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HIGHWAY RESEARCH REPORT

MECHANICAL PROPERTIES AND SPECIFICATIONS FOR WELDED JOINTS ON LARGE HIGH STRENGTH STEEL REINFORCING BARS

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FINAL REPORT

STATE OF CALIFORNIA

TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636328

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads September, 1968

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STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

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September 1968

Final Report
M&R No. 636328
D-4-28

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

MECHANICAL PROPERTIES AND SPECIFICATIONS

FOR

WELDED JOINTS ON LARGE HIGH STRENGTH STEEL

REINFORCING BARS

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Very truly yours,

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REFERENCE: Nordlin, E. F., Jonas, P. G., and Kendrick, C. B., "Mechanical Properties and Specifications for Welded Joints on Large High Strength Reinforcing Bars." State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report No. M&R 636328.

ABSTRACT: The strengths and ductilities of 35 manually and semi-automatically welded joints of No. 14 and 18 bars of ASTM A-408, A-431, and A-432 reinforcing steel are recorded and compared with the properties of unwelded bars. The results indicate that:

1. No butt welded joint in large steel reinforcing bar will insure more than about 90% of the tensile strength of the unwelded bar.

2. Electrodes of 308 stainless steel are not suitable for welding butt joints on ASTM A-431 and A-432 reinforcing steel.

3. Welded reinforcing steel joints which are prepared in accordance with the proposed welding specification presented in this report should preserve at least 85% of the tensile strength and 50% of the ductility available in the unwelded bar.

KEY WORDS: Ductility, ductility tests, elongation, high-strength steels, joining, procedures, reinforcement, reinforcing steel, specifications, steel reinforcement, strength, tensile strength, testing, test results, ultimate strength, weldability, welded joints, welding, welding electrodes, welding rods, weldments, weld metal, yield, yield point, yield strength.

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ACKNOWLEDGMENTS

The authors wish to express their appreciation to the personnel of the Bridge Specifications Section of the Bridge Department of the State of California for their advice and assistance in preparing the proposed specification presented in this report.

Special thanks are extended to Mr. George Sherman and his staff of the General Services Section of the Materials and Research Department for their helpful suggestions and review of this report.

This is the final report of a research project to evaluate the mechanical properties of welded joints on large, high strength reinforcing bars and to develop specifications for welding these bars.

This work was done in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads. (Federal Program No. D-4-28). The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads.

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INTRODUCTION

This project was conducted to determine the best way to weld large size high strength steel reinforcing bars. The necessity for splicing such bars has increased with their increased use. However, welding must be carefully controlled if the properties of the bars are to be preserved at the splice and this initiated the investigation covered in this report.

SUMMARY

The results of mechanical tests of butt welds in large size bars were as follows:

A. Gas Metal Arc Welds on ASTM A-408, made with E60S-3 Electrode.
79±1 Ksi ultimate - 46±2 Ksi yield - 12± 3% elongation at 16", 100% unwelded strength with 61% unwelded ductility.
(Based on tests of 7 weld joints and 5 unwelded bars from 3 sources. Six joints failed outside the weld and 1 in the heat affected zone.)

B. Gas Metal Arc Welds on ASTM A-432, made with 1.90 Mn Electrode.
93±4 Ksi ultimate - 56±10 Ksi yield - 6± 3% elongation at 16", 92% unwelded strength with 52% unwelded ductility.
(Based on tests of 9 weld joints and 7 unwelded bars from 5 sources. Three joints failed outside the weld and 6 in the heat affected zone.)

C. Gas Metal Arc Welds on ASTM A-431, made with 1.90 Mn Electrode.
119±8 Ksi ultimate - 95±5 Ksi yield - 2± 2% elongation at 16", 96% unwelded strength with 49% unwelded ductility.
(Based on tests of 5 weld joints and 4 unwelded bars from 3 sources. All joints failed in the heat affected zone.)

D. Manual Arc Welds on ASTM A-432 made with E11018M Electrode.
94±4 Ksi ultimate - 55±15 Ksi yield - 7± 4% elongation at 16", 91% unwelded strength with 61% of unwelded ductility.
(Based on tests of 8 weld joints and 2 unwelded bars from 2 sources. Four joints failed outside the weld and 4 in the heat affected zone.)

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E. Manual Arc Welds on ASTM A-431 made with E11018M Electrode.
120±5 Ksi ultimate - 101±2 Ksi yield - 2± 1% elongation at 16", 89% unwelded strength with 56% of unwelded ductility.
(Based on tests of 4 weld joints and 2 unwelded bars from one source. All joints failed in the heat affected zone.)

F. Manual Arc Welds on ASTM A-431 made with 308 Stainless Electrode.
83 Ksi ultimate - 83 Ksi yield - 1± 1% elongation at 16", 60% unwelded strength with 37% of unwelded ductility.
(Based on tests of 2 welds and 2 unwelded bars from one source. Both joints failed in the weld metal.)

CONCLUSIONS

1. No butt welded joint in Nos. 14 or 18 steel reinforcing bar will insure more than about 90% of the tensile strength of the unwelded bar.

2. Electrodes of 308 stainless steel are not suitable for welding butt joints on ASTM A-431 and A-432 or equivalent reinforcing steel.

3. Welded reinforcing steel joints which are prepared in accordance with the proposed welding specification presented in this report should preserve at least 85% of the tensile strength and 50% of the ductility available in the unwelded bar.

4. Cracking at weld joints on reinforcing steel is associated with the formation of a hard high carbon (+0.40% C) martensite metal grain structure in the heat affected zones of these joints. The elimination of such cracking requires that such joints not be allowed to cool below the "martensite start" temperature long enough to permit the formation of a softer bainite-pearlite metal grain structure.

   The composition of most high strength reinforcing steels with carbon contents above 0.40% is such that the "martensite start" temperature is about 475°F. About one hour at this temperature or 10 minutes at 800°F is required to form the softer metal grain structure during the post weld cooling period.

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Since the formation of carbon martensite is irreversible, reheating a weld joint which has been allowed to cool below the "martensite start" temperature too rapidly will not effectively prevent cracking in the heat affected zones of welds on these types of reinforcing steel.

Cracks in joints which have been subjected to the prescribed temperature controls are evidence that the "martensite start" temperature of the reinforcing steel at that joint is higher than the prescribed minimum preheat, interpass, and post weld cooling temperatures. In such cases these temperatures generally must be increased to permit welding without the formation of cracks.

RECOMMENDED SPECIFICATIONS

A. Proposed Specification for Welding Reinforcing Steel to be Used by the California Division of Highways

Welded Splices

The detail of welded joints in reinforcing bars shall conform to the details shown in AWS D2.0 and AWS D12.1, and the following:

Partial penetration butt welds will not be approved.

Joint details and dimensions shall conform to the requirements listed in the following Table of Butt Welded Joints, unless approved otherwise by the Engineer.

TABLE OF BUTT WELDED JOINTS

Welding Position of Bars	Type of Weld	Groove & Bevel Angle	Root Openings Max.	Additional Requirements. Note Number
Vertical	Double U-Groove	45°	1/8"	1
Vertical	Double Bevel-Groove	45°	1/8"	1 & 2
Vertical	Double J-Groove	45°	1/8"	1 & 2
Horizontal	Double Vee-Groove	60°	1/8"	1, 3 & 4
Horizontal	Double U-Groove	60°	1/8"	1, 3 & 4
Horizontal	Single Vee-Groove	60°	1/8"	4 & 5
Horizontal	Single U-Groove	60°	1/8"	4 & 5

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Note No. 1: The initial root weld pass shall be gouged out and rewelded from the back side.

Note No. 2: The square face of the joint shall be located at the bottom of the joint.

Note No. 3: Joints shall be welded without backing.

Note No. 4: Welding positions may be either flat or overhead.

Note No. 5: Joint may be used when lack of accessibility prevents the initial root pass from being gouged out and rewelded. Backing shall be provided around 180° of the reinforcing bars. Maximum clearance between the backing and the bars shall be 1/32". Deformations shall be removed from the bars in the backing contact areas.

Reinforcing bars spliced by welding shall not deviate from the layout line by more than 1/4 inch over a 3-1/2 foot length of bar.

Reinforcing bars at a welded joint shall not be offset at the weld by more than the following: For reinforcing bars No. 10, or smaller the offset shall not exceed 1/8 inch. For reinforcing bars No. 11 and No. 14 the offset shall not exceed 3/16 inch. For reinforcing bars No. 18 the offset shall not exceed 1/4 inch.

The ends of reinforcing bars shall be trimmed back or shaped by carbon arc, oxyacetylene cutting or by sawing. Sheared surfaces of bars shall be trimmed back not less than 1/2 inch.

1. Welding -- Welding reinforcing bar splices shall conform to the requirements in AWS D2.0, AWS D12.1, and to any special ruling or addendum, and the following:

Before any electrodes or flux-electrode combinations are used, the Contractor, at his expense, shall furnish certified copies of test reports for all the pertinent tests specified in ASTM Designation: A233 (AWS A5.1), in ASTM Designation: A316 (AWS A5.5), or in ASTM Designation: A559 (AWS A5.18), whichever is applicable, made on electrodes or flux-electrodes to be used. If electrodes are to be used which are of a size for which tests are not required by the specifications governing the process applicable to those electrodes, the test reports shall be furnished for electrodes of the size nearest and of the same classification and brand as those to be used. The tests may have been made for process qualification or quality control, and shall have been made within one year prior to the manufacture of the electrodes and fluxes to be used. The report shall include the manufacturer's certification that the process and material

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requirements were the same for manufacturing the tested electrodes and the electrodes to be used. All pertinent information concerning the tests required by the applicable electrode specifications shall be reported. The forms and certificates shall be as directed by the Engineer.

Electrodes for manual shielded metal arc welding of reinforcing bars, ASTM Designation: A615, Grade 40, shall conform to the requirements of ASTM Designation: A233 (AWS A5.1) for E7015, E7016, E7018, or E7028 electrodes.

Electrodes for manual shielded metal arc welding of reinforcing bars, ASTM Designation: A616, Grade 50, shall conform to the requirements of ASTM Designation: A316 (AWS A5.5) for E9018M electrodes. Electrodes shall be supplied in hermetically sealed containers.

Electrodes for manual shielded metal arc welding of reinforcing bars, ASTM Designation: A615 and A616, Grades 60, shall conform to the requirements of ASTM Designation: A316 (AWS A5.5) for E10018-M electrodes. Electrodes shall be supplied in hermetically sealed containers.

Solid and composite electrodes for semi-automatic gas metal-arc welding of reinforcing bars, ASTM Designation: A615, Grade 40, shall conform to the requirements of ASTM Designation: A559 (AWS A5.18) for E70S-6, E70T-1, E70T-5 or E70U-1 electrodes.

Electrodes for semi-automatic welding of reinforcing bars, ASTM Designation: A616, Grade 50, shall be capable of producing a weld metal deposit with properties conforming to the mechanical, usability, and soundness requirements specified in ASTM Designation: A316, Section 6, for E9018-M electrodes.

Electrodes for semi-automatic welding of reinforcing bars, ASTM Designations: A615 and A616, Grades 60, shall be capable of producing a weld metal deposit with properties conforming to the mechanical usability, and soundness requirements specified in ASTM Designation: A316, Section 6, for E10018-M electrodes.

When the manual welding process is used, weaving of the electrode shall not exceed 3 diameters of the electrode, except on the final pass.

Reinforcing bars shall be preheated for a distance of not less than 6 inches on each side of the joint to be welded, before welding is commenced.

The minimum preheat and interpass temperature for reinforcing bars, ASTM Designation: A615, Grade 40, shall be 400°F for bars No. 8 or larger, and 200°F for bars No. 7 or smaller.

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The minimum preheat and interpass temperature for reinforcing bars, ASTM Designation: A615, Grade 60, and ASTM Designation: A616, Grade 50 and Grade 60, shall be 475°F and the post weld cooling of the welds shall be controlled as follows:

When control of post weld cooling is specified, the cooling rate at the surface of the weld shall not exceed 100°F per hour as the splice cools from 575° to 250°F after welding.

Alternately, if the splice is unrestrained and has not cooled below 475°F from welding, the contractor at his option may reheat the splice to not less than 700°F nor more than 850°F for not less than 10 minutes and then allow it to air cool to ambient temperature.

All welding shall be protected from air currents, drafts, and precipitation to prevent loss of heat or loss of arc shielding. The method of protecting the welding area from loss of heat or loss of arc shielding shall be subject to approval by the Engineer.

The Contractor shall obtain and maintain an accurate and complete record of heat or lot numbers for all the reinforcing bars used in welded splices. This record shall be kept current and made available to the Engineer.

Reinforcing bars which cannot be identified by heat shall be identified by lot. The term "lot" shall be considered to consist of not more than 10 tons of steel, shall come from a single primary source (producer and mill), shall be of one size, and shall be segregated in accordance with any additional requirements listed in the ASTM Specification for the bar (chemical composition and grade of bar).

2. Welding Qualification -- Procedures which are to be used in making welded splices in reinforcing bars shall be qualified, before use in the work, by tests performed on sample welded splices as provided herein.

Welders employed to make welded splices in reinforcing bars shall be qualified, before welding splices to be used in the work, by tests performed on sample welded splices as provided herein.

Welding procedures and welders may be approved by the Engineer, at his discretion, based upon approval of previous tests performed on sample welded splices.

Completed sample welded splices shall be at least 30 inches long with the splice at mid-length.

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The sample welded splices shall be welded and tested in the presence of the Engineer or his authorized representative. When samples are tested by a commercial agency, the test shall be witnessed by the Engineer or his authorized representative.

The straightness and offset of sample welded splices shall comply with the requirements for welded splices.

Each butt weld procedure test shall consist of three sample butt welded splices in the largest reinforcing bar size to be welded with the procedure, except that procedures for No. 18 bars may be qualified by test procedures on No. 14 bars.

Separate welding procedure tests shall be submitted for each heat or lot of reinforcing bar used, except that separate tests will not be required for each heat of reinforcing bars conforming to ASTM Designation: A615, Grade 40.

Separate sample welded splices shall be submitted for qualification for each welding position which will be used in the procedure. Test samples of butt welding procedures which are to be used in the flat welding position may be prepared by rolling the test reinforcing bar as it is welded.

Each butt welding procedure test that is qualified using a welded joint detail as set forth in these specifications will also be considered qualified for use in the other welded joint details for the same position of reinforcing bars.

Each welder qualification test for butt weld splices shall consist of two sample butt welded splices in the largest reinforcing bar size to be welded, except that welders for No. 18 bars may be qualified by test on No. 14 bars.

A separate welder qualification test shall be submitted for each welding position and for each welding procedure that the welder is expected to use on the work.

Each welder applying for qualification shall prepare and weld sample splices without assistance of any kind and shall use reinforcing bars with the same ASTM designation and the same welding equipment that he will use during the work.

Each qualified welder test for welding reinforcing bars shall be considered to also qualify the same welder on all reinforcing bar sizes smaller than those used in making the tests.

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The welder that welds the sample welded splices for procedure qualification tests shall be considered qualified to weld with that procedure by virtue of his welding of the approved test weld. The Contractor, at his option, may provide that welder and procedure qualification tests are made simultaneously.

Two sample welded splices made for qualifying butt welding procedures and one of the sample welded splices made for welder qualification will be tested in tension. These samples shall have an ultimate tensile strength of not less than the specified minimum ultimate tensile strength of the unspliced reinforcing bar. One remaining sample welded splice from either of the welding procedure or welder qualification tests will be nicked and broken transversely through the weld. This fractured weld face shall have no defects exceeding the limits set forth in Section 52-1.085C, "Nondestructive Weld Tests."

Labor, material, and equipment for fabricating sample welded splices shall be furnished by the Contractor at his expense, and no separate payment will be made therefor.

3. Nondestructive Weld Tests -- Welding inspection will be performed in accordance with the requirements of the AWS, and the following:

All welding performed either in the shop or in the field shall be subject to radiographic and other nondestructive testing at the discretion of the Engineer, as hereinafter specified.

Should nondestructive testing be required, the Contractor shall provide sufficient access facilities in the shop and at the job site to permit the Engineer or his agent to perform the tests. Such tests will be performed without charge to the Contractor.

The soundness of welds as determined from test weld fractures or by radiographic or other nondestructive testing shall conform to the following: There shall be no undercut, incomplete fusion, lack of penetration, or cracks in the weld. The weld shall show no fusion defects totaling more in the sum of their maximum dimensions nor longer in any single defect in its maximum dimension than the limits given in the following Table of Defect Dimensions:

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TABLE OF DEFECT DIMENSIONS

Bar Size No.	Sum of Defect Dimensions, Inches	Single Defect Dimension, Inches
8	3/16	1/8
9	3/16	1/8
10	1/4	1/8
11	1/4	3/16
14	5/16	3/16
18	7/16	1/4

B. Tentative Supplement to Proposed Specification for Welding Reinforcing Steel

The following specifications are presently under consideration to supplement the proposed specifications in A above:

Requirements for arc welding splices on reinforcing bars, ASTM Designation: A615, Grade 75, shall conform to the requirements specified in Section A of this report and the following:

Electrodes for manual shield metal arc welding shall conform to the requirements of ASTM Designation: A316 (AWS A5.5) for E12018-M electrodes. Electrodes shall be supplied in sealed containers.

Electrodes for semi-automatic welding shall be capable of producing a weld metal deposit with properties conforming to the mechanical usability and soundness requirements specified in ASTM Designation: A316 (AWS 5.5) for 12018-M electrodes.

The minimum preheat and interpass temperature shall be 475° and post weld cooling shall be controlled as specified in Section A above.

DESCRIPTION OF WORK

To provide specimens for this project, fifty-five 5 ft. lengths of #14 and #18 reinforcing bars were obtained from five suppliers and separated into fifteen groups based on bar size, heat number, and the welding method to be used on the bar. One or two bars from each group were held intact for control testing

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while the remaining bars were cut in half and rejoined using the welding method designated for that group.

After welding had been completed, the bars were sent to the University of California at Berkeley for testing in their five million pound machine. Stress strain curves, ultimate loads, and 16" elongations at failure were recorded in the presence of a Materials and Research Department witness. The records together with the test remnants were returned to the laboratory in Sacramento for checking and further evaluation.

A. TEST SPECIMEN WELDING PROCEDURES

1. Preparation

All bars having sheared ends were recut using an oxyacetylene torch or a power hacksaw. This was done to remove any shear cracks and cold worked material remaining from the shearing operation.

Slag from the torch cuts was removed by wire brushing and grinding.

2. Aligning, Tack Welding, and Groove Preparation

a. The ends of the bars were butted in an aligning jig and tack welded together with a single short arc bead extending one half way around the bar.

Manual electrodes were not used for this initial tack weld in order to avoid the possibility of trapping flux and contaminating the subsequent short arc weld passes.

b. Using a carbon air arc or an oxyacetylene torch, the bars which were to be positioned horizontally for welding were chamfered equally from the butted end of each bar on the side of the joint opposite the initial tack weld so as to provide a joint preparation consisting of a symmetric V groove with a 60° included angle and a depth of 1/8" plus of 1/2 the bar diameter.

c. The bars which were to be positioned vertically were chamfered from the butted end of each bar on the side of the joint opposite the initial tack weld so as to provide a joint preparation consisting of an asymmetric V groove with a 20° angle on the lower face and a 45° angle on the upper face and provide a depth of 1/8" + 1/2 the bar diameter.

d. The faces of the weld grooves were cleaned with a slag hammer and a wire brush and then ground lightly with a disc grinder.

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e. In each joint the initial groove was welded approximately 2/3 full. Then the joint was rotated 180° and chamfered to the same groove configuration on the opposite side. Care was taken to penetrate into the root passes of the first side to eliminate any lack of fusion, porosity or slag. This second groove was welded completely except for cover passes. Then the bar was turned over again and the welding of the initial groove was completed.

f. Each joint was preheated to 400° or 500° for a length of about 4" on either side of the joint. Interpass temperatures were not allowed to exceed 600°F.

3. Gas Metal-Arc Welding Procedures

a. Filler Pass Technique

For the horizontally positioned bars, three or four initial oscillating passes were made across the root of each groove until it was filled such that its width at the bottom was about 1 inch. Bonding these three or four laterally oscillated passes to each joint face was critical. Hence care was taken during each of these initial passes to dwell the arc momentarily at each joint face with a slight pause in the oscillating across to the opposite face.

The remaining weld passes that were used to fill the grooves were deposited using horizontal stringer beads.

Electrodes were manipulated to minimize the convexity or concavity of each weld bead and the weld metal deposits were kept as flat and even as possible. Successive passes were welded from opposite directions.

For the vertically positioned bars, after the initial oscillating root passes had been completed, the remaining passes were deposited using vertical upward stringer beads to avoid any lack of fusion that might have resulted from downhand welding.

b. Cover Passes

Cover passes approximately one inch wide were welded in a vertical upward direction around joints on vertically positioned bars.

Cover passes about one half inch wide were welded in the flat position around joints on horizontally positioned bars.

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c. Filler Metal

A-408 bar
0.035" dia. wire, 80 Ksi Ultimate, Chem. -
0.09C - 100 Mn - 0.45 Si - 0.024S - 0.017P

A-431 and A-432 bar
0.035" dia. wire, 120 Ksi Ultimate, Chem. -
0.10C - 1.90 Mn - 0.73 Si - 0.035S - 0.017P-0.55 Mo

d. Shielding Gas - 75% Argon, 25% CO_2.

4. Manual Shielded Metal Arc Welding Procedures

a. Pass Technique

The same weld sequences as the short arc were used except that the weld passes were kept to a width of three diameters of the electrode. Each weld pass was slagged with a chipping hammer and the wire brushed.

b. Filler Metal

A-431 bar
1/8" and 5/32" dia. E11018 electrodes, smaller electrodes used for root passes.

A-432 bar

1/8" dia. E9018 electrodes for root passes and 5/32" dia. E11018 electrodes used for remainder of weld.

B. TESTING PROCEDURES

The reinforcing bars with and without joints were tested at the mechanics laboratory of the University of California at Berkeley using their 5,000,000 lb. machine.

Elongations were measured over 16" gage lengths in order to facilitate comparisons with bar joints which were mechanically spliced with sleeves of such a size that a 16" extensometer was required to span the sleeve length. These comparisons are not recorded in this report. Two linear voltage differential transformers were attached to the extensometer to sense strain. Readout was provided by an XY recorder which automatically plotted the summed signals from the LVDT's on the x axis versus the machine load on the y axis. Each tension test was plotted in this fashion until the yield strain had been exceeded and then the extensometer was removed so the specimen could be loaded to failure.

The reported yield strengths were taken to be 1/2 the sums of the 0.2% offset yield and the 0.5% total strain yield.

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Ultimate strengths were determined by dividing the ultimate load by the nominal section.

The results of the various tests are shown in detail in the APPENDIX of this report.

C. ANALYSIS OF DATA

The results of 35 tension tests of welded joints of No. 14 and No. 18 reinforcing bars were compared with the tension test results of 18 corresponding unwelded bars in order to provide data for this report. Eighteen of these 35 tests failed outside the 16" gage length in areas of the test bars which were not affected by welding. The inferences drawn from these 18 tests were as follows:

1. The load at failure represented the strength of the unwelded bar.

2. The strength of the weld exceeded the strength of the unwelded bar.

3. The recorded elongation through the central 16" welded region at failure was less than it would have been had the bar failed inside the gage length.

4. The yield point determinations remained unaffected by this difficulty.

Based on these inferences, the ultimate strength values in each of these 18 tests were averaged into the control bar test results for their respective groups to improve the various group values for the ultimate strength of the bases, and each of these 18 ultimate strengths were also included in the weld test results for their respective groups in order to provide enough information to justify the extraction of some workable conclusions from the data.

Elongations through the unbroken weld section in each of these 18 tests were included in the weld joint test results for their respective groups unless they were very low relative to the ductility of the control bar and bars failing inside the gage. In such latter cases it was presumed that failure outside the weld area had occurred before the welded portion of the bar had strained significantly beyond the yield point.

The results reported herein cover tests conducted on both No. 14 and No. 18 bars supplied by Bethlehem, Pacific States, Columbia, Western Rolling Mill, and Judson. Tests were grouped by heat number and bar size. No attempt was made to differentiate between the results of welding horizontally positioned versus welding vertically positioned bar nor between welding No. 14 bar versus welding No. 18 bar because

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of the limited number of tests. Test results for each class of bar and welding system were averaged by groups except in those cases where no significant differences in group results was apparent. No attempt was made to differentiate test results by supplier.

The results of the various tests performed are shown in detail in the APPENDIX of this report.

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APPENDIX

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Table A-1

GAS METAL-ARC WELDED JOINTS ON ASTM A408 REINFORCING BARS

(Welded at 20-21 Volts & 140-150 Amps under a 20 cfh gas shield of 75% A-25% CO_2 using .035" Linde 82 wire (.09C, 1.00 Mn, 0.45 Si) fed at 260-263 ipm on bars preheated to 400°F.)

	Bar Position	Ultimate Strength	Yield Strength	Elongation @ 16"	Failure Location
Group 1 - Pacific States Steel Heat No. 24006 - Size 14 bar					
Control A-1	-	79.4 Ksi	46.0 Ksi	19.5%	
Control A-2	-	80.4 Ksi	47.0 Ksi	21.1%	
Joint 10H	Horizontal	79.6 Ksi	46.7 Ksi	11.4%	Base
Joint 11V	Vertical	78.6 Ksi	45.8 Ksi	9.4%	H.A.Z.(1)
Joint 14V	Vertical	80.9 Ksi	48.0 Ksi	6.2%	Base
Group 4 - Columbia Steel (.22 C, .52 Mn. .01 P, .04S - Mill Chemistry) Heat No. 23058 - Size 18 bar		75.0 Ksi	47.7 Ksi	25% @ 2"	(Mill Test)
Control J		72.3 Ksi	42.0 Ksi	16.8%	
Joint 65H	Horizontal	79.0 Ksi	44.0 Ksi	13.3%	Base
Group 5 - Pacific States Steel Heat No. 14973 - Size 18 bar					
Control B_1		78.0 Ksi	46.0 Ksi	18.0%	
Control B_2		78.0 Ksi	47.5 Ksi	22.0%	
Joint 12V	Vertical	79.2 Ksi	47.2 Ksi	12.0%	Base
Joint 13H	Horizontal	79.0 Ksi	46.2 Ksi	13.0%	Base
Joint 15V	Vertical	78.2 Ksi	46.2 Ksi	12.0%	Base

(1) H.A.Z. - i.e., heat affected zone of joint.

Figure A-2

GAS METAL-ARC WELDED REINFORCING BAR TENSILE TEST

GROUP I

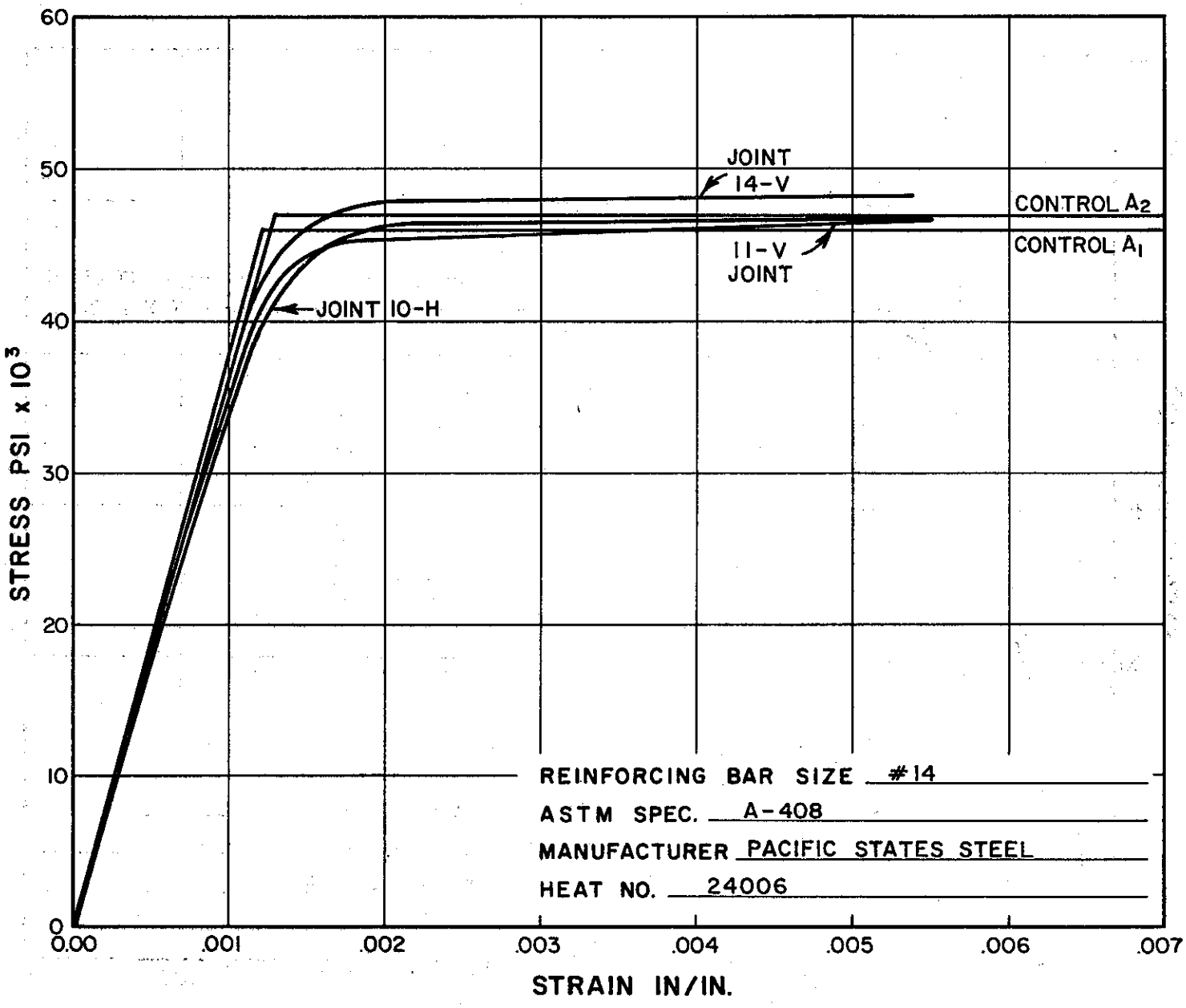

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Figure A-3

GAS METAL-ARC WELDED REINFORCING BAR TENSILE TEST

GROUP 4

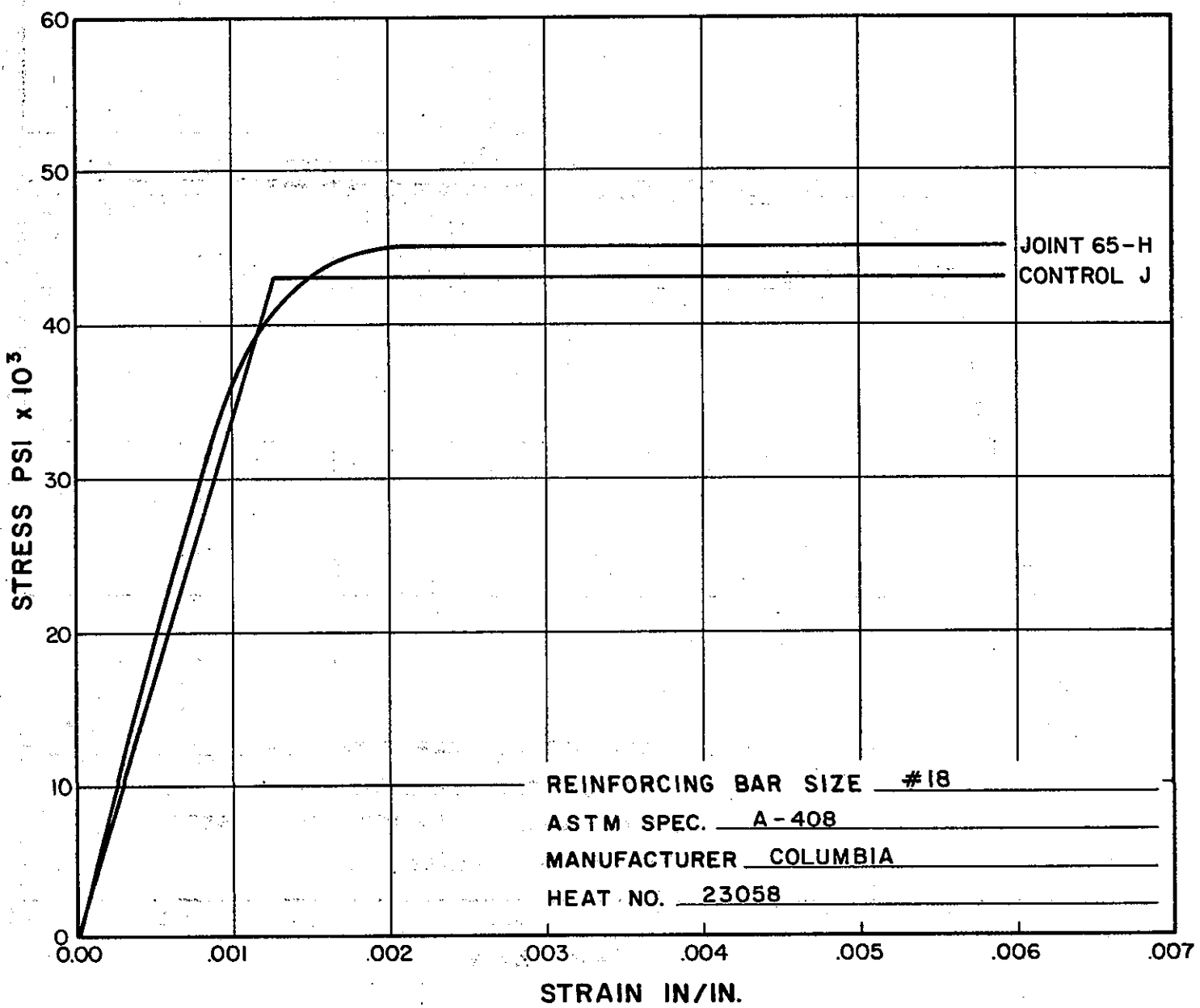

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Figure A-4

GAS METAL-ARC WELDED REINFORCING BAR TENSILE TEST

GROUP 5

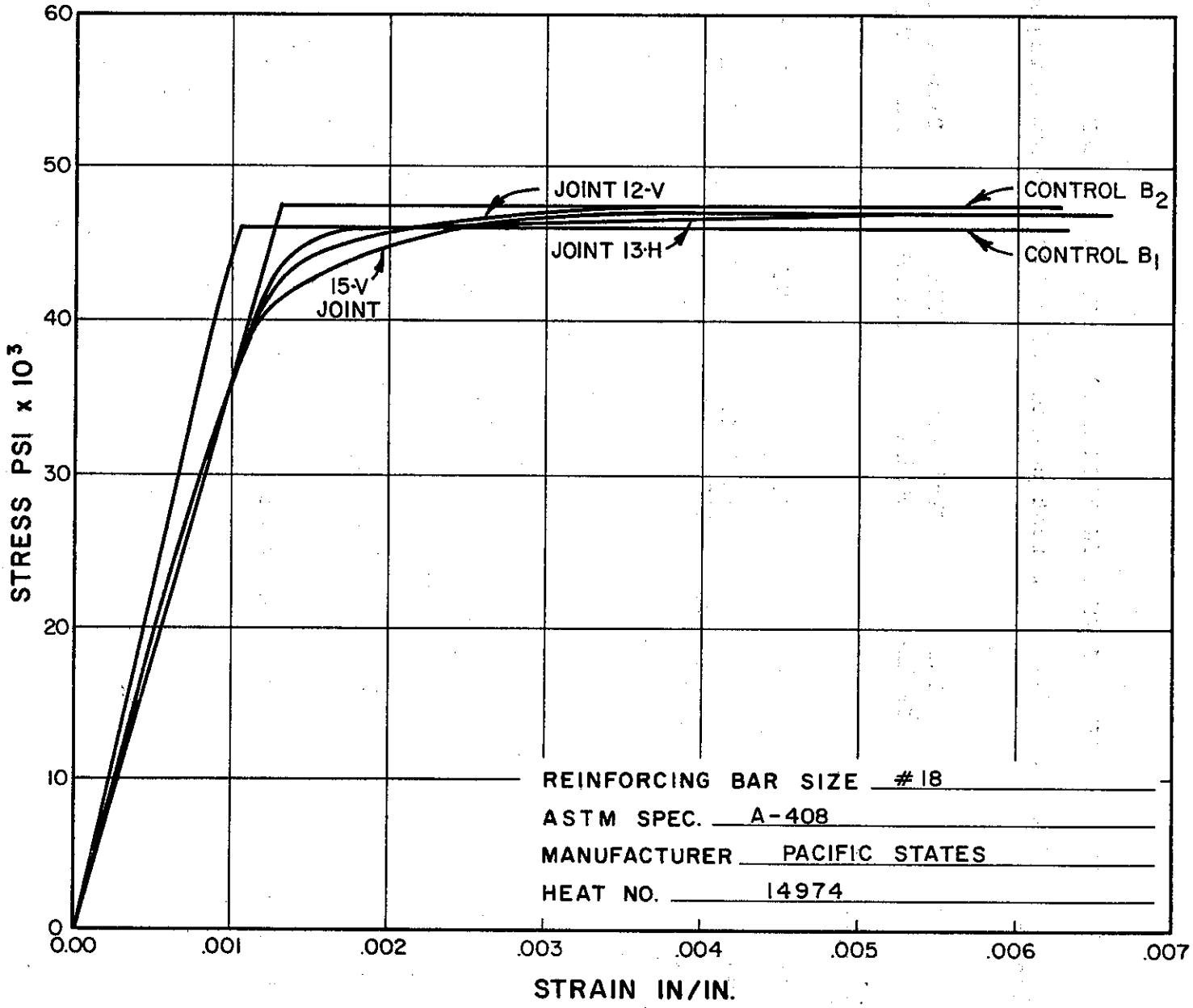

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Table A-5

MANUALLY WELDED JOINTS ON ASTM A-431 REINFORCING BARS

(Welded using E11018 electrodes (1/8" for root passes and 5/32" for remaining section on joints preheated to 400°F.)

	Bar Position	Ultimate Strength	Yield Strength	Elongation @ 16"	Failure Location
Group 12 Bethlehem Steel Heat No. 322-E183 Size 18 bars					
Control G_1	--	No Fracture	97.8 Ksi	0.4%	at 103.8 Ksi pulled out of jaw
Control G_2	--	138.0 Ksi	97.8 Ksi	3.1%	--
Joint 22H	Horizontal	122.5 Ksi	99.5 Ksi	1.6%	H.A.Z. (1)
Joint 23H	Horizontal	114.0 Ksi	100.0 Ksi	0.8%	H.A.Z.
Joint 24V	Vertical	124.3 Ksi	103.0 Ksi	1.6%	H.A.Z.
Joint 25V	Vertical	120.0 Ksi	101.0 Ksi	3.1%	H.A.Z.

(1) H.A.Z. - i.e., heat affected zone of joint

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Figure A-6

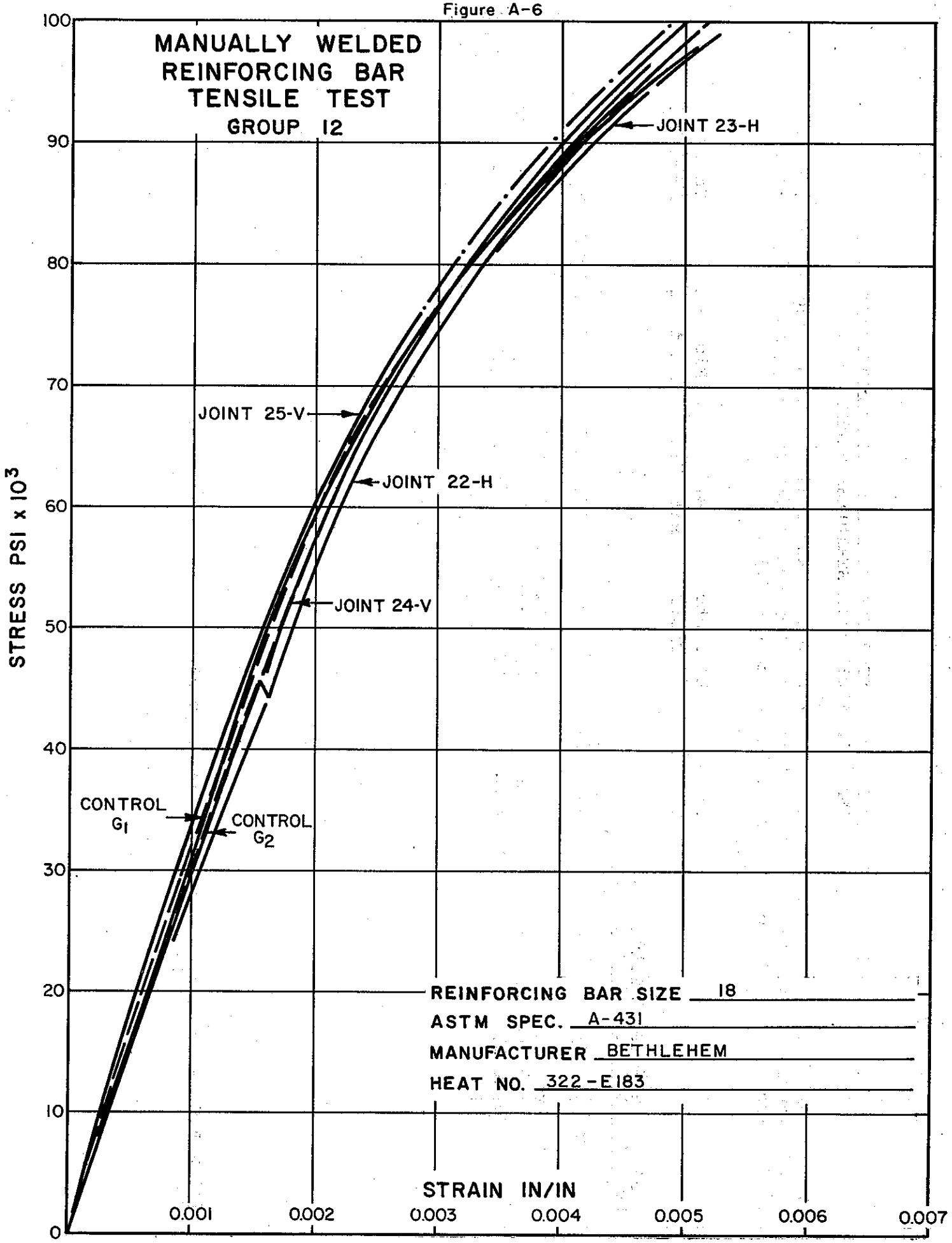

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Table A-7

JOINTS ON ASTM A-431 REINFORCING BARS MANUALLY WELDED OVER JOINT CHAMFERS FACED WITH STAINLESS STEEL

(Welded using E11018 electrodes (1/8" for root passes and 5/32" for remaining section) against bonding surfaces of stainless steel which were prepared by facing the joint chamfers with E 308 electrodes. All joints were preheated to 400°F.)

	Bar Position	Ultimate Strength	Yield Strength	Elongation @ 16"	Failure Location
Group 13 Bethlehem Steel Heat No. 322-E183 Size 18 Bar					
Control G_1	--	No Fracture	97.8 Ksi	0.4% at 103.8 Ksi pulled out of jar	
Control G_2	--	138.0 Ksi	97.8 Ksi	3.1%	
Joint 26H	Horizontal	83.0 Ksi	83.0 Ksi	0.8%	Weld (1)
Joint 27V	Vertical	83.0 Ksi	83.0 Ksi	1.6%	Weld

(1) H.A.Z. - i.e., heat affected zone of joint

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Figure A-8

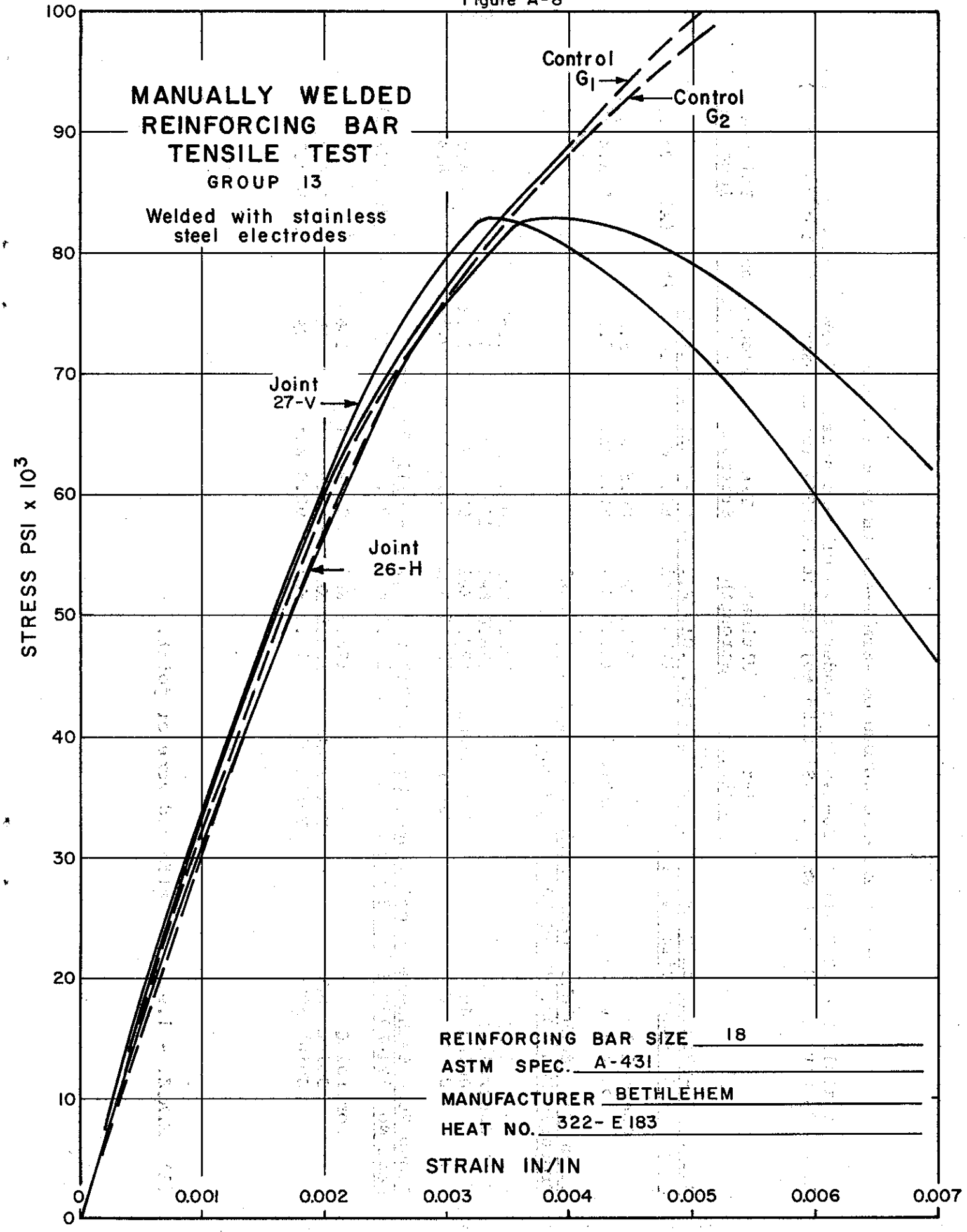

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Table A-9

GAS METAL-ARC WELDED ON ASTM A-431 REINFORCING BARS

(Welded at 19.5 - 22 Volts & 130-140 Amps under a 20 cfh gas shield of 75% A-25% CO_2 using 0.035" Linde 83 wire (.10C, 1.90 Mn, 0.73 Si 0.55 Mo) fed at 263-264 ipm on bars preheated to 400°F.)

	Bar Position	Ultimate Strength	Yield Strength	Elongation @ 16"	Failure Location
Group 10 - Bethlehem Steel - (.39 C, .84 Mn. .010 P,.028 S - Mill Chemistry)					
Heat No. 323-K860 Size 14 bar		127.1 Ksi	85.6 Ksi	16% @ 2"	(Mill Test)
Control P	--	123.5 Ksi	86.5 Ksi	5.5%	
Joint 63V	Vertical	123.0 Ksi	90.2 Ksi	3.1%	H.A.Z.(1)
Group 25 - Bethlehem bars purchased from Soule' Steel					
Probably Heat No. 32I-H730 Size 18 bar					
Control D_1		123.0 Ksi	100.0 Ksi	3.5%	
Control D_2		128.0 Ksi	102.7 Ksi	3.1%	
Joint 4H	Horizontal	122.0 Ksi	99.6 Ksi	3.1%	H.A.Z.
Joint 5V	Vertical	111.5 Ksi	100.8 Ksi	0.8%	H.A.Z.
Group 26 - Bethlehem Steel (.36C, 88 Mn, .012 P, .032 S - Mill Chemistry)					
Heat No. 321-H730 Size 18 bar		136.4 Ksi	93.0 Ksi	13% @ 2"	(Mill Test)
Control Q		128.5 Ksi	92.9 Ksi	1.6%	
Joint 58H	Horizontal	126.5 Ksi	92.6 Ksi	0%	H.A.Z.
Joint 59V	Vertical	110.0 Ksi	92.9 Ksi	0%	H.A.Z.

(1) H.A.Z. - i.e., heat affected zone of joint.

Figure A-10

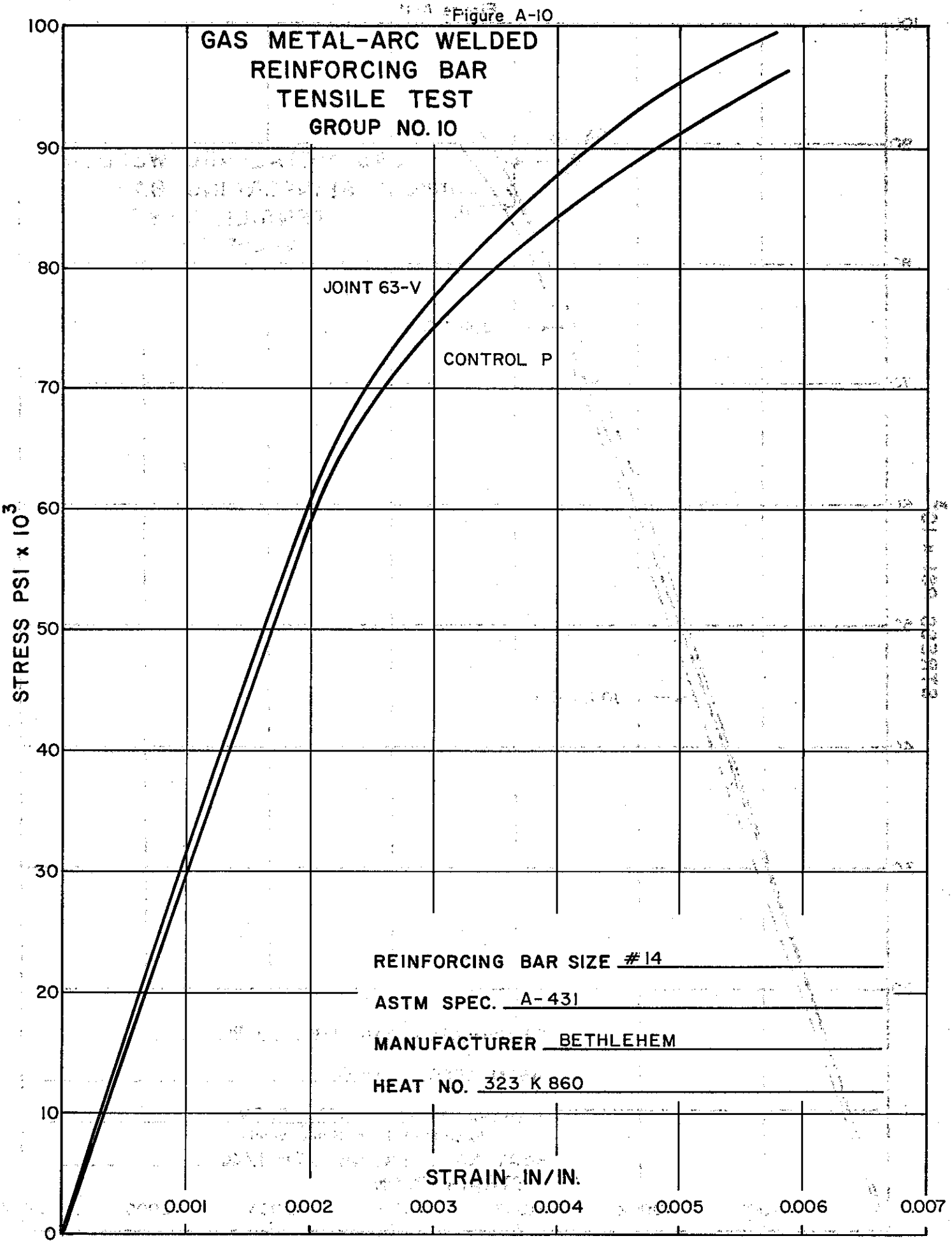

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Figure A-11

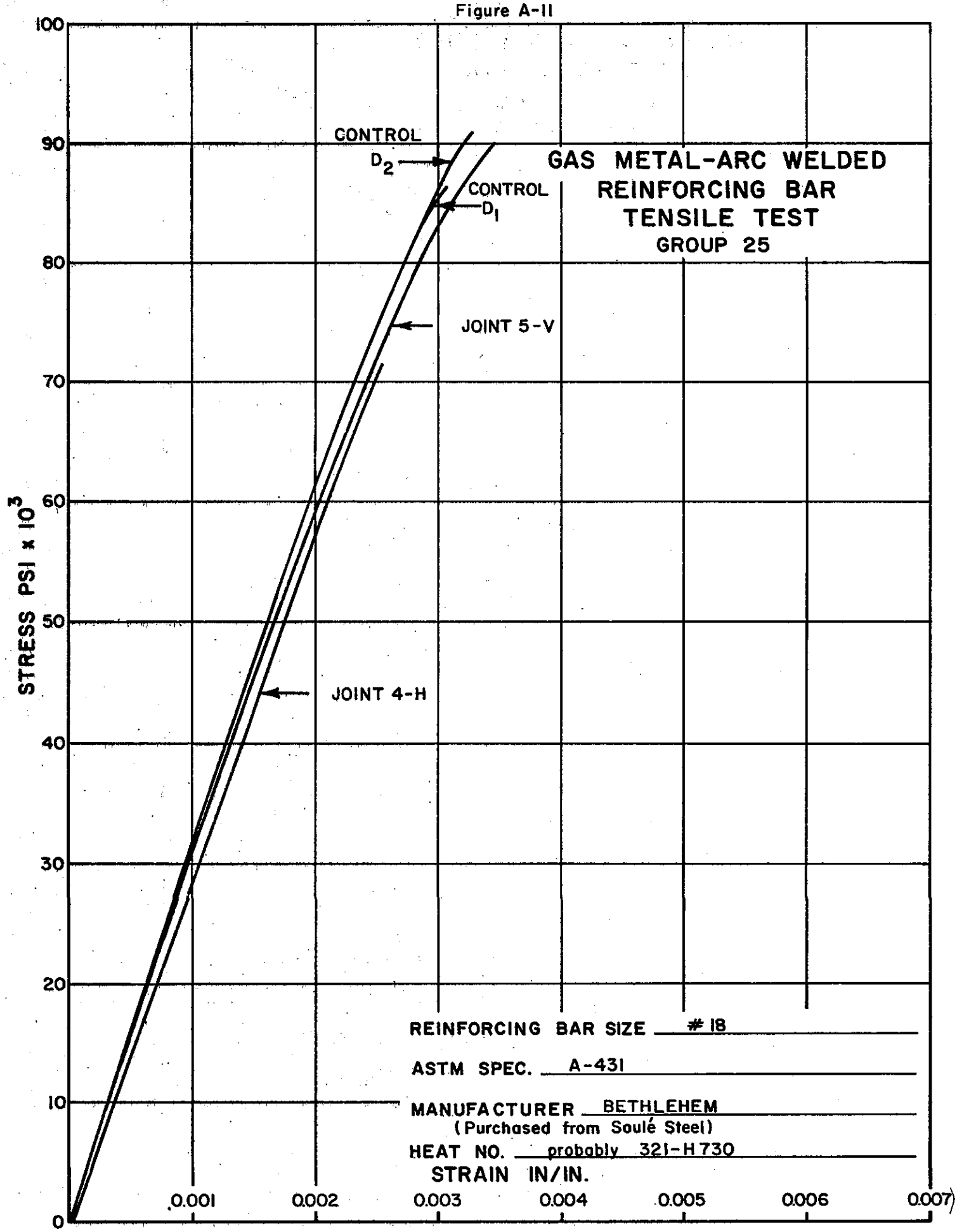

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Figure A-12

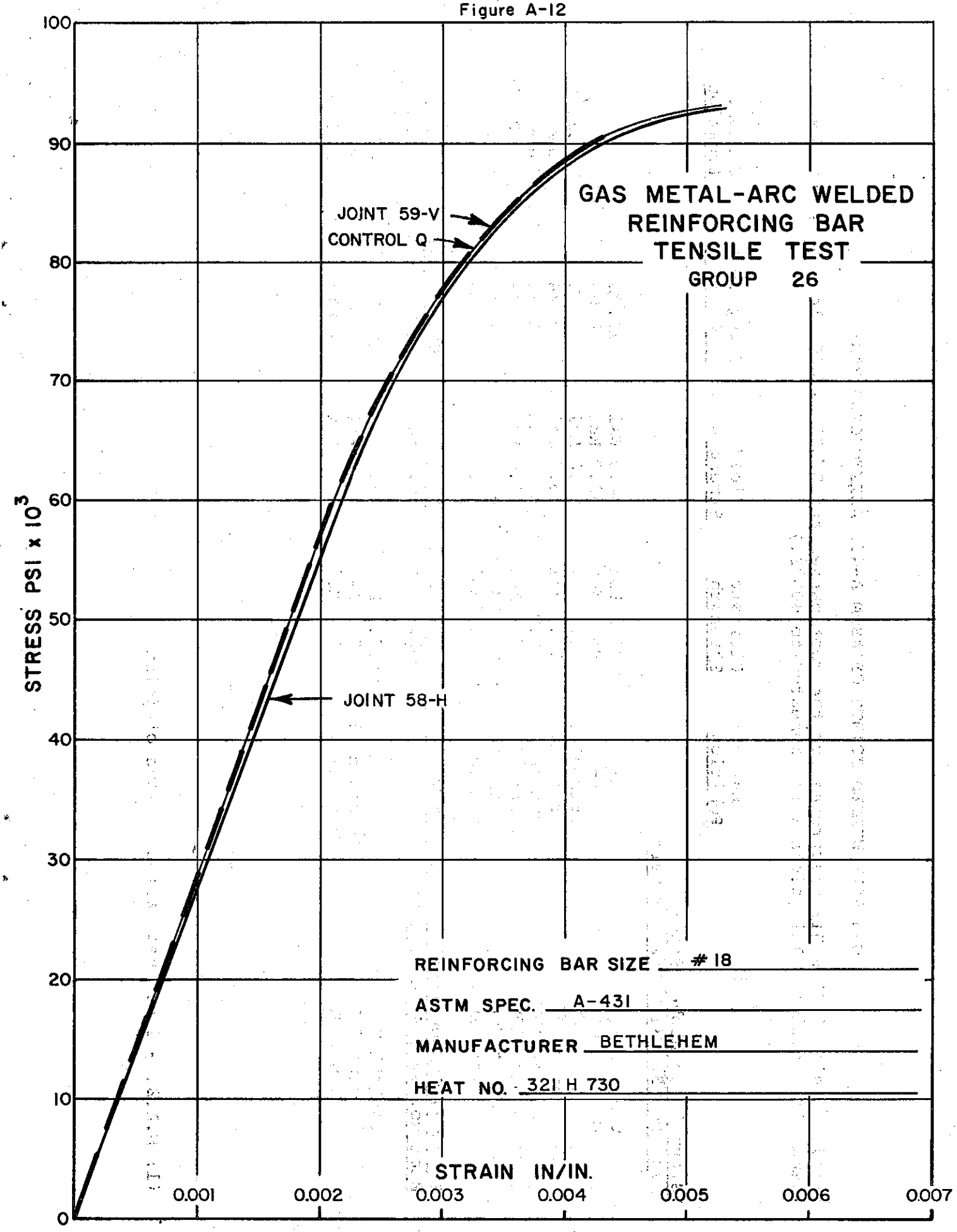

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Table A-13

MANUALLY WELDED JOINTS ON ASTM A-432 REINFORCING BARS

(Welded using 1/8" E9018 electrodes for the root passes and 5/32" E11018 electrodes for the remaining section. All joints were preheated to 400°F.)

	Bar Position	Ultimate Strength	Yield Strength	Elongation @ 16"	Failure Location
Group 21 Bethlehem Steel Heat No. 323 K170 Size 18 bars					
Control H_1	--	95.5 Ksi	64.0 Ksi	11.0%	
Control H_2	--	96.7 Ksi	63.0 Ksi	8.0%	
Joint 16H	Horizontal	93.5 Ksi	65.0 Ksi	9.4%	H.A.Z.(1)
Joint 17H	Horizontal	96.5 Ksi	65.6 Ksi	6.2%	Base
Joint 18V	Vertical	100.0 Ksi	66.6 Ksi	12.5%	Base
Joint 19V	Vertical	92.5 Ksi	61.0 Ksi	4.7%	H.A.Z.
Joint 20H	Horizontal	88.5 Ksi	65.8 Ksi	2.3%	H.A.Z.
Joint 21V	Vertical	95.2 Ksi	64.0 Ksi	7.8%	Base
Group 27 Judson Steel (.40 C, .75 Mn, .008 P, .046 S, .26 Si, cbt Mill Chemistry) Heat No. 1223 Size 18 bars		103.5 Ksi	60.3 Ksi	18.% @ 2"	(Mill Test)
Control T	--	95.0 Ksi	57.5 Ksi	10.5%	--
Joint 72H	Horizontal	75.3 Ksi	45.0 Ksi	9.4%	Base
Joint 73V	Vertical	67.3 Ksi	44.3 Ksi	2.8%	H.A.Z.

(1) H.A.Z. - i.e., heat affected zone of joint

Figure A-14

MANUALLY WELDED REINFORCING BAR TENSILE TEST

GROUP 21

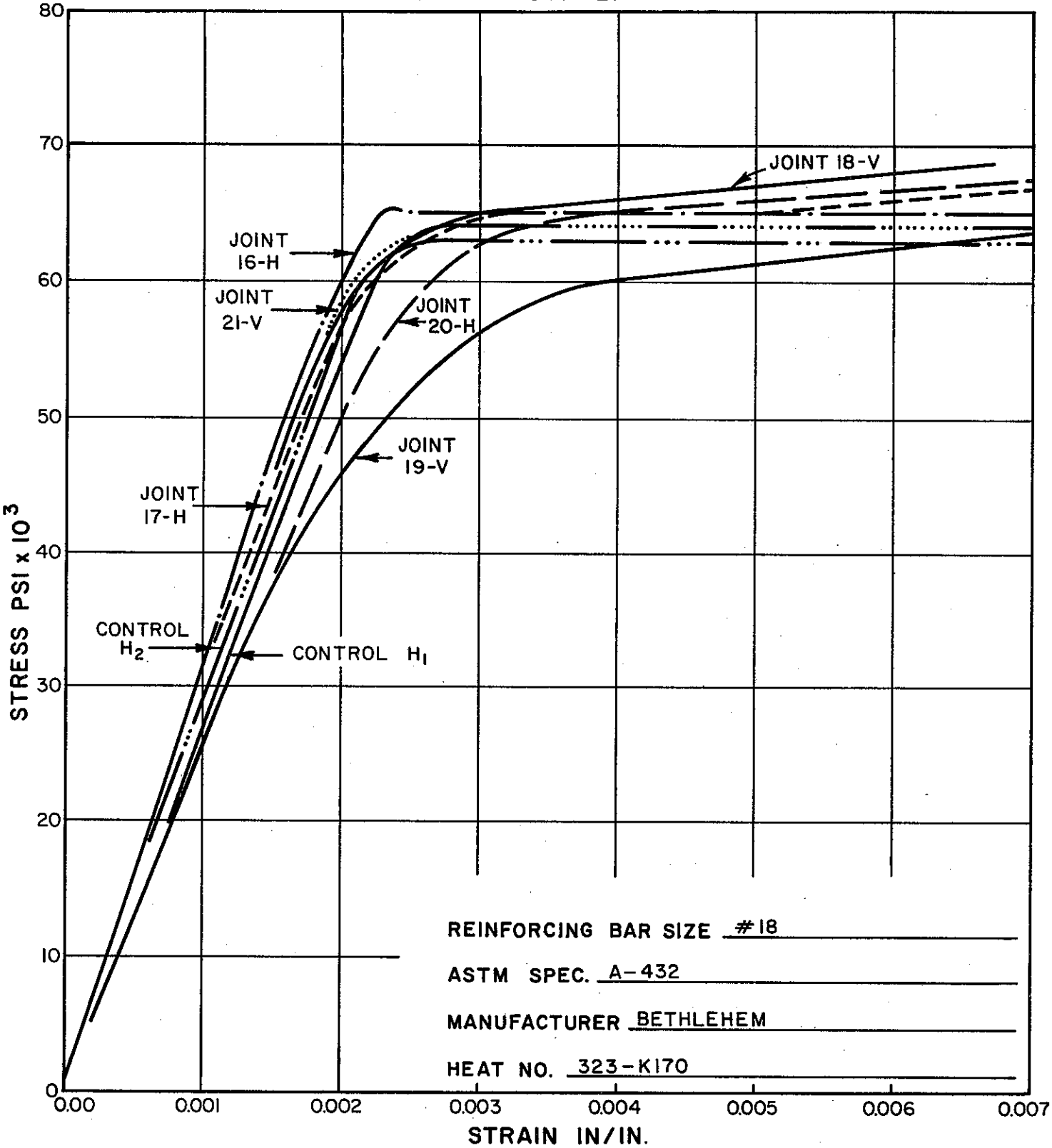

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Figure A-15

MANUALLY WELDED REINFORCING BAR TENSILE TEST

GROUP 27

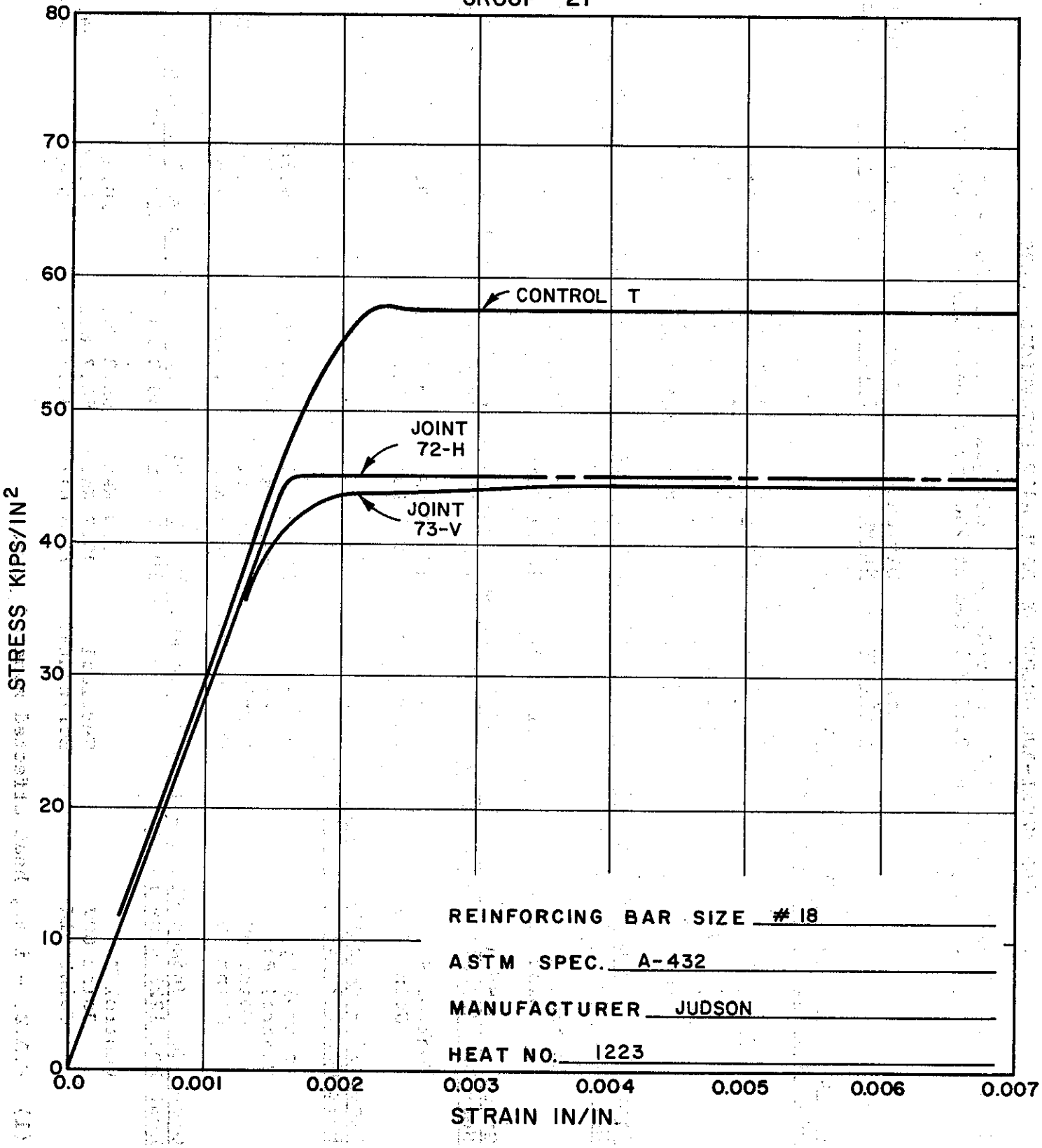

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Table A-16

GAS METAL-ARC WELDED ON ASTM A432 REINFORCING BARS

(Welded at 21.5-22 Volts & 130 Amps under a 20 cfh gas shield of 75% A-25% CO_2 using .035" Linde 83 wire (.10 C, 1.90 Mn, 0.73 Si 0.55 Mo) fed at 260 ipm on bars preheated to 400°F.)

	Bar Position	Ultimate Strength	Yield Strength	Elongation @ 16"	Failure Location
Group 15 - Western Rolling Mill					
Heat No. 36212 - Size 14 bar					
Control E_1	--	100.5 Ksi	44.7 Ksi	12.5%	
Control E_2	--	100.5 Ksi	45.0 Ksi	12.5%	
Joint 6V	Vertical	90.6 Ksi	45.5 Ksi	3.5%	H.A.Z.(1)
Joint 7H	Horizontal	93.4 Ksi	47.0 Ksi	4.8%	H.A.Z.
Joint 57H	Horizontal	93.8 Ksi	45.4 Ksi	5.5%	H.A.Z.
Group 16 - Judson Steel - (.38 C, .90 Mn, .008 P, .044 S, .33 Si, .031 Cb Mill Chemistry)					
Heat No. 310 - Size 14 bar		110.0 Ksi	68.0 Ksi	18.0% @ 2"	(Mill Test)
Control R		94.2 Ksi	58.1 Ksi	6.6%	
Joint 62H	Horizontal	100.1 Ksi	60.5 Ksi	7.7%	Base
Group 17 - Bethlehem Steel - (.37 C, .83 Mn, .017 P, .062 S Mill Chemistry)					
Heat No. 322K829 - Size 14 bar		100.9 Ksi	70.0 Ksi	23% @ 2"	(Mill Test)
Control S	--	106.7 Ksi	76.0 Ksi	10.2%	
Joint 64V	Vertical	88.9 Ksi	63.0 Ksi	3.9%	H.A.Z.
Group 19 - Bethlehem Steel					
Heat No. 322J834 - Size 18 bar					
Control F_1	--	102.2 Ksi	67.5 Ksi	4.3%	
Control F_2	--	99.8 Ksi	66.6 Ksi	4.3%	
Joint 8V	Vertical	97.5 Ksi	-	7.8%	H.A.Z.
Joint 9H	Horizontal	92.5 Ksi	67.7 Ksi	7.8%	H.A.Z.
Group 20 - Judson Steel - (.40 C, .75 Mn, .008 P, .046 S, .26 Si, + Cb Mill Chemistry)					
Heat No. 1223 Size 18 bar		103.5 Ksi	60.3 Ksi	18% @ 2"	(Mill Test)
Control T		95.0 Ksi	58.2 Ksi	10.2%	
Joint 60V	Vertical	90.7 Ksi	56.7 Ksi	8.2%	Base
Joint 61H	Horizontal	75.8 Ksi	46.7 Ksi	9.4%	Base

(1) H.A.Z. - i.e., heat affected zone of joint.

Figure A-17

GAS METAL-ARC WELDED REINFORCING BAR TENSILE TEST

GROUP 15

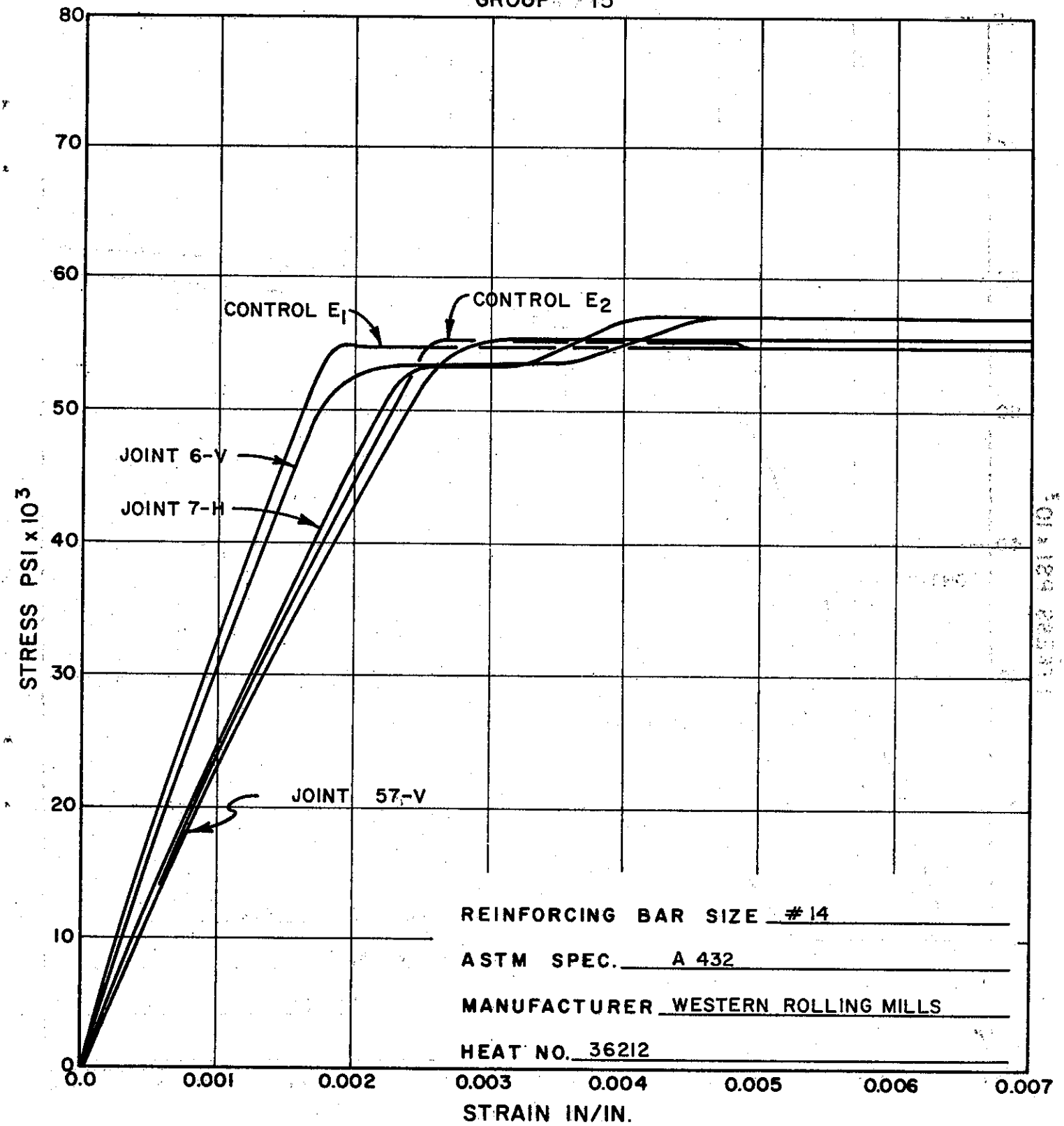

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Figure A-18

GAS METAL-ARC WELDED REINFORCING BAR TENSILE TEST

GROUP 16

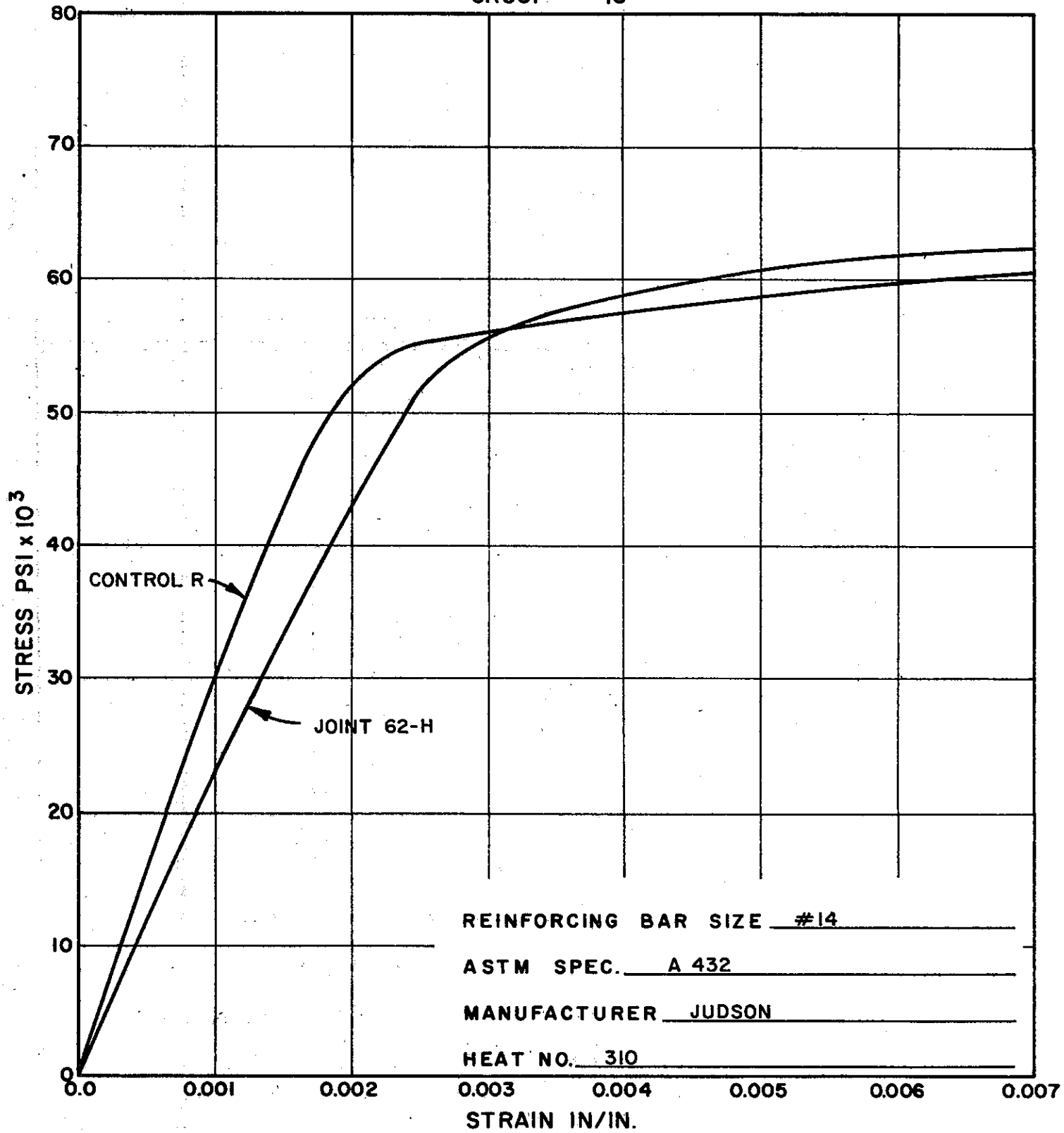

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Figure A-19

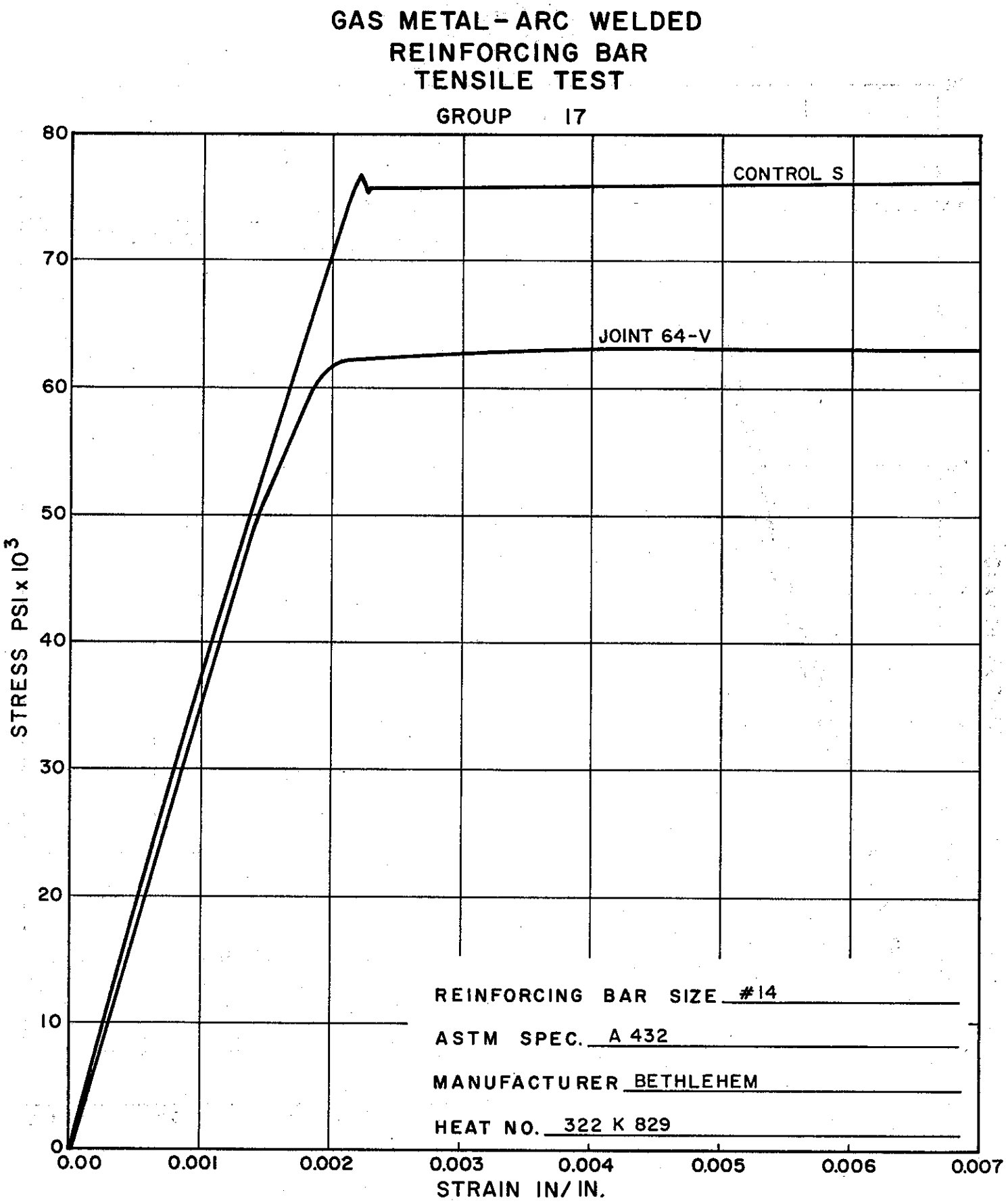

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Figure A-20

GAS METAL-ARC WELDED REINFORCING BAR TENSILE TEST

GROUP 19

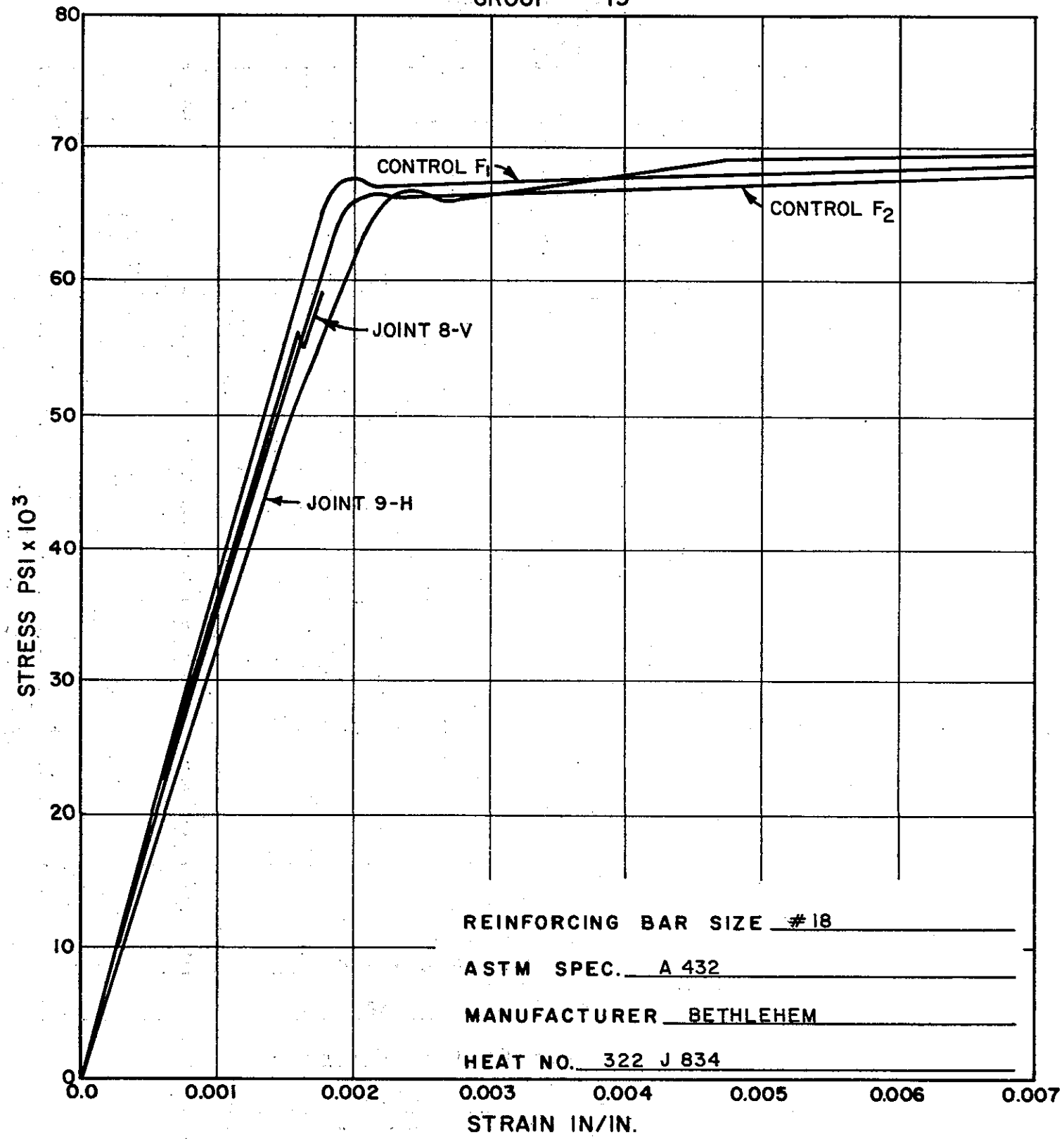

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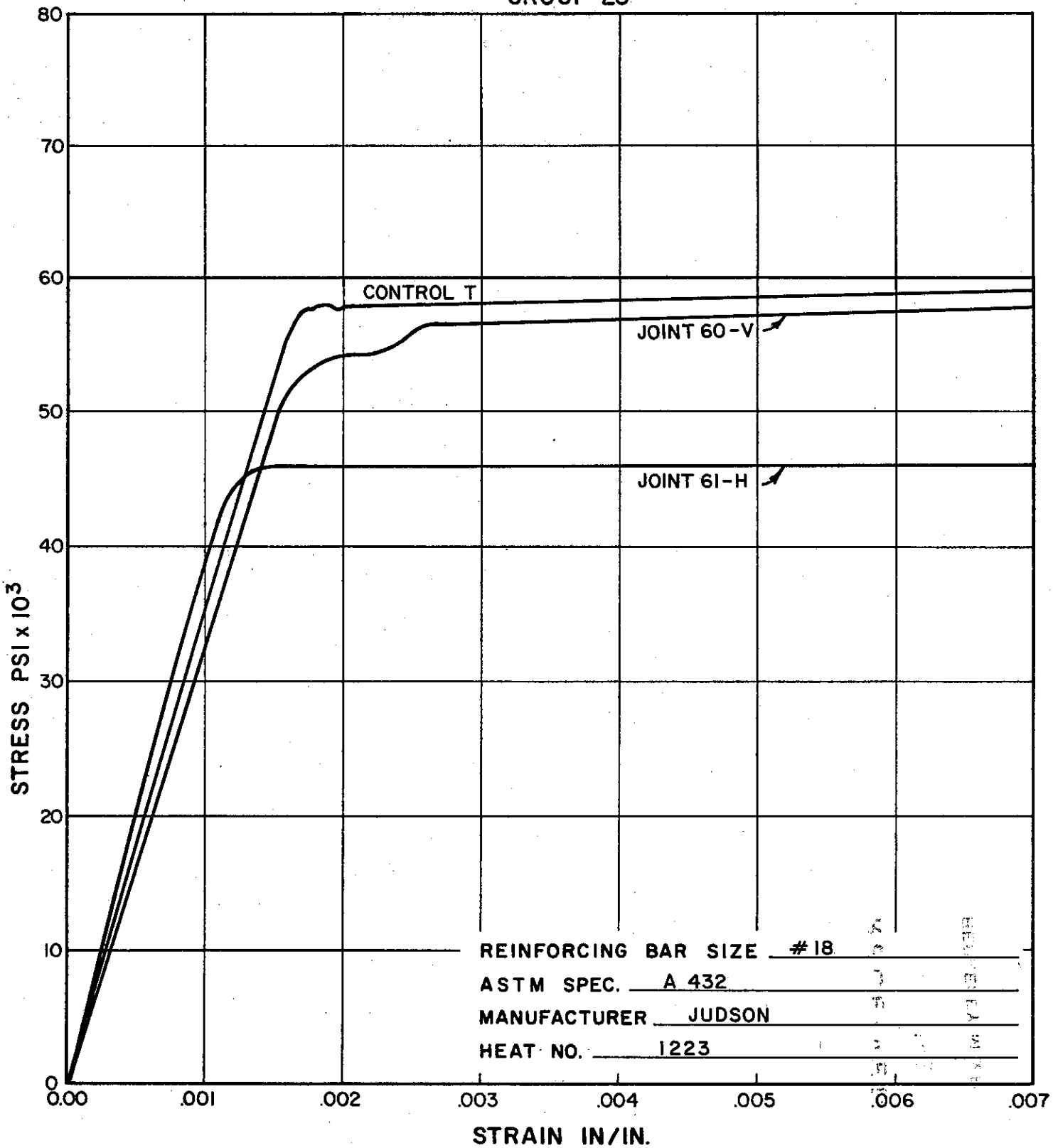
Figure A-21

GAS METAL-ARC WELDED REINFORCING BAR TENSILE TEST

GROUP 20



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