WADC TECHNICAL REPORT 54-270
PART 2
ASTIA DOCUMENT No. AD 97283

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

FRANK J. VAWTER
GLEN J. GUARNIERI
LUKE A. YERKOVICH
GEORGE DERRICK

CORNELL AERONAUTICAL LABORATORY, INC.

SEPTEMBER 1956

[redacted]

FEB 6 1[illegible]

MATERIALS LABORATORY
CONTRACT No. AF 33(616)-190
PROJECT No. 7360

WRIGHT AIR DEVELOPMENT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

Carpenter Litho & Prtg. Co., Springfield, O.
600 - November 1956

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", 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.

This report covers work conducted from December 1953 to December 1954.

ABSTRACT

The establishment of high-temperature creep and rupture properties of materials is a prerequisite for design if exposure to elevated temperature in service is anticipated. These properties, which are determined from the conventional tensile creep test, are of questionable value if stress conditions other than tension are encountered. To supplement these existing tensile creep and rupture data, this project was initiated to determine the high-temperature creep strengths of a number of structural aircraft alloys when subjected to compression, bearing, and shear stresses.

Tensile creep data are included for A-70 commercially-pure titanium, C-110M titanium alloy and SAE 4130 alloy steel sheet. Bearing creep data are presented for A-70 and C-110M titanium, 4130 steel and type 321 stainless steel. In addition, results of shear-pin deformation tests on 2117-T4 aluminum, Monel and type 301 stainless steel wire and compression creep test results for 2024-T3 aluminum sheet and plate and C-110M titanium alloy sheet are included.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. R. WHITMORE
Technical Director
Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

Figure Page

INTRODUCTION

In the assembly of aircraft structural members, rivets and other mechanical fasteners which have been adopted as practical and acceptable methods of joining are usually required to carry and transmit loads. As a consequence, the ability of joined members to sustain loads imposed upon them is in most cases dependent upon the strength characteristics of the element forming the joint and in some instances upon the stress conditions created in the joint area. When load is transmitted through a joint, a complex and concentrated stress pattern is induced which can promote failure in any of a number of ways. However, in spite of the stress complexities, determinations of the shear and bearing characteristics of joints have provided sufficient guidance to permit the accomplishment of satisfactory design in the range of temperature where the effects of creep are not encountered.

Concurrent with the structural materials problem which has arisen because of high speed flight, it has become apparent that certain conventional design characteristics, heretofore regarded as controlling the usefulness of structures, cannot be utilized. Instead, it has been observed that many of these same design characteristics must be defined according to their influences on particular creep processes associated with the temperature conditions generated in flight. In this regard, the shear, bearing, and compression creep behaviors of aircraft materials as well as their tensile-creep behaviors are believed to be important design criteria in modern aircraft construction.

Under the sponsorship of the Materials Laboratory of the Wright Air Development Center, a test program has been in progress for the past two years to determine the creep characteristics of structural alloys under the influence of shear, bearing, and compression stresses for correlation with appropriate tensile-creep characteristics.

This interim report summarizes the results of the second year's work performed in the investigation.

TEST MATERIALS AND PROGRAM

Various aircraft sheet, plate and rivet structural alloys were selected to be tested in tension, compression, bearing, and shear to determine the creep and rupture characteristics in the time range up to 1000 hours according to the following temperature and type of load schedule as shown in Table 1 below.

TABLE 1

SCHEDULE OF TESTS

Material	Temp. °F	Tension	Compression	Bearing	Shear
2024-T3 Sheet	300	A	B	A	
	450	A	B	A	
	600	A	B	A	
2024-T3 Plate	300	A			A
	450	A	B		A
	600	A	B		B
Type 321 Stainless Steel Sheet	1000	A			
	1200	A	C	B	
	1350	A	C	B	
C-110M Titanium Sheet	600	A			
	700	B	B	B	
	800	A	B	B	
A-70 Titanium Sheet	700	B	C	B	
	800	B	C	B	
4130 Steel Sheet	800	B	C	B	
	900	B	C	B	
	1000	B	C	B	
Type 301 Stainless Steel Wire	1200	A			B
	1350	A			B
Monel Wire	1000	A			B
	1200	A			B
2117-T4 Aluminum Wire	300	B			B
	450	B			B
	600	A			B

A = Data included in WADC Technical Report 54-270, Part 1.
B = Data included in this report.
C = Data to be presented in a subsequent report.

Composition and room-temperature tensile properties of all the alloys were described previously except for the A-70 titanium and 4130 steel sheets which were recently added to this test program.

A-70 Titanium Sheet (No Specification)

One sheet of annealed A-70 commercially-pure titanium sheet 0.064 by 36 by 96 inches was purchased from Rem-Cru Titanium, Inc., Midland, Pa. Chemical analysis is certified as less than 0.1% carbon and 0.070% nitrogen. Mechanical properties are as follows:

Ultimate Tensile Strength	100,500 psi
Yield Strength (0.2% Offset)	87,200 psi
Elongation in 2 Inches	21.5%

SAE 4130 Alloy Steel Sheet (AN-QQ-S-685 Cond. N.)

Five pieces 0.063 by 18 by 72 inches hot rolled SAE 4130 alloy steel sheet, normalized, pickled and oiled were received from Newport Steel through a local supplier. The certified chemical analysis as given by the supplier is as follows:

C	Mn	P	S	Si	Cr	Mo
0.31	0.51	0.012	0.032	0.27	0.96	0.18

Mechanical properties as certified by the manufacturer are:

Ultimate Tensile Strength	109,000 psi
Yield Strength (0.2% Offset)	79,600 psi
Elongation in 2 Inches	16.0%
Grain Size	8

The mechanical properties of the above two materials were determined by this laboratory also and are presented in Table 14.

The test apparatus used to establish these creep and rupture characteristics have been discussed in detail in the previous interim report WADC TR 54-270, Part 1 dated June 1954.

TENSILE CREEP RESULTS

The tensile creep properties of all the project test materials have been determined in order to establish a basis for correlation of the compression, bearing, and shear creep results. Tensile creep properties of 2117-T4 aluminum, A-70 commercially-pure titanium, C-110M titanium alloy and SAE 4130 alloy steel at several temperatures are presented in this report. All tests were conducted on the material in its as-received condition and the axis of loading was parallel to the direction of rolling.

2117-T4 Rivet Wire

The results of tensile creep tests on 2117-T4 aluminum 3/8-inch diameter rivet wire at 300 and 450°F are listed in Table 15. Stress-time curves for total deformation and creep are presented in logarithmic form in Figures 1 and 2. This material was tested after straightening from coil form and subsequent heat treating to obtain the original T4 condition.

At 300°F, the greater amount of total specimen deformation occurs on loading and subsequent creep is of minor significance within the time periods under consideration. A break in the rupture line in the stress-time curves at 300°F (Figure 1) is observed at approximately 400 hours which may be attributed to an overaging effect. At 450°F, (Figure 2) overaging occurs after much shorter time as indicated by a similar break in the rupture line at only 20 hours.

A-70 Commercially-Pure Titanium Sheet

Two series of tensile creep tests were conducted on A-70 titanium sheet (0.064 inch) at 700 and 800°F. A few tests were run at 600°F, but as a result of the insignificant creep deformation occurring, testing at this temperature was discontinued. Results of the tests at 700 and 800°F are compiled in Table 16 and are graphically illustrated in the design-type total deformation and creep curves of Figures 3 and 4.

C-110M Titanium

The results of tensile creep testing C-110M titanium alloy sheet at 700°F are illustrated in Figure 5. These data are compiled in Table 17. A series of tensile creep tests were conducted on this alloy at 800°F and the results included in the previous summary report (1)*.

---

*See bibliography.

SAE 4130 Alloy Steel Sheet

The tensile creep properties of the 4130 steel have been determined at temperatures of 800, 900, and 1000°F. The results of these tests are plotted for both creep and total deformation values as logarithmic stress-time curves in Figures 6, 7, and 8. Compilation of these test data is included in Table 18.

Like 2117 aluminum at 300°F, the 4130 steel at 800°F exhibits minor creep effects compared to the deformation obtained upon initial loading. While relatively small amounts of deformation occur upon loading at 1000°F in the stress range studied, creep deformation becomes significant with time.

At all test temperatures, no significant tempering effect was evident as indicated by change in hardness of the creep specimens. Although the microstructure apparently was undisturbed by the 1000°F exposure, surface oxidation was noticeable.

BEARING CREEP RESULTS

In structural joints, load is transmitted from one member to another by rivets, spot welds, or some type of mechanical fastener. Bearing stresses developed in pinned or riveted joints may cause the metal under stress to creep or plastically deform particularly at elevated temperatures. As a result, the bearing creep and rupture strengths of structural metals should be known for efficient design purposes.

Testing was conducted on sheet materials to determine bearing-hole creep deformation and rupture properties on specimens with a bearing-hole diameter of 0.125 inch and an edge distance of 1.5D. Edge distance is defined as the distance from the center of the bearing hole to the edge of the sheet and is expressed as a function of the diameter i.e., 1.0D, 1.5D, or 2.0D.

An evaluation study of bearing creep and rupture properties has been completed on five aircraft sheet materials. These alloys are (1) 2024-T3 aluminum, (2) A-70 commercially-pure titanium, (3) C-110M titanium alloy, (4) SAE 4130 alloy steel, and (5) type 321 stainless steel. Test temperatures were the same as those used in corresponding tensile creep tests with stresses of a magnitude to produce 1.0 or 2.0% total bearing-hole deformation and rupture in a 1 to 200-hour range.

A comparison of bearing and tensile creep values was made to determine if any consistent relationships were apparent for materials subjected to tensile and bearing stresses. If uniform relationships for specific temperatures exist then bearing creep strengths could be approximated from appropriate tensile creep data. Bearing creep is conventionally measured as the percent deformation of the hole rather than the strain of the indefinite gage length of the metal surrounding the hole. Consequently, there is no logical reason to tabulate ratio values obtained by comparing the tension creep behavior of the metal on the one hand with bearing deformation of a hole on the other. Where such comparisons have been made, large changes in the ratio values occur at constant temperature with change in time and percent deformation. Therefore, a correlation was made of bearing creep and rupture stresses by arbitrarily selecting tensile creep-rupture stress as a common denominator. Bearing strength values were selected which produced 1.0, 2.0, 5.0, and 10.0% total bearing-hole deformation and rupture in 1, 10, 50, 100, 150, and 200 hours. These stresses were divided by the tensile stress required for rupture in a corresponding time.

2024-T3 Aluminum Sheet

Even though bearing creep and total deformation properties were determined for the 2024-T3 alloy and results were included in the previous summary report (1), these values were employed together with tensile creep rupture properties of this alloy to calculate the bearing tensile strength ratios in Table 2 on page 7. The legend for this table and the four tables that follow, depicting bearing-tensile ratios, is as follows:

T_S = Tensile creep-rupture stress.

B_S = Bearing creep-rupture stress.

B_1 = Bearing creep stress for 1.0% total bearing-hole deformation.

B_2 = Bearing creep stress for 2.0% total bearing-hole deformation.

B_5 = Bearing creep stress for 5.0% total bearing-hole deformation.

B_{10} = Bearing creep stress for 10.0% total bearing-hole deformation.

TABLE 2

RATIOS OF STRESSES FOR VARIOUS DEGREES OF BEARING-HOLE DEFORMATION AND TENSILE CREEP-RUPTURE AT CORRESPONDING TIME PERIODS FOR 2024-T3 ALUMINUM SHEET

Temp. °F	Time Hours	$\frac{B_1}{T_S}$	$\frac{B_2}{T_S}$	$\frac{B_5}{T_S}$	$\frac{B_{10}}{T_S}$	$\frac{B_S}{T_S}$
300	1					1.57
	10				1.43	1.52
	50			1.19	1.43	1.57
	100			1.23	1.49	1.55
	150				1.53	1.54
	200				1.54	1.53
450	1		0.96	1.48		1.53
	10		0.89	1.35		1.50
	50		0.89	1.33		1.50
	100		0.78	1.35		1.53
	150		0.69	1.34		1.53
	200		0.66	1.37		1.56
600	1					1.63
	10	0.61	0.96	1.33	1.53	1.60
	50	0.60	0.96	1.28	1.45	1.61
	100	0.60	0.96	1.29	1.47	1.61
	150	0.60	0.98	1.28	1.47	1.61
	200	0.60	0.97	1.28	1.46	1.61

The B_S/T_S values in the above table are quite consistent throughout the time range at each temperature but vary a slight amount from one temperature level to the next. The B_X/T_S values increase with increasing amounts of bearing deformation as would be expected since the bearing stress must be increased to produce larger amounts of deformation in the same time periods. In the case of the B_2/T_S values at 450°F, the ratios decrease with increasing time which is consistent with the 2.0% total bearing-deformation line in logarithmic stress-time curves (1) having a greater slope than the tensile-rupture line. However, the 1.0 and 2.0% bearing-hole deformation lines of the log-log plot of stress and time at 600°F have almost the same slope as the tensile-rupture line at this temperature and therefore the ratios are constant for the times indicated.

A-70 Commercially-Pure Titanium Sheet

A compilation of the bearing creep test results for A-70 titanium sheet at 700 and 800°F are presented in Table 19. These values are illustrated as logarithmic stress-time curves for both creep and total deformation properties in Figures 9 and 10. The comparison of bearing-hole deformation and tensile creep-rupture strength are presented as ratios in Table 3.

TABLE 3

RATIOS OF STRESSES FOR VARIOUS DEGREES OF
BEARING-HOLE DEFORMATION AND TENSILE CREEP-RUPTURE
AT CORRESPONDING TIME PERIODS FOR A-70 TITANIUM SHEET

Temp. °F	Time Hours	$\frac{B_1}{T_S}$	$\frac{B_2}{T_S}$	$\frac{B_5}{T_S}$	$\frac{B_{10}}{T_S}$	$\frac{B_S}{T_S}$
	1				1.65	1.72
	10				1.64	1.73
700	50			1.37	1.58	1.74
	100			1.25	1.48	1.69
	150				1.43	1.63
	200					1.61
	1	No Data				
	10	0.41	0.71	1.16	1.34	1.64
800	50	0.45	0.64	1.15	1.33	1.69
	100		0.63		1.34	1.71
	150					1.69
	200					1.70

The B_S/T_S ratios are fairly constant for both temperatures and are slightly higher than the B_S/T_S ratios for 2024-T3. The slight decrease in the B_{10}/T_S ratio at 700°F would again indicate a greater slope of the logarithmic stress-time plot for 10% bearing-hole deformation as compared to the tensile creep-rupture line.

C-110M Titanium Alloy Sheet

An investigation of the bearing creep properties of C-110M titanium alloy sheet was conducted at 700 and 800°F and results of these tests are included in Table 20. Figures 11 and 12 illustrated these results as log-log plots of stress and time for various amounts of total deformation and creep as well as bearing rupture. Table 4, page 9, lists the bearing-tensile strength ratios as calculated from the above results.

TABLE 4

RATIOS OF STRESSES FOR VARIOUS DEGREES OF BEARING-HOLE DEFORMATION AND TENSILE CREEP-RUPTURE AT CORRESPONDING TIME PERIODS FOR C-110M TITANIUM SHEET

Temp. °F	Time Hours	$\frac{B_5}{T_S}$	$\frac{B_{10}}{T_S}$	$\frac{B_S}{T_S}$
700	1	No Data		
	10	1.09	1.40	
	50	1.06	1.41	1.62
	100	1.11	1.50	1.65
	150	1.11	1.50	1.64
	200			1.63
800	1	1.04	1.34	
	10	0.86	1.15	1.76
	50	0.71	1.05	1.63
	100	0.64		1.62
	150	0.62		1.64
	200	0.59		1.65

The constancy of the B_S/T_S ratios is again evident in this table and are similar to those ratios for A-70. However, a decrease in B_5/T_S ratios with increasing time is observed in the results at 800°F whereas these values at 700°F remain relatively constant.

SAE 4130 Alloy Steel Sheet

Table 21 includes results of the bearing creep tests on SAE 4130 alloy steel sheet at 800, 900, and 1000°F. Graphic illustrations of these results are depicted in the stress-time design curves of Figures 13, 14, and 15. Bearing-tensile ratios were determined for this alloy at the three test temperatures by using these values and the tensile creep-rupture strengths interpolated from Figures 6, 7, and 8. These ratios are included in Table 5, page 10.

TABLE 5

RATIOS OF STRESSES FOR VARIOUS DEGREES OF BEARING-HOLE DEFORMATION AND TENSILE CREEP-RUPTURE AT CORRESPONDING TIME PERIODS FOR SAE 4130 ALLOY STEEL SHEET

Temp. °F	Time Hours	$\frac{B_2}{T_S}$	$\frac{B_5}{T_S}$	$\frac{B_{10}}{T_S}$	$\frac{B_S}{T_S}$
800	1	No Data			
	10		1.30		1.67
	50		1.30		1.70
	100		1.30		1.71
	150				1.71
	200				1.71
900	1	No Data			
	10		1.20	1.42	1.63
	50			1.39	1.62
	100			1.39	1.63
	150				1.63
	200				1.62
1000	1	0.72	1.25	1.44	
	10	0.61	1.12	1.37	1.61
	50			1.35	1.61
	100				1.64
	150				1.71
	200				1.71

Type 321 Stainless Steel Sheet

The results of bearing creep tests on type 321 stainless steel sheet at 1200 and 1350°F are listed in Table 22 and the stress-time design curves are illustrated in Figures 16 and 17. The bearing-tensile strength ratios are presented in Table 6, page 11.

TABLE 6

RATIOS OF STRESSES FOR VARIOUS DEGREES OF BEARING-HOLE DEFORMATION AND TENSILE CREEP-RUPTURE AT CORRESPONDING TIME PERIODS FOR TYPE 321 STAINLESS STEEL SHEET

Temp. °F	Time Hours	$\frac{B_1}{T_S}$	$\frac{B_2}{T_S}$	$\frac{B_5}{T_S}$	$\frac{B_{10}}{T_S}$	$\frac{B_S}{T_S}$
1200	1	No Data				
	10		0.81	1.11	1.28	1.68
	50		0.86	1.22	1.46	1.68
	100		0.78	1.20	1.40	1.66
	150					1.71
	200					1.72
1350	1	0.57	0.88	1.25	1.46	
	10	0.36	0.71	1.10	1.30	1.72
	50		0.59		1.46	1.81
	100		0.53			1.87
	150		0.51			1.91
	200		0.49			1.96

While the B_S/T_S ratios at 1200°F are fairly constant there is an increase in ratio as time for rupture increases at 1350°F. The B_2/T_S ratios at 1350°F decrease for increasing times.

SHEAR-PIN DEFORMATION AND RUPTURE RESULTS

In order to determine the effects of a sustained constant load on a rivet in service at elevated temperatures, a "shear-creep" testing program was conducted on several aircraft rivet alloys. These materials included 2024-T3 3/16-inch aluminum plate, 2117-T4 3/8-inch diameter wire and Monel and type 301 stainless steel 1/2-inch diameter wire. Specimens 1/8-inch in diameter by 1/2-inch long were taken from the center sections of the test materials. Since a pin loaded in such a manner may undergo a slight amount of bending as well as shear displacement, deformation readings were taken as the total displacement of a shear blade in inches rather than percentages of the shear-pin area, and results are presented as shear-pin deformation rather than shear strain.

By utilizing the resulting data from these tests, the design engineer could predict the displacement of the plates or the rivets in a structural joint under constant load. While these types of data are desirable, they are seldom available. However, if an empirical relationship could be established between shear and tensile creep data, the former type of data could be predicted from tensile values.

A correlation of data similar to that described for bearing creep was made with the shear-pin deformation results. Ratios were established for 0.002 inch, 0.005 inch, 0.010 inch and 0.020 inch of shear blade displacement and shear-pin rupture versus tensile creep rupture.

2024-T3 Aluminum Alloy Plate

Shear-pin deformation and rupture tests were conducted on 1/8-inch diameter pins taken from the center section, in a longitudinal direction, of 2024-T3 aluminum alloy 3/16-inch plate. Tests at 300 and 450°F have been previously presented (1) and results at 600°F are included in this report. Table 23 is a compilation of results at 600°F. Logarithmic stress-time deformation and rupture curves were prepared from these data and are illustrated in Figure 18. Ratios of shear strength to tensile rupture strength were calculated for various amounts of shear-pin deformation and rupture. The ratios are presented in Table 7, page 13, for all test temperatures. The legend for the abbreviations in Tables 7, 8, 9, and 10 is as follows:

T_S = Tensile creep-rupture stress.

S_S = Shear-pin rupture stress.

S_2 = Shear stress for 0.002 inch of shear-pin deformation.

S_5 = Shear stress for 0.005 inch of shear-pin deformation.

S_{10} = Shear stress for 0.010 inch of shear-pin deformation.

S_{20} = Shear stress for 0.020 inch of shear-pin deformation.

TABLE 7

RATIOS OF STRESSES FOR VARIOUS DEGREES OF SHEAR-PIN DEFORMATION AND TENSILE CREEP-RUPTURE AT CORRESPONDING TIME PERIODS FOR 2024-T3 ALUMINUM PLATE

Temp. °F	Time Hours	$\frac{S_2}{T_S}$	$\frac{S_5}{T_S}$	$\frac{S_{10}}{T_S}$	$\frac{S_{20}}{T_S}$	$\frac{S_S}{T_S}$
300	1	0.63				0.63
	10	0.58				0.62
	50					0.61
	100					0.60
	150					0.59
	200					0.58
450	1	0.25	0.33			0.43
	10	0.30	0.37			0.43
	50	0.23	0.39			0.43
	100	0.20	0.40			0.43
	150		0.41			0.48
	200		0.41			0.48
600	1	No Data				
	10	0.36	0.42	0.45	0.49	0.51
	50	0.40	0.47	0.51	0.53	0.57
	100	0.42	0.49	0.52	0.55	0.58
	150			0.54	0.56	0.59
	200					0.59

The following observations were made from the above ratios:

(1) S_S/T_S ratios are fairly consistent for each series of tests but vary with test temperature.

(2) The shear deformation vs. tensile rupture stress ratios determined from the shear deformation values increase for increasing amounts of deformation as would be expected since with constant tensile rupture stress, shear stress increases to obtain larger amounts of shear-pin deformation in the same time period.

(3) For a particular test temperature and deformation value, these ratios are constant for all time periods investigated.

2117-T4 Aluminum Rivet Wire

An analysis of the shear-pin deformation characteristics of

2117-T4 aluminum rivet wire was conducted at 300, 450, and 600°F. The results of these tests are presented in Table 24. Stress-time design curves for creep and total deformation are illustrated in Figures 19, 20, and 21. The tests at 300°F produced an insignificant amount of deformation after load, consequently only a rupture line is included in Figure 19. A set of shear to tension ratios, similar to those determined for the 2024-T3 alloy, are presented in Table 8 below.

TABLE 8

RATIOS OF STRESSES FOR VARIOUS DEGREES OF SHEAR-PIN DEFORMATION AND TENSILE CREEP RUPTURE AT CORRESPONDING TIME PERIODS FOR 2117-T4 RIVET WIRE

Temp. °F	Time Hours	$\frac{S_2}{T_S}$	$\frac{S_5}{T_S}$	$\frac{S_{10}}{T_S}$	$\frac{S_{20}}{T_S}$	$\frac{S_S}{T_S}$
300	1	No Data				
	10					0.67
	50					0.66
	100					0.64
	150					0.63
	200					0.62
450	1	No Data				
	10		0.50			0.55
	50		0.53			0.54
	100		0.53			0.57
	150		0.50			0.56
	200					0.55
600	1		0.50	0.55	0.59	0.65
	10	0.46	0.52	0.56	0.60	0.65
	50	0.46	0.54	0.60	0.63	0.68
	100		0.54	0.59	0.65	0.69
	150		0.55	0.59	0.64	0.69
	200			0.59	0.64	0.69

As was observed in the 2024-T3 ratios, the S_S/T_S ratios for 2117-T4 at 450°F are also somewhat lower than those values obtained at 300 and 600°F. The deformation ratios are constant for each set of values.

Monel Rivet Wire

Two series of shear-pin deformation tests were run on annealed

Monel rivet wire at 1000 and 1200°F. The results of these tests are included in Table 25 and graphically illustrated in Figures 22 and 23. Shear-pin deformation and rupture versus tensile creep-rupture ratios established for this alloy are presented in Table 9, Since deformations on the order of 0.010 inch (S_{10}) occurred on loading in the majority of those tests, no S_2/T_S through S_5/T_S ratios could be determined and only limited S_{10}/T_S ratios were obtained.

TABLE 9

RATIOS OF STRESSES FOR VARIOUS DEGREES OF SHEAR-PIN DEFORMATION AND TENSILE CREEP RUPTURE AT CORRESPONDING TIME PERIODS FOR MONEL RIVET WIRE

Temp. °F	Time Hours	$\frac{S_{10}}{T_S}$	$\frac{S_{20}}{T_S}$	$\frac{S_S}{T_S}$
1000	1		0.57	0.71
	10		0.60	0.72
	50		0.60	0.72
	100		0.63	0.72
	150		0.65	0.72
	200		0.66	0.72
1200	1	0.50	0.57	
	10	0.47	0.62	0.68
	50		0.56	0.66
	100		0.54	0.63
	150		0.55	0.61
	200		0.57	0.66

The rupture ratios for Monel at 1000°F are higher than those calculated for 2024-T3 and 2117-T4. A slight decrease in the ratios is observed at 1200°F.

Type 301 Stainless Steel Rivet Wire

Type 301 stainless steel rivet wire was investigated for shear-pin deformation at test temperatures of 1200 and 1350°F. Table 26 is a listing of these test results. Typical stress-time design curves for these tests are illustrated in Figures 24 and 25. Ratios of shear deformation and rupture to tensile creep-rupture are presented in Table 10, page 16.

TABLE 10

RATIOS OF STRESSES FOR VARIOUS DEGREES OF SHEAR-PIN DEFORMATION AND TENSILE CREEP RUPTURE AT CORRESPONDING TIME PERIODS FOR TYPE 301 STAINLESS STEEL WIRE

Temp. °F	Time Hours	$\frac{S_{10}}{T_S}$	$\frac{S_{20}}{T_S}$	$\frac{S_S}{T_S}$
1200	1			0.75
	10	0.52	0.59	0.70
	50	0.51	0.61	0.69
	100		0.62	0.69
	150			0.68
	200			0.68
1350	1	0.47		0.77
	10	0.52	0.61	0.74
	50		0.64	0.72
	100		0.64	0.72
	150		0.62	0.72
	200			0.71

The above ratios appear to be approximately equal for each corresponding group at both test temperatures.

COMPRESSION CREEP RESULTS

2024-T3 Aluminum Plate

The 2024-T3 aluminum plate has been creep tested in compression at 450 and 600°F. The results of these series of tests are summarized in Table 27. Conventional creep and total-deformation design curves are plotted in Figures 26 and 27. Figures 28 and 29 are a comparison of the tension and compression creep characteristics at several percentages of total deformation and creep respectively for this material at 450°F. The tension-compression comparison curves for 600°F are graphically illustrated in Figures 30 and 31. These data indicate that there is no substantial difference between compression and tension deformation rates although the alloy persistently displays slightly higher creep strengths in tension than in compression.

A relationship between compression and tension creep characteristics was made by establishing ratio values between the stresses in tension and compression required to produce 0.5 and 1.0% total deformation and creep in like time periods. A ratio value of 1.0 would indicate that identical stresses are required in tension and compression to obtain a particular strain value in the same time period. A value less than 1.0 implies that the stress is lower in compression than in tension whereas ratio values greater than 1.0 denote that higher stresses in compression than in tension are required to produce equal amounts of deformation in the same time period. The symbols in the tables illustrating these stress relationships are as follows:

$C_{0.5}$ = Compressive stress for 0.5% strain.

$C_{1.0}$ = Compressive stress for 1.0% strain.

$T_{0.5}$ = Tensile stress for 0.5% strain.

$T_{1.0}$ = Tensile stress for 1.0% strain.

TABLE 11

RATIOS OF COMPRESSION STRESS VS. TENSION STRESS
FOR 2024-T3 PLATE

Temp. °F	Time Hours	Total Deformation $\frac{C_{0.5}}{T_{0.5}}$	Total Deformation $\frac{C_{1.0}}{T_{1.0}}$	Creep $\frac{C_{0.5}}{T_{0.5}}$	Creep $\frac{C_{1.0}}{T_{1.0}}$
450	10	1.00	1.00	0.97	0.98
	50	0.90	0.96	0.95	0.95
	100	0.91	0.95	0.98	0.95
	200	0.97	0.93	0.90	0.99
	500		0.89		0.89
600	10	0.88	0.90	0.91	0.92
	50	0.92	0.94	0.95	0.95
	100	0.93	0.96	0.94	0.97
	200	0.96	0.99	0.97	0.99
	500		1.00	0.97	1.01
	1000		1.03		1.05

An average of the above ratios would indicate that compression creep strength, while not significant, is slightly less than tensile creep strength.

2024-T3 Aluminum Alloy Sheet

Compression creep tests were conducted on this alloy at 300, 450, and 600°F. The results of these tests are compiled in Table 28 and summarized graphically in Figures 32, 33, and 34 for 300, 450, and 600°F respectively. Comparisons of the tension-compression behavior of this alloy in terms of various amounts of creep or total deformation at the 300, 450, and 600°F temperatures are presented in Figures 35 through 39.

At 300°F, after a relatively large deformation on loading, the compression tests decelerate to an almost insignificant creep rate. Figures 36 and 37 illustrate that the tension and compression creep tests progress at approximately the same rate with the exception of the lower stress tests (12,000 and 15,000 psi) where the tension creep test deformed at a somewhat greater rate. However, the 2024-T3 aluminum sheet like the 2024-T3 plate at 600°F exhibits higher creep strengths in tension than in compression although these differences again are not significant.

Similar ratios, as were presented for 2024-T3 plate, are listed in Table 12 below depicting the relative creep strength of 2024-T3 sheet in tension and compression.

TABLE 12

RATIOS OF COMPRESSION STRESS VS. TENSION STRESS
FOR 2024-T3 SHEET

Temp. °F	Time Hours	Total Deformation $\frac{C_{0.5}}{T_{0.5}}$	Total Deformation $\frac{C_{1.0}}{T_{1.0}}$	Creep $\frac{C_{0.5}}{T_{0.5}}$	Creep $\frac{C_{1.0}}{T_{1.0}}$
300	10			1.10	
	50			1.10	
	100			1.11	
	200			1.12	
	500			1.28	
450	10	0.91	0.95	0.97	1.04
	50	1.00	0.97	1.02	1.01
	100	1.05	1.00	1.06	1.01
	200	1.00	1.12	1.10	1.15
	500		1.21		1.26
600	10	0.89	1.04	0.98	1.05
	50	0.85	1.01	0.93	1.02
	100	0.83	1.04	0.89	1.05
	200	0.81	1.00	0.84	1.04
	500		1.00		1.03

The above ratio values in some instances are less than 1.0 and in other cases are slightly greater than 1.0. The average of these ratios would indicate almost identical tension and compression creep strength values at these temperatures.

C-110M Titanium (Annealed)

Data obtained from the compression creep tests at 700 and 800°F are summarized in Table 29. Logarithmic plots of stress and time for various levels of total deformation and creep are included in Figures 40 and 41 for 700 and 800°F respectively. These compression creep characteristics are compared with tension data in Figures 42 through 45 at the 700 and 800°F temperature levels.

The following table illustrates in the form of ratios, the creep strength values of C-110M sheet in tension and compression.

TABLE 13

COMPRESSION STRESS VS. TENSION STRESS RATIOS
FOR C-110M TITANIUM ALLOY SHEET

Temp. °F	Time Hours	Total Deformation		Creep	
		$\frac{C_{0.5}}{T_{0.5}}$	$\frac{C_{1.0}}{T_{1.0}}$	$\frac{C_{0.5}}{T_{0.5}}$	$\frac{C_{1.0}}{T_{1.0}}$
700	10		0.93	0.90	0.91
	50		0.95	0.96	0.93
	100		0.92	1.01	0.93
800	10	1.05	1.03	1.08	1.03
	50		1.08	0.96	1.12
	100		1.03		1.11

At 700°F, the ratios illustrate that compression creep strength is slightly less than tension while at 800°F the converse is observed.

Probably the most important single factor which has been observed to cause an alloy to display differences in its tension-compression total-deformation characteristics is the initial loading behavior of the alloy with respect to tension and compression stress. In keeping with the usual characteristics of displaying lower yield strengths in compression than in tension when loaded parallel to the direction of working, the test alloys indicate this same general trend at elevated temperatures as is demonstrated in Figure 46 for the three alloys.

SUMMARY

The tensile creep properties have been determined for sheet stock of A-70 commercially-pure titanium, C-110M titanium alloy and SAE 4130 alloy steel.

In addition to the three above materials, bearing creep characteristics have also been investigated for type 321 stainless steel sheet. The results of these tests indicate that for an edge distance of 1.5D, the bearing creep-rupture stress will range from 1.5 to 1.8 times the tensile creep-rupture stress for a like time period. For each material and temperature, the ratio is fairly constant for time periods of 1 to 200 hours.

An investigation of high temperature shear-pin deformation properties has been made for 2117-T4 aluminum, Monel and type 301 stainless steel rivet wires. The rupture stresses determined for these materials are 43 to 75% of the corresponding tensile creep stress causing rupture in the same time period. As was the case for bearing creep, these percentages are also constant for each particular material and test temperature.

Compression creep tests have been conducted on 2024-T3 aluminum sheet and plate and C-110M titanium alloy sheet and the stresses obtained are in close agreement with corresponding tensile creep results.

BIBLIOGRAPHY

1. Vawter, F. J., Guarnieri, G.J., Yerkovich, L. A., Derrick, G., "Investigation of the Compressive, Bearing, and Shear Creep-Rupture Properties of Aircraft Structural Metals and Joints at Elevated Temperatures", WADC Technical Report 54-270, Part 1, June 1954.

TABLE 14

ROOM TEMPERATURE TENSILE PROPERTIES OF 4130 STEEL AND A-70 TITANIUM SHEET

Material	Thickness Inches	Direction of Rolling	0.2% Yield Strength PSI	Ultimate Strength PSI	Modulus of Elasticity PSI	% Elongation in 2 Inches
SAE 4130	0.062	Longitudinal	74,000	99,000	Not Determined	17.0
"	"	"	74,000	98,000	" "	16.0
"	"	Transverse	69,000	98,000	" "	17.0
"	"	"	70,000	97,000	" "	19.0
A-70	"	Longitudinal	75,800	93,900	14. x 10^6	26.5
"	"	"	75,800	93,100	14. x 10^6	25.0
"	"	Transverse	90,800	99,800	16.5 x 10^6	25.5
"	"	"	88,100	100,000	16.9 x 10^6	24.5

TABLE 15

TENSILE CREEP-RUPTURE CHARACTERISTICS OF 2117-T4 ALUMINUM RIVET WIRE

Temp. °F	Stress P.S.I.	% Elong. on Loading	Time in Hours for Deformation of												Fracture Hours	Time of Test Hours	% Elong. in 2 in.	Min. Creep Rate % Per Hour	RE Hardness		Specimen
			1.0%		2.0%		3.0%		4.0%		5.0%		6.0%								
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					Before	After	
300	25,000	1.86		OL	490.					660.					818.5	818.5	6.	0.00083	82	89	276-7
	26,000	2.375		OL	310.	OL	563.			7.		510.			597.5	597.5	13.	0.00076	82	88	276-6
	27,000	2.92		OL	3.	OL	363.			2.		5.		370.	394.5	394.5	7.5	0.00063	82	91	276-2
	28,000	3.36		OL	1.	OL		OL				0.5		110.	115.	115.	7.5	0.00265	82	95	276-22
	30,000	5.6		OL		OL	0.3	OL	1.3	OL		OL			25.75	25.75	9.	0.010	82	95	276-9
	32,000	6.4	No Readings Taken After Loading												4.5	4.5	14.		82	92	276-26
			0.5%		1.0%		1.5%		2.0%		2.5%		3.0%								
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD							
450	6,200	0.031	840.	825.		980.									988.	988.	2.5	0.00040	82	30	276-28
	7,000	0.017	510.	470.											597.	597.	11.	0.0010	82	30	276-11
	8,000	0.148	340.	295.	372.	372.	373.	373.							374.	374.	12.	0.0010	82	30	276-30
	9,000	0.108	126.	116.	149.	146.	160.	158.	164.	163.	166.	165.	166.	166.	167.	167.	9.	0.0017	82	33	276-8
	11,000	0.104	70.5	65.5	82.5	81.	87.8	87.							93.	93.	3. *	0.004	82	40	276-12
	12,000	0.137	43.	39.	53.	52.	55.5	55.		55.9					56.	56.	6.	0.006	82	25	276-24
	13,000	0.111	38.	33.5	47.	45.5	50.6	50.	52.	51.75					52.75	52.75	8.	0.006	82	47	276-3
	15,000	0.148	15.	11.5	20.5	19.5	22.5	22.2		23.4					23.75	23.75	6.5	0.021	82	56	276-23
	20,000	0.284	1.05	0.20		1.55									1.75	1.75	1. *	0.29	82	71	276-27

* Specimens fractured outside of gage marks.

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 16

TENSILE CREEP-RUPTURE CHARACTERISTICS OF ANNEALED A-70 TITANIUM SHEET

Temp. °F	Stress P.S.I.	% Elong. on Loading	Time in Hours for Deformation of														Fracture Hours	Time of Test Hours	% Elong in 2 In.	Min. Creep Rate % Per Hour	RB Hardness		Specimen
			0.1%		0.2%		0.3%		0.5%		1.0%		2.0%		5.0%								
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					Before	After	
	18,000	0.18	80.	OL	195.		320.	92.	575.	345.	1185.	990.					discon-tinued	1136.	1.15	0.00078	100	102	313-46
	21,000	0.23	22.	OL	115.	OL	175.	8.	265.	150.	492.	392.		695.*			"	640.5	1.73	0.00060	100	103	313-45
	25,000	0.48	5.0	OL	25.	OL	49.	OL	85.		170.	90.	290.	240.	505.	480.	1028.	1028.	58.	0.0027	100	104	313-44
700	28,000	0.94	0.25	OL	6.5	OL	25.	OL	50.	OL	111.		195.	116.	339.	300.	515.3	515.3	22.5	0.006	99	103	313-42
	30,000	1.31	0.25	OL	0.8	OL	2.5	OL	15.	OL	51.	OL	111.	29.	206.	174.	351.5	351.5	34.5	0.011	99	104	313-43
	32,000	4.77		OL		OL		OL	0.08	OL	2.	OL	67.	OL	177.		195.	195.	18.2	0.012	99	103	313-37
	32,500	4.04		OL		OL		OL		OL	0.08	OL	28.	OL	154.	0.08	194.	194.	16.5	0.016	99	103	313-40
	33,000	No Strain Measurement															0.17	0.17	41.		99	104	313-36
	34,000	" " "															0.05	0.05	36.		99	105	313-39
	7,000	0.07	20.	0.6	65.	35.	160.	85.	1100.	440.							discon-tinued	1111.	0.57	0.00008	98	100	313-64
	7,500	0.09	35.		100.	40.	210.	110.	700.	360.							"	1035.	0.63	0.00012	99	100	313-68
	8,500	0.04	14.	5.	25.	24.	55.	46.	105.	95.	294.	271.					"	433.	1.24	0.00118	98	100	313-65
	10,000	0.07	13.	1.	25.5	18.	41.	28.	65.	57.	121.	113.					"	121.5	1.07	0.0063	98	101	313-24
800	11,000	0.10	4.		14.	4.	25.	14.	44.	35.	78.	71.					"	117.5	1.69	0.009	98	101	313-63
	13,000	0.17	6.5	OL	13.	0.15	21.	8.5	34.	23.	57.	50.	89.	83.	163.	159.	736.	736.	56.	0.0135	98	101	313-26
	17,000	0.54	0.8	OL	2.7	OL	5.3	OL	10.3	OL	21.5	10.	35.	28.5	58.	54.5	192.5	192.5	70.	0.039	98	100	313-28
	21,000	1.06	0.4	OL	1.	OL	1.5	OL	4.	OL	9.3	OL	15.9	8.7	25.5	22.8	60.3	60.3	51.5	0.068	98	102	313-29
	25,000	1.61		OL	0.2	OL	0.35	OL	0.85	OL	3.3	OL	6.8	0.5	12.5	10.1	24.8	24.8	35.5	0.194	98	102	313-31
	30,000	4.14		OL	0.02	OL	0.10	OL	0.26	OL	0.85	OL	2.1	OL	4.05*	0.64	5.7	5.7	24.	0.73	98	102	313-34
	32,000	Rupture Data Only															1.1	1.1	30.5		98	104	313-30

Specimens 313-37, 40, and 42 fractured outside of the gage length

* By Extrapolation

C = Creep

TD = Total Deformation

OL = On Loading

TABLE 17

TENSILE CREEP-RUPTURE CHARACTERISTICS OF ANNEALED C-110M TITANIUM ALLOY SHEET

Temp. °F	Stress P.S.I.	% Elong. on Loading	Time in Hours for Deformation of 0.1% C	0.1% TD	0.2% C	0.2% TD	0.3% C	0.3% TD	0.5% C	0.5% TD	1.0% C	1.0% TD	2.0% C	2.0% TD	5.0% C	5.0% TD	Fracture Hours	Time of Test Hours	% Elon. in 2 In.	Min. Creep Rate % Per Hour	RC Hardness Before	RC Hardness After	Specimen
700	55,000	0.51	4.5	OL	15.	OL	32.	OL	56.	OL	103.	54.	172.	140.	347.	320.	discontinued	366.	5.88	0.006	34	38	274-75
	65,000	0.58		OL		OL	2.	OL	11.	OL	37.	7.5	74.	55.	150.	135.	447.	447.	46.	0.0186	34	42	274-71
	75,000	0.70	1.8	OL	9.	OL	15.5	OL	25.	OL	43.	15.5	66.	51.5	105.3	98.5	240.	240.	36.	0.0165	32	43	274-81
	80,000	0.82	0.8	OL	4.	OL	7.5	OL	15.	OL	28.	3.	45.	32.	72.	66.	171.5	171.5	47.	0.024	34	41	274-74
	85,000	0.82	0.25	OL	1.5	OL	2.7	OL	6.5	OL	16.	1.	28.5	19.	52.	46.8	100.	100.	28.	0.052	34	42	274-70
	90,000	0.86	0.8	OL	2.3	OL	4.	OL	7.5	OL	16.5	0.95	29.	19	46.4	42.6	82.5	82.5	39.	0.052	34	42	274-89
	100,000	1.70	0.1	OL	0.22	OL	0.35	OL	0.8	OL	2.1	OL	5.3	0.35	13.5*	9.6	25.5	25.5	23.	0.30	33	42	274-77

* By Extrapolation
C = Creep
TD = Total Deformation
OL = On Loading

TABLE 18

TENSILE CREEP-RUPTURE CHARACTERISTICS OF NORMALIZED SAE 4130 STEEL SHEET

Temp. °F	Stress PSI	% Elong. on Load-ing	Time in Hours for Deformation of														Frac-ture Hours	Time of Test Hours	% Elong. in 2 In.	Min. Creep Rate % Per Hour	RB Hardness		Speci-men
			0.1%		0.3%		0.5%		1.0%		2.0%		3.0%		5.0%								
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					Before	After	
800	52,000	0.31	1.2	OL	38.	OL	203.	6.		457.							Discon-	457.	1.	0.00052	95	98	300-63
	54,000	0.39	2.	OL	27.	OL	100.	2.	640.	177.							tinued	640.	1.39	0.00068	94	98	300-36
	58,000	0.45	0.5	OL	12.	OL	39.	0.1	182.	52.							"	186.	1.46	0.00026	94	97	300-58
	60,000	0.41	0.5	OL	5.5	OL	25.		112.	33.		300.					"	331.	2.09	0.0026	95	99	300-28
	63,000	0.57	0.4	OL	4.	OL	15.	OL	57.	10.	210.	110.		297.			"	305.	3.01	0.0052	95	98	300-27
	65,000	0.80	0.2	OL	1.5	OL	6.	OL	22.5	0.75	88.	32.	200.	106.	485.	350.	"	1407.	10.8	0.0053	94	103	300-15
	66,000	1.05	0.04	OL	0.14	OL	0.8	OL	5.5	OL	26.	5.	53.	25.	133.	87.	840.	840.	29.	0.023	94	105	300-69
	68,000	1.94		OL	0.08	OL	0.18	OL	1.25	OL	5.3		12.3	1.3	32.5	12.9	221.3	221.3	30.5	0.093	93	105	300-24
	70,000	2.01		OL	0.07	OL	0.19	OL	0.85	OL	3.05	OL	5.9*	0.82		5.9*	57.5	57.5	19.5	0.35	93	100	300-14
	73,000	2.75		OL		OL	0.07	OL	0.25	OL	0.96	OL	1.9		4.	1.19	14.7	14.7	23.	0.88	93	102	300-18
	74,500	3.16		OL		OL		OL	0.17	OL	0.53	OL	0.93	OL	1.84	0.46	5.3	5.3	21.	2.	94	102	300-19
900	35,000	0.124	3.	OL	23.	5.3	110.	41.	580.	445.	Discontinued							613.		0.00090	95	94	300-64
	37,000	0.165	2.6	OL	32.	2.5	95.	40.	395.	287.	"							451.		0.00135	93	94	300-61
	40,000	0.214	0.8	OL	11.5	0.33	38.	10.	155.	93.	"							170.		0.0033	93	97	300-62
	43,000	0.231	0.7	OL	5.5	0.10	14.	4.5	64.	36.	"							97.3		0.0062	93	97	300-45
	46,000	0.31	0.55	OL	3.1	OL	9.	1.5	28.	14.5	85.	65.	165.	137.	324.	299.	738.	738.	16.	0.0127	94	100	300-53
	51,000	0.33	0.23	OL	1.5	OL	3.4	0.60	8.7	4.7	24.	18.	46.	38.	92.	84.	260.	260.	20.5	0.044	94	101	300-21
	54,000	0.42	0.08	OL	0.50	OL	1.11	0.05	3.5	1.55	10.3	7.1	19.	15.2	43.	36.	101.	101.	(1)	0.077	95	100	300-37
	57,000	0.50		OL	0.20	OL	0.50	OL	1.50	0.50	4.	3.2	6.5	5.2	11.4	10.3	31.4	31.4	26.	0.40	93	101	300-30
	60,000	0.60		OL	0.08	OL	0.19	OL	0.56	0.13	1.36	0.90	2.03	1.65	3.17	2.85	5.55	5.55	18.	1.23	95	99	300-22
	63,000	1.11		OL		OL	0.05	OL	0.16	OL	0.44	0.13	0.70	0.40	1.23	0.93	3.10	3.10	24.	3.7	94	99	300-23

* By Extrapolation

(1) Specimen fractured outside gage marks

C = Creep

TD = Total Deformation

OL = On Loading

TABLE 18 (cont.)

TENSILE CREEP-RUPTURE CHARACTERISTICS OF NORMALIZED SAE 4130 STEEL SHEET

Temp. °F	Stress PSI	% Elong. on Load-ing	Time in Hours for Deformation of														Frac-ture Hours	Time of Test Hours	% Elong. in 2 In.	Min. Creep Rate % Per Hour	RB Hardness		Speci-men
			0.1%		0.3%		0.5%		1.0%		2.0%		3.0%		5.0%						Before	After	
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD							
	16,000	0.10	6.	OL	80.	37.	210.	136.	575.	502.	Discontinued							616.		0.00132	95	94	300-54
	19,000	0.11	1.8	OL	22.	9.	70.	40.	203.	172.	"							205.		0.00385	95	94	300-31
	22,000	0.16	1.9	OL	14.	4.	34.	18.	102.	82.	240.	215.	Discontinued					258.		0.0073	95	92	300-56
	23,000	0.19	1.3	OL	11.	1.75	24.5	11.5	60.	46.	140.	123.	220.	205.	348.	337.	583.	583.	14.*	0.0121	94	93	300-32
	25,000	0.155	0.8	OL	5.5	1.	13.	7.	39.	30.	90.	82.	139.	130.	217.	211.	426.	426.	21.	0.0190	95	90	300-7
1000	28,000	0.204	0.63	OL	3.4	0.6	6.7	3.2	19.	13.4	43.	39.	64.	60.	106.	102.	213.1	213.1	23.5	0.041	94	92	300-59
	30,000	0.22	0.3	OL	1.6	0.25	3.2	1.5	7.2	5.6	14.6	12.8	23.	21.2	40.	38.3	96.3	96.3	27.	0.1325	93	91	300-2
	35,000	0.24		OL	1.1	0.1	2.	0.9	4.8	3.4	10.5	9.1	16.	14.6			44.8	44.8	16.	0.179	94	92	300-12
	40,000	0.27		OL	0.2		0.5	0.2	1.2	0.8	2.65	2.2	4.1	3.7	6.7	6.4	14.5	14.5	25.	0.66	93	96	300-3
	45,000	0.33		OL		OL	0.2	0.05	0.5	0.3	1.	0.8	1.4	1.3	2.2	2.1	4.25	4.25	28.	1.88	95	96	300-11
	48,000	0.69		OL		OL		OL	0.04		0.08	0.05	0.13	0.10	0.23	0.19	0.50	0.50	29.	20.	94	96	300-68

* Fractured out side gage length

C = Creep

TD = Total Deformation

OL = On Loading

TABLE 19

BEARING CREEP-RUPTURE CHARACTERISTICS OF ANNEALED A-70 TITANIUM SHEET

Temp. °F	Stress PSI	% Elong. on Loading	Time in Hours for Bearing-Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Min. Creep Rate % Per Hour	Hardness Before Test RB	Specimen
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%						
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					
700	40,000	4.04	47.	OL	108.	OL	236.	OL		OL		104.			Overheated at 150 Hrs.		Discontinued	236.	0.0074	100	313B-28
	45,000	3.73	8.	OL	29.	OL	69.	OL	103.	OL	149.	41.		165*				150.	0.017	100	313B-10
	50,000	9.25		OL	0.03	OL	5.5	OL	70.	OL	128.	OL	190.	0.02		195.	243.	243.	0.010	98	313B-30
	52,000	14.92		OL		OL		OL	0.05	OL	0.4	OL	81.	OL	129.	0.4	130.3	130.3	0.025	99	313B-26
	53,000	6.25	0.09	OL	1.	OL	12.	OL	29.	OL	50.	OL	81.	38.		94.	117.5	117.5	0.051	101	313B-17
	54,000	9.95		OL		OL	0.08	OL	0.7	OL	29.	OL	72.		103.	72.5	104.8	104.8	0.043	101	313B-20
	55,000	8.97		OL		OL	0.25	OL	4.5	OL	33.5	OL	64.5	0.03	83.	68.	85.1	85.1	0.054	100	313B-11
	56,000	7.5		OL		OL	0.05	OL	0.11	OL	1.6	OL	46.8	0.08	68.2	55.	70.7	70.7	0.046	101	313B-12
	57,000							No Deformation Data									0.06	0.06		100	313B-22
	58,000							Fractured immediately after loading												100	313B-24
800	10,000	0.44			100.	42.	450.	234.										496.	0.00156	99	313B-4
	15,000	0.74			24.	1.1	88.	37.		110.								140.	0.0104	99	313B-6
	25,000	1.14			6.1	OL	17.	4.1	30.	15.	58.	41.	135.	117.	251.	239.	484.	484.	0.066	100	313B-9
	30,000	1.44			4.2	OL	12.2	1.5	17.4	8.5	25.5	19.8	42.	38.	66.	63.	141.	141.	0.113	99	313B-27
	35,000	2.45			1.20	OL	3.8	OL	6.	0.5	9.8	5.2	17.6	14.2	29.	26.7	59.9	59.9	0.38	100	313B-21
	35,000	1.95			1.20	OL	3.3		5.5	1.2	9.6	5.5	19.2	15.6		31.*	71.2	71.2	0.42	100	313B-16
	40,000	3.50			1.15	OL	3.	OL	4.	OL	6.3	2.1	10.8	7.8	16.*	15.*	26.6	26.6	0.60	99	313B-7
	42,000	3.16			0.30	OL	1.25	OL	2.	OL	3.4	1.1	6.4	4.6	10.8	9.5	19.5	19.5	1.25	99	313B-14
	50,000	7.48			0.13	OL	0.50	OL	0.85	OL	1.42	OL	2.55	0.70	3.8*	2.96	4.25	4.25	2.6	99	313B-19
	52,000	6.66			0.05	OL	0.15	OL	0.32	OL	0.76	OL	1.67	0.40	2.35*	2.07	2.67	2.67	4.5	100	313B-13

C = Creep
TD = Total Deformation
OL = On Loading
* = By Extrapolation

TABLE 20

BEARING CREEP-RUPTURE CHARACTERISTICS OF C-110M TITANIUM ALLOY SHEET

Temp. °F	Stress PSI	% Elong. on Loading	Time in Hours for Bearing-Hole Deformation Expressed as Percent of the Diameter												Fracture Hours	Time of Test Hours	Min. Creep Rate % Per Hour	Specimen
			1.0%		2.0%		3.0%		5.0%		10.0%		20.0%					
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD				
700	55,000	1.85	90.	OL		2.		120.*								104.	<0.0057	274B-42
	65,000	2.21	28.	OL	162.	OL		16.								164.	<0.0043	274B-23
	75,000	2.66	38.	OL	110.	OL		4.		139.						140.	<0.012	274B-44
	85,000	3.	29.	OL	79.	OL		OL		79.						93.	0.018	274B-35
	100,000	3.89	15.	OL	45.	OL	73.	OL	120.	18.	211.	144.				233.	0.035	274B-41
	115,000	4.06	6.	OL	18.5	OL	38.	OL	65.	5.6	115.	76.	187.	159.	356.	356.	0.059	274B-22
	130,000	5.15	3.3	OL	9.	OL	17.	OL	30.	OL	57.	29.	98.	79.	174.	174.	0.14	274B-21
	150,000	7.6	1.1	OL	2.9	OL	5.5	OL	11.5	OL	26.	3.9		29.4	70.	70.	0.33	274B-33
	160,000	8.34	0.33	OL	0.86	OL	1.7	OL	3.4	OL	7.8	0.65	16.*	9.4	24.1	24.1	1.	274B-18
	164,000	14.9		OL	0.18	OL	0.33	OL	0.69	OL	1.75	OL	3.9	0.07	4.25	4.25	4.3	274B-39
	175,000	14.7		OL	0.09	OL	0.18	OL	0.40	OL	1.18	OL	2.12*	0.45	2.23	2.23	7.7	274B-29
800	10,000	0.42	26.5	8.	164.	87.										236.5	0.0046	274B-28
	15,000	0.69	12.5	1.5	61.	23.		82.								83.	(1)	274B-24
	20,000	0.89	7.5	.3	30.	9.	74.	35.	268.	170.						265.	0.0082	274B-27
	30,000	1.03	4.1	OL	13.5	4.	28.	13.	80.	52.						93.2	0.036	274B-26
	45,000	1.79	2.6	OL	7.	0.10	12.	3.5	25.5	13.5	66.	52.		133.5	503.	503.	0.118	274B-34
	55,000	1.99	1.3	OL	3.2	OL	5.2	1.3	10.6	5.2	26.	19.9		49.6	150.	150.	0.316	274B-30
	65,000	2.63	0.8	OL	1.9	OL	3.	0.2	5.5	2.3	12.4	8.8		21.8	63.25	63.25	0.735	274B-32
	84,000	3.08	0.4	OL	1.	OL	1.6	OL	2.9	0.95	5.6	4.05		9.	23.6	23.6	1.51	274B-19
	100,000	4.02	0.18	OL	0.40	OL	0.62	OL	1.	0.18	1.92	1.18		2.86	8.6	8.6	4.60	274B-20
	110,000	4.06	0.11	OL	0.20	OL	0.3	OL	0.47	0.10	0.87	0.55		1.23	2.6	2.6	10.2	274B-31

* By Extrapolation

Note: Nominal Hardness of as-received material = 35-37 RC

C = Creep

TD = Total Deformation

OL = On Loading

(1) = Not Determinable

TABLE 21

BEARING CREEP-RUPTURE CHARACTERISTICS OF NORMALIZED SAE 4130 STEEL SHEET

Temp. °F	Stress PSI	% Elong. on Load-ing	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Frac-ture Hours	Time of Test Hours	Min. Creep Rate % Per Hour	RB Hardness Before Test	Speci-men
			1%		2%		3%		5%		10%		20%		30%						
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					
	88,000	3.23	11.	OL	186.	OL		OL		124.							Discon-	286.8	0.0036	96	300B-39
	92,000	3.02	8.	OL	106.	OL		OL		104.							tinued	118.	0.006	96	300B-37
	100,000	3.95	1.5	OL	22.	OL		OL		1.7							"	45.	0.015	96	300B-42
	110,000	7.86	0.2	OL	1.4	OL	3.6	OL	14.	OL	75.	1.5	450*	123.			(1)	435.3	0.024	93	300B-4
800	118,000	7.55	0.04	OL	0.25	OL	0.7	OL	2.9	OL	15.1	0.5	58.8	25.		71.	170.8	170.8	0.21	97	300B-31
	119,000	7.79		OL	0.09	OL	0.38	OL	2.	OL	14.	0.15	53.2	21.3		64.	139.4	139.4	0.20	96	300B-33
	120,000	8.62	0.04	OL	0.11	OL	0.25	OL	1.4	OL	8.2	0.05	38.5	11.4		41.*	95.8	95.8	0.30	96	300B-36
	122,000	10.15		OL	0.04	OL	0.09	OL	0.37	OL	1.95	OL	7.7	1.9		7.6	15.6	15.6	1.56	96	300B-35
	123,000	10.15		OL		OL	0.12	OL	0.31	OL	1.19	OL	4.52	1.15		4.5	8.3	8.3	2.78	97	300B-40
	128,000	13.1		OL		OL		OL	0.03	OL	0.09	OL		0.04		0.31	0.75	0.75	28.	95	300B-34
			0.5%		1%		2%		3%		5%		10%		20%						
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					
	46,000	2.06	11.	OL	36.	OL	165.	OL		31.							Discon-	354.	0.0029	93	300B-10
	52,000	2.28	4.3	OL	25.	OL	91.5	OL		12.							tinued	91.5	0.012	93	300B-17
	56,000	2.48	2.	OL	8.5	OL	43.	OL		2.1		74.*					"	63.8	0.014	93	300B-15
	62,000	1.92	0.95	OL	4.5	OL	35.			5.5							"	65.1	0.016	93	300B-8
	70,000	2.33	0.37	OL	1.9	OL	10.	OL	24.8	0.75		19.					"	24.8	0.063	93	300B-12
900	77,000	3.17		OL	1.	OL	3.6	OL	10.	OL	33.	3.		65.			"	68.8	0.043	93	300B-3
	85,000	3.20		OL	0.2	OL	0.8	OL	2.	OL	5.5	0.65	21.	10.	72.3	52.7	158.3	158.3	0.16	93	300B-6
	90,000	4.17		OL	0.15	OL	0.5	OL	1.3	OL	3.5	0.12	13.2	4.9	35.3	25.8	69.6	69.6	0.46	93	300B-7
	95,000	4.82		OL	0.05	OL	0.12	OL	0.28	OL	0.85		2.95	0.92	8.07	5.6	16.8	16.8	2.	94	300B-14
	100,000	6.21		OL		OL	0.05	OL	0.12	OL	0.32	OL	1.14	0.19	3.15	1.94	7.	7.	4.7	94	300B-9
	103,000	7.96		OL		OL		OL	0.03	OL	0.08	OL	0.23	0.02		0.40	1.33	1.33	26.	93	300B-5

* By Extrapolation
(1) Bearing Pin failed
C = Creep
TD = Total Deformation
OL = On Loading

TABLE 21 (cont.)

BEARING CREEP-RUPTURE CHARACTERISTICS OF NORMALIZED SAE 4130 STEEL SHEET

Temp. °F	Stress PSI	% Elong. on Load-ing	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Frac-ture Hours	Time of Test Hours	Min. Creep Rate % Per Hour	RB Hardness Before Test	Speci-men
			0.5%		1%		2%		3%		5%		10%		20%						
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					
1000	22,000	0.91	3.	OL	25.		150.	30.	405.	165.							Discon-tinued	405.	0.0037	94	300B-24
	27,000	1.27	1.6	OL	17.	OL	90.	6.1		70.								116.3	0.013	95	300B-25
	33,000	1.4	0.85	OL	6.1	OL	35.	1.3	63.*	20.							"	41.8	0.026	94	300B-26
	40,000	1.24	0.25	OL	1.2	OL	6.3	0.55	17.	4.5		29.					"	41.5	0.062	94	300B-27
	48,000	1.59	0.12	OL	0.5	OL	2.1	0.08	5.6	1.	17.	7.6	51.	40.	110.*	105.5*	196.2	196.2	0.147	94	300B-23
	54,000	1.86	0.07	OL	0.30	OL	0.9		2.25	0.3	6.	2.5	18.8	14.	40.4	37.	75.	75.	0.38	94	300B-22
	60,000	2.26	0.05	OL	0.20	OL	0.65	OL	1.2	0.15	2.5	1.	6.1	4.5	12.4*	11.2	23.5	23.5	1.33	92	300B-19
	65,000	2.83		OL	0.07	OL	0.2	OL	0.4		0.96	0.22	2.7	1.7	6.	5.1	11.3	11.3	2.88	94	300B-18
	70,000	3.36		OL		OL	0.11	OL	0.21	OL	0.5	0.09	1.25	0.75	2.64	2.2	5.1	5.1	6.55	94	300B-21
	75,000	4.28		OL		OL	0.05	OL	0.11	OL	0.23		0.54	0.27	1.13	0.90	2.1	2.1	16.3	94	300B-20

* By Extrapolation

C = Creep

TD = Total Deformation

OL = On Loading

TABLE 22

BEARING CREEP-RUPTURE CHARACTERISTICS OF ANNEALED TYPE 321 STAINLESS STEEL SHEET

Temp. °F	Stress PSI	% Elong. on Loading	Time in Hours for Bearing-Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Min. Creep Rate % Per Hour	RB Hardness Before Test	Specimen
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%						
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					
1200	21,000	0.88	28.	OL	73.	4.	174.	78.		182.							Discontinued	236.1	0.0068	84	210B-10
	24,000	1.04	24.	OL	50.	OL	102.	49.		100.							"	114.3	0.020	83	210B-8
	30,000	1.20	4.	OL	19.5	OL	52.	12.5	85.	45.							"	93.8	0.031	84	210B-11
	36,000	1.50	5.5	OL	9.5	OL	19.	5.3	30.	14.	56.	37.	104.	90.5	170.	162.	262.	262.	0.079	83	210B-5
	42,000	2.15	0.25	OL	1.1	OL	7.5	OL	14.5	0.75	27.4	13.	51.	41.5	76.8*	73*	111.8	111.8	0.13	83	210B-4
	46,000	2.87	0.2	OL	1.	OL	3.	OL	7.8		15.7	3.7	30.5	22.2	52.2*	46.8	81.4	81.4	0.23	83	210B-21
	50,000	4.04	0.1	OL	0.3	OL	1.7	OL	4.8	OL	10.1	0.2	18.1	12.2	27.9	24.7	36.	36.	0.32	83	210B-18
	55,000	4.29	0.04	OL	0.1	OL	0.3	OL	0.7	OL	2.2	0.03	6.1	2.8	11.6	9.7	14.9	14.9	1.25	80	210B-3
	60,000	5.9		OL	0.06	OL	0.15	OL	0.3	OL	0.84	OL	2.61	0.56	5.2*	3.8	6.8	6.8	2.7	82	210B-7
	66,000	8.55		OL		OL	0.04	OL	0.09	OL	0.23	OL	0.72		1.57*	0.87	2.2	2.2	10.2	84	210B-1
1350	5,000	0.27	20.	5.	100.	45.	340.	240.									Discontinued	420.	0.00244	84	210B-25
	10,000	0.49	2.5		9.5	2.5	50.	22.		70.							"	68.	0.0197	83	210B-17
	14,000	0.59	2.	OL	6.3	1.7	21.	11.		29.							"	48.	0.045	84	210B-19
	19,000	0.93	0.9	OL	2.9	0.1	9.3	3.4	17.5	10.	35.	26.7	75.	69.	136.	130.	253.5	253.5	0.114	84	210B-9
	25,000	1.17	0.3	OL	0.8	OL	2.3	0.6	4.1	2.	7.6	5.6	16.1	14.1	29.3	28.1	55.9	55.9	0.55	84	210B-20
	30,000	1.36		OL	0.11	OL	0.8		1.3	0.6	2.9	1.8	6.1	5.3	10.9	10.4	20.3	20.3	1.34	83	210B-2
	35,000	1.78		OL	0.07	OL	0.3		0.58	0.12	1.15	0.64	2.48	2.03	4.47	4.16	9.2	9.2	3.53	83	210B-15
	41,000	2.52		OL		OL	0.06	OL	0.10		0.25	0.08	0.67	0.47	1.13	1.06	2.6	2.6	11.4	83	210B-16

* = By Extrapolation
C = Creep
TD = Total Deformation
OL = On Loading

TABLE 23

SHEAR CREEP-RUPTURE CHARACTERISTICS OF 2024-T3 ALUMINUM PLATE

Temp. °F	Stress PSI	In. Elong. on Load-ing	Time in Hours for Shear Deformation of 0.0020 In. C	0.0020 In. TD	0.0050 In. C	0.0050 In. TD	0.010 In. C	0.010 In. TD	0.020 In. C	0.020 In. TD	0.030 In. C	0.030 In. TD	0.040 In. C	0.040 In. TD	Frac-ture Hours	Time of Test Hours	Min. Creep Rate In. Per Hour	Speci-men
600	2500	0.00016	26.	23.	115.	110.	190.	188.	263.	262.	293.	293.	311.	311.	319.5	319.5	0.000029	211S-52
	2800	0.00031	40.	32.	112.	107.	163.	160.	213.	212.	248.	247.			260.	260.	0.000036	211S-56
	3000	0.00043	4.	2.	22.	18.	67.	64.	114.	113.	134.	134.	144.	144.	153.5	153.5	0.00011	211S-63
	3300	0.00048	2.5	1.5	10.	9.	32.	30.	61.5	61.	75.	75.			86.5	86.5	0.00022	211S-58
	3600	0.00065	4.	2.5	16.	13.	28.5	27.	43.	42.	49.	49.	51.	51.	51.75	51.75	0.000256	211S-64
	4000	0.0010	1.8	0.5	7.6	5.8	13.	12.							20.5	20.5	0.00050	211S-46
	4500	0.00056	0.3	0.2	1.1	0.9	2.5	2.3	5.8	5.7					8.9	8.9	0.0026	211S-62
	5000	0.00115	0.12	0.05	0.5	0.34	1.40	1.25	2.55	2.45	3.09	3.05			3.75	3.75	0.005	211S-51
			Time in Minutes for Shear Deformation															
	6000	0.00126	2.5	1.	8.	5.	22.5	18.	42.5	40.	53.5	52.5		57.	1.	1.	0.021	211S-65

C = Creep
TD = Total Deformation

TABLE 24

SHEAR CREEP-RUPTURE CHARACTERISTICS OF 2117-T4 ALUMINUM RIVET WIRE

Temp. °F	Stress PSI	Inch Elong. on Load-ing	Time in Hours for Shear Deformation of												Frac-ture Hours	Time of Test Hours	Min. Creep Rate Inch Per Hour	Speci-men
			0.010 Inch		0.0125 Inch		0.0150 Inch		0.0175 Inch		0.020 Inch							
			C	TD	C	TD	C	TD	C	TD	C	TD						
	17,000	0.0082				202.		216.							219.	219.	0.000	276S-19
	18,000	0.0097				75.		97.							102.	102.	0.000005	276S-18
300	19,000	0.0095		0.2		1.		47.							50.	50.	0.000014	276S-22
	20,000	0.0118		OL				1.		25.					27.50	27.50	0.00002	276S-17
	21,000	0.0135		OL		OL						2.5			7.16	7.16	0.00025	276S-21
	22,000	0.0175	0.13	OL		OL		OL		OL		0.02			1.83	1.83	0.0025	276S-20
			0.002 Inch		0.005 Inch		0.010 Inch		0.015 Inch		0.020 Inch		0.025 Inch					
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD				
	4,600	0.00075	68.	26.	197.	175.	255.	252.	274.	272.	284.	283.			307.	307.	0.000018	276S-16
	5,000	0.00080	89.	50.	150.	142.	169.	167.	175.	174.	178.	178.			186.	186.	0.000018	276S-15
	5,500	0.00080	90.	63.	129.	125.	144.	143.	149.	148.	152.	152.	154.	154.	156.	156.	0.000018	276S-13
450	6,000	0.00074	55.	42.	88.	87.	99.	98.	103.	103.	104.	104.			105.	105.	0.000018	276S-10
	7,000	0.00070	27.	20.	40.5	39.	46.3	45.8		48.					52.	52.	0.000042	276S-9
	8,000	0.0021	6.	OL	15.5	10.	19.4	18.5	20.2	20.	21.	21.			21.5	21.5	0.00025	276S-12
	9,000	0.0015	2.4	.25	7.5	5.7	9.9	9.5		10.5					10.75	10.75	0.00047	276S-11
			Time in Minutes for Shear Deformation															
	13,000	0.00298	1.4	OL	8.4	1.4	15.6	12.	19.5	17.5		20.6			0.367	0.367	0.025	276S-14

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 24 (cont.)

SHEAR CREEP-RUPTURE CHARACTERISTICS OF 2117-T4 ALUMINUM RIVET WIRE

Temp. °F	Stress PSI	Inch Elong. on Loading	Time in Hours for Shear Deformation of												Fracture Hours	Time of Test Hours *	Min. Creep Rate Inch Per Hours	Specimen
			0.002 Inch		0.005 Inch		0.010 Inch		0.020 Inch		0.030 Inch		0.040 Inch					
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD				
600	1,400	0.000175	57.	53.	180.	175.	280.	279.	410.	408.	485.	485.	510.	510.	558.	558.	0.00002	276S-1
	1,800	0.00032	10.	9.	31.	30.	57.	56.	102.	102.	131.	131.	148.	148.	170	170.	0.000125	276S-3
	2,000	0.000336	4.	3.	12.1	11.6	21.	20.7	37.5	37.	47.2	47.			65.	65.	0.00029	276S-2
	2,200	0.000624	4.2	2.4	9.4	8.8	13.9	13.5	19.8	19.6	23.2	23.1			30.	30.	0.00039	276S-4
	2,500	0.00152	.4		1.7	1.1	3.	2.6	4.6	4.4					9.33	9.33	0.0024	276S-7
			Time in Minutes for Shear Deformation															
	3,000	0.0016	7.		22.	15.	41.	35.	67.	63.	95.	86.		109.	2.5	2.5		276S-5
	3,500	0.0024	2.	OL	7.	2.	16.	12.	29.	26.	37.	35.	42.	41.	58 Min.	58 Min		276S-8

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 25

SHEAR DEFORMATION CHARACTERISTICS OF 1/2 INCH DIAMETER MONEL WIRE

Temp. °F	Stress PSI	Inch Elong. on Loading	Time in Hours for Shear Deformation of												Fracture Hours	Time of Test Hours	Min. Creep Rate Inch Per Hours	Specimen
			0.005 Inch		0.010 Inch		0.015 Inch		0.020 Inch		0.030 Inch		0.040 Inch					
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD				
1000	18,000	0.0062	12.	OL	102.	2.5	323.	62.	476.	286.		545.			600.	600.	0.00002	230S-2
	20,000	0.0122	1.	OL	6.	OL	22.		54.	4.	132.	38.			155.	155.	0.00011	230S-10
	21,000	0.0135		OL	3.	OL	14.		28.	1.	80.	16.		60.	88.	88.	0.00016	230S-9
	22,000	0.0105	0.5	OL	4.	OL	12.	0.5	20.	3.2	32.	19.6		31.5	34.25	34.25	0.00058	230S-3
	23,000	0.0137	0.4	OL	2.	OL	5.8	0.1	11.8	0.80	21.8	7.		17.	25.	25.	0.00081	230S-7
	25,000	0.0132	0.15	OL	0.8	OL	2.2	0.05	4.3	.35	8.3	2.7		7.1	10.	10.	0.0022	230S-4
	28,000	0.0143	0.10	OL	0.34	OL	0.68		1.3	0.12		0.75		1.7	2.25	2.25	0.067	230S-6
	30,000						No Readings								.75	.75		230S-5
1200	8,000	0.00139	12.	6.	50.	36.			205.	182.	352.	342.	397.	390.	431.	431.	0.000063	230S-15
	9,000	0.00432	6.		23.6	7.5			90.	58.	164.	142.	177.	170.	197.	197.	0.00013	230S-19
	10,000	0.00448	2.		10.6	4.2			42.	27.	73.	64.	83.	79.	86.	86.	0.00027	230S-13
	11,000	0.0036	1.5		6.7	2.2			28.	21.	48.	43.	56.	53.	59.	59.	0.00047	230S-12
	12,000	0.0038	1.3		4.3	1.5			15.4	11.		21.6		24.8	26.	26.	0.00086	230S-11
	13,000	0.00521	0.4		1.75	.3			6.8	2.		9.2			14.	14.	0.00185	230S-14
	15,000	0.0101	0.1		0.5	OL			2.	.50	3.	2.		3.	3.6	3.6	0.0071	230S-16
	15,600	0.0123			No Deformation Readings Taken										2.25	2.25		230S-17
	18,000	0.0128			" " " "										0.70	0.70		230S-18

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 26

SHEAR-PIN DEFORMATION CHARACTERISTICS OF 1/2 INCH DIAMETER TYPE 301 STAINLESS STEEL WIRE

Temp. °F	Stress PSI	Inch Elong. on Loading	Time in Hours for Shear-Pin Deformation of 0.005 Inch C	0.005 Inch TD	0.010 Inch C	0.010 Inch TD	0.020 Inch C	0.020 Inch TD	0.030 Inch C	0.030 Inch TD	0.040 Inch C	0.040 Inch TD	Fracture Hours	Time of Test Hours	Min. Creep Rate Inch Per Hour	Specimen
1200	14,000	0.00555	140.	OL		85.								450.	0.0000062	277S9
	17,000	0.00423	16.		59.	20.	152.	110.	245.	210.	287.	277.	291.5	291.5	0.00010	277S8
	18,000	0.00403	14.		43.	18.	100.	78.	147.	130.	164.	160.	164.3	164.3	0.00018	277S3
	19,000	0.00848	3.	OL	12.		40.	16.	66.	45.	83.5	69.5	89.5	89.5	0.00035	277S4
	20,000	0.00554	3.5	OL	15.	3.	38.	25.5	52.	46.		55.4	60.	60.	0.00045	277S5
	22,000	0.01122	0.5	OL	3.	OL	12.5	2.5	24.	11.3	29.5	22.8	30.25	30.25	0.00083	277S6
	24,000	0.0093	0.65	OL	2.4	0.11	7.8	2.8		8.1			13.	13.	0.0020	277S7
	30,000		No Deformation Readings Taken										1.40	1.40		277S10
1350	9,000	0.001317	9.	4.	40.	30.	168.	155.	276.	266.	334.	328.	357.25	357.25	0.000075	277S14
	10,000	0.00198	8.	2.	30.	2.1	108.	94.	165.	157.			196.5	196.5	0.00012	277S17
	11,000	0.00497	0.8		4.	0.8	27.	13.5	57.5	42.		73.	95.25	95.25	0.00031	277S12
	12,000	0.00578	0.9	OL	2.5	0.5	10.5	5.3	26.5	16.5	36.	31.	40.8	40.8	0.00050	277S11
	13,000	0.00321	0.9	0.2	3.2	1.6	10.2	7.4					25.25	25.25	0.0011	277S16
	14,000	0.00403	0.5		1.5	0.6	4.5	3.2		7.			11.5	11.5	0.0024	277S13
	18,000	0.01132	No Readings Taken After Loading										2.2	2.2		277S15

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 27

COMPRESSION CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY PLATE

Temp. °F	Stress PSI	% Compression on Loading	Time in Hours for Deformation of										Time of Test Hours	% Compression in 1.5 In.	Hardness After Test RF	Specimen
			0.1%		0.2%		0.3%		0.5%		1.0%					
			C	TD	C	TD	C	TD	C	TD	C	TD				
450	12,000	0.15	14.	OL	32.	4.	80.	18.	222.	125.	445.	386.	538.5	1.43	81	211CC-27
	15,000	0.18	25.	OL	52.	0.6	91.	31.	150.	95.	274.	240.	384.8	1.94	83	211CC-26
	17,000	0.22	9.	OL	25.	OL	55.	6.	127.	48.	250.	209.	311.	1.55	86	211CC-14
	20,000	0.22	2.5	OL	10.	OL	20.	2.	45.	18.	95.	80.	141.6	1.69	90	211CC-13
	23,600	0.26	1.1	OL	6.	OL	11.2	0.3	21.3	8.2	41.5	32.	87.5	2.50	91	211CC-9
	26,000	0.29	1.1	OL	4.2	OL	7.5		14.	4.5	25.5	19.6	42.5	2.68	94	211CC-10
	30,000	0.31	0.5	OL	1.2	OL	1.9	OL	3.1	1.1	6.1	4.4	18.	4.5	95	211CC-12
600	3,500	0.075	16.	2.	55.	24.	135.	70.	320.	250.	810.	730.	833.	1.08	58	211CC-24
	4,500	0.07	4.5	1.	10.	4.5	20.	10.5	44.	33.5	168.	151.	232.	1.30	64	211CC-21
	5,000	0.13	2.5	OL	8.	1.4	15.	6.	28.5	19.5	63.5	55.	85.	1.40	67	211CC-20
	6,000	0.10	1.4	OL	3.2	1.4	5.3	3.2	9.6	7.3	21.7	19.2	66.5	2.9	67	211CC-19
	7,000	0.11	0.45	OL	1.3	0.4	2.2	1.2	4.	3.	9.5	8.4	17.3	1.64	72	211CC-25

C = Creep

TD = Total Deformation

OL = On Loading

Type 2S Aluminum restraining fixture wedges were used

Nominal hardness of as-received material = 100 RF

TABLE 28

COMPRESSION CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY SHEET

Temp. °F	Stress PSI	% Compression on Loading	Time in Hours for Compression Deformation of 0.1%		0.2%		0.3%		0.5%		1.0%		2.0%		3.0%		Time of Test Hours	% Compression in 1.5 In.	Hardness After Test RF	Specimen
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD				
300	45,000	0.89	4.5	OL	20.	OL		OL		OL		5.					163.	1.16	103	212CC-33
	48,000	1.15	4.5	OL	20.	OL	140.	OL		OL		OL					142.3	1.45	103	212CC-34
	50,000	1.44	1.3	OL	4.	OL	12.	OL		OL		OL					313.	1.92	105	212CC-29
	52,000	1.70	0.8	OL	2.4	OL	5.	OL	25.	OL		OL		5.			164.	2.33	104	212CC-39
	54,000	2.18	0.25	OL	2.3	OL	4.7	OL	11.	OL		OL		OL			118.8	2.85	103	212CC-40
	56,000	2.72	0.07	OL	0.3	OL	1.	OL	3.5	OL		OL		OL		0.85	140.	3.57	105	212CC-42
450	12,000	0.13	13.	OL	50.	6.	100.	30.	240.	145.	600.	503.					286.3	1.23	83	212CC-47
	15,000	0.15	10.3	OL	40.	3.	68.	22.	117.	80.	233.	198.					641.6	1.43	87	212CC-46
	17,000	0.23	7.5	OL	25.	OL	41.	4.5	82.	36.	162.	128.					186.	1.41	89	212CC-21
	18,000	0.23	5.6	OL	16.	OL	24.5	3.	45.	22.	88.	68.					100.	1.38	90	212CC-22
	20,000	0.32	1.7	OL	6.	OL	11.3	OL	20.8	5.2	42.	29.					66.	1.58	90	212CC-23
	22,500	0.25	1.	OL	3.7	OL	6.8	0.25	13.6	5.4	28.4	21.5					45.1	1.90	93	212CC-20
	24,000	0.34	1.6	OL	3.5	OL	5.5	OL	9.2	2.8	17.5	12.					17.8	1.36	96	212CC-24
	26,000	0.38	0.2	OL	1.1	OL	2.	OL	4.5	0.4	12.8	6.2					164.	2.06	89	212CC-5
	27,000	0.35	0.35	OL	1.5	OL	2.8	OL	5.8	1.	11.6	7.8					18.8	2.09	96	212CC-26
	29,000	0.40	0.1	OL	0.8	OL	1.4	OL	2.8	0.16	5.75	3.5					18.	2.26	94	212CC-27
600	3,000	0.04	3.	1.5	15.	10.	37.	29.	115.	98.	480.	450.					791.	1.26	51	212CC-44
	4,000	0.13	4.2	OL	12.	2.7	20.	10.	37.	26.	90.	75.					152.	1.53	55	212CC-32
	5,000	0.07	1.3		4.5	2.	9.	5.	20.	16.	43.	40.					90.	1.65	58	212CC-31
	6,000	0.13	0.45	OL	1.4	0.25	2.6	1.1	5.	3.4	11.1	9.5					17.6	1.65	67	212CC-30
	7,000	0.15	0.2	OL	0.8	0.06	1.5	0.4	3.	1.9	6.8	5.7					6.5	1.13	72	212CC-45

C = Creep
TD = Total Deformation
OL = On Loading

Type 2S Aluminum restraining fixture wedges were used

Nominal Hardness of as received material = RC 100

TABLE 29

COMPRESSION CREEP CHARACTERISTICS OF C-110M TITANIUM ALLOY SHEET

Temp. °F	Stress PSI	% Compression on Loading	Time in Hours for Deformation of												Time of Test Hours	% Compression in 1.5 In.	(1) RC Hardness After Test	Specimen
			0.1%		0.2%		0.3%		0.5%		1.0%		2.0%					
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD				
700	45,000	0.52	8.	OL	29.	OL	58.	OL	120.	OL	236.	115.			259.5	1.67	35	274CC-6
	55,000	0.58	5.	OL	16.	OL	28.	OL	47.	OL	93.	39.5		132.	143.5	2.11	35	274CC-5
	70,000	0.84	0.85	OL	3.4	OL	7.1	OL	14.6	OL	31.3	2.2		36.6	43.3	2.17	35	274CC-1
	80,000	1.25	0.2	OL	1.2	OL	2.6	OL	5.5	OL	13.5	OL		9.4	16.5	2.43	35	274CC-4
800	15,000	0.15	2.	OL	8.	0.4	17.	4.5	40.	22.	155.	105.			162.5	1.17	35	274CC-13
	20,000	0.17	2.	OL	6.5	0.2	11.5	3.7	22.5	13.	61.	46.5			63.8	1.20	37	274CC-12
	25,000	0.24	1.1	OL	3.1	OL	5.4	0.45	10.2	4.5	24.	17.			64.5	2.04	37	274CC-11
	30,000	0.30	0.4	OL	1.3	OL	2.3	OL	4.5	1.3	10.6	6.9			18.1	1.86	35	274CC-15
	40,000	0.52	0.13	OL	0.46	OL	0.8	OL	1.5	OL	3.35	1.45			3.5	1.55	37	274CC-16

(1) Nominal hardness of as-received material = RC 34
Type 304 Stainless Steel restraining fixture wedges were used.

C = Creep

TD = Total Deformation

OL = On Loading

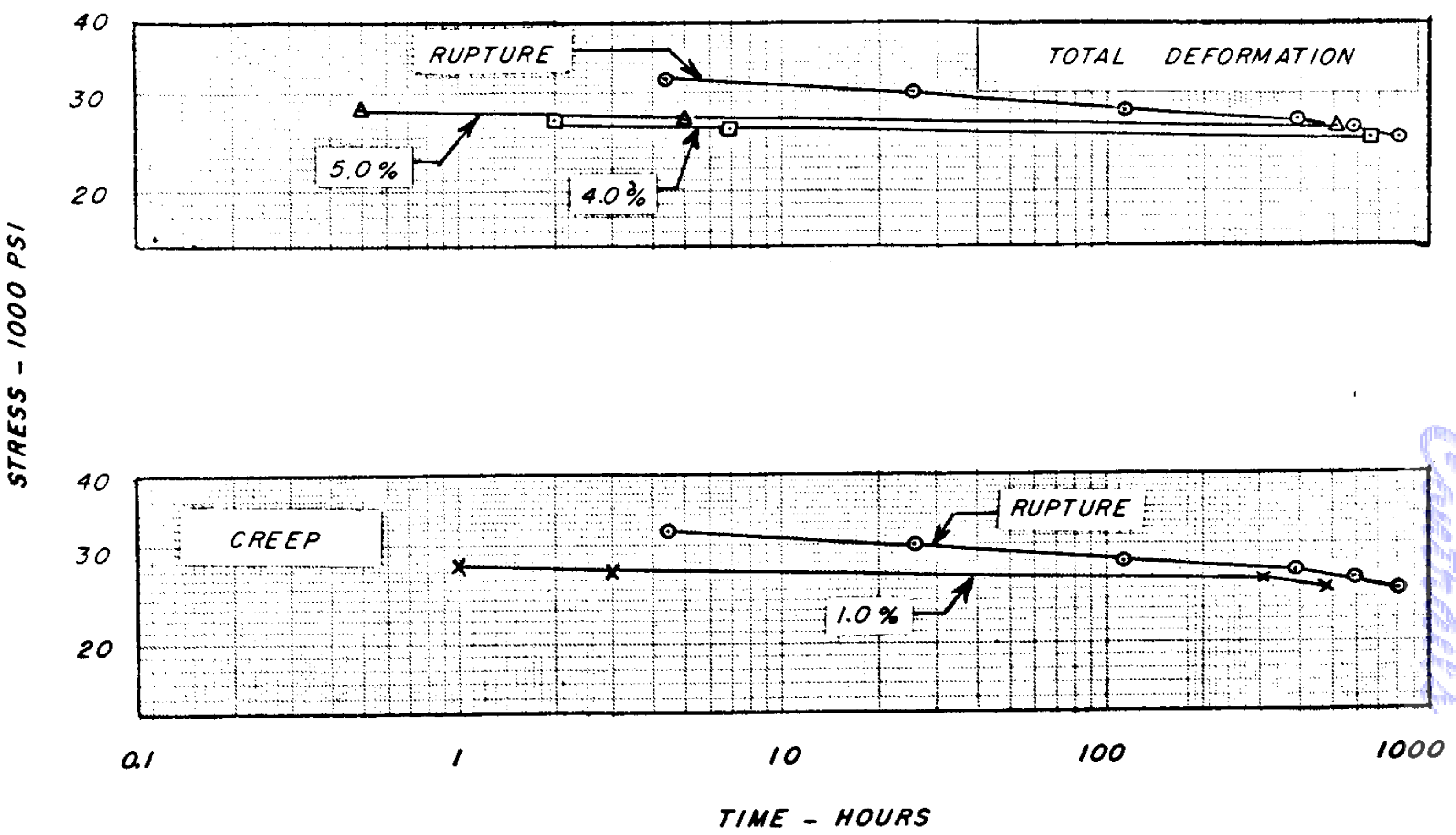

Figure I TENSILE CREEP CHARACTERISTICS OF 2117 - T4 ALUMINUM RIVET WIRE AT 300° F.

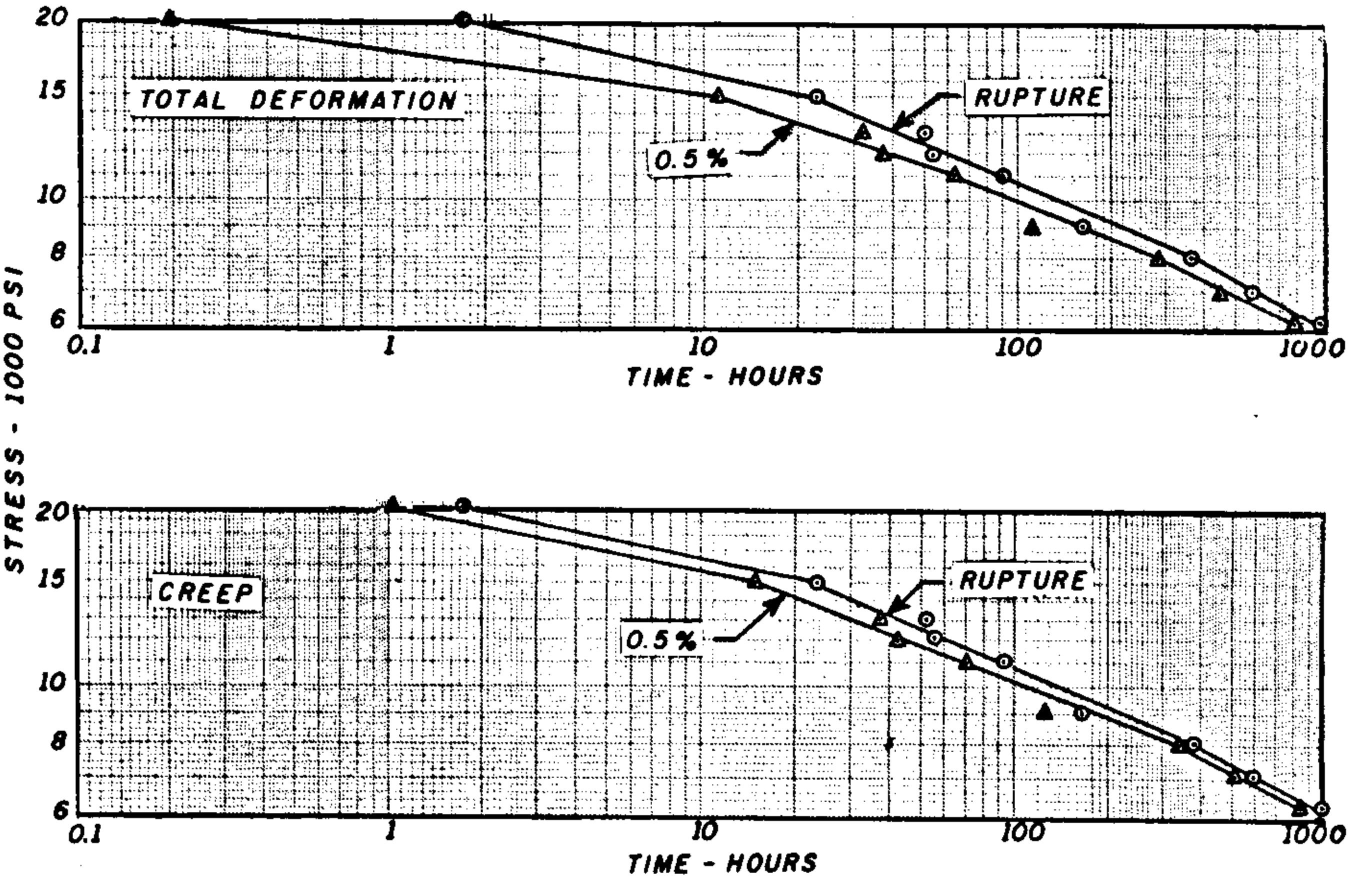

Figure 2 TENSILE CREEP – RUPTURE CHARACTERISTICS OF 2117-T4 ALUMINUM RIVET WIRE AT 450° F.

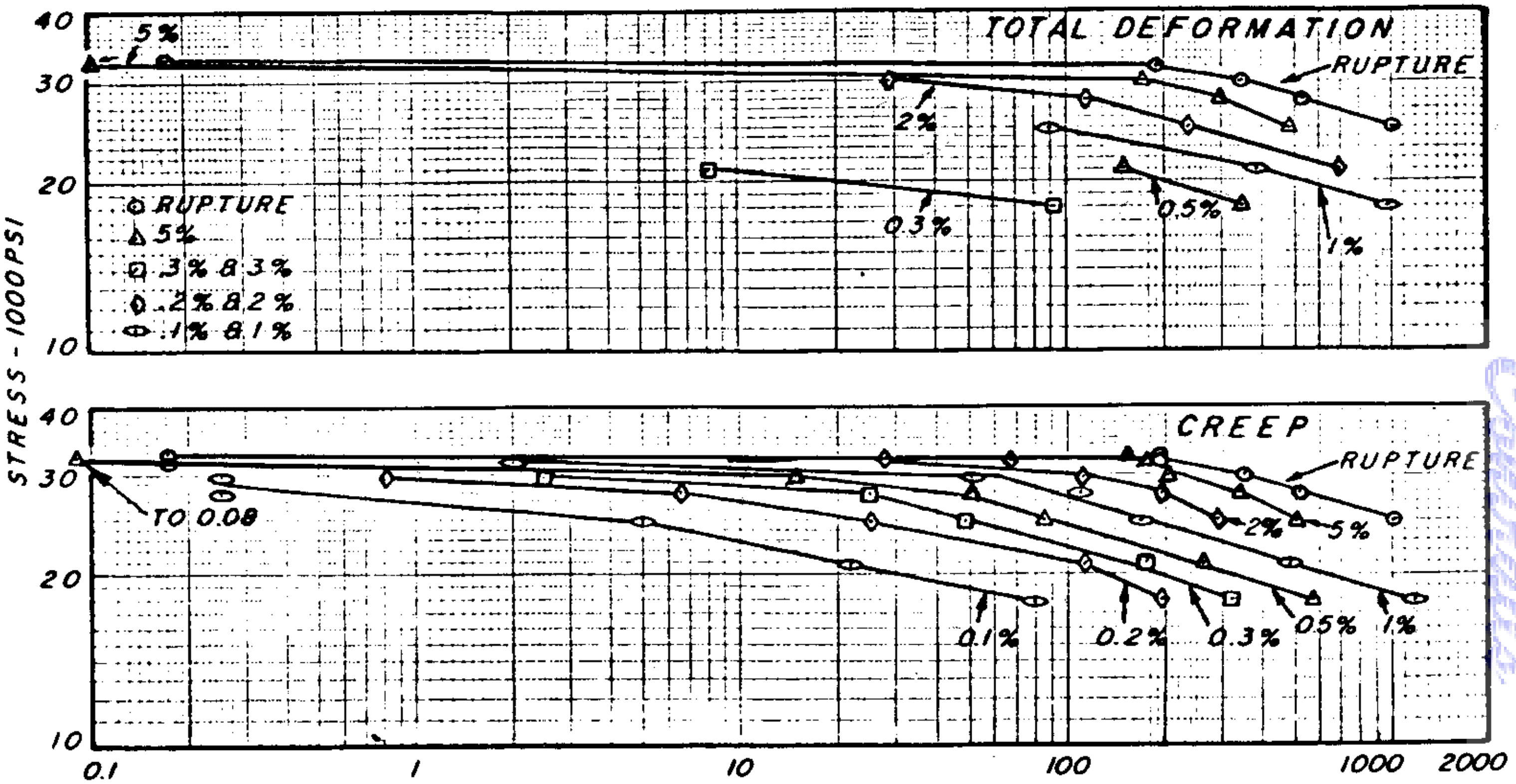

FIGURE 3 TENSILE CREEP - RUPTURE CHARACTERISTICS OF ANNEALED A-70 TITANIUM SHEET AT 700° F.

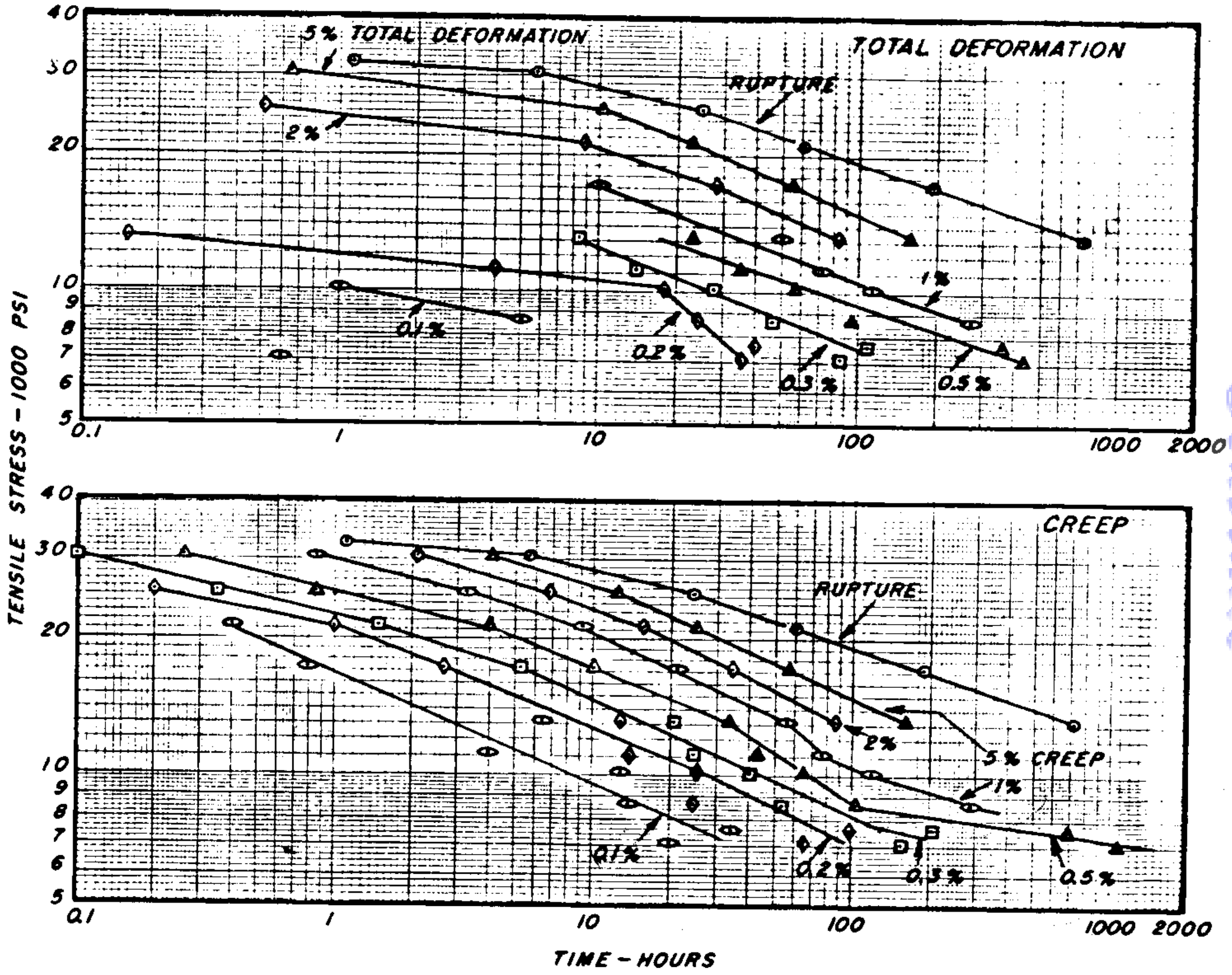

FIGURE 4 TENSILE CREEP-RUPTURE CHARACTERISTICS OF ANNEALED A-70 TITANIUM SHEET AT 800°F.

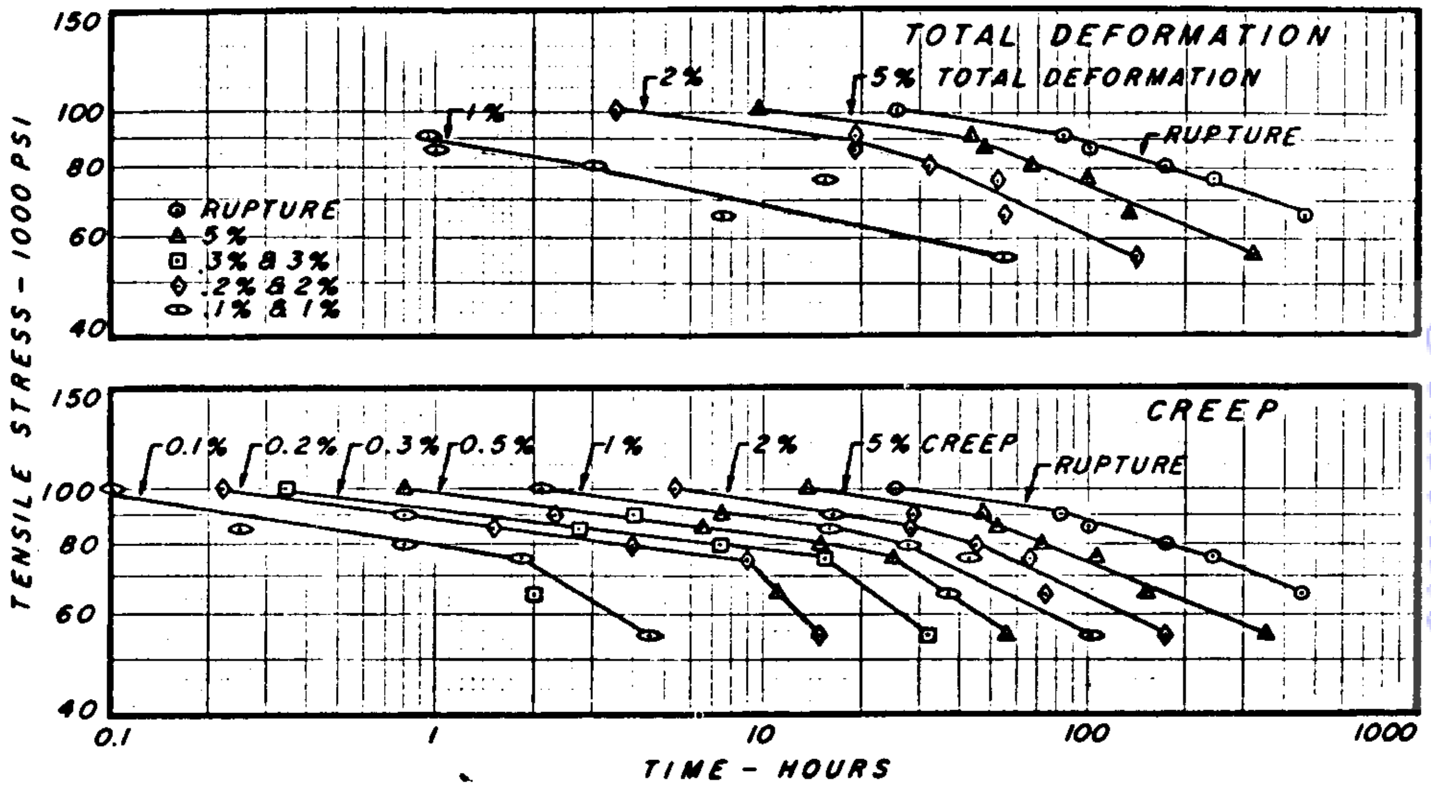

FIGURE 5 TENSILE CREEP-RUPTURE CHARACTERISTICS OF ANNEALED C-110M TITANIUM ALLOY SHEET AT 700° F.

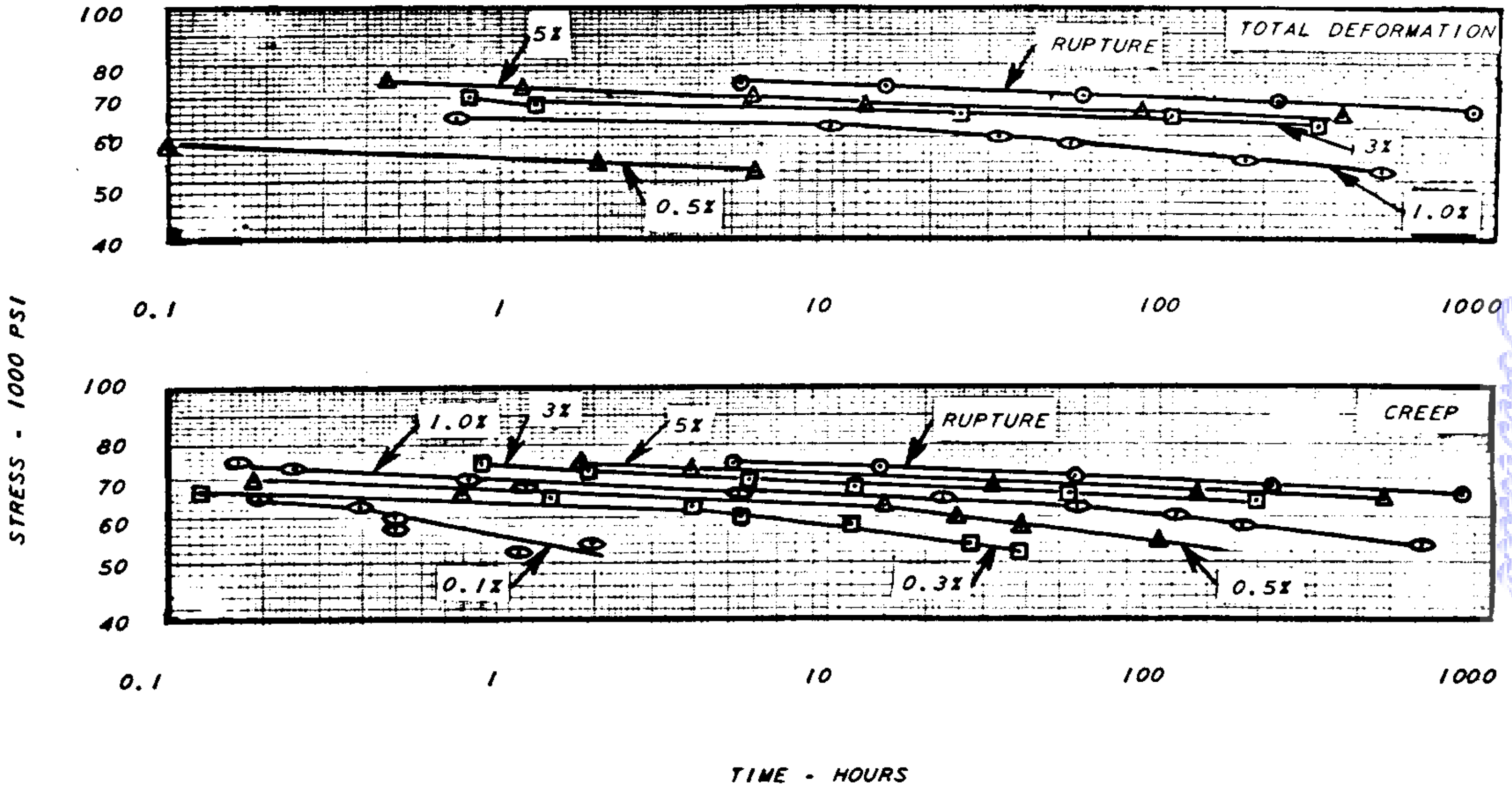

Figure 6 TENSILE CREEP-RUPTURE CHARACTERISTICS OF NORMALIZED SAE 4130 STEEL SHEET AT 800°F.

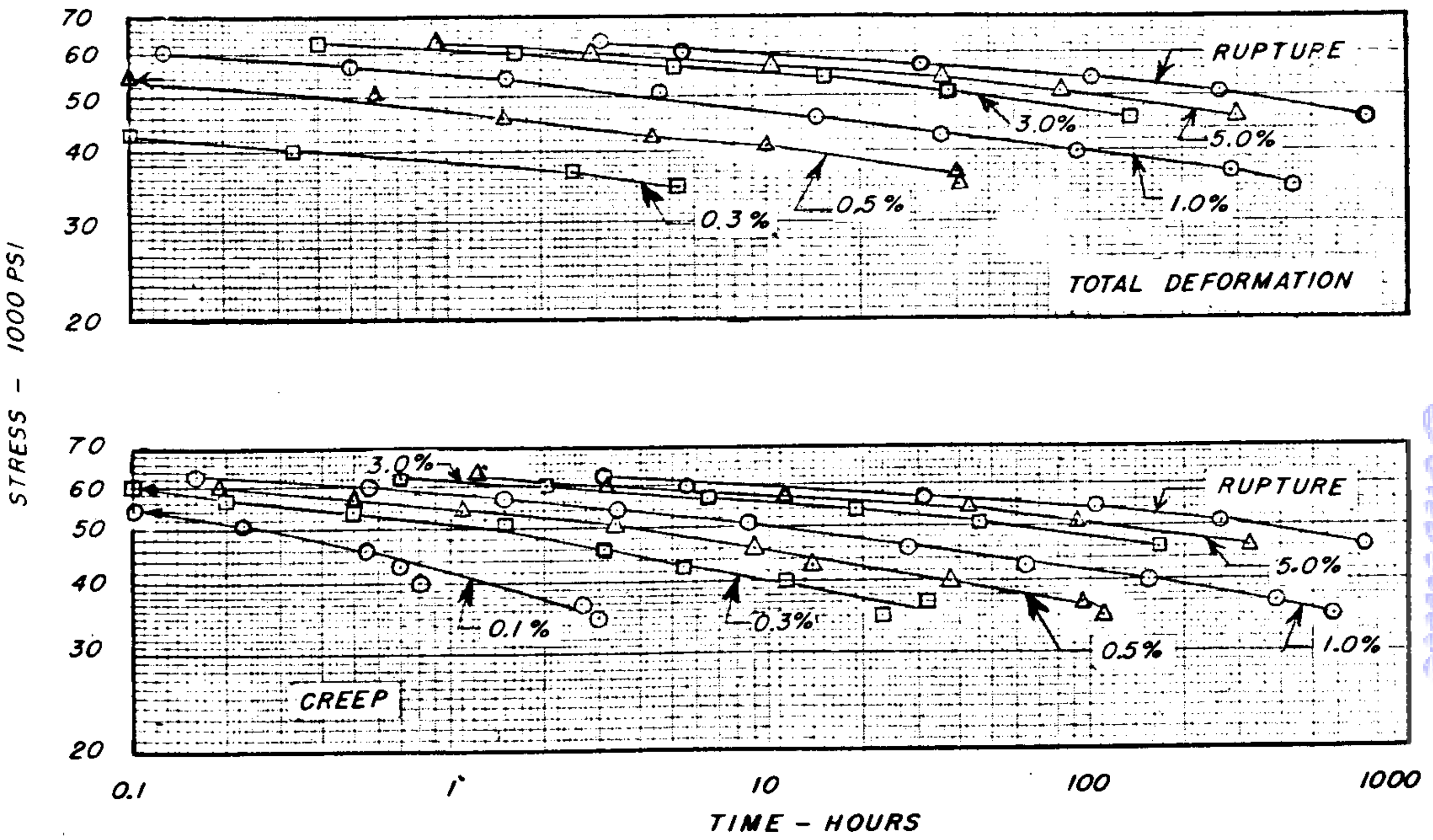

Figure 7 TENSILE CREEP-RUPTURE CHARACTERISTICS OF NORMALIZED SAE 4130 STEEL SHEET AT 900°F.

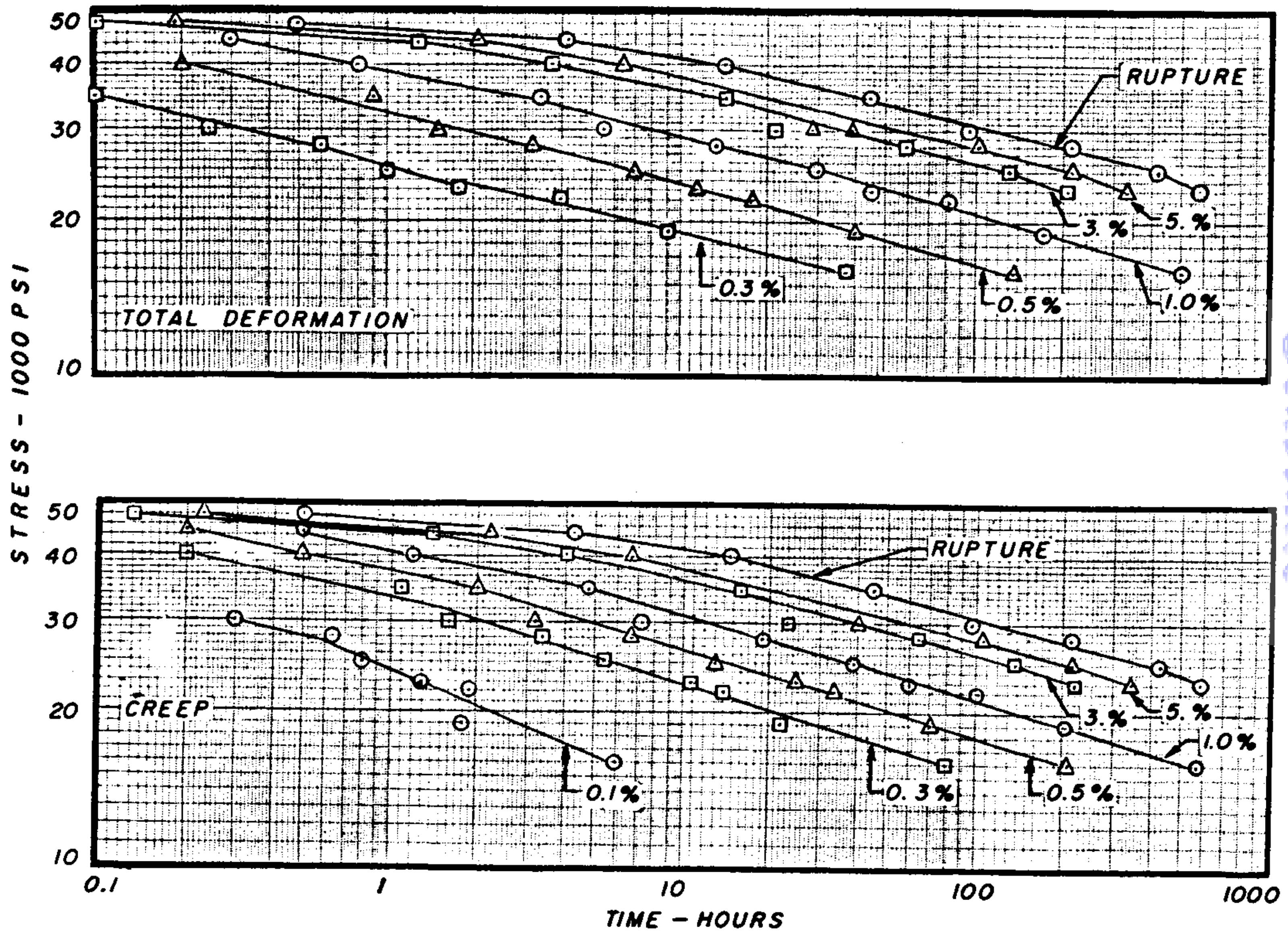

Figure 8 TENSILE CREEP-RUPTURE CHARACTERISTICS OF NORMALIZED SAE 4130 STEEL SHEET AT 1000° F.

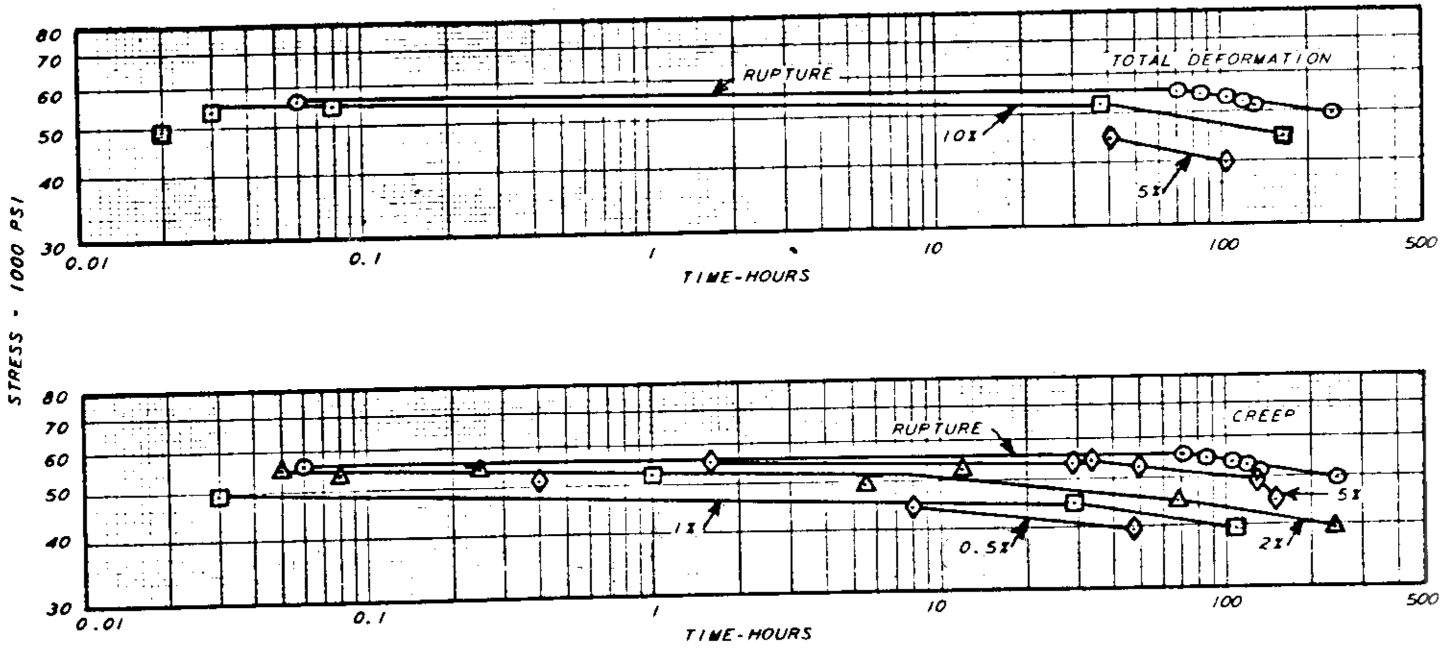

FIGURE 9 BEARING CREEP-RUPTURE CHARACTERISTICS OF ANNEALED A-70 TITANIUM SHEET AT 700°F

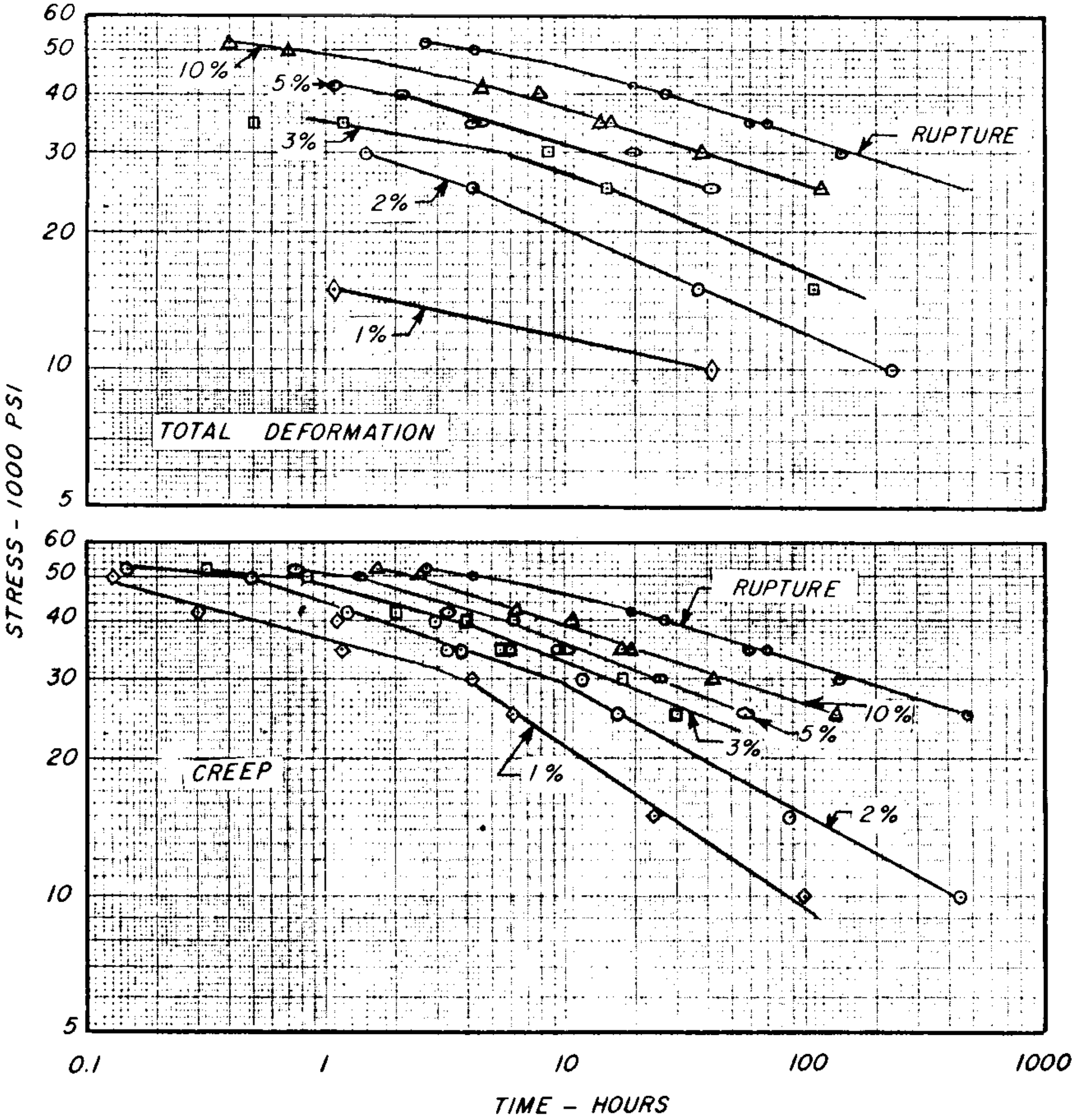

Figure 10 BEARING CREEP - RUPTURE CHARACTERISTICS OF A-70 TITANIUM SHEET AT 800° F.

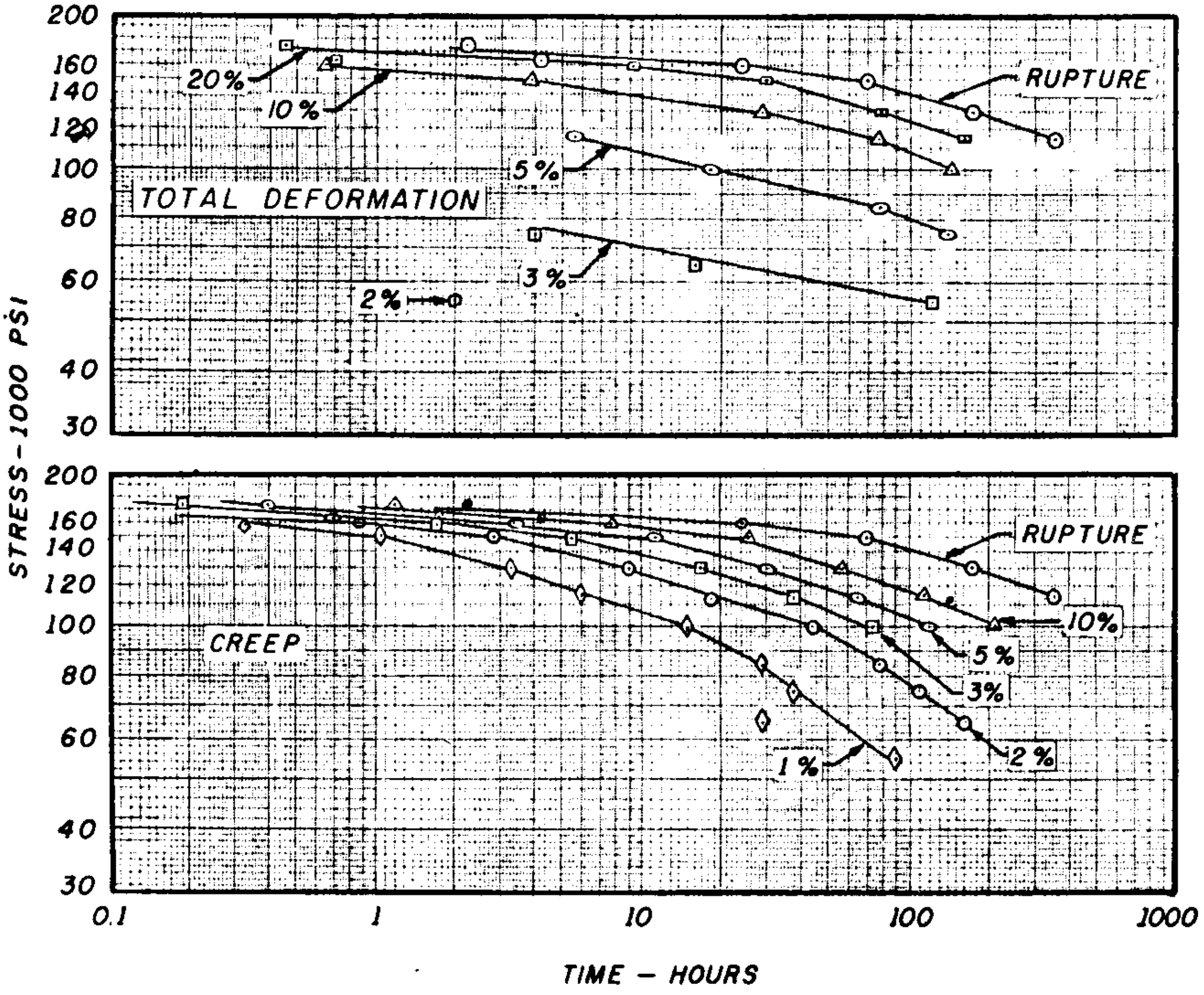

Figure 11 BEARING CREEP-RUPTURE CHARACTERISTICS OF C-110M TITANIUM ALLOY SHEET AT 700° F.

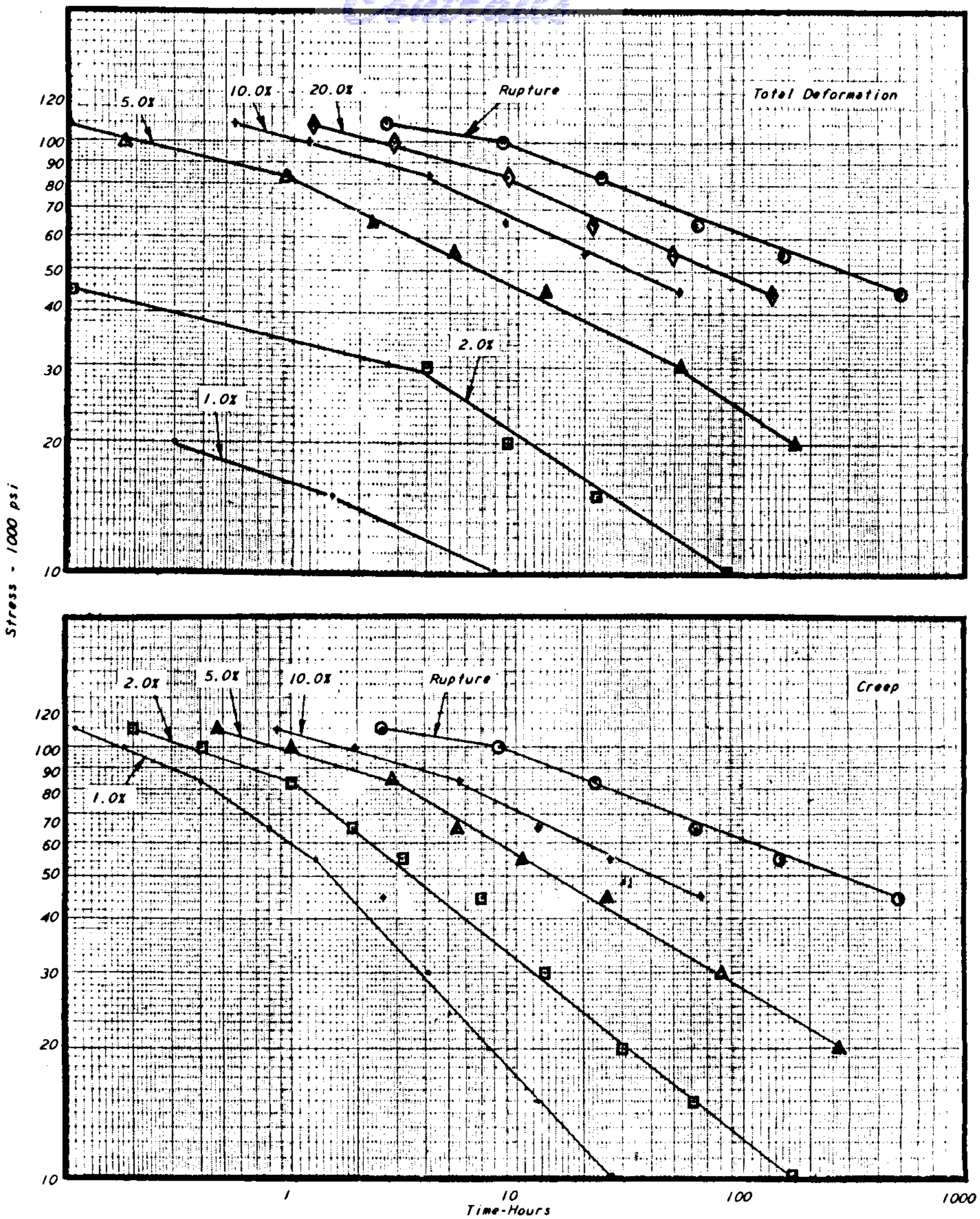

Figure 12 - BEARING CREEP-RUPTURE CHARACTERISTICS OF C-110M TITANIUM ALLOY SHEET AT 800° F

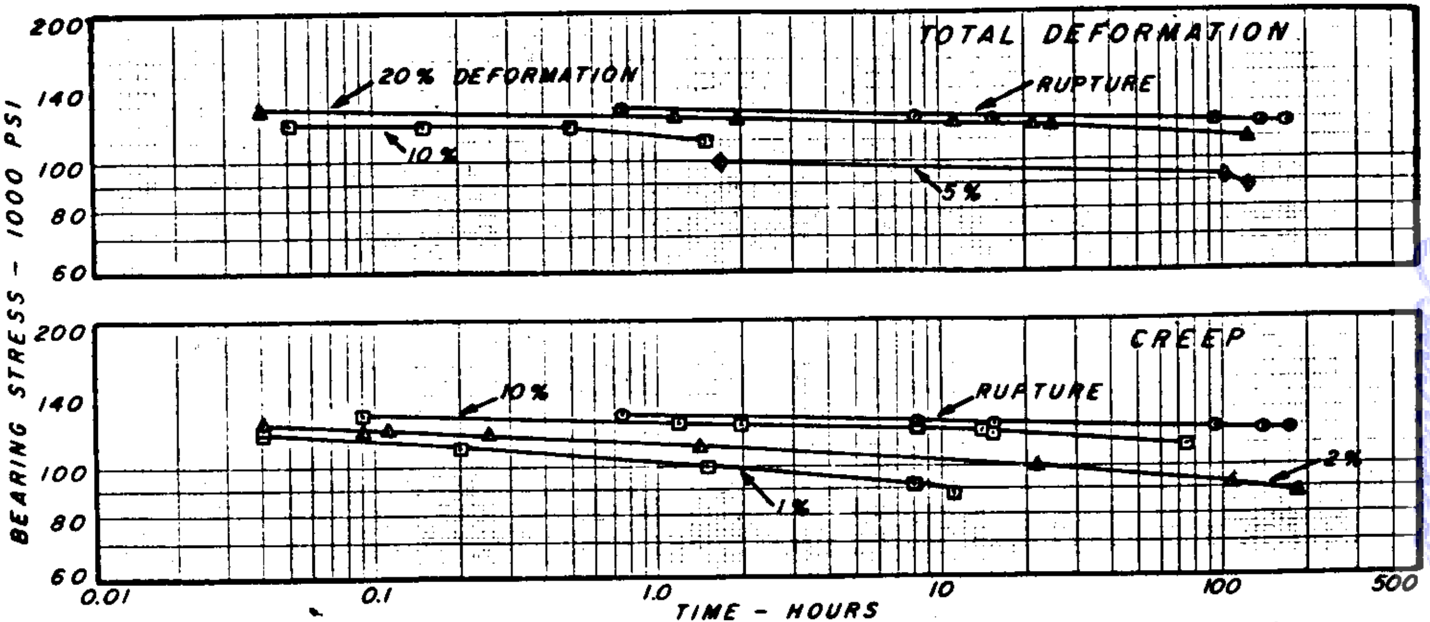

FIGURE 13 BEARING CREEP - RUPTURE CHARACTERISTICS OF NORMALIZED SAE 4130 STEEL SHEET AT 800° F

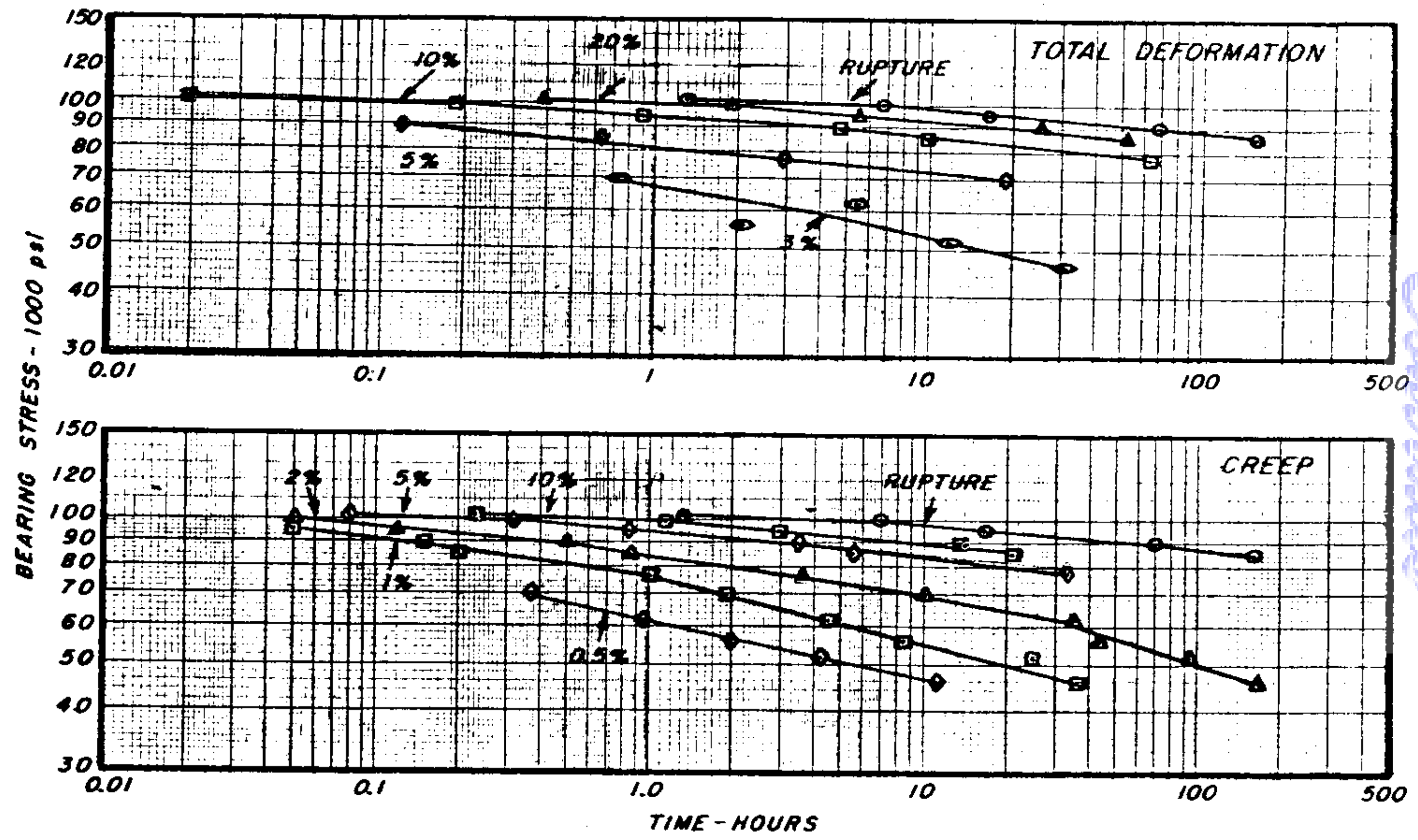

FIGURE 14 BEARING CREEP-RUPTURE CHARACTERISTICS OF NORMALIZED SAE4130 STEEL SHEET AT 900°F.

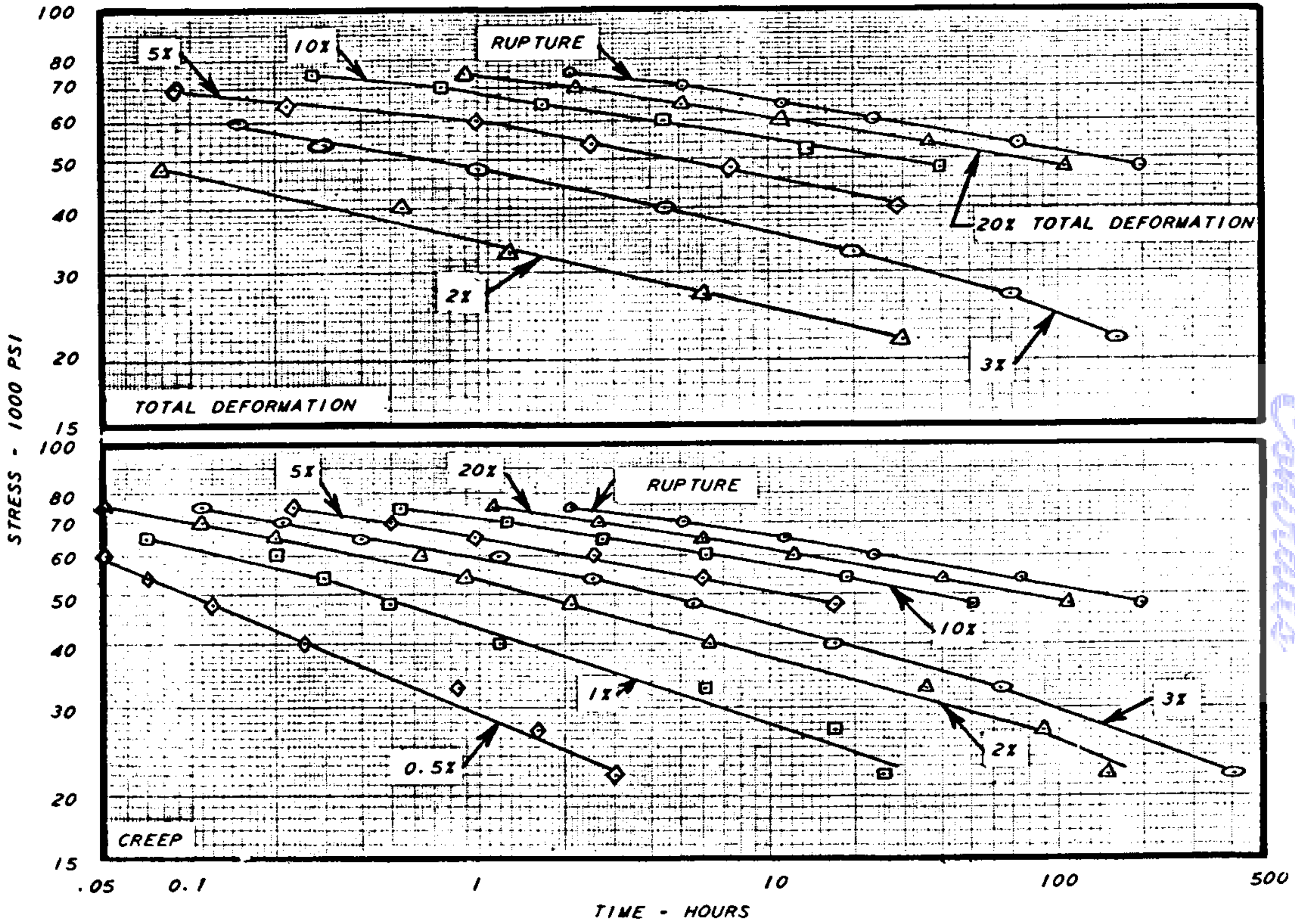

Figure 15 BEARING CREEP-RUPTURE CHARACTERISTICS OF NORMALIZED SAE 4130 STEEL SHEET AT 1000°F.

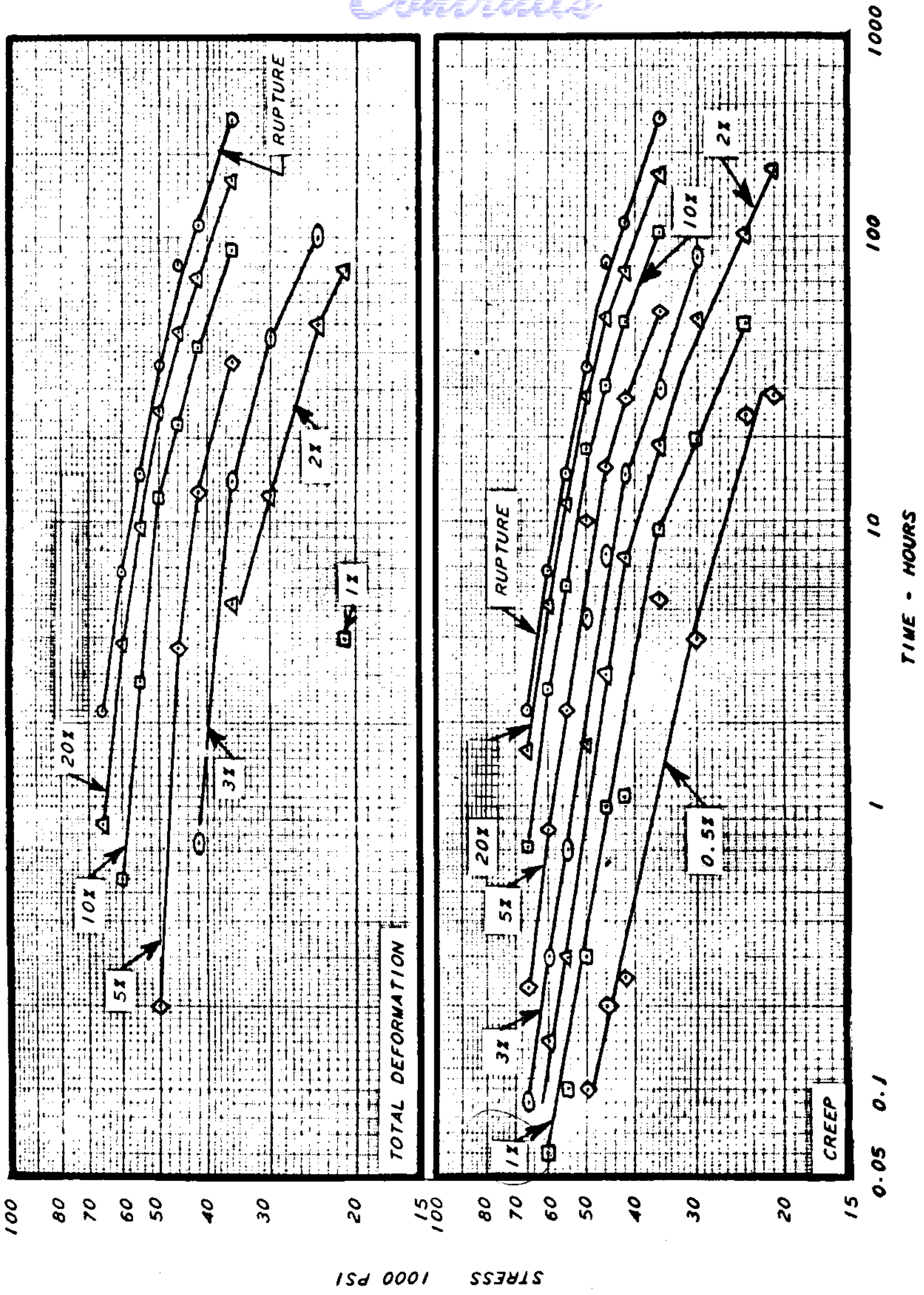

Figure 16 BEARING CREEP-RUPTURE CHARACTERISTICS OF ANNEALED TYPE 321 STAINLESS STEEL SHEET AT 1200°F

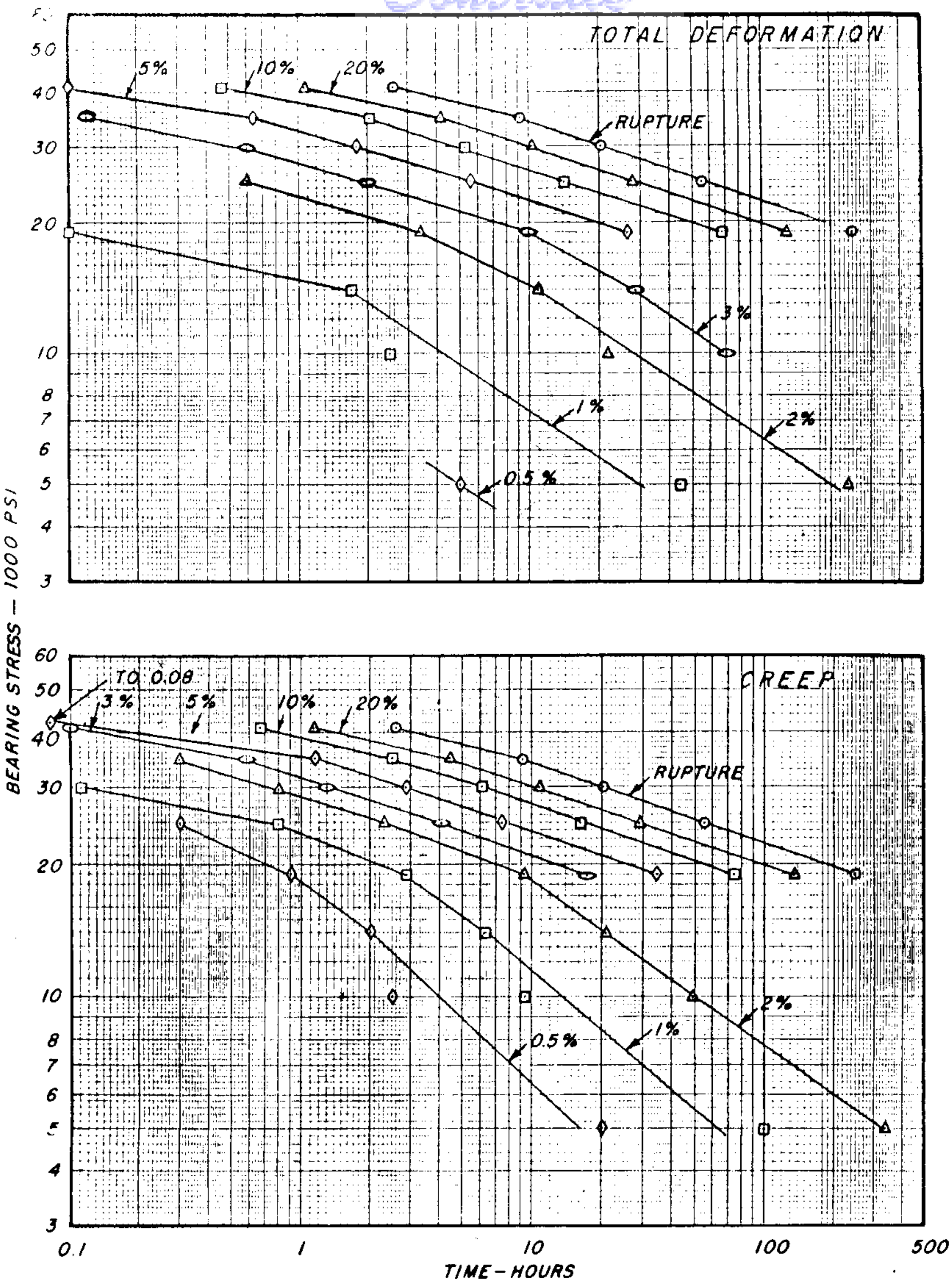

FIGURE 17 BEARING CREEP–RUPTURE CHARACTERISTICS OF ANNEALED TYPE 321 STAINLESS STEEL SHEET AT 1350°F

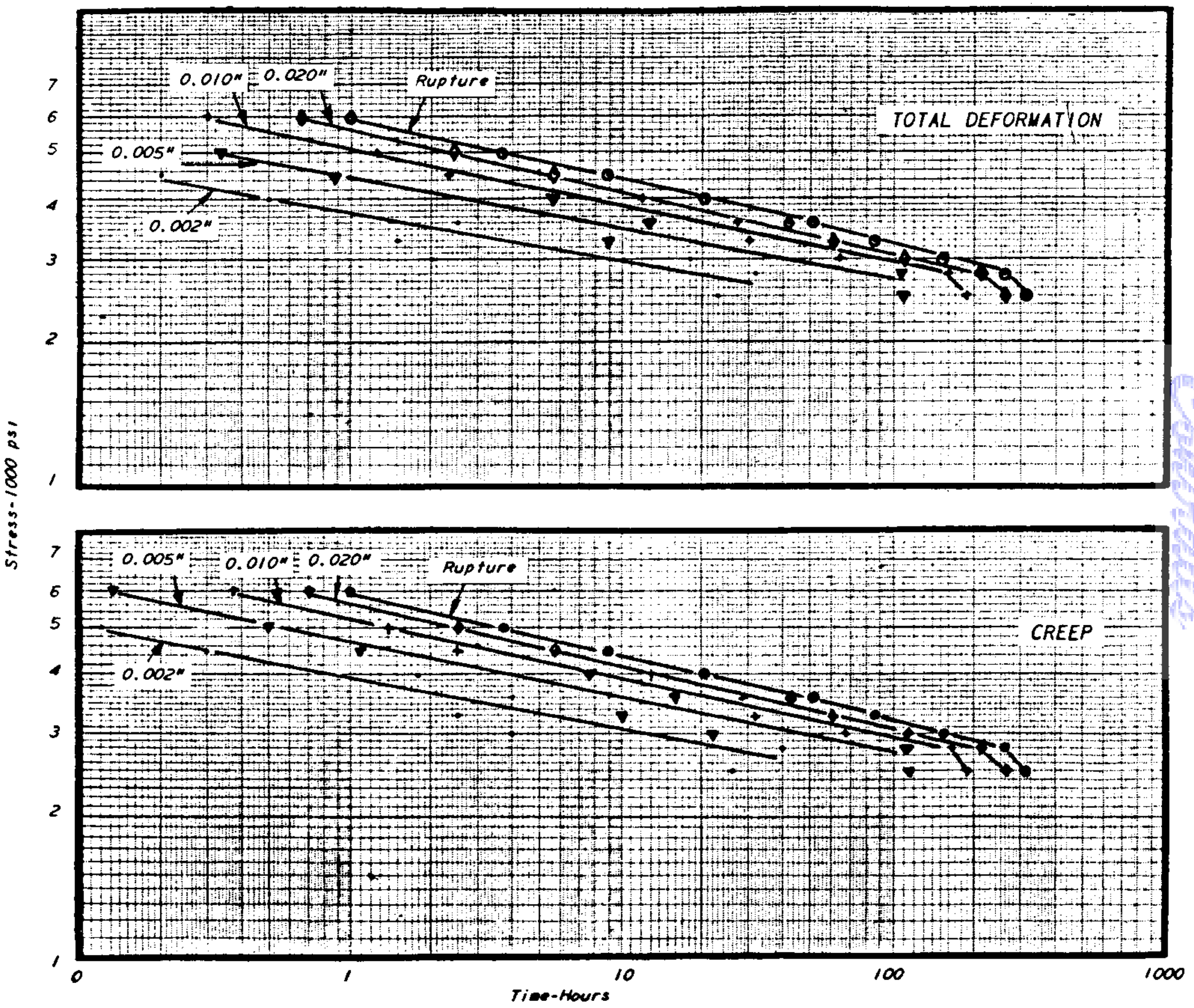

Figure 18 Shear-Pin Deformation Characteristics of 2024-T3 Aluminum Plate at 600°F.

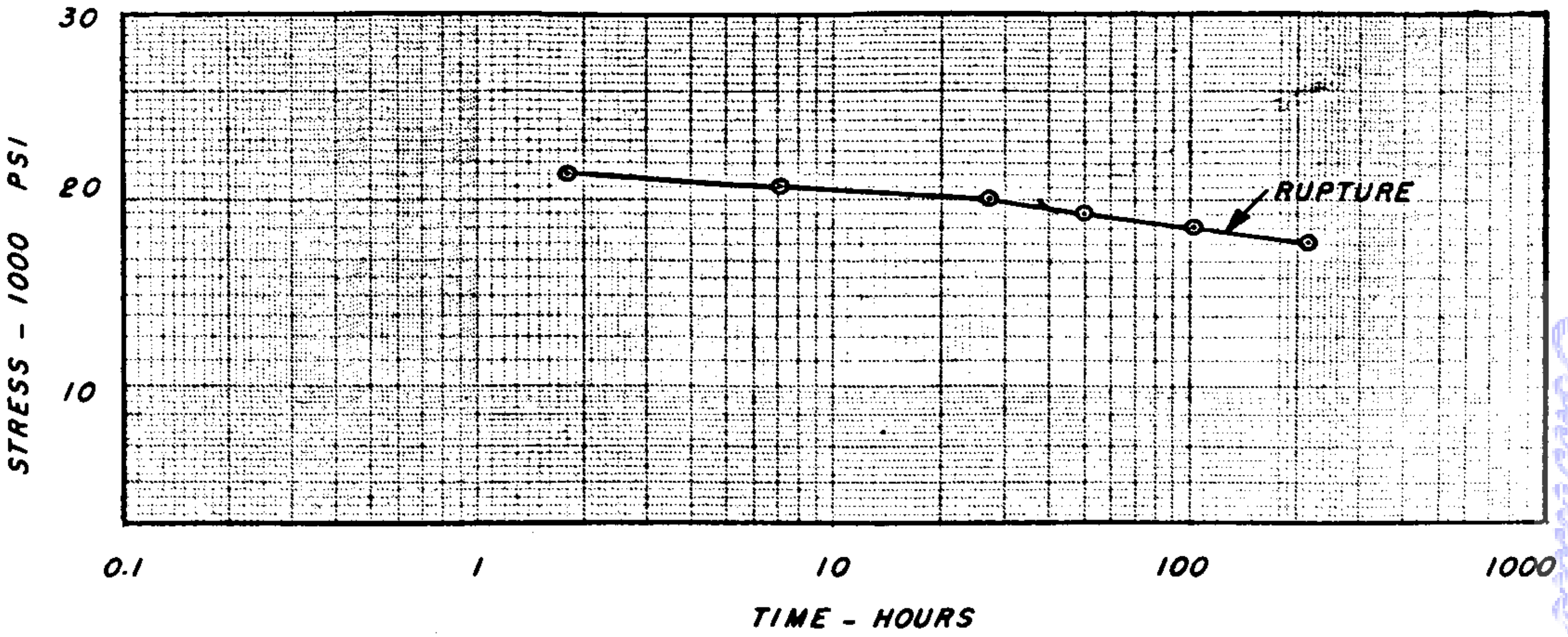

Figure 19 SHEAR-PIN DEFORMATION CURVE FOR
2117-T4 ALUMINUM RIVET WIRE
AT 300° F.

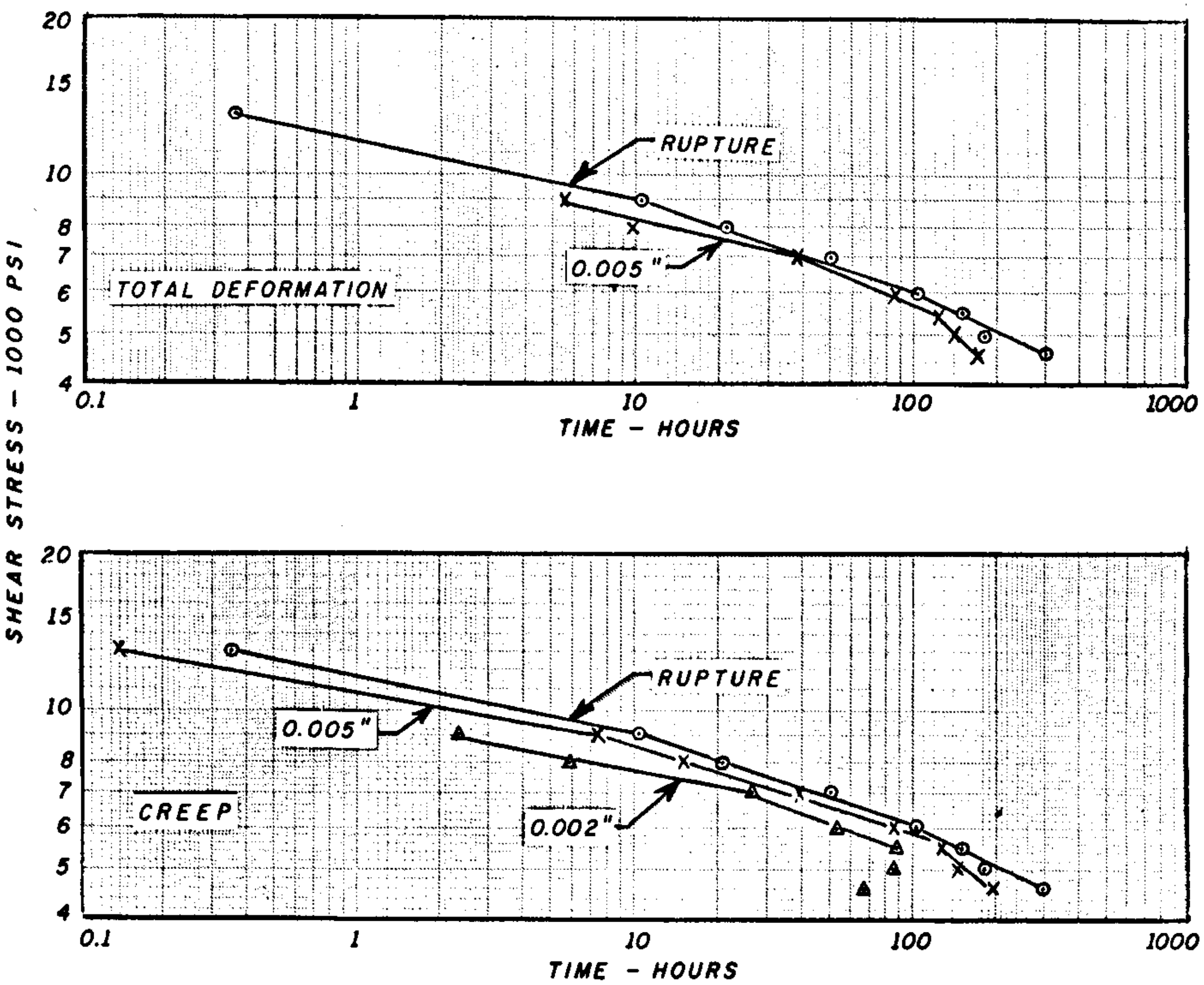

Figure 20 SHEAR-PIN DEFORMATION CHARACTERISTICS OF 2117-T4 ALUMINUM RIVET WIRE AT 450°F.

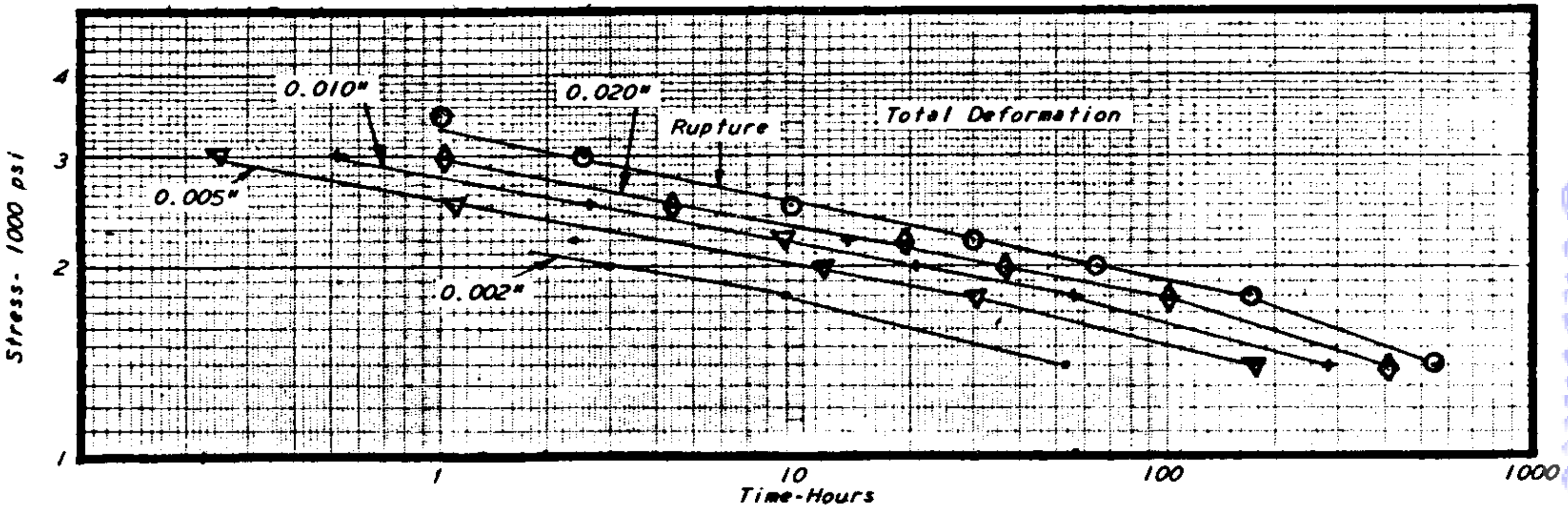

Figure 21 Shear-Pin Deformation Characteristics of 2117-T4 Aluminum Rivet Wire at 600°F.

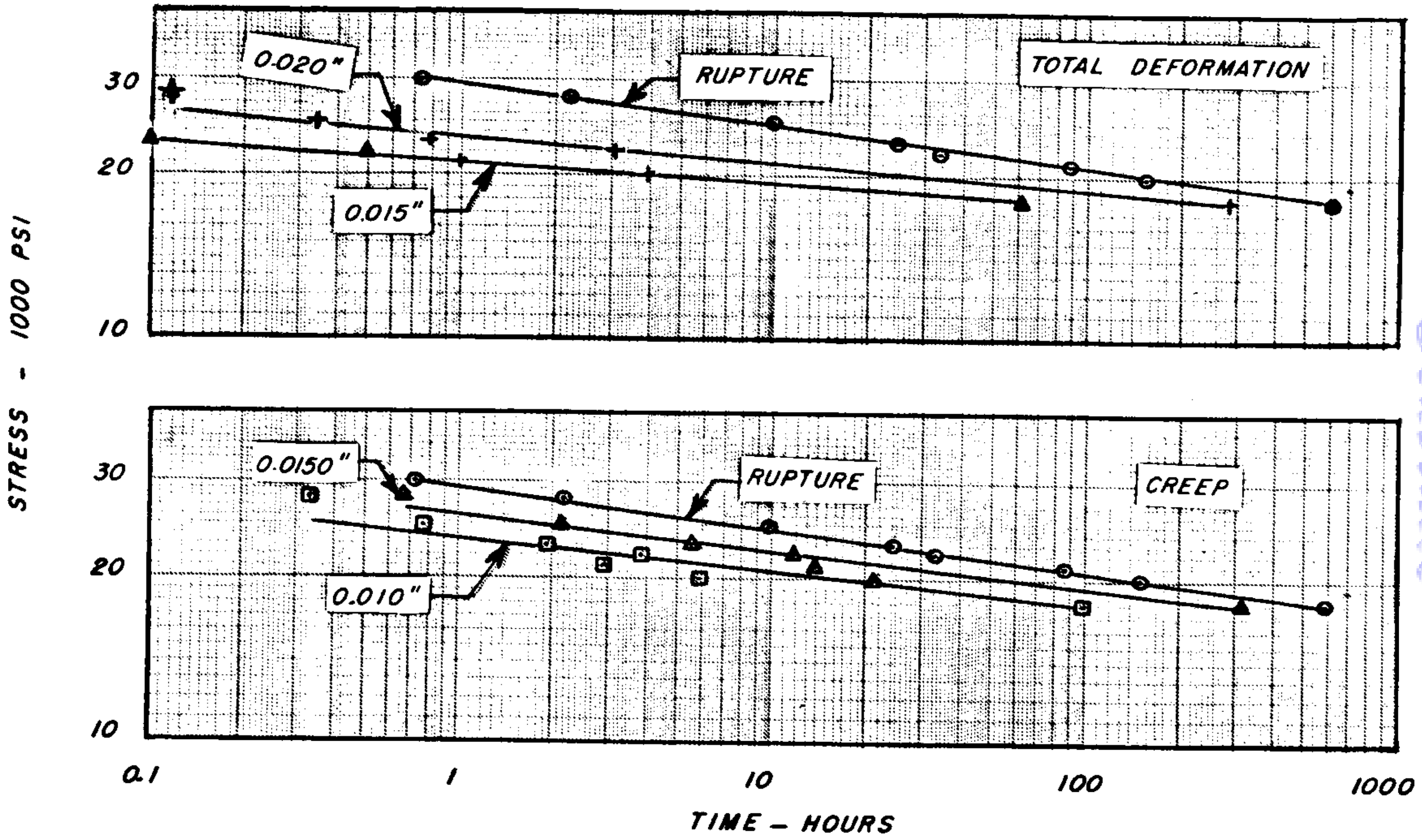

Figure 22 SHEAR-PIN DEFORMATION CHARACTERISTICS OF MONEL AT 1000° F.

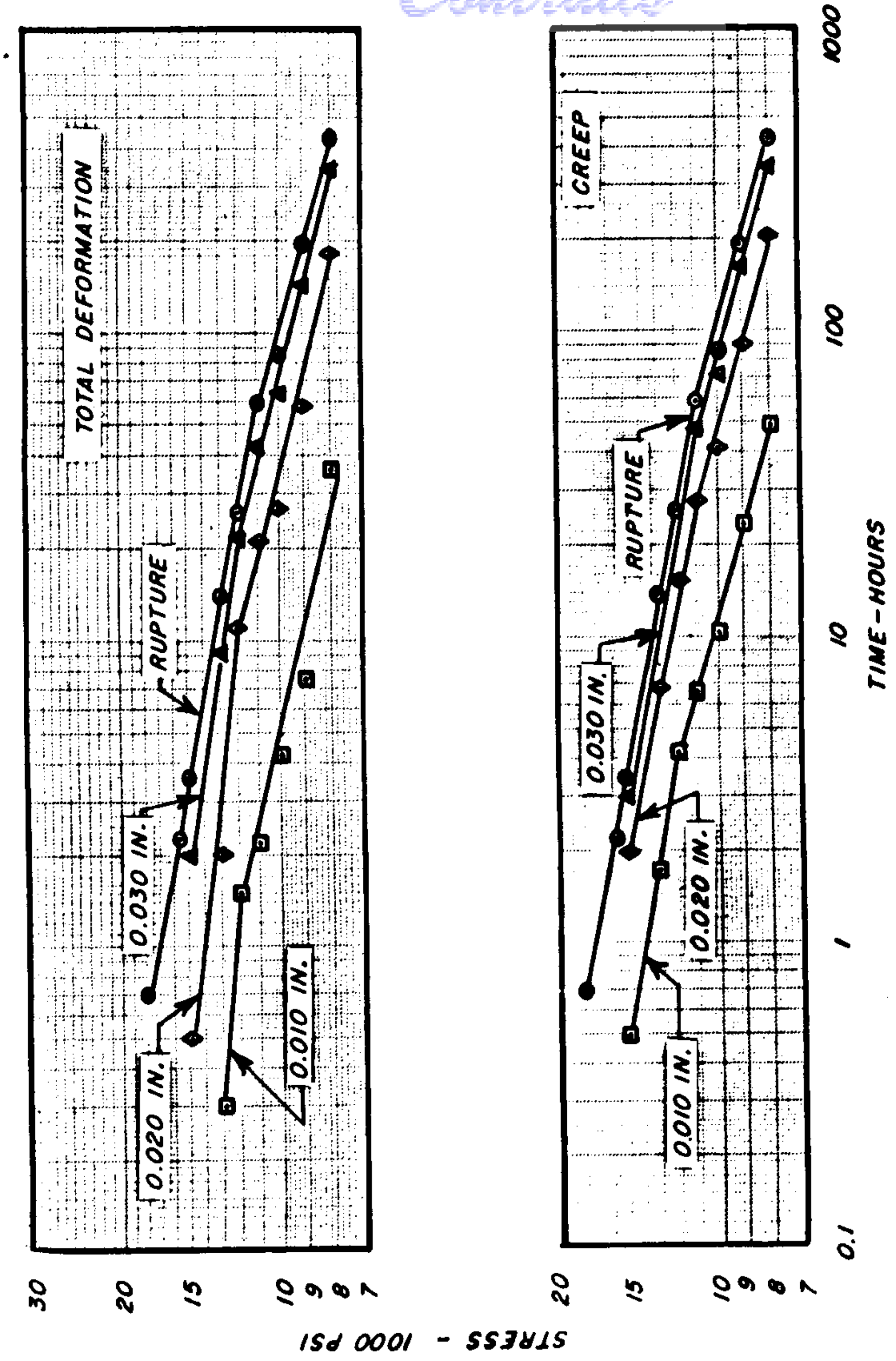

Figure 23 SHEAR-PIN DEFORMATION CHARACTERISTICS OF ½ INCH DIAMETER MONEL WIRE AT 1200°F.

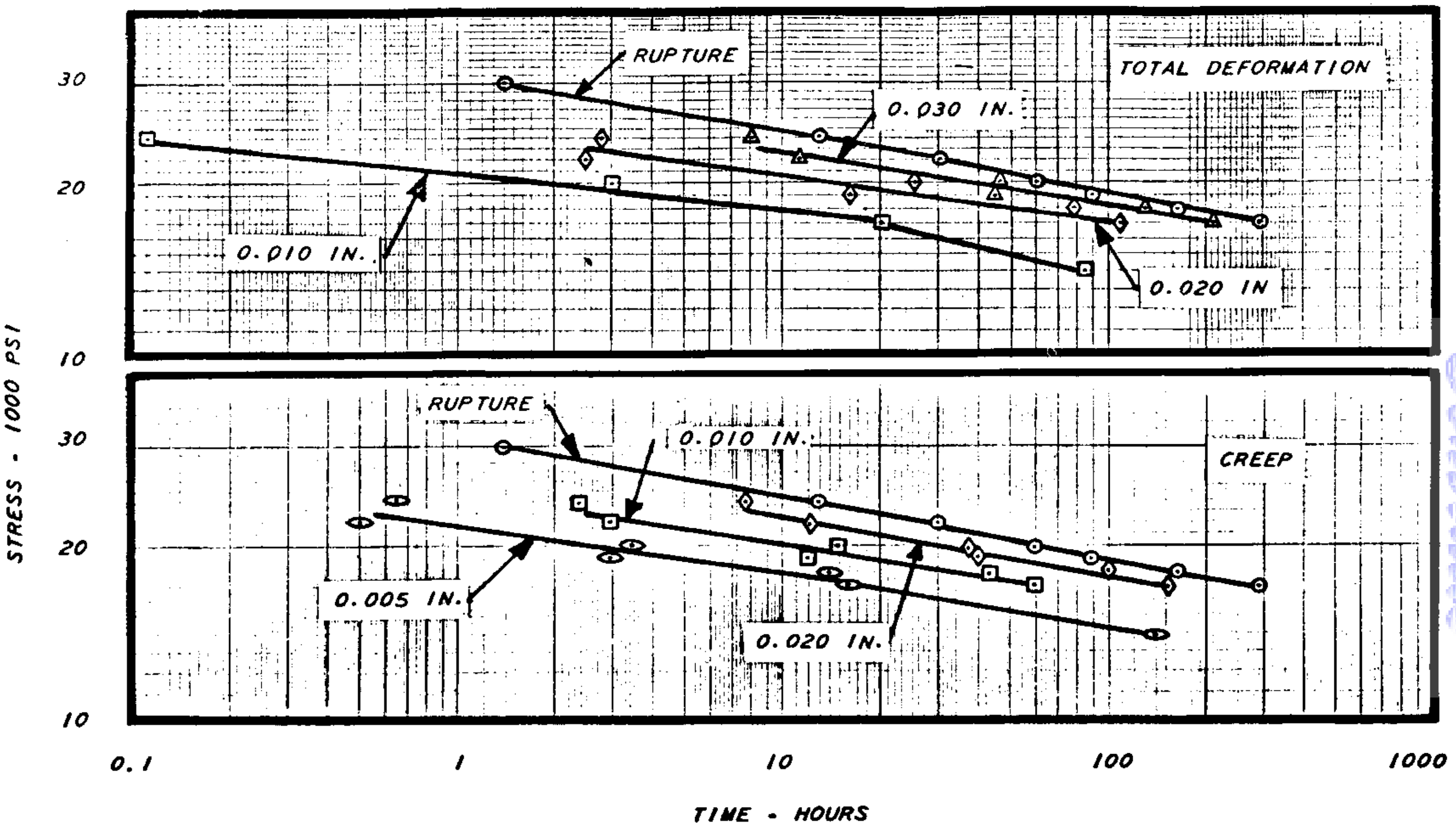

Figure 24 SHEAR-PIN DEFORMATION CHARACTERISTICS OF 1/2 INCH DIAMETER TYPE 301 STAINLESS STEEL WIRE AT 1200° F

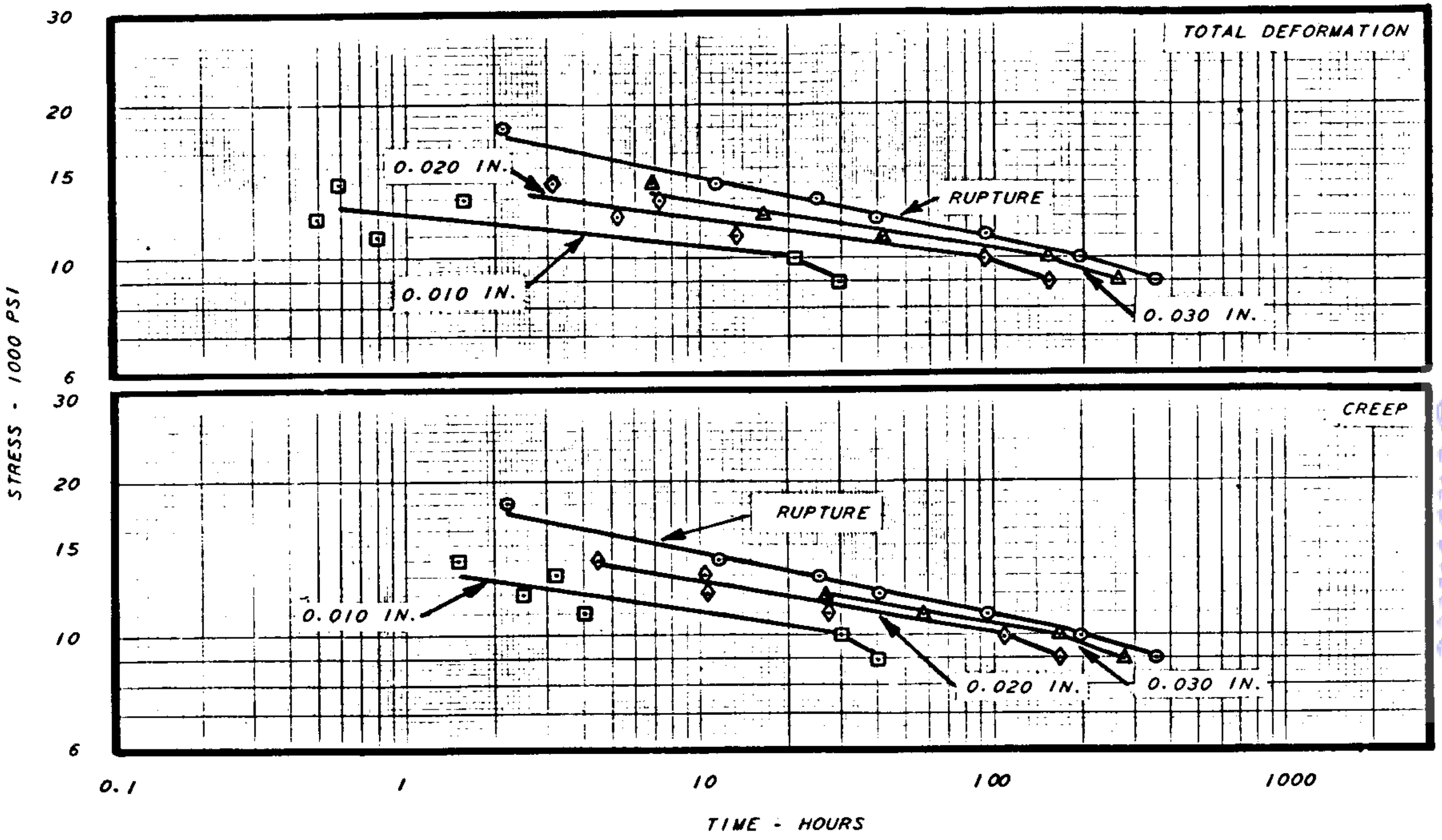

Figure 25 SHEAR-PIN DEFORMATION CHARACTERISTICS OF 1/2 INCH DIAMETER TYPE 301 STAINLESS STEEL WIRE AT 1350°F.

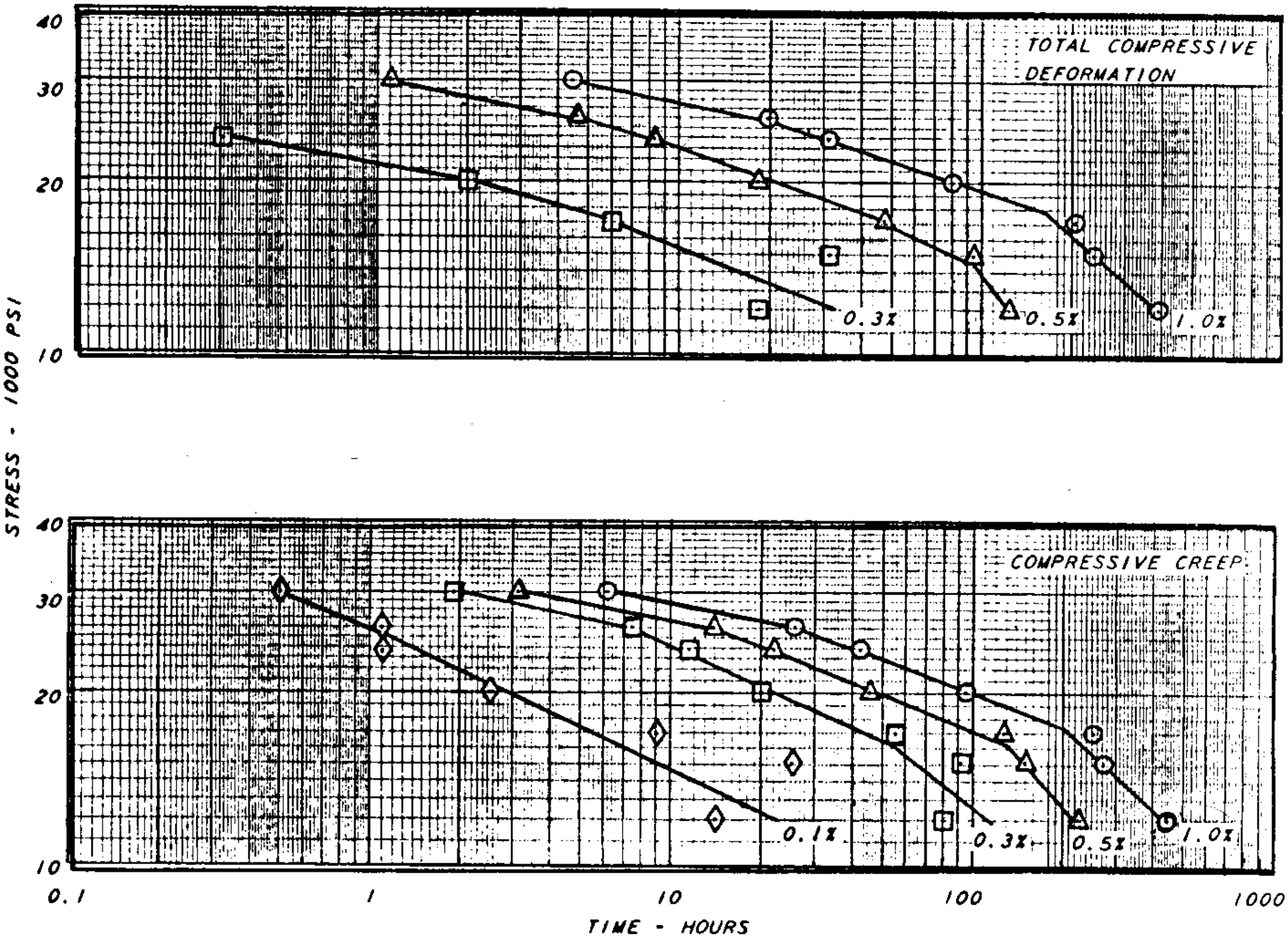

Figure 26 COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM PLATE AT 450°F USING TYPE 1100 ALUMINUM RESTRAINING FIXTURE WEDGES

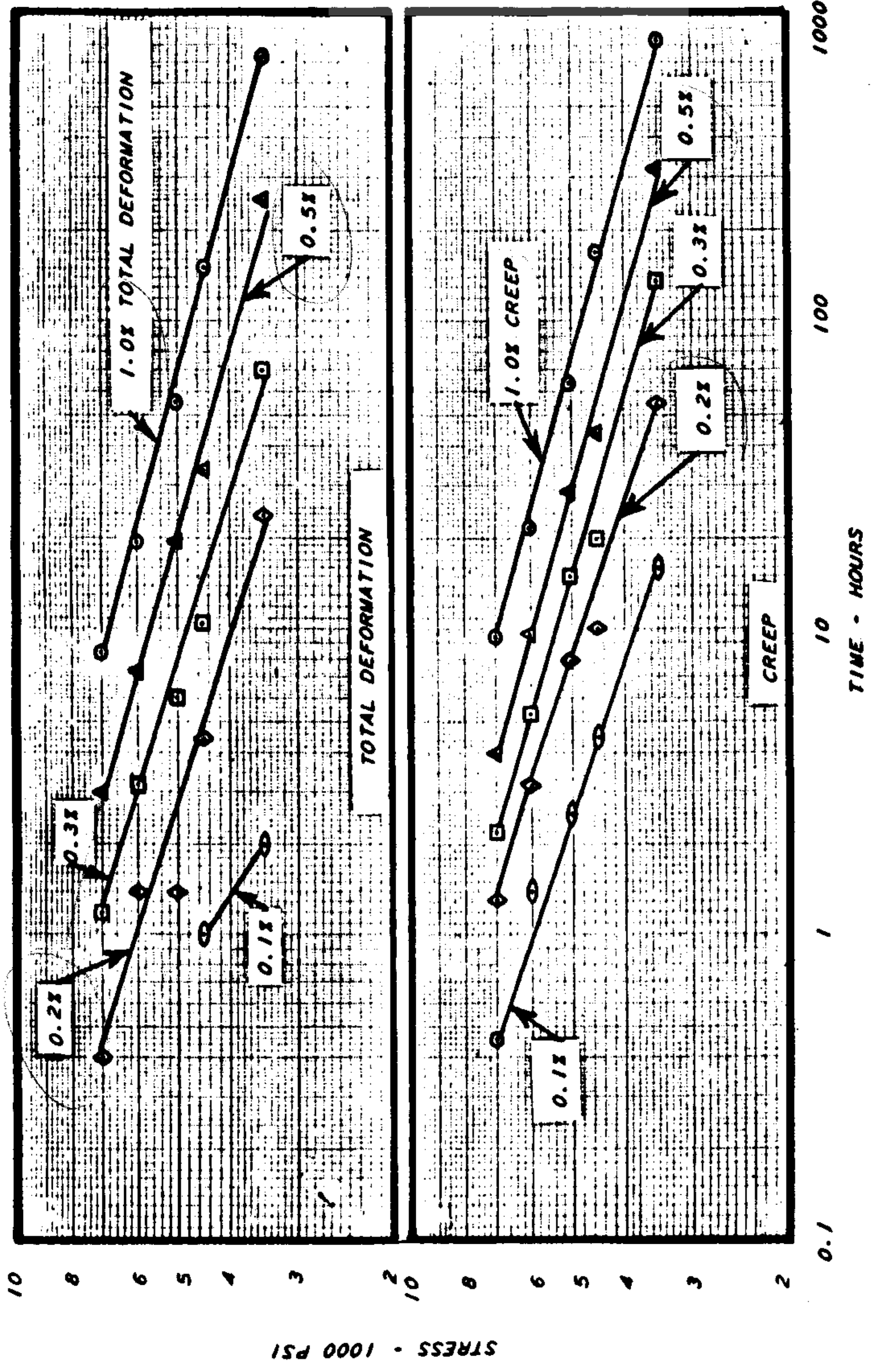

Figure 27 COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY PLATE AT 600°F.

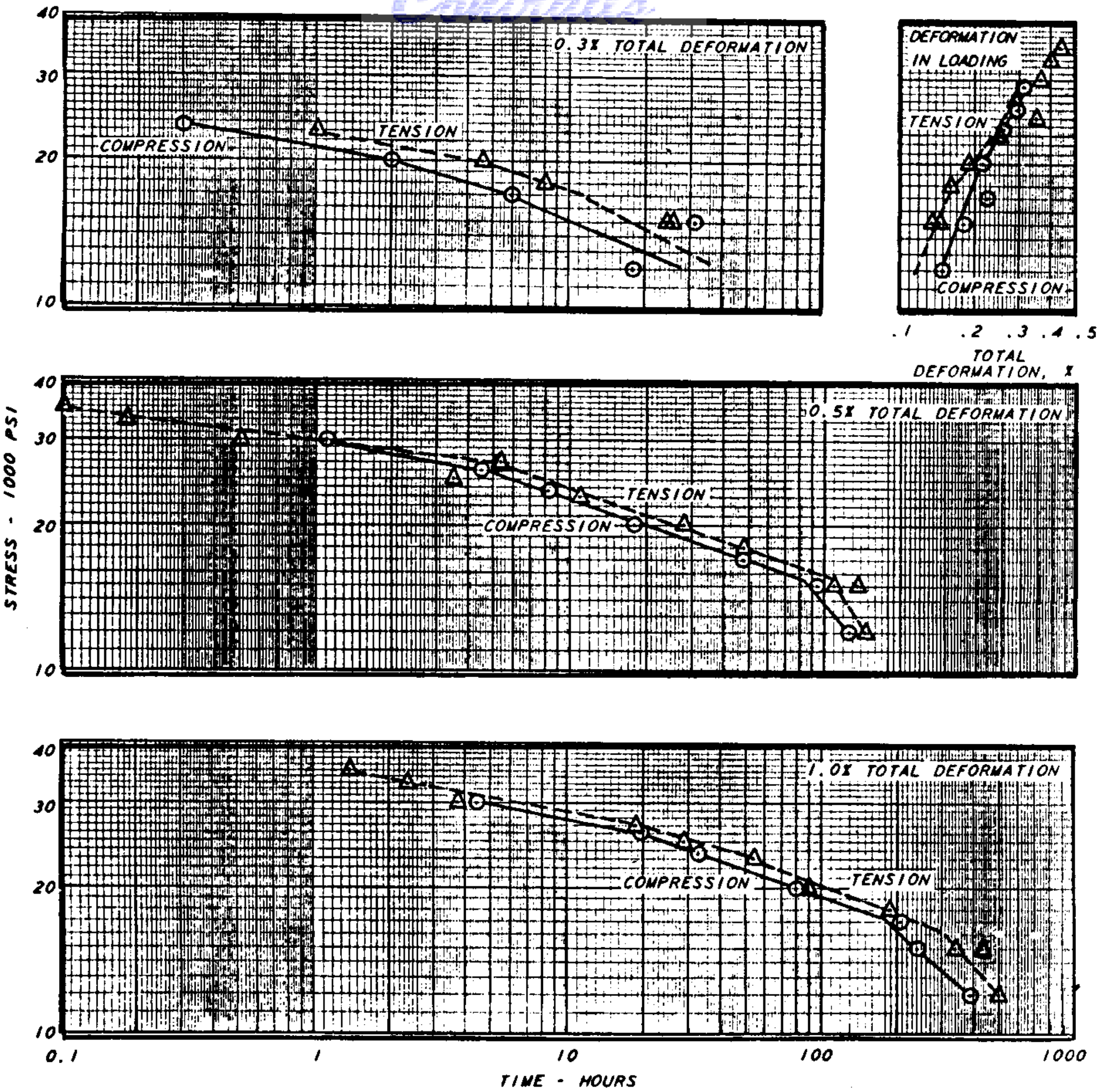

Figure 28 COMPARISON OF TENSION AND COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM PLATE AT 450°F USING TYPE 1100 ALUMINUM RESTRAINING FIXTURE WEDGES

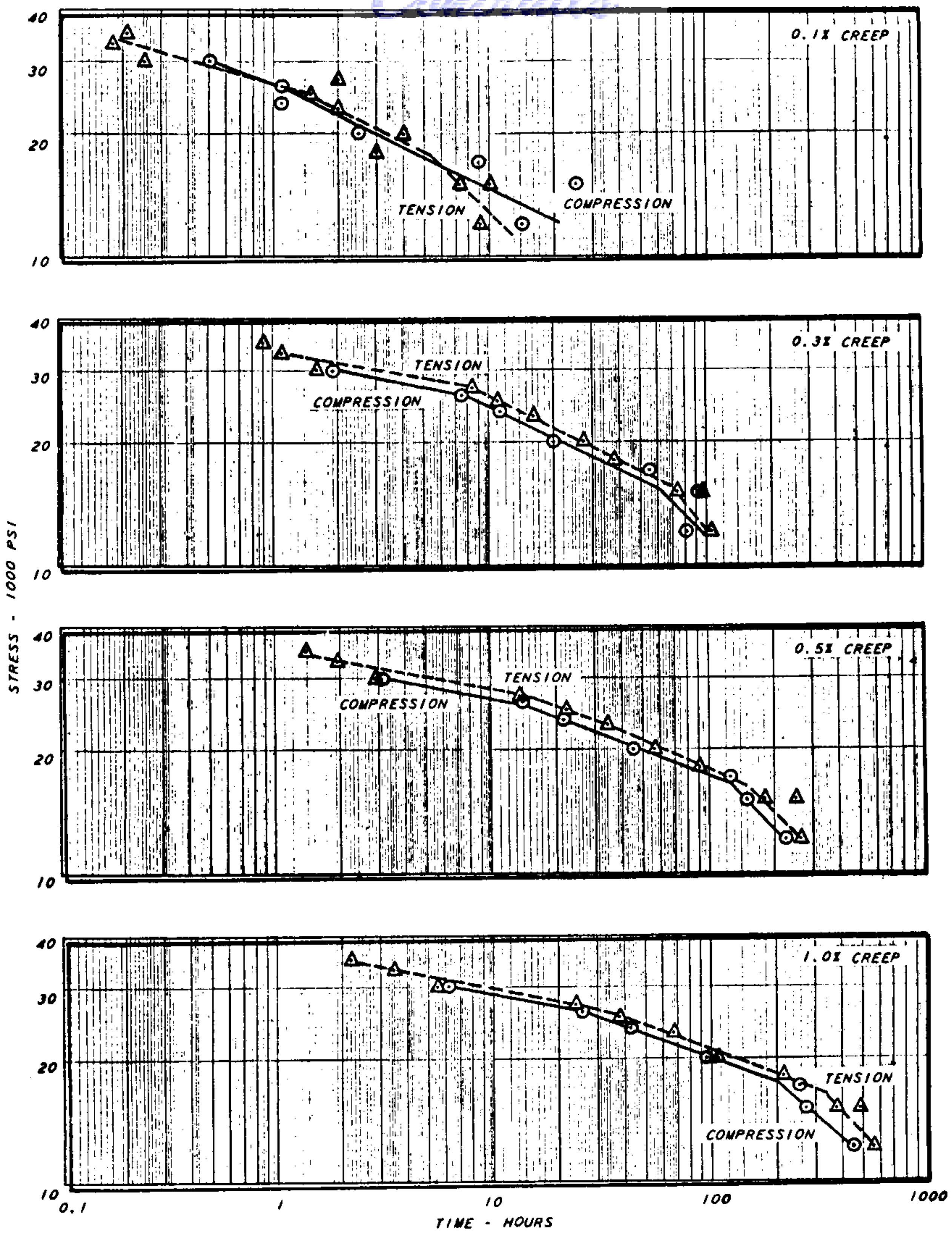

Figure 29 COMPARISON OF TENSION AND COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM PLATE AT 450°F USING TYPE 1100 ALUMINUM RESTRAINING FIXTURE WEDGES

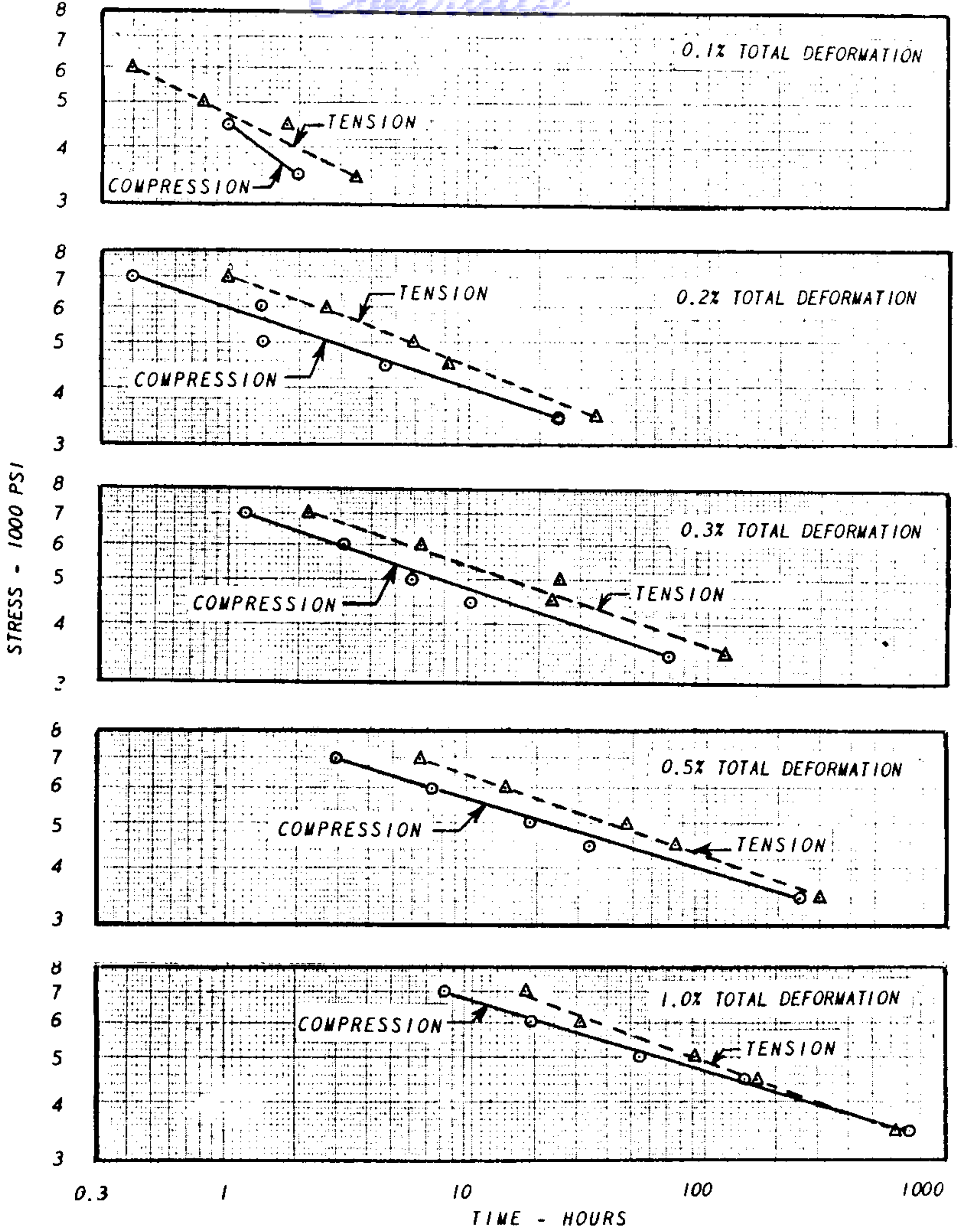

Figure 30 COMPARISON OF TENSION AND COMPRESSION TOTAL DEFORMATION CHARACTERISTICS FOR 2024-T3 ALUMINUM ALLOY PLATE AT 600°F.

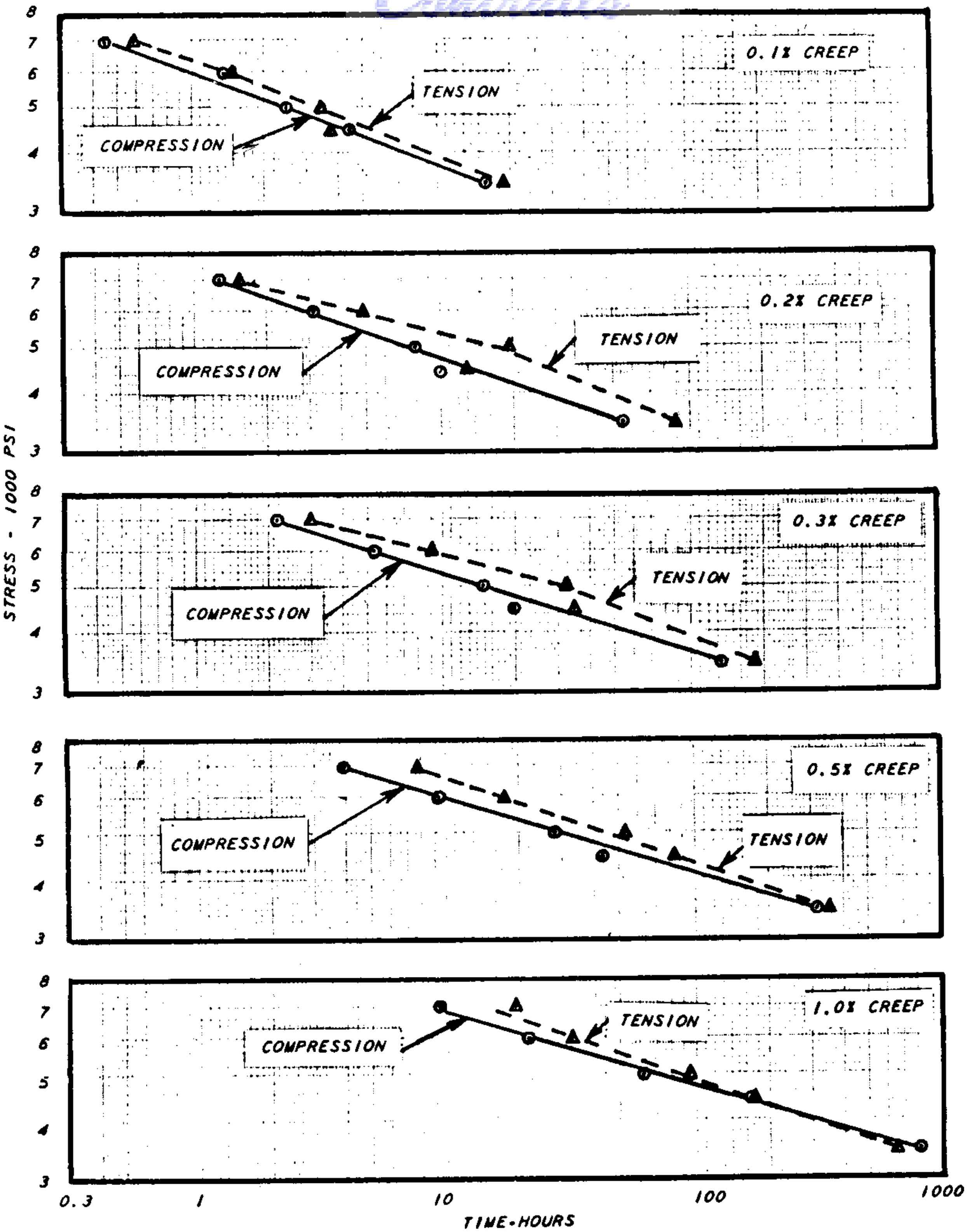

Figure 31 COMPARISON OF TENSION AND COMPRESSION - CREEP CHARACTERISTICS FOR 2024-T3 ALUMINUM ALLOY PLATE AT 600°F.

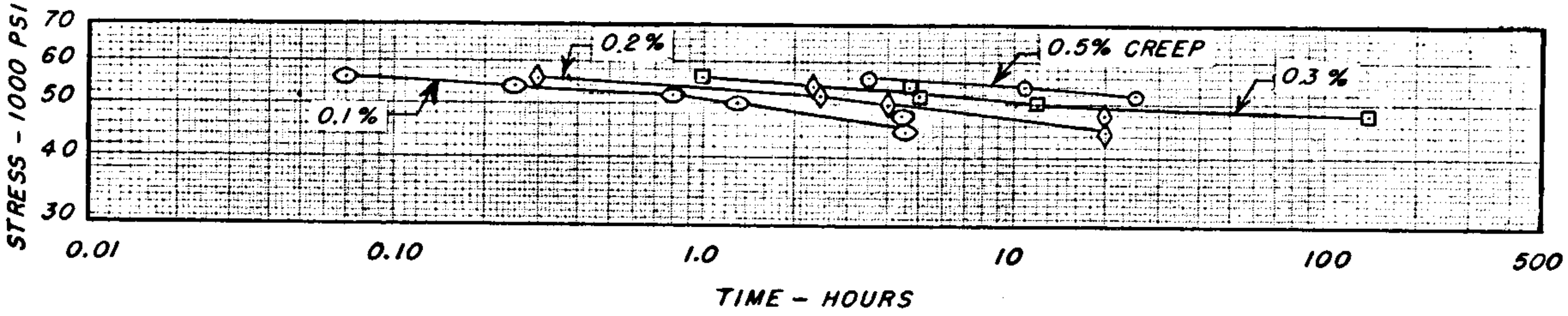

Figure 32 COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM SHEET AT 300° F.

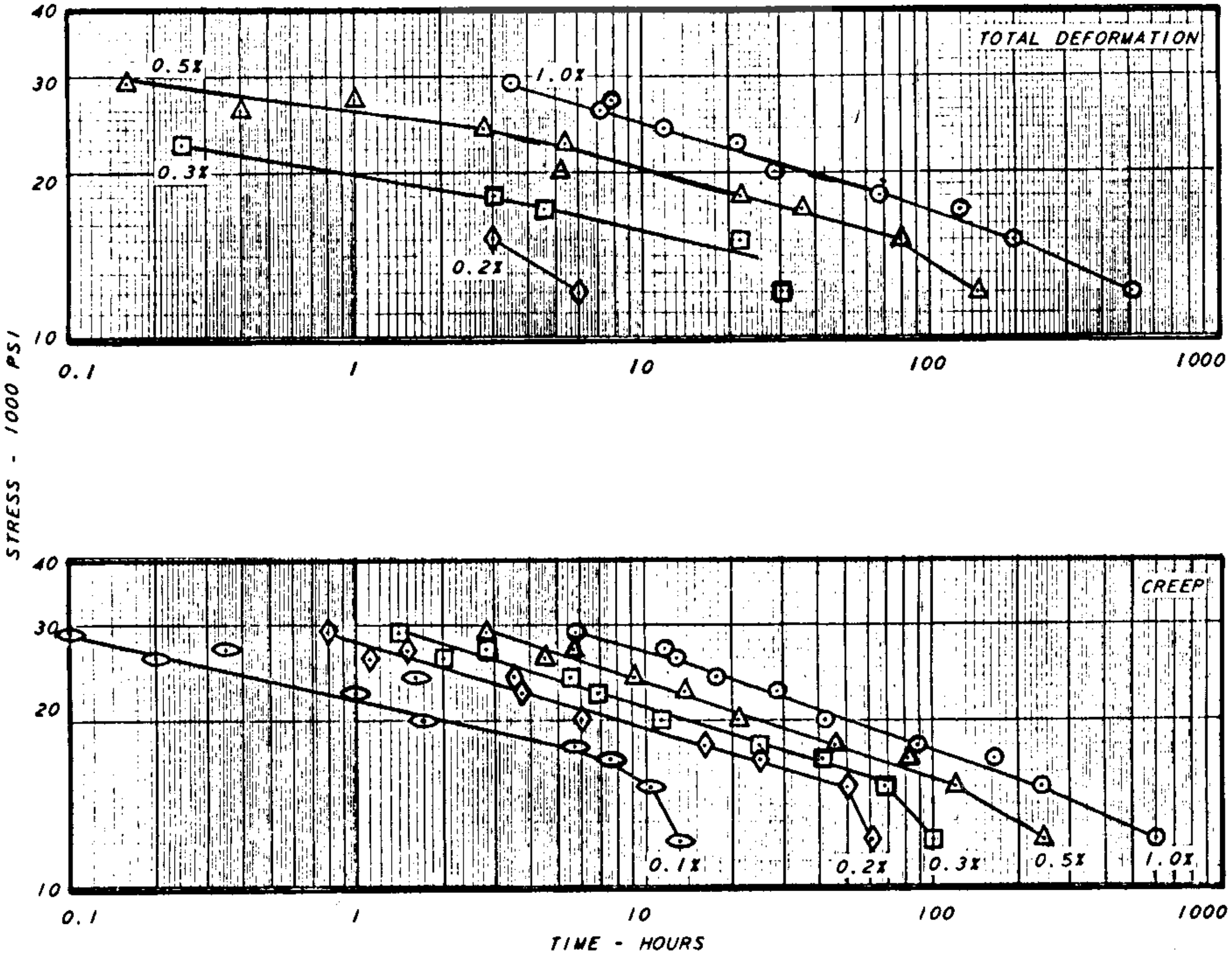

Figure 33 COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY SHEET AT 450°F USING 1100 ALUMINUM RESTRAINING FIXTURE WEDGES

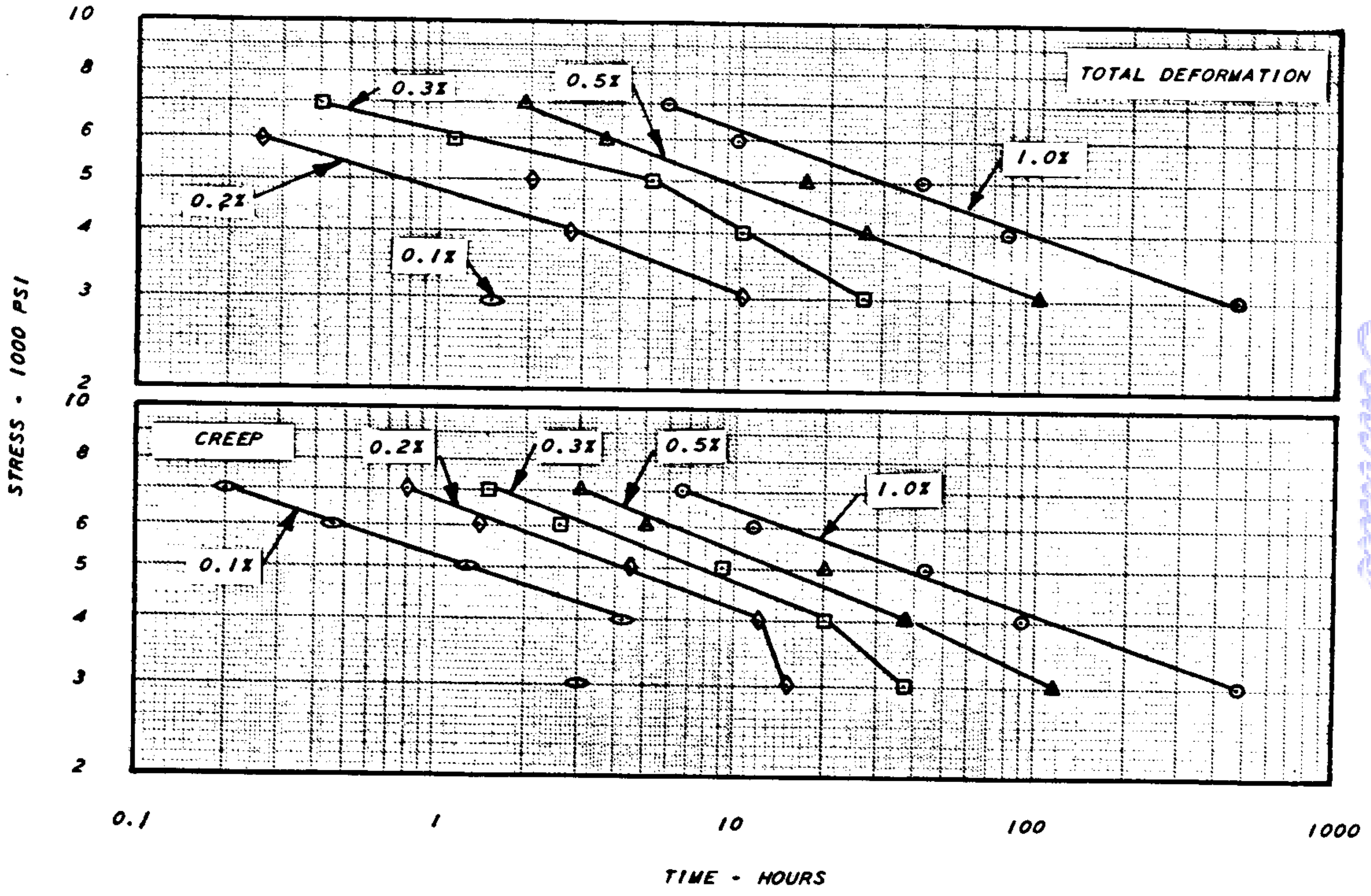

Figure 34 COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY SHEET AT 600°F.

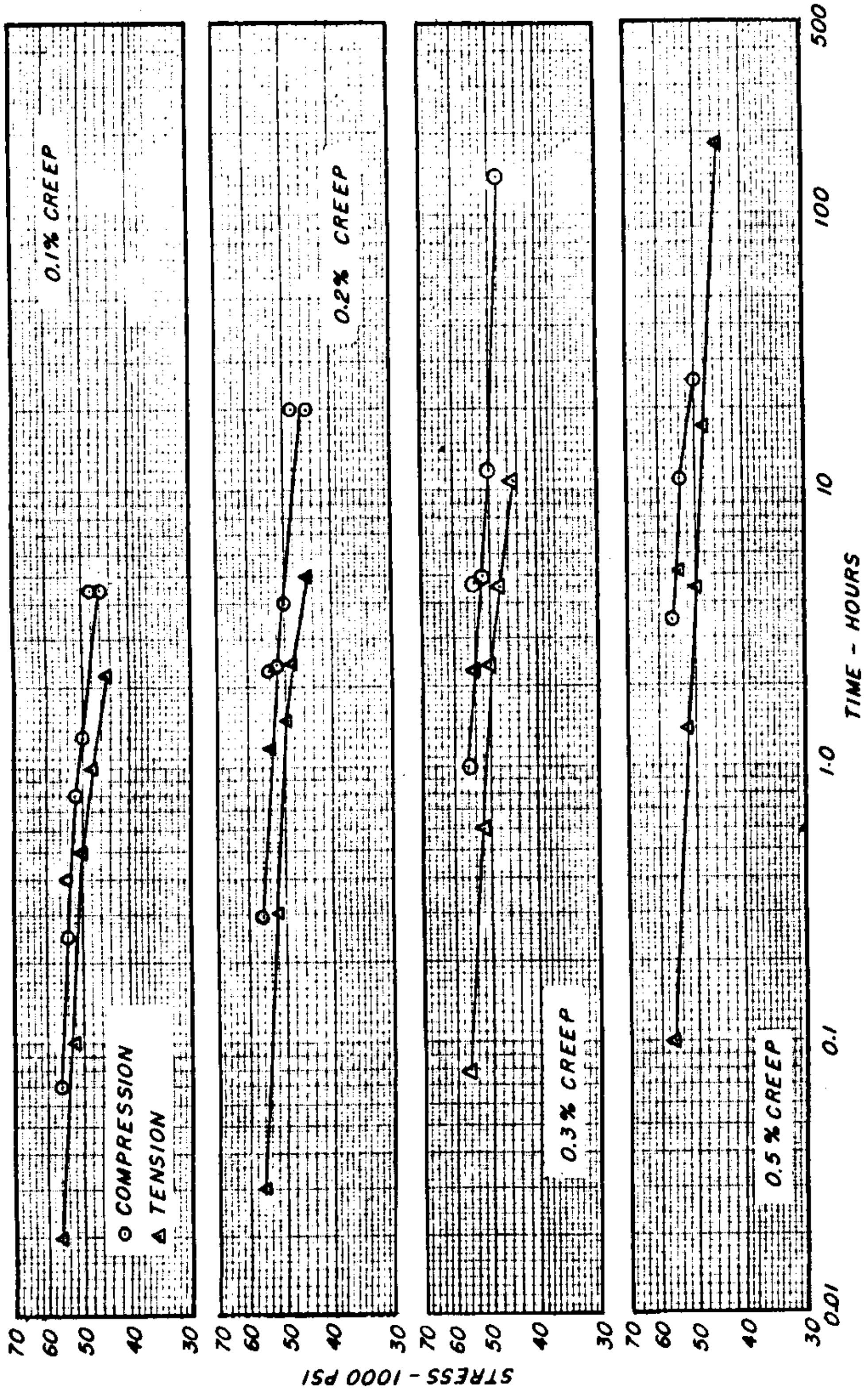

Figure 35 COMPARISON OF TENSION AND COMPRESSION – CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM SHEET AT 300°F.

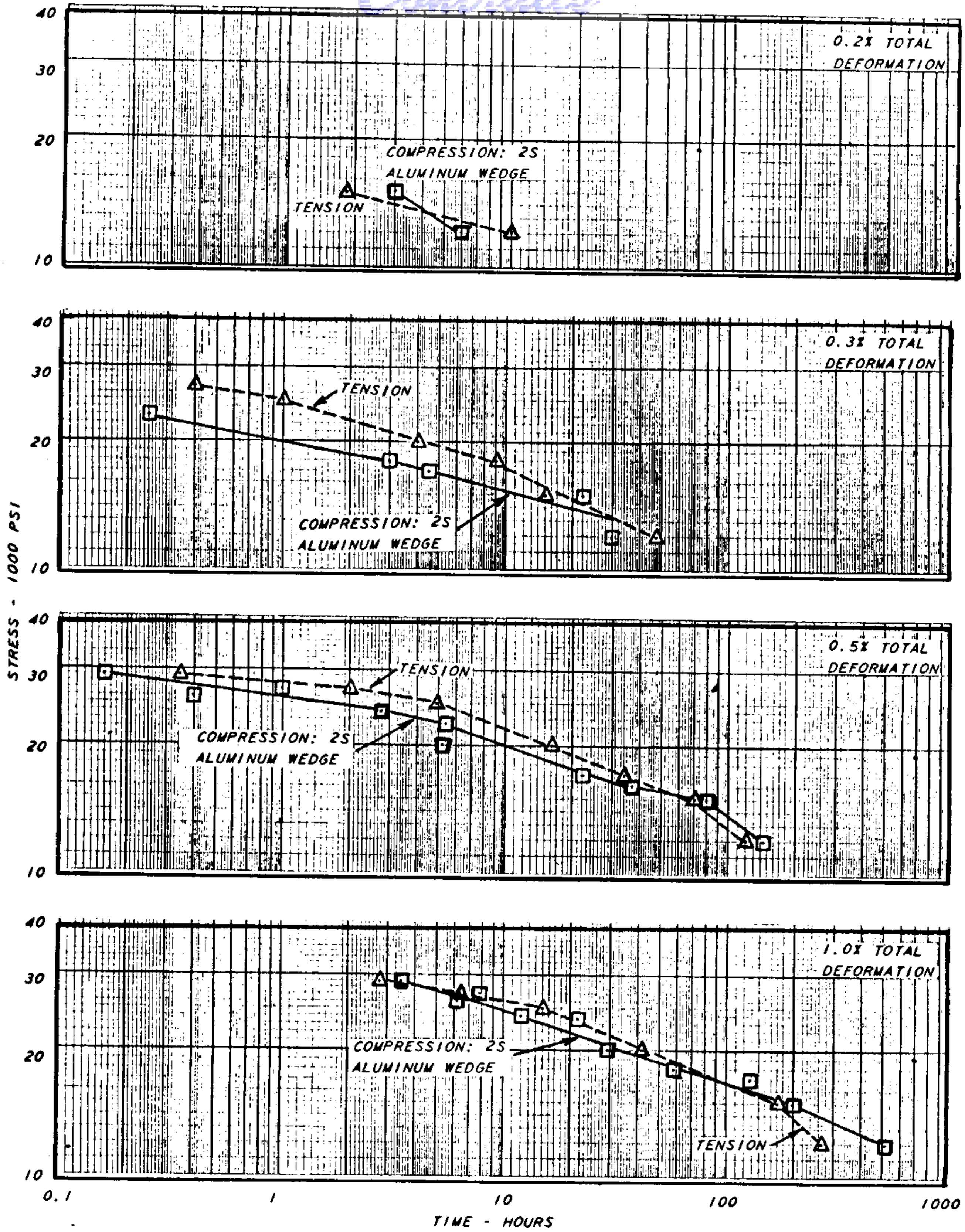

Figure 36 COMPARISON OF TENSION AND COMPRESSION-TOTAL DEFORMATION CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY SHEET AT 450°F

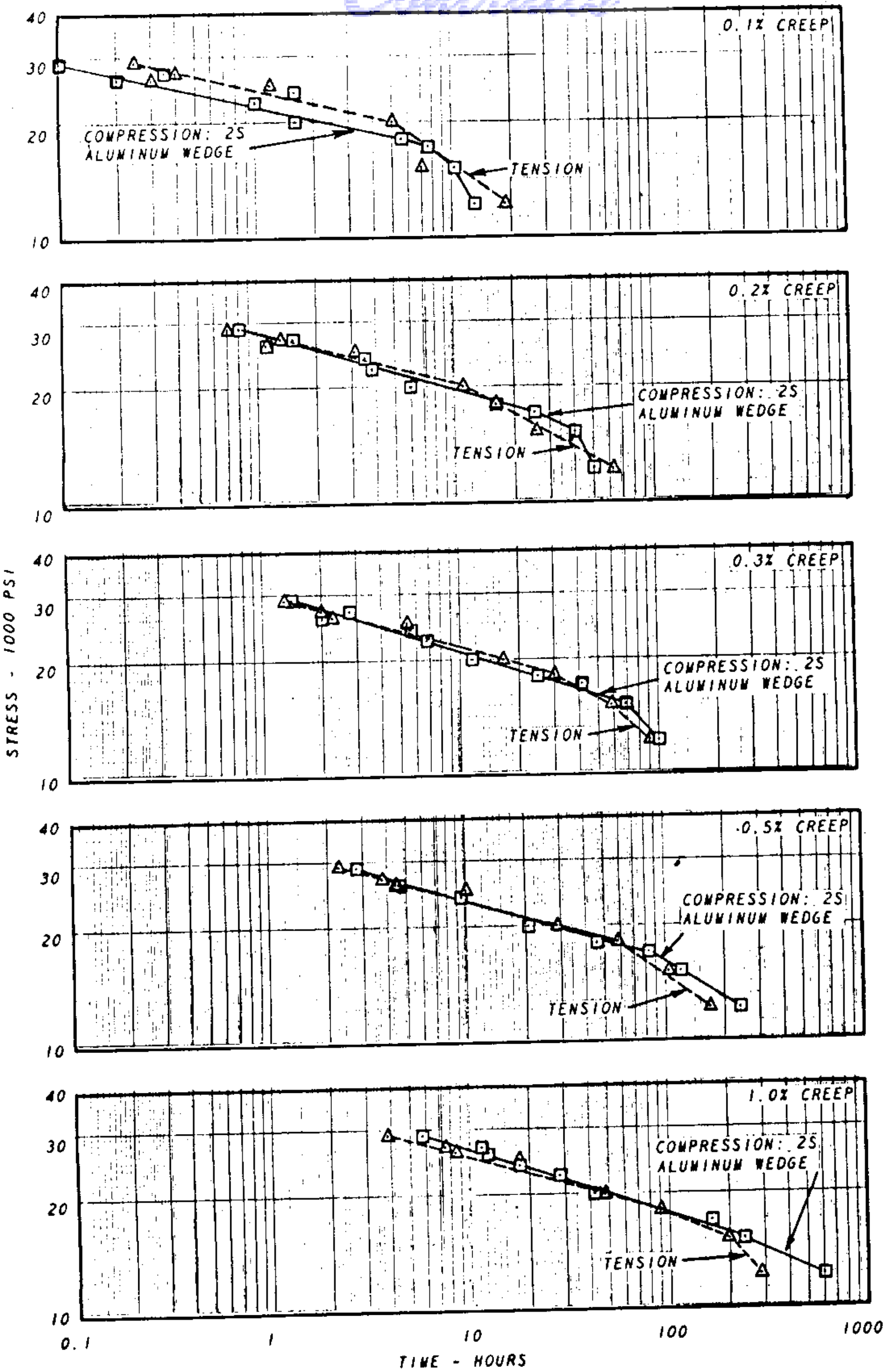

Figure 37 COMPARISON OF TENSION AND COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY SHEET AT 450°F.

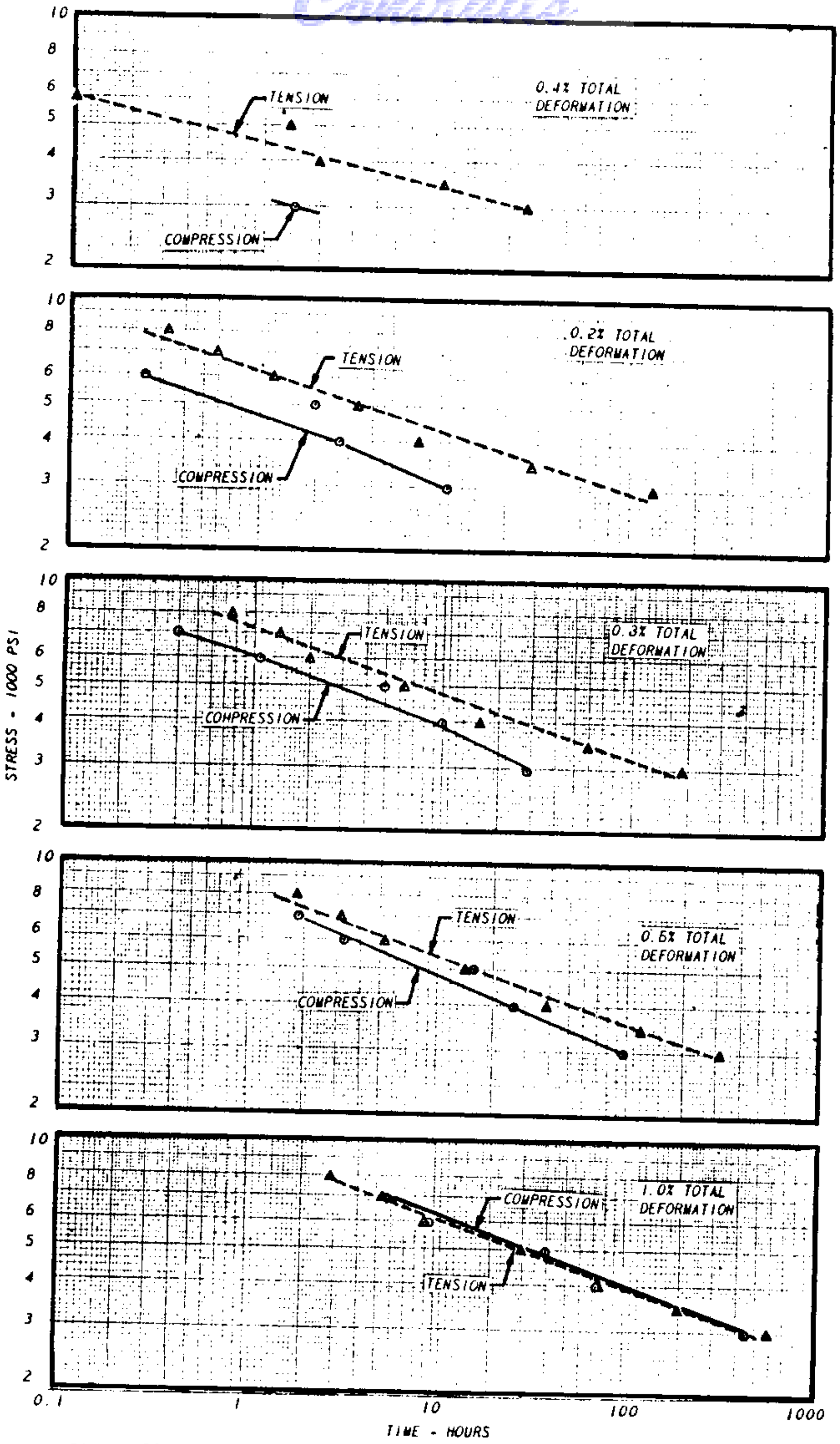

Figure 38 COMPARISON OF TENSION AND COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALLUMINUM ALLOY SHEET AT 600°F

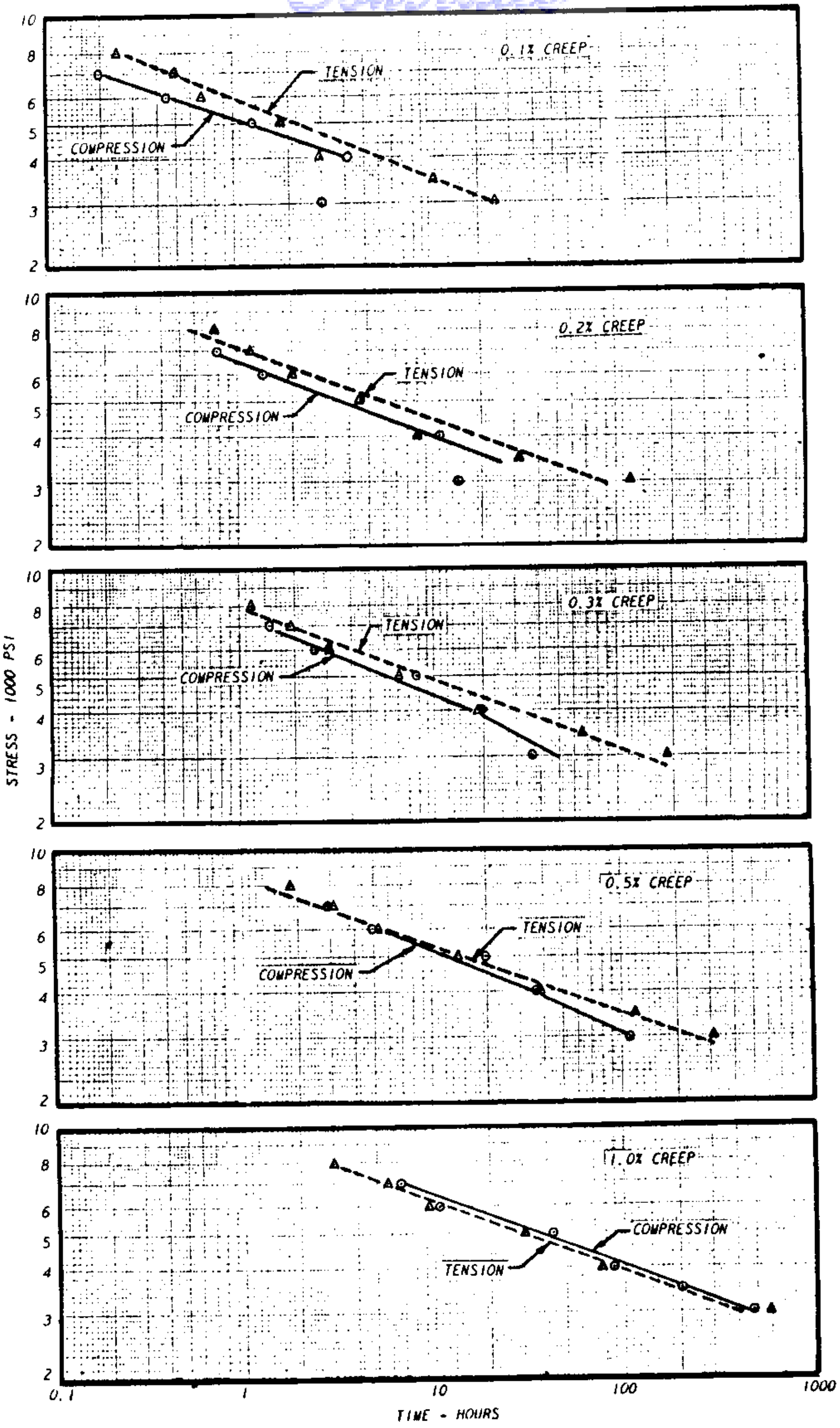

Figure 39 COMPARISON OF TENSION AND COMPRESSION-CREEP CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY SHEET AT 600°F

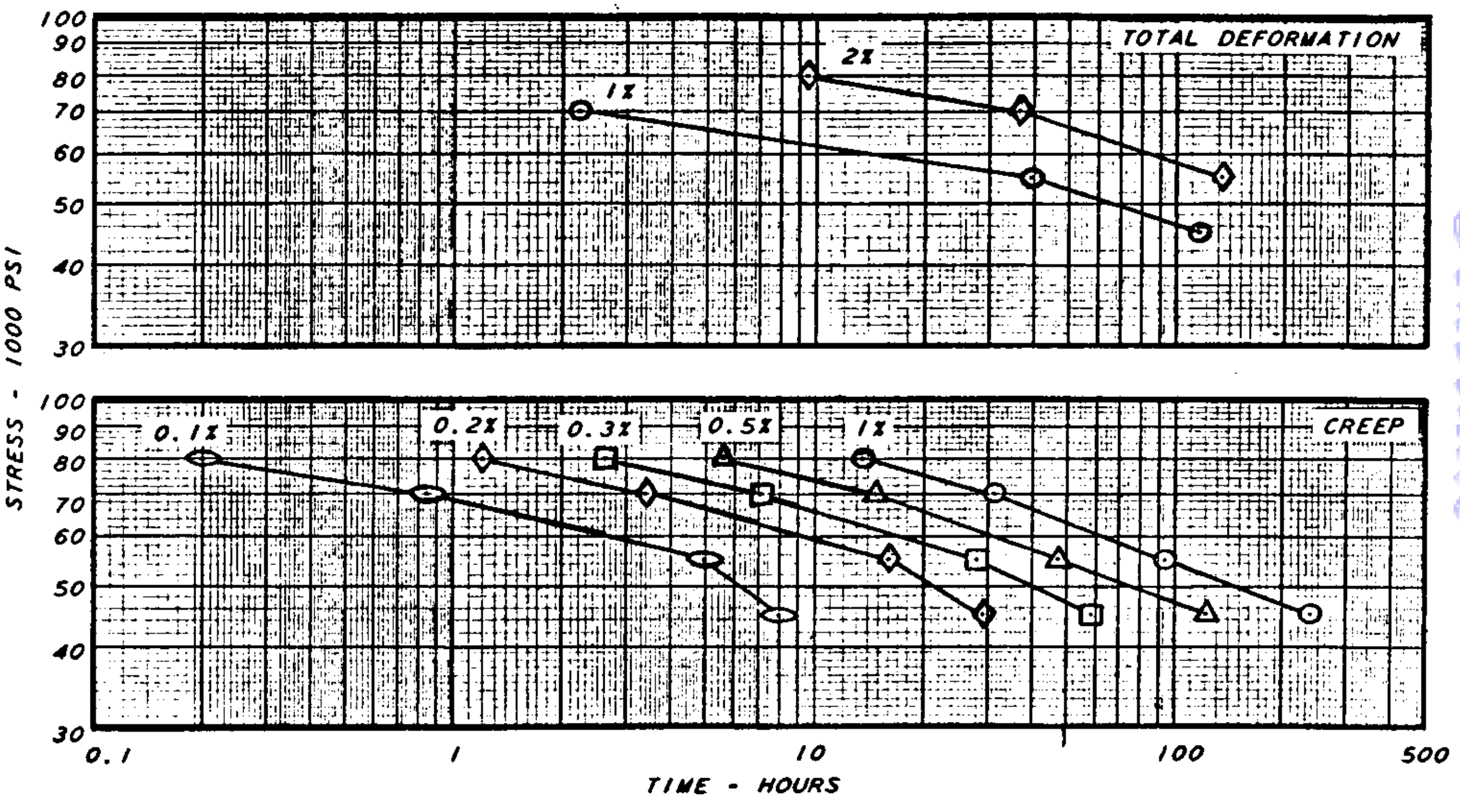

Figure 40 COMPRESSION-CREEP CHARACTERISTICS OF C-110M TITANIUM ALLOY SHEET AT 700°F

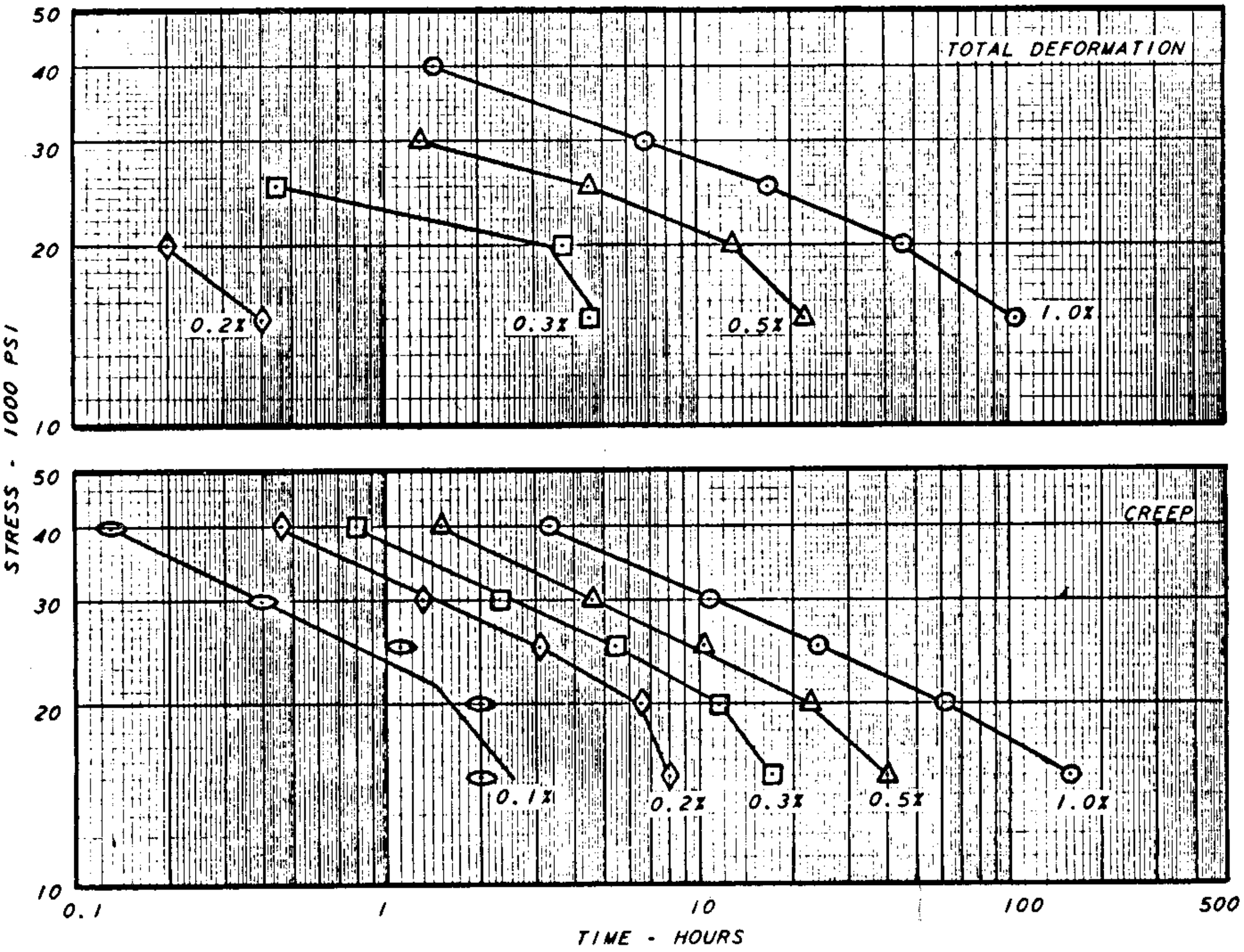

Figure 41 COMPRESSION-CREEP CHARACTERISTICS OF C-110M TITANIUM ALLOY SHEET AT 800°F

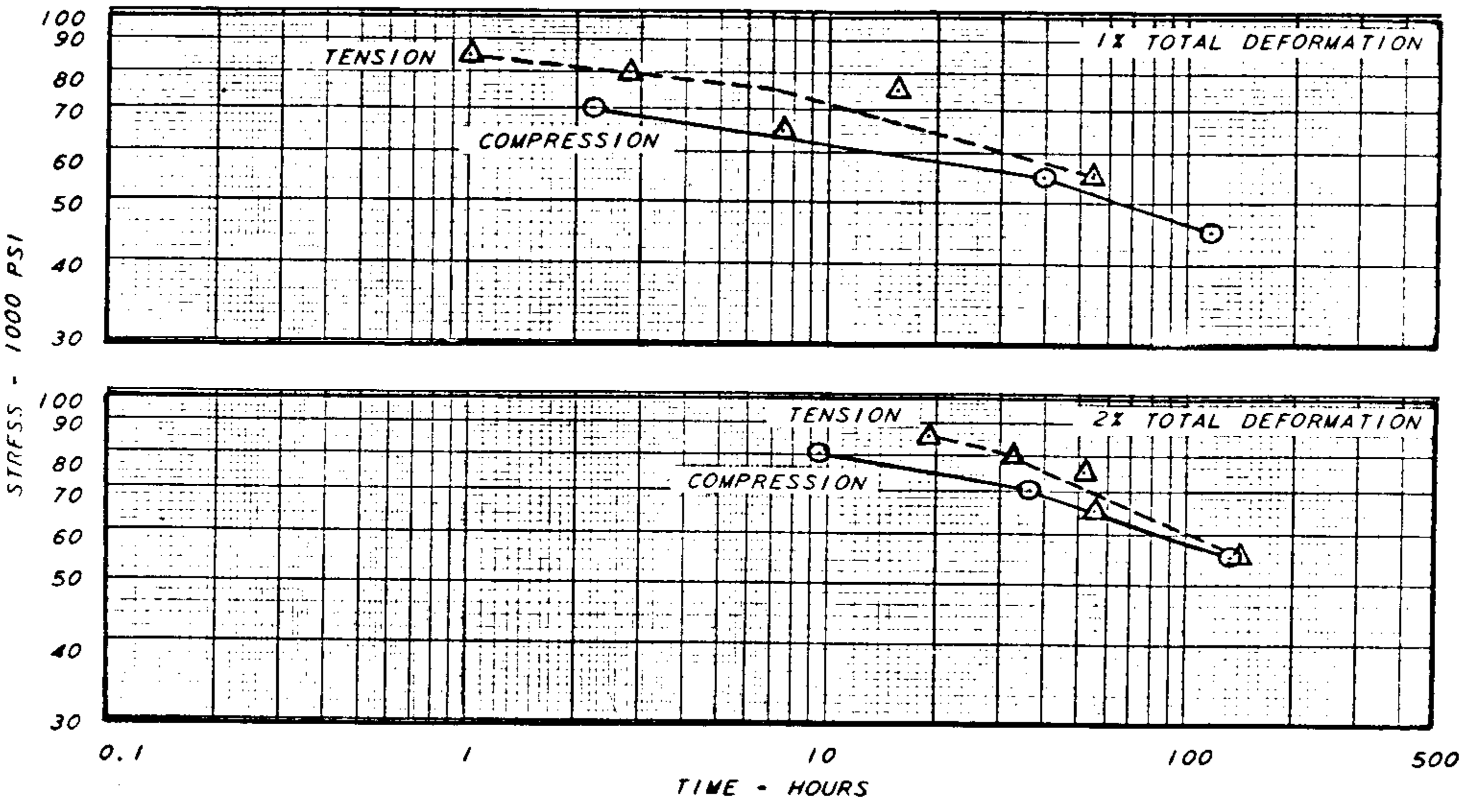

Figure 42 COMPARISON OF TENSION AND COMPRESSION-CREEP CHARACTERISTICS FOR C-110M TITANIUM ALLOY SHEET AT 700°F

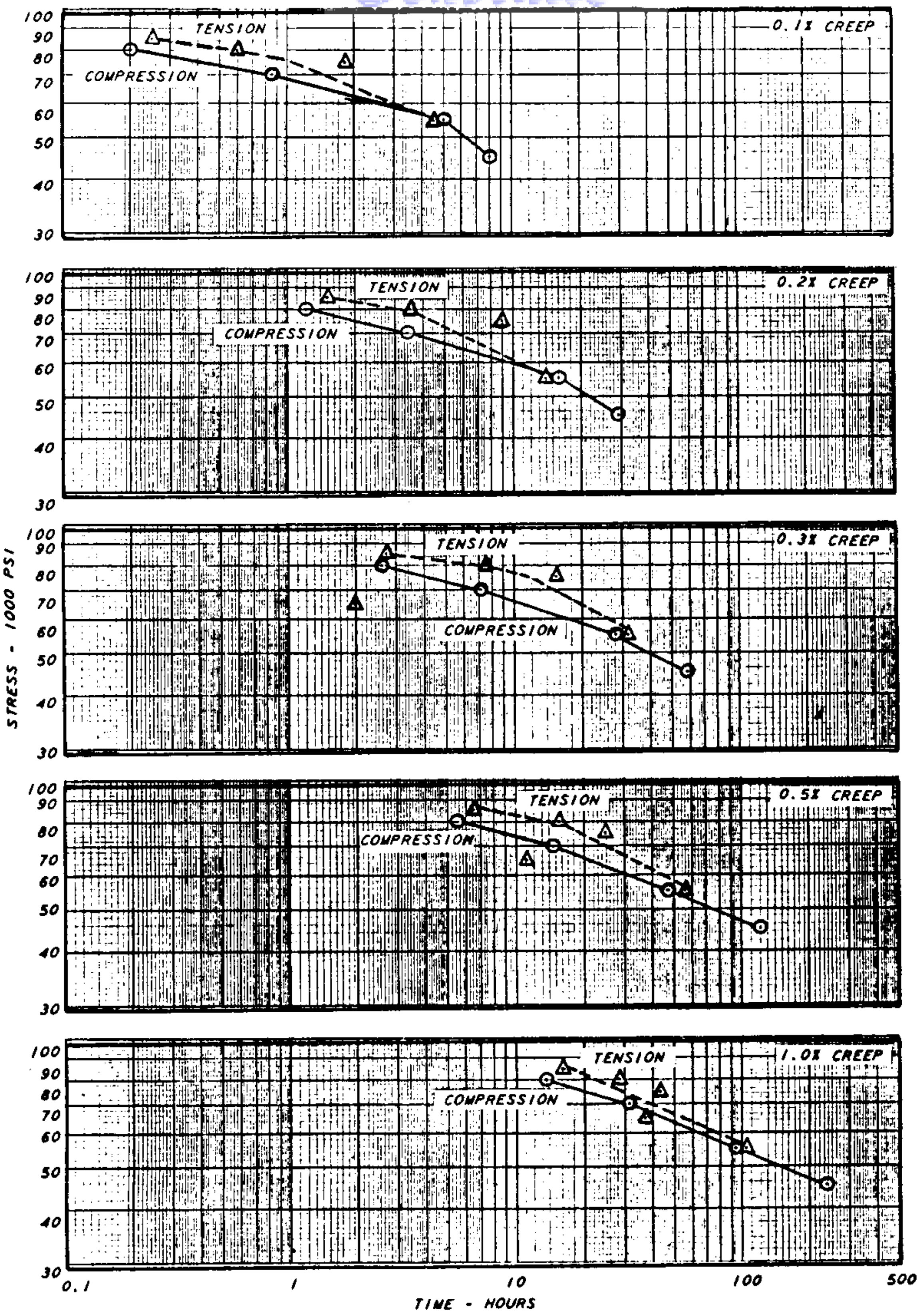

Figure 43 COMPARISON OF TENSION AND COMPRESSION-CREEP CHARACTERISTICS FOR C-110M TITANIUM ALLOY SHEET AT 700°F.

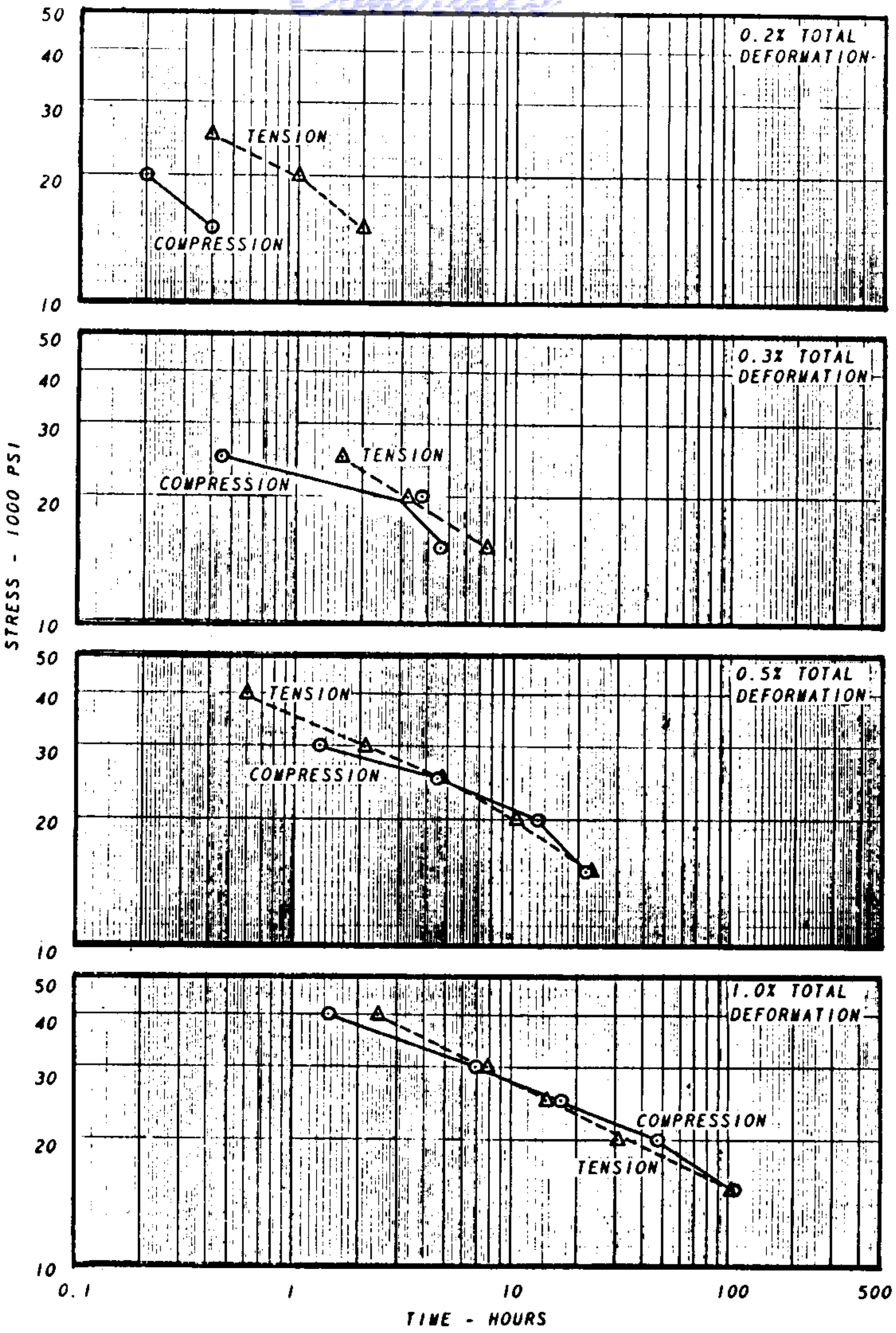

Figure 44 COMPARISON OF TENSION AND COMPRESSION-CREEP CHARACTERISTICS FOR C-110M TITANIUM ALLOY SHEET AT 800°F

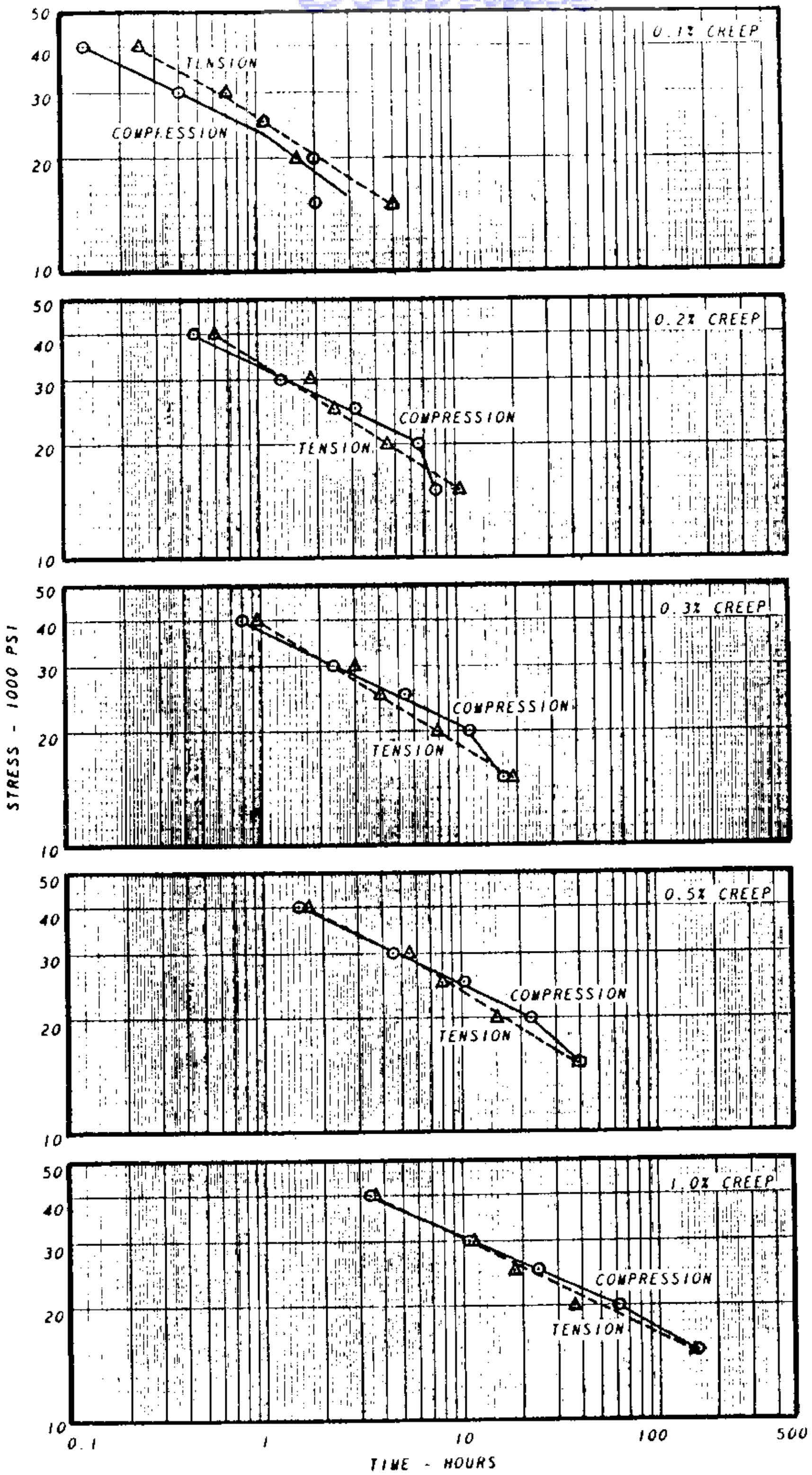

Figure 45 COMPARISON OF TENSION AND COMPRESSION-CREEP CHARACTERISTICS FOR C-110M TITANIUM ALLOY SHEET AT 800°F.

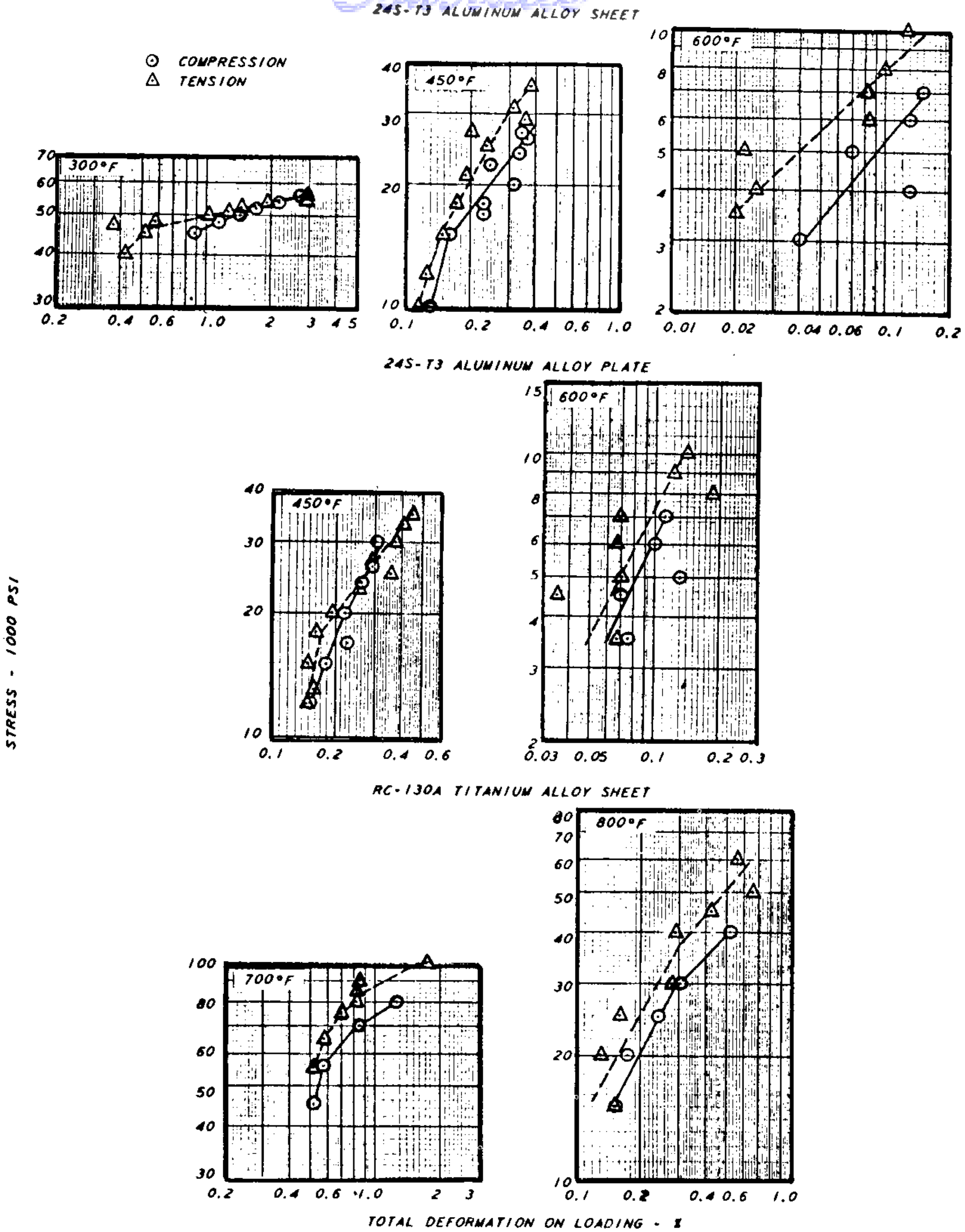

Figure 46 COMPARISION OF TENSION AND COMPRESSION STRESS VS DEFORMATION ON LOADING FOR 2024-T3 ALUMINUM SHEET AND PLATE AND C-110M TITANIUM ALLOY SHEET AT INDICATED TEMPERATURES