THE EFFECT OF ADHESIVE COATINGS ON THE FATIGUE PROPERTIES OF 2014-T AND 7075-T AT NORMAL AND ELEVATED TEMPERATURES

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ABSTRACT

A problem of current practical interest to the field of Aeronautics is whether cement coatings associated with strain gages and fatigue warning indicators have appreciable effect upon fatigue characteristics.

Fatigue tests in rotary bending were conducted at room temperature, 200°F and 400°F on plain specimens of 2014-T and 7075-T and specimens coated with a synthetic resin lacquer, a synthetic resin cement, and an epoxy resin cement.

The effect of these coatings was slight at room temperature, falling within the scatter band, but apparently affording a small increase in fatigue life. At 200°F there was no definite effect, but at 400°F there was a pronounced lowering of fatigue life for all the coated specimens. Parallel results were obtained in 2014-T and 7075-T.

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I. INTRODUCTION

In the course of a continuing research program in fatigue of metals by the GALCIT staff, a question arose as to whether cement coatings might affect fatigue characteristics. The question was related, not only to the usual use of cement to attach strain gages, but also to the use of cement to attach fatigue failure prediction wires.

The Cooperative Wind Tunnel propeller blades have fatigue warning wires at the root section. Cement covers the entire highly stressed region at the root. Operating temperatures go up to 250°F. It has been proposed that fatigue warning wires, alone, or in conjunction with strain gages be used on highly stressed aircraft parts, notably wing fittings. These might be installed for flight test and then left on for possible continuous use in service.

Dr. S. R. Valluri was conducting a developmental study in the field of fatigue failure prediction which involved the cementing of a flat pattern of fine wire to a small test specimen. The amount of specimen surface in the critical region which was covered by cement was relatively large; hence, if an effect existed, it might cause a considerable change in the fatigue life. Therefore, Valluri tested a small number of coated specimens to determine whether a trend was detectable. From these tests, which were conducted at room temperature, it was decided that a more comprehensive study was justified.

This report presents the results of an initial phase of this study. The purpose of the tests described herein was to determine the effect of cement coatings on the fatigue properties of aluminum alloys at room and elevated temperatures. Further, it was desired to know whether different types of cement produced different effects. Rotary bending tests were conducted at room temperature, 200°F, and 400°F on plain specimens and on three groups of specimens, each coated with a different cement. The tests were duplicated in 2014-T and 7075-T. The data obtained are presented in tables and graphs of S-N curves.

II. DESCRIPTION OF APPARATUS AND TEST SPECIMENS

In order to carry out fatigue testing at elevated temperatures, it was necessary to design some items and to bring together others to form a test setup which comprised several components. The components of the test equipment are described individually in the remainder of this section.

1. Fatigue Testing Machines

The tests were conducted on eight BALDWIN-SOUTHWARK R. R. MOORE FATIGUE TESTING MACHINES. Four of these machines were purchased in the latter part of 1954; the other four had been in the department for a number of years. The new machines do not differ from the old in any essential manner. The old machines had previously been modified to accommodate a speed control rheostat, and the circuits of the new ones were altered to include such provision so that similarity would be maintained between the two groups of machines. The speed control feature, however, was not used in the tests described herein. The machines were run at their nominal speed of 10,000 rpm. The actual speeds of operation varied from one machine to another, the slowest running at approximately 8,000 rpm, and the fastest at 14,000 rpm. It was considered that in this speed range the speed has negligible effect upon fatigue life; hence, no attempt was made to synchronize the machines nor to account for any effect of rpm.

As indicated earlier, these machines test the specimen in pure cyclic bending. The load is applied by placing weights on a tray, the nominal stress obtained per pound of load applied being calculated as follows:

$$S = \frac{16WL}{\pi d^3}$$

With a minimum specimen diameter, d, of 0.3 in., and L = 4 in., this formula gives

$$S = 755W \text{ psi}$$

where W is the applied load including the tare weight of 10 lbs.

For the convenience of those who may use these machines later, Appendix 1, Operation of R. R. Moore Machines, has been included in this report. It presents some of the operational problems which one can expect to encounter and the techniques which were found to solve or minimize these problems.

Fig. 1 is a photograph of one of the R. R. Moore machines.

2. Furnaces

The furnaces used in this program were designed by the author and Capt. G. Stalk, whose work in a related field required the use of the same equipment. The first furnace was constructed by Capt. Stalk and the author. Eight more furnaces were built by the GALCIT Machine Shop personnel.

Fig. 2 is a drawing of the furnace details. Figs. 3 and 4 are photographs of the furnace, as mounted, in the open and closed positions.

The primary difficulty involved in the design of the furnace was the severe space limitation. The minimum spacing between the specimen support barrels was 1.7 inches and it occurred when a specimen failed, therefore, the allowable length of the furnace had to be less than 1.7 inches.

Requirements on the size of the heating coil determined to a large extent the interior size of the furnace. The end walls of the furnace were of necessity rather thin, there being room only for one 1/8 inch layer of asbestos on each end; hence, the losses were very high and a high input was required. The worst feature of this situation was that the bearings would attain a very high temperature and might require special cooling. Such was not the case; satisfactory operation at the 400°F level was obtained.

A larger furnace certainly was desirable, but it presented greater difficulties in the long run. A larger furnace would have had to enclose part of the bearing housings; thus the bearings would have been operating at approximately the same temperature as the specimen. More serious than this, however, was that the load support points would have to be inside the furnace. In its final configuration the furnace was constructed from 5-inch transite pipe, inside of which 1/8 inch asbestos sheeting was laminated to give an inside diameter of 3 inches. The ends of the furnace consisted of one layer of asbestos covered by 0.020 inches aluminum. The furnace details are best seen in Fig. 2.

Considerable experimenting with the coils was done to get a satisfactory temperature distribution along the length or span of the specimen. Of the configurations tested, a flat-wound coil of 23-gage Tophet C wire was finally found to give the best spanwise temperature distribution. The coil was made up of two 48-inch lengths of wire, one in the top half and one in the bottom half of the furnace, the two sections of coil being connected in series. Results of all calibrations are given in Part III.

As can be seen in Fig. 2, a hollow, threaded section of brass pipe was used to hold and position the thermocouple. With the thermocouple fixed in the pipe by a set screw and touching the specimen, the thermocouple could be positioned positively by withdrawing it from the specimen by a certain number of turns of the nut.

The furnace was designed to be capable of operation at 700°F in case temperatures higher than 400°F were to be investigated. In calibration a temperature of 750°F was reached; however, at this temperature, furnace deterioration would be considerably speeded up and thermocouple and coil life would be short. At 400°F, the furnace life, not including the coils, was probably indefinite; the coil life at 400°F had considerable scatter, but averaged in the thousands of hours. Numerous supports for the upper coil increased its life by preventing sagging with attendant shorting of loops, and were required to maintain the proper temperature.

The furnaces were found to be susceptible to error because of air blowing past them. Since streams of air emanated from the electric motors, it was necessary to install air deflectors to prevent movement of the air past the furnaces. These deflectors were simple shapes of sheet metal or pasteboard.

3. Furnace Thermocouple

The thermocouple wires were contained in a two-hole ceramic insulator. This was inserted into the furnace through a brass tube which was supported by a bracket on top of the furnace. As described earlier, the thermocouple was positioned by a nut threaded on the brass tube. Pressure against the nut was maintained by a compression spring.

The first thermocouples used were of iron and constantan, but the high air temperatures within the furnace caused these to have an unsatisfactory life. Consequently, a change was made to Chromel and Alumel (22-gage). These materials demonstrated high resistance to the temperatures encountered and resulted in very satisfactory thermocouples. The thermocouple leads to the temperature control units were insulated duplex Chromel-Alumel (20-gage). The thermocouple and lead wires were joined about two inches above the ceramic insulator. The thermocouple sensing juncture was formed by welding.

4. Temperature Control Units

Furnace temperatures were controlled by pyrometers into which the thermocouple voltage was impressed. Relay contacts in the furnace element lines were actuated by the pyrometers.

Six of the eight R. R. Moore machines were fitted with furnaces. Of the six pyrometers, two were SYM-PLY-TROL's, manufactured by Assembly Products, Inc., Chagrin Falls, Ohio. The four remaining pyrometers were the Series J Gardsman, made by West Instrument Corporation, 525 North Noble St., Chicago 22, Illinois.

The furnace thermocouples actually read air temperatures in the furnaces, which were higher than the temperature range covered by the pyrometers. Therefore, it was necessary to place a shunt resistance in each pyrometer to change its effective resistance and thus the scale factor of its indicator dial. The shunt resistances were chosen for convenience to make the pyrometer setting approximately equal to the desired specimen temperature.

5. Circuitry

Fig. 6 is a wiring diagram for one motor and one furnace. The diagram is self-explanatory, but several points are worthy of comment. The standard wiring of the R. R. Moore machines provides for stopping of the motor when a specimen failed. This is accomplished by one of the bearing housings falling onto a cut-off switch. This switch was utilized to also shut off the furnace upon specimen failure.

It can be seen in the figure that a ballast resistor was placed across the contactor points. The function of this resistor was to allow a lowered current in the furnace elements when the contactor was open, rather than have the current interrupted completely. The main advantage of this arrangement was that it decreased the amplitude of the temperature oscillation. Without the ballast resistor, and because of the very small amount of insulation on the furnace ends, the specimen temperature would plunge abruptly about 15°F at the 400°F level when the current stopped. The temperature recovered rapidly when the current resumed, but such a drop was considered to be unacceptable; hence, the ballast resistors were incorporated in the circuit. Another very useful feature of the ballast resistor was that, by maintaining the furnace elements at a red heat, the life of the elements was increased considerably. With completely interrupted current the coils underwent rapid and large temperature changes which caused continual working of the wire.

Because the ballast resistor closed the furnace circuit when the main contactor points were open, it was necessary to have a secondary contactor to open the circuit when a specimen failed. This secondary contactor was actuated only when a specimen failed, remaining closed throughout the time a specimen was running.

A powerstat was used in each furnace circuit so that the minimum adequate current could be selected. Use of minimum current contributed to a small temperature spread by decreasing the overshoot and also lengthened the life of the furnace coils.

In the actual circuit assembly, power was brought to a large table on which was mounted the circuit breakers, powerstats, pyrometers, contactors, and ballast resistors. This arrangement consolidated the controls, saved space, and allowed the setup to be portable. To further the portability of the apparatus, the wiring from the table to the R. R. Moore machines had plugs at both ends to permit quick disconnects; this feature was equally valuable in that it permitted removal of power from, and isolation of, certain parts of the circuit.

6. Specimens

All of the specimens used in these tests were made according to the specifications of Ref. 1, Fig. 9, p. 30, with D = 0.3 in., and R = 9.875 in.

The 2014-T specimens were made from the forged butt of a propeller blade from the Cooperative Wind Tunnel. The material for the specimens was taken well in from the surface to avoid the forging effects near the surface and to have the grain structure along the long dimension of the specimen.

The 7075-T specimens were cut with the grain from a 3/4 in. rolled plate. Again the material near the edges was not used.

Specimens were polished with 600 Emery paper followed by levigated alumina, using a slow lathe rotation and a rapid, manual longitudinal motion. The specimens were polished to a 5 μ finish; "μ" referring to the surface roughness in microinches. Besides a close visual inspection of each specimen, spot checks of actual surface roughness were made with Physicists Research Co. Profilometer, Type Q, Model 1.

7. Cements

Three cements were tested at room temperature, 200°F, and 400°F. A fourth, Duco, which has a cellulose nitrate base, was partially investigated at room temperature. The Duco was not taken to higher temperatures, as it is not resistant to elevated temperatures.

Several other cements were cursorily investigated by heating samples spread on sheet metal and with fine wire imbedded in the cement. These were placed in a laboratory furnace and heated first to 200°F and then to 400°F. The shear strength was checked roughly by pulling the wire from the cement.

As a result of these tests and, considering that it was desirable to use cements with different bases, two cements were chosen. These were Miracle Adweld No. 185 and Acorn 20-B-04. Also chosen was Silosyn, which is actually not a cement but rather a protective coating material.

Silosyn can be generally described as a nitro-cellulose, modified acrylic resin lacquer, and was designed as an elastic protective coating for metals other than ferrous. It is produced by W. P. Fuller & Co., 222 N. Ave. 23, Los Angeles, California. The author discussed this material with one of the chemists who developed it; he stated that since Silosyn was not designed for strength purposes, the manufacturer has run no strength test on it. He further stated that because of its composition it would have low strength compared to standard adhesives. By comparing the test results obtained for Silosyn with those obtained for 20-B-04 and Adweld No. 185, the effect of coating strength in modifying fatigue characteristics might be qualitatively determined.

Adweld No. 185 is an epoxy resin type adhesive, manufactured by Miracle Adhesive Corp., 214 East 53rd Street, New York 22, N. Y. This material requires the use of a catalyst in the proportions of 15 drops of catalyst to one teaspoon of adhesive. An excess of catalyst shortens the pot life. The material is capable of developing shear strengths of 2,000 psi.

Acorn 20-B-04 is a synthetic resin solvent cement manufactured by Acorn Adhesives Co., Inc., 678 Clover St., Los Angeles 31, California. Shear strength at room temperature is around 2,000 psi for application at room temperature.

III. TEST PROCEDURE

Use of the R. R. Moore machines at room temperature required only a simple test procedure. At elevated temperatures the procedure became more involved. Other phases of the program such as calibration and coating of specimens presented diverse specializations of procedure. Hence, for the sake of clarity, the discussion of the various procedural aspects of the investigation will be presented individually below.

1. Test Program

It was intended initially to test a sufficiently large number of specimens to allow the use of statistical methods of analysis. Since only four fatigue testing machines were available, of which two were used by Capt. Stalk, until the last three months of the test period, it was not possible to complete such a detailed program. It was decided, therefore, to cover the temperatures and cements originally planned upon and test as many specimens as time would permit.

The cements to be studied were those described in Part II. The temperatures of interest were room temperature, 200°, 400°, and 600°F. After testing at 400°F and noting the deterioration of the cements at this temperature, the 600°F tests were eliminated. The specimens which were to have been used at 600°F were divided among the three lower temperatures for testing, along with a number of spare specimens.

2. Calibration

Two main types of calibration were required. The first was to determine the temperature distribution along the specimen, or spanwise temperature distribution, at each test temperature level, and the second was to determine the proper pyrometer setting in the actual test setup to give a desired specimen temperature.

The calibration for spanwise temperature distribution was conducted several times to determine whether repeatability could be obtained and to get averages. The temperature distribution was determined by placing five thermocouples on a specimen mounted in the machine. Each thermocouple was placed under the head of a screw. One thermocouple was placed at the center of the specimen; two were placed 1/4 inch to each side of center; and two were located 3/4 inch to each side of center. The following approximate percentage variations of temperature were obtained; that is, variation from the temperature at the center thermocouple:

Temperature °F	1/4-inch thermocouples	3/4-inch thermocouples
200	1.7 °/o	4.5 °/o
400	3.0 °/o	3.7 °/o
600	2.9 °/o	5.5 °/o

Although these variations were subject to change because of errors inherent in the calibration, it was considered that these values represented the actual conditions well enough to comprise both a satisfactory distribution and calibration.

The main source of error in the calibration was that it was a static calibration; whereas the actual testing is dynamic, the specimen rotating at approximately 10,000 rpm. Because of the very small size of the test specimen and the close clearances between furnace, bearing housings, and specimen, it was not feasible to install slip rings and conduct a dynamic calibration. It was necessary, therefore, to assume that the spanwise temperature distribution during operation would be close enough to that shown above to be satisfactory.

Since the furnaces were all made to the same specifications and the coils wound alike, it was assumed that the same spanwise temperature distribution, within adequate limits, would exist in each furnace. Hence this calibration was performed on only one furnace.

The table above shows that the maximum variation at the 1/4 in. thermocouples was 3 $^{o}/o$. Since the specimen stress is a maximum at the center, most specimens will break within the 1/2 in. at the center of the specimen and so this is the region of primary interest. It would seem very unlikely that under the worst possible combination of factors the temperature variation could exceed 5 $^{o}/o$ in the center 1/2 in. of the specimen.

The calibration to determine pyrometer settings for actual specimen testing was accomplished by placing one thermocouple under the head of a screw at the center of the specimen. In both this instance and the calibration for spanwise temperature distribution, the calibration thermocouples were attached to a Leeds and Northrup Portable Precision Potentiometer No. 8662. The pyrometer reading would then be adjusted until the desired specimen temperature was obtained.

Each of the pyrometer setting controls had looseness in the mechanism. Because of this looseness, repositioning of the indicator to an earlier-used reading could lead to an error of from 5 to 10 degrees. Since this error was unacceptable, a new calibration was always accomplished after movement of a pyrometer setting.

The position of the furnace thermocouple relative to the specimen had considerable effect upon specimen temperature. For each calibration the furnace thermocouple was spaced from the specimen by a certain number of turns of the positioning nut. The thermocouple was not subsequently moved until another calibration was made. A change in the thermocouple position from two turns to three turns away from the specimen would cause the specimen temperature to drop approximately 5°F. Further withdrawal of the furnace thermocouple would cause a non-linear drop in specimen temperature; however, this condition was not investigated thoroughly, as it was not of primary significance in these tests because the thermocouple was always calibrated for a specific position.

The specimen temperature oscillated around each temperature level because of current fluctuations inherent in the type of pyrometer control. At the 200°F level the variation averaged $\pm$ 2°F, or $\pm$ 1 °/o, prior to installation of the ballast resistors described in Part II. After installation of these resistors, the temperature fluctuation was never greater than $\pm$ 1°F. As both of these variations were well within acceptable limits, no distinction is made between specimens tested under the two conditions. All specimens at 400°F were tested after installation of the ballast resistors. The variation at this level averaged $\pm$ 3°F, or $\pm$ 0.75 °/o, with the maximum being $\pm$ 5°F.

The calibration for pyrometer setting was again a static calibration; hence, it was necessary to assume that rotation of the specimen during testing would not appreciably affect its temperature, and that the static calibration was valid.

3. Application of Specimen Coating

Three methods of applying the cement coatings to the specimens were considered. These were spraying, dipping, and applying with a brush. Spraying was not actually attempted by the author, as the method had already been tried with only slight success by Valluri. He found that the spray dried too much before reaching the specimen, resulting in poor adhesion and very poor thickness control.

The author experimented with dipping the specimens, but found the method unsatisfactory. A thin mixture resulted in excessive flow of the cement while drying and too thin a coating. A heavily viscous mixture also had too much flow, tending to produce a tapered coating and one that was too thick. The author was unable to obtain a mixture of the proper consistency, and it is questionable whether one existed, since excessive flow occurred in all mixes. Furthermore, this method required that one end of the specimen, where it would fit into the chuck, be covered by masking tape.

The third method, brush application, presented the fewest difficulties and resulted in a satisfactory coating. Viscosity of the pot mixture was important, but fairly wide latitude existed. The primary difficulty was to prevent bubbles from forming in the coating. Since stirring a mixture caused bubbles, it was found to be desirable to prepare a large mix, seal it, and let it sit until the bubbles had risen to the surface. Then application of the mixture with reasonable care would not cause formation of many bubbles. Any that might form could be brushed away from the center of the specimen; since the maximum stress occurred at the center of the specimen, good quality of the coating within the center inch was emphasized.

Prior to application of the coating, each specimen was cleaned with acetone. The cement was applied with a camel's hair brush. As soon as a specimen was coated, it was turned end over end a number of times until the cement had set in order to prevent too much flow in one direction. All of the coated specimens were allowed to dry at room temperature for a minimum of two days before testing.

The coating thickness at the center of the specimen was checked on most of the specimens. The method consisted merely of using a micrometer before and after coating; hence, a number of errors were inherent in the method. The thickness might not be uniform around the circumference; therefore, use of the micrometer on different diameters could lead to slight errors. However, the method was consistent with the accuracies expected in fatigue testing.

The thickness of the Silosyn and Acorn 20-B-04 Coatings averaged about 0.002 in., while the Adweld No. 185 was about 0.006 in. The Adweld No. 185 can not be thinned, except slightly by an excess of catalyst which shortens pot life; however, it brushed well in its natural state. On the other hand the first two cements would not work well when heavy enough to give a thicker coating. It was decided not to laminate these in order to increase the thickness. Therefore, it was necessary to accept a thicker coating of Adweld No. 185.

4. Method of Testing

After completing the usual preliminaries, placing the desired load on the tray and setting the revolution counter to zero, the procedure varied with the test temperature. At room temperature it was only necessary to place the specimen in the machine, start it rotating, and immediately apply the load. If the load was applied before starting the machine, there was greater danger of transient vibration during acceleration.

During calibration, the time to attain and stabilize at a temperature level was determined. For 200°F the time was 45 minutes; for 400°F, 1 hour and 30 minutes. If a specimen was loaded while the furnace and bearing housings were still hot, these times could be reduced to 30 minutes. Therefore, specimens tested at temperature were preheated for at least the appropriate times listed above. At 200° and 400°F it was especially important that rotation of the specimen be started before application of the load in order to prevent immediate, excessive creep at high stress levels. One specimen at 400°F was permanently deformed in the short interval between application of the load and starting the machine.

All specimens that underwent a visible transient vibration were discarded. Also, specimens which received a rest period were discarded. This does not include specimens which were changed form one machine to another, and immediately restarted.

IV. DISCUSSION OF RESULTS

The data on all satisfactory specimen tests are presented in Tables I through XXIV. These data are plotted as S-N curves in Figs. 7 through 30. Summary comparison curves are presented in Figs. 31 through 36.

Pictures of failed specimens have not been included, as typical fractures were obtained. Pictures of these may be found in References 2 and 3. Fig. 9 of Reference 2, the first plate, shows the profile of a $5\,\mu$ specimen at 100 diameters.

Reference 4, pp. 12-14, presents a calculation of the percentage error in the determination of stress because of the uncertainty in the measurement of load, load arm, and specimen diameter. This calculation is for a rotating-cantilever fatigue machine; although P should be replaced by P/2 at the beginning of the computation to make it apply to the pure rotary bending case, the 2 drops out in the calculation. Using the same values of uncertainties as in the reference, and correcting a differentiation error in $\frac{\partial S}{\partial D}$ ($\frac{\partial S}{\partial D}$ should equal $\frac{-3PL}{\pi/32D^4}$), an error of $\pm$ 0.34 $^o/o$ is obtained for a load of 27 lbs., L = 4 in., and D = 0.3 in. The stress resulting from this load, with its maximum possible deviation is 20,371 $\pm$ 69 psi.

In presenting the data, the stress has been rounded off to the nearest 10 psi. This has introduced an error which in no case exceeds 0.05 $^o/o$. It is evident that these errors are negligible.

Besides these errors, the possible sources of inaccuracies and scatter are:

a. Vibration of rotating parts.

b. Heating of specimen due to vibration and friction.

c. Unavoidable impacts on specimen during loading.

d. Lag between starting and load application.

e. Production variations.

f. Non-homogeneity of the metal.

Of these factors, all are negligible or were carefully controlled except for the last one. As is well known (see Ref. 4, p. 75), non-homogeneity of the material, especially as affected by inclusions, is the largest factor in causing scatter.

Since it was not possible to test enough specimens at each stress level to permit use of statistical methods, the S-N curves in Figs. 7 through 30 are average curves which have been faired through the data points. To facilitate comparison, these curves have been redrawn without their accompanying test points in the summary curves, Figs. 31 through 36. Hence, in using the comparison curves and in drawing conclusions, it is necessary to remember that these curves were not arrived at statistically.

At room temperature, the effect of the coatings was small. The 2014-T curves lie within the expected scatter band for plain specimens, but each curve for coated specimens is slightly above that of the plain. A beneficial effect of the coatings is indicated for 7075-T, where the curves lie well above that for the plain surface. The more pronounced effect upon 7075-T may be due to its greater notch-sensitivity which allows more improvement by an inhibitor of crack propagation. The shrinkage associated with drying of the cements could induce surface compressive stresses which would produce effects similar to those obtained by shot-peening or cold rolling. It is not definitely established, however, that the coatings used do inhibit crack propagation. It may be that the apparently slight increase in fatigue life is due to corrosion resistance of the coating. The mechanism of corrosion fatigue and protection against it afforded by coatings are discussed in Ref. 6, p. 140. It should be noted that the corrosiveness of the fluid in which the tests are conducted is very important to the degree of improvement attained.

At $200^{o}F$ the data plot into curves which are superimposed within narrow bands for each alloy. It is apparent that at this temperature the effect of the coatings is negligible. However, in view of the results obtained at $400^{o}F$, the $200^{o}F$ results may have significance. The slight beneficial effect present at room temperature is apparently offset at $200^{o}F$ by a deleterious effect resulting from the higher temperature.

At $400^{o}F$ a very pronounced lowering of fatigue strength occurred in all the coated specimens. See Figs. 35 and 36. Since this is a reversal of the room temperature trend, a cross-over region of temperature must exist, and the data at $200^{o}F$ indicate that this region is near $200^{o}F$. Good agreement was obtained between the 2014-T and 7075-T results. In both cases Silosyn caused the least decrease, and this decrease occurred at the shorter life expectancies. In fact, Silosyn was unique in that its curve crosses that of the plain specimens in the region above 10^7 cycles. Adweld No. 185 showed the greatest decrease in fatigue strength for 2014-T, while Acorn 20-B-04 caused the greatest decrease for 7075-T. For both alloys, however, the curves for these two coatings lie close together, and the primary significance is that both curves are far below that for the uncoated material.

If coatings induce surface compressive stresses, as suggested earlier, these stresses would be relieved at high temperatures, should the coatings become plastic because of the heat. All of the coatings showed evidence of plastic flow at 400°F, and this could partially explain why the coatings were not beneficial. However, this would not explain how the coatings lowered the fatigue strength. It is possible that heat-induced changes in the coatings accelerated corrosion fatigue.

It is interesting to consider the effect of coating strength in altering fatigue life. Silosyn, which has a low strength compared to the other two cements, produced about the same results at room temperature and 200°F as the other coatings. At 400°F, however, Silosyn was the least harmful. These results indicate that strength of the coating is not the primary factor in determining its effectiveness.

Adweld No. 185 exhibited the usual characteristics of an epoxy resin in room temperature tests. Brittleness caused many circumferential cracks in the coating in the high stress region. Also, the low peel strength was demonstrated by flaking off of the cement for as much as a sixteenth of an inch on either side of a fracture. Silosyn and 20-B-04 did not display either of these characteristics. Neither did Adweld No. 185 show these effects at the elevated temperatures, which is an indication of plasticity in the coating.

Discoloration of the coatings at 200^{o}F was slight. Silosyn was not noticeably discolored, while Adweld No. 185 and Acorn 20-B-04 turned to a light tan color. At 400^{o}F Silosyn and 20-B-04 became medium brown, and Adweld turned to a very dark brown. Although the specimens were all pre-heated, discoloration evidently was not complete at the end of the pre-heat period, because the longer a specimen ran, the darker it became. The rate of discoloration decreased with time, however. This effect was much more evident at 400^{o}F than at 200^{o}F.

Since every point on the surface of a specimen underwent a complete reversal of stress during each cycle, the effect of creep probably does not complicate the data obtained (ref. 6, p. 123). The temperature and rate of straining (cycle frequency and nominal stress) do affect creep phenomena, but since the tests were all run at approximately the same speed, any creep which might have existed should not have affected the comparison between coated and uncoated specimens. The effect of creep would be to lower the outer fiber stress, and hence cause a displacement and change in slope of the S-N curves. Since the main purpose in this study was to compare the uncoated and coated test results, a quantitative study of creep phenomena was not attempted.

CONCLUSIONS

From the results obtained in this investigation, it can be concluded that:

1. All of the coatings tested provide at best only a slight improvement in fatigue life at room temperature. Apparently 7075-T is benefitted a little more than 2014-T.

2. The coatings produced no discernible effect at 200°F.

3. At 400°F there was a pronounced lowering of fatigue life of the coated specimens, both for 2014-T and 7075-T, except for the Silosyn coating at long life expectancies. Also, Silosyn was least harmful in the shorter life range.

4. Strength of the coating is not the primary factor in determining its effect upon fatigue life.

5. The mechanism by which the coatings affect fatigue life, slightly improving it at room temperature and definitely lowering it at 400°F, is not clear and should be the subject of further study.

The following recommendations are made:

1. As an aid to determination of the way in which the coating influences fatigue strength, coatings of other materials, such as a Bakelite thermosetting cement, might be investigated. Also, a trend study at a temperature above 400°F might lend further information by indicating whether the harmful effects of coatings continue to increase with temperature.

2. Since fatigue phenomena are fundamentally statistical in nature, trends are often hard to detect without the results of a

large number of specimen tests. Further studies should emphasize the testing of a statistically adequate number of specimens at each stress level. 7075-T data presented here could be reused, as a large amount remains of the plate from which these specimens were taken.

3. A study should be made to determine whether thickness of the coating affects fatigue characteristics. Also, means of producing more uniform coatings should be investigated.

4. A quantitative analysis of creep effect should be made. Although this may be only of secondary importance in the comparison of results on coated and uncoated specimens subject to the same creep conditions, it nevertheless has an effect upon the stress level of the tests as a whole.

REFERENCES

1. ASTM Special Technical Publication No. 91, Manual on Fatigue Testing, 1949, p. 30.

2. Cooley, James S., Lt. Cmdr., U. S. N., "Reversed Bending Fatigue Properties of 25S-T, 75S-T, and 76S-T Aluminum Alloys," California Institute of Technology, AE Thesis, 1949.

3. Dervishyan, Aram O., "Fatigue Stress Concentration Studies on Aluminum Alloys," California Institute of Technology, AE Thesis, 1952.

4. Epremian, E. and Mehl, R. F., "Investigation of Statistical Nature of Fatigue Properties," NACA TN2719, June 1952.

5. Dieter, G. E., and Mehl, R. F., "Investigation of the Statistical Nature of the Fatigue of Metals," NACA TN2019, September 1953.

6. Grover, H. J., Gordon, S. A., and Jackson, L. R., "Fatigue of Metals and Structures," NAVAER 00-25-534, Bureau of Aeronautics, Department of the Navy, 1954.

APPENDIX I

Operation of R. R. Moore Machines

Of the many factors which affect the performance of the R. R. Moore machines, none is more important than the quality of the specimens. The two most important quality features are the taper of the specimen end where it fits into the chuck and the alignment of the centerlines of the threaded ends. If either of these details is improperly made, severe vibrations will occur during operation with failure of the specimen likely to occur in the chuck. Continued operation of this type can also damage the bearings so that later operation with satisfactory specimens will be rough.

Lubrication of the bearings is also important to satisfactory operation. At room temperature smoothest performance is obtained with as little oil as possible. If enough oil is used to cause overflow, the bearing action on the oil will generate enough heat to warm the specimen. At elevated furnace temperatures, however, the bearings and their housings become hot from furnace radiation and conduction through the specimen. It is necessary at these temperatures to oil until overflow occurs in order to insure that sufficient lubrication is available and to help dissipate the heat.

The lubricant used was one part Bardahl to eight parts of regular SAE-10 motor oil. Addition of the Bardahl seemed to improve bearing operation at elevated temperatures.

Cup grease should be added periodically to the motor bearing lubrication points. The rotation counters should occasionally be oiled with SAE-10 oil.

Care should be exercised to avoid starting a motor unless the flexible coupling probe is inserted and tightened in a bearing housing; otherwise, centrifugal force will cause the flexible coupling to beat against the support frame and eventually disintegrate. Should this situation accidentally arise, the stop button can not be reached and it is necessary to pull an electrical plug to remove the power to the motor.

About the only other maintenance requirement is that the motor commutator brushes be changed periodically as determined by wear.

TABLE I

S-N Data for 2014-T
Room Temperature, Uncoated Specimens

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	60	45,300	44
2	55	41,520	119
3	50	37,750	394
4	45	33,980	449
5	"	"	3,121
6	"	"	476
7	40	30,200	6,656
8	"	"	1,493
9	35	26,420	8,170
10	"	"	5,807
11	32.5	24,540	11,635
12	30	22,650	78,491

TABLE II

S-N Data for 2014-T
Room Temperature, Silosyn Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	60	45,300	25
2	55	41,520	107
3	50	37,750	402
4	45	33,980	2,728
5	40	30,200	1,253
6	"	"	6,362
7	"	"	5,376
8	37.5	28,310	3,746
9	35	26,420	10,021
10	"	"	1,869
11	32.5	24,540	34,574
12	30	22,650	54,931

TABLE III

S-N Data for 2014-T
Room Temperature, Adweld No.185 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	60	45,300	95
2	55	41,520	139
3	50	37,750	673
4	45	33,980	2,933
5	40	30,200	8,544
6	"	"	3,110
7	37.5	28,310	9,966
8	35	26,420	7,371
9	"	"	18,212
10	"	"	11,318
11	30	22,650	71,951

TABLE IV

S-N Data for 2014-T
Room Temperature, Acorn 20-B-04 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	60	45,300	26
2	55	41,520	143
3	50	37,750	379
4	"	"	4,733
5	45	33,980	1,662
6	"	"	317
7	"	"	8,289
8	40	30,200	8,390
9	"	"	872
10	35	26,420	20,305
11	"	"	27,687
12	30	22,650	100,000*

* Removed before failure

TABLE V

S-N Data for 2014-T
200°F, Uncoated

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	50	37,750	171
2	45	33,980	224
3	40	30,200	417
4	"	"	321
5	37.5	28,310	602
6	35	26,420	2,480
7	32.5	24,540	4,376
8	30	22,650	8,197
9	"	"	13,360
10	27.5	20,760	10,592
11	25	18,880	44,189
12	22.5	16,990	71,782

TABLE VI

S-N Data for 2014-T
200°F, Silosyn Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	50	37,750	145
2	45	33,980	206
3	40	30,200	615
4	35	26,420	2,410
5	30	22,650	5,473
6	"	"	4,886
7	27.5	20,760	11,166
8	25	18,880	7,114
9	"	"	14,964
10	"	"	11,825
11	22.5	16,990	40,333

TABLE VII

S-N Data for 2014-T
200°F, Adweld No.185 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	50	37,750	116
2	45	33,980	320
3	40	30,200	666
4	35	26,420	2,565
5	30	22,650	5,809
6	27.5	20,760	6,477
7	"	"	11,024
8	25	18,880	14,033
9	22.5	16,990	28,790

TABLE VIII

S-N Data for 2014-T
200^oF, Acorn 20-B-04 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	55	41,520	59
2	50	37,750	76
3	45	33,980	238
4	40	30,200	320
5	"	"	352
6	35	26,420	1,651
7	"	"	1,131
8	30	22,650	2,539
9	27.5	20,760	9,581
10	"	"	4,145
11	25	18,880	15,015
12	22.5	16,990	38,213

TABLE IX

S-N Data for 2014-T
400^{o}F, Uncoated Specimens

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	45	33,980	175
2	40	30,200	860
3	"	"	518
4	35	26,420	795
5	"	"	1,478
6	30	22,650	2,783
7	27.5	20,760	7,525
8	"	"	6,161
9	25	18,880	7,821
10	"	"	9,174
11	22.5	16,990	24,429
12	20	15,100	31,479

TABLE X

S-N Data for 2014-T
$400^{o}F$, Silosyn Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	35	26,420	205
2	30	22,650	275
3	"	"	936
4	27.5	20,760	1,094
5	25	18,880	3,771
6	"	"	3,897
7	22.5	16,990	6,314
8	"	"	14,342
9	22	16,610	3,486
10	"	"	19,830
11	20	15,100	77,530

TABLE XI

S-N Data for 2014-T
400°F, Adweld No.185 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $\times 10^{-3}$
1	32.5	24,540	798
2	27.5	20,760	344
3	25	18,880	687
4	22.5	16,990	1,798
5	"	"	537
6	20	15,100	2,616
7	"	"	3,854
8	17.5	13,210	3,600
9	"	"	8,546
10	16.5	12,460	11,366
11	16	12,080	15,053

TABLE XII

S-N Data for 2014-T
400°F, Acorn 20-B-04 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	35	26,420	617
2	30	22,650	665
3	25	18,880	1,125
4	22.5	16,990	4,355
5	"	"	1,509
6	20	15,100	1,260
7	"	"	3,960
8	"	"	18,825
9	18.5	13,970	15,298
10	17.5	13,210	15,771
11	16.5	12,460	42,852

TABLE XIII

S-N Data for 7075-T
Room Temperature, Uncoated

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	60	45,300	161
2	55	41,520	188
3	50	37,750	386
4	45	33,980	904
5	42.5	32,090	44,557
6	"	"	22,023
7	"	"	5,013
8	40	30,200	946
9	"	"	1,628
10	"	"	2,402
11	"	"	20,800
12	37.5	28,310	1,020
13	"	"	1,264
14	"	"	33,568
15	"	"	100,000*
16	35	26,420	1,776
17	"	"	35,070
18	"	"	78,937
19	32.5	24,540	44,586*

* Removed before failure

TABLE XIV

S-N Data for 7075-T
Room Temperature, Silosyn Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	60	45,300	117
2	55	41,520	314
3	50	37,750	734
4	47.5	35,860	613
5	"	"	6,096
6	"	"	1,616
7	45	33,980	9,200
8	42.5	32,090	9,628
9	"	"	65,836
10	"	"	2,726
11	40	30,200	2,792
12	"	"	63,625*
13	37.5	28,310	49,179*

* Removed before failure

TABLE XV

S-N Data for 7075-T
Room Temperature, Adweld No.185 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	60	45,300	213
2	55	41,520	690
3	50	37,750	1,302
4	47.5	35,860	1,025
5	"	"	5,081
6	"	"	2,114
7	45	33,980	12,336
8	42.5	32,090	15,136
9	"	"	3,973
10	40	30,200	38,470*

* Removed before failure

TABLE XVI

S-N Data for 7075-T
Room Temperature, Acorn 20-B-04 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	60	45,300	138
2	55	41,520	300
3	50	37,750	689
4	47.5	35,860	1,214
5	45	33,980	1,575
6	"	"	860
7	"	"	5,000
8	42.5	32,090	9,178
9	"	"	20,190
10	40	30,200	50,669

TABLE XVII

S-N Data for 7075-T
200°F, Uncoated Specimens

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	55	41,520	203
2	50	37,750	401
3	45	33,980	1,319
4	40	30,200	1,662
5	"	"	5,855
6	37.5	28,310	6,509
7	35	26,420	11,757
8	"	"	9,044
9	32.5	24,540	43,661

TABLE XVIII

S-N Data for 7075-T
200°F, Silosyn Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	55	41,520	230
2	50	37,750	468
3	45	33,980	780
4	40	30,200	4,197
5	"	"	2,370
6	35	26,420	19,547
7	"	"	9,143
8	32.5	24,540	46,102
9	"	"	11,198
10	30	22,650	48,281*

* Removed before failure

TABLE XIX

S-N Data for 7075-T
200°F, Adweld No.185 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	55	41,520	391
2	50	37,750	530
3	45	33,980	629
4	"	"	771
5	40	30,200	1,792
6	"	"	1,405
7	37.5	28,310	2,765
8	35	26,420	6,316
9	"	"	11,877
10	32.5	24,540	15,198
11	"	"	23,224
12	30	22,650	20,152

TABLE XX

S-N Data for 7075-T
$200^{\circ}F$, Acorn 20-B-04 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	55	41,520	433
2	50	37,750	471
3	45	33,980	610
4	"	"	1,550
5	40	30,200	959
6	"	"	3,850
7	"	"	3,762
8	37.5	28,310	5,401
9	"	"	3,353
10	"	"	2,288
11	35	26,420	38,649
12	"	"	21,870

TABLE XXI

S-N Data for 7075-T
400°F, Uncoated Specimens

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	45	33,980	209
2	40	30,200	737
3	"	"	542
4	37.5	28,310	5,439
5	"	"	12,721
6	"	"	4,667
7	35	26,420	744
8	"	"	3,708
9	"	"	4,388
10	30	22,650	3,046
11	"	"	18,791
12	27.5	20,760	64,116
13	"	"	24,209
14	25	18,880	8,873
15	22.5	16,990	63,434
16	20	15,100	68,450*

* Removed before failure

TABLE XXII

S-N Data for 7075-T
400°F, Silosyn Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	40	30,200	321
2	35	26,420	1,026
3	32.5	24,540	1,858
4	30	22,650	12,488
5	"	"	1,221
6	27.5	20,760	6,139
7	"	"	6,465
8	26.5	20,010	17,079
9	25	18,880	73,571*

* Removed before failure

TABLE XXIII

S-N Data for 7075-T
400°F, Adweld No.185 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	35	26,420	137
2	32.5	24,540	328
3	30	22,650	2,590
4	"	"	959
5	27.5	20,760	2,627
6	"	"	1,178
7	25	18,880	11,839
8	"	"	2,566
9	22.5	16,990	28,002

TABLE XXIV

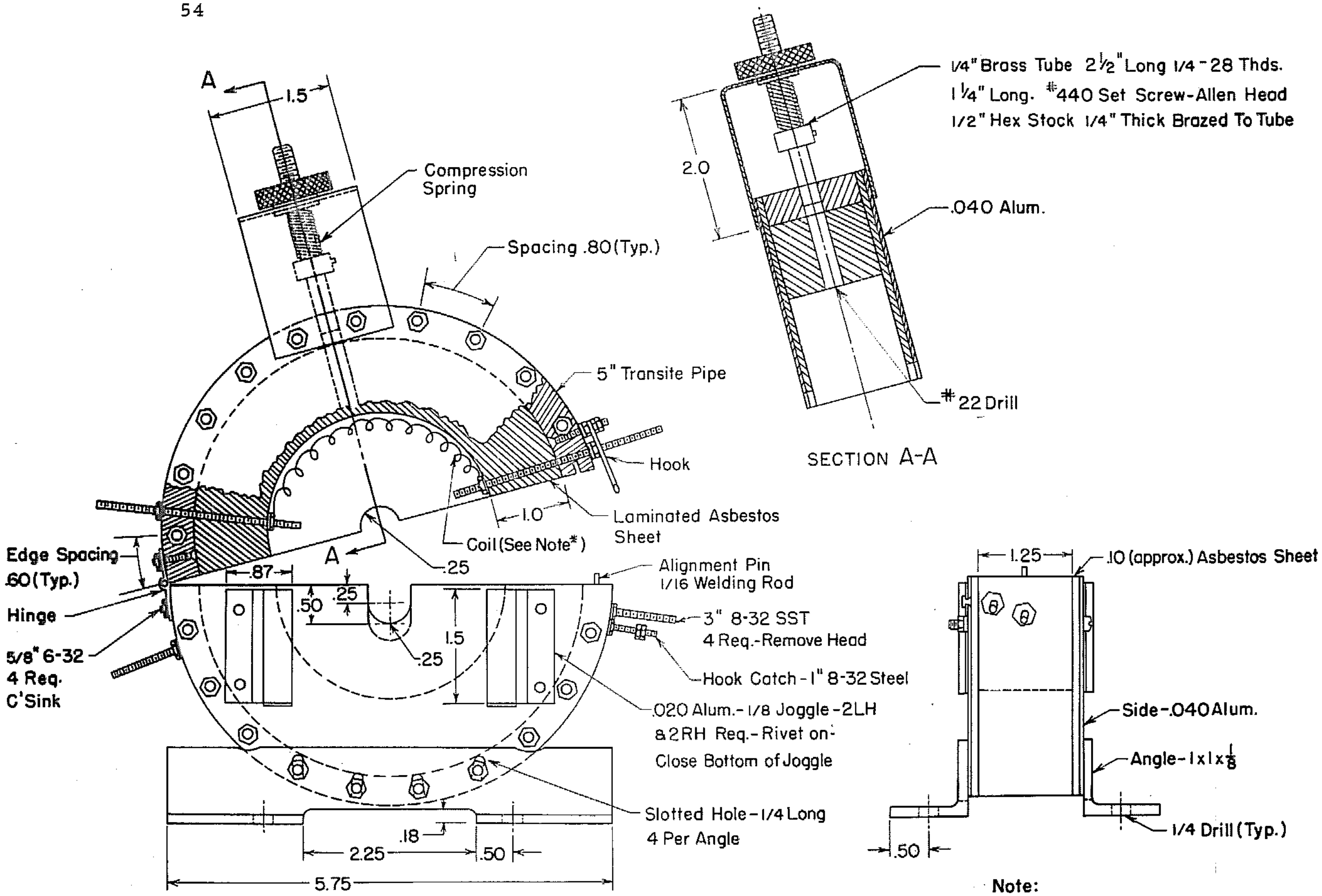
S-N Data for 7075-T
400°F, Acorn 20-B-04 Coating

Specimen Number	Applied Load lb	S Stress psi	N No. of Cycles $x10^{-3}$
1	40	30,200	289
2	35	26,420	355
3	30	22,650	842
4	27.5	20,760	5,242
5	"	"	8,453
6	25	18,880	7,563
7	"	"	20,786
8	22.5	16,990	5,665
9	"	"	1,630
10	20	15,100	2,495
11	"	"	39,902
12	17.5	13,210	62,490*

* Removed before failure

Fig. 1

R. R. Moore Machine



Note:

1. *Coil - 48" No.23 Tophet-C wound into flat coil - 1.10 wide x .20 (approx.) deep.
2. All dimensions inches

FURNACE FOR R.R. MOORE
FATIGUE TESTING MACHINE
FIG. 2

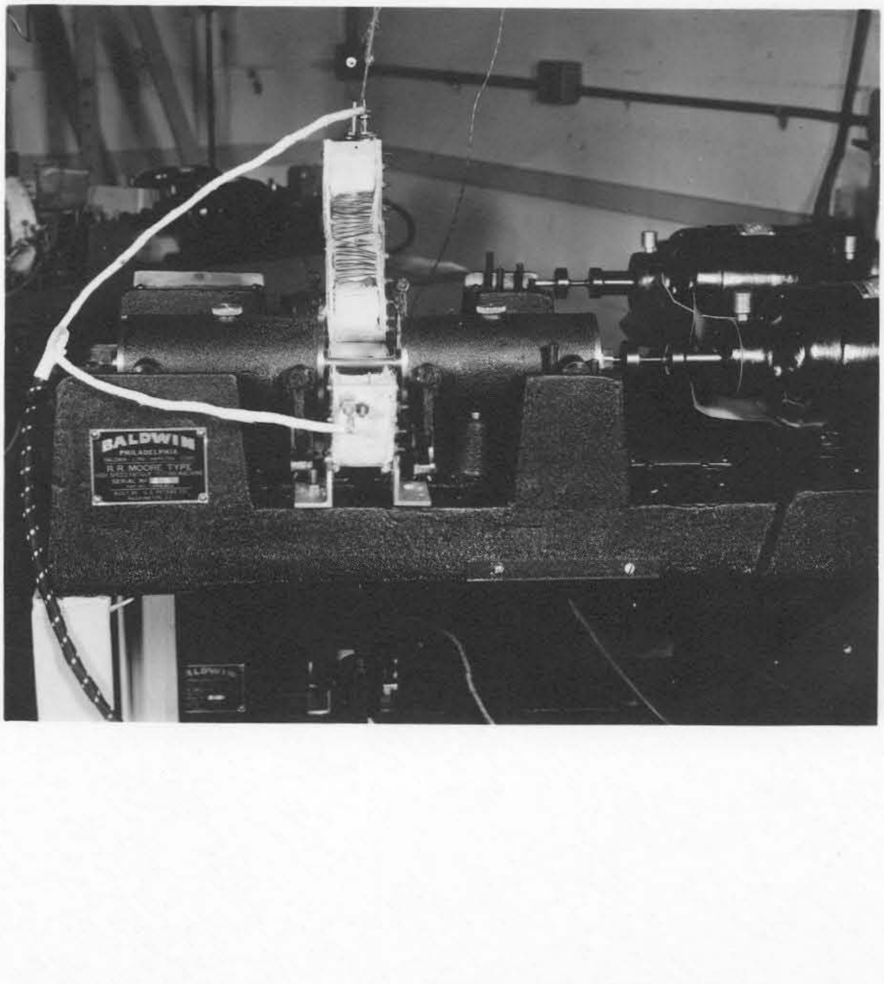


Fig. 3

Furnace for Use with

R. R. Moore Machine - Open

Fig. 4

Furnace for Use with

R. R. Moore Machine - Closed

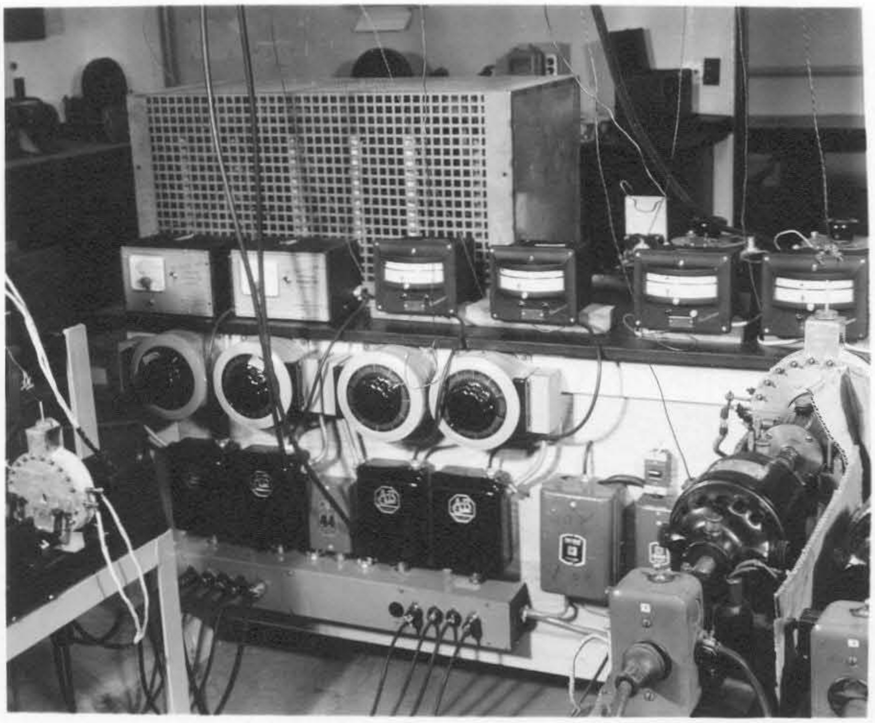
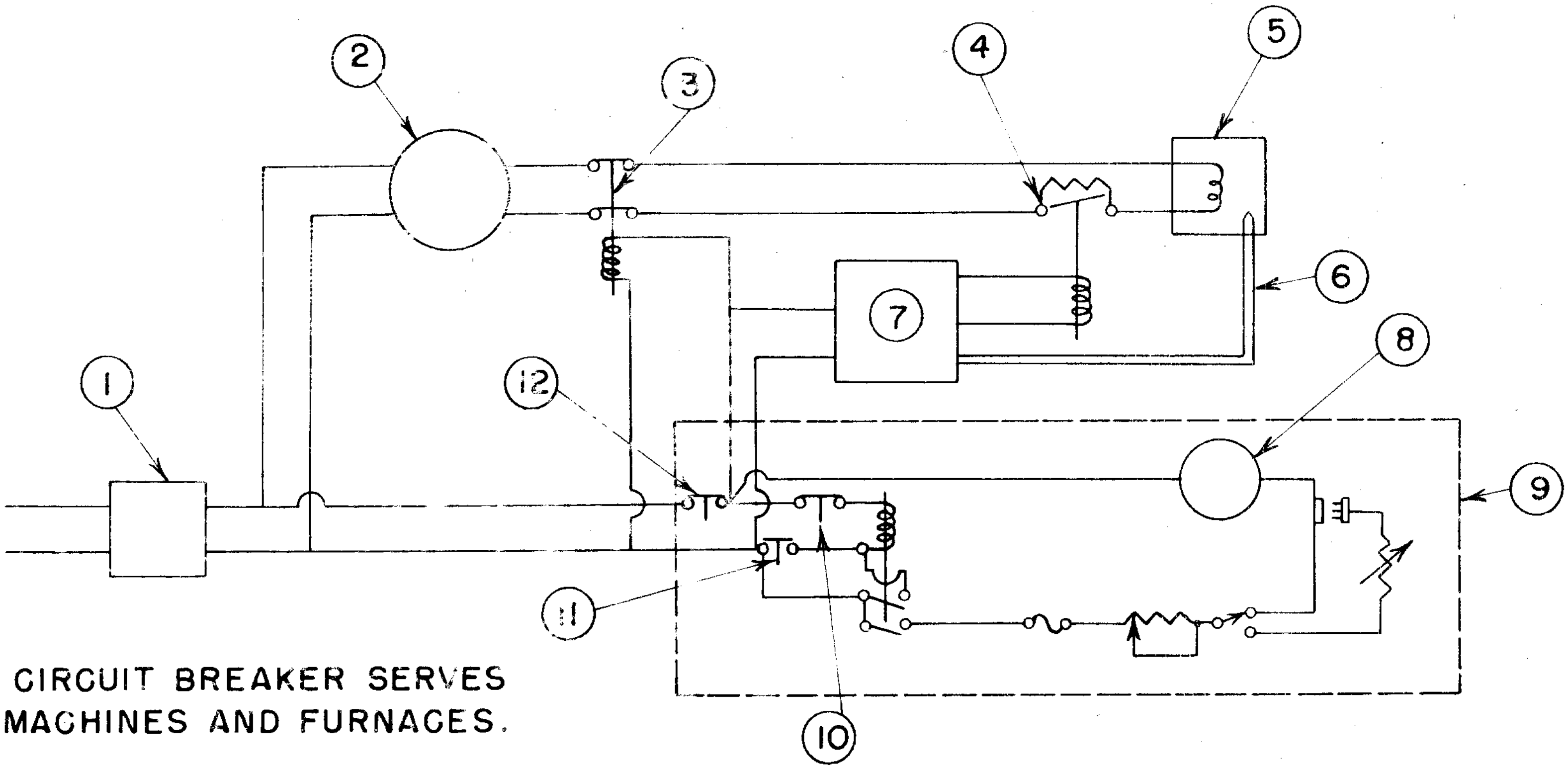


Fig. 5

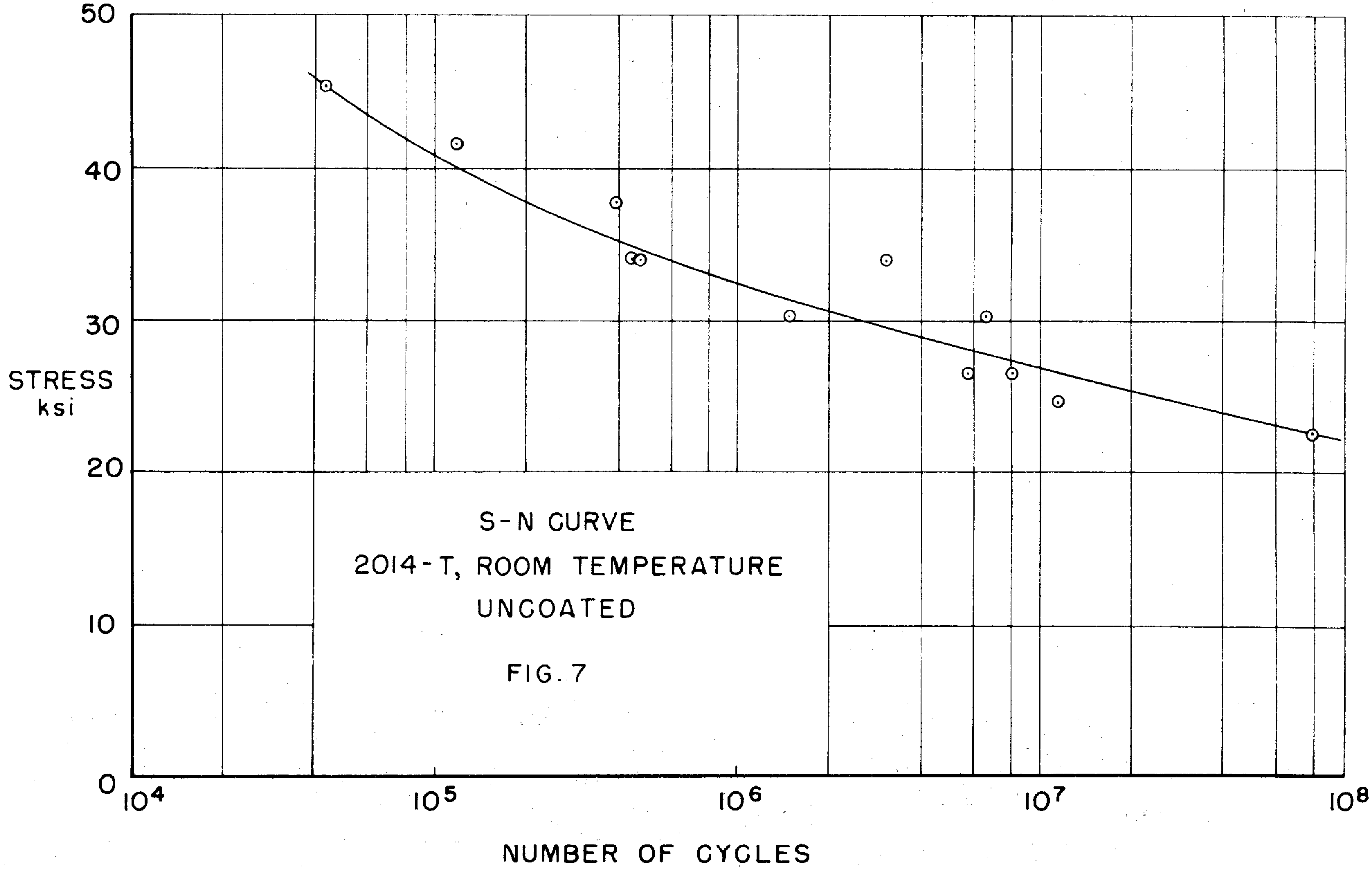
General View of Control Table



NOTE:
EACH CIRCUIT BREAKER SERVES TWO MACHINES AND FURNACES.

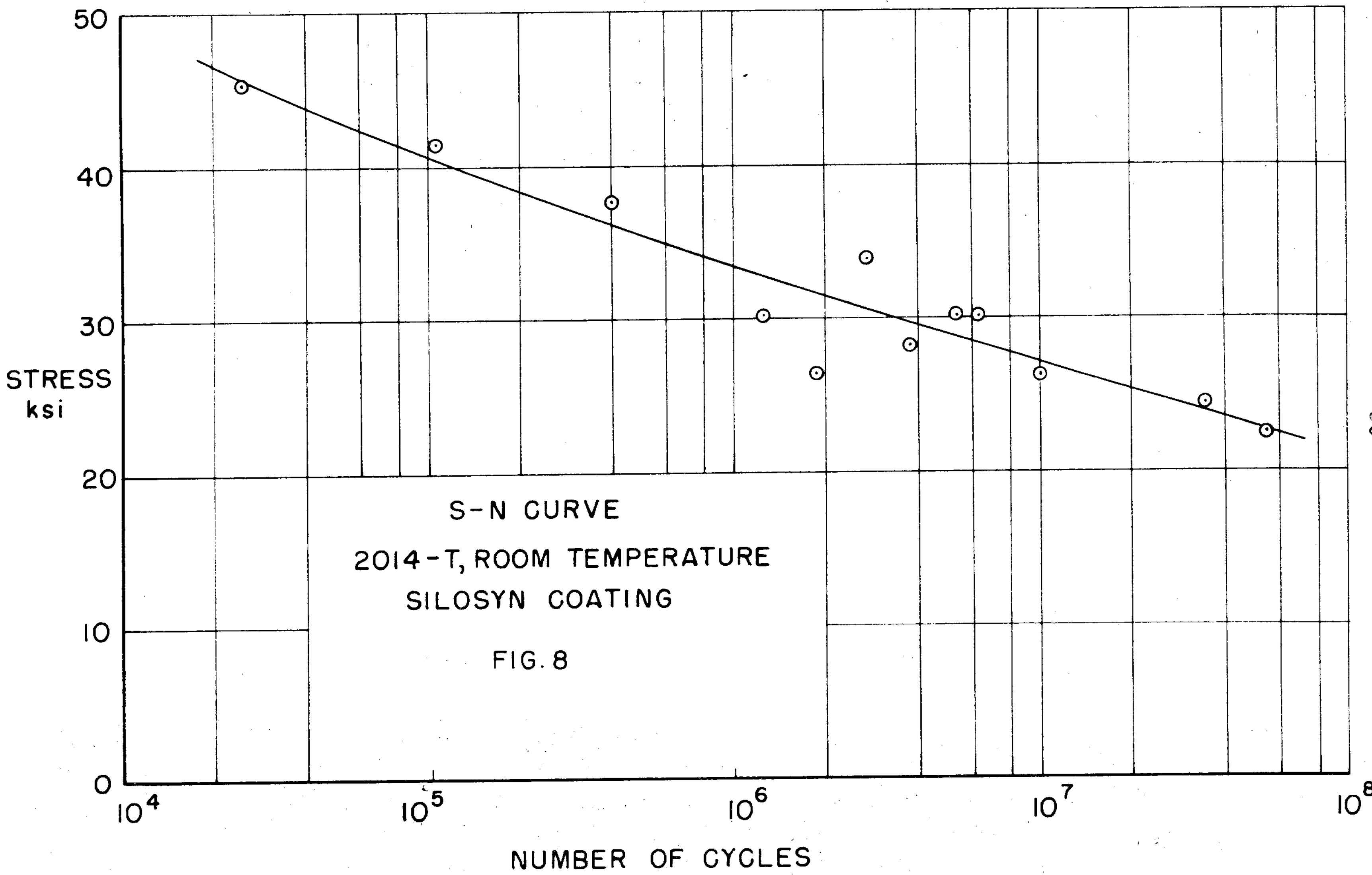
(1) CIRCUIT BREAKER
(2) POWERSTAT
(3) FURNACE CUT-OFF RELAY
(4) FURNACE CUT-OFF RELAY AND BALLAST RESISTOR
(5) FURNACE
(6) THERMOCOUPLE
(7) PYROMETER
(8) MOTOR
(9) R.R.MOORE MACHINE
(10) STOP SWITCH
(11) START SWITCH
(12) SPECIMEN FAILURE CUT-OFF SWITCH

FIG. 6



S-N CURVE
2014-T, ROOM TEMPERATURE
UNCOATED

FIG. 7



S-N CURVE

2014-T, ROOM TEMPERATURE

SILOSYN COATING

FIG. 8

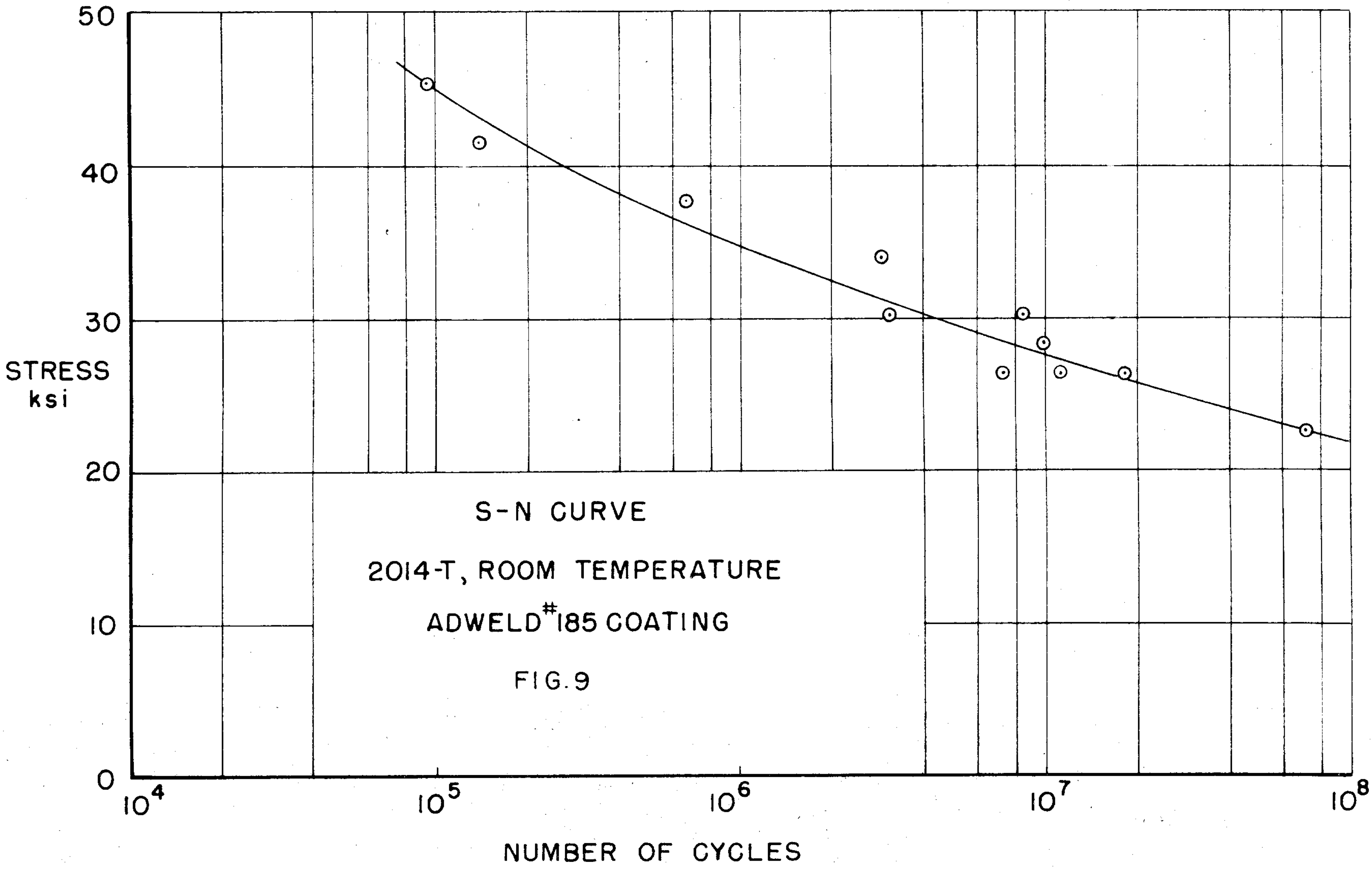

S-N CURVE
2014-T, ROOM TEMPERATURE
ADWELD # 185 COATING
STRESS ksi
50
40
30
20
10
0
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES

FIG. 9

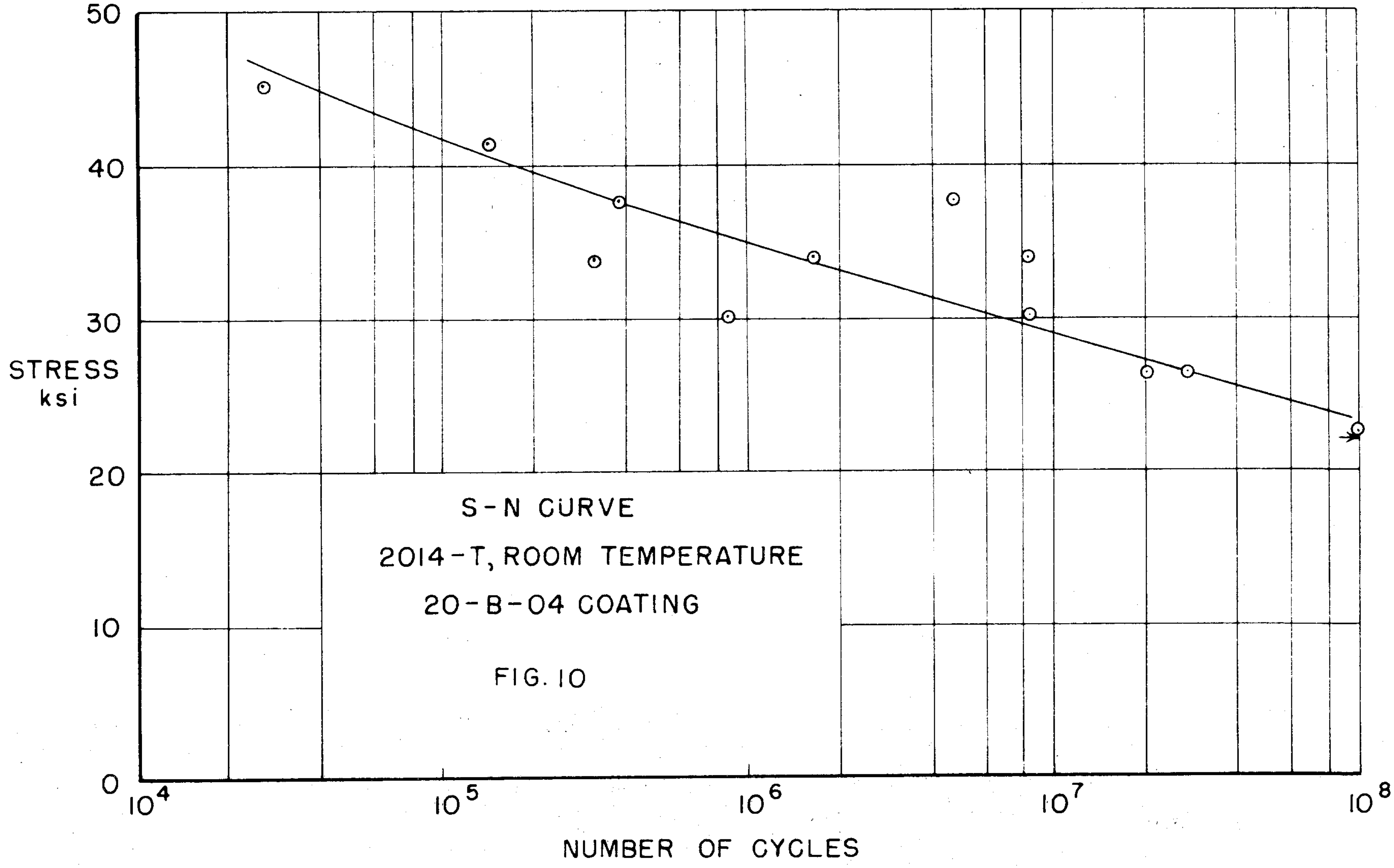
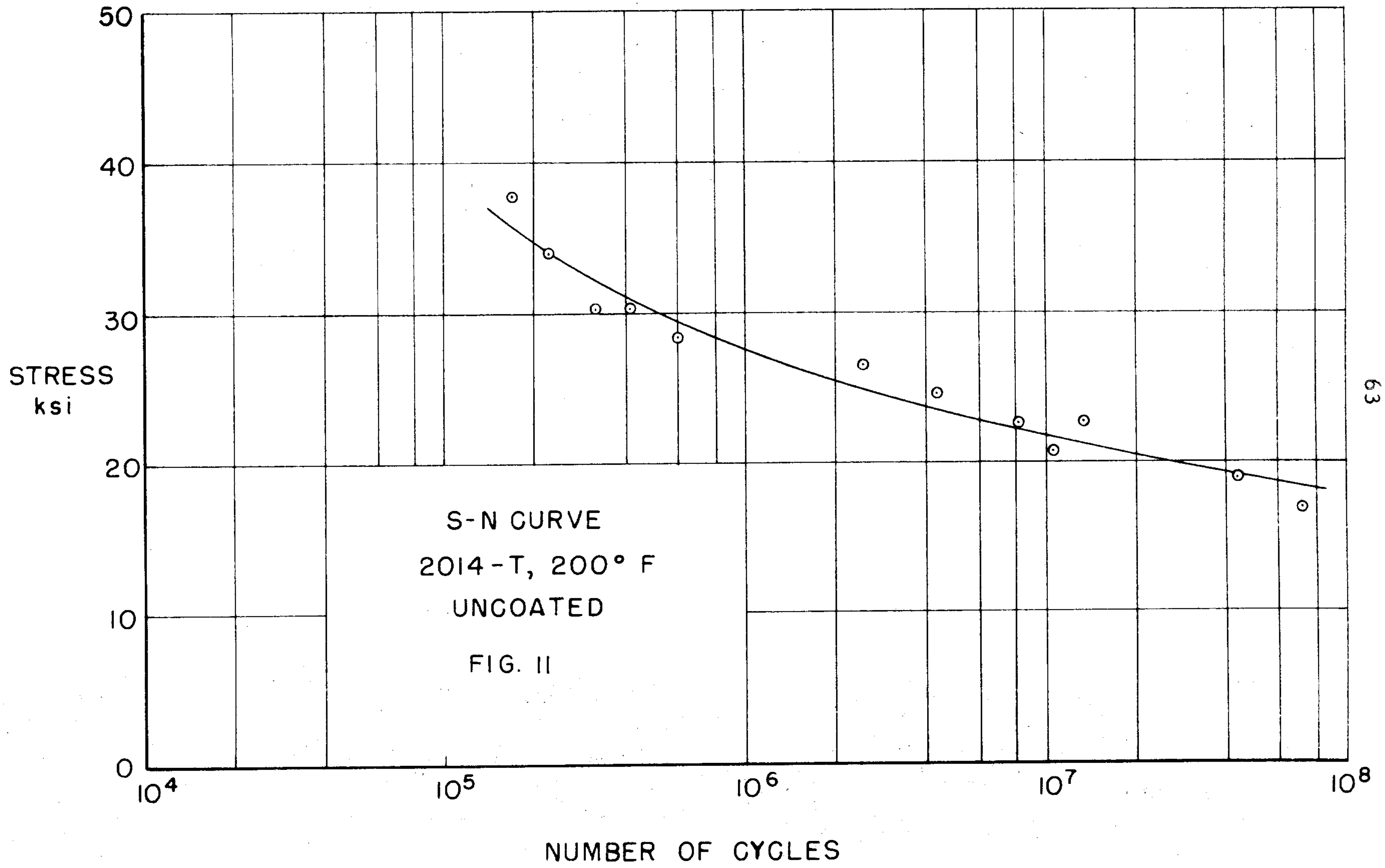
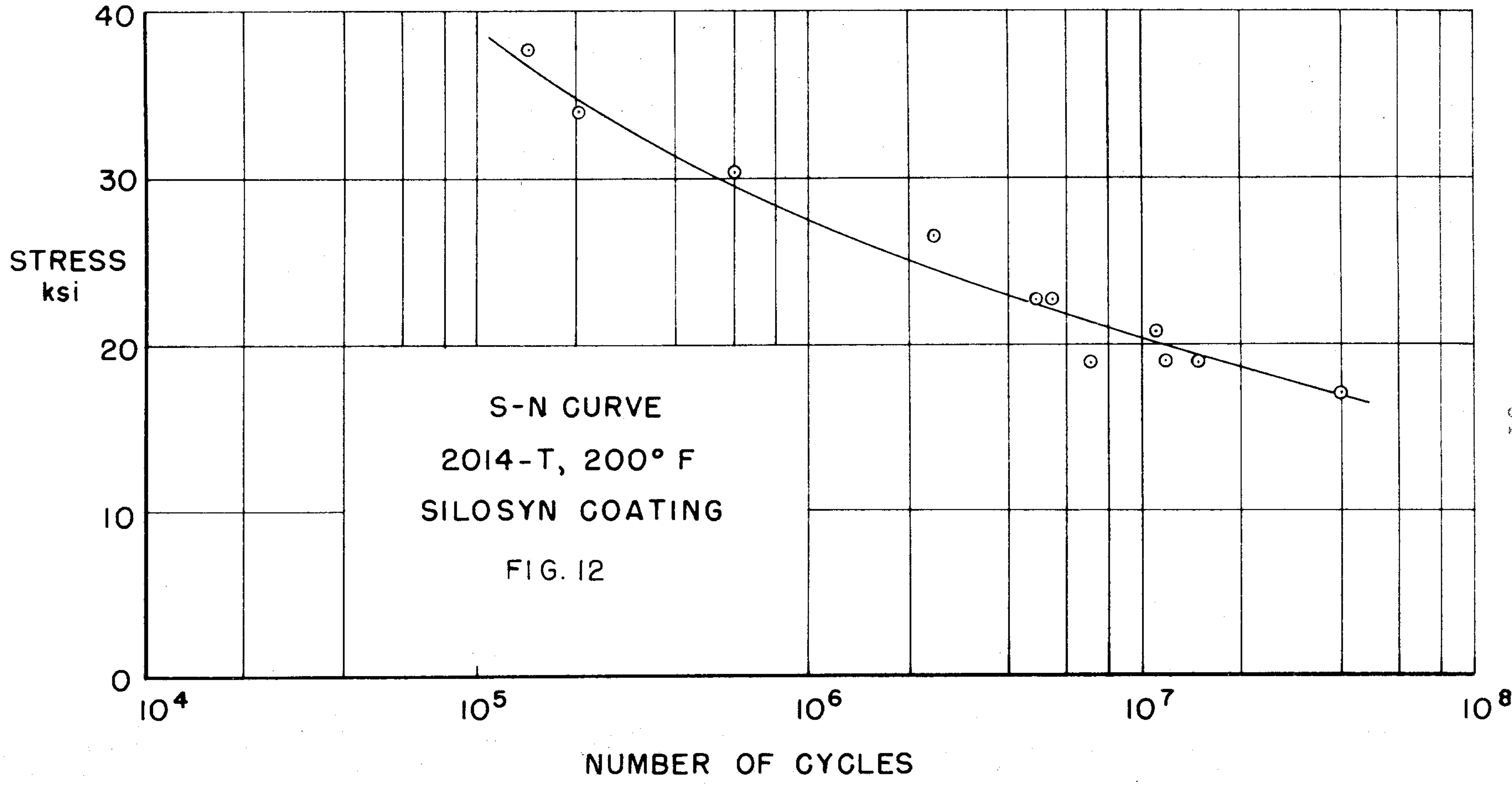

S-N CURVE
2014-T, ROOM TEMPERATURE
20-B-04 COATING
STRESS ksi
50
40
30
20
10
0
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES

FIG. 10

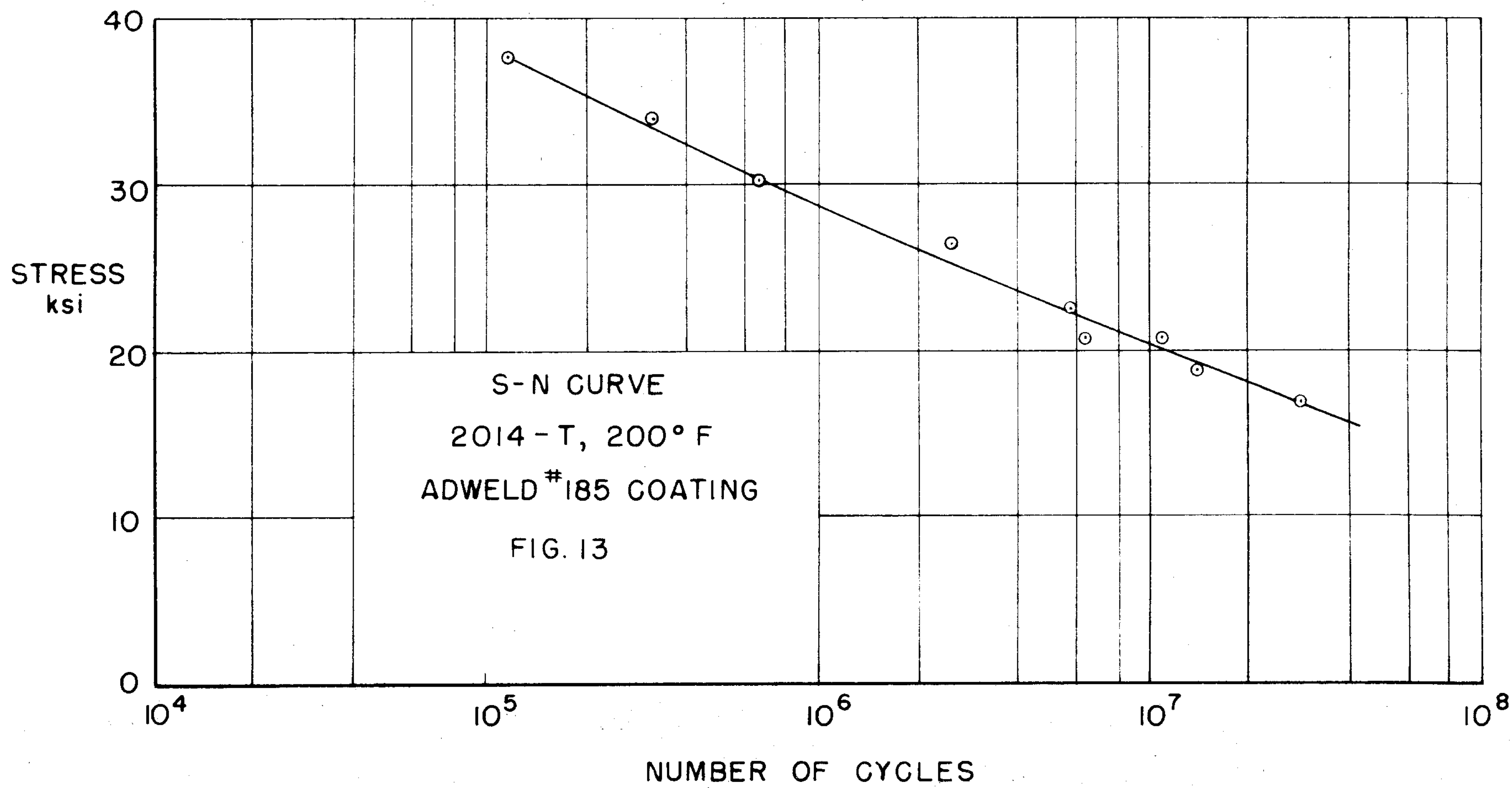


S-N CURVE
2014-T, 200° F
UNCOATED

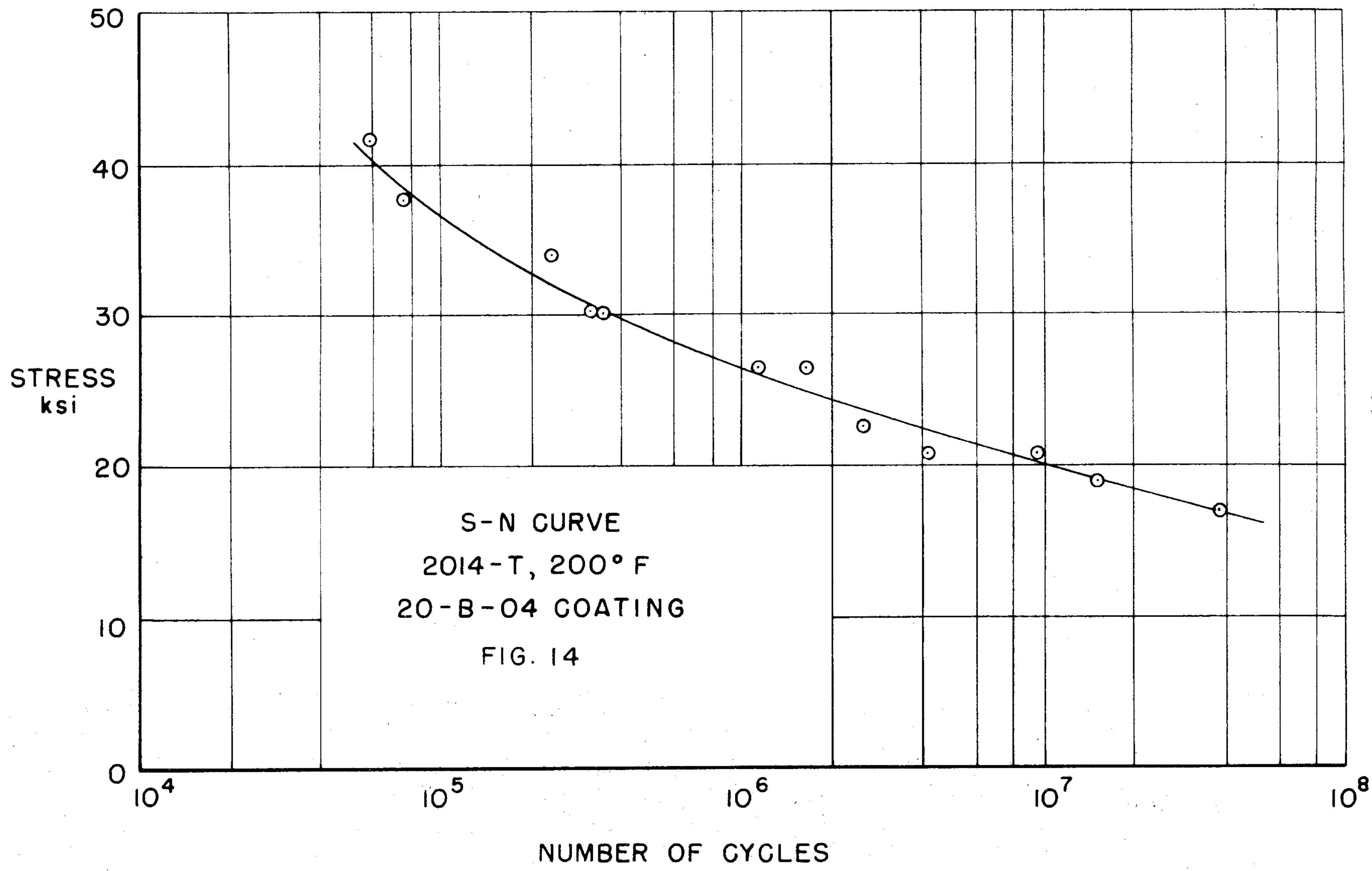
FIG. 11



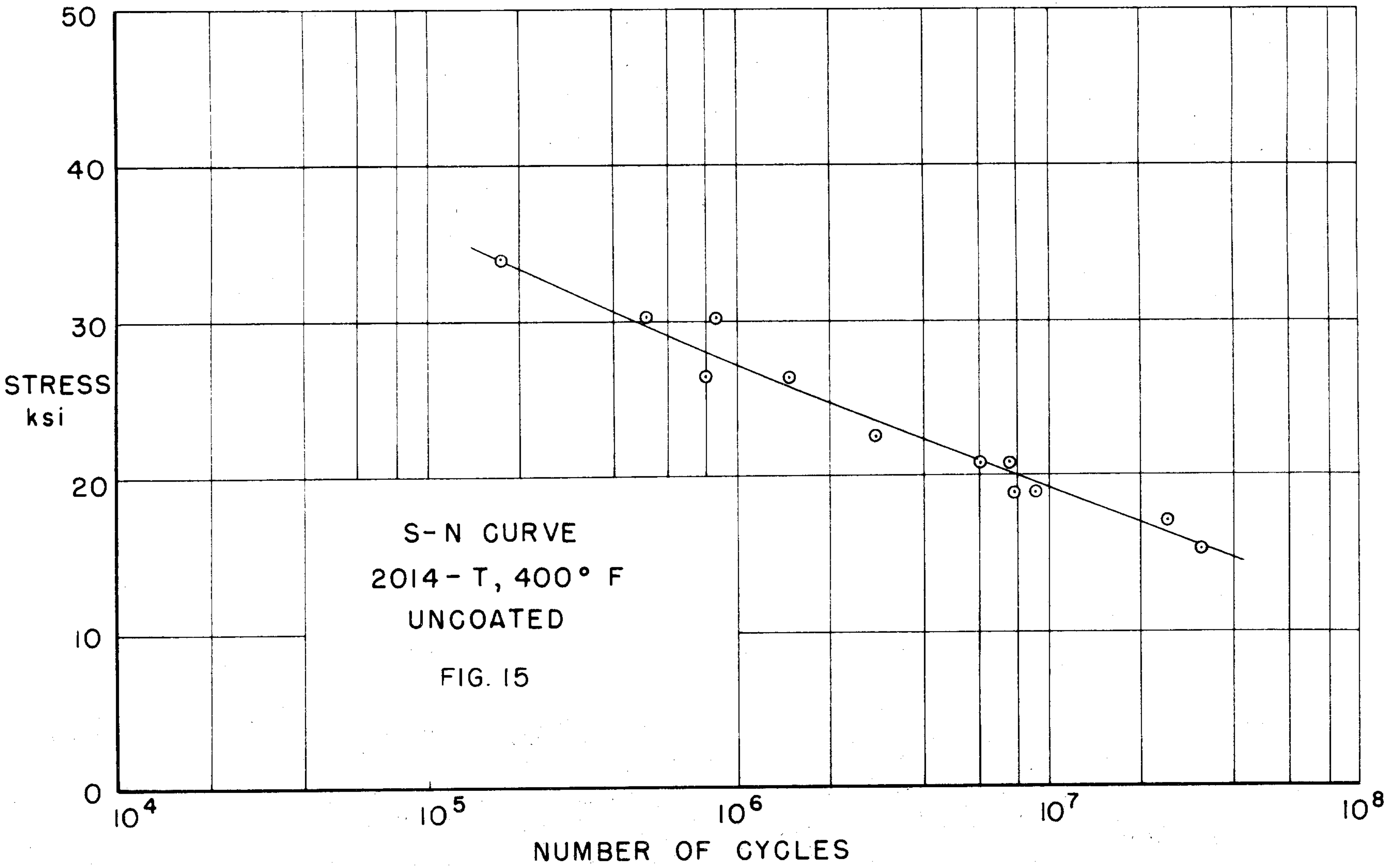
S-N CURVE
2014-T, 200° F
SILOSYN COATING
FIG. 12



S-N CURVE
2014-T, 200° F
ADWELD #185 COATING
FIG. 13

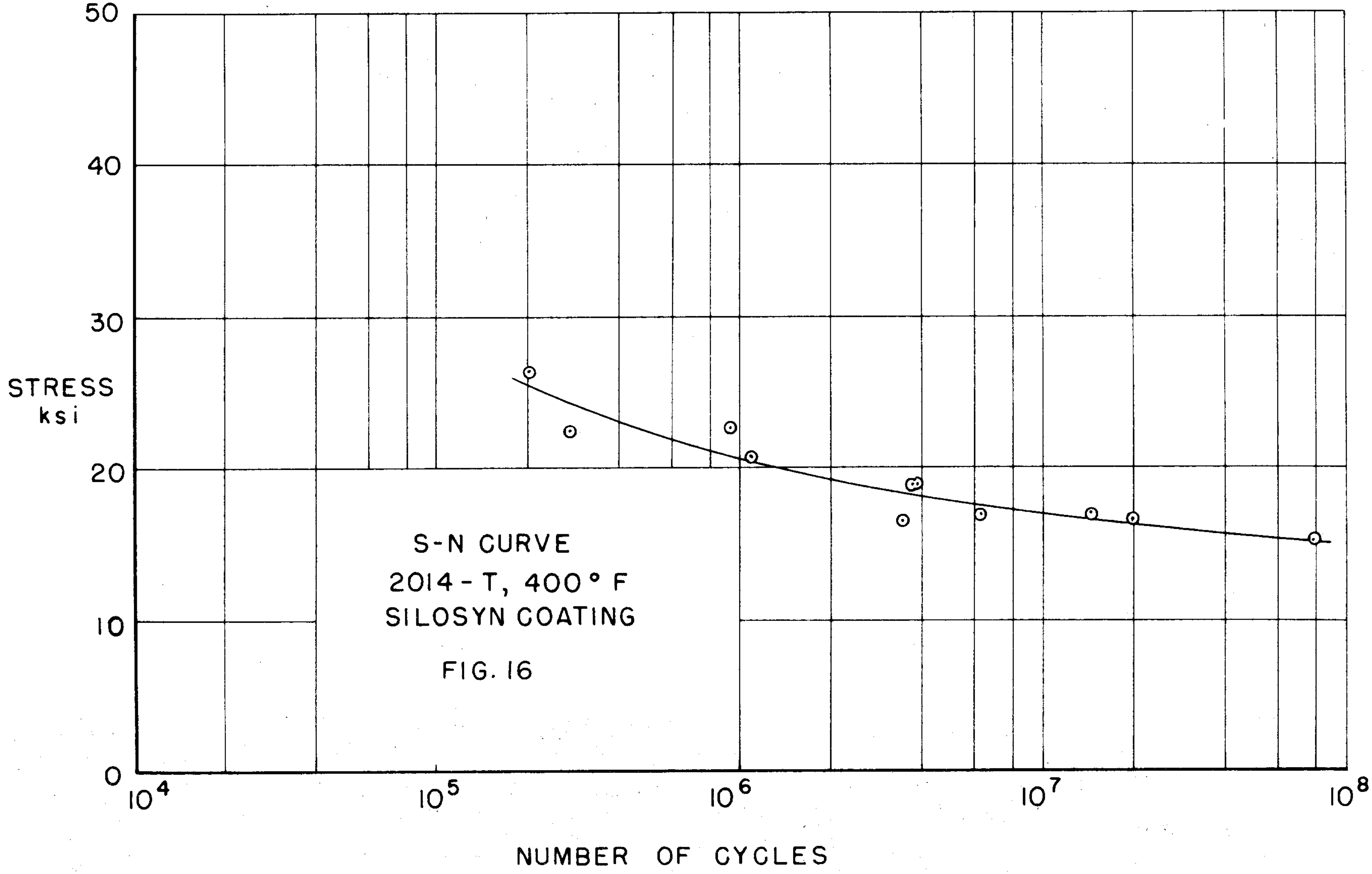


S-N CURVE
2014-T, 200° F
20-B-04 COATING
FIG. 14



S-N CURVE
2014-T, 400° F
UNCOATED

FIG. 15



S-N CURVE
2014 - T, 400° F
SILOSYN COATING

FIG. 16

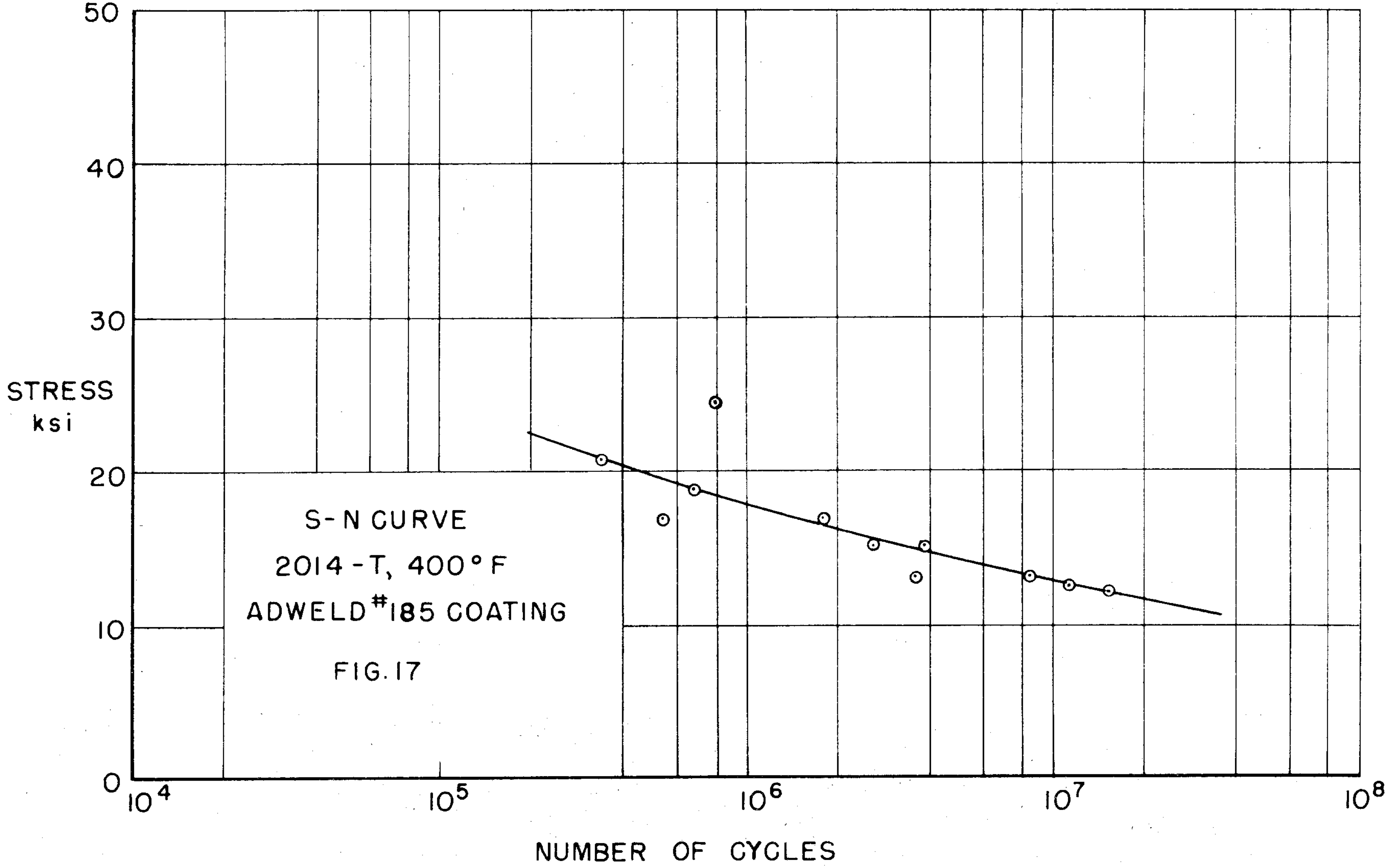

S-N CURVE
2014-T, 400° F
ADWELD #185 COATING
STRESS ksi
50
40
30
20
10
0
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES

FIG. 17

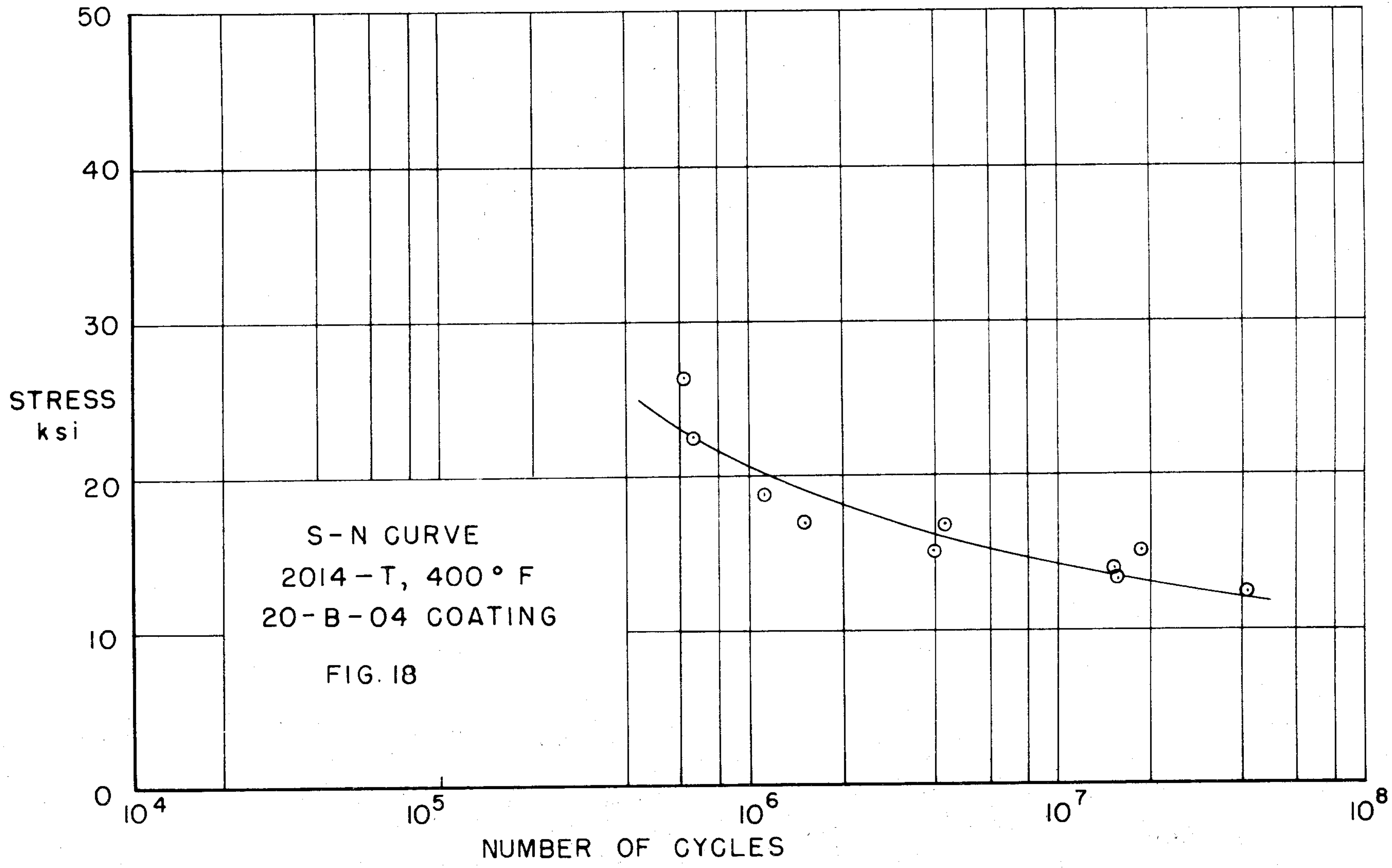
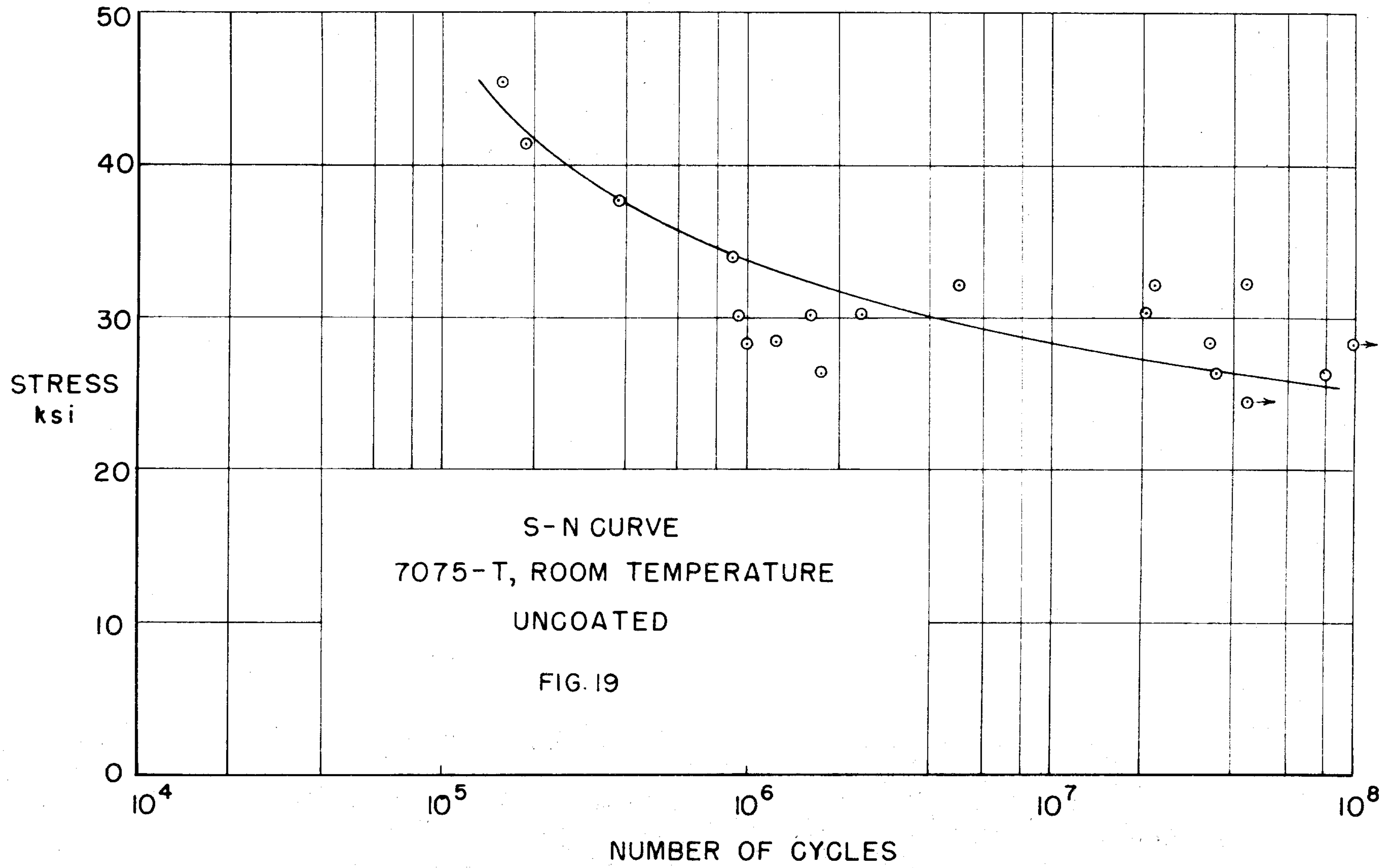
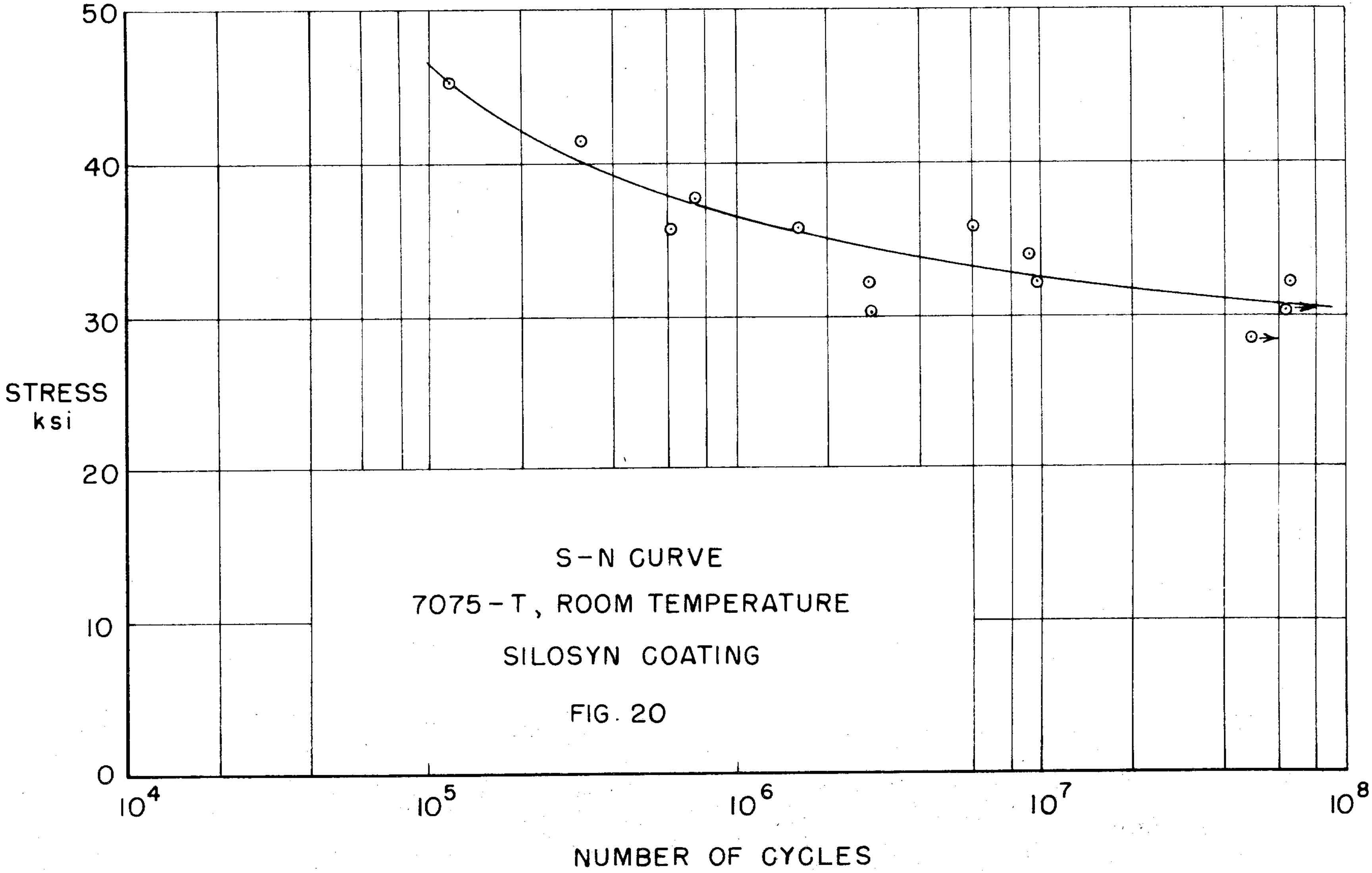

50
40
30
20
10
0
STRESS
ksi
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES
S-N CURVE
2014-T, 400° F
20-B-04 COATING

FIG. 18

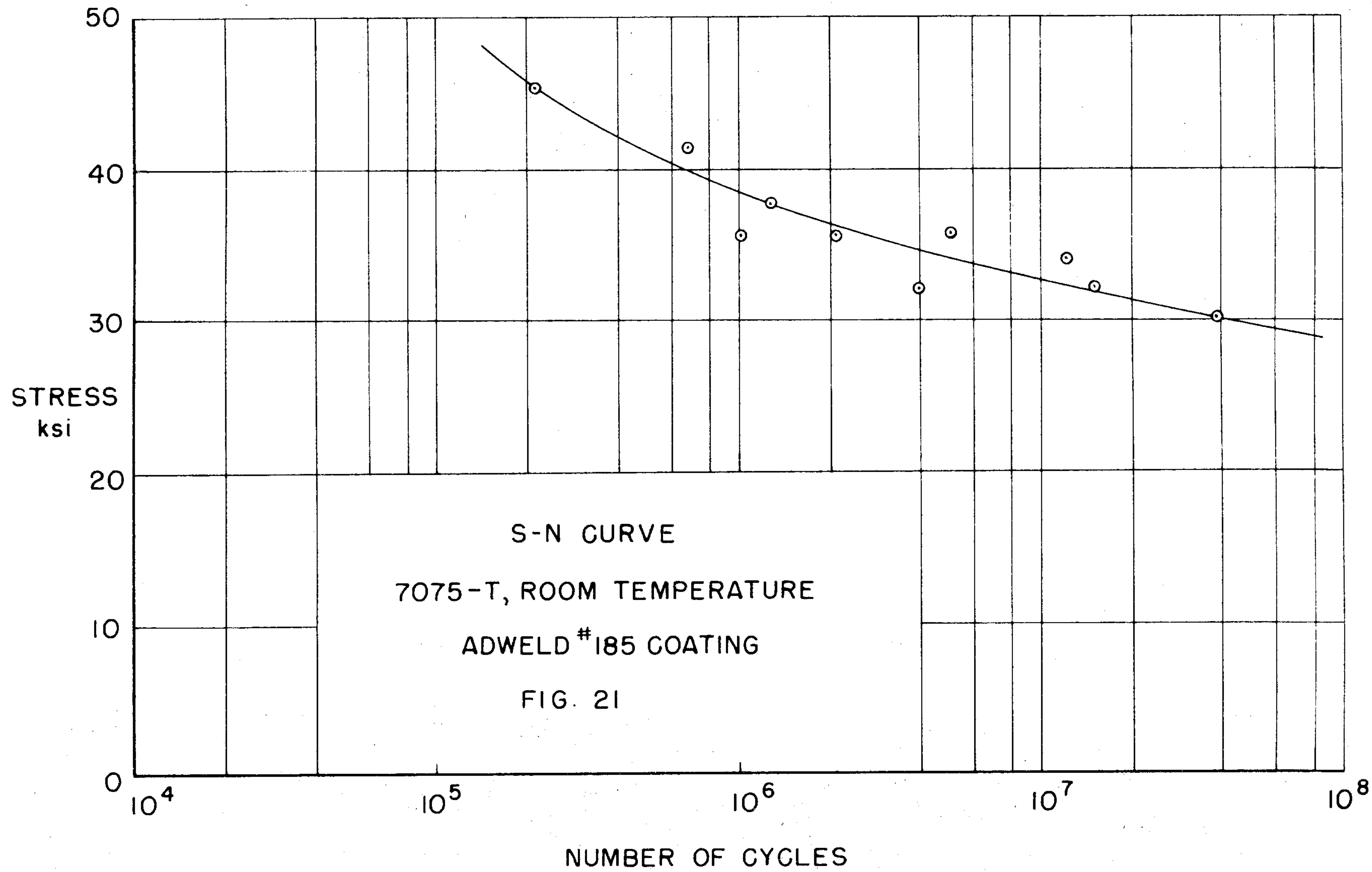


S-N CURVE
7075-T, ROOM TEMPERATURE
UNCOATED

FIG. 19



S-N CURVE
7075-T, ROOM TEMPERATURE
SILOSYN COATING
FIG. 20

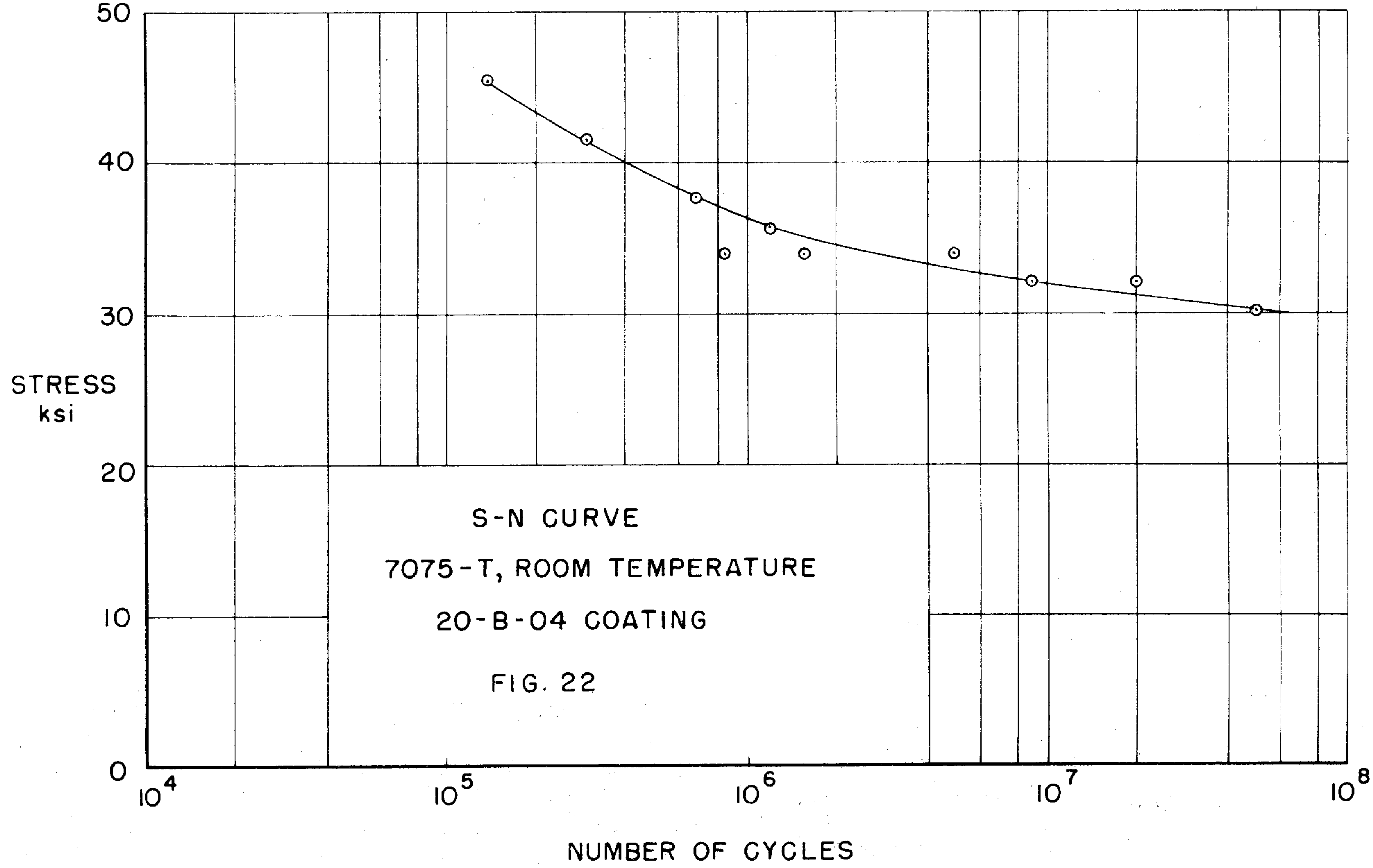


S-N CURVE

7075-T, ROOM TEMPERATURE

ADWELD #185 COATING

FIG. 21

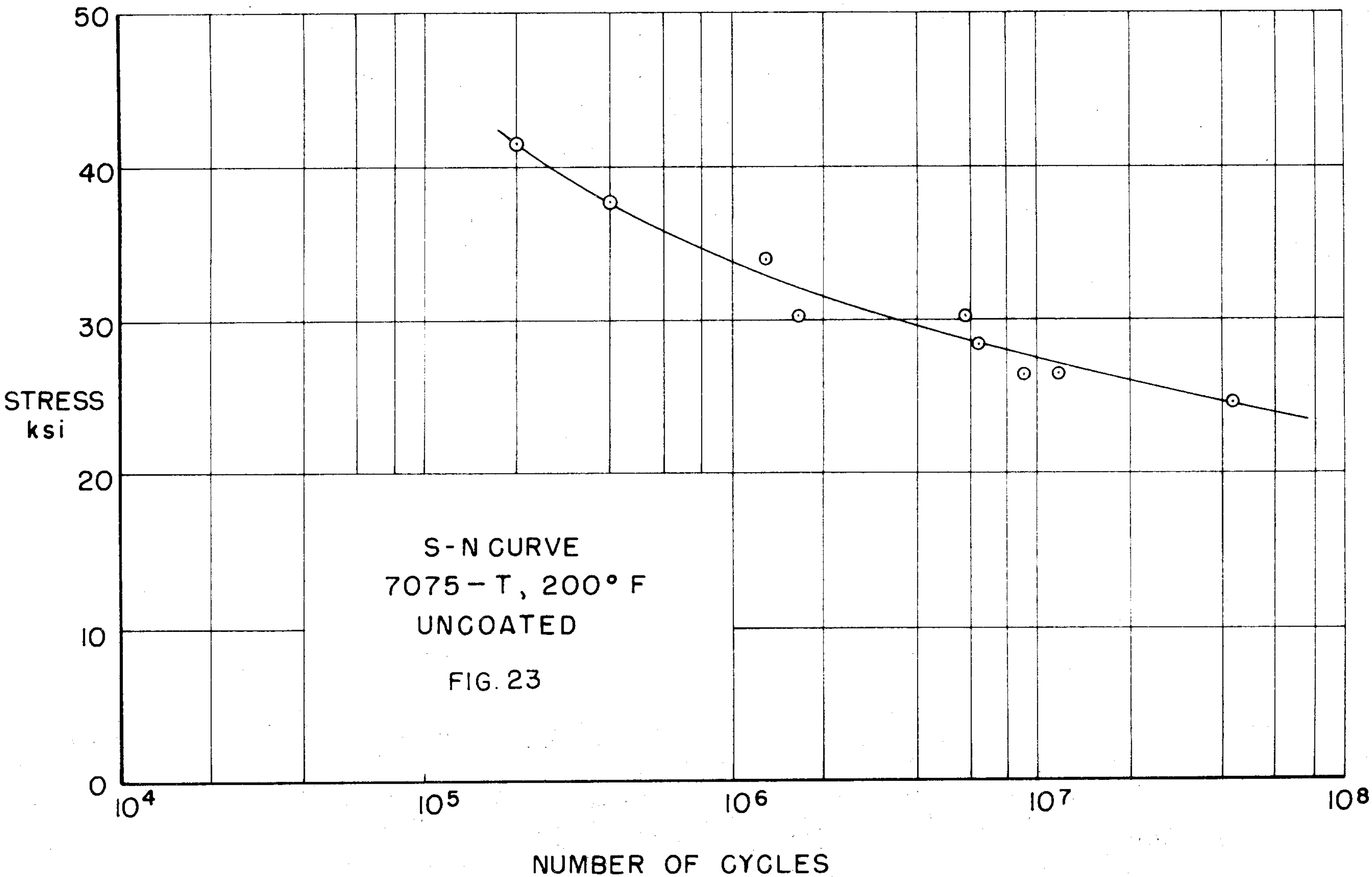


S-N CURVE

7075-T, ROOM TEMPERATURE

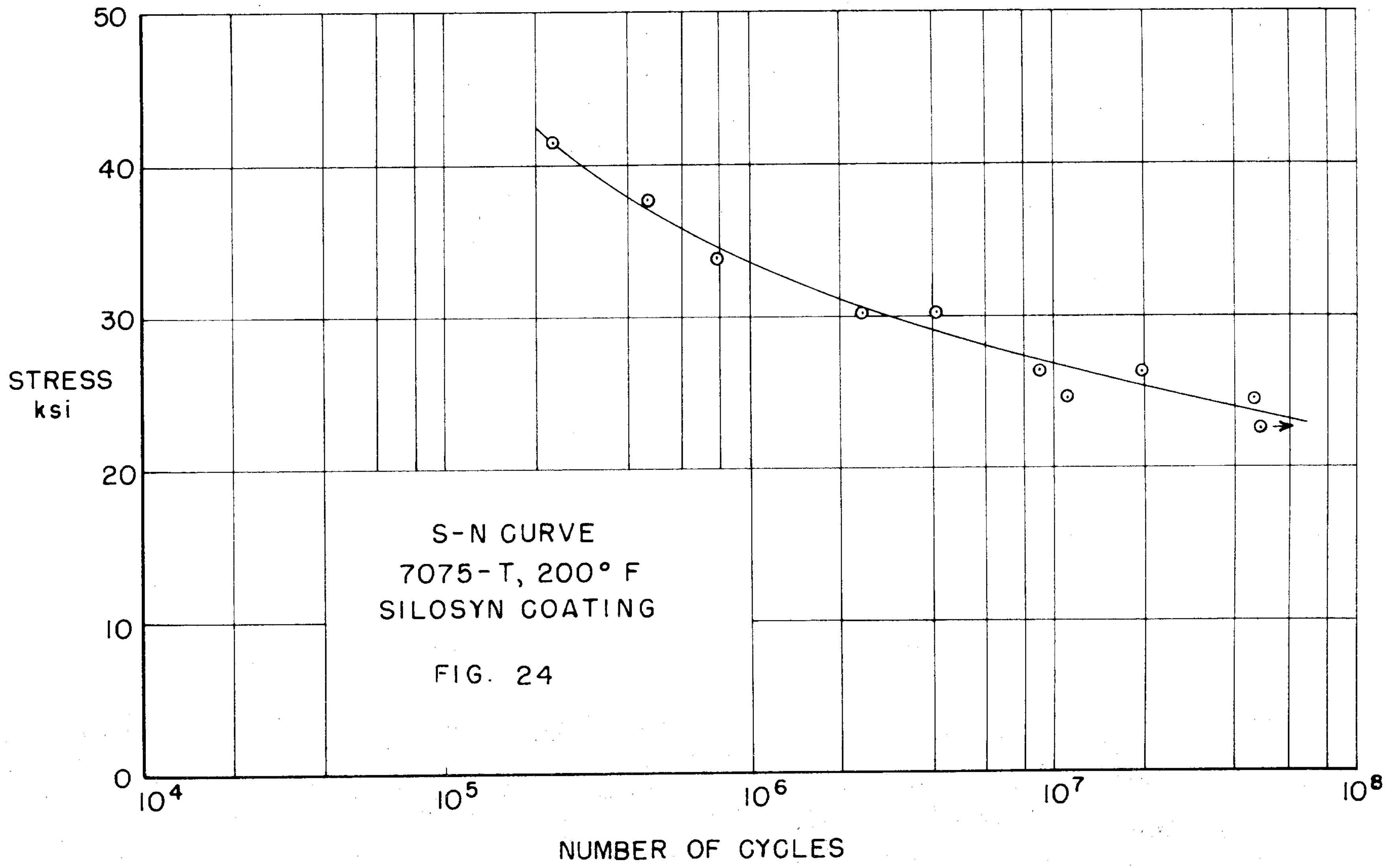
20-B-04 COATING

FIG. 22



S-N CURVE
7075 – T, 200° F
UNCOATED

FIG. 23



S-N CURVE
7075-T, 200° F
SILOSYN COATING

FIG. 24

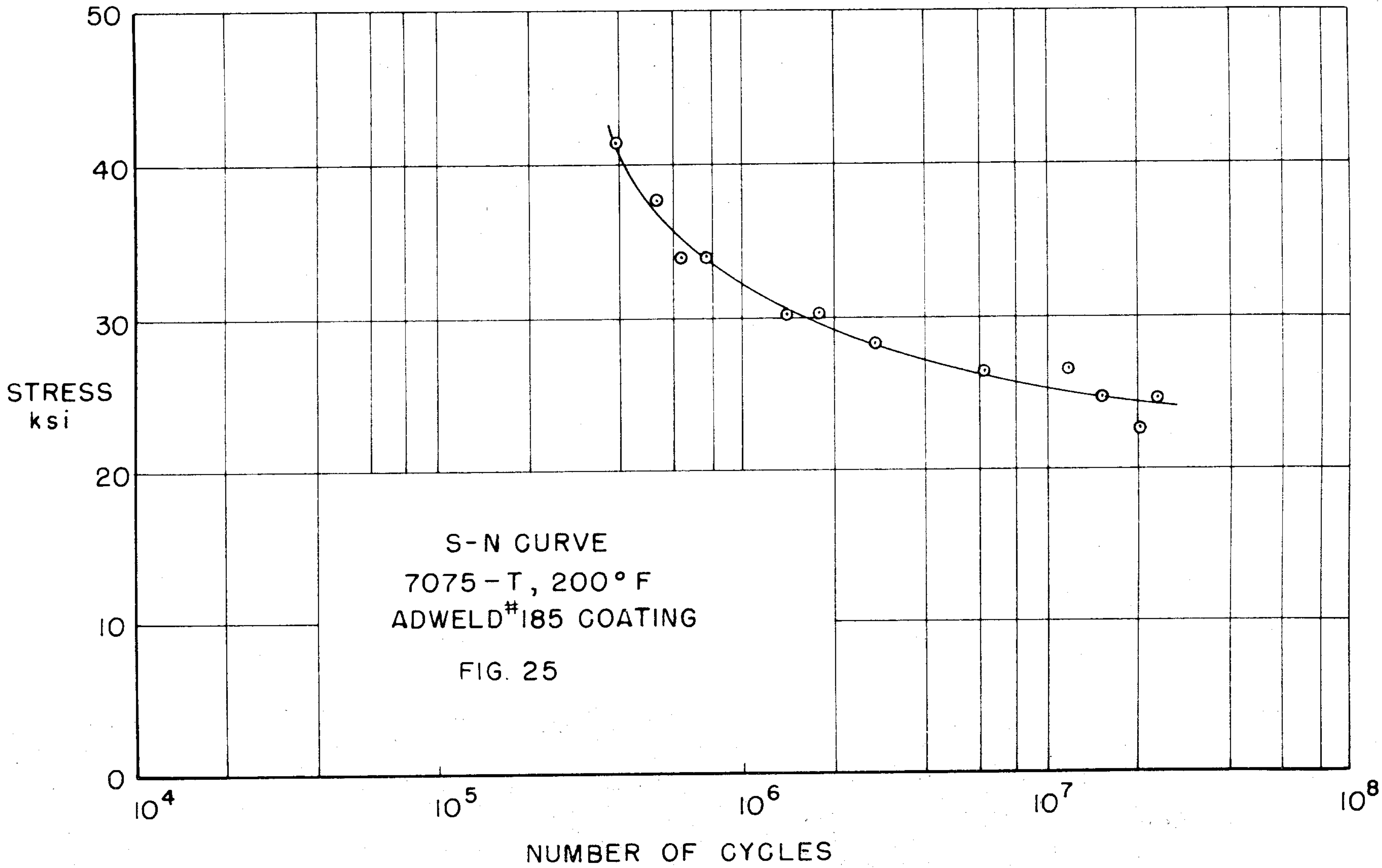
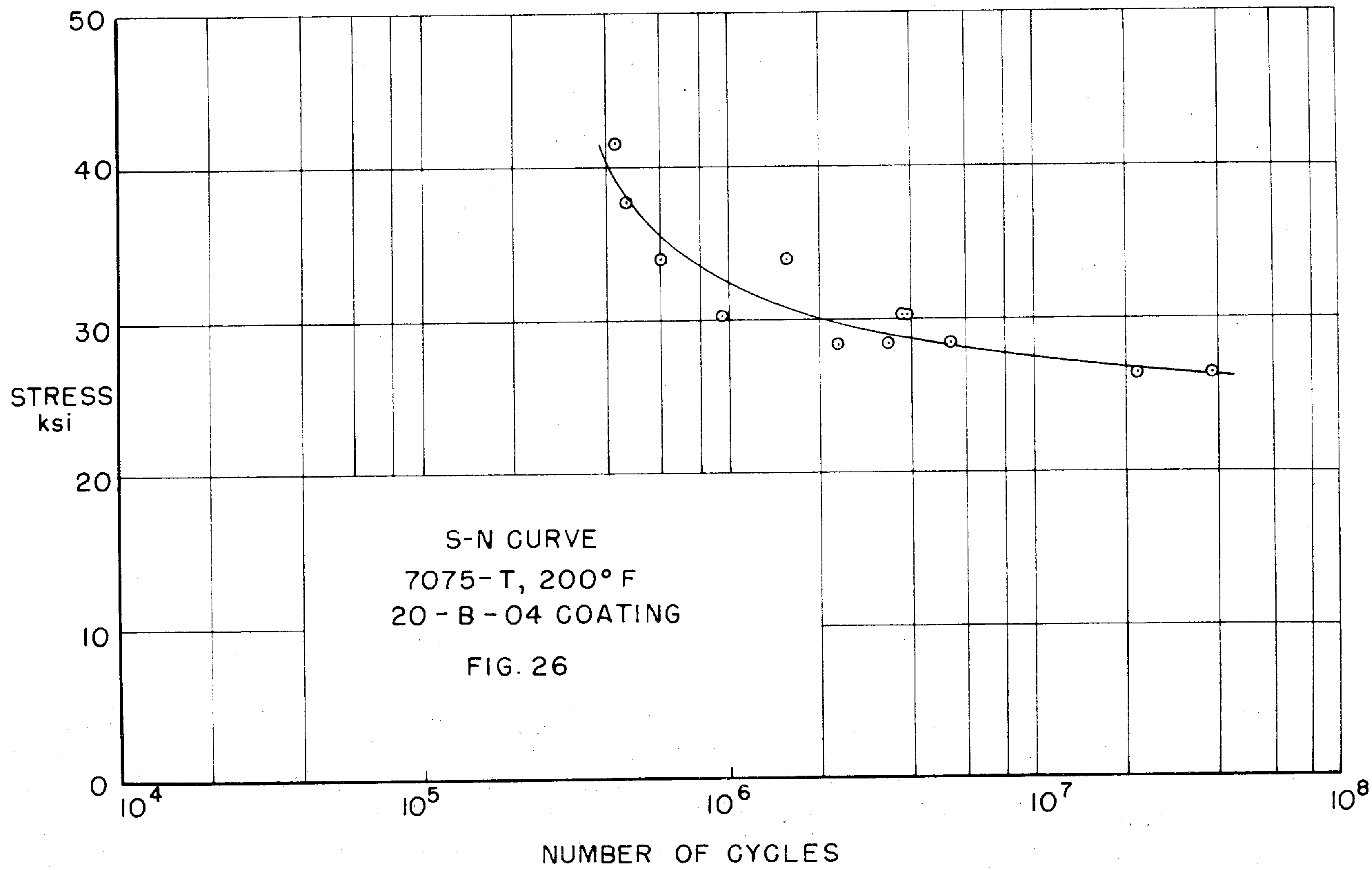
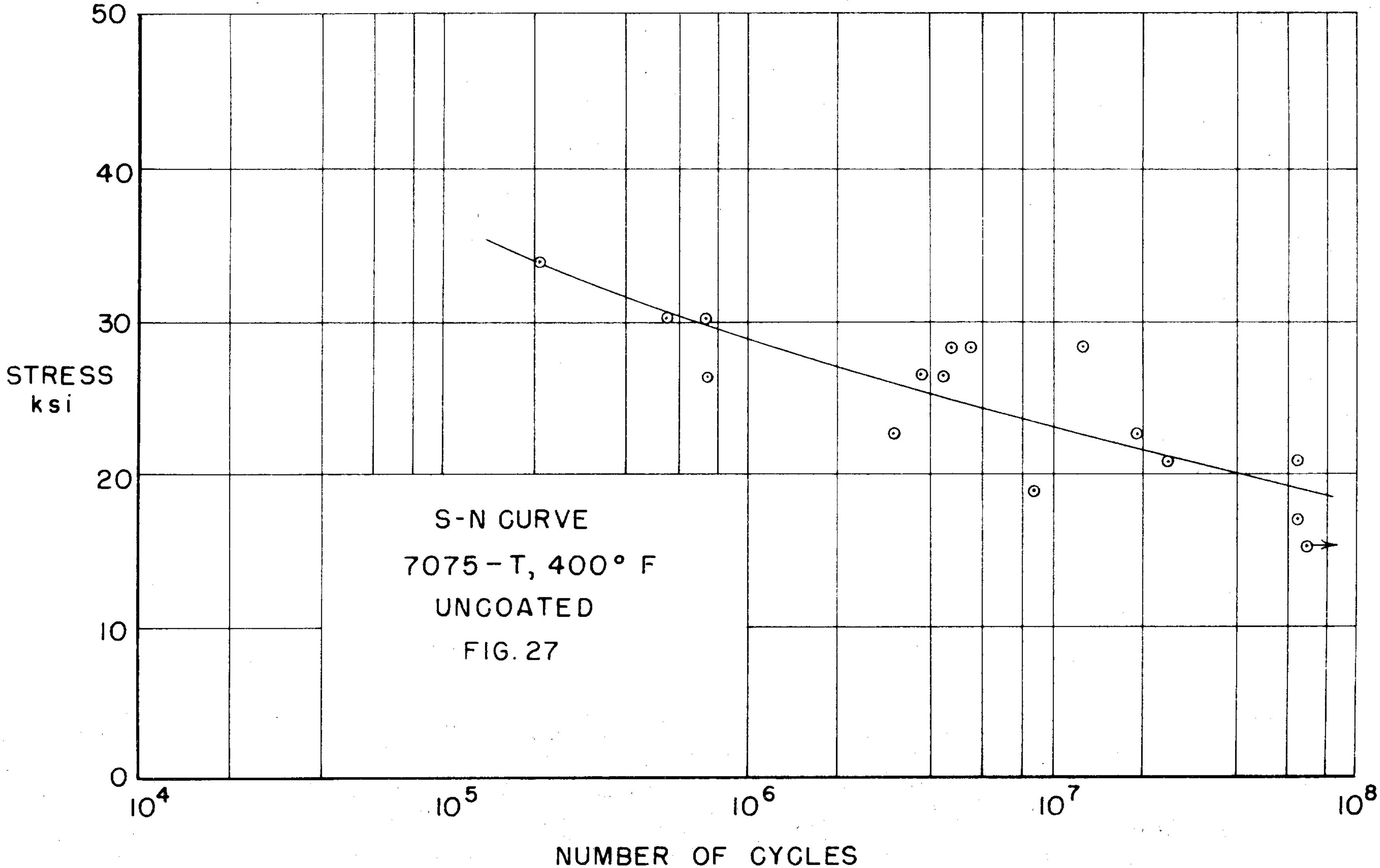

50
40
30
20
10
0
STRESS
ksi
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES
S-N CURVE
7075-T, 200° F
ADWELD #185 COATING

FIG. 25

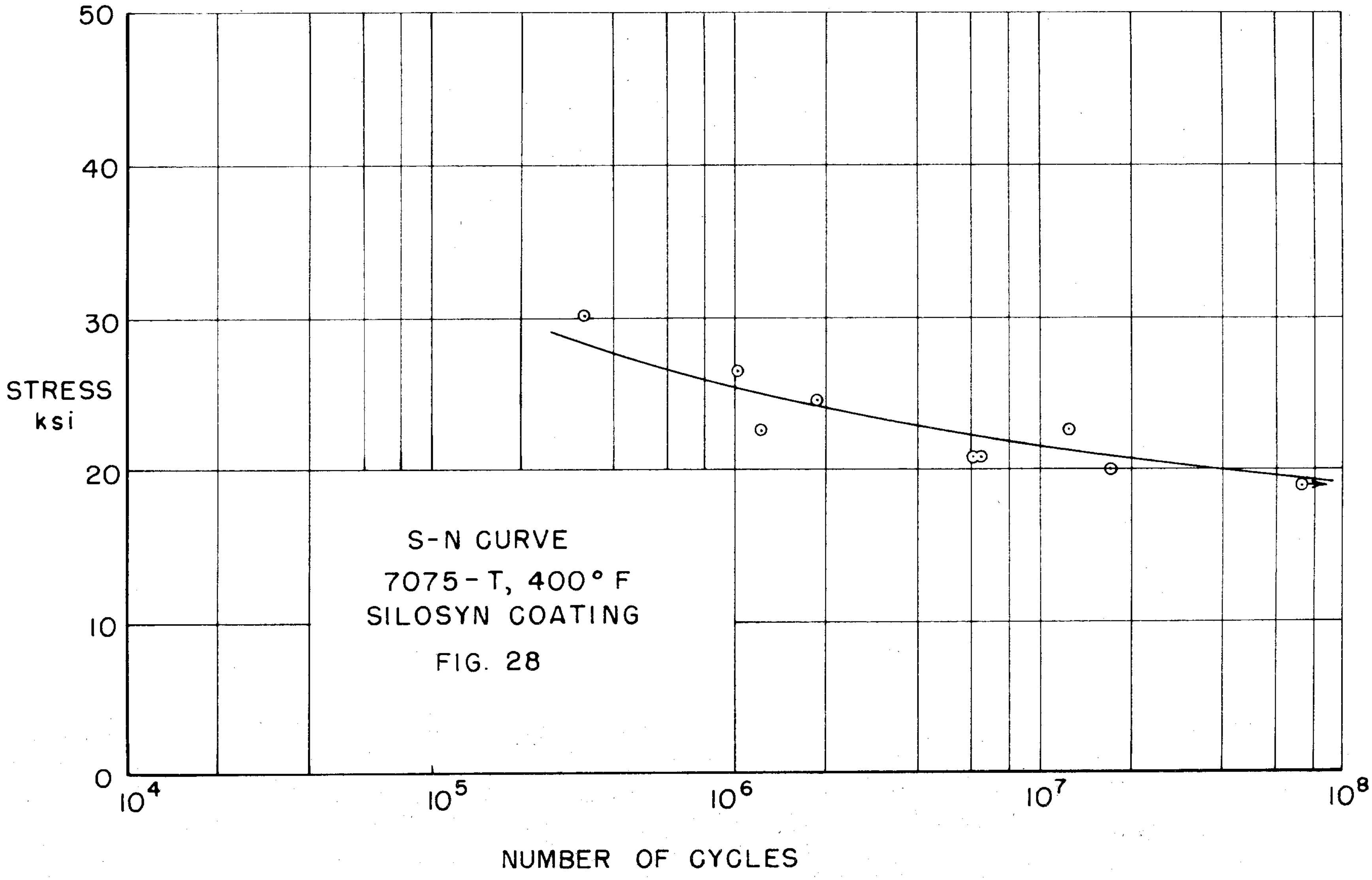


S-N CURVE
7075-T, 200° F
20-B-04 COATING

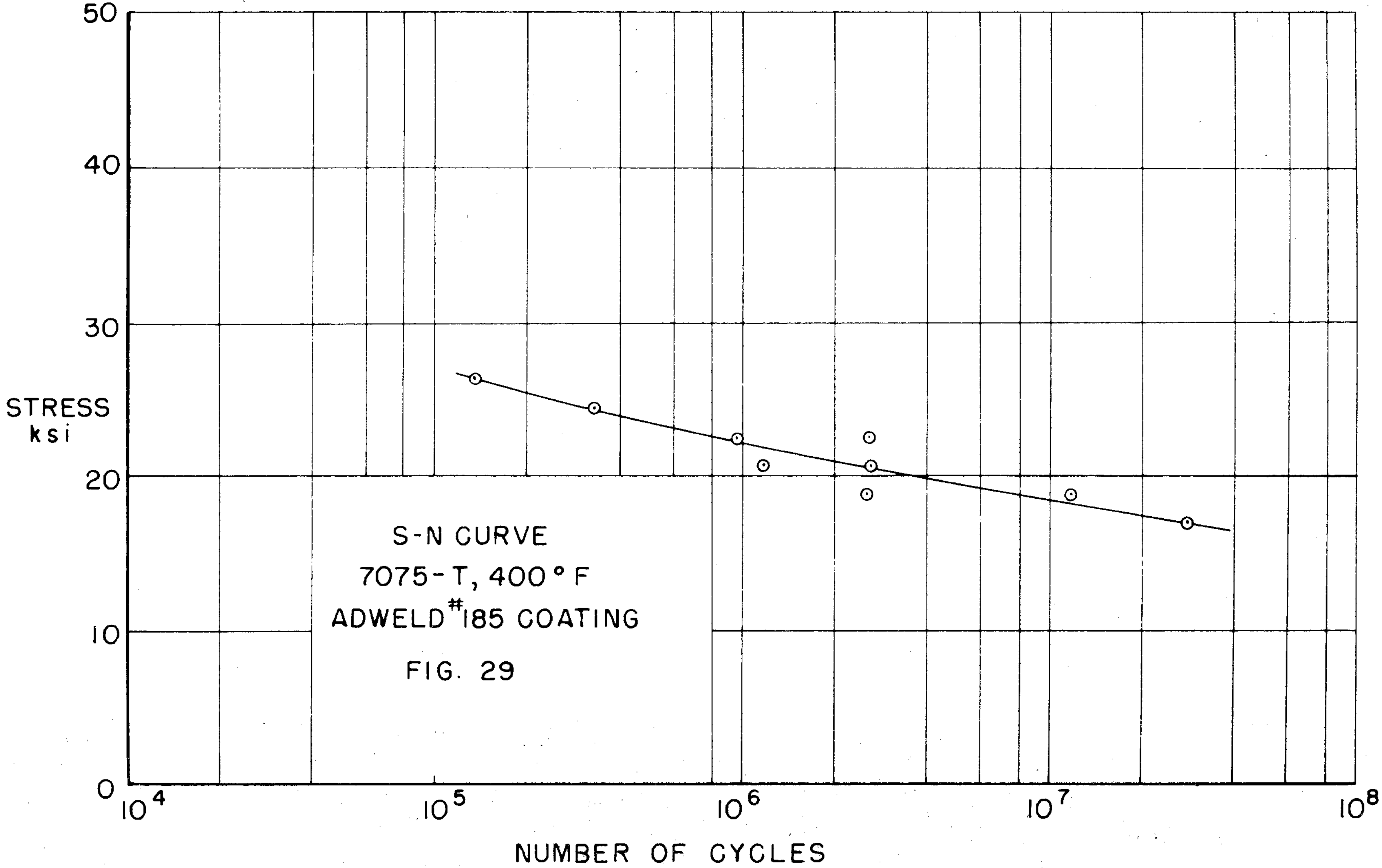
FIG. 26



S-N CURVE
7075-T, 400° F
UNCOATED
FIG. 27

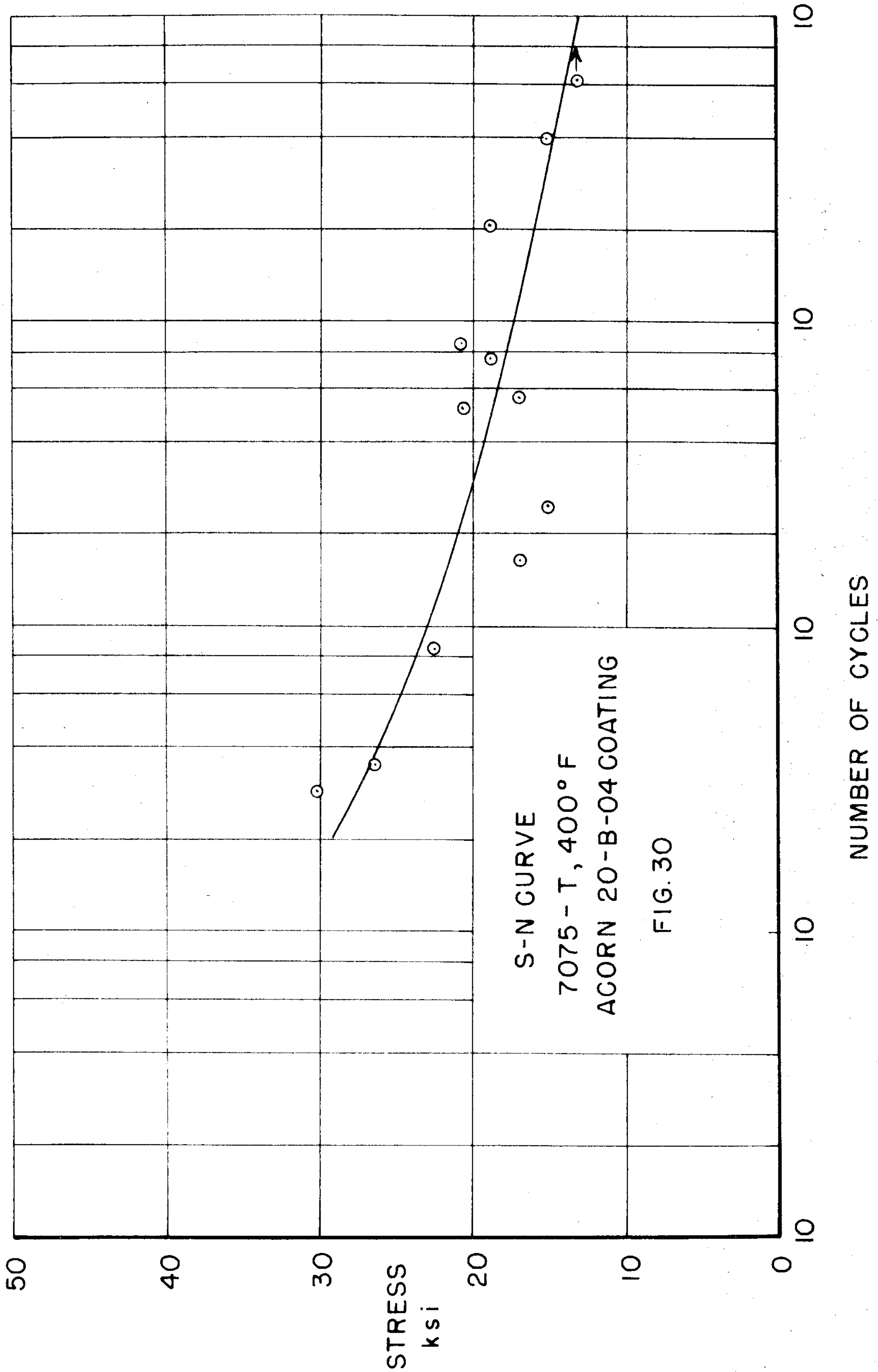


S-N CURVE
7075-T, 400° F
SILOSYN COATING
FIG. 28



S-N CURVE
7075-T, 400° F
ADWELD # 185 COATING

FIG. 29



S-N CURVE
7075 - T, 400° F
ACORN 20-B-04 COATING
FIG. 30

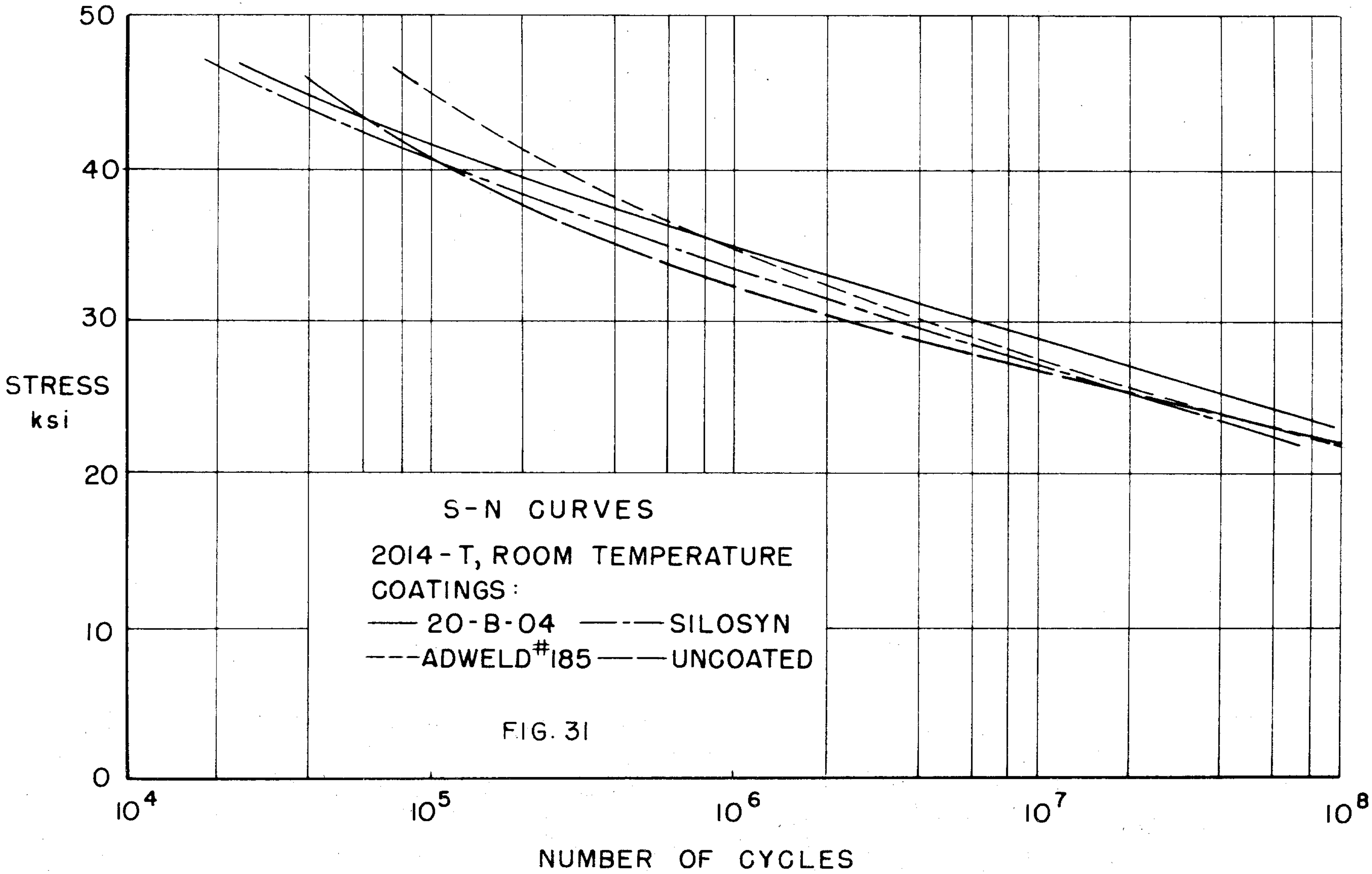

50
40
30
20
10
0
STRESS
ksi
S-N CURVES
2014-T, ROOM TEMPERATURE
COATINGS:
20-B-04
SILOSYN
ADWELD#185
UNCOATED
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES

FIG. 31

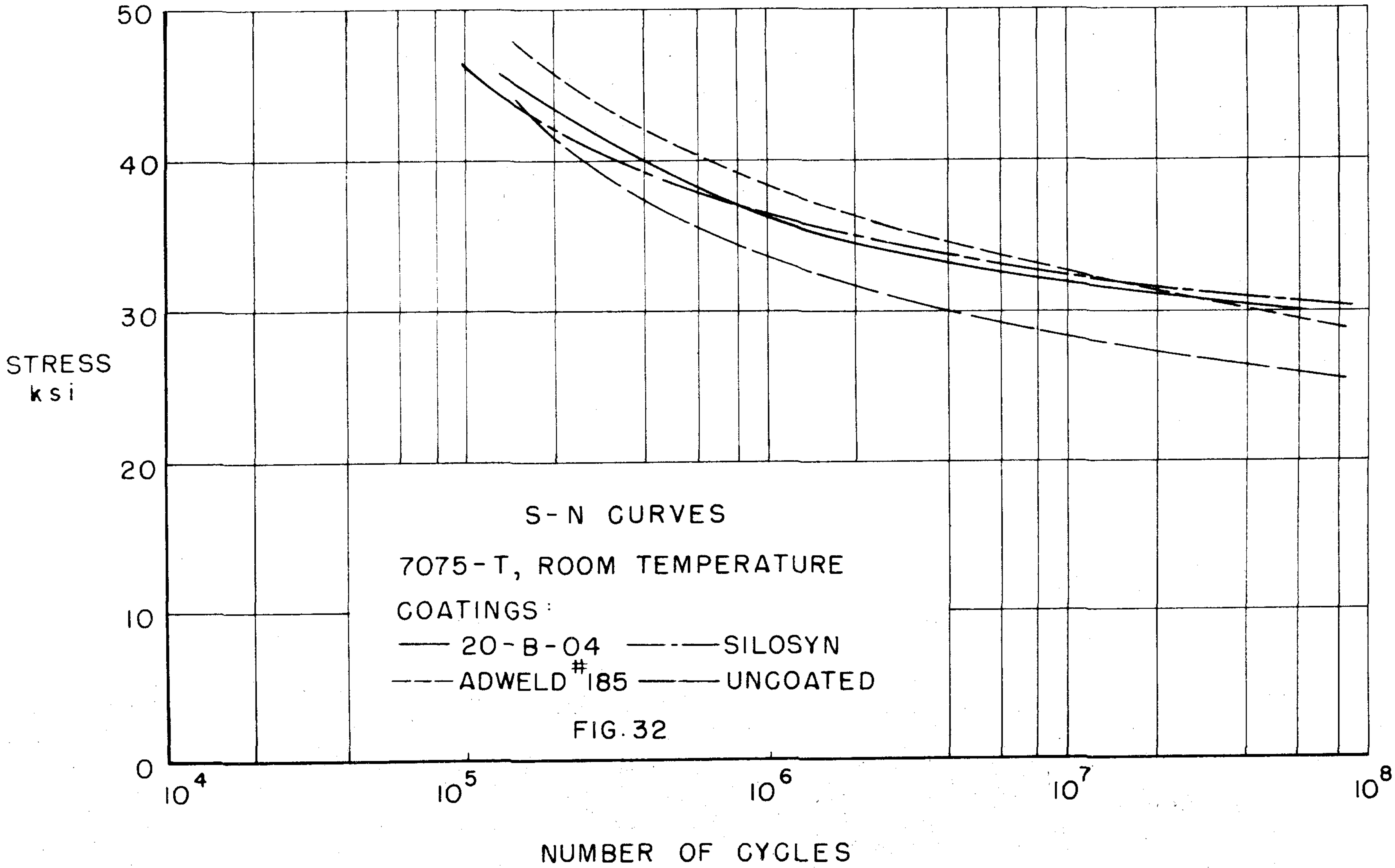

50
40
30
20
10
0
STRESS
ksi
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES
S-N CURVES
7075-T, ROOM TEMPERATURE
COATINGS:
20-B-04
SILOSYN
ADWELD #185
UNCOATED

FIG. 32

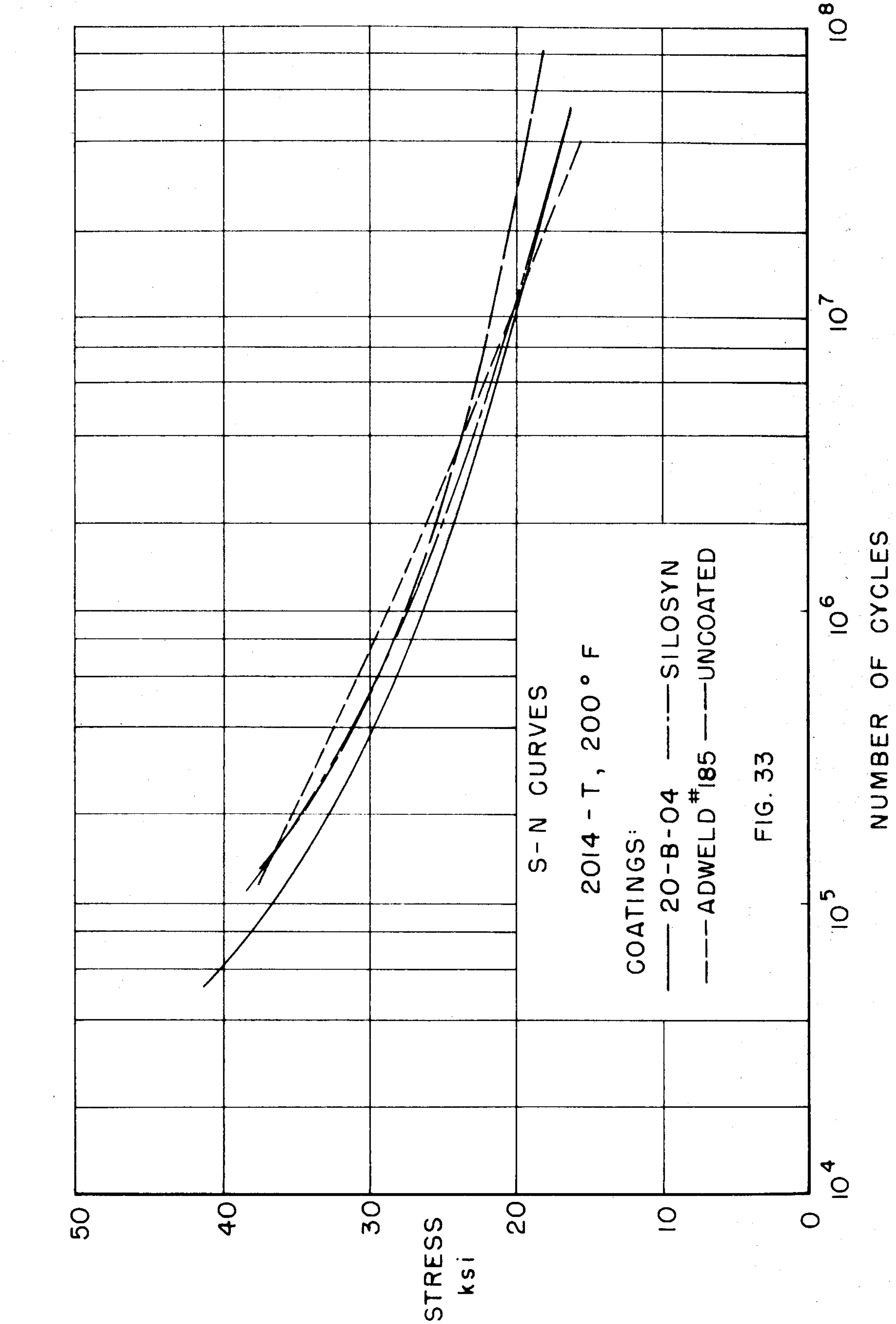

S-N CURVES
2014 - T, 200° F
COATINGS:
20-B-04
SILOSYN
ADWELD #185
UNCOATED
STRESS ksi
NUMBER OF CYCLES
0
10
20
30
40
50
10^4
10^5
10^6
10^7
10^8

FIG. 33

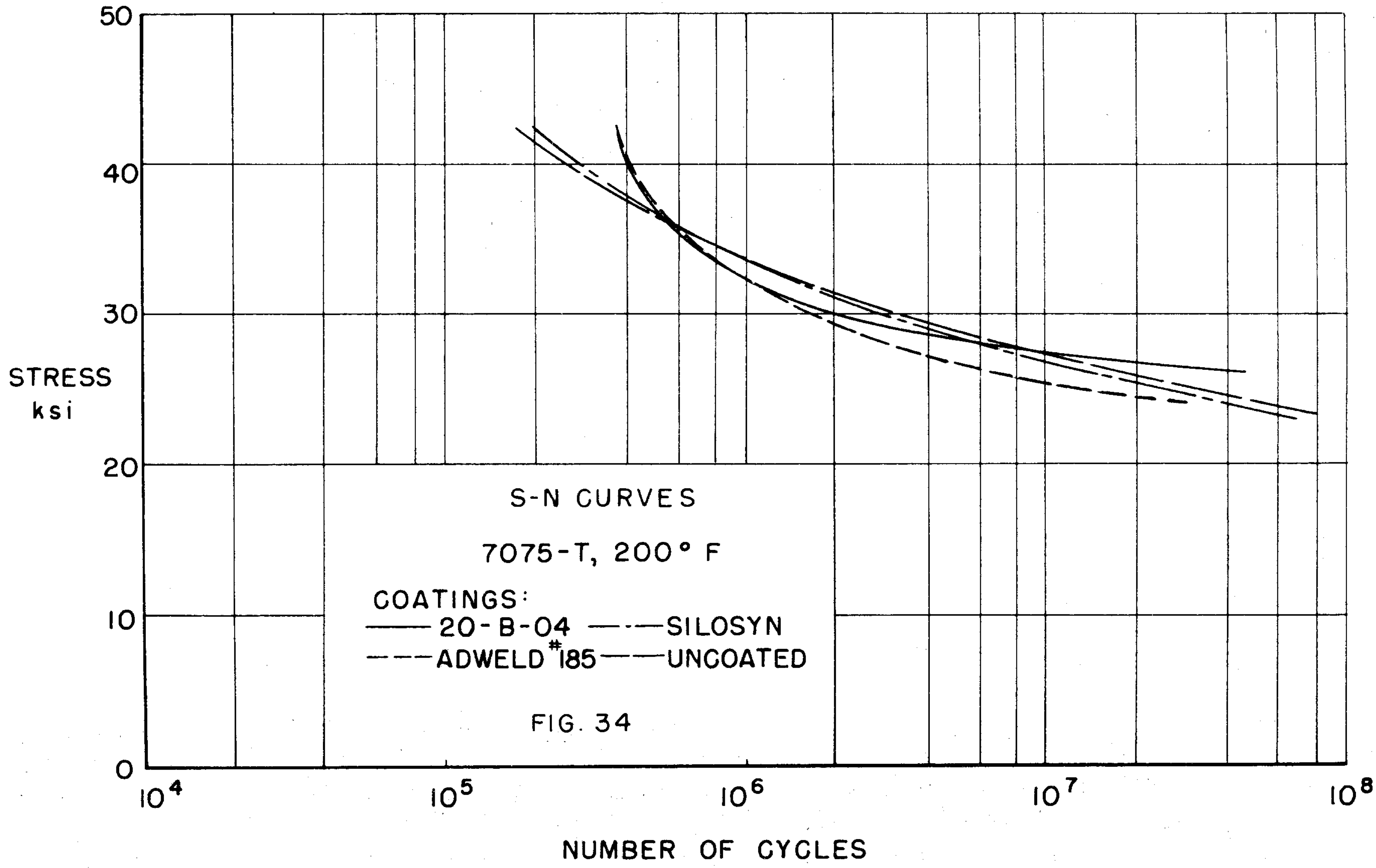

50
40
30
20
10
0
STRESS
ksi
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES
S-N CURVES
7075-T, 200° F
COATINGS:
20-B-04
SILOSYN
ADWELD #185
UNCOATED

FIG. 34

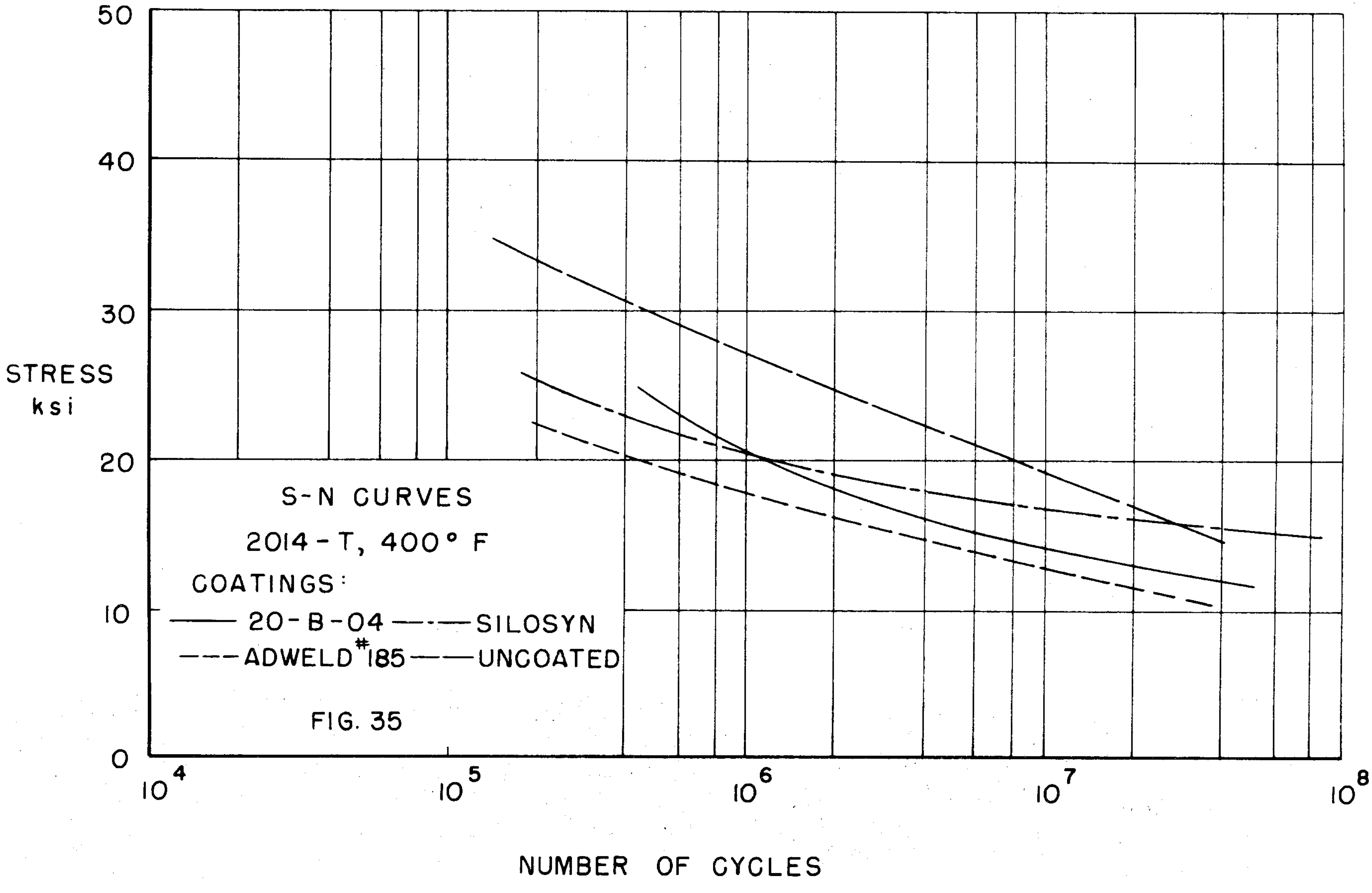

S-N CURVES
2014-T, 400° F
COATINGS:
20-B-04
SILOSYN
ADWELD #185
UNCOATED
STRESS ksi
50
40
30
20
10
0
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES

FIG. 35

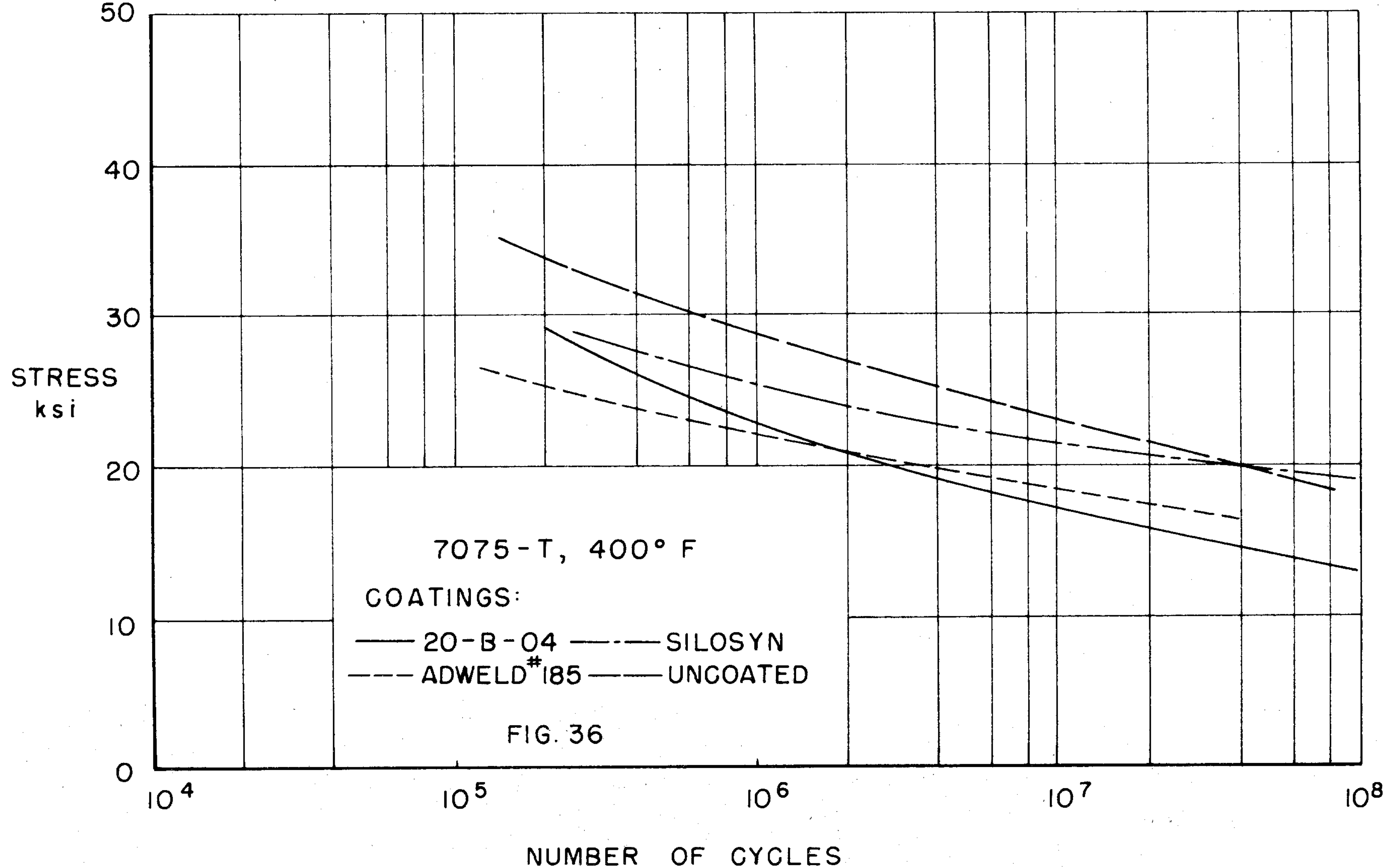

50
40
30
20
10
0
STRESS
ksi
10^4
10^5
10^6
10^7
10^8
NUMBER OF CYCLES
7075-T, 400° F
COATINGS:
20-B-04
SILOSYN
ADWELD #185
UNCOATED

FIG. 36