A STUDY OF THE EFFECTS OF PRE-STRETCHING ON THE FATIGUE LIFE OF 17-7 PH STAINLESS STEEL SHEET

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A STUDY OF THE EFFECTS OF PRE-STRETCHING
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APPROVED:

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TABLE OF CONTENTS

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LIST OF TABLES

LIST OF FIGURES

SUMMARY

In fabricating components of an aircraft from sheet stock, it is desirable to adopt a production sequence which will permit the high temperature portion of the heat treatment cycle to be completed before the material is formed to its final shape. There are three reasons for this: (a) flat stock can be handled much more easily for heat treatment than formed parts; (b) a more uniform temperature, and hence more uniform properties, can be achieved over the entire sheet by processing flat sheets; (c) warpage after forming due to the heat treatment process is minimized. In the case of the 17-7 PH stainless steel sheet with which this study was concerned, the material must be process annealed to 1750° F. following receipt by the customer, sub-zero cooled, and then aged at 950° F. to produce the fully hardened properties. It would be very desirable to complete the process annealing before forming the production parts, for the reasons above. However, due to a number of factors, the effect of the cold working which would result from forming following the process annealing on the fatigue life of the completed parts is unpredictable. A test was developed to evaluate the effects of pre-stretching on the 17-7 PH stainless steel sheet. The procedure for this test and its results are described.

Standard laboratory fatigue test specimens with a twelve inch radius in the reduced section were cut from 0.025 inch thick 17-7 PH stainless steel sheet in the annealed condition as received from the manufacturer. The specimens were process annealed in preparation for final heat treatment as recommended by the manufacturer, and then divided into four groups. One group was left unchanged; the other three groups of specimens were statically stretched beyond the elastic limit in a universal testing machine to three arbitrary values of total strain: 2.0, 3.5, and 5.0 per cent total strain in two inches. The heat treatment process was completed for all specimens following the stretching operation. The specimens were fatigue tested in axial load fatigue test machines using a stress ratio R of 0.1 to produce an S-N curve for each group. A comparison of the S-N curves indicated that pre-stretching the specimens increased their fatigue life at intermediate stress levels, with the greater amounts of pre-stretch producing greater improvements in the fatigue life. Residual stresses induced in the specimens by the pre-stretching were felt to be the main contributing factor in the increased fatigue life.

INTRODUCTION

With the advent of high-speed aircraft, many materials previously rejected from consideration for use in aircraft structures on a basis of strength to weight ratios are being re-examined and new alloys are being developed to take advantage of the high-temperature properties of the materials. Among such alloys is 17-7 PH stainless steel, a proprietary grade of steel manufactured by the Armco Steel Corporation, Middletown, Maryland, having a minimum guaranteed ultimate tensile strength of 210,000 psi at room temperature. Since the development of 17-7 PH stainless steel, Armco has developed another alloy, PH 15-7 Mo, which possesses an even more favorable strength to weight ratio. Both of these materials, which belong to the group of alloys known as precipitation hardening stainless steels, are intended for use in the range of temperatures below 1000° F. Comparable alloys are produced under proprietary grade designations AM 350 and AM 355 by the Allegheny-Ludlum Corporation, Pittsburgh, Pennsylvania. Both materials are shipped to the customer in a stable annealed condition. Heat treatment by the customer consists of: process annealing, subzero cooling to effect a transformation from an austenitic to a martensitic structure, and precipitation hardening at a relatively low temperature.

17-7 PH alloy was selected for the test program developed in this study on a basis of availability. Although this material shows inferior properties to PH 15-7 Mo, other tests conducted on the two materials (1) suggest that their response to various test programs is comparable and that the results of this program should be indicative of the performance of PH 15-7 Mo.

PROGRAM OBJECTIVE

The object of the program described herein was to evaluate the effect of pre-stretching, such as might be encountered in cold working or forming in the process annealed condition, on the fatigue life of 17-7 PH stainless steel heat treated after the pre-stretching operation to Condition RH 950.

MATERIAL

The composition of 17-7 PH stainless steel is (2):

Carbon	0.09 Per Cent Maximum
Manganese	1.00 Per Cent Maximum
Phosphorus	0.04 Per Cent Maximum
Sulfur	0.03 Per Cent Maximum
Silicon	1.00 Per Cent Maximum
Chromium	16.00 to 18.00 Per Cent
Nickel	6.50 to 7.75 Per Cent
Aluminum	0.75 to 1.50 Per Cent
Iron	Remainder

The material is shipped from the vendor in Condition TH 1950, having been annealed for one hour at 1950° F. In this stable annealed condition, this material exhibits a yield strength (0.2 per cent offset) of 40,000 psi, ultimate tensile strength of 130,000 psi, and elongation of 35 per cent in two inches (3). The heat treatment specified by the manufacturer consists of annealing at 1750° F., followed by eight hours at -100° F. and then heating to 950° F. for one hour to produce the full hard condition, which is identified as Condition RH 950. The minimum guaranteed physical properties of the material at room temperature when properly heat treated by the consumer are listed below. Properties for PH 15-7 Mo are also listed for comparison.

Property	17-7 PH	PH 15-7 Mo
Ultimate Tensile Strength (psi)	210,000	225,000
Yield Strength (psi for 0.2 per cent permanent set)	190,000	200,000
Per Cent Elongation in 2 Inches	5	4
Hardness (Rockwell Scale)	C46	C46

The samples tested were taken from three sheets of 0.025 inch nominal thickness. The mechanical properties of the sheets after heat treatment are shown in Table 1. These properties were determined from tensile tests on standard tensile specimens (Figure 1) of two inch gage length. A typical stress-strain curve for the material is shown in Figure 2.

THE FATIGUE TESTING MACHINES

The fatigue test program was conducted in nine axial-load fatigue machines of frequency range 400-3600 cycles per minute. The testing machines, which are all identical, are a resonant-beam type developed by Lockheed Aircraft Corporation, Marietta, Georgia, having a variable speed drive. For this series of tests, the change between the minimum load and the maximum load was effected by varying the speed and the amount of unbalance of the eccentric rather than by approaching the point of resonance of the system. Figure 3 is a photograph of one bank of the machines; Figures 4 and 5 show a typical machine and the installation of a typical test specimen; Figure 6 is a photograph of the control console for the machines. A description of the fatigue testing machines is given in the Appendix.

DESCRIPTION OF TEST PROGRAM

With the best control of conditions that was possible, 110 identical standard fatigue test sheet specimens were produced from 0.025 inch thick 17-7 PH stainless steel material. Three specimens were used to obtain static load-strain curves; three strain levels, 2.0, 3.5, and 5.0 per cent total strain, were selected for test specimen comparison. The specimens were randomly divided into four groups. The specimens in one group were left unchanged. The specimens in the second group were pre-stretched to 2.0 per cent total strain, in the third group to 3.5 per cent, and the specimens in the fourth group were pre-stretched to 5.0 per cent total strain. The four groups were then final heat treated to Condition RH 950, after which all groups of specimens were fatigue tested in axial load fatigue machines. The S-N curves for the groups were compared to determine the effect of the pre-stretching on the fatigue life of the material.

PREPARATION OF TEST SPECIMENS

For this test program, three 0.025 inch thick 17-7 PH stainless steel sheets, three feet wide and four, five, and ten feet long, were obtained. (The use of only one sheet would have been more desirable, but there was insufficient material in a single sheet to produce the number of specimens required for the test.) The sheets were divided into three inch by eighteen inch blanks, and each blank was numbered and the location of the blank was recorded so that random selection of the specimens could be made at a later time. The sheets were then sheared along the divisions to form sixty specimen blanks from the large sheet, thirty from the second sheet, and twenty from the small sheet.

A standard laboratory fatigue test sheet specimen with a twelve inch radius reduced section was machined from each blank using a fly cutter. (Ten blanks were retained and made into standard coupons.) Figure 1 shows the dimensions to which the fatigue test specimens were machined. To reduce the likelihood of premature failure due to stress raisers, the edges of the specimens were deburred in the reduced section with 180 grit emery paper. The pre-stretching of this type specimen would obviously result in somewhat misleading results regarding the actual relationship between the amount of pre-stretch and the fatigue life, since the pre-stretch was based on the total average strain over a two inch gage length. The varying width of the fatigue specimen over this gage length would result in varying stress and consequently in varying amounts of strain over the cross sections (4). However, the specimen shape was selected for this program on the basis of producing reliable fatigue results and of showing the trend rather than the specific relationship of the pre-stretch to the fatigue life.

(A more ideal specimen for this type test would be one in which a center length of about two inches is straight, with a twelve inch radius tangent to the straight section at each end. This type of specimen was considered for this test but it was felt that obtaining a smooth transition from the radius portion of the specimen to the straight portion would be too difficult without an appropriate tool.)

Standard ASTM laboratory sheet tensile test specimens of two inch gage length were cut from scattered locations in the three sheets for use in establishing the material properties of the specimens after heat treatment. All specimens, both tension and fatigue types, were cut with the major axis along the grain of the sheet. Figure 1 shows the shape of the tensile test specimens.

The specimens were randomly divided by sheets into nine heats for process annealing and heat treatment. This was accomplished by drawing numbers of the specimens from each sheet from a hat to correspond to heat designations drawn from another hat. ("Heat" as used here refers to a grouping into separate lots, not to the heat treatment process itself.)

Tension test specimens were included with the fatigue specimens in the nine heats. Each heat was first vapor degreased using perchloroethylene, and then cleaned using Wyandotte F-1027 alkaline cleaner at 140-160° F. Following the immersion in the alkaline cleaner for fifteen minutes, the specimens were rinsed in running cold water for five minutes and then air dried. The purpose of the degreasing and cleaning was to minimize the formation of scale on the surface of the specimens during the heat treatment, inasmuch as the brittle scale could affect the fatigue life of the specimens.

Following the cleaning, each heat was process annealed in an electrically heated air furnace. (Processing all specimens simultaneously would have reduced the number of variables which might affect the test program, but the laboratory facilities would not accommodate over twenty specimens at one time.) The manufacturer of the material specifies a ten minute treatment at 1750° F.; about eight minutes were required to return the furnace to this temperature following insertion of the specimens, however, so they were left in the furnace for eighteen minutes.

After the process annealing, the fatigue test specimens were pre-stretched to varying amounts as described in the discussion of the test procedure which follows. Each heat was then sub-zero cooled to -100° F. for eight hours and then aged at 950° F. for one hour in accordance with the heat treatment specification of the manufacturer.

Each of the nine heats was prepared in similar manner. The specimens were then assembled into the four test groups which were to be used in the test program.

TEST PROCEDURE

Material Properties Tests.--To determine the material properties of the 17-7 PH stainless steel sheet which was used in this test program, a number of tensile coupon tests were performed in a Riehle 30,000 pound capacity universal testing machine, Figure 7, using a head travel rate of 0.5 inches per minute. A two-inch gage length extensometer and an autographic recorder were used to obtain load-deflection curves from these tests. For the tests, the standard ASTM tensile coupons described in the preceding section were used to determine the material properties of the sheets as received, the properties after process annealing, and the properties of the nine heats following final heat treatment.

Static Tests of Fatigue Test Specimens.--In addition to the tensile coupon tests described above, three of the three inch by eighteen inch fatigue test specimens were statically tested to failure to provide a basis for selection of amounts of pre-stretch after process annealing. These tests were run in the Riehle machine, using the autographic recorder to determine the load-strain curves for the specimens. Figure 8 shows a typical load-strain curve obtained in this manner.

Following the pre-stretching and final heat treatment of the fatigue test specimens, eight more of the specimens were statically tested to provide an indication of the effects of the several amounts of pre-stretch on the static properties following final heat treatment. Table 2 is a tabulation of the results of these tests.

Pre-Stretching of Fatigue Test Specimens.--On the basis of the load-strain curves obtained from the static tests of the three fatigue test specimens in the process annealed condition, described above and shown in Figure 8, it was concluded that total average strains of 2.0, 3.5, and 5.0 per cent over a two inch gage length were reasonable values to which to pre-stretch the fatigue test specimens for the test program. These strains were considered to be significantly beyond the yield point of the material and yet they fell below the peak of the load-strain curve.

Following the 1750° F. process annealing of the specimens in nine heats, a random division of ninety-two of the specimens into four test groups was made. This was done by drawing the numbers of the specimens in each heat from a hat, one at a time, and assigning the specimen of that number to each succeeding group in turn. Specimens from the ten foot sheet in the first heat were divided in this manner first, then specimens from the five foot sheet, then from the four foot sheet. The next heat was similarly divided, beginning with the next group where the preceding heat left off. The remaining specimens were placed in the first group to be used in various ways as the test program might dictate.

The first group was not pre-stretched. Each specimen in the other three groups was placed in turn in the Riehle universal testing machine, utilizing three inch wide grips with ball-and-socket alignment. The two inch gage length extensometer was attached across the minimum section, and the autographic recorder was engaged. The specimen was then loaded at a head travel rate of 0.50 inch per minute. When the total strain from the zero load point reached the desired value as indicated by the recorder, loading was discontinued and the specimen was returned to its heat for final heat treatment.

Fatigue Tests.--The process annealed, pre-stretched, final heat treated specimens were fatigue tested in axial load fatigue test machines. On the basis of past experience in the fatigue testing of specimens, which indicates that stress levels from 40 to 67 per cent of the ultimate tensile strength of the material will generally yield useful data for fatigue curves, five arbitrary maximum stress levels were selected for the tests: 120, 100, 90, 80, and 70 KSI. Four specimens from each group were randomly selected for the three highest stress levels, five for the 80 KSI level, and six for the 70 KSI level in order to give more data for determining the fatigue life as the endurance limit was approached. For all specimen fatigue tests, a stress ratio R of 0.1

was used, i.e., the load was varied cyclically about a mean tension load from the maximum load to one tenth of the maximum load. This procedure is standard practice at the Lockheed Aircraft Corporation for evaluating tension fatigue specimens, although other standards exist which are in more widespread use.

The loads to which each specimen was to be subjected were determined on the basis of the minimum cross sectional area of the specimen after final heat treatment, as measured to the third significant figure with micrometers.

Nine fatigue machines were used for the tests. Since more specimens were available for the lower stress level tests, the eccentrics of the machines were first set for the lower level tests and these tests were conducted before higher load level tests were run in order to gain familiarity with the machines. The highest stress level tests were completed next, and then the intermediate levels were completed. On the basis of partial test data, it was concluded that half of the 80 KSI specimens should be run at 140 KSI to provide information at the higher stress level. Also, one specimen from each group from the 90 and 100 KSI levels was statically tested to provide a comparison of the material properties of each group after pre-stretching and final heat treatment. These changes reduced the number of specimens available for the 80, 90, and 100 KSI level tests.

Each machine was automatically stopped by failure of the specimen, as described in the appendix. An upper limit of five million cycles was arbitrarily taken, on the basis of available data on the fatigue properties of steels (5). If the specimen remained unbroken after this number of cycles, it was removed from the machine and the next specimen was installed.

RESULTS

Tensile Coupon Tests.--Results of the static tests of the tensile coupons are presented in Table 1. The tests indicated the following average properties for the material as received from the vendor:

Ultimate Tensile Strength	135,500 psi
0.2 Per Cent Yield Strength	46,600 psi
Per Cent Elongation in 2 Inches	30-35

Results were consistent between sheets, suggesting that all sheets were from the same heat.

Average material properties following process annealing were:

Ultimate Tensile Strength	153,000 psi
0.2 Per Cent Yield Strength	57,900 psi
Per Cent Elongation in 2 Inches	7.9

The properties were consistent between sheets and also between heats, with the exception of the first two heats, in which partial transformation to the martensitic stage may have occurred to some extent since these heats were processed several days before the remaining heats. In Table 1, these two heats are not shown.

Following final heat treatment, the remaining tensile specimens were tested. Average results were:

Ultimate Tensile Strength	237,200 psi
0.2 Per Cent Yield Strength	214,000 psi
Per Cent Elongation in 2 Inches	4.8

The properties were consistent between sheets and between heats, indicating a consistency of the heat treatment process. The results are in good agreement with typical values of strength and elongation quoted by the manufacturer (6).

On the basis of these results, it is felt that all specimens could be considered to have equal material properties.

Statically Tested Fatigue Specimens.--Table 2 presents the results of static tests of fatigue test specimens which were tested in the process annealed condition to provide a basis for the selection of the amount of pre-stretch to use in the test program. Figure 8 shows a typical load-strain curve for the heat treated fatigue specimens. The effects of pre-stretching on the static properties of the specimens after final heat treatment are shown in Table 2 and in Figure 9. Although the data pertaining to the effects of pre-stretch on the static properties were felt to be questionable because of the scatter between specimens and the small number of specimens tested, a trend of lowered mechanical properties with increase of pre-stretch up to a point, followed by an increase in properties as the amount of pre-stretch was further increased, seems to be indicated. Another work (7) on PH 15-7 Mo steel, which was also felt to be based on insufficient data to form a definite conclusion, seems to verify this trend. This is suggested as an area in which an extension to higher strains might warrant additional study.

<u>Fatigue Tests</u>.--Figures 10-13 show the test failure points for all specimens which were tested, with the exception of those which were obviously inconsistent. The failures were analyzed by the "least-of-n" statistical method (8). The resulting curves appear to justify the use of this method for the purpose of this test program. A separate S-N curve was constructed for each group of specimens; the groups were also compared by plotting the several curves on a single graph. In Figures 10-13, the S-N curves are based on the "least-of-n" method. The S-N curves for the individual groups are compared in Figure 14. From the comparison, it appears that the effect of pre-stretching is to slightly increase the fatigue life at intermediate stress levels. A greater amount of pre-stretching appears to have a more beneficial effect than a lesser amount.

Pre-stretching the material is felt to have a number of effects on its fatigue life. One possible effect is to induce minute cracks in the material, reducing its fatigue life considerably. This phenomenon has been found to occur in the pre-stretching of 7075-T6 material (9), but apparently did not enter into the test of 17-7 PH sheet which is described in this study. Another possible effect is that the total life of the specimen can be considered by Miner's cumulative damage theory to have been reduced by the single application of load which produced the pre-stretch. This effect would reduce the fatigue life of more highly strained specimens by a greater amount than the specimens with lower amounts of pre-stretch. On the other hand, the cold working experienced by the material in the pre-stretching should increase the yield strength and consequently increase the fatigue life at a given stress level. Too, pre-stretching could affect the metallurgical processes resulting from the heat treatment cycle, having an adverse or a beneficial effect on the fatigue life.

On the basis of the static tensile properties shown in Table 2 and in Figure 9, it is felt that the effect of pre-stretching in the case of the 17-7 PH stainless steel sheet tested in this program was to reduce the amount of precipitation hardening experienced by the material. Cold working was apparently of less significance than the effects of metallurgical changes, as indicated by the reduced tensile strength and increased elongation for the specimens pre-stretched to 2.0 and 3.5 per cent total strain; however, it is possible that effects of cold working were more significant for the 5.0 per cent pre-stretched specimens. Miner's cumulative damage effects are felt to have been negated by the final heat treatment after the pre-stretching.

Another effect of pre-stretching is to induce residual stresses at areas of local stress concentration. From tests of specimens containing notches, it has been conclusively shown that pre-stretching can effect residual compressive stresses at the point of stress concentration, significantly increasing the fatigue life of the specimen. If an unnotched specimen is considered to contain local irregularities or flaws creating inner stress concentrations, it could be theorized that pre-stretching would have the same type of effect on these local regions of stress that it would on an externally induced notch. Final heat treatment after loading the specimen would tend to relieve the residual stresses induced by the pre-stretching, but the net result should still be beneficial.

For the program covered in this study, it is felt that the inducing of residual stresses was the primary factor in increasing the fatigue life of the specimens, and that the effects due to residual stresses were offset partially by metallurgical changes caused by the pre-stretching.

CONCLUSIONS

1. Pre-stretching of 17-7 PH stainless steel sheet appears to slightly increase the fatigue life of the basic material at intermediate stress levels by creating residual stresses in the material at local irregularities or flaws.

2. A fatigue test specimen specifically shaped to provide comparative fatigue data on the basis of the amount of pre-stretch would be a useful laboratory tool for this type of investigation. Such a specimen is described on page 8.

3. The use of a "least-of-n" statistical method for a program in which a trend is desired seems justified in that it appears to reliably indicate the trend and yet does not require a complex analysis of the data. For more precise evaluation, a more extensive program and a more thorough statistical approach is felt to be needed.

TABLE 1

MECHANICAL PROPERTIES OF TEST MATERIALS

These data were obtained from tests of standard tensile test specimens having 0.025 x 0.50 inch minimum section. The specimens were taken from three sheets.

Condition	Total Number of Specimens		Ultimate Tensile Strength Psi	0.2 Per Cent Yield Stress	Per Cent Elongation in Two Inches
As Received	6	Minimum	130,000	44,800	30-35
		Maximum	141,500	47,200	(Approx.)
		Average	135,500	46,600	
Process Annealed 1750° F.	5	Minimum	147,500	55,800	7.2
		Maximum	154,000	61,000	8.4
		Average	153,000	57,900	7.9
Final Heat Treated RH 950	24	Minimum	232,500	210,000	4.2
		Maximum	242,500	220,000	5.3
		Average	237,200	214,000	4.8

TABLE 2

MATERIAL PROPERTIES OF STATICALLY TESTED FATIGUE SPECIMENS

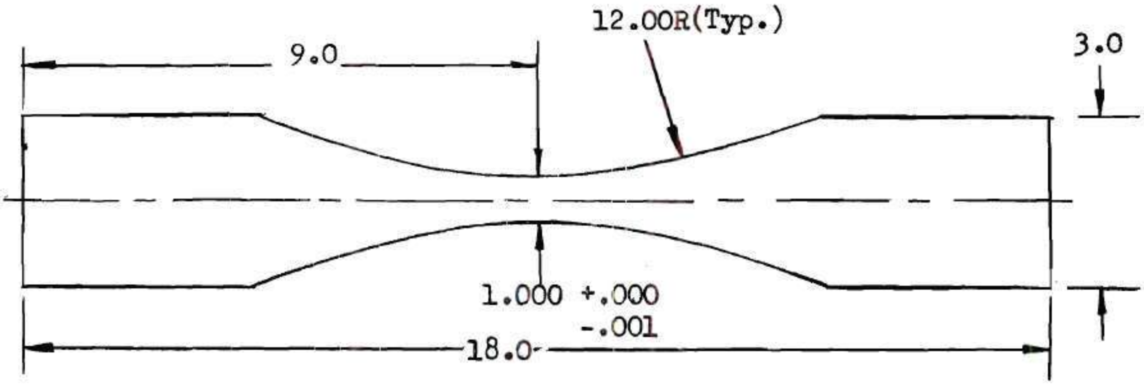
These data were based on static tests of 0.025 x 1.00 inch minimum section fatigue test specimens. See Figure 1 for specimen configuration.

Condition	Group	Specimen Number	Pre-Stretch	Ultimate Tensile Strength Psi	0.2 Per Cent Yield Strength Psi	Per Cent Elongation in Two Inches
Process Annealed	-	73	None	154,100	54,100	7.2
		18		153,400	60,700	6.0
		103		151,100	-	-
			Average	152,900	57,400	6.6
Final Heat Treated RH 950	1	101A	None	243,900	-	-
		74		223,200	196,400	4.2
		31		222,200	174,600	4.3
		59		239,100	214,300	4.4
		102		230,400	211,500	4.1
		78		232,400	210,900	4.3
			Average	231,800	201,500	4.3
Final Heat Treated RH 950	2	26	2.0 Per Cent	222,400	-	-
		2		230,600	219,000	3.1
			Average	226,500	219,000	3.1

TABLE 2

MATERIAL PROPERTIES OF STATICALLY TESTED FATIGUE SPECIMENS (Continued)

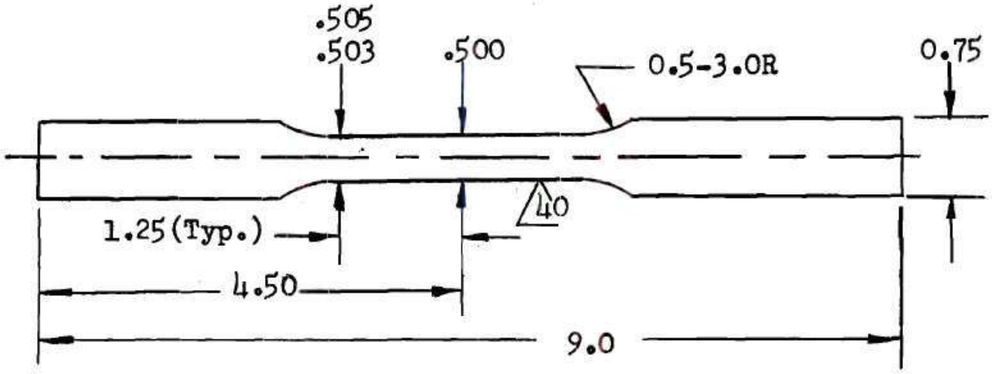
Condition	Group	Specimen Number	Pre-Stretch	Ultimate Tensile Strength Psi	0.2 Per Cent Yield Strength Psi	Per Cent Elongation in Two Inches
Final Heat Treated RH 950	3	11A	3.5 Per Cent	224,000	200,000	4.1
		67		220,400	198,000	4.5
			Average	222,200	199,000	4.3
Final Heat Treated	4	70C	5.0 Per Cent	216,600	198,400	4.3
		3		234,500	228,900	2.1
			Average	225,600	213,700	3.2



Fatigue Test Specimen

0.025 Inch Thick Sheet

Symmetrical about Centerline



Tensile Coupon--Two Inch Gage Length

0.025 Inch Thick Sheet

Symmetrical about Centerline

Figure 1. Test Specimen Configuration

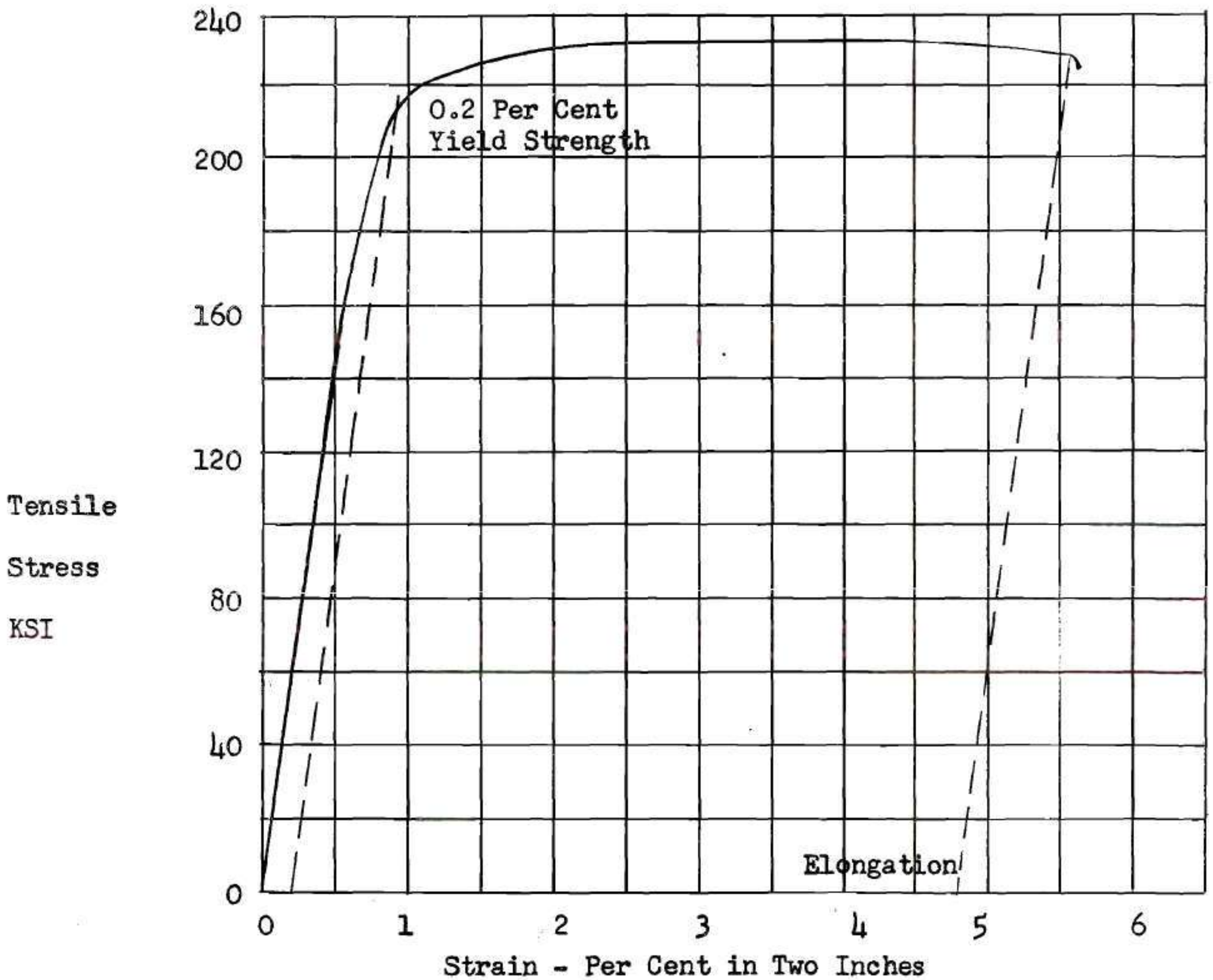


Figure 2. Stress-Strain Curve for 0.025 17-7 PH Sheet in Condition RH 950

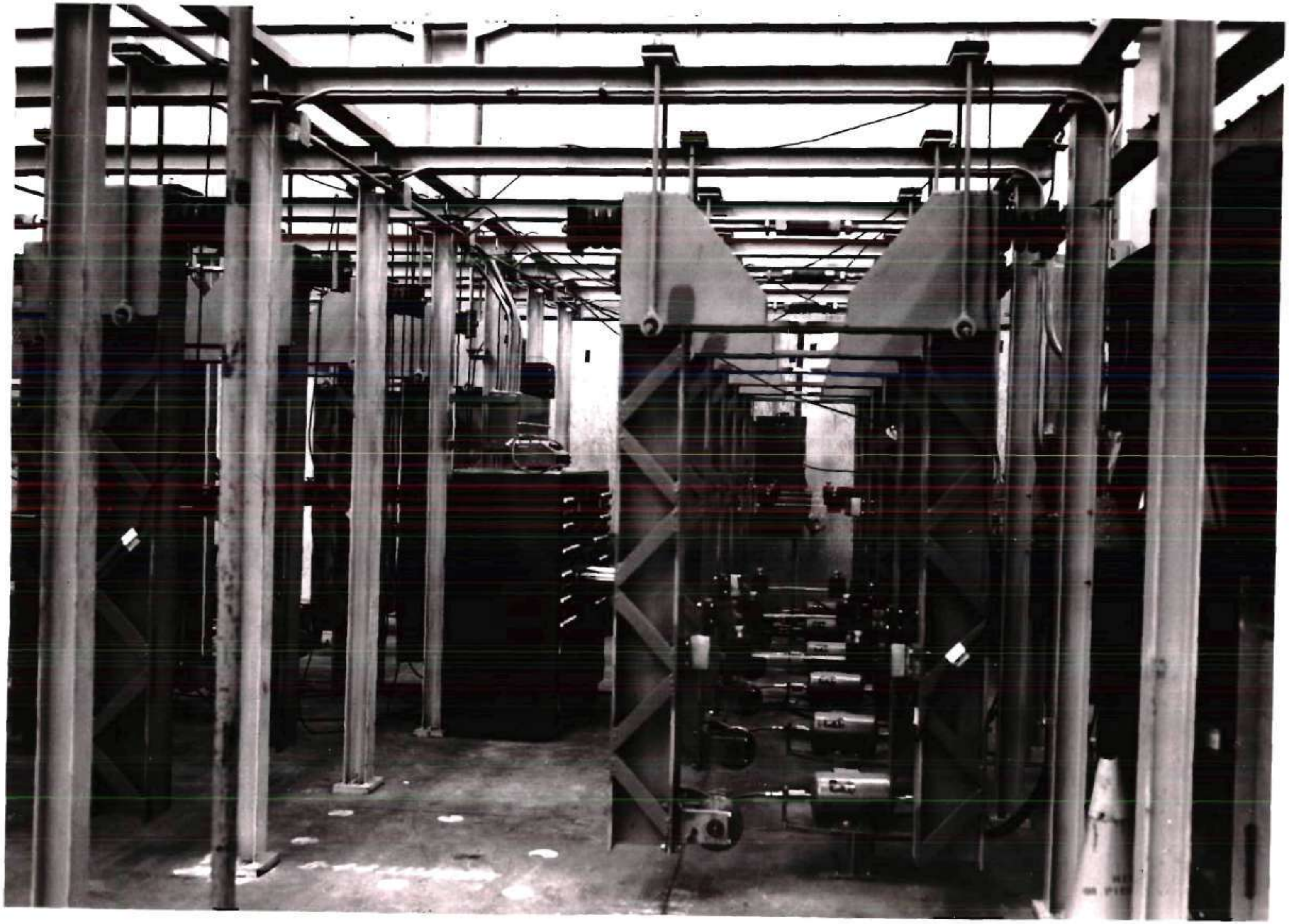


Figure 3. Axial Load Fatigue Test Machines and Console

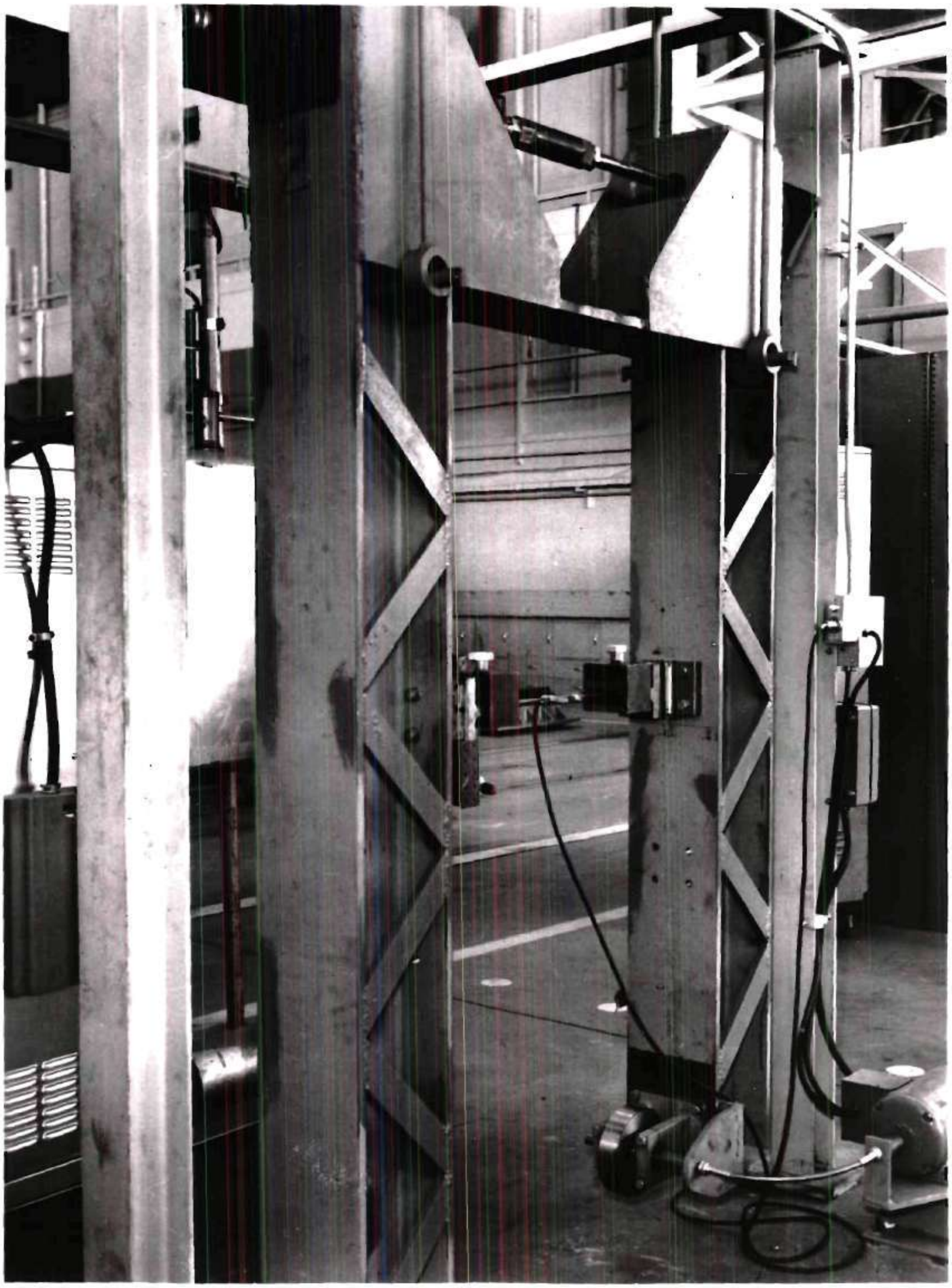


Figure 4. Typical Fatigue Test Machine

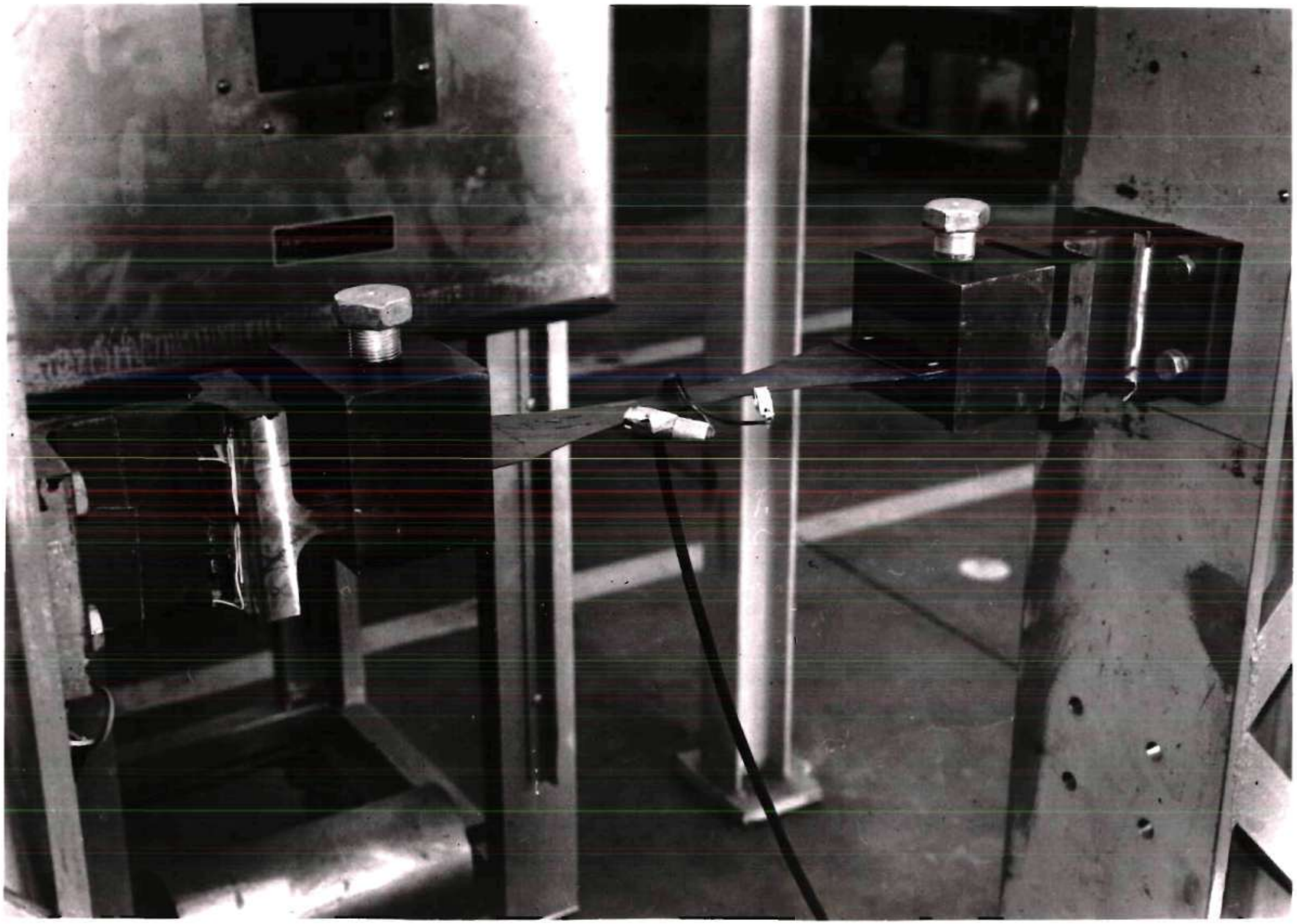


Figure 5. Installation of Typical Specimen in Fatigue Test Machine

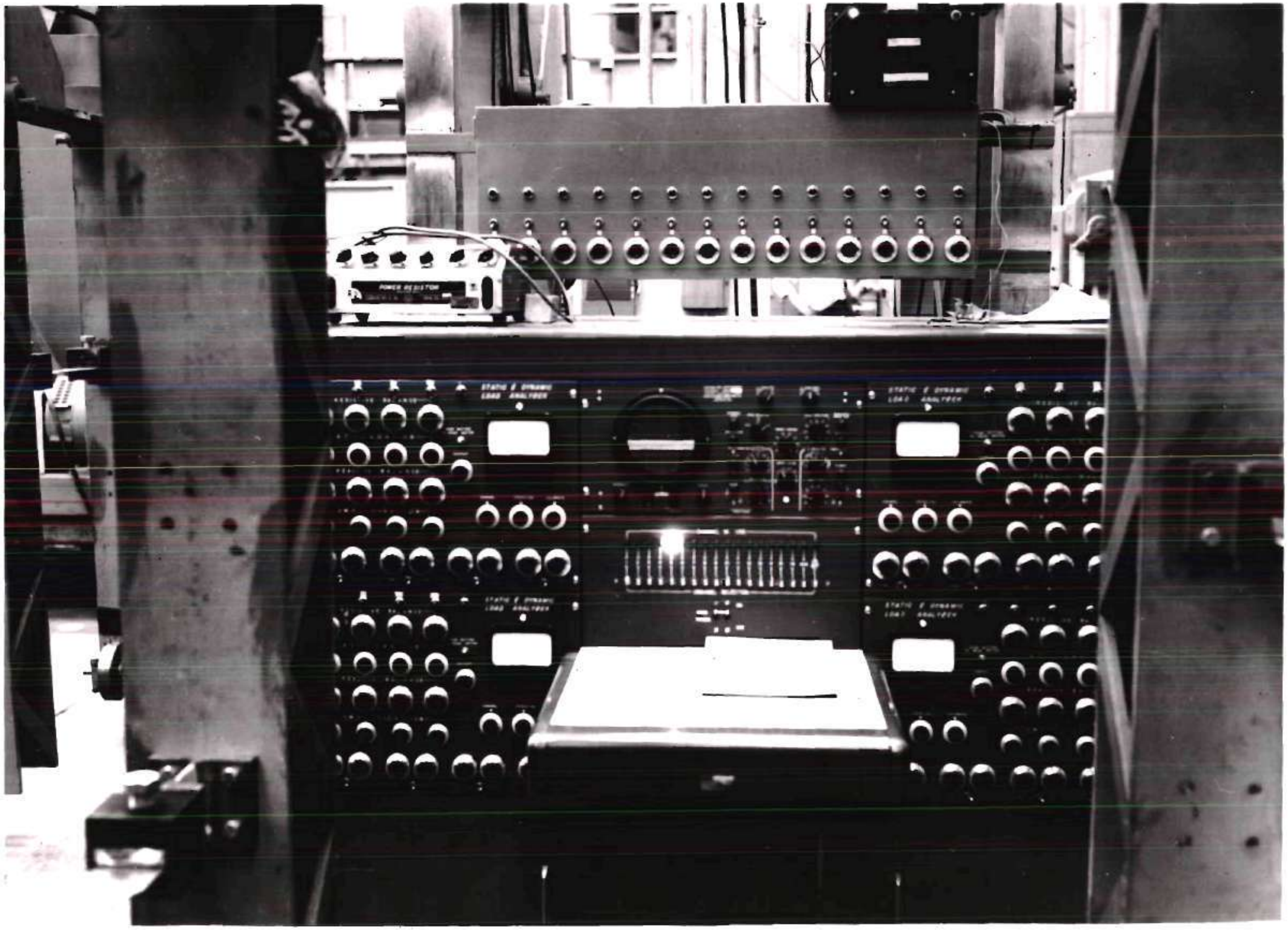


Figure 6. Control Console for Operation of Fatigue Test

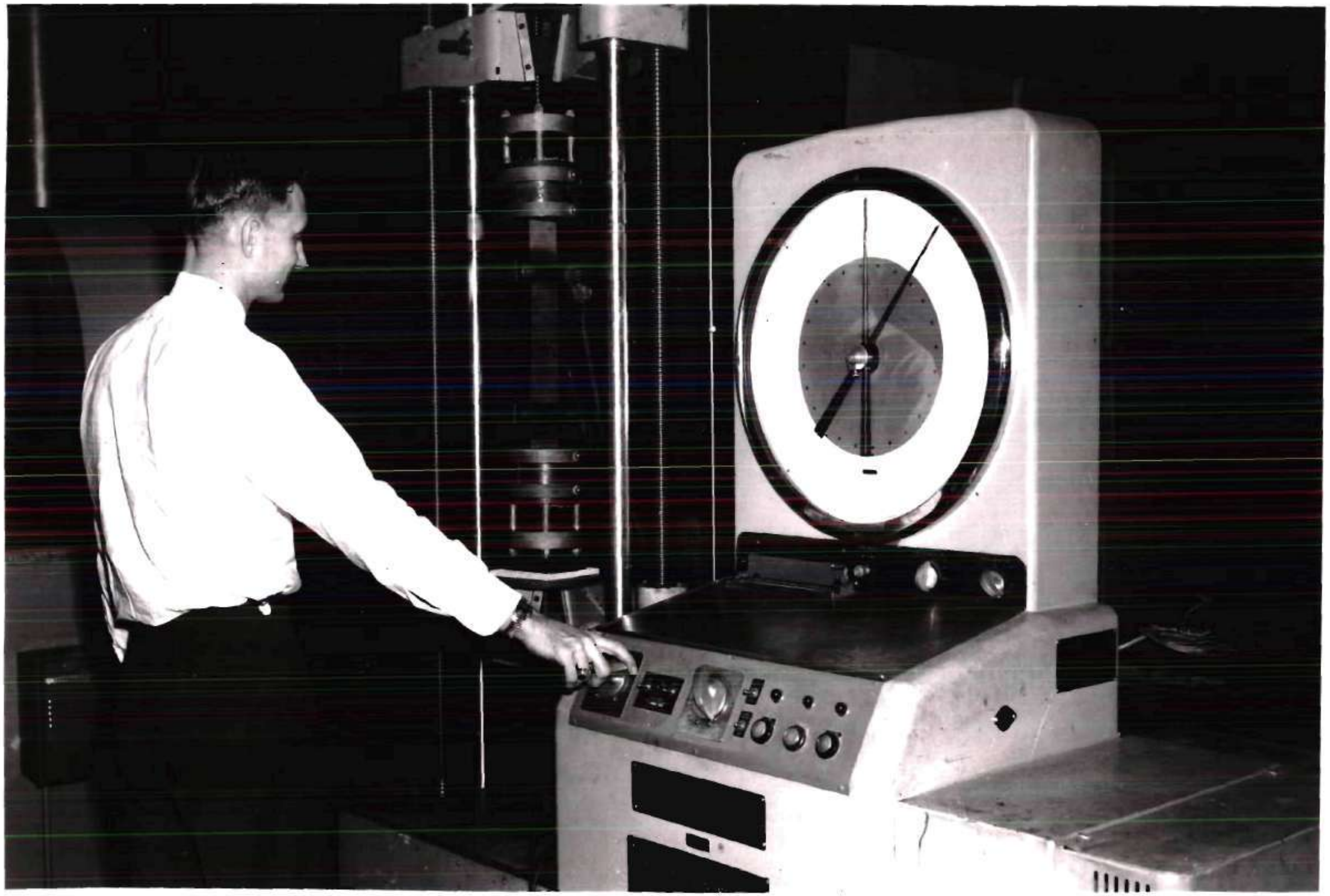


Figure 7. Riehle Universal Testing Machine Used in Determining Mechanical Properties and in Pre-Stretching Fatigue Test Specimens

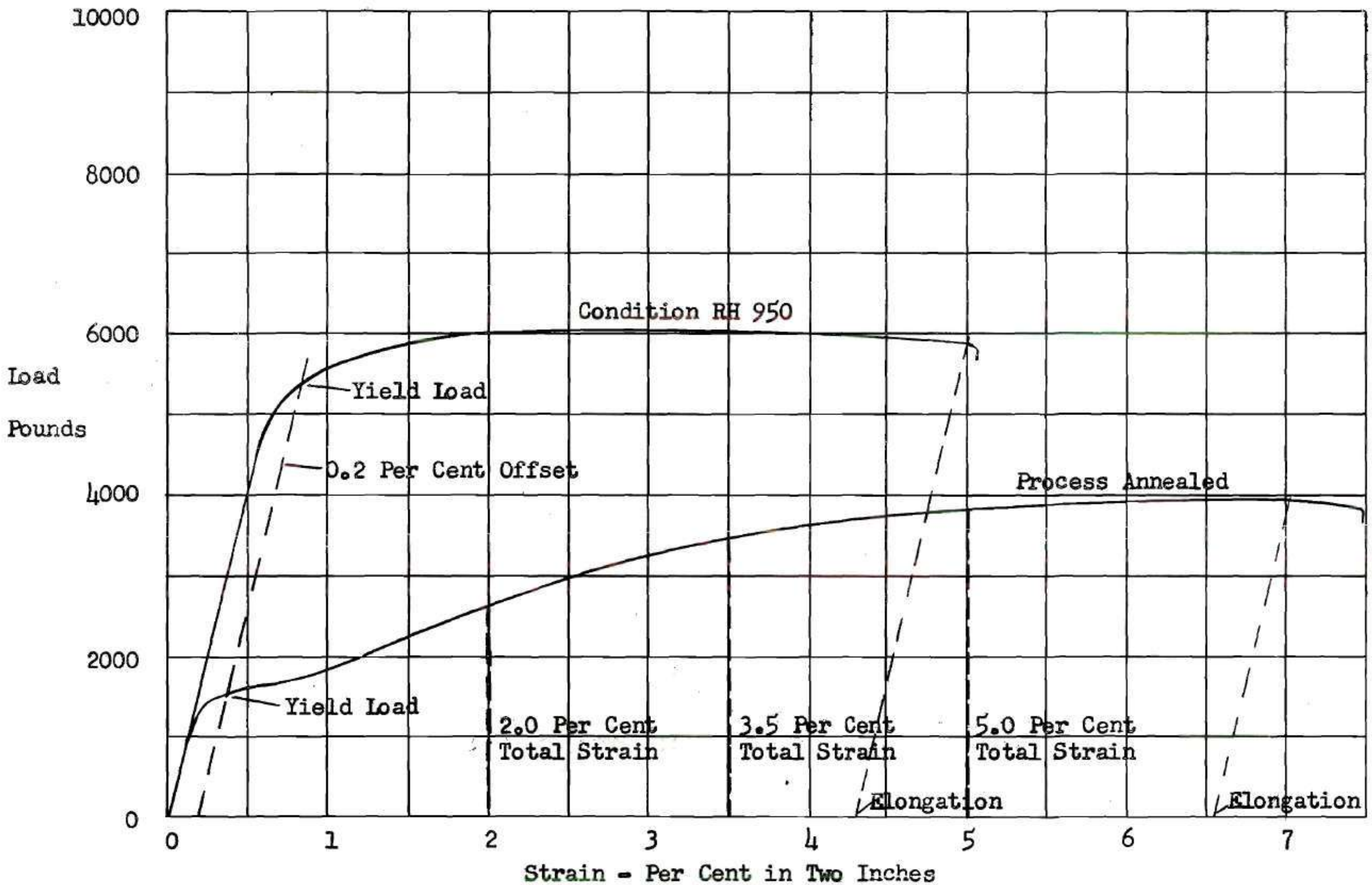


Figure 8. Load-Strain Curves for 0.025 17-7 PH Fatigue Test Specimens

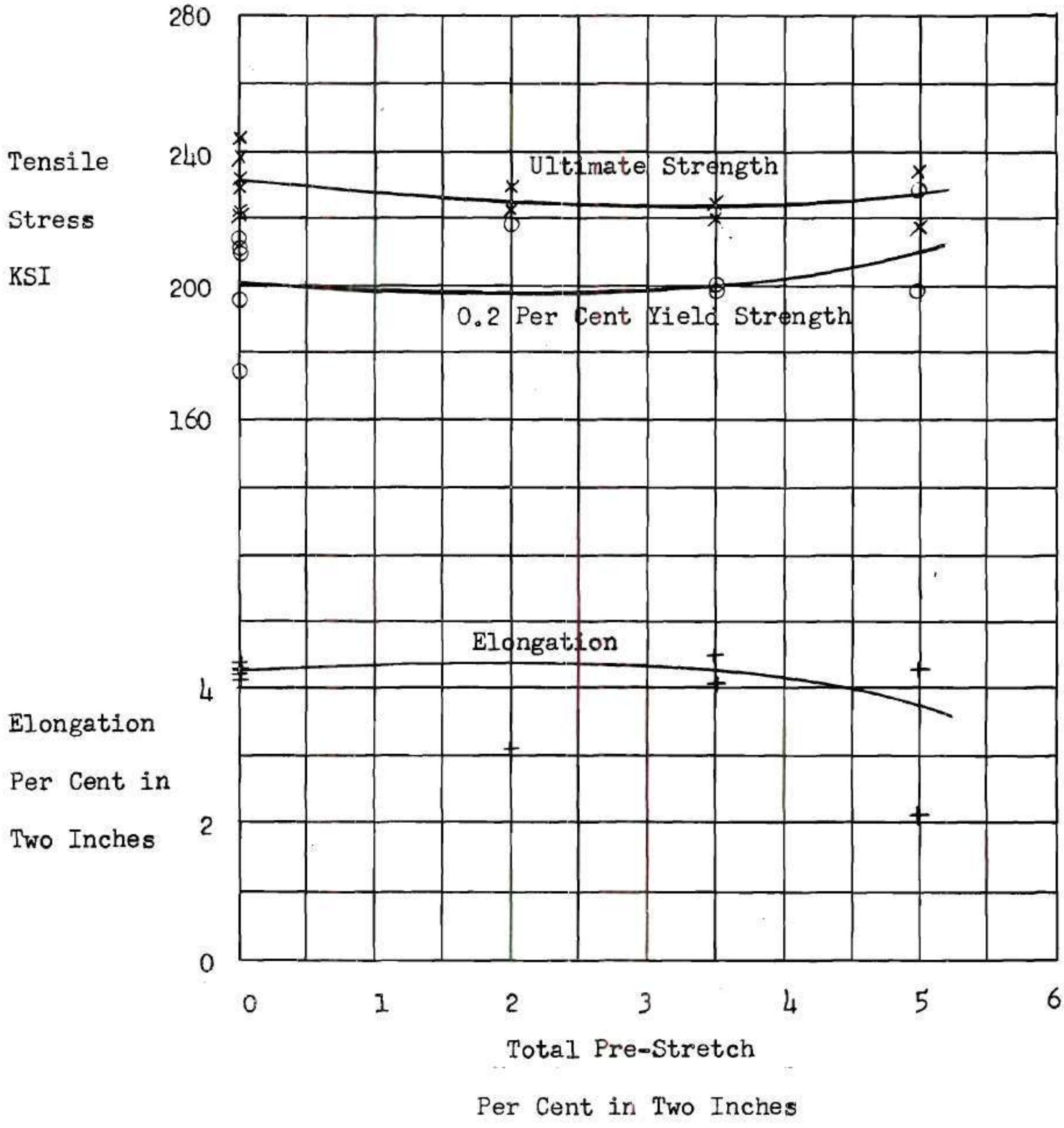


Figure 9. Effects of Pre-Stretching After Process Annealing on the Mechanical Properties of 17-7 PH Stainless Steel Sheet Specimens

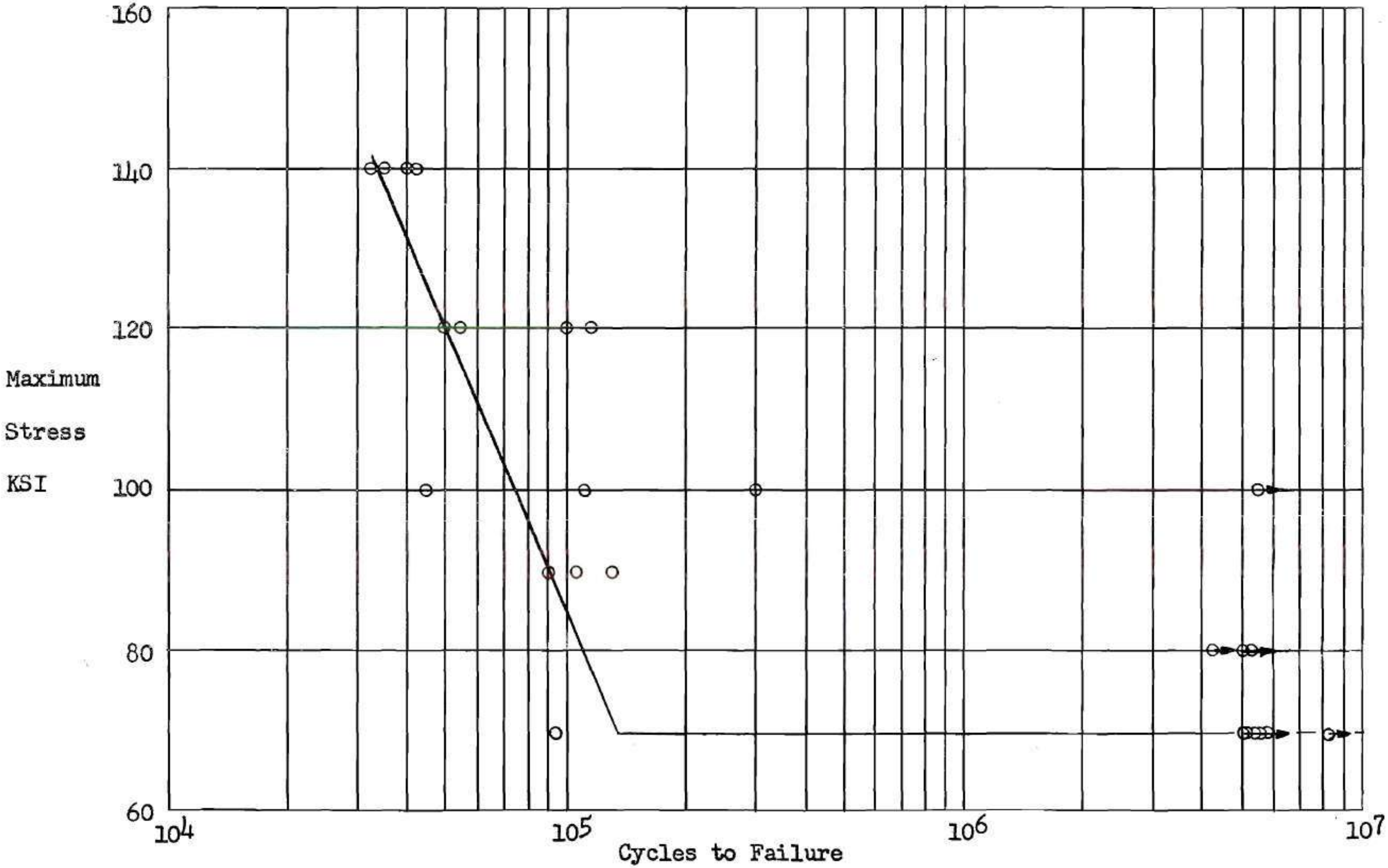


Figure 10. S-N Curve for Non-Pre-Stretched 0.025

17-7 PH Stainless Steel Sheet

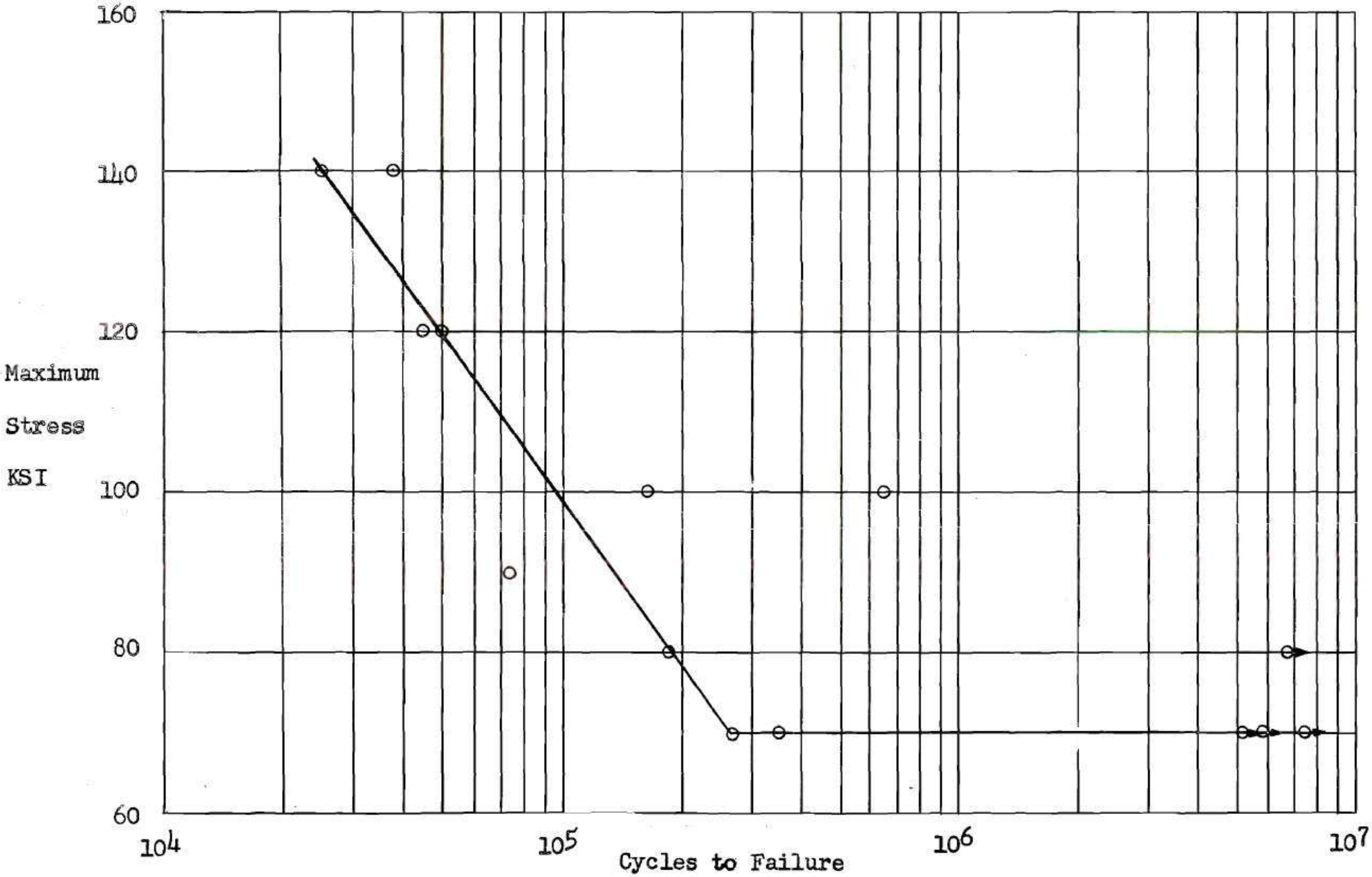


Figure 11. S-N Curve for 0.025 17-7 PH Stainless Steel Sheet Pre-Stretched 2.0 Per Cent After Process Annealing

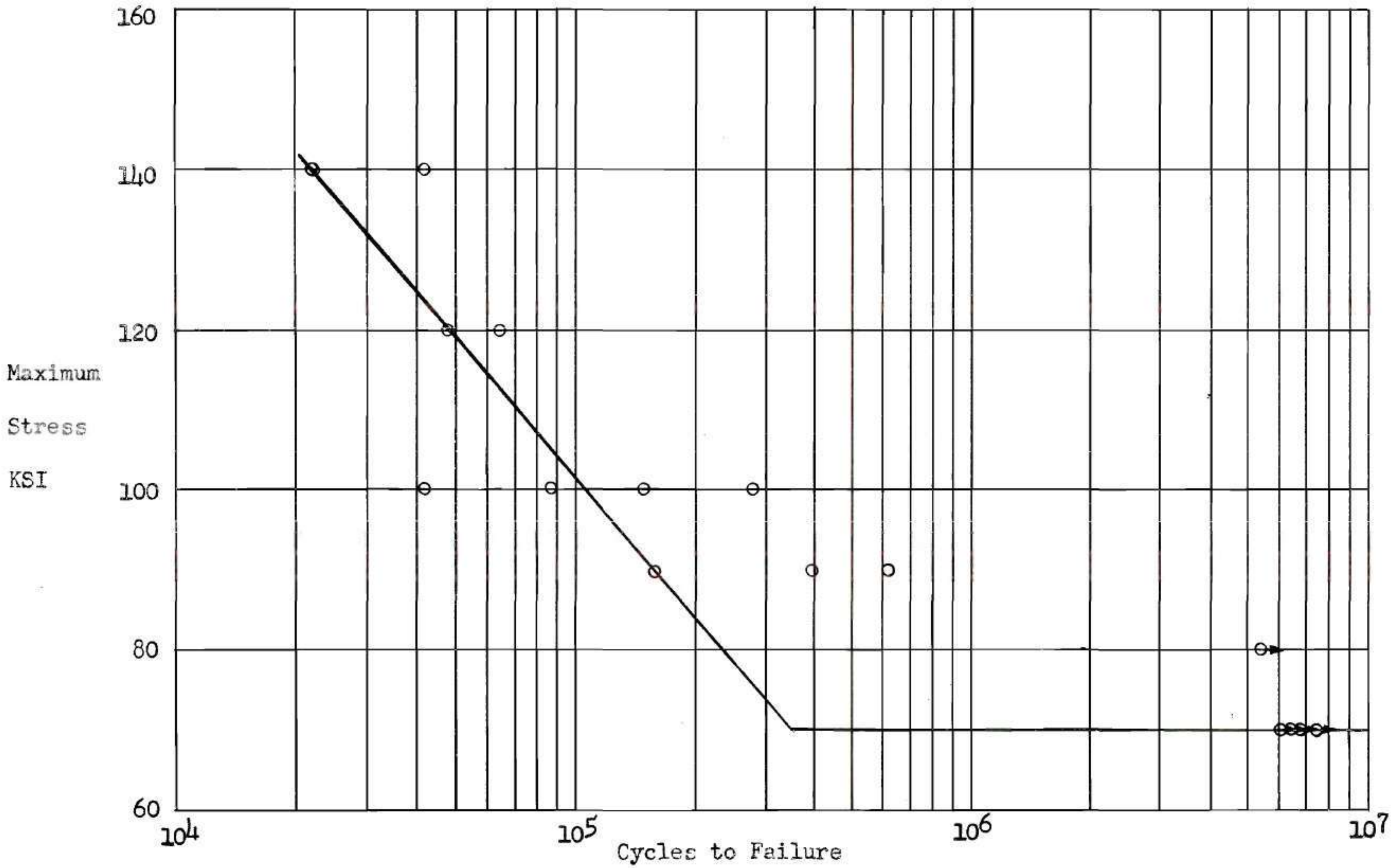


Figure 12. S-N Curve for 0.025 17-7 PH Stainless Steel Sheet

Pre-Stretched 3.5 Per Cent After Process Annealing

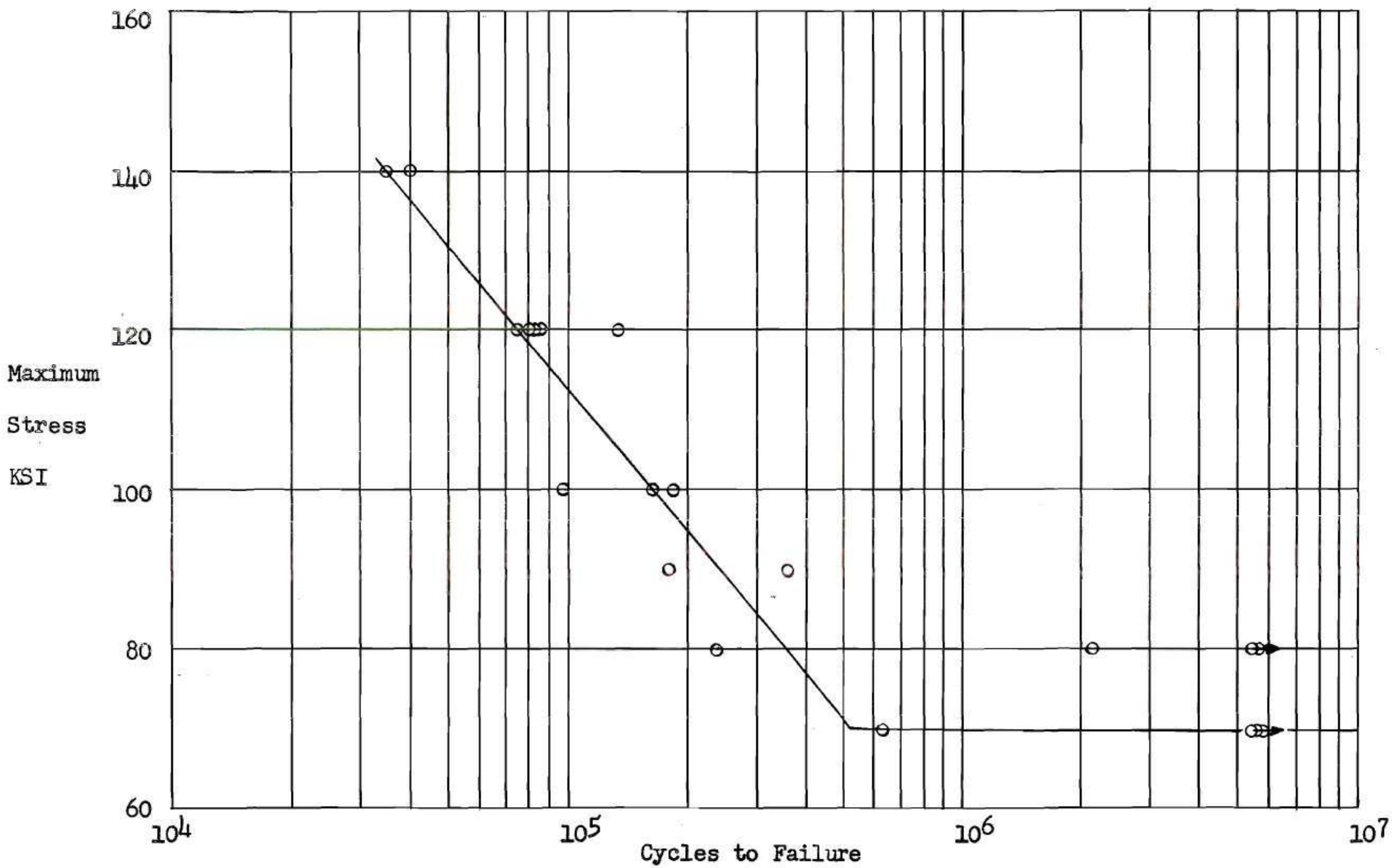


Figure 13. S-N Curves for 0.025 17-7 PH Stainless Steel Sheet Pre-Stretched 5.0 Per Cent After Process Annealing

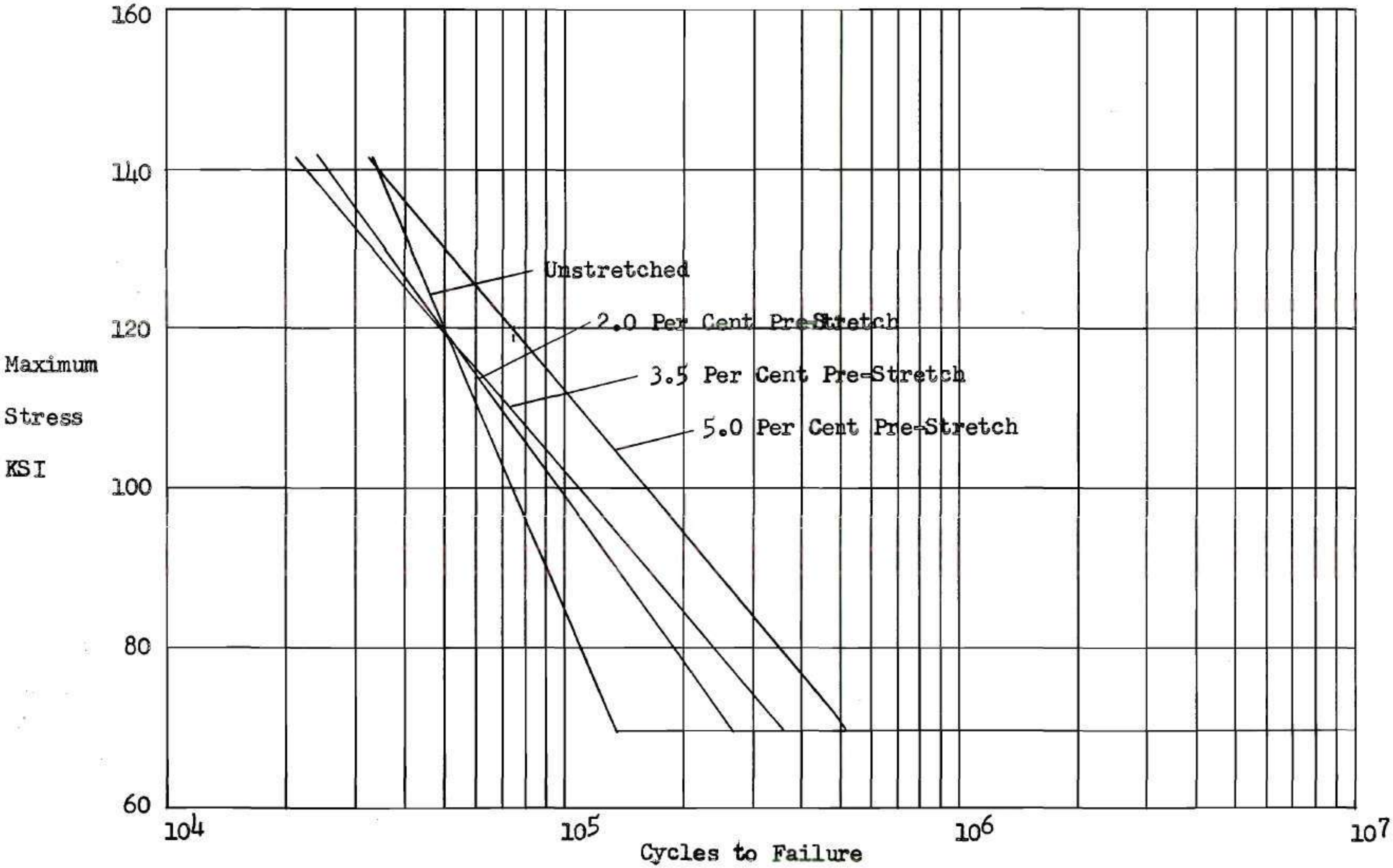


Figure 14. Effects of Pre-Stretching on the Fatigue Life of 0.025 17-7 PH Stainless Steel Sheet

APPENDIX

DESCRIPTION OF AXIAL LOAD FATIGUE MACHINE

Nine identical fatigue machines were used for the fatigue tests. A description of the machines follows:

The axial load fatigue test machine developed by the Structural Research Laboratory of the Georgia Division of Lockheed Aircraft Corporation is basically a resonant beam fatigue machine having a 10,000 pound maximum mean load, 15,000 pound maximum alternating load. Figure 4 is a photograph of a typical machine. The specimen is attached to two load beams mounted vertically, both of which swing freely from pivot points at their upper ends. Thus, where the normal type fatigue machine has one fixed end and one resonant beam, the Lockheed machine utilizes two beams whose action is essentially independent of the support. The beams act much like a tuning fork in producing the loads on the specimen.

The specimen grips are strain gaged to form a load transducer; the transducer has been calibrated by static loading in a universal testing machine. On one load beam is an eccentric mass mounted on a rotating shaft, which is connected to a variable speed electric motor by a flexible coupling. The force produced by the rotation of the eccentric is used to excite the beam system. To set up a test, a value of load midway between the desired maximum and minimum loads is applied as a pre-load by adjusting springs connected between the beams above the pivot point. The variable speed motor is then started and is gradually increased in speed until the resonating beams stress the specimen to the desired load level as indicated by the electrical signal from the load transducer.

The specimen is electrically insulated from the frame of the test machine by micarta sheets placed between the specimen and the grips, and a twenty-eight volt electrical system operating a cutoff solenoid is wired such that the specimen is part of the electrical circuit. Figure 5 shows a typical installation of a test specimen and the electrical clips for the cutoff system. Failure of the specimen breaks the circuit, automatically stopping the machine. The number of cycles of load which have been applied at the time of the failure is indicated by a mechanical counter which records the number of revolutions of the shaft of the motor which drives the eccentric.

The nine fatigue test machines are all operated from one control console, which also controls five other machines which were not used in these tests. Figure 6 shows the console, which consists of a bank of helipots for each machine and an oscilloscope which is common to the fourteen channels. The circuit for each machine is balanced against the transducer for that machine by adjusting a helipot until the oscilloscope records a minimum signal when a voltage corresponding to a specific load is impressed upon the circuit by an externally connected laboratory potentiometer. This adjustment calibrates the circuit such that one unit count of the reading helipot corresponds to a particular value of load in the specimen (five to fifteen pounds, depending on the specific transducer being used). Other helipots are provided for zero adjustment and capacitive balance of the circuit. To determine the maximum or minimum load being applied to the specimen, the oscilloscope is set by the resistive helipot to read a minimum signal at one peak; the setting of the helipot then indicates the load corresponding to that peak.

A desirable feature of the variable speed machine is that specific loads can be attained simply by varying the speed of rotation of the eccentric mass. For low loads, the beams need not be tuned in the neighborhood of resonance, but rather the disturbing force of the eccentric can be used to drive the system. For optimum use at low loads, the eccentric is offset a minimum amount and the machine is run at a high speed in order to produce the desired load and simultaneously expedite the test. For higher loads, approaching the capacity of the machine, it is necessary to tune the beams by the addition of weights to the system in order to produce the necessary loads, inasmuch as the force produced by the eccentric itself is insufficient.

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