THE SHEAR, FATIGUE, BEND, IMPACT, AND LONG-TIME-LOAD STRENGTH PROPERTIES OF STRUCTURAL METAL-TO-METAL ADHESIVES IN BONDS TO 24S-T3 ALUMINUM ALLOY

Information Reviewed and Reaffirmed

May 1959

INFORMATION REVIEWED
AND REAFFIRMED
1965

No. 1836

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

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

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THE SHEAR, FATIGUE, BEND, IMPACT, AND LONG-TIME-LOAD STRENGTH PROPERTIES OF STRUCTURAL METAL-TO-METAL ADHESIVES IN BONDS TO 24S-T3 ALUMINUM ALLOY[1, 2, 3, 4]

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Summary

The shear, fatigue, bend, impact, and long-time-load strength properties of nine commercially available adhesives, of the type formulated for structurally bonding metal to metal, were determined by procedures described in Air Force Specification No. 14164, "Adhesive, Metal to Metal, Structural," September 20, 1949. These procedures consisted of testing lap joints of 0.064-inch 24S-T3 clad aluminum alloy in shear at 72° to 76° F., at 178° to 182° F., at -65° to -70° F., after exposure to salt-water spray, and after immersion in aircraft fluids; in fatigue at 72° to 76° F. and at -65° to -70° F.; in long-time loading at 72° to 76° F. and at 178° to 182° F.; and in bending at 72° to 76° F. Bonds between 24S-T3 bare aluminum blocks were also tested in impact resistance at 72° to 76° F. and at -65° to -70° F.

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[1]This progress report is one of a series prepared and distributed by the Forest Products Laboratory under U. S. Navy Bureau of Aeronautics Order No. NAer 01319 and U. S. Air Force No. USAF-18(600)-70. Results here reported are preliminary and may be revised as additional data become available.

[2]The fatigue tests for this study were made under the supervision of Wayne C. Lewis, Engineer, Forest Products Laboratory.

[3]The test data included in this study on the shear strength of the adhesive bonds after exposure to salt-water spray and after immersion in aircraft fluids and on bend and impact strength were taken from Wright Air Development Center Report RDO No. 614-11, "Properties of Adhesive Bonded Aluminum Alloy Lap Joints," by B. W. Andrews, U. S. Air Force.

[4]Report originally published June 1953.

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

The adhesives tested in this study by the static shear tests at 72° to 76° F., at 178° to 182° F., and at -65° to -70° F. generally met the requirements of the Air Force Specification No. 14164 with the exception of two adhesives, one in the low-temperature tests and one in the high-temperature test. The average values for the shear strength of both these adhesives were so close to the requirements, however, that, for practical purposes, all adhesives tested can be considered to meet these shear strength requirements.

The shear strength values obtained on the aluminum lap-joint specimens after exposure to salt-water spray and after immersion in aircraft fluids also generally met, with a few exceptions, the requirements of the specification.

Two of the nine adhesives tested for fatigue strength failed to meet the requirement of the Air Force Specification for fatigue strength at 72° to 76° F. The other adhesives had good fatigue properties, and the failures in many of the tests, particularly at low stresses and at -65° to -70° F., were tension failures in the metal rather than in the adhesive bond.

Five of the nine adhesives tested did not meet the requirements of the Air Force Specification for strength in long-time loading at 178° to 182° F. All of the adhesives met the actual strength requirements of the long-time-loading test at 72° to 76° F., but five showed a greater deformation in the adhesive bond during 200 hours of loading at 72° to 76° F. than is permitted by the Air Force Specification.

All of the adhesives tested met the bend strength requirement of the specification. Only one of the adhesives tested, however, produced bonds with impact strength values at both 72° to 76° F. and -65° to -70° F. that exceeded the minimum requirements of the specification.

Several recommendations for possible changes in the Air Force Specification No. 14164 are made, based on the experience obtained from the tests in this study.

Introduction

Adhesives have been formulated during the past 10 years that give good bonding of metals to metals, wood, and low-density core materials. Because preliminary evaluation of bonds made with these adhesives showed that the adhesives are suitable for making high-strength structural bonds, these adhesives are now being used for many structural and nonstructural applications in aircraft construction. In such construction, adhesive bonding has advantages over fastening with rivets in the speed of the operation, in more uniform distribution of stresses from one structural member to another, and in the production of smoother airfoil sections. These adhesives have also made possible metal-faced sandwich constructions that have high stiffness for their weight.

Air Force Specification No. 14164, "Adhesive, Metal to Metal, Structural," September 20, 1949, prescribes certain requirements for adhesives for structurally bonding metal to metal in aircraft. The main requirements of this specification include the shear strength in lap joints of clad aluminum alloy at 72° to 76° F., at -65° to -70° F., at 178° to 182° F., after exposure to salt-water spray, and after immersion in aircraft fluids; the fatigue resistance of these bonded joints at 72° to 76° F. and at -65° to -70° F.; and their long-time-load strength at 72° to 76° F. and at 178° to 182° F.; and their bend strength at 72° to 76° F. Impact strength properties at 72° to 76° F. and at -65° to -70° F. between adhesive-bonded aluminum blocks are also required. At the time this specification was issued the performance requirements were based on a limited amount of data obtained on a few adhesives or on earlier data obtained by test methods that differed slightly from those finally adopted for the specification.

The purpose of this study was, first, to evaluate in the manner prescribed by the Air Force Specification a number of the principal metal-bonding adhesives that are currently being used in the aircraft industry and, second, to determine from the results of the tests the advisability of changing certain testing techniques or performance requirements of the specification. The bonding conditions used with the adhesives were within the range recommended by the adhesive manufacturer, and, therefore, the test data will indicate whether these typical adhesives meet the present requirements of Air Force Specification No. 14164.

Test Materials and Procedures

Adhesive Processes

The adhesive processes evaluated in this study were:

Adhesive 25 -- a high-temperature-setting formulation of the neoprene-phenolic type.

Adhesive 25 (primer) and Adhesive 26 (secondary) (this process will be subsequently referred to as adhesive 25-26) -- adhesive 25 used in combination with secondary adhesive 26, which is a high-temperature-setting formulation of the phenol-resin type used as a secondary adhesive for primed metal surfaces. This secondary adhesive is used when pressures must be lower than those that give good bonds with the direct-bonding adhesive 25 alone.

Adhesive 33 -- a high-temperature-setting adhesive formulation of the vinyl-phenolic type. This adhesive has been reported to have the same composition as adhesive 35, except that it is prepared by another adhesive manufacturer. Because of the reported similarity, only a limited number of tests were made to compare the performance of adhesive 33 with adhesive 35.

Adhesive 34 -- a high-temperature-setting, two-component formulation of a phenol resin solution and a vinyl polymer powder.

Adhesive 35 -- a high-temperature-setting formulation of the vinyl-phenolic type.

Adhesive 36 -- a high-temperature-setting adhesive formulation of the neoprene-phenolic type.

Adhesive 37 -- adhesive 36 used in combination with a second resin component containing a nylon resin in order to obtain better flow characteristics than those obtained with adhesive 36 alone.

Adhesive 38 -- an adhesive process similar to adhesive 37, except that the two resin components were impregnated on a nylon-fabric tape. Two bonding runs were made with adhesive tape manufactured by different manufacturers.

Adhesive 41 -- a formulation of epoxy-type resins that was cured, for this study, at a temperature of 200° F.

Types and Preparation of Specimens

The lap-joint specimens prepared and tested in this study were of two types, 1/2- and 3/8-inch overlap of 0.064-inch 24S-T3 clad aluminum alloy (AN-A-13), as specified in Air Force Specification No. 14164.

The lap-joint specimens were prepared for the shear tests at the three test temperatures, long-time-load tests, and fatigue tests by bonding together two 4- by 13-inch pieces of 0.064-inch, clad aluminum alloy with a 1/2- or 3/8-inch overlap. Ten lap-joint specimens, 1 inch wide and approximately 7-1/2 inches long, were then cut from each of the bonded panels with a metal-cutting bandsaw operating at such a speed that there was no appreciable heating or observed damaging of the specimens.

Lap-joint specimens for the salt-water spray and fluid-immersion tests were prepared in 6-inch-wide test panels of the 1/2-inch lap-joint from which five 1-inch-wide specimens could be cut. Two specimens were cut from the outer edges of these panels as controls before exposing, and the other three test specimens were cut from each of the panels after exposure to salt-water spray or immersion in the aircraft fluids.

The impact test specimens were prepared by bonding together 6-inch-long strips of 3/8- by 1-inch and 3/4- by 1-3/4-inch bare 24S-T3 aluminum alloy bars. The two bars were bonded together in stepwise fashion with the 1-inch face of the smaller bar bonded to the 1-3/4-inch face of the other bar and with the back edges of both bars in the same plane. Five 1-inch-wide test specimens were then cut with a metal cutting saw from each of these bonded assemblies.

All bonding surfaces of the aluminum alloy were cleaned by first wiping the surfaces with a clean cloth saturated with benzene, and then immersing the metal for 10 minutes at 140° to 160° F. in a solution of the following composition by weight: 1 part of sodium dichromate, 10 parts of concentrated sulfuric acid, and 30 parts of water. After removal from the solution, the surfaces were thoroughly rinsed in cold and in warm tap water and quickly dried.

The clean metal surfaces were bonded with the several adhesives under the bonding conditions given in table 1. The bonding conditions were within the range recommended by the adhesive manufacturers for use with their adhesives at the time of this study. The adhesive was always applied to the metal surfaces within 2 hours after the surfaces were cleaned.

The lap-joint specimens for the bend and immersion tests were made in a separate bonding run from that used in preparing the specimens for the shear, long-time-load, and fatigue tests. The bonding conditions, however, were essentially those given in table 1.

Number and Distribution of Test Specimens

For tests 1, 2, 3, 6, and 7 of the Air Force Specification 14164, nine panels (90 specimens) of the 1/2-inch-overlap type were prepared with each of the adhesive processes evaluated in this study. Specimens for the tests were selected in the following manner (test specimens were numbered 1 through 10 across each of the bonded panels):

Test 1, shear strength at 72° to 76° F. -- Specimens 1, 5, and 10 from each panel (27 specimens).

Test 2, shear strength at 178° to 182° F. -- Specimen 8 from each panel (9 specimens).

Test 3, shear strength at -65° to -70° F. -- Specimen 7 from panels 1 through 6 (6 specimens).

Test 6, long-time strength at 72° to 76° F. -- Specimens 3, 4, and 9 of odd-numbered panels and specimens 4 and 9 of even-numbered panels (23 specimens).

Test 7, long-time strength at 178° to 182° F. -- Specimens 2, 3, and 6 of even-numbered panels and specimens 2 and 6 of odd-numbered panels (22 specimens).

(Specimen 7 of panels 7, 8, and 9 -- extra specimens used for creep tests when required.)

For tests 4 and 5 of the Air Force Specification No. 14164, six panels (60 specimens) of the 3/8-inch-overlap type were also prepared with each of the adhesive processes, and the specimens for testing were selected in the following manner:

Test 4, fatigue strength at 72° to 76° F. -- Specimens 2, 3, and 4 of even-numbered panels and specimens 7, 8, and 9 of odd-numbered panels (18 specimens).

Control static-shear test at 72° to 76° F. -- Specimens 1 and 5 of even-numbered panels and specimens 6 and 10 of odd-numbered panels (12 specimens).

Test 5, fatigue strength at -65° to -70° F. -- Specimens 7, 8, and 9 of even-numbered panels and specimens 2, 3, and 4 of odd-numbered panels (18 specimens).

Control static-shear test at -65° to -70° F. -- Specimens 6 and 10 of even-numbered panels and specimens 1 and 5 of odd-numbered panels (12 specimens).

For tests 8 and 11 through 16 of the Air Force Specification No. 14164, 13 6-inch-wide test panels of 1/2-inch lap-joints of 0.064-inch clad 24S-T3 aluminum alloy bonded with each adhesive were divided in 6 groups of 2 panels each for exposure to the salt-water spray and immersion conditions and a single panel for the bend tests. Specimens 1-inch wide were cut from the outer edges of each panel for controls, and the center portion was exposed or tested.

For tests 9 and 10 of the Air Force Specification No. 14164, 10 1-inch-wide specimens for testing in impact, 5 at 72° F. (test 9) and 5 at -65° to -70° F. (test 10), were cut from the 2 6-inch-wide assemblies of aluminum bars bonded together with each of the adhesives.

Methods of Test

Unless otherwise noted, the adhesive processes were evaluated by the methods specified in tests 1 through 16 of Air Force Specification No. 14164.

Tests 1, 2, and 3. Lap-shear strength at 72° to 76° F., at 178° to 182° F., and at -65° to -70° F. --The individual test specimens were placed in Templin-type testing grips, with the jaws of the grips extending over the specimen, so that the ends of the jaws were 1 inch from the overlap area. Loads were applied in tension on the grips with a universal-type hydraulic testing machine loaded at such a rate that the stress was applied on the joint area at a rate of 600 pounds per square inch per minute (300 pounds per one-half square inch per minute).

For the tests at 178° to 182° F. and at -65° to -70° F., suitable chambers at the test temperature were placed around the specimen in the test machine (figs. 1 and 2) to ensure that the adhesive bond was stressed at the specified temperature.

The general practice in testing metal lap-joint specimens at elevated temperatures at the Forest Products Laboratory has been to place the specimen in the test grip within the chamber at the desired temperature, closing the door of the chamber rapidly so that the heat loss would be at a minimum, and then to start loading of the test specimen 2 to 4 minutes after the test chamber reaches the desired temperature. As the test chambers used for this study were moderately efficient, approximately 10 minutes were allowed between the placing of the specimen in the test grip and the loading of the test specimen. This method of testing was used for the first groups of specimens tested at

178° to 182° F. Air Force Specification No. 14164, however, states that the properties of the adhesive bonds shall be determined after exposure for at least one-half hour to the controlled temperature condition. Therefore, all later specimens were tested after exposure for one-half hour instead of 10 minutes.

The use of the 30-minute exposure would normally be expected to give approximately the same results as the 10-minute exposure at 178° to 182° F., except for adhesives that were not completely cured in the original cure cycle. There is no reason to believe, however, that any of the adhesives in this study received significant additional cure at 178° to 182° F. Aging of adhesive bonds at 178° to 182° F. might decrease the shear strength at this temperature range, but there was no indication that the additional 20 minutes at 178° to 182° F. before testing affected the test results obtained on the adhesives evaluated in the present work.

Tests 4 and 5. Fatigue strength[5] at 72° to 76° F. and at -65° to -70° F.--As controls, four specimens (two specimens at each temperature condition) from each of the bonded panels having 3/8-inch lap joints were tested statically in shear at 72° to 76° F. and at -65° to -70° F. by the same test procedures as were used for tests 1 and 3. The control specimens selected for testing at each temperature were the two outside specimens from groups of five adjacent specimens from one panel, with the three center specimens being tested in fatigue at the same temperature.

For the fatigue tests, specimens with 3/8-inch lap joints were cut to an over-all length of 5-7/8 inches and were placed in test grips of the type shown in figure 3. The grips were designed so that the plane of loading (produced by lines through the center of the pins in the grips) coincided with the plane of the glue line in the unloaded specimen. The distance from the end of the lap in the specimen to the grips was 1 inch. The details of these grips are shown in figure 4.

The lap-joint specimens were loaded in tension through the grips by a direct-stress fatigue machine of 4,000-pound capacity (fig. 5.). This machine was equipped with electronic controls so that, if the specimen failed or the maximum repeated load decreased more than 15 pounds, the machine stopped automatically until the loading was corrected. Specimens were loaded at a rate of 900 cycles per minute.

[5]Fatigue strength tests at 72° to 76° F. were previously made on adhesive 35 in a cooperative project with the Air Force, and, therefore, only check tests of the fatigue data previously obtained were made in this study.

Individual test specimens were placed in the machine, and various loads placed on them in tension before the loading cycles were started. Loading in any cycle varied from the maximum selected to 10 percent of that maximum. The 10 percent minimum was selected, rather than the 1 percent required by Specification No. 14164, because it was believed that the precision at the 1-percent level might actually result in placing the specimen in slight compression at indeterminate times. Actual maximum loads were selected to give a range in number of cycles to failure regularly spaced from at least 10 million cycles to not more than 5,000 cycles. Automatic counters recorded the cycles of loading to failure. Tests at room temperature were made in a controlled room where the relative humidity and temperature were maintained at 50 percent and 75° F., respectively.

For the fatigue tests made at -65° to -70° F., it was necessary to enclose the test specimens in a cooling chamber of the type shown in figure 6. Dry ice was placed in trays in the center of the chamber, and a circulating fan equipped with a thermostat control was used to maintain the temperature on the surface of the specimen near the joint at -65° to -70° F. The test machine was also provided with controls that stopped the tests when the testing temperature became warmer than -50° F.

Tests 6 and 7. Long-time-load strength at 72° to 76° F. and at 178° to 182° F.--Data on the strength in long-time loading of the bonded joints were obtained by applying dead loads to specimens with 1/2-inch lap joints by the use of a cantilever loading apparatus (fig. 7). The specimens were placed in a test fixture of the type shown in figure 8 and were held in place by 3/8-inch-diameter pins passed through the test fixture and through 13/32-inch holes in the ends of the specimens. The test fixture was attached to the frame of the test machine and, through metal straps, to the loading lever. Weights were added to the ends of the lever to apply the proper stress to the test specimens. Each of the levers of the test machine was calibrated with a standard steel bar attached to an electric strain gage, so that the actual applied loads were known for the various weights applied at the end of the various levers.

Loads selected to produce failures, with regular spacing over a range varying from at least 200 hours to less than 1 hour, were applied to each group of specimens. Before the test specimens were loaded, the loading lever was raised with a hydraulic jack, and the specimen was placed in the test fixture. The proper weights, as determined from calibration data, were placed at the end of the lever. The hydraulic jack was then released at such a rate that the desired load was applied in 2 to 3 minutes. The clocks shown in the background of figure 7 were started, and the starting time was recorded. These clocks were in circuit with a switch that stopped them when the specimen failed and the lever arm dropped. Weighted threads with a rosin coating were looped over the shaft of the minute hand of the clocks, so that displacement of this thread would indicate the day and hour of failure.

For the standard-temperature tests, the temperature of the room in which the loading was done was maintained at 72° to 76° F. For the high-temperature tests, a chamber heated by electric light bulbs (fig. 8) was thermostatically controlled, so that the adhesive in the lap joint was at a temperature of 178° to 182° F.

For those bonds that did not fail in 200 hours of loading at either temperature, measurements were taken of the amount of deformation of the adhesive bond at that time. Before they were loaded, a fine line had been scribed on the specimens across the polished edge of the bonded joint normal to the plane of the aluminum sheet. To determine the deformation of the bond, the offset of this line was measured with a measuring microscope (fig. 9), both when the specimen was under load and one week after removal of the load from the specimen.

Test 8. Bend strength at 72° to 76° F.[3]--Bend strength values were obtained on the 1/2-inch lap-joint specimens by centering the specimens flatwise for test as a simple beam, loaded at the center, over a 1-1/2-inch span. The supports and loading blocks were rounded to a radius of 1/4 inch at the point of contact. Load was applied at a rate of approximately 200 pounds per minute. The maximum load was recorded.

Tests 9 and 10. Impact strength at 72° to 76° F. and at -65° to -70° F.[3]--The impact specimens were tested in a pendulum-type impact machine having a 30-foot-pound head. The specimen was held firmly in place to the base of the machine as required by the Air Force Specification 14164. The position of the specimen was adjusted so that the flat striking surface of the head struck the 1-square-inch block at a point 0.1 inch above the bond line, and so that the pendulum was at its maximum velocity at time of impact. The energies absorbed from the swinging pendulum in causing the specimens to fail were computed from calibrations for the test machine.

Tests 11 through 16. Shear strength after exposure to salt-water spray and fluid immersion.[3]--The 1/2-inch lap-joint specimens were exposed as 3-3/4-inch-wide test panels to the following conditions:

Test 11 -- 30-day-exposure to salt-water spray (Federal Specification QQ-M-151).

Test 12 -- 30-day-immersion in tap water.

Test 13 -- 7-day-immersion in ethylene glycol (Military Specification MIL-E-5559).

Test 14 -- 7-day-immersion in anti-icing fluid (Military Specification MIL-F-5566).

Test 15 -- 7-day-immersion in hydraulic oil (Military Specification MIL-0-5606).

Test 16 -- 7-day-immersion in hydrocarbon fluid (Military Specification MIL-H-3136, type III).

These panels were then cut into individual test specimens, and the shear strength of the specimens was determined at 72° to 76° F. as in test 1. The shear strength of the control specimens cut from each of the bond panels before exposure was also determined in this same manner.

All joint specimens prepared in this study were measured before testing for adhesive-film thickness with a measuring microscope. After the tests, all specimens were examined, and the percentages of bond failure in adhesion to metal, cohesion of the adhesive, and other types of failures were estimated.

Results and Discussion

The average results of the shear tests made at -65° to -70° F., at 72° to 76° F., and at 178° to 182° F.; the fatigue tests made at -65° to -70° F. and at 72° to 76° F.; and the long-time loading tests made at 72° to 76° F. and at 178° to 182° F. are summarized in table 2. The average results of the impact tests at 72° to 76° F. and at -65° to -70° F., the bend tests at 72° to 76° F., and the shear tests made at 72° to 76° F. after salt-water spray and immersion exposures are summarized in table 2a.

Shear Strength

The adhesives tested in this study met the shear strength requirements of the Air Force Specification No. 14164 with the exception of adhesive 25-26 in the low-temperature (-65° to -70° F.) shear test and adhesive 38 in the elevated-temperature (178° to 182° F.) shear test.

Adhesive 25-26 can, for all practical purposes, also be considered to meet the shear strength requirements at -65° to -70° F. (2,500 pounds per square inch), because the bond strength values for the 1/2-inch lap joints bonded with this adhesive process averaged close (2,414 pounds per square inch) to the specification requirement. The 3/8-inch lap joints bonded with adhesive 25-26 that were tested in shear at -65° to -70° F. or at 72° to 76° F. as controls for the fatigue tests (table 2, test conditions 4 and 5) showed a higher average bond strength at the low temperature, even with some individual specimens having low bond strength values, than at 72° to 76° F. There was poor correlation between shear test results obtained on these 1/2- and 3/8-inch lap joints bonded with adhesive 25-26 and tested at -65° to -70° F., but, as discussed later under fatigue tests, this adhesive process and also adhesive 25 appear to have a strength-transition temperature near -70° F. This strength transition near -70° F. for the adhesive 25-26 may account for the inconsistent results obtained when shear tests are made on this adhesive at -65° to -70° F.

The elevated-temperature shear strength results obtained with adhesive 38, run 2, averaged so close (1,166 pounds per square inch) to the specification requirement (1,250 pounds per square inch) that this adhesive, along with all of the other adhesives tested in this study, can probably be considered to meet the shear strength requirements of the Air Force Specification No. 14164.

Two conditions required for conducting the shear tests in this specification deserve some further consideration and possible modification. The loading rate of 600 to 700 pounds per square inch per minute (300 to 350 pounds per one-half square inch per minute) is considerably slower than is the usual practice in much of the routine testing of such lap joints in various plants and laboratories. It is known that faster rates of loading will give somewhat higher failing loads in this test, and some of the high shear values reported by other laboratories for some of these same adhesives were obtained when faster rates of loading were used than prescribed in the specification. It would seem that a rate of 600 to 700 pounds per minute on the 1/2-square-inch specimen would be reasonable, but some further tests should be made to determine the relationship between results with the two rates of loading. The maximum period that the specimens should be exposed to the test temperature conditions, before loading as well as the minimum period (30 minutes), should be stated in this specification in order to eliminate any wide variation in the method of making these tests. Exposure of undercured specimens at 180° F. for several hours without load before testing might significantly improve their subsequent joint performance.

Shear Strength after Salt-water Spray and Immersion Exposures

As shown in table 2a, exposure to salt-water spray and immersion in water and organic fluids had little effect on the shear strength of the bonded aluminum lap joints with the exceptions that adhesives 25 and 25-26 in the 30-day-exposure to salt-water spray, adhesive 38 in the 30-day-immersion in tap water, and adhesive 36 in the 7-day-immersion in hydrocarbon fluid fell below the shear strength requirement of 2,000 pounds per square inch of Air Force Specification No. 14164.

Fatigue Strength

The individual test data obtained in the fatigue tests of the adhesives are given in tables 3 through 20. These test data are presented in two graphical forms in figures 10 through 25. In the one graphical form, these data are presented, as required by Air Force Specification No. 14164, to show the relationship between the maximum repeated stresses, expressed in pounds per square inch, and the number of cycles to failure. In the other graphical form, these data are presented to show the relationship between maximum repeated stresses, expressed as a percentage of the static shear strength for the panel from which the individual test specimens were selected, and the number of cycles to failure. In each instance, the S-N curve was located by inspection and a smooth curve was drawn through the plotted points. The second graphical form is believed to have certain advantages over the first form in that minor variations in the quality of bonds from one panel to the next panel are not so likely to cause variability in the relationship between stress and the number of cycles to failure. This second method of representation also has an advantage in that the percentage values obtained can be applied more directly to computing the probable fatigue strength of other adhesive bonds made with these same adhesives when the control strengths vary from those obtained in this study.

The fatigue strength values for the various adhesives were determined, as required in the Air Force Specification, by inspection for the stress at which the S-N curves (stress in pounds per square inch) intersect the 10-million-cycle ordinate. These fatigue strength values are summarized in table 2. Of the nine metal-bonding adhesives tested in this study for fatigue strength at 72° to 76° F. and at -65° to -70° F., only two adhesives (adhesives 33 and 35[6]) failed to meet the requirement of the Air Force Specification No. 14164 that the adhesive-bonded joints should have a fatigue strength for 10 million cycles of at least 650 pounds per square inch when tested at 72° to 76° F. and at -65° to -70° F. The bonds made with adhesives 33 and 35 failed to meet the requirements for fatigue strength at 72° to 76° F., but at -65° to -70° F. the fatigue strength exceeded the requirement of the specification.

The results of these fatigue tests have shown that, in general, this procedure is a satisfactory method of test for determining the fatigue strength of the metal-bonding adhesives. With any one adhesive-test temperature condition, the number of cycles to failure at any one stress level generally fell within a small range, and, as a result, the curve to show the relationship between stress and number of cycles to failure (S-N curve) was easy to locate by inspection.

When three of the adhesives (adhesives 36, 37, and 38) were being tested in fatigue at 72° to 76° F., it was necessary to monitor frequently the test machine during the tests at the high stresses to compensate for the yield of the adhesive bonds. With the one adhesive (adhesive 37), a number of specimens failed by a continuous yielding at the high-stress levels before the fatigue machine could be initially adjusted and the cyclic loading started.

A different phenomenon was observed during the testing of two of the other adhesives (adhesives 25 and 25-26). Some of the specimens being tested in fatigue at -65° to -70° F. failed while being adjusted with 40 to 70 percent of static strength before the cyclic loading could be started. These failures were in adhesion, and frequently the adhesive separated from both faying surfaces of the lap joint. Other specimens from this same group that did not fail during the initial adjustment gave test points that appeared to be a reliable indication of the fatigue characteristics for these adhesives. Because there were only a limited number of

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[6] Adhesives 33 and 35 are reported to be the same adhesive formulation prepared by different manufacturers.

specimens that did not fail prematurely in the fatigue tests at -65° to -70° F., the fatigue curves for adhesives 25 and 25-26 at -65° to -70° F. must be considered as only approximations.

In static shear strength tests made for the Air Force at temperatures from 75° to -130° F. on lap-joint aluminum specimens bonded with adhesive 25, this adhesive displayed a strength-transition temperature near -70° F., and at -80° F. the strength was less than one-third of the strength at -65° F. Similar static shear strength tests over the range from 75° to -130° F. have not been made on the other adhesives. This change in strength near -70° F. for adhesive 25 may account for some of the specimens bonded with adhesives 25 and 25-26 failing immediately when given an initial load in the fatigue machine at -65° to -70° F. Because of the immediate failure of some of the lap-joint specimens bonded with adhesives 25 and 25-26 when given a low stress in the fatigue machine at -65° to -70° F., it is recommended that caution be exercised when using these two adhesives and that such temperature limitations of the other metal-bonding adhesives be similarly investigated in lap joints.

When low stresses were applied to the 3/8-inch lap-joint specimens of 0.064-inch, 24S-T3 clad aluminum alloy bonded with the adhesives having good fatigue resistance, the failures were, in most instances, tension failures in the metal. In actual design of bonded joints, it would be normal practice to have the ratio of overlap to the thickness of metal greater than used in this fatigue specimen. In practically all instances when two sheets of metal are to be lap jointed together with these metal-bonding adhesives, therefore, primary concern should be with the fatigue characteristics of the metal rather than of the adhesive.

In making these fatigue tests, only one major change was made in the test method from that outlined in the Air Force Specification No. 14164. This specification states that the cyclic load applied to the specimen shall be tensile and shall vary from the maximum selected to approximately 1 percent of the maximum. In the tests for this study, the cyclic loads were varied from the maximum selected to 10 percent of that maximum in order to avoid any zero or negative stresses being applied to the specimens when there was a slight reduction in the applied load during the repeated stressing. With pin-connected fittings, any zero or negative loading would cause excessive chattering in the fittings and make it difficult to maintain proper alinement of the specimen.

The Air Force Specification No. 14164 does not state the distance from the ends of the test grips to the lap of the joint that should be used in making fatigue tests on these aluminum lap joints. It is believed that this dimension should be standardized. It was found in some exploratory tests, with specimens bonded with a phenol-butyral-resin formulation, that distances of 1/2, 1, and 2 inches from the ends of the grips to the lap of the joint did not affect the strength results obtained in static shear tests, but that in fatigue tests, at 72° to 76° F., a 2-inch distance resulted in a lower number of cycles to failure at a particular stress level than did distances of 1/2 or 1 inch. A distance of 1 inch was therefore used for all fatigue tests made in this study, and this distance is believed to be suitable for use in any revisions of this test method.

Long-time-load Strength

The individual test data for the long-time-loading tests are given in tables 21 through 30 with the graphical representation of these data presented in figures 26 through 33. The relationship between the stress applied in pounds per square inch and the time to failure is shown in these figures as the smooth curve through the points of minimum stress. The values for strength in long-time-loading, determined as required by the Air Force Specification as the stress at which the curves intersect the 200-hour ordinate, are summarized in table 2.

The long-time-loading tests made on the adhesives included in this study showed that, at 72° to 76° F., one adhesive (adhesive 38) approached closely the strength requirement of 1,600 pounds per square inch (with an average value of 1,590 pounds per square inch) and that all of the other adhesives exceeded this requirement, in several cases by wide margins. Measurements made, as required in the specification, to determine the amount of deformation occurring in the specimens that did not fail in 200 hours of loading at 72° to 76° F. showed that bonds made with adhesives 36, 37, and 38 displayed considerable deformation, or creep (from 0.0144 to 0.0308 inch when under load and 0.0105 to 0.0186 inch after unloading). Adhesives 25 and 25-26 also showed about the same amount of deformation while still under load at 72° to 76° F., but the permanent deformation (observed after unloading) was approximately half of that under load and thus much less than for adhesives 36, 37, and 38. Paragraph 4.3.3.6 of the specification states that specimens which are not failed in 200 hours shall in that time deform no more than an amount equal to twice the thickness of the adhesive film. This would seem to refer to deformation under load rather than to deformation after recovery. On this basis, adhesives 25, 25-26, 36, 37, 38 (run 2) would fail to meet this requirement.

In the long-time-load strength tests at 178° to 182° F., only four of the nine adhesives evaluated in this study met the specification requirement of 800 pounds for 200 hours or longer. One of the adhesives (adhesive 34) that failed to meet this requirement had a long-time strength (720 pounds) that was only slightly less than that required by the specification, but adhesives 36, 37, 38, and 41 had strength values that were only about one-half of that required by the specification.

These long-time-loading tests appear to be a suitable means for evaluating this property of the metal-bonding adhesives. There is some question of the validity of the present limitation on the amount of deformation under load during the 200-hour period at 72° to 76° F. with respect to the bond thickness. The present requirement specifies that this deformation under load shall not be more than twice the bond thickness. It is quite possible that two adhesives may both meet the strength requirement of 1,600 pounds per square inch after 200 hours of loading at 72° to 76° F. One adhesive may barely meet the load requirement and in doing so not undergo much deformation. The other adhesive may withstand loading of 2,400 pounds or more for 200 hours and, in supporting this heavier load, may suffer somewhat more deformation than is currently permitted. If the test were run so that only 1,600 pounds was applied, however, this adhesive might deform very slightly under load and meet the requirement. The present deformation requirement, which neglects the actual magnitude of the load at 200 hours, thus penalizes the higher-strength adhesives. Consideration might be given to specifying that deformation be measured only on specimens loaded with 1,600 pounds per square inch for 200 hours at 72° to 76° F. Consideration might also be given to evaluation of the deformation after the load is removed in addition to, or in place of, the deformation under load.

For production or control testing of these adhesives, the method of testing strength in long-time loading could probably be simplified by merely applying the load required by the specification to a limited number of specimens and then noting if the bonds would withstand 200 hours of loading without failure.

Beam Bend Strength in Lap-joint Specimen

The beam bend strength of all adhesives tested met the requirement of Air Force Specification No. 14164 of 150 pounds for this test. It was found in exploratory tests that the exact centering of the loading block over the center of the lap was important in order to obtain reproducible results.

Impact Strength

Of the nine adhesives tested only one (adhesive 34) met the room- and low-temperature impact strength requirements of Air Force Specification No. 14164, and it did this by a good margin. Adhesives 35 and 36 met the requirement for impact at 72° to 76° F. but not at -65° to -70° F. The low-temperature impact strength values of adhesives 25 and 25-26 were unusually low and considerably lower than those of other adhesives tested.

Conclusions

The nine adhesives evaluated in this study, in general, met the shear strength requirements at the three test temperatures, after exposure to salt-water spray, and after immersion in water and aircraft fluids. One or two exceptions were noted in certain tests. No change seems necessary in the specified strength requirements for these tests, but consideration should be given to increasing the rate of load for the shear test and to more definitely stating the length of period to be used for conditioning the specimens before the shear tests at -65° to -70° F. and at 178° to 182° F.

Only two of the nine adhesives evaluated failed to meet the requirements for fatigue strength at 72° to 76° F., and all of the adhesives met the requirements for fatigue strength at -65° to -70° F. It is recommended that the present strength requirements for these tests be retained. Test loads applied should be from the maximum selected to 10 percent of that maximum, and the distance from the test grip to the end of the lap should be specified as 1 inch. These conditions were used in the present study.

Consideration should also be given to eliminating the expensive fatigue test at -65° to -70° F., as the fatigue strength at low temperatures, determined by the present method, exceeded the fatigue strength at 72° to 76° F. for adhesives evaluated, and in most instances the specimens tested at -65° to -70° F. failed in the metal when the applied stresses were low. Failure in the metal was also noted in some fatigue tests at 72° to 76° F., and it may be necessary to shorten the overlap in order to obtain all failures in the adhesive bond.

Five of the nine adhesives tested did not meet the requirement for strength in long-time loading at 178° to 182° F. All of the adhesives met the strength requirements for the long-time-load test at 72° to 76° F., but five of the adhesives showed a greater deformation in the adhesive bond during 200 hours at 72° to 76° F. than is permitted by Air Force Specification 14164.

The deformation permitted during the long-time-load tests should be modified so as not to penalize adhesives having high strength in long-time loading. It is also possible that the requirements for qualifying adhesives by the long-time-load tests could be simplified by running only a limited number of tests at a single specified load, such as 800 pounds per square inch, for a standard time period, such as 200 hours, and noting failure or absence of failure after this period.

All of the adhesives tested met the bending strength requirements of the specification.

Only one of the nine adhesives tested met the requirement for impact strength at both 72° to 76° F. and at -65° to -70° F. The values obtained in this test seem to depend greatly on the method of holding the test specimens; and it is doubtful if the present method is reproducible to the extent required for this specification.

Table 1.--Bonding conditions used in preparation of lap-joint specimens of 24S-T3 clad aluminum alloy[1, 2]

Adhesive	Adhesive spread[3]	Assembly condition	Curing time and temperature[4]	Pressure
				P.s.i.
Adhesive 25	6 double-pass spray coats	18 to 24 hours of air drying	25 minutes at 325° F.	200
Adhesive 25 with adhesive 26	5 double-pass spray coats of adhesive 25	18 hours of air drying for adhesive 25	25 minutes at 325° F. for adhesive 25	No pressure used during the curing of adhesive 25
	1 light brush coat of adhesive 26 applied over the cured adhesive 25	18 hours of air drying followed by precuring for 30 minutes at 185° - 190° F. for adhesive 26	15 minutes at 300° F. for adhesive 26	50
Adhesive 33	5 double-pass spray coats	18 hours of air drying followed by precuring for 45 minutes at 200° F.	24 minutes at 300° F.	200 (pressure was not applied during the first 9 minutes of curing)
Adhesive 34	1 medium brush coat of liquid; powder sprinkled into liquid	18 to 24 hours of air drying	15 minutes at 300° F.	200
Adhesive 35	5 double-pass spray coats	18 hours of air drying followed by precuring for 45 minutes at 200° F.	24 minutes at 300° F.	200 (pressure was not applied during the first 9 minutes of curing)
Adhesive 36	10 light spray coats	1 hour of air drying followed by precuring for 45 minutes at 160° F.	35 minutes at 330° F.	200

(Sheet 1 of 3)

Table 1.--Bonding conditions used in preparation of lap-joint specimens of 24S-T3 clad aluminum alloy[1], [2] (Continued)

Adhesive	Adhesive spread[3]	Assembly condition	Curing time and temperature[4]	Pressure
				P.s.i.
Adhesive 37	10 light spray coats of adhesive 36	1 hour of air drying followed by precuring for 45 minutes at 160° F. for adhesive 36	35 minutes at 330° F.; both adhesive components cured together	200
	2 brush coats of second resin adhesive applied over air-dried adhesive 36	1 hour of air drying followed by precuring for 45 minutes at 200° F. for second resin component		
Adhesive 38, run 1	3 light spray coats of adhesive 36, 1 sheet of tape adhesive	3 to 5 hours of air drying for adhesive 36	35 minutes at 330° F.; both adhesive 36 and tape cured together	90-100
Adhesive 38, run 2	4 light spray coats of adhesive 36, 1 sheet of tape adhesive	3 to 5 hours of air drying for adhesive 36	1 hour at 330° F.[5]; both adhesive 36 and tape cured together	90-100
Adhesive 41	1 medium brush coat	Immediate assembly	45 minutes at a glue-line temperature of 200° F. (approximately 40 additional minutes were required for the oven and adhesive bond to reach this temperature)	Contact

Table 1.--Bonding conditions used in preparation of lap-joint specimens of 24S-T3 clad aluminum alloy[1], [2] (Continued)

Footnotes --

[1]These bonding conditions were within the range of conditions generally recommended by the manufacturer of the adhesive.

[2]The aluminum-alloy sheets were prepared for bonding by washing their surfaces with benzene and then immersing the sheets for 10 minutes at 140° to 160° F. in a solution of the following composition by weight: 1 part of sodium dichromate, 10 parts of concentrated sulfuric acid, and 30 parts of water. After removal from the solution, the sheets were rinsed and dried.

[3]All adhesives were applied to both metal surfaces. The final thicknesses of the cured adhesive film in the bonds are given in table 2.

[4]The curing time is the total time in the press at the platen temperature, except where noted otherwise. The time normally required for the adhesive film to reach the platen temperature was less than 5 minutes.

[5]The initial curing of the adhesive was started with a lower platen temperature of approximately 300° F., so that one-half of the 1-hour pressing period was used in bringing the glue-line temperature to 330° F.

(Sheet 3 of 3)

Table 2.--Summary of test results obtained in evaluation of structural metal-bonding adhesives in lap-joints of 0.064-inch 24S-T3 clad aluminum alloy

Test condition	Air Force Spec. No. 14164 shear strength requirement	Test results[1] for: Adhesive 25	Adhesives 25 and 26	Adhesive 33	Adhesive 34	Adhesive 35	Adhesive 36	Adhesive 37	Adhesive 38 (Run 1)	Adhesive 38 (Run 2)	Adhesive 41
	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.
1. Standard-temperature (72° to 76° F.) shear strength[2]	2,500	3,236 65-6.4-27	3,382 96-5.0-27	4,561 86-2.9-27	4,230 76-3.4-27	3,898 80-3.0-27	3,442 86-3.6-27	3,555 92-5.8-27	2,496 83-7.3-27	2,679 79-10.3-27	3,578 97-5.3-27
2. Elevated-temperature (178° to 182° F.) shear strength[2]	1,250	[5]1,959 94-5.1-9	[5]2,009 97-5.7-9	[6]4,025 73-2.9-9	[5]1,304 99-3.7-9	[5]3,406 94-2.9-9	[5]1,600 81-4.4-9	[5]1,516 69-5.3-9	[5]934 30-7.6-9	[6]1,166 81-8.4-9	[6]1,668 45-6.3-8
3. Low-temperature (-65° to -70° F.) shear strength[2]	2,500	[6]4,442 18-4.7-6	[6]2,414 8-6.1-6	[6]3,292 11-2.9-6	[6]3,466 100-3.7-6	[6]2,758 72-3.0-6	[6]4,946 23-4.0-6	[6]5,090 57-5.6-6	[6]2,486 69-8.2-6	[6]3,302 98-8.1-6	[6]2,509 98-6.8-6
4. Standard-temperature (72° to 76° F.) fatigue strength[3,4] (10 million cycles)	650	[7]1,325	[7]1,240	470	770	[8]500	685	735	840	830	1,100
Control strength[3] (72° to 76° F.)	---	3,405 66-7.6-12	2,966 93-4.5-12	5,187 92-3.3-12	4,263 85-4.5-12	4,132 81-5.3-12	3,806 79-5.9-10	3,511 96-5.9-12	2,716 76-6.5-10	2,681 72-9.1-12	4,316 99-6.0-12
5. Low-temperature (-65° to -70° F.) fatigue strength[3,4] (10 million cycles)	650	[7]1,150	[7]1,075	675	[7]1,240	850	[7]1,095	[7]1,180	---	[7]1,350	1,100
Control strength[3] (-65° to -70° F.)	---	4,835 23-([9])-12	3,957 17-([9])-12	3,909 15-3.3-12	4,261 96-4.4-12	2,799 42-5.3-11	5,477 33-5.8-10	5,363 90-6.0-12	3,179 76-7.7-10	3,723 100-9.0-12	2,950 97-5.3-12
6. Standard-temperature (72° to 76° F.) long-time strength[2,4]											
200 hr.	1,600	1,975	2,180	3,680	3,300	3,680	2,140	2,050	1,590	1,590	2,990
10 hr.	---	2,035	3,350	3,705	3,390	3,705	2,290	2,260	1,665	1,680	3,190
1 hr.	---	2,210	2,495	3,750	3,510	3,750	2,595	2,700	1,850	1,975	3,450
7. Elevated-temperature (178° to 182° F.) long-time strength[2,4]											
200 hr.	800	1,000	1,185	1,620	720	1,560	400	430	390	350	310
10 hr.	---	1,050	1,310	1,720	725	1,640	575	630	435	550	550
1 hr.	---	1,450	1,495	1,805	760	1,805	790	910	530	780	1,010

[1]These results were obtained on lap-joint specimens fabricated under the bonding conditions described in table 1. The first values given are the shear strength results. Listed underneath the shear strength results are: First, the estimated percentage of cohesion failure in the adhesive; second, the adhesive film thickness in mils; and third, the number of specimens averaged in the result. The rate of loading for tests 1, 2, and 3 and the control tests for tests 4 and 5 was 600 pounds per square inch per minute.

[2]Test results obtained with a 1/2-inch overlap specimen.

[3]Test results obtained with a 3/8-inch overlap specimen.

[4]Values are taken from smooth curves drawn through the minimum-strength values.

[5]Bonded joints tested approximately 10 minutes after being placed in test chamber at desired temperature.

[6]Bonded joints tested approximately 30 minutes after being placed in test chamber at desired temperature.

[7]Failures at or near this stress were tension failures of the metal.

[8]Values obtained from a limited number of tests made to confirm test data obtained for this adhesive in a previous study for the Wright Air Development Center.

[9]Thickness of film was not observed.

Table 2a.--Summary of test results[1] obtained in evaluation of structural metal-bonding adhesives in lap joints of 0.064-inch 24S-T3 clad aluminum alloy and in impact-type specimens of 24S-T3 bare aluminum alloy

Test condition	Air Force Spec. No. 14164 strength requirement	Test results for Adhesive 25	Adhesives 25 and 26	Adhesive 33	Adhesive 34	Adhesive 35	Adhesive 36	Adhesive 37	Adhesive 38	Adhesive 41
	P.s.i.									
8. Standard-temperature (72° to 76° F.) bend strength[2]	150 (pounds)	196 (3,020)	167 (2,590)	173 (4,515)	210 (4,870)	196 (4,660)	168 (2,710)	197 (3,040)	186 (2,630)	172 (3,980)
9. Standard-temperature (72° to 76° F.) impact strength[3]	10 (foot-pounds)	4.0 (7.0)	6.7 (3.0)	7.0 (5.0)	28.2 (7.0)	10.5 (5.0)	15.7 (10.0)	9.0 (4.0)	4.0 (7.0)	5.6 (3.0)
10. Low-temperature (-65° to -70° F.) impact strength[3]	5 (foot-pounds)	0.42 (7.0)	0.60 (3.0)	2.6 (5.0)	24.0 (7.0)	3.5 (5.0)	2.6 (10.0)	1.4 (4.0)	3.1 (7.0)	6.4 (3.0)
11. Shear strength - after 30-day salt-water spray (Federal Specification QQ-M-151)[4]	2,000	870-100 (3,385)	[5]1,715-90 (3,070)	4,375-10 (4,200)	4,990-30 (5,015)	4,945-10 (4,470)	2,720-60 (2,950)	[5]2,750-90 (3,680)	[5]2,495-90 (2,930)	[5]3,440-100 (4,295)
12. Shear strength - after 30-day immersion in tap water[4]	2,000	3,410-100 (3,385)	3,330-100 (3,255)	4,615-10 (4,250)	4,685-20 (4,855)	4,920-10 (4,485)	2,885-50 (3,470)	3,455-80 (3,550)	[5]1,970-90 (2,760)	3,260-90 (4,020)
13. Shear strength - after 7-day immersion in ethylene glycol (Military Specification MIL-E-5559)[4]	2,000	2,985-70 (2,895)	2,980-90 (3,015)	4,290-0 (4,525)	5,135-20 (5,055)	4,730-0 (4,875)	2,765-70 (2,680)	3,375-90 (3,150)	2,605-70 (2,500)	3,955-90 (4,010)
14. Shear strength - after 7-day immersion in anti-icing fluid (Military Specification MIL-F-5566)[4]	2,000	3,425-100 (3,315)	3,440-100 (3,175)	4,250-0 (4,530)	4,195-20 (5,170)	3,870-0 (4,600)	3,195-50 (3,210)	3,680-80 (3,510)	3,015-90 (2,880)	3,850-90 (4,300)
15. Shear strength - after 7-day immersion in hydraulic oil (Military Specification MIL-O-5606)[4]	2,000	3,170-100 (3,020)	2,895-100 (3,140)	4,110-10 (4,380)	4,872-30 (4,985)	4,760-10 (4,735)	2,475-50 (2,560)	3,230-90 (3,190)	2,430-60 (2,665)	3,845-90 (3,865)
16. Shear strength - after 7-day immersion in hydrocarbon fluid (Military Specification MIL-H-3136, Type III)[4]	2,000	2,905-100 (3,015)	2,610-100 (2,960)	4,505-10 (4,670)	4,980-20 (4,880)	4,860-10 (4,710)	1,855-60 (2,695)	3,130-90 (3,300)	2,300-80 (2,550)	3,985-90 (4,005)

[1]These results, taken from Wright Air Development Center Technical Note WCRTS 52-112, "Properties of Adhesive Bonded Aluminum Alloy Lap Joints," were obtained by the WADC on specimens fabricated by the Forest Products Laboratory using essentially the same conditions as listed in table 1.

[2]The first value given for the bend strength tests is the average load in pounds to cause failure in bending for three 1/2-inch lap-joint specimens cut from one panel, when loaded at the center over a 1-1/2-inch span. The second value, in parentheses, for the bend tests is the shear test value in pounds per square inch obtained when two specimens cut from the same panel were tested at 72° to 76° F. as controls.

[3]The first value given for the impact strength tests is the average impact strength in foot-pounds for five impact specimens consisting of 3/8-inch-thick 24S-T3 bare aluminum alloy blocks bonded for 1 square inch to 3/4-inch-thick 24S-T3 bare aluminum alloy. The second value, in parentheses, is the average adhesive film thickness in mils. The impact specimens were prepared in groups of five cut from a single bonded assembly using a milling machine cut-off saw.

[4]The first value given for the salt-water spray and immersion tests is the average shear strength in pounds per square inch for six 1/2-inch lap-joint specimens cut from two 3-3/4-inch-wide test panels following the indicated test exposure. The second value, after the dash, is the average estimated percentage of cohesion failure of the adhesive in the bond area. The third value, in parentheses, is the average shear strength in pounds per square inch for four control test specimens cut prior to exposure from the edges of the same two panels.

[5]There was evidence of corrosion in glue line of edge specimens.

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Table 3.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 25[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
25-10-2	3,520	2,460	70	19,500	95	5	0.0066
3	3,520	1,410	40	21,587,900	Specimen did not fail		.0056
4	3,520	1,935	55	258,900	Tension failure in metal		.0056
25-11-7	3,210	2,250	70	39,000	95	5	.0086
8	3,210	1,280	40	6,521,700	Tension failure in metal		.0089
9	3,210	1,765	55	508,100	........do.........		.0082
25-12-2	3,260	1,960	60	232,300	........do.........		.0087
3	3,260	980	30	22,169,800	Specimen did not fail		.0083
4	3,260	2,120	65	39,300	95	5	.0089
25-13-7	3,710	2,230	60	35,200	95	5	.0070
8	3,710	1,110	30	27,234,900	Specimen did not fail		.0071
9	3,710	2,410	65	14,800	100	0	.0073
25-14-2	3,420	1,710	50	470,000	Tension failure in metal		.0081
3	3,420	1,540	45	1,441,500	........do.........		.0079
4	3,420	2,565	75	2,900	100	0	.0081
25-15-7	3,310	1,655	50	473,100	Tension failure in metal		.0077
8	3,310	1,480	45	1,813,400	........do.........		.0076
9	3,310	2,480	75	3,600	100	0	.0076

[1]Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch, 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at 72° to 76° F. for two test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 4.--Summary of individual results of fatigue tests at -65° to -70° F. of lap-joint specimens bonded with adhesive 25[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
25-10-7	4,950	3,465	70	[4] 0	0	100	0.0073
8	4,950	1,980	40	157,000	0	100	.0071
9	4,950	1,240	25	5,886,600	Tension failure in metal		.0074
25-11-2	4,920	3,445	70	[4] 0	0	100	.0092
3	4,920	1,970	40	[4] 0	0	100	.0080
4	4,920	1,230	25	2,941,200	Tension failure in metal		.0084
25-12-7	4,630	2,780	60	40,600	35	65	.0082
8	4,630	1,390	30	1,100	0	100	.0083
9	4,630	1,390	30	3,197,800	Tension failure in metal		.0085
25-13-2	5,410	3,245	60	[4] 0	0	100	.0072
3	5,410	1,625	30	1,051,800	Tension failure in metal		.0065
4	5,410	2,705	50	16,500	30	70	.0067
25-14-7	5,620	2,810	50	9,700	40	60	.0079
8	5,620	2,250	40	[4] 0	0	100	.0074
9	5,620	2,250	40	[4] 0	0	100	.0074
25-15-2	4,470	2,235	50	[4] 0	0	100	.0074
3	4,470	1,115	25	20,031,600	Specimen did not fail		.0079
4	4,470	2,680	60	[4] 0	0	100	.0077

[1] Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2] Control-strength values are the average shear strength at -65° to -70° F. for two test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3] Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

[4] Specimen failed while load was being adjusted.

Table 5.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 25-26[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
26-10-2	2,815	1,970	70	73,900	100	0	0.0039
3	2,815	1,125	40	25,390,500	Specimen did not fail		.0042
4	2,815	1,210	43	20,447,400	........do.........		.0043
26-11-7	2,980	2,980	70	1,700	100	0	.0050
8	2,980	1,190	40	23,783,500	Specimen did not fail		.0048
9	2,980	2,085	70	201,600	100	0	.0047
26-12-2	2,980	1,790	60	267,600	100	0	.0047
3	2,980	895	30	23,656,900	Specimen did not fail		.0046
4	2,980	1,280	43	2,650,300	Tension failure in metal		.0046
26-13-7	2,905	1,740	60	205,500	100	0	.0060
8	2,905	870	30	20,305,300	Specimen did not fail		.0050
9	2,905	1,305	45	2,040,100	Tension failure in metal		.0052
26-14-2	3,155	1,580	50	666,300	........do.........		.0045
3	3,155	1,357	43	936,300	........do.........		.0044
4	3,155	1,295	41	25,543,200	Specimen did not fail		.0043
26-15-7	2,965	1,480	50	718,200	Tension failure in metal		.0040
8	2,965	1,335	45	1,963,800	........do.........		.0041
9	2,965	2,075	70	14,400	100	0	.0041

[1]Tests were made in an axial-loading fatigue machine at the rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at 72° to 76° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 6.--Summary of individual results of fatigue tests at -65° to -70° F. of lap-joint specimens bonded with adhesive 25-26[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
26-10-7	[4]5,070	3,550	70	0	15	85	0.0050
8	[4]5,070	2,030	40	0	10	90	.0041
9	[4]5,070	1,265	25	4,749,700	Tension failure in metal		.0046
26-11-2	4,780	3,345	70	0	10	90	.0044
3	4,780	1,915	40	0	10	90	.0045
26-12-7	4,950	2,970	60	7,000	10	90	.0051
8	4,950	1,485	30	4,650,400	Tension failure in metal		.0048
9	4,950	1,980	40	2,300	10	90	.0053
26-13-2	[5]4,890	2,935	60	0	10	90	.0057
3	[5]4,890	2,445	50	9,900	20	80	.0056
4	[5]4,890	1,955	40	0	15	85	.0059
26-14-7	[4]4,910	2,455	50	28,200	20	80	.0058
8	[4]4,910	980	20	20,230,800	Specimen did not fail		.0055
9	[4]4,910	2,945	60	0	10	90	.0058
26-15-2	4,820	2,410	50	0	15	85	.0055
3	4,820	965	20	20,120,600	Specimen did not fail		.0056
4	4,820	1,445	30	4,602,100	Tension failure in metal		.0052

[1]Tests were made in an axial-loading fatigue machine at the rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at -65° to -70° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

[4]Control strength based on only one test.

[5]The average of satisfactory controls in other panels was used as the control strength, because the controls for this panel were low and erratic.

Table 7.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 33[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
33-10-2	5,000	3,500	70	300	60	40	0.0029
3	5,000	2,000	40	5,000	20	80	.0025
4	5,000	750	15	410,000	15	85	.0027
33-11-7	5,355	3,750	70	100	25	75	.0032
8	5,355	2,140	40	2,000	20	80	.0034
9	5,355	805	15	260,400	5	95	.0030
33-12-2	5,135	3,080	60	200	5	95	.0031
3	5,135	1,540	30	13,600	20	80	.0030
4	5,135	515	10	2,563,600	20	80	.0030
33-13-7	5,200	3,120	60	200	35	65	.0033
8	5,200	1,560	30	10,000	20	80	.0032
9	5,200	520	10	2,636,900	30	70	.0030
33-14-2	5,120	2,560	50	900	20	80	.0034
3	5,120	1,025	20	68,900	5	95	.0037
4	5,120	410	8	20,609,700	Specimen did not fail		.0031
33-15-7	5,310	2,655	50	800	30	70	.0034
8	5,310	1,060	20	69,900	10	90	.0037
9	5,310	425	8	20,609,700	Specimen did not fail		.0030

[1]Tests were made in an axial-loading fatigue machine at the rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at 72° to 76° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 8.--Summary of individual results of fatigue tests at -65° to -70° F. of lap-joint specimens bonded with adhesive 33[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
33-10-7	4,000	2,800	70	3,500	30	70	0.0033
8	4,000	1,600	40	125,200	20	80	.0036
9	4,000	720	18	7,082,300	15	85	.0032
33-11-2	3,815	2,670	70	[4] 1	5	95	.0033
3	3,815	1,525	40	101,700	5	95	.0033
4	3,815	955	25	1,167,300	10	90	.0031
33-12-7	4,190	2,515	60	8,400	15	85	.0029
8	4,190	1,255	30	493,000	10	90	.0031
9	4,190	1,050	25	1,903,800	10	90	.0022
33-13-2	4,055	2,435	60	1,000	10	90	.0036
3	4,055	1,215	30	404,400	5	95	.0032
4	4,055	730	18	4,432,000	20	80	.0032
33-14-7	3,800	1,900	50	39,900	10	90	.0032
8	3,800	760	20	20,168,200	Specimen did not fail		.0029
33-15-2	3,570	1,785	50	73,400	10	90	.0035
3	3,570	715	20	4,052,600	15	85	.0030

[1]Tests were made in an axial-loading fatigue machine at the rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at 72° to 76° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

[4]Specimen failed during first application of load.

Table 9.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 34[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
34-10-2	4,280	3,000	70	2,800	85	15	0.0044
3	4,280	1,710	40	72,700	95	5	.0050
4	4,280	840	19.5	4,787,200	95	5	.0051
34-11-7	4,210	2,950	70	3,600	80	20	.0045
8	4,210	1,685	40	68,600	95	5	.0046
9	4,210	675	16	35,702,000	Specimen did not fail		.0048
34-12-2	4,660	2,800	60	5,400	95	5	.0038
3	4,660	1,400	30	273,000	95	5	.0038
4	4,660	840	18	6,149,600	95	5	.0043
34-13-7	3,980	2,390	60	3,500	95	5	.0052
8	3,980	1,195	30	276,800	95	5	.0048
9	3,980	715	18	11,857,100	100	0	.0049
34-14-2	4,710	2,355	50	20,800	100	0	.0026
3	4,710	1,180	25	576,200	100	0	.0033
4	4,710	755	16	6,791,000	Tension failure in metal		.0036
34-15-7	3,740	1,870	50	45,300	100	0	.0055
8	3,740	935	25	969,600	100	0	.0079
9	3,740	600	16	40,206,600	Specimen did not fail		.0068

[1] Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch, 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2] Control-strength values are the average shear strength at 72° to 76° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3] Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 10.--Summary of individual results of fatigue tests at -65° to -70° F. of lap-joint specimens bonded with adhesive 34[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
34-10-7	3,640	2,550	70	4,300	50	50	0.0050
8	3,640	1,455	40	1,631,500	80	20	.0051
9	3,640	1,640	45	970,200	75	25	.0044
34-11-2	4,055	2,835	70	1,900	60	40	.0043
3	4,055	1,620	40	2,659,000	Tension failure in metal		.0043
4	4,055	1,825	45	319,800	95	5	.0042
34-12-7	4,695	2,815	60	9,700	95	5	.0045
8	4,695	1,410	30	4,927,100	Combination failure in metal and joint		.0048
9	4,695	1,880	40	1,010,200	100	0	.0047
34-13-2	4,410	2,650	60	12,300	90	10	.0035
3	4,410	1,325	30	11,940,400	Tension failure in metal		.0038
4	4,410	1,765	40	901,500	95	5	.0043
34-14-7	4,365	2,180	50	99,900	100	0	.0037
8	4,365	1,530	35	1,296,200	Tension failure in metal		.0033
9	4,365	1,090	25	20,749,000	Specimen did not fail		.0033
34-15-2	4,390	2,195	50	49,800	60	40	.0047
3	4,390	1,535	35	2,664,100	Tension failure in metal		.0044
4	4,390	1,095	25	20,230,000	Specimen did not fail		.0052

[1]Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at -65° to -70° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 11.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 35[1]

Specimen No.[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
AF-35-1-2	4,850	3,510	72.4	1,300	100	0	(5)
3	4,850	2,505	51.6	4,700	100	0	....
5	4,850	1,000	20.6	270,500	75	25	....
AF-35-2-1	4,945	3,510	71.0	1,600	90	10	....
3	4,945	2,005	40.6	31,300	40	60	....
4	4,945	1,000	20.2	322,400	35	65	....
AF-35-3-2	4,915	3,510	71.4	800	100	0	....
4	4,915	2,005	40.8	9,800	100	0	....
5	4,915	500	10.2	21,000,000	Specimen did not fail		....
AF-35-4-1	5,220	3,005	57.6	7,600	90	10	....
3	5,220	2,005	38.4	47,400	10	90	....
5	5,220	500	9.6	32,636,000	Specimen did not fail		....
AF-35-5-1	5,140	3,005	58.4	4,000	100	0	....
2	5,140	1,505	29.3	31,000	80	20	....
4	5,140	500	9.8	20,260,000	Specimen did not fail		....
AF-35-6-2	5,260	3,005	57.1	6,900	60	40	....
3	5,260	1,505	28.6	102,300	60	40	....
5	5,260	1,000	19.0	282,100	45	55	....
AF-35-7-1	5,240	2,505	47.8	14,100	50	50	....
3	5,240	1,505	28.7	99,000	20	80	....
4	5,240	750	14.3	2,372,400	30	70	....
AF-35-8-2	4,485	2,450	54.7	4,400	100	0	....
4	4,485	1,000	22.3	120,500	100	0	....
5	4,485	750	16.7	776,800	100	0	....
35-10-2	4,110	2,880	70	1,300	100	0	0.0060
3	4,110	615	15	3,633,700	45	55	.0054

(Sheet 1 of 2)

Table 11.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 35[1] (Continued)

Specimen No.[2]	Control strength[3]	Maximum repeated stress[4]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
35-11-7	4,380	2,630	60	5,900	95	5	0.0053
8	4,380	525	12	19,043,900	30	70	.0055
35-12-2	3,570	1,785	50	3,700	100	0	.0067
35-13-7	4,060	1,625	40	11,900	100	0	.0060
35-14-2	4,430	1,330	30	115,500	95	5	.0049
35-15-7	4,180	835	20	247,600	100	0	.0047

[1]Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch, 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Specimens AF-35-1-2 through AF-35-8-5 were prepared and tested under Air Force Purchase Order No. (33-038)50-1078E. Specimens 35-10-2 through 35-15-7 were tested in the present study to compare the results with those previously obtained in the Air Force project.

[3]Control-strength values are the average shear strength at 72° to 76° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[4]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

[5]The adhesive-film thicknesses were not measured and recorded for all of the fatigue specimens prepared with adhesive 35 in the Air Forces study, but those specimens that were measured had adhesive-film thicknesses of 0.0020 to 0.0025 inch.

(Sheet 2 of 2)

Table 12.--Summary of individual results of fatigue tests at -65° to -70° F. of lap-joint specimens bonded with adhesive 35[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
35-10-7	3,290	2,305	70	8,900	95	5	0.0053
8	3,290	1,315	40	400,200	95	5	.0056
9	3,290	1,150	35	651,500	70	30	.0055
35-11-2	2,420	1,695	70	52,700	40	60	.0057
3	2,420	970	40	2,357,600	25	75	.0057
4	2,420	725	30	20,118,100	Specimen did not fail		.0055
35-12-7	2,290	1,375	60	208,200	40	60	.0057
8	2,290	690	30	20,550,000	Specimen did not fail		.0056
9	2,290	1,030	45	1,875,800	30	70	.0051
35-13-2	3,020	1,810	60	82,200	100	0	.0059
3	3,020	905	30	7,332,000	95	5	.0057
4	3,020	1,360	45	753,600	100	0	.0059
35-14-7	2,770	1,385	50	272,400	30	70	.0046
8	2,770	970	35	3,337,800	20	80	.0049
9	2,770	1,110	40	1,574,800	20	80	.0050
35-15-2	3,130	1,565	50	216,600	100	0	.0046
3	3,130	785	25	20,000,000	Specimen did not fail		.0049
4	3,130	1,095	35	1,299,600	100	0	.0049

[1]Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at -65° to -70° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 13.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 36[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
36-10-2	4,100	2,800	68	1,300	75	25	0.0060
3	4,100	2,050	50	20,300	85	15	.0056
4	4,100	820	20	1,884,100	75	25	.0051
36-11-7	3,460	2,420	70	6,200	80	20	.0046
8	3,460	1,385	40	160,400	75	25	.0052
9	3,460	690	20	8,823,200	85	15	.0040
36-12-2	3,740	2,245	60	5,900	80	20	.0053
3	3,740	1,495	40	197,300	90	10	.0076
4	3,740	560	15	29,462,600	Specimen did not fail		.0071
36-14-2	3,880	2,330	60	6,300	85	15	.0069
3	3,880	1,165	30	134,100	75	25	.0056
4	3,880	700	18	10,708,900	40	60	.0055
36-15-7	3,830	1,915	50	22,200	85	15	.0067
8	3,830	1,150	30	338,000	75	25	.0052
9	3,830	690	18	10,003,600	80	20	.0060

[1] Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch, 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2] Control-strength values are the average shear strength at 72° to 76° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3] Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 14.--Summary of individual results of fatigue tests at -65° to -70° F. of lap-joint specimens bonded with adhesive 36[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
36-10-7	5,470	3,830	70	7,100	85	15	0.0073
8	5,470	2,735	50	11,200	85	15	.0064
9	5,470	1,370	25	2,633,600	Tension failure in metal		.0067
36-11-2	5,330	3,730	70	8,100	85	15	.0060
3	5,330	2,130	40	156,500	85	15	.0068
4	5,330	1,330	25	2,594,400	65	35	.0058
36-12-7	5,230	3,140	60	21,100	75	25	.0059
8	5,230	2,090	40	146,400	90	10	.0069
9	5,230	2,615	50	13,500	90	10	.0074
36-14-7	5,720	3,430	60	20,400	70	30	.0048
8	5,720	1,715	30	707,100	95	5	.0055
9	5,720	1,145	20	6,286,800	Tension failure in metal		.0057
36-15-2	5,630	2,815	50	41,700	80	20	.0050
3	5,630	1,690	30	959,600	Tension failure in metal		.0053
4	5,630	1,125	20	16,910,300	60	40	.0046

[1]Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at -65° to -70° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 15.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 37[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
37-10-2	3,760	2,630	70	[4] 5	90	10	0.0057
3	3,760	1,880	50	23,400	90	10	.0059
4	3,760	770	20.5	6,244,700	90	10	.0062
37-11-7	3,530	2,470	70	[4] 5	85	15	.0061
8	3,530	1,765	50	55,200	85	15	.0061
9	3,530	705	20	22,353,400	70	30	.0057
37-12-2	3,500	2,100	60	100	75	25	.0068
3	3,500	1,050	30	993,600	80	20	.0065
4	3,500	875	25	1,859,500	90	10	.0065
37-13-7	3,460	2,075	60	[4] 5	80	20	.0053
8	3,460	1,040	30	1,048,900	85	15	.0054
9	3,460	865	25	2,365,300	90	10	.0050
37-14-2	3,590	1,435	40	205,300	65	35	.0058
3	3,590	900	25	21,677,200	Specimen did not fail		.0065
4	3,590	720	20	22,139,300	........do..........		.0061
37-15-7	3,235	1,295	40	481,100	85	15	.0056
8	3,235	810	25	24,516,400	Specimen did not fail		.0056
9	3,235	810	25	15,325,000	70	30	.0058

[1]Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at 72° to 76° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

[4]The number of cycles to failure was estimated because the specimen failed during adjustment of fatigue machine, apparently due to accumulative creep in adhesive.

Table 16.--Summary of individual results of fatigue tests at -65° to -70° F. of lap-joint specimens bonded with adhesive 37[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
37-10-7	5,470	3,830	70	17,200	85	15	0.0052
8	5,470	2,190	40	153,900	60	40	.0056
9	5,470	1,530	28	773,500	20	80	.0074
37-11-2	5,310	3,720	70	36,600	80	20	.0062
3	5,310	2,120	40	368,000	70	30	.0059
4	5,310	1,485	28	1,498,100	Tension failure in metal		.0074
37-12-7	5,470	3,280	60	21,300	90	10	.0066
8	5,470	1,640	30	2,012,000	Tension failure in metal		.0058
9	5,470	1,365	25	4,420,000	........do........		.0074
37-13-2	5,190	3,115	60	58,800	75	25	.0057
3	5,190	1,560	30	8,137,400	Tension failure in metal		.0059
4	5,190	1,140	22	21,240,300	Specimen did not fail		.0052
37-14-7	5,320	2,660	50	67,200	75	25	.0057
8	5,320	1,860	35	361,900	65	35	.0055
9	5,320	1,330	25	4,747,800	Tension failure in metal		.0051
37-15-2	5,420	2,710	50	129,500	65	35	.0059
3	5,420	1,895	35	1,420,000	90	10	.0063
4	5,420	1,190	22	6,113,000	Tension failure in metal		.0052

[1]Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at -65° to -70° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 17.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 38[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
				RUN 1			
38-10-2	2,680	1,875	70	300	25	75	0.0080
3	2,680	1,070	40	14,700	10	90	.0075
4	2,680	535	20	31,164,200	Specimen did not fail		.0082
38-12-2	2,570	1,540	60	100	80	20	.0078
3	2,570	1,030	40	381,200	70	30	.0095
4	2,570	900	35	676,300	50	50	.0100
38-13-7	2,950	1,770	60	5	60	40	.0063
8	2,950	885	30	12,068,500	40	60	.0078
9	2,950	760	28	21,478,400	Specimen did not fail		.0074
38-14-2	2,720	1,360	50	4,700	20	80	.0055
3	2,720	815	30	19,653,800	90	10	.0082
4	2,720	825	28	9,028,700	60	40	.0075
38-15-7	2,660	1,330	50	1,400	35	65	.0076
8	2,660	530	20	21,232,600	Specimen did not fail		.0068
9	2,660	930	35	4,456,300	85	15	.0081
				RUN 2			
38-2-10-2	2,755	1,930	70	64,000	80	20	.0098
3	2,755	1,100	40	2,234,200	60	40	.0101
4	2,755	965	35	4,762,400	75	25	.0101
38-2-11-7	2,545	1,780	70	18,000	70	30	.0098
8	2,545	1,020	40	2,151,500	85	15	.0096
9	2,545	890	35	8,378,600	Specimen did not fail		.0100

(Sheet 1 of 2)

Table 17.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 38[1] (Continued)

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
38-2-12-2	2,565	1,540	60	193,800	60	40	.0097
3	2,565	770	30	17,079,800	Specimen did not fail		.0091
4	2,565	1,155	45	168,600	60	40	.0090
38-2-13-7	2,535	1,520	60	339,000	85	15	.0105
8	2,535	760	30	14,824,500	Specimen did not fail		.0104
9	2,535	1,140	45	724,200	Tension failure in metal		.0106
38-2-14-2	2,890	1,445	50	438,800	Tension failure in metal		.0105
3	2,890	1,010	35	1,679,800	80	20	.0101
38-2-15-7	2,790	1,395	50	183,500	60	40	.0094
8	2,790	975	35	447,900	60	40	.0087

[1] Tests were made in an axial-loading fatigue machine at the rate of 900 cycles per minute. Tension loading produced shear stresses in the single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2] Control-strength values are the average shear strength at 72° to 76° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3] Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

(Sheet 2 of 2)

Table 18.--Summary of individual results of fatigue tests at -65° to -70° F. of lap-joint specimens bonded with adhesive 38 (run 2)[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
38-2-10-7	3,820	2,675	70	12,300	100	0	0.0097
8	3,820	1,530	40	5,033,000	Tension failure in metal		.0097
9	3,820	1,335	35	11,615,400	........do.........		.0092
38-2-11-2	3,640	2,550	70	13,500	100	0	.0099
3	3,640	1,455	40	21,879,100	Specimen did not fail		.0100
38-2-12-7	3,660	2,195	60	125,800	100	0	.0091
8	3,660	1,100	30	20,372,300	Specimen did not fail		.0089
9	3,660	2,930	80	4,600	100	0	.0088
38-2-13-2	3,890	2,335	60	158,400	Tension failure in metal		.0108
3	3,890	1,165	30	20,097,700	Specimen did not fail		.0103
4	3,890	3,110	80	5,000	100	0	.0105
38-2-14-7	3,640	1,820	50	505,700	Tension failure in metal		.0097
38-2-15-2	3,670	1,835	50	832,200	........do.........		.0087
3	3,670	1,470	40	3,419,200	........do.........		.0087

[1]Tests were made in an axial-loading fatigue machine at the rate of 900 cycles per minute. Tension loading produced shear stresses in the single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at -65° to -70° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 19.--Summary of individual results of fatigue tests at room temperature of lap-joint specimens bonded with adhesive 41[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
41-10-2	3,950	2,765	70	300	90	10	0.0090
3	3,950	1,580	40	53,200	95	5	.0090
4	3,950	1,185	30	22,000,500	Specimen did not fail		.0090
41-11-7	4,540	3,180	70	200	95	5	.0057
8	4,540	1,815	40	17,800	95	5	.0058
9	4,540	1,590	35	120,300	95	5	.0066
41-12-2	4,340	2,005	60	2,600	100	0	.0064
3	4,340	1,300	30	20,906,700	Specimen did not fail		.0057
4	4,340	1,520	35	276,500	90	10	.0060
41-13-7	4,980	2,990	60	100	95	5	.0045
8	4,980	1,495	30	146,000	100	0	.0058
9	4,980	1,495	30	73,000	95	5	.0063
41-14-2	4,260	2,130	50	5,800	100	0	.0075
3	4,260	850	20	18,413,900	Specimen did not fail		.0057
4	4,260	1,065	25	20,862,200	........do..........		.0059
41-15-7	3,830	1,915	50	16,100	100	0	.0086
8	3,830	1,150	30	560,000	100	0	.0096
9	3,830	960	25	20,817,700	Specimen did not fail		.0093

[1]Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at 72° to 76° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 20.--Summary of individual results of fatigue tests at -65° to -70° F. of lap-joint specimens bonded with adhesive 41[1]

Specimen No.	Control strength[2]	Maximum repeated stress[3]		Cycles to failure	Cohesion failure	Adhesion failure	Adhesive-film thickness
	P.s.i.	P.s.i.	Percent of control		Percent	Percent	Inch
41-10-7	3,000	2,100	70	12,800	50	50	0.0064
8	3,000	1,200	40	19,728,300	Specimen did not fail		.0056
9	3,000	1,500	50	754,600	60	40	.0048
41-11-2	3,130	2,190	70	2,600	70	30	.0037
3	3,130	1,250	40	8,569,000	Tension failure in metal		.0044
41-12-7	2,860	1,715	60	22,300	40	60	.0081
8	2,860	860	30	17,142,400	90	10	.0083
9	2,860	1,145	40	4,981,400	Tension failure in metal		.0072
41-13-2	2,940	1,765	60	40,600	70	30	.0063
4	2,940	2,060	70	7,900	80	20	.0062
41-14-7	2,950	1,475	50	285,700	90	10	.0043
8	2,950	1,325	45	3,440,800	Tension failure in metal		.0039
9	2,950	2,360	80	2,900	80	20	.0043
41-15-2	2,820	1,410	50	2,769,600	Tension failure in metal		.0064
3	2,820	1,270	45	2,110,500	25	75	.0060
4	2,820	2,255	80	1,500	85	15	.0096

[1]Tests were made in an axial-loading fatigue machine at a rate of 900 cycles per minute. Tension loading produced shear stresses in single-lap specimens. The 1-inch-wide specimens were made from 0.064-inch 24S-T3 clad aluminum alloy with a 3/8-inch lap.

[2]Control-strength values are the average shear strength at -65° to -70° F. for 2 test specimens cut from the same panel as the fatigue-test specimens. The control specimens were the 2 outside specimens and the fatigue specimens the 3 center specimens in a group of 5 specimens.

[3]Minimum repeated stress for each cycle of loading was 10 percent of the maximum for that cycle.

Table 21.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 25.

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[1]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[2]: After loading	Creep measurement[2]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
			Under test at 72° to 76° F.					
25-7-3	0.02	2,800	83.7	5	95	0.0075	—	—
25-4-4	.10	2,500	80.1	25	75	.0088	—	—
25-6-4	.22	2,400	70.8	10	90	.0088	—	—
25-2-4	.44	2,400	74.3	0	100	.0082	—	—
25-5-3	.50	2,300	71.6	20	80	.0092	—	—
25-8-4	1.13	2,200	65.2	5	95	.0080	—	—
25-9-4	2.25	2,300	67.8	0	100	.0066	—	—
25-1-3	4.33	2,150	70.2	5	95	.0073	—	—
25-7-4	4.36	2,050	61.3	5	95	.0089	—	—
25-7-9	5.63	2,100	62.8	5	95	.0081	—	—
25-6-9	6.72	2,200	64.9	5	95	.0094	—	—
25-5-4	13.75	1,950	60.7	25	75	.0099	—	—
25-3-9	20.33	2,050	68.4	20	80	.0082	—	—
25-3-4	23.37	2,000	66.7	70	30	.0087	—	—
25-9-3	24.20	2,150	63.4	0	100	.0068	—	—
25-8-9	34.80	2,000	59.3	5	95	.0082	—	—
25-1-9	45.72	2,000	65.3	10	90	.0073	—	—
25-5-9	77.53	1,950	60.7	5	95	.0095	—	—
25-1-4	More than 200.00	1,950	63.6	Not broken		.0069	0.0150	0.0066
25-2-9	" 200.00	1,950	60.4	"		.0080	.0202	.0105
25-9-9	" 200.00	1,900	56.0	"		.0076	.0166	.0078
			Under test at 178° to 182° F.					
25-7-7	0.03	1,600	47.8	0	100	.0049	—	—
25-8-3	0.08	1,600	47.4	5	95	.0085	—	—
25-6-3	0.23	1,600	47.1	5	95	.0089	—	—
25-4-2	0.80	1,500	48.1	10	90	.0083	—	—
25-6-2	1.03	1,550	45.7	5	95	.0093	—	—
25-9-6	1.63	1,400	41.2	5	95	.0070	—	—
25-8-6	2.70	1,200	35.5	5	95	.0086	—	—
25-4-3	3.17	1,300	41.6	10	90	.0087	—	—
25-6-6	3.72	1,100	32.4	25	75	.0090	—	—
25-7-2	4.15	1,300	38.3	25	75	.0089	—	—
25-9-2	5.39	1,400	41.2	0	100	.0071	—	—
25-3-6	8.25	1,050	35.0	35	65	.0084	—	—
25-5-6	10.92	1,000	31.1	40	60	.0091	—	—
25-5-2	12.00	1,100	34.2	50	50	.0090	—	—
25-2-6	14.33	1,050	32.5	15	85	.0088	—	—
25-7-5	14.65	1,050	31.3	20	80	.0088	—	—
25-2-2	20.75	1,200	37.1	30	70	.0087	—	—
25-2-3	41.65	1,100	34.0	20	80	.0075	—	—
25-8-2	More than 200.00	1,000	29.6	40	60	.0090	—	—
25-9-7	" 200.00	950	28.0	40	60	.0055	—	—
25-1-2	" 200.00	950	31.0	Not broken		.0075	.0200	.0182
25-3-2	" 200.00	800	26.7	"		.0083	.0164	.0154

[1] The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[2] The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after the load was removed.

Z M 86590 F

Table 22.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.063-inch 24S-T3 clad aluminum alloy bonded with adhesives 26 and 25

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[1]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[2]: After loading	Creep measurement[2]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
			Under test at 72° to 76° F.					
26-6-4	0.03	2,500	76.2	0	100	0.0056	--	--
26-7-7	.18	2,450	73.8	0	100	.0058	--	--
26-3-4	.45	2,500	74.2	0	100	.0052	--	--
26-3-3	.82	2,500	74.2	0	100	.0054	--	--
26-5-3	1.48	2,475	71.5	0	100	.0051	--	--
26-8-4	6.87	2,350	70.3	0	100	.0044	--	--
26-1-9	8.48	2,400	70.9	0	100	.0044	--	--
26-2-4	10.48	2,450	69.9	0	100	.0046	--	--
26-3-9	11.80	2,350	69.7	0	100	.0051	--	--
26-9-4	14.00	2,400	71.2	0	100	.0062	--	--
26-5-9	14.17	2,450	70.8	0	100	.0045	--	--
26-9-7	15.67	2,250	66.7	0	100	.0053	--	--
26-7-9	24.70	2,450	73.8	0	100	.0046	--	--
26-6-9	33.30	2,400	73.2	0	100	.0051	--	--
26-7-4	53.68	2,250	67.7	0	100	.0048	--	--
26-5-4	58.12	2,300	66.4	0	100	.0045	--	--
26-7-3	65.98	2,300	69.2	0	100	.0052	--	--
26-2-9	136.92	2,200	62.8	0	100	.0047	--	--
26-4-9	171.42	2,175	64.2	0	100	.0054	--	--
26-9-9	198.00	2,200	65.3	0	100	.0058	--	--
26-9-3	More than 200.00	2,200	65.3	0	100	.0053	0.0129	0.0070
26-1-3	" 200.00	2,150	63.5	0	100	.0043	.0123	.0062
26-4-4	" 200.00	2,150	63.5	0	100	.0063	.0126	--
			Under test at 178° to 182° F.					
26-6-6	0.22	1,600	48.8	0	100	.0053	--	--
26-4-3	.57	1,550	45.7	0	100	.0056	--	--
26-1-2	.68	1,600	47.2	0	100	.0048	--	--
26-8-6	.75	1,500	44.8	0	100	.0051	--	--
26-6-3	1.27	1,300	39.6	0	100	.0050	--	--
26-4-6	1.57	1,450	42.7	0	100	.0053	--	--
26-9-2	1.65	1,550	45.9	0	100	.0060	--	--
26-3-6	3.60	1,400	41.5	5	95	.0055	--	--
26-6-2	3.75	1,450	44.2	5	95	.0046	--	--
26-2-2	7.62	1,350	38.5	5	95	.0046	--	--
26-9-6	9.73	1,400	41.5	0	100	.0051	--	--
26-5-6	12.92	1,400	40.1	5	95	.0044	--	--
26-8-3	16.83	1,300	38.8	5	95	.0047	--	--
26-8-2	27.40	1,300	38.8	5	95	.0044	--	--
26-1-6	28.05	1,250	36.8	10	90	.0049	--	--
26-3-2	30.00	1,200	35.6	20	80	.0051	--	--
26-2-6	71.23	1,200	34.2	15	85	.0050	--	--
26-2-3	118.21	1,200	34.2	25	75	.0046	--	--
26-5-2	178.28	1,300	37.5	20	80	.0047	--	--
26-4-2	More than 200.00	1,150	33.9	15	85	.0048	.0150	.0142
26-7-2	" 200.00	1,150	34.6	35	65	.0052	--	--
26-7-6	" 200.00	1,000	30.0	20	80	.0043	.0163	.0148

[1] The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[2] The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after load was removed.

Z M 87128 F

Table 23.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 33[1]

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[2]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[3]: After loading	Creep measurement[3]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
Under test at 72° to 76° F.								
33-9-4	0.45	3,750	81.4	20	80	0.0037	....	....
33-3-4	.50	3,800	85.2	40	60	.0022	....	....
33-6-4	.85	3,725	80.4	40	60	.0032	....	....
33-5-4	More than 200.00	3,800	83.4	Not broken		.0033	0.0000	0.0000
33-7-4	....do.... 200.00	3,700	79.6	........do........		.0029	.0000	.0000
33-7-3	....do.... 200.00	3,600	77.4	........do........		.0035	-.0000	.0000
Under test at 178° to 182° F.								
33-4-2	1.10	1,800	38.1	35	65	.0029	....	....
33-4-3	6.05	1,750	37.1	35	65	.0029	....	....
33-4-6	9.07	2,000	42.4	40	60	.0031	....	....
33-2-3	9.17	1,900	40.3	30	70	.0032	....	....
33-2-6	11.48	1,650	34.9	20	80	.0028	....	....
33-3-2	21.88	1,700	38.0	35	65	.0029	....	....
33-6-6	52.12	1,800	38.8	30	70	.0034	....	....
33-5-2	91.45	1,650	36.2	45	55	.0033	....	....
33-1-2	115.75	1,750	38.4	40	60	.0026	....	....
33-8-3	More than 200.00	1,600	38.6	Not broken		.0033	.0072	.0062
33-8-2	....do.... 200.00	1,600	38.6	........do........		.0035	.0090	.0086

[1]Test data for comparison with the more comprehensive test data (table 25) obtained for adhesive 35.

[2]The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[3]The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after the load was removed.

Table 24.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 34

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[1]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[2]: After loading	Creep measurement[2]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
			Under test at 72° to 76° F.					
34-6-9	0.40	3,560	87.1	25	75	0.0039	---	---
34-4-4	.67	3,530	79.9	25	75	.0034	---	---
34-6-4	.68	3,524	86.3	30	70	.0038	---	---
34-7-4	4.22	3,500	87.1	15	85	.0037	---	---
34-2-4	5.34	3,440	83.2	20	80	.0029	---	---
34-3-4	12.50	3,420	79.3	25	75	.0050	---	---
34-3-9	16.11	3,484	79.1	40	60	.0041	---	---
34-7-3	20.13	3,350	85.7	10	90	.0038	---	---
34-3-3	31.63	3,350	79.9	25	75	.0053	---	---
34-1-9	38.67	3,440	85.5	25	75	.0029	---	---
34-8-4	57.93	3,420	79.8	35	65	.0035	---	---
34-9-3	58.58	3,500	79.3	5	95	.0031	---	---
34-1-4	85.53	3,484	87.0	25	75	.0032	---	---
34-5-4	176.33	3,484	79.4	35	65	.0036	---	---
34-7-9	185.97	3,304	82.2	20	80	.0042	---	---
34-5-9	More than 200.00	3,524	80.5	Not broken		.0031	0.0000	0.0000
34-2-9	" 200.00	3,400	82.3	"		.0027	.0005	.0005
34-4-9	" 200.00	3,400	77.0	"		.0044	.0009	.0009
34-9-4	" 200.00	3,320	75.0	"		.0032	.0014	.0014
34-9-9	" 200.00	3,316	74.9	"		.0038	.0004	.0004
34-8-9	" 200.00	3,264	76.3	"		.0026	.0000	.0000
			Under test at 178° to 182° F.					
34-4-3	.13	1,000	22.6	0	100	.0034	---	---
34-3-6	.15	950	22.0	0	100	.0048	---	---
34-2-3	.38	875	21.2	0	100	.0030	---	---
34-8-6	.61	800	18.7	5	95	.0034	---	---
34-8-2	1.00	800	18.7	5	95	.0035	---	---
34-2-6	1.40	780	18.9	0	100	.0026	---	---
34-9-2	1.53	750	16.9	0	100	.0033	---	---
34-6-2	2.58	740	18.1	0	100	.0042	---	---
34-2-2	2.63	705	17.0	0	100	.0025	---	---
34-7-7	2.67	740	18.4	5	95	.0043	---	---
34-8-7	2.92	730	17.1	5	95	.0037	---	---
34-6-3	More than 200.00	730	17.8	Not broken		.0047	.0041	.0040
34-7-2	" 200.00	725	18.0	"		.0037	.0014	.0014
34-8-3	" 200.00	705	16.5	"		.0030	.0074	.0067
34-7-6	" 200.00	700	17.4	"		.0040	.0007	.0007
34-4-2	" 200.00	650	14.6	"		.0035	.0038	.0038
34-3-2	" 200.00	580	13.5	"		.0042	.0027	.0026

[1]The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[2]The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after the load was removed.

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Table 25.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 35.

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[1]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[2]: After loading	Creep measurement[2]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
			Under test at 72° to 76° F.					
35-6-4	0.03	3,900	100.7	30	70	0.0026	---	---
35-9-9	.03	3,850	97.5	10	90	.0028	---	---
35-5-3	.03	3,800	100.9	5	95	.0031	---	---
35-7-4	.06	3,800	98.0	35	65	.0035	---	---
35-7-9	.20	3,775	94.8	5	95	.0030	---	---
35-3-9	.97	3,800	102.5	10	90	.0030	---	---
35-6-9	1.16	3,750	96.7	5	95	.0028	---	---
35-7-3	5.53	3,775	94.8	25	75	.0036	---	---
35-8-9	6.47	3,775	96.5	5	95	.0030	---	---
35-1-3	7.45	3,700	87.1	5	95	.0028	---	---
35-9-4	8.60	3,750	95.0	5	95	.0029	---	---
35-3-4	173.35	3,675	99.1	20	80	.0031	---	---
35-8-4	More than 200.00	3,750	95.9	Not broken		.0037	0.0005	0.0004
35-1-9	" 200.00	3,700	87.1	"		.0029	.0004	.0004
35-1-4	" 200.00	3,650	85.9	15	85	.0025	.0019	Broke at 225 hours
35-9-3	" 200.00	3,500	88.6	Not broken		.0030	.0000	.0000
35-4-9	" 200.00	3,200	84.0	"		.0030	.0000	.0000
			Under test at 178° to 182° F.					
35-3-6	.15	2,000	53.9	0	100	.0031	---	---
35-1-6	.26	1,700	40.0	5	95	.0032	---	---
35-8-7	.45	2,000	51.2	0	100	.0035	---	---
35-2-6	.92	2,000	52.0	0	100	.0028	---	---
35-5-6	1.12	1,750	46.5	0	100	.0031	---	---
35-8-2	1.28	1,800	46.0	0	100	.0034	---	---
35-3-2	1.70	2,000	53.9	0	100	.0028	---	---
35-1-2	2.80	1,750	41.2	5	95	.0032	---	---
35-2-3	2.82	1,900	49.4	5	95	.0030	---	---
35-6-2	2.93	1,800	46.4	0	100	.0028	---	---
35-4-2	3.35	1,950	51.2	0	100	.0027	---	---
35-2-2	3.65	2,000	52.0	5	95	.0029	---	---
35-9-6	4.42	1,900	48.1	0	100	.0029	---	---
35-8-3	7.07	1,650	42.2	0	100	.0031	---	---
35-5-2	7.20	1,800	47.8	0	100	.0030	---	---
35-4-6	8.53	1,600	42.0	0	100	.0034	---	---
35-9-2	10.26	1,700	43.0	0	100	.0033	---	---
35-6-3	10.78	1,750	45.1	0	100	.0028	---	---
35-6-6	42.75	1,600	41.2	0	100	.0030	---	---
35-7-2	More than 200.00	1,700	42.7	Not broken		.0041	.0075	.0075
35-7-7	" 200.00	1,550	38.9	"		.0030	.0049	.0048
35-4-3	" 200.00	1,500	39.4	"		.0030	.0067	.0067
35-7-6	" 200.00	1,500	37.6	"		.0035	.0018	.0018
35-8-6	" 200.00	1,000	25.6	"		.0034	.0060	.0059

[1] The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[2] The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after the load was removed.

Table 26.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 36.

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[1]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[2]: After loading	Creep measurement[2]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
			Under test at 72° to 76° F.					
36-3-9	0.07	3,000	87.6	10	90	0.0036	---	---
36-9-9	.33	2,800	81.2	10	90	.0038	---	---
36-2-4	.70	3,000	87.1	5	95	.0040	---	---
36-4-4	.90	2,600	81.0	5	95	.0049	---	---
36-1-9	1.67	2,500	70.1	10	90	.0036	---	---
36-1-4	3.33	2,430	68.1	15	85	.0047	---	---
36-7-9	3.85	2,800	79.9	5	95	.0037	---	---
36-3-4	12.50	2,500	73.0	10	90	.0042	---	---
36-7-3	14.62	2,350	67.0	5	95	.0045	---	---
36-5-3	20.63	2,700	76.9	5	95	.0044	---	---
36-8-9	31.83	2,400	69.8	10	90	.0040	---	---
36-5-9	35.25	2,200	62.6	5	95	.0042	---	---
36-6-4	36.40	2,300	68.5	5	95	.0044	---	---
36-1-3	57.27	2,200	61.7	10	90	.0042	---	---
36-9-3	91.47	2,200	63.8	10	90	.0035	---	---
36-7-4	99.13	2,150	61.3	10	90	.0046	---	---
36-1-9	117.66	2,150	60.3	10	90	.0036	---	---
36-9-4	More than 200.00	2,150	62.3	Not broken		.0041	0.0184	0.0110
36-5-4	" 200.00	2,100	59.8	"		.0038	.0220	.0119
36-8-4	" 200.00	2,100	61.1	"		.0037	.0220	.0105
			Under test at 178° to 182° F.					
36-3-2	.10	1,000	29.2	25	75	.0042	---	---
36-4-6	.15	800	24.9	25	75	.0045	---	---
36-2-6	.26	900	26.1	25	75	.0037	---	---
36-2-3	1.00	800	23.2	25	75	.0037	---	---
36-8-6	1.12	700	20.4	45	55	.0035	---	---
36-6-6	1.28	800	23.9	35	65	.0042	---	---
36-7-6	2.73	700	20.0	25	75	.0048	---	---
36-1-6	4.22	700	19.6	5	95	.0037	---	---
36-9-2	7.63	650	18.8	15	85	.0048	---	---
36-4-2	8.42	600	18.7	5	95	.0045	---	---
36-6-3	14.22	575	17.1	15	85	.0037	---	---
36-5-2	15.80	600	17.1	10	90	.0040	---	---
36-3-6	22.25	700	20.5	5	95	.0045	---	---
36-8-3	37.73	450	13.1	15	85	.0039	---	---
36-7-2	48.33	500	14.3	10	90	.0042	---	---
36-5-6	82.07	600	17.1	5	95	.0047	---	---
36-6-2	129.72	400	11.9	5	95	.0041	---	---
36-4-3	174.40	400	12.5	20	80	.0050	---	---
36-1-2	More than 200.00	550	15.4	Not broken		.0047	.0183	.0128
36-8-2	" 200.00	400	11.6	"		.0041	.0188	.0098
36-2-2	" 200.00	350	10.2	"		.0042	.0293	.0112
36-9-6	" 200.00	350	10.1	"		.0035	.0140	.0126

[1]The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[2]The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after the load was removed.

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Table 27.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 37.

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[1]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[2]: After loading	Creep measurement[2]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
			Under test at 72° to 76° F.					
37-2-4	0.60	2,800	75.9	5	95	0.0051	---	---
37-3-4	.73	2,800	76.4	5	95	.0065	---	---
37-1-9	1.83	2,600	70.4	5	95	.0064	---	---
37-3-3	2.63	2,670	72.9	5	95	.0076	---	---
37-2-9	5.92	2,700	73.9	5	95	.0052	---	---
37-4-4	8.07	2,500	66.0	5	95	.0043	---	---
37-9-3	8.52	2,300	66.8	5	95	.0047	---	---
37-1-4	14.28	2,400	65.1	10	90	.0051	---	---
37-4-9	15.26	2,500	66.0	5	95	.0043	---	---
37-7-3	17.12	2,100	60.9	5	95	.0052	---	---
37-8-4	19.48	2,150	61.9	5	95	.0059	---	---
37-5-4	25.72	2,000	60.6	5	95	.0054	---	---
37-6-9	27.22	2,200	62.4	5	95	.0062	---	---
37-8-9	36.75	2,000	57.5	5	95	.0060	---	---
37-9-4	44.33	2,100	61.1	10	90	.0057	---	---
37-3-9	96.32	2,050	55.9	10	90	.0055	---	---
37-1-3	More than 200.00	2,000	54.2	10	90	.0067	0.0173	Broke at 217 hours.
			Under test at 178° to 182° F.					
37-8-3	.32	1,000	28.8	40	60	.0059	---	---
37-3-6	.60	1,000	27.3	25	75	.0055	---	---
37-5-2	.92	800	24.2	40	60	.0043	---	---
37-9-2	1.12	900	26.2	25	75	.0049	---	---
37-6-6	1.72	900	25.5	25	75	.0043	---	---
37-4-6	6.00	700	18.5	40	60	.0052	---	---
37-1-6	6.72	750	20.3	10	90	.0045	---	---
37-2-3	7.42	800	21.9	15	85	.0062	---	---
37-6-3	7.97	800	22.7	10	90	.0057	---	---
37-7-2	9.75	500	14.5	30	70	.0045	---	---
37-9-6	12.73	500	14.5	25	75	.0046	---	---
37-2-6	12.87	700	19.1	35	65	.0048	---	---
37-7-6	14.13	600	17.4	40	60	.0058	---	---
37-1-2	18.85	550	15.0	10	90	.0047	---	---
37-4-2	23.35	650	17.1	10	90	.0038	---	---
37-8-2	31.97	550	16.0	15	85	.0063	---	---
37-6-2	48.30	600	17.0	15	85	.0064	---	---
37-3-2	79.77	650	17.8	20	80	.0073	---	---
37-8-7	101.17	450	12.9	40	60	.0057	---	---
37-2-2	More than 200.00	500	13.6	Not broken		.0050	.0153	0.0139
37-8-6	" 200.00	400	11.5	"		.0054	.0223	.0193
37-7-7	" 200.00	400	11.6	"		.0053	.0220	.0197
37-4-3	" 200.00	370	9.8	"		.0042	.0134	.0121

[1] The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[2] The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after the load was removed.

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Table 28.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 38. (Run 1)

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[1]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[2]: After loading	Creep measurement[2]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
			Under test at 72° to 76° F.					
38-4-4	0.08	2,234	95.4	0	100	0.0071	---	---
38-3-4	.20	2,420	92.6	40	60	.0068	---	---
38-1-3	.25	2,092	82.6	20	80	.0067	---	---
38-7-3	.26	2,050	91.0	5	95	.0077	---	---
38-2-9	.67	2,310	88.0	25	75	.0068	---	---
38-3-9	1.75	1,790	68.6	0	100	.0078	---	---
38-5-9	2.67	2,000	86.0	5	95	.0102	---	---
38-7-9	4.75	1,700	75.4	0	100	.0082	---	---
38-5-4	5.95	1,950	83.9	20	80	.0090	---	---
38-1-4	6.50	1,796	70.9	25	75	.0048	---	---
38-9-9	7.83	1,700	66.4	20	80	.0079	---	---
38-4-9	11.00	1,860	79.4	15	85	.0074	---	---
38-1-9	15.17	1,870	73.6	25	75	.0067	---	---
38-3-3	15.77	1,980	75.7	20	80	.0061	---	---
38-7-4	16.22	1,656	73.5	0	100	.0089	---	---
38-2-4	31.70	1,770	67.4	40	60	.0067	---	---
38-9-4	52.53	1,900	74.2	15	85	.0074	---	---
38-8-4	112.26	1,900	69.3	10	90	.0065	---	---
38-8-9	140.68	1,600	58.3	0	100	.0080	---	---
38-9-3	185.42	1,600	62.5	15	85	.0088	---	---
38-5-3	More than 200.00	1,546	66.5	Not broken		.0106	0.0173	0.0159
38-6-9	" 200.00	1,540	62.1	"		.0095	.0144	.0124
38-6-4	" 200.00	1,534	61.9	"		.0105	.0148	.0132
			Under test at 178° to 182° F.					
38-1-6	.02	800	31.6	35	65	.0086	---	---
38-2-6	.02	800	30.5	50	50	.0071	---	---
38-6-2	.02	750	30.3	25	75	.0075	---	---
38-2-2	.08	700	26.7	50	50	.0068	---	---
38-5-2	.12	800	34.4	25	75	.0072	---	---
38-8-2	.13	700	25.5	25	75	.0076	---	---
38-9-2	.47	600	23.4	80	20	.0086	---	---
38-4-3	1.17	600	25.6	35	65	.0064	---	---
38-8-3	1.43	500	18.2	75	25	.0076	---	---
38-7-6	2.55	550	24.4	30	70	.0079	---	---
38-4-6	5.27	450	19.2	30	70	.0070	---	---
38-2-3	7.15	450	17.1	65	35	.0073	---	---
38-8-6	13.15	500	18.2	50	50	.0051	---	---
38-9-6	41.62	400	15.6	40	60	.0087	---	---
38-9-7	57.70	400	15.6	35	65	.0075	---	---
38-3-6	116.67	400	15.3	50	50	.0069	---	---
38-5-6	177.98	420	18.0	15	85	.0093	---	---
38-6-6	197.92	380	15.3	35	65	.0093	---	---
38-6-3	More than 200.00	380	15.3	Not broken		.0086	.0175	.0173
38-1-2	" 200.00	350	13.8	"		.0053	.0165	.0109
38-4-2	" 200.00	350	15.0	"		.0063	.0178	.0137
38-8-7	" 200.00	350	12.8	"		.0082	.0141	.0117

[1]The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[2]The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after the load was removed.

Z M 85792 F

Table 29.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 38 (run 2)[1]

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[2]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[3]: After loading	Creep measurement[3]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
			Under test at 72° to 76° F.					
38-2-5-9	0.06	2,500	91.6	15	85	0.0098	....	....
38-2-6-9	.28	2,200	84.2	25	75	.0091	....	....
38-2-3-4	1.28	2,000	75.7	20	80	.0105	....	....
38-2-1-9	1.52	1,900	67.6	15	85	.0073	....	....
38-2-5-4	3.78	2,200	80.6	20	80	.0096	....	....
38-2-4-9	6.48	2,100	77.3	15	85	.0083	....	....
38-2-8-9	7.12	2,000	75.3	15	85	.0083	....	....
38-2-3-9	16.65	1,800	68.1	25	75	.0084	....	....
38-2-2-9	21.13	1,800	65.7	15	85	.0096	....	....
38-2-3-3	31.60	1,600	60.5	30	70	.0084	....	....
38-2-4-4	99.58	1,650	60.7	15	85	.0102	....	....
38-2-2-4	115.80	1,700	62.0	20	80	.0102	....	....
38-2-8-4	More than 200.00	1,600	60.2	Not broken		.0099	0.0280	0.0166
38-2-8-2	....do.... 200.00	1,550	58.3	........do........		.0106	.0308	.0186
			Under test at 178° to 182° F.					
38-2-6-3	.12	1,000	38.3	25	75	.0094	....	....
38-2-7-6	1.33	800	31.4	20	80	.0100	....	....
38-2-1-6	11.58	600	21.3	15	85	.0083	....	....
38-2-2-6	13.55	800	29.2	25	75	.0091	....	....
38-2-4-3	19.75	500	18.4	5	95	.0098	....	....
38-2-5-6	38.43	450	16.5	20	80	.0090	....	....
38-2-3-6	43.25	500	18.9	20	80	.0102	....	....
38-2-6-2	97.27	350	13.4	20	80	.0104	....	....
38-2-4-2	127.22	400	14.7	10	90	.0108	....	....
38-2-3-2	179.18	350	13.2	15	85	.0100	....	....
38-2-8-3	More than 200.00	320	12.0	Not broken		.0101	.0258	.0161

[1] Test data for comparison with the more comprehensive test data (table 28) obtained in run 1 with adhesive 38 manufactured by another manufacturer.

[2] The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[3] The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after the load was removed.

Table 30.--Test data obtained in long-time-loading tests of 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 41

Specimen No.	Duration of stress	Constant stress	Percentage of control strength[1]	Type of failure: Adhesion to metal	Type of failure: Cohesion	Film thickness	Creep measurement[2]: After loading	Creep measurement[2]: After loading and conditioning
	Hours	P.s.i.		Percent	Percent	Inch	Inch	Inch
			Under test at 72° to 76° F.					
41-8-4	0.01	3,600	102.1	25	75	0.0081	....	....
41-5-9	.01	3,600	91.5	10	90	.0066	....	....
41-3-4	.03	3,200	84.8	15	85	.0055	....	....
41-2-9	.32	3,300	94.7	10	90	.0041	....	....
41-1-3	.40	3,300	100.2	10	90	.0055	....	....
41-5-4	.75	3,500	88.9	10	90	.0058	....	....
41-4-4	1.00	3,800	96.0	10	90	.0035	....	....
41-7-9	1.22	3,400	93.6	10	90	.0036	....	....
41-6-9	4.00	3,300	95.4	5	95	.0062	....	....
41-7-3	33.58	3,100	85.3	5	95	.0042	....	....
41-7-4	114.67	3,380	97.7	5	95	.0037	....	....
41-2-4	181.67	3,000	87.0	10	90	.0020	....	....
41-1-4	More than 200.00	3,200	97.3	Not broken		.0040	0.0004	0.0000
41-5-3	....do.... 200.00	3,200	81.2	........do........		.0055	.0000	....
41-4-9	....do.... 200.00	3,200	81.0	........do........		.0038	.0000	....
41-3-9	....do.... 200.00	2,900	76.6	........do........		.0039	.0000	....
41-6-4	....do.... 200.00	2,600	75.0	........do........		.0076	.0000	....
			Under test at 178° to 182° F.					
41-9-2	.03	700	22.2	10	90	.0089	....	....
41-4-2	.68	1,200	30.4	5	95	.0050	....	....
41-8-6	.77	700	19.8	5	95	.0056	....	....
41-2-3	.93	900	26.1	10	90	.0033	....	....
41-2-2	.98	1,000	29.0	10	90	.0044	....	....
41-3-2	1.50	600	15.8	15	85	.0067	....	....
41-5-2	1.67	1,000	25.4	5	95	.0036	....	....
41-1-2	3.02	800	24.4	10	90	.0070	....	....
41-6-3	16.77	500	14.4	10	90	.0083	....	....
41-6-6	27.17	600	17.3	10	90	.0095	....	....
41-4-3	54.87	400	10.1	20	80	.0029	....	....
41-8-2	63.00	325	9.2	25	75	.0089	....	....
41-2-6	81.17	350	10.1	25	75	.0044	....	....
41-6-2	More than 200.00	300	8.7	Not broken		.0066	.0033	.0032
41-5-6	....do.... 200.00	275	7.0	........do........		.0060	.0027	.0026

[1] The control strength was the average strength, at 72° to 76° F. and at a loading rate of 300 pounds per minute, of 3 specimens selected from the same bonded panel as the test specimen.

[2] The creep was measured by observing with a measuring microscope the offset of a fine line scribed across the edge of the bonded joint. Measurements were taken of the amount of creep after 200 hours of loading. These measurements were made both while the specimen was under load and following 1 week of room-temperature conditioning after the load was removed.

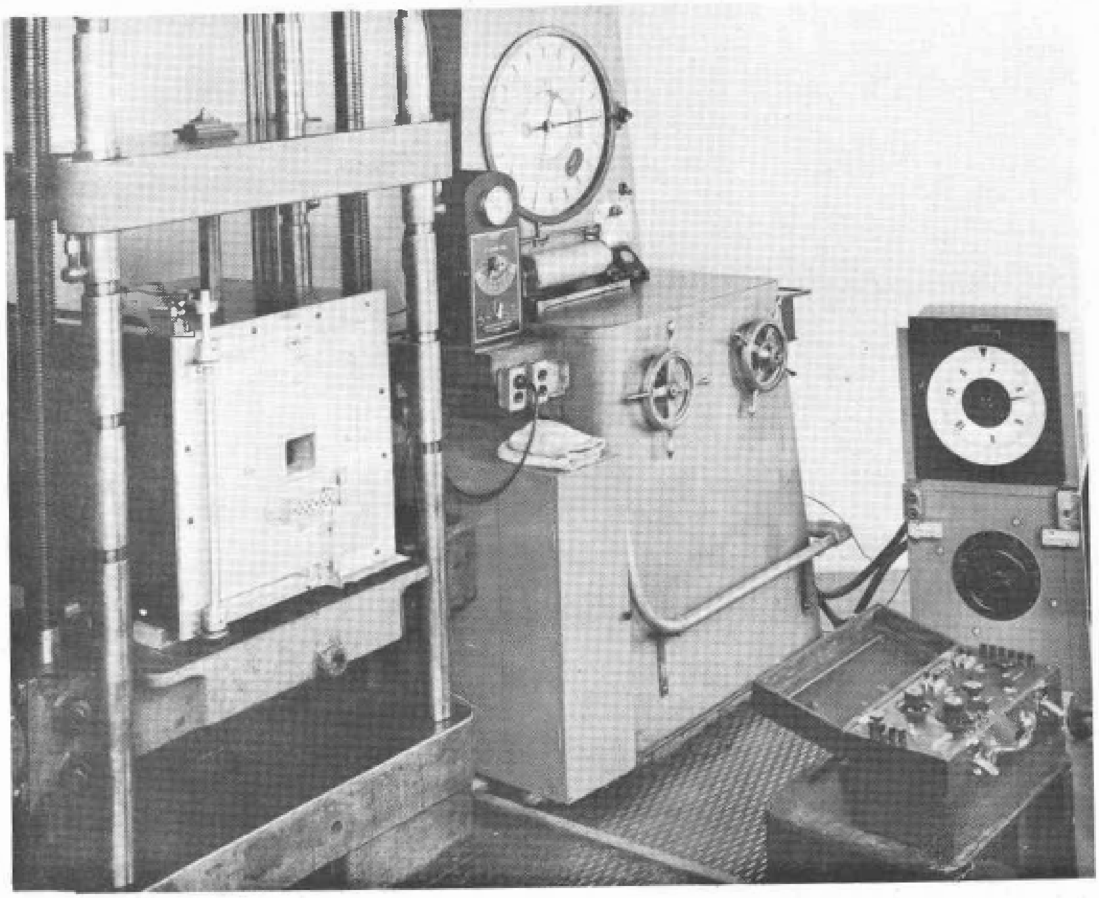


Figure 1. --Test chamber and temperature-controlling apparatus used for maintaining test specimens at 178° to 182° F. during shear strength tests.

Z M 79837 F

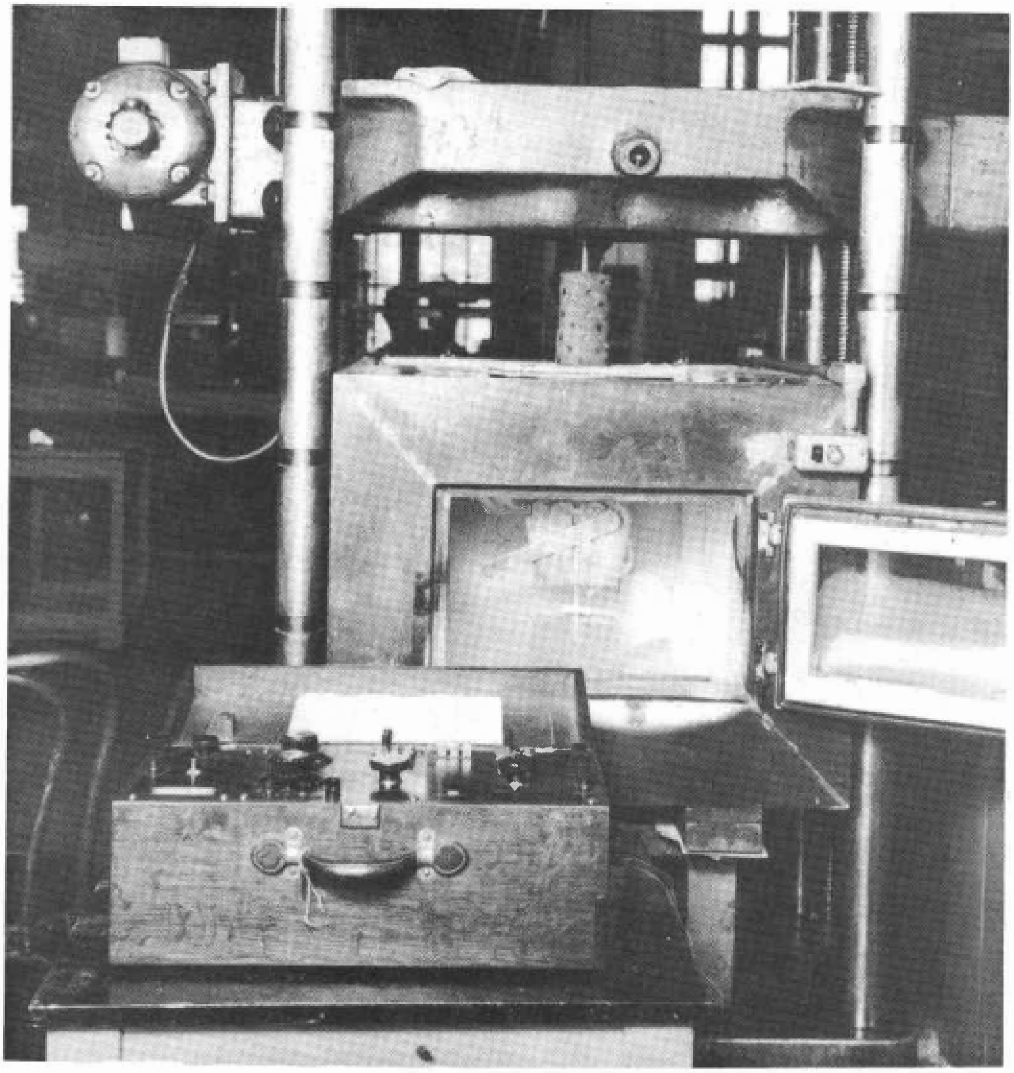


Figure 2. --Test chamber used for maintaining test specimens at -65° to -70° F. during shear strength tests.

Z M 89720 F

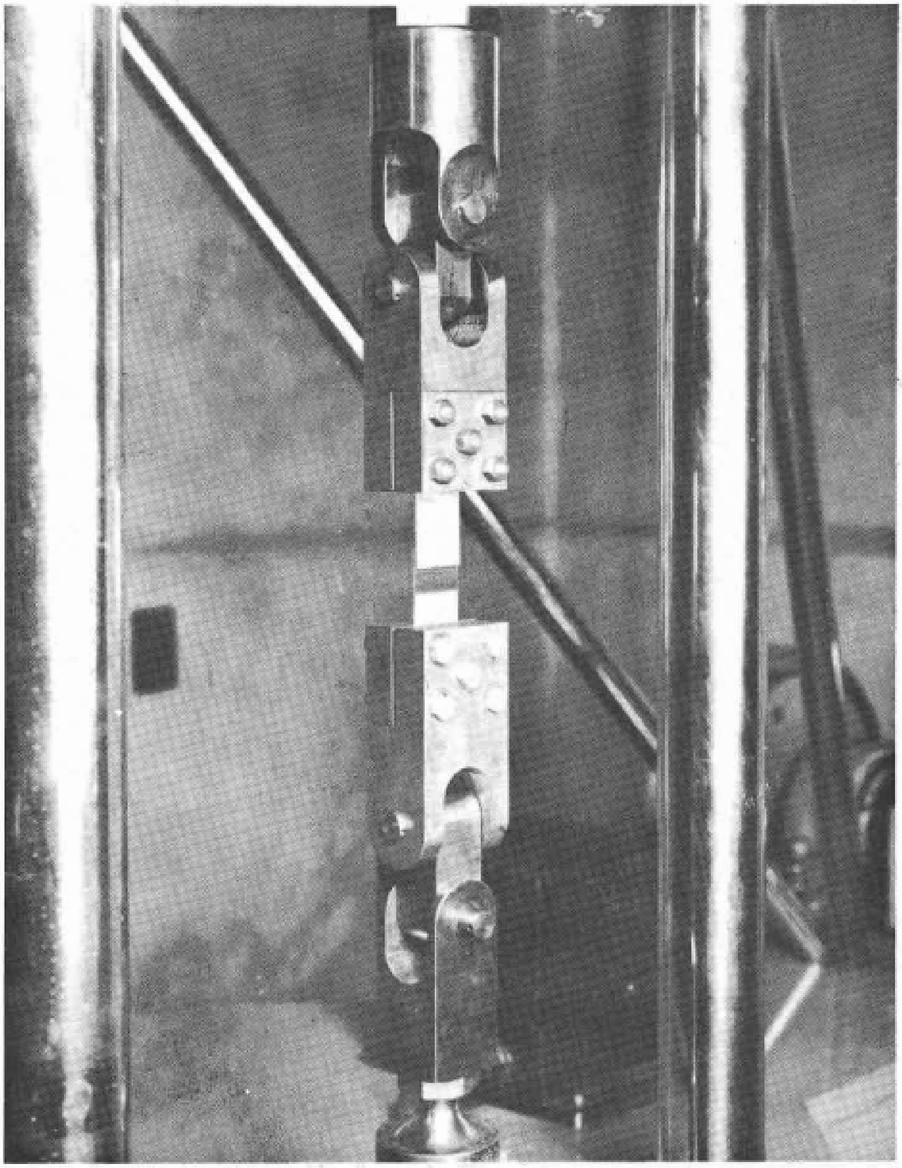
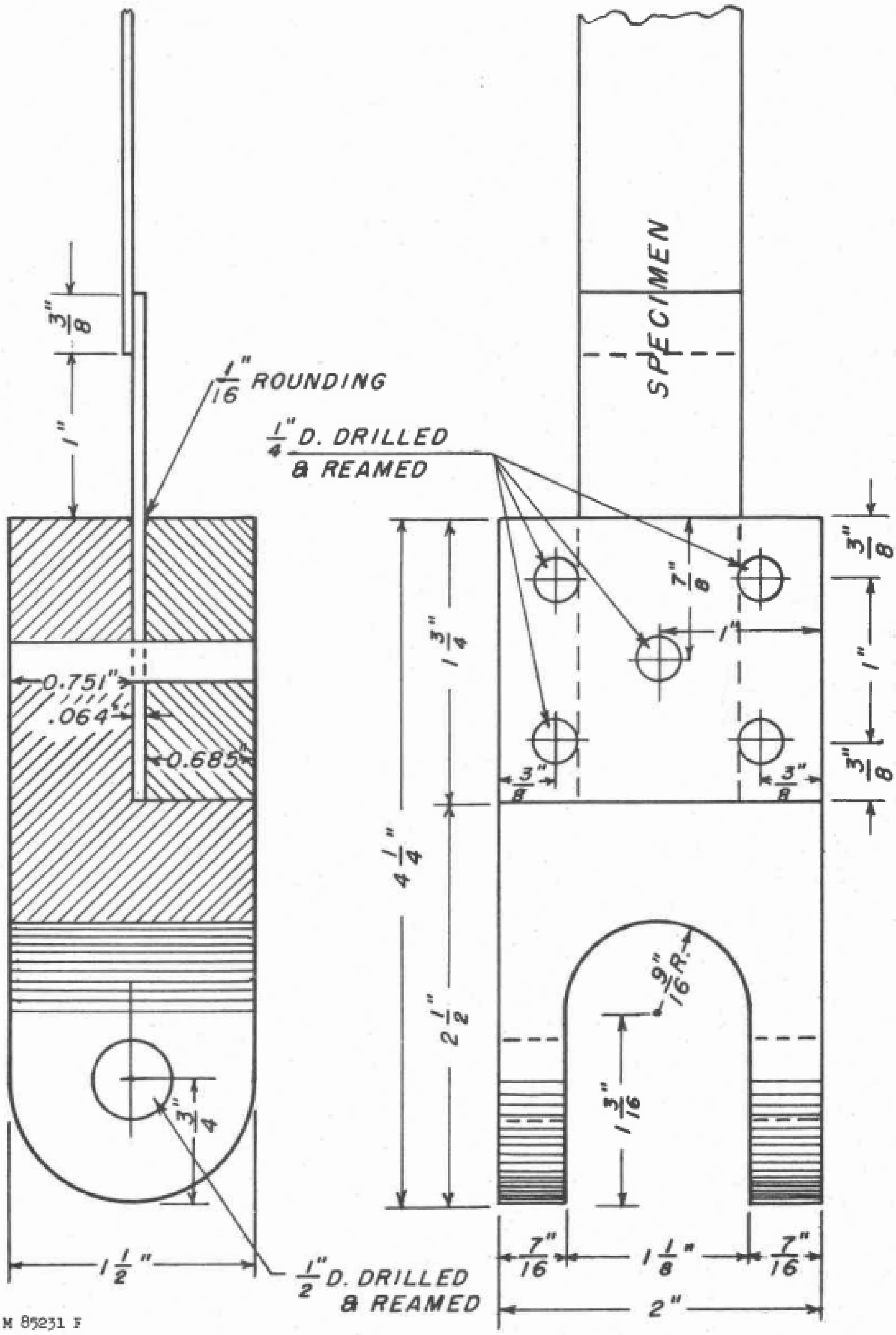


Figure 3. --Test grips used for holding lap-joint specimens of aluminum during fatigue strength tests.

Z M 83456 F



Z M 85231 F

Figure 4. --Detailed drawing of test grips used for holding lap-joint specimens of aluminum during fatigue strength tests.

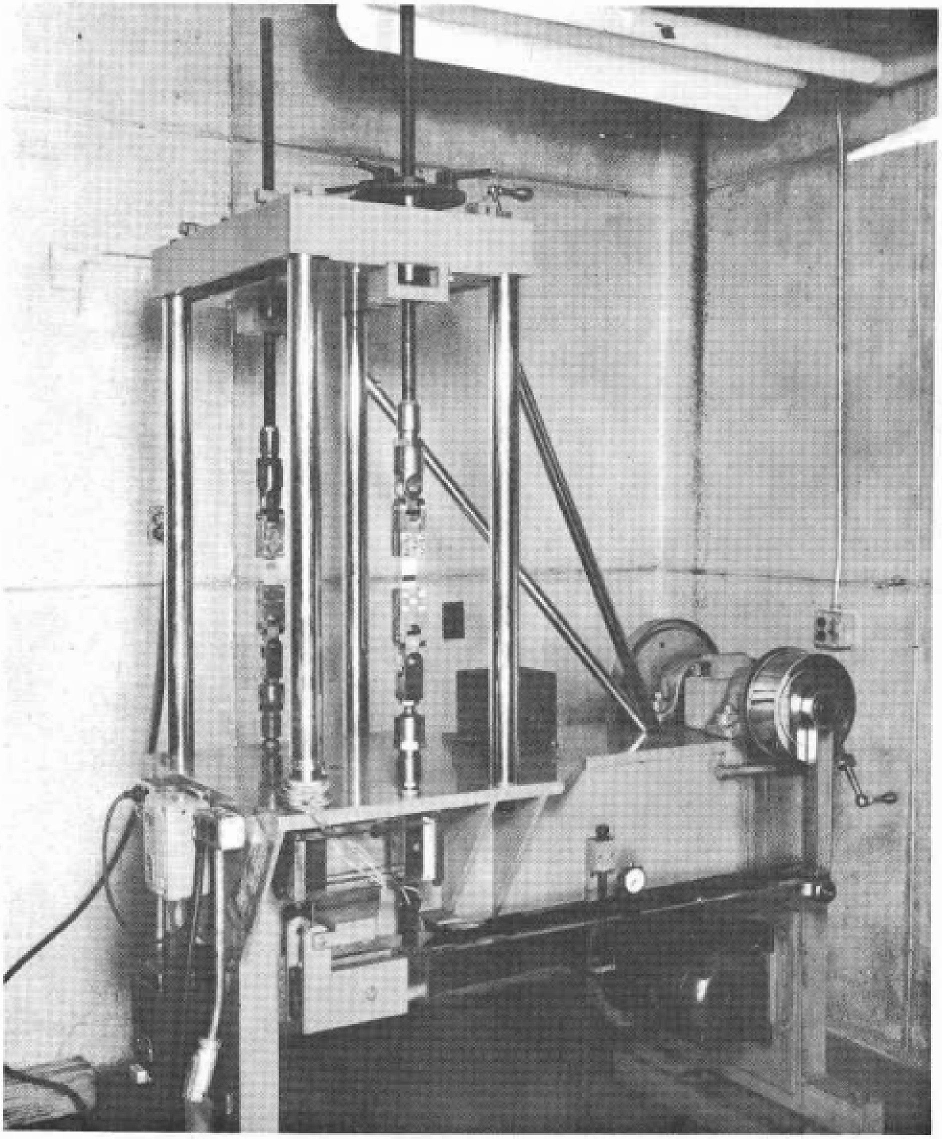


Figure 5. --Direct-stress fatigue machine with test grips and specimens in place for determination of the fatigue strength of adhesive bonds in aluminum lap-joint specimens.

Z M 83455 F

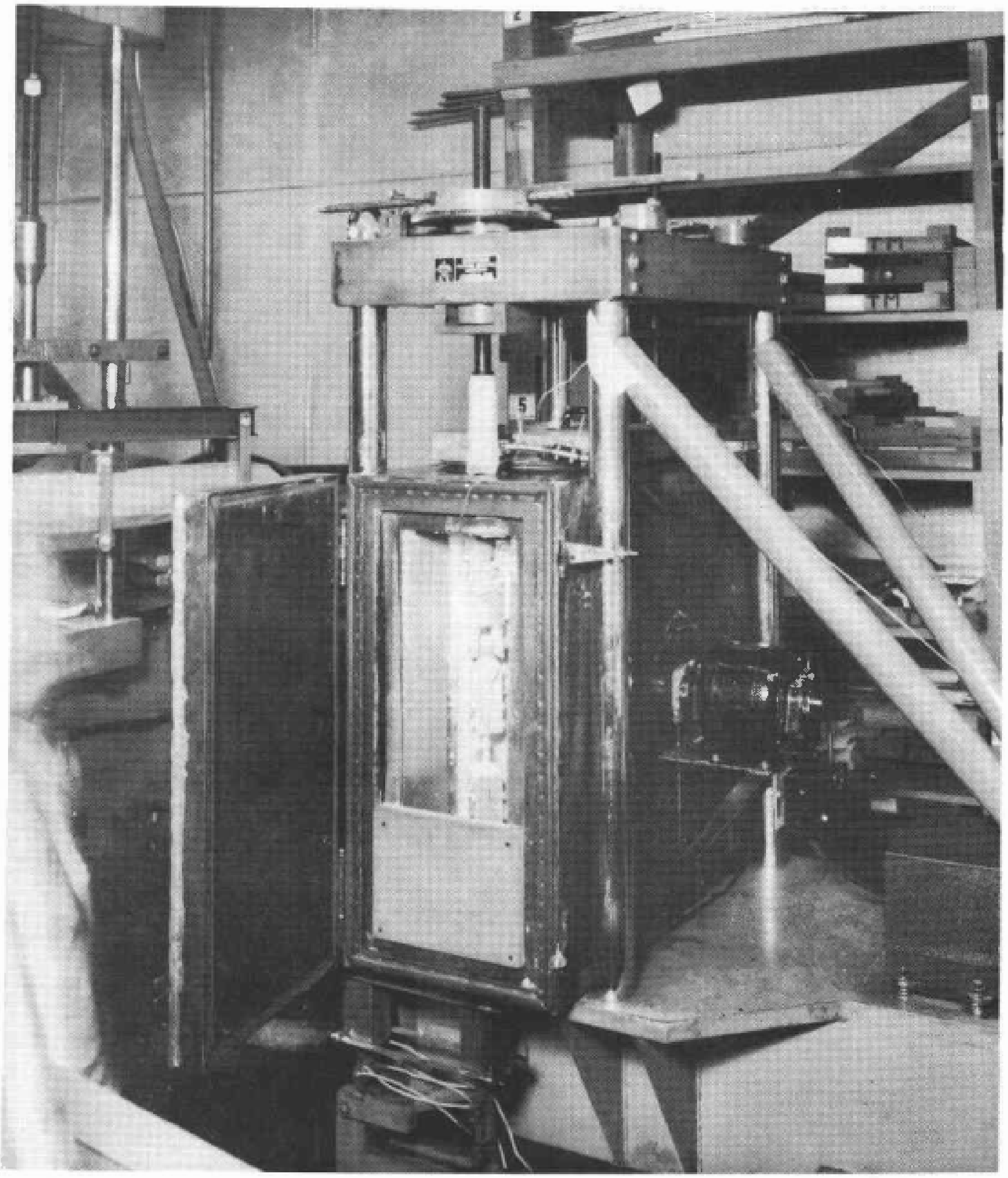


Figure 6. --Test chamber used for maintaining test specimens at -65° to -70° F. during fatigue strength tests.

Z M 89719 F

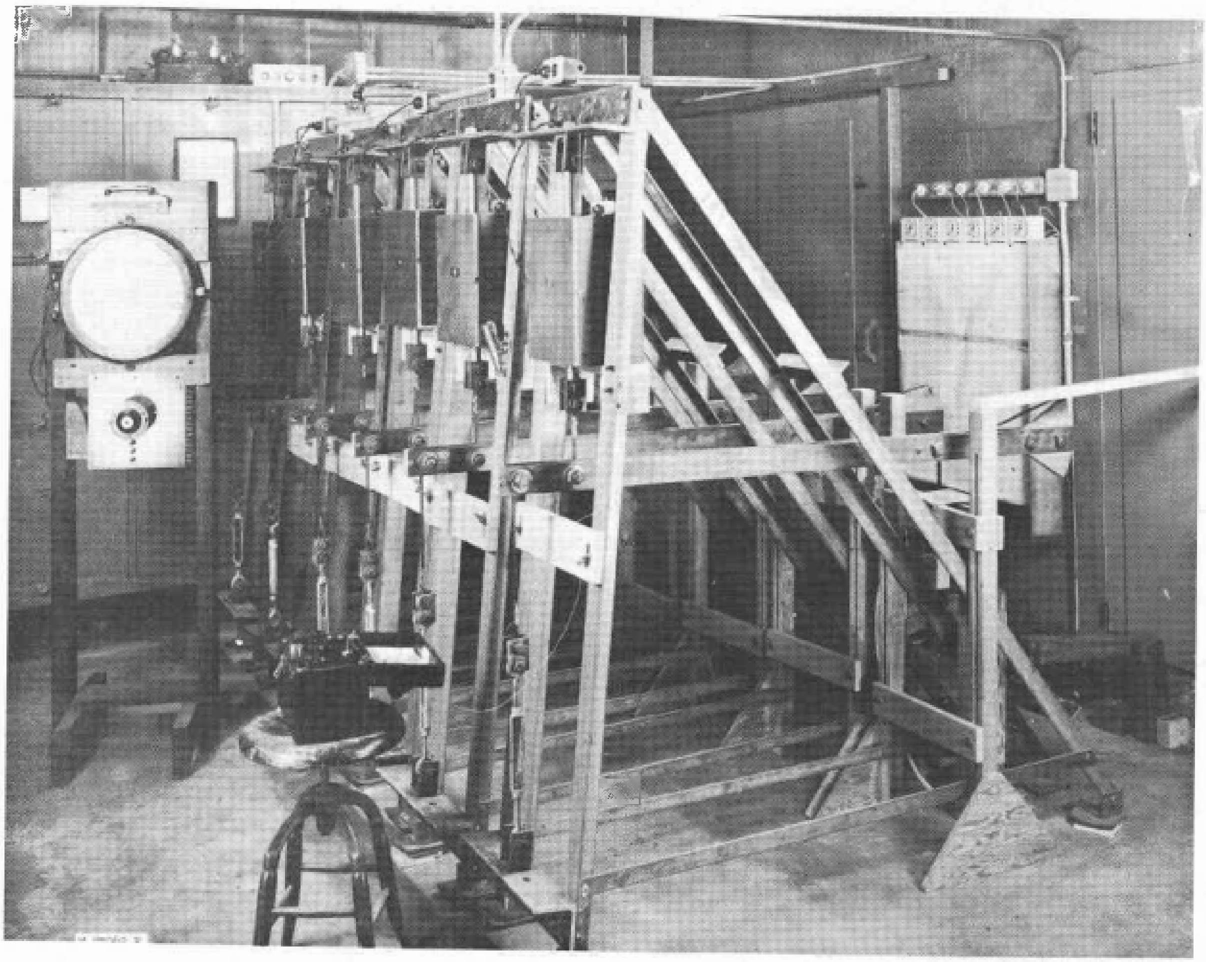


Figure 7. --Cantilever loading apparatus used in determining the long-time strength of **adhesive** bonds in aluminum lap-joint specimens.
Z M 85062 F

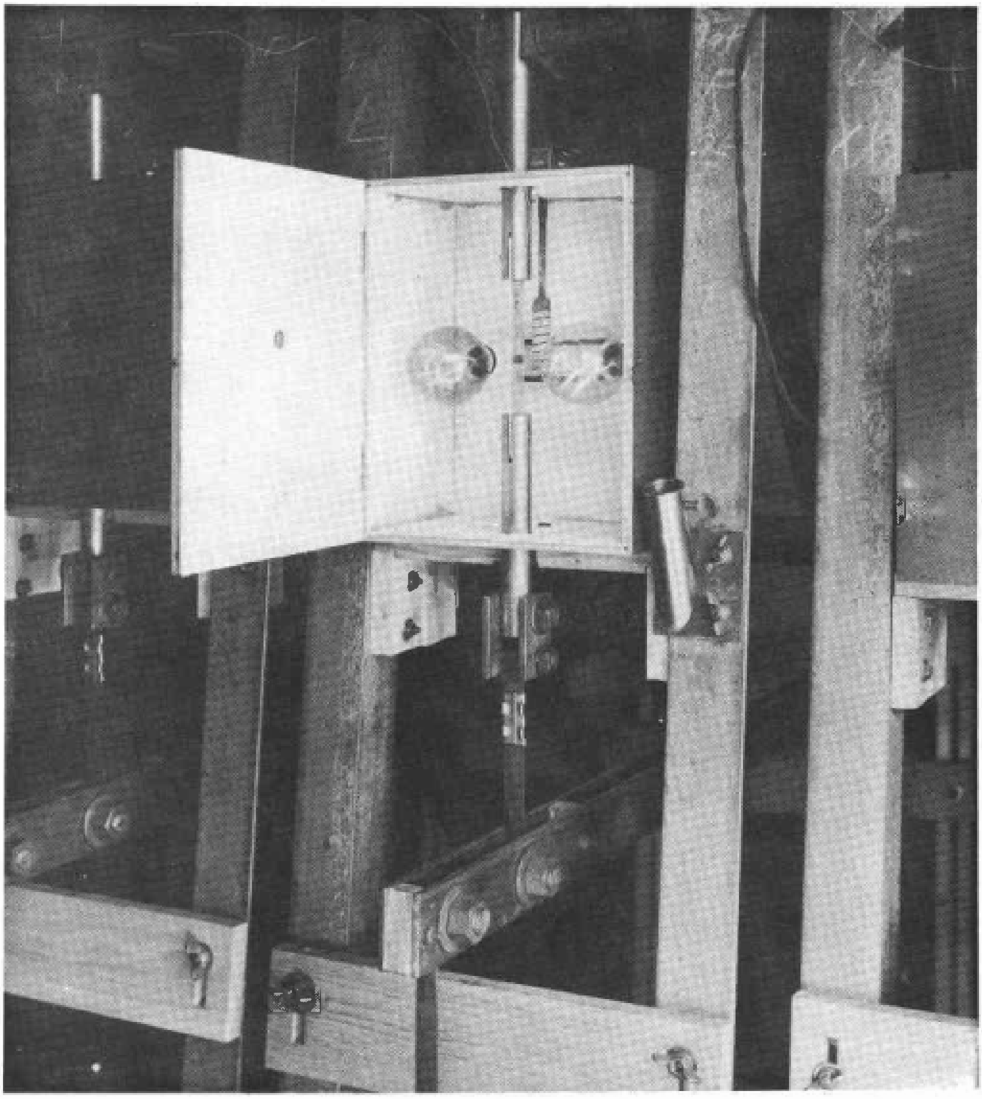


Figure 8. --Arrangement of test specimen, test fixture, and thermostatically controlled heating chamber in the test apparatus for determining the long-time strength of adhesive bonds in aluminum lap-joint specimens.

Z M 85063 F

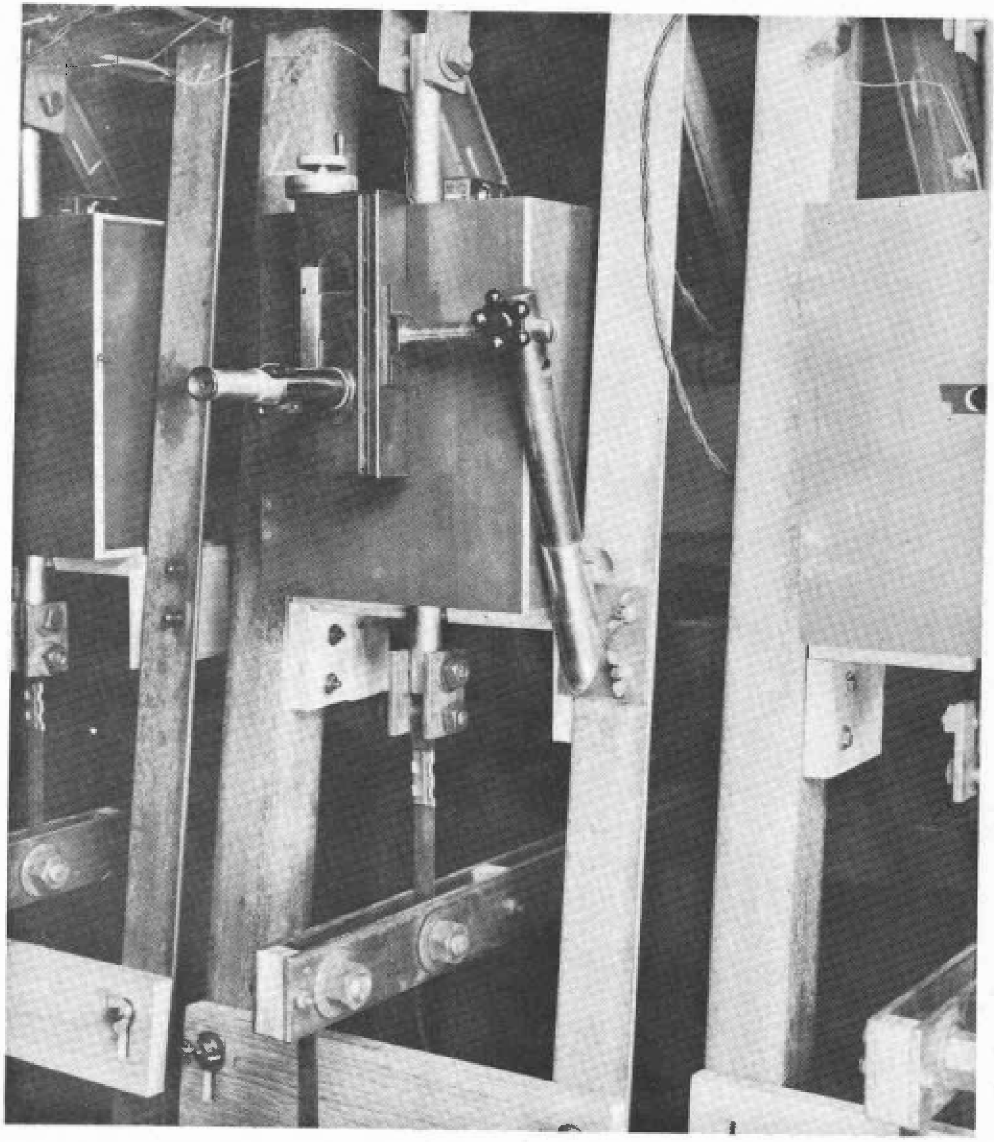


Figure 9. --Arrangement of measuring microscope on cantilever loading apparatus for measuring the deformation of adhesive bonds in aluminum lap-joint specimens during long-time loading.

Z M 85064 F

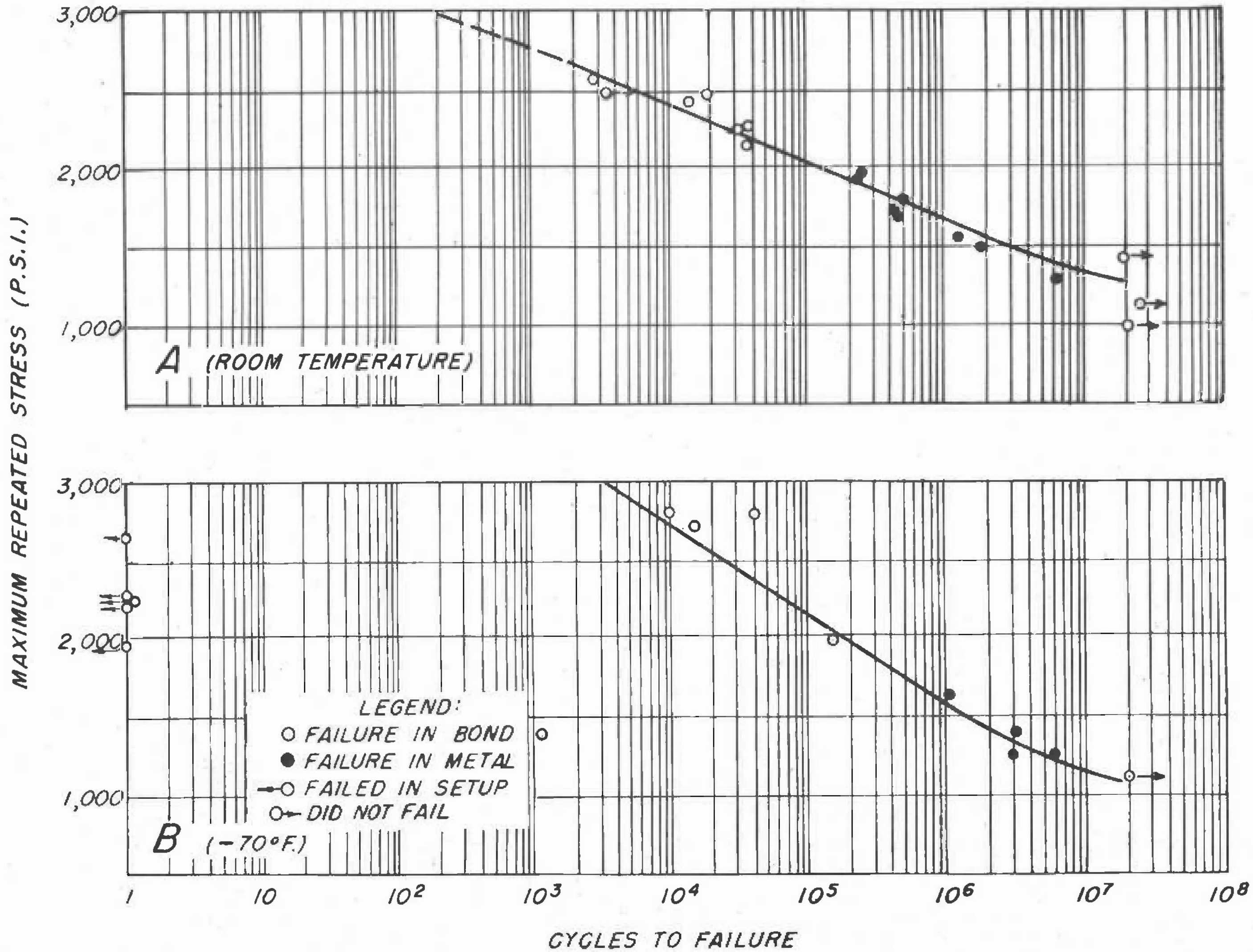


Figure 10. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 25. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 25. Maximum repeated stresses are expressed in pounds per square inch. The stress ratio was 0.10.

Z M 89683 F

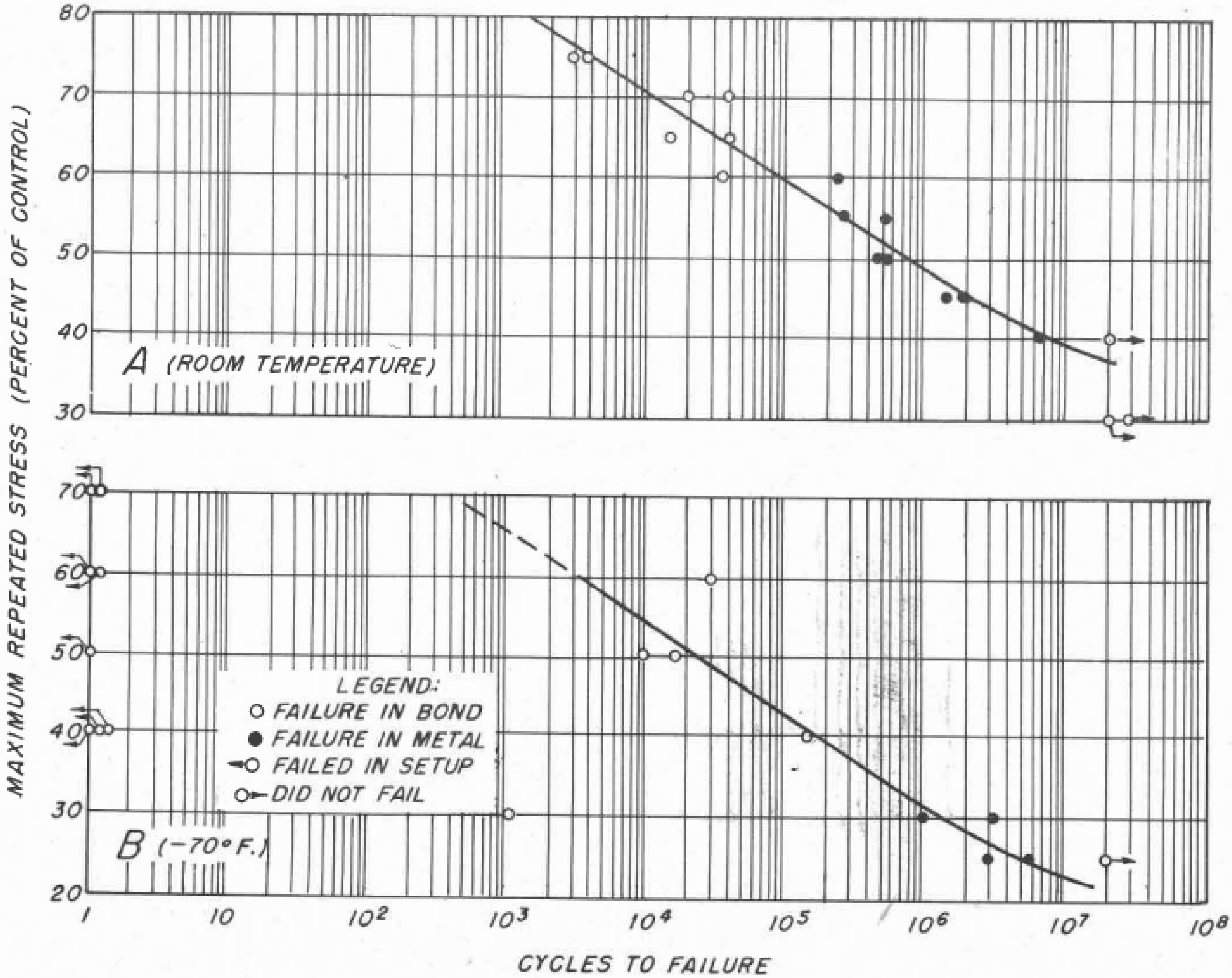


Figure 11. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 25. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 25. Maximum repeated stresses are expressed as percentages of the control strength. The stress ratio was 0. 10.

Z M 89682 F

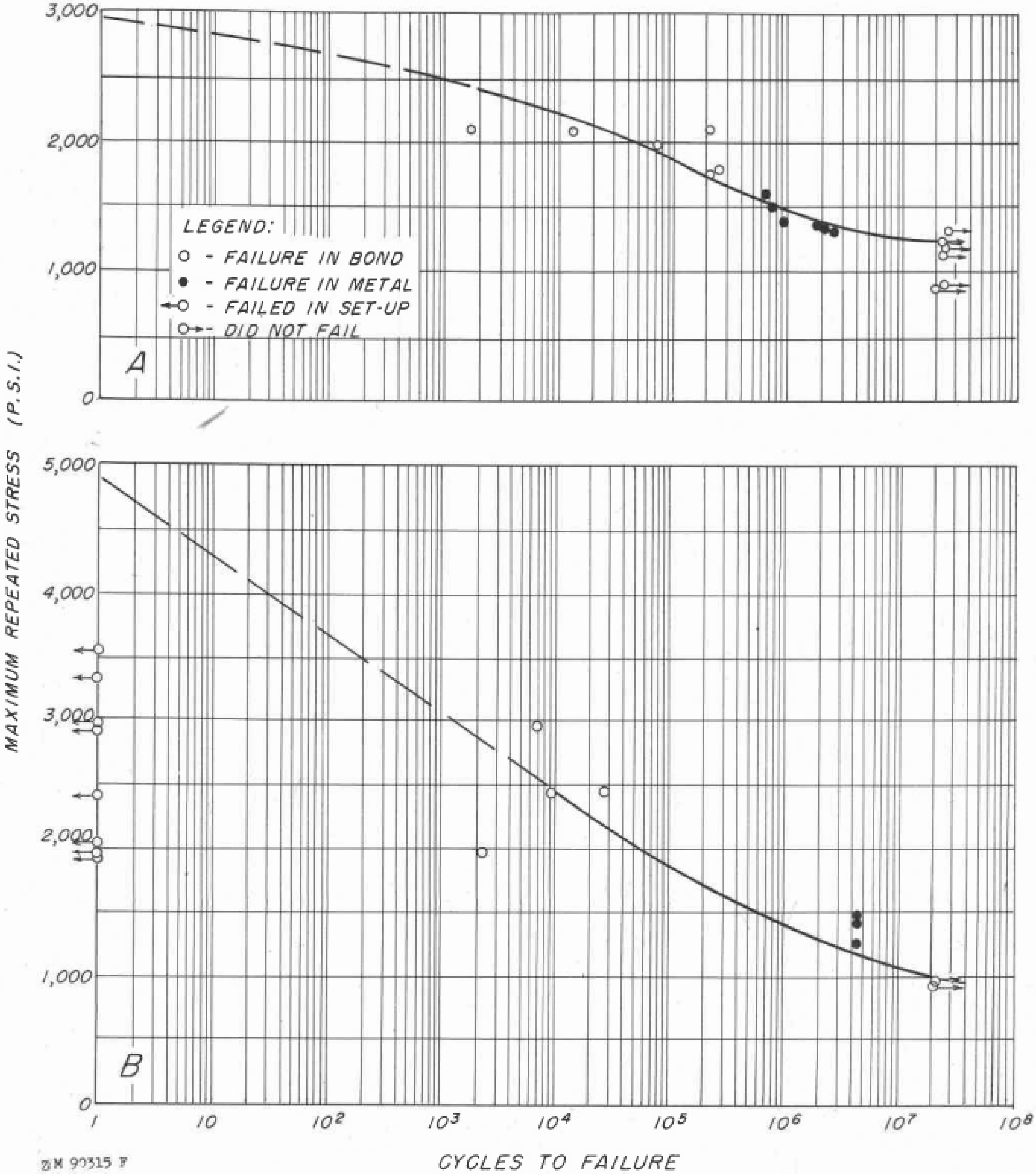
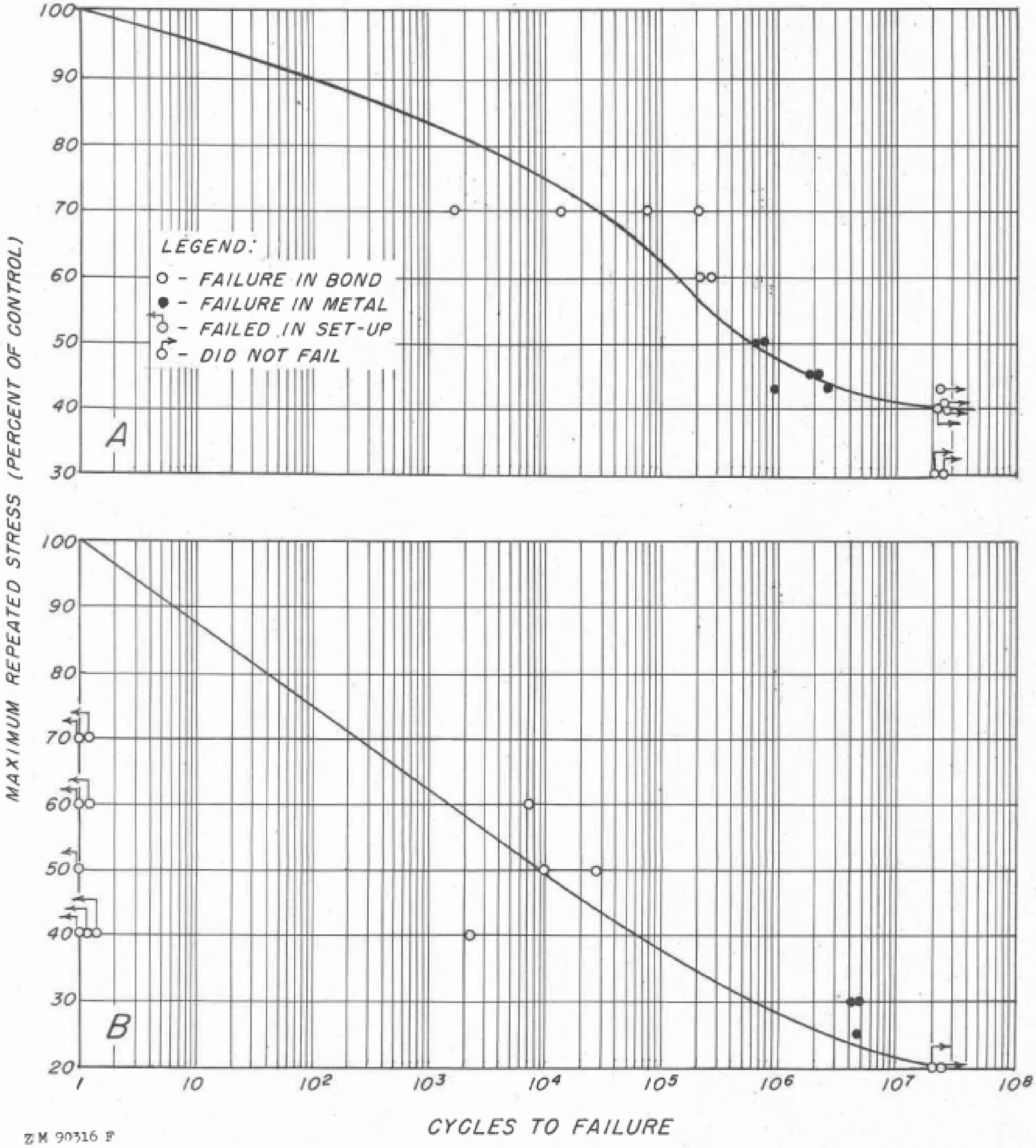
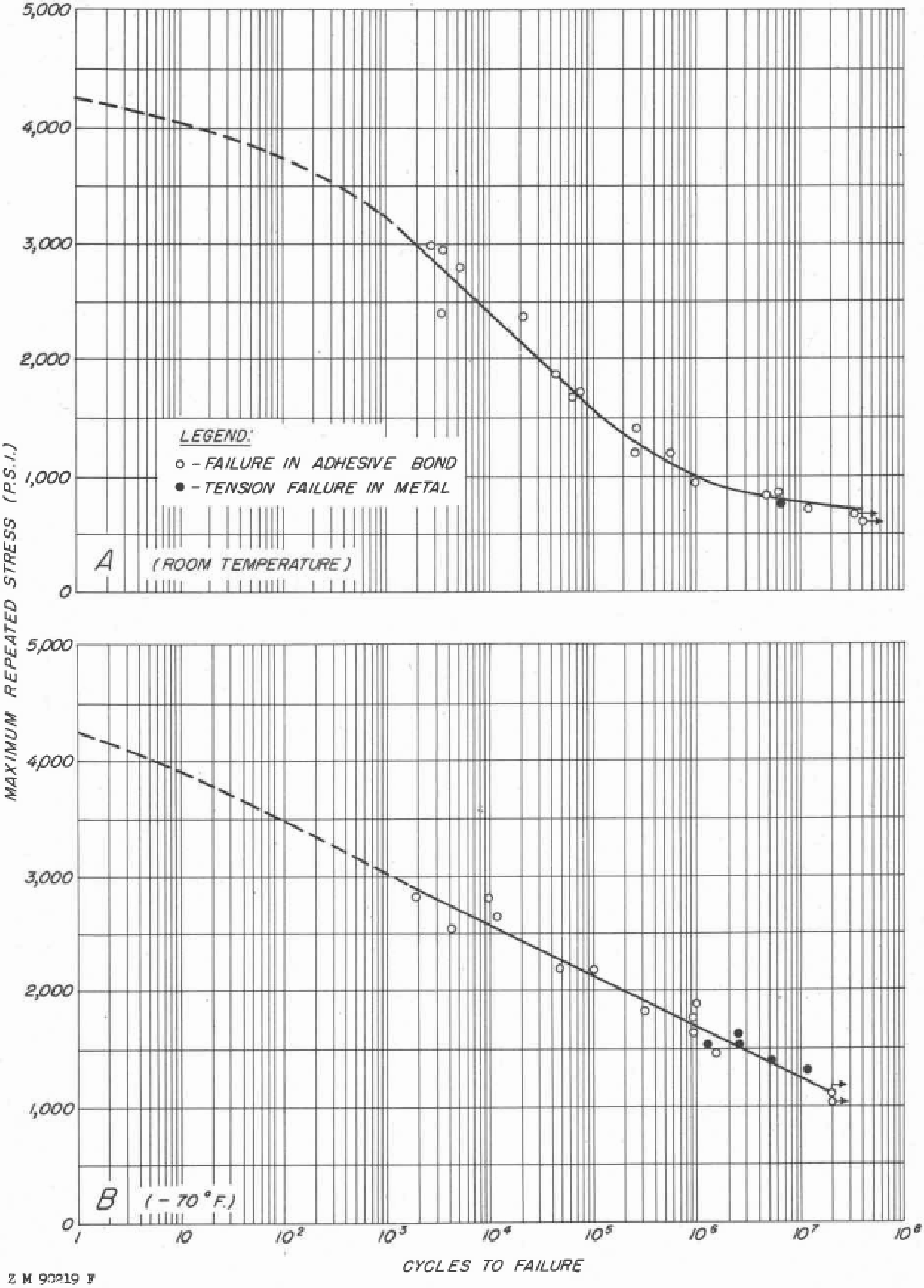


Figure 12. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 25-26. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 25-26. Maximum repeated stresses are expressed in pounds per square inch. The stress ratio was 0.10.



Z M 90316 F

Figure 13. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 25-26. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 25-26. Maximum repeated stresses are expressed as percentages of the control strength. The stress ratio was 0.10.



Z M 90219 F

Figure 14. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 34. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 34. Maximum repeated stresses are expressed in pounds per square inch. The stress ratio was 0. 10. The test points with arrows attached are for specimens that did not fail.

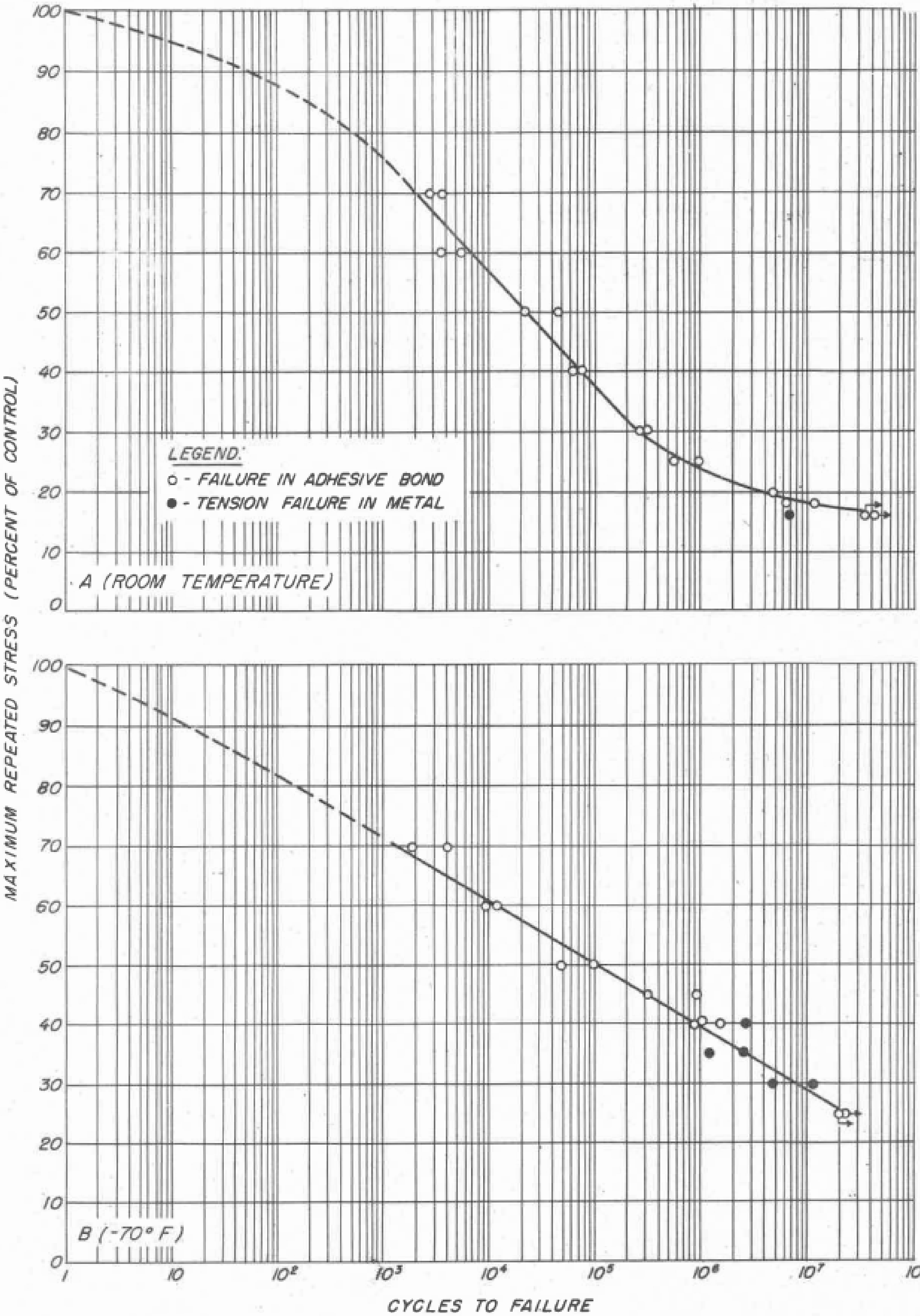


Figure 15. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 34. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 34. Maximum repeated stresses are expressed as percentages of the control strength. The stress ratio was 0.10. The test points with arrows attached are for specimens that did not fail.

Z M 90218 F

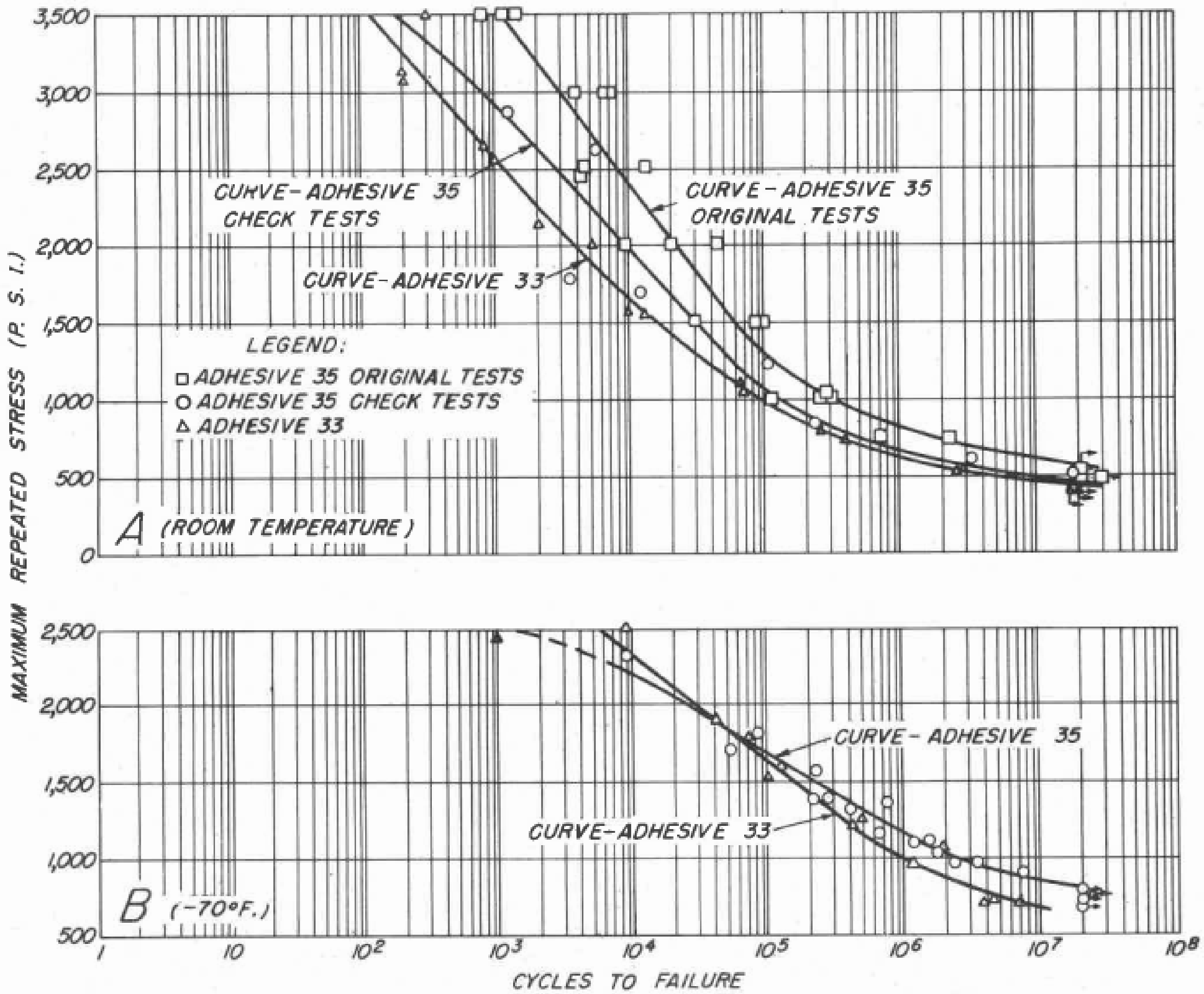


Figure 16. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 33 and with adhesive 35. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 33 and with adhesive 35. Maximum repeated stresses are expressed in pounds per square inch. The stress ratio was 0. 10. The test points with arrows attached are for specimens that did not fail.

Z M 89594 F

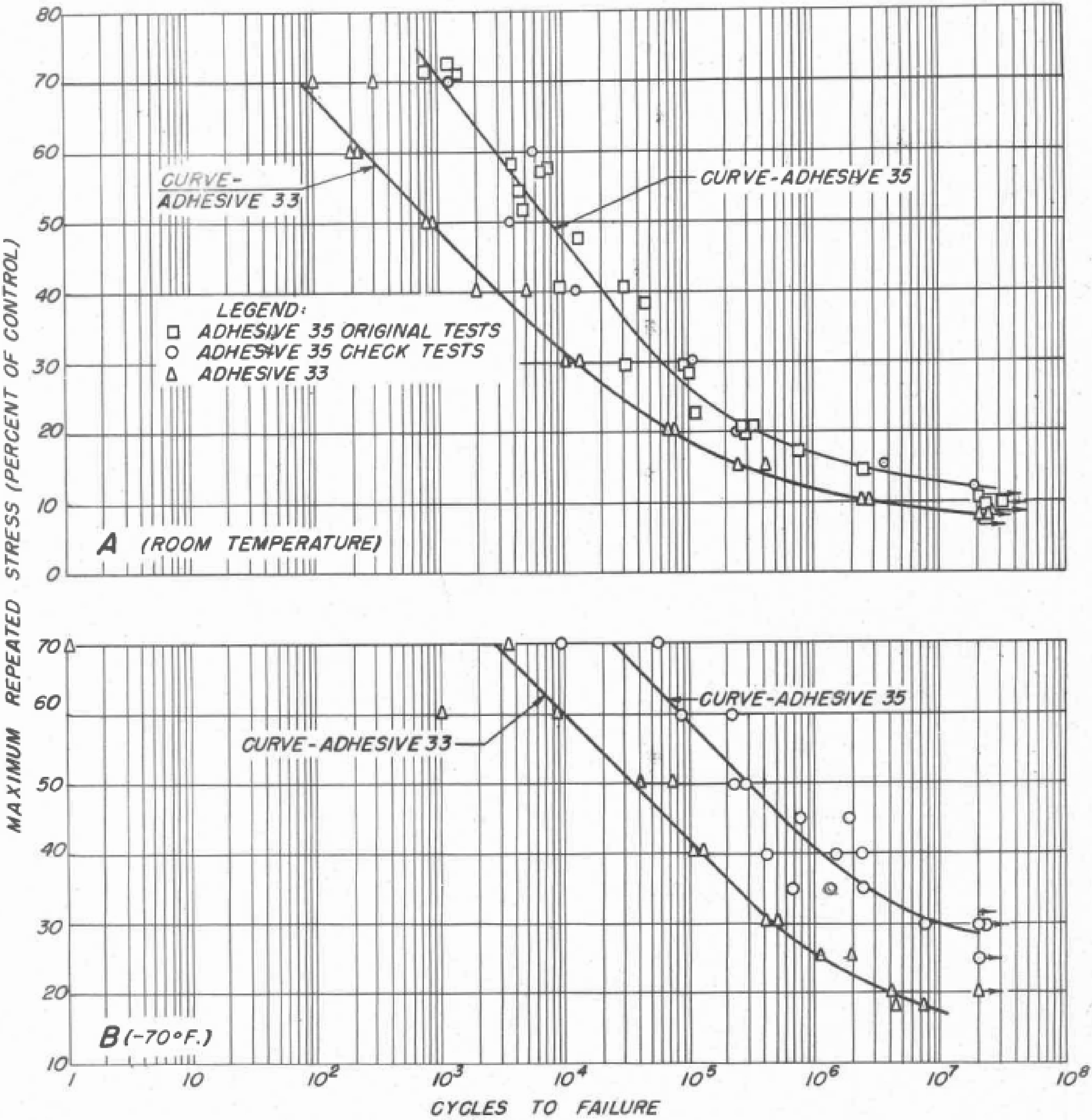


Figure 17. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 33 and with adhesive 35. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 33 and with adhesive 35. Maximum repeated stresses are expressed as percentages of the control strength. The stress ratio was 0.10. The test points with arrows attached are for specimens that did not fail.

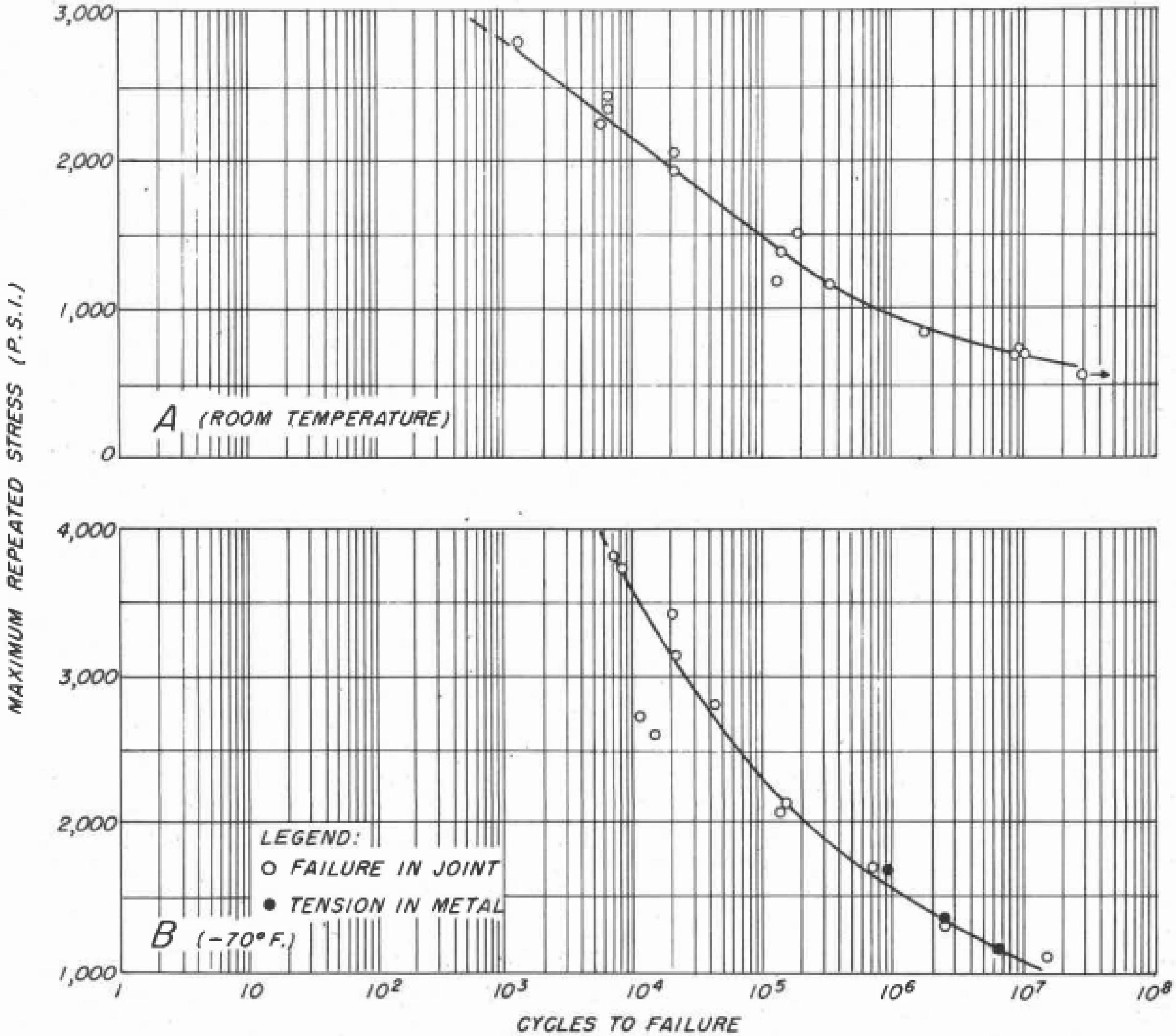


Figure 18. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 36. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 36. Maximum repeated stresses are expressed in pounds per square inch. The stress ratio was 0.10. The test point with arrow attached is for a specimen that did not fail.

Z M 89675 F

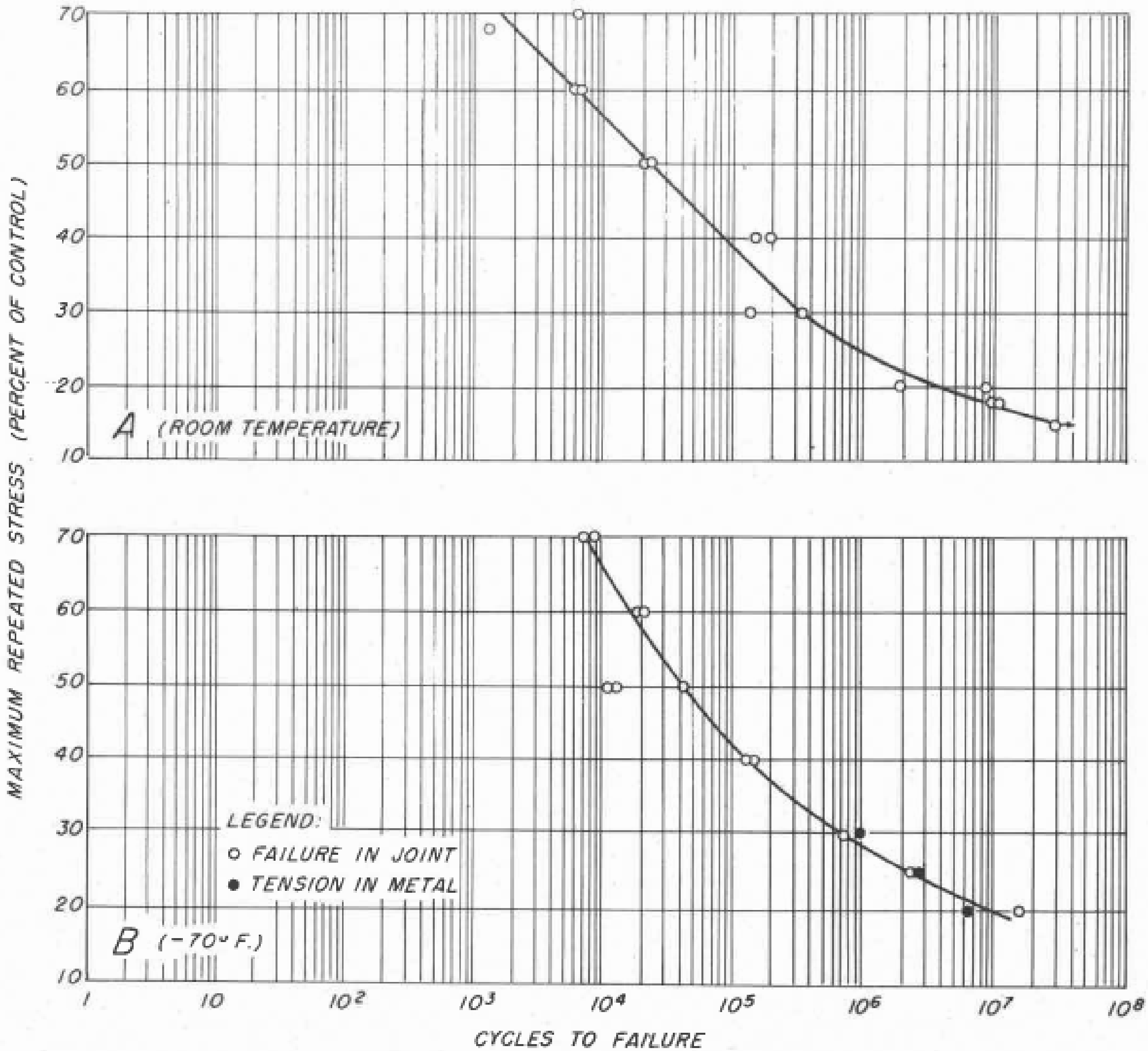


Figure 19. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 36. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 36. Maximum repeated stresses are expressed as percentages of the control strength. The stress ratio was 0. 10. The test point with arrow attached is for a specimen that did not fail.

Z M 89674 F

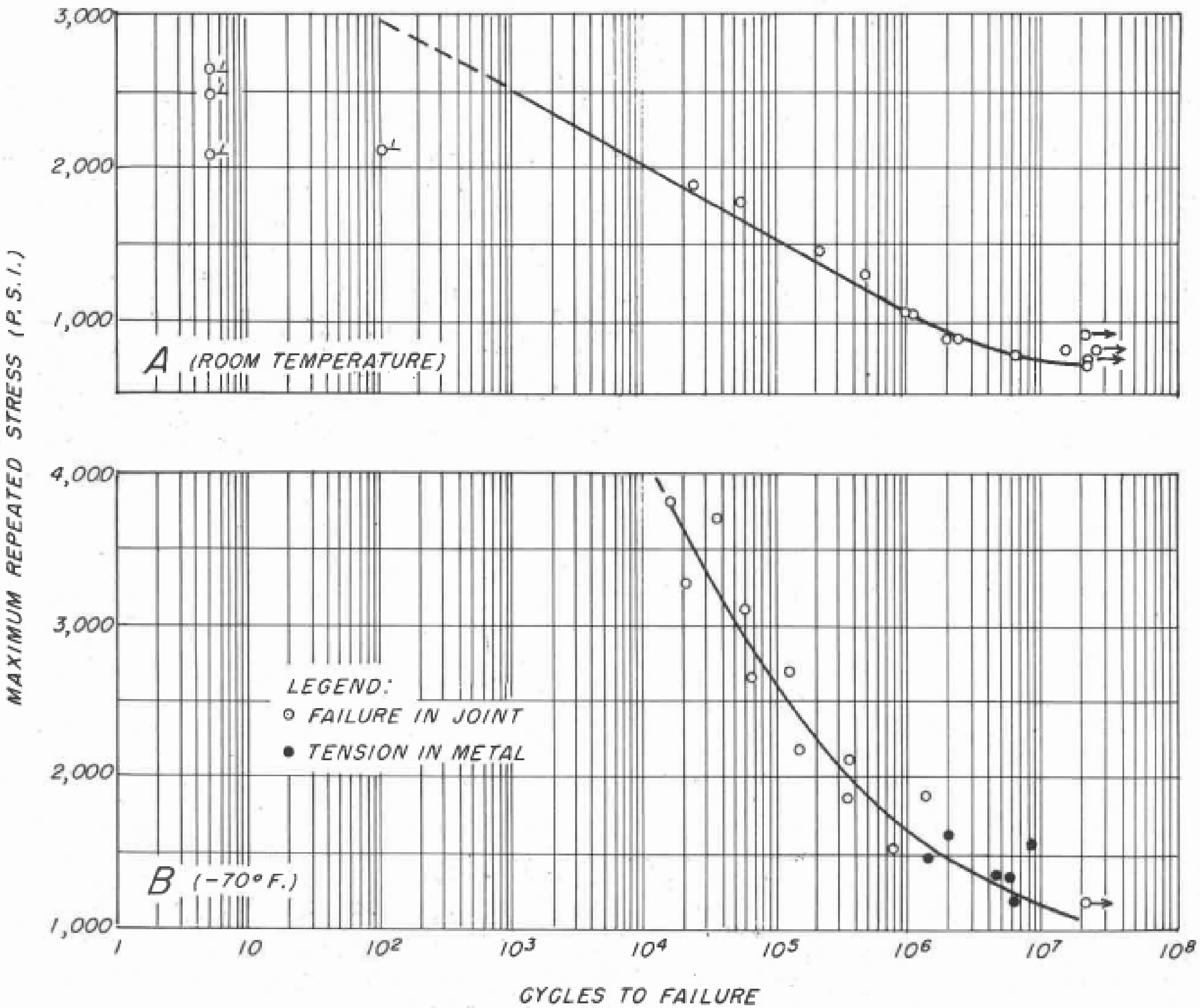


Figure 20. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 37. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 37. Maximum repeated stresses are expressed in pounds per square inch. The stress ratio was 0.10. The test points with arrows attached are for specimens that did not fail. The test points marked[1] are for specimens that were adversely affected by creep during adjustment of load and failed prematurely.

Z M 89679 F

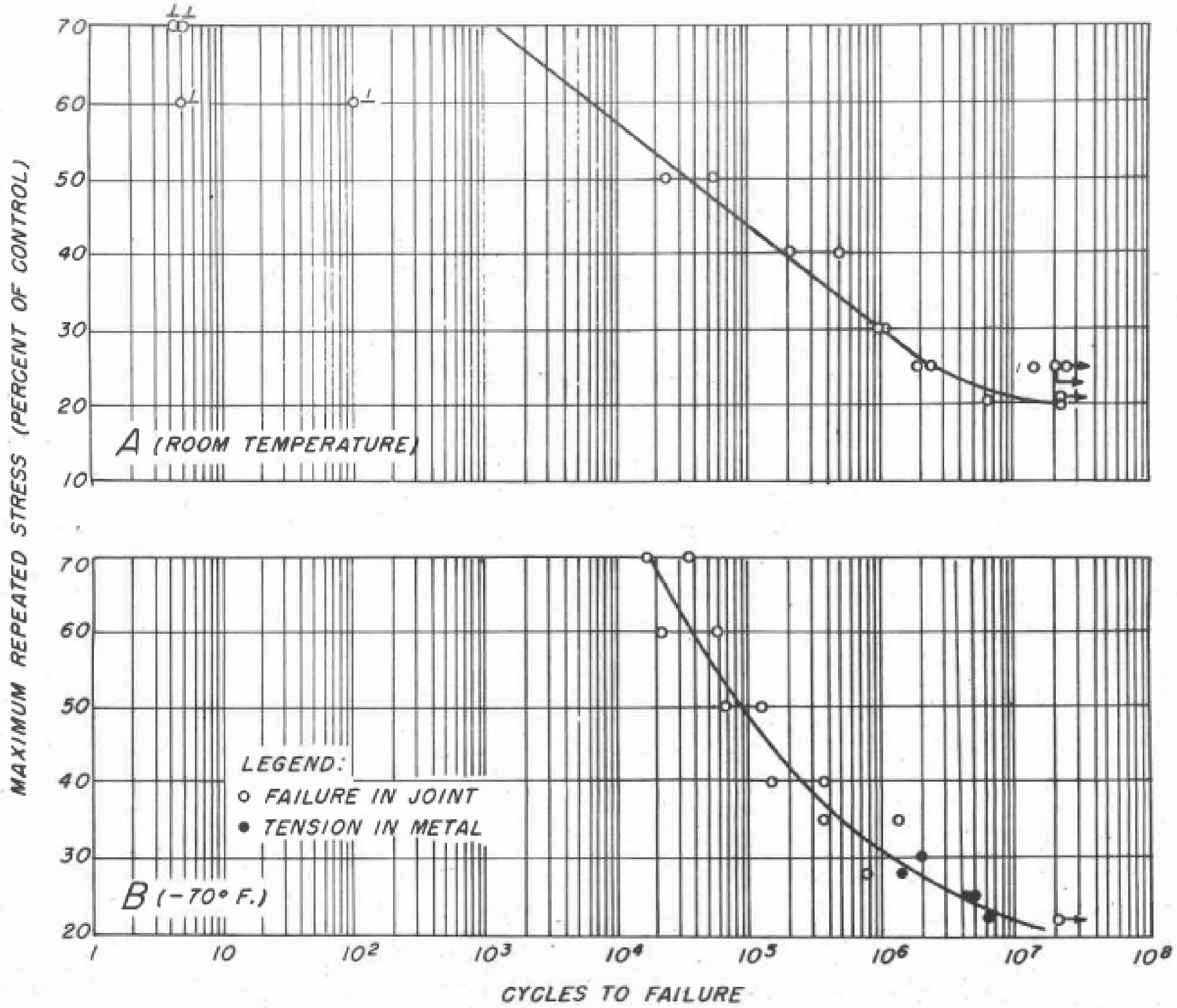
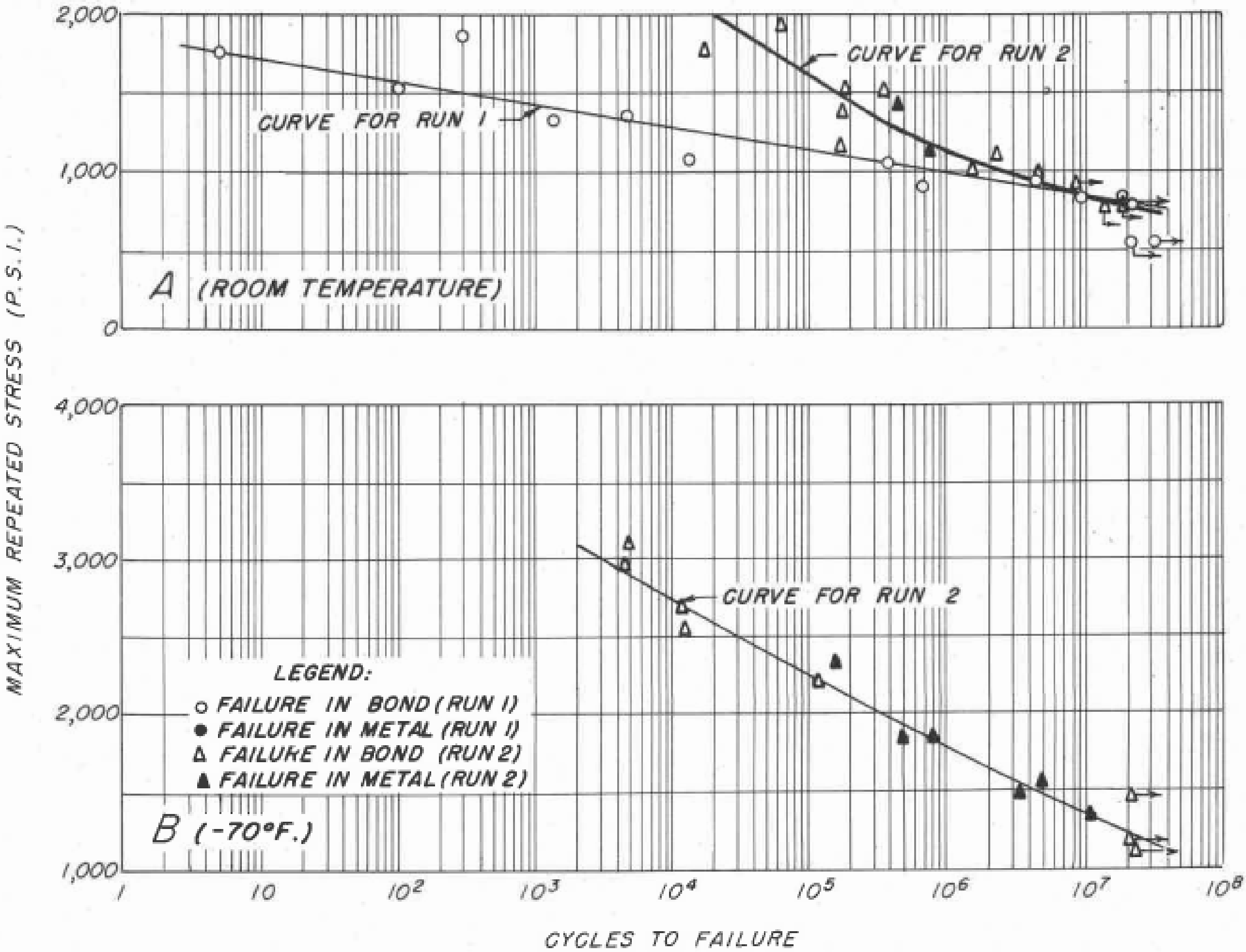


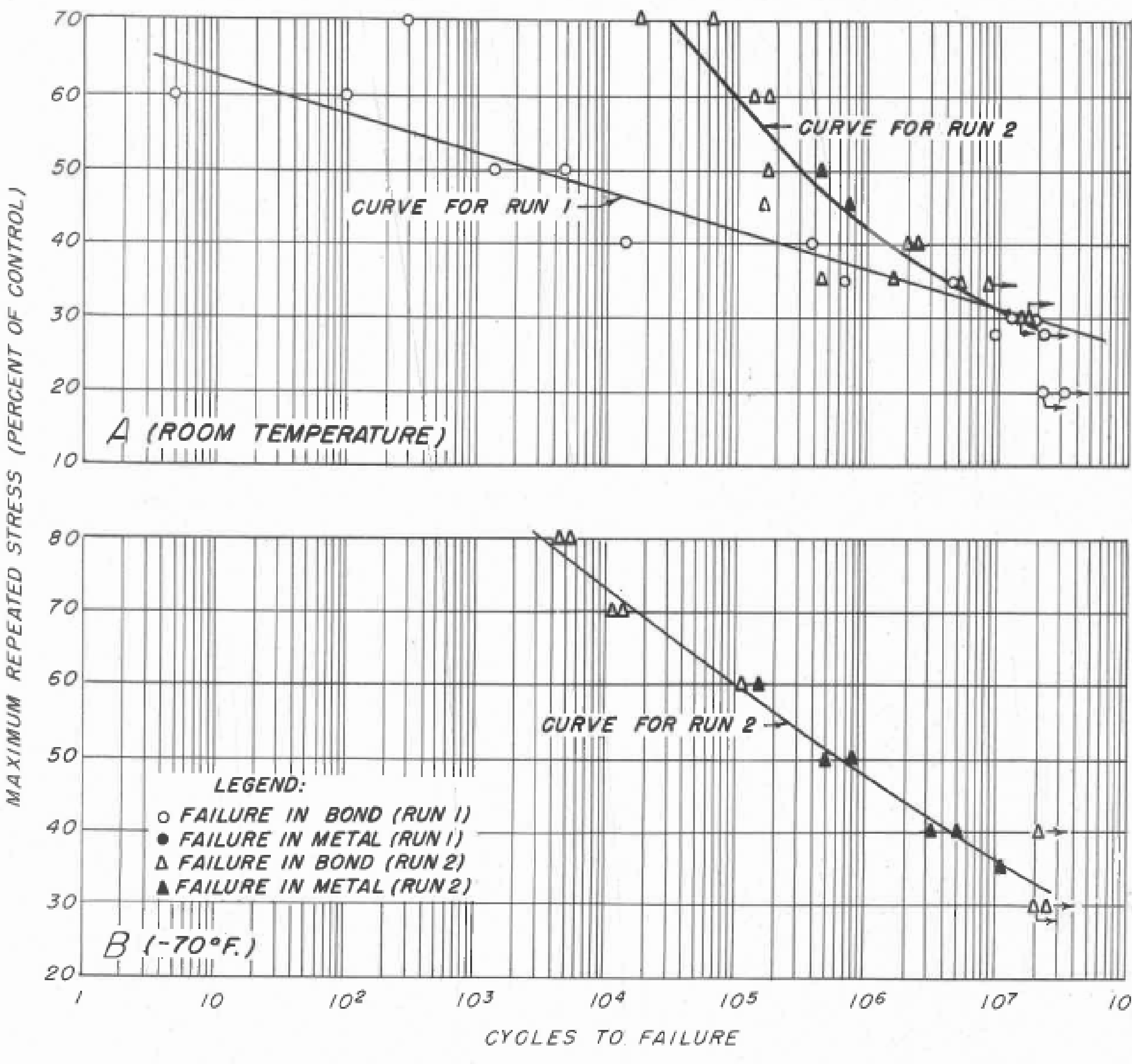
Figure 21. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 37. B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 37. Maximum repeated stresses are expressed as percentages of the control strength. The stress ratio was 0. 10. The test points with arrows attached are for specimens that did not fail. The test points marked 1 are for specimens that were adversely affected by creep during adjustment of load and failed prematurely.

Z M 89678 F



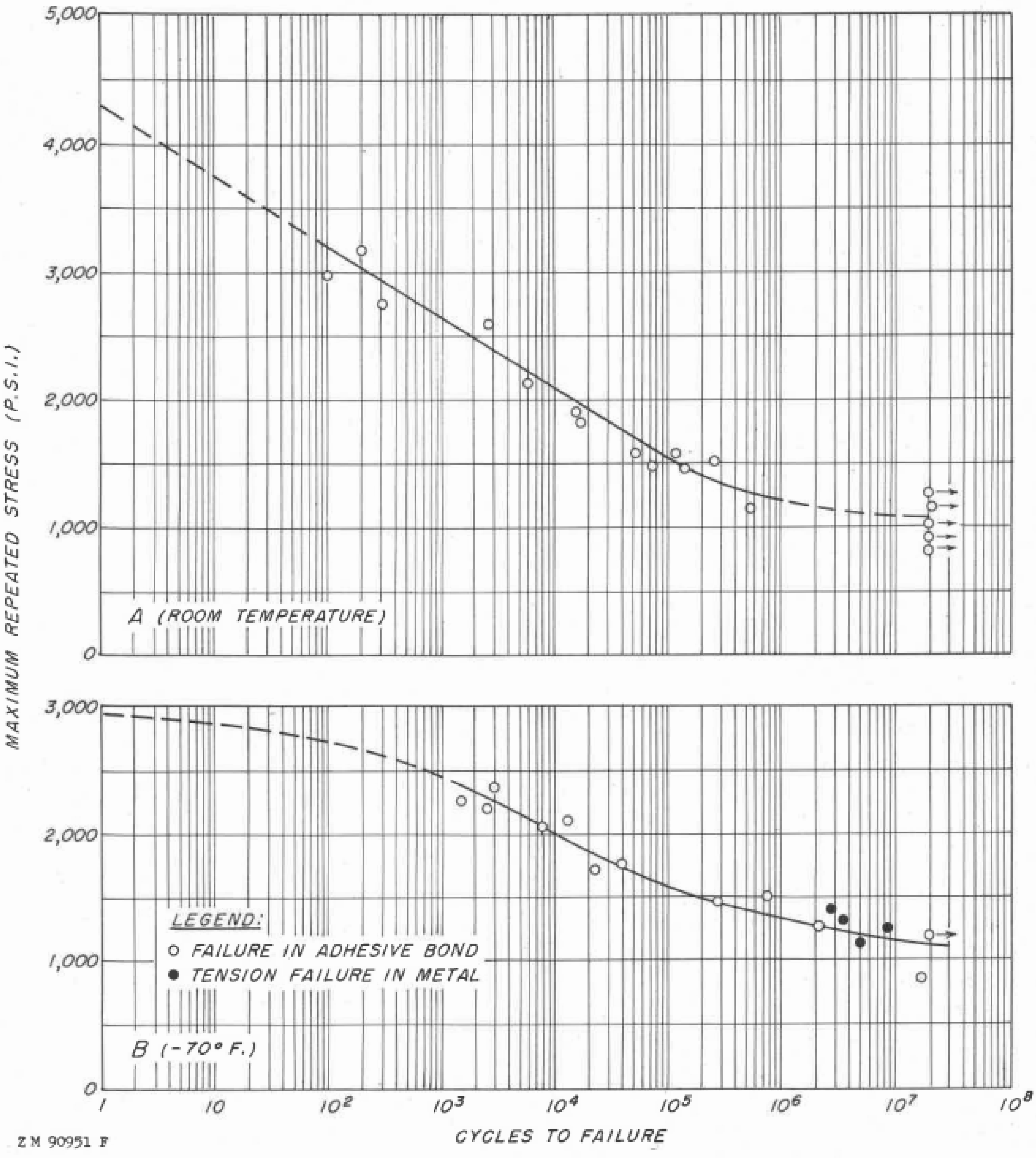
Z M 90313 F

Figure 22--A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 38 (Runs 1 and 2). B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 38 (Run 2). Maximum repeated stresses are expressed in pounds per square inch. The stress ratio was 0.10. The test points with arrows attached are for specimens that did not fail.



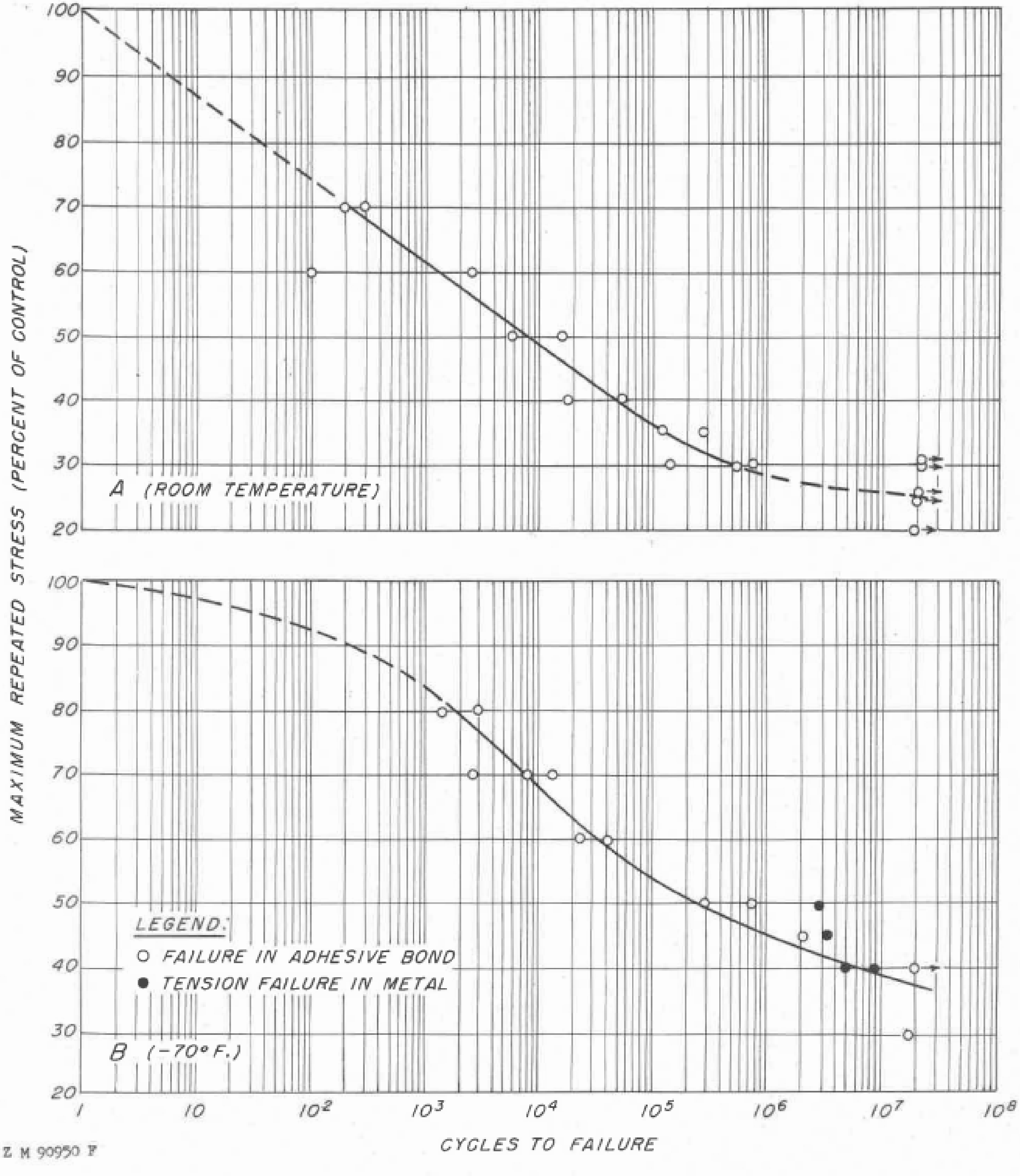
Z M 90314 F

Figure 23.--A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 38 (Runs 1 and 2). B. S-N fatigue curve at -65° to -70° F. for specimens bonded with adhesive 38 (Run 2). Maximum repeated stresses are expressed as percentages of the control strength. The stress ratio was 0.10. The test points with arrows attached are for specimens that did not fail.



Z M 90951 F

Figure 24. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 41. B. S-N fatigue curve at -70° F. for similar specimens bonded with adhesive 41. Maximum repeated stresses are expressed in pounds per square inch (calculated). The stress ratio was 0. 10. Test points with arrows attached are for specimens that did not fail.



Z M 90950 F

Figure 25. --A. S-N (stress-number of cycles to failure) fatigue curve at room temperature (75° F.) for single-lap specimens of 24S-T3 clad aluminum alloy bonded with adhesive 41. B. S-N fatigue curve at -70° F. for similar specimens bonded with adhesive 41. Maximum repeated stresses are expressed as percentages of the average static (control) strength of matched specimens. The stress ratio was 0: 10. Test points with arrows attached are for specimens that did not fail.

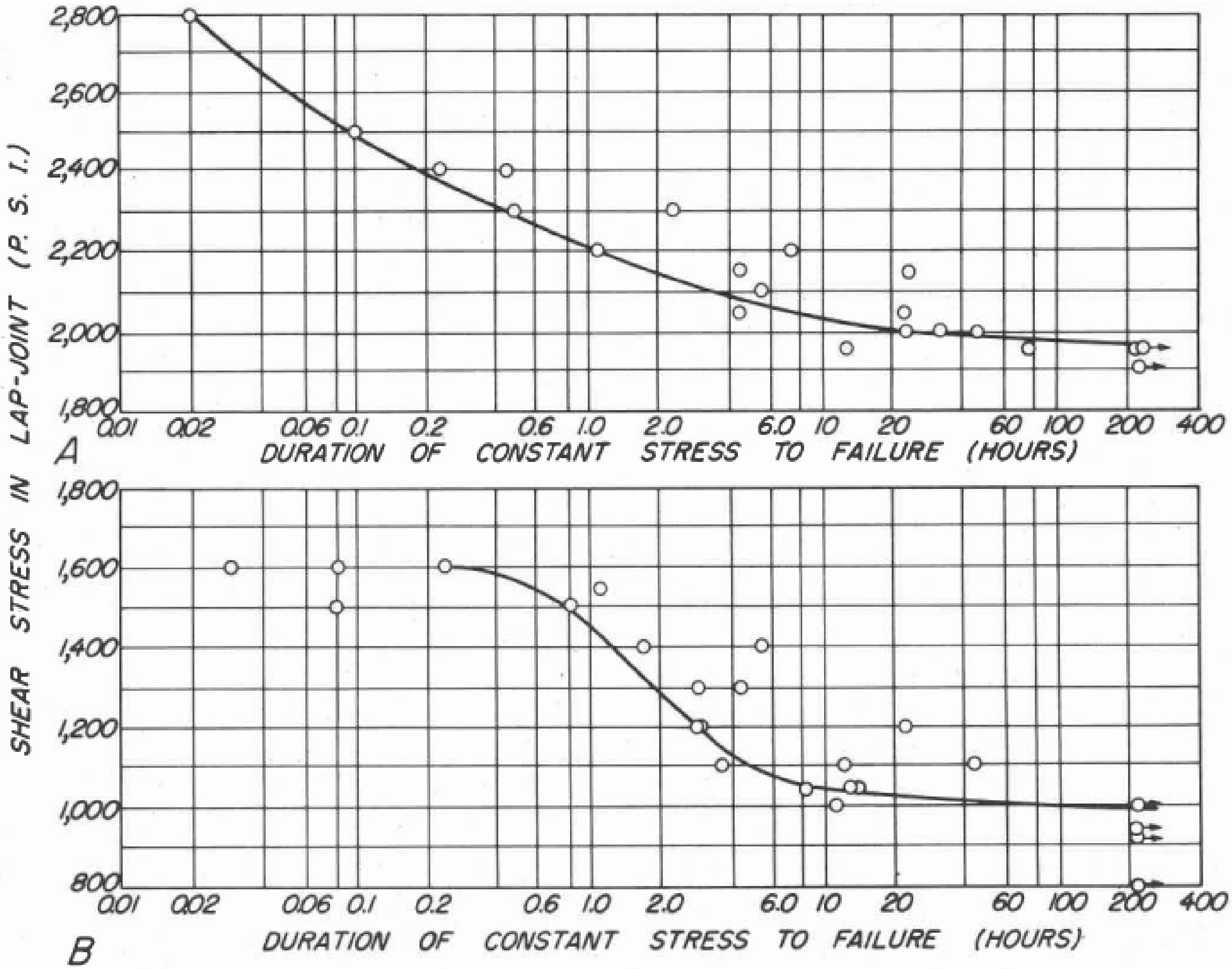


Figure 26. --Time to failure in long-time-load tests at various stress levels for 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 25. Test points with arrows attached are for specimens that did not fail. A, exposed at 72° to 76° F.; B, exposed at 178° to 182° F.

Z M 86674 F

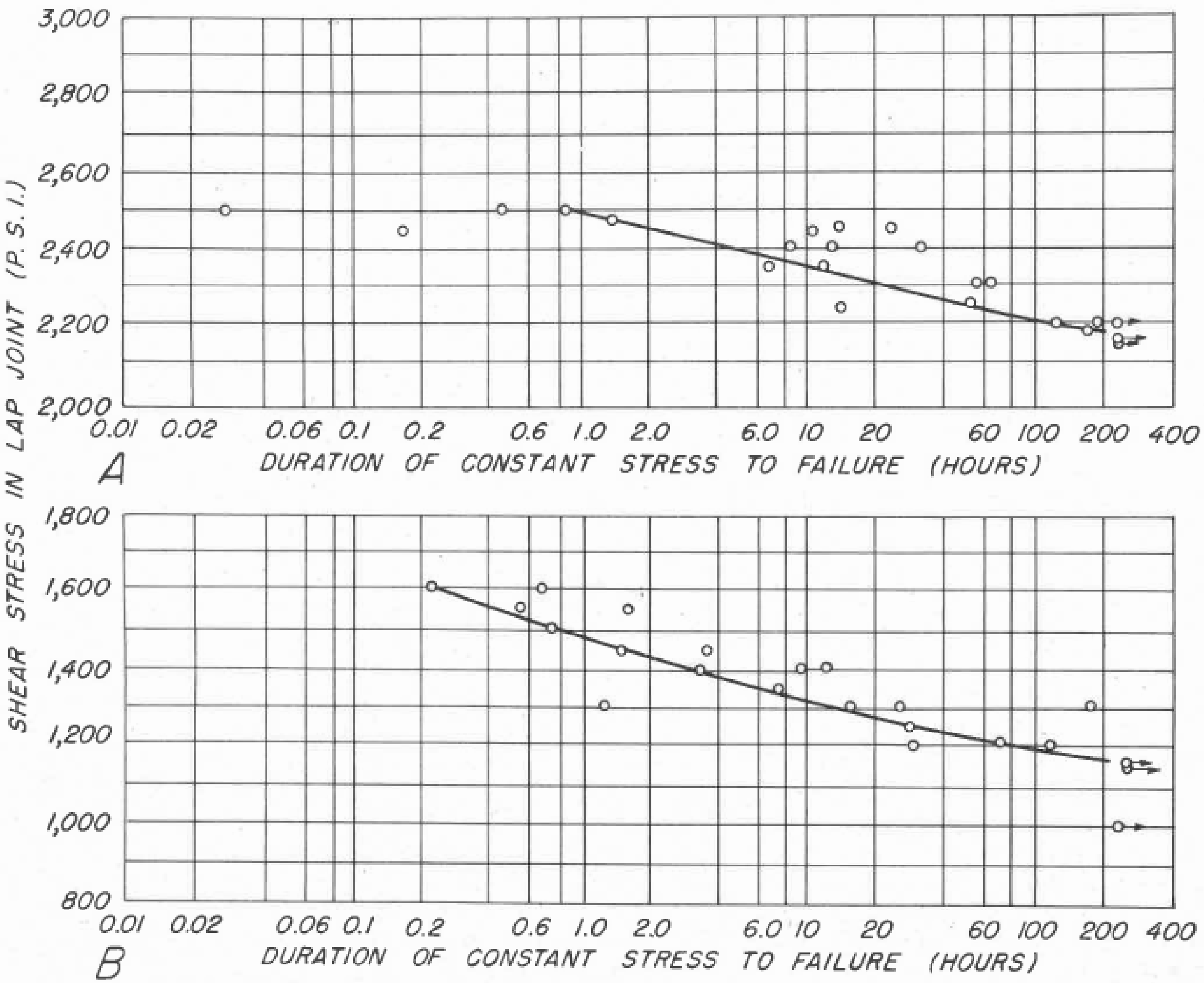


Figure 27. --Time to failure in long-time-load tests at various stress levels for 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesives 26 and 25. Test points with arrows attached are for specimens that did not fail. A, exposed at 72° to 76° F.; B, exposed at 178° to 182° F.

Z M 87127 F

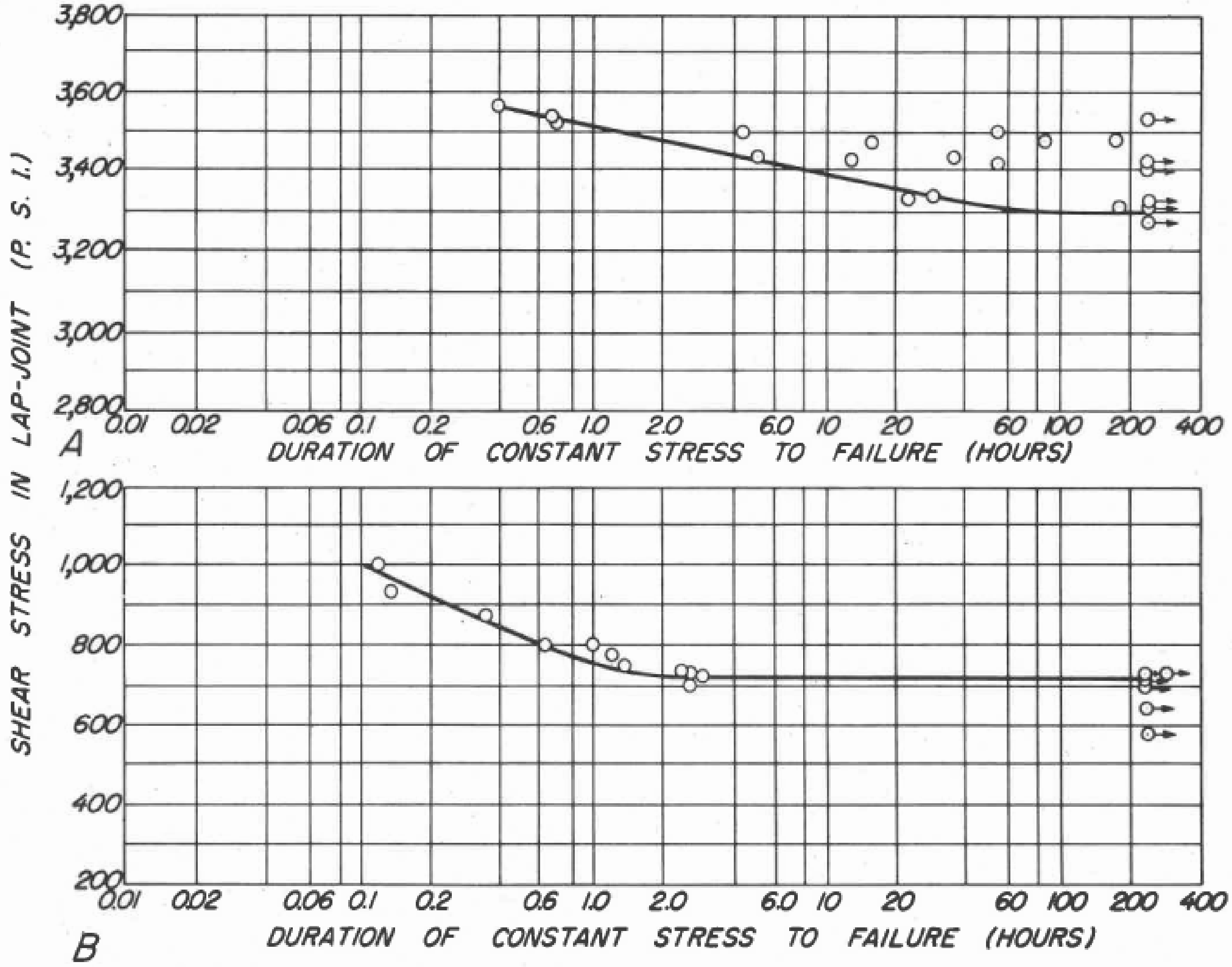


Figure 28. --Time to failure in long-time-load tests at various stress levels for 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 34. Test point with arrows attached are for specimens that did not fail. A, exposed at 72° to 76° F.; B, exposed at 178° to 182° F.

Z M 86672 F

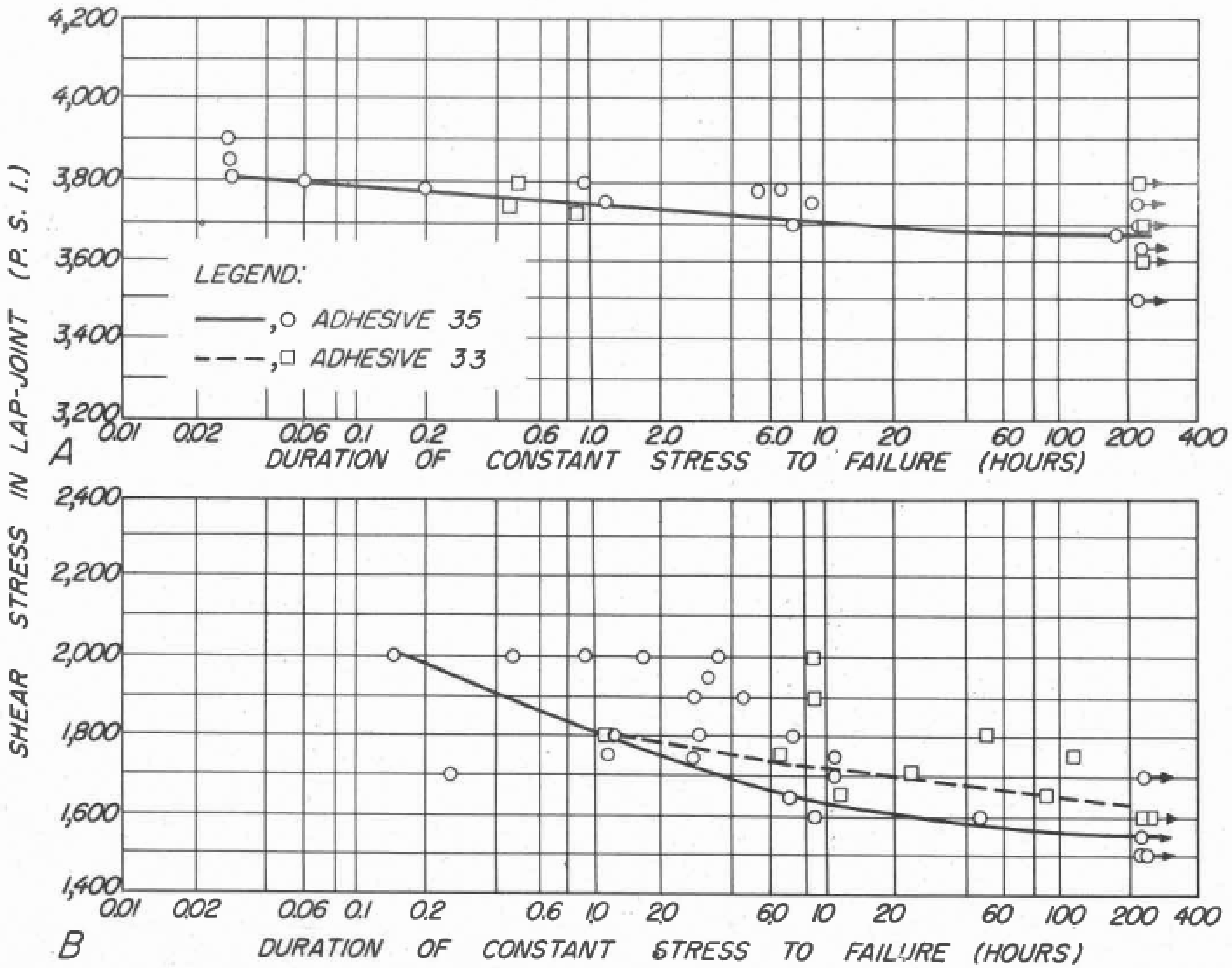


Figure 29. --Time to failure in long-time-load tests at various stress levels for 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 35, and comparative specimens bonded with adhesive 33. Test points with arrows attached are for specimens that did not fail. A, exposed at 72° to 76° F. (the curve for minimum results with adhesive 33 coincides with that for adhesive 35); B, exposed at 178° to 182° F.

Z M 86673 F

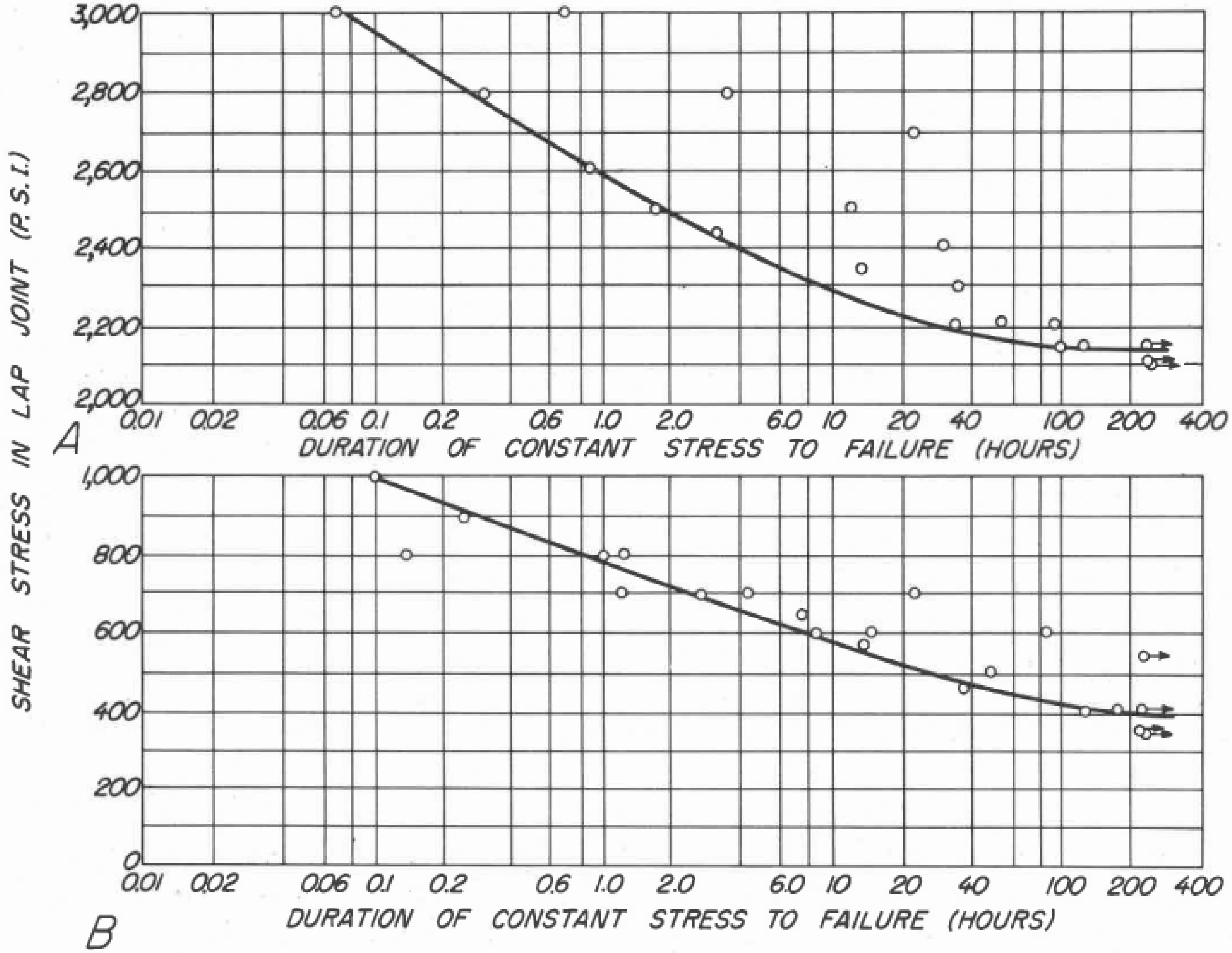


Figure 30. --Time to failure in long-time-load tests at various stress levels for 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 36. Test points with arrows attached are for specimens that did not fail. A, exposed at 72° to 76° F.; B, exposed at 178° to 182° F.

Z M 85787 F

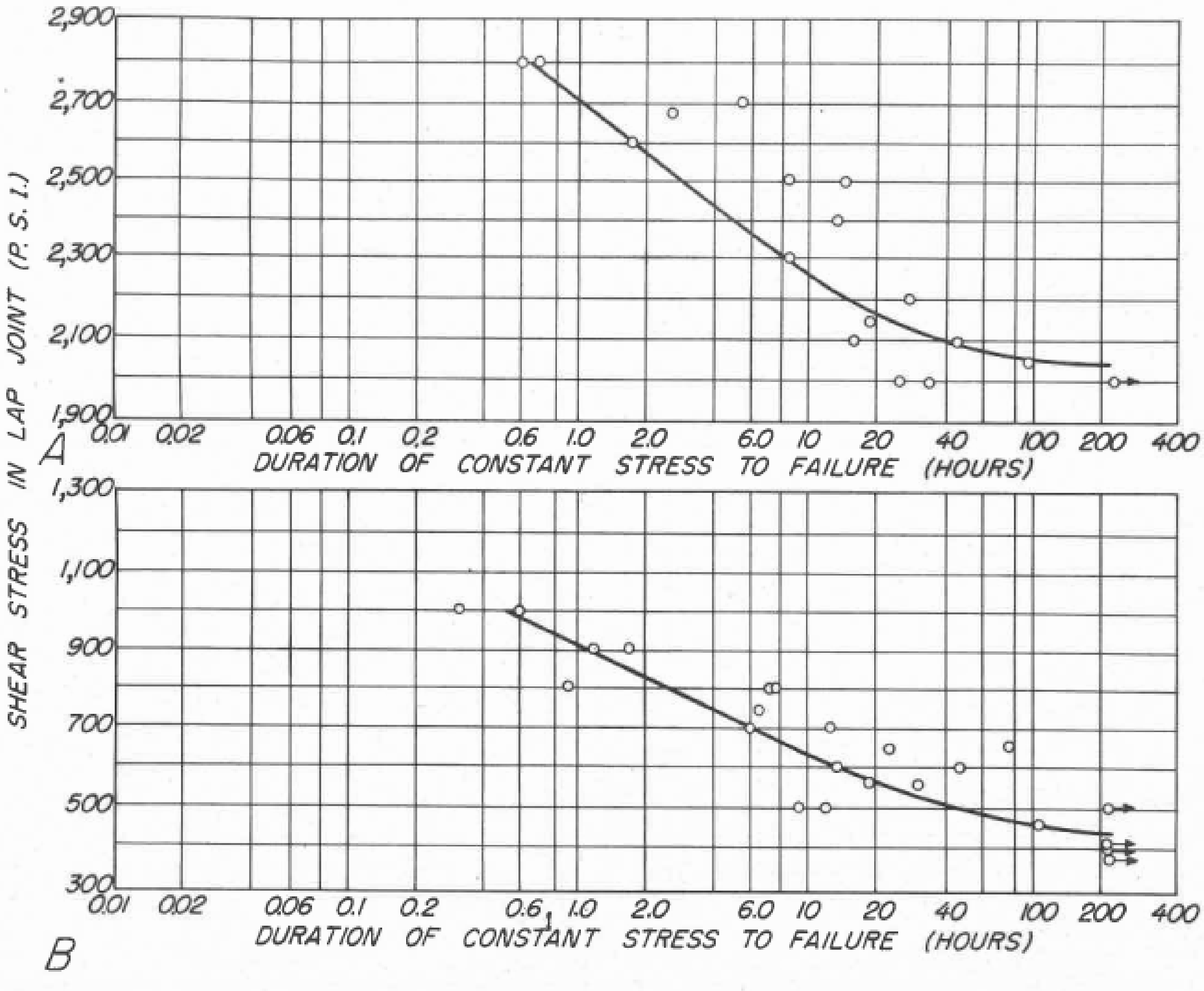


Figure 31. --Time to failure in long-time-load tests at various stress levels for 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 37. Test points with arrows attached are for specimens that did not fail: A, exposed at 72° to 76° F.; B, exposed at 178° to 182° F.

Z M 85788 F

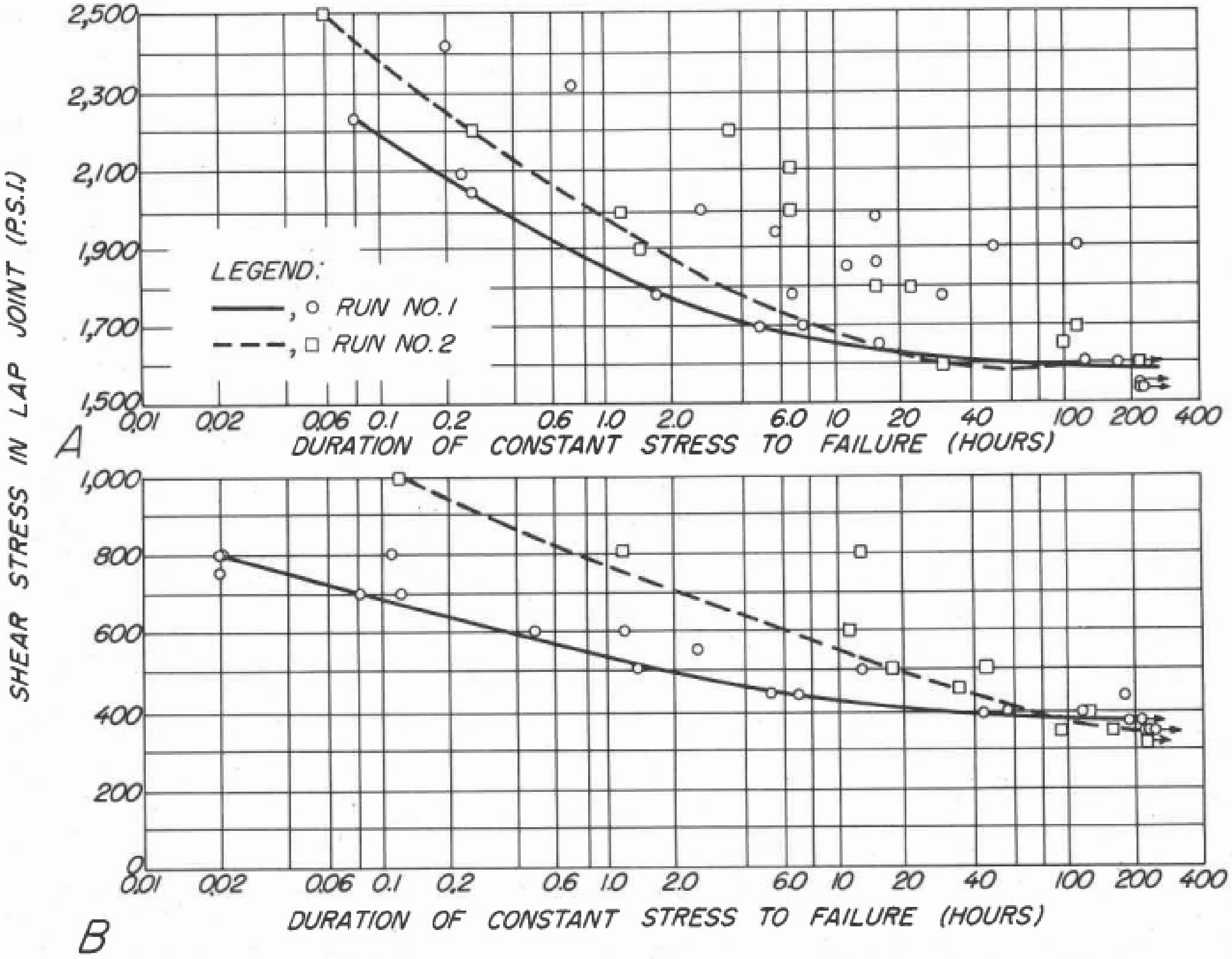


Figure 32. --Time to failure in long-time-load tests at various stress levels for 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 38. Test points with arrows attached are for specimens that did not fail. A, exposed at 72° to 76° F.; B, exposed at 178° to 182° F.

Z M 85789 F

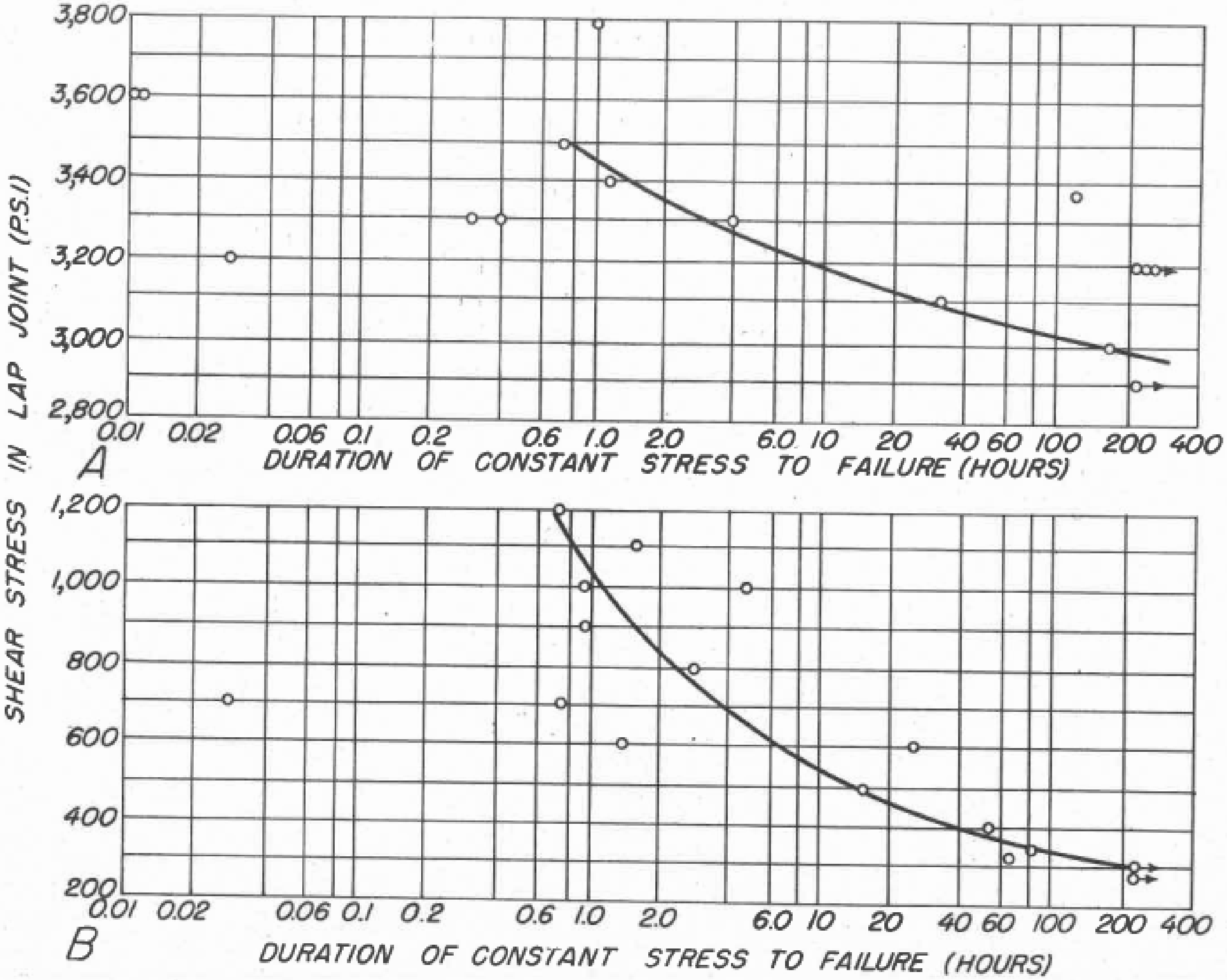


Figure 33. --Time to failure in long-time-load tests at various stress levels for 1/2-inch lap-joint specimens of 0.064-inch 24S-T3 clad aluminum alloy bonded with adhesive 41. Test points with arrows attached are for specimens that did not fail. A, exposed at 72° to 76° F.; B, exposed at 178° to 182° F.

Z M 90217 F

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