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WADC TECHNICAL REPORT 54-270

PART I

**INVESTIGATION OF THE COMPRESSIVE, BEARING
AND SHEAR CREEP-RUPTURE PROPERTIES OF
AIRCRAFT STRUCTURAL METALS AND
JOINTS AT ELEVATED TEMPERATURES**

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FOREWORD

This report was prepared by Cornell Aeronautical Laboratory, Inc. under USAF Contract No. AF 33(616)-190. This contract was initiated under Project No. 7360 "Materials Analysis and Evaluation Techniques", Task 73605 "Design Data for Metals", formerly RDO No. 619-11 "Substitutes for Critical and Strategic Materials", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Mr. K. D. Shimmin acting as project engineer.

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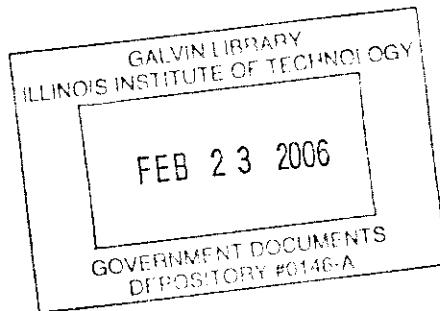
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ABSTRACT

The intent of this investigation is to supplement conventional tensile creep data of several aircraft structural alloys with compression, bearing, and shear properties as well. While these data alone are of interest, a correlation is being attempted between tensile creep and compression, bearing, and shear creep properties so that the latter type of data may be predicted from tensile creep properties alone.

This report includes descriptions of equipment and fixtures for conducting tensile, compression, bearing, and shear creep tests. Tensile creep properties are reported at several test temperatures for the following alloys: (1) 2024-T3 aluminum sheet, 0.064 and 3/16 inch thick; (2) C-110M titanium sheet; (3) type 321 stainless steel sheet; (4) 2117-T4 aluminum rivet wire; (5) Monel rivet wire; and (6) type 301 stainless steel rivet wire. Bearing and shear creep characteristics are included for the 2024-T3 aluminum alloy.



PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

A handwritten signature in black ink, appearing to read "M. R. Whitmore".

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Contrails

TABLE OF CONTENTS

	Page
INTRODUCTION	1
TEST MATERIALS	2
24S-T3 Aluminum	2
Type 321 Stainless Steel	2
RC-130-A Titanium	3
Type 301 Stainless Steel	3
Monel	3
Al7S-T4 Aluminum	4
TEST SPECIMENS	4
Tensile Creep	4
Bearing Creep	5
Shear (Pin) Deformation	5
Compression Creep	5
TEST APPARATUS	5
Tensile Creep	6
Bearing Creep	6
Shear (Pin) Deformation	6
Compression Creep	7
TEMPERATURE CONTROL	9
Tensile Creep	9
Bearing Creep	9
Shear (Pin) Deformation	10
Compression Creep	10
TEST PROGRAM	10
TEST RESULTS	11
Tensile Creep	11
Bearing Creep	14
Shear (Pin) Deformation	16
Compression Creep	17
WORK IN PROGRESS	19
BIBLIOGRAPHY	20

Controls
LIST OF TABLES

Table	Page
1. Project Program Indicating Tests to be Conducted	11
2. Comparison of Creep-Rupture Values for Types 301 and 302 Stainless Steel	14
3. Bearing-Tensile Stress Ratios for Creep and Rupture for 24S-T3 Aluminum Sheet at Indicated Temperatures	15
4. Ratio of Shear Stress-Rupture Strength to Tensile Stress-Rupture Strength	16
5. Comparison of Room Temperature Mechanical Properties for 24S-T3 Aluminum 3/16-Inch Plate in Compression and Tension	18
6. Room Temperature Tensile Properties of Test Materials.	21
7. Tensile Creep Characteristics of 24S-T3 Sheet	22
8. Tensile Creep-Rupture Characteristics of 24S-T3 Sheet.	23
9. Tensile Creep-Rupture Characteristics of 24S-T3 Sheet.	24
10. Tensile Creep-Rupture Characteristics of 24S-T3 3/16-Inch Plate	25
11. Tensile Creep Characteristics of 24S-T3 3/16-Inch Plate	26
12. Tensile Creep-Rupture Characteristics of 24S-T3 Plate.	27
13. Tensile Creep Characteristics of Type 321 Stainless Steel Sheet	28
14. Tensile Creep Characteristics of Type 321 Stainless Steel Sheet	29
15. Tensile Creep Characteristics of Type 321 Stainless Steel Sheet	30
16. Tensile Creep-Rupture Characteristics of RC-130-A Titanium Alloy Sheet	31
17. Tensile Creep-Rupture Characteristics of RC-130-A Titanium Alloy Sheet	32
18. Tensile Creep Characteristics of Annealed Monel 1/2-Inch Diameter Wire	33
19. Tensile Creep-Rupture Characteristics of Annealed Monel 1/2-Inch Diameter Wire	34
20. Tensile Creep-Rupture Characteristics of Type 301 Stainless Steel 1/2-Inch Diameter Wire	35
21. Tensile Creep-Rupture Characteristics of Type 301 Stainless Steel 1/2-Inch Diameter Wire	36
22. Tensile Creep Characteristics of Al7S-T4 3/8-Inch Diameter Rivet Wire	37
23. Bearing Creep-Rupture Characteristics of 24S-T3 Sheet.	38
24. Bearing Creep-Rupture Characteristics of 24S-T3 Sheet.	39
25. Bearing Creep-Rupture Characteristics of 24S-T3 Sheet.	40
26. Shear Pin Deformation-Rupture Characteristics of 24S-T3 Plate	41
27. Shear Pin Deformation-Rupture Characteristics of 24S-T3 Aluminum Plate	42
28. Compression and Tensile Creep Characteristics of 24S-T3 Aluminum Sheet at 26,000 P.S.I.	43

Controls
LIST OF ILLUSTRATIONS

Figure	Page
1. Tensile Creep Specimens	44
2. Bearing Creep Specimen	47
3. Shear Creep Specimen	48
4. Compression Creep Specimens for Sheet and Plate Material	49
5. Four-Unit Tensile Creep Apparatus	50
6. Bearing Creep Test Fixture Assembly With Deformometers and Strain Gage Attached	51
7. Cantilever Strain Gage for Bearing and Shear Creep Deformation Measurements	52
8. Shear Creep Test Fixture Assembly	53
9. Close-Up of Shear Creep Test Fixture With Deformometers Removed	53
10. Schematic Diagram of Compression Loading Equipment . . .	54
11. Static Loading Compression Creep Unit	55
12. Compression Creep Restraining Fixture Assembly	56
13. Assembled Specimen-Restraining Fixture-Compressometer Setup	57
14. Tensile Creep-Rupture Characteristics of 24S-T3 Sheet at 300°F	58
15. Tensile Creep-Rupture Characteristics of 24S-T3 Sheet at 450°F	59
16. Tensile Creep-Rupture Characteristics of 24S-T3 Sheet at 600°F	60
17. Tensile Creep-Rupture Characteristics of 24S-T3 3/16-Inch Plate at 300°F	61
18. Tensile Creep-Rupture Characteristics of 24S-T3 3/16-Inch Plate at 450°F	62
19. Tensile Creep-Rupture Characteristics of 24S-T3 3/16-Inch Plate at 600°F	63
20. Hardness Vs. Aging Times at 300°F for Stressed and Unstressed 24S-T3 Sheet and Plate Specimens	64
21. Hardness Vs. Aging Times at Indicated Temperatures for Stressed and Unstressed 24S-T3 Sheet Specimens	65
22. Hardness Vs. Aging Times at Indicated Temperatures for Stressed and Unstressed 24S-T3 Plate Specimens	66
23. Tensile Creep-Rupture Characteristics of Type 321 Stainless Steel Sheet at 1000°F	67
24. Tensile Creep-Rupture Characteristics of Type 321 Stainless Steel Sheet at 1200°F	68
25. Tensile Creep-Rupture Characteristics of Type 321 Stainless Steel Sheet at 1350°F	69
26. Tensile Creep-Rupture Characteristics of RC-130-A Titanium Alloy Sheet at 800°F	70

Contents

Figure	Page
27. Tensile Creep-Rupture Characteristics of Monel 1/2-Inch Diameter Wire at 1000°F	71
28. Tensile Creep-Rupture Characteristics of Monel 1/2-Inch Diameter Wire at 1200°F	72
29. Tensile Creep-Rupture Characteristics of Type 301 Stainless Steel 1/2-Inch Diameter Wire at 1200°F	73
30. Tensile Creep-Rupture Characteristics of Type 301 Stainless Steel 1/2-Inch Diameter Wire at 1350°F	74
31. Tensile Creep-Rupture Characteristics of Al7S-T4 3/8-Inch Diameter Rivet Wire at 600°F	75
32. Bearing Creep-Rupture Characteristics of 24S-T3 Sheet at 300°F	76
33. Bearing Creep-Rupture Characteristics of 24S-T3 Sheet at 450°F	77
34. Bearing Creep-Rupture Characteristics of 24S-T3 Sheet at 600°F	78
35. Shear Deformation-Rupture Characteristics of 24S-T3 3/16-Inch Plate at 300°F	79
36. Shear Deformation-Rupture Characteristics of 24S-T3 Plate at 450°F	80
37. Calibration Curve of Compression Creep Restraining Fixture	81
38. Compression Test Setup for Determining Restraining Fixture Forces and Stress-Strain Characteristics	82
39. Force in Restraining Fixture Vs. Compression-Deformation of 24S-T3 Aluminum Plate for Various Restraining Fixture Wedges	83
40. Load Vs. Compression-Deformation Curves for 24S-T3 Aluminum Plate Under the Influence of Various Restraining Fixture Wedges	84
41. Time Vs. Total Deformation Curves for Tensile and Compression Creep of 24S-T3 Aluminum Sheet at 450°F and 26,000 PSI	85

Contrails

ERRATA

The designations of three of the alloys used in this investigation have been changed since the initiation of this program. In this report the alloys are referred to by their former designations as follows: (1) 2024-T3 aluminum alloy, formerly designated 24S-T3 aluminum alloy; (2) 2117-T4 aluminum alloy, formerly designated A17S-T4 aluminum alloy; and (3) C-110M titanium alloy, formerly designated RC-130-A titanium alloy.

Contrails

INTRODUCTION

The elevated temperature creep-rupture properties of aircraft structural alloys are of particular concern in the design of present day aircraft. Structural components are continually subjected to elevated temperature due to their proximity to the jet power plant as well as the high temperature generated by skin friction at supersonic speeds.

High-temperature creep and rupture strengths are normally determined from tension-loading tests. However, structural components seldom fail as a result of a pure tensile stress, but rather from a combination of several complex load patterns. For example, riveted joints may fail by rupturing the sheet, shearing of the rivet, or the bearing stresses on the plate may be excessive to cause loosening of the joint. Other structural members may be loaded in compression and fail by buckling. Therefore, prediction of the high-temperature service life from tensile creep-rupture properties alone would be of questionable accuracy.

This study has been initiated to investigate the high-temperature creep-rupture characteristics of several aircraft structural sheet and rivet alloys when subjected to compression, bearing, and shear stresses. While these data would be of considerable interest from a design standpoint, it is anticipated that relationships can be established between these particular creep properties with tension creep properties. These relationships could then be utilized to predict service life of materials stressed in compression, bearing, and shear from tensile creep properties when the former types of data are not available.

The initial effort for this project consisted of the design and construction of apparatus and fixtures for conducting tensile, compression, bearing, and shear creep-rupture tests. The tensile creep apparatus is conventional and special fixtures were used in conjunction with this equipment for bearing and shear testing. Two special compression creep test machines were also constructed. All test apparatus is described in detail in this report.

Tensile creep properties are included for all alloys being investigated. Bearing creep properties are presented for 24S-T3 sheet at 300, 450, and 600°F, as well as shear creep characteristics of 24S-T3 plate at 300 and 450°F.

Contrails

TEST MATERIALS

The following alloys are being investigated for this study: 24S-T3 aluminum, type 321 stainless steel, RC-130-A titanium, type 301 stainless steel, annealed Monel and Al7S-T4 aluminum. The 24S-T3 aluminum, 321 stainless steel and RC-130-A titanium are to be tested for tension, compression, and bearing creep properties and were purchased as 0.064-inch thick sheet. The remaining alloys are to be tested for tension and shear creep properties and were acquired as 1/2-inch diameter wires except for the Al7S-T4 which was received as 3/8-inch diameter wire. Since the 24S-T3 aluminum is to be tested in shear, and compression creep properties are to be determined for two different gages, additional sheets 3/16 inch thick were also obtained. Room temperature mechanical properties were determined for these materials and are listed in Table 6.

24S-T3 Aluminum (Government Specification QQ-A-355b)

This alloy was purchased in 0.064 and 3/16-inch sheets from the Aluminum Company of America through their local distributor and is certified by them to possess the following chemical analysis and mechanical properties:

	<u>Min.</u>	<u>Max.</u>
Cu	3.8	4.9
Si		0.50
Fe		0.50
Mn	0.3	0.90
Mg	1.2	1.8
Zn		0.10
Cr		0.10
Others each		0.05
Others total		0.15
Al	Remainder	
	<u>Tensile Strength</u>	<u>Yield Strength</u>
0.064-inch sheet	64,000 p.s.i. min.	42,000 p.s.i. min.
3/16-inch sheet	64,000 p.s.i. min.	42,000 p.s.i. min.
		<u>Elongation</u>
		17% in 2 inches min.
		15% in 2 inches min.

In order to differentiate between the 0.064 and 3/16-inch sheets, the 3/16-inch material will be hereafter referred to as "plate".

Type 321 Stainless Steel (AMS - 5510D)

Type 321 stainless steel sheet 0.064 inch thick was purchased from

Contrails

a local Armco distributor. The chemical analysis of this material as stated by the supplier is the following:

C	0.051
Mn	1.30
P	0.027
S	0.012
Si	0.72
Ni	9.68
Cr	17.57
Ti	0.60

A mechanical property report was not received with the material.

RC-130-A Titanium (No specification)

Two sheets of this alloy 0.064 x 30 x 90 inches were received from Rem-Cru Titanium, Inc., Midland, Pennsylvania. These sheets were certified to conform to the following chemical analysis and mechanical properties:

C	<0.1
N	0.027
Mn	6.76
Ti	Bal.

Tensile Strength p.s.i. 146,900
Yield Strength p.s.i. 137,200
Elongation 16% in 2 inches

Type 301 Stainless Steel (No specification available)

Armco 17-7 stainless type 301, one-half inch diameter centerless ground wire was purchased from the Armco Steel Corp., Middletown, Ohio. Although mechanical property data were not included with the certified analysis, the chemical analysis is as follows:

C	0.096
Mn	1.86
P	0.023
S	0.013
Si	0.57
Cr	17.21
Ni	7.58

Monel (Government specification QQ-N-281)

Annealed Monel bars, one-half inch diameter, were purchased from

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the International Nickel Company to conform to Federal Specification QQ-N-281, chemically. The certified analysis is as follows:

C	0.17
Mn	1.03
Fe	1.57
S	0.007
Si	0.07
Cu	31.9%
Ni	65.19

A mechanical property report was not received with the material.

Al7S-T₄ Aluminum (No Specification Available)

This material was received in a coil of three-eighths inch diameter rivet wire from the Aluminum Company of America. A subsequent straightening and heat treating operation (solution treated at 940°F for one hour followed by a water quench) was necessary to return the material to its original T₄ condition. Nominal chemical analysis is as follows:

	<u>Min.</u>	<u>Max.</u>
Cu	2.2	3.0
Fe		1.0
Si		0.80
Mn		0.20
Mg	0.20	0.50
Zn		0.10
Cr		0.10
Other Total		0.15
Each		0.05
Al		Bal.

Minimum shear strength per physical test report for the original stock is 29,800 p.s.i.

TEST SPECIMENS

Tensile Creep

The tensile sheet and plate specimens for creep testing were machined from 16 x 1 inch strips and were taken from the stock so that the axis of loading would be parallel to the rolling direction. These strips had a reduced gage section 5 x 1/2 inch. The width of the gage

Controls

section of the plate material was decreased to one-fourth inch to lessen the dead-weight load in the creep machine. Tensile creep specimens are illustrated in Figure 1. Each specimen was tested in the "as-received" condition except the Al7S-T₄ rivet wire. This material was received in a coil which necessitated straightening and a subsequent heat treatment to obtain its original T₄ condition.

Bearing Creep

The bearing creep specimen is illustrated in Figure 2. The edge distance, or the distance from the center of the bearing hole to the edge of the sheet, was selected for all tests as 1.5 times the diameter of the bearing hole. As in the case of the tensile specimens, the axis of loading is also parallel to the direction of rolling.

Shear (Pin) Deformation

An illustration of the shear creep specimen is shown in Figure 3. These specimens were machined from the center of the test material and in such a manner that loading would be normal to the direction of rolling. Holes 1/16 inch diameter by 5/64 inch were drilled in the ends of the specimen for insertion of thermocouples.

Compression Creep

These specimens are coupons, 3/4 x 2-9/16 inches for sheet and 2-5/8 inches for plate, with the long dimension being parallel to the direction of rolling. Although no elaborate machining is necessary in preparation of these specimens, considerable care is taken in making all corners square and all opposing faces parallel to insure axiality in loading. These specimens for sheet and plate are illustrated in Figure 4.

TEST APPARATUS

The tension, bearing, and shear creep tests were conducted in conventional lever-loaded (10:1 ratio) creep machines of Cornell Aeronautical Laboratory, Inc. design. Since these machines were designed primarily for tensile creep-testing, special fixtures were necessary to adapt this equipment for bearing and shear creep tests. Separate loading frames of different design were used for compression-creep testing.

Controls

Tensile Creep

A photograph of a four-unit tensile creep apparatus is illustrated in Figure 5. As this equipment is of standard design, a detailed description is unnecessary. Deformation of the tensile creep specimen is measured by the relative displacement of two pairs of extensometer rods attached at the extremities of the two-inch gage length. This movement is detected by a special cantilever-beam strain gage(1)* which delivers an output signal to a four-arm bridge circuit. This signal is proportional to the relative displacement of the extensometer arms and is automatically recorded on a Dyanlog strain-time recording instrument. A sensitivity of 0.00004 in/in/div, for a two-inch gage section, with a long time accuracy of 0.0004 in/in/div is obtained with the strain recording system.

Bearing Creep

The bearing-creep specimen holder and deformometer are shown in Figure 6. This equipment consists essentially of a clevis of two hardened tool-steel plates riveted to a spacer bar to maintain a clearance of 0.070 inch. Two holes 5/32 inch in diameter were drilled and reamed in line through these plates. The bearing specimen is then placed between the two plates and a hardened tool-steel pin is inserted through the 5/32 inch holes and the bearing test hole of the specimen. The complete unit is then secured in the tensile creep machine at pin connected joints and bearing load is applied to the specimen by the tool-steel pin.

The effective bearing area is calculated as the product of the bearing hole diameter and the thickness of the sheet. The bearing hole deformation is measured by the relative displacement between the bearing pin and the stress-free corners of the bottom edge of the specimen. Two deformometer arms are attached to a stress-free area of the specimen holder above the bearing pin hole. The other pair of deformometer arms are clamped to the bottom edge of the specimen. These four deformometer arms engage a cantilever electrical strain gage (Figure 7) similar to the type employed in the tensile-creep tests, but of higher sensitivity because of the short gage length, and deformation is recorded in the same manner. This system is capable of detecting deformation of the one-eighth inch bearing hole in the order of 0.013% of diameter per division of the strain recorder. This represents a movement of 0.000016 inch. Results are calculated as percent deformation of the bearing hole diameter.

Shear (Pin) Deformation

The test fixture (Figures 8 and 9) for shear creep testing is similar

*See bibliography

Controls

in design to the type employed for bearing creep testing and is a modification of the device illustrated in Figure SM-17T (2). This fixture consists of a clevis to hold the shear specimen and a blade to apply the stress. The clevis was assembled by riveting two hardened 0.125 inch thick, high speed tool-steel plates to a stainless steel spacer bar which was ground to maintain a clearance of 0.126 inch between the plates. Two one-eighth inch diameter holes were drilled and reamed in line through both plates at the centerline and 1-1/2 inches from the top edges. The shear blade, also of hardened high-speed tool steel, 4 x 1-1/4 x 0.125 inches, was drilled and reamed for 0.125 inch hole, 0.44 inch from one end. Other necessary holes were drilled in the shear blade and spacer bar for attaching the fixture in the creep test unit. All holes were accurately drilled to insure axial loading. When the shear blade is placed between the two steel plates and the 0.125 inch diameter holes aligned, the specimen can then be inserted in the fixture.

The deformometer and strain gage for shear creep tests are identical to the type used for bearing creep. However, deformation values are presented in inches, rather than percent. Since total deformation from a shear load may be a result of compression, bending, as well as shearing, the displacement of the shear blade will then indicate a summation of all these conditions and not just deformation occurring in shear. The results are therefore presented in total deformation in inches as no true analysis of percent shear strain can be made.

Compression Creep

In the development of equipment for compression creep-testing, greater care must be exercised in the construction and assembly of components than is normally associated with tensile-testing equipment. These requirements and precautions arise from the specific nature of the test, for, under compression loading, all materials have a tendency to buckle. For the case of sheet and plate materials subjected to compressive loads, compression testing requires that a lateral supporting feature be incorporated in the equipment design in order to maintain as closely as possible a state of axial compression. For this program, in which the compression-creep behaviors of sheet and plate alloys are to be determined, equipment has been designed and constructed to perform the following functions: (a) apply and maintain a constant compressive load on the specimen, (b) provide lateral support to the specimen, (c) control and maintain specimen test temperature, and (d) measure the specimen gage length deformation which occurs under load.

When conducting compression tests on sheet materials, testing equipment generally is arranged to accommodate the use of a compression subpress which incorporates a guided ram for providing the load to a laterally supported specimen. While subpresses are well suited for conducting room temperature compression tests, at elevated temperatures

Controls

their bulkiness greatly increases the problems of obtaining and maintaining equilibrium test temperatures.

For this portion of the investigation two loading units have been built incorporating the compression subpress principles; however, loading rams and restraining fixtures are completely divorced from one another. Figure 10 illustrates schematically the method of loading used to place the specimen under a steady compression load. Load is applied to the specimen by a 10:1 lever which acts through a series of knife edges arranged alternately perpendicular between the loading lever and loading ram. The actual test unit is presented in Figure 11 which shows the unit equipped with furnace and adjustable roller bearings that act to guide the loading ram. In this manner the effect of a subpress is produced without the addition of massive fixtures in the furnace. For rigid and sturdy construction, the loading frame is made of welded 18-inch ship channel.

In conjunction with the guided loading-rams to apply the load on the specimen, some provision must be made to prevent specimen buckling during the course of a test. To perform this function, a restraining fixture has been devised which utilizes two type 302 stainless-steel plates between which the specimen is sandwiched. The restraining-fixture plates are grooved for the insertion of thermocouples to measure temperature at various positions on the specimen gage length. The restraining force which holds the assembly together is created by inserting a wedge between the strap of the fixed and adjustable halves of the fixture. The restraining fixture for conducting the compression creep study is presented as a sketch in Figure 12 to illustrate the important components in its make-up and the manner of assembly. Figure 13 illustrates the fixture and compressometer assembled for testing. This design of restraining fixture for compression creep-testing permits the use of variable thickness specimens and appears sufficiently compact and sturdy for conducting compression creep tests at temperatures up to 1200°F.

Specimen strain is measured over a 1-1/2-inch gage length by means of a set of compressometers engaging the specimen edges with set screws which seat in punch marks. Since each compressometer arm has only single point contact with the specimen, vertical slide pins connecting the upper and lower compressometer halves have been provided to limit angular motion of the compressometer arms. These compressometers engage cantilever beams to which resistance strain gages are cemented and the method of continuous strain recording is identical to that presented for tension creep testing with the same order of sensitivity and accuracy being obtained.

Contrails

TEMPERATURE CONTROL

All the creep tests conducted for this study other than compression creep utilized furnaces of similar design, but with certain modifications to adapt them to the particular type of test and the material being tested. The furnaces are the verticle tube type using a resistance-heating coil of Nichrome V wire. To compensate for heat losses, the coil windings were concentrated at the ends of the furnace. These windings were also tapped at the top, middle and bottom sections of the furnace so that voltage input could be regulated to those particular zones, making possible a fine adjustment for optimum temperature distribution. Temperature is maintained by a potentiometer type temperature controller.

In order to minimize the effect of exposure at elevated temperatures, each specimen was held at the proper test temperature for a maximum of two hours prior to loading.

Tensile Creep

To obtain temperature measurements for tensile creep, three porcelain-bead insulated, 18 gage, chromel-alumel thermocouples were wired, one inch apart over the two inch gage length, to the specimen. Asbestos cord was then wrapped around the bead of each thermocouple to reduce radiation effects. Previous experience has proven the reliability of this method so that temperature corrections are unnecessary. A 3°F maximum variation in temperature was maintained in the gage length test section of the specimen throughout the duration of the test. Specimen temperature readings were made by a precision potentiometer with an accuracy of $\pm 0.5^{\circ}\text{F}$.

Bearing Creep

In view of the fact that the bearing test area of the specimen is inaccessible for temperature measurement during the progress of the test, a survey was necessary to determine the most desirable and reliable area for attaching the control thermocouple. A glass insulated 30 gage, chromel-alumel thermocouple was peened in a 0.040-inch hole between the bearing hole and the edge of the specimen. Other thermocouples were placed on the sides of the specimen and another on the centerline of the specimen one-fourth inch above the bearing hole. Using a 24S-T3 specimen, temperatures were recorded at all locations when the peened in thermocouple indicated 300, 450 and 600°F . The thermocouple above the bearing hole proved to be most satisfactory with the least divergence from desired test temperature. This area was then used during actual bearing creep tests. Necessary corrections were made so that the effective bearing area was at the proper test temperature. Similar temperature surveys are necessary on each alloy prior to testing at a

Controls

particular test temperature.

Shear (Pin) Deformation

As 24S-T3 aluminum plate has been the only alloy investigated for shear pin deformation properties to date, a temperature survey to determine the most desirable method of attaching the control thermocouple has been made on this alloy alone. A dummy specimen was prepared with a shallow 5/32 x 1/16-inch hole in one end of the specimen and a 0.040-inch hole drilled to the center. Thermocouples were placed in these holes by (1) peening, and (2) by cementing with a high temperature cement. The specimen was placed in the test fixture and heated to the proper test temperature. These tests proved that no temperature gradient existed between the thermocouple in the center of the specimen and the one secured at the end. There was also no variation between the peened thermocouples and the cemented ones. However, the ease in installing the cemented couple was the deciding factor in using this method for all future tests.

Compression Creep

The specimen test temperature is maintained by a 5KVA, three zone, resistance wound furnace, vertically split and hinged to accommodate test specimen set-up. The furnace, regulated by a conventional potentiometric controller to maintain test temperature within $\pm 3^{\circ}\text{F}$ of the nominal test temperature is powered by auto-transformers which permit the adjustment of temperature distribution in the various zones. Temperature measurements are made at the top, middle and bottom specimen gage section with five chromel-alumel thermocouples pressed against the specimen and shielded by asbestos from the restraining fixture. A precision potentiometer accurate to within one-half of 1°F is used to indicate the test section temperatures and to serve as a guide for temperature adjustment in the various zones of the furnace.

TEST PROGRAM

The complete program for tensile, compression, bearing and shear creep testing is tabulated below, listing the type of material and the various properties to be determined for each.

Contrails

TABLE 1

PROJECT PROGRAM INDICATING TESTS TO BE CONDUCTED

Material	Test Temp. °F	Tension	Bearing	Shear	Compression
24S-T3 Sheet	300	x	x		x
	450	x	x		x
	600	x	x		x
24S-T3 Plate	300	x		x	x
	450	x		x	x
	600	x		x	x
RC-130-A Titanium Sheet	600	x	x		x
	800	x	x		x
Type 321 Stainless Steel Sheet	1000	x	x		x
	1200	x	x		x
	1350	x	x		x
Type 301 Stainless Steel Wire	1200	x		x	
	1350	x		x	
Monel Wire	1000	x		x	
	1200	x		x	
Al7S-T4 Aluminum Wire	300	x		x	
	450	x		x	
	600	x		x	

TEST RESULTS

Tensile Creep24S-T3 Sheet

Tensile creep tests were conducted on this alloy at temperatures of 300, 450 and 600°F. These temperatures were selected as representative of a low, intermediate and high range insofar as possible service conditions are concerned. At 300°F, aging effects are not apparent until several hundred hours at test and even then these effects are offset by continuous strain hardening. Fracture ductility values at 300°F were noted to vary inversely with time for rupture. Stresses to produce rupture in longer times resulted in ductility values in the order of 1.0% while the tests that failed in the ten-hour range had fracture ductility

Contrails

values in excess of 10.0%.

The effects of overaging become apparent on the creep properties of this alloy at 450°F after approximately 50 hours, as illustrated by the change in the slope of the rupture line in Figure 15. At 600°F, 24S-T3 is in a decidedly overaged condition and the alloy becomes progressively weakened as the test duration times increase. Tables 7 to 9 are compilations of pertinent data determined from these tests. Stress-time design curves are presented in Figures 14 to 16.

24S-T3 Plate

Because of the variations in properties that exist from heat to heat of the same alloy, it was considered essential to conduct tensile creep tests on the 3/16-inch 24S-T3 material as well, rather than utilize the 24S-T3 sheet data for future correlations between shear and compression creep properties of the plate. These tests were run because of the aforementioned reason and not because significant changes in properties were to be expected from the variation in the gage of the alloy. The results of these tensile creep tests are listed in Tables 10 to 12 for temperatures of 300, 450, and 600°F and are graphically illustrated in Figures 17 to 19.

Inasmuch as considerable instability of the microstructure exists in the 24S-T3 alloy in the 300 to 600°F temperature range, the overaging characteristics of the sheet and the plate were examined in the form of room temperature hardness changes. Such data were considered to have possible value for future correlation of the simple tension creep-rupture tests with those of compression, bearing, and shear tests. The room-temperature hardness changes taken from both unloaded specimens heated for various durations of time and from the gage lengths of the creep-rupture specimens are illustrated in Figures 20 to 22.

At 300°F, artificial aging occurs in the unloaded specimen, but this is masked in the loaded specimen by accumulated strain hardening. Softening occurs readily after exposure at 450 and 600°F, with the overaging reaction being accelerated by tensile loading. No significant change in hardness was apparent between the stressed and unstressed specimens at corresponding exposure times for the plate material at 450°F. However, overaging or softening was found to definitely accelerate in the stressed sheet material at 450°F and at 600°F in both stressed sheet and plate.

Type 321 Stainless Steel Sheet

Type 321 stainless steel was tested at 1000, 1200, and 1350°F to obtain creep-rupture and 1.0% total deformation values at test

Controls

duration times ranging from 1 to 1000 hours. Tensile creep-characteristics at these temperatures are presented in Tables 13 to 15 while log stress vs. log time curves for creep and total-deformation values are included in Figures 23 to 25.

The 1000°F temperature is relatively low for defining deformation properties of this material by creep tests in the 1 to 1000 hour range. High stresses, well above the yield strength are required to produce rupture in a time range of several hundred hours with resulting deformation on loading exceeding 5.0%.

RC-130-A Sheet

The tensile creep characteristics of RC-130-A sheet have been investigated at 600 and 800°F. The results of these tests are presented in Tables 16 and 17. Log stress vs. log time curves for tests at 800°F are illustrated in Figure 26.

While tensile creep tests were conducted on this alloy at 600 and 800°F, design curves are presented alone for the tests at 800°F. Creep is relatively insignificant at 600°F as specimen deformation appears to be primarily dependent upon initial loading conditions.

Monel

Tensile creep-rupture tests were conducted on annealed one-half inch diameter Monel wire at 1000 and 1200°F at various stresses to produce rupture as well as 1.0% total deformation in a 1 to 1000 hour range. The data from these tests are listed in Tables 18 and 19 and accompanying log stress vs. log time curves are presented in Figures 27 and 28.

The data and characteristic breaks in the rupture lines are similar to those reported by Grant and Bucklin (3). The more pronounced change in slope of the stress-time line for rupture at 1200°F is probably associated with intergranular oxidation and intergranular failure at times beyond 100 hours.

Type 301 Stainless Steel

Type 301 stainless steel one-half inch diameter wire was acquired primarily for an analysis of shear creep properties; however, the tensile creep characteristics of the alloy are essential in order to establish relationships between tensile and shear creep properties. The results of these tensile creep tests at 1200 and 1350°F are listed in Tables 20 and 21. Figures 29 and 30 illustrate stress-time design curves resulting from these tests.

Controls

Stainless steel wire or round bar stock, one-half inch diameter or less, is normally received from the mill in an annealed plus cold drawn condition; this was the case with this alloy. The cold drawing operation causes a slight increase in mechanical properties as indicated by the room temperature values given in Table 6. It was decided to conduct all creep tests in the as-received condition in order that the test results be more representative of commercial material. The cold drawing may also have contributed to the slightly higher creep-rupture values when compared with type 302 stainless steel sheet in both the annealed and 1/2-hard condition (4). Such a comparison is presented below.

TABLE 2

COMPARISON OF CREEP-RUPTURE VALUES FOR
TYPES 301 AND 302 STAINLESS STEEL

Temp. °F	Alloy	Condition	100 Hour Rupture Strength P.S.I.
1200	Type 302 Stainless Steel Sheet	Annealed	21,000
	Type 302 Stainless Steel Sheet	1/2 hard	32,000
	Type 301 Stainless Steel Wire	Annealed & cold drawn	28,000
1350	Type 302 Stainless Steel Sheet	Annealed	12,900
	Type 302 Stainless Steel Sheet	1/2 hard	16,000
	Type 301 Stainless Steel Wire	Annealed & cold drawn	15,000

Al7S-T4 Rivet Wire

At the present time tensile creep-characteristics of Al7S-T4 rivet wire have been determined only at 600°F. The results of these tests are listed in Table 22 and these data are graphically presented in Figure 31. The tensile creep-behavior of the alloy is presently being investigated at 300 and 450°F and results will be included in a subsequent report.

Bearing Creep

The investigation of bearing creep properties thus far has been conducted on 24S-T3 aluminum sheet at test temperatures of 300, 450

Contrails

and 600°F. Stresses were selected to produce rupture of the specimen in 1 to 1000 hours. The bearing creep results are expressed as percent increase in the bearing-hole diameter as listed in Tables 23 to 25 and illustrated in the design curves of Figures 32 to 34.

While there is no direct correlation between the uniform deformation of the metal in the 2-inch gage section of a tensile-creep specimen and the deformation of the hole of the bearing creep specimen, an empirical comparison was made between the tensile and bearing creep properties for corresponding percentages of creep and rupture. It is possible that by utilizing these ratios, a given amount of bearing-hole deformation might be predicted from the tensile-creep properties for a given hole diameter, edge distance, and other known geometry of a joint.

TABLE 3

BEARING-TENSILE STRESS RATIOS FOR
CREEP AND RUPTURE FOR 24S-T3 ALUMINUM SHEET AT INDICATED TEMPERATURES

Temp. °F	Time in Hours	Bearing-Tensile Stress Ratios for Creep of		
		1.0%	2.0%	Rupture
300	1	1.39		1.57
	10	1.25		1.62
	50	1.18		1.57
	100	1.25		1.55
	200	1.14		1.53
	500	0.98		1.38
	1000			1.31
450	1	1.24	1.47	1.53
	10	1.01	1.19	1.50
	50	0.51	1.12	1.50
	100		1.12	1.53
	200		1.03	1.56
	500		0.99	1.84
	1000			
600	1			1.63
	10	0.77	1.11	1.60
	50	0.73	1.08	1.61
	100	0.73	1.09	1.61
	200	0.70	1.09	1.61
	500	0.66	1.05	1.59
	1000			1.59

Controls

It may be observed from the bearing-tension ratios that the rupture ratios are fairly consistent at all temperatures and times for rupture. While the mode of loading may differ in the bearing and tensile creep test, direct relationship between the creep-rupture strength should be possible as a material failure does occur in each case. Since the mechanism to produce rupture will be the same regardless of the rupture time, it is conceivable that these ratios should be common for all time and temperature ranges.

On the other hand, the ratios for 1.0 and 2.0% creep are not constant but appear to decrease for increasing times. As was indicated previously, there is no direct relationship between percent creep of the bearing hole and percent creep of the tensile specimen so therefore there is no basis to anticipate that these ratios should also be constant. Creep deformation for the bearing creep test is dependent on the distortion of the bearing hole on loading, cold working of the metal below the hole and the distribution of the bearing stresses, all of which will vary with the original bearing stress so that a constant ratio of bearing-tensile creep values is highly improbable.

Shear (Pin) Deformation

Thus far, only two series of high-temperature shear pin deformation tests have been completed. Shear-pin specimens one-eighth inch diameter were machined from 3/16-inch 24S-T3 aluminum plate and were tested at 300 and 450°F. Shear deformation-rupture properties at 450°F were determined for a time range from 1 to over 1000 hours. The shear deformation tests at 300°F, as well as all subsequent tests, will be conducted in a 1 to 200 hour range. The complete results for these experiments are included in Tables 26 and 27. Deformation values are presented in inches which is a measure of the travel of the shear blade as it passes through the specimen. Log stress vs. log time for rupture and low values of shear pin displacement are graphically illustrated in Figures 35 and 36. A correlation of the tensile creep and shear deformation rupture properties were made at 300 and 450°F and results are presented below:

TABLE 4

RATIO OF SHEAR STRESS-RUPTURE STRENGTH TO TENSILE STRESS-RUPTURE STRENGTH

Temp.	Failure Time	Shear Stress-Rupture Stress	Tensile Stress-Rupture Stress	Ratio
300	1 Hour	37,000 p.s.i.	59,000 p.s.i.	0.626
	10 Hours	35,000 "	56,000 "	0.625
	50 "	34,000 "	54,500 "	0.624
	100 "	32,000 "	54,000 "	0.591
	200 "	28,800 "	50,500 "	0.568

Contrails

Temp.	Failure Time	Shear Stress-Rupture	Tensile Stress-Rupture	Ratio
		Stress	Stress	
450	1 Hour	17,000 p.s.i.	40,000 p.s.i.	0.425
	10 Hours	13,000 "	30,000 "	0.433
	50 "	10,700 "	25,000 "	0.427
	100 "	9,800 "	23,000 "	0.426
	200 "	9,000 "	19,500 "	0.461
	500 "	7,100 "	14,700 "	0.483
	1000 "	5,900 "	12,000 "	0.491

Compression Creep

In the determination of room-temperature yield strength of 24S-T3 aluminum sheet, Kotanchik, et al (5) have demonstrated that the lateral restraining force has a direct and appreciable influence on the yield stress when plates are used to provide specimen restraint. No appreciable effect with increasing restraint was observed when a roller type fixture was used. Inasmuch as this program employs the plate type restraining fixture in which the restraining force is created by a wedge, it was considered advisable to determine the restraining forces involved when the specimen is deformed up to and beyond the 0.2% offset yield. At the same time information regarding the best choice of wedge material could be obtained in order that the effect of restraint may be reduced to a minimum.

The preliminary study to determine the magnitudes of the restraining forces was conducted under short-time room-temperature compression testing conditions using the restraining fixture designed for the compression creep program. Prior to making the compression tests, strain gages were cemented to the restraining fixture strap and the fixture was calibrated under load. Figure 37 presents the calibration curve of the restraining fixture. Using this calibration as an index, room-temperature compression tests on 24S-T3 plate were performed, employing wedges of 2S aluminum, type 302 stainless, and hardened AISI 4340 steel. During the course of establishing the compression stress-strain relationship of the 24S-T3 plate, strain gage readings were recorded to indicate the generated restraining forces. Figure 38 shows the room temperature set-up for conducting the compression tests to determine these restraining forces. For specimen deformations of approximately 2%, when employing the various wedge materials, curves relating restraining force and specimen deformation are presented in Figure 39. It can be seen that the aluminum wedge results in the least increase in supporting force with specimen deformation while the hardened steel and the stainless steel wedges display considerably larger specimen supporting forces with increasing specimen deformation. Examination of the wedges subsequent to testing indicates that the supporting force increase is related to the hardness of the wedge material and consequently its resistance to "brinelling". However, despite the variations in the degree of specimen restraint, no changes as demonstrated by the stress-strain relationships

Contrails

in Figure 40 were observed for the 0.2% yield stresses. The results of these room-temperature compression tests are presented in the following table along with companion short time room temperature tensile data obtained on the same lot of 24S-T3 aluminum.

TABLE 5

COMPARISON OF ROOM TEMPERATURE MECHANICAL PROPERTIES FOR
24S-T3 ALUMINUM 3/16 INCH PLATE IN COMPRESSION AND TENSION

Test	Direction of Rolling	Type of Wedge	Wedge Hardness	0.2% Yield Stress	Modulus of Elasticity	Diameter of Impression
					$\times 10^6$ P.S.I.	in Wedge MM
Compression	Longitudinal	AISI 4340	40 RC	45,250	9.63	No impression
"	"	Type 302 Stainless Steel	94 RB	45,300	9.64	1.6
"	"	2S Aluminum		45,250	9.90	3.3
Tension	"	None		55,500	9.80	
"	"	None		56,200	9.60	

These test results show a rather large decrease in the 0.2% yield stress due to compression loading. The observations agree with the results presented for this type alloy in ANC-5.

To determine the effect of restraint on the compression-creep behavior of 24S-T3 aluminum sheet and plate, a series of creep tests was conducted under a static compression stress of 26,000 p.s.i. at 450°F. As in the short-time room-temperature compression tests, the specimens were subjected to various degrees of restraint in order that this variable could be evaluated with respect to the compression-creep behavior of the test specimen. For these conditions of preliminary compression-creep testing, Table 28 presents a summary of the creep data along with a comparison of the appropriate tension-creep characteristics. These results are graphically illustrated as time-total deformation curves in Figure 41. It appears from these time-total deformation relationships that the selection of the wedge material has a significant influence on the creep-deformation process in compression and that a soft wedge, one which will deform as the

Controls

restraining force tends to increase, should be used so that a truer indication of compression-creep behavior may be established.

Consideration is being given to substituting a soft-spring device for the wedge, with the objective of maintaining the lateral restraining forces fairly constant and at a minimum required value during the course of a compression-creep test.

WORK IN PROGRESS

The necessary creep tests to complete this study as tabulated in the "Test Program" of this report are being continued. In addition to the six alloys previously described, RC 70 titanium and AISI 4130 sheet will also be investigated for tensile, compression and bearing creep characteristics.

Controls

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Controls

TABLE 6
ROOM TEMPERATURE TENSILE PROPERTIES OF TEST MATERIALS

Material	Size	Direction of Rolling	Ultimate Stress P.S.I.	Yield Stress P.S.I. (0.2% Offset)	% Elongation in 2 In.	Modulus of Elasticity P.S.I.
24S-T3	0.062" thick	Transverse	70,000	43,000	19.0	9.2 x 10 ⁶
		Longitudinal	69,800	46,300	21.5	9.2 x 10 ⁶
	0.190" thick	Transverse	69,400	51,400	18.5	10.2 x 10 ⁶
		Longitudinal	69,700	51,400	17.5	10.1 x 10 ⁶
Type 321 Stainless Steel 0.065" thick (Annealed)	0.065" thick	Transverse	69,100	46,800	18.5	9.7 x 10 ⁶
		Longitudinal	69,400	49,200	16.5	9.8 x 10 ⁶
	1/2" diameter	Transverse	71,300	55,500	15.0	9.8 x 10 ⁶
		Longitudinal	71,200	56,200	17.0	9.6 x 10 ⁶
RC-130-A	0.065" thick	Transverse	89,300	54,800	47.5	28 x 10 ⁶
		Longitudinal	87,300	50,500	50.5	
	3/8" diameter	Transverse	89,500	40,000	56.5	32 x 10 ⁶
		Longitudinal	87,400	45,300	51.5	30 x 10 ⁶
Al7S-T4	1/2" diameter	Transverse	153,000	131,000	19.5	Not determined
		Longitudinal	151,000	135,500	21.0	
Monel	1/2" diameter	Transverse	150,000	137,300	21.5	
		Longitudinal	150,500	137,000	19.6	"
Type 301 Stainless Steel	1/2" diameter	Transverse	112,000	50,000	51.0	54.0
		Longitudinal	115,000	47,000	51.0	52.0

Controls

TABLE 7

TENSILE CREEP CHARACTERISTICS OF 24S-T3 SHEET

Temp. of F	Stress P.S.I.	% Elong. on Load-	Time in Hours for Deformation of						Frac- ture Time of Test Hours	% Elong. in 2 In.	Min. Creep Rate % Per Hour	Hardness RB	Original-After nail test	Speci- men	
			C	TD	C	TD	C	TD							
40,000	0.422	395.	10.	-	445.	-	559.	559.	1.25	0.000278	78	82	212-42		
45,000	0.524	195.	0.1	-	175.	-	268.	268.	1.0	0.000625	78	84	212-45		
47,000	0.370	340.	27.	427.	375.	490.	504.	504.	2.5	0.00069	76	84	212-11		
48,000	0.581	14.	0.1	220.	10.	20.	279.	279.	1.5	0.0022	74	85	212-4		
49,000	0.958	5.	0.1	18.	1.	15.	144.	144.	2.0	0.001	76	85	212-9		
50,000	1.01	4.	0.1	15.	0.1	15.	73.	73.	2.5	0.001	76	84	212-3		
51,000	1.26	1.	0.1	2.4	0.1	1.9	61.	61.	2.5	0.001	76	84	212-7		
52,100	1.45	1.75	0.1	60.	1.5	1.5	66.0	66.0	3.5	0.01	76	83	212-1		
54,000	1.91	5.	0.1	12.	0.1	15.7	0.5	13.	15.8	16.0	4.0	76	85	212-2	
55,000	2.89	0.7	0.1	1.9	0.1	7.	0.1	0.1	2.2	17.5	7.5	0.091	74	83	212-5
56,000	2.88	0.2	0.1	1.2	0.1	0.1	0.02	0.02	1.5	6.75	7.5	0.42	76	84	212-25
56,000	No extensometers used									28.50	28.50	8.0	76	84	212-22
57,000	3.79	0.2	0.1	0.7	0.1	0.1	0L	0L	0.6	14.0	14.0	8.5	76	84	212-24
57,000	No extensometers used									22.5	22.5	7.5	76	84	212-23
58,000	No extensometers used									12.5	12.5	11.0	74	85	212-8

C = Creep
TD = Total deformation
OL = On loading

Controls

TABLE 8
TENSILE CREEP RUPTURE CHARACTERISTICS OF 24S-T3 SHEET

Temp. °F	Stress P.S.I.	% Elong. on Load- ing	Time in Hours for Deformation of												Frac- ture Time of Test Hours	% Elong. in 2 In.	Hardness "RPN"	Speci- men	
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					
2350	10,000	0.114	9.	OL	65.	8.	250.	180.	470.	440.	636.	625.	710.	718.5	5.0	0.0016	99	68	
	12,000	0.125	17.	OL	58.	12.	170.	124.	286.	263.	392.	383.	428.	428.3	4.5	0.00363	99	74	
	15,000	0.146	7.	OL	24.	3.	100.	64.0	192.	173.0	262.	255.0	293.	293.0	5.0	0.00398	99	80	
	18,000	0.172	7.	OL	16.	1.	56.	34.0	92.	82.0	123.	119.0	146.	145.	5.5	0.007	100	85	
	20,000	0.225	6.	OL	11.	0L	28.	16.0	46.5	41.0	66.	63.0	73.	83.0	7.0	0.0178	100	87	
	21,000	0.187	5.	OL	9.	1.	19.	15.0	39.	34.0	56.	54.0	63.5	62.8	64.0	3.0	0.02175	99	91
	25,000	0.234	1.5	OL	3.5	0L	10.	5.0	17.5	15.0	23.2	22.0	25.5	26.0	3.0	0.0417	99	94	
	27,000	0.198	0.5	OL	1.3	4.	2.0	7.5	6.3	11.	10.5	12.6	12.5	14.0	7.5	0.114	100	93	
	29,000	0.363	0.4	OL	0.7	0L	2.3	0.5	4.	2.8	6.3	5.6	7.5	7.2	8.0	4.5	0.185	99	96
	31,000	0.314	0.1	OL	0.22	0L	0.85	0.2	1.82	1.2	1.97	2.7	3.67	3.5	4.5	6.0	0.455	100	97
	35,000	0.380	.03	OL	.10	0L	0.30	0.07	0.57	0.38	0.87	0.77	1.04	1.12	1.2	7.0	1.28	100	99
WADC TR 54-270 Pt 1																			

C = Creep

TD = Total deformation

OL = On loading

Controls

TABLE 9
TENSILE CREEP RUPTURE CHARACTERISTICS OF 24S-T3 SHEET

Temp. of F.	Stress P.S.I.	% Elong. on Load- ing.	Time in Hours for Deformation of 5.0%												Min. Creep Rate % Per Hour	Hardness "HRW" After Test	Speci- men					
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD								
3,000	0.000	80.	80.	320.	320.	590.	590.								870.5	870.5	6.5	0.00128	100	47		
3,500	0.020	30.	32.	220.	215.	200.	198.	275.	273.	324.	322.	357.	356.	380.	380.	620.	620.	12.0	0.0036	100	49	
4,000	0.025	10.	9.	38.	36.	0.	78.	77.	91.	21.	120.	114.	162.	162.	164.	164.	0	5.5	0.00926	100	54	
5,000	0.022	5.	4.	15.	15.	0.	4.	30.	30.	0.	50.	49.	0.			68.0	68.0	12.0	0.0244	100	58	
6,000	0.083	1.75	1.75	1.5	2.5	4.	5.	9.1	9.1	0.14	314.	017.	251.	7.1		24.0	24.0	31.5	0.118	100	57	
7,000	0.081	1.25	0.	63.	2.5	2.	7.	5.2	8.	5.	8.3	9.7	9.	6		11.6	11.6	5.0	0.144	100	62	
8,000	0.099	0.8	0.	41.	8	1.	6	3	1	2.9	4.	34.	25	4.	804.	755.	12	5.3	5.8	20.0	0.244	
10,000	0.125	0.120	0.	10.	450.	330.	750.	700.	131.	1.	1.261.	251.	371.	391.	491.	491.	1.45	1.45	1.80	1.80	23.0	1.04
																			99	99		

C = Creep

TD = Total deformation

Controls

TABLE 10
TENSILE CREEP RUPTURE CHARACTERISTICS OF 24S-T3 3/16-INCH PLATE

Temp. of P.S.I.	% Elong. on Load-	Stress Load- ing	Time in Hours for Deformation of						Frac- ture Time Hours	Time of Test Hours	Elong. in 2 In.	Min. Creep Rate % Per Hour	Hardness H.R. After Test	Speci- men	
			0.1%	0.2%	0.5%	1.0%	2.0%	3.0%							
25	40,000	0.441	50.	220.	590.	20.	650*		898.	483.	1.5	0.00056	102	101	211-27
	42,000	0.516	25.	175.	550.	0L	535.		513.25	513.25	1.5	0.00061	101	101	211-28
	45,000	0.553	10.	60.	360.	0L	502.	325.	376.3	376.3	3.25	0.00069	100	103	211-31
	47,000	0.626	0.5	1.5	16.	0L	265.	6.15	365.	263.4	1.75	0.00090	101	104.5	211-32
	49,000	0.76	0.88	3.	0L	170.	1.15		374.	440.	3.5	0.00055	101	105.5	211-33
	50,000	No	creep readings taken						420.	438.	3.5	0.000925	100	105.5	211-30
300	50,000	1.28	1.6	6.2	0L	130.	0L	16.	16.	277.4	4.0	0.0022	100	105	211-23
	51,500	1.73		2.7	0L	6.3	0L	250.	1.5	172.0	5.0	0.00396	100	105.5	211-22
	52,000	1.91		2.3	0L	5.6	0L	120.	171.	83.75	5.0	0.0056	99	104	211-34
	53,000	2.47		0.64	0L	6.3	0L		0.71	54.25	7.5	0.0056	100	104.5	211-24
	55,000	No	creep readings taken						6.0	6.0	7.0	0.0368	100	104	211-25
	56,000	3.38		0.70	0L	2.2	0L	10.8	0L	26.0	6.0	0.275	101	104	211-21
	57,000	4.78						1.85	0L	6.0	8.5		100	105	211-35
	58,000	7.0						0L	0L	2.5	12.5				211-20

* Determined by extrapolation

C = Creep

TD = Total deformation

OL = On loading

TABLE II

TENSILE CREEP CHARACTERISTICS OF 24S-T3 3/16-INCH PLATE

Temp. of P.S.I.	% Elong. on Load- ing	Time in Hours for Deformation of												Fracture Time of Test Hours	Time of Test Hours	Min. Creep Rate % Per Hour	Hardness RF After Test	Speci- men
		0.2%	0.5%	1.0%	2.0%	3.0%	C	TD	C	TD	C	TD	C					
12,000	0.146	34	1.0	260	141	555	490	785	764	883	870	935	935	9.0	0.00109	102	75	211-37
13,000	0.158	35	2.0	160	95	300	270	415	404	454	454	460	460	5.0	0.00223	101	76	211-42
15,000	0.148	50	1.0	255	135	485	440	485	440	516.5	516.5	516.5	516.5	2.0	0.00135	101	85	211-39
18,000	0.16	16	2	92	48	212	184	306	300	311	311	311	311	3.5	0.00362	100	86	211-6
20,000	0.19	16	1	56	28	104	92	144	110	151	151	151	151	4.0	0.00685	100	87	211-2
450	23,000	0.254	7	01	33	13.0	68	54	100	101.5	101.5	101.5	101.5	3.0	0.0115	100	93	211-8
25,000	0.35	5	01	24	3.5	38	29.5	52.5	49	57	57	57	57	3.5	0.0130	100	94	211-3
27,000	0.29	4.5	01	13.5	5.0	23	18.5	30	30	30	30	30	30	3.5	0.0286	100	96	211-5
30,000	0.37	0.70	01	2.9	.80	5.5	3.75	8.7	8.0	9.0	9.0	9.0	9.0	4.5	0.159	100	97	211-4
33,000	0.401	0.65	01	2.0	.24	3.4	2.20	5.4	4.6	6.25	6.25	6.25	6.25	4.0	0.222	100	98	211-7
35,000	0.44	0.5	01	1.4	.10	2.2	1.55	3.2	2.8	3.15	3.15	3.15	3.15	2.5	0.344	99	100	211-9

C = Creep

TD = Total deformation

Contrails

TABLE 12
TENSILE CREEP RUPTURE CHARACTERISTICS OF 21S-T3 3/16-INCH PLATE

Temp. of F P.S.I.	Elong. on Load- ing	Time in Hours for Deformation of										Frac- ture Hours	Time of Test Hours	% Elong. in in.	Min. Creep Rate % per Hour	Hardness H _R Orig.-After Original Test	Speci- men	
		0.2%	0.5%	1.0%	2.0%	3.0%	4.0%	5.0%	C	TD	C							
3,500	0.067	90.35	350.300	670.410	945.410	935.						1222.5	8.0	0.00114	100	44	211-38	
4,500	0.035212	9.78	68.180	176.268	266.268	303.	302.	322.	321.	337.	336.	344.	9.0	0.0046	99	52	211-18	
5,000	0.070116	8.57	45.98	93.117	114.	114.						213.	18.	0.00863	100	59	211-11	
6,000	0.0651.5	3.17	15.33	532.5	50.49	557.5	57.					60.	13.	0.02175	99	64	211-15	
600													42.0	10.	0.042	100	65	211-13
7,000	0.0693.3	1.1.5	10.22	21.33.5	33.38.	538.25												
8,000	0.1831.5	.5	3.5	2.0	8.0	7.0	13.5	12.716.	16.				19.5	16.0	0.111	100	69	211-16
9,000	0.1200.7	1.25	1.8	1.4	2.72	5.5	3.7	3.61	2.22	4.17	4.47		4.91	19.0	0.235	100	71	211-17
10,000	0.1390.50	1.1	2.25	2.1	1.1	2.25	2.1	3.				4.0	4.0	12.5	0.289	73	211-12	

C = Creep
TD = Total deformation

Controls

TABLE 13
TENSILE CREEP CHARACTERISTICS OF TYPE 321 STAINLESS STEEL SHEET

Temp. of F.	Stress P.S.I.	% Elong. on Load- ing	Time in Hours for Deformation of												Min. Creep Rate % Hour	Speci- men							
			0.3%			0.5%			0.7%			1.0%			2.0%			3.0%					
			C	TD	C	TD	C	TD	C	TD	TD	C	TD	TD	C	TD	TD	C	TD	TD	C	TD	TD
28	42,000	3.51	90.	OL	275.	OL	345.	OL	420.	OL	OL	OL	OL	OL	500.	OL	OL	OL	OL	OL	527.	5.5	0.00050
	43,000	4.30	75.	OL	205.	OL	257.	OL	307.	OL	OL	OL	OL	OL	260.	OL	OL	OL	OL	OL	614.	12.	0.000486
	44,000	5.80	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	166.	5.98	0.00036
	45,000	4.40	45.	OL	167.	OL	203.	OL	242.	OL	OL	OL	OL	OL	188.	OL	OL	OL	OL	OL	516.	11.	0.00083
	46,000	6.09	150.	OL	200.	OL	227.	OL	257.	OL	320.	OL	OL	OL	OL	OL	OL	OL	OL	OL	404.	13.	0.0013
	47,000	6.29	19.	OL	125.	OL	174.	OL	207.	OL	276.	OL	OL	OL	OL	OL	OL	OL	OL	OL	346.	13.	0.00064
	48,000	7.53	151.	OL	165.	OL	176.	OL	176.	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	231.	12.	0.00060
	49,000	9.00	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	293.	16.	0.00060
	50,000	7.26	40.	OL	80.	OL	110.	OL	138.	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	209.	12.	0.0030
	52,000	9.55	54.	OL	95.	OL	106.	OL	119.	OL	153.	OL	OL	OL	OL	OL	OL	OL	OL	OL	184.	15.	0.0045
1000	56,000	12.3	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	168.	16.	0.0025
	60,000	13.8	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	22.25	21.	0.0031
																							210-34

C = Creep

TD = Total deformation

OL = On loading

Controls

WADC TR 54-270 Pt 1

TABLE 14
TENSILE CREEP CHARACTERISTICS OF TYPE 321 STAINLESS STEEL SHEET

Temp. °F	Stress P.S.I.	% Elong. on Load-	Time in Hours for Deformation of										Min. Creep Rate %	Speci- men							
			C	TD	C	TD	C	TD	C	TD	C	TD									
29	12,000	0.039	40	27	195	180	420	400	767	750	506	505	590	660	936	0.0017	210-35				
	15,000	0.016	95	68	168	165	257	255	396	395	190	188	244	242	324	387	0.000136	210-14			
	18,000	0.05	58	44	91	86	130	125	190	188	117	114	113	111	163	181	324	0.00075	210-12		
1200	20,000	0.08	36	24	59	54	80	77	117	114	114	113	111	103	162	181	362	0.00150	210-11		
	22,000	0.06	24	16	45	44	58	57	77	77	76	76	91	90	102	111.5	215	0.00565	210-7		
	25,000	0.14	3	5	18	13	29	28	39	38	46	45	52	51	58	57	110.5	28.0	0.01420	210-9	
	30,000	0.42	.1	0L	0.2	0.015	1.3	.25	10	7.0	14	12.5	16.5	15.5	19	18	33.5	25.0	0.07280	210-18	
	35,000	2.15			0L	0.04	0L	0.20	0L	1.2	0L	3.5	0.13	5.1	0.80	6.9	3.2	8.0	12.0	0.5	210-24

C = Creep
TD = Total deformation
OL = On loading

Controls

WADC TR 54-270 Pt 1

TABLE 15
TENSILE CREEP CHARACTERISTICS OF TYPE 321 STAINLESS STEEL SHEET

Temp. °F	Stress P.S.I.	% Elong. on Load- ing	Time in Hours for Deformation of												Time of Test Hours	% Elong. in 2 In.	Min. Creep Rate % Per Hour	Speci- men		
			0.2%	0.5%	1.0%	2.0%	3.0%	4.0%	5.0%	C	TD	C	TD	C	TD					
30	6,000	0.032	90	80	150	145	225	220	360	358	497	495	633	630	756	754	792	.0074	210-23	
	7,000	0.0188	20	19	48	47	94	93	185	184	275	274	361	360	448	447	1141	0.0111	210-37	
	8,000	0.06	13	10	36	32	86	80	190	185	287	284	367	365	445	442	630	0.0126	210-36	
	10,000	0.027	5	4	14	13	32.5	32.0	71	70.0	105	104.0	132	131	155	154	251.0	0.0264	210-29	
1350	12,000	0.06	2.5	1.6	8	7	17	16	32	31.5	46	45.5	47	56.5	67	66.5	131.0	0.0577	210-28	
	14,000	0.04	1	1	75	3.5	3	9.5	9.0	19.5	19.0	26.5	26.1	32	31.7	37	36.8	52.0	0.0895	210-26
	17,000	0.12	50	25	1.4	1.2	3.1	2.8	5.1	5.0	7.2	7.0	9.0	8.8	11.0	10.7	25.0	25.0	2300	210-27
	20,000	0.14	30	20	5	3	0.9	0.8	1.8	1.7	2.4	2.3	3.1	3.0	3.6	3.5	12.0	30.0	8750	210-33
	25,000	0.22	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	OL	210-30

C = Creep

TD = Total deformation

OL = On loading

Controls

TABLE 16
TENSILE CREEP-RUPTURE CHARACTERISTICS OF RC-130-A TITANIUM ALLOY SHEET

Temp. OF P.S.I.	Stress Pt 1	% Elong. on Load- ing	Time in Hours for Deformation of												Min. Creep Rate % Per Hour	Speci- men		
			0.1%	0.2%	0.3%	0.5%	1.0%	2.0%	5.0%	C	TD	C	TD	C				
C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	Hours	In.	Time of Test Hours	2 In.	1 In.
85,000	0.67	0L	0L	0L	0L	0L	0L	0L	0L	NF	253.0	1.00	274-5					
95,000	0.63	1.5	0L	200.0	0L	0L	0L	0L	0L	NF	624.0	0.86	274-8					
98,000	0.77	1.0	0L	15.0	0L	255.0	0L	0L	0L	NF	378.0	1.10	274-25					
100,000	0.85	0.7	0L	4.0	0L	160.0	0L	0L	0L	NF	460.0	1.22	274-7					
110,000	1.52	0.7	0L	17.0	0L	74.0	0L	100.0	0L	0L	687.0	2.22	0.000421	274-6				
114,000	2.65	0.06	0L	0.06	0L	0.13	0L	0.2	0L	0.38	0L	7.0	0L	115.0	5.69	0.00375	274-38	
115,000	3.85	0.23	0L	0.23	0L	0.56	0L	1.0	0L	4.5	0L	235.0	0L	35.0	0L	340.0	6.16	0.00330
116,000	6.83	0.15	0L	0.35	0L	0.57	0L	1.2	0L	3.45	0L	18.5	0L	334.0	0L	1114.0	22.00	0.00737
118,000	6.44											OL	OL	OL	OL	950.0	20.00	274-21
119,000												OL	OL	OL	OL	0.0	12.00	274-58
120,000	8.50	0.03	0L	0.07	0L	0.1	0L	0.17	0L	0.33	0L	0.75	0L	OL	OL	3.5	3.5	16.00 1.4
																		274-18

C = Creep deformation

TD = Total deformation

OL = On loading

NF = No fracture

Controls

TABLE 17
TENSILE CREEP-RUPTURE CHARACTERISTICS OF FC-130-A TITANIUM ALLOY SHEET

Temp. $^{\circ}\text{F}$	Stress P.S.I.	Elong. on Load-	Time in Hours for Deformation of						% Creep Min.													
			0.1%	0.2%	0.3%	0.5%	1.0%	2.0%	5.0%	C	TD	C	TD	C	TD							
32	15,000	0.15	6.0	0L	12.0	2.0	20.0	9.0	40.0	2L	0	14.8	0	103.0	700.0	580.0	NF	786.0	2.25	0.00188	274-52	
	20,000	0.13	1.6	0L	4.5	1.0	7.5	4.5	15.0	1L	0	36.0	31.0	107.0	98.0	525.0	500.0	NF	558.0	5.49	0.00682	274-62
	25,000	0.16	1.3	0L	2.6	0.5	4.0	2.0	7.6	5.0	18.0	13.0	43.0	37.0	147.0	140.0	638.0	25.0	0.0212	274-63		
800	30,000	0.28	0.7	0L	1.9	0L	3.1	0.5	5.5	3.0	11.0	9.0	22.5	20.0	265.0	265.0	87.0	0.0163	274-59			
	40,000	0.29	0.25	0L	0.55	0L	0.9	0.1	1.65	1.0	3.6	3.0	5.6	6.5	19.5	17.5	75.0	75.0	0.250	274-48		
	45,000	0.43	0.2	0L	0.47	0L	0.7	0L	1.2	0.2	2.3	1.2	4.4	3.2	9.5	8.8	31.0	31.0	0.495	274-56		
	50,000	0.66	0.18	0L	0.32	0L	0.48	0L	0.78	0L	1.7	0.6	3.4	2.1	8.5	7.3	24.25	24.25	41.0	0.570	274-50	
	60,000	0.56	0.08	0L	0.15	0L	0.22	0L	0.34	0L	0.6	0.25	1.05	0.8	2.13	2.0	6.5	6.5	157.0	1.29	274-53	

C = Creep deformation

TD = Total deformation

NF = No fracture

OL = On loading

Controls

TABLE 18
TENSILE CREEP CHARACTERISTICS OF ANNEALED MONEL 1/2-INCH DIAMETER WIRE

Temp. °F P.S.I.	Stress Load- ing	% Elong. on			Time in Hours for Deformation of 0.2% 0.5% 1.0% 2.0% 3.0% 5.0% 10.0%						Fracture Test	Time of Test	% Elon. in 2 Hours	Min. Creep Rate % Per Hour	RB Hardness Orig.-After Test	Speci- men					
		C	TD	C	TD	C	TD	C	TD	C	TD										
17,000	0.070	85.10	210.166	500.								Discontinued	504.	.00143	62.	69.	230-16				
18,000	0.165	.75	18.	6.100.	72.	450.						"	500.	.00169	63.5	65.5	230-14				
19,000	0.186	.20	5.	0.43105.	28.320.	268						"	333.	.00364	62.5	65.0	230-13				
20,000	0.385	0L	0.5	13.	1.214.	104.	400					"	491.	.00333	62.5	65.0	230-11				
22,000	0.785	0L	0L	3.	47.	6.182.	68.	400.				"	492.	.00497	62.0	68.	230-10				
23,500	1.23	0L	.20	0L	5.0L	30.05	95.	16.280.	154			853.5	853.5	15.5	.0103	62.0	69.	230-15			
1000	25,000	1.65	N	O	R	e	a	d	i	n	E	S	575.	575.	13.	61.5	69.	230-2			
	26,000	1.70	0L	6.	0L	13.	0L	35.	4.	60.	18.	92.	70.312.	250.	413.	113.	72.	230-17			
	28,000	2.62	0L	0L	.20	0L	2.0	0L	16.	47.	8.117.	67.	169.5	169.5	20.	.027	61.5	75.	230-6		
	29,000	2.79	0L	0L	.15	0L	1.5	0L	6.5	23.5	2.	48.	85.5	85.5	20.	.067	61.0	75.	230-9		
	30,000	1.36	0L	0L	.14	0L	1.4	0.2	3.8	.8	16.	6.5	53.	44.	73.0	73.0	33.	.129	61.5	76.	230-3
	32,000	2.28	0L	0L	0L	0L	0L	0L	No Readings				48.0	48.0	26.	61.0	78.	230-1			
	33,000	4.16	0L	0L	0.3	0L	1.	0L	3.2	.07	4.3	20.6L	64.	33.	.580	61.0	76.	230-8			
	40,000	7.65	0L	0L	0L	0L	0L	0L	1.58	1.58	28.		1.58.	1.58.		61.0	81.	230-5			

C = Creep
TD = Total deformation
OL = On loading

Controls

TABLE 19
TENSILE CREEP-RUPTURE CHARACTERISTICS OF ANNEALED MONEL 1/2-INCH DIAMETER WIRE

Temp. °F	Stress P.S.I.	% Elong. on loading	Time in Hours for Deformation of						Fracture Hours	Time Test	Elong. in. 2	% Creep Rate "RB"	Hardness "RB"	
			C	TD	C	TD	C	TD						
34	4,000	.038	43.	27.200	180.	1180.	1050		1154.	0.00055	64	50	230-27	
	6,000	.017	14.	513.	46.	14.	160.	155.	528.	.520	624.	0.0027	64	55
	8,000	.0242	10.59	1.	30.	28.5	69.	66.	210.	205.	365.	522.	520.	685.
	9,000	.0226	7.26	2.2	23.	23.	51.	51.	131.	130.	236.	318.	317.	440.
1200	10,000	.0595	4.83	0.14	3.	13.	30.	27.	64.	61.	108.	104.	155.	152.
	12,000	.0913	1.35	55	4.9	4.	12.	10.	526.	5	25.	42.	5	205.
	14,000	.0865	0.94	0	3.7	2.8	8.	7.0	18.	17.	30.	29.	45.	202.
	15,000	.136	0.90	5.5	2.5	2.0	6.8	5.	911.	511.	0	144.	14.	57.
	16,000	.087	0.412	1.4	1.0	3.0	2.8	7.7	214.	613.	8	146.5	146.5	11.0
	17,000	.355	0L	0.17	0.50	0.251	0.551	1.22	952.	444.5	5.8	113.	36.5	0.0655
	18,000	.694	0L	0L	0.26	1.0	0.45	2.0	01.253.	3.2	3.6	38.9	24.5	0.448
	20,000	.372	0L	0.25	0.1	0.63	0.471	1.17	0.961.	73	2.1	20.5	25.0	0.77
	21,500	1.67	0L	0.01	0L	0.05	0.29	0.01	0.400.	1.	1.5	10.5	22.0	1.7
									0.25	0.25	4.0	4.0	28.0	4.5
											63	71	230-29	
											63	69	230-28	

*Determined by extrapolation

C = Creep

TD = Total deformation

OL = On loading

Controls

TABLE 20
TENSILE CREEP-RUPTURE CHARACTERISTICS OF TYPE 301 STAINLESS STEEL 1/2-INCH DIAMETER WIRE

Temp. of F P.S.I.	Elong. on Load-	Time in Hours for Deformation of						Min. Creep Rate % Per Hour	Hardness RB Before Test	Hardness RB After Test	Speci- men				
		0.1% 0.2% 0.3%			0.5% 1.0% 2.0%										
		C	C	TD	C	TD	C								
21,000	0.145	5.	33.	88.	315.	155.	1400.	1150.	2104.	2104.	1.5				
23,000	0.131	2.0	15.	50.	115.	62.	480.	405.	665.	665.	1.7				
25,000	0.152	0.9	4.3	10.	31.	15.5	63.	54.	108.	142.*	266.3				
1200	27,000	0.160	0.6	2.6	5.2	14.5	6.7	33.	28.5	78.0	17.5				
29,000	0.183	0.2	0.82	1.5	3.8	1.65	13.6	10.	32.	61.25	4.5				
31,000	0.306	0.09	0.32	0.67	1.8	0.3	5.15	3.3	11.4*	44.1	53.				
35,000	0.50			0.167			0.17	1.75	0.85	2.8	29.				
40,000											25.*				
		Extensometers loosened on Loading													

* By extrapolation

C = Creep

TD = Total deformation

Controls

TABLE 21
TENSILE CREEP-RUPTURE CHARACTERISTICS OF TYPE 301 STAINLESS STEEL, 1/2-INCH DIAMETER WIRE

Temp. °F	Stress P.S.I.	% Elong. on Load- ing	Time in Hours for Deformation of 5.0%												Min. Creep % Per Hour	Hardness "RBH" Original After Test	Speci- men		
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					
36	10,000	.070	43.21	598	268	1000	950								1026.5	.000715	103	86	
	11,000	.093	20.6	130	111	410	375								502.	.0018	103	82	
	12,000	.064	1.9	685	60	300	270	565	505						805.	.002	103	87	
	13,000	.076	8.	40	37	30	80	72	160	155	218	215	258	255	.0091	103	85	277-13	
1350	15,000	.125	3.	50	9.0	7.0	22	18	54.9	54.5	68	66	106.3	106.3	.030	104	87	277-2	
	16,000	.100	90	40	3.4	2.5	7.8	6.9	4.1	4.1	21	20.4	21	20.4	.096	104	87	277-19	
	18,000	.106	50	201	70	1.4	3.3	3.0	5.9	5.7	8.0	7.8	9.9	9.5	11.6	11.5	103	86	277-29
	20,000	.1448	25	05	.75	5	1.7	1.35							27.5	27.5	227	86	277-27
	25,000	.276	.02	01	.07	.03	.15	.10	.3	.27					11.45	11.45	528	103	87
	30,000	1.03	N	O	R	e	a	d	i	n	g	s			1.75	1.75	5.9	105	90
															.50	.50	31.0	105	91
																		277-28	

C = Creep
TD = Total deformation
OL = On loading

Controls

TABLE 22
TENSILE CREEP CHARACTERISTICS OF A17S-T4 3/8-INCH DIAMETER RIVET WIRE

Temp. $^{\circ}\text{F}$	Stress P.S.I.	% Elong. on Load- ing	Time in Hours for Total Deformation			Frac- ture Hours	Time of Test Hours	% Elong. in 2 In.	% Creep Rate % Per Hour	Speci- men	Min.
			0.5%	1.0%	2.0%						
600	2,000	0.000				929.	929.	4.0			276-1
	2,200	0.011	170.			479.	479.	6.5	0.00196		276-15
	2,500	0.007	63.	108.	150.	243.5	243.5	21.0	0.0074		276-14
	2,800	0.000	35.	51.	71.	89.	89.	18.0	0.0096		276-5
	3,000	0.018	25.	36.	47.	48.5	48.5	7.0*	0.0094		276-4
	3,600	0.0148	9.4	12.6	15.2	18.75	18.75	15.	0.0128		276-13
	4,000	0.0371	8.			8.0	8.0	2.0*	0.046		276-10
	5,000	0.0296	0.55	0.85		1.16	1.16	2.0*	0.73		276-19

* Fracture occurred outside of 2 inch gage section

Controls

TABLE 23
BEARING CREEP-RUPTURE CHARACTERISTICS OF 24S-T3 SHEET

Temp. °F	Stress P.S.I.	% Def. of Hole on Load- ing	Time in Hours for Deformation of Bearing Hole Diameter of												Min. Creep Rate % Per Hour	Speci- men			
			1.0%			2.0%			3.0%			4.0%			5.0%				
			C	TD	C	C	TD	C	C	TD	C	C	TD	C	C	TD	C		
300	40,000	1.84	720.	OL	3.	900.	20.	850.	OL	652.	100.	578.	420.	497.	464.	711.5	958.	.000666	212-B58
	50,000	2.53	415.	OL	503.	OL	580.	OL	620.	OL	453.	13.	488.	420.	498.	498.	711.5	.00111	212-B57
	62,000	4.06	120.	OL	310.	OL	430.	OL	442.	OL	313.	OL	330.	OL	345.	310.	349.	.00208	212-B63
	66,000	4.21	35.	OL	20.	OL	260.	OL	303.	OL	307.	OL	313.	OL	330.	310.	349.	.00317	212-B56
	70,000	5.45	5.	OL	30.	OL	125.	OL	207.	OL	212.	OL	225.	OL	225.	207.	237.7	.00338	212-B60
	74,000	5.66	5.	OL	12.	OL	67.	OL	98.	OL	112.	OL	112.	OL	112.	28.	112.7	.0059	212-B53
	78,000	7.44	2.0	OL	11.	OL	67.	OL	11.	OL	70.	OL	72.	OL	75.	OL	75.	.0080	212-B52
	82,000	8.85	3.5	OL	11.5	OL	70.	OL	70.5	OL	72.	OL	75.	OL	75.	OL	75.3	.0125	212-B51
	86,000	12.8	2.5	OL	11.	OL	29.	OL	33.5	OL	33.5	OL	33.5	OL	33.5	OL	34.3	.0455	212-B49
	89,000	13.28	N	R	e	a	d	i	n	G	N	O	R	e	a	d	i	.25.5	212-B47
100,000	92,000	17.68	.64	OL	1.6	OL	2.7	OL	4.0	OL	4.9	OL	4.9	OL	4.9	OL	5.5	.74	212-B55
	100,000		F	F	a	c	t	u	r	e	0	a	d	i	n	g	OL		212-B54

C = Creep
TD = Total deformation
OL = On loading

Contrails

TABLE 24
BEARING CREEP-RUPTURE CHARACTERISTICS OF 24S-T3 SHEET

Temp. of F	Stress P.S.I.	% Def. of Hole on Load- ing	Time in Hours for Deformation of Bearing Hole												Diameter of Bearing Hole	Min. Creep Rate % Per Hour	Speci- men			
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD						
10,000	0.462	50.	11.	530.	230.	970.	187.	429.	323.	523.	450.	664.	610.	804.	777.	905.	1028.			
18,500	.802	40.	.50	160.	59.	295.	120.	78.0	160.	130.	192*	168.	222.	285.	277.	905.	.00122			
22,000	0.80	20.	0.83	70.	26.	120.	22.	121.	74.	162.	126.	194.	167.	240.	226.	292.	.00727			
24,000	0.93	18.	0.1	66.	70.	38.	7.0	74.	38.	110.	73.	112.	110.	167.5	167.	251.	.01.98			
25,000	1.03	8.	OL	OL	17.	3.	17.	3.	37.	16.	63.	36.	80.	60.	108.	93.	144.	.01.88		
26,000	1.11	6.	OL	OL	25.	6.0	42.	26.	59.	40.	73.	58.	89.5	81.5	102.8	98.	144.	.02.78		
28,000	1.12	7.0	OL	OL	18.5	3.5	33.5	18.	49.	32.5	59.	48.	75.5	67.6	87.	84.	93.7	.02.61		
29,000	1.09	4.5	OL	OL	13.3	4.0	35.3	14.	34.0	25.0	41.0	34.	51.4	47.	59.	57.	64.0	.02.58		
30,000	1.04	2.1	OL	OL	3.0	9.0	1.6	15.4	7.5	21.7	14.2	26.0	20.3	32.4	29.	37.8	41.	58.	.02.55	
33,000	1.19	3.0	OL	OL	35,000	1.67	2.4	OL	5.9	0.3	10.3	3.0	24.7	7.5	18.3	12.0	23.3	19.4	27.7	.02.51
37,000	1.39	1.60	OL	OL	50,000	1.81	.70	OL	5.0	0.75	8.5	4.0	11.5	7.3	14.0	10.25	17.8	15.3	20.6	.02.45
40,000	1.81	.70	OL	OL	45,000	0.86	.77	.02	1.8	1.0	2.85	2.0	3.80	3.0	4.67	4.0	5.65	5.35	6.25	.02.41
50,000	1.27	.4	OL	OL	55,000	2.4	.04	OL	1.0	0.25	1.53	0.80	2.05	1.4	2.52	1.8	2.88	3.22	3.83	.02.35
60,000	3.2	.058	OL	OL	60,000	3.2	.125	OL	.103	OL	.19	.016	.28	.075	.36	.49	.53	.75	.83	.02.31
																		.50	.50	.50

* Extrapolated

C = Creep

TD = Total deformation

OL = On loading

Controls

TABLE 25
BEARING CREEP-RUPTURE CHARACTERISTICS OF 21S-T3 SHEET

Temp. °F	Stress P.S.I.	% Def. of Hole on Load- ing	Time in Hours for Deformation of Bearing Hole			Diameter of Bearing Hole			Fracture			Min. Creep Rate % Per Hour			Speci- men		
			0.5%	1.0%	2.0%	3.0%	4.0%	5.0%	TD	C	TD	C	TD	C			
40	2,000	0.054	167.	130.	517.	515.	950*	895.							616.		
	3,000	0.11	9.	4.	70.	50.	15.	230.	185.	463.					898.		
	4,000	0.17	6.	3.	30.	15.	4.5	40.	30.	109.	94.	172.	159.	452.	499.		
	5,000	0.23	1.4	0.9	8.	4.	1.2	15.	10.	42.	32.	78.	68.	145.	786.		
	6,000	0.36	0.9	0.9	3.0	3.0	7.0	3.6	20.	16.	35.	31.	49.	54.	90.	174.	
	7,000	0.26	2.	2.	9.	2.5	2.5	2.5	7.2	4.7	13.5	11.	20.	17.2	127.	294.	
	8,000	0.41	1.	1.	1.	2.5	2.5	2.5	7.2	4.7	13.5	11.	20.	17.2	127.	127.	
	9,000	0.52	1.	1.	0L	2.2	5.4	5.0	3.5	8.8	7.0	11.3	10.4	14.3	70.	127.	
	10,000	0.53	0.6	0.6	0L	1.8	4.4	4.2	3.0	6.7	5.5	8.7	7.7	10.5	16.0	127.	
	11,000	0.72	0.9	0.9	0L	1.5	3.5	3.4	2.1	3.7	3.7	3.7	3.7	9.5	16.2	127.	
	15,000	0.95	1.6	1.6	0L	.32	.32	.32	.34	1.8	.76	.76	.76	1.32	1.08	1.52	1.32

* Extrapolated

C = Creep

TD = Total deformation

OL = On loading

Controls

TABLE 26
SHEAR PIN DEFORMATION - RUPTURE CHARACTERISTICS OF 24S-T3 PLATE

Temp. °F	Stress P.S.I.	Deforma- tion in Inches	Time in Hours for Creep of			Fracture Hours	Test Hours	Minimum Creep Rate In Inches Per Hour	Specimen
			0.001	0.002	0.003				
300	31,000	0.0089	3.	34.	158.	167.	170.	0.00000397	211-S37
	32,000	0.00915	2.	12.5	57.	100.	106.25	0.00000179	211-S33
	34,000	0.01149		1.5	8.25	37.5	51.5	0.00000294	211-S35
	35,000	0.01233	0.75	2.7	7.0	11.3	14.5	0.000222	211-S34
	36,000	0.01433	0.22	2.1	4.8	7.2	8.4	0.000357	211-S38
	38,000	0.01822	0.05	.8		1.07	1.07	0.00109	211-S36

C = Creep

TABLE 27

SHEAR PIN DEFORMATION-RUPTURE CHARACTERISTICS OF 21S-T3 ALUMINUM PLATE

Temp. °F	Stress P.S.I.	In. Elong. on Load- ing	Time in Hours for Shear Deformation of												Min. Creep Rate In. Per Hour	Specimen	
			.001II	.002II	.003II	.004II	.005II	.007II	.010II	C	TD	C	TD	C	TD		
3,000	.00019	.120	.340													4.69	211S32
4,500	.00043	.38	.12	.335	.120	.845	.630									.0000019	211S31
5,000	.00077	.14	.1	.70	.22	.180	.84	.320	.205	.500	.370	.810	.710	.1250	.1160	.0000020	211S31
6,000	.00122	.15	.3	.55	.25	.120	.73	.195	.142	.270	.218	.420	.369	.583	.553	.0000065	211S30
7,000	.00174	.28	.3	.100	.40	.196	.124	.286	.220	.341	.310	.392	.378	.420	.416	.000014	211S29
8,000	.00224	.20	.78	.15	.134	.85	.186	.142								.0000087	211S28
9,000	.00289	.10	.40	.10	.44	.136	.96	.168	.138	.200	.188	.215	.212	.212	.221	.000018	211S26
9,500	.00355	.11	.01	.42	.3	.65	.31	.110	.62	.121	.92	.112	.130	.151	.148	.000019	211S16
10,000	.00429	.2	.01	.85	.2	.18	.8	.31	.17	.51	.41	.28	.546	.568	.5	.000032	211S19
11,000	.00155	.1.5	.01	.65	.25	.11	.3	.514	.5	.85	.18	.12	.524	.519	.5	.000097	211S17
12,000	.00206	.4	.01	.2	.3	.3	.1	.1	.4	.2	.2	.6	.6	.4	.0	.00136	211S18
13,000	.00201	.3	.01	1.0	.01	1.9	.3	.2	.7	1.	.3	.1	.8	.5	.2	.00125	211S13
15,000	.00228	.2	.01	.5	.01	.1	.1	.3	.1	.3	.1	.3	.6	.1	.9	.0036	211S20

C = Creep

TD = Total deformation

OL = On loading

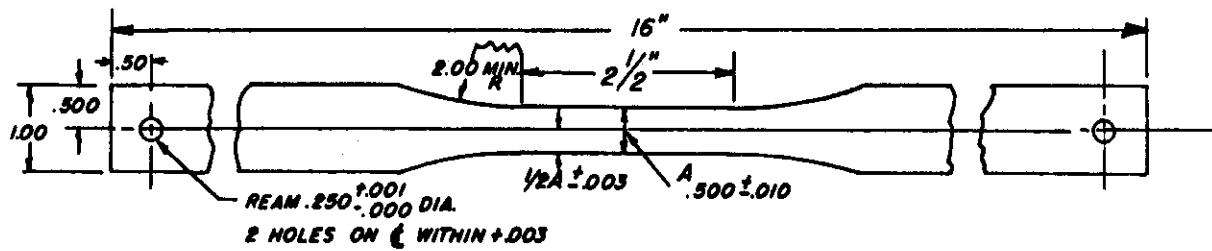
Controls

TABLE 28
COMPRESSION AND TENSILE CREEP CHARACTERISTICS OF 24S-T3 ALUMINUM SHEET AT 26,000 P.S.I.

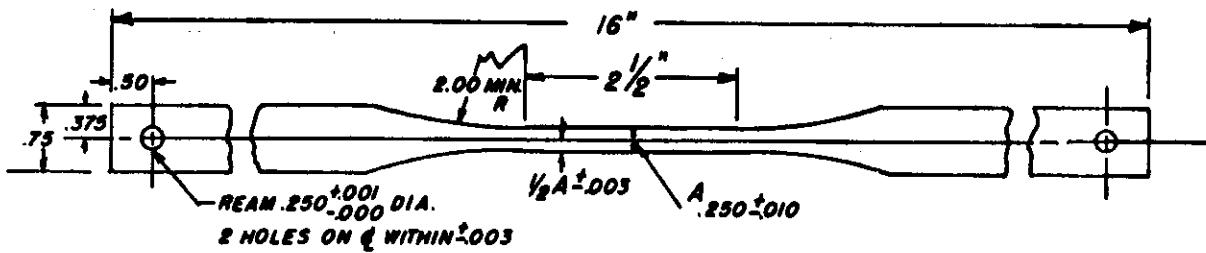
Temp. of F.	Type of Stress P.S.I.	% Elong. on Load- ing	Time in Hours for Deformation of												Type of Wedge	Specimen	
			0.1%	0.2%	0.3%	0.5%	1.0%	1.5%	C	TD	C	TD	C	TD			
450	Compression	0.289	0.7	OL	2.3	OL	4.5	7.7	2.6	14.0	10.5	16.5	17.4	16.5	2.11	304 Stainless Steel	
"	"	0.376	0.2	OL	0.95	OL	2.0	OL	4.6	0.5	12.8	6.2	11.8	16.4	2.06	2S Aluminum	
"	"	0.417	0.2	OL	3.4	OL	5.9	OL	10.1	0.9	18.9	11.8	16.2	70.0	2.32	SAE 4340 (RC-40)	
"	"	0.361	2.4	OL	4.5	OL	6.2	OL	9.6	3.2	16.	11.7	11.7	92.0	2.24	Complete Restraint	
	Tensile	0.319	0.35	OL	1.1	OL	2.2	OL	4.5	0.9	8.7	6.3	9.8	17.0	17.0	4.25	212-47

C = Creep
TD = Total Deformation
OL = On loading

Controls



TENSILE CREEP SPECIMEN FOR SHEET MATERIAL



TENSILE CREEP SPECIMEN FOR PLATE MATERIAL

Figure 1 Tensile Creep Specimens

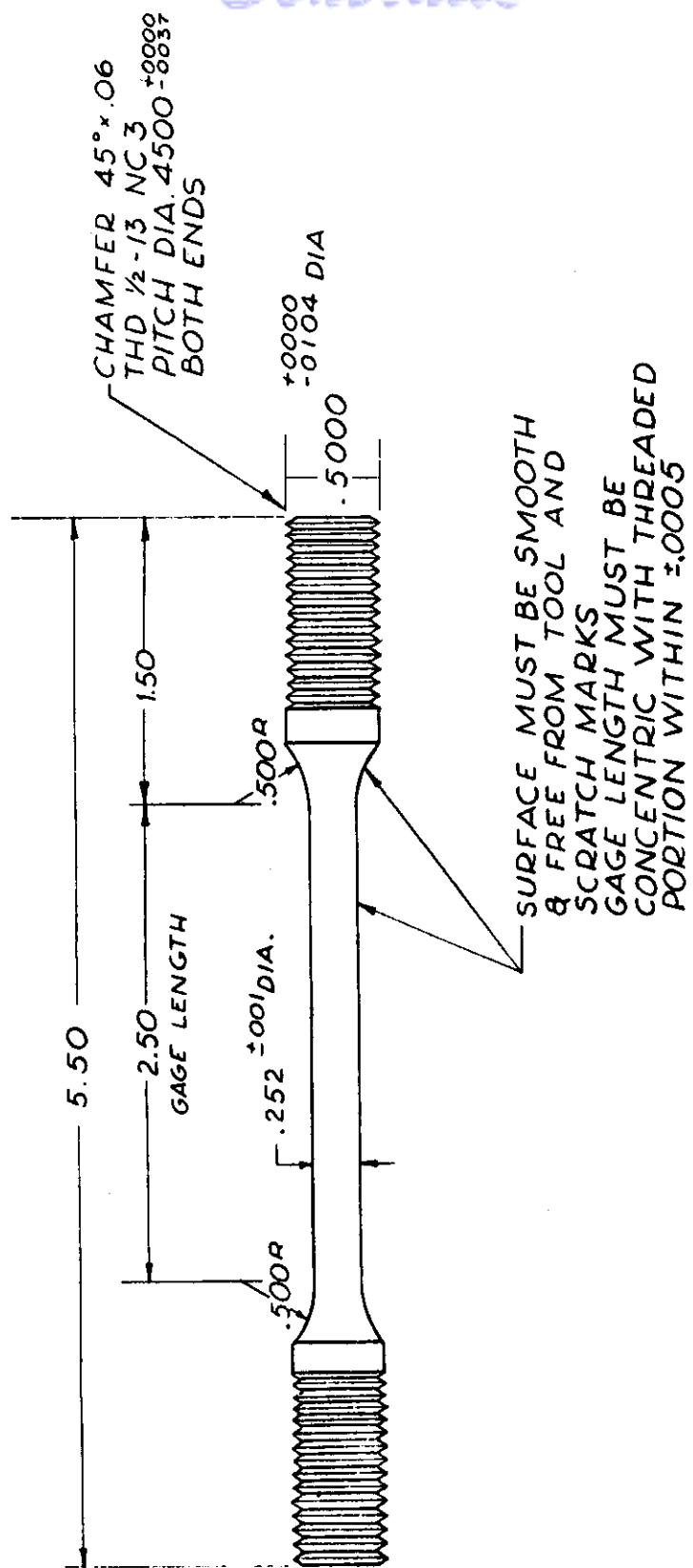


Figure 1 Tensile Creep Specimens
(For 1/2" Diameter Wire)

Controls

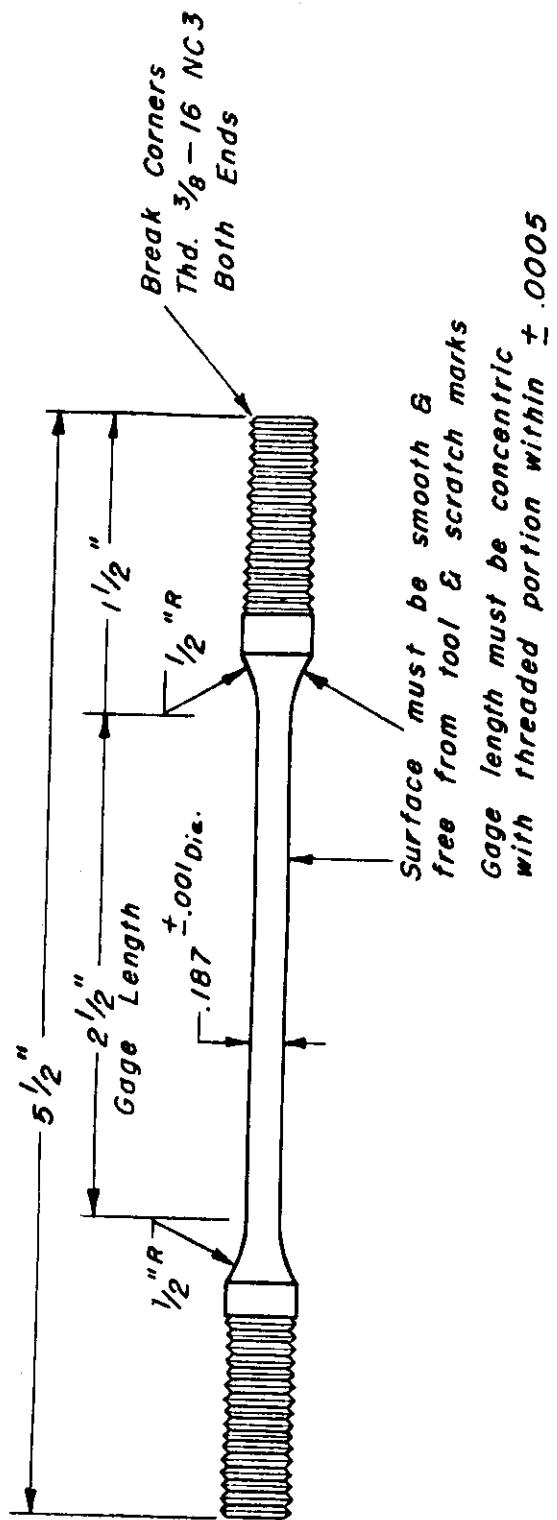
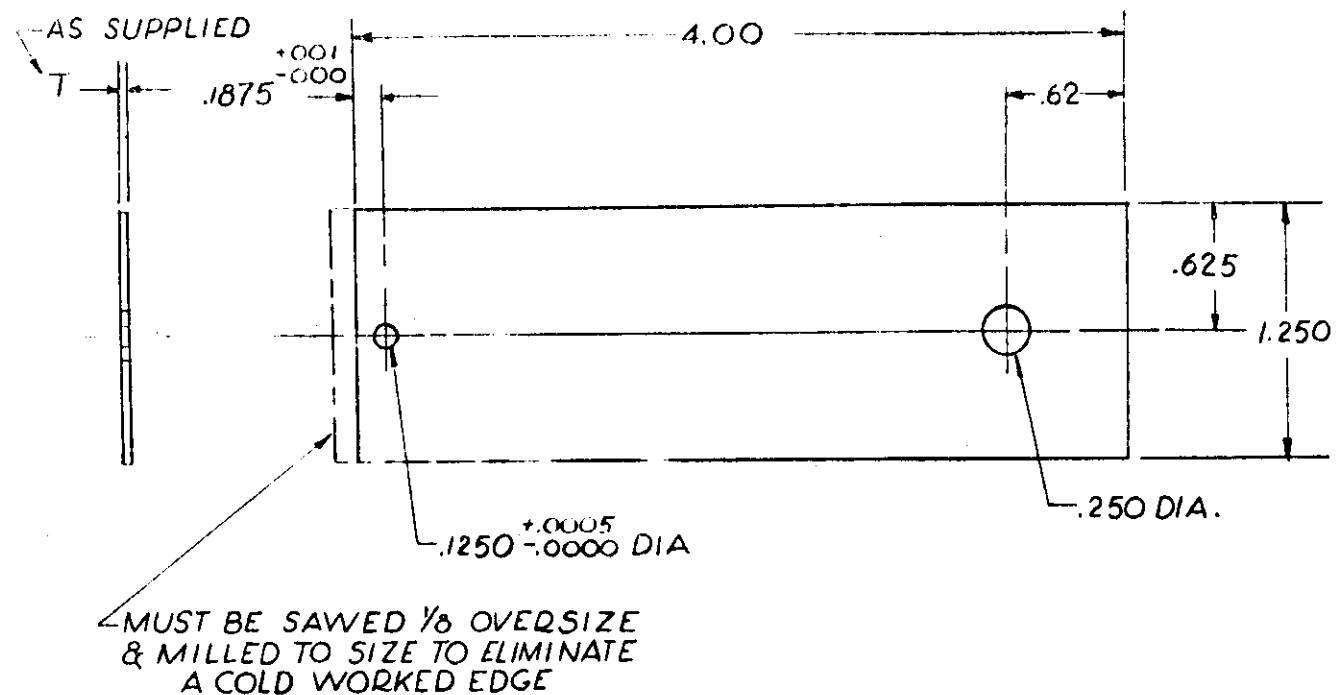


Figure 1 Tensile Creep Specimens
cont. (For 3/8" Diameter Wire)

Controls



NOTE: SPECIMEN MUST BE
CHECKED BY INSPECTION

Figure 2 Bearing Creep Specimen

Controls

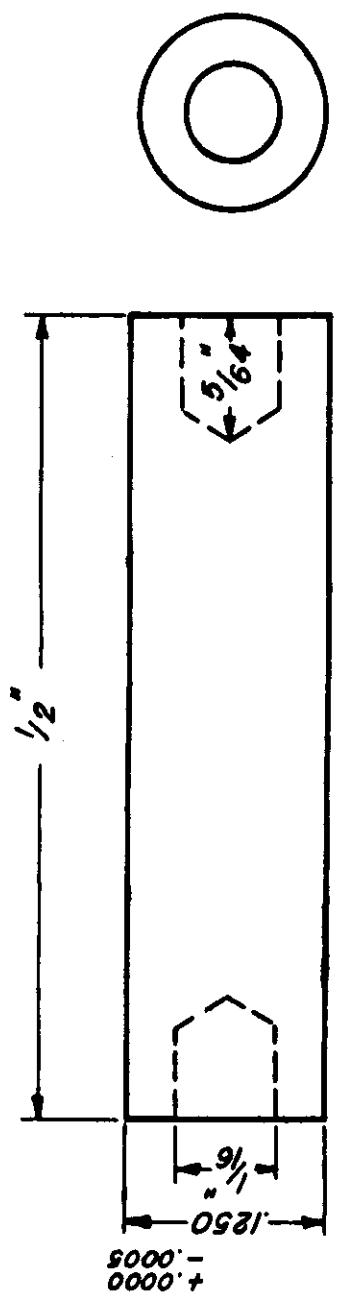


Figure 3 Shear Creep Specimen

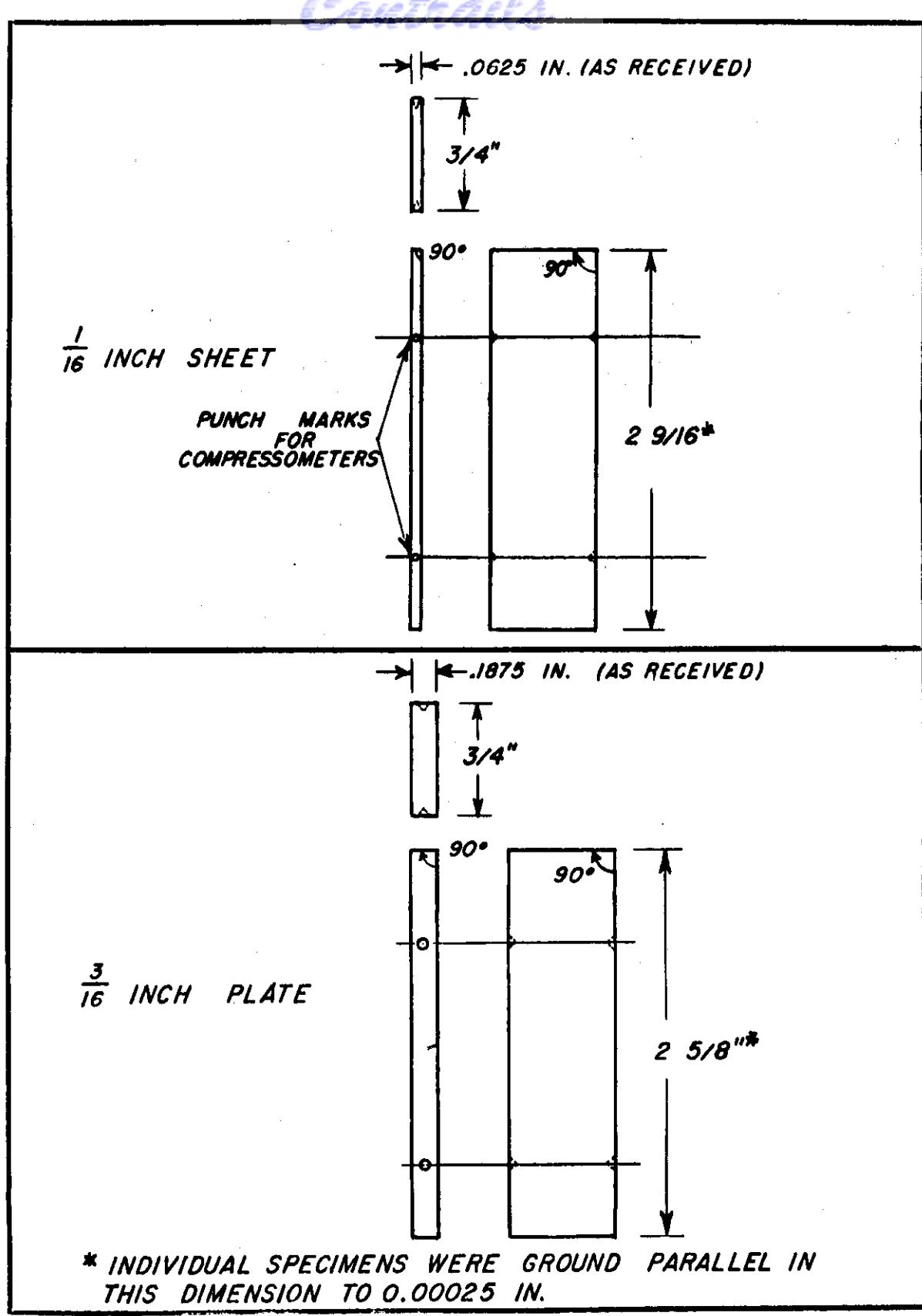


Figure 4- Compression Creep Specimens for Sheet and Plate Material

Controls

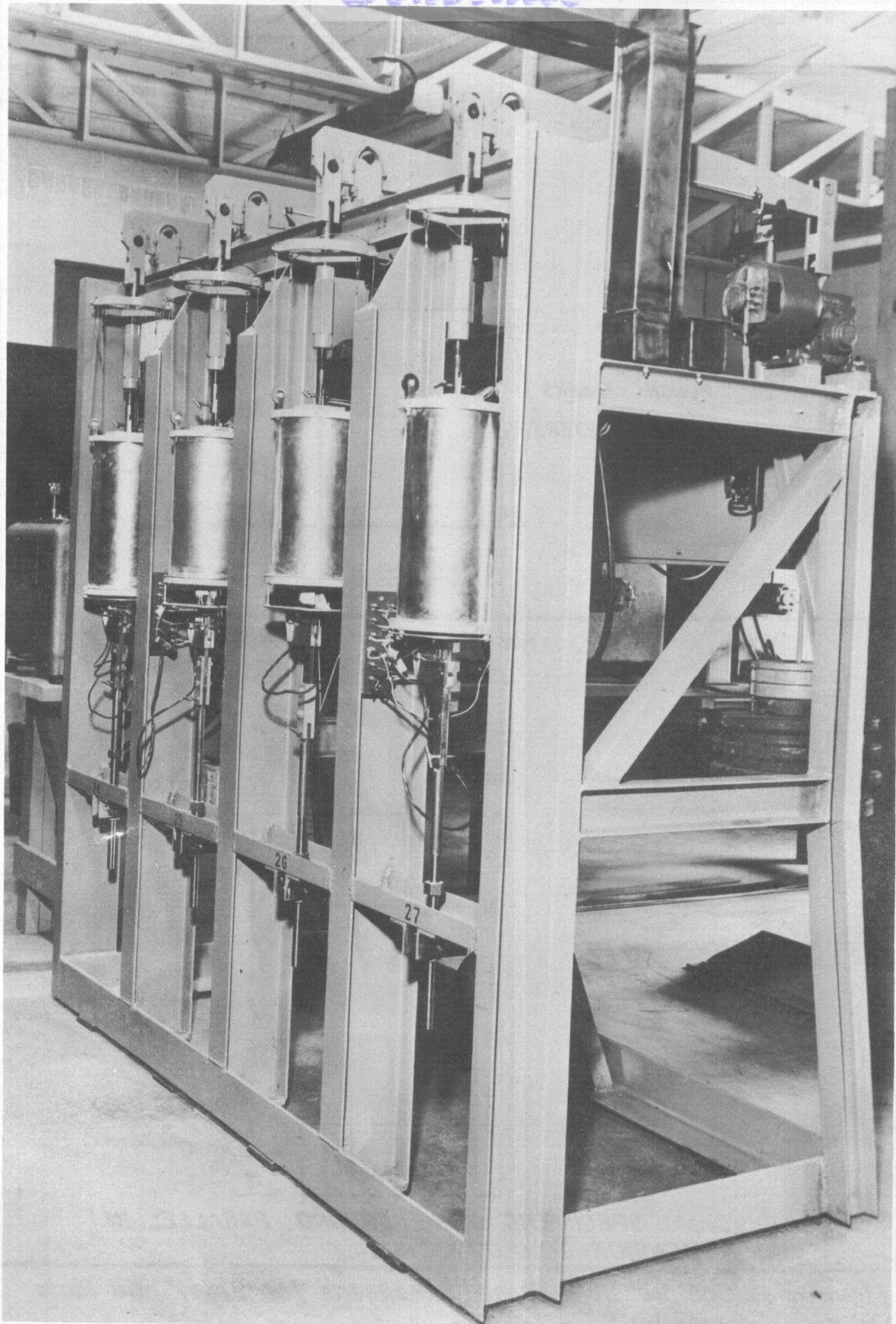


FIGURE 5 FOUR-UNIT TENSILE CREEP APPARATUS

WADC TR 54-270 Pt 1

50

Controls

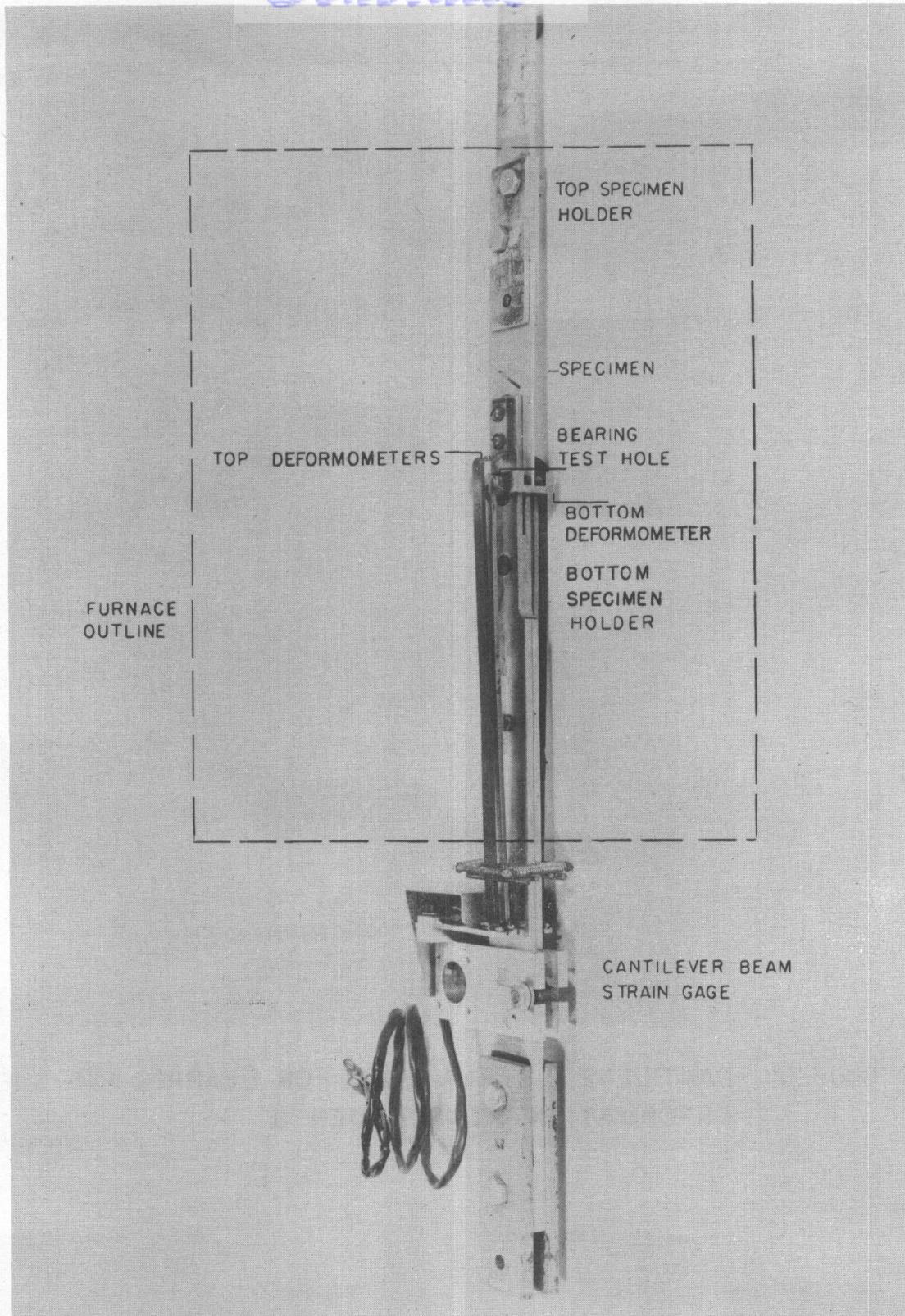


FIGURE 6 BEARING CREEP TEST FIXTURE ASSEMBLY WITH
DEFORMOMETERS & STRAIN GAGE ATTACHED

Controls

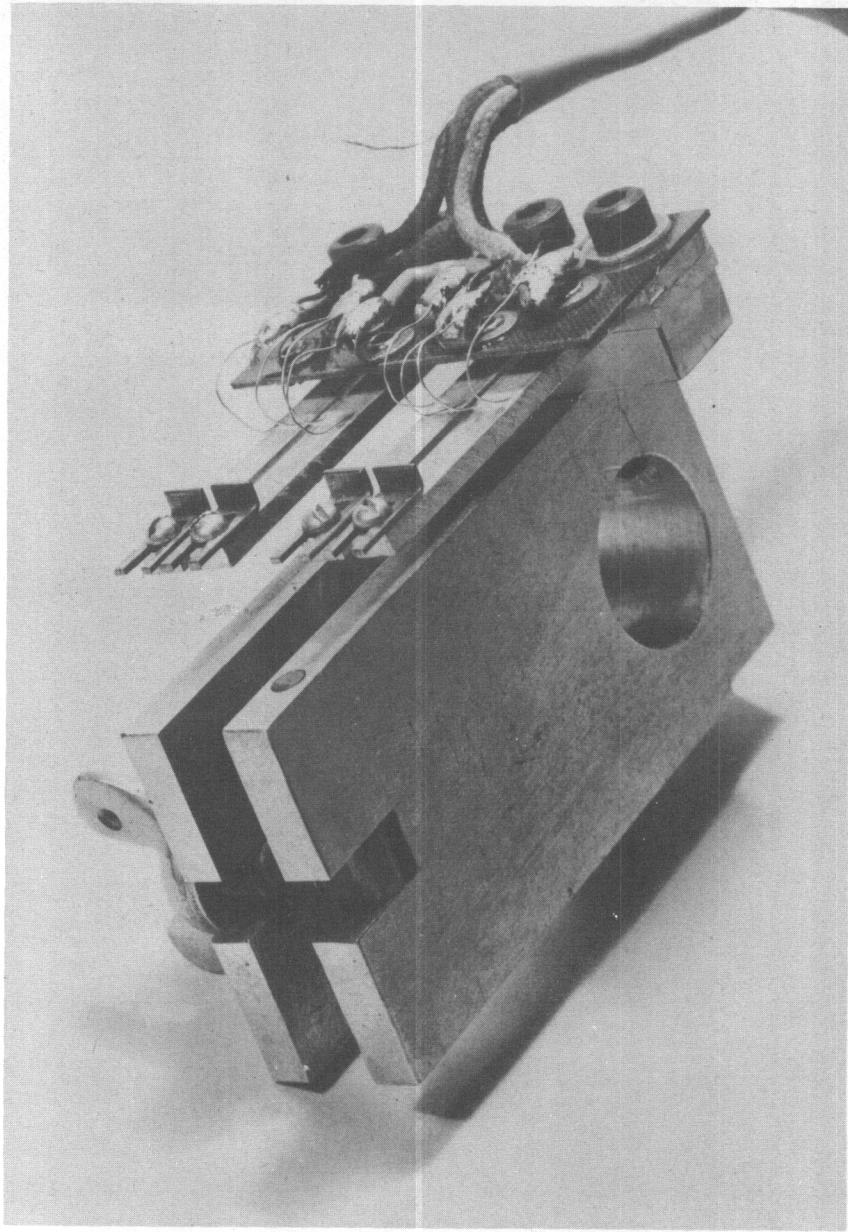
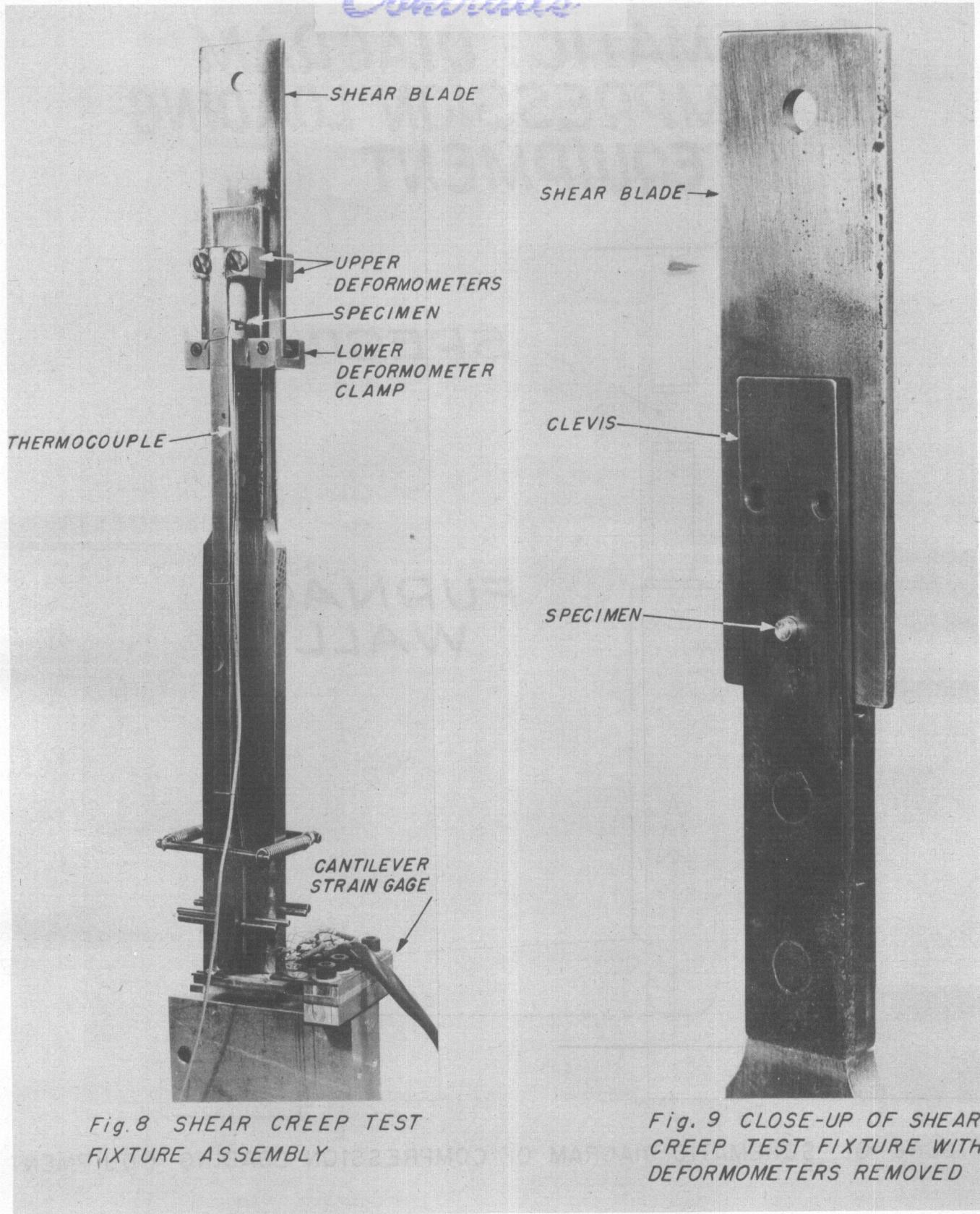


FIGURE 7 CANTILEVER STRAIN GAGE FOR BEARING AND SHEAR CREEP DEFORMATION MEASUREMENTS

Controls



Controls

SCHEMATIC DIAGRAM OF COMPRESSION LOADING EQUIPMENT

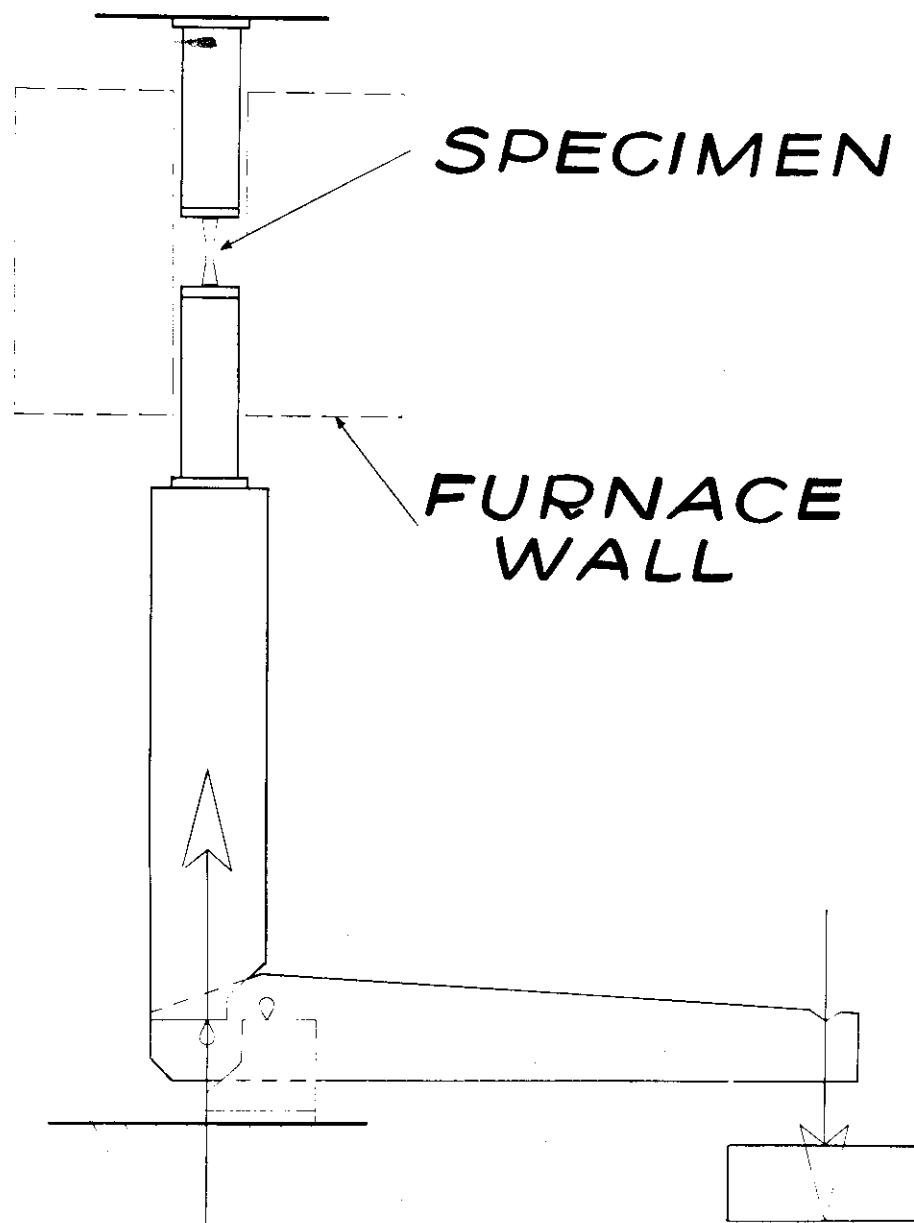


FIGURE 10 SCHEMATIC DIAGRAM OF COMPRESSION LOADING EQUIPMENT

Controls

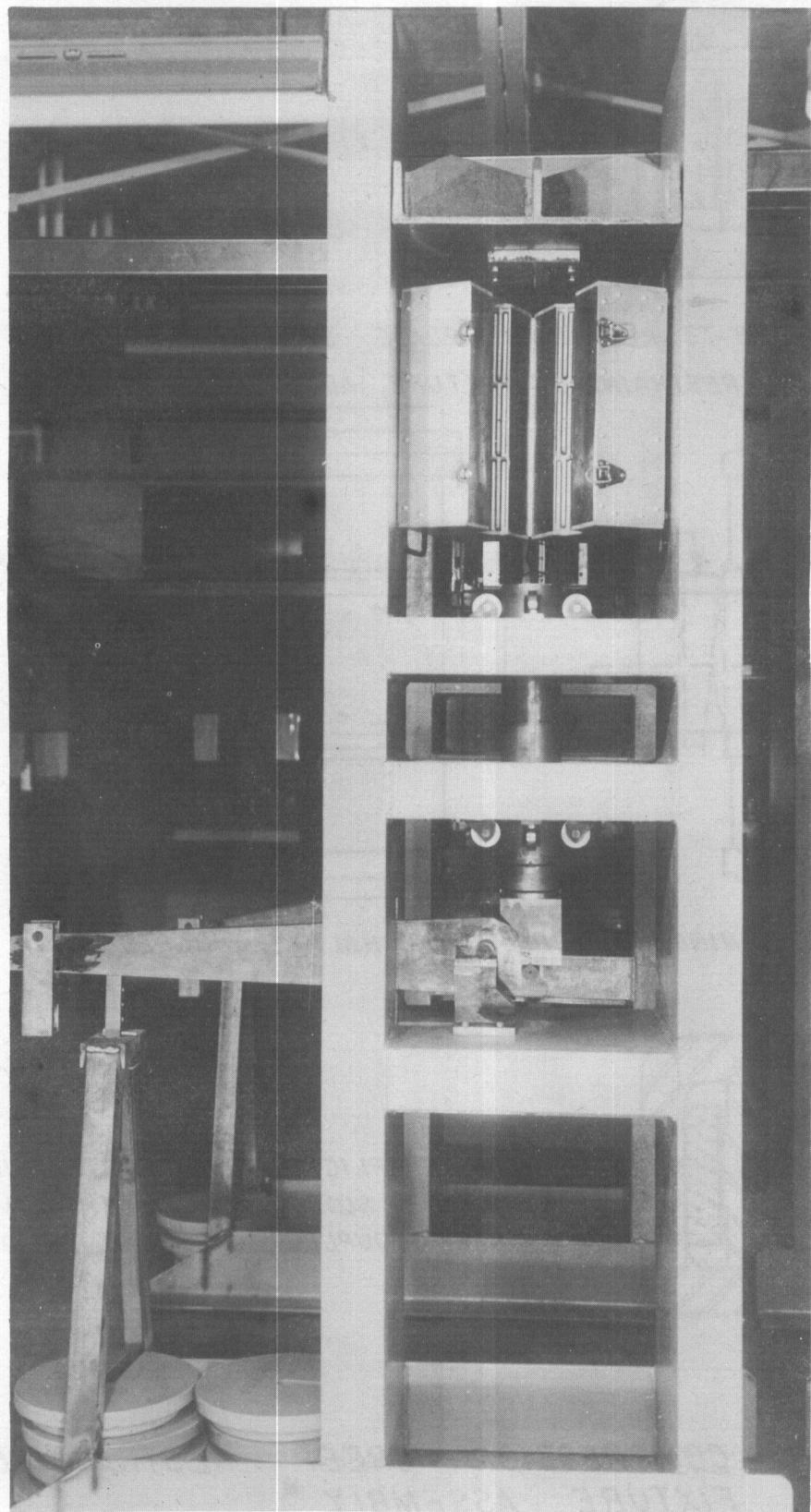


FIGURE II STATIC LOADING COMPRESSION CREEP UNIT

Controls

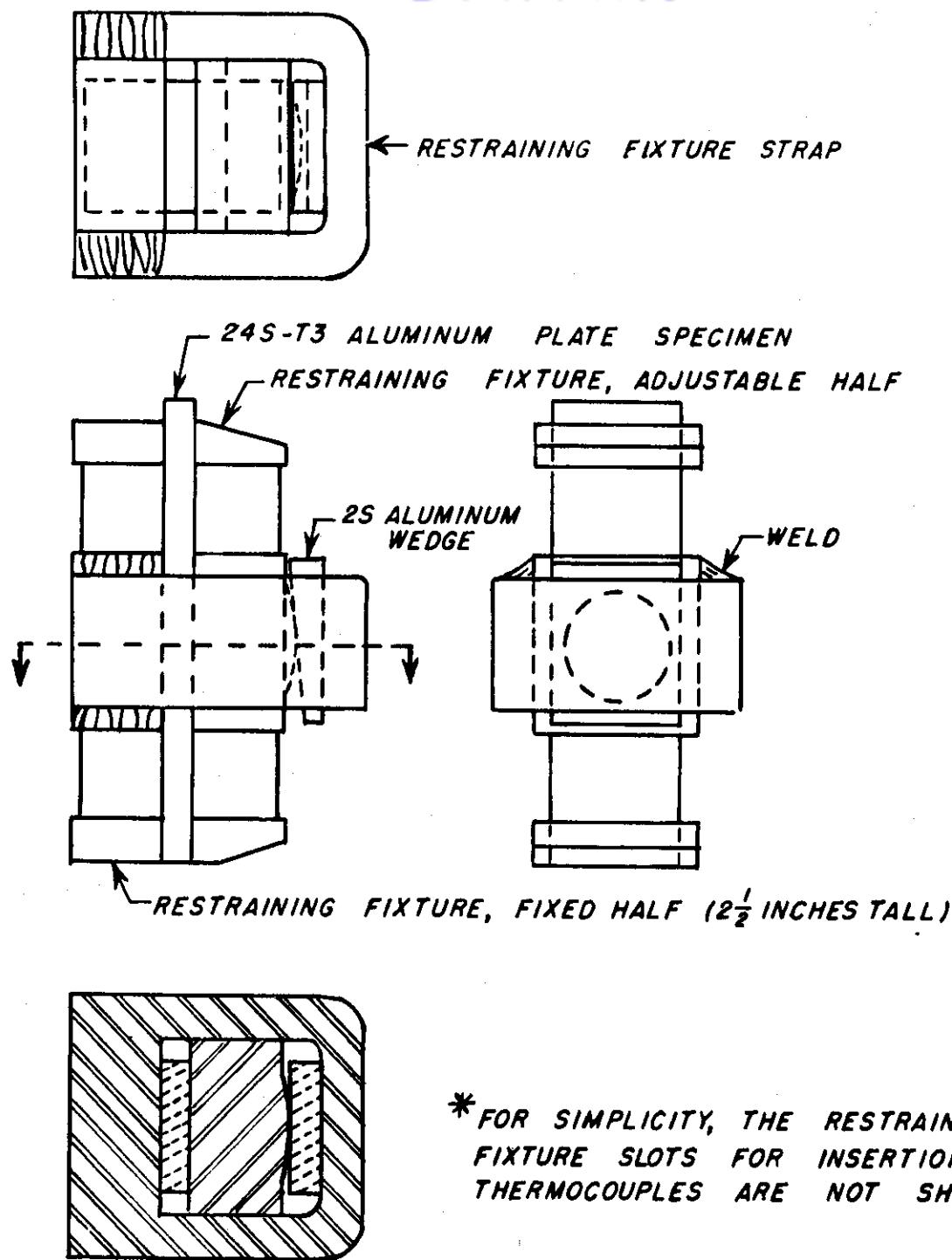
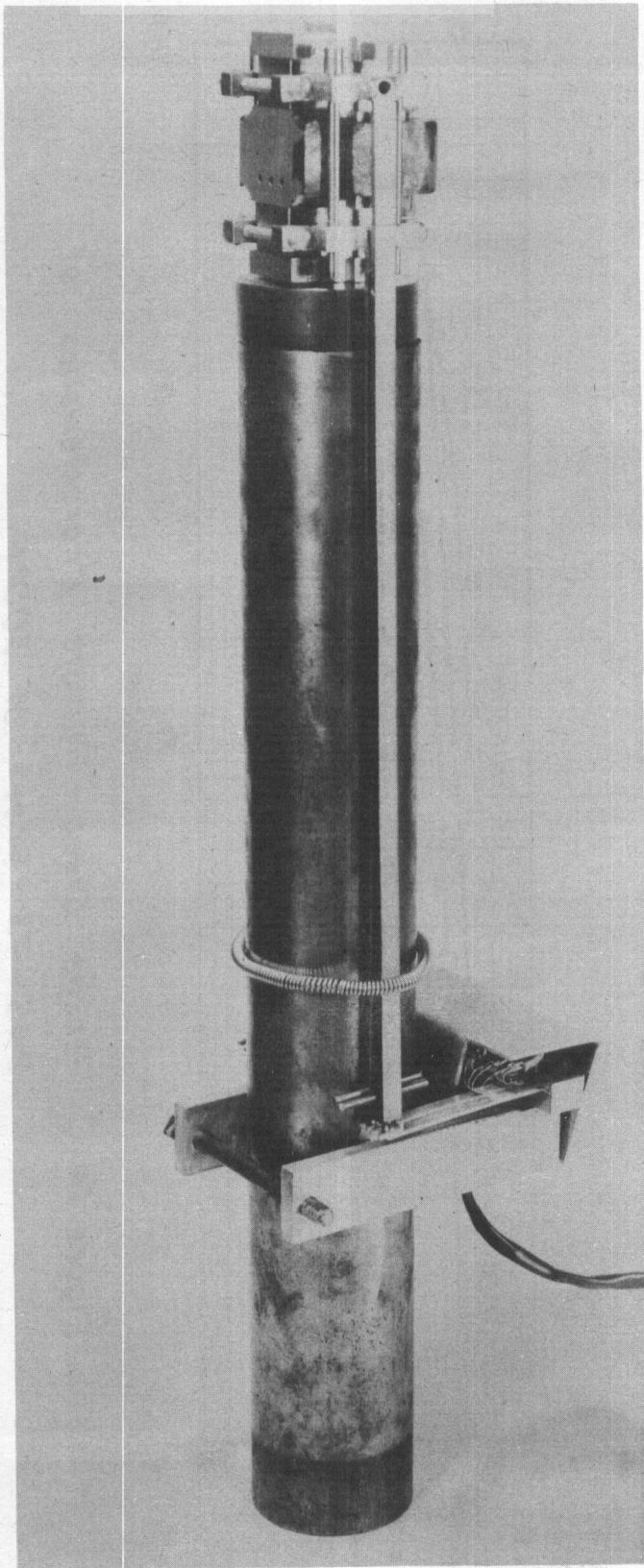


Figure 12 - COMPRESSION CREEP RESTRAINING FIXTURE ASSEMBLY *

Contrails



**FIGURE 13 ASSEMBLED SPECIMEN-RESTRAINING FIXTURE –
COMPRESSOMETER SETUP**

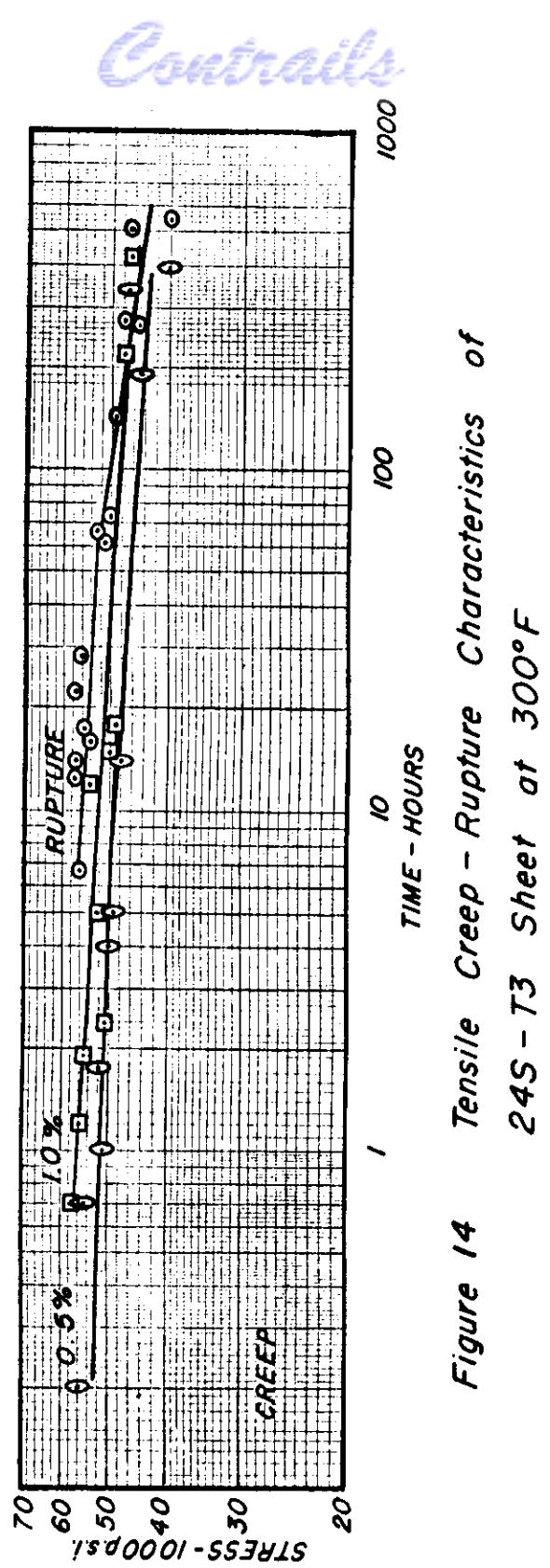


Figure 14 Tensile Creep - Rupture Characteristics of
24S-T3 Sheet at 300°F

Contrails

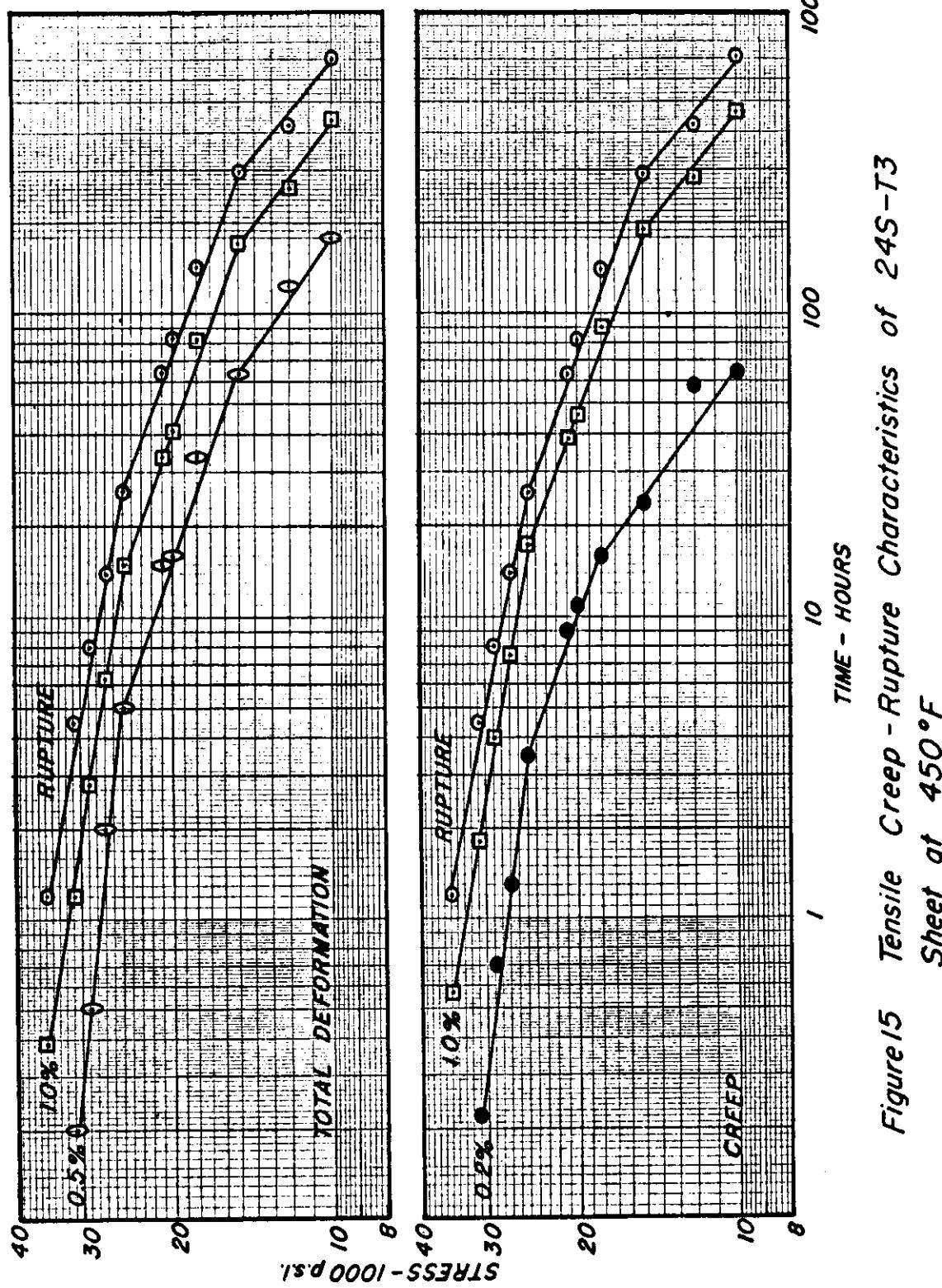


Figure 15 Tensile Creep-Rupture Characteristics of 24S-T3
Sheet at 450°F

Contrails

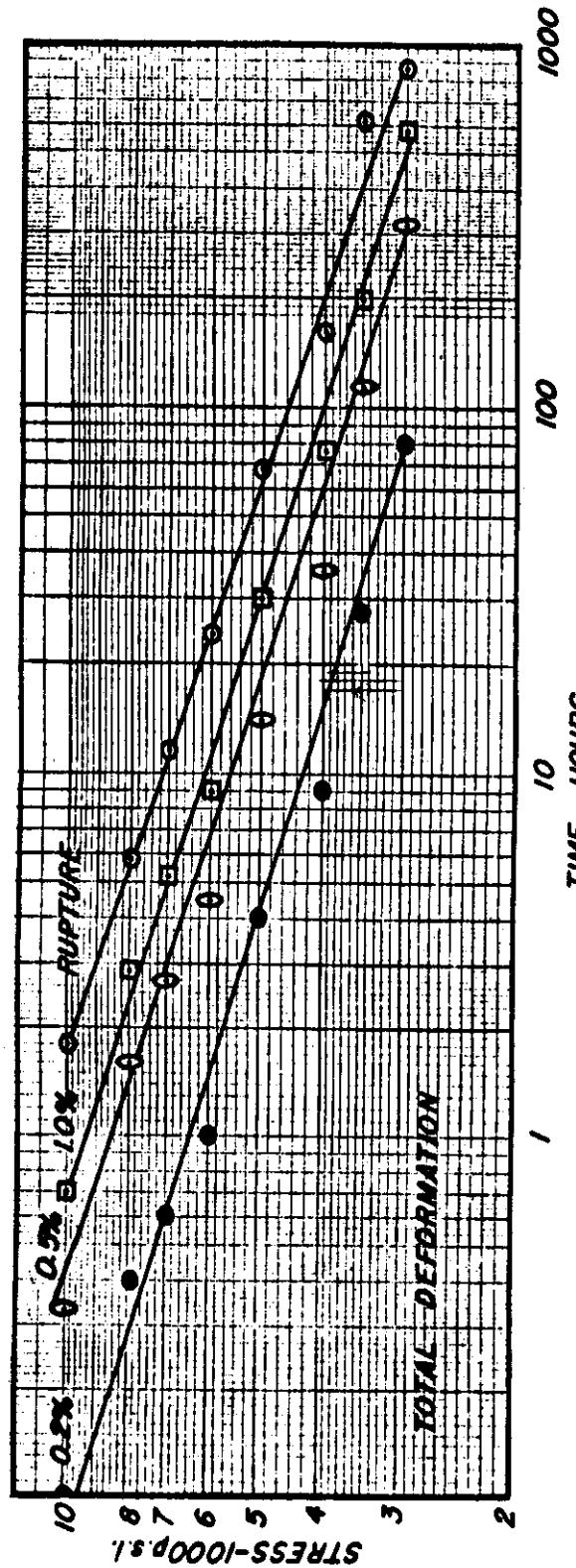


Figure 16 Tensile Creep-Rupture Characteristics of 24S-T3 Sheet at 600°F

Contrails

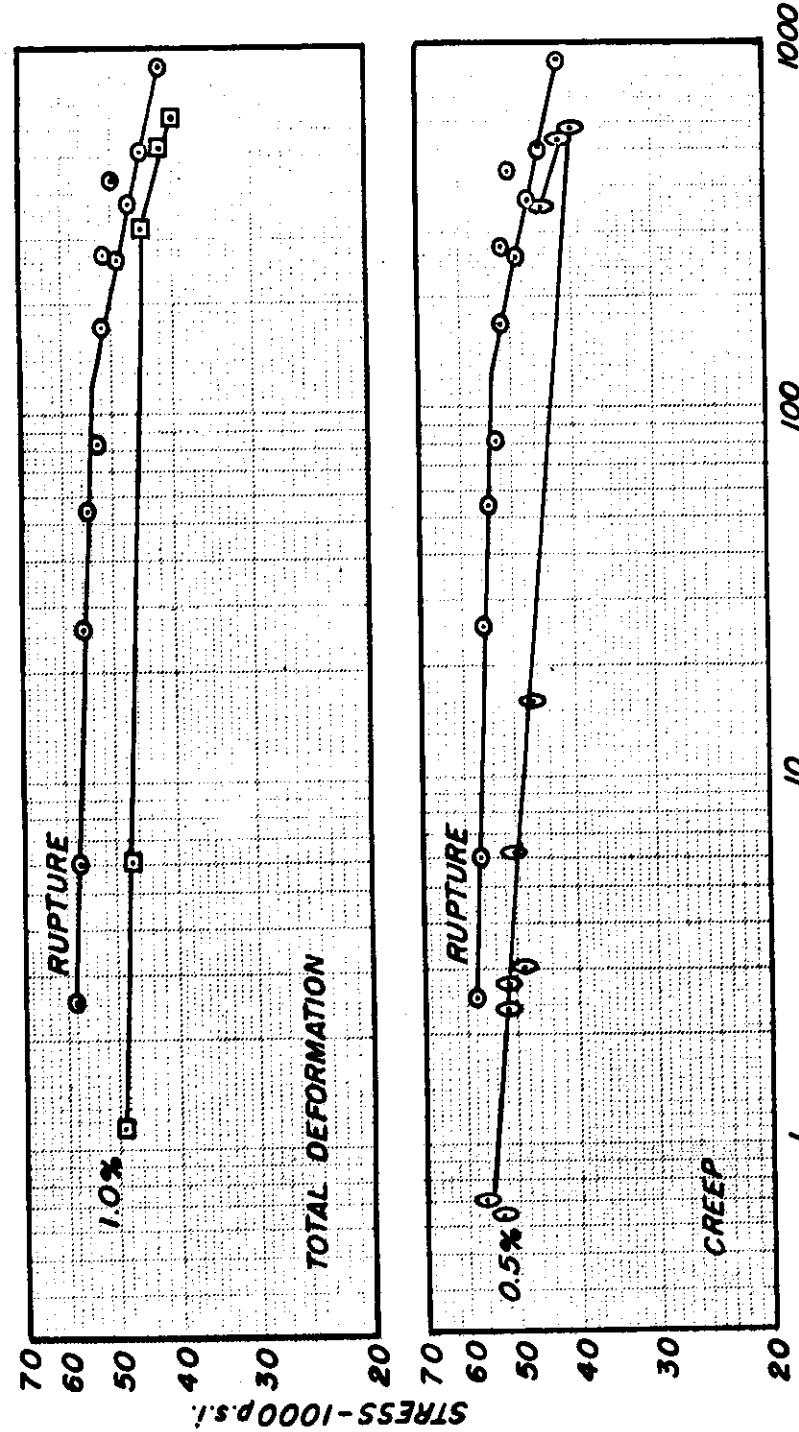


Figure 17 Tensile Creep Rupture Characteristics of 24S-
T3 3/16" Plate at 300°F

Contrails

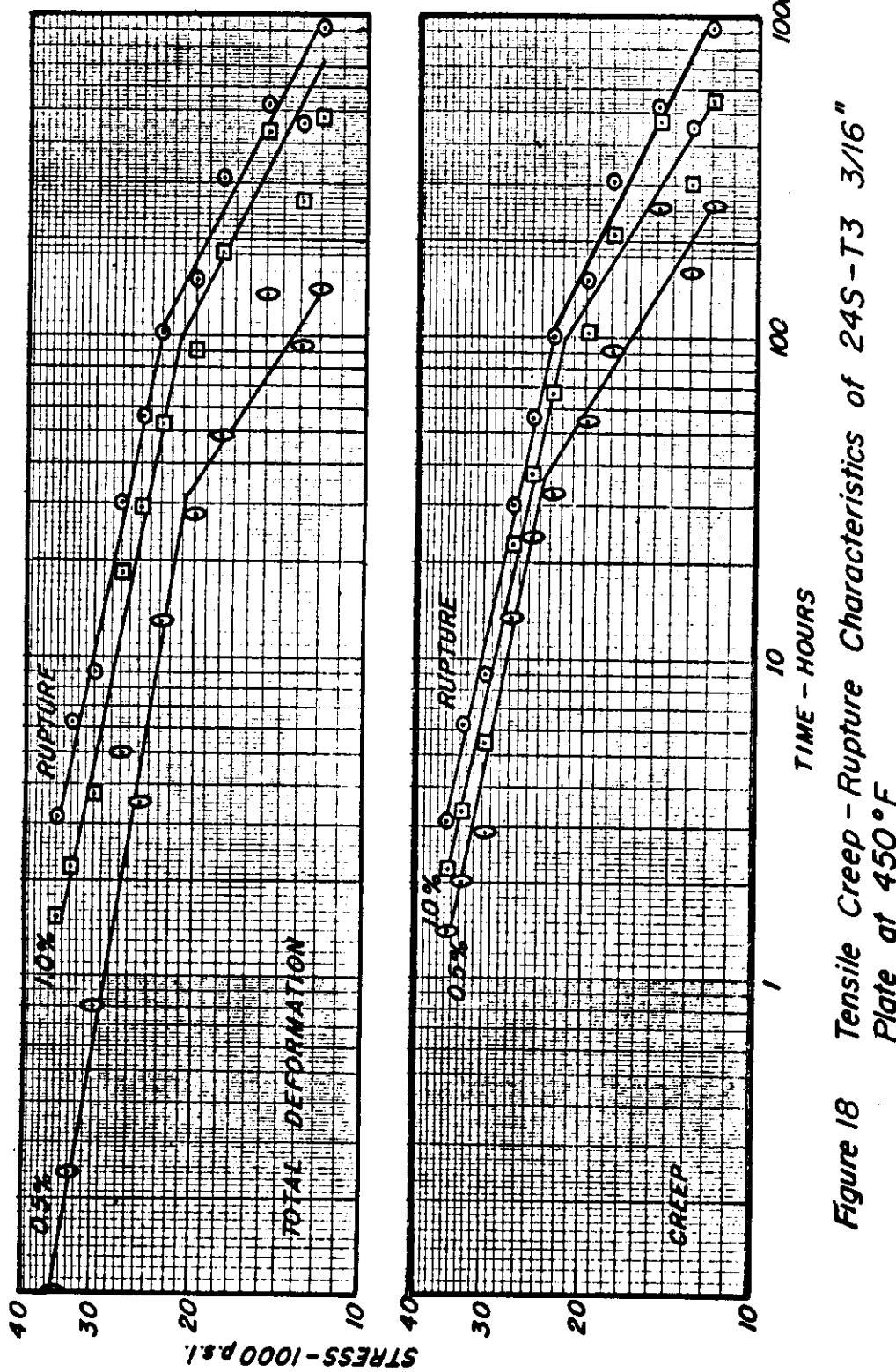


Figure 18 Tensile Creep-Rupture Characteristics of 24S-T3 3/16"
Plate at 450°F

Contrails

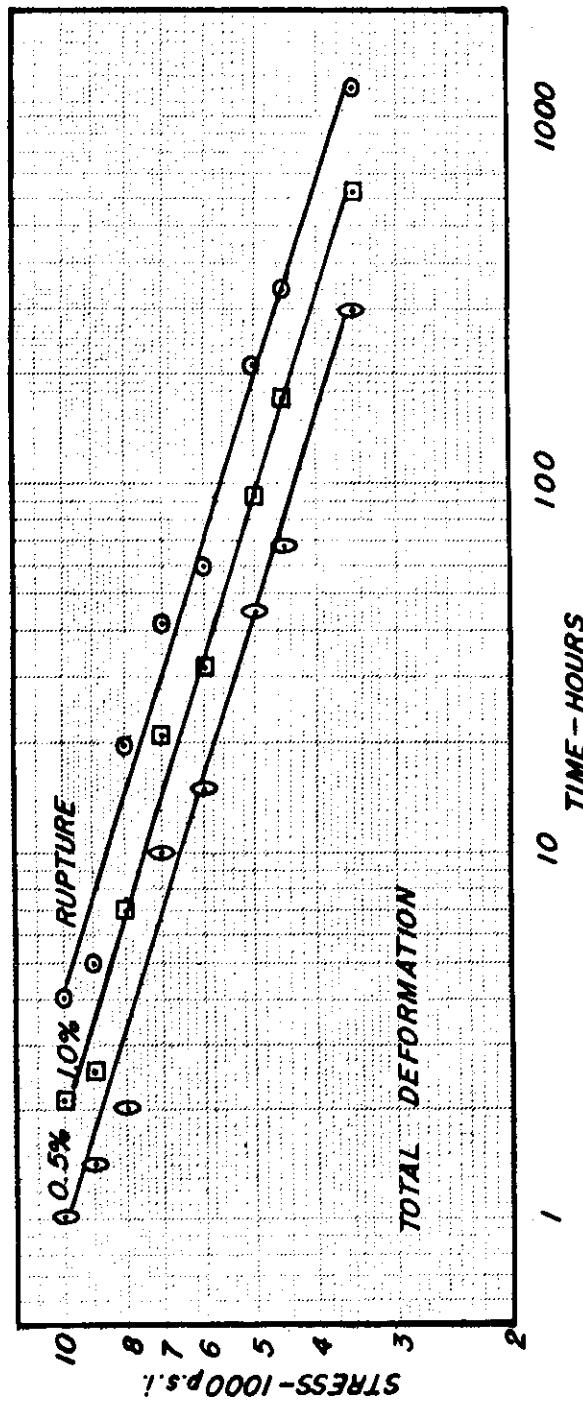


Figure 19 Tensile Creep - Rupture Characteristics of
24S-T3 3/16" Plate 600°F

Contrails

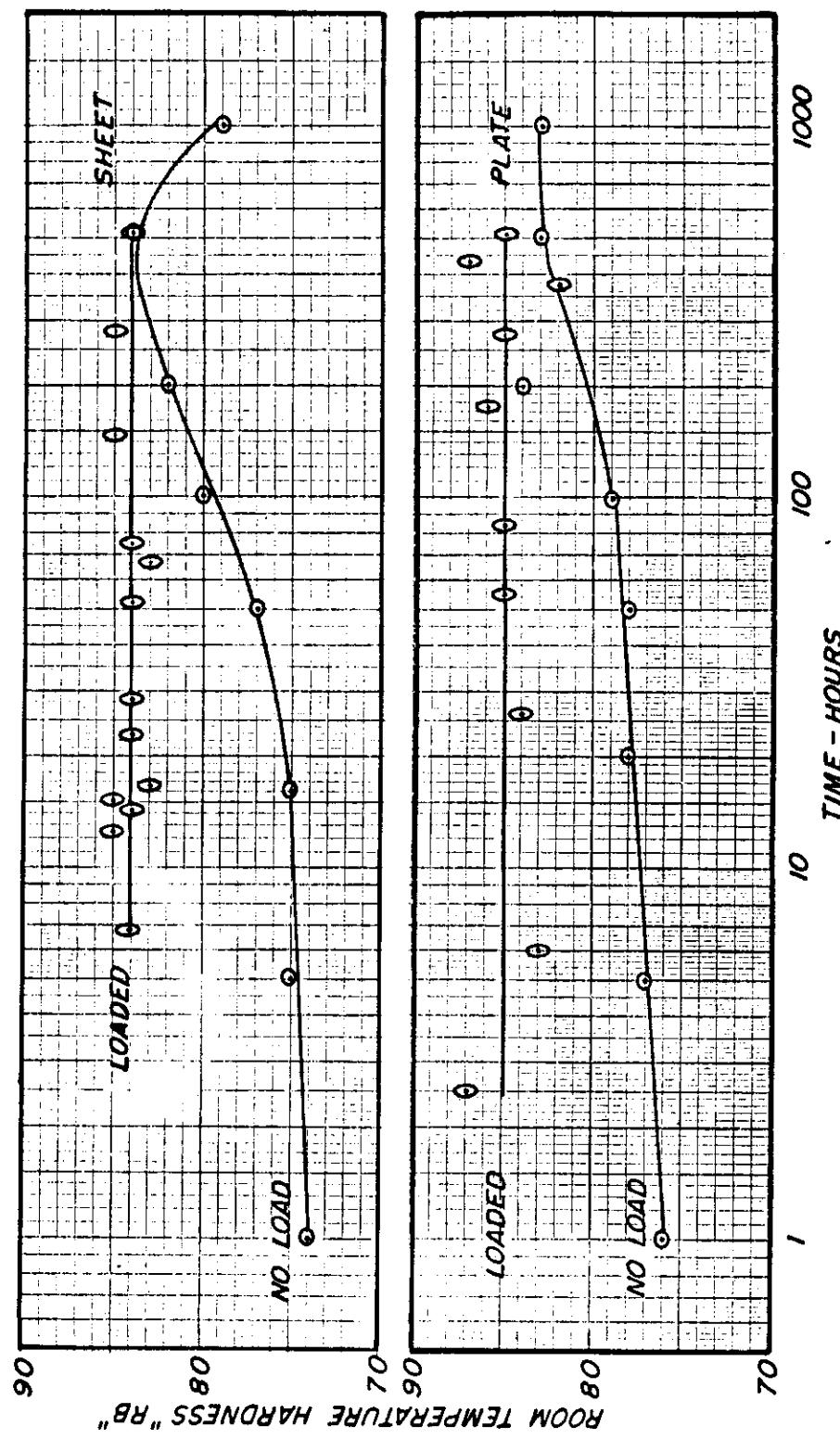


Figure 20 Hardness vs Aging Times at 300°F for Stressed and Unstressed 24S-T3 Sheet & Plate Specimens

Contrails

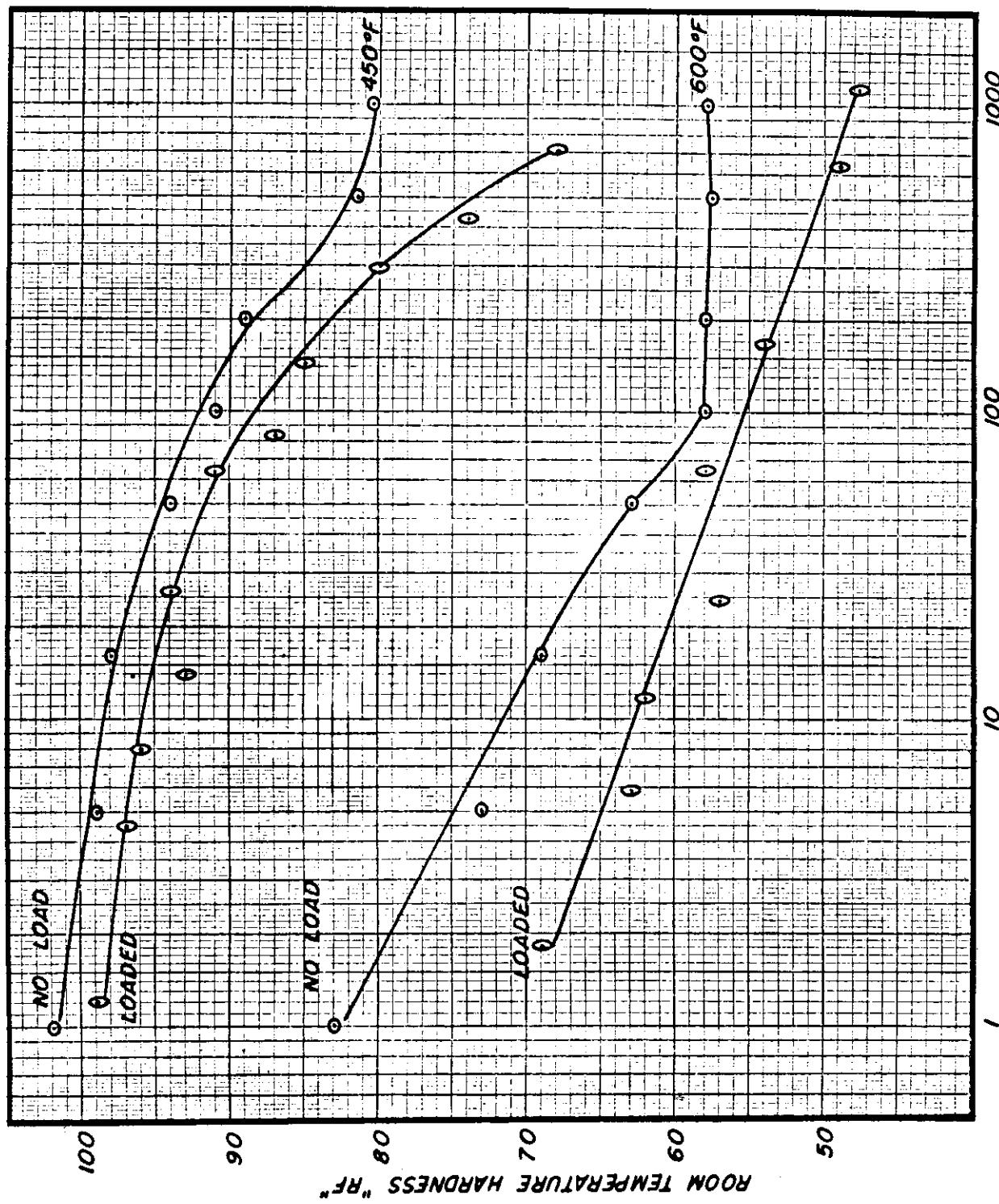


Figure 21 Hardness vs Aging Times at Indicated Temperatures
for Stressed and Unstressed 24S-T3 Sheet Specimens

Contrails

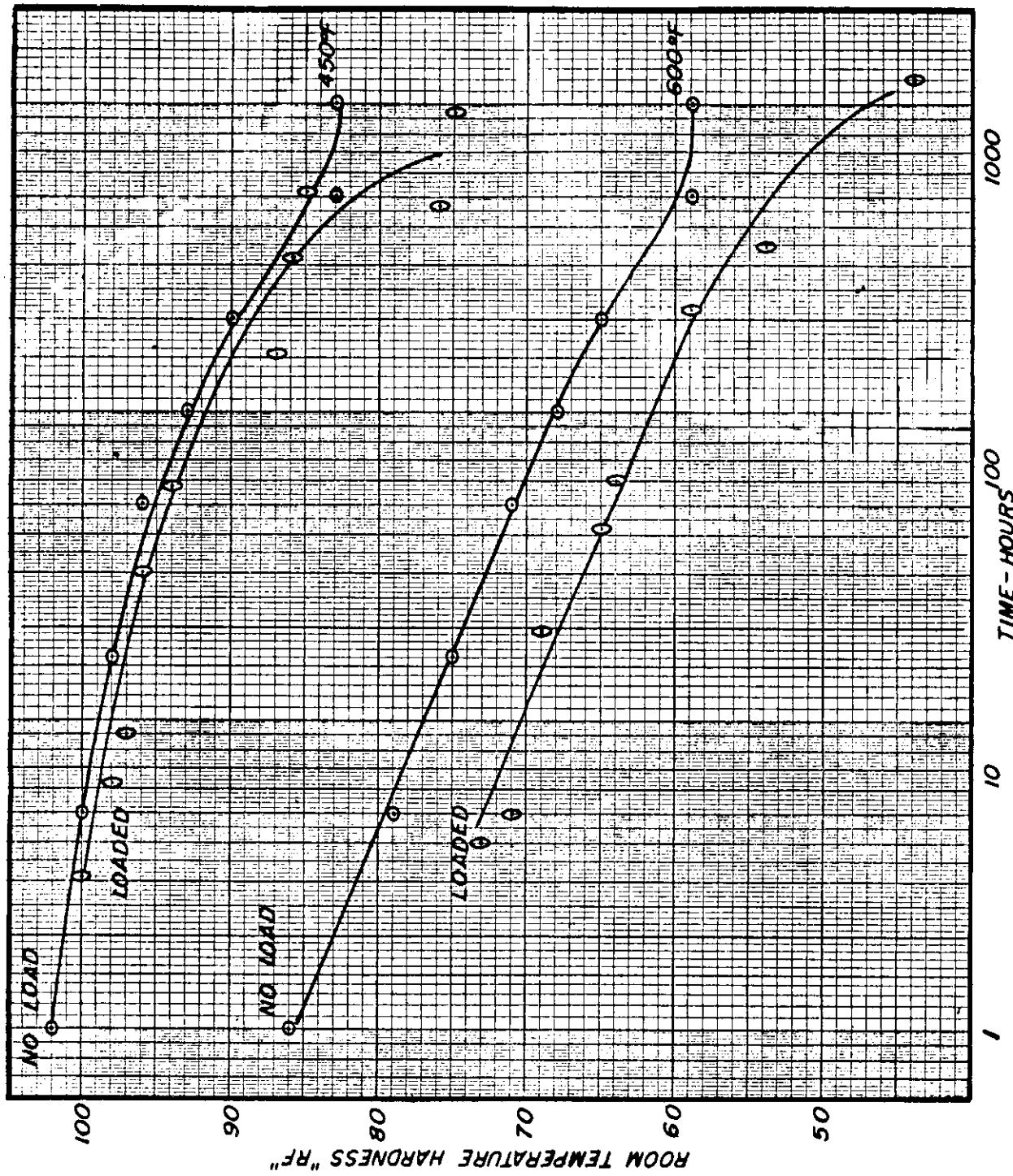


Figure 22 Hardness vs Aging Times at Indicated Temperatures for
Stressed and Unstressed 24S-T3 Plate Specimens

Contrails

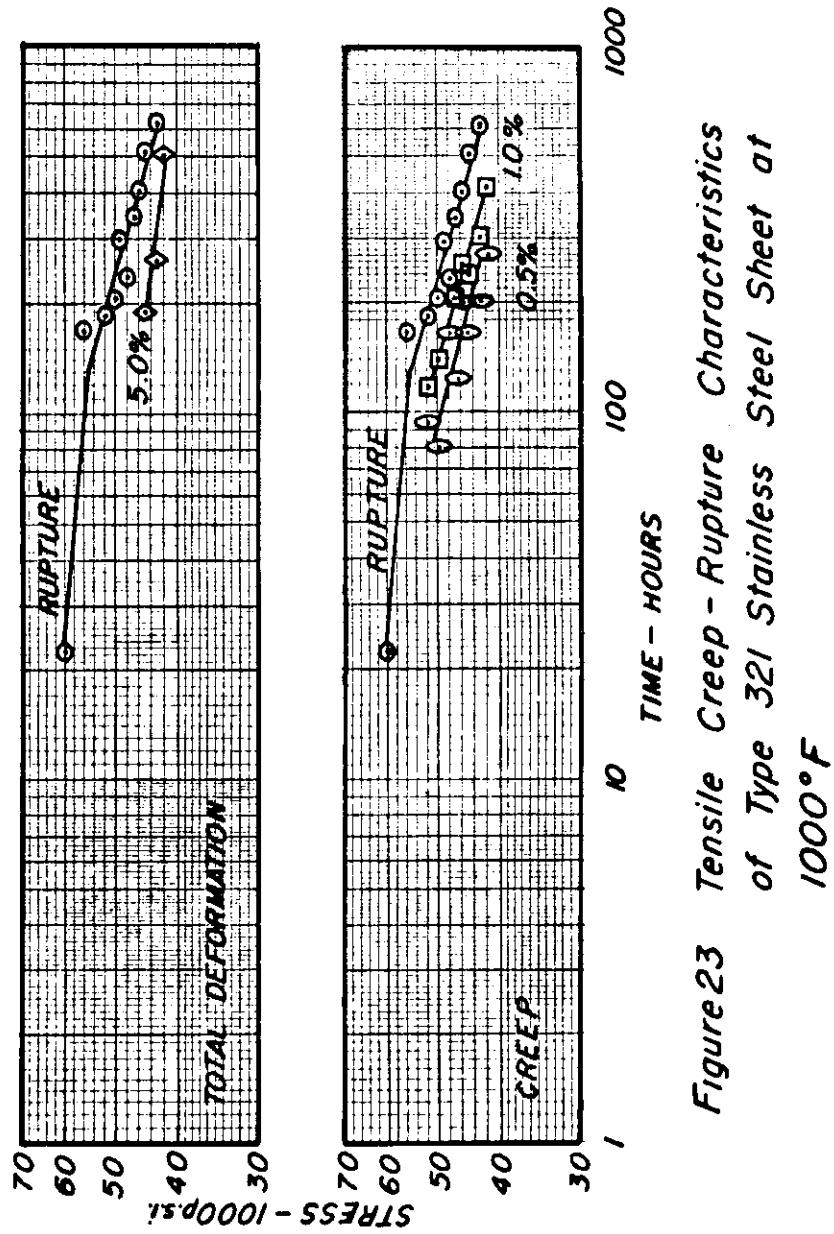


Figure 23 Tensile Creep-Rupture Characteristics
of Type 321 Stainless Steel Sheet at
1000°F

Contrails

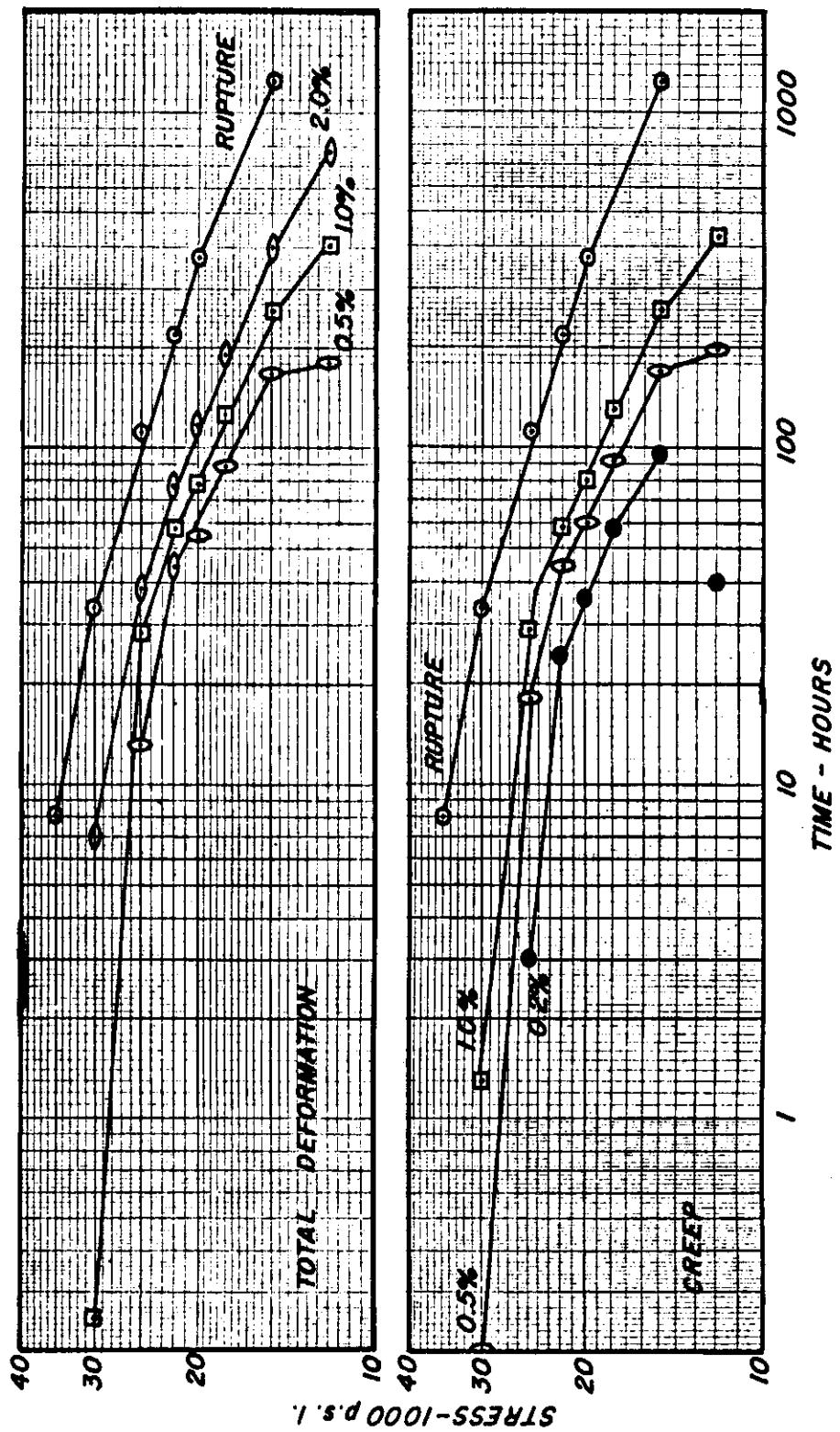


Figure 24 Tensile Creep-Rupture Characteristics of Type 321
Stainless Steel Sheet at 1200°F

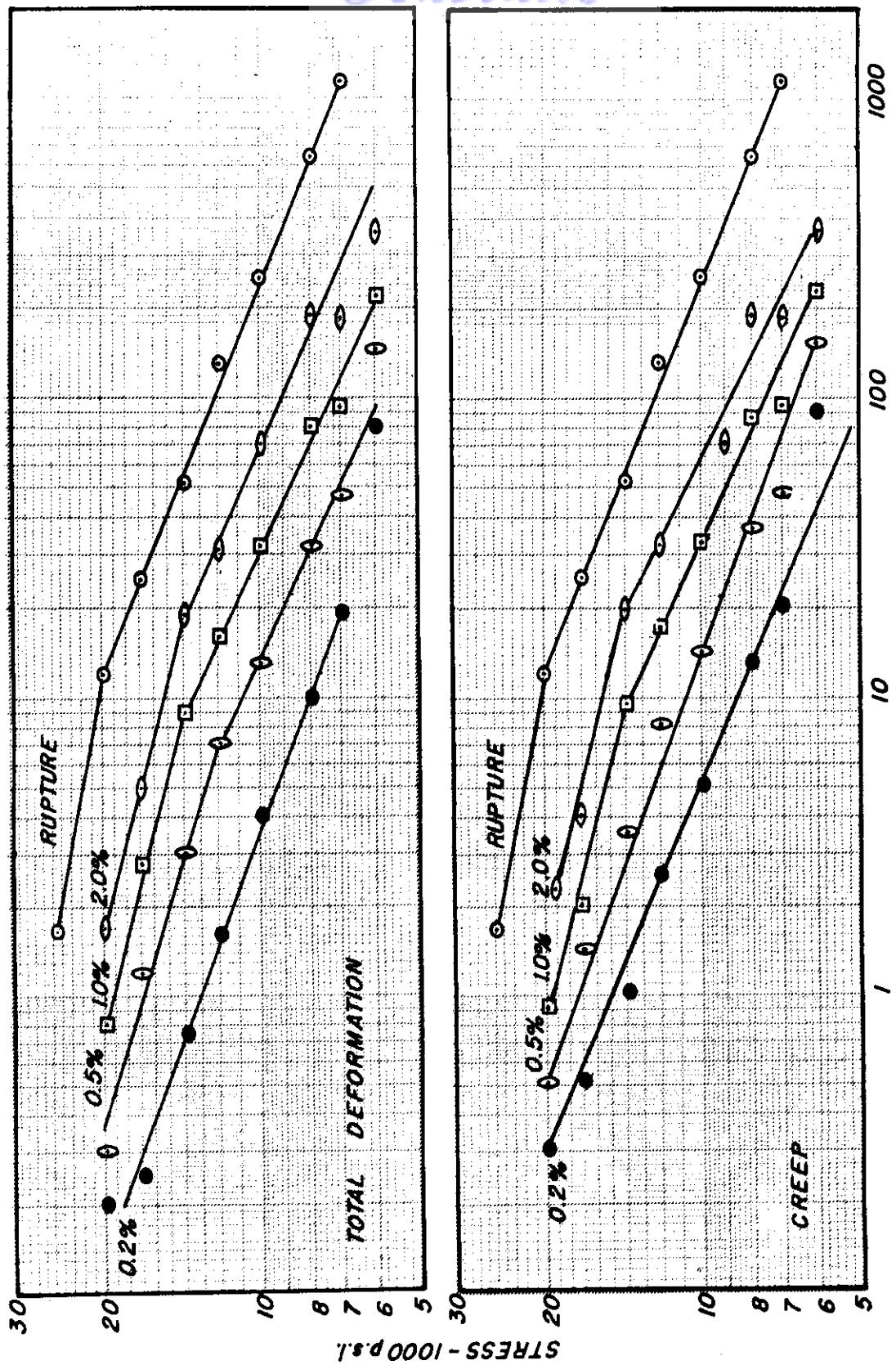


Figure 25 Tensile Creep-Rupture Characteristics of Type 321 Stainless Steel Sheet at 1350°F

Contrails

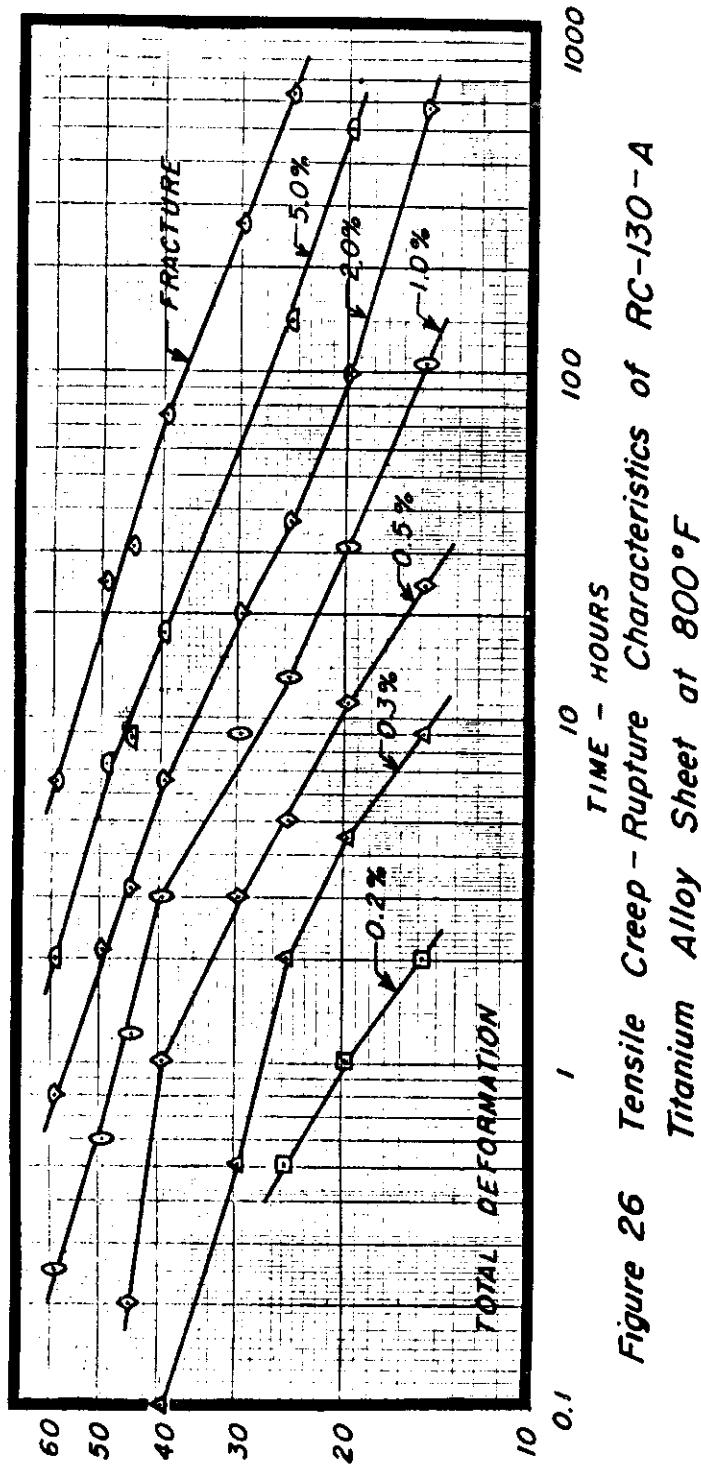
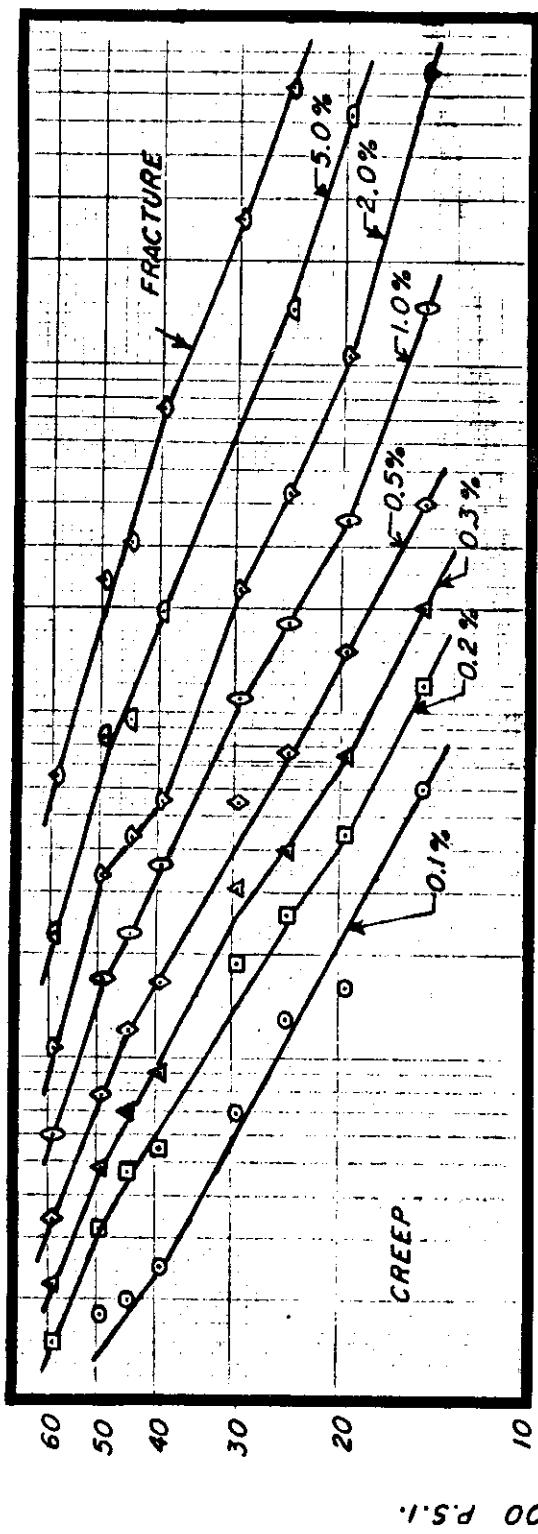


Figure 26 Tensile Creep - Rupture Characteristics of RC-130-A Titanium Alloy Sheet at 800°F

Contrails

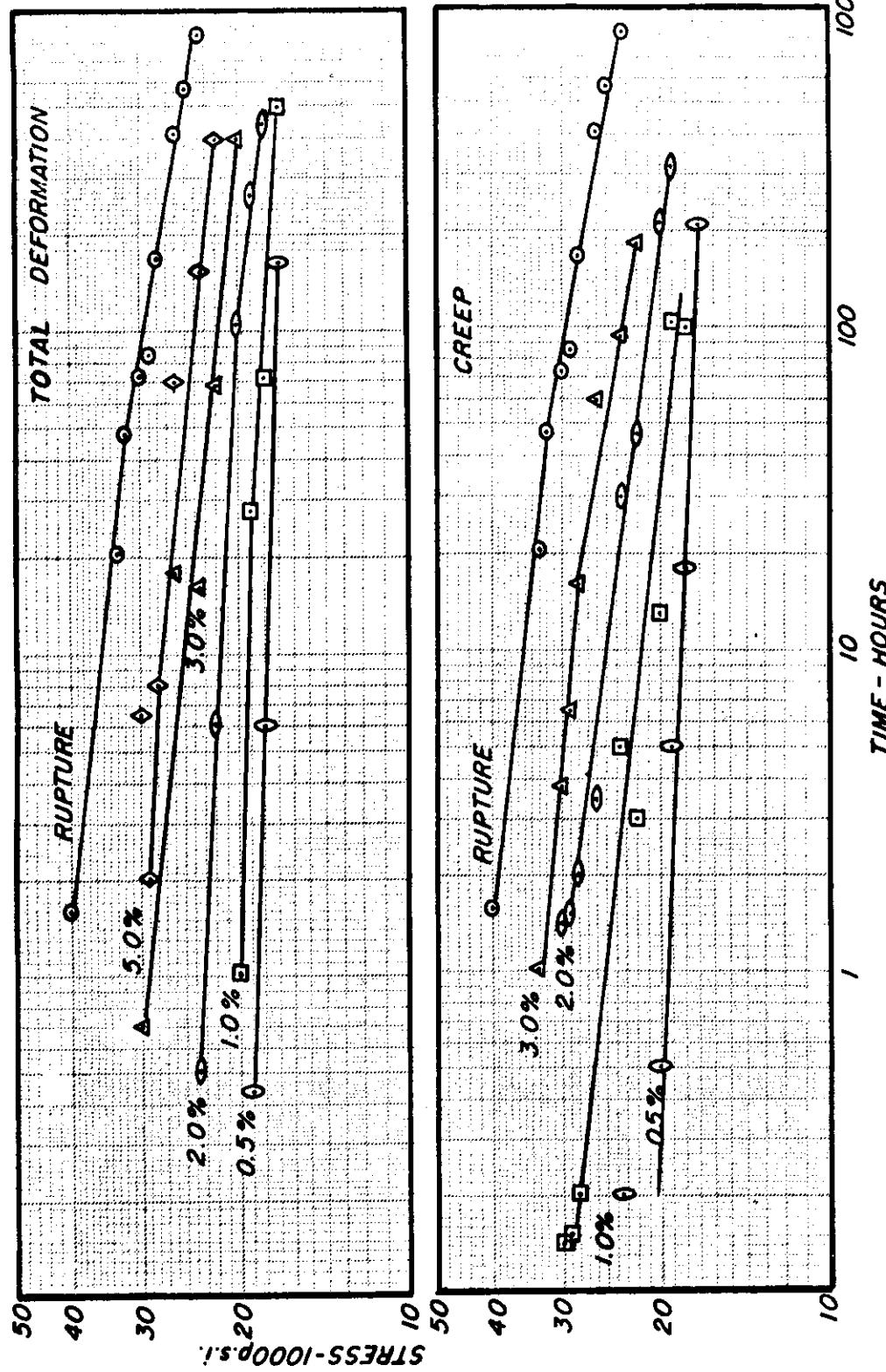


Figure 27 Tensile Creep - Rupture Characteristics of Monel $\frac{1}{2}$ " Diameter Wire at $1000^{\circ} F.$

Contrails

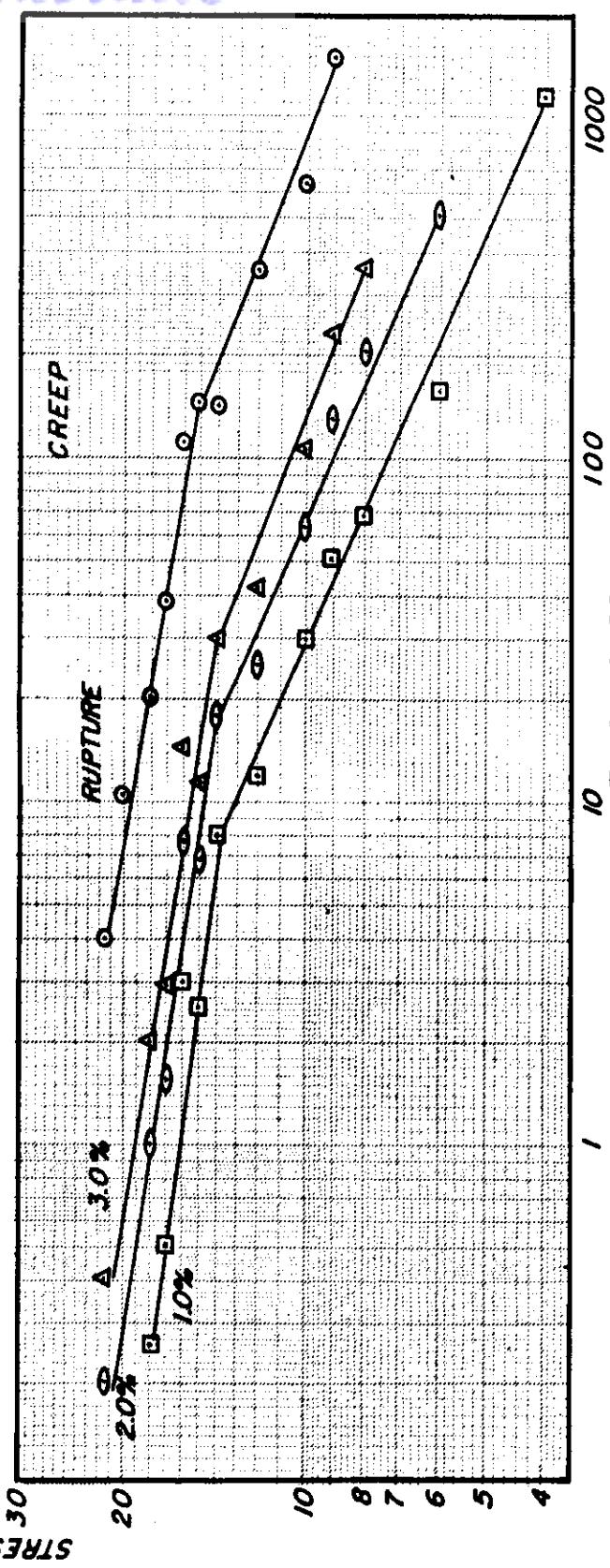
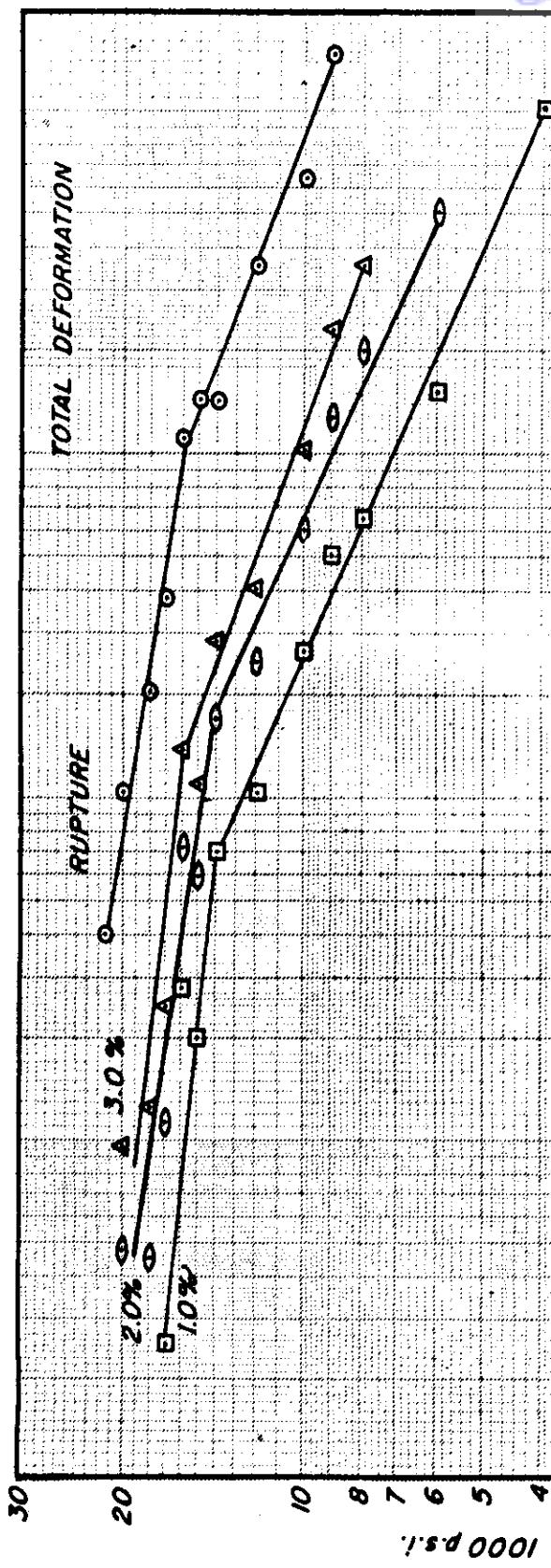


Figure 28 Tensile Creep-Rupture Characteristics of Monel $\frac{1}{2}$ " Diameter Wire at 1200°F.

Contrails

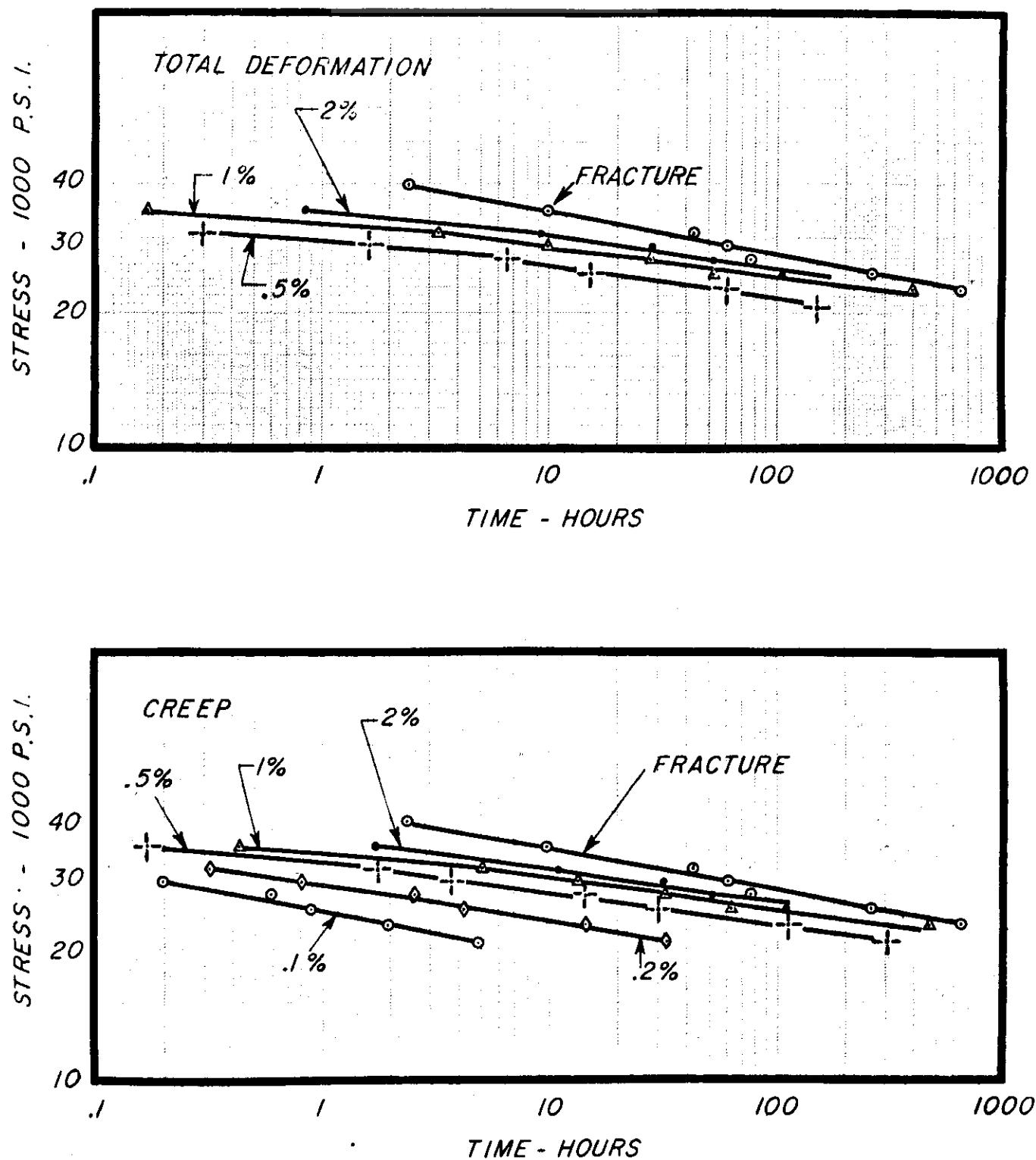


Figure 29 Tensile Creep - Rupture Characteristics of
Type 301 Stainless Steel $\frac{1}{2}$ " Diameter Wire
at 1200°F .

Contrails

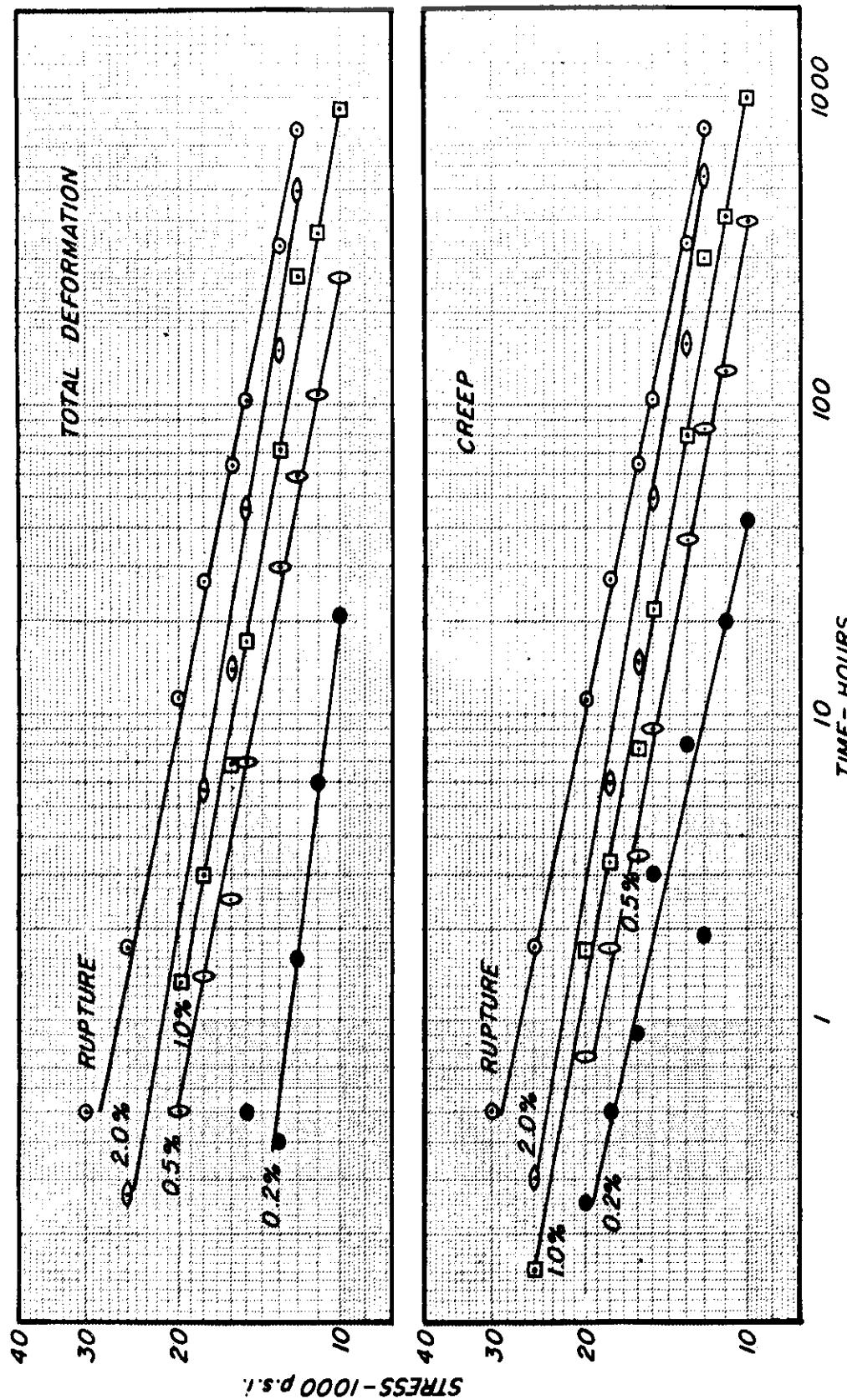


Figure 30 Tensile Creep - Rupture Characteristics of Type 301 Stainless Steel $\frac{1}{2}$ " Diameter Wire at 1350°F.

Contrails

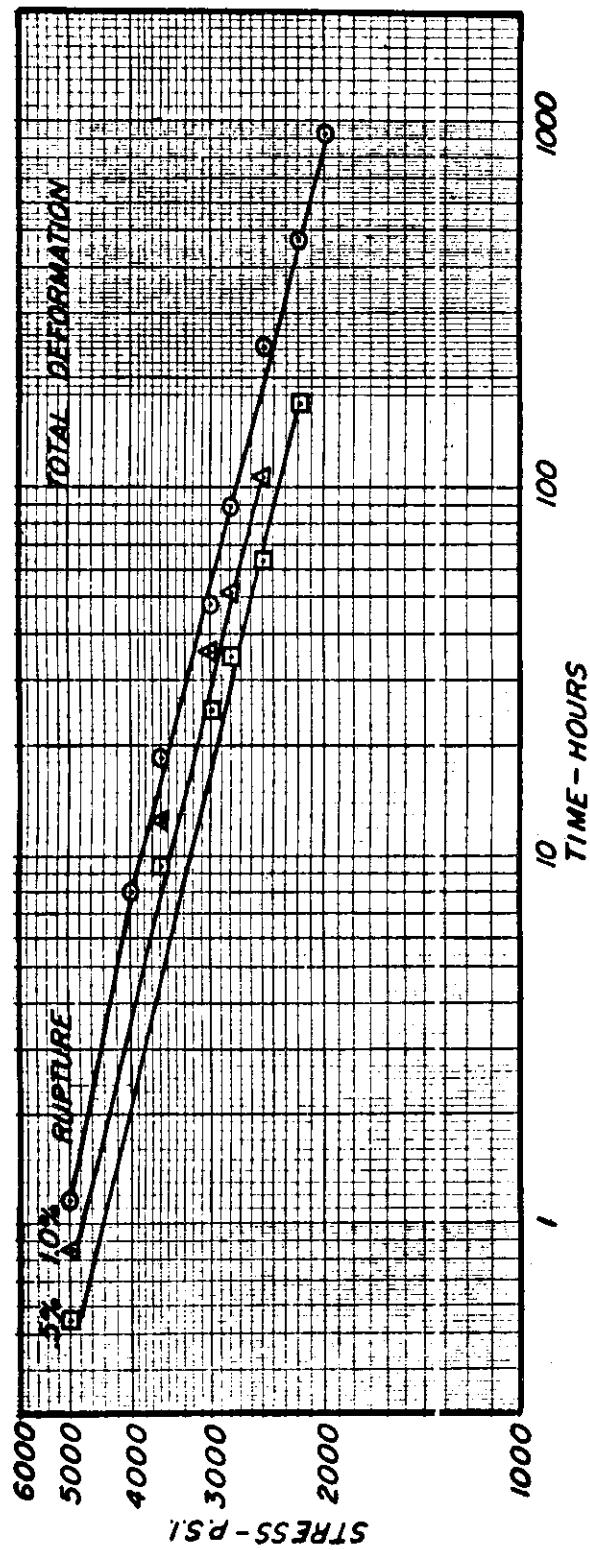


Figure 31 Tensile Creep-Rupture Characteristics of A175-T4 3/8" Dia. Rivet Wire at 600°F

Contrails

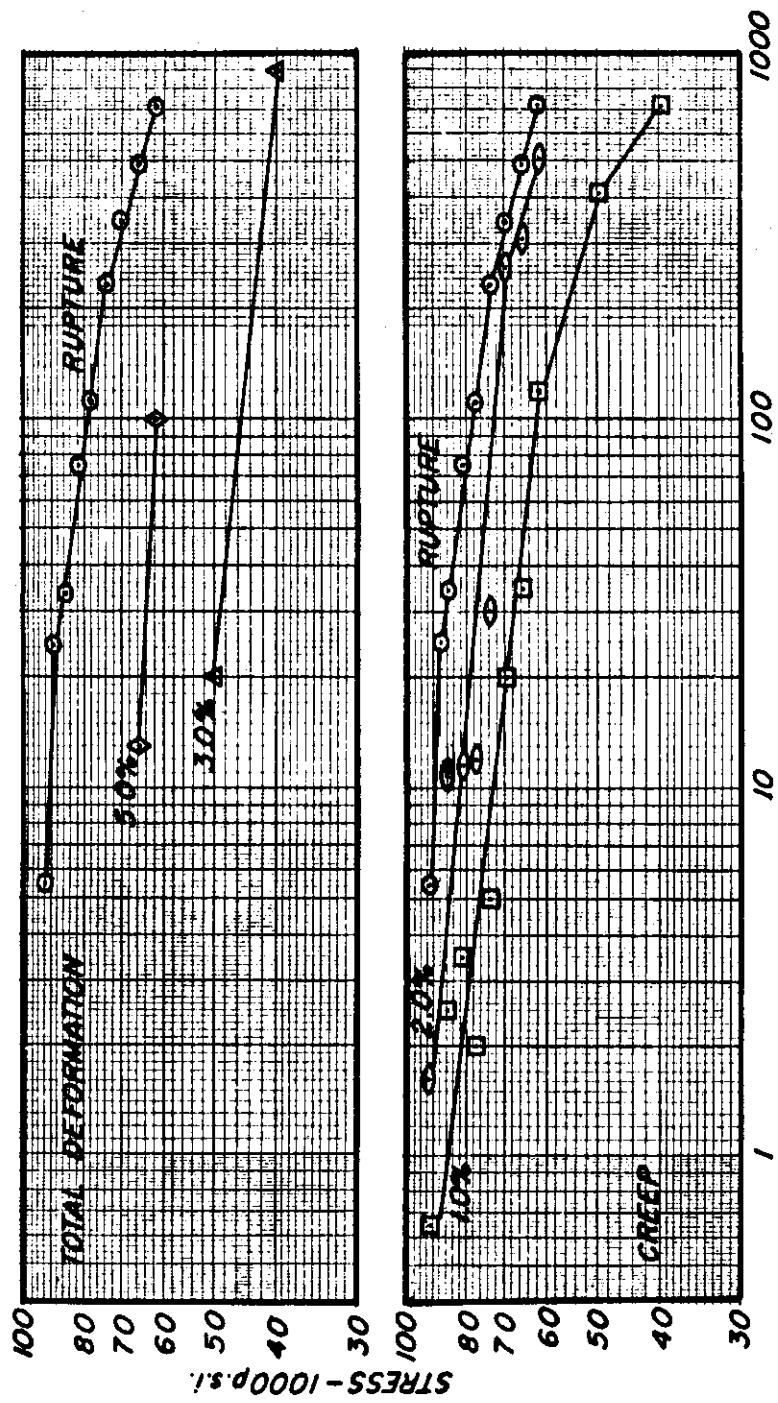
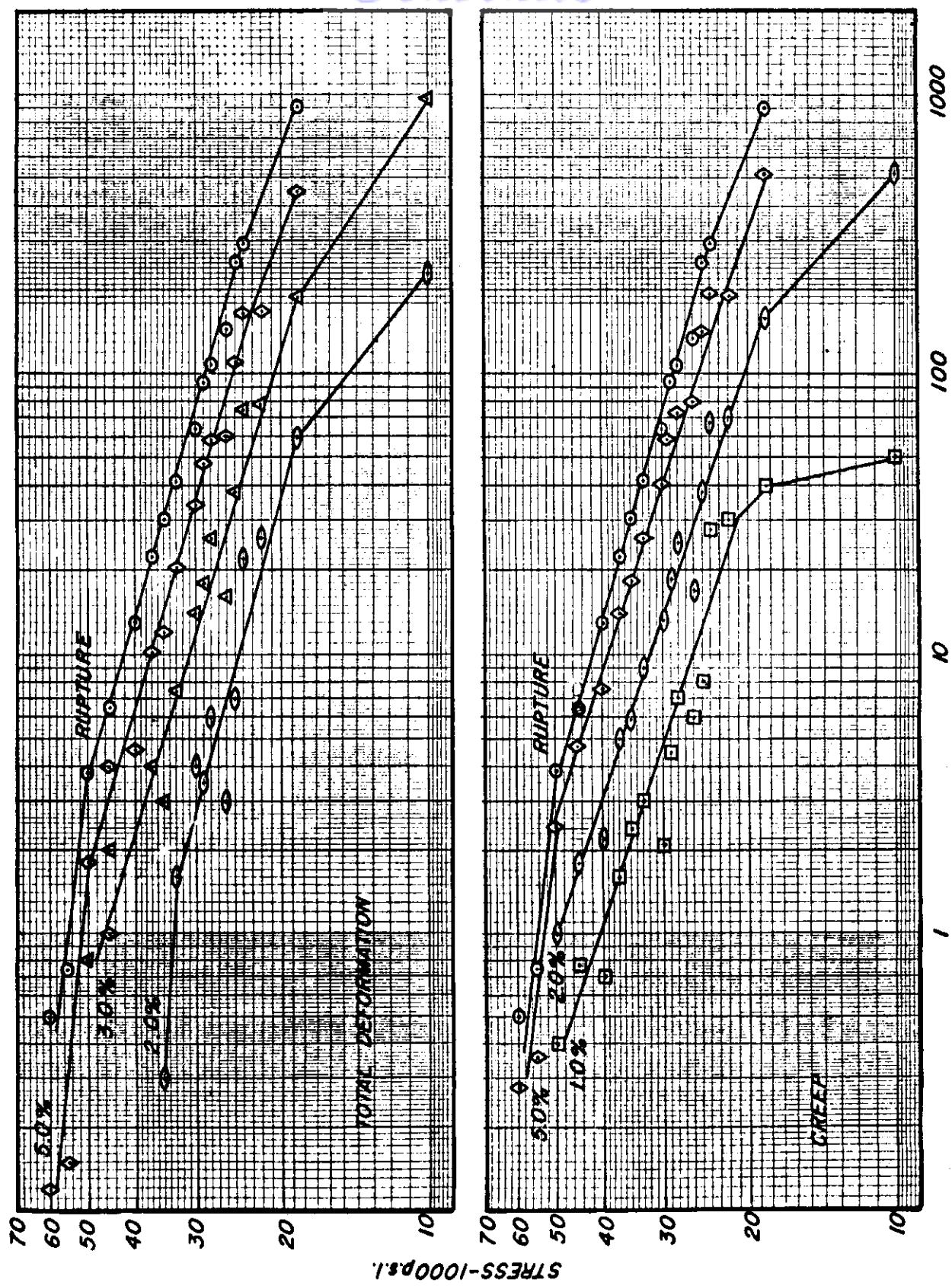


Figure 32 Bearing Creep-Rupture Characteristics of
24S-T3 Sheet at 300°F

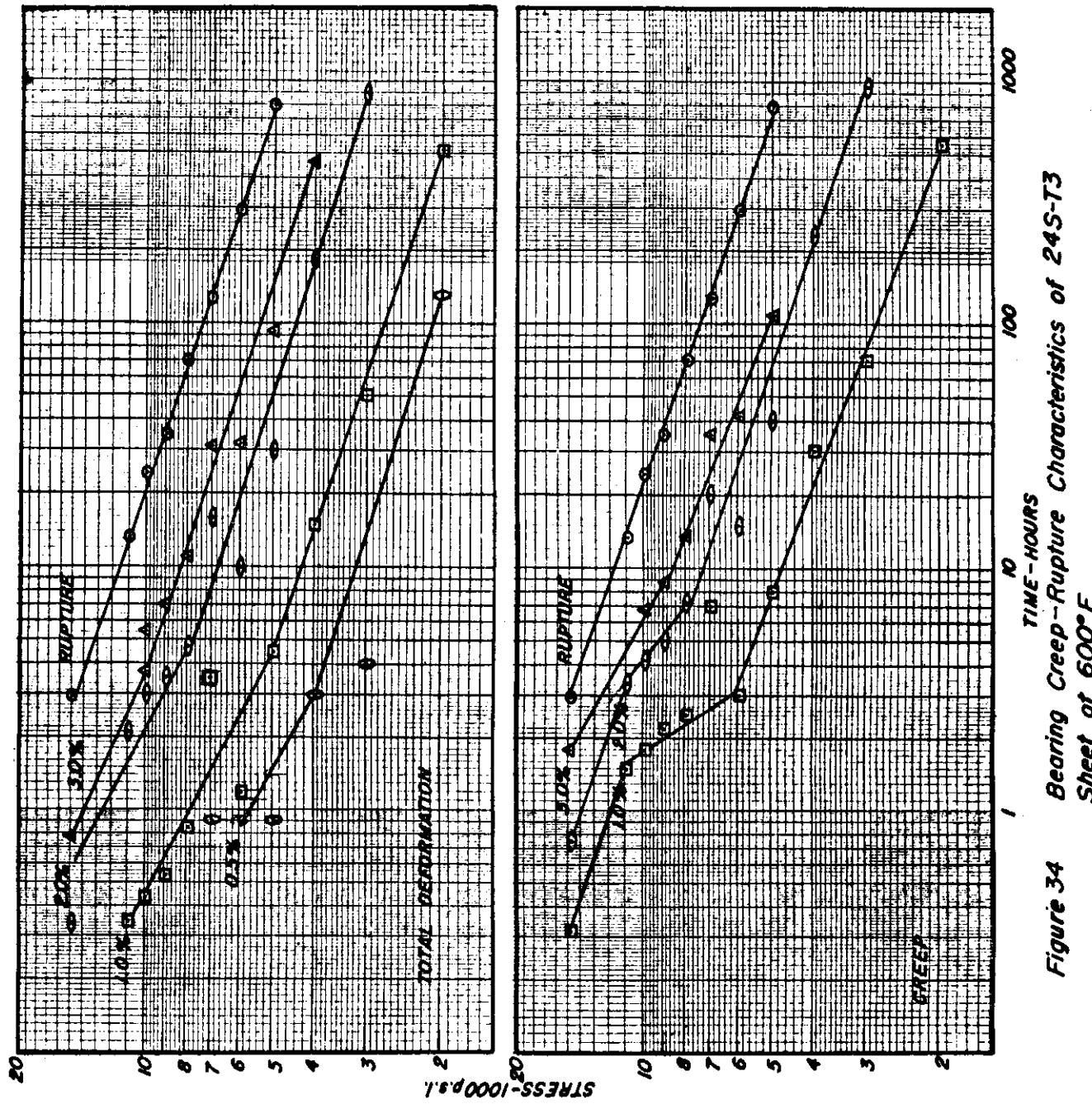
Contrails



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Figure 33 Bearing Creep-Rupture Characteristics of 24S-T3 Sheet at 450°F

Contrails



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78

Contrails

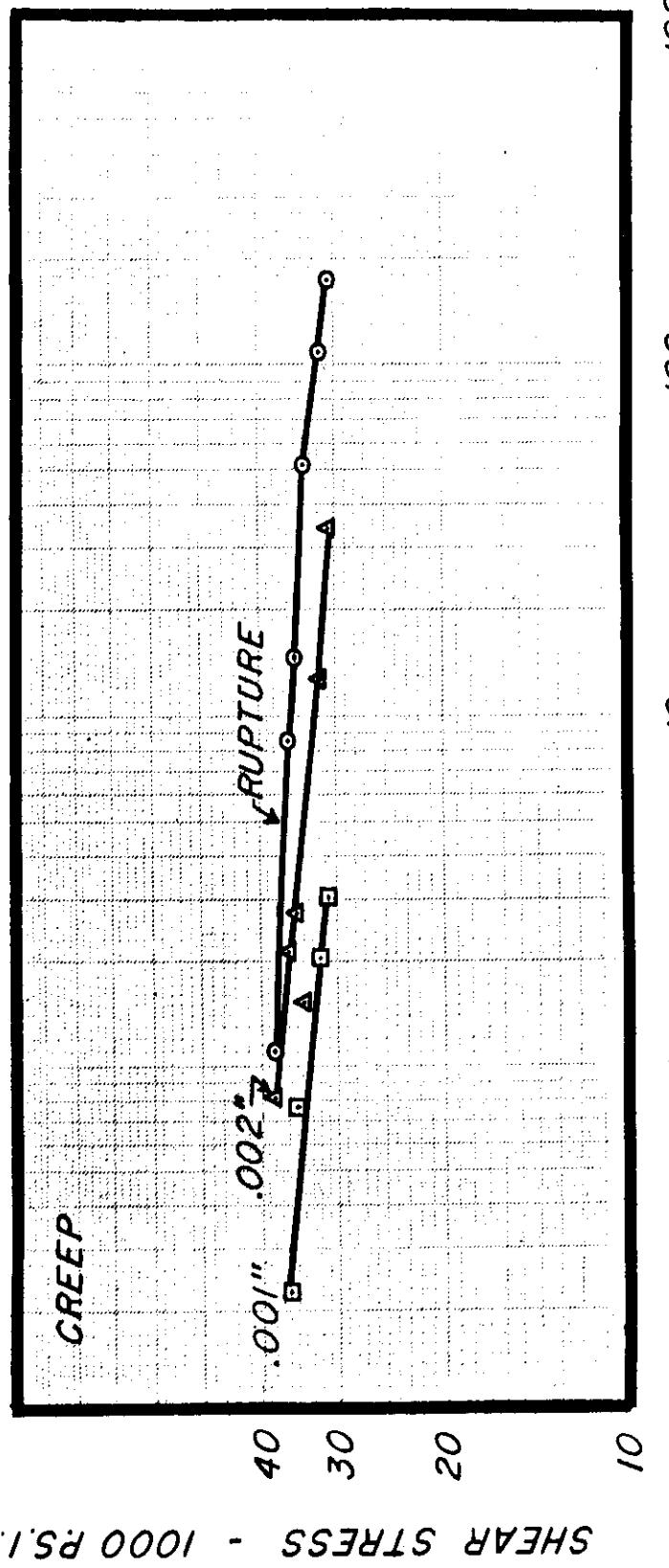
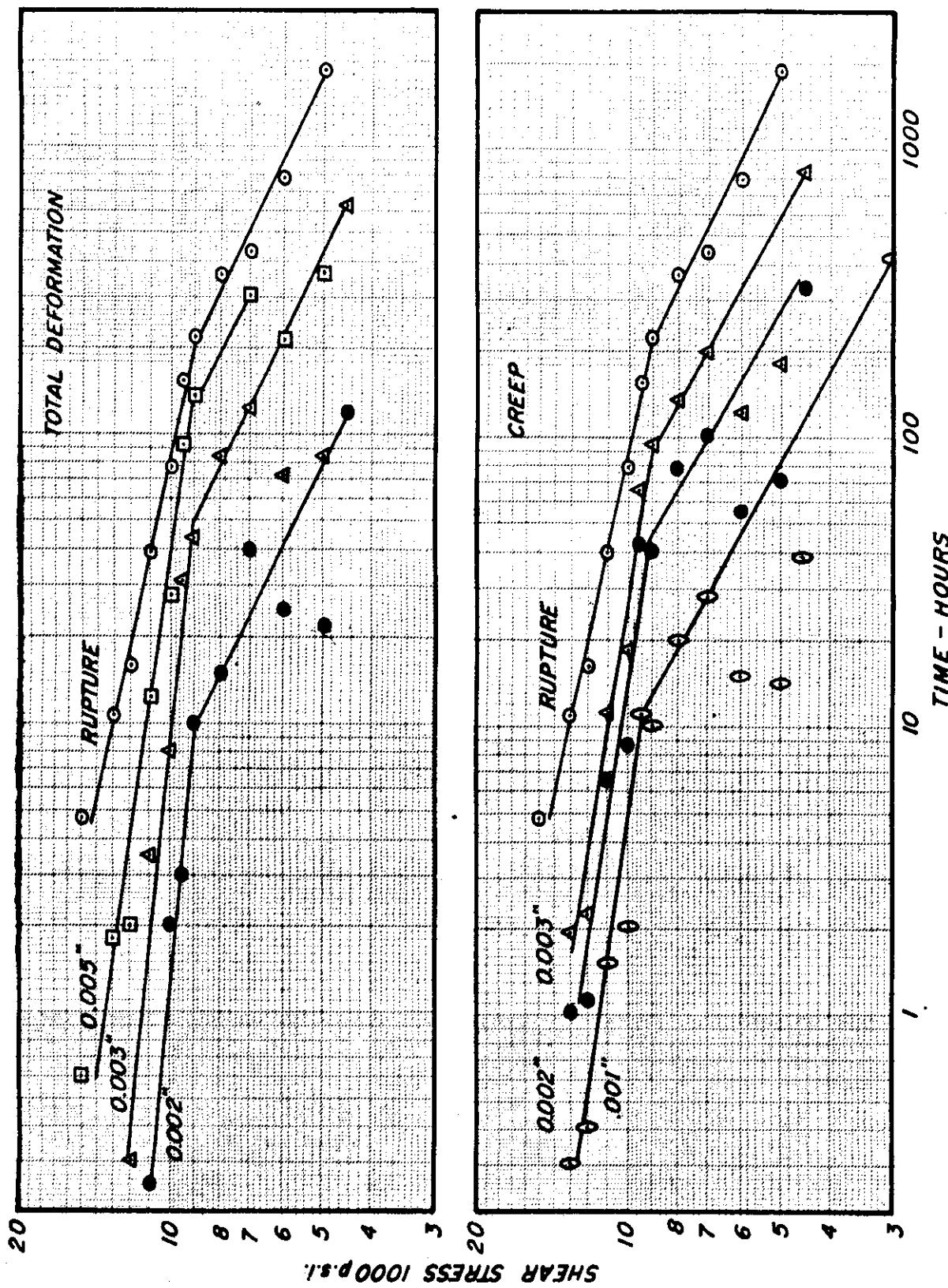


Figure 35 Shear Deformation - Rupture Characteristics of 24-
T3- 3/16" Plate at 300°F.

Contrails



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80

Figure 36 Shear Deformation-Rupture Characteristics of 24S-T3 Plate at 450°F

Contrails

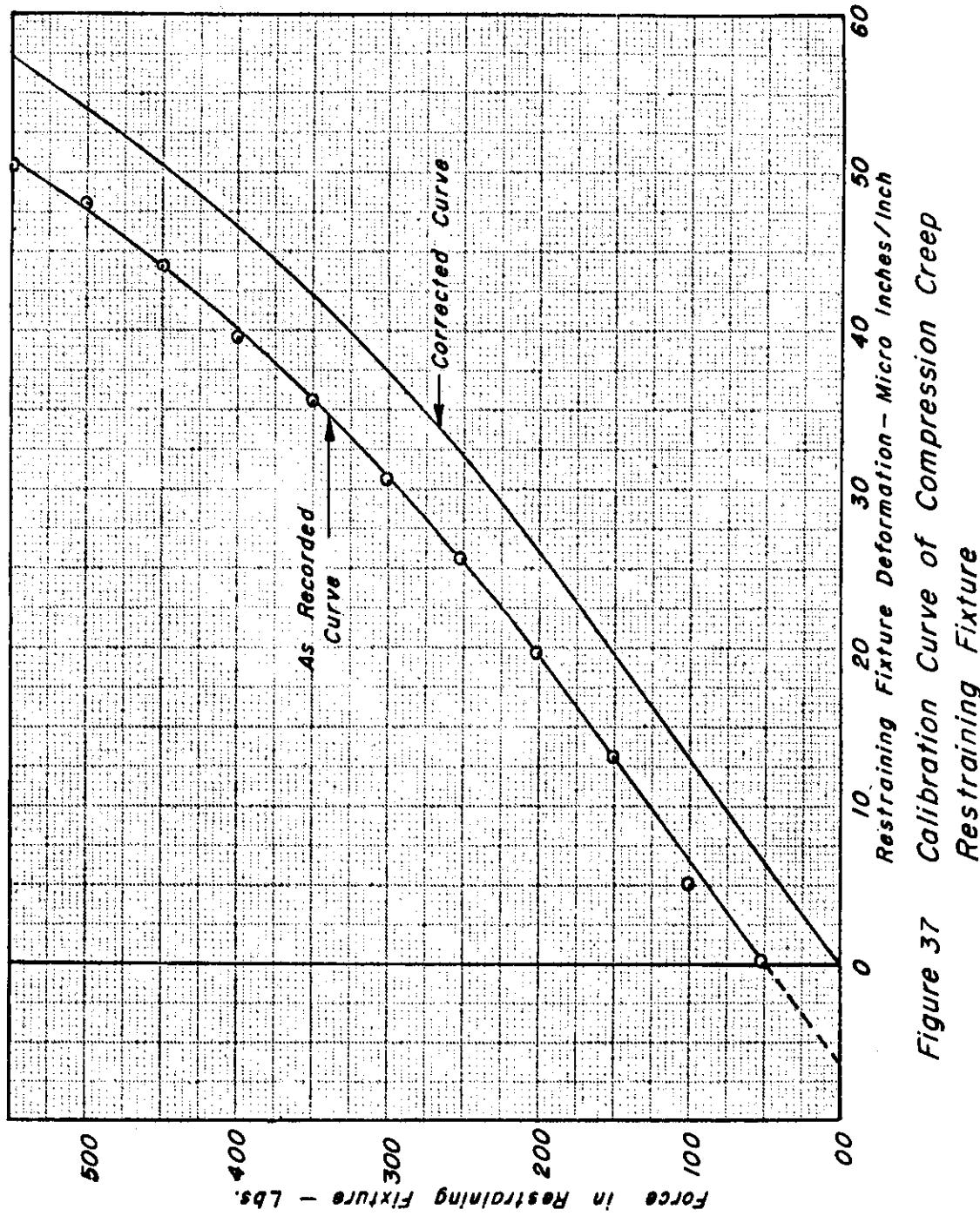


Figure 37 Calibration Curve of Compression Creep
Restraining Fixture

Controls

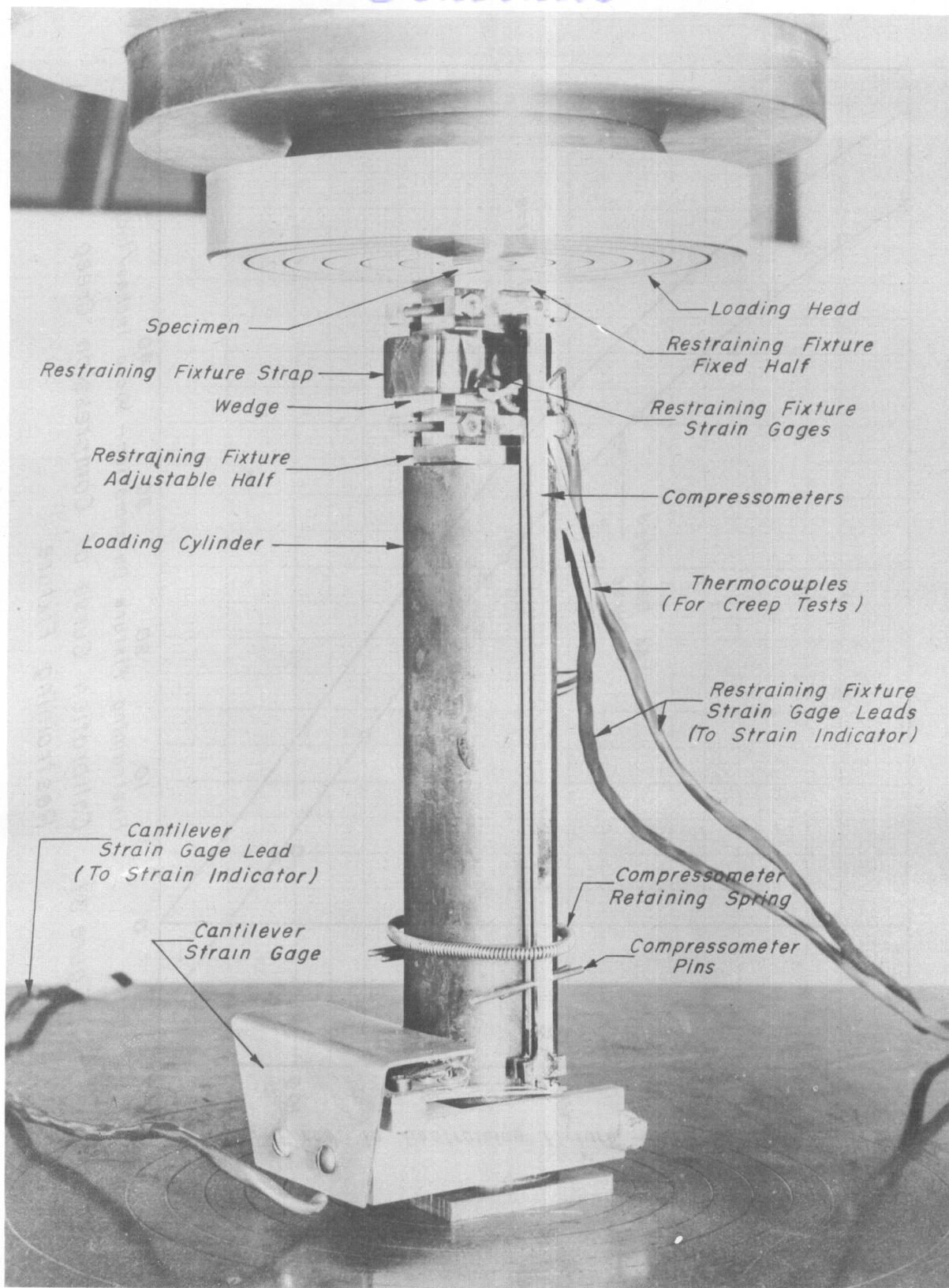


Figure 38 Compression Test Set Up For Determining Restraining Fixture Forces And Stress-Strain Characteristics.

Contrails

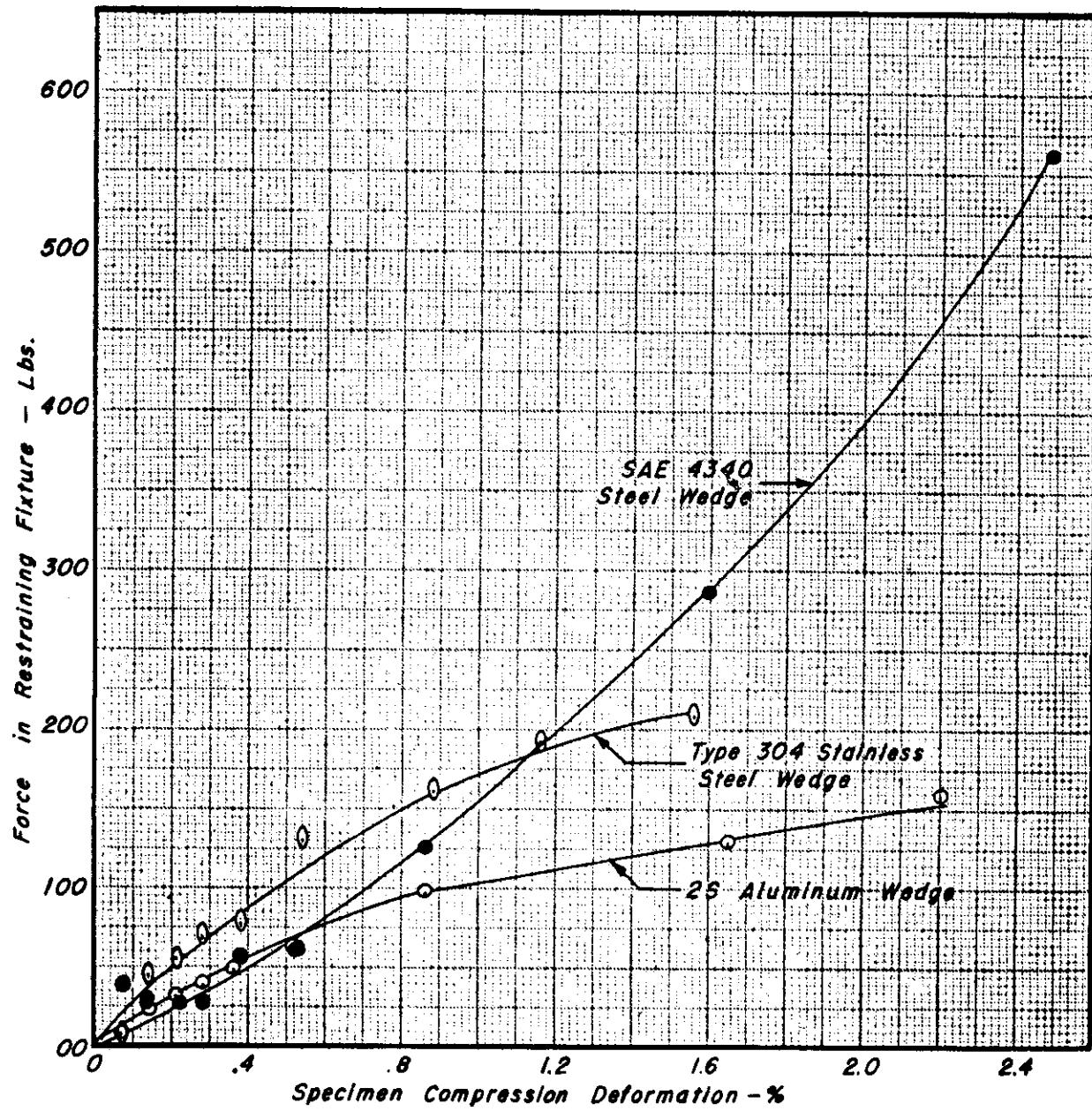


Figure 39 Force in Restraining Fixture Vs. Compression-Deformation of 24S-T3 Aluminum Plate for Various Restraining Fixture Wedges

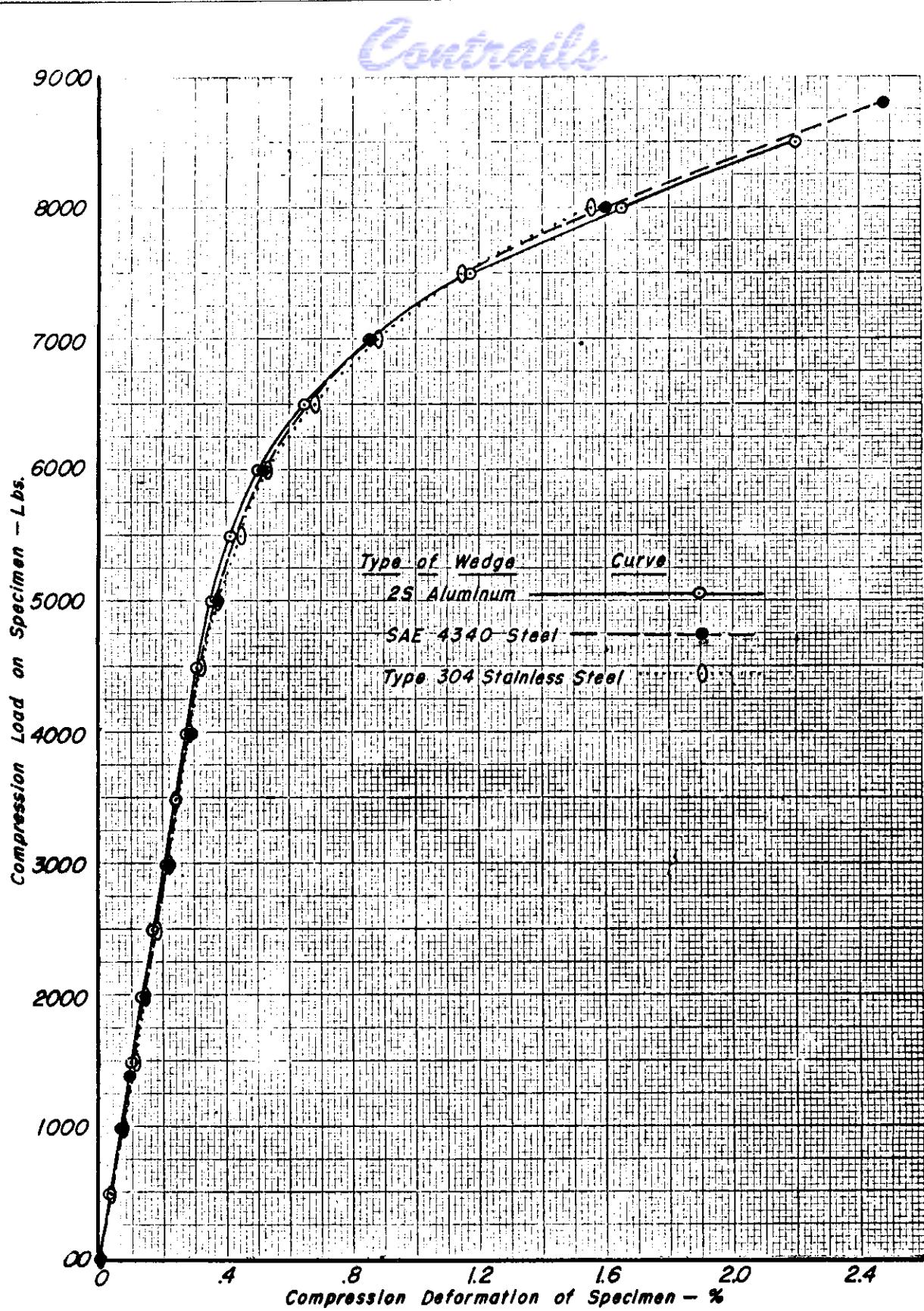


Figure 40 Load Vs. Compression-Deformation Curves for 24S-T3 Aluminum Plate Under the Influence of Various Restraining Fixture Wedges

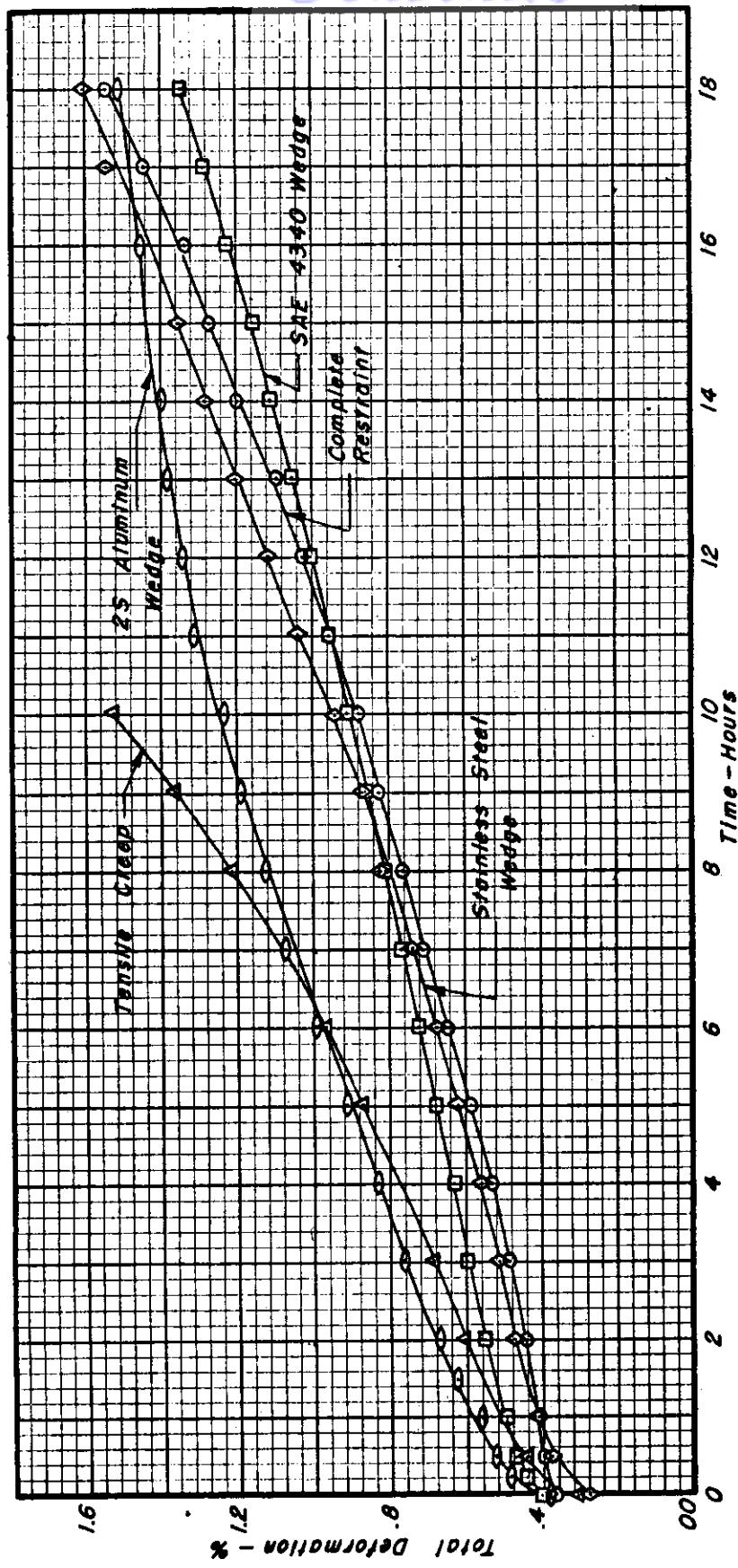


Figure 41 Time Vs. Total Deformation Curves For Tensile & Compression Creep of 24S-T3 Aluminum Sheet At 450°F & 26,000 PSI