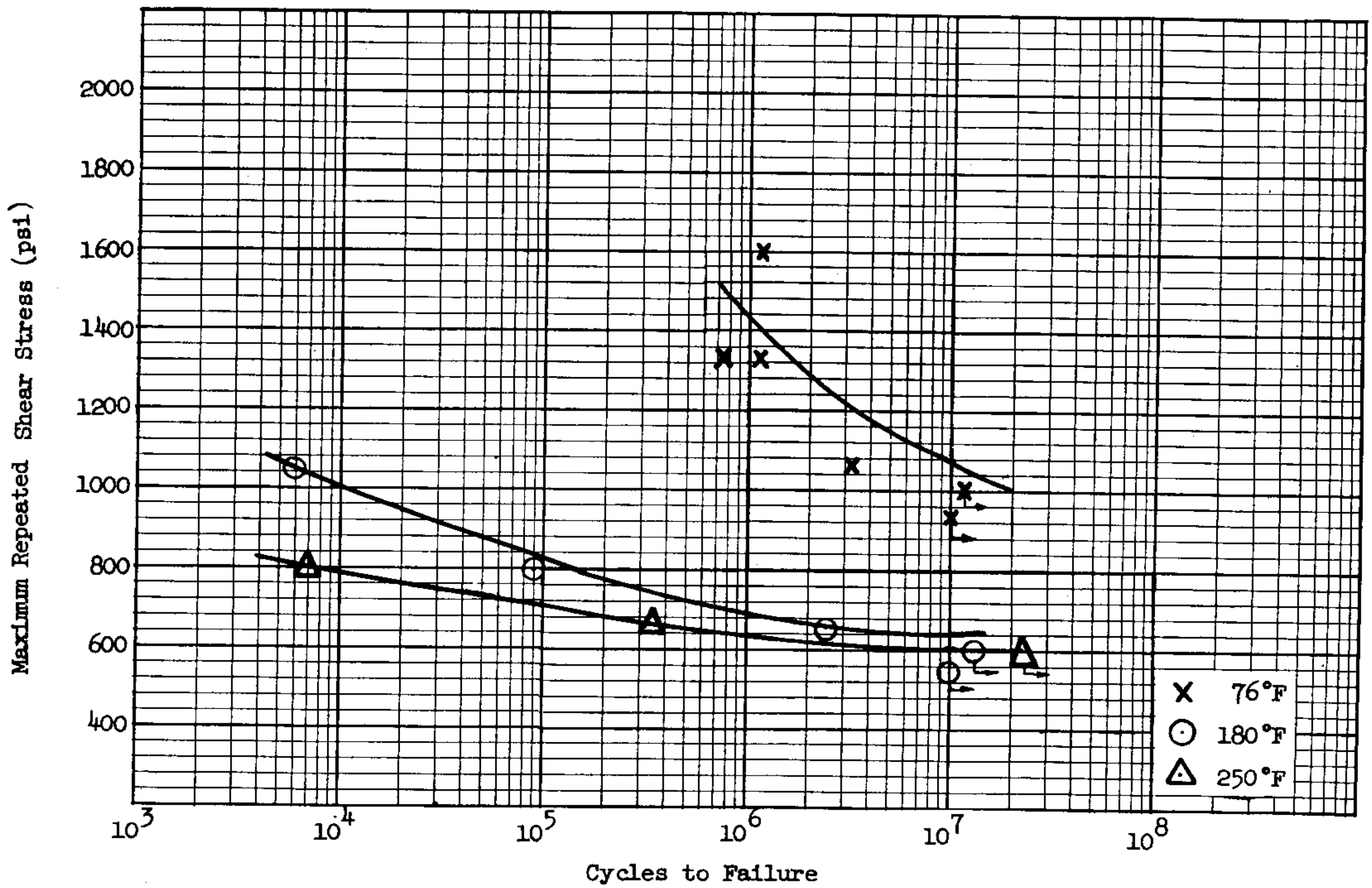


Fig. 52. S-N Fatigue Curves of Plastilock 608 Adhesive at 76° F, and 180° F and 250° F for R = 0.10; 2024-T3 Alclad Aluminum.

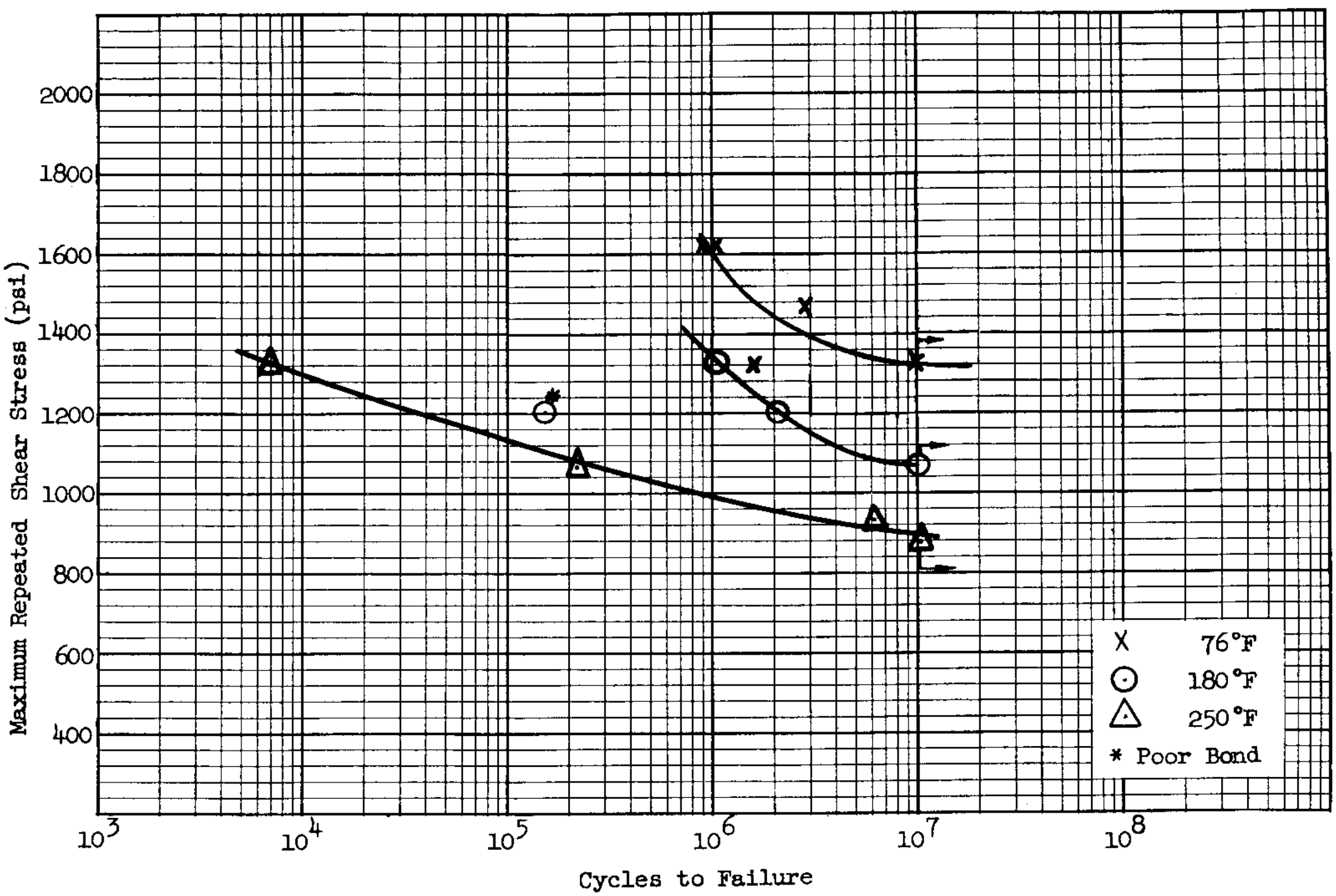


Fig. 53. S-N Fatigue Curves of Metlbond 4021 Adhesive at 76° F, 180° F and 250° F for R = 0.10; 2024-T3 Alclad Aluminum.

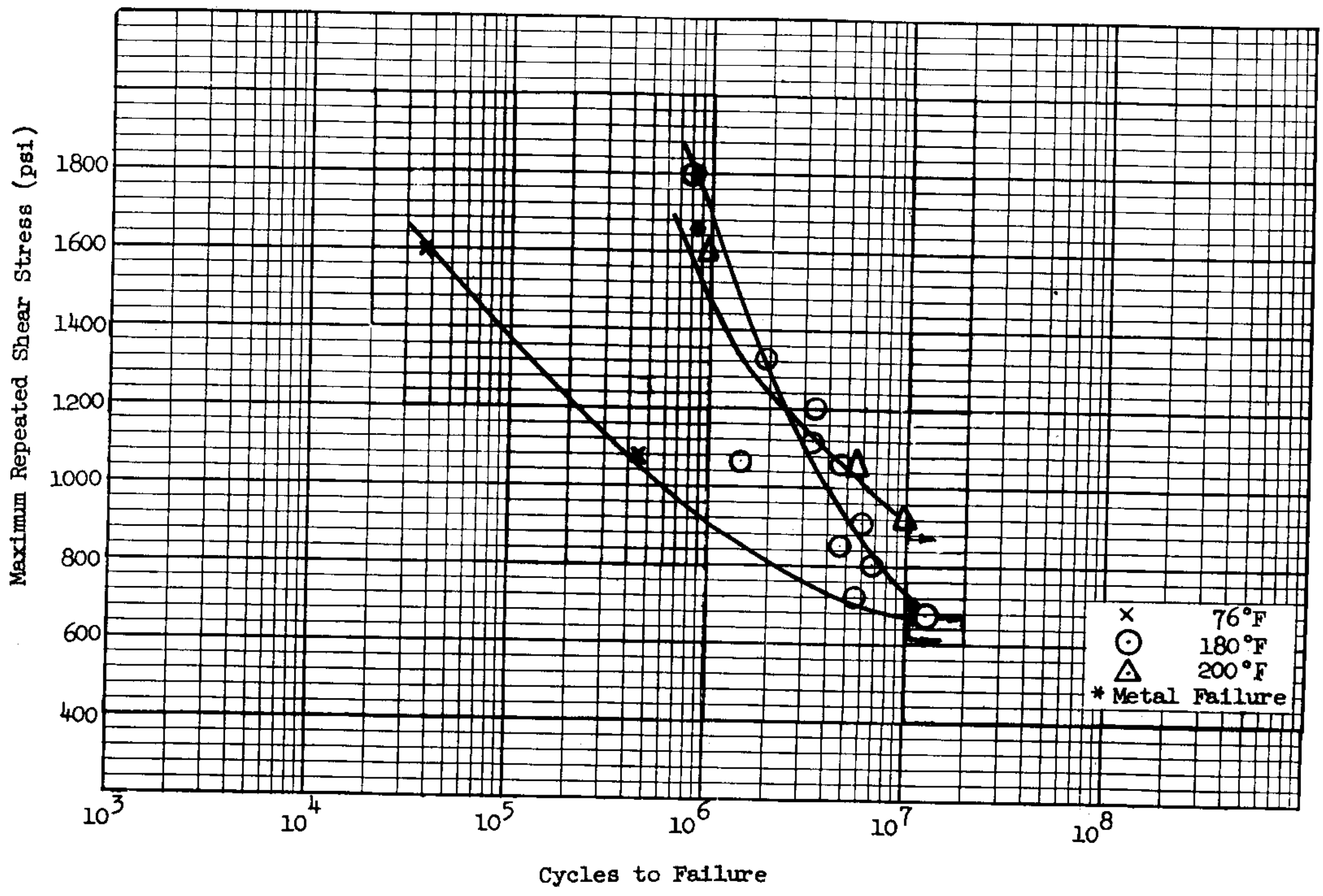


Fig. 54. S-N Fatigue Curves of FM-47 Liquid Adhesive at 76° F, 180° F and 200° F for R = 0.10; 2024-T3 Alclad Aluminum.

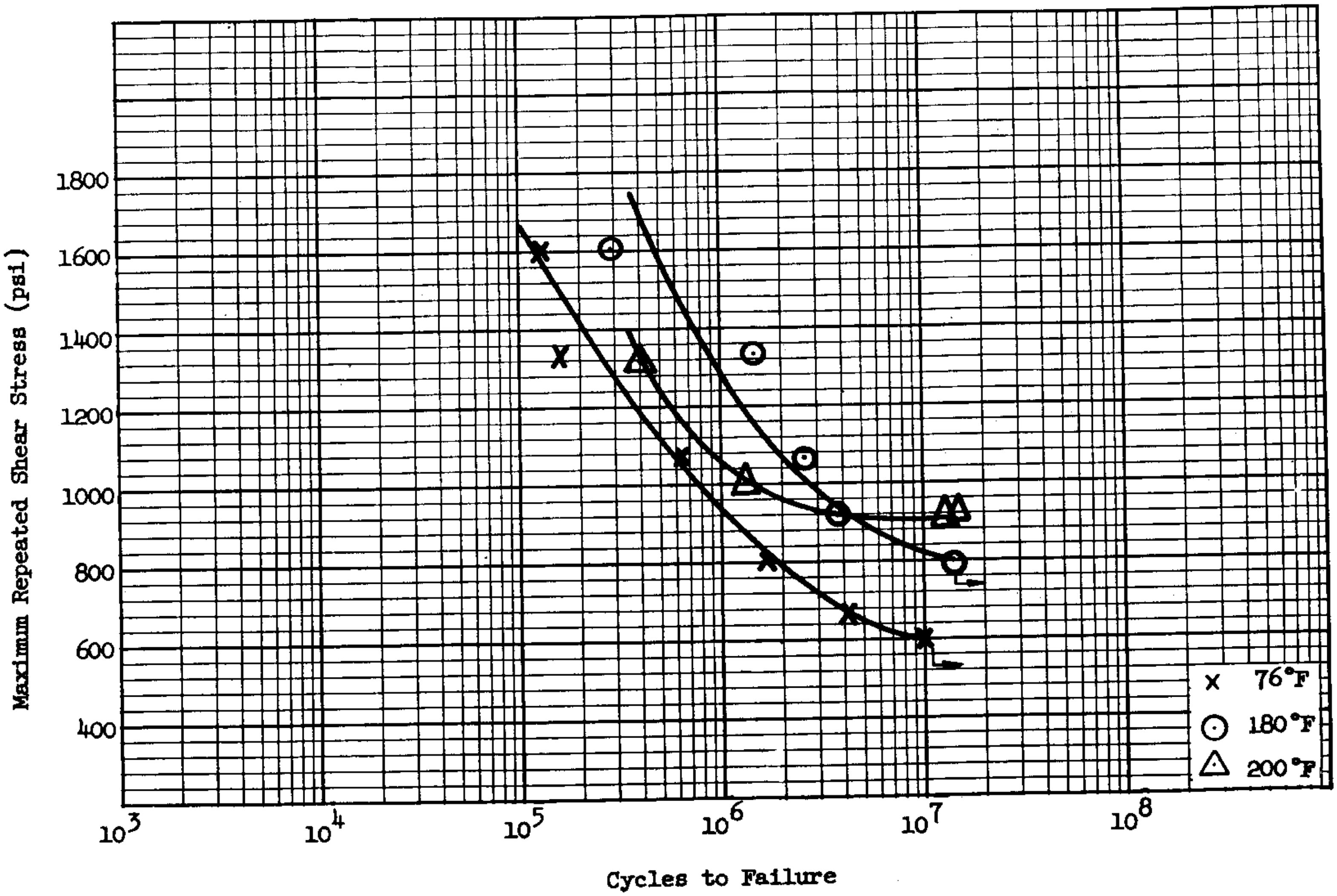


Fig. 55. S-N Fatigue Curves of FM-47 Film Adhesive at 76° F, 180° F and 200° F for R = 0.10; 2024-T3 Alclad Aluminum.

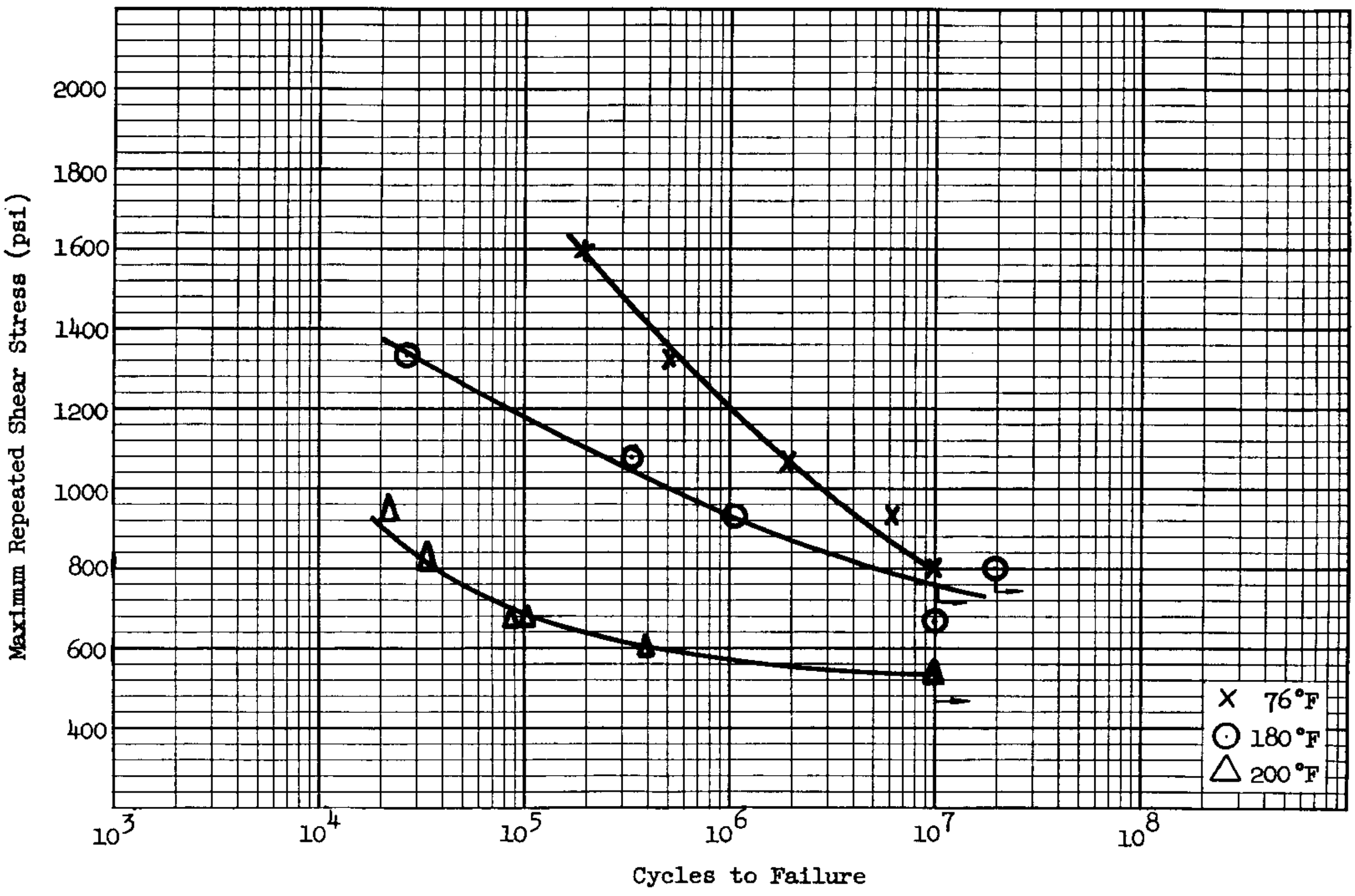


Fig. 56. S-N Fatigue Curves of Redux E Adhesive at 76° F, 180° F and 200° F for R = 0.10; 2024-T3 Alclad Aluminum.

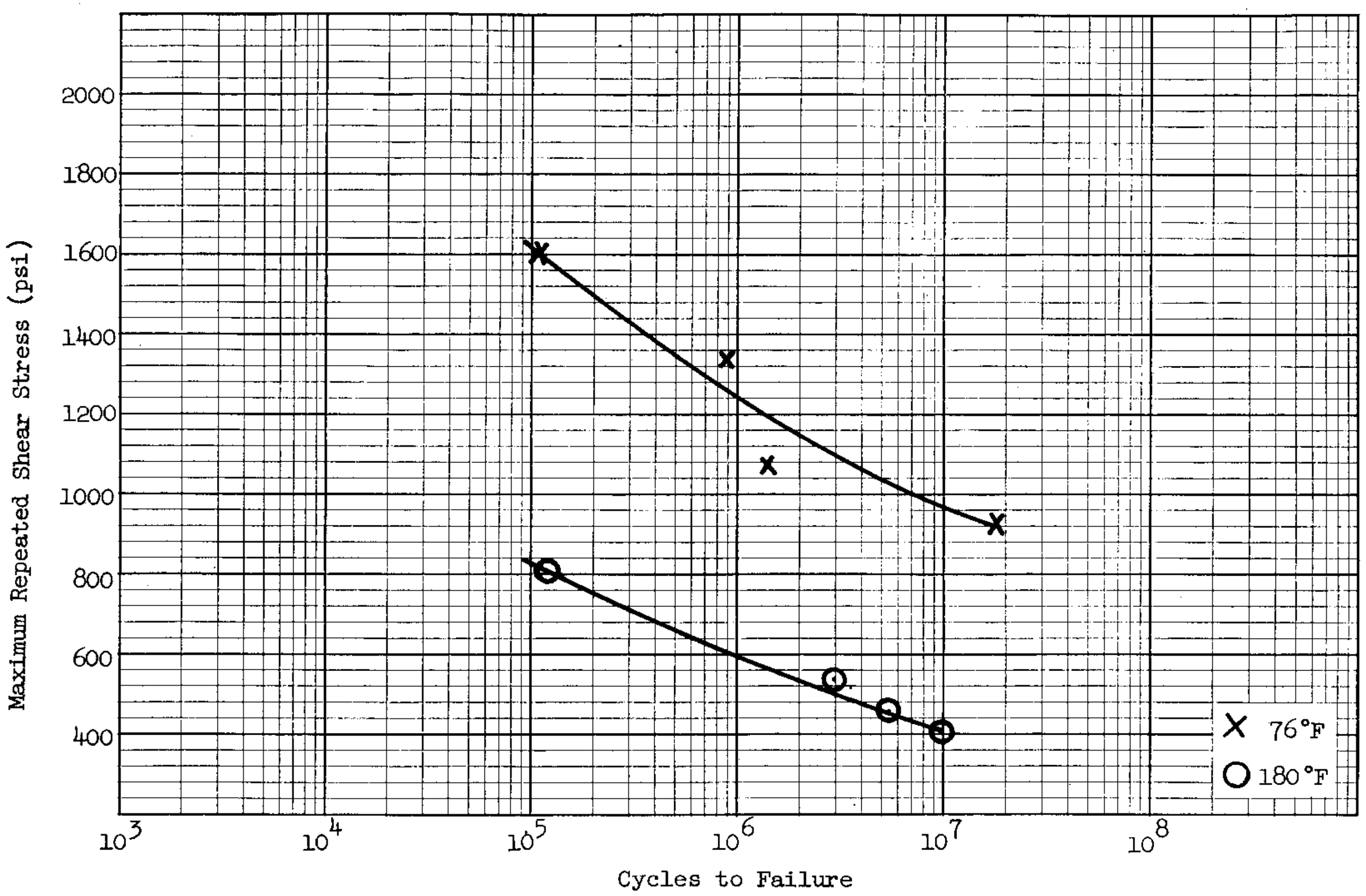


Fig. 57. S-N Fatigue Curves of Cycleweld 55-20 Adhesive at 76° F and 180° F for R = 0.10; 2024-T3 Alclad Aluminum.

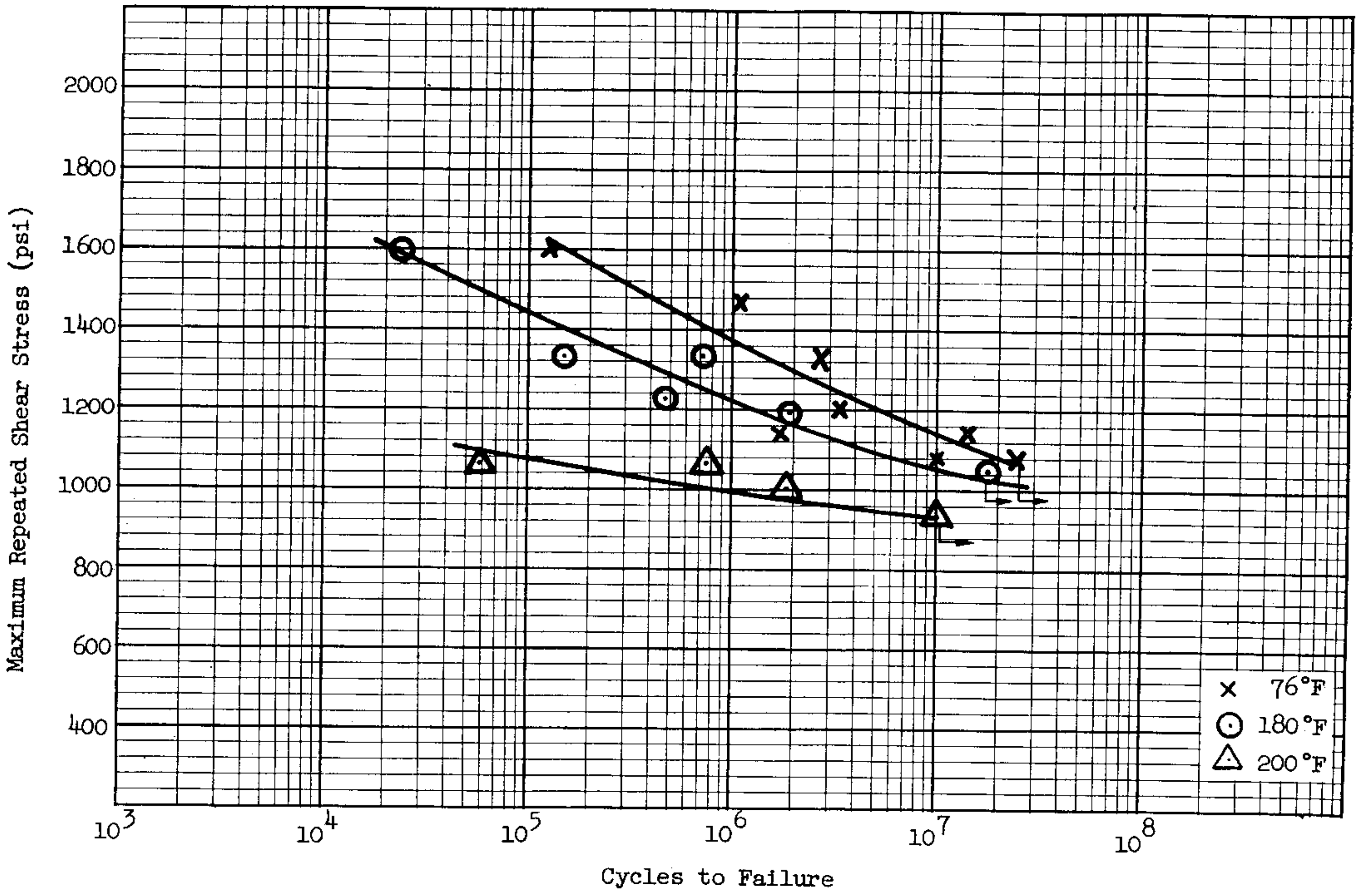


Fig. 58. S-N Fatigue Curves of Epon VIII Adhesive at 76° F, 180° F and 200° F for R = 0.10; 2024-T3 Alclad Aluminum.

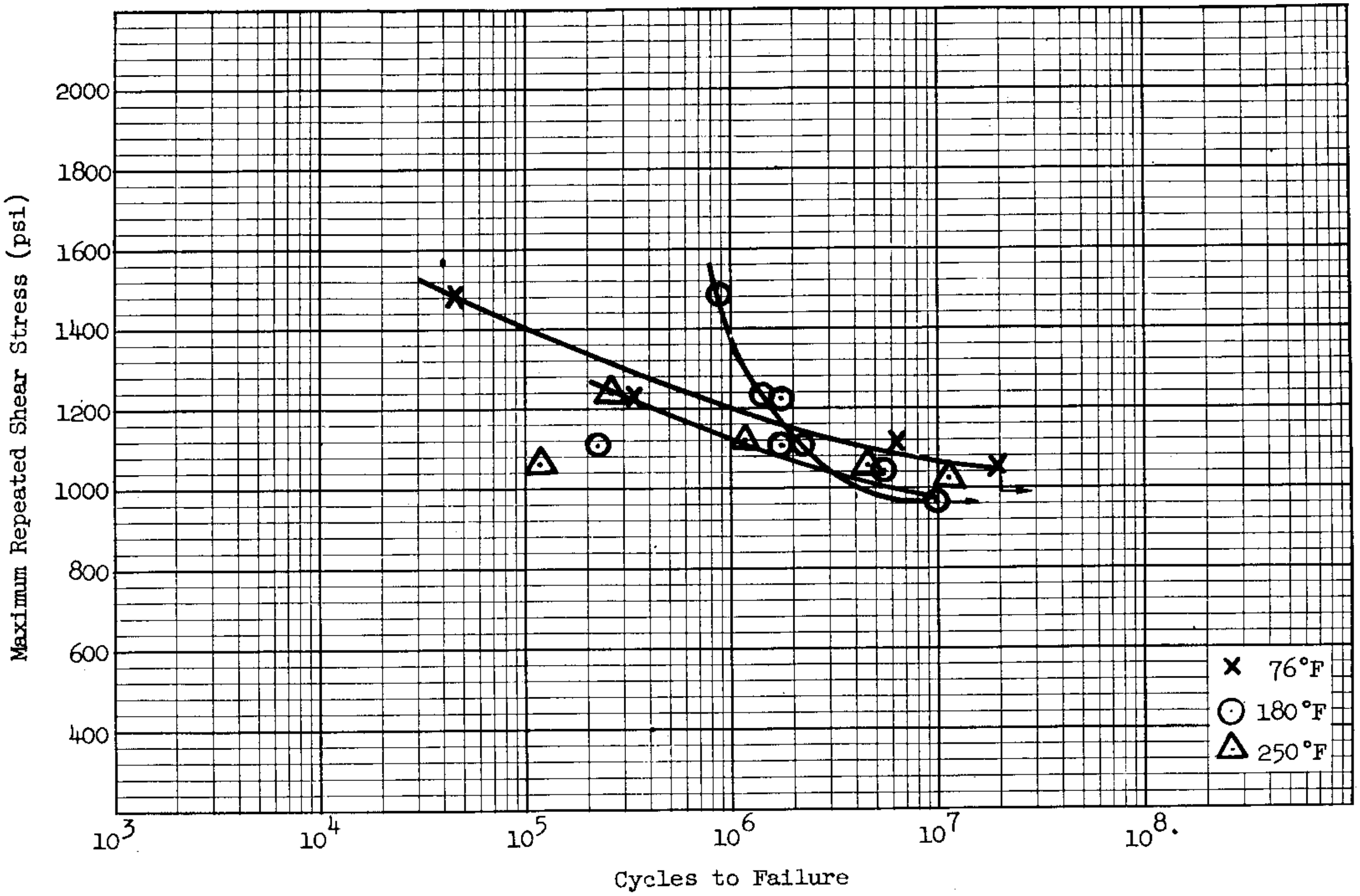


Fig. 59. S-N Fatigue Curves of Shell 422 Adhesive at 76° F, 180° F, and 250° F for R = 0.10; 2024-T3 Alclad Aluminum.

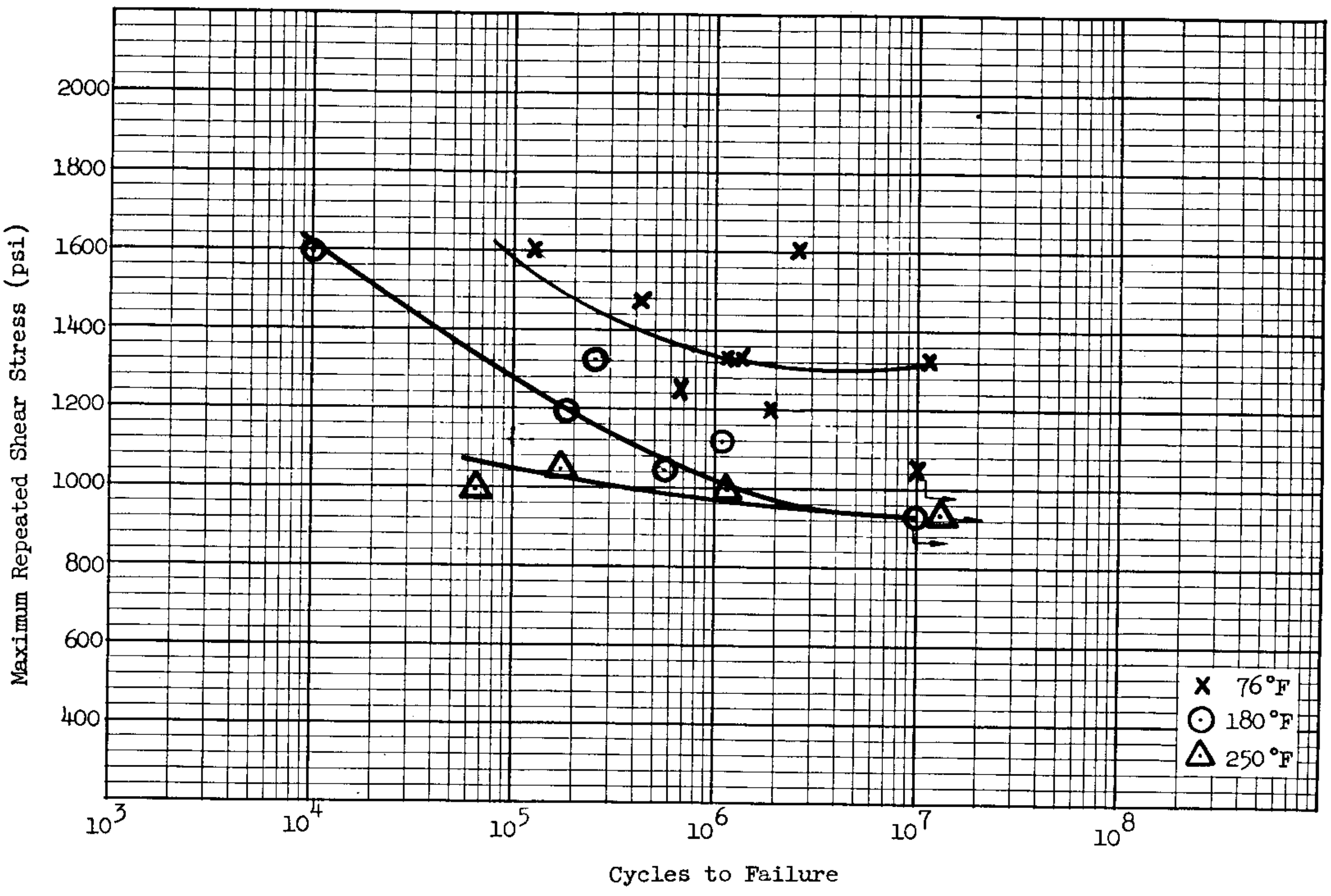


Fig. 60. S-N Fatigue Curves of HT-20 Adhesive at 76° F, 180° F and 250° F for R = 0.10; 2024-T3 Alclad Aluminum.

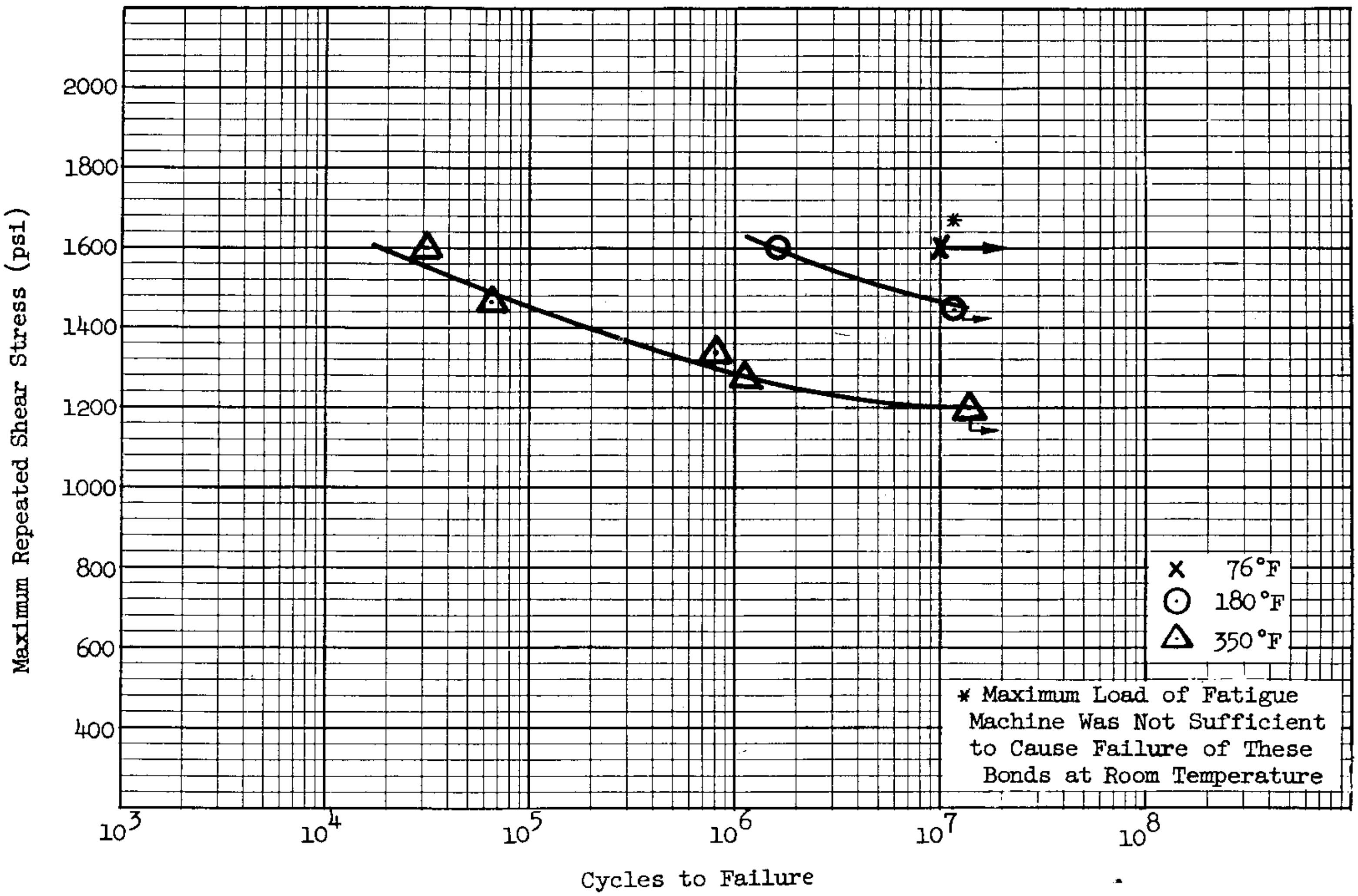


Fig. 61. S-N Fatigue Curves of Shell 422 Adhesive at 76° F, 180° F, and 350° F for R = 0.10; Type 301, 1/2-Hard Stainless Steel.

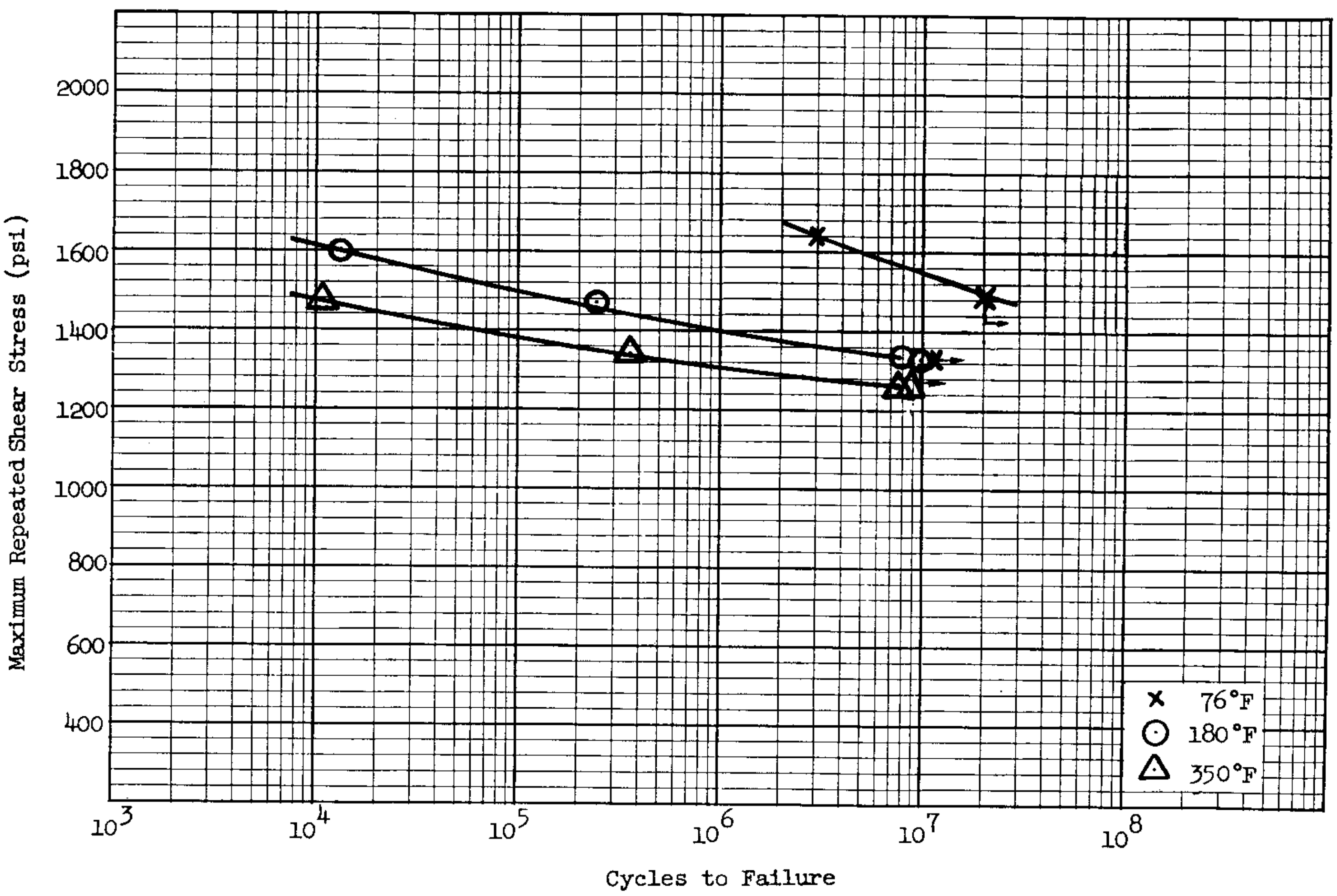


Fig. 62. S-N Fatigue Curves of HT-20 Adhesive at 76° F, 180° F and 350° F for R = 0.10; Type 301, 1/2-Hard Stainless Steel.

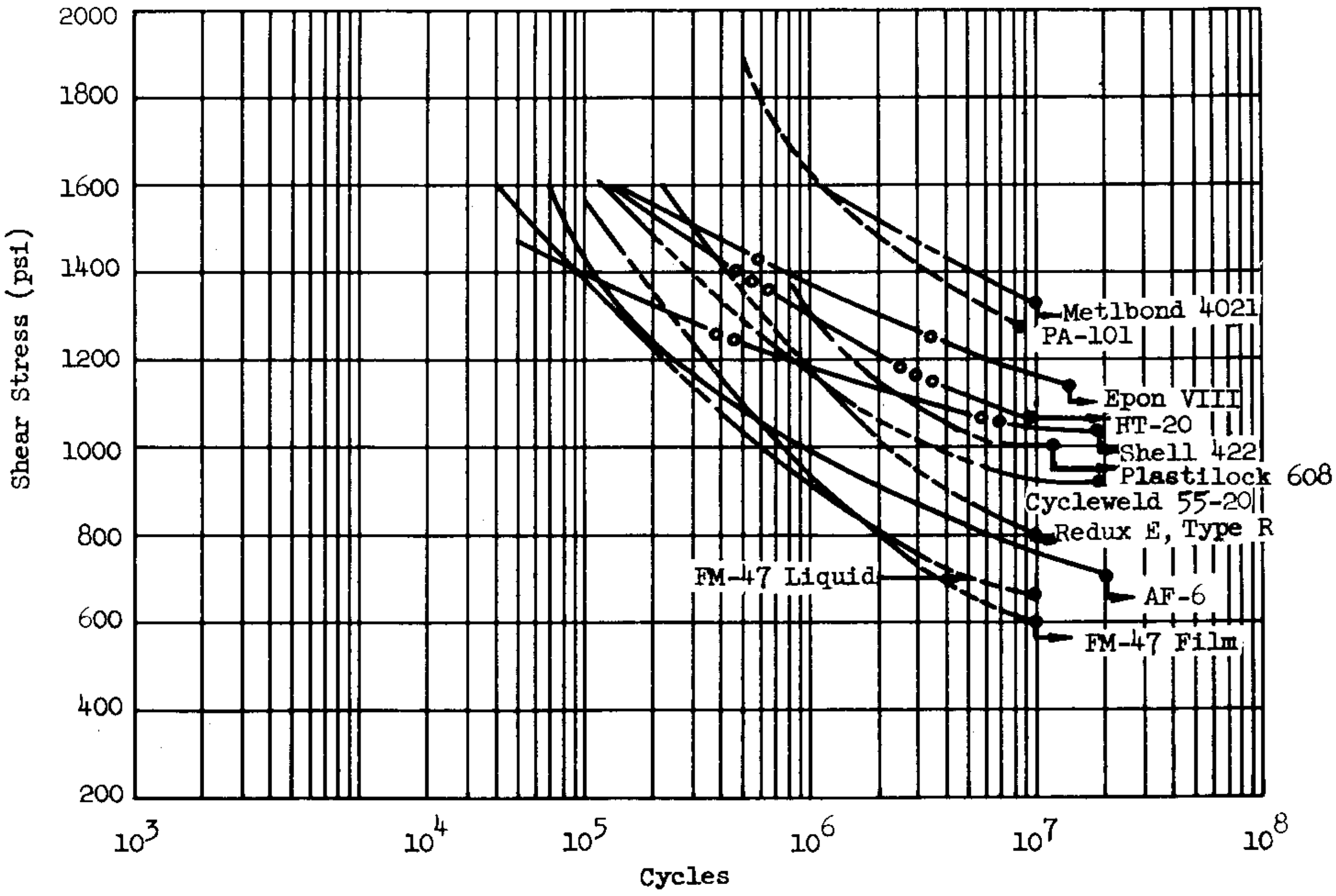


Fig. 63. S-N Fatigue Curves of Adhesives Tested at 76° F on 2024-T3 Alclad Aluminum Joints.

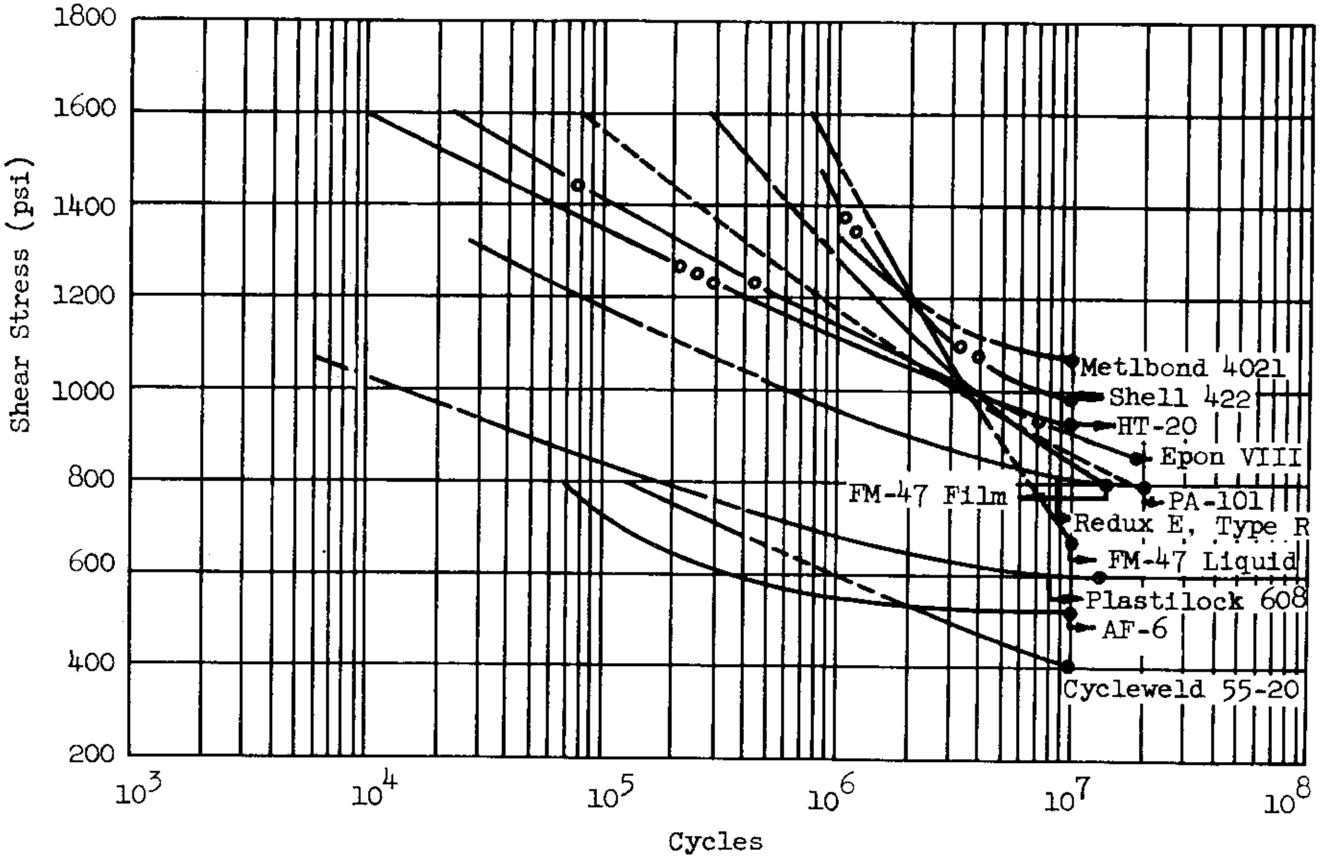


Fig. 64. S-N Fatigue Curves of Adhesives Tested at 180° F on 2024-T3 Alclad Aluminum Joints.

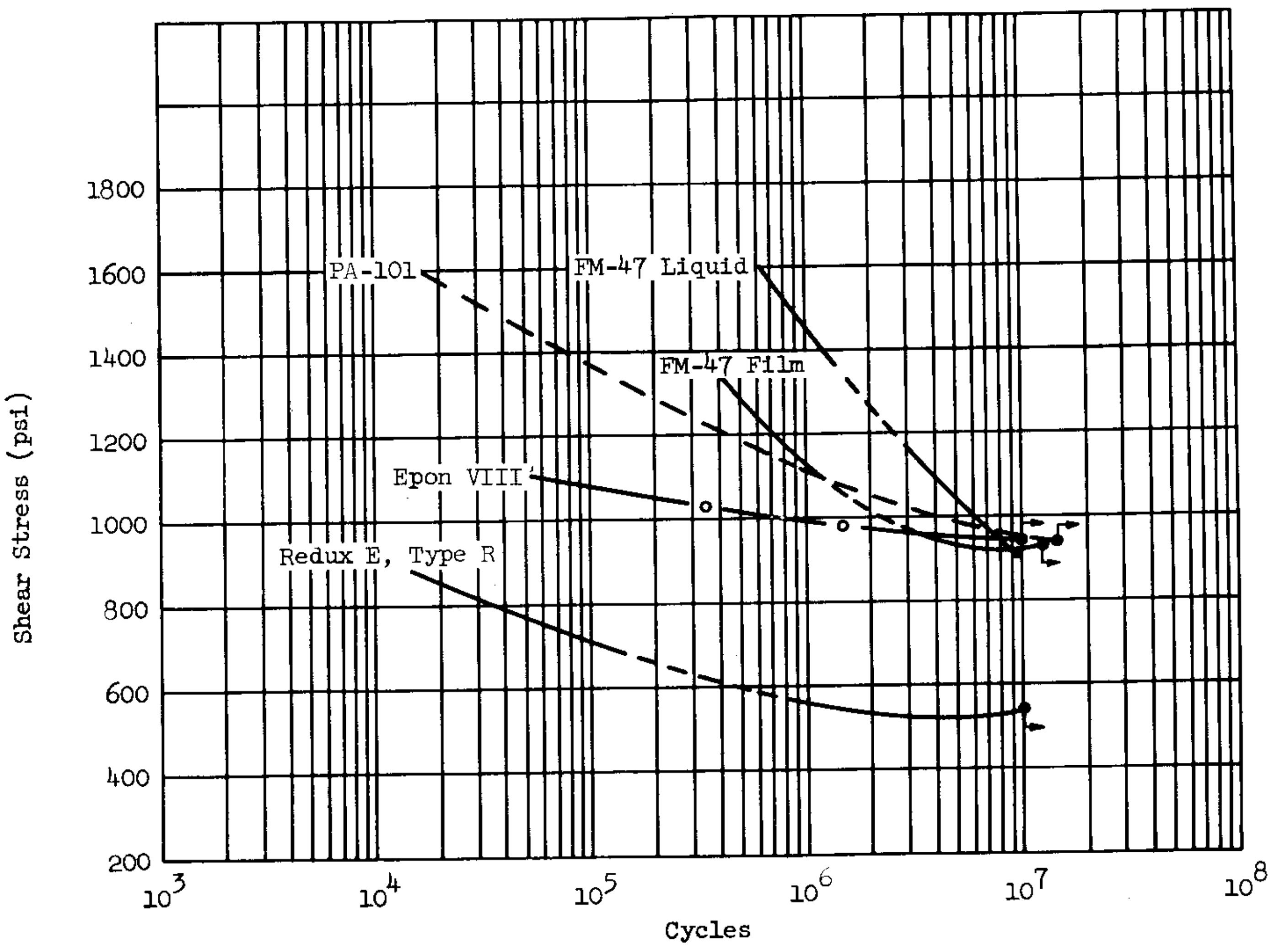


Fig. 65. S-N Fatigue Curves of Adhesives Tested at 200° F on 2024-T3 Alclad Aluminum Joints.

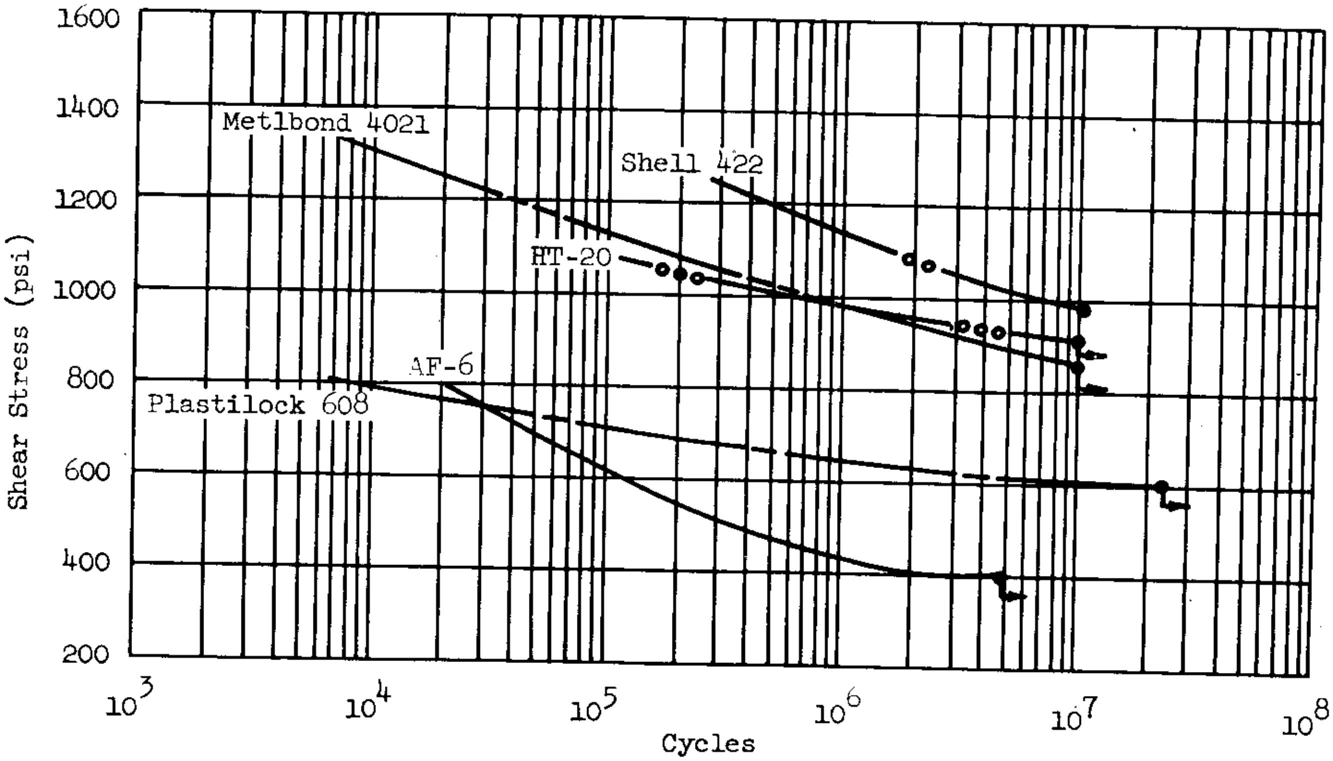


Fig. 66. S-N Fatigue Curves of Adhesives Tested at 250° F on 2024-T3 Alclad Aluminum Joints.

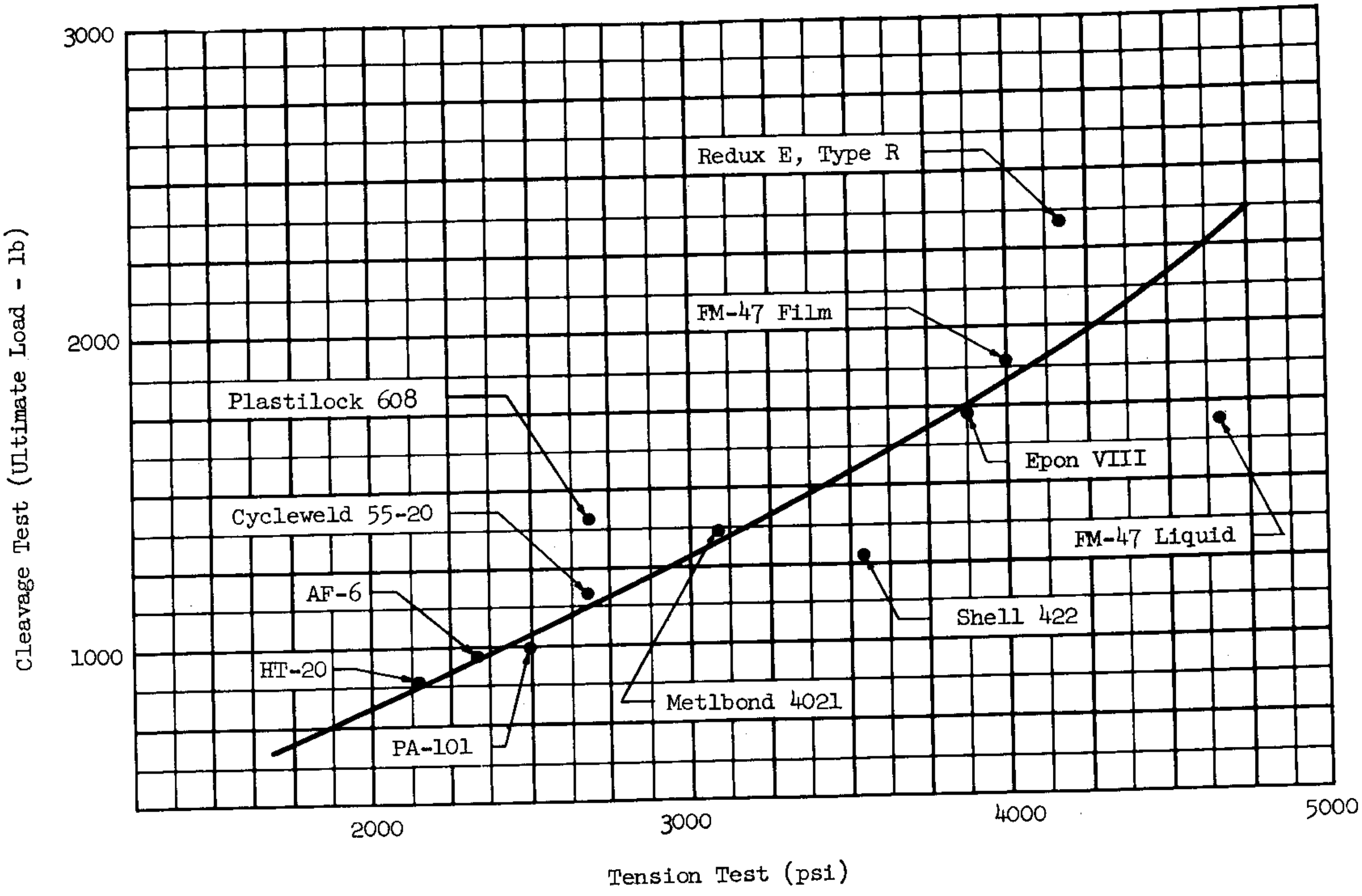


Fig. 67. Relationship of Cleavage Test Data to Tension Data

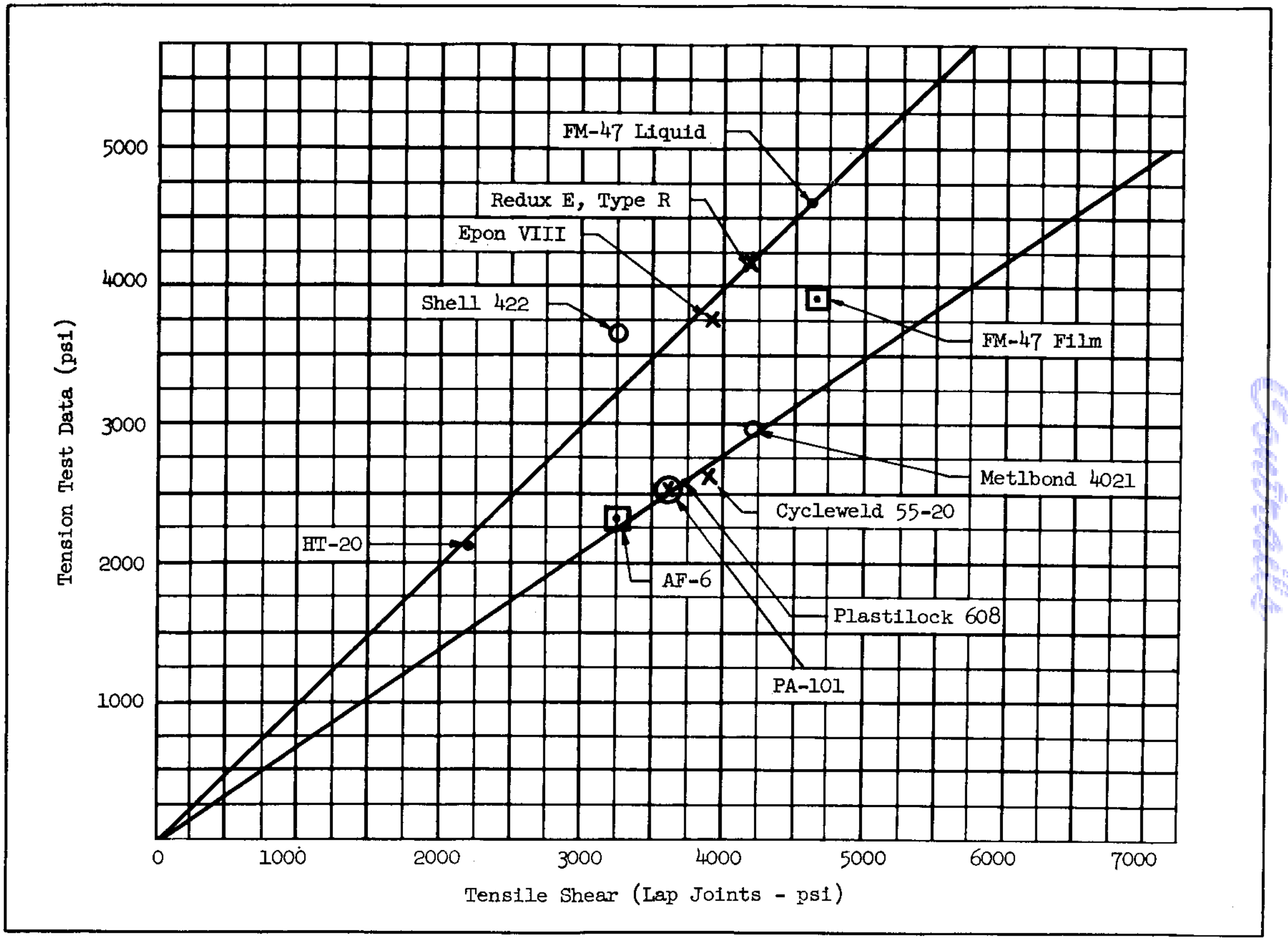


Fig. 68. Relationship of Tensile Shear (Lap Joints) to Tensile Test Data.

V. TABLES

TABLE 1

Bonding Process Details for Preparation of Test Panels

Adhesive	Application of Adhesive	Air Dry Time	Oven Dry	Preheat Time	Curing Temperature	Curing Time	Pressure During Cure
AF-6	AF-6 Film was placed between surfaces to be bonded. No primer was on the metal.	None	None	None	325° F	80 Min	150 psi
PA-101	The prepared adhesive was applied with three brush coats.	16 Hr	1 Hr at 150° F	None	350° F	2 Hr	100 psi
Plastilock 608	The Plastilock 608 was placed between the two clean surfaces to be bonded.	None	None	None	350° F	30 Min	200 psi
Metlbond 4021	A coat of adhesive was brushed on each surface to be bonded. After air drying, film was attached to one of the surfaces.	4 Hr	None	None	350° F	1 Hr	100 psi
FM-47 Liquid	Six spray coats were applied to each surface to be bonded.	16 Hr	1 Hr at 250° F	10 Min	350° F	2 Hr	200 psi

TABLE 1 (CONTINUED)

Adhesive	Application of Adhesive	Air Dry Time	Oven Dry	Preheat Time	Curing Temperature	Curing Time	Pressure During Cure
FM-47 Film	A prime coat of FM-47 Liquid adhesive was sprayed on each surface to be bonded; a piece of FM-47 Film was attached to one of the surfaces	16 Hr	1 Hr at 250°F	10 Min	350°F	2 Hr	200 psi
Redux E - Type R	A thin coat of liquid adhesive was brushed on each bonding surface; powder part of adhesive was sprinkled on top of liquid coat; excess powder was tapped off after a few seconds.	None	20 Min at 180°F	None	295°F	15 Min	100 psi (cooled in press to 190°F before release of pressure
Cycleweld	The Cycleweld 55-20 prepared with thinner was sprayed on each surface to be bonded. This was repeated until a minimum precured (oven dried) film thickness of .004" was produced.	1 Hr	20 Min at 180°F	None	360°F	20 Min	200 psi

TABLE 1 (CONTINUED)

Adhesive	Application of Adhesive	Air Dry Time	Oven Dry	Preheat Time	Curing Temperature	Curing Time	Pressure During Cure
Epon VIII	A thin layer of prepared adhesive was spread on each surface to be bonded	None	None	None	200°F	29 Min	Contact - 2 Psi
Shell 422	The 422 tape was placed between the two clean surfaces to be bonded	None	None	30 Min at 200°F Contact Pressure	330°F	30 Min	25 Psi
HT-20	A prime coat of HT-20 was brushed on surface to be bonded; a piece of HT-20 Film attached to one of the surfaces.	16 Hr	1 Hr at 150°F	1 Min at 350°F	350°F	2 Hr	200 psi

TABLE 2

Correlation of Test Specimen Panels Bonded by the Adhesive Manufacturers and The Glenn L. Martin Company

Tensile Shear Strength at 76° F								
Adhesive	Bonded at Mfg.		Bonded at Mfg.		Bonded at GLM		Bonded at GLM	
	Spec No.	Shear psi	Spec No.	Shear psi	Spec No.	Shear psi	Spec No.	Shear psi
AF-6	S-1133-1	3340	S-1134-1	3230	S-1135-1	3590	S-1136-1	3130
	-2	3200	-2	3280	-2	3620	-2	3330
	-3	3200	-3	3250	-3	3710	-3	3430
	-4	3090	-4	3190	-4	3740	-4	3570
	-5	3180	-5	3100	-5	3680	-5	3640
	-6	3090	-6	3150	-6	3670	-6	3500
	-7	3090	-7	3130	-7	3690	-7	3510
	-8	2920	-8	3150	-8	3540	-8	3620
	-9	3070	-9	3190	-9	3800	-9	3750
	-10	3150	-10	3260	-10	3730	-10	3560
	ave	3133	ave	3193	ave	3677	ave	3504
PA-101	S-1051-1	3450	S-1052-1	4160	S-1127-1	3685	S-1128-1	2820
	-2	3120	-2	3940	-2	3940	-2	3920
	-3	3170	-3	3400	-3	3940	-3	3880
	-4	3490	-4	3740	-4	4070	-4	4200
	-5	3700	-5	3280	-5	4050	-5	3950
	-6	3670	-6	3810	-6	4060	-6	4170
	-7	4000	-7	3460	-7	4190	-7	4280
	-8	3860	-8	3730	-8	3290	-8	3940
	-9	3150	-9	4080	-9	3260	-9	4080
	-10	2860	-10	4040	-10	2510	-10	3315
	ave	3447	ave	3764	ave	3700	ave	3855
Plastilock 608	S-1175-1	3370	S-1177-1	3550	S-1179-1	3220	S-1180-1	3710
	-2	3320	-2	3470	-2	3320	-2	3810
	-3	3090	-3	3280	-3	3400	-3	3725
	-4	3470	-4	3330	-4	3615	-4	3470
	-5	3530	-5	3340	-5	3460	-5	3440
	S-1176-1	3490	S-1178-1	3330	-6	3570	-6	3390
	-2	3450	-2	3380	-7	3700	-7	3405
	-3	3450	-3	3350	-8	3780	-8	3350
	-4	3580	-4	3390	-9	3540	-9	3350
	-5	3500	-5	3420	-10	3530	-10	3420
	ave	3425	ave	3384	ave	3503	ave	3507

TABLE 2 (CONTINUED)

Adhesive	Bonded at Mfg.		Bonded at Mfg.		Bonded at GLM		Bonded at GLM	
	Spec No.	Shear psi	Spec No.	Shear psi	Spec No.	Shear psi	Spec No.	Shear psi
Metlbond 4021	S-1028-1	3780	S-1029-1	3350	S-1111-1	3580	S-1112-1	3690
	-2	4040	-2	3670	-2	3775	-2	3850
	-3	4050	-3	3760	-3	4200	-3	3570
	-4	4070	-4	3750	-4	4250	-4	3990
	-5	4190	-5	3920	-5	3960	-5	4020
	-6	4240	-6	3880	-6	4040	-6	4224
	-7	4160	-7	4020	-7	4520	-7	3940
	-8	4360	-8	4020	-8	4180	-8	4020
	-9	4260	-9	4010	-9	4190	-9	3785
					-10	4420	-10	3900
	ave	4127	ave	3820	ave.	4111	ave	3899
FM-47 Liquid	S-1173-1	4370	S-1174-1	4380	S-1086-1	4625	S-1087-1	4270
	-2	4460	-2	4380	-2	4490	-2	4270
	-3	4240	-3	4190	-3	4440	-3	4340
	-4	4220	-4	3980	-4	4400	-4	4520
	-5	4260	-5	3930	-5	4400	-5	4420
	-6	4140	-6	3960	-6	4390	-6	4400
	-7	4230	-7	4040	-7	4500	-7	4270
	-8	4210	-8	3990	-8	4520	-8	4290
	-9	4340	-9	4130	-9	4450	-9	4420
	-10	4110	-10	3690	-10	4574	-10	4420
	ave	4258	ave	4067	ave	4480	ave	4360
FM-47 Film	S-1171-1	4710	S-1172-1	4740	S-1153-1	4410	S-1154-1	4470
	-2	4610	-2	4630	-2	4300	-2	4490
	-3	4470	-3	4590	-3	4320	-3	4550
	-4	4430	-4	4440	-4	4440	-4	4560
	-5	4440	-5	4360	-5	4430	-5	4560
	-6	4400	-6	4340	-6	4530	-6	4440
	-7	4400	-7	4520	-7	4500	-7	4480
	-8	4420	-8	4370	-8	4530	-8	4200
	-9	4320	-9	3850	-9	4350	-9	4150
	-10	4180	-10	3480	-10	4580	-10	3400
	ave	4438	ave	4332	ave	4439	ave	4330

TABLE 2 (CONTINUED)

Adhesive	Bonded at Mfg.		Bonded at Mfg.		Bonded at GLM		Bonded at GLM	
	Spec No.	Shear psi	Spec No.	Shear psi	Spec No.	Shear psi	Spec No.	Shear psi
Redux E - Type R	S-1042-1	2690	S-1043-1	3580	S-1108-1	3860	S-1109-1	3835
	-2	2720	-2	4010	-2	3900	-2	3550
	-3	2280	-3	3710	-3	3970	-3	3605
	-4	3220	-4	3830	-4	3940	-4	3615
	-5	3570	-5	2800	-5	3735	-5	3500
	-6	3830	-6	2900	-6	3785	-6	3695
	-7	3790	-7	2880	-7	4100	-7	3745
	-8	4130	-8	3840	-8	4090	-8	3980
	-9	2840	-9	3810	-9	4030	-9	3705
	-10	3470	-10	3570	-10	3990	-10	3725
	ave	3254	ave	3493	ave	3940	ave	3695
Cycleweld 55-20	S-1131-1	3320	S-1132-1	3446	S-1141-1	3500	S-1142-1	3570
	-2	3244	-2	3262	-2	3700	-2	3740
	-3	3036	-3	3306	-3	3950	-3	4030
	-4	3042	-4	3369	-4	4130	-4	4220
	-5	3236	-5	3557	-5	4000	-5	4080
	-6	3273	-6	3763	-6	3950	-6	4120
	-7	3314	-7	3750	-7	3940	-7	4010
	-8	3278	-8	3533	-8	3740	-8	4040
	-9	3150	-9	3517	-9	3250	-9	4040
	-10	3171	-10	3504	-10	2730	-10	4070
	ave	3206	ave	3500	ave	3690	ave	3992
Epon VIII	S-1060-1	3570	S-1061-1	3650	S-1030-1	3450	S-1031-1	3300
	-2	4000	-2	3480	-2	3350	-2	3880
	-3	3520	-3	3900	-3	3390	-3	3660
	-4	3630	-4	3610	-4	3410	-4	3390
	-5	3380	-5	3300	-5	3470	-5	3460
	-6	3630	-6	3420	-6	3480	-6	3640
	-7	3650	-7	3460	-7	3930	-7	3540
	-8	3510	-8	3540	-8	3840	-8	3790
	-9	3760	-9	3530	-9	3600	-9	3400
	-10	3510	-10	2970	-10	3160	-10	3740
	ave	3616	ave	3486	ave	3508	ave	3580

TABLE 2 (CONTINUED)

Adhesive	Bonded at Mfg.		Bonded at Mfg.		Bonded at GLM		Bonded at GLM	
	Spec No.	Shear psi	Spec No.	Shear psi	Spec No.	Shear psi	Spec No.	Shear psi
Shell 422	S-1062-1	2250	S-1063-1	2600	S-1070-1	2885	S-1071-1	3095
	-2	2780	-2	2500	-2	2950	-2	3125
	-3	2750	-3	2460	-3	2810	-3	3105
	-4	2800	-4	2510	-4	2865	-4	3075
	-5	2790	-5	2510	-5	2925	-5	3105
	-6	2620	-6	2590	-6	3030	-6	3000
	-7	2720	-7	2550	-7	2880	-7	2940
	-8	2720	-8	2580	-8	2900	-8	2960
	-9	2820	-9	2850	-9	3050	-9	2905
	-10	2760	-10	2860	-10	2175	-10	2875
	ave	2701	ave	2601	ave	2847	ave	3018
HT-20	S-1214-1	2140	S-1215-1	1920	S-1242-1	2000	S-1243-1	2050
	-2	2000	-2	1970	-2	2160	-2	2135
	-3	1835	-3	1915	-3	2190	-3	2185
	-4	1800	-4	2065	-4	2160	-4	2105
	-5	1920	-5	1945	-5	2150	-5	1940
	-6	1770	-6	1700	-6	2160	-6	2200
	-7	1970	-7	1790	-7	2080	-7	2210
	-8	1910	-8	1950	-8	2120	-8	2160
	-9	2080	-9	1830	-9	2060	-9	2040
	-10	1995	-10	1875	-10	2150	-10	2030
	ave	1942	ave	1896	ave	2123	ave	2105

TABLE 3

Tensile Shear Test Data - Tested at 76° to 800°F
After Stabilization with No Aging at Test Temperature
.064-inch 2024-T3 Alclad Aluminum, 1/2-inch Overlap

		Shear Stress in Adhesive (psi)						
Adhesive		76°F	180°F	250°F	350°F	500°F	650°F	800°F
AF-6		2760	1050	830	590			
		3245	1070	1010	620			
		3290	1180	1090	830			
		3550	1130	1130	890			
		3350	1180	1090	770			
	ave	3240	1122	1030	740			
PA-101		3520	2530	1200	875			
		3900	2730	1370	880			
		4000	2580	1430	950			
		4280	2340	1430	880			
		2410	2560	1410	870			
	ave	3606	2548	1368	891			
Plastilock 608		3705	1580	1150	810			
		3630	1570	1190	880			
		3450	1680	1160	840			
		3775	1860	1270	850			
		3975	1820	1280	820			
	ave	3705	1700	1210	840			
Metlbond 4021		4160	2300	1800	1090			
		4200	2440	1810	1040			
		3985	2430	1770	970			
		4250	2340	1700	930			
		4060	2230	1570	1050			
	ave	4130	2340	1730	1016			
FM-47 Liquid		4360	5160	3210	390			
		4860	4820	3010	400			
		4960	4830	3870	690			
		4320	4530	3810	370			
		4130	4300	3970	380			
	ave	4526	4730	3574	446			
FM-47 Film		4330	*	3090	540			
		4520	4930	2890	720			
		4660	4920	2910	500			
		4750	4920	3000	500			
		4550	4590	2810	370			
	ave	4560	4840	2940	526			

*Metal at drill hole failed.

TABLE 3 (CONTINUED)

		Shear Stress in Adhesive (psi)						
Adhesive		76°F	180°F	250°F	350°F	500°F	650°F	800°F
Redux E, Type R		3985	1280	480	230			
		4230	1105	435	216			
		4270	1480	490	235			
		3950	1100	565	290			
		3955	1140	435	275			
	ave	4080	1220	480	250			
Cycleweld 55-20		3770	1415	1080	440			
		4000	1950	650	300			
		3950	1500	455	260			
		3860	1100	735	340			
		3530	800	870	380			
	ave	3820	1353	758	344			
Epon VIII		3630	3850	1400	380			
		3910	3590	1370	710			
		3960	4060	840	480			
		3530	3950	860	400			
		3540	3930	1010	390			
	ave	3712	3876	1096	472			
Shell 422		3320	3040	2580	2070	1530	1330	590
		3232	3000	2720	2200	1665	*	420
		3240	3070	2780	2190	1840	1480	360
		3248	3080	2500	2120	1890	1490	530
		3160	3040	2630	2190	1745	1240	540
	ave	3240	3046	2642	2154	1734	1384	488
HT-20		2130	2090	2610	2440	2020	1110	340
		2140	2070	2610	2380	1880	1130	390
		2240	1980	2550	2270	1600	1100	640
		2060	2460	2610	2280	1680	1150	440
		2260	2360	2770	2710	1590	1110	430
	ave	2165	2190	2630	2416	1754	1118	448

*Metal at drill hole failed.

TABLE 4

Tensile Shear Test Data - Tested at -100°F to 800°F After 1/2-Hour Exposure at Test Temperature .064-Inch 2024-T3 Alclad Aluminum, 1/2-Inch Overlap

		Shear Stress in Adhesive (psi)							
Adhesive		-100°F	-67°F	180°F	250°F	350°F	500°F	650°F	800°F
AF-6		2050	*	1070	740	740			
		3615	*	1330	730	720			
		2640	4310	1360	760	800			
		2240	4360	1420	670	730			
		1950	4270	1150	700	700			
	ave	2499	4315	1265	720	738			
PA-101		2100	1900	2290	1580	920			
		1250	1450	2250	1610	860			
		1650	1660	2250	1730	1020			
		1410	2250	2225	1670	970			
		1120	1800	2250	1230	800			
	ave	1506	1812	2253	1565	914			
Plastilock 608		1870	1980	1600	1230	970			
		1900	2470	1510	1220	950			
		2375	2400	1370	1190	910			
		2330	2860	1560	1120	No Failure; Top Grip Off			
		2510	2990	1595	1080	960			
	ave	2197	2540	1525	1168	948			
Metlbond 4021		1670	3610	1840	1340	480			
		1830	2260	2190	1200	430			
		2080	3230	2310	980	350			
		2650	2930	2220	1120	460			
		1890	2290	2210	1120	490			
	ave	2024	2864	2155	1152	440			
FM-47 Liquid		3300	3280	5170	1910	100			
		3150	3690	4990	2130	150			
		3080	3040	5230	1940	160			
		3130	3510	5200	1790	70			
		2860	3270	5122	1700	40			
	ave	3104	3358	5142	1894	104			
FM-47 Film		2990	3030	3775	1700	200			
		3090	3080	4430	1710	180			
		3220	3040	4380	1560	150			
		3160	3080	4560	1720	180			
		2930	3350	3960	1620	150			
	ave	3070	3116	4221	1662	172			

* Tested at -100°F by mistake

TABLE 4 (CONTINUED)

		Shear Stress in Adhesive (psi)							
Adhesive		-100°F	-67°F	180°F	250°F	350°F	500°F	650°F	800°F
Redux E - Type R		3100	3290	1375	170	100			
		2905	3430	1520	450	170			
		3300	3420	1835	330	210			
		2930	3220	1850	360	310			
		2630	3330	1470	420	140			
	ave	2973	3338	1610	346	186			
Cycleweld 55-20		3310	2480	1320	280	130			
		2630	3640	1350	540	210			
		3000	3800	1260	640	230			
		2960	3750	1310	500	230			
		2880	3590	1210	390	240			
	ave	2956	3452	1290	470	208			
Epon VIII		2680	2740	3360		240			
		2690	2680	3880	950	240			
		2820	2950	3970	780	300			
		2870	2820	3820	820	300			
		2840	2840	3650	800	280			
	ave	2780	2802	3736	837	272			
Shell 422		3010	2100	2975	2600	2260	1150	990	600
		3160	3000	3040	2580	2280	680	900	670
		3180	2995	3010	2520	2210	850	860	530
		3050	2840	2915	2510	2060	1400	790	680*
		2650	2890	2860	2420	2000	1700	740	580*
	ave	3010	2765	2960	2526	2162	1156	856	612
HT-20		2660	2400	2460	2510	1910	1680	950	440
		2280	2520	2290	2720	1880	1570	930	510
		2410	2090	2360	2600	1840	1440	960	470
		2170	2180	2040	2780	1730	1470	990	450
		2470	2360	2250	2490	2040	1550	1010	500
	ave	2398	2310	2280	2620	1880	1542	968	474

* Metal Failure

TABLE 5

Tensile Shear Test Data - Tested at 500°F, 650°F and 800°F After 18-Hour Exposure at Test Temperature .064-Inch 2024-T3 Alclad Aluminum, 1/2-Inch Overlap

Shear Stress in Adhesive (psi)			
Adhesive	500°F	650°F	800°F
Shell 422	1550	Specimens Delaminated During Exposure	
	1600		
	1760		
	1710		
	1750		
	ave 1674		
HT-20	1300		
	1240		
	1190		
	1260		
	1300		
	ave 1258		

TABLE 6

Tensile Shear Test Data - Tested at 350°F to 650°F After 192-Hour Exposure at Test Temperature .064-Inch 2024-T3 Alclad Aluminum, 1/2-Inch Overlap

Shear Stress in Adhesive (psi)			
Adhesive	350°F	500°F	650°F
AF-6	1910 1980 1930 2040 1980 ave 1968		
PA-101	1130 1410 1540 1520 1220 ave 1364		
Plastilock 608	1820 1820 1860 1900 1860 ave 1852		
Metlbond 4021	1350 1270 1230 1270 1360 ave 1296		
FM-47 Liquid	840 820 900 780 850 ave 838		
FM-47 Film	875 1080 1290 1225 1010 ave 1096		

TABLE 6 (CONTINUED)

Shear Stress in Adhesive (psi)			
Adhesive	350°F	500°F	650°F
Redux E, Type R	380 450 480 540 490 ave 468		
Cycleweld 55-20	340 380 425 380 300 ave 365		
Epon VIII	530 480 470 480 460 ave 484		
Shell 422	2330 2250 2270 2160 2050 ave 2212	610 550 550 540 640 578	Specimens Delaminated During Exposure
HT-20	2000 1870 1630 1660 1860 ave 1804	Specimens Delaminated During Exposure	

TABLE 7

Tensile Shear Test Data - Tested at 180°F to 500°F After 1000-Hour Exposure at Test Temperature .064-Inch 2024-T3 Alclad Aluminum, 1/2-Inch Overlap

Adhesive		Shear Stress in Adhesive (psi) 180°F	250°F	350°F	500°F
AF-6		2340	2010	1920	
		2390	2080	1870	
		2490	2130	1740	
		2690	2150	1760	
		2790	2180	1800	
	ave	2540	2110	1818	
PA-101		2240	2450	1190	
		2580	2370	1390	
		2780	2490	1310	
		2530	2340	1410	
		2225	2360	1310	
	ave	2470	2402	1322	
Plastilock 608		2480	2120	1550	
		2560	1980	1630	
		2430	1940	1630	
		2680	1970	1580	
		2550	2100	1520	
	ave	2540	2022	1582	
Metlbond 4021		2530	2100	1320	
		2670	2110	1080	
		2450	2160	1020	
		2730	2240	1040	
		2420	2170	1150	
	ave	2560	2156	1122	
FM-47 Liquid		5230	3360	1200	
		5520	4280	610	
		Failed in Attachment Hole	3660	1220	
		5710	3530	1190	
		5640	3800	840	
	ave	5525	3726	1012	
FM-47 Film		4790	2610	1390	
		5360	2880	1380	
		5450	3010	1390	
		5580	3110	1360	
		5360	2890	1320	
	ave	5308	2900	1368	

TABLE 7 (CONTINUED)

		Shear Stress in Adhesive (psi)			
Adhesive		180°F	250°F	350°F	500°F
Redux E, Type R		3940	2010	490	
		3820	2180	650	
		4070	2340	790	
		3880	2170	670	
		3420	2360	660	
	ave	3825	2212	652	
Cycleweld 55-20		1820	1110	320	
		2710	1550	500	
		2220	1550	510	
		2310	1400	630	
		2110	780	380	
	ave	2285	1278	468	
Epon VIII		3710	2100	500	
		3770	2010	490	
		3610	2320	570	
		3600	2210	570	
		2875	2430	570	
	ave	3513	2214	540	
Shell 422		3220	2670	1400	Specimens Delaminated During Exposure (312 Hours)
		3160	2690	1340	
		3210	2780	1200	
		3080	2840	1550	
		2930	2660	1460	
	ave	3120	2728	1390	
HT-20		2430	2330	2080	Specimens Delaminated During Exposure (312 Hours)
		2370	2410	2050	
		2210	2550	2060	
		2280	2320	1980	
		2320	2570	1950	
	ave	2322	2436	2024	

TABLE 8

Average Tensile Shear Test Data on 2024-T3 Alclad Aluminum Bonded Joints After Exposure at 180°, 250° and 350°F*

Adhesive	Average Tensile Shear Strength (psi)									
	Tested at 180°F after Exposure at 180°F for:			Tested at 250°F after Exposure at 250°F for:			Tested at 350°F after Exposure at 350°F for:			
	0-Hr	1/2-Hr	1000-Hr	0-Hr	1/2-Hr	1000-Hr	0-Hr	1/2-Hr	192-Hr	1000-Hr
AF-6	1122	1265	2540	1030	720	2110	740	738	1968	1818
PA-101	2550	2255	2470	1368	1565	2402	891	914	1364	1322
Plastilock 608	1700	1525	2540	1210	1168	2022	840	948	1852	1582
Metlbond 4021	2350	2155	2560	1730	1152	2156	1016	442	1296	1122
FM-47 Liquid	4730	5152	5525	3575	1894	3726	446	104	838	1012
FM-47 Film	4840	4220	5308	2940	1662	2900	526	172	1096	1368
Redux E, Type R	1220	1610	3825	480	345	2212	249	186	468	652
Cycleweld 55-20	1355	1290	2285	760	470	1278	344	208	365	468
Epon VIII	3875	3735	3513	1095	835	2214	472	272	484	540
Shell 422	3045	2960	3120	2640	2526	2728	2154	2162	2212	1390
HT-20	2190	2280	2322	2630	2620	2436	2416	1880	1804	2024

* This table is a summary of data from preceding tables

TABLE 9

Per Cent Strength Retention After Exposures of up to 1000-Hours at Various Temperatures .064-Inch 2024-T3 Alclad Aluminum, 1/2-Inch Overlap

		Per Cent of Room Temperature Tensile Shear Strength									
Adhesive	Room Temp. Shear Strength (psi)	180°F 0-Hr Soak	180°F 1/2-Hr Soak	180°F 1000-Hr Soak	250°F 0-Hr Soak	250°F 1/2-Hr Soak	250°F 1000-Hr Soak	350°F 0-Hr Soak	350°F 1/2-Hr Soak	350°F 192-Hr Soak	350°F 1000-Hr Soak
AF-6	3239	34.6	39.0	78.4	31.8	22.2	65.2	22.8	22.8	60.8	56.0
PA-101	3606	70.7	62.4	68.5	37.9	43.3	66.7	24.7	25.3	37.8	36.6
Plastilock 608	3707	45.9	41.2	68.5	32.6	31.5	54.5	22.6	25.6	50.0	42.8
Metlbond 4021	4131	63.4	52.0	62.0	41.9	27.9	52.0	24.6	10.7	31.5	27.1
FM-47 Liquid	4526	104.5	114.0	122.0	79.0	41.8	82.5	9.85	2.30	18.5	22.4
FM-47 Film	4560	106.0	92.5	116.0	64.5	36.5	63.6	11.5	3.77	23.9	30.0
Redux E, Type R	4080	30.0	39.5	93.7	11.8	8.45	45.8	6.1	4.55	11.45	16.0
Cycleweld 55-20	3820	35.4	33.8	59.7	19.8	12.3	33.4	9.0	5.45	9.55	12.5
Epon VIII	3712	104.5	100.5	94.5	29.6	22.4	59.6	12.7	7.33	13.0	14.5
Shell 422	3240	94.0	91.5	96.3	81.5	78.0	81.0	66.5	66.8	68.2	43.0
HT-20	2166	101.0	105.0	107	121	121	112	111	86.7	83.3	93.5

TABLE 10

Tensile Shear Test Data - Tested at 76°F to 800°F After Stabilization with No Aging at Test Temperature .063-Inch Type 301, 1/2-Hard Stainless Steel, 2D Finish, 1/2-Inch Overlap

Adhesive	Shear Stress in Adhesive (psi)						
	76°F	180°F	250°F	350°F	500°F	650°F	800°F
AF-6	1990			460	250		
	2750			570	250		
	2750			600	260		
	2750			580	170		
	2640			410	70		
	ave 2570			524	200		
PA-101	2530			150	40		
	1295			175	50		
	1340			190	80		
	1980			190	50		
	2180			300	40		
	ave 1865			201	52		
Plastilock 608	3255			810	200		
	2885			1040	230		
	3040			820	200		
	3420			780	270		
	3080			720	260		
	ave 3130			834	232		
Metlbond 4021	2120			310	50		
	1690			370	40		
	2590			400	70		
	2700			380	60		
	2390			240	50		
	ave 2298			340	54		
FM-47 Liquid	8230			90	30		
	6650			180	30		
	8210			220	30		
	8400			270	20		
	8790			80	30		
	ave 8056			168	28		
FM-47 Film	4555			140	20		
	5445			180	40		
	6295			220	40		
	5960			210	30		
	5775			110	30		
	ave 5606			172	32		

TABLE 10 (CONTINUED)

Adhesive		Shear Stress in Adhesive (psi)						
		76°F	180°F	250°F	350°F	500°F	650°F	800°F
Redux E, Type R		3880			170	70		
		4030			210	60		
		3730			230	60		
		3460			250	60		
		3570			160	60		
	ave	3734			204	62		
Cycleweld 55-20		3150			230	40		
		2910			250	25		
		2510			220	30		
		2260			210	40		
		2890			210	20		
	ave	2744			224	31		
Epon VIII		2830			90			
		3700			220			
		3660			310			
		3130			270			
		3300			220			
	ave	3326			222			
Shell 422		3000	2660	2350	1860	1470	1250	940
		3160	2770	2380	1830	1770	1300	830
		3430	2850	2130	1810	1720	940	680
		3360	2650	2400	1980	1330	970	720
		3120	2610	2430	1870	1370	1350	500
	ave	3214	2708	2338	1870	1532	1162	734
HT-20		2410	2810	2390	2530	1090	1240	250
		2520	2340	2210	2550	1800	1320	180
		2380	2120	2300	2300	1730	90*	180
		2180	2730	2130	2280	1570	1250	340
		2290	2620	2860	2560	1880	1110	270
	ave	2356	2524	2378	2444	1614	1230	244

* Not included in average

TABLE 11

Tensile Shear Test Data - Tested at -100°F to 800°F After 1/2-Hour Exposure at Test Temperature

.063-Inch Type 301 1/2-Hard Stainless Steel, 1/2-Inch Overlap

Adhesive	Shear Stress in Adhesive (psi)							
	-100°F	-67°F	180°F	250°F	350°F	500°F	650°F	800°F
AF-6					500	100		
					550	160		
					560	150		
					510	190		
					480	220		
	ave				520	164		
PA-101					380			
					150			
					230			
					380			
					330			
	ave				294			
Plastilock 608					810	320	40	
					680	510	70	
					790	420	40	
					780	325	60	
					640	360	40	
	ave				740	387	50	
Metlbond 4021					470			
					590			
					580			
					560			
					200			
	ave				480			
FM-47 Liquid					70			
					110			
					140			
					110			
					50			
	ave				96			
FM-47 Film					160			
					140			
					130			
					110			
					100			
	ave				128			

TABLE 11 (CONTINUED)

Adhesive	Shear Stress in Adhesive (psi)							
	-100°F	-67°F	180°F	250°F	350°F	500°F	650°F	800°F
Redux E, Type R					120 260 190 200 220			
	ave				198			
Cycleweld 55-20					120 170 260 270 140			
	ave				192			
Epon VIII					150 90 140 150 120			
	ave				130			
Shell 422	3120 2840 2940 2780 2410	2940 3550 3400 3310 3340	2950 2800 2490 2560 2540	2420 2440 2600 2640 2790	1790 1540 1490 2225 2400	1950 2200 2050 1740 880	1160 1210 1430 1220 530	1040 840 1090 1090 1050
	ave 2818	3308	2668	2578	1889	1764	1110	1022
HT-20	2450 2540 2140 2520 2660	2550 2250 2100 2350 Broke in Cutting	2310 2360 2230 2520 2620	2440 2080 1920 2350 2900	2660 2460 2400 2410 2070	810 1300 1720 1670 1670	940 800 890 870 830	360 310 460 320 340
	ave 2462	2313	2408	2338	2400	1434	866	358

TABLE 12

Tensile Shear Test Data - Tested at 500°F, 650°F and 800°F After 18-Hours Exposure at Test Temperature

.063-Inch Type 301, 1/2-Hard Stainless Steel, 1/2-Inch Overlap

Adhesive	Shear Stress in Adhesive (psi)		
	500°F	650°F	800°F
FM-47 Liquid	380		
	550		
	520		
	420		
	470		
	ave 468		
FM-47 Film	530		
	460		
	500		
	480		
	480		
	ave 490		
Redux E, Type R	210		
	170		
	250		
	240		
	270		
	ave 228		
Cycleweld 55-20	70		
	150		
	190		
	70		
	90		
	ave 114		
Shell 422		Specimens Delaminated During Exposure	
HT-20		Specimens Delaminated During Exposure	

TABLE 13
Tensile Shear Test Data - Tested at 350°F to 650°F After 192-Hour Exposure at Test Temperature
Type 301, 1/2-Hard Stainless Steel, 1/2-Inch Overlap

Adhesive	Shear Stress in Adhesive (psi)		
	350°F	500°F	650°F
AF-6	680	400	
	740	450	
	680	770	
	680	650	
	740	620	
	ave 704	578	
PA-101	630	210	
	660	230	
	510	230	
	640	270	
	270	310	
	ave 542	250	
Plastilock 608	1390	280	
	1140	320	
	1430	170	
	1330	330	
	690		
	ave 1196	275	
Metlbond 4021	1080		
	1140		
	780		
	1010		
	1010		
	ave 1004		
FM-47 Liquid	620	Specimens Delaminated During Exposure	
	790		
	850		
	800		
	640		
	ave 740		
FM-47 Film	720	Specimens Delaminated During Exposure	
	750		
	720		
	780		
	760		
	ave 746		

TABLE 13 (CONTINUED)

Adhesive	Shear Stress in Adhesive (psi)		
	350°F	500°F	650°F
Redux E, Type R	370 580 460 580 640 ave 526	Specimens Delaminated During Exposure	
Cycleweld 55-20	340 540 510 410 400 ave 440	90 100 90 70 88	
Epon VIII	360 380 370 330 350 ave 358		
Shell 422	2130 1970 2110 2400 2400 ave 2210	Specimens Delaminated During Exposure	Specimens Delaminated During Exposure
HT-20	2700 2290 2750 2560 2180 ave 2496	Specimens Delaminated During Exposure	Specimens Delaminated During Exposure

TABLE 14

Tensile Shear Test Data - Tested at 350°F and 500°F After 1000-Hour Exposure at Test Temperature
.063-Inch Type 301, 1/2-Hard Stainless Steel, 1/2-Inch Overlap

Adhesive	Shear Stress in Adhesive (psi)	
	350°F	500°F
AF-6	1060 1140 1050 870 910	Specimens Delaminated During Exposure
	ave 1006	
PA-101	1110 560 710 760 760	Specimens Delaminated During Exposure
	ave 780	
Plastilock 608	1130 790 1030 1430 1330	490 400 360 350 Fell Apart in Oven*
	ave 1142	400
Metlbond 4021	1180 640 910 980 1060	Specimens Delaminated During Exposure
	ave 954	
FM-47 Liquid	410 1150 1420 1240 1350	
	ave 1114	
FM-47 Film	630 1110 1340 1400 1520	
	ave 1200	

* Not included in average

TABLE 14 (CONTINUED)

Adhesive	Shear Stress in Adhesive (psi)	
	350°F	500°F
Redux E, Type R	500 520 600 570 410 ave 520	
Cycleweld 55-20	630 720 790 500 440 ave 616	Specimens Delaminated During Exposure
Epon VIII	520 450 600 230 490 ave 458	
Shell 422	1140 1290 1500 1360 1220 ave 1302	Specimens Delaminated During Exposure
HT-20	1490 1500 1770 ave 1587	Specimens Delaminated During Exposure

TABLE 15

Average Tensile Shear Test Data on .063-Inch Type 301, 1/2-Hard Stainless Steel Bonded Joints After Exposure at 76°F, 350°F and 500°F

Adhesive	Average Tensile Shear Test Data (psi)									
	76°F	Tested at 350°F After Exposure at 350°F for:				Tested at 500°F After Exposure at 500°F for:				
		0-Hr	1/2-Hr	192-Hr	1000-Hr	0-Hr	1/2-Hr	18-Hr	192-Hr	1000-Hr
AF-6	2576	524	520	704	1006	200	164	--	578	*
PA-101	1865	201	294	542	780	52	--	--	250	*
Plastilock 608	3130	834	740	1196	1142	232	387	--	275	400
Metlbond 4021	2298	340	480	1004	954	54	--	--	--	Fell Apart
FM-47 Liquid	8056	168	96	740	1114	28	--	468	*	
FM-47 Film	5606	172	128	746	1200	32	--	490	*	
Redux E, Type R	3734	204	198	526	520	62	--	228	*	
Cycleweld 55-20	2744	224	192	440	616	31	--	114	88	
Epon VIII	3326	222	130	358	458	--	--	--	--	
Shell 422	3214	1870	1889	2210	1302	1532	1764	--	*	
HT-20	2356	2440	2400	2496	660	1614	1434	--	*	

* Specimens Delaminated During Exposure

Note: All Values are 5 Specimen Averages

TABLE 16
Creep Rupture Test Data
2024-T3 Alclad Aluminum, 1/2-Inch Overlap

Adhesive	Spec. No.	Test Temp. (°F)	Stress (psi)	Time to Rupture (Hr)	Remarks
AF-6	S-1151-4	180	1000	0	
	S-1151-5		700	.4	
	S-1476-2		650	6.6	
	S-1151-6		600	1.5	
	S-1151-7		550	24.1	
	S-1151-8		500	213.0	No Failure
	S-1150-1	200	1000	0	
	S-1150-2		900	.1	
	S-1150-3		800	.2	
	S-1150-4		600	1.6	
	S-1151-9		550	4.7	
	S-1150-5		500	4.3	
	S-1151-3		500	30.9	
	S-1151-2		450	213.7	No Failure
	S-1150-6		400	117.8	No Failure
	S-1151-10	250	650	0	
	S-1150-7		600	.1	
	S-1476-8		550	.4	
	S-1150-8		500	.8	
	S-1150-9		400	5.8	
	S-1476-6		350	200.0	No Failure
PA-101	S-1499-1	180	1850	.1	
	S-1164-7		1700	1.6	
	S-1164-8		1600	1.2	
	S-1164-9		1500	1.3	
	S-1499-2		1500	.2	
	S-1164-10		1300	11.4	
	S-1499-3		1200	2.5	
	S-1499-4		1050	23.9	
	S-1499-6		1050	214.7	No Failure
	S-1164-1	200			
	S-1164-2		1800	0	
	S-1164-3		1500	1.0	
	S-1164-4		1300	3.1	
	S-1164-6		1250	28.9	
	S-1499-5		1200	.4	
	S-1499-7		1100	1.2	
	S-1500-5		1050	1.7	
	S-1500-3		1025	6.1	
	S-1500-2		1000	36.0	
	S-1499-8		950	48.8	
	S-1499-9		900	249.4	No Failure

TABLE 16 (CONTINUED)

Adhesive	Spec. No.	Test Temp. (°F)	Stress (psi)	Time to Rupture (Hr)	Remarks
PA-101 (Cont'd)	S-1500-7	250	1000	.3	
	S-1500-6		950	.5	
	S-1499-10		900	.2	
	S-1500-4		875	1.5	
	S-1500-1		800	235.4	No Failure
Plastilock 608	S-1187-2	180	2000	0	
	S-1187-4		1700	0	
	S-1187-6		1450	0	
	S-1187-8		1300	.1	
	S-1188-1		1100	.7	
	S-1188-8		1000	7.9	
	S-1188-2		900	12.1	
	S-1188-3		800	247.4	No Failure
	S-1188-9	200	950	2.1	
	S-1188-4		900	3.9	
	S-1188-5		800	31.0	
	S-1188-6		770	20.5	
	S-1188-7		750	208.0	No Failure
	S-1188-10		700	197.9	No Failure
	S-1553-3	250	850	.3	
	S-1553-7		800	.7	
	S-1553-6		750	.9	
	S-1553-5		700	3.2	
	S-1553-4		600	197.5	No Failure
Metlbond 4021	S-1124-5	180	2000	0	
	S-1124-6		1800	.1	
	S-1124-7		1600	.2	
	S-1125-6		1900	.1	
	S-1125-7		1600	4.9	
	S-1124-8		1400	1.7	
	S-1125-5		1300	214.0	No Failure
	S-1124-1	200	2000	0	
	S-1125-4		1600	.3	
	S-1124-2		1500	.1	
	S-1125-8		1400	4.7	
	S-1124-3		1300	1.5	
	S-1124-4		1200	13.4	
	S-1125-3		1200	182.8	
	S-1125-10	250	1250	1.4	
	S-1124-9		1200	.8	
	S-1125-9		1100	9.9	
	S-1124-10		1000	.5	
	S-1125-1		900	118.9	Test Stopped, No Failure
	S-1125-2		900	216.5	No Failure

TABLE 16 (CONTINUED)

Adhesive	Spec. No.	Test Temp. (°F)	Stress (psi)	Time to Rupture (Hr)	Remarks
FM-47 Liquid	S-1561-3	180	3710	.1	
	S-1561-8		3592	2.5	
	S-1561-6		3512	18.6	
	S-1561-7		3386	95.2	No Failure
	S-1561-4		3276	13.1	
	S-1561-9		3200	93.0	
	S-1561-10		3100	196.5	No Failure
	S-1562-3	200	3512	.1	
	S-1562-6		3318	1.4	
	S-1562-4		3202	1.0	
	S-1562-2		3092	1.5	
	S-1562-7		3010	4.5	
	S-1562-9		2700	10.3	
	S-1568-4		2300	210.5	No Failure
	S-1563-6	250	1208	.1	
	S-1563-4		1080	1.1	
	S-1563-7		1044	0.3	
	S-1563-3		994	.3	
	S-1563-9		884	.3	
	S-1563-8		800	1.6	
	S-1563-10		686	.6	
	S-1567-6		502	210.4	No Failure
FM-47 Film	S-1558-4	180	3518	.2	
	S-1558-8		3280	.1	
	S-1558-2		3078	.7	
	S-1558-7		3008	5.0	
	S-1558-6		2870	19.3	No Failure
	S-1558-9		2800	2.3	
	S-1558-10		2653	15.0	
	S-1566-6		2498	213.2	No Failure
	S-1559-3	200	3210	.1	
	S-1559-8		3020	.1	
	S-1559-6		2884	.8	
	S-1559-2		2810	.1	
	S-1559-7		2794	.5	
	S-1559-4		2684	18.6	
	S-1559-9		2494	2.2	
	S-1559-10		2353	12.5	
	S-1566-2		2400	233.0	No Failure

TABLE 16 (CONTINUED)

Adhesive	Spec. No.	Test Temp. (°F)	Stress (psi)	Time to Rupture (Hr)	Remarks
FM-47 Film (Cont'd)	S-1560-6	250	1298	.2	
	S-1560-4		1212	.2	
	S-1560-7		1112	.3	
	S-1560-3		1016	.4	
	S-1560-9		906	.2	
	S-1560-8		812	1.5	
	S-1560-10		696	1.0	
	S-1560-2		610	7.9	
	S-1566-3		499	69.5	
	S-1566-4		449	213.2	No Failure
Redux E, Type R	S-1267-7	180	1300	.2	
	S-1267-8		1150	.5	
	S-1267-3		1000	237.8	No Failure
	S-1266-1		1000	.3	
	S-1266-2		900	1.0	
	S-1266-3		800	6.8	
	S-1267-9	200	800	.9	
	S-1269-10		750	3.3	
	S-1473-6		725	.1	
	S-1473-8		725	1.4	
	S-1473-4		700	262.6	No Failure
	S-1267-4	225	800	0	
	S-1554-3		750	.3	
	S-1554-10		700	.2	
	S-1267-5		600	.6	
	S-1473-2		550	.8	
	S-1473-10		525	0	
	S-1267-6		500	200.0	No Failure
Cycleweld 55-20	S-1204-5	180	1000	.1	
	S-1204-6		900	.1	
	S-1204-7		800	.9	
	S-1204-8		700	4.0	
	S-1204-9		600	4.0	
	S-1203-1		500	.1	
	S-1203-2		400	4.5	
	S-1203-3		400	62.0	
	S-1203-4		400	212.6	No Failure
	S-1503-1	200	600	4.1	
	S-1503-2		560	6.7	
	S-1503-3		500	60.6	
	S-1503-4		480	78.6	
	S-1503-6		460	84.2	
	S-1503-5		450	261.9	No Failure

TABLE 16 (CONTINUED)

Adhesive	Spec. No.	Test Temp. (°F)	Stress (psi)	Time to Rupture (Hr)	Remarks
Cycleweld 55-20 (Cont'd)	S-1203-6	250	450	.1	
	S-1203-7		400	.3	
	S-1203-8		350	.6	
	S-1203-9		275	3.0	
	S-1203-10		175	263.0	No Failure
Shell 422	S-1083-2	200	2800	1 Min	
	S-1083-4		2600	3 Min	
	S-1498-7		2600	.1	
	S-1083-5		2500	2.3	
	S-1083-3		2400	40.6	
	S-1084-5		2350	60.4	
	S-1084-6		2300	131.6	
	S-1083-1		2000	117.6	No Failure
	S-1552-6	250	2200	0	
	S-1552-5		2050	0	
	S-1552-7		1900	.1	
	S-1552-2		1875	.1	
	S-1552-4		1850	11.4	
	S-1552-8		1800	11.2	
	S-1552-3		1700	147.5	
	S-1498-1	350	1650	.2	
	S-1498-2		1600	1.8	
	S-1498-3		1500	3.9	
	S-1498-5		1450	103.9	
	S-1498-4		1400	212.9	No Failure
HT-20	S-1501-1	180	2400	0	
	S-1502-6		2050	0	
	S-1502-4		2025	.1	
	S-1501-2		2000	.1	
	S-1502-3		1975	.1	
	S-1502-8		1950	237.5	
	S-1502-7		1925	64.3	
	S-1501-3		1700	211.3	No Failure
	S-1556-10	250	2100	.1	
	S-1556-3		2025	.9	
	S-1556-4		2000	.1	
	S-1556-8		1950	.8	
	S-1556-6		1850	208.8	No Failure
	S-1501-10	350	1600	0	
	S-1501-7		1540	.1	
	S-1501-8		1520	.1	
	S-1501-4		1500	85.3	
	S-1501-5		1450	233.4	No Failure

TABLE 17
Creep Rupture Test Data
Type 301, 1/2-Hard Stainless Steel, 1/2-Inch Overlap

Adhesive	Spec. No.	Test Temp. (°F)	Stress (psi)	Time to Rupture (Hr)	Remarks
Shell 422	S-1470-2	180	3400	0	
	S-1470-3		3100	.2	
	S-1470-4		2900	11.3	
	S-1470-6		2850	.6	
	S-1470-7		2750	5.8	
	S-1470-1		2650	186.5	
	S-1470-10	250	2500	.1	
	S-1469-10		2450	5.0	
	S-1470-8		2400	12.2	
	S-1470-9		2325	13.7	
	S-1469-1		2225	7.5	
	S-1469-2		2125	67.5	
	S-5659-8		2050	133.5	
	S-1469-9	350	2200	.4	
	S-1469-3		2150	.1	
	S-1469-4		2100	2.3	
	S-1469-8		2000	22.1	
	S-1469-6		1900	234.8	No Failure
HT-20	S-1326-2	180	2400	0	
	S-1543-6		2050	.1	
	S-1284-1		2000	0	
	S-1284-9		1950	.2	
	S-1326-3		1850	0	
	S-1543-2		1800	200.0	No Failure
	S-1557-4	250	2000	0	
	S-1557-6		1950	.1	
	S-1557-9		1900	.1	
	S-1557-2		1875	.5	
	S-1557-5		1750	209.6	No Failure
	S-1326-10	350	1650	1.1	
	S-1326-8		1550	65.6	
	S-1326-3		1500	3.0	
	S-1326-7		1475	43.0	
	S-1543-4		1450	117.0	
	S-1326-1		1400	202.4	No Failure

TABLE 18
Impact Test Data at 76°F and -100°F
Impact Speed 12.75 ft/sec
.125 Inch 2024-T3 Alclad Aluminum, 3/4-Inch Overlap

Adhesive	Spec. No.	Load (ft-lb)	
		76°F	-100°F
AF-6	S-1462-1	14.5	2.5
	through -10	15.0	2.5
		16.5	2.5
		15.5	3.0
		16.5	2.5
	ave	15.6	2.6
PA-101	S-1457-1	16.5	2.0
	through -10	15.5	2.0
		15.5	2.0
		15.0	2.0
		16.5	2.5
	ave	15.8	2.1
Plastilock 608	S-1223-1	16.0	2.0
	through -10	15.5	2.0
		16.0	2.0
		17.0	2.0
		16.0	
		16.0	
	ave	16.0	2.0
Metlbond 4021	S-1458-1	28	3.0
	through -10	25.0	3.0
		26.5	2.5
		27.5	3.0
		27.0	2.5
	ave	26.8	2.8
FM-47 Liquid	S-1455-1	4.5	3.5
	through -10	4.5	3.5
		7.5	3.5
		5.5	4.5
		5.5	3.5
	ave	5.5	3.7
FM-47 Film	S-1456-1	4.5	4.5
	through -10	5.0	4.5
		6.5	4.5
		4.5	5.0
		5.5	4.5
	ave	5.2	4.6

TABLE 18 (CONTINUED)

Adhesive	Spec. No.	Load (ft-lb) 76°F	Load (ft-lb) -100°F
Redux E, Type R	S-1464-1 through -10	7.0	4.5
		9.0	3.5
		7.5	3.5
		7.5	4.5
		7.0	5.0
	ave	7.6	4.2
Cycleweld 55-20	S-1459-1 through -10	28.0	3.5
		23.5	2.5
		25.0	3.5
		23.5	2.5
		22.5	3.5
	ave	24.5	3.1
Epon VIII	S-1460-1 through -10	5.0	4.0
		5.5	4.5
		5.5	5.5
		4.5	5.5
		5.5	4.5
	ave	5.2	4.8
Shell 422	S-1461-1 through -10	5.0	3.5
		4.5	5.5
		5.0	4.5
		4.5	3.0
		5.0	3.5
	ave	4.8	4.0
HT-20	S-1463-1 through -10	3.5	3.5
		3.5	3.0
		4.5	3.5
		4.0	3.0
		3.5	3.5
	ave	3.8	3.3

TABLE 19
Cleavage Test of Bonded Specimens
Tested at 76°F

Adhesive	Specimen No.	Ultimate Load (lb)
AF-6	S-1316-1	685
	S-1316-2	975
	S-1316-3	995
	S-1316-4	1025
	S-1316-5	1040
		ave 944
PA-101	S-1309-1	215
	S-1309-2	675
	S-1309-3	765
	S-1309-4	1280
	S-1309-5	1165
		ave 820
	S-1309-6	940
	S-1309-7	1220
	S-1309-8	1112
	S-1309-9	1134
	S-1309-10	172
		ave 915
Plastilock 608	S-1310-1	530
	S-1310-2	900
	S-1310-3	1315
	S-1310-4	1500
	S-1310-5	1400
		ave 1130
	S-1310-6	1424
	S-1310-7	1384
	S-1310-8	1392
	S-1310-9	1460
	S-1310-10	1264
		ave 1385
Metlbond 4021	S-1311-1	935
	S-1311-2	1275
	S-1311-3	1595
	S-1311-4	1640
	S-1311-5	1625
		ave 1414

TABLE 19 (CONTINUED)

Adhesive	Specimen No.	Ultimate Load (lb)
FM-47 Liquid	S-1307-1	900
	S-1307-2	805
	S-1307-3	800
	S-1307-4	1120
	S-1307-5	1240
		ave 973
	S-1527-1	1700
	S-1527-2	1438
	S-1527-3	1066
	S-1527-4	460
	S-1527-5	660
		ave 1065
FM-47 Film	S-1313-1	2110
	S-1313-2	1860
	S-1313-3	2055
	S-1313-4	1720
	S-1313-5	1650
		ave 1879
Redux E, Type R	S-1308-1	1825
	S-1308-2	2240
	S-1308-3	2435
	S-1308-4	2595
	S-1308-5	2675
		ave 2354
Cycleweld 55-20	S-1314-1	1440
	S-1314-2	2320
	S-1314-3	1670
	S-1314-4	1140
	S-1314-5	270
		ave 1368
	S-1525-1	1012
	S-1525-2	1170
	S-1525-3	1262
	S-1525-4	1216
	S-1525-5	1218
		ave 1175
Epon VIII	S-1317-1	1750
	S-1317-2	1680
	S-1317-3	1615
	S-1317-4	1740
	S-1317-5	1800
		ave 1717

TABLE 19 (CONTINUED)

Adhesive	Specimen No.	Ultimate Load (lb)
Shell 422	S-1315-1	1000
	S-1315-2	1090
	S-1315-3	1045
	S-1315-4	925
	S-1315-5	15
		ave 815
	S-1526-1	1262
	S-1526-2	1292
	S-1526-3	1170
	S-1526-4	1366
	S-1526-5	1226
		ave 1263
HT-20	S-1312-1	70
	S-1312-2	920
	S-1312-3	875
	S-1312-4	730
	S-1312-5	195
		ave 558
	S-1524-1	810
	S-1524-2	798
	S-1524-3	650
	S-1524-4	780
	S-1524-5	50
		ave 617

TABLE 20

Tension Test Data of 1-Inch Bonded Cylinders
Tested at 76°F

Adhesive	Specimen No.	Ultimate Load (psi)	Remarks
AF-6	S-1370	2370	All Had Uneven Pressure During Bonding - One Side of Each Specimen was Porous
	S-1371	2410	
	S-1372	2250	
	S-1373	2200	
	S-1374	2350	
		ave 2316	
PA-101	S-1514	1990	
	S-1515	2650	
	S-1516	2640	
	S-1517	3080	
	S-1518	2150	
		ave 2502	
Plastilock 608.	S-1340	2825	
	S-1341	2450	
	S-1342	2505	
	S-1343	2660	
	S-1344	2905	
		ave 2670	
Metlbond 4021	S-1375	2900	
	S-1376	3130	
	S-1377	3000	
	S-1378	3190	
	S-1379	3180	
		ave 3080	
FM-47 Liquid	S-1350	3850	All Had Uneven Pressure During Bonding - One Side of Each Specimen was Porous
	S-1351	4585	
	S-1352	5430	
	S-1353	5200	
	S-1354	4165	
		ave 4646	
FM-47 Film	S-1504	3270	All Had Uneven Pressure During Bonding - One Side of Each Specimen Was Porous
	S-1505	4970	
	S-1506	3530	
	S-1507	3860	
	S-1508	4620	
		ave 3978	
Redux E, Type R	S-1380	5240	
	S-1381	2410*	
	S-1382	4350	
	S-1383	3430	
	S-1834	3620	
		ave 4160	

* Porous Glue Line, Insufficient Pressure During Bonding. Not Included in Average.

TABLE 20 (CONTINUED)

Adhesive	Specimen No.	Ultimate Load (psi)	Remarks
Cycleweld 55-20	S-1365	2685	All Had Uneven Pressure During Bonding - One Side of Each Specimen was Porous
	S-1366	2550	
	S-1367	2970	
	S-1368	2500	
	S-1369	2610	
		ave 2663	
Epon VIII	S-1390	4510	
	S-1391	3300	
	S-1392	3960	
	S-1393	3840	
	S-1394	3780	
		ave 3870	
Shell 422	S-1395	3550	
	S-1396	3950	
	S-1397	3220	
	S-1398	3360	
	S-1399	3580	
		ave 3532	
HT-20	S-1509	2300	
	S-1510	2710	
	S-1511	2320	
	S-1512	1780	
	S-1513	1630	
		ave 2148	

TABLE 21

Bend Test Data - Tested on 1-1/2-Inch Span at 76°F
.064 Inch 2024-T3 Alclad Aluminum

Adhesive	Specimen No.	Load (lb)
AF-6	S-1476-1	248
	S-1476-3	240
	S-1476-5	254
	S-1476-7	254
	S-1476-9	230
		ave 245
PA-101	S-1474-1	220
	S-1474-3	248
	S-1474-5	266
	S-1474-7	260
	S-1474-9	264
		ave 251
Plastilock 608	S-1300-2	222
	S-1300-4	224
	S-1300-6	210
	S-1300-8	226
	S-1300-10	240
		ave 224
Metlbond 4021	S-1196-2	232
	S-1196-4	220
	S-1196-6	200
	S-1196-8	224
	S-1196-10	240
		ave 223
FM-47 Liquid	S-1306-1	228
	S-1306-2	232
	S-1306-3	226
	S-1306-4	230
	S-1306-5	234
		ave 230
FM-47 Film	S-1069-2	220
	S-1069-4	206
	S-1069-6	220
	S-1069-8	230
	S-1069-10	222
		ave 220
Redux E, Type R	S-1473-1	204
	S-1473-3	200
	S-1473-5	186
	S-1473-7	212
	S-1473-9	216
		ave 203

TABLE 21 (CONTINUED)

Adhesive	Specimen No.		Load (lb)
Cycleweld 55-20	S-1475-1		250
	S-1475-3		250
	S-1475-5		264
	S-1475-7		230
	S-1475-9		238
		ave	246
Epon VIII	S-1298-1		140
	S-1298-2		130
	S-1298-3		134
	S-1298-4		146
	S-1298-5		134
		ave	137
Shell 422	S-1472-2		144
	S-1472-4		142
	S-1472-6		138
	S-1472-8		138
	S-1472-10		140
		ave	140
HT-20	S-1323-2		126
	S-1323-4		128
	S-1323-6		130
	S-1323-8		130
	S-1323-10		124
		ave	127

TABLE 22

Peel Strength Test Data - Tested at 76°F

Adhesive	Sample No.	P_2 Average Load Total (lb)	T Peel Strength (in.-lb)
AF-6	S-1405	191.0	83.3
	S-1406	161.0	67.3
	S-1407	195.0	85.3
	S-1408	148.0	61.8
	S-1409	197.0	86.3
			ave 76.8
PA-101	S-1425	140.0	57.8
	S-1426	157.0	66.3
	S-1427	134.0	54.8
	S-1428	154.0	64.8
	S-1429	147.0	61.3
			ave 61.0
Plastilock 608	S-1400	190.0	82.8
	S-1401	206.0	90.8
	S-1402	190.0	82.8
	S-1403	205.0	90.3
	S-1404	213.0	94.3
			ave 88.2
Metlbond 4021	S-1430	112.0	43.8
	S-1431	145.0	60.3
	S-1432	94.0	34.8
	S-1433	100.0	37.8
	S-1434	114.0	44.8
			ave 44.3
FM -47 Liquid	S-1410	71.0	23.3
	S-1411	67.4	21.5
	S-1412	64.8	20.2
	S-1413	69.2	22.4
	S-1414	60.8	18.2
			ave 21.1

P_2 is average load applied to climbing peel test apparatus. Determined by use of planimeter.

$T = P_2 (r_o - r_i) - W r_i$

Where: $r_o = 2\frac{1}{2}$ in., $r_i = 2$ in.

Wt of drum, W = 6.1 lb

TABLE 22 (CONTINUED)

Adhesive	Sample No.	P_2 Average Load Total (lb)	T Peel Strength (in.-lb)
FM-47 Film	S-1415	93.0	34.3
	S-1416	90.0	32.8
	S-1417	85.0	30.3
	S-1418	74.0	24.8
	S-1419	87.0	31.3
			ave 30.7
Redux E, Type R	S-1445	38.0	6.8
	S-1446	34.0	4.8
	S-1447	34.0	4.8
	S-1448	34.0	4.8
	S-1449	37.0	6.3
			ave 5.5
Cycleweld 55-20	S-1435	80.0	32.3
	S-1436	106.0	40.8
	S-1437	100.0	37.8
	S-1438	98.0	36.8
	S-1439	98.0	36.8
			ave 36.9
Epon VIII	S-1440	39.0	7.3
	S-1441	37.0	6.3
	S-1442	39.0	7.3
	S-1443	40.0	7.8
	S-1444	37.0	6.3
			ave 7.0
Shell 422	S-1450	34.5	5.0
	S-1451	31.2	5.3
	S-1452	32.2	3.9
	S-1453	34.6	5.1
	S-1454	31.4	3.5
			ave 4.2
HT-20	S-1420	32.0	3.8
	S-1421	37.0	6.3
	S-1422	34.0	4.8
	S-1423	35.0	5.3
	S-1424	33.0	4.3
			ave 4.9

P_2 is average load applied to climbing peel test apparatus. Determined by use of planimeter

$T = P_2 (r_o - r_i) - W r_i$

Where: $r_o = 2\frac{1}{2}$ in., $r_i = 2$ in.

Wt of drum, W = 6.1 lb

TABLE 23
Fatigue Test Data
2024-T3 Alclad Aluminum, 3/8-Inch Overlap

Adhesive	Spec. No.	Test Temp.	Sh. Str. (psi)	Cycles	Remarks
AF-6	S-1492-2	Room Temp.	1600	70,000	Adhesive Failure
	S-1492-3	Room Temp.	1335	166,000	Adhesive Failure
	S-1492-4	Room Temp.	1065	827,000	Adhesive Failure
	S-1492-6	Room Temp.	800	6,518,000	Adhesive Failure
	S-1492-7	Room Temp.	735	20,000,000	No Failure
	S-1493-2	180°F	800	72,000	Adhesive Failure
	S-1493-4	180°F	665	482,000	Adhesive Failure
	S-1493-6	180°F	600	351,000	Adhesive Failure
	S-1493-7	180°F	535	599,000	Adhesive Failure
	S-1493-3	180°F	535	10,000,000	No Failure
	S-1493-9	180°F	465	682,000	Adhesive Failure
	S-1493-10	180°F	400	610,000	Adhesive Failure
	S-1494-2	250°F	800	29,000	Adhesive Failure
	S-1494-6	250°F	665	8,000	Adhesive Failure
	S-1494-7	250°F	535	151,000	Adhesive Failure
	S-1494-4	250°F	400	5,000,000	No Failure
PA-101*	S-1207-2	Room Temp.	1920	499,000	Metal Failure
	S-1207-3	Room Temp.	1600	1,147,000	Metal Failure
	S-1207-7	Room Temp.	1600	1,043,000	Metal Failure
	S-1207-4	Room Temp.	1280	8,391,000	Metal Failure
	S-1207-6	180°F	1600	80,000	Adhesive Failure
	S-1207-7	180°F	1280	1,024,000	Adhesive Failure
	S-1207-9	180°F	1120	182,000	Gas Bubbles in Adhesive Film
	S-1208-4	180°F	1120	1,555,000	Adhesive Failure
	S-1207-10	180°F	960	6,000	Gas Bubbles in Adhesive Failure
	S-1208-2	180°F	960	1,728,000	Adhesive Failure
	S-1208-3	180°F	800	20,000,000	No Failure
	S-1208-6	200°F	1600	19,000	Adhesive Failure
	S-1209-4	200°F	1440	12,000	Adhesive Failure
	S-1208-7	200°F	1280	234,000	Adhesive Failure
	S-1209-2	200°F	1120	1,000,000	Adhesive Failure
	S-1208-10	200°F	1120	198,000	Adhesive Failure
	S-1208-9	200°F	960	15,000,000	No Failure

* 5/16 Inch Lap

TABLE 23 (CONTINUED)

Adhesive	Spec. No.	Test Temp.	Sh.Str. (psi)	Cycles	Remarks
Plastilock 608	S-1495-2	Room Temp.	1600	1,283,000	Metal Failure
	S-1495-3	Room Temp.	1335	1,120,000	Adhesive Failure
	S-1495-4	Room Temp.	1335	724,000	Adhesive Failure
	S-1495-6	Room Temp.	1065	3,198,000	Adhesive Failure
	S-1495-7	Room Temp.	935	10,000,000	No Failure
	S-1495-9	Room Temp.	1000	13,000,000	No Failure
	S-1496-2	180°F	1065	6,000	Adhesive Failure - Creep
	S-1496-3	180°F	800	92,000	Adhesive Failure
	S-1496-6	180°F	665	3,981,000	Adhesive Failure
	S-1496-7	180°F	600	14,000,000	No Failure
	S-1496-4	180°F	535	10,000,000	No Failure
	S-1497-4	250°F	800	7,000	Adhesive Failure - Creep
	S-1497-9	250°F	665	326,000	Adhesive Failure - Creep
	S-1497-2	250°F	600	24,000,000	No Failure
Metlbond 4021	S-1122-2	Room Temp.	1600	935,000	Metal Failure
	S-1477-2	Room Temp.	1600	1,036,000	Metal Failure
	S-1477-7	Room Temp.	1465	2,948,000	Adhesive Failure
	S-1477-3	Room Temp.	1335	1,840,000	Metal Failure
	S-1477-9	Room Temp.	1335	10,000,000	No Failure
	S-1122-7	180°F	1335	1,084,000	Metal Failure
	S-1122-9	180°F	1200	166,000	Adhesive Failure (Poor Bond)
	S-1122-10	180°F	1200	2,012,000	Metal Failure
	S-1122-6	180°F	1065	10,000,000	No Failure
	S-1477-10	250°F	1330	7,000	Adhesive Failure
	S-1478-2	250°F	1065	225,000	Adhesive Failure
	S-1478-3	250°F	935	6,485,000	Adhesive Failure
	S-1478-4	250°F	865	10,000,000	No Failure
FM-47 Liquid	S-1044-2	Room Temp.	1600	37,000	Adhesive Failure
	S-1044-3	Room Temp.	1065	458,000	Adhesive Failure
	S-1044-4	Room Temp.	800	1,973,000	Adhesive Failure
	S-1044-6	Room Temp.	665	10,000,000	No Failure

TABLE 23 (CONTINUED)

Adhesive	Spec. No.	Test Temp.	Sh.Str. (psi)	Cycles	Remarks
FM-47 Liquid (Cont'd)	S-1486-2	180°F	1600	779,000	Metal Failure
	S-1486-3	180°F	1335	1,956,000	Metal Failure
	S-1486-4	180°F	1200	3,410,000	Adhesive Failure
	S-1486-5	180°F	1135	3,504,000	Adhesive Failure
	S-1486-7	180°F	1065	4,249,000	Adhesive Failure
	S-1486-9	180°F	935	5,997,000	Adhesive Failure
	S-1486-10	180°F	865	1,578,000	Adhesive Failure
	S-1487-2	180°F	865	4,909,000	Adhesive Failure
	S-1487-3	180°F	800	6,614,000	Adhesive Failure
	S-1487-4	180°F	735	5,503,000	Adhesive Failure
	S-1487-6	180°F	665	10,000,000	No Failure
	S-1487-7	200°F	1600	770,000	Adhesive Failure
	S-1487-9	200°F	1335	1,455,000	Adhesive Failure
	S-1487-10	200°F	1065	4,584,000	Adhesive Failure
	S-1488-2	200°F	935	9,105,000	Adhesive Failure
FM-47 Film	S-1025-3	Room Temp.	1600	135,000	Adhesive Failure
	S-1026-3	Room Temp.	1335	169,000	Adhesive Failure
	S-1026-4	Room Temp.	1065	659,000	Adhesive Failure
	S-1026-5	Room Temp.	800	1,883,000	Adhesive Failure
	S-1026-6	Room Temp.	665	4,156,000	Adhesive Failure
	S-1027-4	Room Temp.	600	10,000,000	No Failure
	S-1027-2	180°F	1600	294,000	Adhesive Failure
	S-1027-7	180°F	1335	1,562,000	Adhesive Failure
	S-1027-6	180°F	1065	2,570,000	Adhesive Failure
	S-1027-3	180°F	935	3,376,000	Adhesive Failure
	S-1027-5	180°F	800	15,000,000	No Failure
	S-1027-9	200°F	1335	422,000	Adhesive Failure
	S-1026-1	200°F	1065	1,452,000	Adhesive Failure
	S-1025-6	200°F	935	13,113,000	Adhesive Failure
	S-1025-4	200°F	935	14,000,000	No Failure
Redux E, Type R	S-1480-7	Room Temp.	1600	206,000	Adhesive Failure
	S-1480-6	Room Temp.	1335	521,000	Adhesive Failure
	S-1480-2	Room Temp.	1065	1,984,000	Adhesive Failure
	S-1480-4	Room Temp.	935	6,310,000	Adhesive Failure
	S-1480-3	Room Temp.	800	10,000,000	No Failure
	S-1481-7	180°F	1335	27,000	Adhesive Failure
	S-1481-6	180°F	1065	349,000	Adhesive Failure
	S-1480-9	180°F	935	136,000	Adhesive Failure
	S-1481-4	180°F	935	1,061,000	Adhesive Failure
	S-1480-10	180°F	800	75,000	Adhesive Failure
	S-1481-3	180°F	800	20,000,000	No Failure
	S-1481-2	180°F	665	10,000,000	No Failure

TABLE 23 (CONTINUED)

Adhesive	Spec. No.	Test Temp.	Sh.Str. (psi)	Cycles	Remarks
Redux E, Type R (Cont'd)	S-1481-9	200°F	935	23,000	Adhesive Failure
	S-1481-10	200°F	800	33,000	Adhesive Failure
	S-1482-2	200°F	665	113,000	Adhesive Failure
	S-1482-6	200°F	665	106,000	Adhesive Failure
	S-1482-7	200°F	600	403,000	Adhesive Failure
	S-1482-4	200°F	535	10,000,000	No Failure
Cycleweld 55-20	S-1199-2	Room Temp.	1600	119,000	Adhesive Failure
	S-1199-4	Room Temp.	1335	918,000	Adhesive Failure
	S-1199-6	Room Temp.	1065	1,754,000	Adhesive Failure
	S-1199-7	Room Temp.	935	19,559,000	Adhesive Failure
	S-1490-2	180°F	800	129,000	Adhesive Failure
	S-1490-4	180°F	535	3,004,000	Adhesive Failure
	S-1490-7	180°F	465	5,571,000	Adhesive Failure
	S-1490-6	180°F	400	10,000,000	No Failure
Epon VIII	S-1483-2	Room Temp.	1600	137,000	Adhesive Failure
	S-1483-7	Room Temp.	1465	1,181,000	Adhesive Failure
	S-1483-3	Room Temp.	1335	2,780,000	Adhesive Failure
	S-1483-4	Room Temp.	1200	3,340,000	Adhesive Failure
	S-1485-6	Room Temp.	1135	1,893,000	Adhesive Failure
	S-1485-9	Room Temp.	1135	15,000,000	No Failure
	S-1485-7	Room Temp.	1065	10,000,000	No Failure
	S-1483-6	Room Temp.	1065	25,000,000	No Failure
	S-1484-3	180°F	1600	24,000	Adhesive Failure
	S-1484-4	180°F	1335	157,000	Adhesive Failure
	S-1483-9	180°F	1335	740,000	Adhesive Failure
	S-1484-2	180°F	1200	551,000	Adhesive Failure
	S-1484-7	180°F	1200	1,960,000	Adhesive Failure
	S-1484-6	180°F	1065	19,000,000	No Failure
	S-1483-10	180°F	1065	10,000,000	No Failure
	S-1484-9	200°F	1065	58,000	Adhesive Failure
	S-1485-2	200°F	1065	789,000	Adhesive Failure
	S-1485-4	200°F	1000	1,855,000	Adhesive Failure
	S-1484-10	200°F	935	10,000,000	No Failure
Shell 422	S-1080-2	Room Temp.	1475	47,000	Adhesive Failure
	S-1080-3	Room Temp.	1230	359,000	Adhesive Failure
	S-1080-6	Room Temp.	1110	6,908,000	Adhesive Failure
	S-1080-7	Room Temp.	1045	20,000,000	No Failure

TABLE 23 (CONTINUED)

Adhesive	Spec. No.	Test Temp.	Sh. Str. (psi)	Cycles	Remarks
Shell 422 (Cont'd)	S-1082-7	180°F	1475	938,000	Adhesive Failure
	S-1080-7	180°F	1230	1,803,000	Metal Failure
	S-1082-2	180°F	1230	1,625,000	Adhesive Failure
	S-1081-2	180°F	1110	1,856,000	Metal Failure
	S-1080-10	180°F	1110	240,000	Adhesive Failure
	S-1082-4	180°F	1110	2,158,000	Adhesive Failure
	S-1082-6	180°F	1045	6,002,000	Adhesive Failure
	S-1080-9	180°F	985	10,000,000	No Failure
	S-1081-3	250°F	1230	270,000	Adhesive Failure
	S-1081-4	250°F	1110	1,379,000	Adhesive Failure
	S-1081-6	250°F	1045	123,000	Adhesive Failure
	S-1081-7	250°F	1045	4,514,000	Adhesive Failure
	S-1081-9	250°F	985	10,981,000	Adhesive Failure
HT-20	S-1549-2	Room Temp.	1600	127,000	Adhesive Failure
	S-1549-6	Room Temp.	1600	2,673,000	Adhesive Failure
	S-1549-4	Room Temp.	1465	417,000	Adhesive Failure
	S-1549-7	Room Temp.	1335	1,450,000	Adhesive Failure
	S-1550-6	Room Temp.	1335	1,170,000	Adhesive Failure
	S-1549-3	Room Temp.	1335	12,120,000	Adhesive Failure
	S-1550-7	Room Temp.	1265	679,000	Adhesive Failure
	S-1550-10	Room Temp.	1200	1,959,000	Adhesive Failure
	S-1151-2	Room Temp.	1065	10,000,000	No Failure
	S-1549-9	180°F	1600	10,000	Adhesive Failure
	S-1549-10	180°F	1335	254,000	Adhesive Failure
	S-1550-2	180°F	1200	195,000	Adhesive Failure
	S-1550-3	180°F	1135	1,213,000	Adhesive Failure
	S-1550-4	180°F	1065	575,000	Adhesive Failure
	S-1550-9	180°F	935	10,000,000	No Failure
	S-1551-4	250°F	1065	178,000	Adhesive Failure
	S-1551-6	250°F	1000	63,000	Adhesive Failure
	S-1551-9	250°F	1000	1,241,000	Adhesive Failure
	S-1551-10	250°F	935	10,000,000	No Failure

TABLE 24
Fatigue Test Data
Type 301, 1/2-Hard Stainless Steel, 3/8-Inch Overlap

Adhesive	Spec. No.	Test Temp.	Sh.Str. (psi)	Cycles	Remarks
Shell 422	S-1465-2	Room Temp.	1600	10,000,000	No Failure - Maximum Load of Fatigue Machine was not Sufficient to Cause Failure of these Bonds at Room Temperature
	S-1465-3	180°F	1600	1,709,000	Adhesive Failure
	S-1465-4	180°F	1465	10,000,000	No Failure
	S-1465-6	350°F	1600	33,000	Adhesive Failure
	S-1465-7	350°F	1465	66,000	Adhesive Failure
	S-1465-9	350°F	1335	849,000	Adhesive Failure
	S-1465-10	350°F	1265	1,348,000	Adhesive Failure
	S-1466-2	350°F	1200	15,000,000	No Failure
HT-20	S-1324-4	Room Temp.	1600	4,086,000	Adhesive Failure
	S-1324-6	Room Temp.	1465	20,000,000	No Failure
	S-1324-5	Room Temp.	1335	10,000,000	No Failure
	S-1324-7	180°F	1600	14,000	Adhesive Failure
	S-1324-10	180°F	1600	14,000	Adhesive Failure
	S-1325-2	180°F	1465	257,000	Adhesive Failure
	S-1325-3	180°F	1335	10,000,000	No Failure
	S-1324-9	180°F	1335	10,000,000	No Failure
	S-1325-6	350°F	1465	11,000	Adhesive Failure
	S-1325-4	350°F	1335	382,000	Adhesive Failure
	S-1325-9	350°F	1265	8,293,000	Adhesive Failure

VI. REFERENCES

1. Military Specification MIL-A-5090B, "Adhesive; Airframe Structural, Metal to Metal", 1954.

2. Military Specification MIL-A-9067A, "Adhesive Bonded Metal Aircraft and Parts; Process and Inspection Requirements", 1955.

3. Federal Specification MMM-A-175, "Adhesives: Methods of Testing, Method 1011", 1951.

4. ASTM Tentative Standard D-1062-49T, "Cleavage Test", 1949.

5. Mordfin, L., "Creep and Creep-Rupture Characteristics of Some Riveted and Spot-Welded Lap Joints of Aircraft Materials", NACA Technical Note 3412, 1955.

6. Eickner, H. W., "The Shear, Fatigue, Bend, Impact, and Long-Time-Load Strength Properties of Structural Metal-Metal Adhesives in Bonds to 24S-T3 Aluminum Alloy", Forest Products Laboratory Report No. 1836, June 1953.

7. WADC qualification tests on adhesives for MIL-A-5090B Specification.

8. Merriman, H. R., and Bomhardt, W., "Fatigue Life of Adhesive Bonded Joints", The Glenn L. Martin Company ER-7033-1, January 1955.

9. Tooley, D. A., "Development of Production Equipment, Methods and Fabrication Criteria for Metal Adhesives" (Contract No. AF33(600)-19263).

10. Schenck Fatigue Testing Machines, Bulletin 51-550, The R. Y. Ferner Co., Inc.

11. Engel, Hemming and Merriman, "Structural Plastics", McGraw-Hill Co., New York, 1950.

12. Kuenzi, E. W., "Determination of Mechanical Properties of Adhesives for Use in the Design of Bonded Joints".

13. Yurenka, S.,"Metal Adhesive Peel Testing",paper presented at ARTC Committee W-78 meeting, Madison, Wis., April 23, 1956.

14. Reese, J. P., and Merriman, H. R., "Fatigue Tests of Production Sandwich Panels", The Glenn L. Martin Company ER-7980-4 App 1, January 25, 1956.

APPENDIX

INDEX OF MATERIALS

IDENTITY AND SOURCE

APPENDIX

INDEX OF MATERIALS

IDENTITY AND SOURCE

A. METALS

Aluminum alloy, 2024-T3 alclad - Federal Specification, QQ-A-362.
Stainless steel, Type 301, 1/2-hard, 2D Finish - Military Specification, MIL-S-5059A(ASG).

B. ADHESIVES

Scotchweld AF-6	Minnesota Mining and Mfg. Co. Adhesives & Coatings Division 411 Piquette Ave., Detroit 2, Michigan.
PA-101	Bloomingdale Rubber Co. Flower Street, Chester, Pennsylvania.
Plastilock 608	B. F. Goodrich Co. Industrial Products Division, Akron, Ohio.
Metlbond 4021	Narmco, Inc. 600 Victoria Street Costa Mesa, California.
FM-47 Liquid	Bloomingdale Rubber Co. Flower Street, Chester, Pennsylvania.
FM-47 Film	Bloomingdale Rubber Co. Flower Street, Chester, Pennsylvania.
Redux E, Type R	Ciba Company, Inc. 627 Greenwich Street, New York 14, N.Y.
Cycleweld 55-20	Cycleweld Cement Products 5437 West Jefferson, Trenton, Michigan.

Epon VIII	Shell Chemical Corp. 380 Madison Avenue, New York 17 N.Y.
Shell 422	Shell Development Co. 4560 Horton Street, Emeryville 8, California.
HT-20	Bloomingdale Rubber Co. Flower Street, Chester, Pennsylvania.

C. CLEANING MATERIALS

Sprex AN-9	DuBois Company 1120 West Front Street, Cincinnati, Ohio.
Activol 57X	Haas Miller Corporation 4th and Bristol Streets, Philadelphia, Pennsylvania.
Sulfuric Acid	Federal Specification 0-A-115
Hydrofluoric Acid	Federal Specification 0-H-795
Nitric Acid	Federal Specification 0-A-88
Sodium Dichromate	Federal Specification 0-S-595A