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DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

PHYSICAL TESTING OF MECHANICALLY SPLICED REINFORCING BAR USING A SLEEVE WITH METAL FILLER PROCESS

67-68

July 1967

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

July 1967

Interim Report
M & R No. 636328

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

PHYSICAL TESTING OF MECHANICALLY
SPLICED REINFORCING BAR USING A
SLEEVE WITH METAL FILLER PROCESS

ERIC F. NORDLIN
Principal Investigator

PAUL G. JONAS
Co-Principal Investigator

DENNIS L. SCHAROSCH
Co-Investigator

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Messrs. G. A. Hood, A. P. Bezzone, and H. L. Payne of the Bridge Department of the State of California for their cooperation in reviewing the data received from these tests.

The author also wishes to thank Mr. J. R. Stoker, supervisor of the Structural Materials Section's Physical Testing Laboratory, Mr. L. S. Hannibal, supervisor of the Machine and Fabrication shops, and J. E. Barton, supervisor of the Electronic and Computer Data Acquisition Section. Without the support of these people along with their immediate subordinates, the objectives of this program would not have been met.

This is the first of two reports to be issued under project title, "Welding Procedures for High Strength Reinforcing Steels". The work was done under the 1966-67 Work Program HPR D-4-28 in cooperation with the United States Department of Transportation, Federal Highway Administration, Bureau of Public Roads. It should be recognized that the, "Opinions, findings, and conclusions expressed in this publication are those of the authors and are not necessarily those of the Bureau of Public Roads".

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KEY WORDS: Reinforcing steel, bars, joining, couplings, splicing, physical tests.

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I. INTRODUCTION

The purpose of this study was to physically test, in air, a sleeve with metal filler mechanical reinforcing bar butt splice. Tests were conducted on two sizes (14s and 18s) and three grades A-408 intermediate, A-432, and A-431 reinforcing steel bar hereafter called rebar. The splice characteristics tested for were:

1. Stress-strain diagram.
2. Yield strength (based on .5% offset)
3. Percent elongation at failure.
4. Ultimate strength.
5. Cyclic tension to compression, elevated cyclic tension, elevated cyclic compression hysteresis (load-slip) diagrams and limit diagrams.

The study resulted in two classifications of testing:

1. Tensile
2. Cyclic

The data was recovered by two different techniques:

1. Tensile tests were handled by the million pound testing machine at the University of California at Berkeley using a 16 inch gauge length extensometer reading into the machine load-elongation chart recorder.
2. Cyclic tests were handled by the 440,000 pound Baldwin testing machine at the Materials and Research Department, California Division of Highways, located in Sacramento, using a relative slip recording instrument reading into an electronic data acquisition system. An IBM 360 digital computer was programmed to accept the raw data, compute, and print out load-slip data for engineering analysis.

It should be noted that the word "slip" as used in the following report refers to the relative movement of the plane on the rebar to its original position at the face of the sleeve.

The word "stress" refers to the nominal stress in the rebar.

The word "scan" refers to the data acquisition system responding to a record-data command given by the testing engineer. When a scan command is given, the data acquisition system reads, records, and prints-out all instrument values associated with the test specimen (see Appendix E).

One kip = 1,000 LBF (pound force)

II. CONCLUSION

The following conclusions are drawn from physically testing in air of a sleeve with metal filler mechanical reinforcing bar butt splice.

1. Distortion in the stress-strain diagram representing the mechanical rebar butt splice tested is the result of the rebar slipping in the sleeve.

2. Significant rebar slipping occurs on loading the splice in tension and increases as a log function of the cycle (slip increases but at a decreasing rate with cycle).

3. With proper controls, rebar slipping on splices in complete compression can be held to acceptable values.

4. Utilizing manufacturer's recommended splicing procedures resulted in splices containing filler material with one, two, or all of the following:

    a. premature solidification voids

    b. interface (shrinkage) voids

    c. sponge shrinkage

III. RECOMMENDATIONS

We recommend that the sleeve with metal filler process for mechanically butt splicing reinforcing steel bar be accepted for use in any area where complete compressive loads are insured.

We recommend that there be careful consideration of the data prior to accepting splices of this type for tension applications. The results of this in air study show significant slip occurring with increased slipping as a log function of cyclic tensile loadings. We believe that the slip as well as the slip rate at the fatigue loads employed in this report are substantial. The design engineer, after careful consideration of the slip data given herein, may, however, conclude that because of low tensile stresses in the rebar the slip will be small or negligible and may approve the use of this splicing process.

We recommend that controls be properly executed to insure optimum performance of the splice. The most basic recommended controls are:

1. Axial alignment of the reinforcing steel and sleeve.
2. Proper preheating and loose mill scale removal.
3. Proper gapping between the bars.
4. Appropriate sleeve.
5. An acceptable fill of the filler material.

IV. INFORMATION

The sleeve with metal filler process employed in this study for mechanically butt splicing rebars is shown in Figure 1. This process involves a powdered metallic compound which reacts exothermically, locking the internal serrations of the sleeve with the deformation pattern of the rebar. The filler material is a copper alloy that has a relatively low melting temperature. Prior to starting the reaction, asbestos rope is packed around the ends of the sleeve to prevent filler material from escaping. The reaction takes place in a graphite crucible placed directly over a ½ inch diameter hole in the sleeve. Once the spark gun starts the reaction, it takes approximately 60 seconds before the joining process is completed. Crucible and clamping fixtures can be removed almost immediately after the reaction has ended.

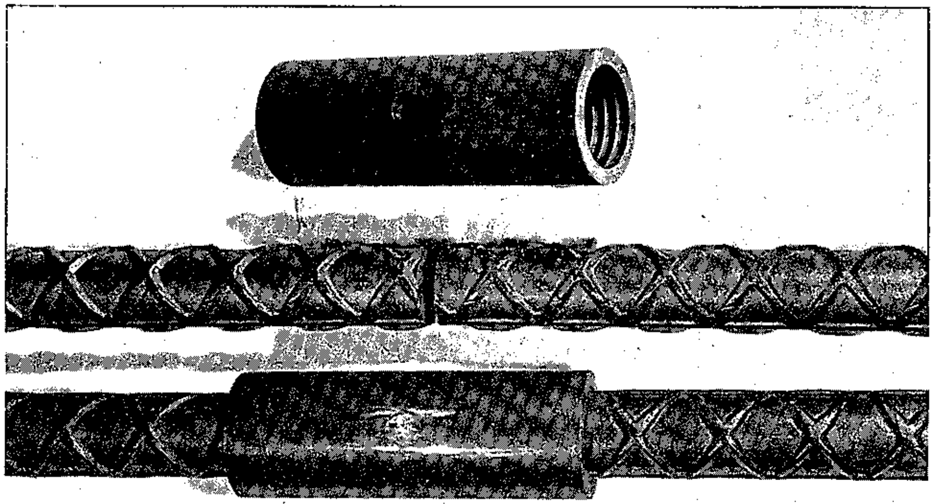


FIGURE 1 SLEEVE WITH METAL FILLER BUTT SPLICE

Splicing of the specimens for the tensile tests were conducted in both the horizontal and vertical positions. A small angle iron support was constructed and used to insure reasonable alignment of the rebars in both splicing position.

The splicing of the specimens for the fatigue tests was conducted with a substantially improved jig; one which insured perfect axial alignment of the spliced specimens. All fatigue specimens were spliced in the horizontal position as shown in Figure 2.

All specimens were spliced by the West Coast representative of Erico Products, Inc. at the Materials and Research Department, California Division of Highways, Sacramento, and witnessed by both the research weldor and the research engineer assigned to the program. The process is patented by Erico Products Inc. under the trade name of Cadweld.

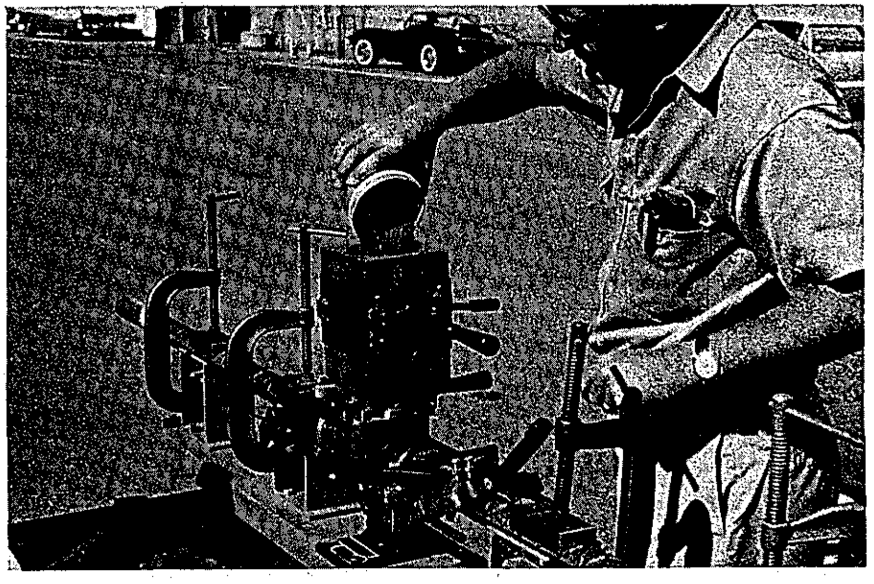


FIGURE 2 SPECIMEN PREPARATION

V. TEST PROCEDURE

A. Tensile Testing

The complete tensile testing of the mechanical rebar splices was performed in the following manner. Specimens were placed in the tensile testing machine followed by attaching a sixteen inch gage length extensometer across the spliced area. Unspliced specimens, called control bars, identically matching the spliced specimens as to size, grade, and heat, were also tested. The tensile testing machine was equipped with a load-elongation chart recorder into which was electrically fed machine load and extensometer output.

The tensile testing program of the mechanically butt spliced rebar consisted of ten groups. The number of spliced specimens varied from one specimen as in Group 7 and Group 8 to eight specimens as in Group 22 (see Table 1)

TENSILE TEST SPECIMEN GROUP

Group	No. Tested	Sleeve Length	Spliced Position	Steel Fabricator	Size	Grade
3	6	7"	Horizontal	Columbia	14s	A-408 Inter.
6	2	9"	Vertical	Pacific States Stl.	18s	A-408 Inter.
7	1	9"	Horizontal	Columbia	18s	A-408 Inter.
8	1	9"	Horizontal	Bethlehem	18s	A-408 Inter.
11	2	8"	Horizontal	Bethlehem	14s	A-431
14	3	12"	Vertical	Judson	18s	A-431
18	6	8"	Horizontal	Columbia	14s	A-432
22	8	10" & 12"	Horizontal	Columbia	18s	A-432
23	3	12"	Vertical	Judson	18s	A-432
24	2	12"	Vertical	Bethlehem	18s	A-432

TABLE 1

Data recovered from the tensile testing of the specimens included:

1. Continuous load-elongation record throughout specimen yielding.

2. Ultimate strength.

3. Percent elongation at failure.

B. Cyclic Testing

The cyclic testing of the mechanically butt spliced rebar was performed in the following manner. The procedure for cycling the specimens was categorized into three phases:

Phase 1. Tension to compression cycling

Phase 2. Elevated tensile cycling

Phase 3. Elevated compressive cycling.

Each phase consisted of one each of the following specimens:

14s, A-408 intermediate grade

18s, A-408 intermediate grade

14s, A-432

18s, A-432

The individual specimens of Phase 1 were tested from tension to compression for 99 cycles. The stress levels are noted:

Phase 1. Specimen #01. 14s, A-432 ± 40,000 psi

#02. 18s, A-432 ± 25,000 psi

#03. 18s, A-408 inter ± 25,000 psi

#04. 14s, A-408 inter ± 26,700 psi

The individual specimens of Phase 2 were tested at elevated tension stress for 400 cycles. The stress levels are noted:

Phase 2. Specimen #05. 14s, A-408 inter +13,300 psi to +26,700 psi

#06. 18s, A-408 inter +12,500 psi to +25,000 psi

#07. 18s, A-432 +12,500 psi to +25,000 psi

#08. 14s, A-432 +13,300 psi to +26,700 psi

The individual specimens of Phase 3 were tested at elevated compressive stress for 400 cycles. The stress levels are noted:

Phase 3. Specimen #09. 14s, A-432 -13,300 psi to -26,700 psi

#10. 18s, A-432 -12,500 psi to -25,000 psi

#11. 18s, A-408 inter -12,500 psi to -25,000 psi

#12. 14s, A-408 inter -13,300 psi to -26,700 psi

Data recovered from cycling the specimens consisted of monitoring slip as a function of load increments and cycle.

VI. DATA ANALYSIS

A. Tensile Testing

The data obtained from the tensile testing machine was grouped into like size, like grade, and like manufacturers, and plotted together with the control bars on a stress-strain diagram. Deviations within the groups are readily seen with this type of presentation (see Appendix A). Note the spliced specimens are numbered whereas the unspliced control bars associated with a particular group are lettered with a subscript to distinguish the difference.

All spliced specimens show a marked deviation in stress-strain pattern when compared to the unspliced control bars. The plot of the spliced specimens as seen from the diagram show two, sometimes three, abrupt changes in strain rate. This has raised concern as to what the cause may be. Since a number of various manufacturers' bars of different deformation patterns were used, we do not believe that rebar deformation patterns play a significant part in causing the distorted stress-strain pattern.

An important point to bring up is the increased rigidity the spliced specimens show at the lower stress levels when compared to unspliced control bars (see Appendix A). Once this characteristic is accepted, it is possible to extrapolate the initial slope of a spliced specimen upward and compare it to the actual curve of that specimen at elevated loads, the difference of which is contended to be the over-all slip of that bar within the sleeve. The proof of this is seen in Figure 3. This figure has tensile specimen #41 replotted from the machine record, and the data representing the total slip of two fatigue specimens each subtracted from specimen #41. Note that the line extrapolated upward with the initial slope of specimen #41 passes through the data representing specimen #41 with slip eliminated. The two fatigue specimens are identified as 04F and 05F indicating the fourth and fifth fatigue specimens tested. These three specimens data can be compared as they represent specimens of similar size bar, similar grade bar, similar manufacture, and similar sleeve lengths.

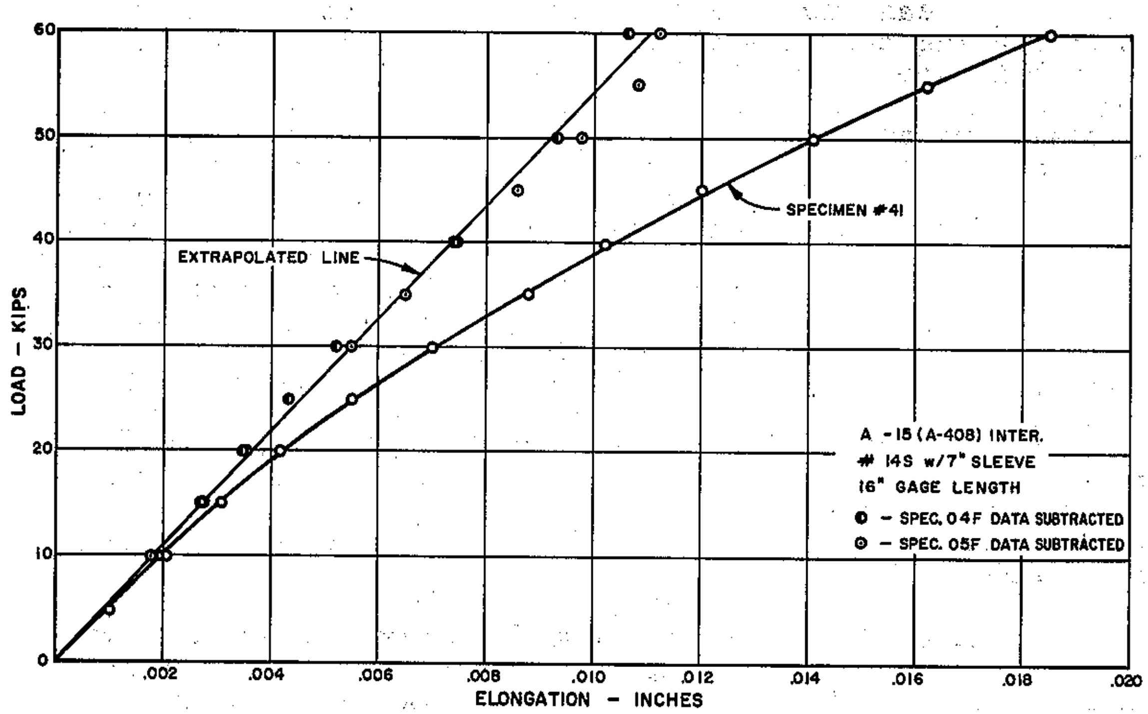


FIGURE 3 SLIP ANALYSIS

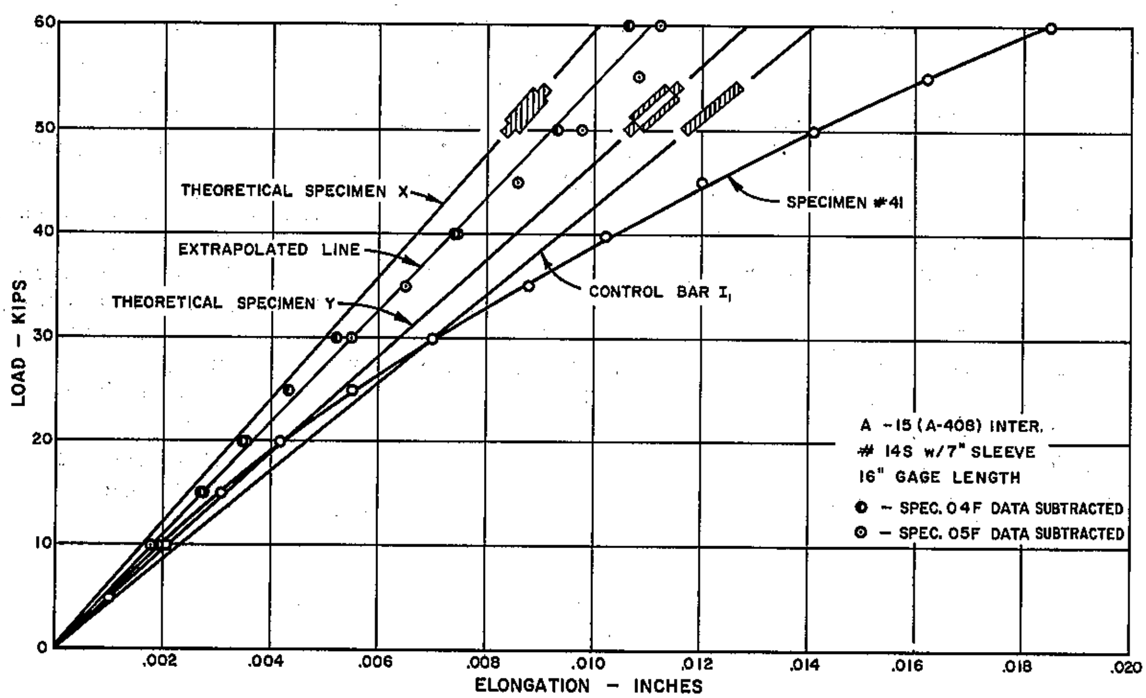


FIGURE 4 COMPARISON ANALYSIS

We can carry this analysis one step further by incorporating theoretical curves of possible analogous specimens (see Figure 4). The three analogous specimens proposed for comparison are: (1) Theoretical specimen X representing an identical external geometry as specimen #41 with the cross section assumed to be solid steel within the 16" gage length. (2) Theoretical specimen Y representing the same external geometry as before except the imaginary bar within the sleeve is removed. (3) The third analogous specimen represents the unspliced control bar of the group. The comparison curves were generated by summing up the elongations of the given sections at convenient loads and based on the assumption that Young's modulus equals 30 x 10^6 psi. It is now possible to see how the spliced specimen compares, particularly if slip can be eliminated. This analysis, we believe, is sufficient to justify the conclusion that the distorted stress-strain diagrams of mechanically butt spliced rebar is the result of the rebar slipping within the sleeve.

Although there has been distorted stress-strain patterns for the various spliced specimens, the minimum requirements by ASTM for ultimate strengths has been achieved. Every spliced specimen was tested with not one falling below the minimum ultimate strength. The ultimate strength of each specimen with its respective control bars along with yield points based on .5% offset and percent elongations are tabulated in Table 2.

In analyzing the data in Table 2, particularly percent elongation, one must be aware of the procedure used. The percent elongation was determined by comparing the increased gage length after failure with that of the 16" gage length under no load prior to testing. The significant point to keep in mind is that the increased gage length recorded after failure consists of three things, (1) permanent strain of the two lengths of rebar extending out each end of the sleeve to the gage marks, (2) permanent strain of the sleeve, and (3) the slip of the two rebars within the sleeve. Because over-all joint performance was desired, no attempt was made to measure slip during the tensile program of specimen testing, and therefore no corrections are available to tabulate percent elongation after failure excluding slip. The fact that the values of percent elongation after failure are low, including slip, supports the statement that the rigidity of the rebar-sleeve joint is increased.

SPECIMEN TENSILE TEST RESULTS

Bar Size	Group No.	A15	A432	A431	Bar No.	Spliced Rebar Yield	Spliced Rebar Ult.	Spliced Rebar % Elong.	Bar Letter	Control Rebar Yield	Control Rebar Ult.	Control Rebar % Elong.	Remarks
14s	3	X			38	48 ksi	81 ksi	10	I_1	46 kis	76 ksi	19	Bar failure 21" out.
14s	3	X			39	49	84	19	I_2	43	75	21	Bar failure 2" out.
14s	3	X			40	44	76	9					Bar failure 6" out.
14s	3	X			41	45	80	9					Bar failure 11" out.
14s	3	X			68	44	79						Pulled out of coupler.
14s	3	X			69	46	80	11					Bar failure 14" out.
18s	6	X			56	41	72	13	B_1	46	78	18	Failed in coupler.
18s	6	X			67	41	72	14	B_2	47	78	22	Sheared out of coupler.
18s	7	X			29	44	79	11	K	45	80	14	Bar failure 6" out.
18s	8	X			28	41	71	12	J	42	73	17	Deformations sheared.
14s	11			X	70	55	120	3	P	84	124	6	Broke in middle of coupler.
14s	11			X	71	63	119	3					Broke in middle of coupler.
18s	14			X	51	60	101	4	N_1	59	100	8	Bar failure 20" out.
18s	14			X	52	56	101	4	N_2	59	102	11	Bar failure 19" out.
18s	14			X	53	58	101	7					Sheared out of coupler.
14s	18		X		42	64	111	13	L_1	60	107	13	Bar failure 14" out.
14s	18		X		43	64	112	13	L_2	60	107	13	Bar failure 2" out.
14s	18		X		44	60	108	8					Bar failure 6" out.
14s	18		X		45	59	107	4					Bar failure 12" out.
14s	18		X		46	60	107	6					Bar failure 16" out.
14s	18		X		47	60	107	6					Bar failure 17" out.
18s	22		X		30	55	100	5	M_1	60	102	3	Bar failure 6" out.
18s	22		X		31	57	101	6	M_2	60	107	6	Bar failure 8" out.
18s	22		X		32	60	109	5					Bar failure 21" out.
18s	22		X		33	57	109	5					Bar failure 22" out.
18s	22		X		34	61	102	2					Bar failure 19" out.
18s	22		X		35	65	114	3					Bar failure 16" out.
18s	22		X		36	60	101	3					Bar failure 10" out.
18s	22		X		37	60	100	3					Bar failure 8" out.
18s	23		X		48	57	94	6	O_1	60	95	12	Bar failure 10" out.
18s	23		X		49	59	97	5	O_2	61	94	13	Bar failure 4" out.
18s	23		X		50	57	94	6					Bar failure 16" out.
18s	24		X		54	54	135	2	U	65	96	11	Bar failure 18" out.
18s	24		X		55	61	96	4					Bar failure 22" out.

Yield Points Based on .5% Offset.

TABLE 2

The size 18s, A-431 grade control bars did not meet the minimum ASTM yield strength and therefore the comparative data from the spliced tensile specimens using the size 18s, A-431 grade rebar are inconclusive. All other specimens sizes 14s and 18s of grades A-408 inter. and A-432 plus the size 14s, A-431 grade were spliced with bars whose control bars met the minimum yield strength, % elongation, and ultimate strengths as specified by ASTM.

In group #22 there are eight specimens of which the first four, specimens number 30, 31, 32 & 33 were spliced with 10" long sleeves and the last four, specimens numbers 34, 35, 36, & 37 were spliced with 12" long sleeves.

This concludes the data analysis of the tensile testing program of the mechanical splice.

B. Fatigue Testing

The data obtained from the fatigue testing of the mechanically butt spliced rebar was tabulated with slip as a function of load and cycle. Appendix B contains the first and last cycle computer print-out record scans for each fatigue specimen. The loads were selected for the convenience of the testing machine operator in the stress range desired. Instrumentation is described in Appendix E.

A scan (reading, recording, and printing) by the data acquisition system was taken at convenient loads throughout each cycle with particular emphasis to obtain maximum and minimum load readings of the cycle. The two methods of plotting the data took the form of (1) hysteresis diagrams and (2) limit diagrams (see Appendix C).

The loops on the hysteresis diagram represent the slip as a function of load continuously plotted during a given cycle.

The limit diagram shows the slip plotted at each consecutive cycle for a given load. A positive slope indicates a continuing trend of the rebar slipping apart. Conversely, a negative slope indicates a continuing trend of the rebar slipping together. Zero slope indicates no significant trend to increase or decrease slipping from an established slip.

To read the specimen identification noted in the title box of each fatigue specimen graph, one needs only to remember three things. The first group of numbers and letter represents the order in which the specimen was tested, e.g., 6F indicates the 6th fatigue specimen tested. The second group indicates size, e.g., 14s or 18s. The third group indicates the grade, e.g., A-408G reads A-408 intermediate grade.

Example: 8F - 14s A-432G reads the 8th fatigue specimen which was a size 14s rebar of a grade A-432.

In reading the fatigue specimen graphs, zero slip (0) represents the relative position of the sleeve and the rebar prior to applying any load. (Represents the initial cast geometry.) All movements (slips) are plotted relative to this initial zero point. The instrumentation used during the test measured slip at each end of the sleeve independently. Figure 5 and 6 shows the instrument in place on a specimen. To obtain the total slip of a given sleeve, the slip of the top must be summed with the slip of the bottom. The sleeve top and the sleeve bottom are relative to the position the sleeve took while in the testing machine. All data plotted along with the radiographs are identified with either top or bottom noted. Although the instrument on the specimen was measuring two significant parameters, namely slip plus normal elongation of the rebar within the sleeve end and a point of contact of the instrument on the rebar, the computer was programmed to subtract the normal elongation of this gage length at the load the data was taken, resulting in data representing absolute slip. Three linear variable differential transformers (LVDT's) were positioned 120° apart at each end of the sleeve. The data from the top three were averaged to give the representative movement (slip) of that side. The bottom data were handled the same as the top.

Data from the first four fatigue specimens are plotted in Appendix C-1. These specimens were subjected to equivalent tension to compression loads resulting in the most severe test of the entire fatigue series. This is supported by the limit diagrams of the first four specimens (note the large slopes). Slip was substantially more on the first four specimens even after 99 cycles than the slip of any of the remaining eight specimens after 400 cycles. The hysteresis diagrams of the first four specimens also show, after a few cycles, the lack of ability of the specimens to support large loads until an appreciable slip has occurred.

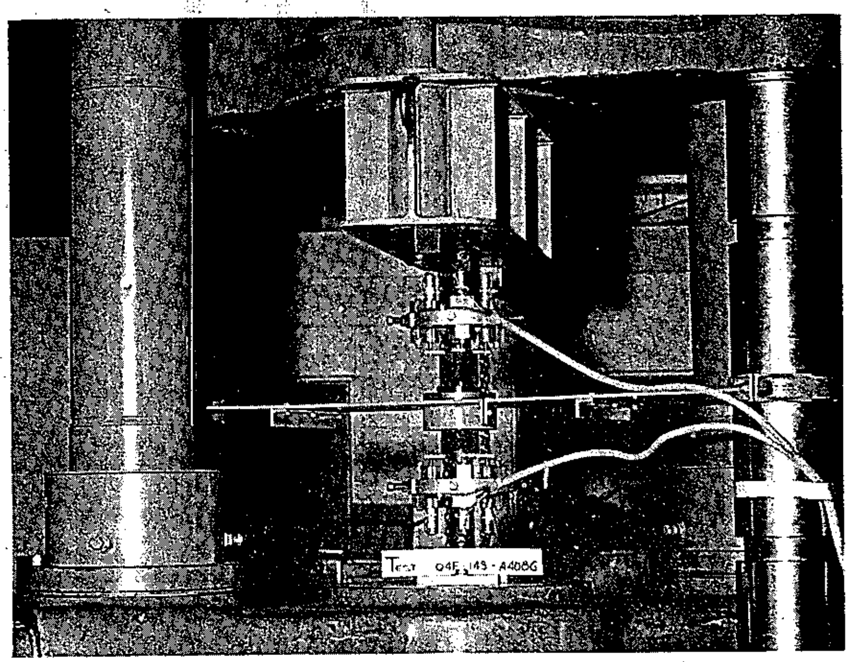


FIGURE 5 FATIGUE SET-UP

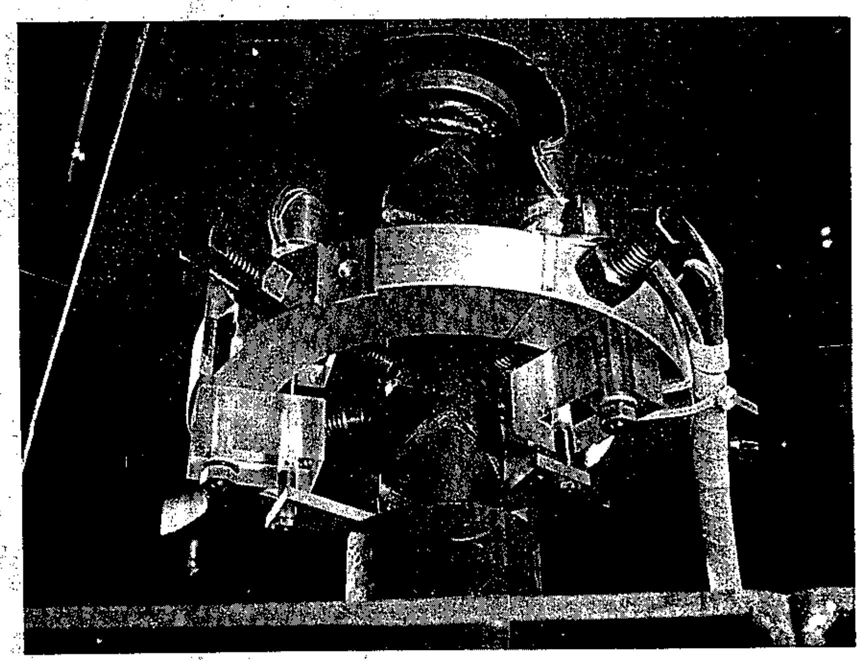


FIGURE 6 SLIP INSTRUMENT

For Example:

The top of specimen 2F-18s-A432G hysteresis loop indicates a slip of .001" to support a tensile load of 40,000 pounds on the first cycle loading. After 99 cycles of 25,000 psi tension-compression stressing, a slip of .0095" is required to support that same load.

Slips in this phase of cyclic testing approached .015" out per side as witnessed from the computer print-outs and diagrams.

A minor problem confronted the test of fatigue specimen #01F. The problem was fatiguing of the pointers riding on the sleeve and attached to the (LVDT) system. The fatiguing of the points was a long-term occurrence (spread out over the entire fatigue test of specimen #01F). The correction was made by drawing the hysteresis loops for the 38th and the 99th cycle and compressing them back to the origin such that the zero shift after compression was offset by approximately the same amount as is witnessed on the remaining three fatigue specimen hysteresis loops. This positioned the limits of the 38th and the 99th cycles, the values of which were plotted on the limit diagram. From the information of the remaining three specimens, that of straight-line limit diagrams, the points of cycles 1, 38, and 99 were connected with a straight line resulting in the corrected data. The problem of fatiguing the points during subsequent testing was alleviated by sanding the points flat along with heat-treating them. Specimen #01F also was the only one stressed cyclically over 25,000 psi.

The zero load values on the limit diagram are the results of relieving the maximum loadings. For example, the upper line of the limit diagram represents the slip during that cycle at maximum tension load (see Appendix C-1). The zero tension plot is the result of residual slip after relieving the maximum tension load in that cycle. The same reasoning applies for the lower line on the limit diagram, which represents the slip under the maximum compressive load at a given cycle. The zero compression plot represents the residual slip after the maximum compressive load was removed.

The second phase of fatigue testing, although plotted in a similar fashion as before, consisted of testing with different load limits. The second four specimens, number 05F thru 08F, were stressed to 25,000 psi tension and relaxed to 12,500 psi tension cycled not 99 times but 400 times (see Appendix C-2). The maximum slip as witnessed from the data output or the plots approaches .010" out per side after 400 cycles. It is seen from reviewing these data and comparing it to that of the previous phase that the slips are somewhat less even though an additional 300 cycles was subjected to the specimens. Approximately every 25 cycles the load was reduced to zero allowing data for a hysteresis loop to be taken. Reducing the load to zero also resulted in a convenient place to end testing for the day.

The third phase of fatigue testing was conducted with compressive loadings. The data were plotted similarly to that of the previous two phases. The maximum stress in compression was 25,000 psi after which the stress was relaxed to 12,500 psi compression completing the cycle (see Appendix C-3). Approximately every 50 cycles the compressive load was allowed to relieve to zero; the data of such cycles allowed the plotting of hysteresis loops. Cycling the spliced specimens numbers 09F thru 12F under compressive cyclic loadings resulted in small amounts of rebar slippage. The amount of slippage per side approaches .003" at the maximum compressive load after 400 cycles. The specimens were so rigid after the first cycle that it was only convenient to graph the hysteresis loops of cycle #1 and #400.

Table 3 was prepared by taking all the specimens that were exposed, partly or completely, to tensile fatigue loadings and grouping them together. Table 4 was similarly constructed with specimens exposed, partly or completely, to compressive fatigue loadings. Both tables show nominal slip at the top and at the bottom of a given specimen and the point to which they change after fatigue testing. The table also compares the change between a given specimen (top and bottom) as well as between similar specimens. The data comprising Tables 3 and 4 is taken from the norms on the limit diagrams of the particular specimen, load, and cycle noted in the title boxes.

SPECIMEN FATIGUE TEST

TENSION

Specimen	Max. Tension Load	First Cycle's Slip Top X 10^{-3} in.	First Cycle's Slip Bottom X 10^{-3} in.	Last Cycle's Slip Top X 10^{-3} in.	Last Cycle's Slip Bottom X 10^{-3} in.	Δ Top X 10^{-3} in.	Δ Bottom X 10^{-3} in.	Δ Top – Δ Bottom X 10^{-3} in.
#1 14s A432	90,000 lb.	8.4	9.3	12.7	13.7	4.3	4.4	- .1
#2 18s A432	100,000 lb.	8.4	5.9	11.7	9.7	3.3	3.8	- .5
#3 18s A408	100,000 lb.	8.0	10.0	11.4	12.9	3.4	2.9	+ .5
#4 14s A408	60,000 lb.	5.4	1.8	10.9	6.1	5.5	4.3	+1.2
#5 14s A408	60,000 lb.	3.8	3.1	5.3	4.1	1.5	1.0	+ .5
#6 18s A408	100,000 lb.	5.3	4.9	6.6	6.2	1.3	1.3	0
#7 18s A432	100,000 lb.	7.5	6.7	8.7	9.3	1.2	2.6	-1.4
#8 14s A432	60,000 lb.	3.0	1.8	3.5	2.7	.5	.9	- .4

TABLE 3

SPECIMEN FATIGUE TEST

COMPRESSION

Specimen	Max. Comp. Load	First Cycle's Slip Top X 10^{-3} in.	First Cycle's Slip Bottom X 10^{-3} in.	Last Cycle's Slip Top X 10^{-3} in.	Last Cycle's Slip Bottom X 10^{-3} in.	Δ Top X 10^{-3} in.	Δ Bottom X 10^{-3} in.	Δ Top – Δ Bottom X 10^{-3} in.
#1 14s A432	90,000 lb.	-3.9	-4.9	-6.2	-6.2	2.3	1.3	+1.0
#2 18s A432	100,000 lb.	- .8	- .8	-4.3	- .8	3.5	0	+3.5
#3 18s A408	100,000 lb.	-2.0	-2.6	-3.0	-3.5	1.0	.9	+ .1
#4 14s A408	60,000 lb.	-1.9	-2.4	-4.0	-2.1	2.1	-.3	+2.4
#9 14s A432	60,000 lb.	-1.5	-1.8	-2.1	-1.8	.6	0	+ .6
#10 18s A432	100,000 lb.	-1.6	-2.4	-1.6	-2.4	0	0	0
#11 18s A408	100,000 lb.	-2.2	-2.0	-2.2	-2.0	0	0	0
#12 14s A408	60,000 lb.	-1.3	-1.1	-1.5	-1.3	.2	.2	0

TABLE 4

VII. RADIOGRAPHY

Radiographs of each spliced specimen were taken prior to testing as well as after testing to permit a visual picture of the change in rebar position within the sleeve. The slips, however, were not of sufficient magnitude to be discernible with the radiographic technique used. Slips of 1/16" or more would be required before decisive statements on visual slip seen with radiographs could be made. Table 5 was prepared with radiographic interpretation of filler material characteristics.

The radiographs, however, did pick up voids located in the top section of the horizontally spliced sleeves in the majority of the prepared specimens caused by premature solidification of the filler material. Even though preheating of the rebar, graphite crucibles, and sleeve was properly executed, the expanding gases within the sleeve were not allowed to vent fast enough to insure complete filling. Possible improvements could be made in this area.

A common occurrence of shrinkage voids (interface separations) on almost all surfaces within the sleeve can be observed on the radiographs of the specimens (see Appendix D). Shrinkage voids on radiographic film look like fine hair-line cracks superimposed on the projection of the sleeve and rebar. Exceptions are found directly beneath the filler hole where entering molten material on occasion melts and alloys the immediate interfaces enough to prevent separation on cooling.

Shrinkage voids are inherent in casting of a material having a greater coefficient of volumetric expansion into a sleeve having a lesser coefficient of volumetric expansion. The significant point to be brought up resulting from the above accepted fact is that voids in the form of hair-line separations of any significant size, especially along bearing surfaces, allow movement (or slip) however small prior to transferring any load. The fatigue tests show that once all the shrinkage voids are collapsed, as shown in phase #3, there exists little or no increase in slipping. This plus the fact that once the rebars have slipped eliminating the shrinkage voids between the ends of the rebar, substantial loads are then transferred compressively through the filler material located between the bars, greatly reducing any further increase in slip under a given load situation.

Sponge shrinkage was quite evident in radiographs of number 18s rebars. The effect on the physical properties of the sponge or porosity of the cast filler material as it existed in the specimens is not readily seen from these tests. It is inconclusive from the tests run that any detrimental effects can be contributed to the presence of sponge solidified filler material. It is conjectured, however, that increased overall physical performance of the butt splice would be achieved if premature solidification voids, shrinkage voids, and sponge shrinkage of the filler material is kept to a minimum.

RADIOGRAPHIC FILLER

METAL INTERPRETATION

SPECIMEN IDENT.	SOLIDIFICATION VOIDS	SHRINKAGE VOIDS	SPONGE SHRINKAGE
1F-14s-A432	X	X	
2F-18s-A432	X	X	
3F-18s-A408	X	X	X
4F-14s-A408	X	X	
5F-14s-A432		X	
6F-18s-A432	X	X	X
7F-18s-A408	X	X	X
8F-14s-A408	X		
9F-14s-A432	X	X	
10F-18s-A432	X	X	
11F-18s-A408			X
12F-14s-A408		X	

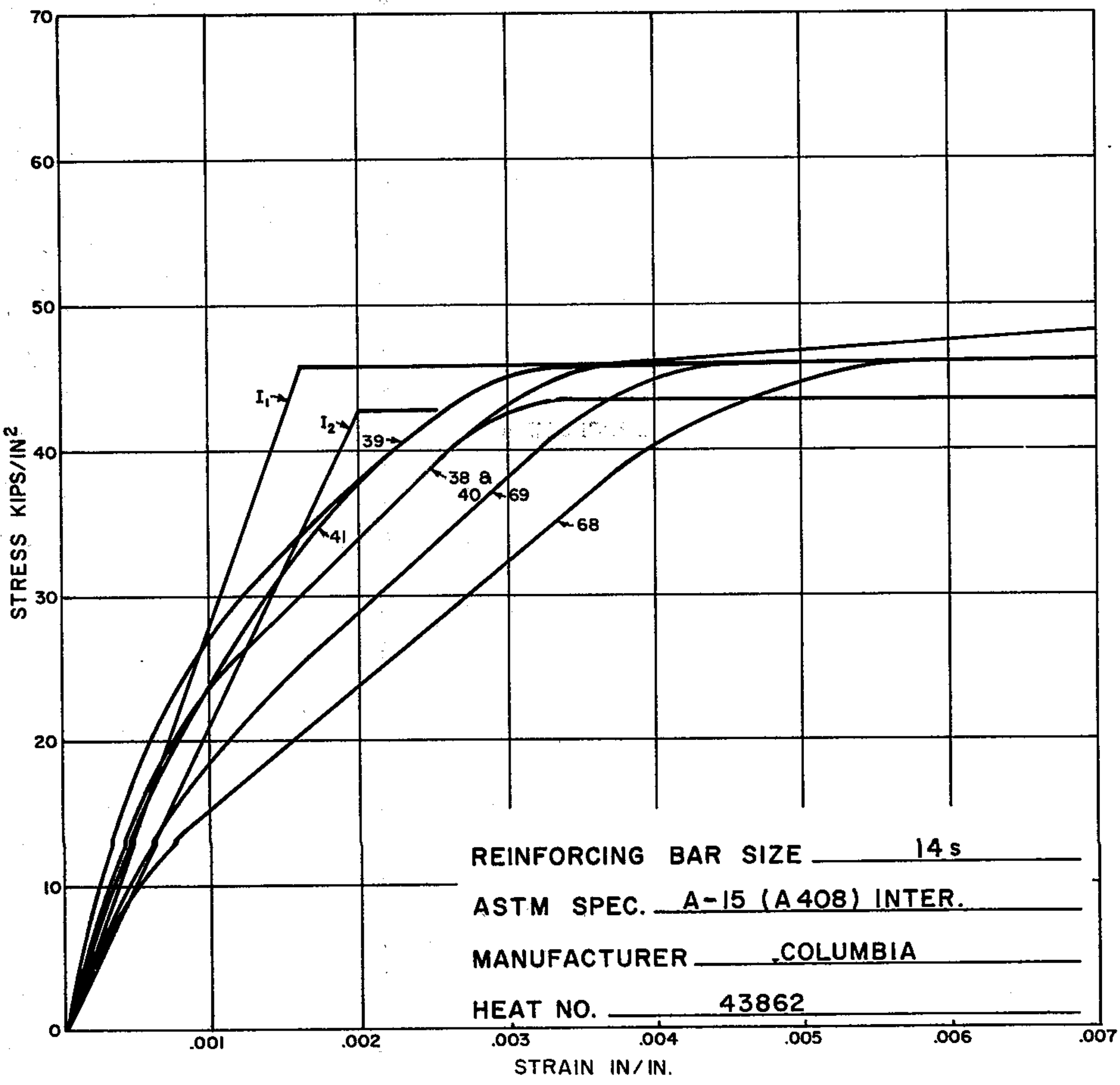
TABLE 5

APPENDIX A

SLEEVE WITH METAL FILLER
TENSILE TEST

GROUP NO. 3

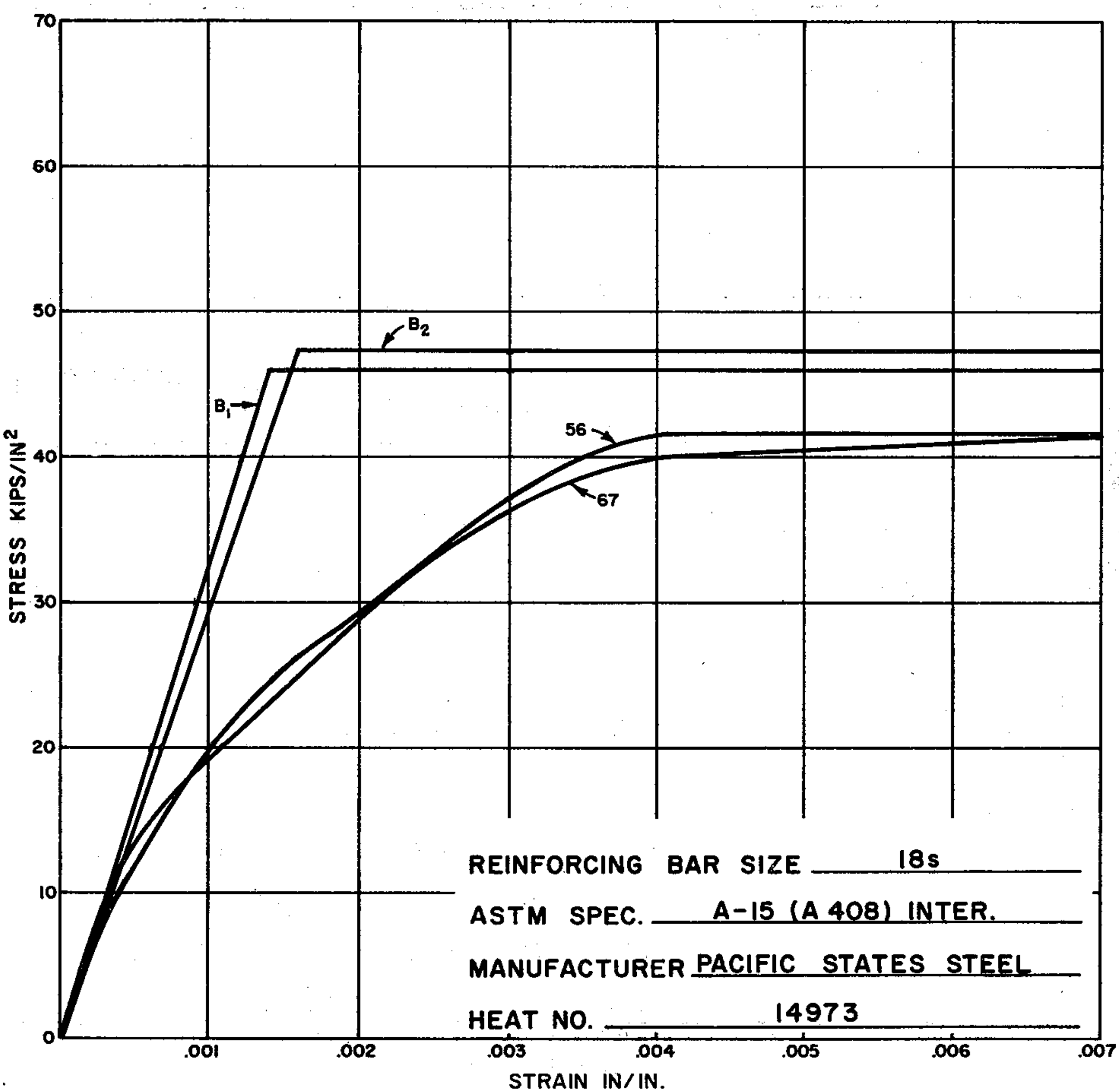
DATE: AUGUST 1964



SLEEVE WITH METAL FILLER
TENSILE TEST

GROUP NO. 6

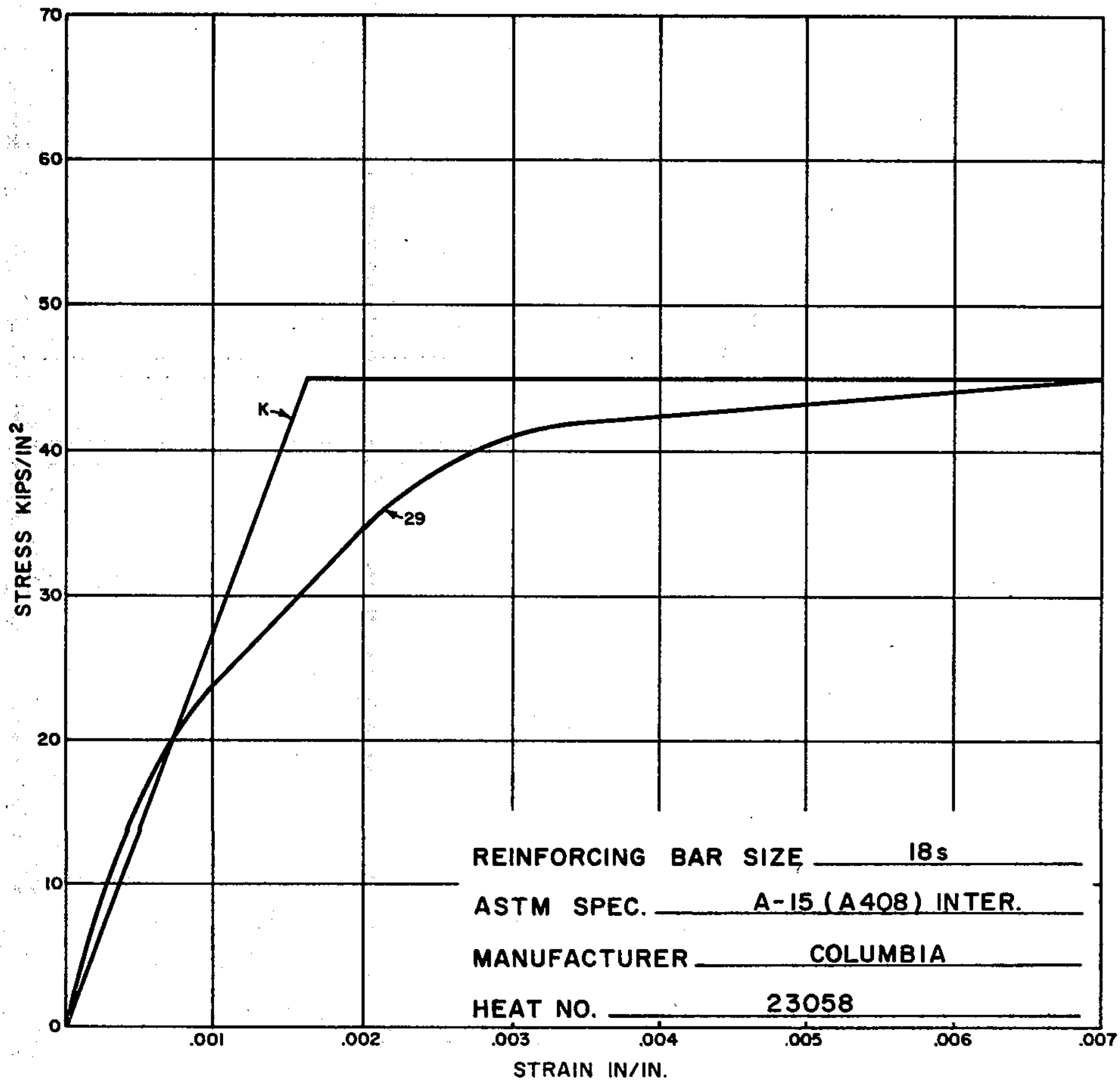
DATE: AUGUST 1964



SLEEVE WITH METAL FILLER
TENSILE TEST

GROUP NO. 7

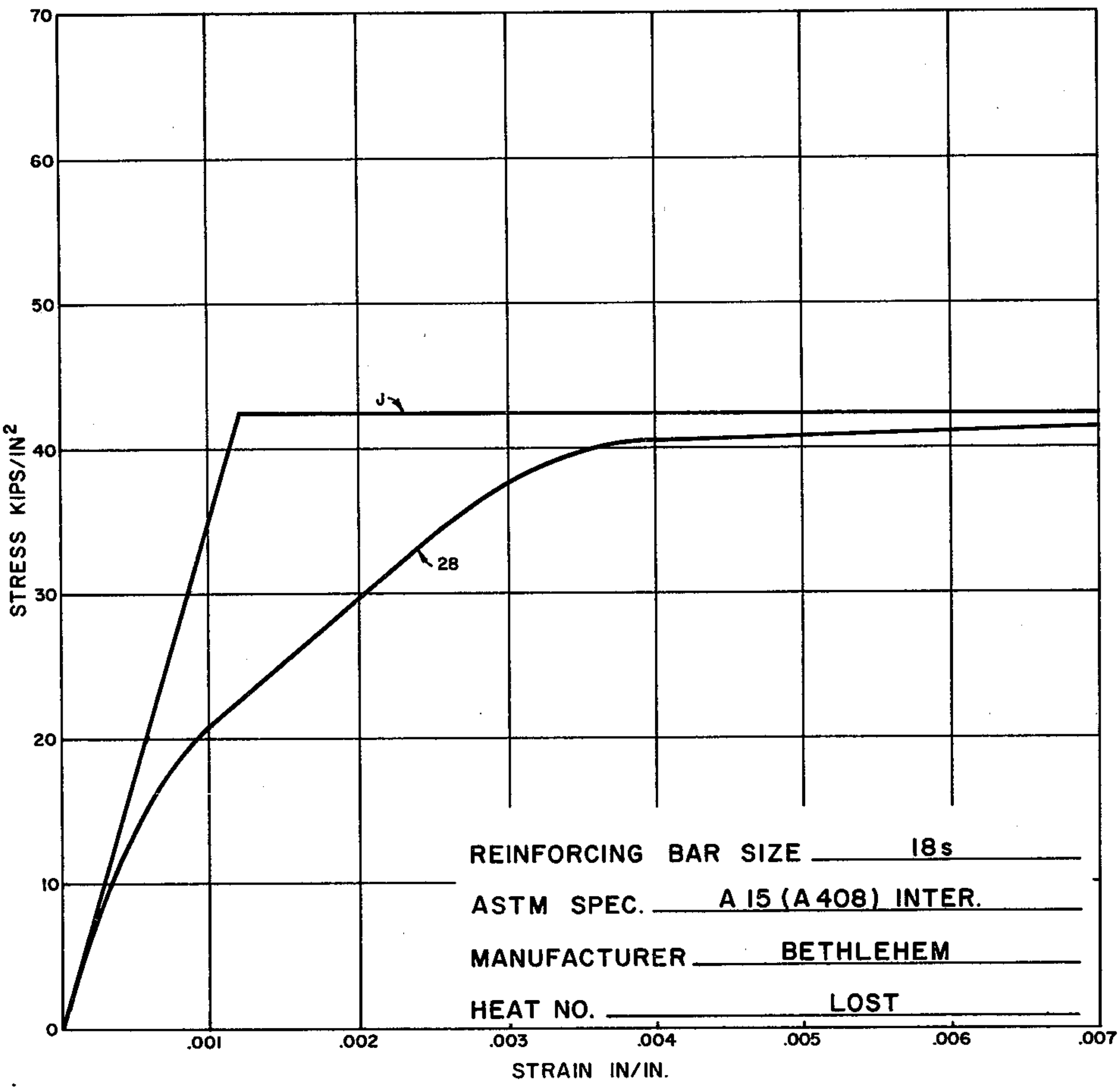
DATE: AUGUST 1964

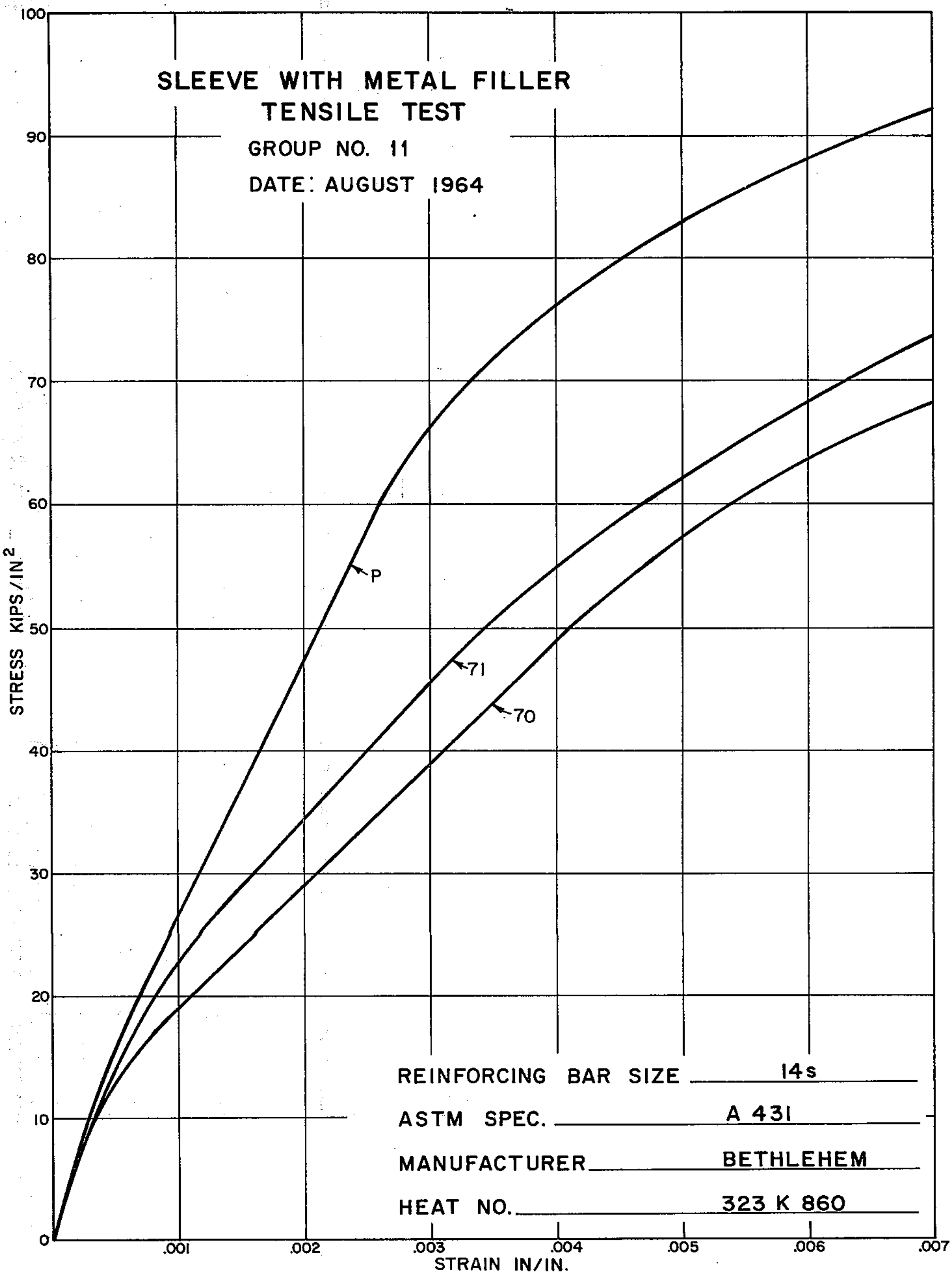


SLEEVE WITH METAL FILLER
TENSILE TEST

GROUP NO. 8

DATE: AUGUST 1964

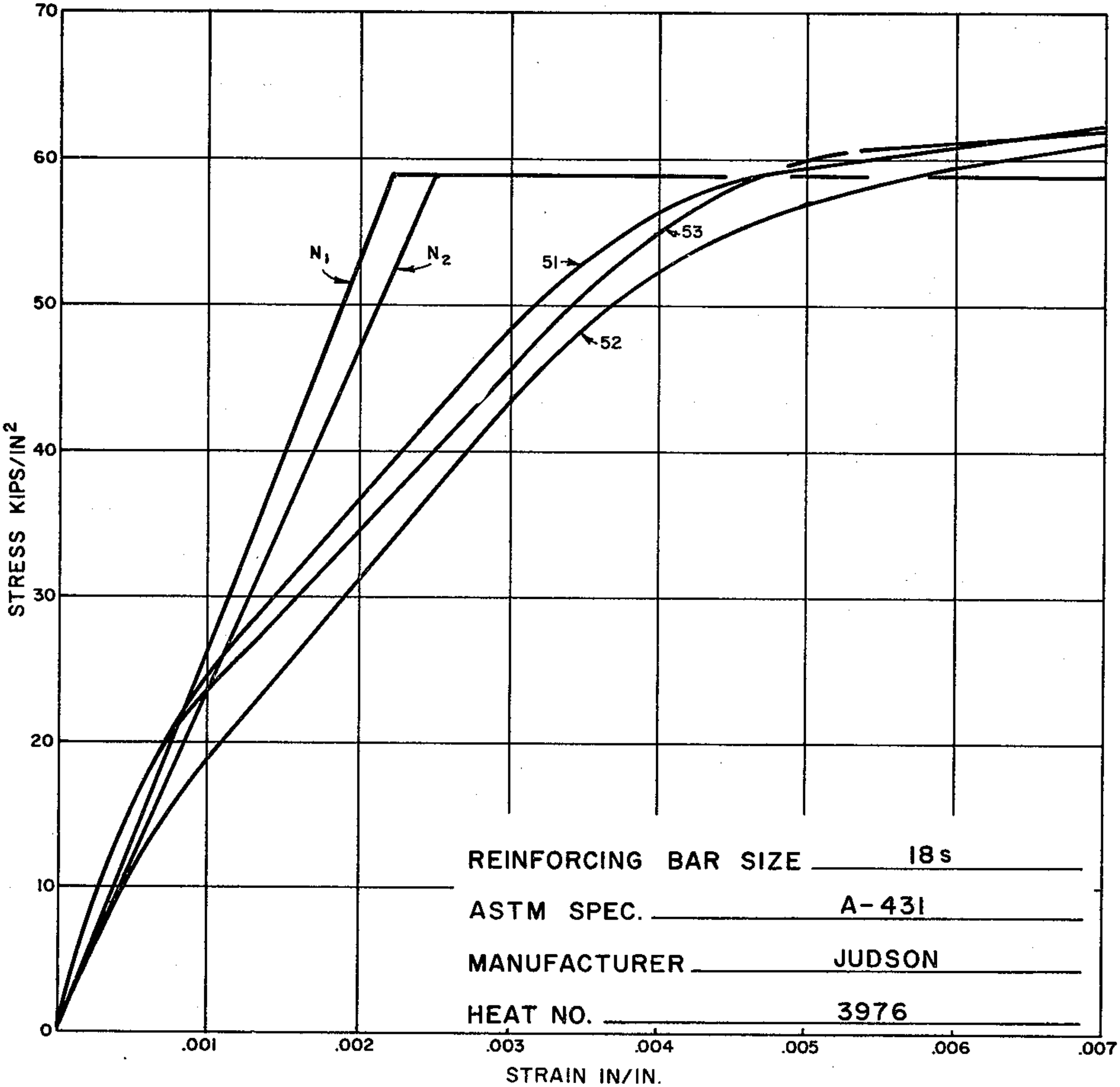



SLEEVE WITH METAL FILLER
TENSILE TEST
GROUP NO. 11
DATE: AUGUST 1964
STRESS KIPS/IN²
STRAIN IN/IN.
100
90
80
70
60
50
40
30
20
10
0
.001
.002
.003
.004
.005
.006
.007
P
71
70
REINFORCING BAR SIZE 14s
ASTM SPEC. A 431
MANUFACTURER BETHLEHEM
HEAT NO. 323 K 860

SLEEVE WITH METAL FILLER
TENSILE TEST

GROUP NO. 14

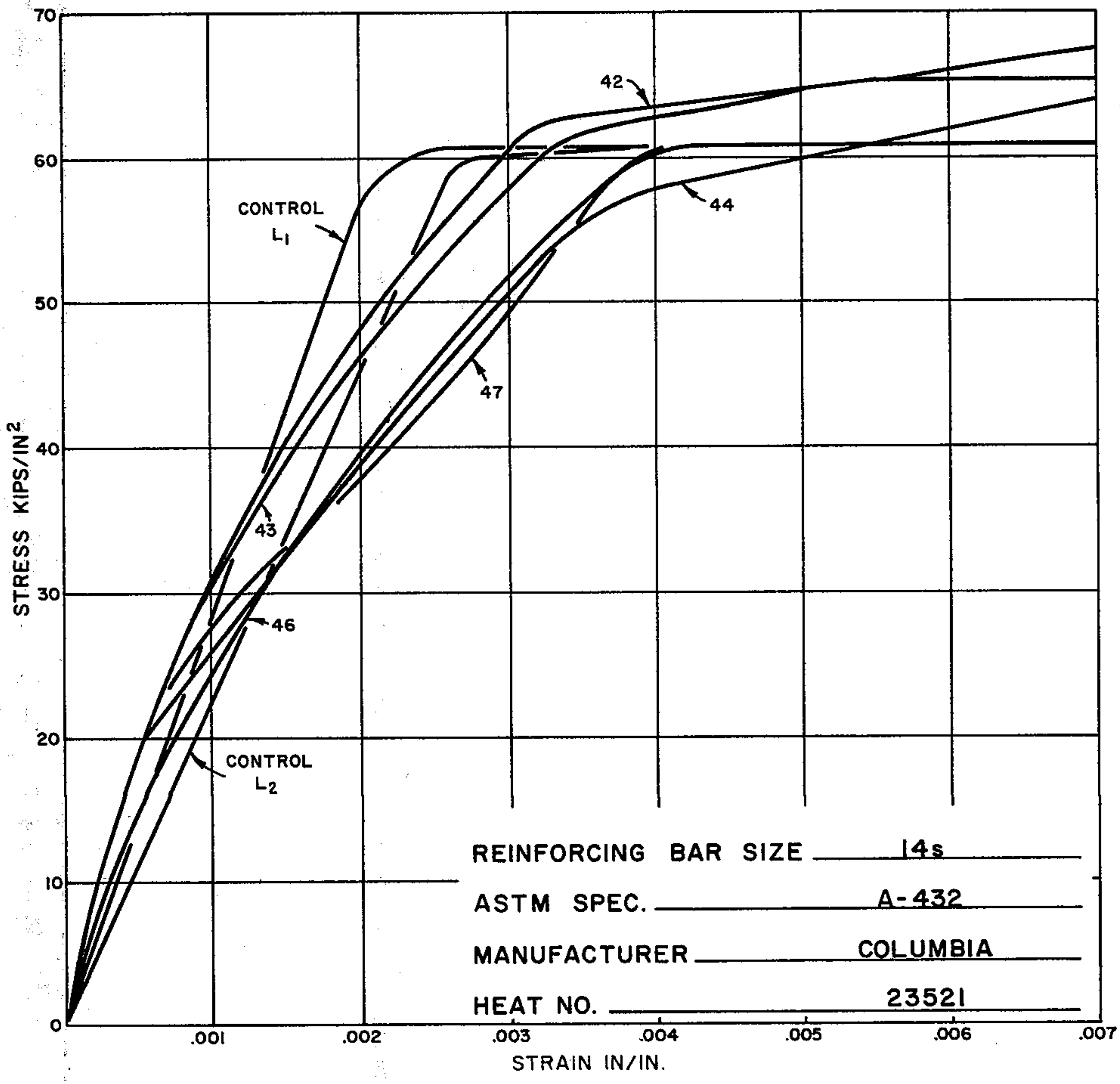
DATE: AUGUST 1964



SLEEVE WITH METAL FILLER
TENSILE TEST

GROUP NO. 18

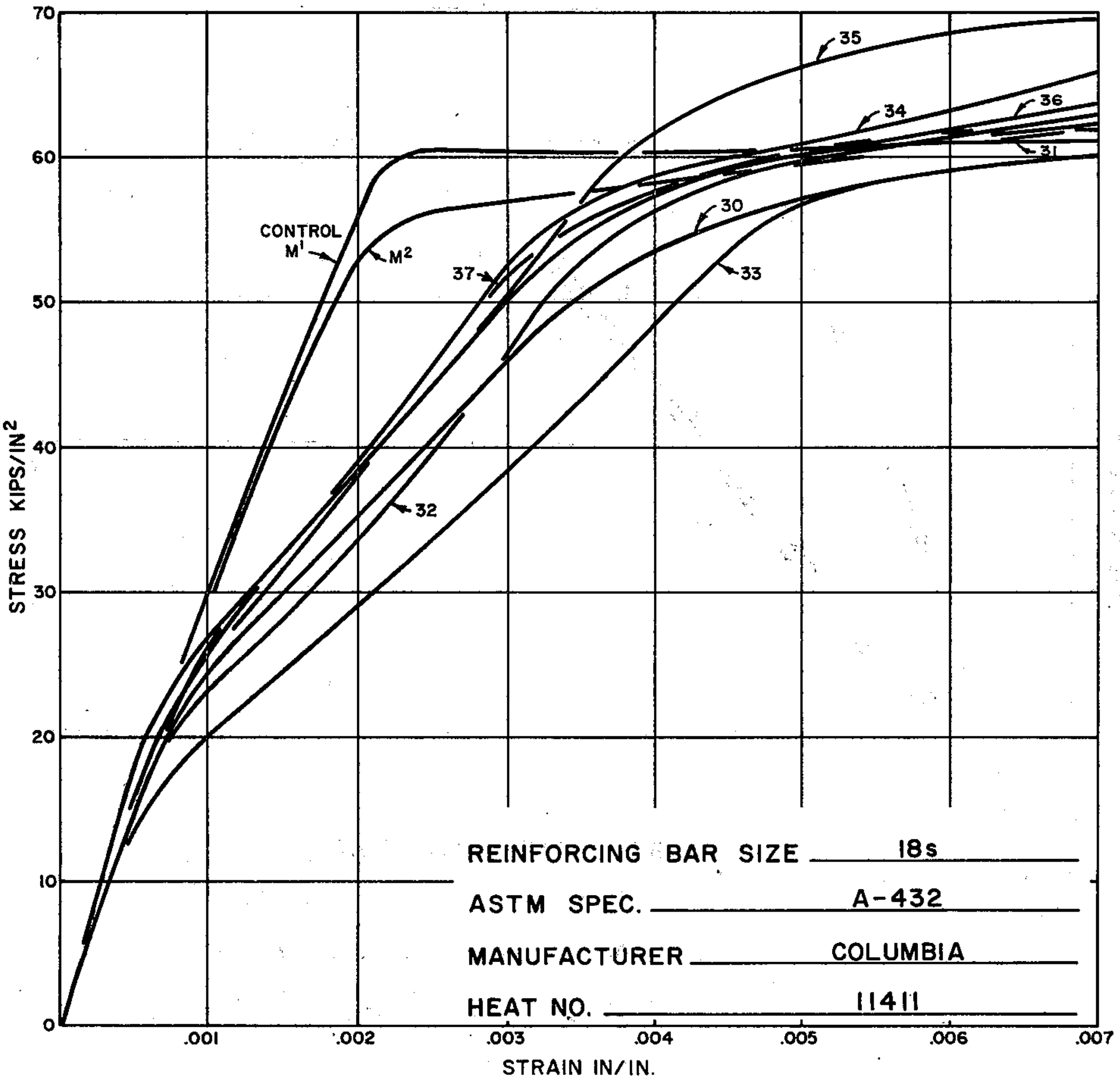
DATE: AUGUST 1964



SLEEVE WITH METAL FILLER
TENSILE TEST

GROUP NO. 22

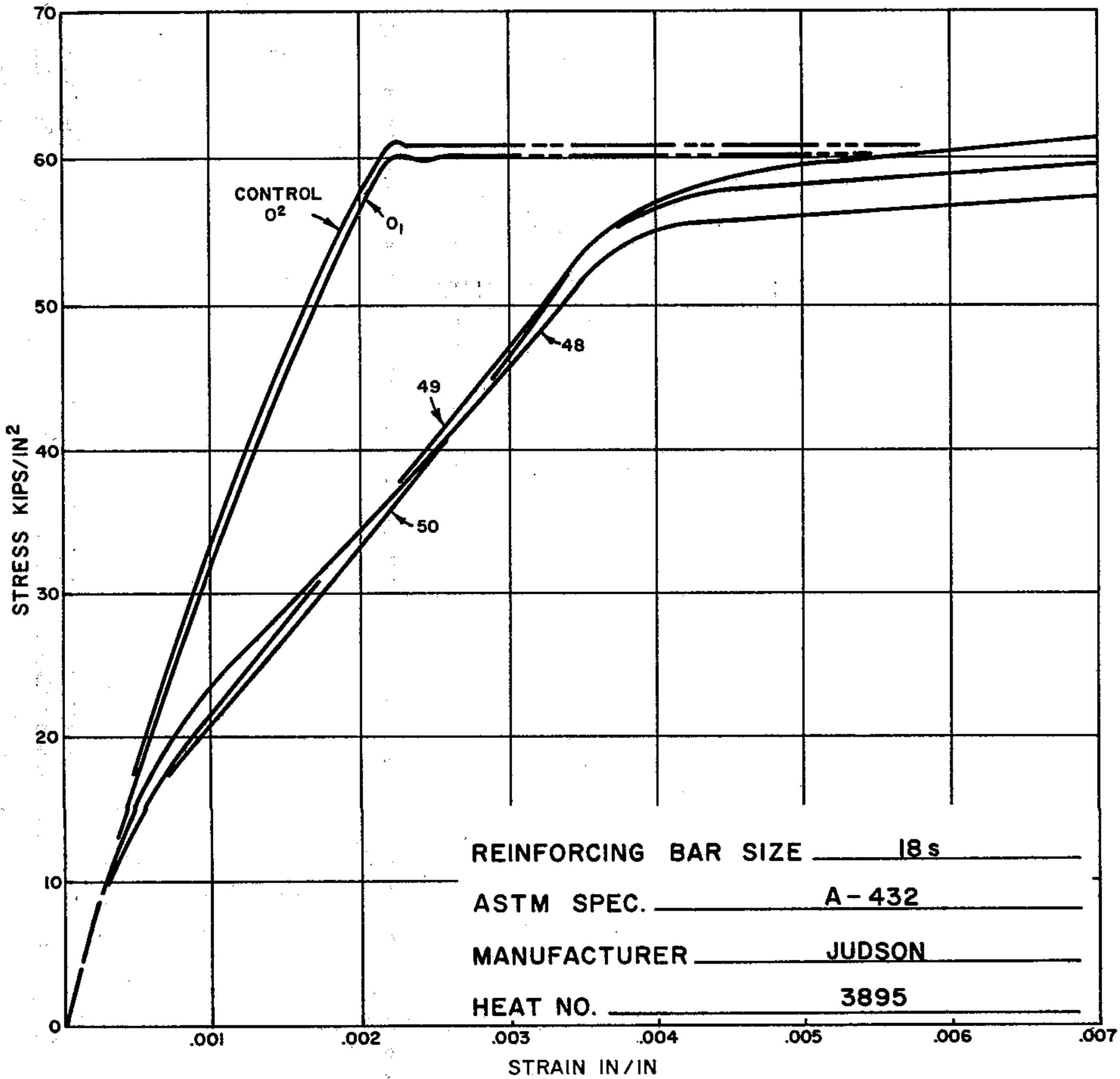
DATE: AUGUST 1964



SLEEVE WITH METAL FILLER
TENSILE TEST

GROUP NO. 23

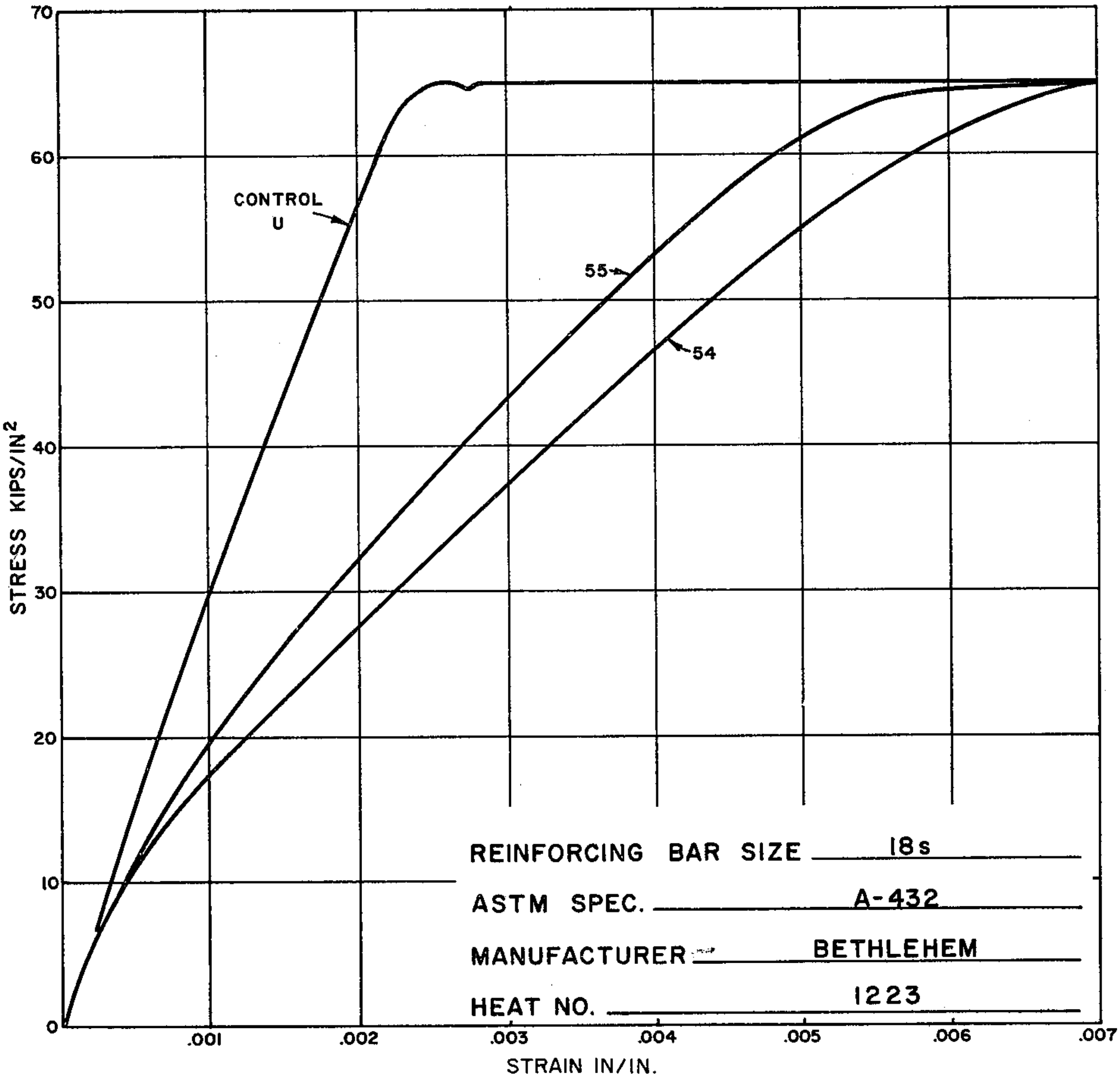
DATE: AUGUST 1964



SLEEVE WITH METAL FILLER
TENSILE TEST

GROUP NO. 24

DATE: AUGUST 1964



APPENDIX B

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1	****	LVDT NO. 2	****	LVDT NO. 3	****
LVDT NO. 4	****	LVDT NO. 5	****	LVDT NO. 6	****

COMPRESSION LOAD CELL **** TENSION PRESS ****

AREA .0 SQ. IN.

SPECIMEN IDENT. IF14SA432G DATE 8/30/66

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
1024	-0.0000	0.0001
15491	0.0004	0.0003
30393	0.0015	0.0012
45359	0.0025	0.0024
60179	0.0039	0.0041
75244	0.0058	0.0061
90436	0.0084	0.0093
852	0.0049	0.0061
18	0.0046	0.0058

CYCLE 01 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	0.0046	0.0055
-1976	0.0046	0.0054
-15068	0.0036	0.0040
-28605	0.0022	0.0021
-44069	0.0003	0.0001
-59434	-0.0013	-0.0016
-74305	-0.0028	-0.0033
-89225	-0.0039	-0.0049
-2618	-0.0002	-0.0013

CYCLE 98 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
-444	0.0118	0.0142
-1432	0.0114	0.0139
-15760	0.0048	0.0066
-29692	0.0026	0.0040
-45600	0.0014	0.0023
-60422	0.0005	0.0016
-75688	0.0000	0.0008
-90509	-0.0006	-0.0000
-2272	0.0055	0.0068

CYCLE 99 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
-72	0.0066	0.0078
1151	0.0069	0.0082
15555	0.0119	0.0137
30275	0.0141	0.0165
45195	0.0152	0.0177
60143	0.0161	0.0188
74800	0.0171	0.0198
89874	0.0179	0.0207
716	0.0123	0.0156
-5577	0.0117	0.0150

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1 **** LVDT NO. 2 **** LVDT NO. 3 ****
LVDT NO. 4 **** LVDT NO. 5 **** LVDT NO. 6 ****
COMPRESSION LOAD CELL **** TENSION PRESS ****
AREA **** SQ. IN.

SPECIMEN IDENT. 2F18SA432G DATE 11/ 1/66

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
20344	0.0004	0.0003
40479	0.0010	0.0009
59970	0.0023	0.0017
79815	0.0046	0.0034
100169	0.0077	0.0059
145	0.0054	0.0035

CYCLE 01 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	0.0052	0.0035
-19910	0.0043	0.0026
-40857	0.0030	0.0019
-58742	0.0015	0.0013
-78702	-0.0001	0.0004
-100390	-0.0014	-0.0008
-592	0.0013	0.0008
-49	0.0014	0.0009

CYCLE 99 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
-108	0.0017	0.0031
20625	0.0079	0.0056
39962	0.0095	0.0072
60016	0.0108	0.0083
79942	0.0115	0.0091
100169	0.0121	0.0098
18	0.0076	0.0057

CYCLE 99 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
-98	0.0076	0.0057
-19317	-0.0002	0.0031
-40265	-0.0023	0.0015
-59088	-0.0030	0.0005
-80480	-0.0037	-0.0003
-100687	-0.0042	-0.0009
-99995	-0.0042	-0.0009
-5462	0.0019	0.0032

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1 7.043 LVDT NO. 2 6.772 LVDT NO. 3 7.763
LVDT NO. 4 7.640 LVDT NO. 5 6.719 LVDT NO. 6 6.730
COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 4.000 SQ. IN.

SPECIMEN IDENT. 3F18SA408G DATE 12/ 7/66

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
20162	0.0000	0.0001
39436	0.0007	0.0008
59408	0.0021	0.0023
79670	0.0046	0.0058
99579	0.0074	0.0091
-226	0.0054	0.0074

CYCLE 01 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	0.0054	0.0071
-18230	0.0045	0.0060
-38832	0.0024	0.0025
-59878	0.0004	0.0005
-80974	-0.0009	-0.0009
-102910	-0.0018	-0.0019
-2371	0.0003	0.0003

CYCLE 99 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
-217	0.0011	0.0006
20407	0.0077	0.0100
39799	0.0090	0.0110
59653	0.0099	0.0119
79688	0.0107	0.0128
99942	0.0115	0.0133
-199	0.0076	0.0096

CYCLE 99 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	0.0076	0.0095
-37597	-0.0013	-0.0009
-58396	-0.0022	-0.0019
-79838	-0.0027	-0.0024
-101922	-0.0032	-0.0029
-98	0.0011	0.0005
-5309	0.0012	0.0006

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1	7.043	LVDT NO. 2	6.772	LVDT NO. 3	7.763
LVDT NO. 4	7.640	LVDT NO. 5	6.719	LVDT NO. 6	6.730

COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 2.250 SQ. IN.

SPECIMEN IDENT. 4F14SA408G DATE 12/20/66

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
10457	-0.0000	0.0001
20461	0.0003	0.0004
30121	0.0009	0.0009
39780	0.0015	0.0013
49513	0.0028	0.0020
59517	0.0048	0.0031
59417	0.0049	0.0032
-9	0.0035	0.0017

CYCLE 01 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	0.0031	0.0010
-9436	0.0029	0.0006
-18922	0.0023	0.0002
-29247	0.0015	-0.0003
-39721	0.0005	-0.0007
-48762	-0.0005	-0.0012
-59384	-0.0015	-0.0019
-148	-0.0002	-0.0007

CYCLE 99 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
-18	-0.0002	0.0008
10530	0.0057	0.0018
20616	0.0079	0.0031
30302	0.0091	0.0042
40007	0.0097	0.0049
49848	0.0104	0.0056
59843	0.0111	0.0062
-9	0.0084	0.0037

CYCLE 99 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	0.0084	0.0036
-9386	0.0020	0.0027
-19564	-0.0012	0.0011
-29642	-0.0024	-0.0003
-40116	-0.0031	-0.0012
-49009	-0.0036	-0.0018
-59631	-0.0040	-0.0020
-98	-0.0003	0.0010
-5156	-0.0001	0.0013

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1 7.043 LVDT NO. 2 6.772 LVDT NO. 3 7.763
LVDT NO. 4 7.640 LVDT NO. 5 6.719 LVDT NO. 6 6.730
COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 2.250 SQ. IN.

SPECIMEN IDENT. 5F14SA408G DATE 1/18/67

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
5360	-0.0001	0.0000
10493	0.0001	0.0001
15582	0.0002	0.0002
20525	0.0004	0.0003
25377	0.0006	0.0006
30275	0.0008	0.0007
34964	0.0011	0.0010
39744	0.0014	0.0014
44978	0.0018	0.0017
49921	0.0023	0.0021
54991	0.0030	0.0025
59907	0.0040	0.0032
49667	0.0039	0.0033
39753	0.0037	0.0030
29967	0.0034	0.0027

CYCLE 400 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
30239	0.0049	0.0033
35100	0.0048	0.0033
40025	0.0050	0.0037
45050	0.0051	0.0038
50111	0.0053	0.0039
54927	0.0055	0.0039
60007	0.0056	0.0040
54664	0.0056	0.0042
49640	0.0055	0.0040
44905	0.0053	0.0039
39708	0.0052	0.0038
34973	0.0050	0.0036
30257	0.0049	0.0035
25305	0.0047	0.0033
20280	0.0046	0.0032
15346	0.0044	0.0031
10194	0.0042	0.0030
5070	0.0041	0.0029
0	0.0039	0.0027

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1 7.043 LVDT NO. 2 6.772 LVDT NO. 3 7.763
LVDT NO. 4 7.640 LVDT NO. 5 6.719 LVDT NO. 6 6.731
COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 4.000 SQ. IN.

SPECIMEN IDENT. 6F18SA408G DATE 1/25/67

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
263	-0.0001	0.0002
10521	0.0000	0.0006
20607	0.0001	0.0008
30339	0.0004	0.0011
40034	0.0006	0.0012
49848	0.0010	0.0017
59734	0.0015	0.0019
69775	0.0022	0.0024
79843	0.0030	0.0031
90083	0.0040	0.0039
99951	0.0053	0.0050
89829	0.0054	0.0050
79480	0.0052	0.0048
69539	0.0050	0.0047
59626	0.0048	0.0045
49431	0.0046	0.0044

CYCLE 400 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
49703	0.0056	0.0055
100023	0.0065	0.0062
74691	0.0060	0.0059
49694	0.0056	0.0054
25296	0.0048	0.0048
-145	0.0040	0.0042

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1 7.043 LVDT NO. 2 6.772 LVDT NO. 3 7.763
LVDT NO. 4 7.640 LVDT NO. 5 6.719 LVDT NO. 6 6.730
COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 4.000 SQ. IN.

SPECIMEN IDENT. 7F18SA432G DATE 2/ 1/67

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
10285	0.0001	-0.0002
20407	0.0003	0.0000
30221	0.0006	0.0003
39617	0.0010	0.0009
49776	0.0018	0.0016
59716	0.0026	0.0025
69594	0.0037	0.0035
79725	0.0051	0.0045
90065	0.0064	0.0058
99815	0.0077	0.0072
89638	0.0077	0.0072
79525	0.0075	0.0070
69367	0.0074	0.0069
59517	0.0072	0.0067
49485	0.0069	0.0065

CYCLE 01 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	0.0078	0.0074

CYCLE 02 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
49413	0.0069	0.0065
59843	0.0068	0.0063

CYCLE 400 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
49431	0.0078	0.0086
99779	0.0088	0.0098
74573	0.0084	0.0092
49540	0.0078	0.0086
25178	0.0071	0.0080
-208	0.0061	0.0070

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1 7.043 LVDT NO. 2 6.772 LVDT NO. 3 7.763
LVDT NO. 4 7.640 LVDT NO. 5 6.719 LVDT NO. 6 6.730
COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 2.250 SQ. IN.

SPECIMEN IDENT. 8F14SA432G DATE 2/15/67

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
5378	-0.0000	0.0001
10412	0.0001	0.0001
15645	0.0002	0.0003
20634	0.0004	0.0006
25522	0.0006	0.0005
30457	0.0007	0.0007
35137	0.0010	0.0009
40025	0.0012	0.0011
45086	0.0015	0.0013
49984	0.0019	0.0016
54973	0.0023	0.0018
59744	0.0029	0.0020
54728	0.0030	0.0021
49685	0.0029	0.0019
44905	0.0027	0.0019
39735	0.0026	0.0018
34810	0.0025	0.0016
29958	0.0022	0.0016

CYCLE 400 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
29940	0.0030	0.0021
60179	0.0038	0.0030
49875	0.0036	0.0027
39871	0.0033	0.0023
29949	0.0030	0.0020
20253	0.0026	0.0018
10167	0.0024	0.0015
-45	0.0020	0.0013

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1	6.976	LVDT NO. 2	6.690	LVDT NO. 3	7.075
LVDT NO. 4	7.518	LVDT NO. 5	6.695	LVDT NO. 6	6.723

COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 2.250 SQ. IN.

SPECIMEN IDENT. 9F14SA432G DATE 4/ 5/67

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
0	0.0000	-0.0000

CYCLE 01 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	-0.0000	-0.0000
-10523	-0.0001	-0.0001
-18922	-0.0002	-0.0002
-28160	-0.0004	-0.0004
-38980	-0.0008	-0.0009
-49256	-0.0011	-0.0013
-59631	-0.0015	-0.0018
-28852	-0.0013	-0.0014

CYCLE 02 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
-36	-0.0022	-0.0024

CYCLE 02 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
-28556	-0.0012	-0.0014
-59582	-0.0016	-0.0018
-30038	-0.0014	-0.0015

CYCLE 401 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
197	-0.0007	-0.0006
-8843	-0.0008	-0.0007
-18230	-0.0010	-0.0009
-28506	-0.0012	-0.0012
-38881	-0.0014	-0.0014
-48663	-0.0018	-0.0018
-58791	-0.0019	-0.0019
-48910	-0.0018	-0.0018
-37399	-0.0016	-0.0016
-28506	-0.0014	-0.0014
-18773	-0.0012	-0.0012
-9831	-0.0009	-0.0009
247	-0.0007	-0.0006
-5225	-0.0005	-0.0005

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1 6.976 LVDT NO. 2 6.690 LVDT NO. 3 7.075
LVDT NO. 4 7.518 LVDT NO. 5 6.695 LVDT NO. 6 6.723
COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 4.000 SQ. IN.

SPECIMEN IDENT. 10F18SA432G DATE 4/13/67

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
0	0.0001	-0.0001

CYCLE 01 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	0.0000	-0.0000
-9732	0.0001	-0.0007
-19613	-0.0001	-0.0007
-29939	-0.0003	-0.0007
-39968	-0.0004	-0.0009
-50047	-0.0005	-0.0010
-59335	-0.0006	-0.0011
-70500	-0.0008	-0.0012
-80085	-0.0010	-u.0014
-90312	-0.0012	-0.0016
-102861	-0.0014	-0.0019
-89571	-0.0017	-0.0022
-80628	-0.0017	-0.0023
-68969	-0.0016	-0.0022
-59878	-0.0016	-0.0021
-50738	-0.0014	-0.0020
-39820	-0.0012	-0.0019
-29593	-0.0010	-0.0018
-19267	-0.0008	-0.0017
-10128	-0.0006	-0.0014
-49	-0.0001	-0.0010

CYCLE 401 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
-642	0.0003	-0.0017
-19119	0.0001	-0.0016
-39178	-0.0002	-0.0017
-49997	-0.0004	-0.0020
-59928	-0.0004	-0.0022
-80332	-0.0009	-0.0024
-100687	-0.0011	-0.0026
-79393	-0.0011	-0.0025
-60224	-0.0008	-0.0023
-49355	-0.0007	-0.0023
-39079	-0.0005	-0.0021
-18773	-0.0002	-0.0018
-5262	0.0001	-0.0013

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1	6.976	LVDT NO. 2	6.690	LVDT NO. 3	7.075
LVDT NO. 4	7.518	LVDT NO. 5	6.695	LVDT NO. 6	6.723

COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 4.000 SQ. IN.

SPECIMEN IDENT. 11F18SA408G DATE 4/14/67

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
18	-0.0000	-0.0000

CYCLE 01 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	-0.0000	-0.0000
-9090	0.0001	0.0001
-17934	0.0000	-0.0000
-27864	-0.0001	-0.0001
-39079	-0.0004	-0.0003
-48910	-0.0007	-0.0006
-58544	-0.0009	-0.0008
-68574	-0.0011	-0.0009
-78751	-0.0013	-0.0012
-89176	-0.0016	-0.0015
-100934	-0.0020	-0.0019
-89966	-0.0021	-0.0020
-79393	-0.0020	-0.0020
-69710	-0.0019	-0.0019
-59187	-0.0018	-0.0018
-49108	-0.0016	-0.0016
-102465	-0.0021	-0.0020
-49009	-0.0016	-0.0017

CYCLE 401 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
395	-0.0008	-0.0003
-17291	-0.0009	-0.0003
-37745	-0.0013	-0.0005
-48416	-0.0014	-0.0007
-59137	-0.0016	-0.0009
-80579	-0.0020	-0.0013
-100193	-0.0023	-0.0015
-79640	-0.0022	-0.0016
-59631	-0.0019	-0.0013
-49652	-0.0018	-0.0012
-38239	-0.0016	-0.0009
-17785	-0.0012	-0.0005
395	-0.0008	-0.0002
-5037	-0.0007	-0.0001

MATERIALS AND RESEARCH DEPARTMENT
ABSOLUTE COUPLER SLIP ANALYSIS

CALIBRATION FACTORS

LVDT NO. 1 6.976 LVDT NO. 2 6.690 LVDT NO. 3 7.075
LVDT NO. 4 7.518 LVDT NO. 5 6.695 LVDT NO. 6 6.723
COMPRESSION LOAD CELL 9.881 TENSION PRESS 1.814
AREA 2.250 SQ. IN.

SPECIMEN IDENT. 12F14SA408G DATE 4/19/67

CYCLE 01 TENSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
000	0.0000	0.0000
9	-0.0001	0.0001

CYCLE 01 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	-0.0000	0.0000
-9189	-0.0001	-0.0000
-18675	-0.0002	-0.0002
-28358	-0.0004	-0.0003
-39523	-0.0005	-0.0005
-49800	-0.0007	-0.0008
-59137	-0.0011	-0.0010
-49256	-0.0012	-0.0013
-39326	-0.0012	-0.0012
-29297	-0.0012	-0.0010

CYCLE 401 COMPRESSION

LOAD (LBS)	DELTA LENGTH-TOP (INCHES)	DELTA LENGTH-BOTTOM (INCHES)
0	-0.0007	-0.0003
-10770	-0.0006	-0.0004
-20058	-0.0008	-0.0005
-30186	-0.0009	-0.0007
-40215	-0.0011	-0.0009
-49602	-0.0012	-0.0011
-59582	-0.0014	-0.0012
-49800	-0.0014	-0.0012
-39474	-0.0014	-0.0011
-30334	-0.0013	-0.0010
-20305	-0.0011	-0.0008
-11066	-0.0009	-0.0006
98	-0.0006	-0.0002
-4961	-0.0003	-0.0000

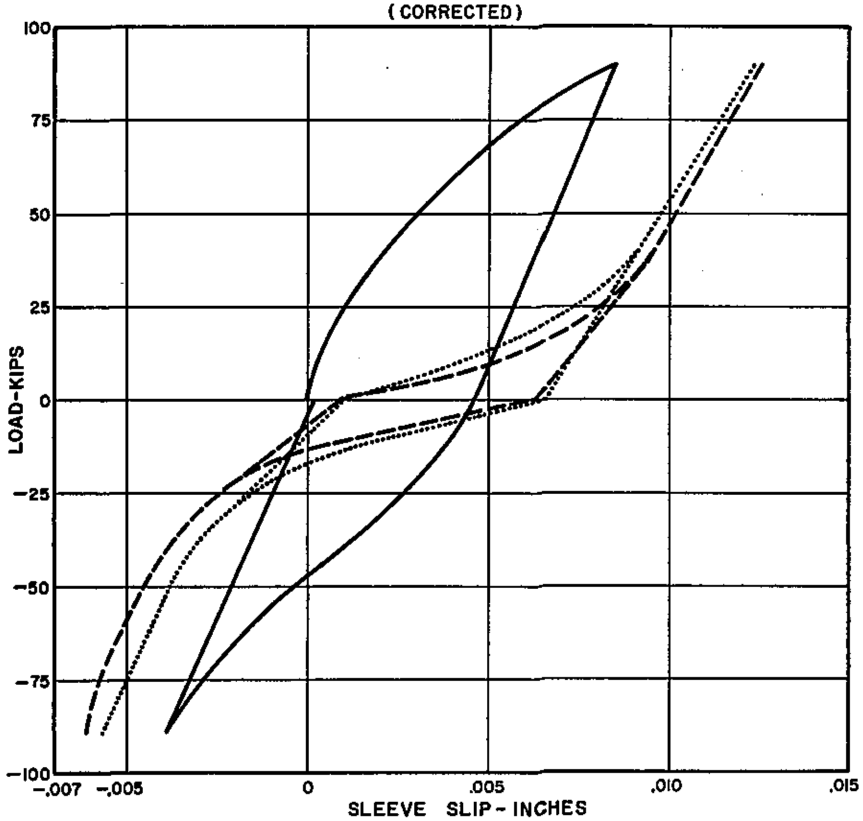
APPENDIX C-1

SLEEVE WITH METAL FILLER FATIGUE TEST

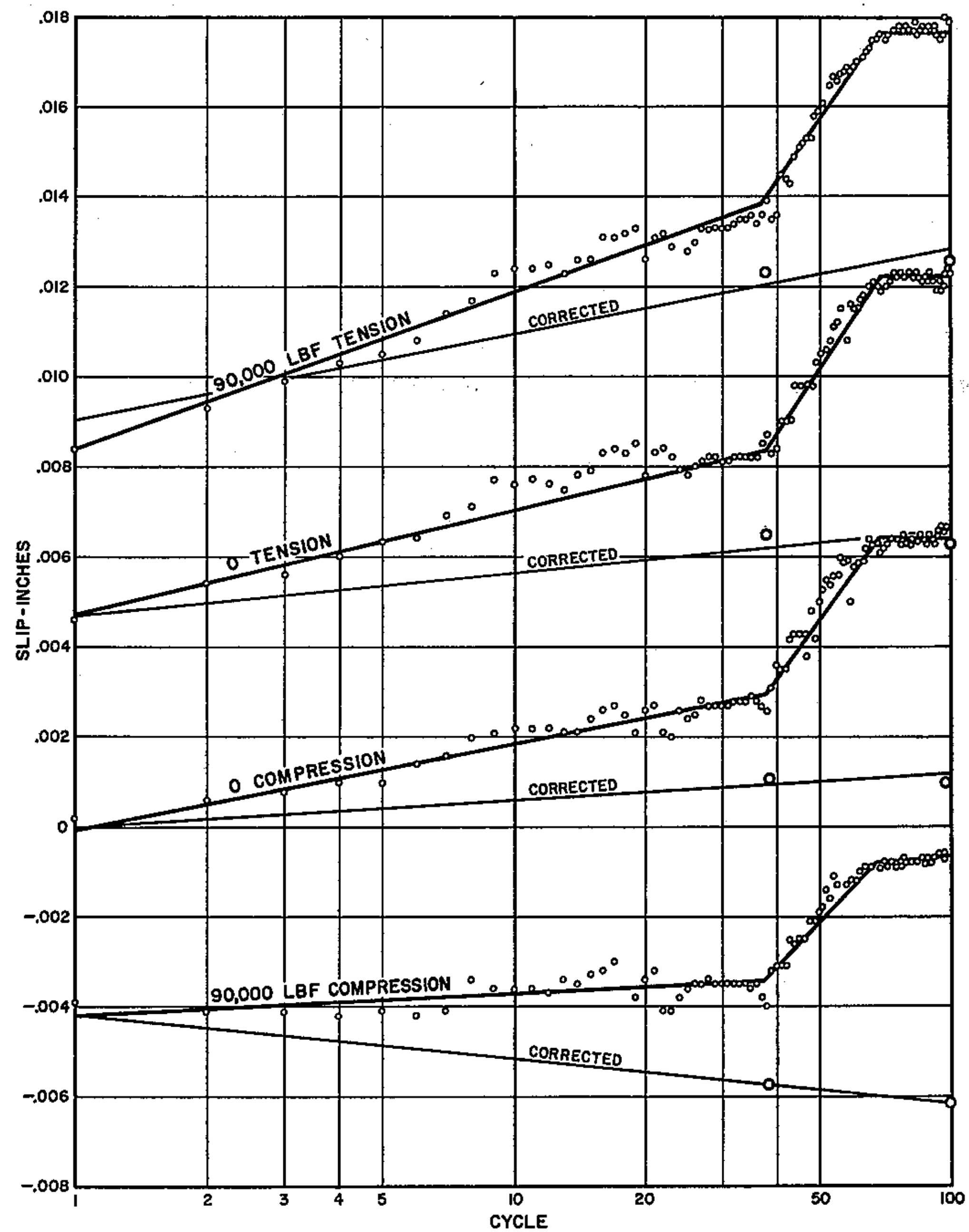
SPEC. NO. IF - 14S - A4326 TOP
DATE AUGUST 30, 1966
MANUFACTURER: COLUMBIA
HEAT NO. 43436

LEGEND
- CYCLE NO. 1
- CYCLE NO. 38
- CYCLE NO. 98

HYSTERESIS DIAGRAM (CORRECTED)



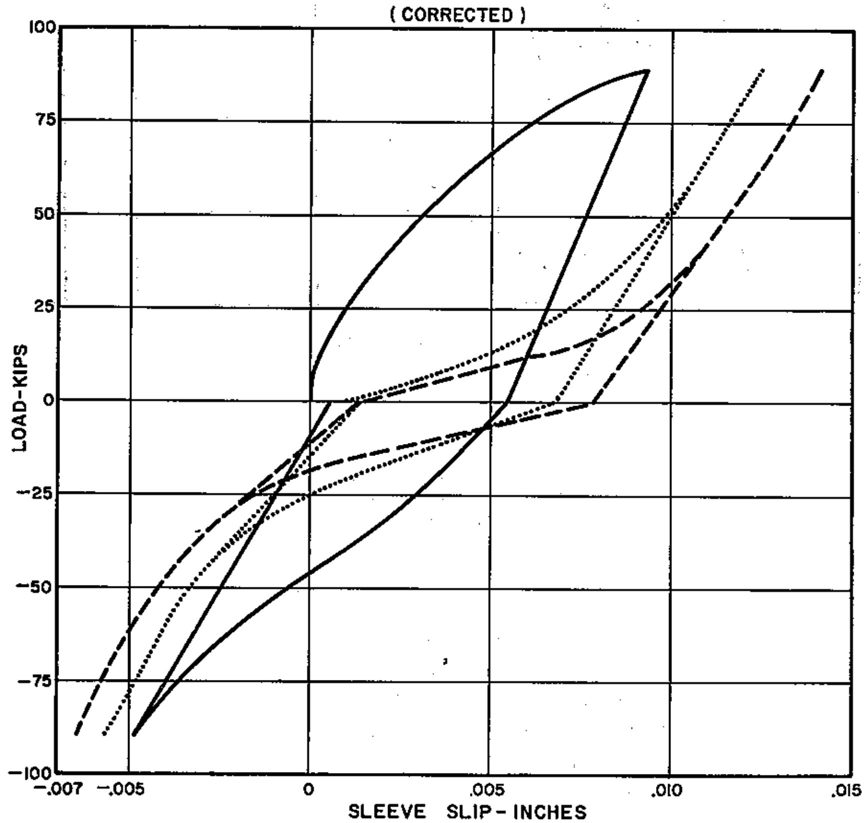
LIMIT DIAGRAM



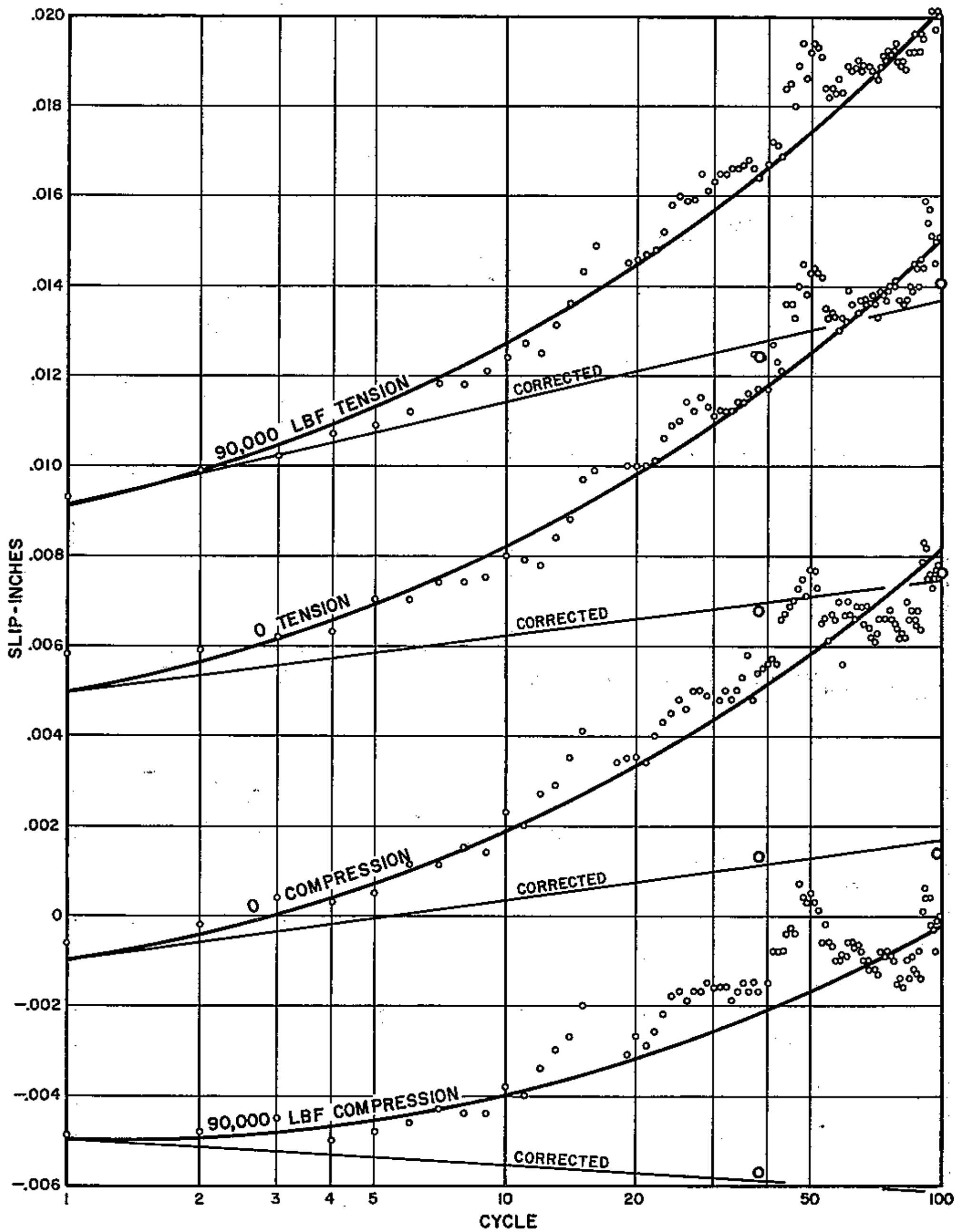
SLEEVE WITH METAL FILLER
FATIGUE TEST

SPEC. NO. IF - 14S - A432G BOTTOM
DATE AUGUST 30, 1966
MANUFACTURER: COLUMBIA
HEAT NO. 43436

HYSTERESIS DIAGRAM
(CORRECTED)



LIMIT DIAGRAM

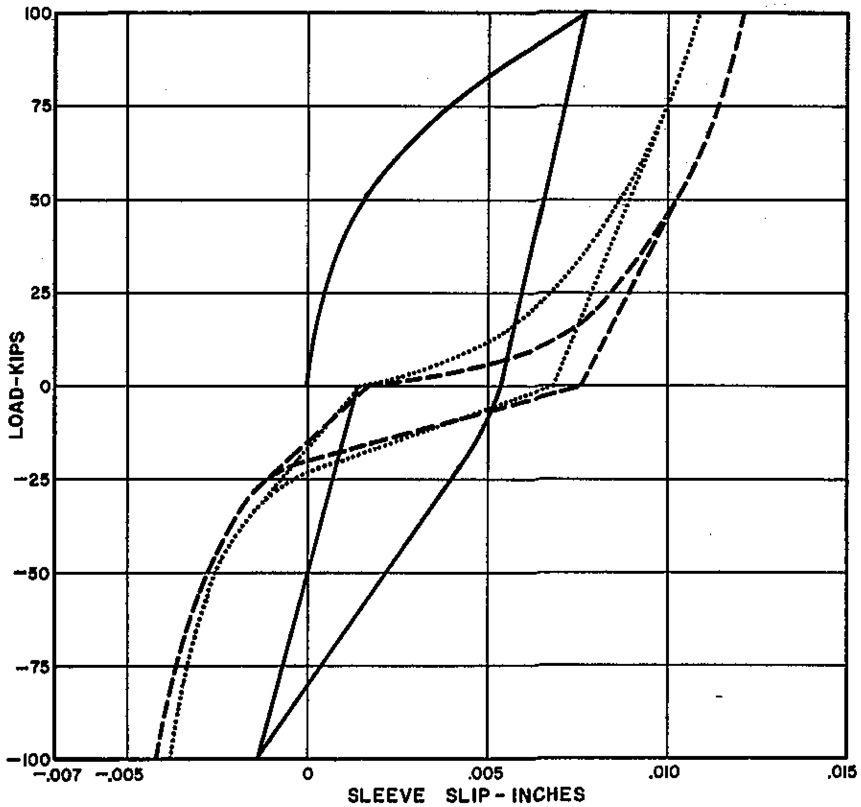


SLEEVE WITH METAL FILLER
FATIGUE TEST

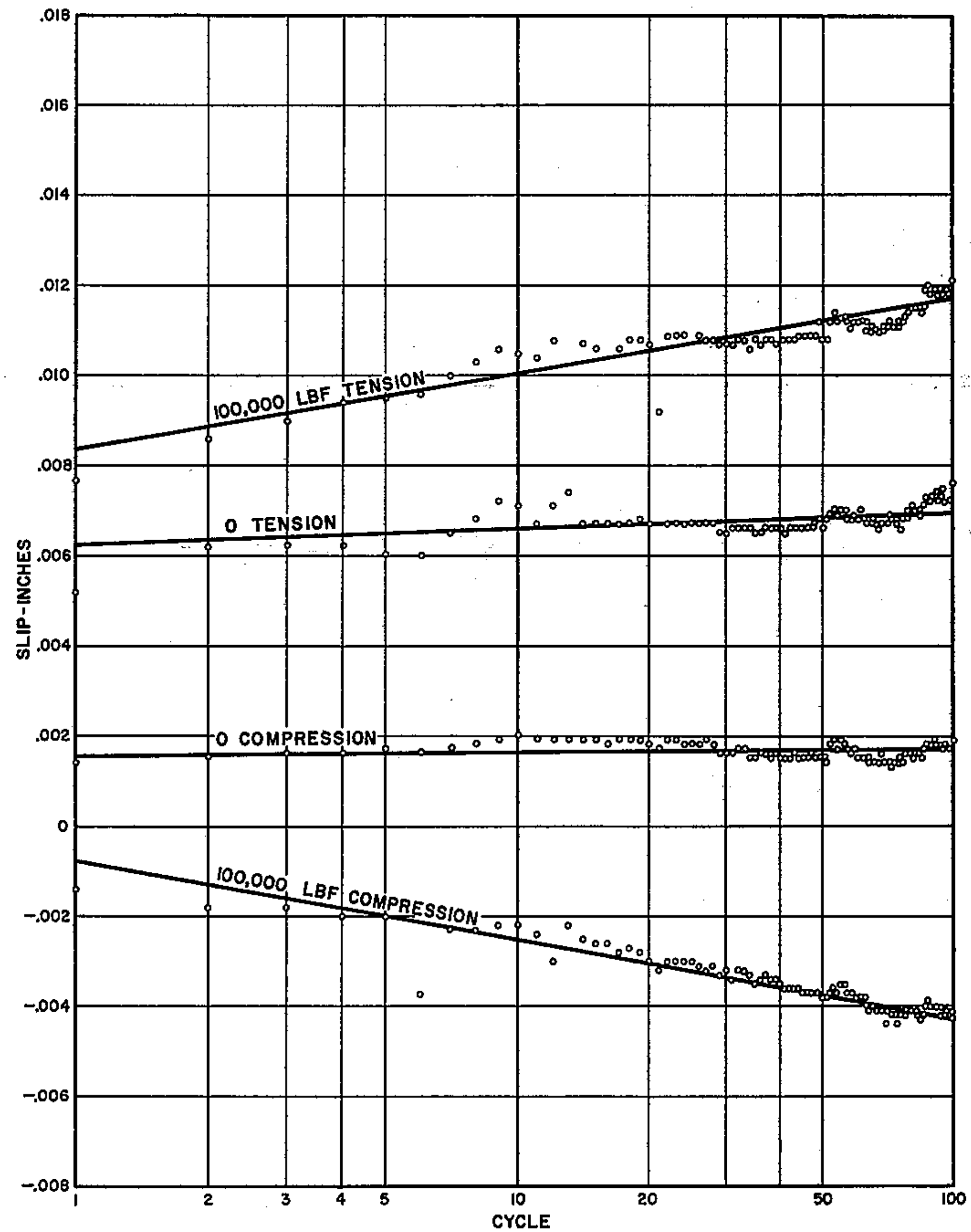
SPEC. NO. 2F-18S - A432G TOP
DATE NOVEMBER 1, 1966
MANUFACTURER: COLUMBIA
HEAT NO. 33884

LEGEND
- ——— CYCLE NO. 1
- ········ CYCLE NO. 51
- — — — CYCLE NO. 99

HYSTERESIS DIAGRAM



LIMIT DIAGRAM

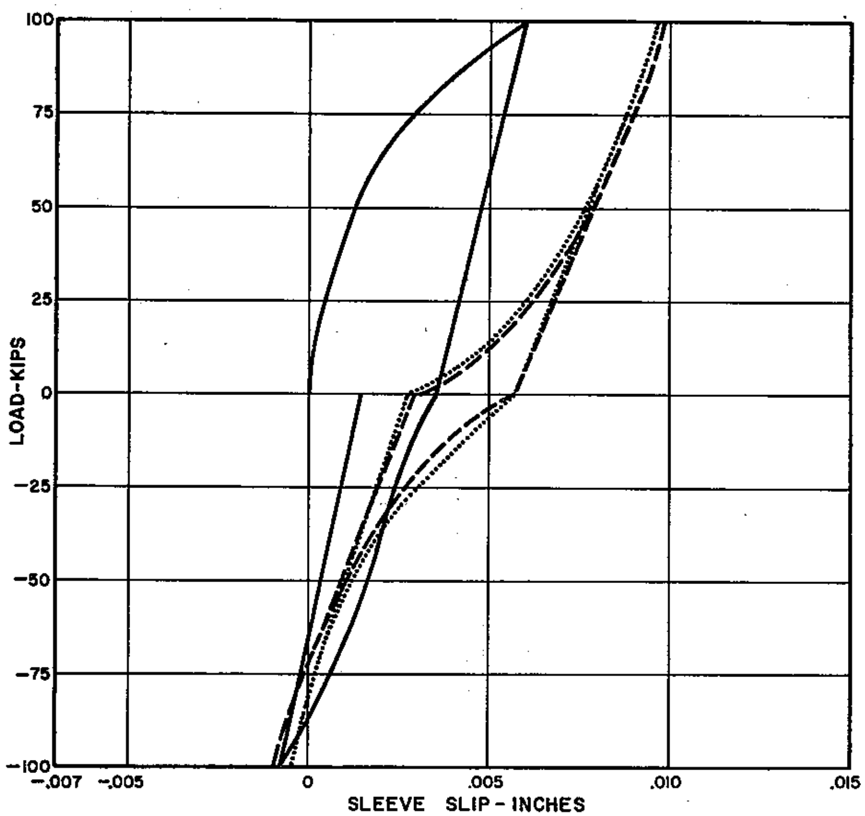


SLEEVE WITH METAL FILLER
FATIGUE TEST

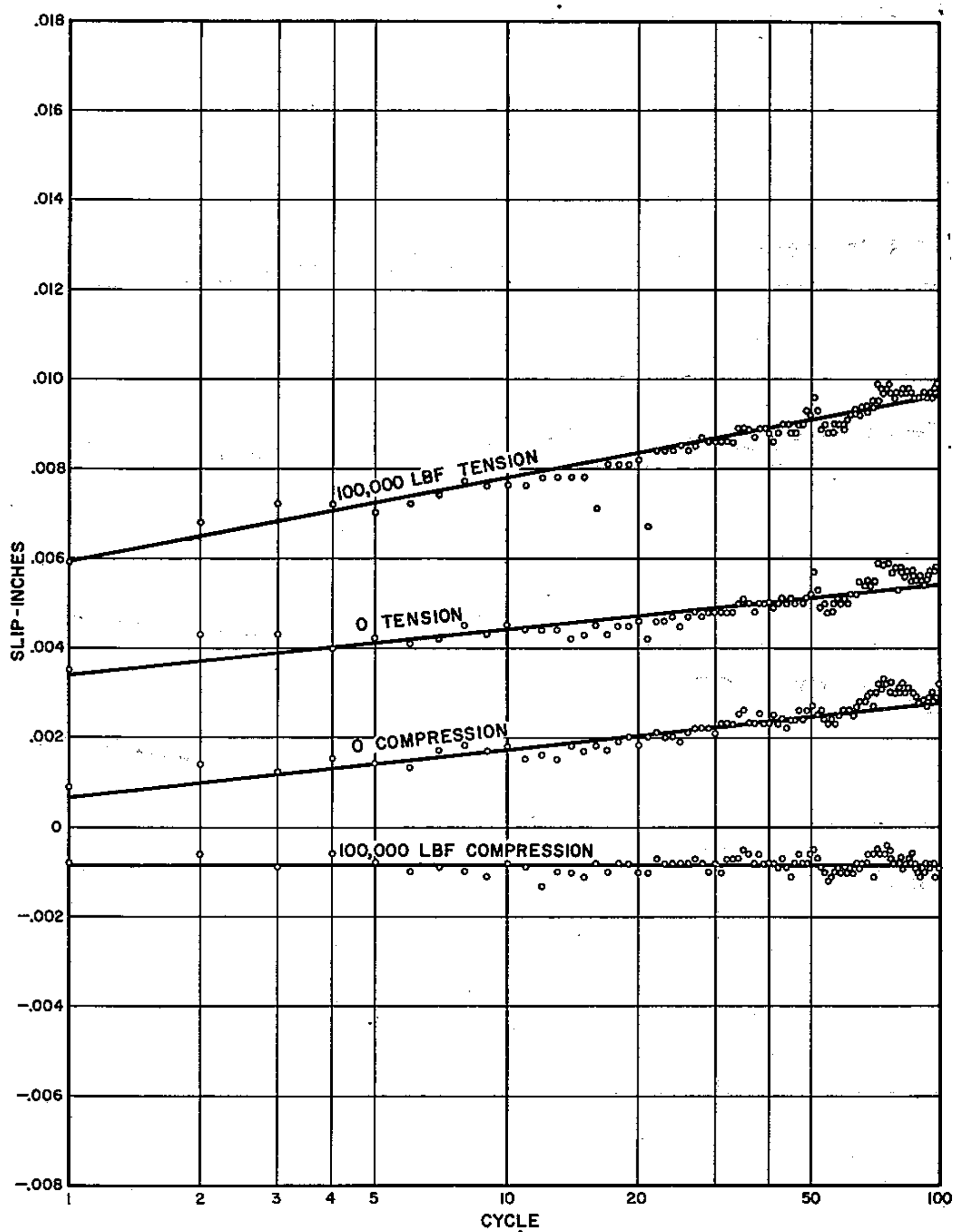
SPEC. NO. 2F - 18S - A432G BOTTOM
DATE NOVEMBER 1, 1966
MANUFACTURER: COLUMBIA
HEAT NO. 33884

LEGEND
- CYCLE NO. 1 (solid)
- CYCLE NO. 51 (dotted)
- CYCLE NO. 99 (dashed)

HYSTERESIS DIAGRAM



LIMIT DIAGRAM

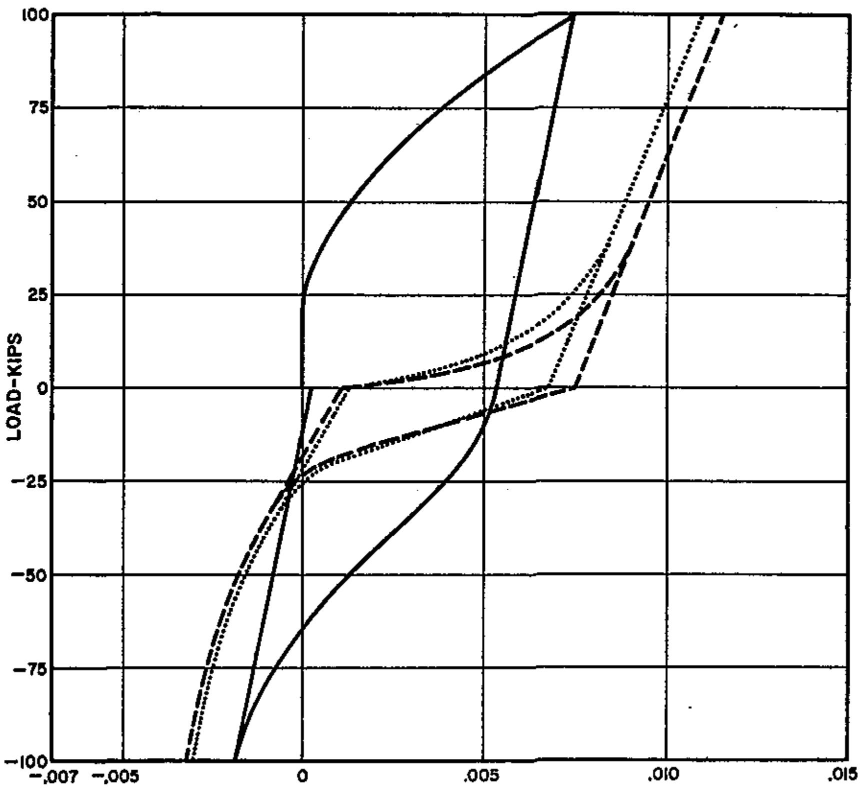


SLEEVE WITH METAL FILLER
FATIGUE TEST

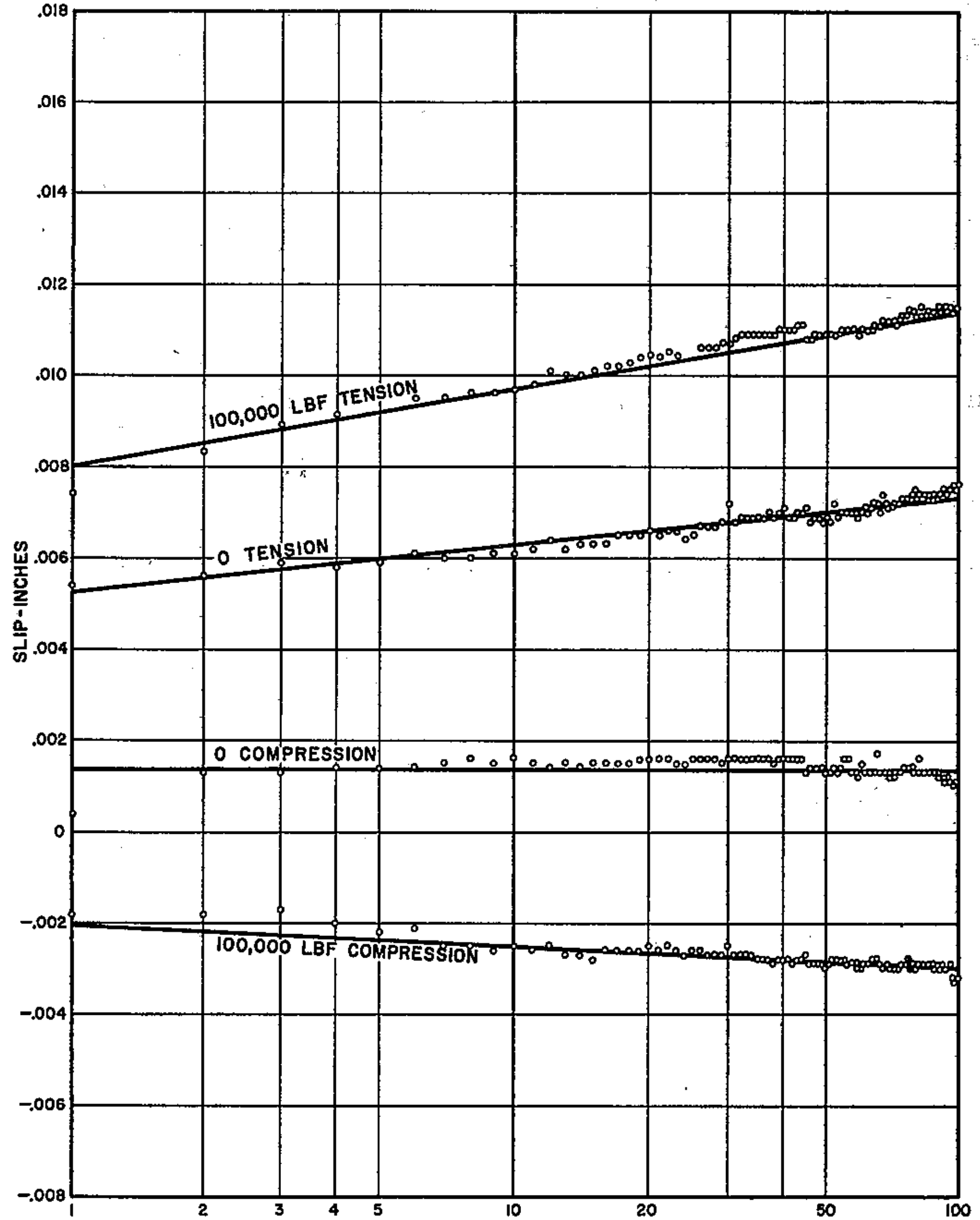
SPEC. NO. 3F-18S-A408G TOP
DATE DECEMBER 7, 1966
MANUFACTURER: COLUMBIA
HEAT NO. 33522

LEGEND
CYCLE NO. 1
CYCLE NO. 50
CYCLE NO. 99

HYSTERESIS DIAGRAM



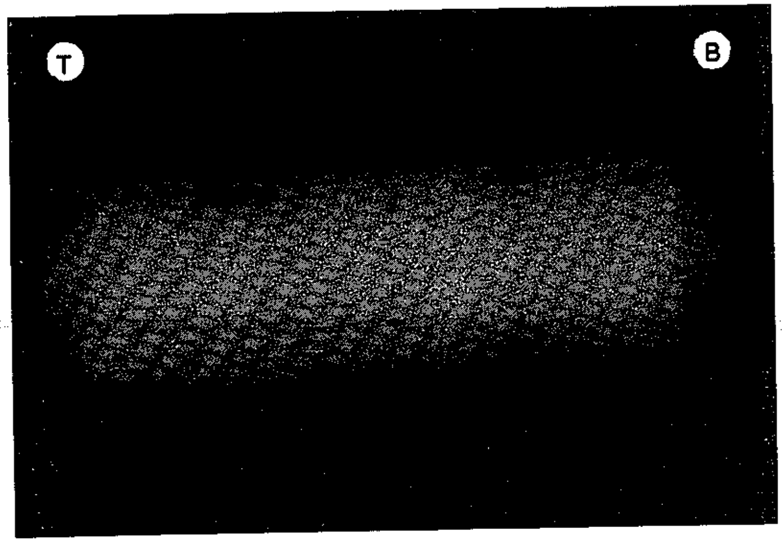
LIMIT DIAGRAM



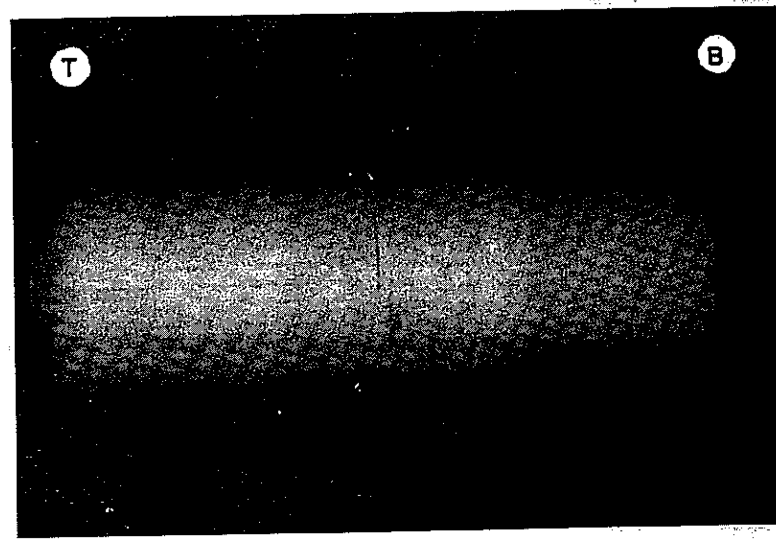
APPENDIX D

RADIOGRAPHS

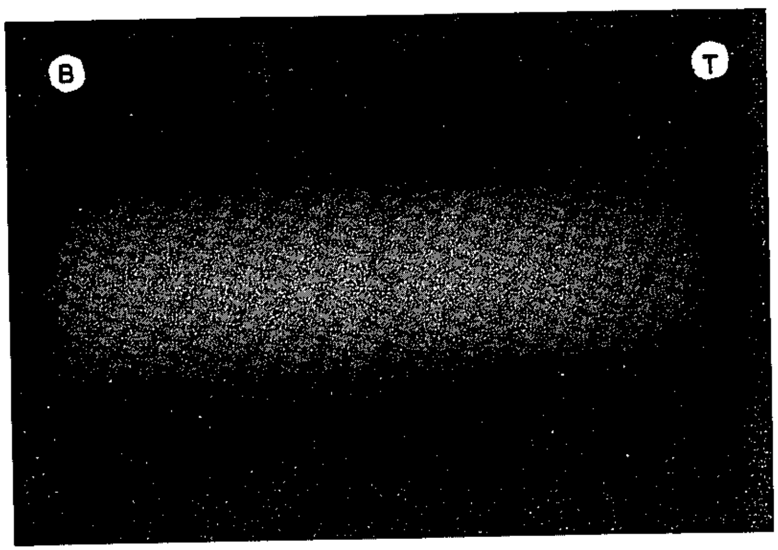
BEFORE FATIGUE TEST PHASE #1



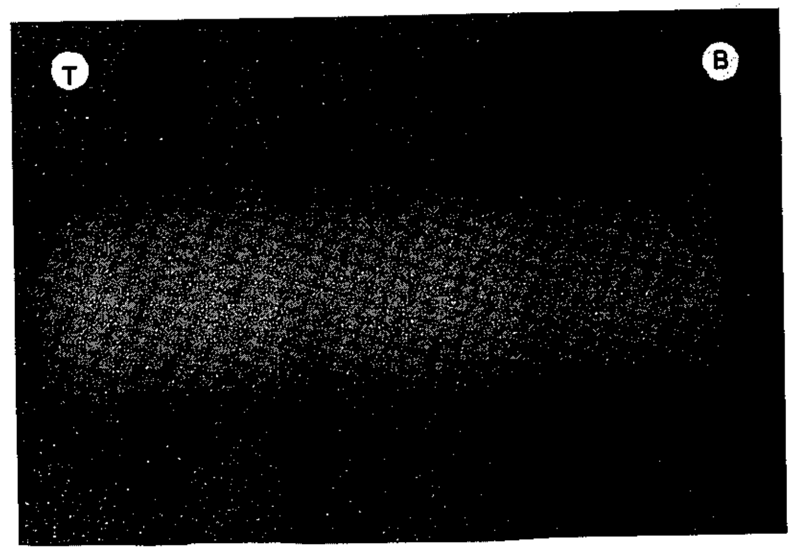
01F 14S A432G



02F 18S A432G



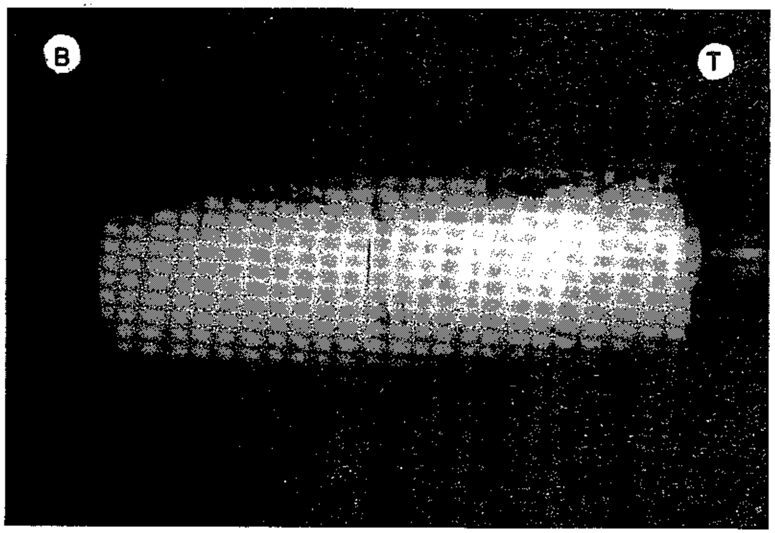
03F 18S A408G



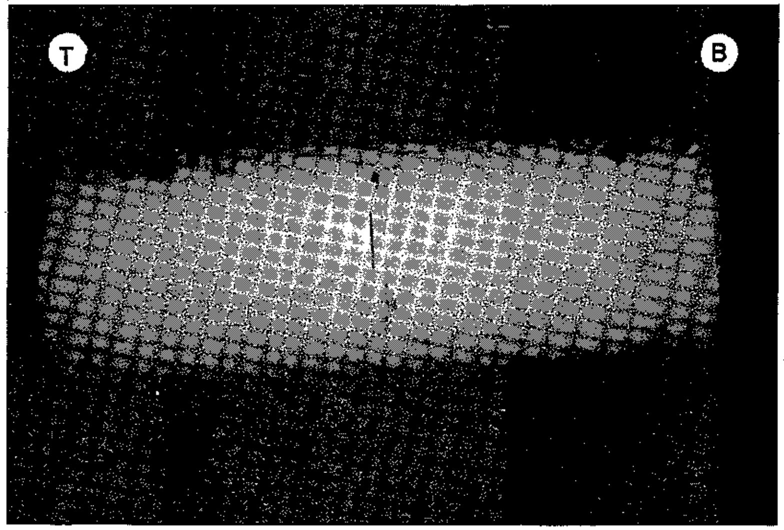
04F 14S A408G

RADIOGRAPHS

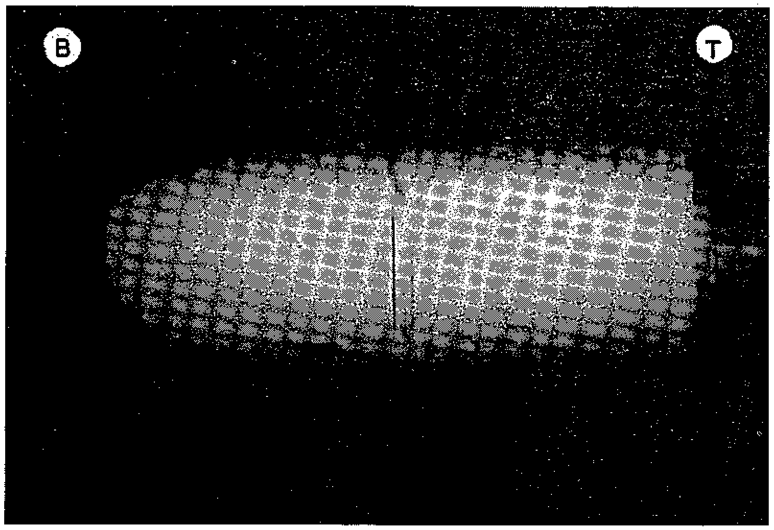
AFTER FATIGUE TEST PHASE #1



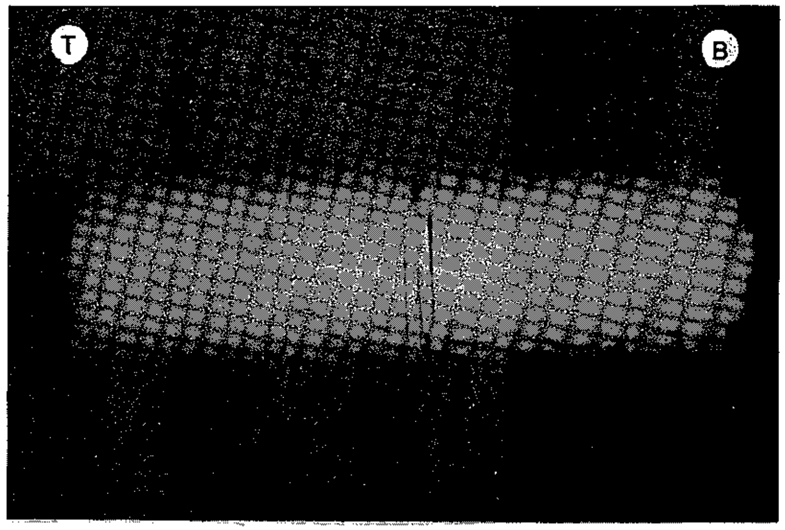
01F 14S A432G



02F 18S A432G



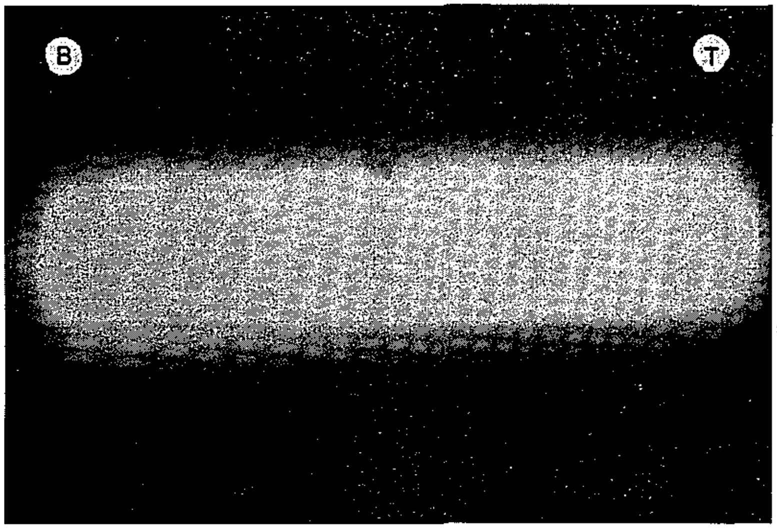
03F 18S A408G



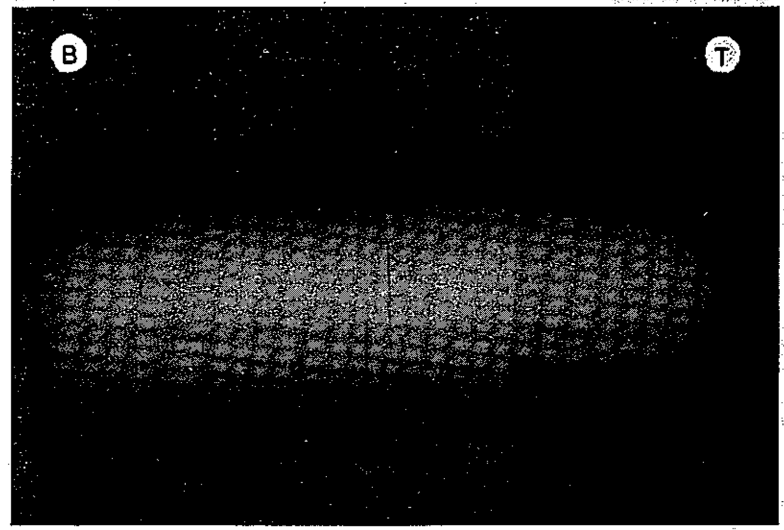
04F 14S A408G

RADIOGRAPHS

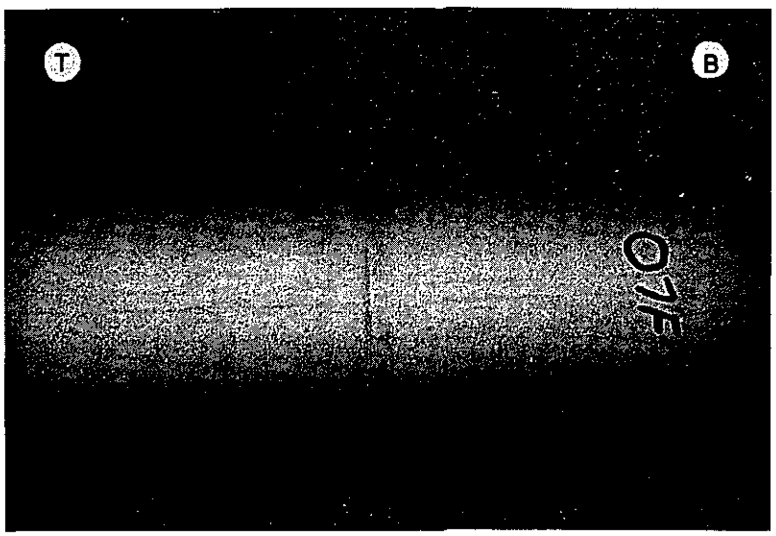
BEFORE FATIGUE TEST PHASE #2



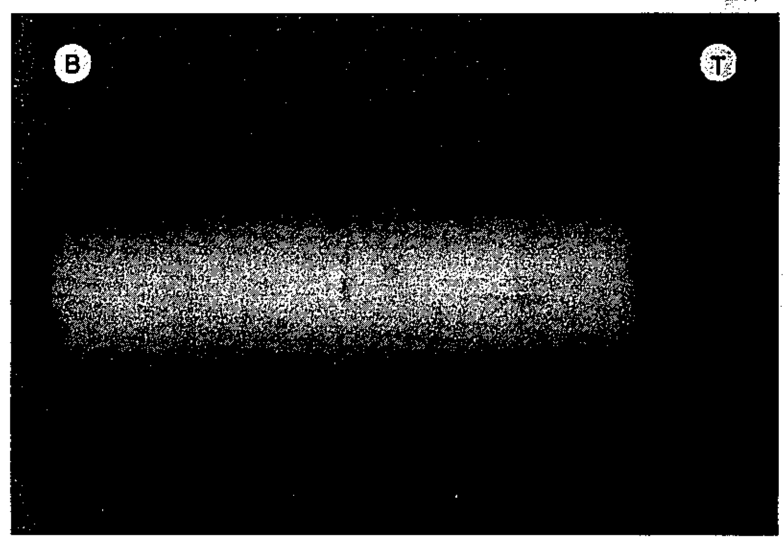
05F 14S A432G



06F 18S A432G



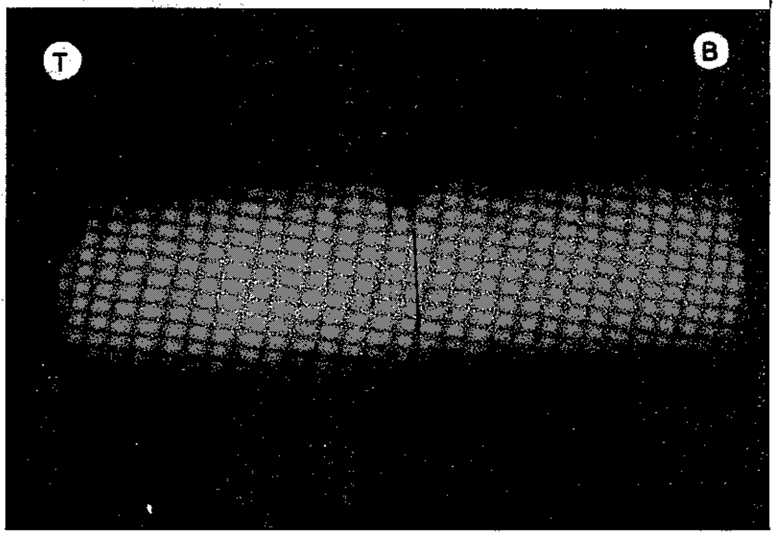
07F 18S A408G



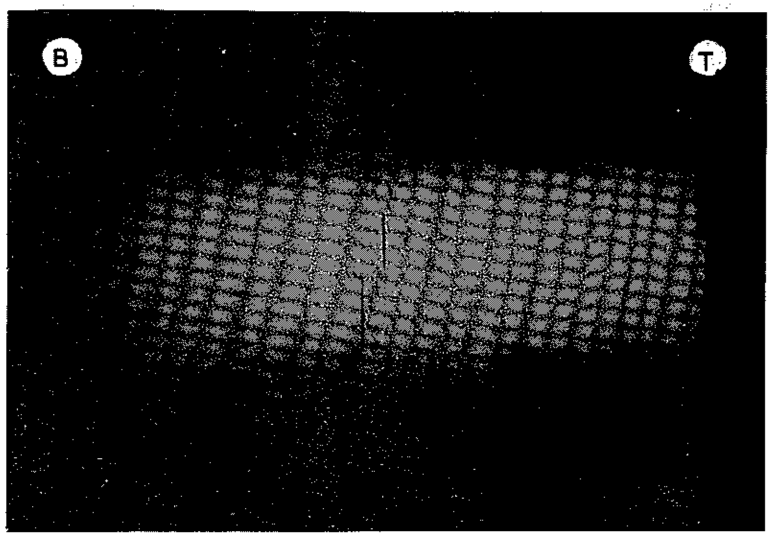
08F 14S A408G

RADIOGRAPHS

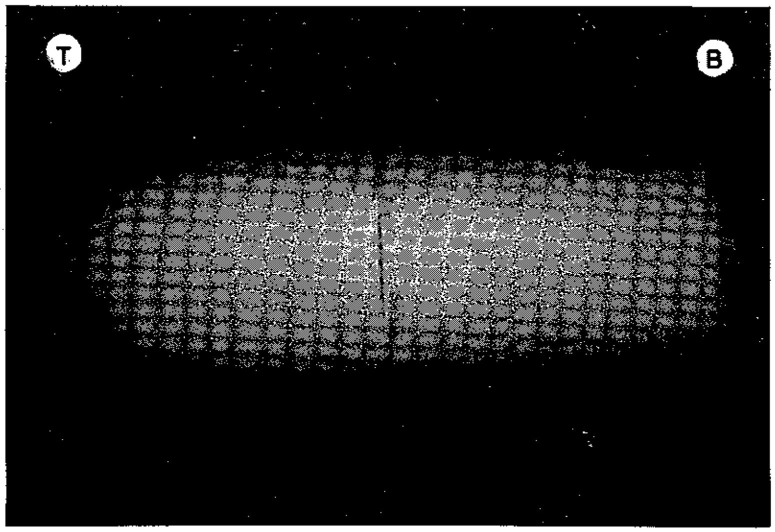
AFTER FATIGUE TEST PHASE #2



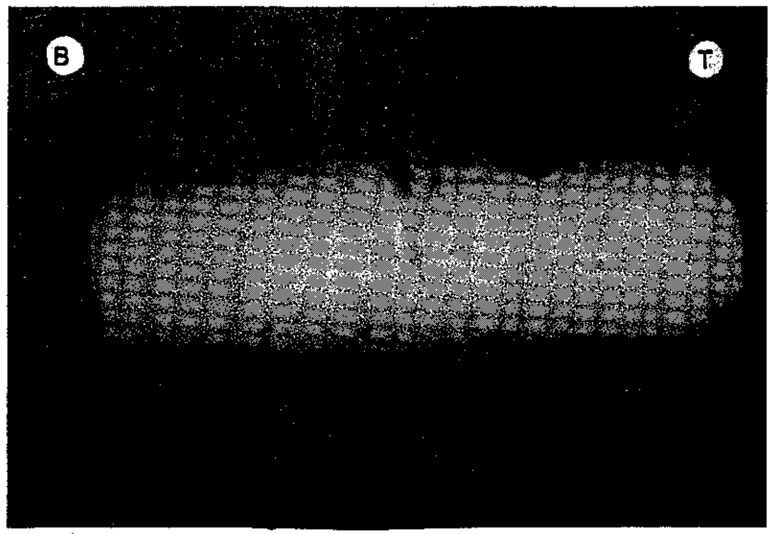
05F 14S A432G



06F 18S A432G



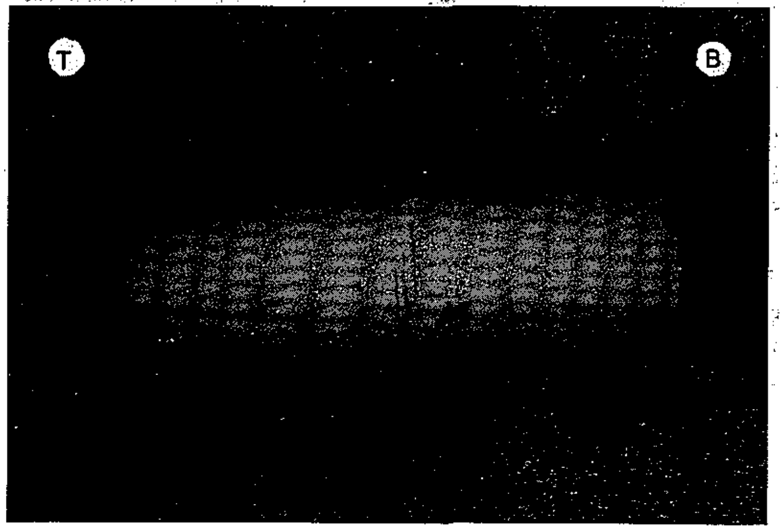
07F 18S A408G



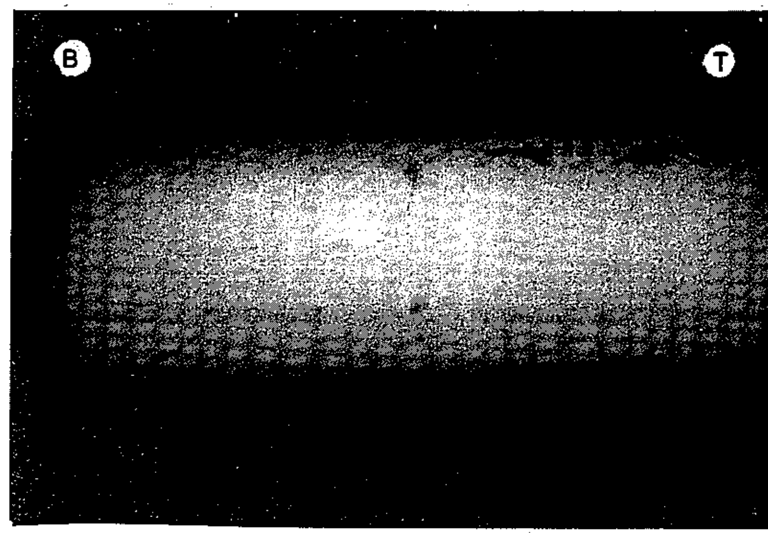
08F 14S A408G

RADIOGRAPHS

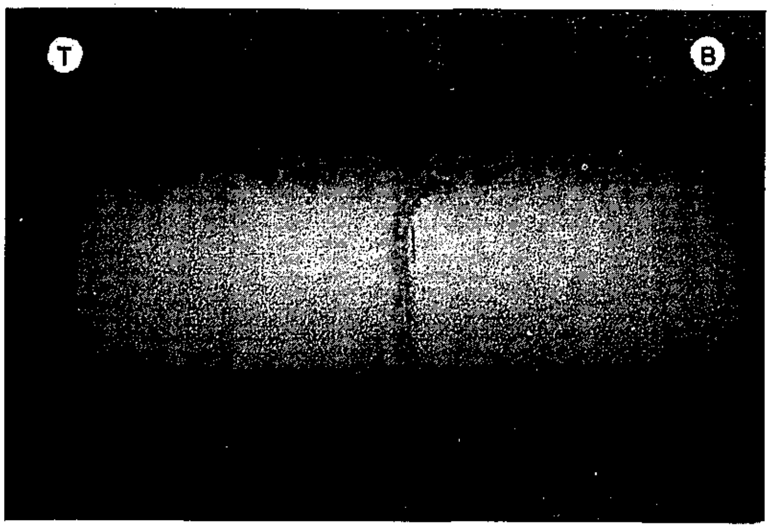
BEFORE FATIGUE TEST PHASE # 3



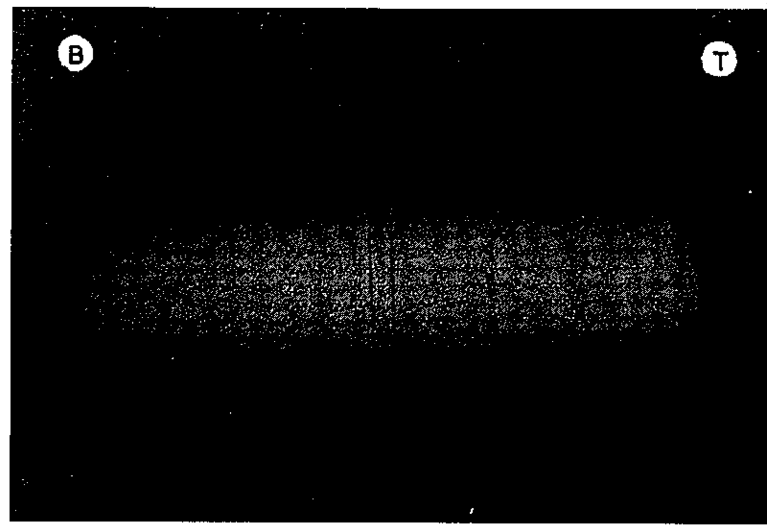
09F 14S A432G



10F 18S A432G



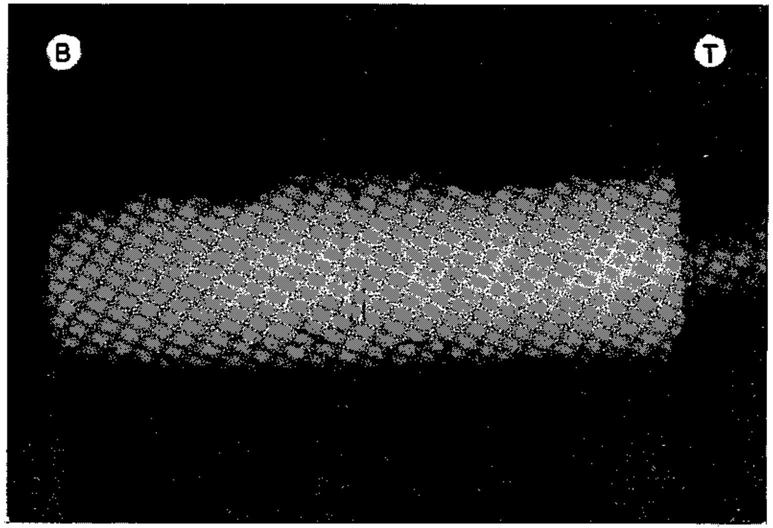
11F 18S A408G



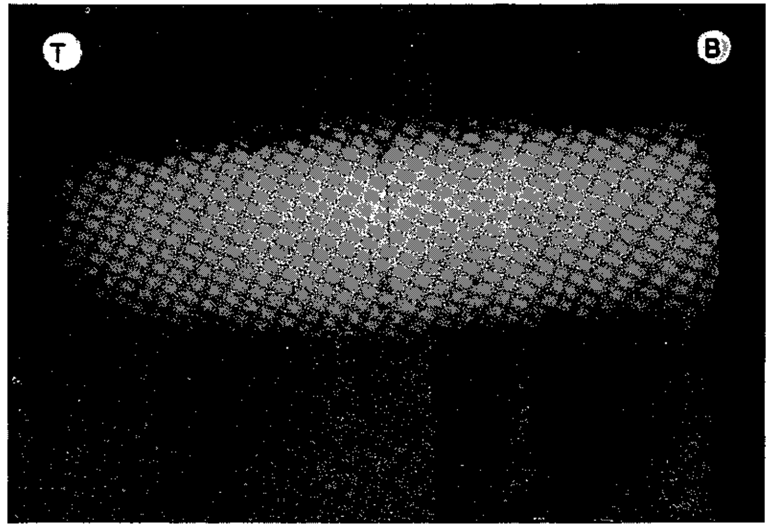
12F 14S A408G

RADIOGRAPHS

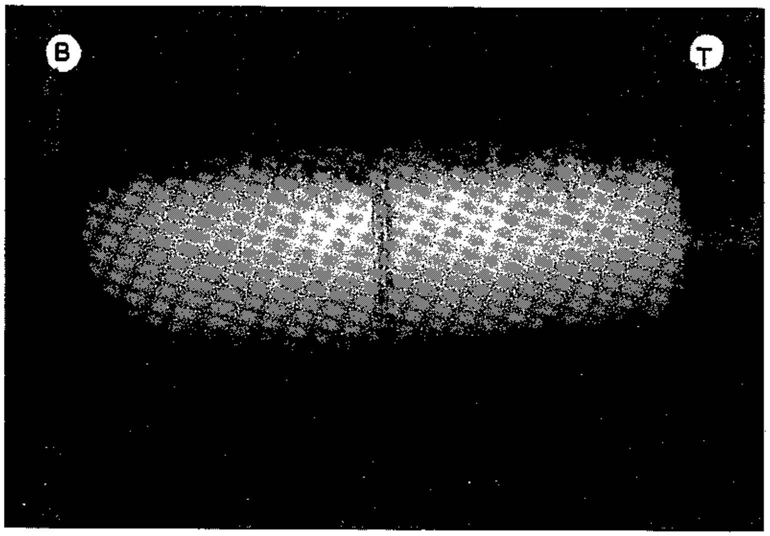
AFTER FATIGUE TEST PHASE # 3



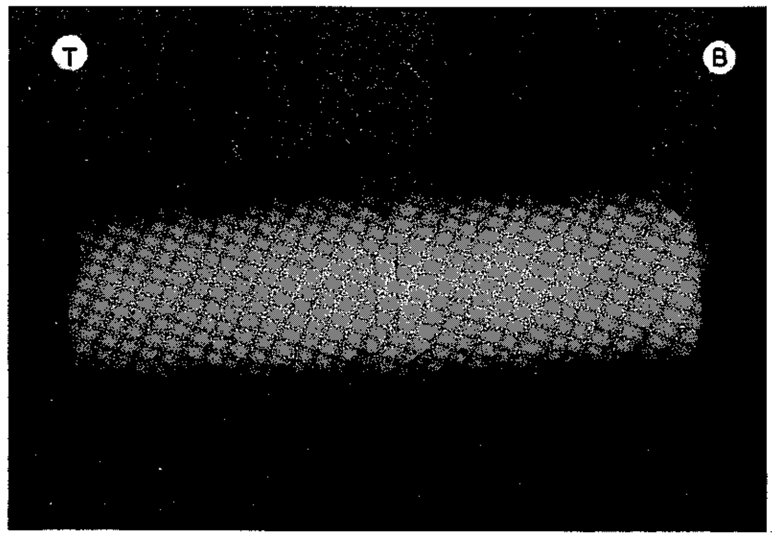
09F 14S A432G



10F 18S A432G



11F 18S A408G



12F 14S A408G

APPENDIX E

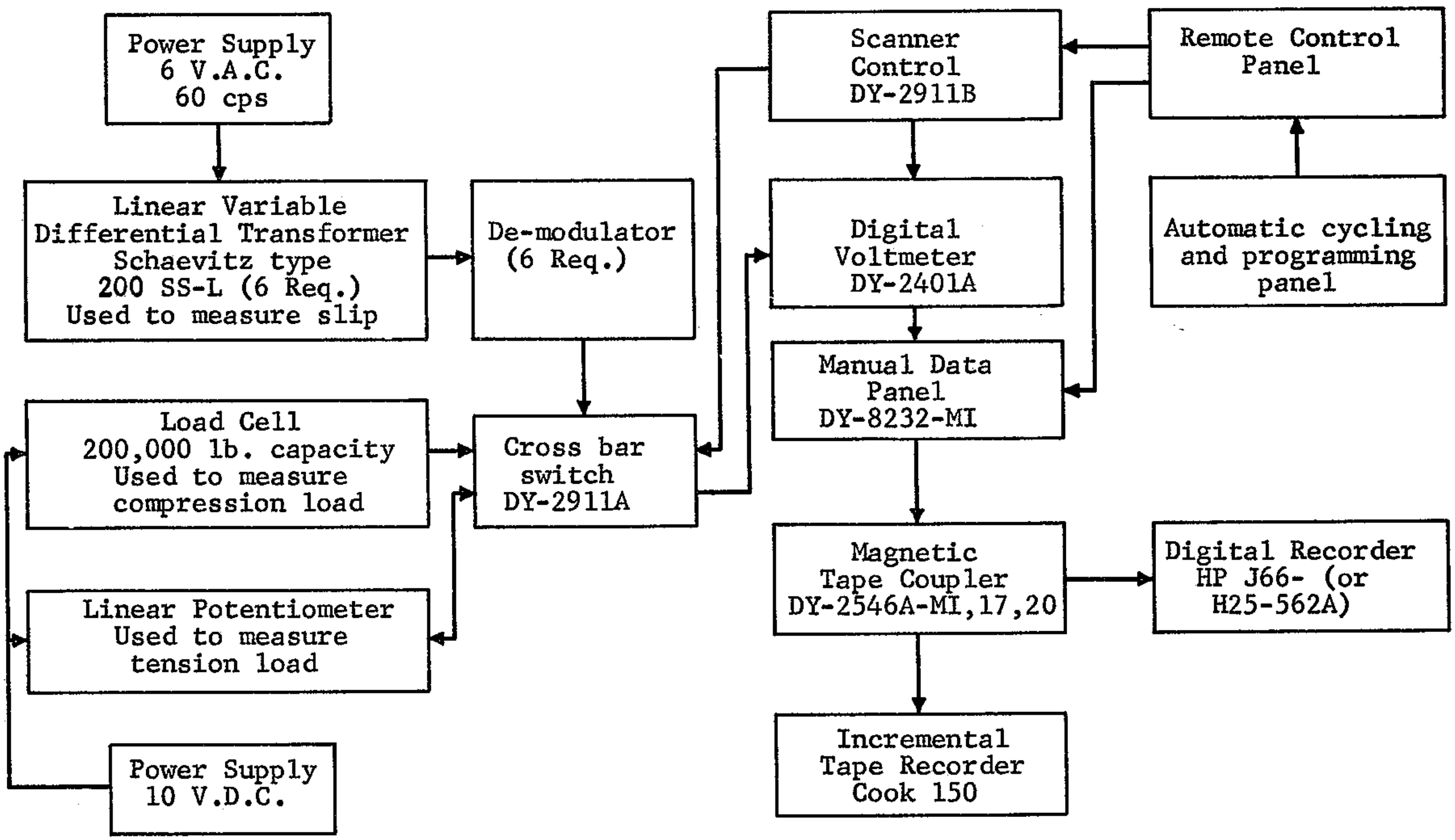
DATA ACQUISITION SYSTEM FOR COUPLER CREEP RESEARCH PROGRAM

A 200,000 lb. capacity load cell was used to measure compression loads. Tension loads were obtained via a linear potentiometer mechanically connected into the testing machine measuring system. The extensometer consisted of 6 Schaevitz model 200-SS-L linear variable differential transformers mounted on a frame as shown in Figures 5 and 6.

Extensometer and load data were recorded on both printed and magnetic tape. A Dymec #2911A guarded crossbar switch was used to switch the individual data circuits into the readout equipment. The crossbar switch was controlled by a Dymec #2911B crossbar scanner which also supplied channel identification to the recording equipment. Cycle number data were supplied by the automatic cycling and programming panel. The manual entry panel contained provision for supplying the recording equipment with 12 characters of digital information that could be set into the panel manually. These entries were used for test identification and date. The crossbar sequentially switched the data circuits into a Dymec #2401A integrating digital voltmeter. The digital voltmeter supplied 7 characters of digital information (5 data, 1 polarity, and 1 decimal point) to the recording equipment.

All of the information characters were supplied to a Dymec #2546 magnetic tape coupler which converted the information from parallel entry BCD form to serial entry IBM 7 channel NRZ form for entry into the magnetic tape recorder. The coupler also forwarded the information to the Hewlett Packard H25562A digital recorder which printed the records on paper tape. The magnetic tape recorder used was a Cook 150 incremental magnetic tape recorder.

INSTRUMENTATION SCHEMATIC

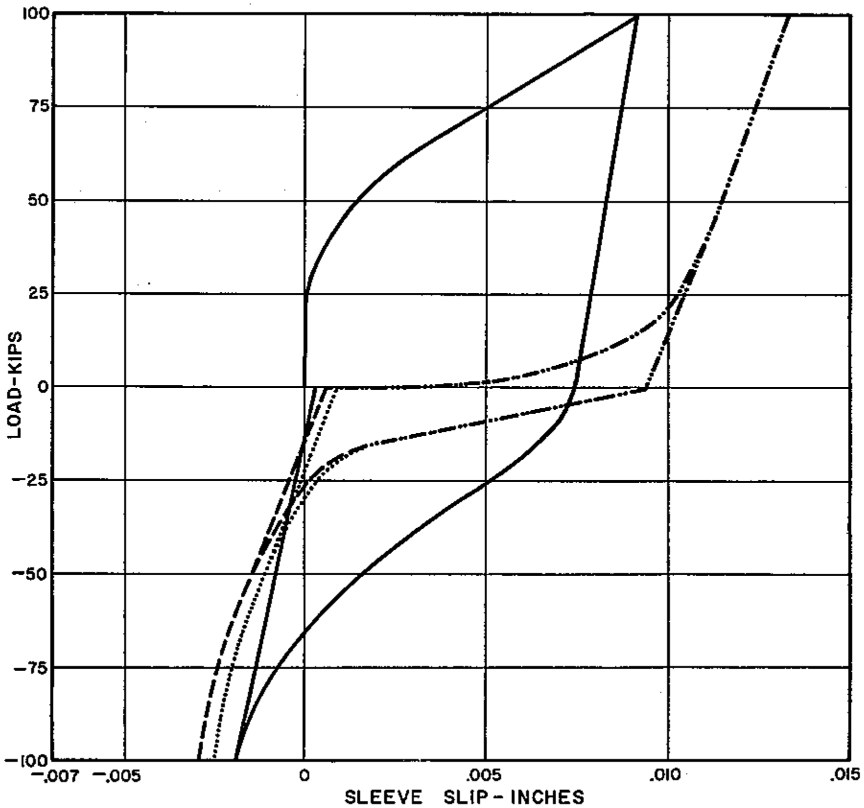


SLEEVE WITH METAL FILLER FATIGUE TEST

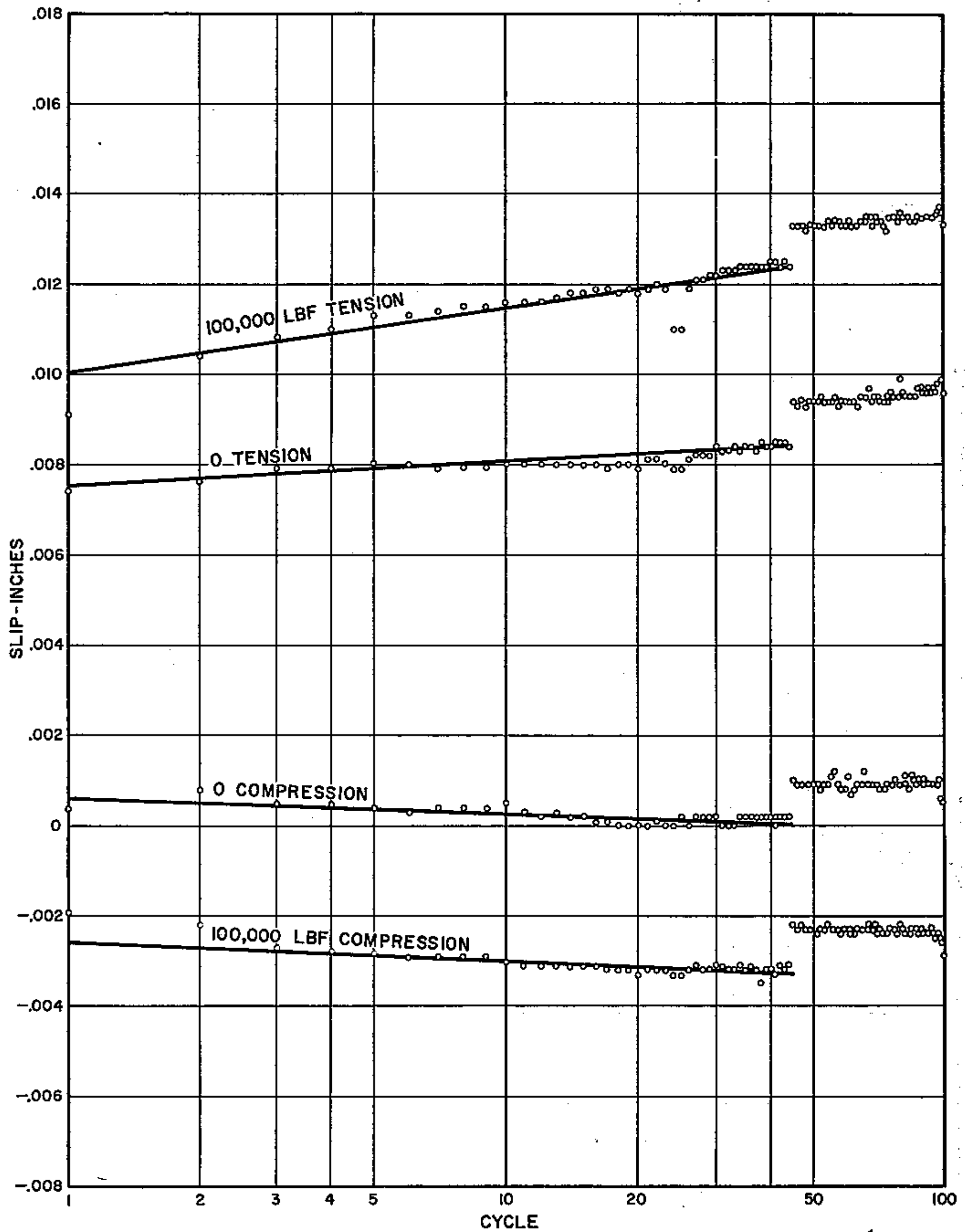
SPEC. NO. 3F-18F-A4086 BOTTOM
DATE DECEMBER 7, 1966
MANUFACTURER: COLUMBIA
HEAT NO. 33522

LEGEND
CYCLE NO. 1
CYCLE NO. 50
CYCLE NO. 99

HYSTERESIS DIAGRAM



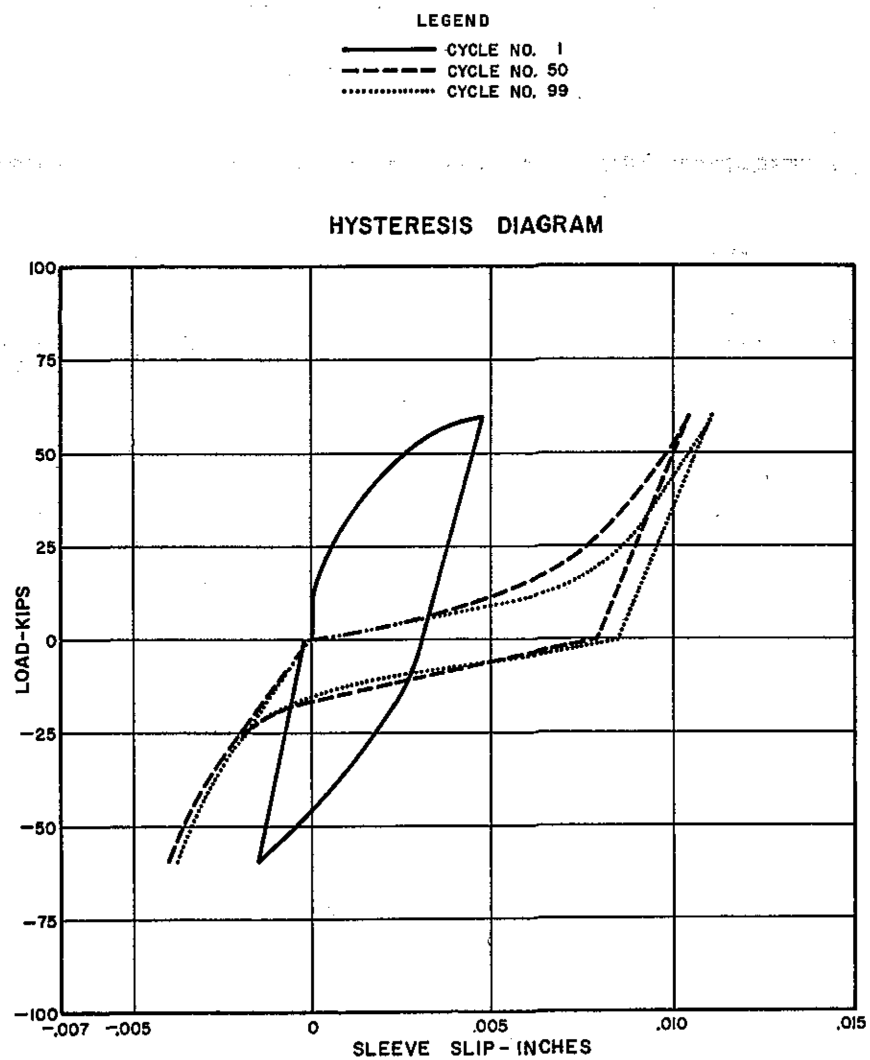
LIMIT DIAGRAM



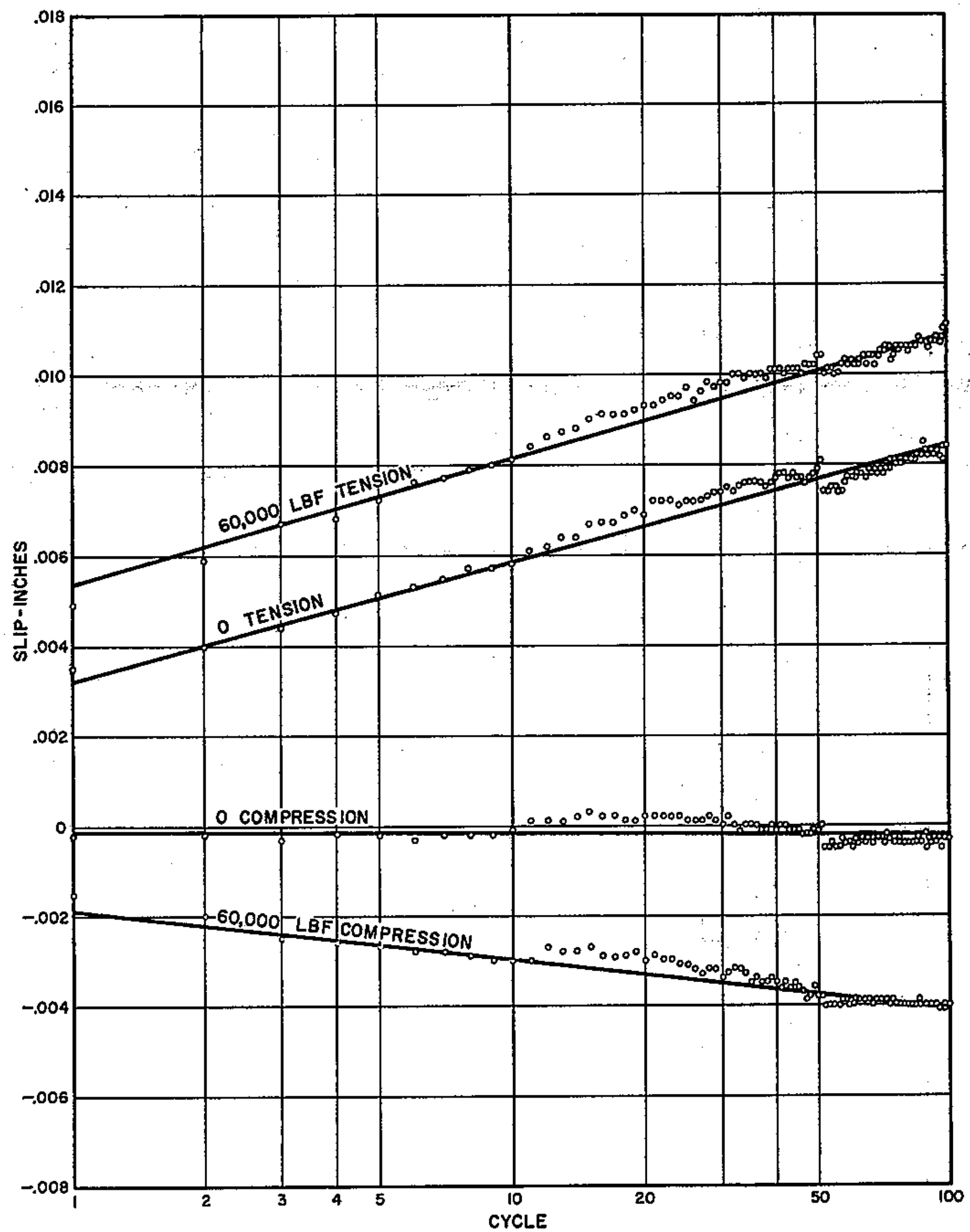
SLEEVE WITH METAL FILLER FATIGUE TEST

SPEC. NO. 4F-14S-A4086 TOP
DATE DECEMBER 20, 1966
MANUFACTURER: COLUMBIA
HEAT NO. 33918

HYSTERESIS DIAGRAM



LIMIT DIAGRAM

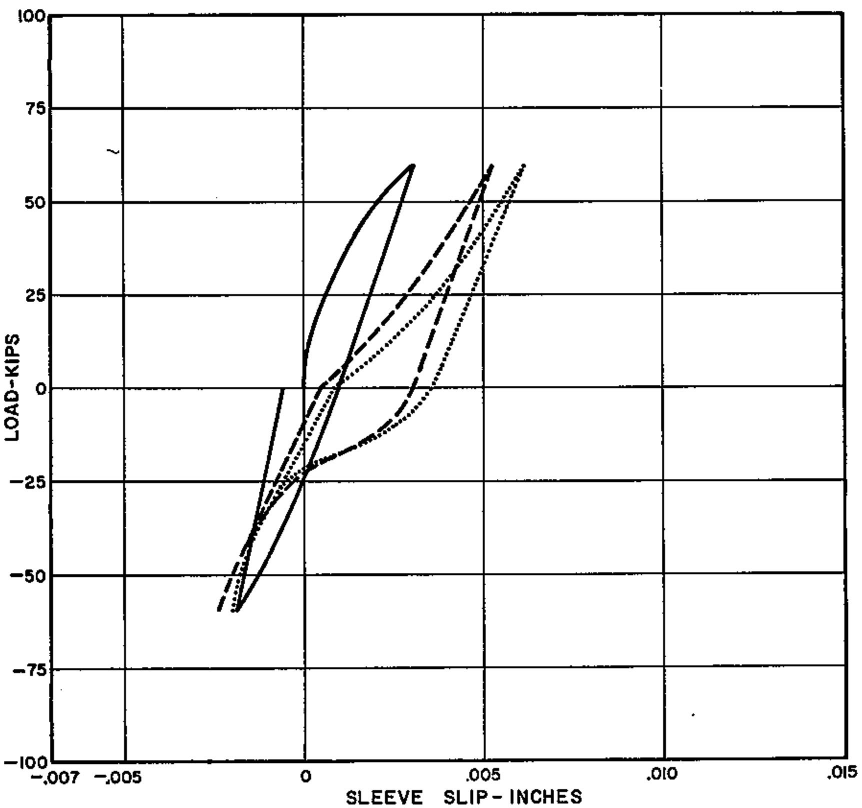


SLEEVE WITH METAL FILLER
FATIGUE TEST

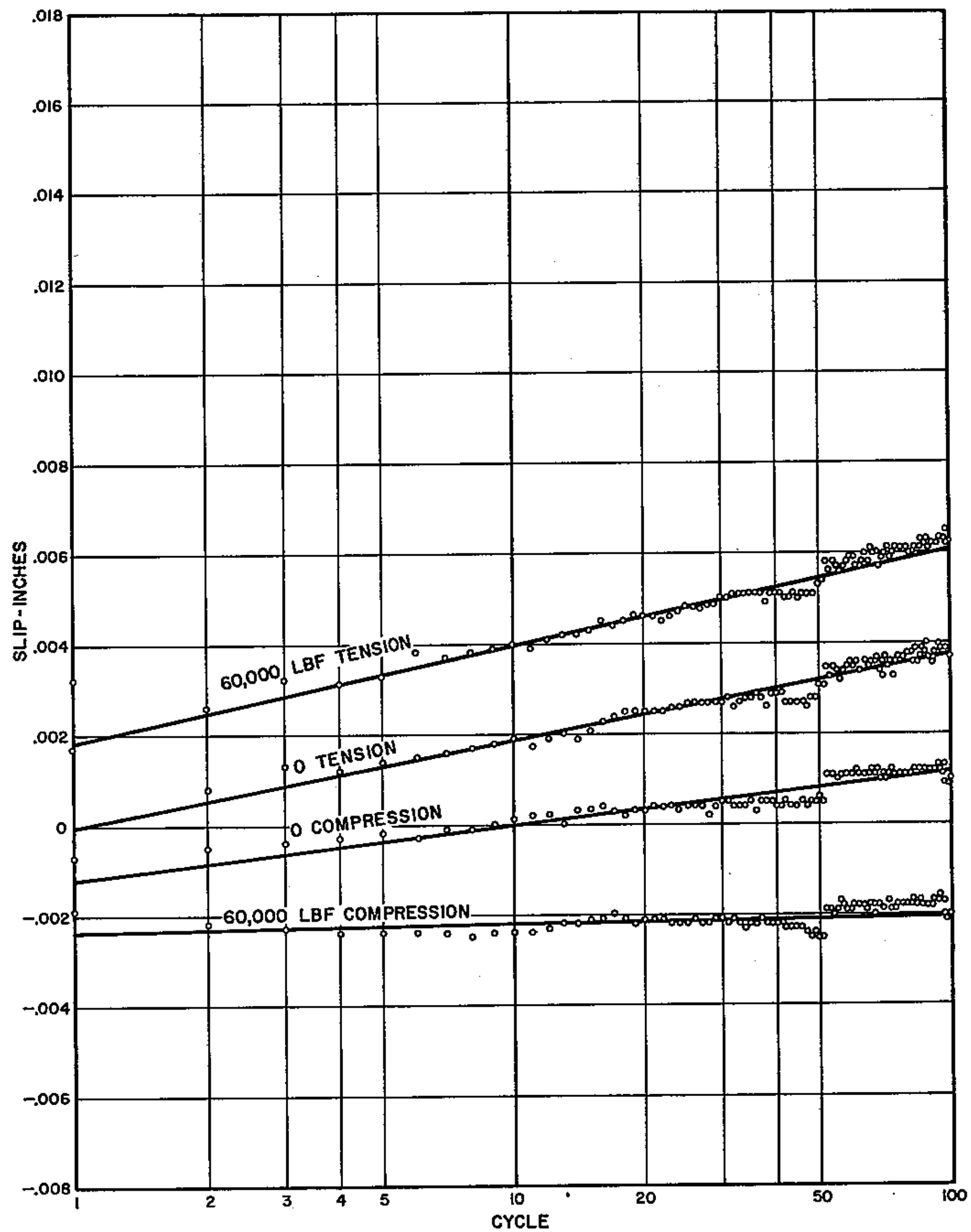
SPEC. NO. 4F-14S-A4086 BOTTOM
DATE DECEMBER 20, 1966
MANUFACTURER: COLUMBIA
HEAT NO. 33918

LEGEND
—— CYCLE NO. 1
– – – CYCLE NO. 50
········ CYCLE NO. 99

HYSTERESIS DIAGRAM



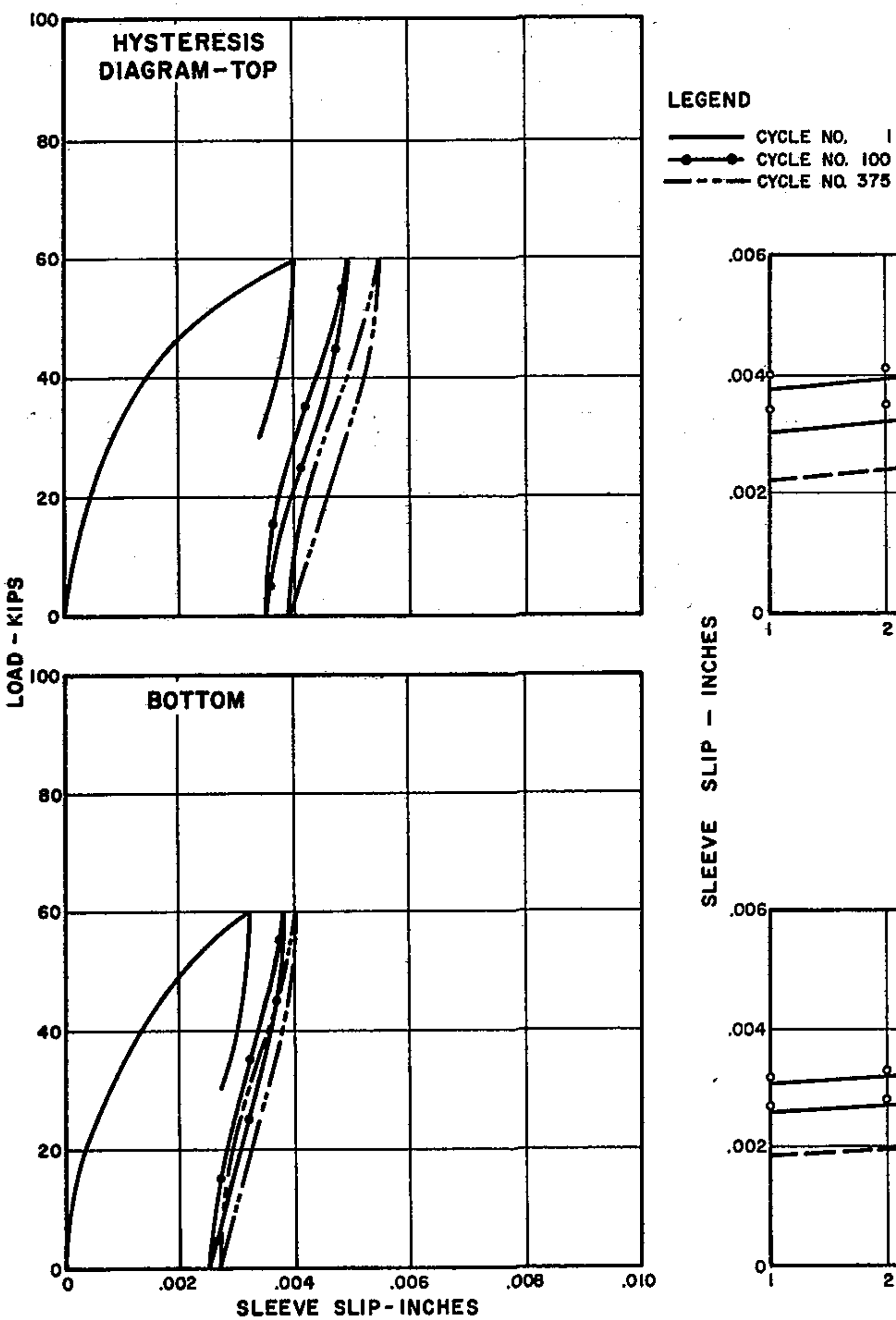
LIMIT DIAGRAM

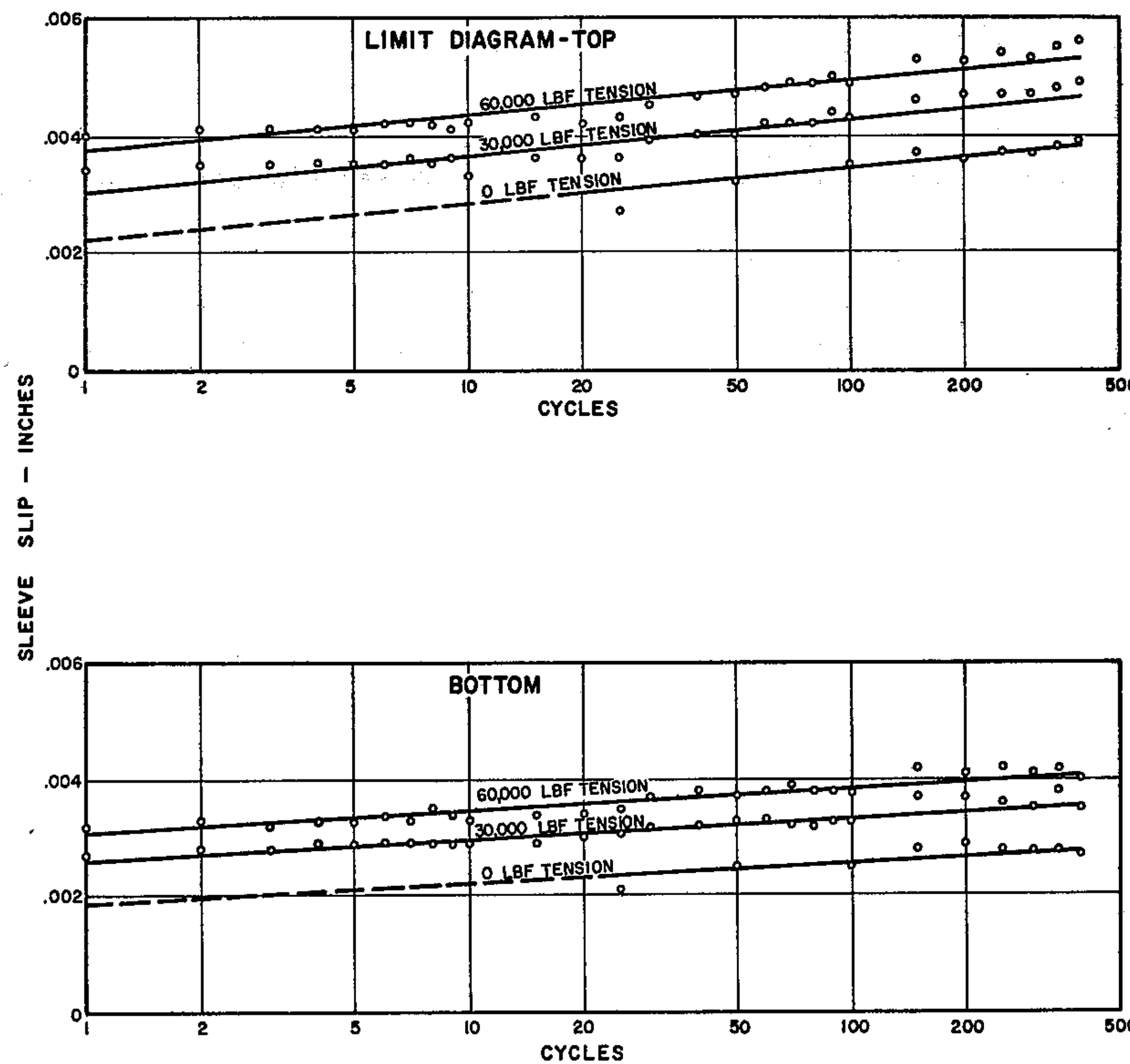


APPENDIX C-2

SLEEVE WITH METAL FILLER
FATIGUE TEST

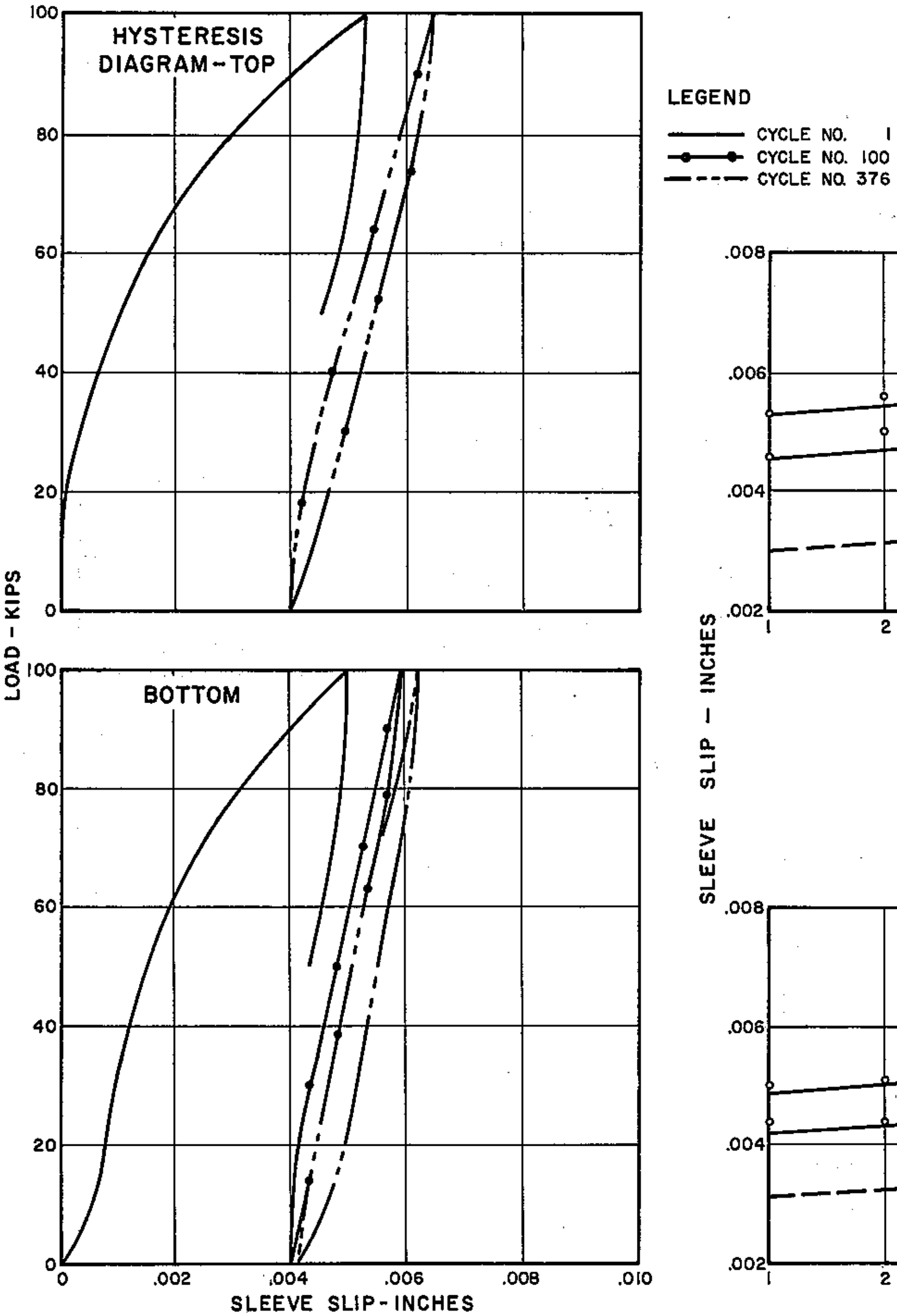
SPEC. NO. 5F-14S-A408G
DATE JANUARY 18, 1967
MANUFACTURER: COLUMBIA
HEAT NO. 33918

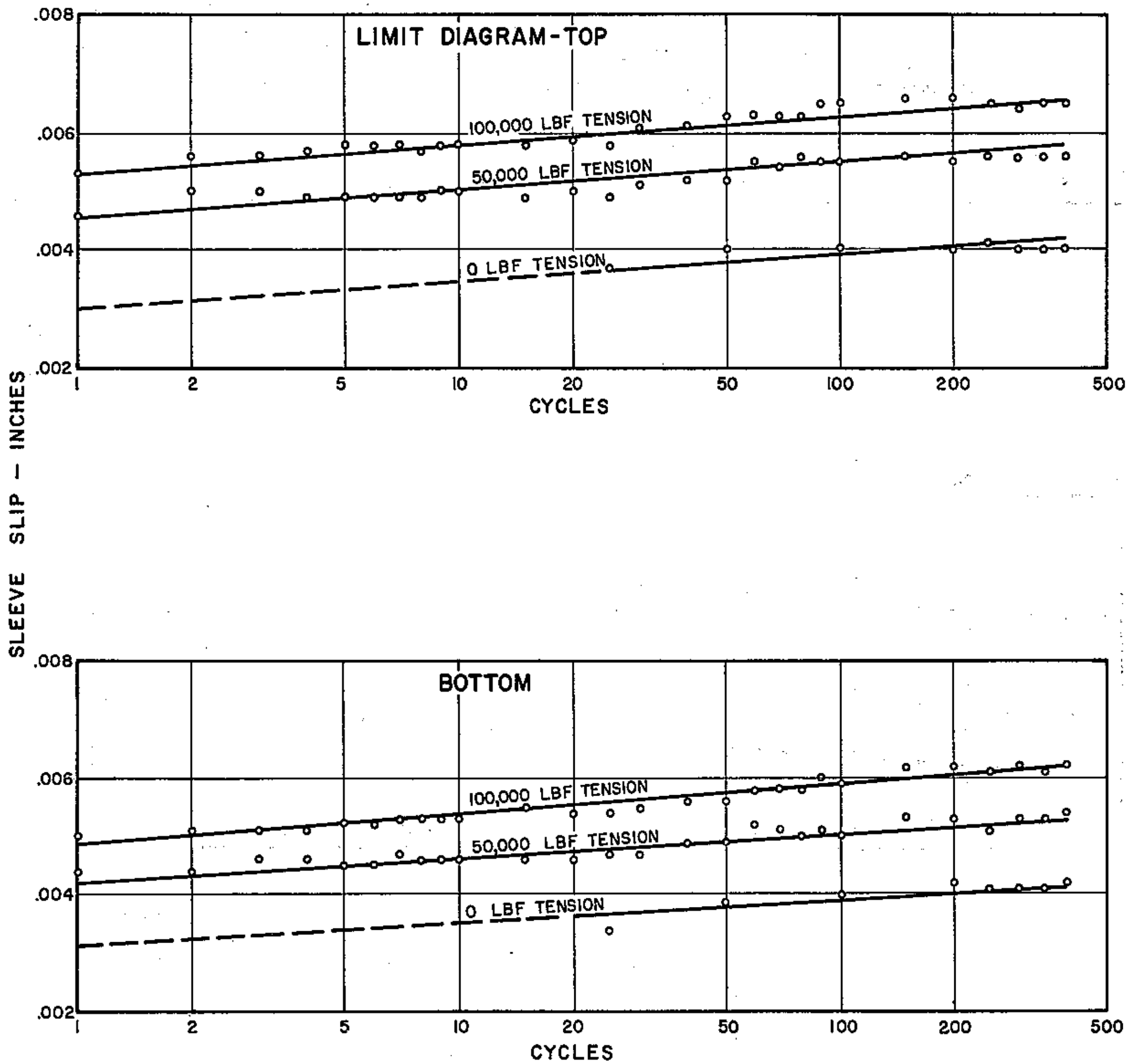




SLEEVE WITH METAL FILLER
FATIGUE TEST

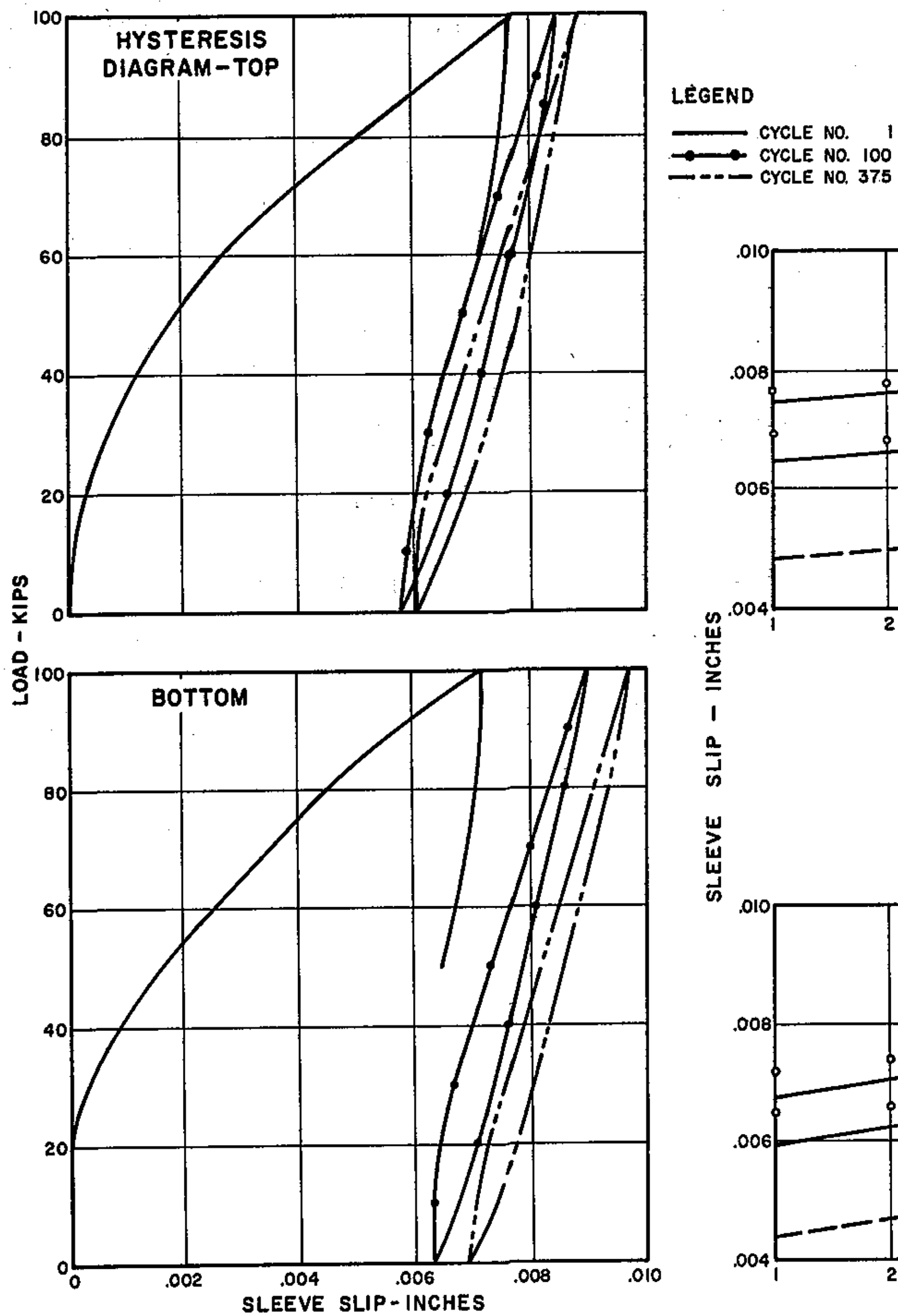
SPEC. NO. 6F-18S-A408G
DATE JANUARY 25, 1967
MANUFACTURER: COLUMBIA
HEAT NO. 33522

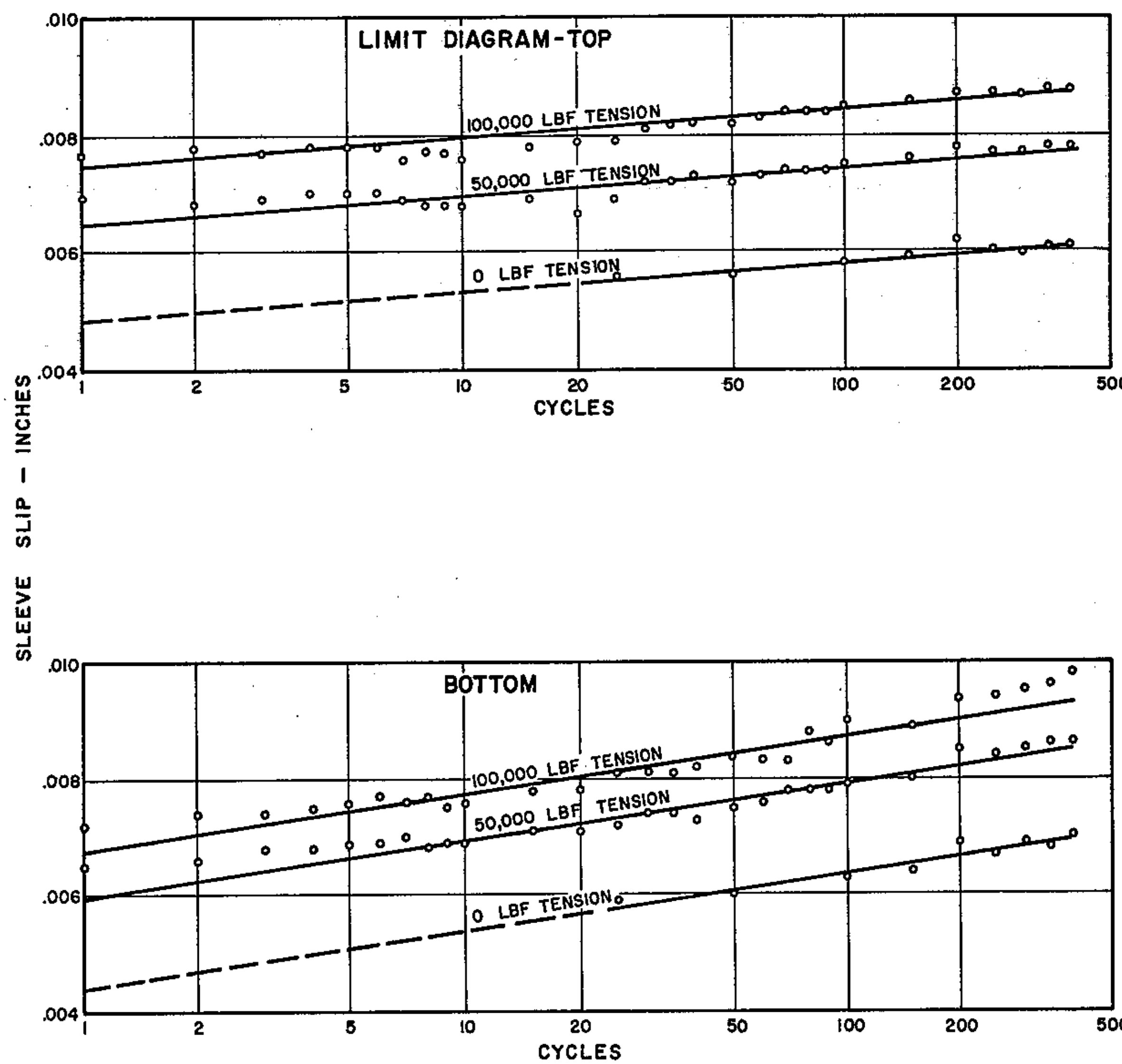




SLEEVE WITH METAL FILLER
FATIGUE TEST

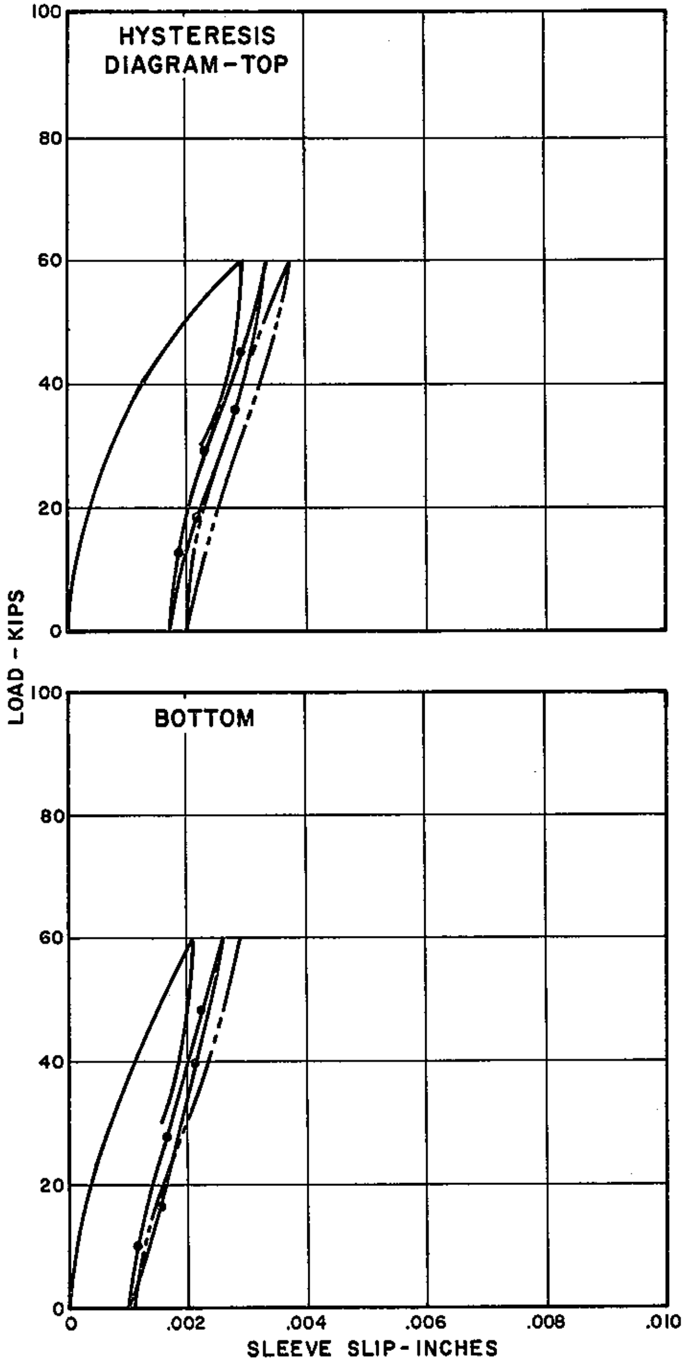
SPEC. NO. 7F-18S-A432G
DATE FEBRUARY 1, 1967
MANUFACTURER: COLUMBIA
HEAT NO. 33884

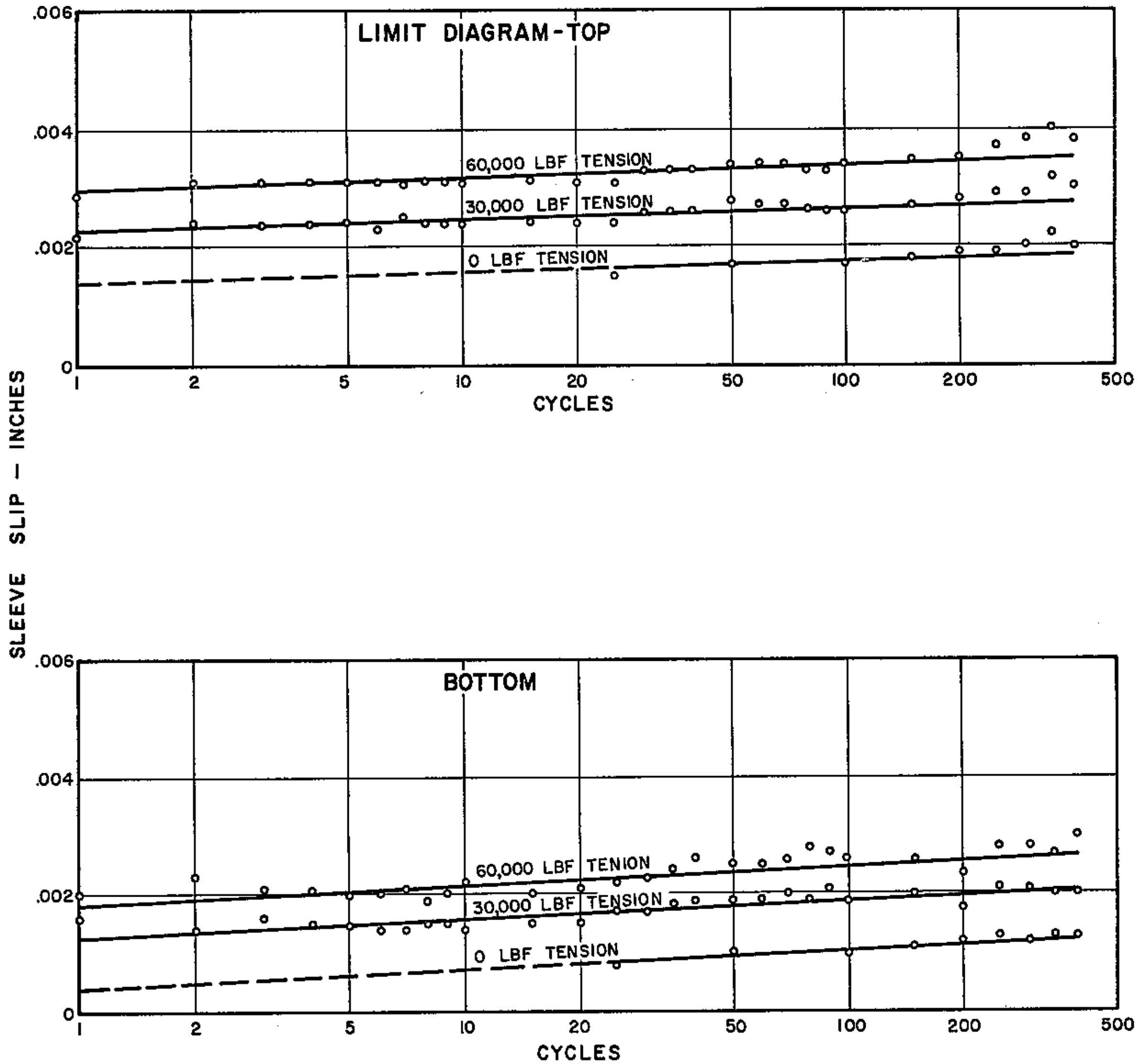




SLEEVE WITH METAL FILLER
FATIGUE TEST

SPEC. NO. 8F - 14S - A432G
DATE FEBRUARY 15, 1967
MANUFACTURER: COLUMBIA
HEAT NO. 43436

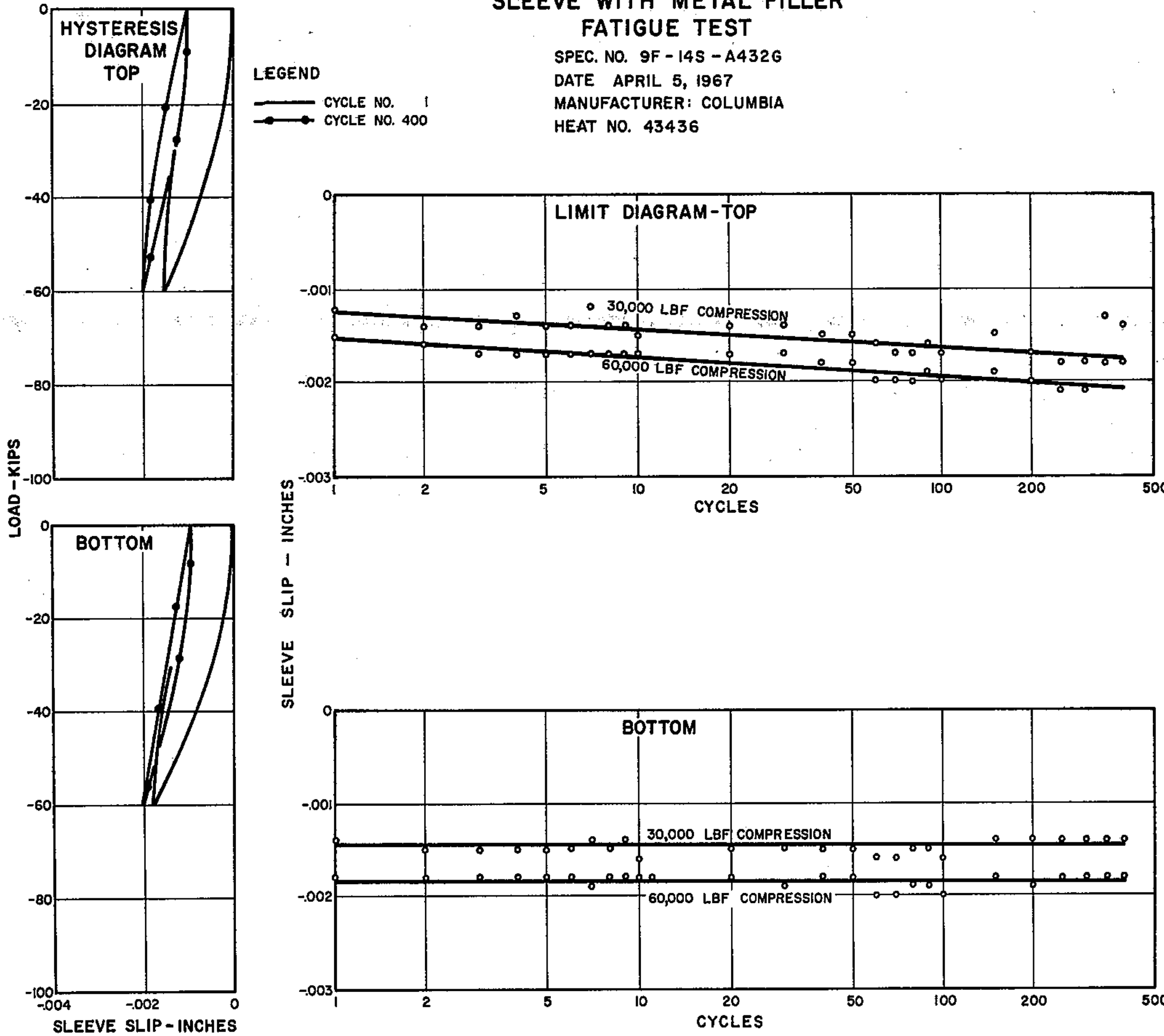




APPENDIX C-3

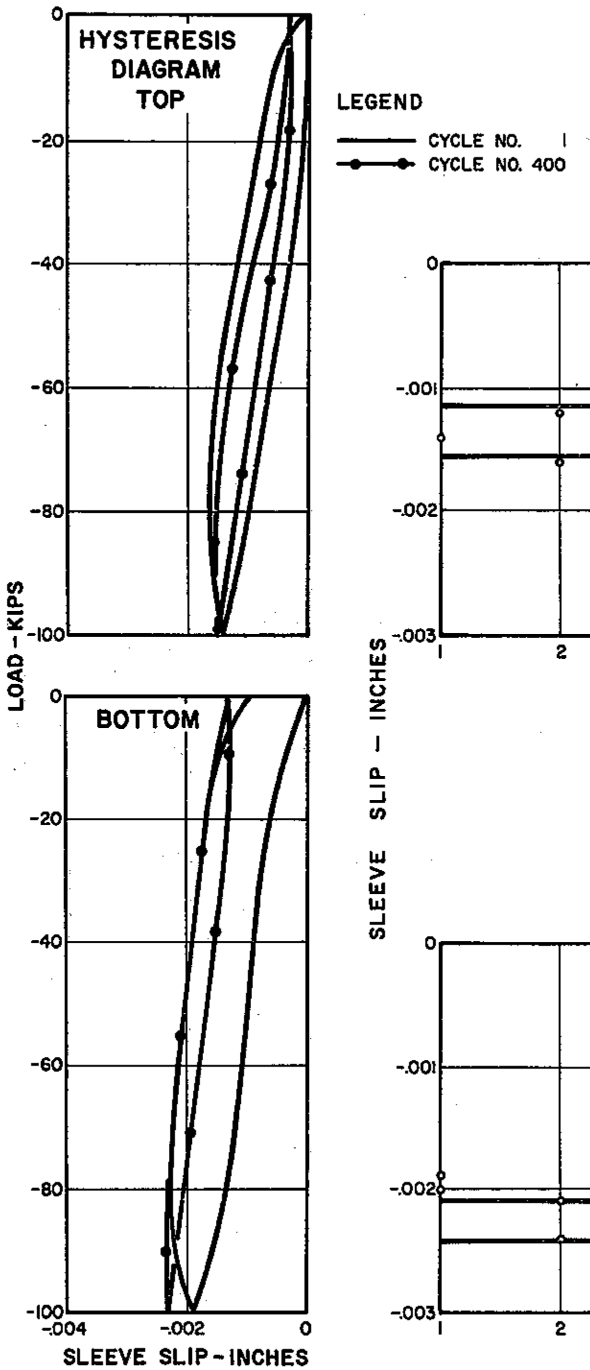
SLEEVE WITH METAL FILLER
FATIGUE TEST

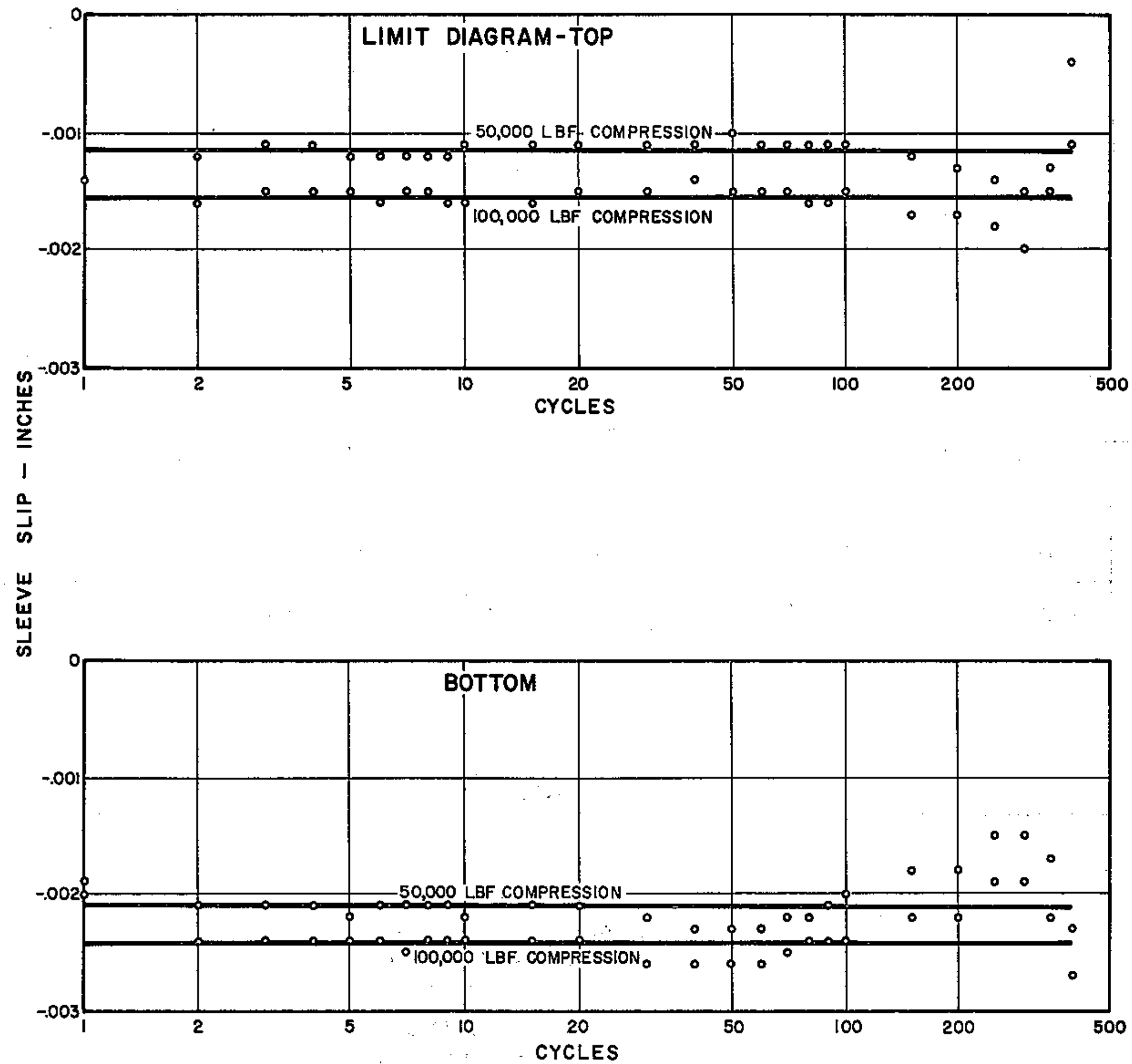
SPEC. NO. 9F - 14S - A432G
DATE APRIL 5, 1967
MANUFACTURER: COLUMBIA
HEAT NO. 43436



SLEEVE WITH METAL FILLER
FATIGUE TEST

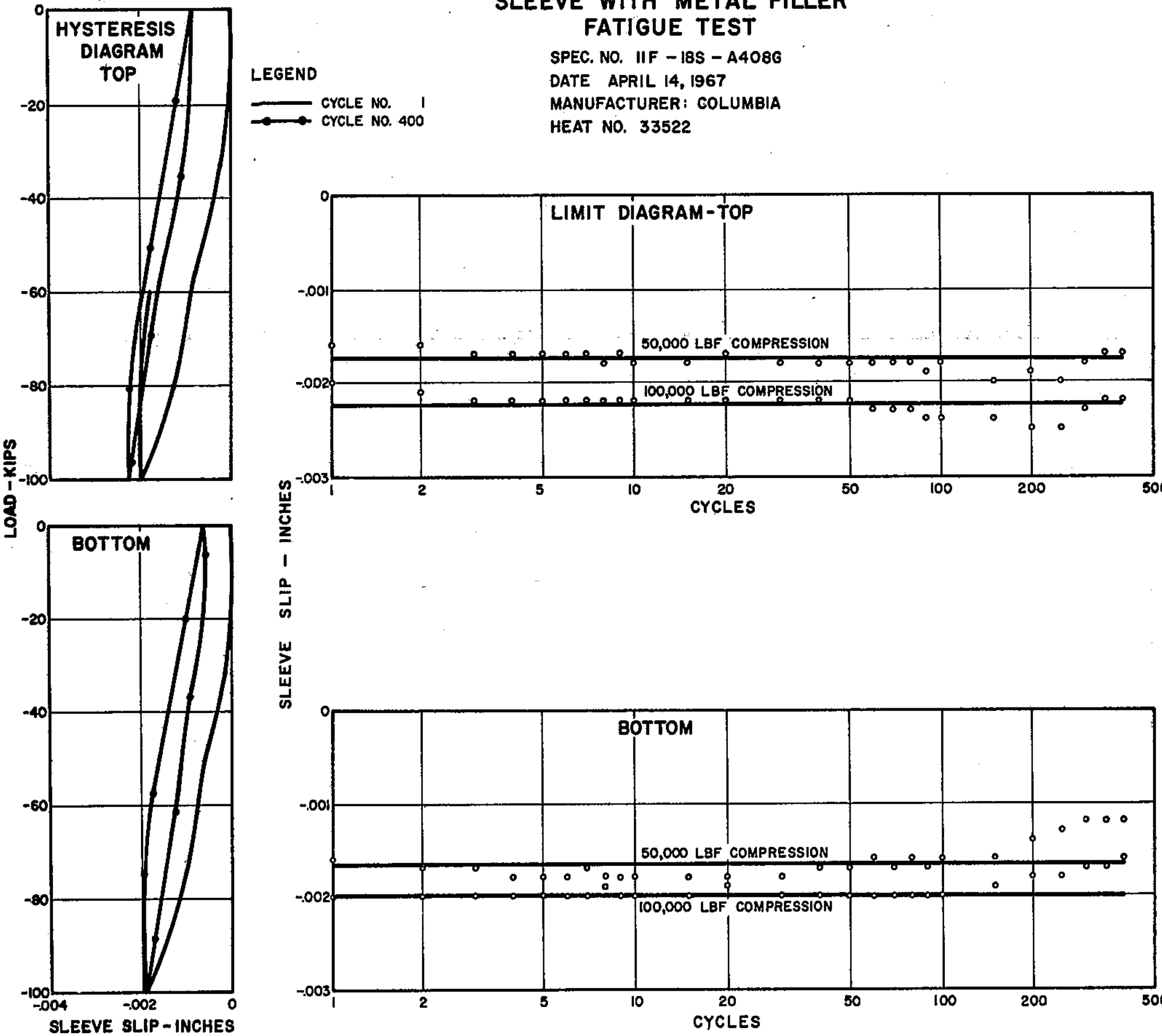
SPEC. NO. 10F – 18S A432G
DATE APRIL 13, 1967
MANUFACTURER: COLUMBIA
HEAT NO. 33884





SLEEVE WITH METAL FILLER FATIGUE TEST

SPEC. NO. 11F - 18S - A408G
DATE APRIL 14, 1967
MANUFACTURER: COLUMBIA
HEAT NO. 33522



SLEEVE WITH METAL FILLER
FATIGUE TEST

SPEC. NO. 12F-14S-A408G
DATE APRIL 19, 1967
MANUFACTURER: COLUMBIA
HEAT NO. 33918