WADC TECHNICAL REPORT 54-270
PART 3
ASTIA DOCUMENT No. 151194

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

LUKE A. YERKOVICH

CORNELL AERONAUTICAL LABORATORY, INC.

MAY 1958

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.
500 — July 1958

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". The work was administered under the direction of the Materials Laboratory, Directorate of Laboratories, Wright Air Development Center, with Messrs. K.D. Shimmin and E.L. Horne acting as project engineers.

This report covers work conducted from January 1955 to December 1955.

The efforts of Mr. Frank J. Vawter and Mr. George Derrick in conducting the test program and Mr. Glen J. Guarnieri in supervision are gratefully acknowledged.

ABSTRACT

The establishment of high-temperature creep and rupture properties of materials is a prerequisite for efficient design if exposure to elevated temperature in service is expected. These properties, which are generally determined from the conventional creep test, are not necessarily applicable if stress conditions other than tension are encountered. This project was initiated to supplement the usual tensile creep and rupture data. The high-temperature creep strengths of a number of structural aircraft alloys were determined when under the influence of compression, bearing, and shear stresses. Specifically, data of these types are required to formulate high temperature joint design criteria.

This report summarizes three years study on the creep behavior of fifteen sheet, plate, and bar alloys creep tested in tension, compression, bearing, and shear. In addition, correlations of tensile creep and rupture properties with compression, bearing and shear creep-rupture properties have been made and are presented in tabular form.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Richard R. Kennedy

RICHARD R. KENNEDY
Chief, Metals Branch
Materials Laboratory

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (continued)

LIST OF ILLUSTRATIONS (continued)

INTRODUCTION

With the realization of supersonic speed in aircraft, there have been numerous changes in aircraft design to meet the strength and stability requirements demanded by such high speed. Associated with high speed flight, aerodynamic heating presents a major obstacle which appears to limit the attainment of even higher speeds since the conventionally used materials in aircraft construction undergo weakening to the point where creep becomes a major factor controlling useful life.

In the assembly of aircraft structural members, rivets and other mechanical fasteners which have been adopted as practical and acceptable methods of fabrication 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 condition created in the joint area. When loads are transmitted through joints, complex and concentrated stress patterns are induced which can promote failure in any of a number of ways. However, in spite of these stress complexities, determinations of 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 problems which have arisen from 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 recognized that many of these same design characteristics must be defined according to their influences on particular creep processes associated with the temperatures generated in flight. By way of illustration, Mordfin (1)* found that tensile-creep data could not be used to predict the creep and rupture characteristics of riveted joints loaded in tension, while an investigation dealing with high-temperature compression-creep behavior (2) disclosed that materials may display major differences in their creep characteristics under compression and tension stresses. In this regard, it seems that the shear, bearing, and compression creep behaviors of aircraft materials as well as their tensile-creep behaviors are 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 conducted in the past three-year period to determine the creep characteristics of aircraft structural alloys under the influence of shear, bearing, and compression stresses for correlation with appropriate tensile creep characteristics. By the method of expressing shear, bearing, and com-

*See bibliography.

"Manuscript released by author August 1956 for publication as a WADC Technical Report."

pression creep in terms of tensile creep, it may be possible to utilize easily obtained tensile creep data in the construction of composite structures with particular emphasis directed toward improving the performance of joints undergoing high-temperature deformation.

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 their creep and rupture characteristics under the influence of these types of stresses. The chemical analyses of the test alloys, as furnished by the suppliers, are presented in Table 1, page 4 and the mechanical property data typifying the short-time room-temperature tensile characteristics of these alloys, both longitudinal and transverse to the rolling direction, are summarized in Table 2, page 5.

To establish a basis for correlation of creep and rupture under the various types of loading with tensile creep and rupture, high-temperature creep-rupture tests were conducted on all materials in the time range from a few to 1000 hours according to the temperature and load schedule presented in Table 3, page 6.

All tests were performed under static load conditions using test apparatus and temperature control and creep strain measuring instrumentation discussed in detail in the first interim report issued for this investigation (3).

TENSILE CREEP RESULTS

As a supplement to the tensile creep-rupture properties of the test alloys presented in references 3 and 4, tensile creep-rupture characteristics of titanium alloy A-110AT and the heat resistant alloys 19-9DX and A-286 are included in this report. Consistant with the previous tensile-creep determinations, tensile creep tests on these three alloys were conducted at several temperature and stress levels to permit presentation of data in conventional stress-time design charts. In all instances of tensile creep testing, the axis of specimen loading was parallel to the direction of working.

A-110AT Titanium Alloy Sheet

Tensile creep-rupture characteristics of A-110AT titanium alloy sheet were determined at 600, 800, and 1000°F. Test results are compiled in Table 4 and graphically illustrated as stress-time curves in Figure 1 at 800°F and Figure 2 at 1000°F. At 600°F, creep behavior of this alloy is of little interest since the deformation characteristics are almost entirely dependent upon initial load application.

TABLE 1

CHEMICAL ANALYSES OF TEST MATERIALS

Alloy	C	Si	Mn	S	P	Cr	Ni	Cu	Fe	Mo	W	V	Al	Mg	Zn	Ti	Sn	N	Other
2024-T3 Al Sheet & Plate		0.50	0.30-0.90			0.10		3.8-4.9	0.50				Bal.	1.20-1.80	0.10				0.15
2117-T4 Al Bar		0.80	0.20			0.10		2.2-3.0	1.00				Bal.	0.20-0.50	0.10				0.15
A-70 Ti Sheet	<0.1															Bal.		0.070	
C-110M Ti Sheet	<0.1		6.76													Bal.		0.027	
A-110AT Ti Sheet	<0.1												5.9			Bal.	1.9	0.03	
A-110AT Ti Bar	<0.1												4.3			Bal.	2.2	0.02	
SAE 4130 Steel Sheet	0.31	0.27	0.51	0.032	0.012	0.96			Bal.	0.18									
Monel Bar	0.17	0.07	1.03	0.007			65.19	31.94	1.57										
Type 301 SS Bar	0.096	0.57	1.86	0.013	0.023	17.21	7.58		Bal.										
Type 321 SS Sheet	0.051	0.72	1.30	0.012	0.027	17.57	9.68		Bal.							0.60			
A-286 Alloy Sheet	0.050	0.58	1.24	0.012	0.024	14.01	24.87		Bal.	1.24		0.32	0.25			2.25			
A-286 Alloy Bar	0.042	0.66	1.44	0.016	0.026	14.64	24.95		Bal.	1.24		0.28				2.05			
19-9DX Alloy Sheet	0.29	0.56	1.10	0.011	0.018	19.81	9.06	0.14	Bal.	1.43	1.39					0.50			
19-9DX Alloy Bar	0.31	0.64	1.28	0.020	0.014	19.08	8.77	0.13	Bal.	1.60	1.33					0.44			

TABLE 2

ROOM TEMPERATURE MECHANICAL PROPERTIES OF TEST ALLOYS

Alloy	Direction Of Rolling	Yield Strength PSI 0.2% Offset *	Ultimate Strength PSI *	% Elongation in 2 Inches *
2024-T3 Al Alloy Sheet	Transverse	44,650	69,900	20.5
	Longitudinal	51,400	69,500	18.0
2024-T3 Al Alloy Plate	Transverse	48,000	69,300	17.5
	Longitudinal	55,850	71,250	16.0
2117-T4 Al Alloy Bar	Longitudinal	27,350	50,000	28.5
A-70 Titanium Sheet	Transverse	89,450	99,900	25.0
	Longitudinal	75,800	93,500	25.5
C-110M Titanium Alloy Sheet	Transverse	133,250	152,000	20.5
	Longitudinal	137,150	150,250	20.5
A-110AT Titanium Alloy Sheet	Transverse	129,000	138,500	15.0
	Longitudinal	127,000	138,900	17.5
A-110AT Titanium Alloy Bar	Longitudinal	115,250	131,000	12.5
SAE 4130 Alloy Steel Sheet	Transverse	69,500	97,500	18.0
	Longitudinal	74,000	98,500	16.5
Monel Alloy Bar	Longitudinal	22,000	80,950	51.0
Type 301 SS Alloy Bar	Longitudinal	48,500	113,500	53.0
Type 321 Stainless Steel Alloy Sheet	Transverse	54,800	88,300	49.0
	Longitudinal	42,650	88,450	54.0
A-286 Alloy Sheet	Transverse	110,000	154,300	22.0
	Longitudinal	112,000	156,000	22.0
A-286 Alloy Bar	Longitudinal	112,500	149,050	18.0
19-9DX Alloy Sheet	Transverse	81,600	117,500	31.0
	Longitudinal	80,600	117,200	31.0
19-9DX Alloy Bar	Longitudinal	100,250	128,650	25.0

* = Average of duplicate determinations.

TABLE 3

SUMMARY OF TEST PROGRAM

Material	Temp. °F	Tension	Compression	Bearing	Shear
2024-T3 Aluminum Alloy Sheet	300	a	b	a, c	
	450	a	b	a, c	
	600	a	b	a, c	
2024-T3 Aluminum Alloy Plate	300	a			a
	450	a	b		a
	600	a	b		b
2117-T4 Aluminum Alloy Bar	300	b			b
	450	b			b
	600	a			b
A-70 Titanium Sheet	700	b	c	b	
	800	b	c	b	
C-110M Titanium Alloy Sheet	600	a			
	700	b	b	b	
	800	a	b	b	
A-110AT Titanium Alloy Sheet	600	c			
	800	c	c	c	
	1000	c	c	c	
A-110AT Titanium Alloy Bar	600	c			
	800	c			c
	1000	c			c
SAE 4130 Alloy Steel Sheet	800	b	c	b, c	
	900	b	c	b, c	
	1000	b	c	b	
Monel Alloy Bar	1000	a			b
	1200	a			b
Type 301 Stainless Steel Alloy Bar	1200	a			b
	1350	a			b
Type 321 Stainless Steel Alloy Sheet	1000	a			
	1200	a	c	b	
	1350	a	c	b, c	

TABLE 3 (Contd.) SUMMARY OF TEST PROGRAM

Material	Temp. °F	Tension	Compression	Bearing	Shear
19-9DX Alloy Sheet	1000	c			
	1200	c	c	c	
	1350	c	c	c	
	1500	c			
19-9DX Alloy Bar	1000	c			c
	1200	c			c
	1350	c			c
	1500	c			
A-286 Alloy Sheet	1000	c			
	1200	c			
	1350	c	c		
	1500	c			
A-286 Alloy Bar	1000	c			c
	1200	c			c
	1350	c			c

a = Data presented in WADC TR 54-270 Pt 1, Ref. 3.
b = Data presented in WADC TR 54-270 Pt 2, Ref. 4.
c = Data presented in WADC TR 54-270 Pt 3, this report.

In spite of the fact that stresses in excess of the yield strength of this alloy were applied, there had been only a very small accumulation of creep for times up to several thousand hours, indicating its creep insensitivity at the 600°F temperature level.

A-110AT Titanium Alloy Bar

A series of tensile-creep tests were performed on one-half inch diameter A-110AT titanium bar at 600, 800, and 1000°F. The results of these tests are summarized in Table 5 and graphically presented as stress-time curves for various amounts of creep and total deformation at the 800 and 1000°F temperature levels in Figures 3 and 4 respectively. Like the sheet A-110AT titanium, at 600°F the bar material also displays a deformation behavior dependent upon magnitude and initial application of stress with subsequent insensitivity to creep in the time ranges of interest in this program. This observation is supported by the 600°F data for which stresses of 88,000 and 90,000 psi caused rupture on loading while the slightly lower stress of 86,000 psi produced 3.13% deformation on loading and only about 0.3% creep in the time span of 283 hours.

19-9DX Alloy Sheet

Tensile creep-rupture properties have been determined for 19-9DX heat resistant alloy sheet at 1000, 1200, 1350, and 1500°F. This alloy was tested in the "as-received condition" which consisted of hot rolling then subsequently annealing at 1800°F and cold processing to a 2D finish. Data illustrating the high temperature creep deformation and rupture behavior of the 19-9DX alloy sheet are presented in Table 6. In addition, these data are represented graphically in Figures 5 through 8 relating stress and time for creep and total deformation at the various test temperatures.

19-9DX Alloy Bar

In addition to the 19-9DX alloy sheet, tensile creep rupture tests were conducted on one-half inch diameter 19-9DX alloy bar at 1000, 1200, 1350, and 1500°F. This material was also tested in the "as-received condition", which consisted of hot rolling followed by a stress relieving treatment at 1250°F. The high temperature tensile creep-rupture characteristics of this bar alloy are summarized in Table 7 and illustrated in the form of stress-time design curves in Figures 9 through 12 for the specific test temperatures.

A-286 Alloy Sheet

The A-286 alloy sheet was tested in an age hardened condition using the following heat treatment procedure. After rolling, the sheet was annealed at 1800°F, air quenched then processed to a 2D finish and subsequently aged at 1325°F for 16 hours. Tensile creep-rupture tests on this alloy were conducted at the 1000, 1200, 1350, and 1500°F temperature levels. Results of these series of tests are presented in Table 8 and summarized graphically in Figures 13 through 16 as conventional stress-time design curves.

A-286 Alloy Bar

Like the companion A-286 sheet alloy, tensile-creep tests were conducted on A-286 bar in the age hardened condition. After austenitizing at 1800°F and oil quenching, the alloy bar was exposed for 16 hours at 1325°F and air cooled. Tensile-creep tests on this bar alloy were performed at 1000, 1200 and 1350°F and the data summarizing its creep behavior at these temperature levels are presented in Table 9. Graphical representation of the creep and rupture characteristics of A-286 alloy bar in the form of stress-time charts are illustrated in Figures 17 through 19.

BEARING AND SHEAR CREEP

In the fabrication of composite structures when mechanical fasteners are used, load transmission from one member to another can cause failure by shear in the fastener, excessive flow of metal under stress around the fastener or by a combination of both. Under ordinary temperature conditions correlations of shear and bearing characteristics with tensile characteristics fulfill the requirements of structural design. If, on the other hand, operating circumstances are expected whereby creep strength becomes the predominating factor controlling life, it must be recognized that correlations obtained under conditions of creep testing may be necessary. In this regard, all sheet test alloys were subjected to bearing creep-rupture studies, and all plate and bar alloys to shear creep-rupture studies to establish their behaviors under these types of stresses at temperatures corresponding to those used in the tensile-creep phase of the investigation.

BEARING CREEP RESULTS

In addition to the bearing creep-rupture data presented in references 3 and 4 (determined for a 0.125 inch diameter hole and using an edge distance to hole diameter ratio of 1.5) bearing data have been determined for several of the test alloys with varying edge distances to hole diameters to indicate the effects of these variables on bearing creep and rupture behavior.

2024-T3 Aluminum Alloy Sheet

Bearing creep-rupture characteristics of 2024-T3 aluminum alloy sheet were determined at 300, 450, and 600°F using a 0.125 inch diameter hole and an edge distance to hole diameter of 2.0. The results of this series of tests are compiled in Table 10 and summarized as stress-time curves in Figures 20 through 22 for the specific temperature levels.

To observe the influence of varying hole diameter on bearing creep and rupture, the 2024-T3 aluminum sheet was tested at 450°F for bearing hole diameters ranging from 0.064 to 0.1875 inch using a constant edge distance to hole diameter ratio of 1.5. These data summarizing the bearing creep-rupture behavior for the varying hole diameters are presented in Table 11.

In keeping with the procedure employed in previous reports, the high-temperature bearing characteristics are expressed as ratios of tensile rupture strength for definite time periods. The correlation of bearing creep-rupture stress to tensile rupture stress for the 2024-T3 aluminum alloy is summarized in Tables 25 and 26 of Appendix I and illustrates the effects of varying bearing hole diameter and edge distance to bearing hole diameter ratio.

A-70 Titanium Sheet

Data pertaining to the bearing creep-rupture behavior of A-70 titanium sheet for a bearing hole diameter of 0.125 inch and an edge distance to hole diameter ratio of 1.5 have been presented in reference 4 at 700 and 800°F. These bearing creep-rupture characteristics for the 1.5D condition expressed in terms of tension-rupture behavior at various time levels up to 500 hours are summarized in Table 27 of Appendix I.

C-110M Titanium Alloy Sheet

The bearing creep-rupture characteristics of C-110M titanium alloy sheet have been determined at 700 and 800°F for a bearing hole diameter of 0.125 inch and an edge distance to hole diameter of 1.5. These data have been summarized in reference 4 in various tabular and chart forms. Correlations relating bearing creep-rupture characteristics with tensile rupture characteristics at the 700 and 800°F temperature levels for this alloy are compiled in Table 28 of Appendix I.

A-110AT Titanium Alloy Sheet

Bearing creep-rupture tests on this titanium alloy, using a 0.125 inch diameter bearing hole and an edge distance to hole diameter ratio of 2.0, were conducted at 800 and 1000°F. Data illustrating the total deformation, creep and rupture behavior of A-110AT titanium at the selected test temperature are presented in Table 12 and summarized as stress-time curves in Figure 23 at 800°F, and Figure 24 at 1000°F.

For the particular boundaries employed in the bearing creep rupture determination of A-110AT titanium, correlations have been made with this alloy's tensile rupture characteristics. At specific time levels in the range of 10 to 500 hours Table 29 of Appendix I represents the relationships between bearing creep and tensile rupture stress determined in this investigation.

SAE 4130 Alloy Steel Sheet

To supplement the bearing creep-rupture data at 800, 900, and 1000°F determined for an edge distance to bearing hole diameter rate of 1.5 and presented in reference 4, bearing creep tests were conducted on type 4130 steel at 800 and 900°F using an edge distance to hole diameter ratio of 2.0. Test results for the 2.0D condition are compiled in Table 13 and summarized as conventional stress-time curves in Figures 25 and 26 at 800 and 900°F respectively.

For both the 1.5D and 2.0D conditions, the bearing creep-rupture behavior of 4130 alloy steel is correlated with tensile rupture behavior in Table 30 of Appendix I.

Type 321 Stainless Steel Sheet

In addition to the bearing creep-rupture data for type 321 stainless steel at 1200 and 1350°F for the 1.5D condition summarized in reference 4, bearing tests were conducted on this alloy at 1350°F using a 2.0D ratio to compare bearing creep and rupture behavior with regard to edge distance variation. For the 2.0D condition and a 0.125 inch diameter bearing hole, test results are presented in Table 14 and graphically illustrated in Figure 27.

Correlations of bearing creep-rupture stress and tensile rupture stress at various time levels for both the 1.5D and 2.0D condition are compiled in Table 31 of Appendix I.

19-9DX Alloy Sheet

Bearing creep-rupture tests on heat resistant 19-9DX alloy sheet using a 0.125 inch diameter bearing hole and an edge distance to hole diameter ratio of 2.0 were conducted at the 1200 and 1350°F temperature levels. Data indicating the total deformation, creep and rupture behavior of this alloy under bearing stress at the test temperatures are presented in Table 15 and summarized in graphical form in Figure 28 at 1200°F and Figure 29 at 1350°F.

The correlation of bearing creep-rupture stress to tensile rupture stress for this alloy is presented in Table 32 of Appendix I

SHEAR-PIN DEFORMATION AND RUPTURE RESULTS

A "shear-creep" testing program was conducted on all plate and bar alloys to relate high-temperature long-time shear characteristics with corresponding high-temperature long-time tensile characteristics. Throughout the shear test program, specimens 1/8 inch in diameter by 1/2 inch long were prepared from the various test alloys and deformed in double shear. Since a pin loaded in this manner may undergo a slight amount of bending as well as shear displacement, deformation values were recorded as total shear blade displacement in inches rather than percentages of shear-pin area, and the results obtained represent shear-pin deformation rather than shear strain.

High-temperature long-time shear data for 2024-T3 aluminum plate, 2117-T4 aluminum alloy bar, Monel alloy bar and type 301 stainless steel bar have been reported in references 3 and 4 at several selected temperature levels. These data are however presented in this report as correlations with corresponding tensile rupture data and are summarized in Tables 33, 34, 36, and 37 of Appendix II respectively.

A-110AT Titanium Alloy Bar

The shear-pin deformation characteristics of A-110AT titanium alloy bar were determined at 800 and 1000°F for shear stresses which produced rupture in the range from a few to 500 hours. The results of these determinations are presented in Table 16 and represented in terms of total deformation and creep as stress-time curves in Figures 30 and 31 for the 800 and 1000°F temperature levels respectively.

The relationships of shear-pin deformation and rupture properties with corresponding tensile rupture characteristics for this alloy at various time levels are summarized in Table 35 of Appendix II.

19-9DX Alloy Bar

Shear-pin deformation and rupture tests were conducted on 19-9DX heat resistant alloy bar at 1000, 1200, and 1350°F. Data illustrating the behavior of this alloy exposed to selected shear stresses are presented in Table 17 and summarized in the stress-time curves for total deformation and creep in Figures 32 through 34 for the specific test temperatures.

The correlations of shear-pin deformation properties with tensile rupture properties at the test temperatures for various amounts of shear-pin deformation and rupture, expressed as a ratio of tensile rupture stress at several time levels, are presented in Table 38 of Appendix II.

A-286 Alloy Bar

Specimens prepared from A-286 heat resistant alloy bar were subjected to shear stresses at 1000, 1200, and 1350°F. The shear-pin deformation and creep characteristics of this alloy at the test temperatures are summarized in Table 18 for the various stresses applied. Stress-time curves illustrating the high-temperature shear creep and rupture behavior of A-286 are presented in Figures 35 through 37.

The relationships of shear-pin deformation and rupture, expressed as ratios of tensile-rupture stress in equivalent time periods in the 10 to 500 hour range, are summarized in Table 39 of Appendix II for the test temperatures employed.

COMPRESSION CREEP RESULTS

For those conditions in which compressive stresses at elevated temperatures are generated in members, compression creep strain and column buckling present two major problems in current aircraft designs. In spite of the fact that materials may display large variations in their tension-compression stress-strain characteristics tensile creep data, applied with suitable stress analysis procedures and ample safety factors, have been used with considerable success in the treatment of the creep and creep buckling problems. Higgins (5) however, points out the importance of compression-creep data in the proper handling of methods developed for designing structures involving high-temperature compression loading.

Concurrent with the study to evaluate materials with respect to bearing and shear creep-rupture, a program was conducted to investigate the high-temperature creep behavior of various alloys under the influence of compressive stress. In this regard, all sheet and plate test materials were tested in compression creep at temperatures corresponding to those employed in the tension-creep study for establishing the relationship between tension and compression creep.

The high-temperature compression creep and total deformation behaviors of 2024-T3 aluminum alloy sheet at 300, 450, and 600°F, 2024-T3 aluminum alloy plate at 450 and 600°F, and titanium alloy sheet C-110M at 700 and 800°F have been reported in reference 4. These compression creep data have been correlated with appropriate tensile-creep data and the relationships expressed as compression creep stress to tensile creep stress ratios at specific time levels are summarized in Tables 40, 41, and 43 of Appendix III respectively.

A-70 Titanium Sheet

The compression creep and total deformation characteristics of A-70 titanium sheet have been determined at 700 and 800°F. The results of these determinations are presented in Table 19 and illustrated as stress-time curves in Figures 38 and 39.

Correlations of the tension-compression total deformation characteristics up to 2% at the 800°F temperature level are summarized in Table 42 of Appendix III. At 700°F these correlations were not possible since at the stress levels employed in the test program the 2.0% total deformation was obtained on initial application of load.

A-110AT Titanium Alloy Sheet

Compression-creep tests were conducted on A-110AT titanium alloy sheet at 800 and 1000°F. Data illustrating the compression creep and total deformation characteristics up to 2% are presented in Table 20 and summarized as stress-time curves for these test temperatures in Figures 40 and 41.

The relationships of compression total deformation behaviors with corresponding tensile total deformations on a stress ratio basis at various time levels in the 10 to 500 hour range are summarized in Table 44 of Appendix C.

SAE 4130 Alloy Steel Sheet

A series of compression-creep tests were performed on SAE 4130 alloy steel sheet at 800, 900, and 1000°F. The results of these tests are compiled in Table 21 and graphically presented as stress-time curves for various amounts of creep and total deformation at the test temperatures in Figures 42 through 44.

The correlations of the tensile total deformation and compression total deformation characteristics on a stress basis at the 800, 900, and 1000°F temperature levels are summarized in Table 45 of Appendix III.

Type 321 Stainless Steel Alloy Sheet

The compression creep and total deformation behaviors of type 321 stainless steel sheet have been determined at 1200 and 1350°F for various static compression stresses. Test results indicating the behavior of this alloy in compression up to 2% total deformation at the 1200 and 1350°F temperature levels are summarized in Table 22 and graphically represented as stress-time curves in Figures 45 and 46 respectively.

The stress ratio correlations for the tension-compression total-deformation characteristics of the type 321 stainless steel alloy are presented in Table 46 of Appendix III.

19-9DX Alloy Sheet

Compression-creep tests were conducted on heat resistant 19-9DX alloy sheet at 1200 and 1350°F. Data illustrating the compression creep and total deformation behavior at these temperatures are presented in Table 23 and summarized as stress-time curves in Figures 47 and 48.

The relationships of compression total deformation with corresponding tensile total deformation expressed as ratios of stresses at various time levels are compiled in Table 47 of Appendix III.

A-286 Alloy Sheet

Compression-creep tests were conducted on heat resistant A-286 alloy sheet at 1350°F. Results of these tests are compiled in Table 24 and illustrated in Figure 49 as stress-time curves for various quantities of creep and total deformation.

The relationships of compression total deformation with corresponding tensile total deformation on a stress ratio basis at selected time levels are summarized in Table 48 of Appendix III.

SUMMARY

Various aircraft structural alloys have been exposed to a tension, compression, bearing, and shear creep test program to establish their high-temperature creep and rupture properties under the influence of these types of stresses. From results obtained in this investigation, it has been found that the test alloys display creep characteristics under compression, bearing, and shear stresses quite similar to those obtained in tension creep testing. The high-temperature creep and rupture behaviors of the test alloys have been presented in various tabular and chart forms and correlations of compression, bearing, and shear creep vs. tension creep on a stress basis have been made to assist in the assignment of creep stress values to members undergoing creep strain other than tension. Data of these types are especially suitable for the high-temperature design of composite structures and joints wherein shear and bearing stresses promote failure by creep.

BIBLIOGRAPHY

1. Mordfin, Leonard, "Creep and Creep-Rupture Characteristics of Some Riveted and Spot-Welded Lap Joints of Aircraft Materials" NACA TN 3412, June 1955.

2. Yerkovich, L. A. and Guarnieri, G. J., "Compression-Creep Properties of Several Metallic and Cermet Materials at High Temperatures", Presented at the Fifty-Eighth Annual Meeting of ASTM June 26 to July 1, 1955, Preprint 94f to be Published in ASTM Proceedings.

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

4. Vawter, F. J., Guarnieri, G. J., Yerkovich, L. A. and Derrick, G., "Investigation on the Compressive, Bearing, and Shear Creep-Rupture Properties of Aircraft Structural Metals and Joints at Elevated Temperatures", WADC TR 54-270, Part 2, August 1955.

5. Higgins, T. P., Jr., "Effect of Creep on Column Deflection", Weight Strength Analysis of Aircraft Structures by F. R. Shanley, U. S. Air Force Project Rand, July 1, 1952, Chapter 20.

TABLE 4

TENSILE CREEP-RUPTURE CHARACTERISTICS OF A-110AT TITANIUM ALLOY SHEET

Temp. °F	Stress PSI	% 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	Hardness RC Before	Hardness RC After	Specimen
	55,000	0.438	0.8	OL	9.	OL	26.	OL	150.	0.3	450.	220.					-	487.	1.54	0.00104	40	39	390-7
	60,000	0.504	0.25	OL	2.3	OL	6.	OL	33.	OL	162.	155.	340.	270.	500.	486.	859.2	859.2	26.	0.0036	40	40	390-5
	65,000	1.65	0.25	OL	1.4	OL	2.6	OL	6.5	OL	30.	OL	96.	30.	-	144.	152.5	152.5	6.	0.013	39	39	390-6
800	70,000	3.03	0.3	OL	0.7	OL	1.2	OL	2.4	OL	10.5	OL	40.	OL	85.	38.	95.8	95.8	10.	0.036	40	40	390-4
	74,000	4.38	0.07	OL	0.25	OL	0.4	OL	0.85	OL	3.	OL	14.	OL	51.4	1.2	62.2	62.2	13.	0.069	40	40	390-1
	78,000						No Strain Record										33.0	33.0	17.	-	40	41	390-2
	80,000	-					Ruptured 10 Seconds After Loading												20.	-	40	40	390-3
	10,000	0.054	25.	10.	53.	36.	100.	73.	305.	245.	660.							668.	1.06	0.0013	38	40	390-13
	15,000	0.241	5.	OL	30.	OL	42.	0.8	80.	37.	184.	138.						210.5	1.38	0.0053	38	38	390-12
	19,000	0.167	1.8	OL	13.	0.5	16.	6.	29.	20.	61.	50.	120.	110.	250.	245.	914.	914.	90.	0.015	39	40	390-16
1000	23,000	0.185	2.7	OL	5.5	0.1	9.	2.9	13.5	9.	24.5	20.	48.	44.	109.	104.	359.5	359.5	82.	0.043	39	39	390-11
	30,000	0.300	0.5	OL	1.8	OL	3.	OL	5.	1.8	8.3	6.7	12.8	11.4	24.8	23.8	75.7	75.7	63.	0.09	39	39	390-15
	40,000	0.462	0.14	OL	0.5	OL	0.75	OL	1.4	0.02	2.7	1.6	4.	3.5	5.85	5.65	13.15	13.15	55.	0.33	40	40	390-10
	50,000	0.666	0.02	OL	0.05	OL	0.09	OL	0.16	OL	0.44	0.09	0.91	0.62	1.5	1.45	2.85	2.85	29.	1.7	39	40	390-9

C - Creep
TD - Total Deformation
OL - On Loading

TABLE 5

TENSILE CREEP-RUPTURE CHARACTERISTICS OF A-110AT TITANIUM ALLOY BAR

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	RC Hardness		Speci-men
			0.5%		1.0%		2.0%		3.0%		4.0%		5.0%								
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					Before	After	
	86,000	3.13														283.	3.5		33	34	391-17
600	88,000				Ruptured immediately after loading.												11.0		33	34	391-16
	90,000				Ruptured on loading.												11.5		32	32	391-14
	48,000	0.344	90.	7.	154.	112.	253.	220.								305.	3.8	0.0025	32	33.5	391-12
	52,000	0.395	57.	5.	110.	75.										117.	1.46	0.0045	33	32.	391-5
	60,000	0.565	3.5	OL	14.	3.	59.	33.	87.	72.					284.	284.	35.	0.02	31	34.5	391-2
800	68,000	0.995	0.9	OL	3.		12.	3.	24.	12.	36.	24.		36.	100.	100.	25.	0.083	31	34	391-4
	75,000				No deformation readings.										24.75	24.75	17.		30	33.5	391-1
	80,000	4.47	0.1	OL	0.2	OL	0.6	OL	1.1	OL	1.9	OL	2.9	0.1	12.4	12.4	21.	0.83	31	35	391-6
	86,000				Ruptured immediately after loading.												12.		31	33	391-8
	10,000	0.090	44.	31.	126.	109.										166.	1.5	0.006	32	32.5	391-13
	14,000	0.130	17.	11.	38.	32.	88.	80.								112.	2.5	0.0175	32	30	391-11
	20,000	0.191	4.	2.4	8.4	6.6	17.	15.4	25.7	24.	34.2	32.6			208.	208.	68.	0.115	33	33	391-10
1000	25,000	0.262	1.	0.6	2.4	1.8	5.0	4.2	8.	7.2		10.2			62.	62.	92.	0.35	31	31	391-9
	35,000	0.360	0.18	0.04	0.4	0.25	0.85	0.7	1.2	1.1	1.44	1.4		1.6	7.25	7.25	71.	2.3	32	30	391-3
					Time in Minutes																
	50,000	0.635	1.	OL	2.2	0.8	4.6	3.	7.6	5.6	11.	8.7			0.7	0.7	49.	16.	33	33	391-7

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 6

TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9DX SHEET

Temp. °F	Stress PSI	% Elong. on Load-ing	Time in Hours for Deformation of: 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	10.0% C	10.0% TD	Frac-ture Hours	Time of Test Hours	% Elon. in 2 In.	Min. Creep Rate % Per Hour	Hardness RA Before	Hardness RA After	Specimen
1000	65,000	1.34	3.	OL	5.	OL	16.	OL	55.	OL	195.	25.	420.	395.			639.	639.	10.	0.0065	62	64	384-32
	70,000	6.50	1.	OL	1.5	OL	2.	OL	5.	OL	13.	OL	53.	OL	107	34	122.	122.	21.	0.067	62	64	384-30
	75,000	-					No Strain Readings										28.	28.	24.	-	62	65	384-29
	80,000	6.12	0.25	OL	0.5	OL	0.75	OL	2.	OL	4.5	OL	12.	OL			31.	31.	17.	0.24	62	67	384-31
	80,000						No Strain Readings										39.4	39.4	18.	-	62	67	384-35
	80,000	-					Ruptured on Loading										-	-	18.	-	61	64	384-36
1200	27,000	0.152	35.	0.5	115.	18.	335.	165.	715.	615.							-	723.	1.2	0.00093	61	59	384-16
	31,000	0.185	5.5	0.05	15.	1.3	46.	16.	190.	135							-	209.	1.25	0.0032	60	59	384-19
	33,000	0.221	4.3	OL	14.	0.8	33.	12.	130.	80.	305.	273.	525.	516.			643.	643.	14.	0.0045	60	60	384-18
	36,000	0.206	1.1	OL	2.8	0.2	8.	2.7	35	22.5	102.	89.	225.	219.			296.	296.	19.	0.015	61	60	384-12
	39,000	0.220	0.23	OL	0.7	0.03	2.2	0.55	10.	6.	28.	24.	76.	74.			134.	134.	33.	0.053	60	60	384-8
	42,000	0.256	0.05	OL	0.19	-	0.6	0.2	2.5	1.3	8.6	6.9	25.3	24.3			46.	46.	22.	0.15	61	60	384-6
	46,000	0.439	0.02	OL	0.05	OL	0.13	0.01	0.5	0.16	2.1	1.3	7.25	6.7			16.1	16.1	32.	0.55	62	61	384-5
	50,000	1.05	-	OL	-	OL	0.04	OL	0.16	OL	0.4	0.13	1.53	1.3			4.1	4.1	26.	2.0	62	61	384-3
	52,000	1.47	-	OL	-	OL	0.02	OL	0.06	OL	0.19	0.02	0.69	0.44			2.1	2.1	37.	5.5	62	61	384-2

TABLE 6 (cont'd.) TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9DX SHEET

Temp °F	Stress PSI	Elong. on Loading	Time in Hours for Deformation of														Fracture Hours	Time of Test Hours	% Elon. in 2 In.	Min. Creep Rate % Per Hour	Hardness RA		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	
1350	6,000	0.018	100.	90.	200.	190.	320.	310.	680.	650.	1590.	1694.						1694.	1.02	0.0019	62	62	384-20
	8,000	0.04	90.	60.	195.	150.	290.	250.	500.	450.	800.	780.						837.	1.06	0.004	62	62	384-28
	12,000	0.088	3.	-	28.	5.	65.	32.	120.	92.	205.	190.	340.	335.	568.	565.	772.	772.	20.	0.0037	60	58	384-17
	16,000	0.074	1.9	-	19.	4.5	37.	24.	48.	51.	102.	98.	148.	146.	208.	206.	257.	257.	18.	0.0059	60	60	384-15
	19,000	0.14	0.5	OL	4.3	0.2	13.	6.	38.	20.	69.	64.	97.	95.	131.	130.	167.	167.	28.	0.0087	62	58	384-13
	22,000	0.20	0.8	OL	3.	OL	5.8	0.8	16.5	5.8	32.	27.5	52.	49.	71.	69.5	88.9	88.9	30.	0.026	61	58	384-11
	25,000	0.15	0.45	OL	1.3	0.09	3.	0.85	11.	4.7	27.5	21.5	46.	44.	63.	62.5	75.2	75.2	27.	0.031	62	58	384-1
	28,000	0.25	0.06	OL	0.22	OL	0.47	0.2	1.	0.35	2.75	1.85	6.3	5.4	12.8	12.6	18.25	18.25	23.	0.29	62	58	384-10
	31,000	0.23	0.02	OL	0.07	OL	0.13	0.01	0.3	0.1	0.8	0.56	1.8	1.55	3.82	3.72	6.45	6.45	23.	1.1	61	59	384-7
	33,000	0.26	0.02	OL	0.04	OL	0.07	-	0.14	0.05	0.36	0.24	0.76	0.65	1.63	1.55	3.2	3.2	38.	2.5	61	58	384-9
	36,000	0.37	-	OL	0.01	OL	0.02	OL	0.035	-	0.08	0.048	0.17	0.14	0.39	0.37	1.	1.	50.	11.	61	59	384-14
1500	2,500	0.007	22.	21.	102.	100.	197.	195.	402.	400.	975.	970.					-	982.	1.02	0.0018	62	62	384-27
	5,000	0.062	8.	2.	22.	13.	34.	25.	64.	54.	120.	114	213.	208.	429.	426.	810.	810.	29.	0.0077	62	57	384-26
	8,000	0.08	0.75	0.1	3.5	1.2	8.	4.5	14.5	12.	29.	27.	53.	51.	95.	94.	171.	171.	30.	0.033	61	57	384-24
	11,000	0.11	0.3	OL	1.4	0.25	2.5	1.3	5.	3.5	10.4	9.5	18.3	17.5	32.4	32.	60.4	60.4	28.	0.0087	61	57	384-23
	14,000	0.154	0.12	OL	0.28	0.03	0.75	0.18	1.6	1.	3.4	2.9	6.2	5.8	11.	10.8	19.1	19.1	36.	0.16	61	57	384-21
	20,000	0.23	0.23	OL	0.05	OL	0.08	-	0.14	0.06	0.31	0.24	0.62	0.56	1.21	1.18	2.4	2.4	44.	2.9	60	56	384-22

C - Creep
TD - Total Deformation
OL - On Loading

TABLE 7

TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9DX 1/2 INCH DIAMETER BAR STOCK

Temp. °F	Stress PSI	% 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	% Elong. in 2 In.	Min. Creep Rate % Per Hour	Hardness RA Before	Hardness RA After	Specimen
1000	65,000	0.275	3.	OL	9.	OL	21.	0.2	42.	11.	137.	80.					—	137.	1.3	0.0054	66.	62.	385-14
	70,000	0.35	0.2	OL	0.9	OL	2.2	OL	5.6	0.5	18.5	9.	43.	34.	118.	109.	190.1	190.1	12.	0.04	66.	64.	385-3
	75,000	0.50	0.12	OL	0.55	OL	1.	OL	2.1	OL	8.5	2.1	21.5	15.	61.		106.3	106.3	15.	0.077	66.	61.	385-12
	80,000	1.65	0.06	OL	0.17	OL	0.22	OL	0.45	OL	1.	OL	2.5	0.27	9.4		15.25	15.25	13.	0.4	66.	65.	385-13
	85,000	2.64	—	OL	—	OL	0.05	OL	0.10	OL	0.32	OL	—	OL			1.85	1.85	13.	—	66.	63.	385-6
1200	35,000	0.18	2.5	OL	5.	0.5	9.	3.	27.	10.	67.	53.					285.	285.	30.	0.012	66.5	59.	385-11
	38,000	0.38	1.5	OL	2.	OL	5.	OL	10.	1.5	26.	14.	56.	46.	86.5	84.	96.	96.	6.	0.032	65.	63.	385-17
	40,000	0.21	1.	OL	2.	OL	3.	1.	6.	3.	17.	12.	34.	32.			62.	62.	12.5	0.04	66.	54.	385-16
	45,000	0.27	0.2	OL	0.7	OL	1.		3.	0.7	8.5	5.5	21.5	18.			48.5	48.5	30.	0.074	66.	63.	385-1
	50,000	0.26						No Strain Readings After Loading									13.5	13.5	42.	—	66.	62.	385-21
	60,000	0.47						No Strain Readings After Loading									2.	2.	31.		66.	64.	385-23
1350	10,000	0.31	3.	2.	9.	7.	24.	20.	58.	55.	101.	98.	143.	142.			337.	337.	—	0.0053	66.	64.	385-20
	15,000	0.076	1.	—	3.	1.5	8.	5.	23.	18.	40.	38.	57.	56.			103.	103.	10.	0.0107	65.5	63.	385-19
	20,000	0.15	—	OL	1.	—	2.	0.5	5.	2.5	15.	12.5	23.	22.		34.5	42.5	42.5	50.	0.045	66.	58.	385-18
	25,000	0.17	0.2	OL	0.4	—	0.7	0.2	1.5	0.8	3.9	3.	8.2	7.6			19.75	19.75	12.	0.2	66.	61.	385-10
	30,000	0.22	—	OL	—	OL	—	—	0.5	0.2	1.3	0.9	2.5	2.2			8.5	8.5	32.	0.7	65.5	61.	385-22
1500	4,000	0.045	1.	0.5	4.	2.	7.	6.	12.5	12.	26.	25.	48.	46.5	99.	98.	309.	309.	72.	0.036	67.	54.	385-8
	7,000	0.05	0.25	0.04	1.7	1.	2.7	2.2	4.4	3.9	7.3	7.	11.7	11.5			44.	44.	113.	0.10	65.5	54.	385-5
	10,000	0.081	0.1	—	0.45	0.2	0.87	0.5	1.6	1.4	2.9	2.7	4.9	4.8			15.4	15.4	77.	0.26	66.5	60.	385-4
	15,000	0.19	0.03	OL	0.09	—	0.15	0.035	0.26	0.15	0.56	0.45	0.92	0.9			3.5	3.5	56.	—	66.	60.	385-2
	20,000	0.29		OL	0.034	OL	0.05		0.10	0.034	0.18	0.14	0.40	0.38			1.3	1.3	61.		66.	62.	385-7

C - Creep

TD - Total Deformation

OL - On Loading

TABLE 8

TENSILE CREEP-RUPTURE CHARACTERISTICS OF HARDENED A-286 ALLOY SHEET

Temp. °F	Stress PSI	% 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	Elong. in 2 In.	Min. Creep Rate % Per Hour	Hardness RD Before Test	Hardness RD After Test	Specimen
1000	95,000	0.456	9.5	OL	130.	OL	320.	OL	710.	4.5		800.					1286.	1286.	1.5	0.0005	50.5	57.	386-39
	100,000	0.548	6.	OL	25.	OL	52.	OL	137.	OL		115.					205.	205.	1.5	0.002	50.	56.	386-36
1200	50,000	0.178	300.	OL	570.	80.	740.	375.	890.	770.							960.	960.	1.	0.0003	50.5	56.5	386-42
	54,000	0.253	170.	OL	218.	OL	253.	170.	287.	237.		305.					311.4	311.4	2.	0.0005	52.	55.5	386-27
	62,000	0.284	50.	OL	82.	OL	106.	12.	130.	88.							141.5	141.5	0.5	0.0019	52.5	54.	386-22
	70,000	0.376	15.	OL	30.	OL	37.	OL	47.	20.		51.					56.1	56.1	1.5	0.0045	52.	55.	386-19
	76,000	0.357	4.	OL	8.	OL	10.5	OL	14.	6.3	18.6	15.6		22.2			22.3	22.3	2.5	0.018	52.5	56.	386-21
	82,000	0.446	1.4	OL	3.1	OL	4.2	OL	6.0	0.8	8.4	6.5		9.9			10.4	10.4	2.5	0.057	52.	56.	386-20
	88,000	0.443	0.37	OL	1.0	OL	1.4	OL	2.0	0.15	3.0	2.2	4.05	3.7			4.25	4.25	3.	0.244	52.	56.	386-24
1350	17,000	0.078	100.	15.	380.	180.	560.	430.	820.	740.	1250.	1200.	1820.	1780.	3100.	3072.	3156.	3156.	7.	0.0004	51.5	44.5	386-30
	22,000	0.085	50.	0.25	125.	60.	160.	130.	225.	204.	347.	322.	514.	503.	719.	717.	722.	722.	6.	0.0013	52.	47.	386-25
	33,000	0.162	13.	OL	32.	0.8	45.	22.	60.	46.	80.	75.	101.	98.	132.	130.	148.8	148.8	10.	0.0046	53.5	50.	386-16
	40,000	0.247	1.8	OL	6.5	OL	11.	0.6	17.	9.	26.	22.	36.	34.3	48.3	47.6	50.3	50.3	7.	0.025	52.	51.5	386-10
	50,000	0.250	0.32	OL	1.0	OL	1.5	0.15	2.4	1.3	3.85	3.1	5.8	5.5	8.75*	8.6*	8.75	8.75	5.5	0.174	53	54.	386-15
	60,000	0.342	0.05	OL	0.15	OL	0 22	OL	0.33	0.1	0.56	0.42	0.85	0.77	1.37	1.32	1.65	1.65	7.5	1.570	52.	53.5	386-18
1500	5,000	.032	55.	30.	125.	105.	200.	180.	350.	325.	620.	613.						764.	1.2	0.0013	51.5	31.5	386-35
	8,000	0.083	13.	4.	38.	15.	60.	40.	95.	80.	170.	160.	320.	305.			1104.	1104.	15.	0.0045	51.5	33.5	386-41
	10,000	0.04	4.5	0.8	16.	13.	20.	20.5	35.5	35.	75.	73.	125.	123.	228.	227.	310.6	310.6	9.	0.0082	53.	33.5	386-31
	15,000	0.04	0.9	0.3	3.0	2.4	5.5	4.7	8.5	8.	16.0	15.5	24.3	24.	43.2	42.0	47.3	47.3	7.5	0.037	51.5	39.	386-33
	20,000	0.10	0.3	OL	0.8	0.3	1.2	0.8	2.1	1.6	3.8	3.45	5.9	5.67	10.0	9.85	13.4	13.4	13.	0.230	52.5	44.	386-32
	30,000	0.18	0.02	OL	0.03		0.05	0.02	0.08	0.05	0.15	0.13	0.28	0.26	0.58	0.56	1.15	1.15	20.	6.30	52.5	44.	386-26

C - Creep

TD - Total Deformation

OL - On Loading

* - Extrapolated from Time-Deformation Curve

TABLE 9

TENSILE CREEP-RUPTURE CHARACTERISTICS OF HARDENED A-286 ALLOY BAR

Temp. °F	Stress PSI	% Elong. on Loading	Time in Hours for Deformation of														Fracture Hours	Time of Test Hours	% Elong. in 2 In.	Min. Creep Rate % Per Hour	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					
	80,000	0.43	4.	OL	24.5	OL	56.	OL	135.5	2.		174.5					346.	346.	2.	0.0017	3[illegible]-15
1000	100,000	1.68	0.1	OL	0.27	OL	0.55	OL	1.05	OL	2.7	OL	6.15	0.6	16.5*	10.7*	19.	19.	8.	0.286	387-14
	110,000	4.39	0.05	OL	0.08	OL	0.12	OL	0.18	OL	0.36	OL	0.80	OL	1.9*	0.2	4.75	4.75	17.	2.38	387-13
	50,000	0.20	40.	OL	97.	OL	140.	40.	196.	140.	250.	239.					298.	298.	2.	0.0018	387-12
	60,000	0.24	9.	OL	20.	OL	30.	5.5	41.	26.	51.5	48.5					67.	67.	2.	0.0095	387-6
1200	60,000	0.26	7.5	OL	21.	OL	31.5	3.2	57.	28.	76.5	69.	83.5	83.5	87.5	87.	90.	90.	7.	0.0060	387-9
	65,000	0.30	4.8	OL	7.6	OL	11.8	OL	18.	7.5	25.5	21.5	30.	29.			34.	34.	3.5	0.020	387-8
	70,000	0.32	1.2	OL	3.9	OL	6.5	OL	11.	3.2	14.8	12.7	17.1	16.6			19.	19.	3.5	0.037	387-7
	80,000	0.40		OL	0.07	OL	0.1	OL	0.16	0.03	0.3	0.19	0.51	0.43	0.92	0.87	1.25	1.25	8.	3.0	387-10
	30,000	0.14	6.	OL	35.	1.8	56.	20.	88.	68.	119.	112.	144.	142.			163.	163.	4.	0.0029	387-4
	32,000	0.15	5.7	OL	25.	1.7	37.	19.	54.	44.	72.	68.	88.	86.	99.*	98.*	122.5	122.5	15.	0.0049	387-3
1350	35,000	0.20	14.	OL	24.	OL	31.5	15.	40.	31.5	52.	48.	64.	62.5	71.*	70.*	88.	88.	19.	0.0060	387-16
	40,000	0.18	0.35	OL	0.7		1.3	0.4	2.6	1.4	4.9	4.2	8.2*	7.6*	16.1*	15.8*	19.5	19.5	>12.	0.16	387-2
	45,000	0.23	0.25	OL	0.5	OL	0.8	0.2	1.4	0.7	2.5*	2.	4.*	3.8*	5.5*	5.4*	6.25	6.25	>6.5	0.35	387-1

C - Creep

TD - Total Deformation

OL - On Loading

* - Extrapolated from Time-Deformation Curve

TABLE 10

BEARING CREEP RUPTURE CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY SHEET FOR AN EDGE DISTANCE OF 2.0D

Temp. °F	Stress PSI	% Elong-on Load-ing	Time in Hours for Bearing Deformation Expressed as Percent of the Diameter														Frac-ture Time Hours	Time of Test Hours	Min. Creep Rate % Per Hour	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				
	80,000	6.98	7	OL	40.	OL	335.	OL		OL		OL						405.	0.00303	212B126
	90,000	8.97	0.1	OL	2.6	OL	13.	OL		OL		OL						18.2	0.077	212B128
300	100,000	13.04		OL	0.25	OL	4.	OL	15.	OL	86.	OL		OL			99.0	99.0	0.0143	212B123
	110,000	19.28		OL	0.30	OL	0.60	OL	1.60	OL	9.6	OL		OL			24.5	24.5	0.143	212B124
	120,000		No strain measurements														4.5	4.5		212B127
	25,000	1.57	6.5	OL	29.	OL	97.	5.		60.								113.	0.015	212B110
	35,000	2.03		OL	4.	OL	12.	OL	18.	3.	29.	18.	59.	47.			109.5	109.5	0.17	212B109
450	40,000	1.95	0.4	OL	2.4	OL	4.5		8.	2.5	12.	8.	27.	20.5		46.	51.	51.	0.29	212B108
	55,000	3.37	0.04	OL	0.07	OL	0.2	OL	0.32	OL	0.62	0.15	1.76	0.95		3.2	4.0	4.0	8.3	212B107
	65,000	4.91		OL		OL		OL	0.02	OL	0.05		0.17	0.05		0.33	0.5	0.5	59.	212B106
	5,000	0.446	10.		65.	15.	217.	150.		300.								307.	0.0067	212B105
	7,000	0.62	2.	OL	7.	0.5	35.	15.	63.	45.	118.	102.						136.	0.035	212B121
600	10,000	0.87	1.	OL	2.8		6.8	3.	10.	7.	16.8	14.	35.	32.			99.	99.	0.238	212B113
	15,000	1.17	0.1	OL	0.45	OL	1.4	0.35	2.0	1.25	3.1	2.5	6.5	5.6			17.	17.	1.39	212B111
	20,000	1.86		OL	0.06	OL	0.13		0.22	0.07	0.37	0.24	0.39	0.68		1.66	2.5	2.5	10.7	212B114

C = Creep

TD = Total Deformation

OL = On Loading

TABLE 11

BEARING CREEP-RUPTURE CHARACTERISTICS OF 2024-T3 ALUMINUM ALLOY SHEET FOR 0.064 AND 0.1875 INCH DIAMETER BEARING HOLES

Temp. °F	Stress PSI	% Elong. on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Time Hours	Time of Test Hours	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			
								0.064 Inch Bearing Hole											
450	25,000	2.64	3.0	OL	11.	OL	43.	OL	72.	1.0	124.	52.	187.	165.		208.	208.5	208.5	212B100
	30,000	3.28	0.35	OL	2.5	OL	10.	OL	19.	OL	36.5	7.	61.5	47.5		68.	68.25	68.25	212B99
	35,000	3.76	0.2	OL	1.2	OL	4.6	OL	8.6	OL	15.	2.	25.4	18.7		28.3	28.8	28.8	212B97
	40,000	4.52	0.06	OL	0.32	OL	1.3	OL	2.6	OL	5.1	0.06	8.7	5.6		9.7	10.	10.	212B98
								0.1875 Inch Bearing Hole											
450	25,000	1.355	2.7	OL	12.5	OL	35.	5.3	55.	26.	85.	66.	117.5	111.			125.2	125.2	212B116
	30,000	1.54	1.4	OL	5.	OL	12.5	1.1	20.	8.5	29.	22.	40.	39.			42.75	42.75	212B120
	35,000	2.02	0.25	OL	1.1	OL	3.2	OL	4.8	1.1	7.5	4.8	11.2	10.1			12.4	12.4	212B115
	45,000	3.00		OL	0.07	OL	0.26	OL	0.51	OL	1.0	0.26	1.9	1.4			2.3	2.3	212B117

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 12

BEARING CREEP-RUPTURE CHARACTERISTICS OF A-110AT TITANIUM ALLOY SHEET FOR AN EDGE DISTANCE OF 2.0D

Temp. °F	Stress PSI	Bearing Hole Deformation on Loading %	Time in Hour for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	Specimen
			5.0%		10.0%		15.0%		20.0%		25.0%		30.0%		40.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
800	140,000	14.8	55.	OL	105.	OL	142.	-	175.	58.	203.	106.	226.	143.		203.	292.	292.	390B1
	150,000	17.8	60.	OL	102.	OL	132.	OL		20.		83.		118.			242.	242.	390B2
	160,000	32.3	23.	OL		OL		OL		OL		OL		OL			47.	47.	390B5
	165,000	35.	7.	OL		OL		OL		OL		OL		OL		7.5	36.	36.	390B29
	170,000				Ruptured on Loading												-	-	390B13
	180,000				Ruptured on Loading												-	-	390B10
1000	50,000	1.90	15.	9.	36.	28.	60.	51.	89.	78.	115.	105.	142.	131.	196.	187.	430.	430.	390B24
	60,000	2.175	7.	4.	17.	12.	29.	24.	30.	35.	52.	47.	66.	60.	95.	88.	151.	151.	390B17
	65,000	2.20	6.	3.	11.	9.	17.	14.5	23.	20.5	29.	26.	35.	32.			83.	83.	390B21
	70,000	2.43	2.7	1.5	5.1	4.	7.5	6.3	10.	8.8	12.4	11.3					51.	51.	390B16
	75,000	3.19	2.3	1.	4.6	3.	6.9	5.5									35.	35.	390B25
	80,000	3.09	1.3	0.5	2.5	1.8	3.5	2.9	4.4	3.9		4.7					16.5	16.5	390B27
	90,000	3.45	0.65	0.2	1.4	0.85	2.	1.6	2.65	2.25	3.3	2.85	3.9	3.5			8.75	8.75	390B26

C - Creep

TD - Total Deformation

OL - On Loading

TABLE 13
BEARING CREEP-RUPTURE CHARACTERISTICS OF SAE 4130 ALLOY STEEL SHEET FOR AN EDGE DISTANCE OF 2.0D

Temp. °F	Stress PSI	% Elong. on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Time Hours	Time of Test Hours	Min. Creep Rate % Per Hour	Specimen
			1.0%		2.0%		5.0%		10.0%		20.0%		30.0%		40.0%					
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD				
	100,000	3.21	15.	OL		OL		140.										236.	0.005	300B48
	120,000	4.10	2.	OL	22.5	OL		0.4										90.2	0.0096	300B51
	140,000	7.84		OL	3.	OL	100.	OL		5.								166.3	0.0167	300B43
800	160,000	13.22		OL		OL	0.9	OL	11.	OL	68.	2.7	133.	47.		112.	274.5	274.5	0.153	300B52
	165,000	13.60		OL		OL	0.8	OL	3.7	OL		1.3					68.75	68.75	1.25	300B46
	170,000	17.42		OL		OL		OL	0.3	OL		0.05	3.2	1.8		6.3	15.5	15.5	2.12	300B50
	175,000	15.00		OL		OL		OL	0.32	OL		0.08		0.85		2.15	4.25	4.25	7.64	300B57
	55,000	1.58	18.	OL	190.	1.8												223.8		300B55
	70,000	2.64	3.5	OL	24.	OL		39.										45.8		300B53
	90,000	3.45	1.0	OL	5.5	OL	66.	3.										91.4	0.025	300B54
900	115,000	5.45		OL		OL	2.0	OL	12.	3.	67.	32.	130.	95.			240.3	240.3	0.16	300B45
	125,000	6.97		OL	0.1	OL	0.6	OL	2.65	2.2		4.7					50.5	50.5	1.16	300B47
	135,000	9.15		OL		OL		OL	0.62		2.7	0.76		2.95			9.8	9.8	4.0	300B49
	145,000	9.88		OL		OL		OL	0.40		1.0	0.40		1.0			1.9	1.9	12.5	300B59

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 14

BEARING CREEP-RUPTURE CHARACTERISTICS OF TYPE 321 STAINLESS STEEL SHEET FOR AN EDGE DISTANCE OF 2.0 D

Temp. °F	Stress PSI	% Bearing Hole Deformation on Loading	Time in Hours for Bearing Hole Deformation Expressed as Percent of the Diameter														Fracture Hours	Time of Test Hours	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			
	14,000	0.407	13.		25.	14.	60.	45.	130.	100.								194.	210B34
	21,000	0.36	2.	0.5	7.	4.	22.	15.	39.	33.								74.	210B33
	26,000	0.80	1.	OL	2.5	0.5	7.5	3.	12.	7.	25.	20.	56.	51.	111.	107.	214.	214.	210B32
1350	37,000	0.87	0.1	OL	0.15		0.7	0.3	1.2	0.7	2.9	2.	7.7	6.8	16.5	16.	37.	37.	210B31
	46,000	2.20		OL	0.1	OL	0.15	OL	0.3		0.7	0.25	2.1	1.5	5.0	4.4	11.5	11.5	210B28
	54,000	3.64		OL		OL	0.07	OL	0.1	OL	0.15	0.05	0.42	0.2	1.1	0.9	3.4	3.4	210B30

C - Creep

TD - Total Deformation

OL - On Loading

TABLE 15

BEARING CREEP-RUPTURE CHARACTERISTICS OF ANNEALED 19-9DX ALLOY SHEET FOR AN EDGE DISTANCE OF 2.0D.

Temp. °F	Stress PSI	% Bearing Hole Deform. on Loading	Time in Hours for Bearing Hole Deformation Expressed As Percentage of the Diameter																Fracture Hours	Time of Test Hours	Specimen
			0.5%		1.0%		2.0%		3.0%		5.0%		10.0%		20.0%		25.0%				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
1200	65,000	3.73			0.5	OL	1.	OL	2.	OL	7.5	0.55	52.	14.2	161.	122.		174.5	346.75	346.75	384B23
	70,000	3.09			0.2	OL	0.5	OL	1.5	OL	4.5	0.5	21.5	9.	65.5	52.			147.	147.	384B16
	75,000	4.34			0.2	OL	0.4	OL	1.	OL	3.	0.15	12.	1.5	33.	23.5		35.	100.	100.	384B7
	80,000	5.73				OL	0.1	OL	0.25	OL	0.65	OL	2.1	0.5	7.2	3.9		7.	31.	31.	384B15
	85,000	5.43				OL	0.1	OL	0.2	OL	0.45	OL	1.6	0.4	7.	3.9		7.	24.75	24.75	384B11
	90,000	6.17				OL	0.1	OL	0.17	OL	0.5	OL	1.6	0.5		2.85		4.7	15.	15.	384B10
	100,000	11.02				OL		OL		OL		OL	0.7	OL	1.7	0.57		1.	5.25	5.25	384B22
1350	22,000	0.77	1.	OL	3.		52.	8.	110.	67.										121.	384B8
	27,000	0.91	0.7		6.2	0.1	44.	9.5	76.	47.	120.	99.								139.	384B7
	35,000	0.88	0.4	OL	1.0	0.1	7.0	2.0	15.	8.5	38.	28.	80.	75.5	127.	124.			244.5	244.5	384B6
	40,000	1.25	0.06	OL	0.23	OL	1.2	0.14	3.0	0.9	11.	4.7	33.	28.5	54.5	52.2			102.8	102.8	384B5
	50,000	1.76	0.01	OL	0.08	OL	0.35		0.85	0.13	2.4	0.95	8.0	5.9	20.5	18.7			44.7	44.7	384B2
	60,000	2.59		OL	0.02	OL	0.07	OL	0.15		34.	0.1	1.14	0.65	3.03	2.55			8.55	8.55	384B4
	70,000	3.66		OL		OL	0.02	OL	0.045	OL	0.10	0.015	0.31	0.15	0.81	0.64			2.6	2.6	384B3

C - Creep

TD - Total Deformation

OL - On Loading

TABLE 16

SHEAR-PIN DEFORMATION CHARACTERISTICS OF A-110AT TITANIUM ALLOY BAR

Temp. °F	Stress PSI	Inches Elong. on Loading	Time in Hours for Total Shear-Pin Deformation of 0.01 In. C	0.01 In. TD	0.02 In. C	0.02 In. TD	0.03 In. C	0.03 In. TD	0.04 In. C	0.04 In. TD	0.05 In. C	0.05 In. TD	Fracture Time Hours	Time of Test Hours	Min. Creep Rate % Per Hour	Specimen
600	55,000	0.021		OL		OL								268.		391S19
	60,000	0.02215		OL		OL								268.		391S20
	60,000		Ruptured on Loading													391S18
	80,000		Ruptured on Loading													391S17
800	40,000	0.0116	118.	OL	257.	94.	400.	236.		380.		470.	487.	487.	0.00007	391S1
	47,000	0.0151	40.	OL	103.	9.	147.	70.		128.		157.	158.	158.	0.00016	391S3
	50,000	0.0197	24.	OL	50.			24.		50.			63.	63.	0.00024	391S6
	55,000	0.0323	9.	OL		OL		OL		5.5		18.4	19.	19.	0.006	391S4
	60,000	0.0244	2.5	OL	9.7	OL		0.5		7.6			9.8	9.8	0.011	391S5
	63,000		Ruptured on Loading													391S8
1000	15,000	0.0042	5.	2.	33.	18.	84.	60.	133.	133.	169.	155.	209.	209.	0.00019	391S11
	17,000	0.0034	6.	3.	38.	19.	57.	48.	76.	70.			105.	105.	0.00034	391S13
	18,000	0.0036	4.	2.	18.	12.	41.	33.	57.	53.	65.	63.	72.	72.	0.00045	391S9
	19,000	0.0049	2.		8.5	4.	17.5	13.	26.5	22.	34.	31.	45.	45.	0.0011	391S15
	20,000	0.0053	1.		10.	5.	22.	16.	32.5	27.5	39.	36.	44.	44.	0.0008	391S12
	22,000	0.0057	1.3		4.7	2.5		7.					19.	19.	0.0018	391S14
	25,000	0.0071	0.4		1.3	0.6	2.2	1.6	3.1	2.5	3.6	3.3	4.0	4.0	0.011	391S16

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 17

SHEAR-PIN DEFORMATION CHARACTERISTICS OF 19-9DX 1/2 INCH DIAMETER BAR STOCK

Temp. °F	Stress PSI	In. Deform. on Loading	Time in Hours for Shear Blade Displacement in Inches														Fracture Hours	Time of Test Hours	Specimen
			0.001 inch		0.002 inch		0.005 inch		0.01 inch		0.02 inch		0.03 inch		0.04 inch				
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
1000	46,000	0.018		OL	2.	OL	16.	OL	58.	OL		2.		82.			187.	187.	385S18
	48,000	0.021	1.	OL	2.	OL	5.	OL	28.	OL		OL		20.		61.	70.	70.	385S20
	50,000	0.022		OL	2.	OL	5.	OL	23.	OL		OL		13.		54.	55.	55.	385S19
	55,000	0.033		OL	0.5	OL	2.	OL		OL		OL		OL			2.25	2.25	385S21
1200	20,000	0.0019		OL	1.		12.	3.	74.	60.	157.	154.	174.	173.		178.	180.	180.	385S6
	22,000	0.0078		OL	0.8	OL	1.	OL	11.	0.5	56.	21.	90.	65.		94.	108.	108.	385S8
	25,000	0.011		OL	0.25	OL	1.	OL	6.	OL	26.5	4.5		24.5			47.	47.	385S3
	28,000	0.0055		OL	0.25	OL	2.5	OL	11.	2.		17.					24.	24.	385S4
	30,000	0.0134		OL		OL	0.4	OL	2.3	OL	10.	0.8		7.			18.	18.	385S2
	35,000	0.0206		OL		OL	0.2	OL	0.6	OL	2.1	OL		0.6		2.	4.75	4.75	385S5
1350	6,000	0.0012		OL	1.		7.	4.	40.	31.	118.	112.	160.	156.	215.	188.	252.	252.	385S17
	7,000	0.0011		OL		0.1	7.	4.	40.	30.	85.	82.	114.	112.	130.	129.	154.	154.	385S16
	8,000	0.0019		OL			1.	0.4	8.	4.	41.	36.	68.	64.	86.	83.	118.	118.	385S11
	9,000	0.0021		OL	0.7	OL	2.	1.	20.	11.	47.	43.					76.	76.	385S14
	10,000	0.0018		OL	0.5		3.	1.5	14.	9.	32.	29.5	39.5	38.5	44.	43.5	47.	47.	385S13
	12,000	0.0029		OL		OL			2.	0.5	15.	11.	24.	21.5	29.2	28.	32.5	32.5	385S10
	20,000	0.0085		OL		OL		OL			1.4	0.6					2.75	2.75	385S15
	25,000	0.0177		OL		OL		OL		OL							0.5	0.5	385S12

C - Creep

TD - Total Deformation

OL - On Loading

TABLE 18
SHEAR-PIN DEFORMATION CHARACTERISTICS OF HARDENED A-286 ALLOY BAR

Temp. °F	Stress PSI	Inch Deform. on Loading	Time in Hours for Shear Blade Displacement of: 0.001 Inch		0.003 Inch		0.005 Inch		0.01 Inch		0.02 Inch		0.03 Inch		0.04 Inch		Fracture Hours	Time of Test Hours	Specimen
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			
1000	48,000	0.0176	3.	OL	16.	OL	66.	OL		OL		10.					314.	314.	387S8
	50,000	0.0194	0.8	OL	13.	OL	52.	OL	122.	OL		1.		124.			137.	137.	387S12
	55,000	0.0182	1.5	OL	8.	OL	28.	OL	69.	OL		3.					77.	77.	387S11
	60,000	0.0205		OL	1.	OL	3.	OL	21.5	OL		OL		20.			42.	42.	387S13
	70,000	0.0258	0.3	OL	1.	OL	2.8	OL	8.4	OL		OL		2.			9.	9.	387S14
1200	26,000	0.0036		OL	0.25	OL	0.33		3.	1.	250.	120.	515.	440.		580.	639.	639.	387S4
	30,000	0.0104		OL		OL		OL	1.	OL	2.	0.8	42.	2.		40.	62.	62.	387S3
	35,000	0.0135		OL		OL		OL	1.	OL	3.6	0.5		2.		10.5	13.2	13.2	387S2
	40,000	0.0151		OL		OL		OL	1.1	OL		0.3		1.			2.3	2.3	387S1
1350	15,000	0.0023	0.33	OL	2.	0.1	10.	3.5	70.	30.	200.	170.		275.			307.	307.	387S5
	20,000	0.0036		OL	0.4	OL	0.5		5.	0.7	38.	28.	56.	51.			65.	65.	387S6
	25,000	0.0075		OL		OL		OL	0.4		5.6	1.	6.4	8.		19.4	23.3	23.3	387S7
	30,000	0.0082		OL		OL		OL	0.5		2.2	0.75	3.6	2.5		3.75	4.	4.	387S10
	35,000	0.017															0.3	0.3	387S9

C - Creep

TD - Total Deformation

OL - On Loading

TABLE 19

COMPRESSION-CREEP CHARACTERISTICS OF A-70 TITANIUM SHEET

Temp. °F	Stress PSI	% Compression on Loading	Time in Hours for Compression Deformation of														Time of Test Hours	% Compression in 1.5 In.	RB Hardness		Specimen
			0.1%		0.2%		0.3%		0.5%		1.0%		2.0%		3.0%						
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD			Before	After	
700	21,000	0.54	20.	OL	110.	OL	175.	OL	308	OL		282.					376.5	1.15	98	102	313CC-4
	25,000	1.31	12.	OL	64.	OL	122.	OL	220.	OL		OL					232.8	1.85	98	103	313CC-3
	28,000	2.60	0.1	OL	17.	OL	56.	OL	138.	OL	305.	OL				100.	307.	3.61	98	102	313CC-6
	30,000	3.40		OL	0.3	OL	9.	OL	83.	OL		OL		OL		OL	183.8	4.12	98	101	313CC-1
800	10,000	0.11	10.	OL	25.	9.	40.	24.	73.	54.	165.	144.					184.8	1.21	98	100	313CC-9
	13,000	0.156	8.	OL	20.	3.5	27.	13.5	41.5	30.5	70.	62.	117.	110.			115.3	2.10	98	102	313CC-8
	15,000	0.21	3.2	OL	10.5	OL	17.	2.7	26.4	16.2	44.3	37.6	72.	66.3			72.3	2.23	98	100	313CC-11
	17,000	0.31	1.15	OL	4.5	OL	8.2	OL	15.5	4.3	28.2	21	44.	39.6			45.0	2.37	98	102	313CC-13
	21,000	0.69	0.58	OL	1.5	OL	2.7	OL	5.3	OL	11.	2.8	19.2	14.		20.8*	19.8	2.79	98	102	313CC-10
	25,000	2.08	0.3	OL	1.1	OL	2.1	OL	3.8	OL	7.4	OL		OL		6.9	9.4	3.50	98	103	313CC-14

C = Creep

TD = Total Deformation

OL = On Loading

Type 2S aluminum restraining fixture wedges were used in all tests

* = By Extrapolation

TABLE 20

COMPRESSION CREEP CHARACTERISTICS OF A-110AT TITANIUM ALLOY SHEET

Temp. °F	Stress PSI	% Compression on Loading	Time in Hours for 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.	Min. Creep Rate % Per Hour	Hardness RC After Test	Specimen
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					
800	65,000	0.90	1.	OL	5.	OL	17.	OL	67.	OL	235.	1.		255.			260.	2.02	0.0038	39	390CC9
	70,000	1.39	1.	OL	3.	OL	9.	OL	26.	OL	95.	OL		39.			143.	2.66	0.007	39	390CC10
	75,000	2.18	0.5	OL	2.	OL	5.	OL	18.	OL	77.	OL		OL		55.	110.	3.53	0.017	39	390CC11
	80,000	3.58		OL	0.5	OL	0.8	OL	2.6	OL	20.4	OL		OL		OL	23.	4.64	0.26	39	390CC13
1000	15,000	0.118	12.	OL	28.	10.	50.	27.	112.	76.	267.	233.					281.	1.15	0.0031	38	390CC8
	19,000	0.155	3.	OL	10.	0.8	17.	6.	35.	21.	95.	75.					97.	1.18	0.0082	38	390CC7
	23,000	0.192	3.8	OL	7.		10.	4.	17.	10.	36.	30.	100.	86.			138.	2.68	0.018	37	390CC6
	30,000	0.212	1.	OL	2.6	OL	4.	1.	6.8	4.	11.6	9.6	235.	20.4			25.	2.35	0.069	37	390CC4
	40,000	0.411	0.2	OL	0.5	OL	1.	OL	1.85	0.2	3.5	2.2	5.1	4.4		6.4	15.2	3.26	0.25	38	390CC3

Hardness before testing 38-40 RC

C - Creep

TD - Total Deformation

OL - On Loading

TABLE 21

COMPRESSION CREEP CHARACTERISTICS OF SAE 4130 ALLOY STEEL SHEET

Temp °F	Stress PSI	% Comp. 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	3.0% C	3.0% TD	Time of Test Hours	% Comp. in 2 In.	Min. Creep Rate % Per Hour	Specimen
	56,000	0.50	0.33	OL	10.	OL	29.	OL	136.	OL		136.					136.	1.0	0.00185	300CC12
	58,000	0.67	0.10	OL	3.	OL	12.	OL	61.	OL		16.					113.	1.27	0.00167	300CC10
	60,000	0.78	0.04	OL	0.60	OL	3.5	OL	20.5	OL	200.	1.0					234.4	1.82	0.00222	300CC4
800	63,000	0.91	0.05	OL	0.30	OL	1.8	OL	8.5	OL	70.	0.04		98.1			98.1	2.0	0.00333	300CC2
	66,000	1.09		OL	0.06	OL	0.20	OL	3.0	OL	25.5	OL		21.0			25.5	2.08	0.018	300CC3
	68,000	1.26	0.01	OL	0.10	OL	0.50	OL	3.1	OL	28.5	OL		10.5			41.5	2.39	0.0125	300CC7
	70,000	1.65		OL	0.03	OL	0.14	OL	0.9	OL	8.2	OL		0.21			17.0	2.93	0.0357	300CC9
	40,000	0.196	1.1	OL	11.		25.	11.	62.	27.	266.	180.					284.5	1.25	0.00208	300CC13
	43,000	0.22	1.0	OL	4.	OL	11.	0.5	40.	12.	180.	100.					212.	1.31	0.00278	300CC1
900	46,000	0.29	0.10	OL	1.	OL	3.5		10.	1.	56.	25.					88.5	1.46	0.0067	300CC6
	51,000	0.376	0.05	OL	0.30	OL	0.60	OL	2.5	0.08		5.		51.		160.	161.3	3.00	0.0071	300CC8
	54,000	0.400	0.05	OL	0.24	OL	0.50	OL	1.7	0.05	7.8	3.		21.			40.6	2.50	0.031	300CC5
	57,000	0.485		OL	0.05	OL	0.20	OL	0.47			0.50		7.		22.	22.2	3.03	0.050	300CC14
	22,000	0.059	1.0	0.25	5.	3.	16.	8.	60.	42.	275.	240.					311.	1.13	0.002	300CC17
1000	25,000	0.098	0.8		2.0	0.8	7.	3.	20.	13.	87.	66.					90.	1.12	0.0053	300CC11
	30,000	0.128	0.5	OL	1.3	0.2	3.0	1.	8.	4.5	26.	21.					40.	1.51	0.027	300CC15
	35,000	0.114	0.03	OL	0.2	0.02	0.6	0.17	1.3	0.9	4.6	3.6	16.2	14.5	36.2	34.	38.	3.19	0.046	300CC16

C = Creep
TD = Total Deformation
OL = On Loading

TABLE 22

COMPRESSION CREEP CHARACTERISTICS OF TYPE 321 STAINLESS STEEL ALLOY SHEET

Temp. °F	Stress PSI	% Comp. on Loading	Time in Hours for Deformation of: 0.1%		0.2%		0.3%		0.5%		1.0%		2.0%		3.0%		Time of Test Hours	% Comp. in 1.5 In.	Min. Creep Rate % Per Hour	Hardness RB After Test	Specimen
			C	TD	C	TD	C	TD	C	TD	C	TD	C	TD	C	TD					
1200	18,000	0.10	46.	OL	70.	46.	84.	70	108.	96.	168.	156.					188.	1.28	0.00167	86	210CC9
	20,000	0.13	46.	OL	64.	40.	76.	60.	92.	85.	136.	125.	244.	230.			280.	2.48	0.00114	88	210CC7
	22,000	0.14	40.	OL	52.	24.	60.	48.	72.	64.	107.	97.					123.	1.37	0.0016	86	210CC6
	25,000	0.17	1.5	OL	6.	0.3	11.	2.5	19.	12.5	31.5	28.					45.	1.80	0.021	87	210CC2
	30,000	0.31		OL	0.2	OL	0.4	OL	1.	0.15	15.	4.					23.5	1.62	0.021	87	210CC1
	35,000	1.38		OL		OL		OL	0.3	OL	6.	OL		0.75		18.	21.5	3.45	0.025	89	210CC8
1350	5,000	0.31	20.	14.	52.	42.	85.	75.	155.	143.	372.	356.					383.	1.06	0.00204	84	210CC12
	7,000	0.05	4.	1.	12.	8.	25.	17.	48.	43.	102.	97.					114.5	1.2	0.0083	84.5	210CC11
	9,000	0.046	2.1	1.5	8.	6.	13.	10.	22.5	20.	46.	44.	84.	82.			135.	3.0	0.020	84	210CC13
	10,000	0.07	2.	1.	7.	3.	12.	9.	23.5	20.	49.	45.	101.	97.			113.	2.32	0.020	84	210CC10
	16,000	0.13	0.4	OL	1.	0.25	1.6	0.8	3.	2.2	7.2	6.	21.	18.5			24.	2.24	0.042	84	210CC3
	20,000	0.14	0.13	OL	0.25	0.05	0.45	0.2	0.85	0.5	1.6	1.4	3.05	2.85			4.	2.77	0.56	86	210CC4

C = Creep

TD = Total Deformation

OL = ON Loading

Hardness before test was 83 RB

TABLE 23

COMPRESSION CREEP CHARACTERISTICS OF ANNEALED 19-9 DX ALLOY SHEET

Temp. °F.	Stress PSI	% Compression 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	0.4% C	0.4% TD	0.5% C	0.5% TD	1.0% C	1.0% TD	2.0% C	2.0% TD	Time of Test Hours	% Compression in 1.5 In.	Min. Creep Rate % Per Hour	Specimen
1200	22,000	0.146	1.	OL	7.6	0.6	33.9	3.9	112.2	17.5	225.	64.5	688.*	579.			640.	1.09	0.00086	384CC7
	25,000	0.264	0.35	OL	0.7	OL	1.1	0.15	2.4	0.45	4.9	0.80	86.7	21.3			427.	1.78	0.0016	384CC8
	28,000	0.649	0.1	OL	0.2	OL	0.35	OL	0.9	OL	1.9	OL	17.3	0.85		82.5	163.	2.19	0.0038	384CC6
	33,000	1.180		OL		OL	0.2	OL	0.3	OL	0.4	OL	1.8	OL	25.	1.1	18.75	2.96	0.0370	384CC5
1350	12,000	0.059	85.	3.	260.	175.	440.	335.	620.	515.	805.	700.					931.	0.63	0.00033	384CC2
	14,000	0.089	3.5		35.	4.	56.	37.	78.	58.	97.	81.	164.	152.			219.	1.56	0.0025	384CC3
	16,000	0.096	2.		5.	2.	11.	5.	20.	11.	40.	21.	76.	70.	142.	135.	147.	2.1	0.0059	384CC1
	18,000	0.108		OL	0.3		1.2	0.2	2.2	1.	4.2	2.	26.	20.	62.	59.	89.	2.7	0.0185	384CC4

C - Creep
TD - Total Deformation
OL - On Loading
* - Extrapolated from Time-Deformation Curve

TABLE 24

COMPRESSION CREEP CHARACTERISTICS OF HARDENED A-286 ALLOY SHEET

Temp. °F	Stress PSI	% Compression Deformation 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	0.4% C	0.4% TD	0.5% C	0.5% TD	1.0% C	1.0% TD	2.0% C	2.0% TD	Time of Test Hours	% Compression in 1.5 In.	Min. Creep Rate % Per Hour	Specimen
1350	30,000	0.177	3.	OL	24.		66.	5.	100.	35.	117.	77.	186.	164.		243.	261.	2.17	0.00235	386CC2
	35,000	0.211	3.	OL	18.	OL	47.	2.	59.	12.	68.	44.	100.	90.			115.	1.61	0.00222	386CC1
	40,000	0.163	15.	OL	35.	3.	44.	25.	52.	39.	60.	47.	85.	78.	116.	111.	137.5	2.50	0.00333	386CC3
	45,000	0.225	3.	OL	7.	OL	11.	2.	16.	6.	22.	10.	48.	35.			136.	1.90	0.0217	386CC4

C = Creep
TD = Total Deformation
OL = On Loading

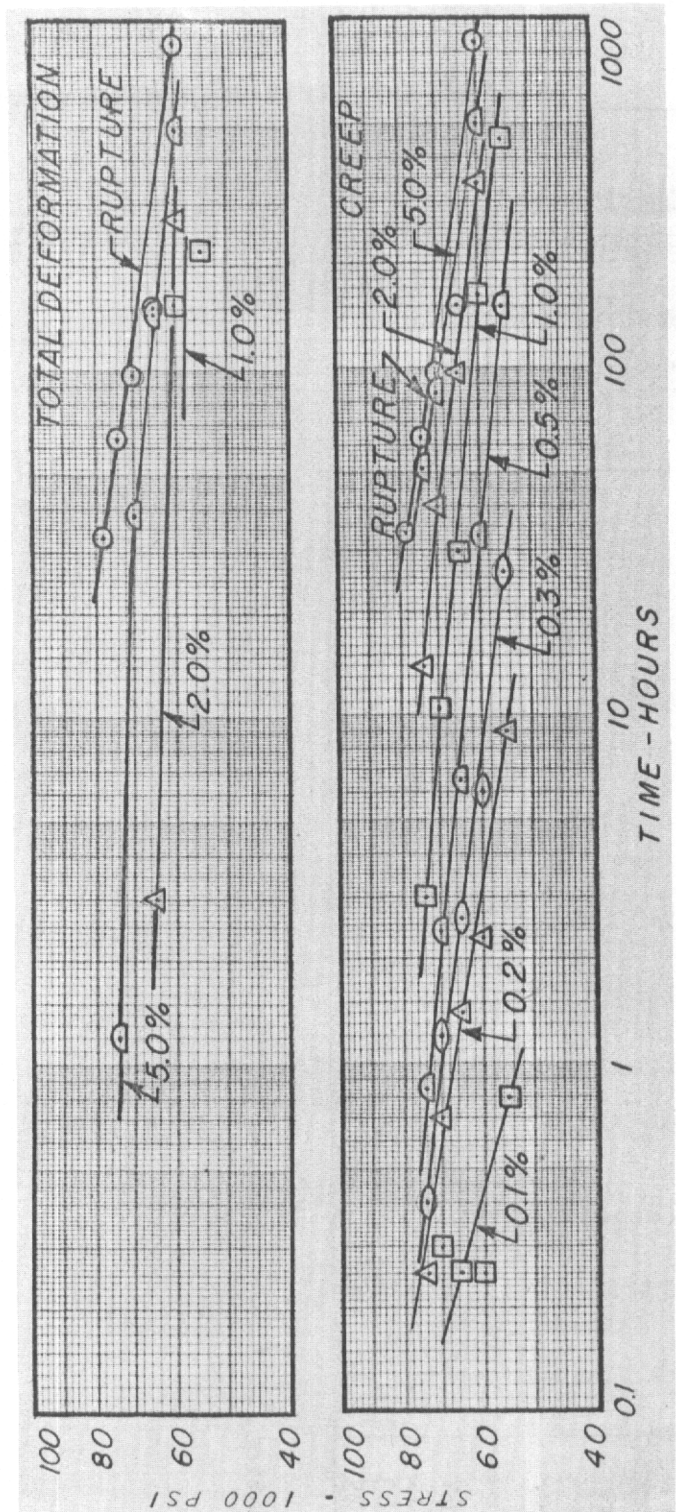

Figure I TENSILE CREEP-RUPTURE CHARACTERISTICS OF A-110AT TITANIUM ALLOY SHEET AT 800°F

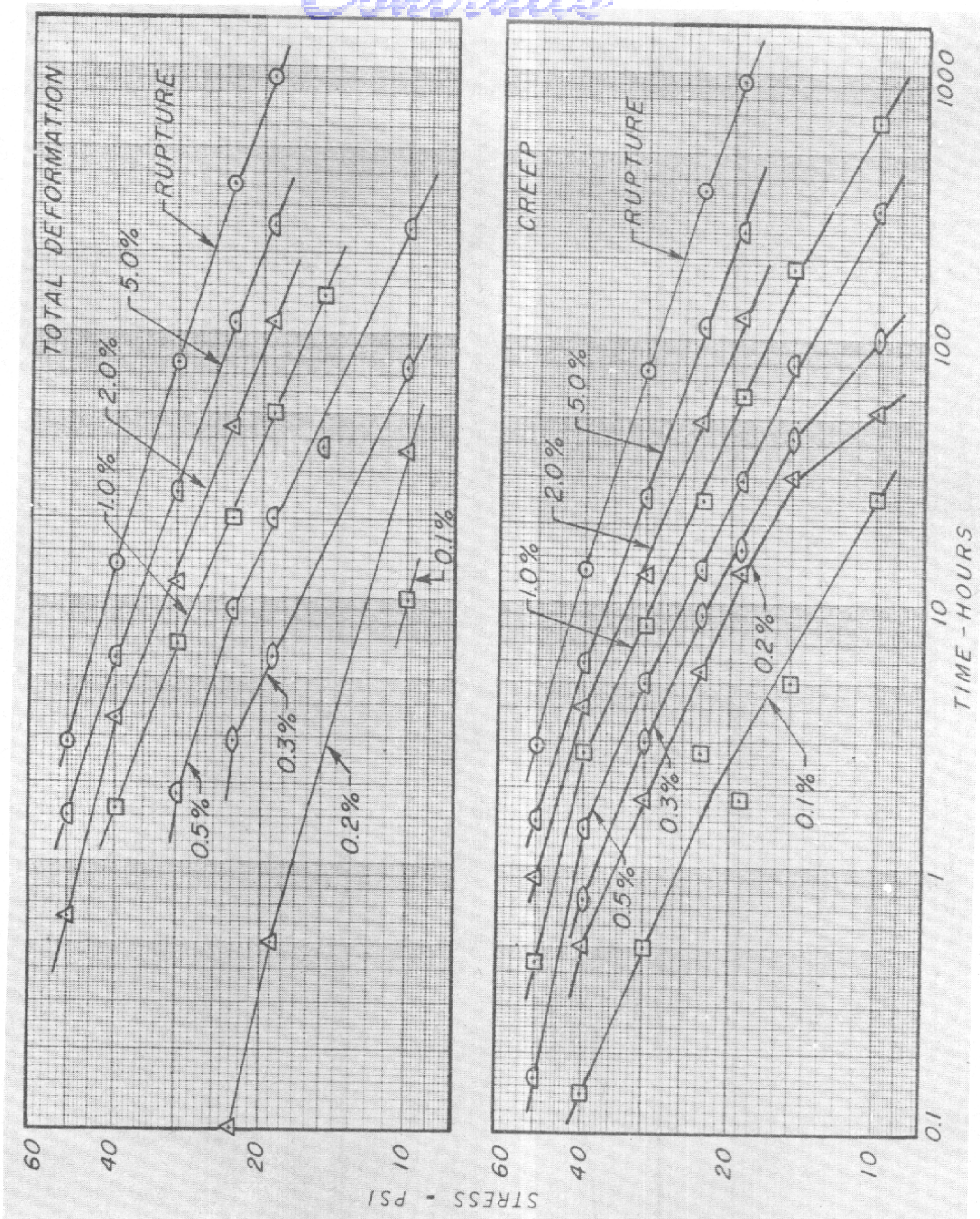

FIGURE 2 TENSILE CREEP-RUPTURE CHARACTERISTICS OF A-110AT TITANIUM ALLOY SHEET AT 1000°F

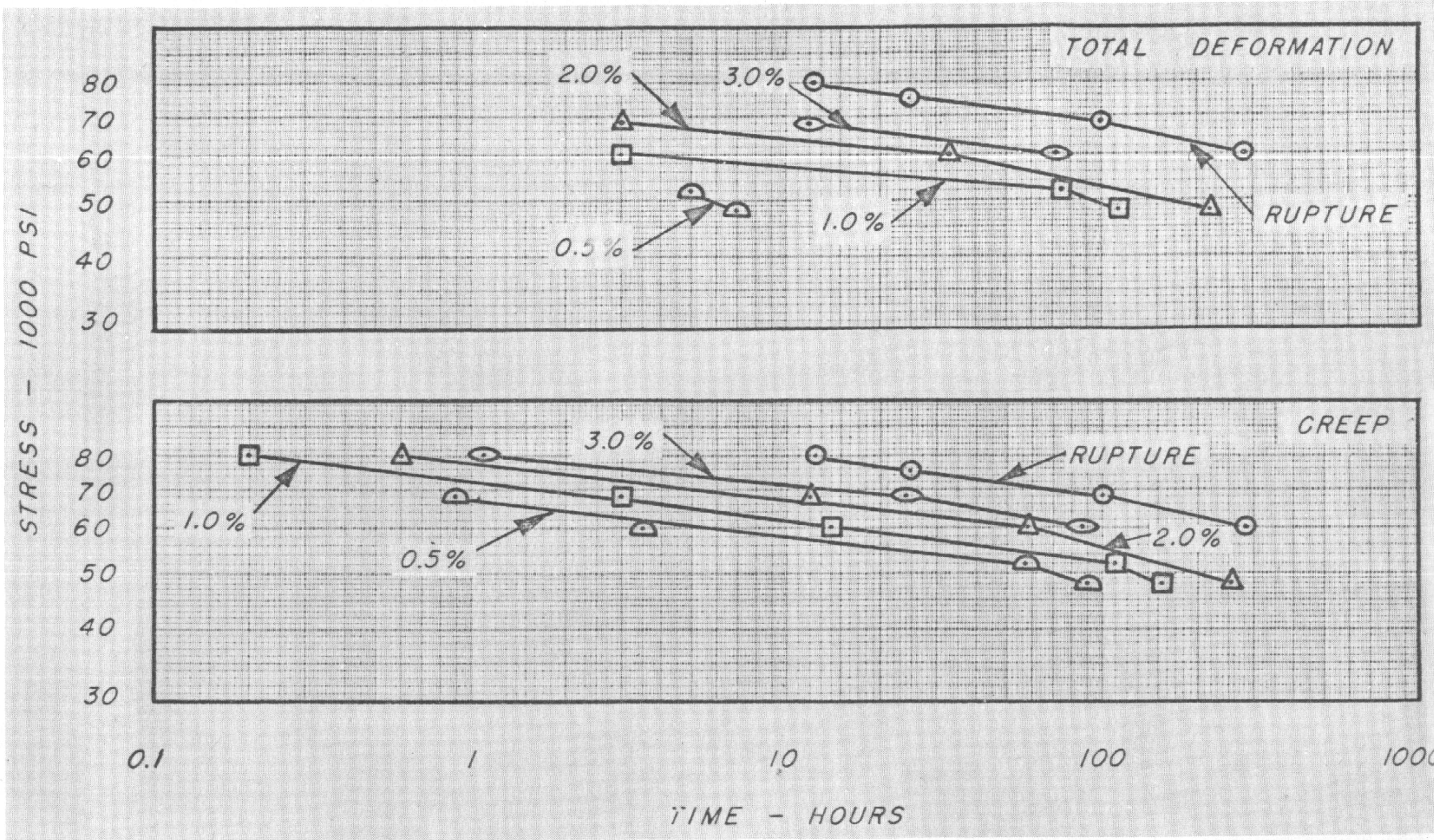

Figure 3 TENSILE CREEP-RUPTURE CHARACTERISTICS OF A-110AT TITANIUM ALLOY 1/2 INCH DIAMETER BAR STOCK AT 800°F

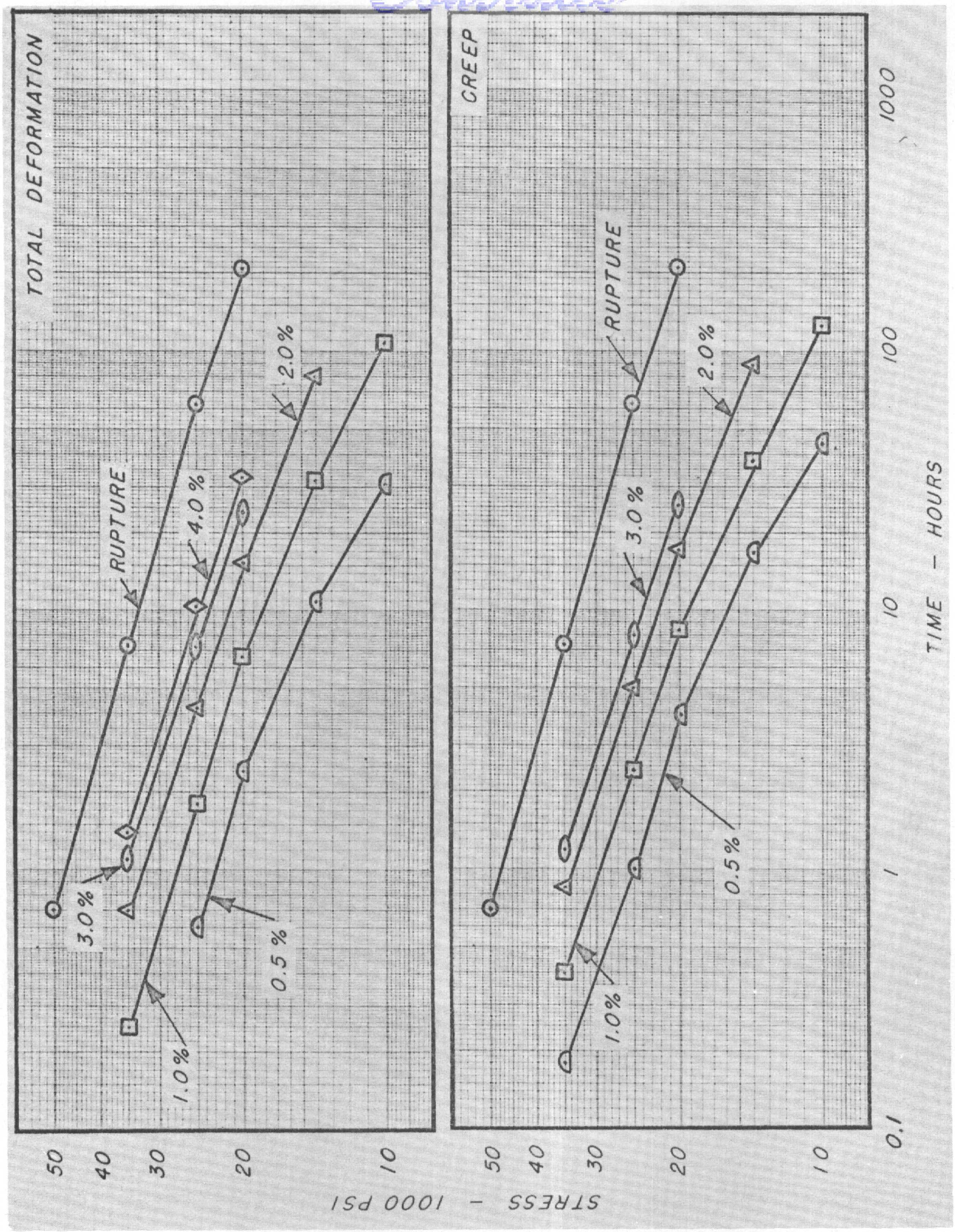

Figure 4 TENSILE CREEP-RUPTURE CHARACTERISTICS OF A-110AT TITANIUM ALLOY 1/2 INCH DIAMETER BAR STOCK AT 1000°F

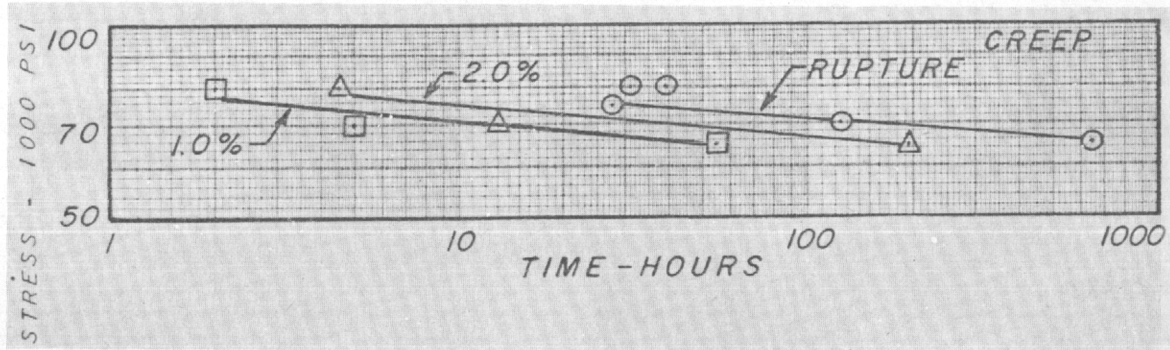

Figure 5 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9 DX SHEET AT 1000°F

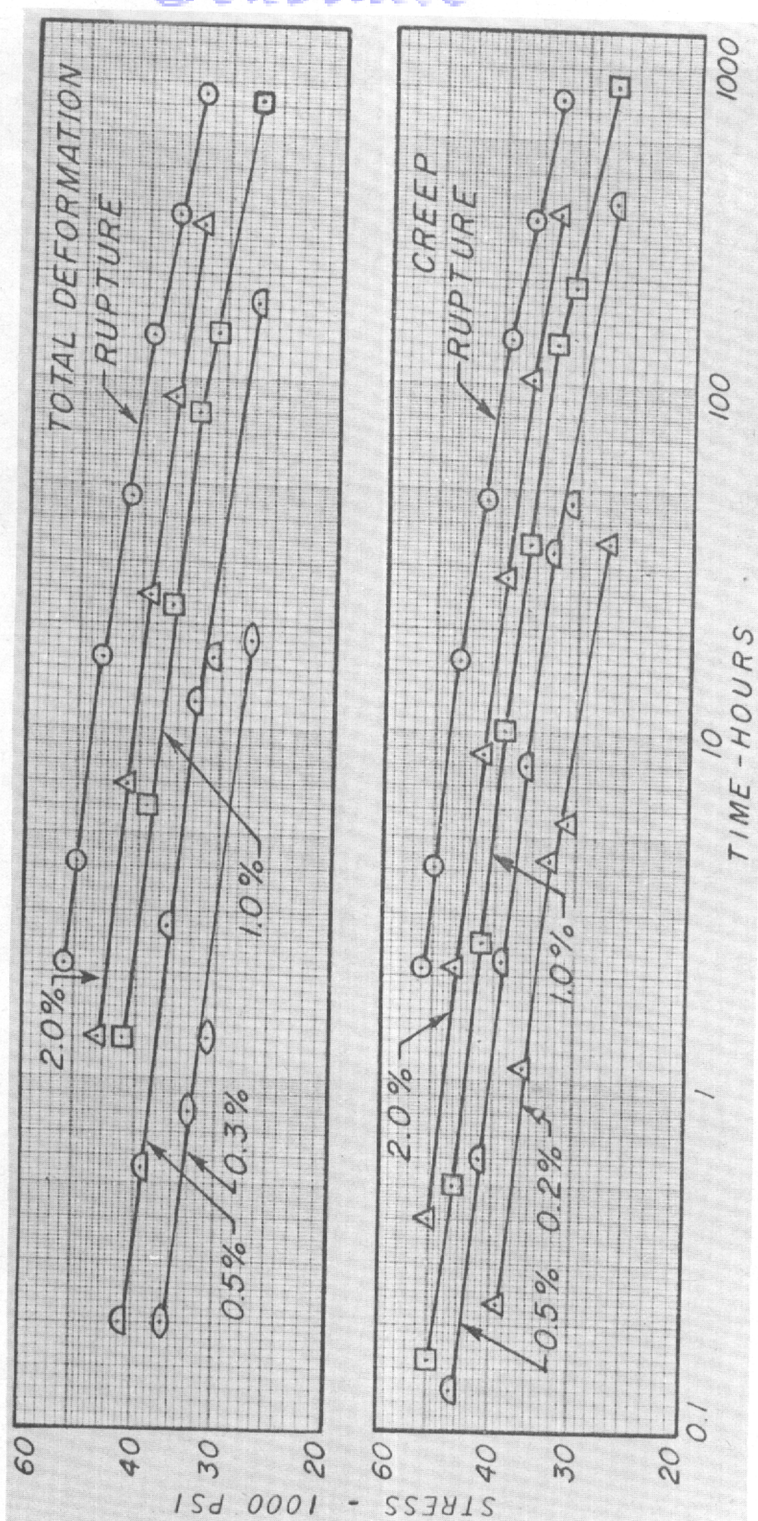

FIGURE 6 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9DX SHEET AT 1200°F

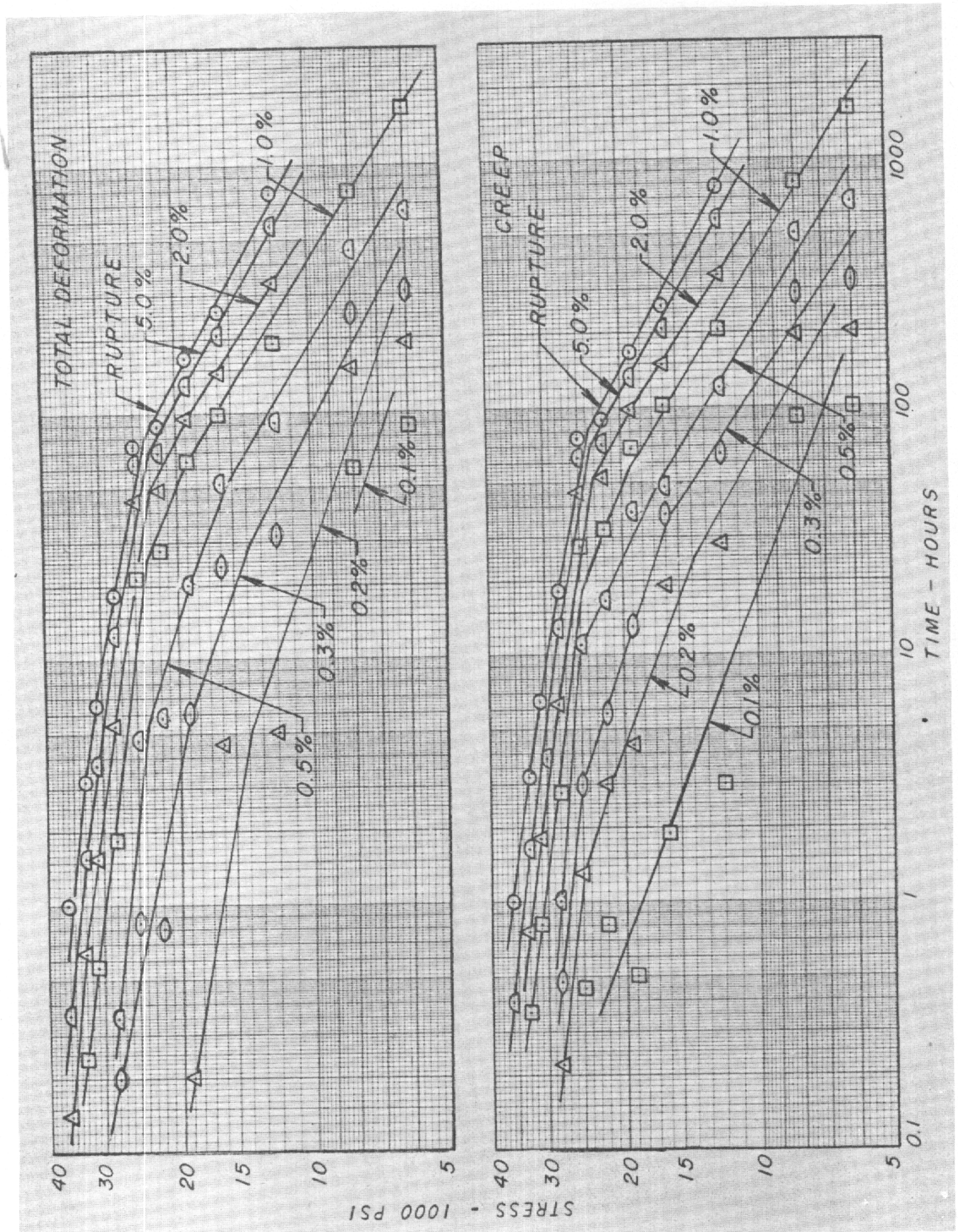

FIGURE 7 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9DX SHEET AT 1350°F

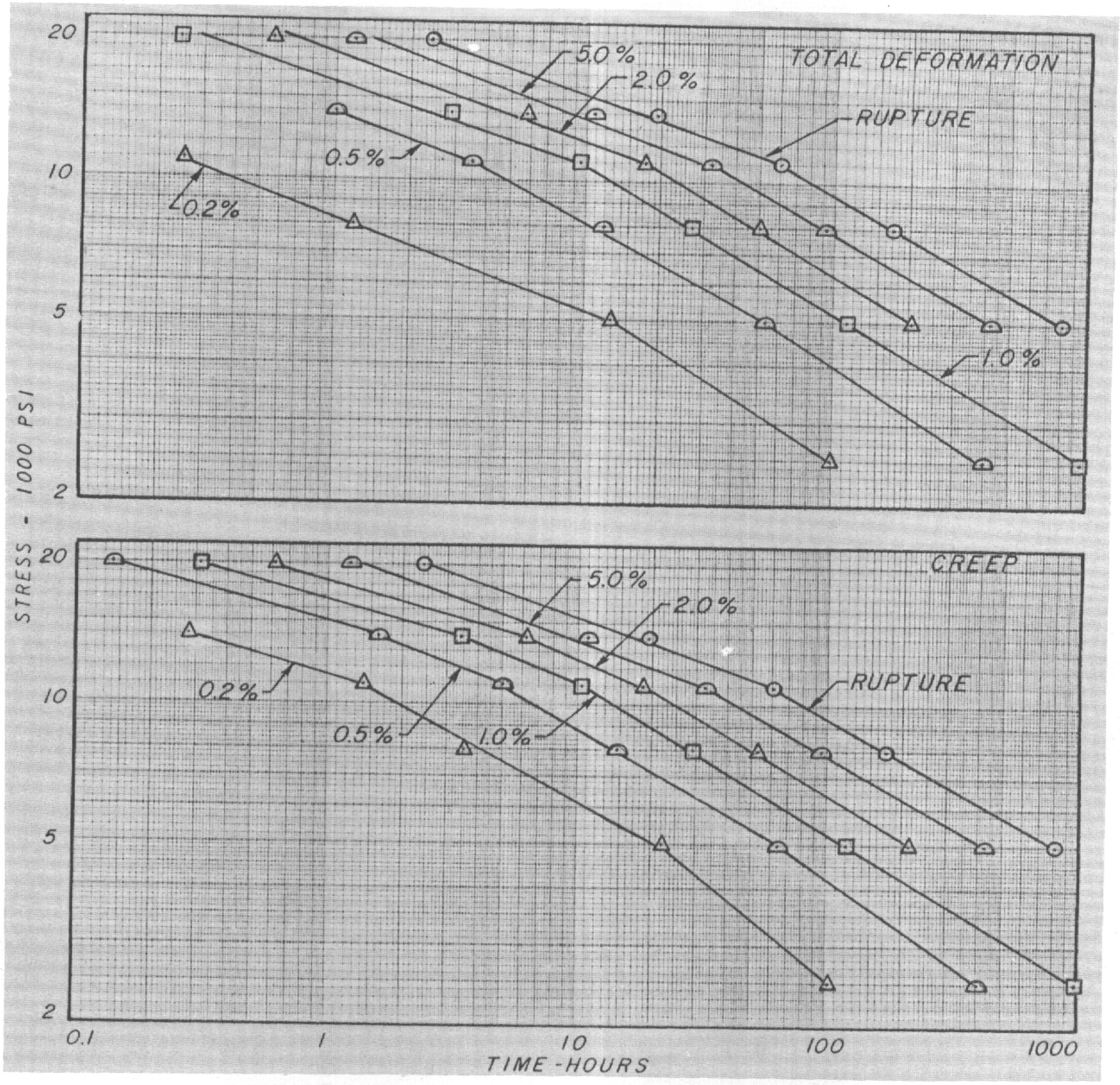

FIGURE 8 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9DX SHEET AT 1500°F

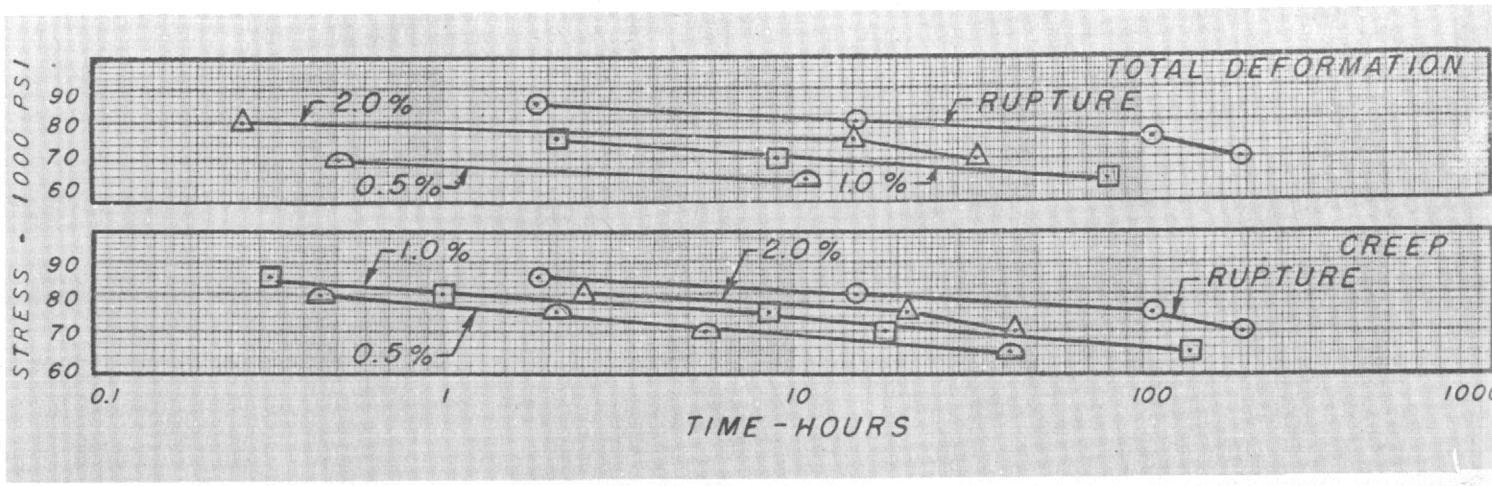

Figure 9 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9 DX $\frac{1}{2}$ INCH DIAMETER BAR STOCK AT 1000°F

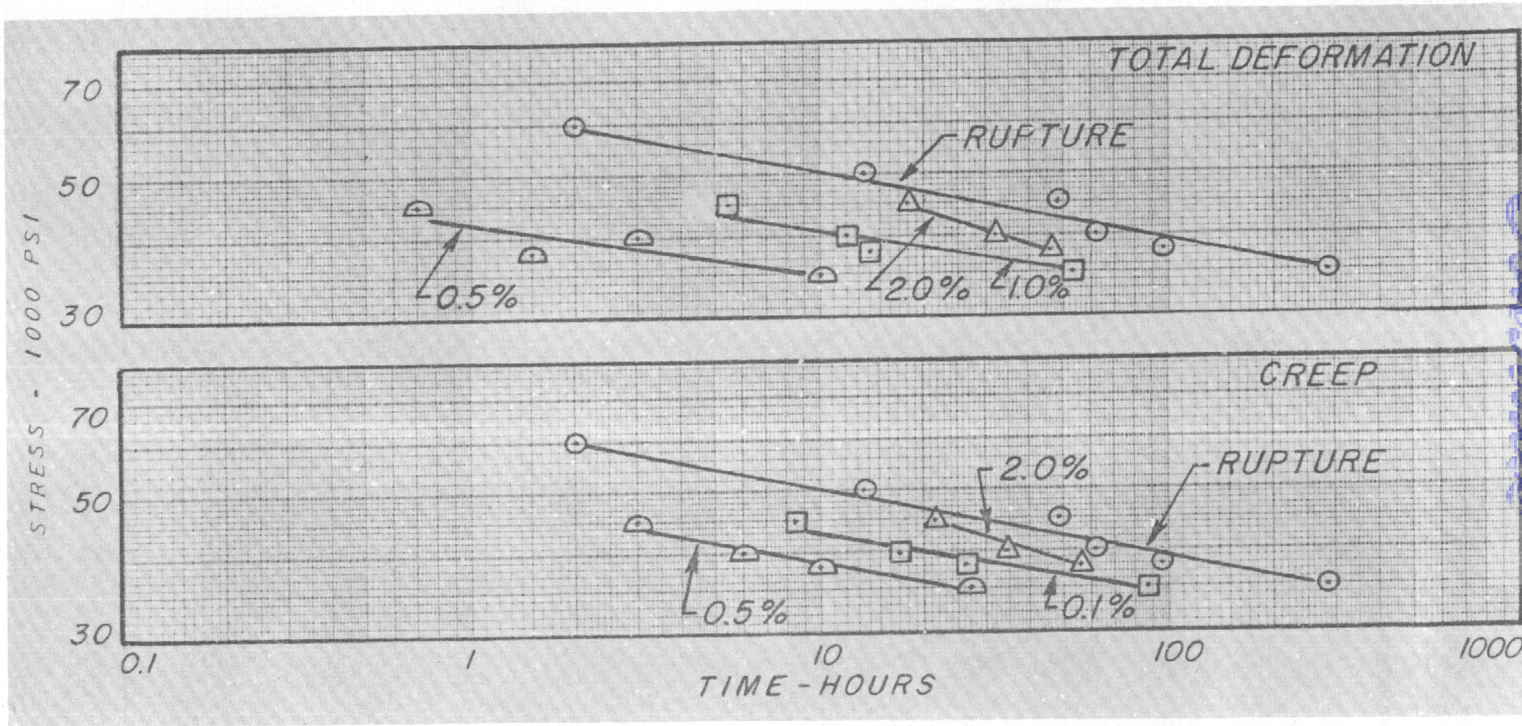

Figure 10 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9 DX ½ INCH DIAMETER BAR STOCK AT 1200° F

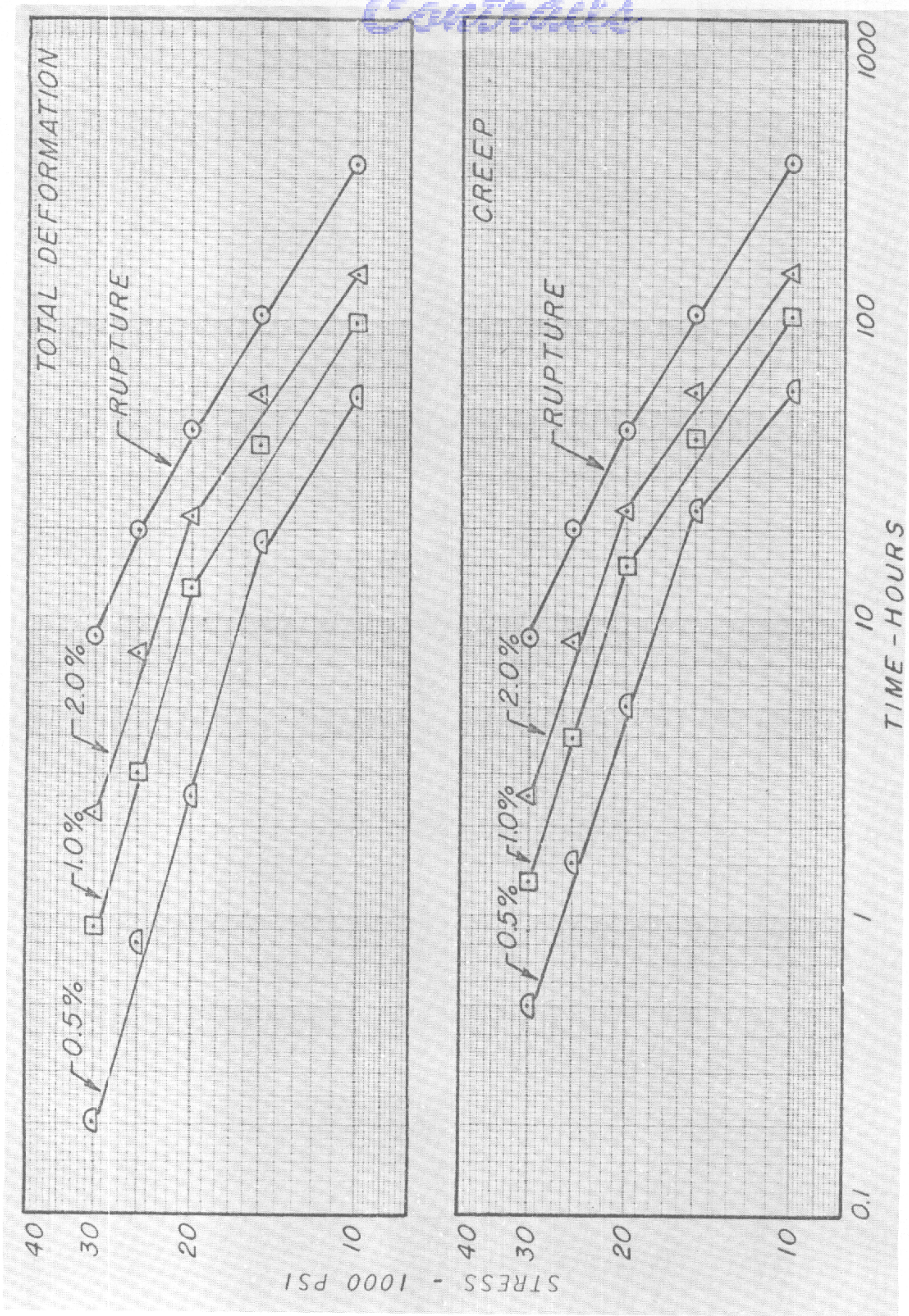

FIGURE 11 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9DX ½ INCH DIAMETER BAR STOCK AT 1350°F

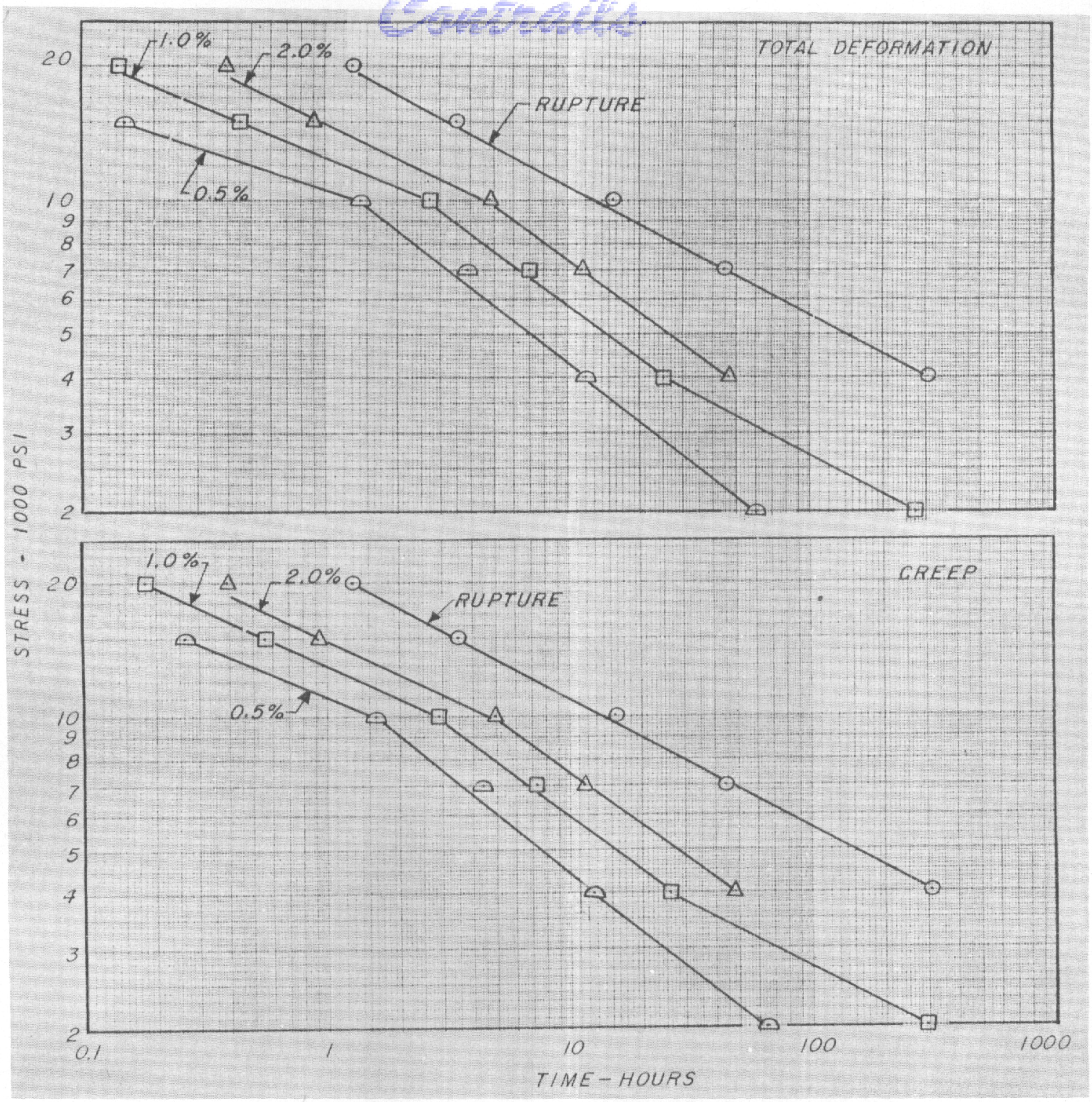

FIGURE 12 TENSILE CREEP-RUPTURE CHARACTERISTICS OF 19-9DX ½ INCH DIAMETER BAR STOCK AT 1500°F.

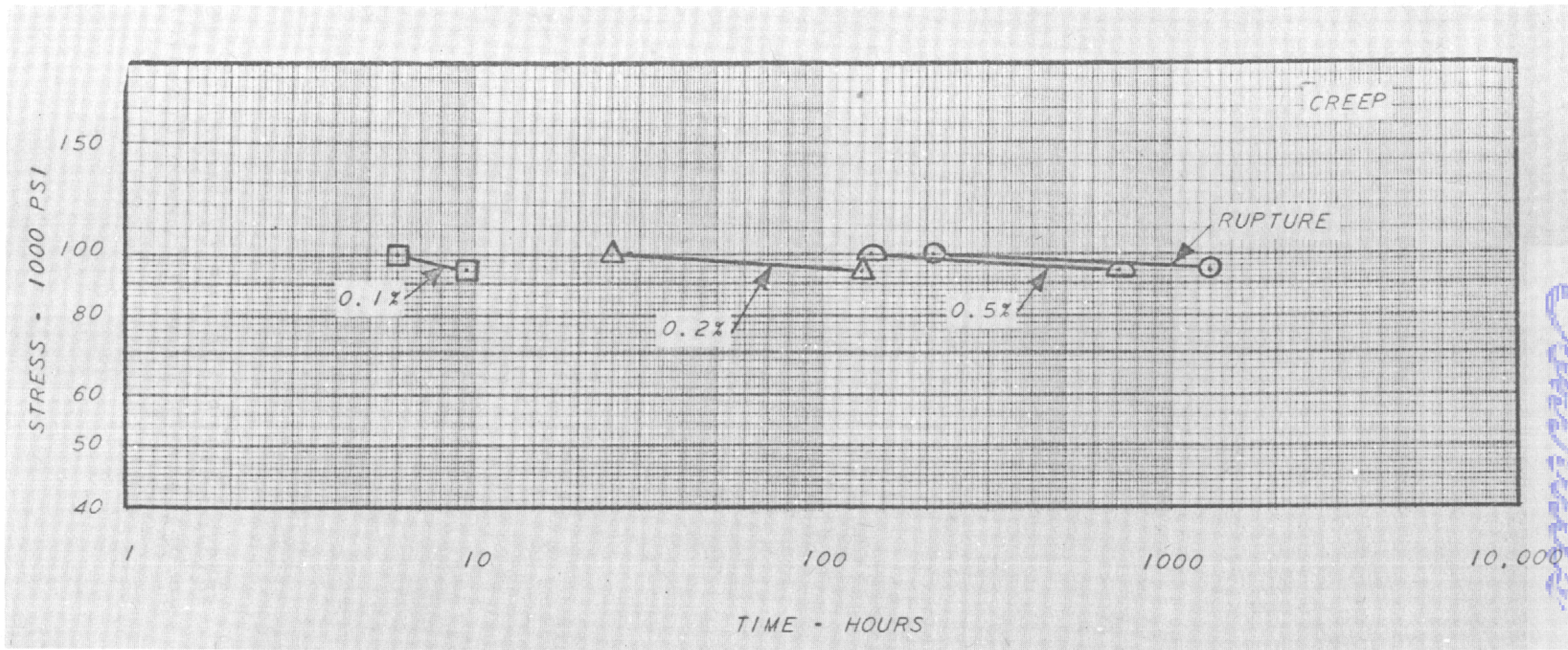

Figure 13 TENSILE CREEP-RUPTURE CHARACTERISTICS OF HARDENED A-286 ALLOY SHEET AT 1000°F

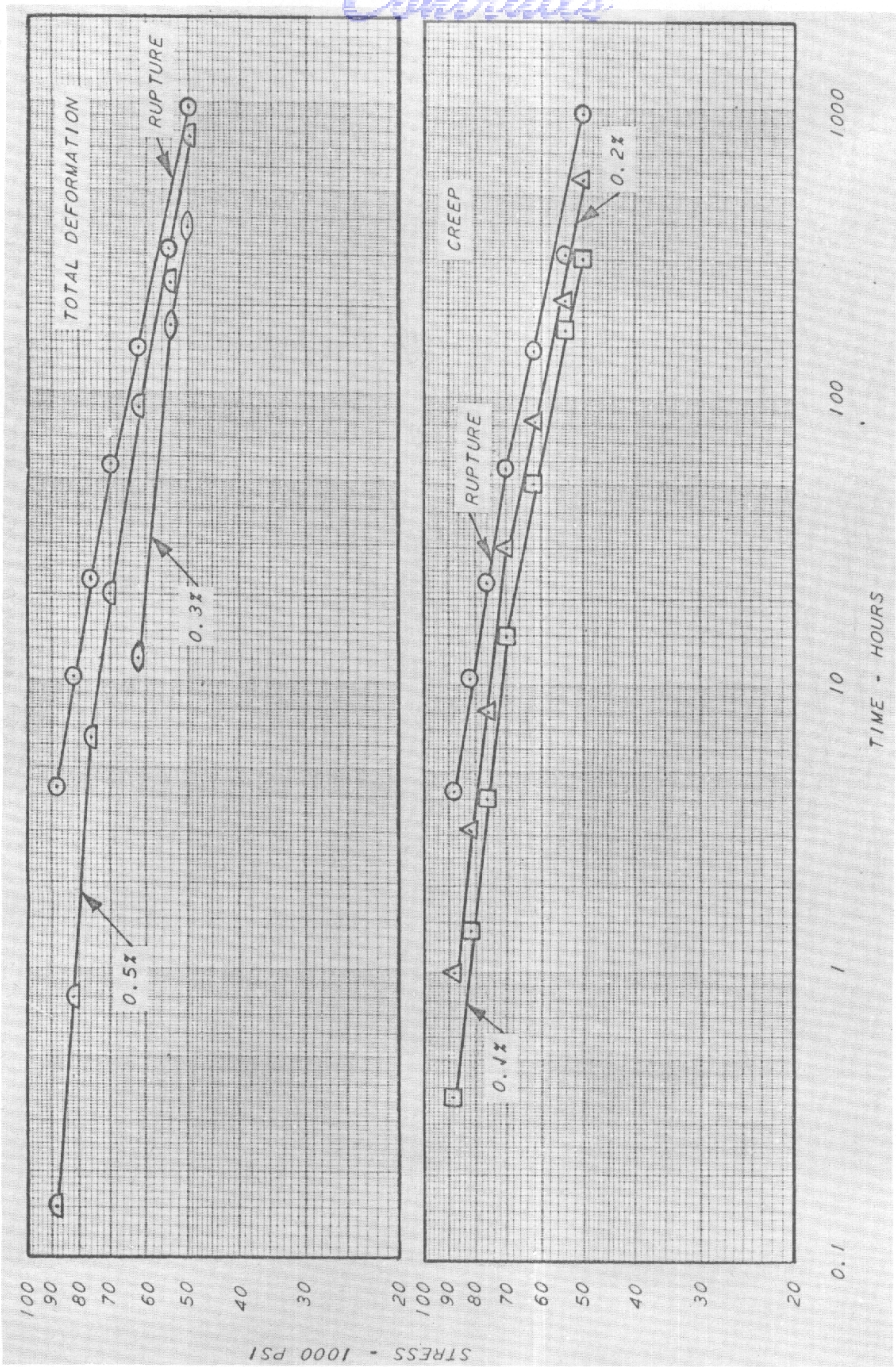

Figure 14 TENSILE CREEP-RUPTURE CHARACTERISTICS OF HARDENED A-286 ALLOY SHEET AT 1200°F

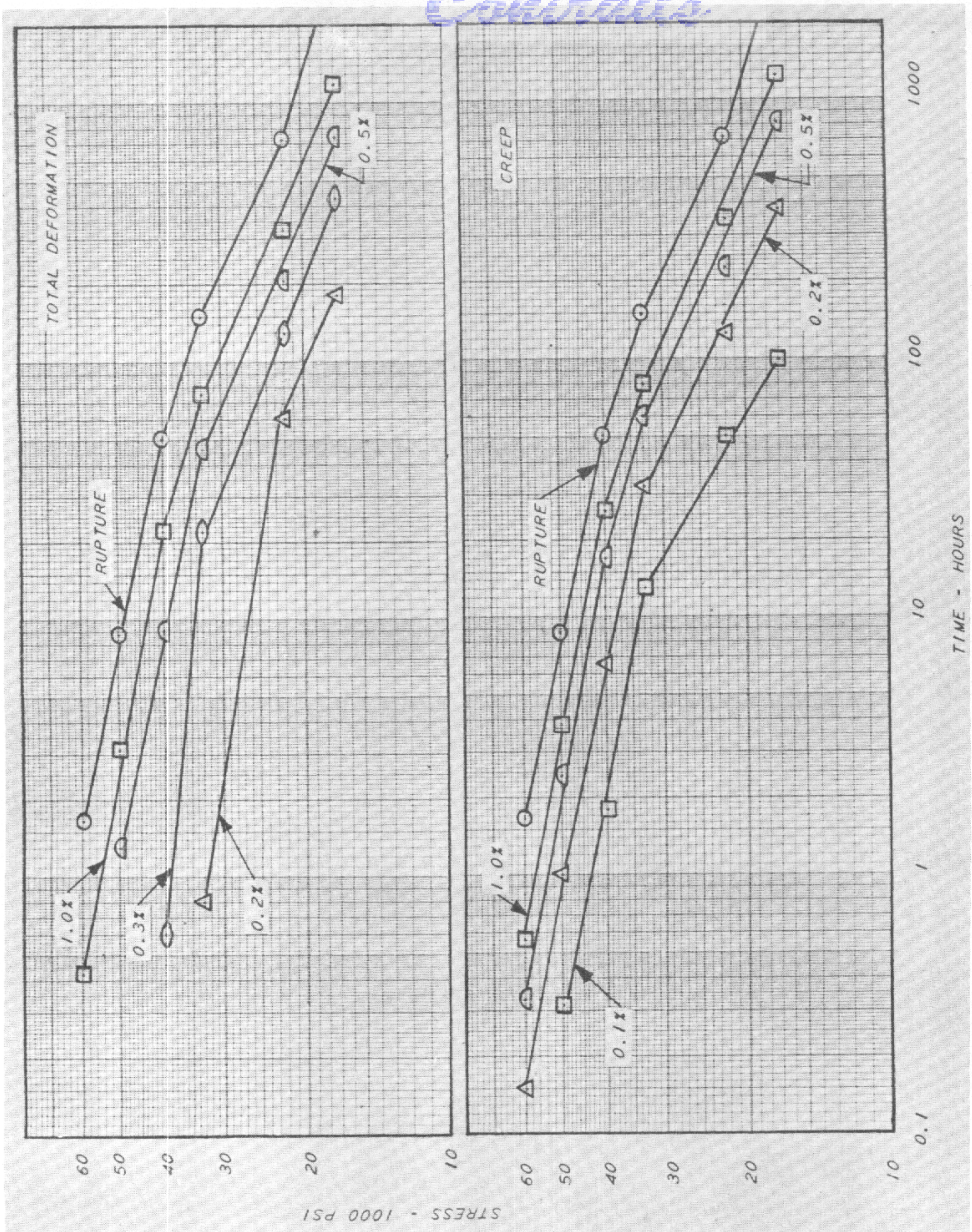

Figure 15 TENSILE CREEP-RUPTURE CHARACTERISTICS OF HARDENED A-286 ALLOY SHEET AT 1350°F

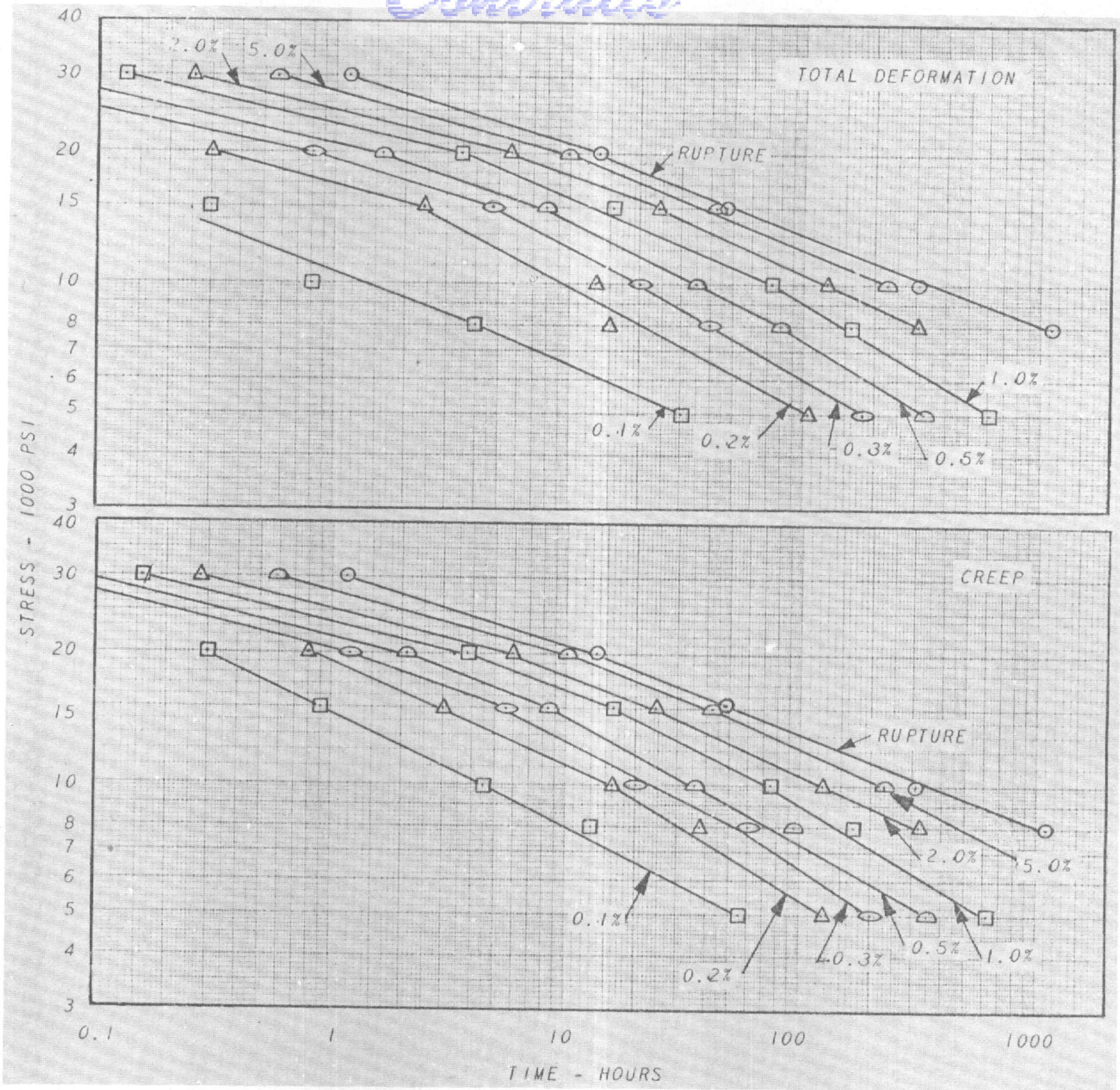

Figure 16 TENSILE CREEP-RUPTURE CHARACTERISTICS OF HARDENED A-286 ALLOY SHEET AT 1500°F

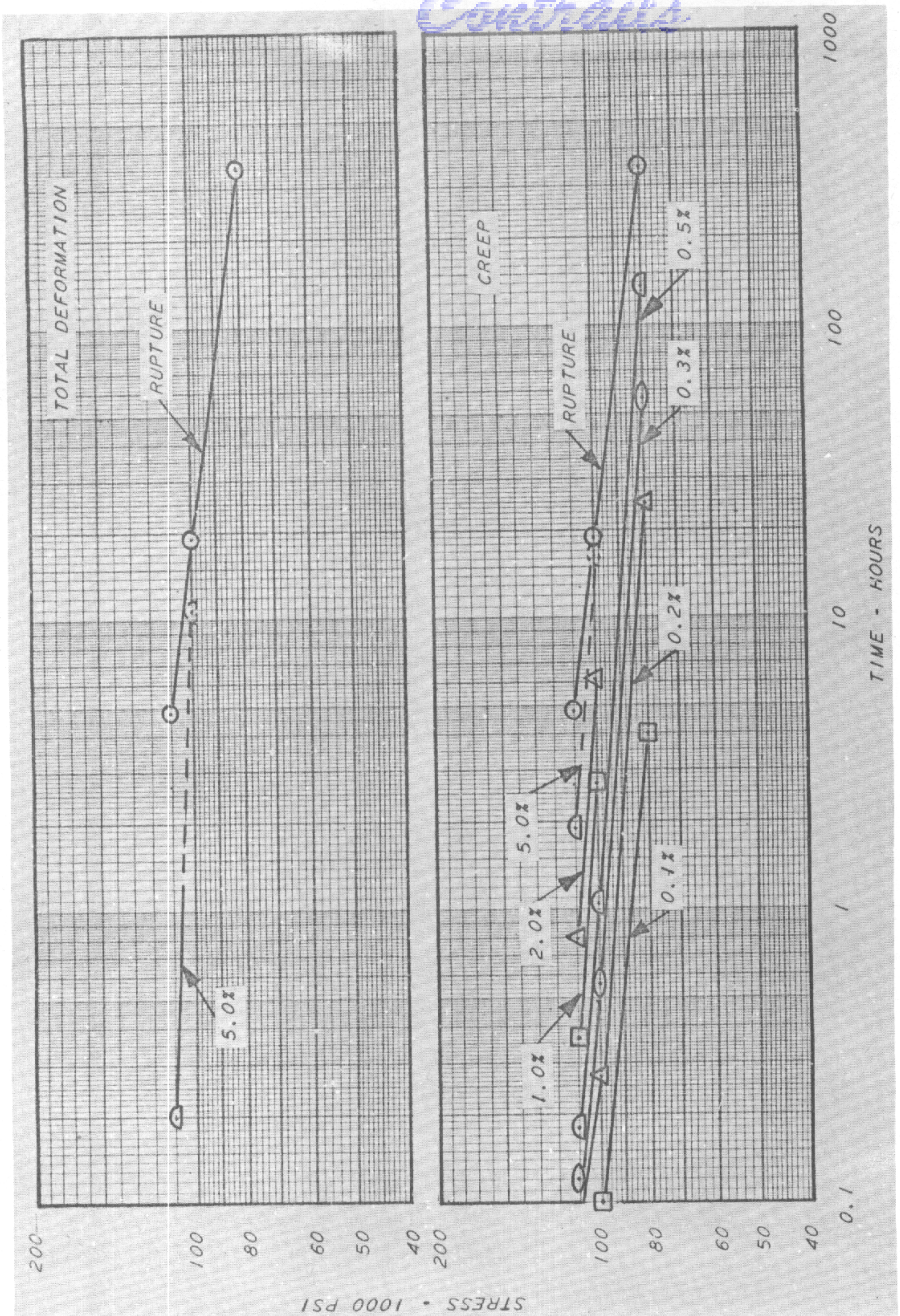

Figure 17 TENSILE CREEP-RUPTURE CHARACTERISTICS OF HARDENED A-286 ALLOY BAR AT 1000°F

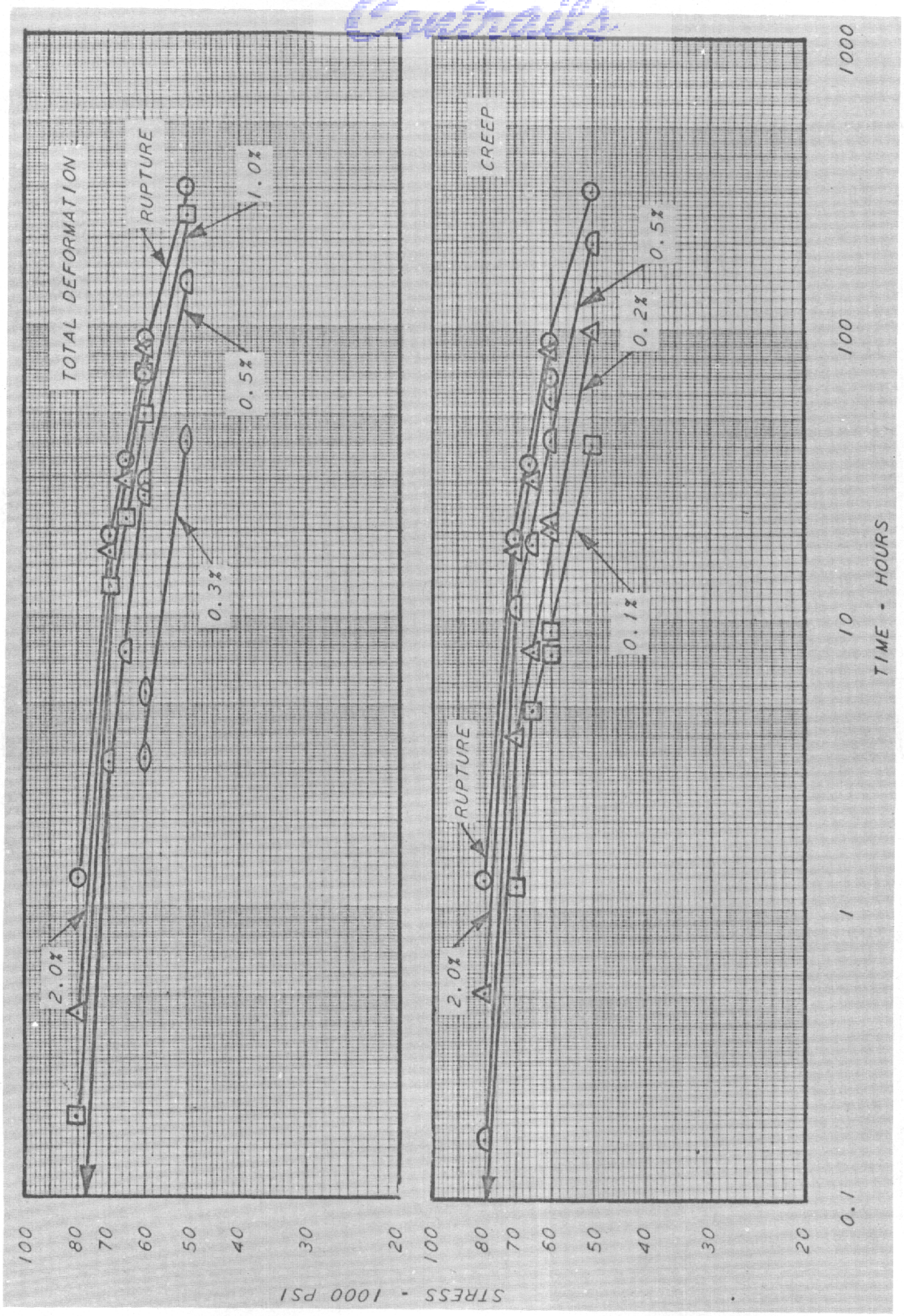

Figure 18 TENSILE CREEP-RUPTURE CHARACTERISTICS OF HARDENED A-286 ALLOY BAR AT 1200°F

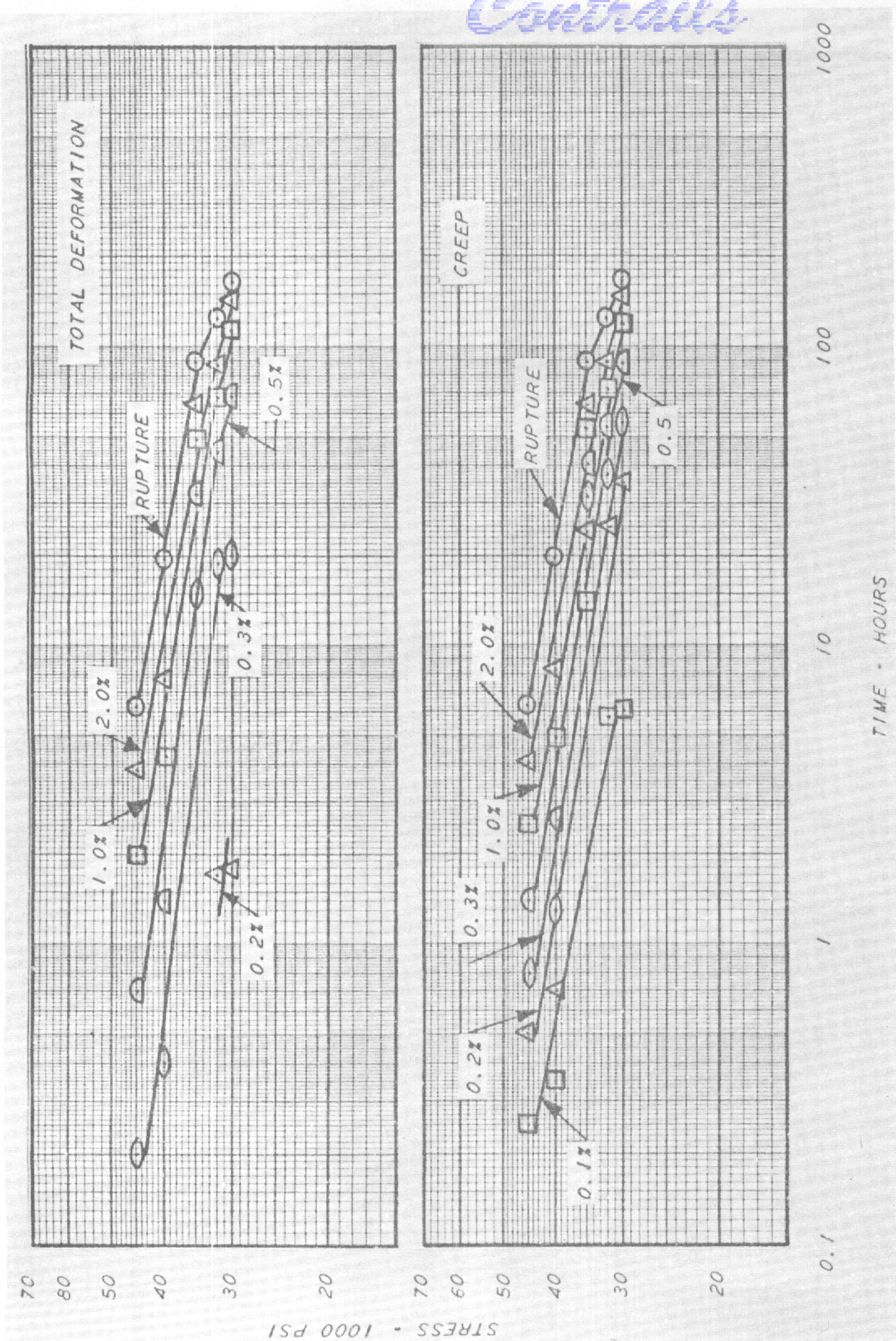

Figure 19 TENSILE CREEP-RUPTURE CHARACTERISTICS OF A-286 ALLOY BAR AT 1350°F

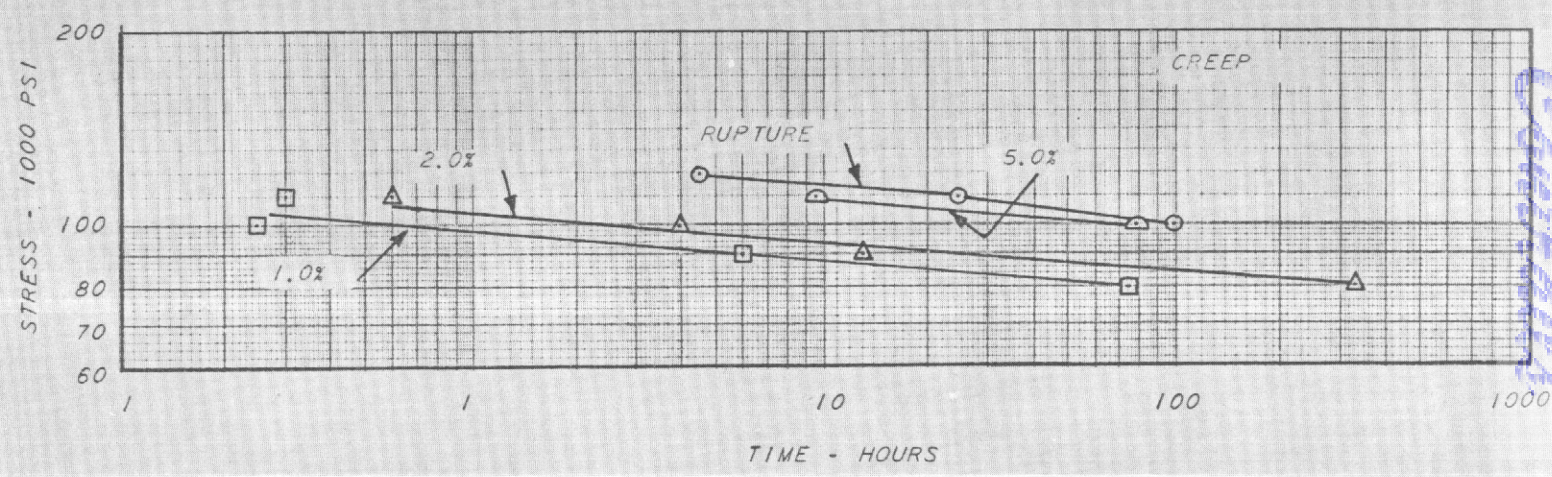

Figure 20 BEARING CREEP-RUPTURE CHARACTERISTICS OF 2024-T3 ALUMINUM SHEET AT 300 F FOR AN EDGE DISTANCE OF 2.0 D.

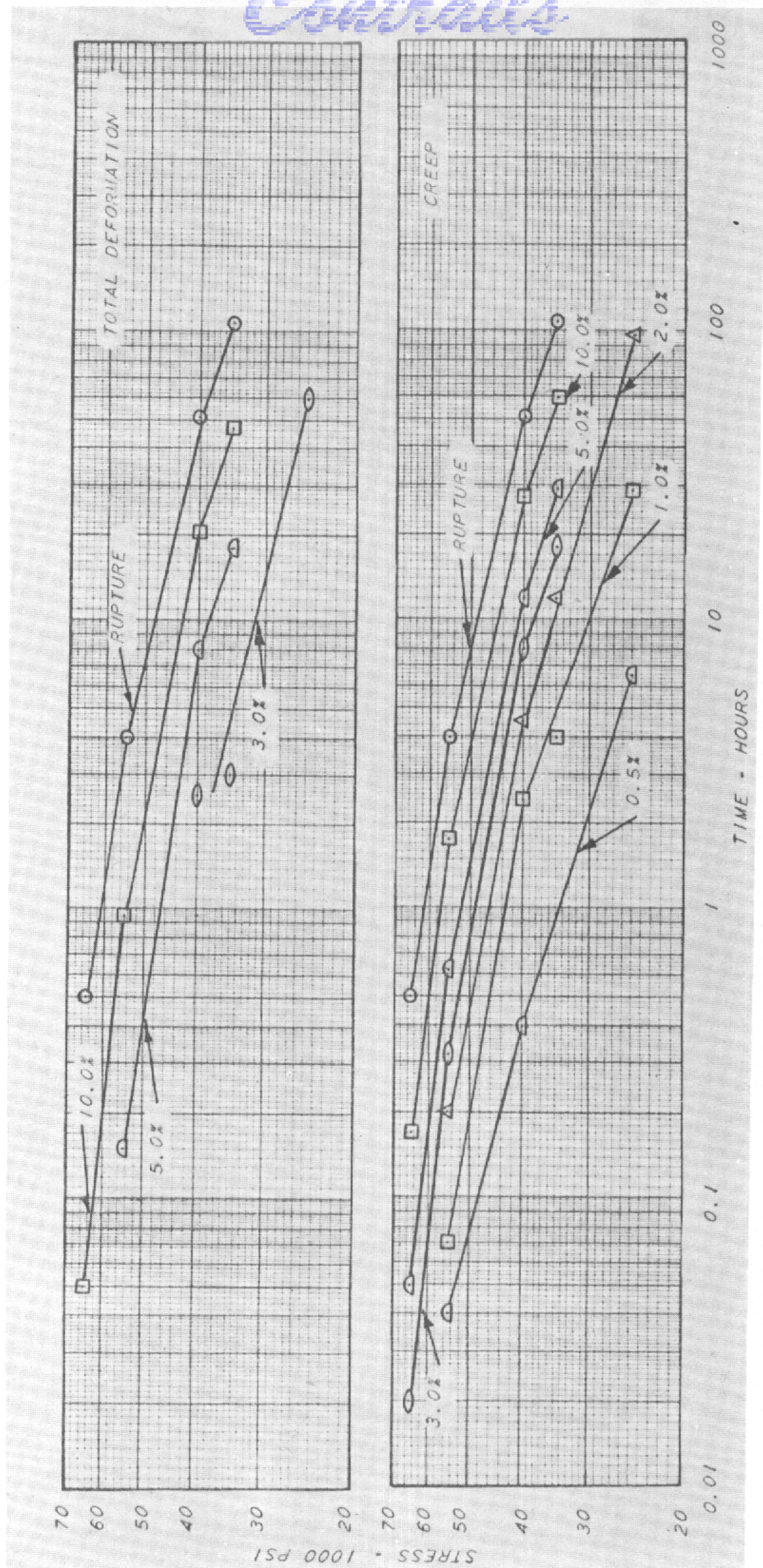

Figure 21 BEARING CREEP-RUPTURE CHARACTERISTICS OF 2024-T3 ALUMINUM SHEET AT 450°F FOR AN EDGE DISTANCE OF 2.0 D.

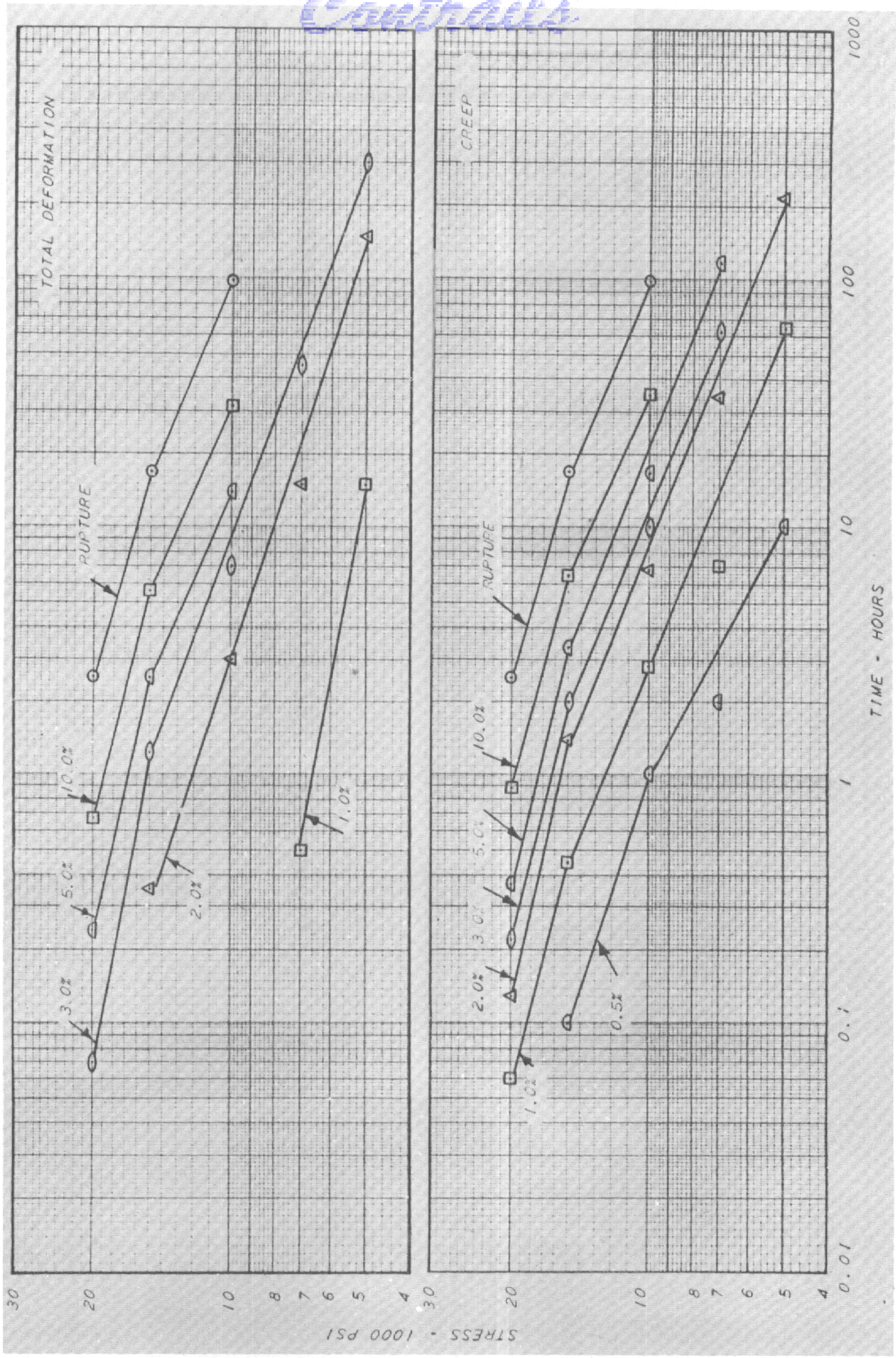

Figure 22 BEARING CREEP-RUPTURE CHARACTERISTICS OF 2024-T3 ALUMINUM SHEET AT 600°F FOR AN EDGE DISTANCE OF 2.0 D

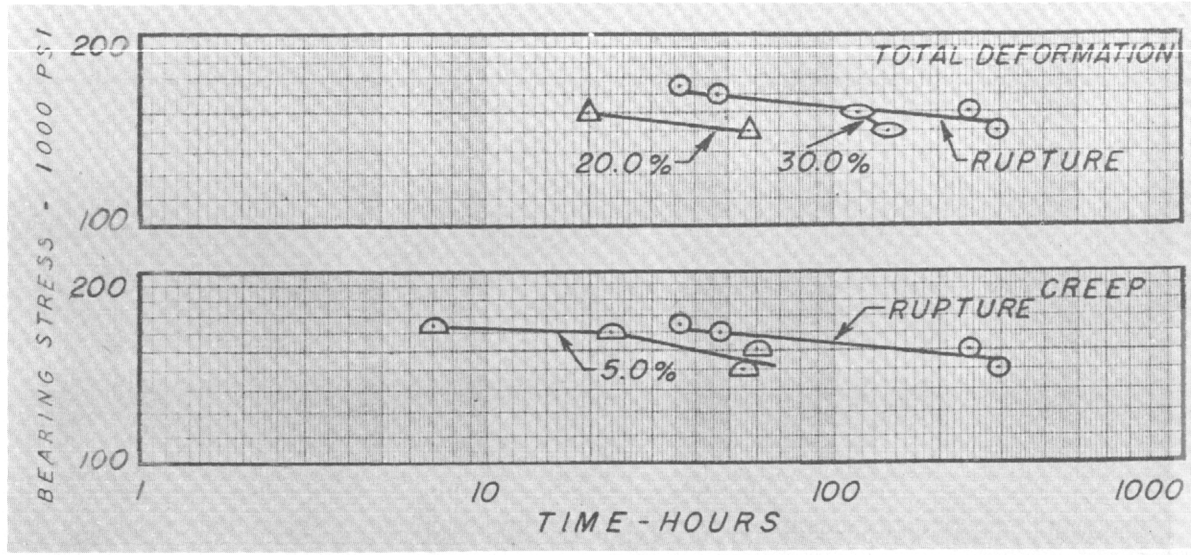

Figure 23 BEARING CREEP-RUPTURE CHARACTERISTICS OF A-110AT TITANIUM ALLOY SHEET AT 800°F FOR AN EDGE DISTANCE OF 2.0 D.

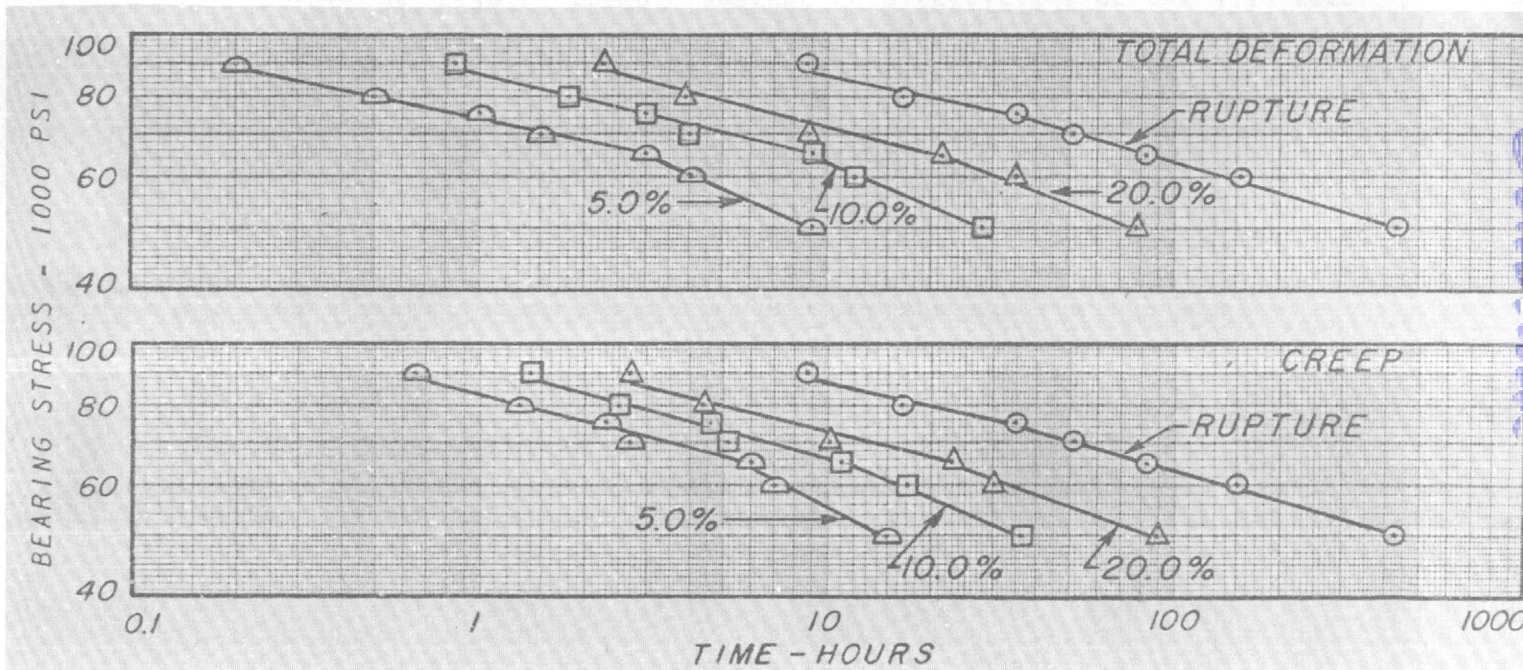

FIGURE 24 BEARING CREEP-RUPTURE CHARACTERISTICS OF A-110AT TITANIUM ALLOY SHEET AT 1000°F FOR AN EDGE DISTANCE OF 2.0D.

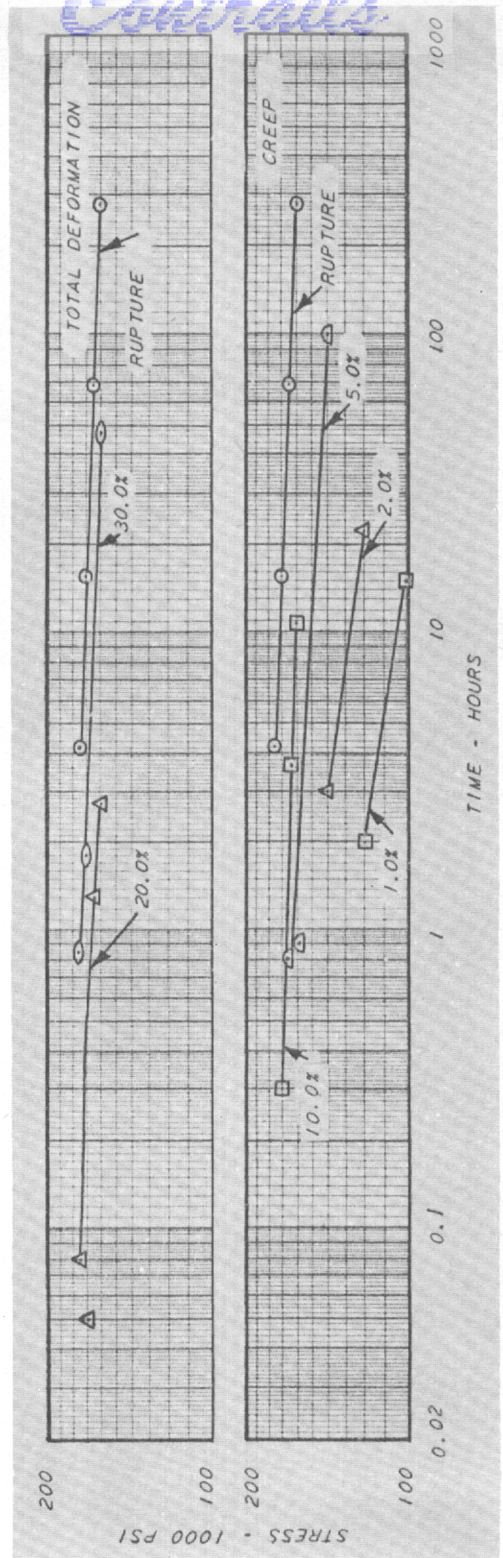

Figure 25 BEARING CREEP - RUPTURE CHARACTERISTICS OF SAE 4130 STEEL SHEET AT 800°F FOR AN EDGE DISTANCE OF 2.0 D.

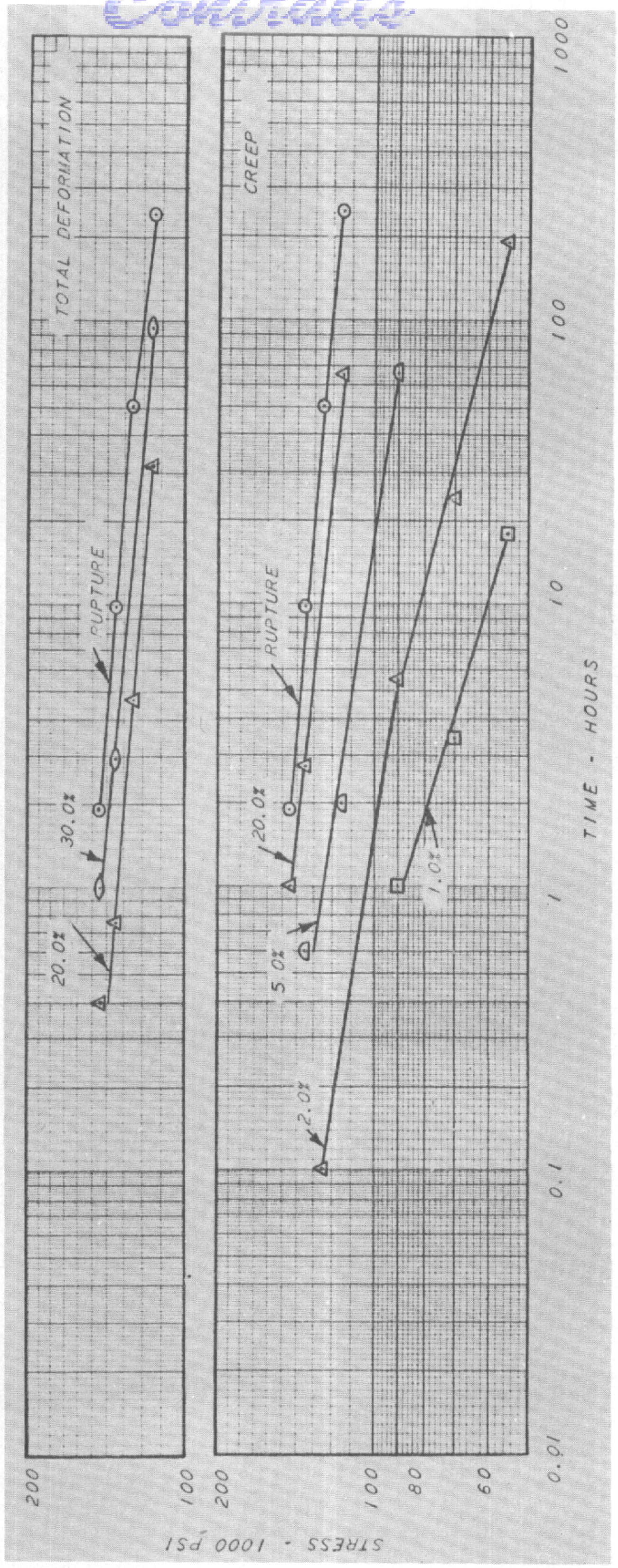

Figure 26 BEARING CREEP - RUPTURE CHARACTERISTICS OF SAE 4130 STEEL SHEET AT 900°F FOR AN EDGE DISTANCE OF 2.0 D.

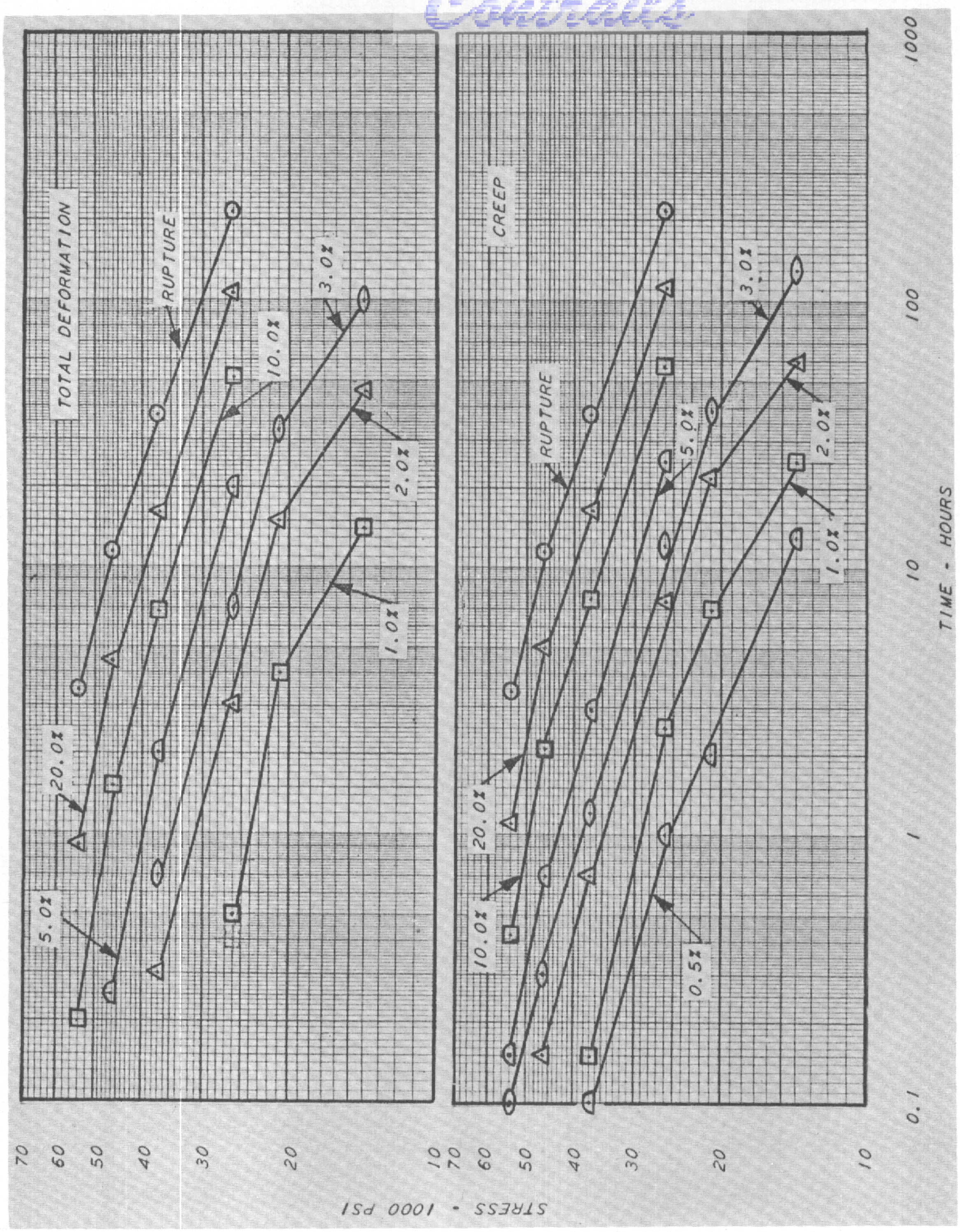

Figure 27 BEARING CREEP-RUPTURE CHARACTERISTICS OF TYPE 321 STAINLESS STEEL SHEET AT 1350° F FOR AN EDGE DISTANCE OF 2.0D

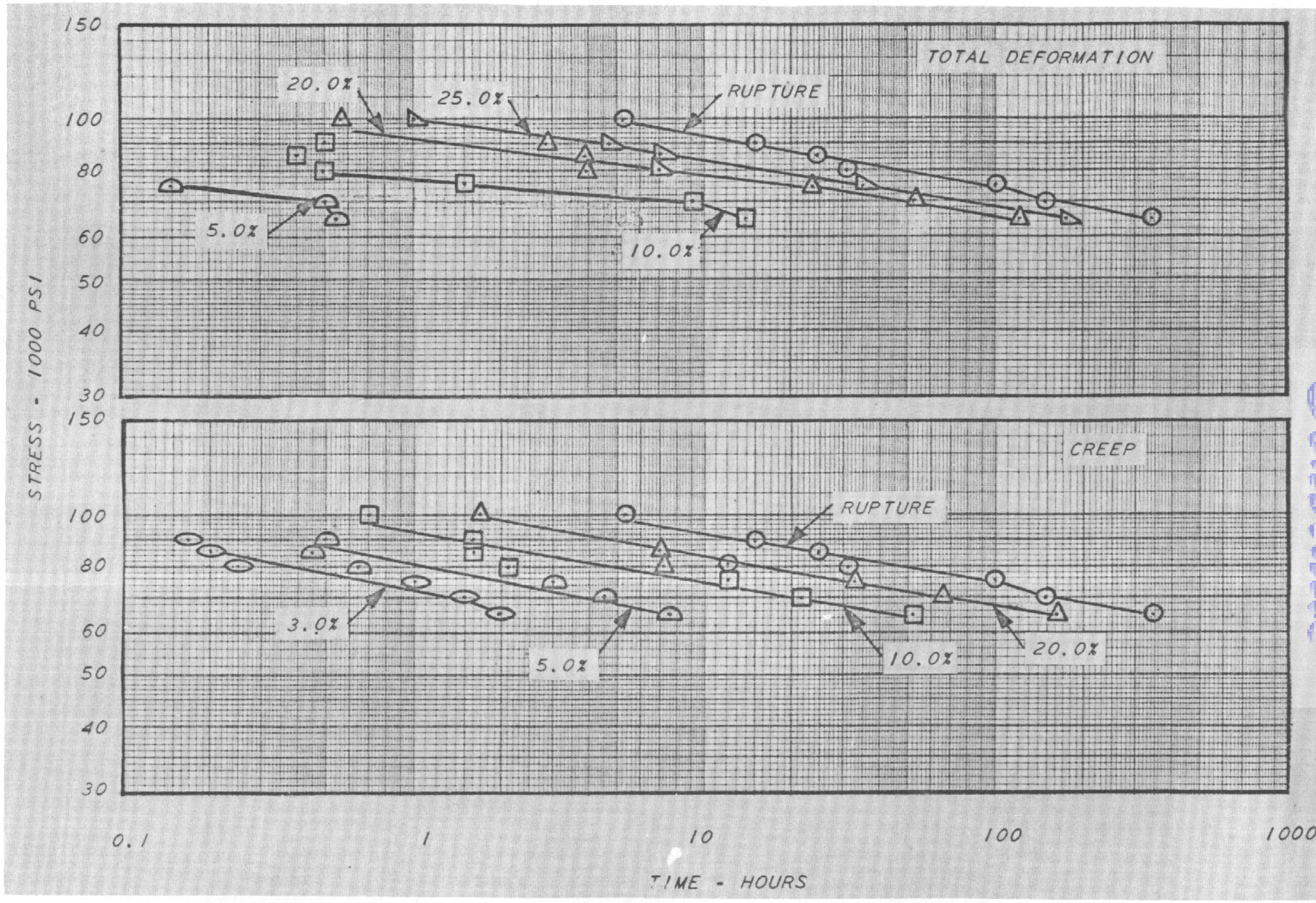

Figure 28 BEARING CREEP-RUPTURE CHARACTERISTICS OF ANNEALED 19-9 DX ALLOY SHEET AT 1200°F FOR AN EDGE DISTANCE OF 2.0 D

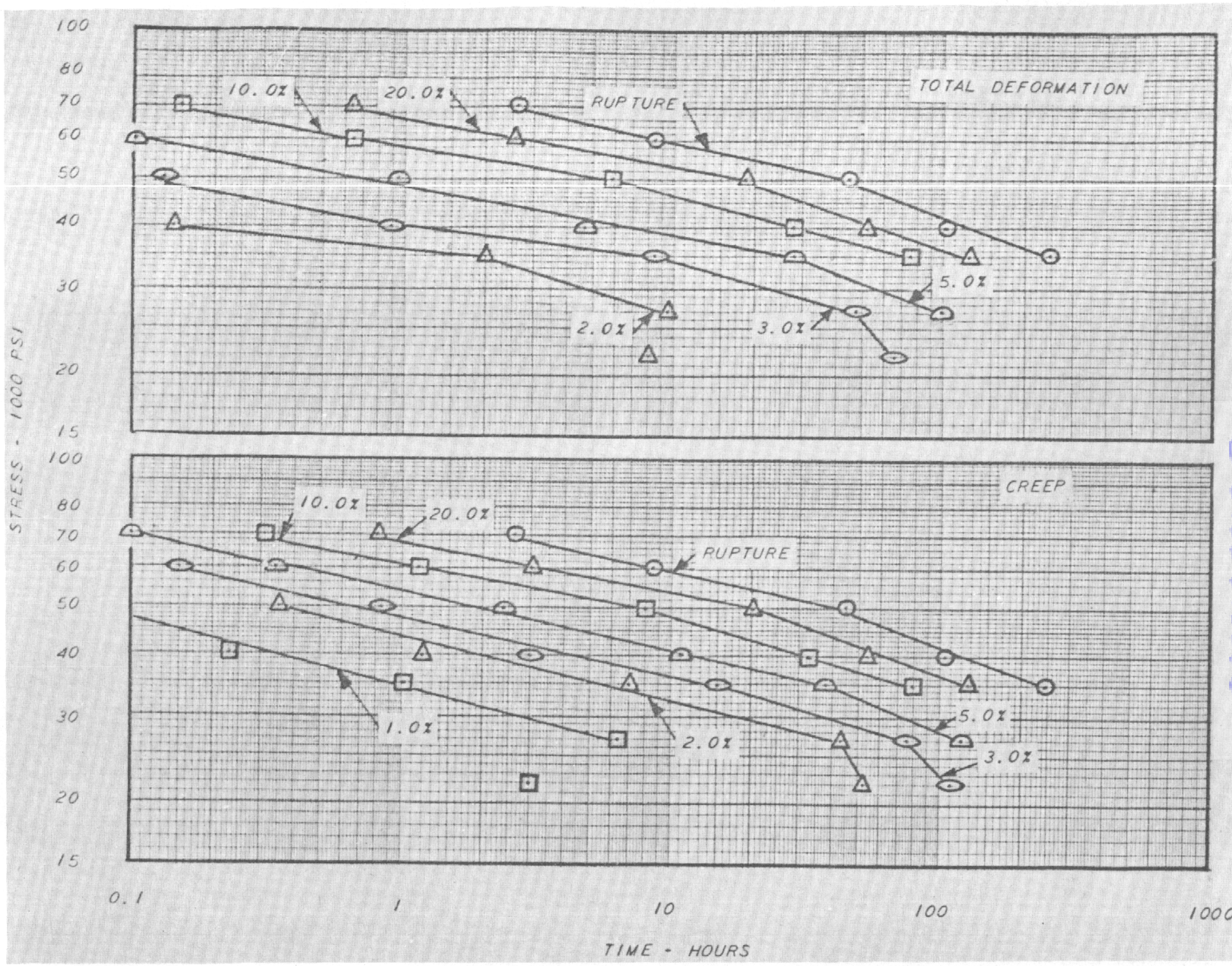

Figure 29 BEARING CREEP-RUPTURE CHARACTERISTICS OF ANNEALED 19-9DX ALLOY SHEET AT 1350°F FOR AN EDGE DISTANCE OF 2.0D

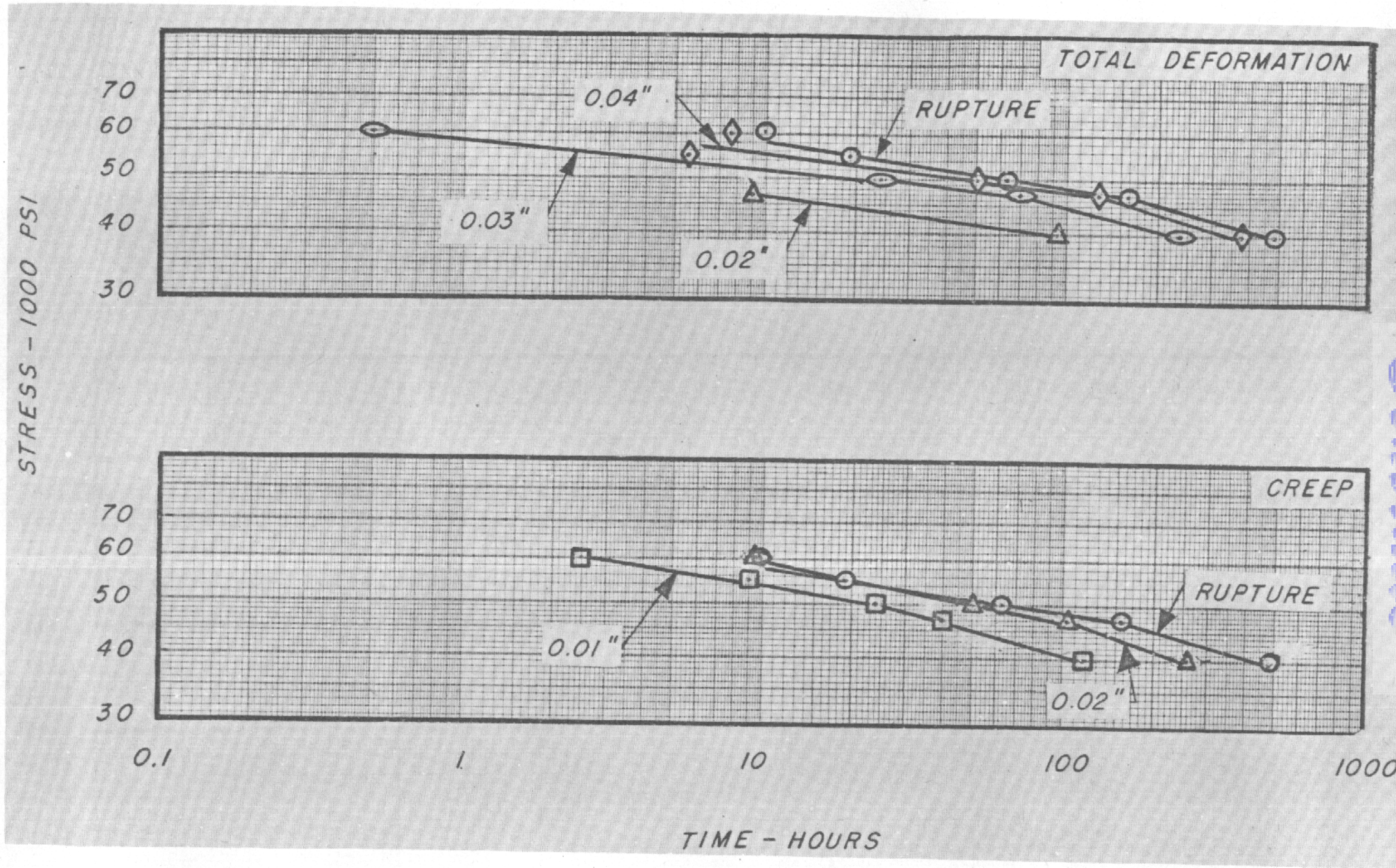

Figure 30 SHEAR-PIN DEFORMATION CHARACTERISTICS OF A-110AT TITANIUM ALLOY 1/2 INCH DIAMETER BAR STOCK AT 800°F

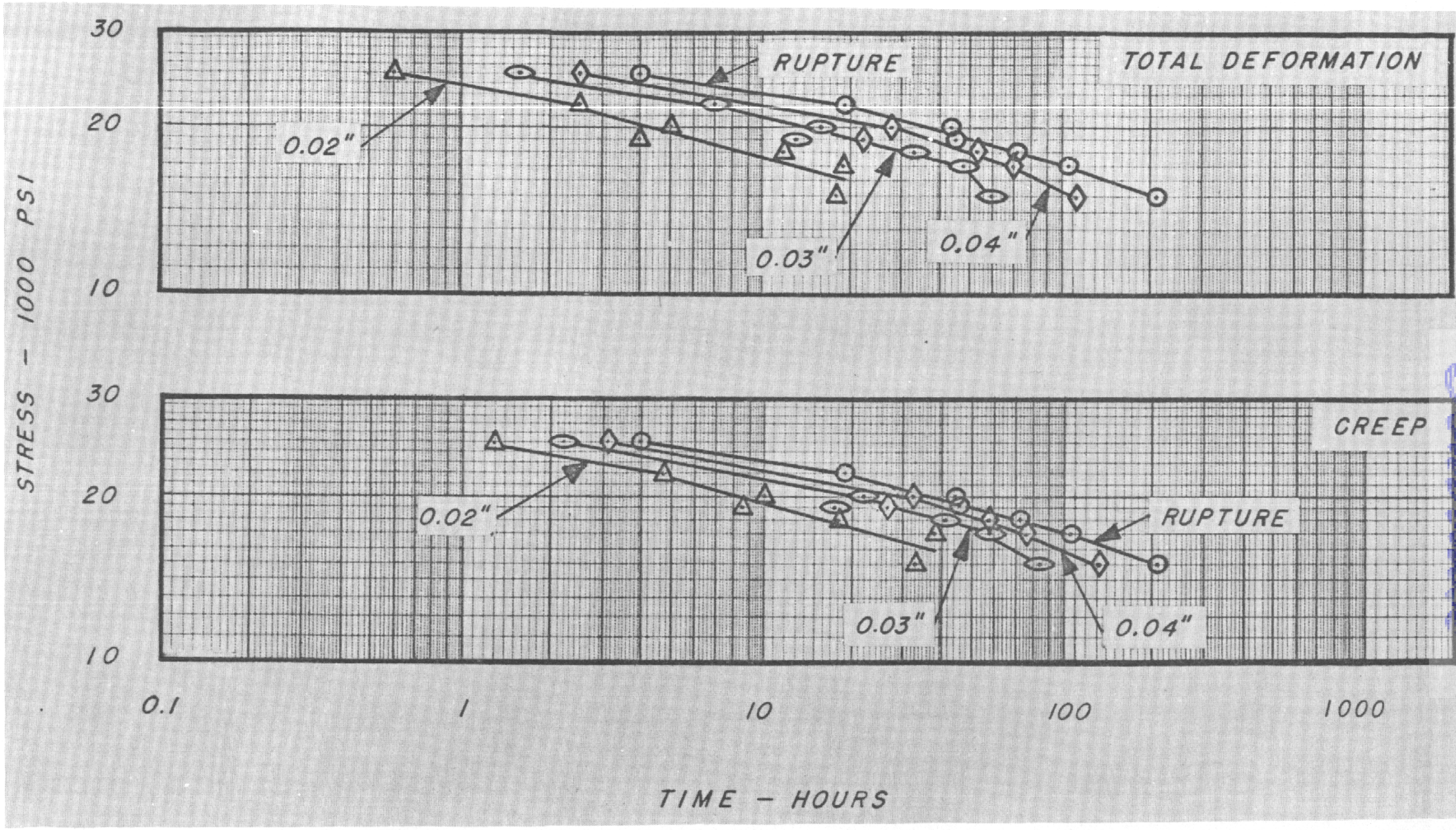

Figure 31 SHEAR-PIN DEFORMATION CHARACTERISTICS OF A-110AT TITANIUM ALLOY 1/2 INCH DIAMETER BAR STOCK AT 1000°F

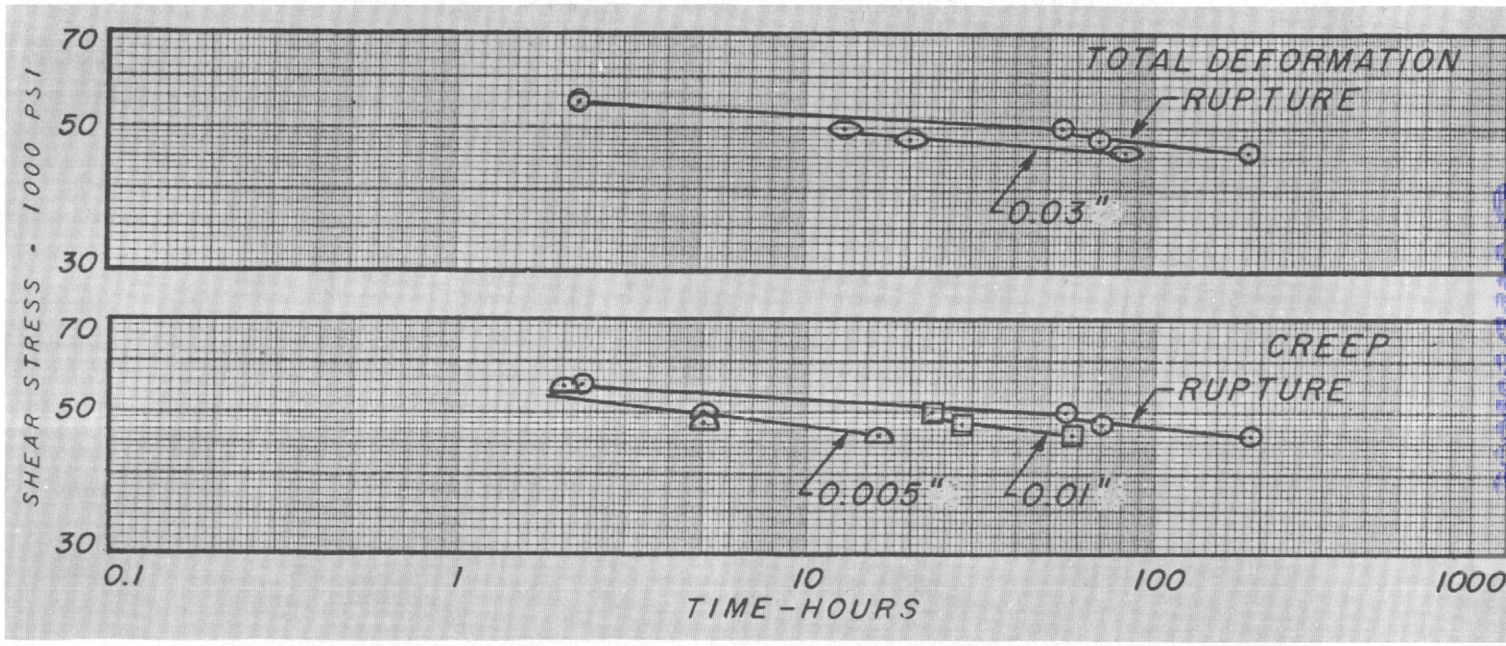

Figure 32 SHEAR-PIN DEFORMATION CHARACTERISTICS OF 19-9 DX $\frac{1}{2}$ INCH DIAMETER BAR STOCK AT 1000°F

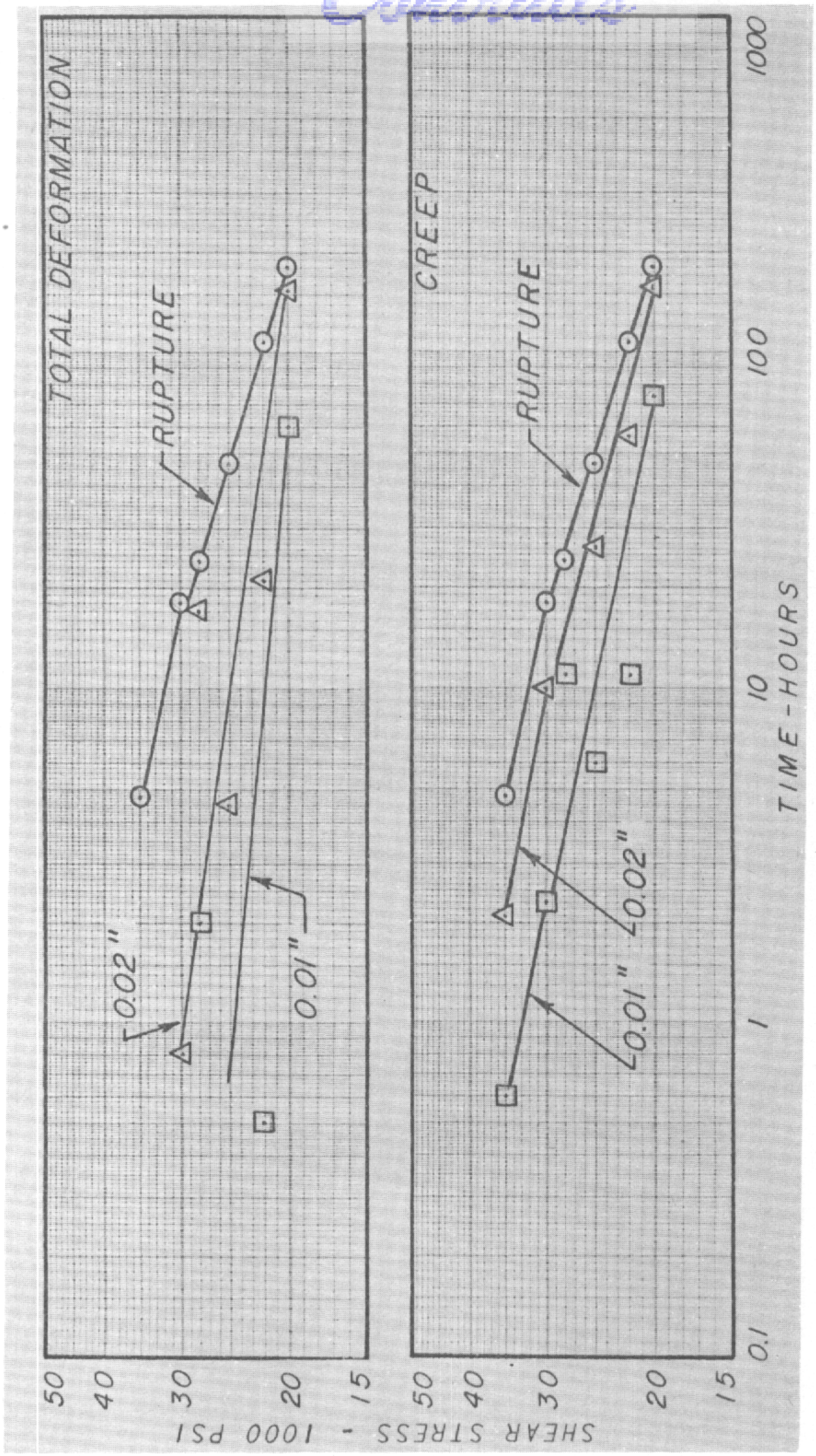

FIGURE 33 SHEAR - PIN DEFORMATION CHARACTERISTICS OF 19-9DX $\frac{1}{2}$ INCH DIAMETER BAR STOCK AT 1200°F

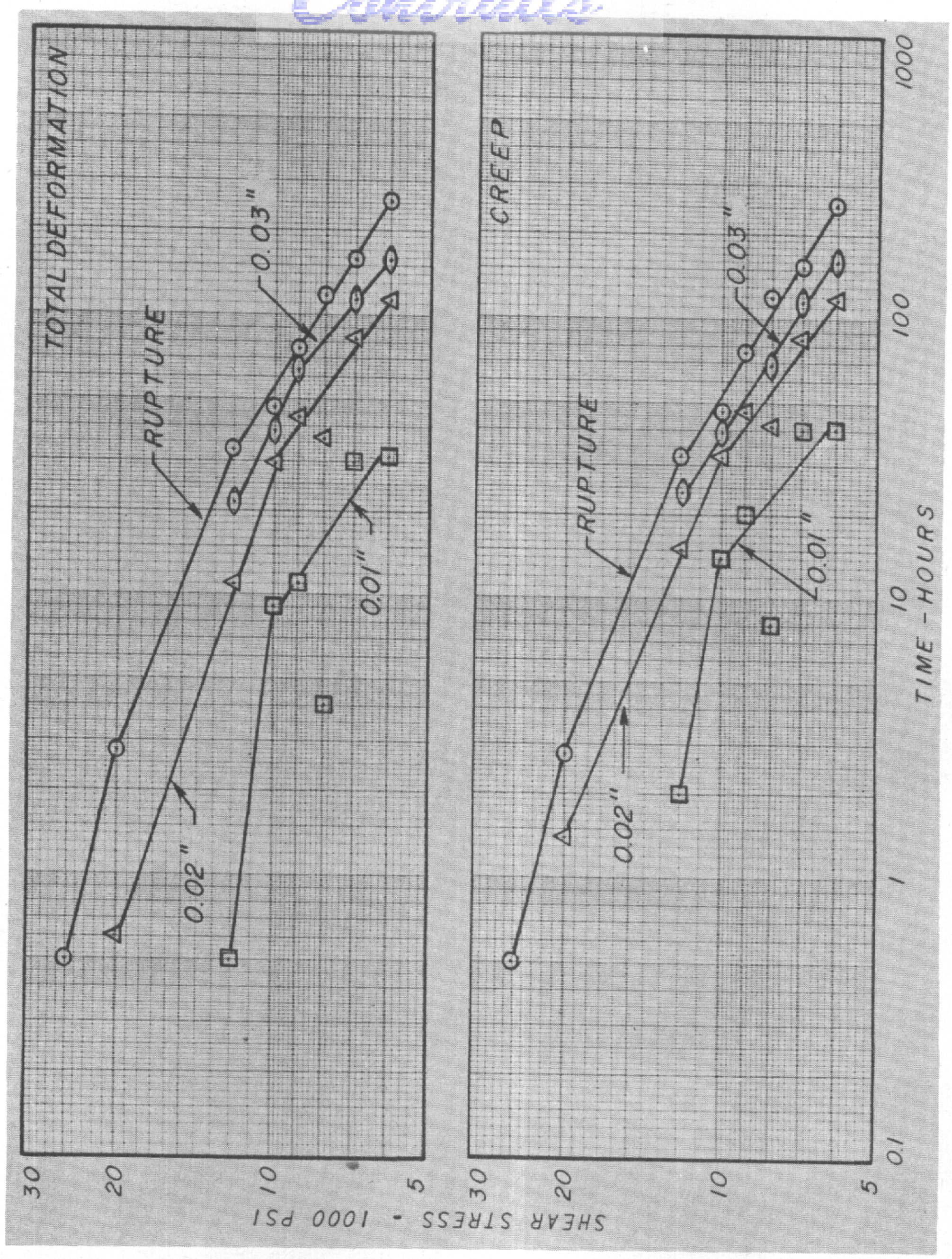

FIGURE 34 SHEAR - PIN DEFORMATION CHARACTERISTICS OF 19-9DX $\frac{1}{2}$ INCH DIAMETER BAR STOCK AT 1350°F

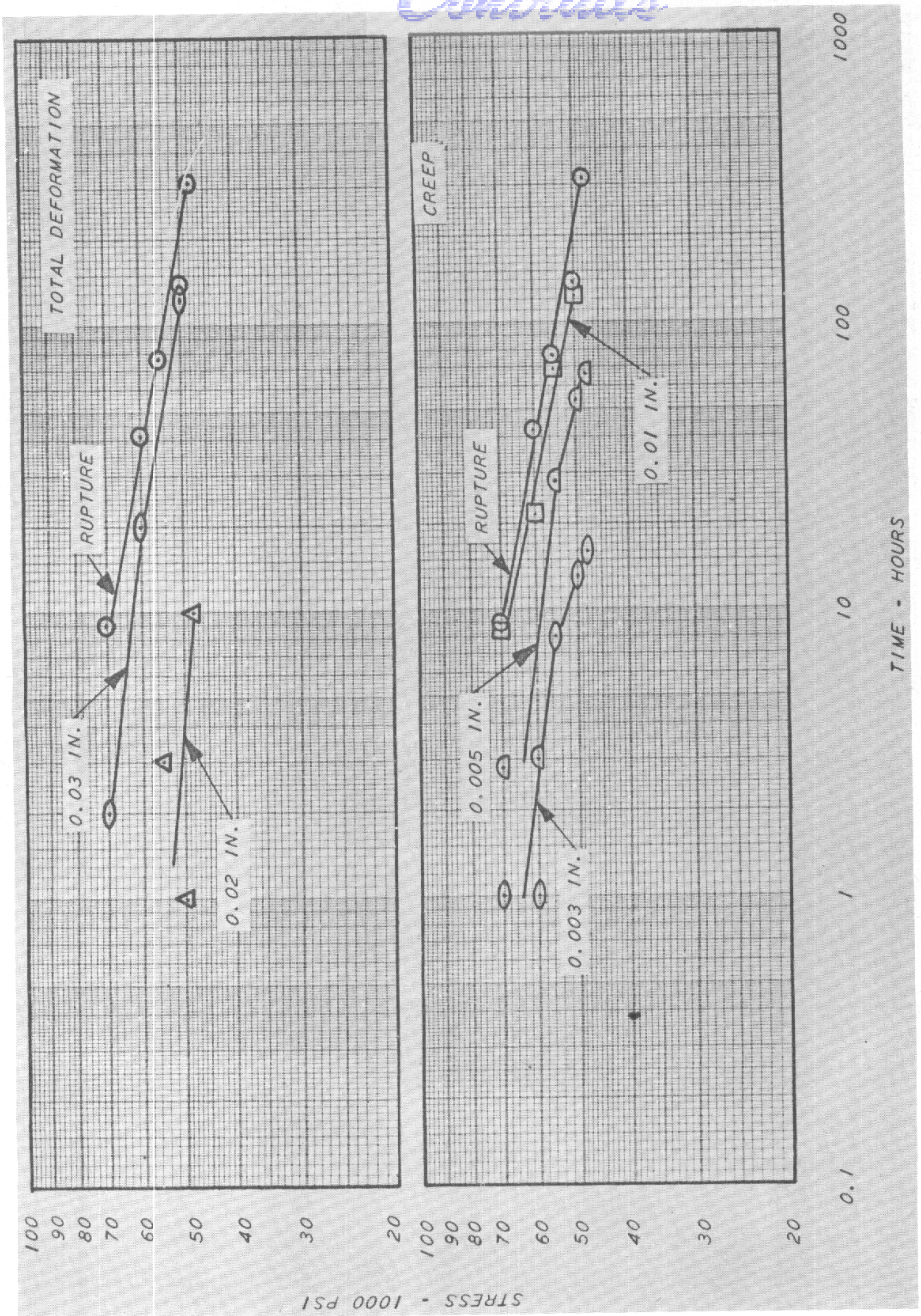

Figure 35 SHEAR-PIN DEFORMATION CHARACTERISTICS OF HARDENED A-286 ALLOY BAR AT 1000°F

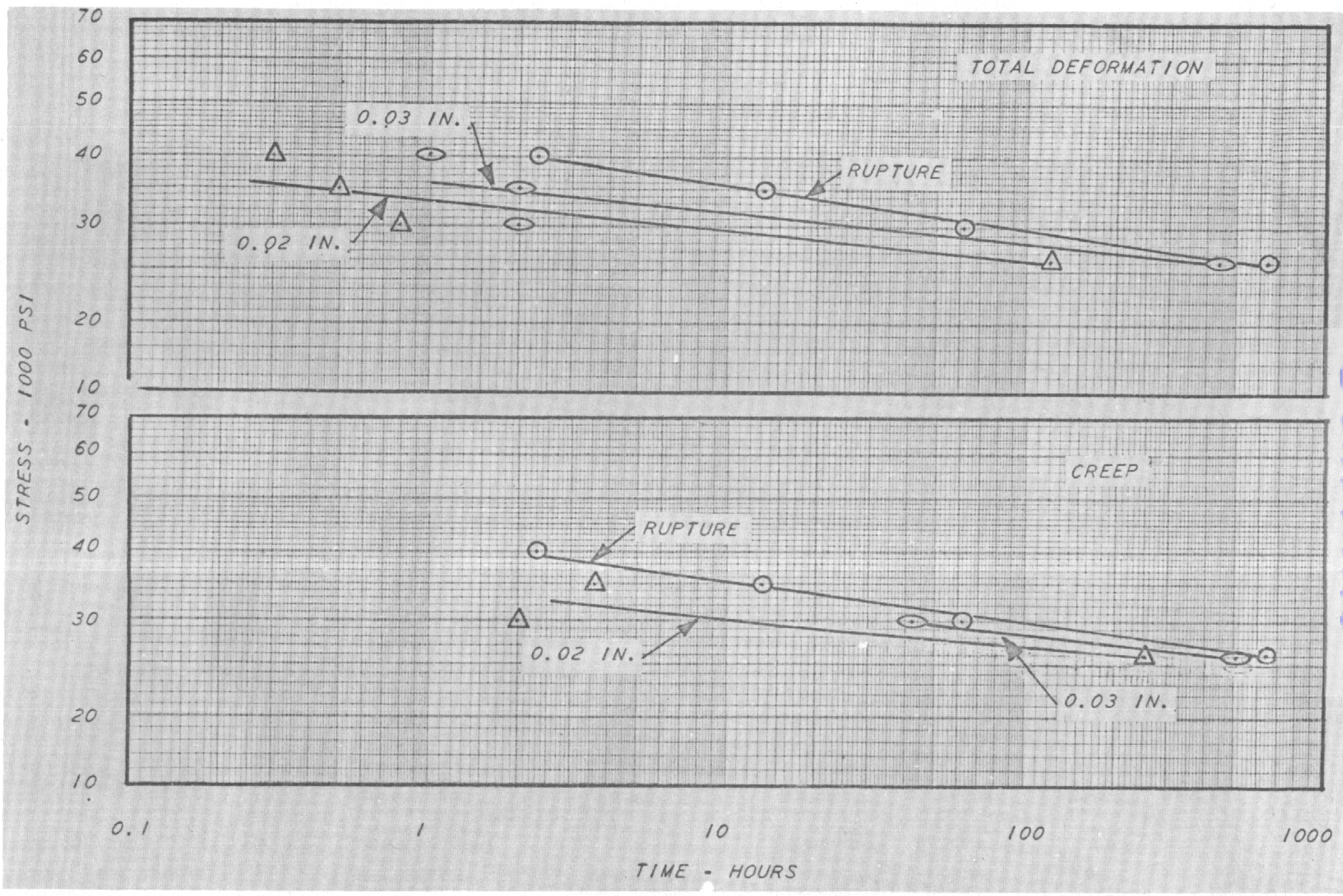

Figure 36 SHEAR-PIN DEFORMATION CHARACTERISTICS OF HARDENED A-286 ALLOY BAR AT 1200°F

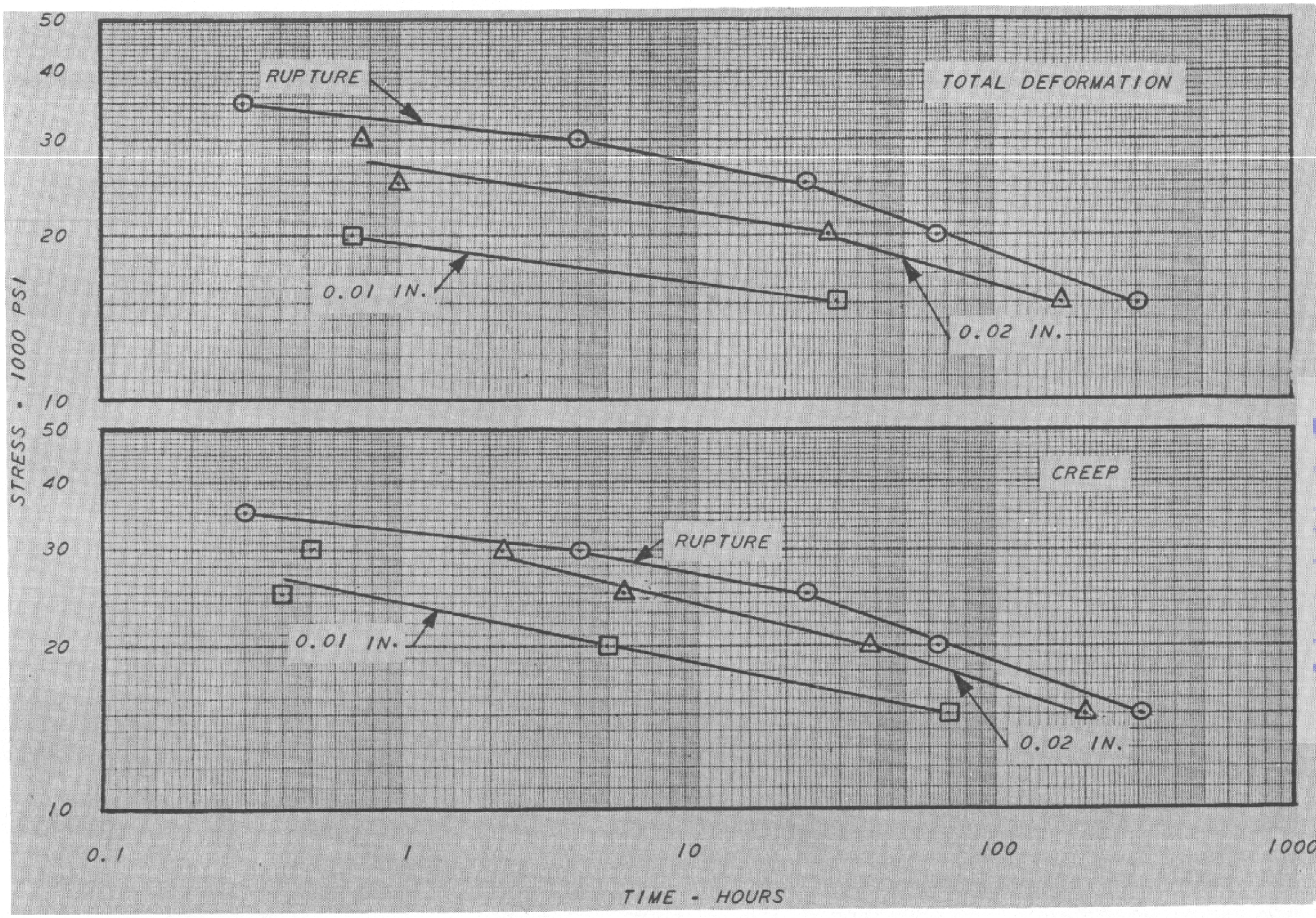

Figure 37 SHEAR-PIN DEFORMATION CHARACTERISTICS OF HARDENED A-286 ALLOY BAR AT 1350°F

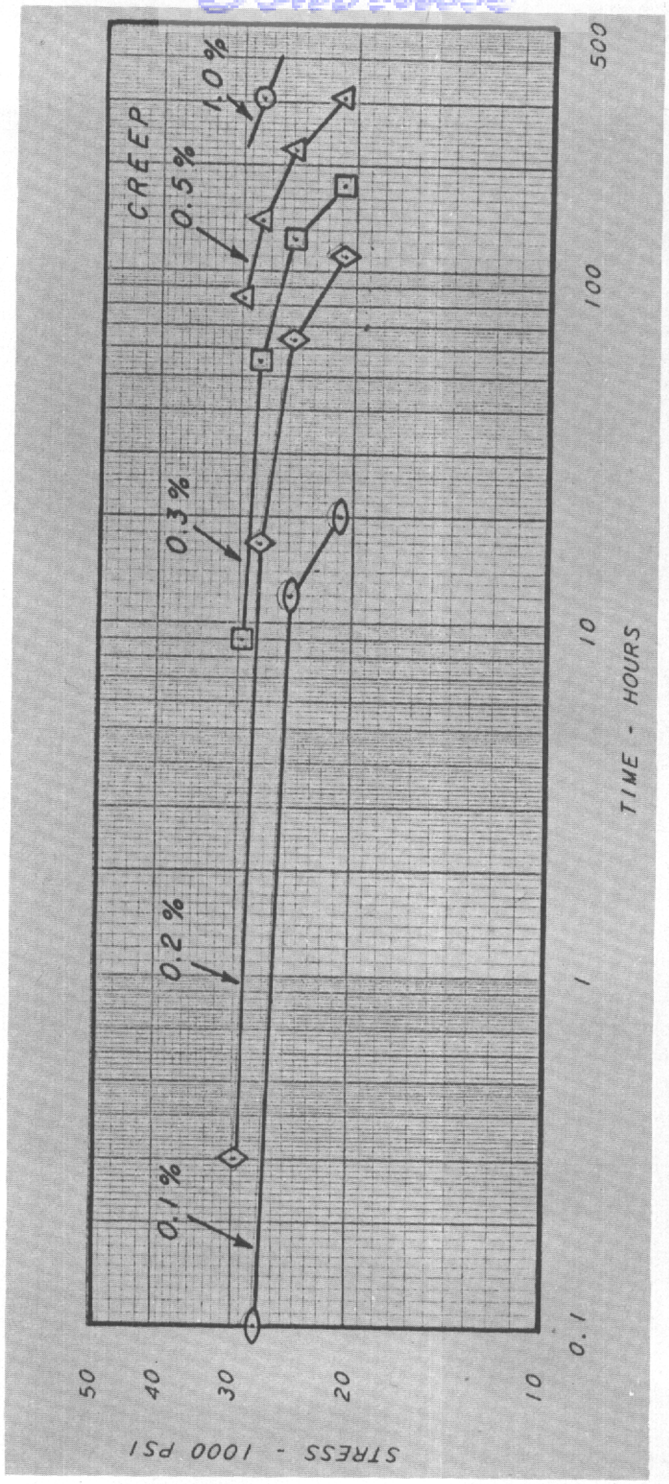

FIGURE 38 COMPRESSION CREEP CHARACTERISTICS OF A-70 TITANIUM SHEET AT 700°F.

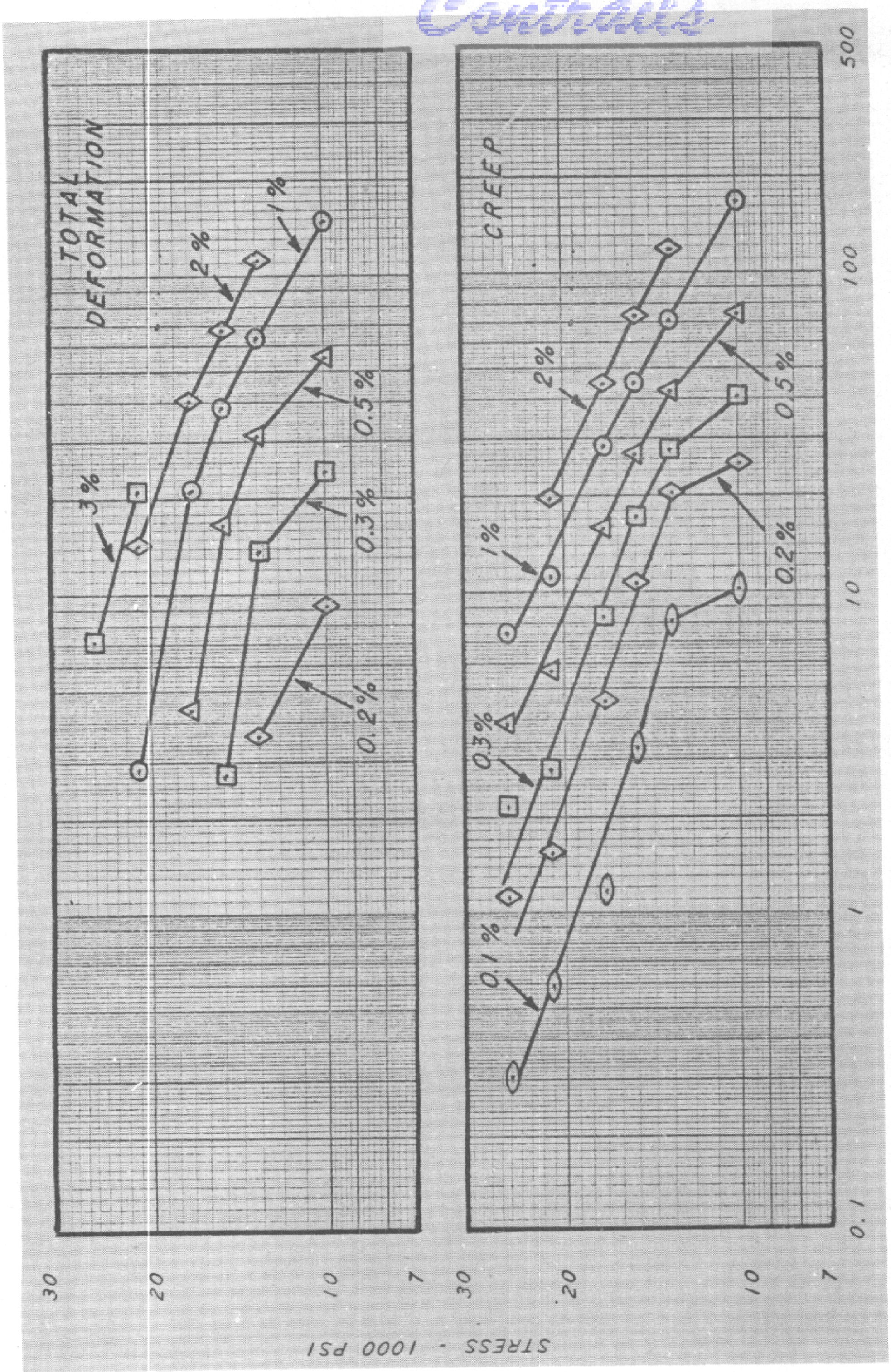

FIGURE 39 COMPRESSION CREEP CHARACTERISTICS OF A-70 TITANIUM SHEET AT 800°F

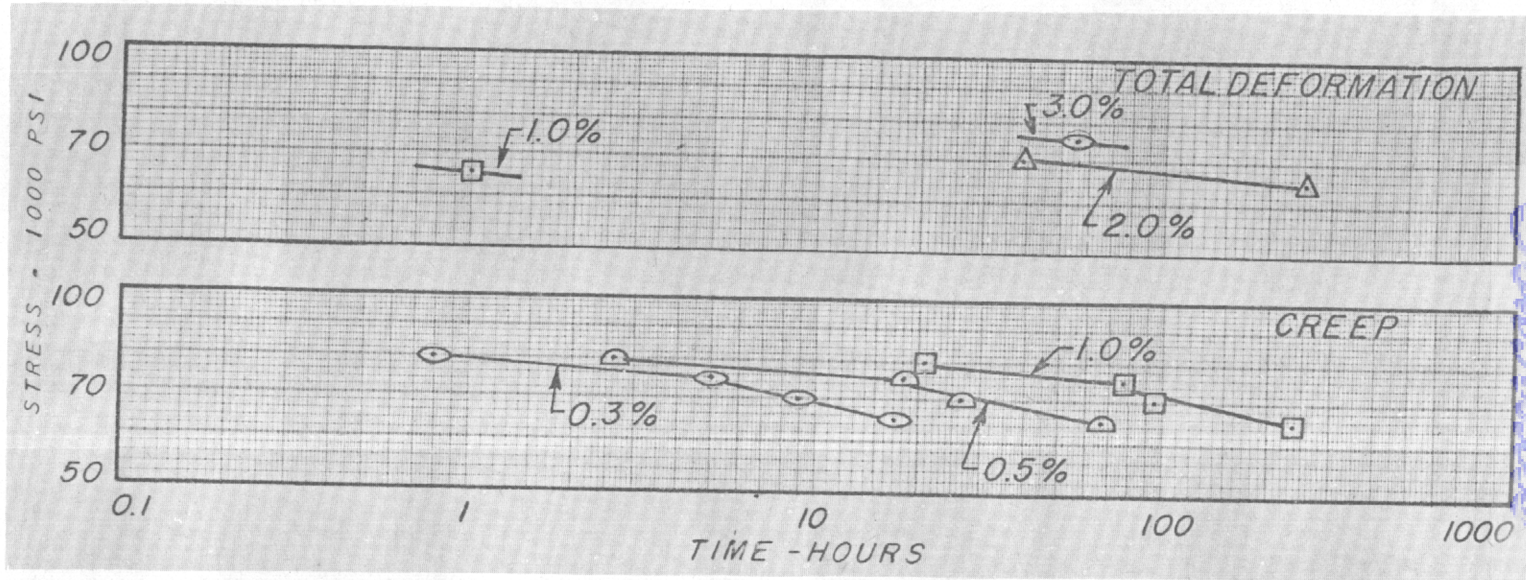

Figure 40 COMPRESSION CREEP CHARACTERISTICS OF A-110AT TITANIUM ALLOY SHEET AT 800°F

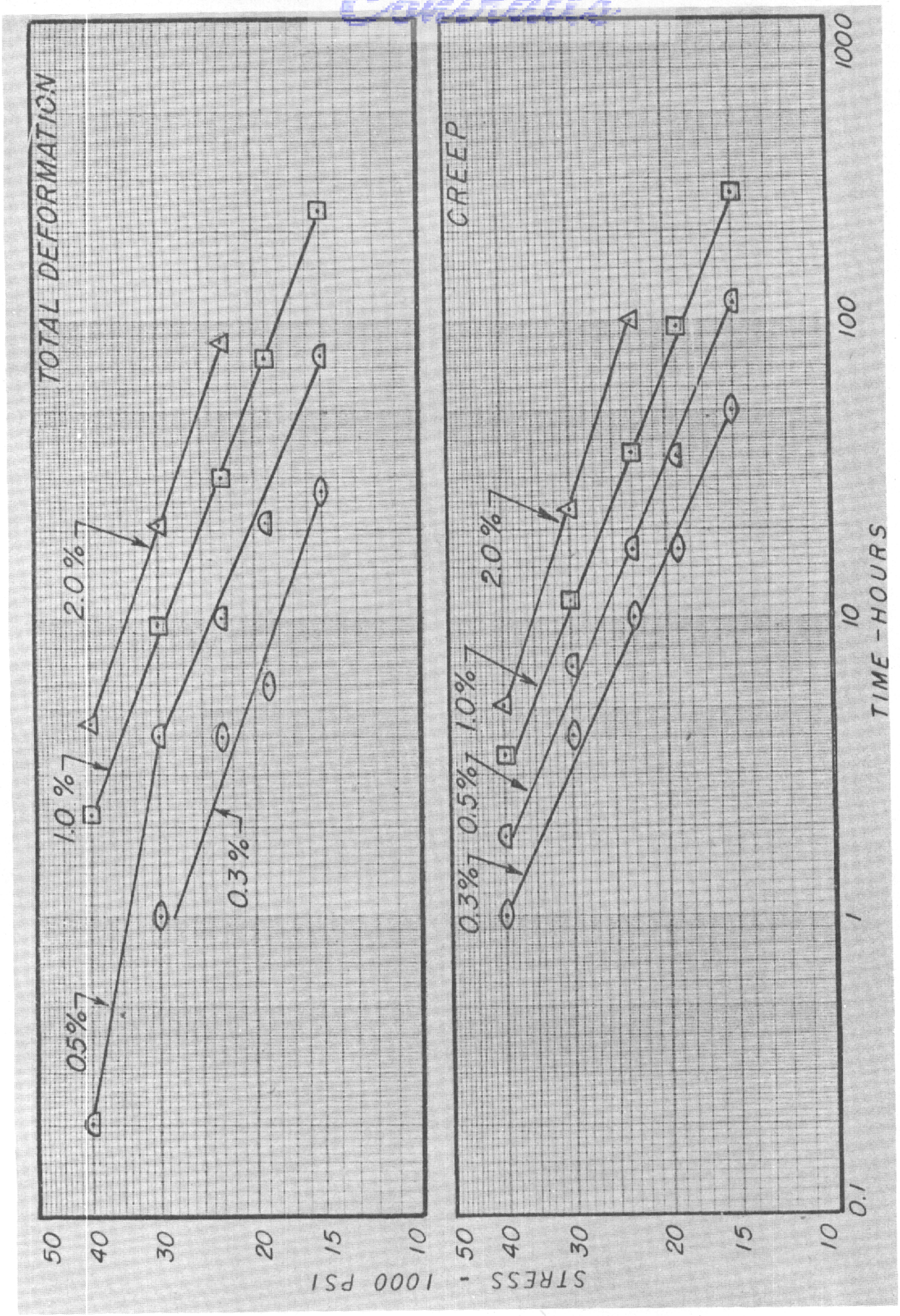

FIGURE 41 COMPRESSION CREEP CHARACTERISTICS OF A-110AT TITANIUM ALLOY SHEET AT 1000°F

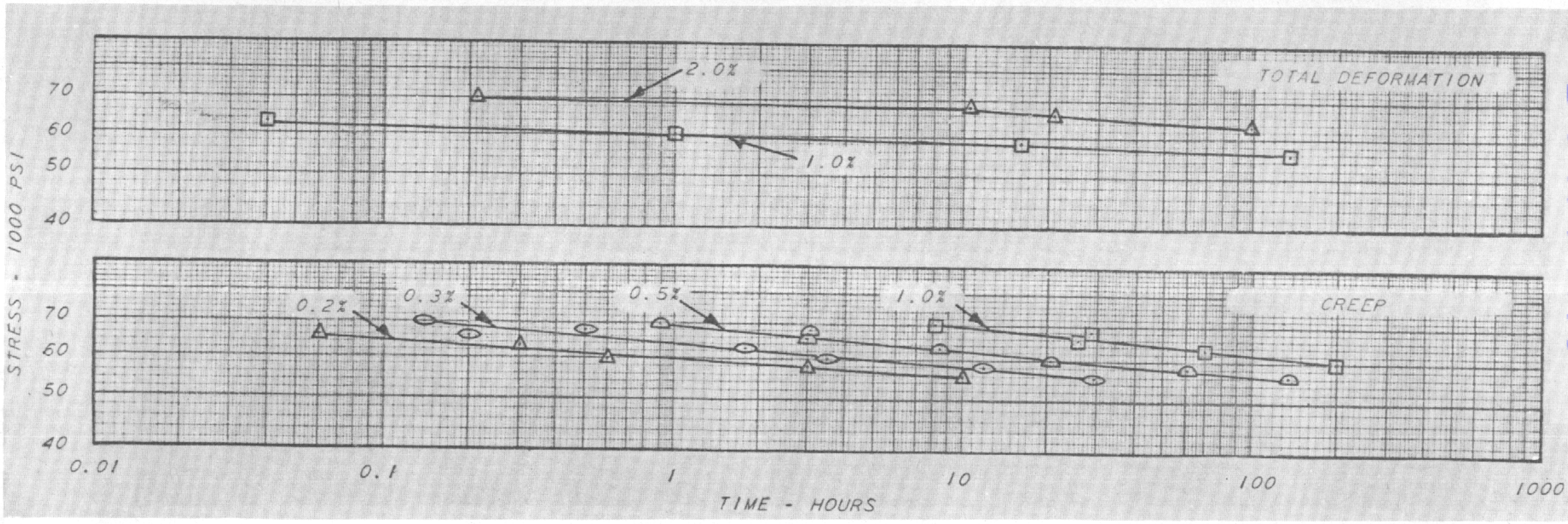

Figure 42 COMPRESSION CREEP CHARACTERISTICS OF SAE 4130 ALLOY STEEL SHEET AT 800° F

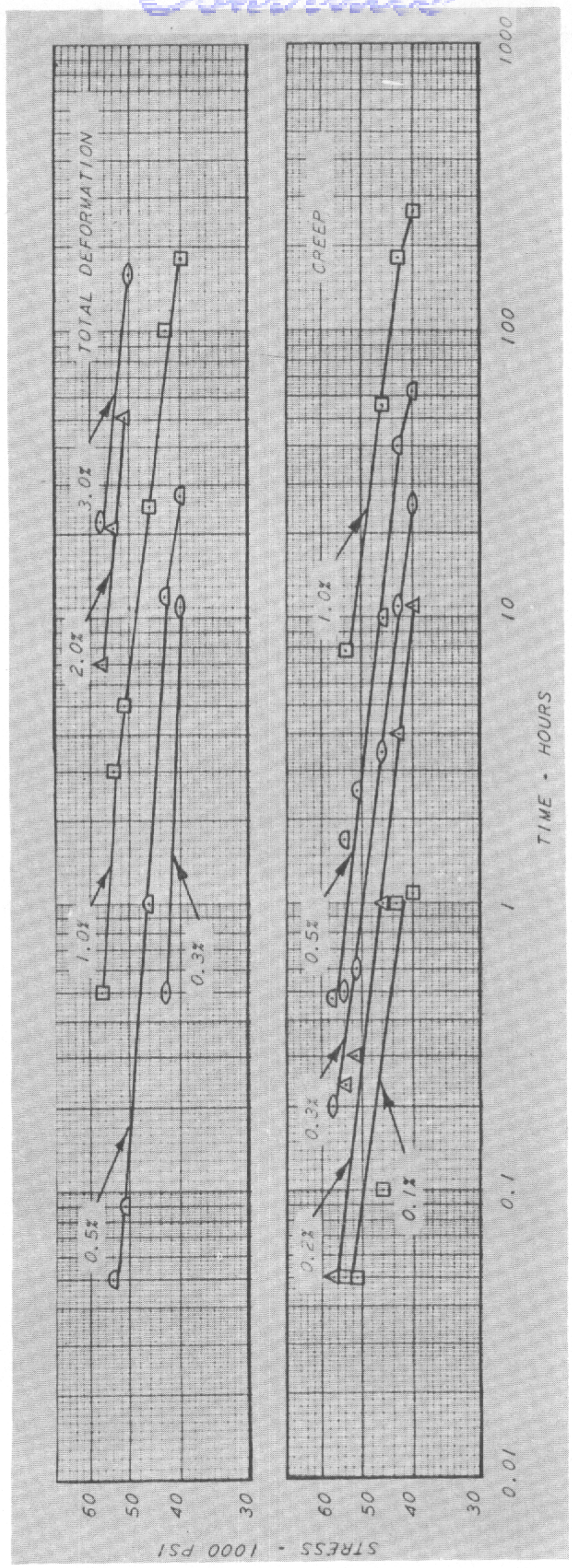

Figure 43 COMPRESSION CREEP CHARACTERISTICS OF SAE 4130 ALLOY STEEL SHEET AT 900°F

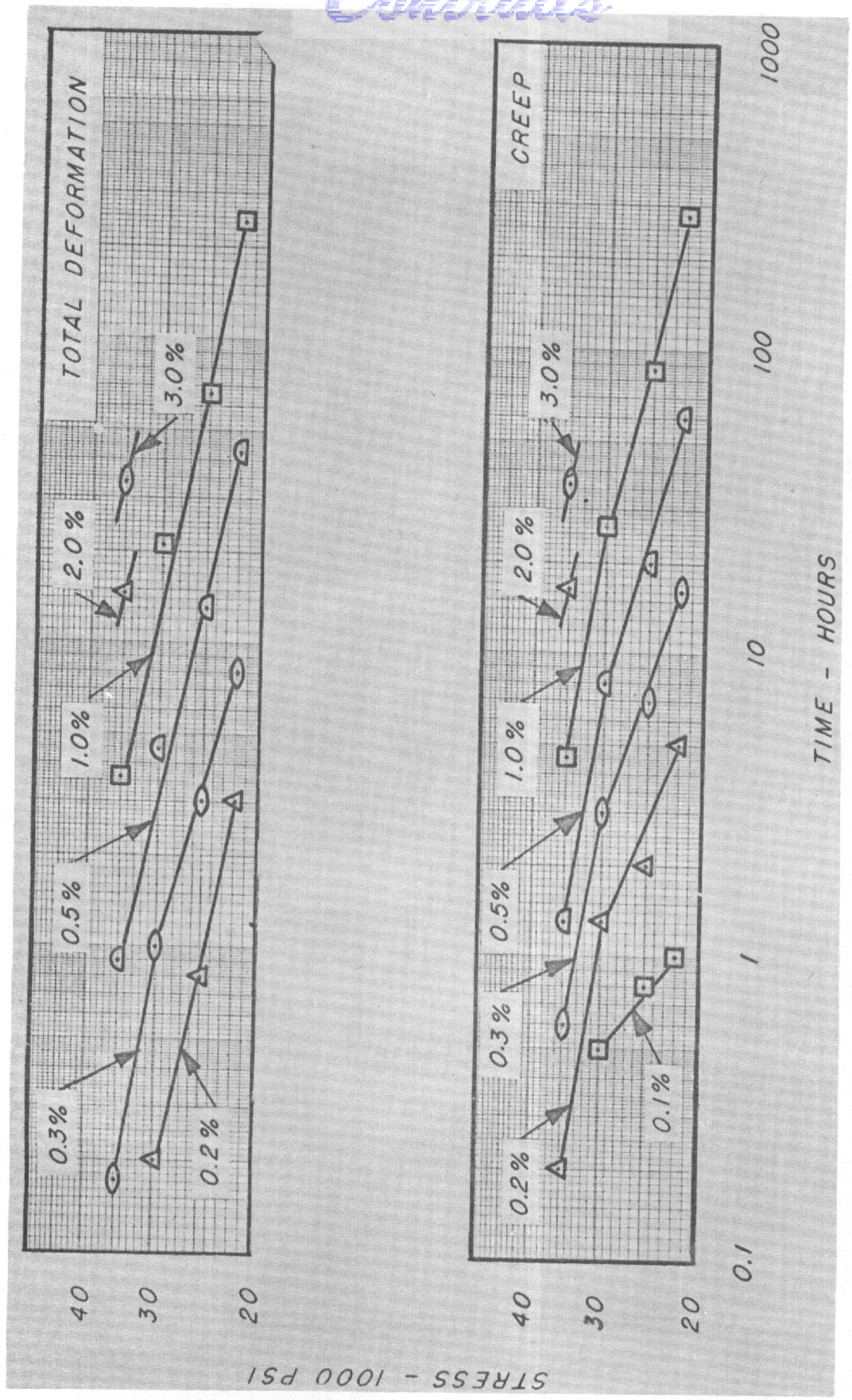

Figure 44 COMPRESSION CREEP CHARACTERISTICS OF 4130 ALLOY STEEL SHEET AT 1000°F

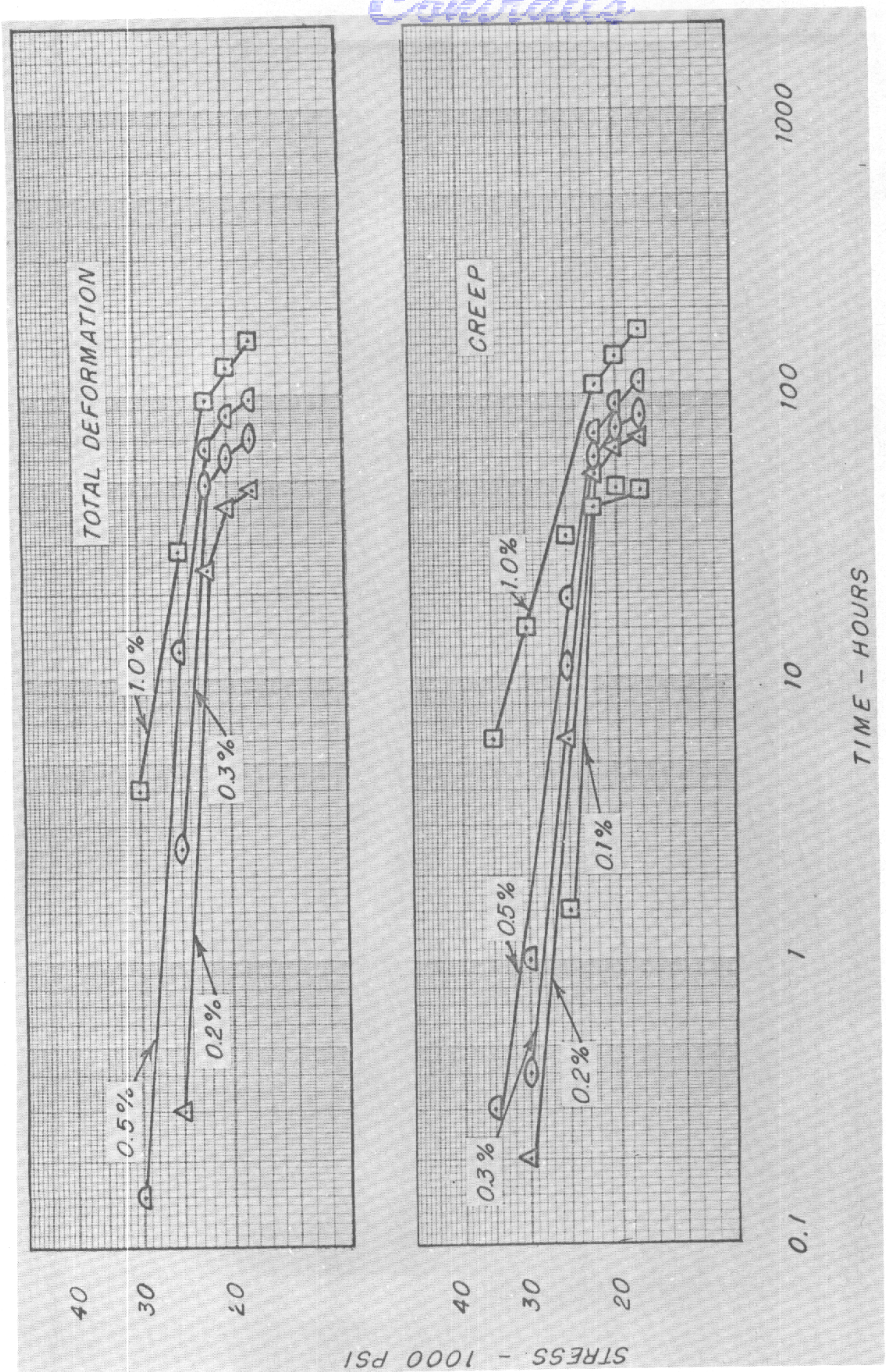

Figure 45 COMPRESSION CREEP CHARACTERISTICS OF TYPE 321 STAINLESS STEEL SHEET AT 1200°F.

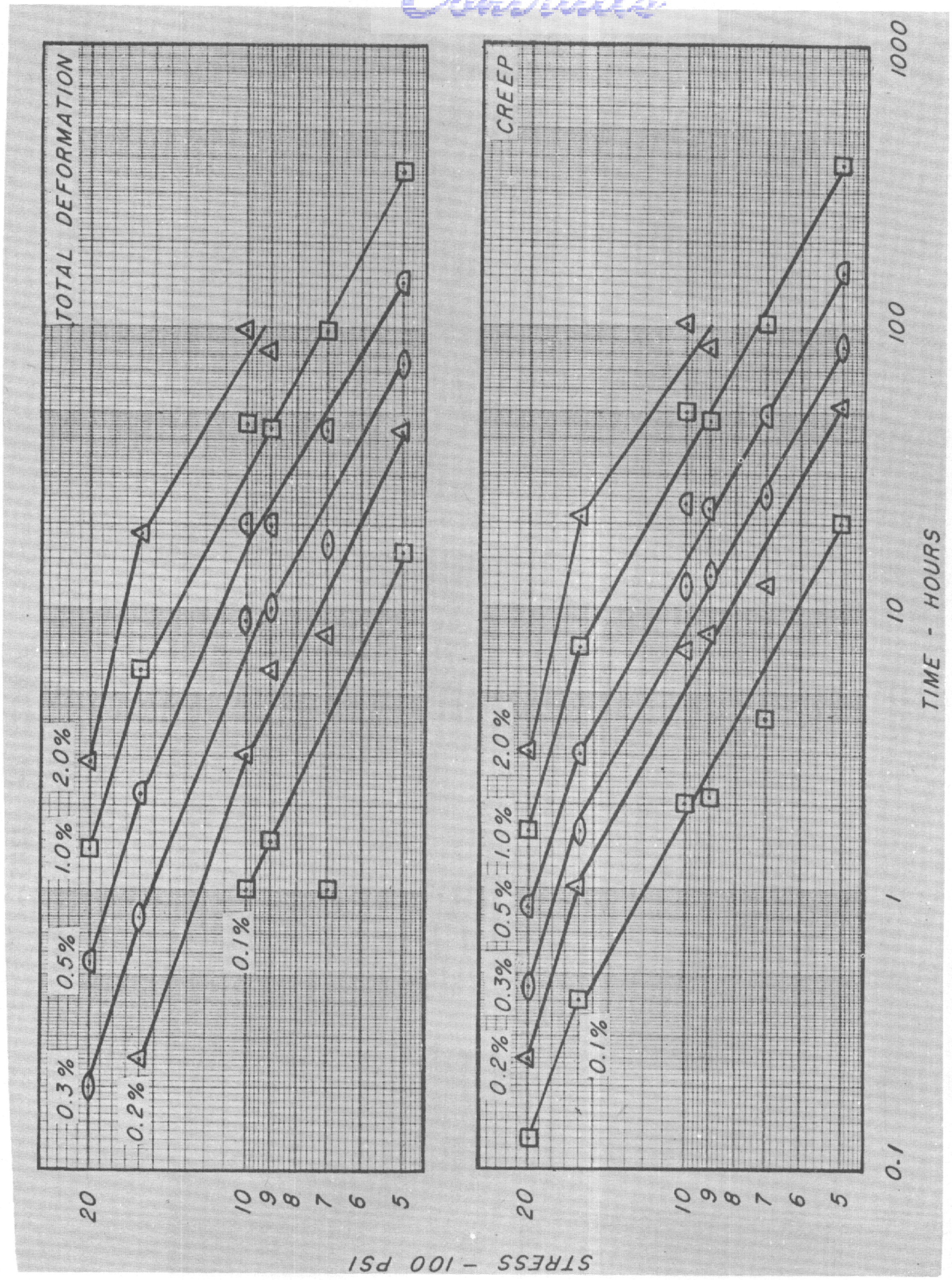

Figure 46 COMPRESSION CREEP CHARACTERISTICS OF TYPE 321 STAINLESS STEEL SHEET AT 1350°F.

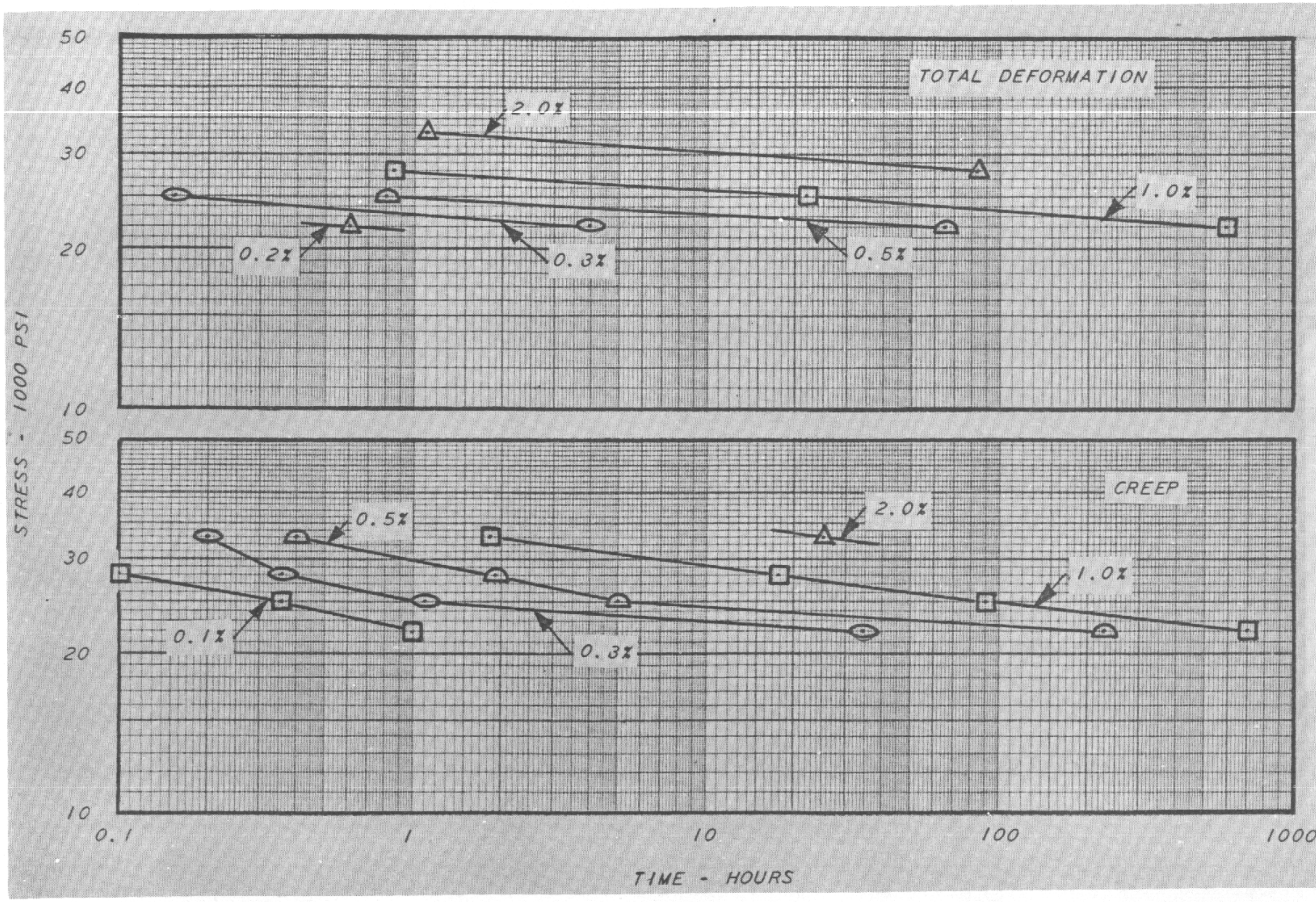

Figure 47 COMPRESSION-CREEP CHARACTERISTICS OF ANNEALED 19-9 DX ALLOY SHEET AT 1200°F

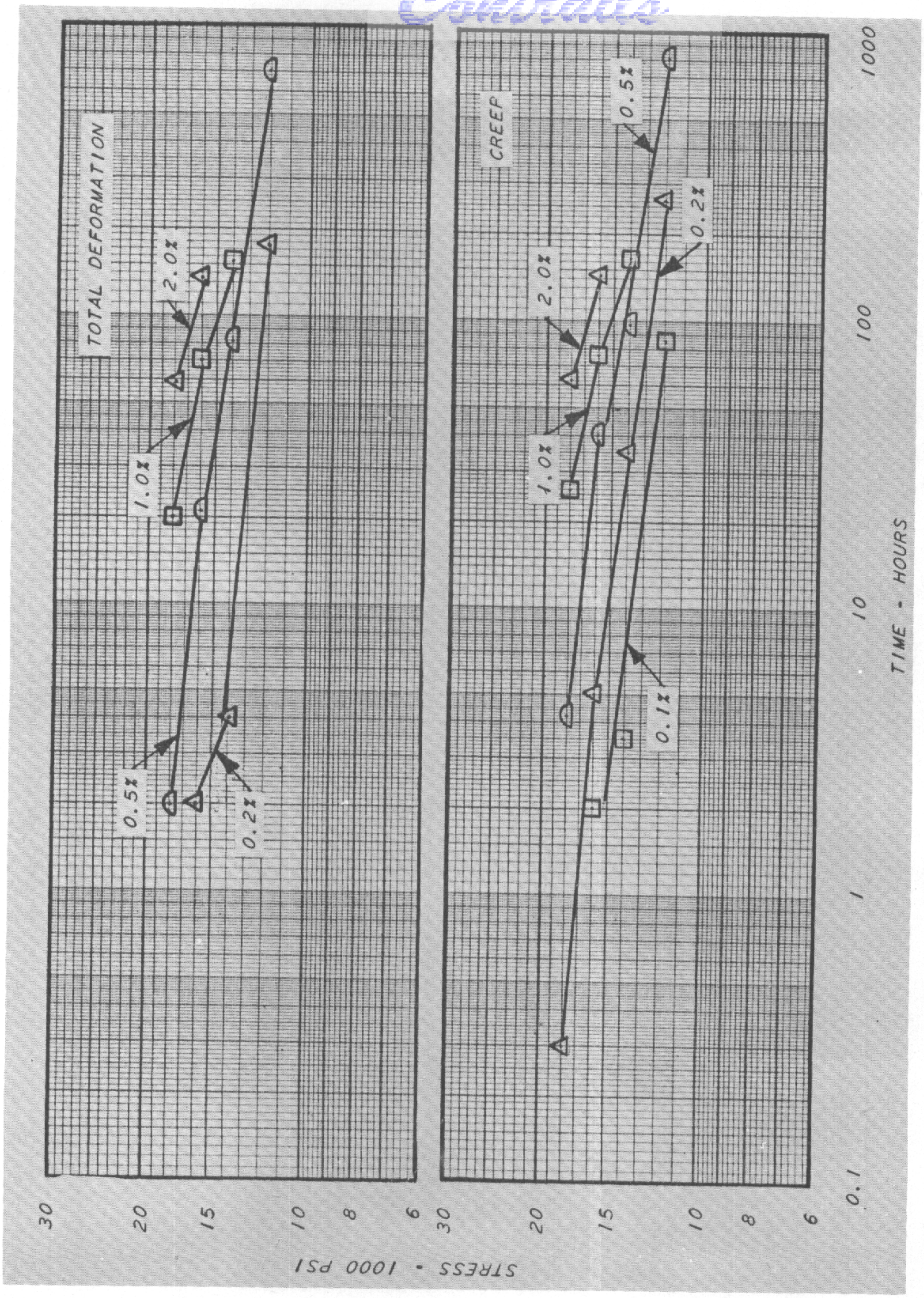

Figure 48 COMPRESSION-CREEP CHARACTERISTICS OF ANNEALED 19-9DX ALLOY SHEET AT 1350°F

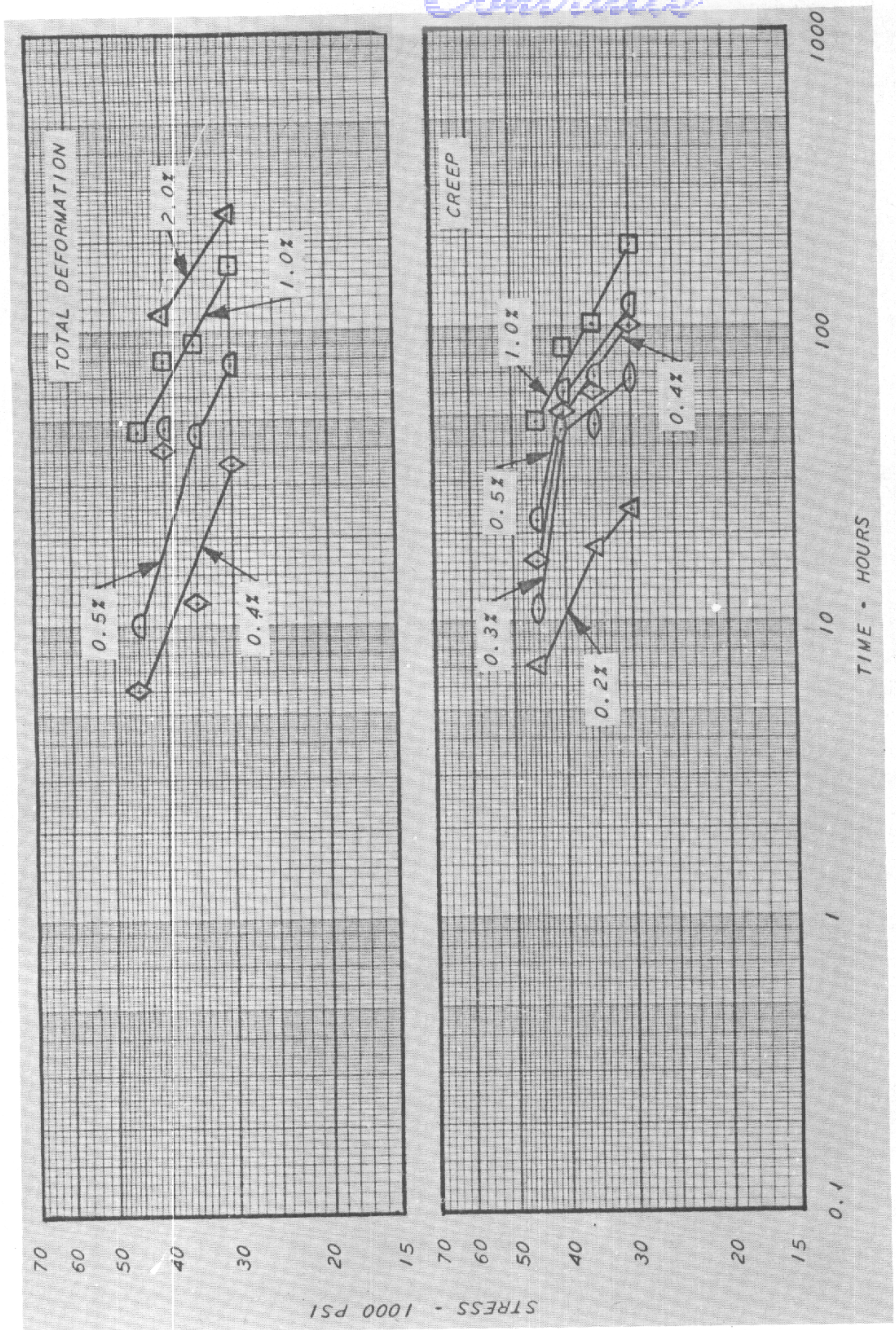

Figure 49 COMPRESSION-CREEP CHARACTERISTICS OF HARDENED A-286 ALLOY SHEET AT 1350°F

APPENDIX I

LIST OF TABLES

TABLE 25

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS
FOR 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURES
USING VARIOUS EDGE DISTANCES AND CONSTANT BEARING HOLE OF 0.125 INCH

Temp. °F	Time in Hours	Bearing-Tensile Stress Ratios for Various Edge Distances and Bearing Hole Deformation of									
		1.0%		2.0%		5.0%		10.0%		Rupture	
		1.5D	2.0D	1.5D	2.0D	1.5D	2.0D	1.5D	2.0D	1.5D	2.0D
	1									1.57	2.15*
	10							1.43		1.52	2.07
	50					1.19		1.43		1.57	1.96
300	100					1.23		1.49		1.55	2.00
	150							1.53		1.54	2.02*
	200							1.54		1.53	
	500							1.47		1.50	
	1	0.46		0.96		1.48	1.33	1.53	1.56	1.53	1.75
	10	0.37		0.89		1.35	1.40	1.49	1.59	1.50	1.78
	50			0.89		1.33	1.39*	1.46	1.62	1.50	1.85
450	100			0.78		1.35		1.51	1.66*	1.53	1.91
	150			0.69		1.34		1.53		1.53	1.94*
	200			0.66		1.37		1.55		1.56	
	500							1.80		1.83	
	1		0.59		1.12		1.53		1.71	1.63*	2.27*
	10	0.61	0.73	0.96	1.15	1.33	1.48	1.53	1.80	1.60	2.22
	50	0.60		0.96	1.17	1.28	1.52	1.45	1.77*	1.61	2.21
600	100	0.60		0.96	1.18	1.29	1.54	1.47		1.61	2.20
	150	0.60		0.98	1.19	1.28	1.56*	1.47		1.61	2.21*
	200	0.60		0.97	1.19*	1.28		1.46		1.61	
	500							1.44		1.62	

* = Ratio calculated from extrapolated stress values.

TABLE 26

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS
FOR 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURES
USING VARIOUS BEARING HOLE DIAMETERS AND CONSTANT EDGE DISTANCE OF 1.5D

Temp. °F	Time in Hours	Bearing-Tensile Stress Ratios for Bearing Hole Sizes and Bearing Hole Deformation of											
		1.0%	2.0%		5.0%			10.0%			Rupture		
		0.125	0.125	0.1875	0.064	0.125	0.1875	0.064	0.125	0.1875	0.064	0.125	0.1875
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	
	500								1.47			1.50	
450	1	0.46	0.96	0.86	1.02	1.48	1.14		1.53			1.53	
	10	0.37	0.89		1.07	1.35	1.18	1.36	1.49	1.27	1.45	1.50	1.32
	50		0.89		1.17	1.33	1.23	1.39	1.46	1.32	1.49	1.50	1.35
	100		0.78			1.35	1.25	1.45	1.51	1.35	1.52	1.53	1.39
	150		0.69			1.34		1.47	1.53	1.37	1.55	1.53	1.41
	200		0.66			1.37			1.55		1.56	1.56	1.42
	500								1.80			1.83	
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	
	500								1.44			1.62	

TABLE 27

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR ANNEALED A-70 TITANIUM SHEET AT ELEVATED TEMPERATURES FOR BEARING HOLE OF 0.125 INCH AND EDGE DISTANCE OF 1.5D

Temp. °F	Time in Hours	Bearing-Tensile Stress Ratios for Bearing Hole Deformation of 1.0%	2.0%	5.0%	10.0%	Rupture
700	1				1.65	1.72
	10			1.40*	1.64	1.73
	50			1.37	1.58	1.74
	100			1.25	1.48	1.69
	150			1.19*	1.43	1.63
	200				1.38*	1.61
	500					1.61*
800	1	0.46	0.97	1.29	1.48	1.70
	10	0.41	0.71	1.09	1.34	1.64
	50	0.45	0.64	1.10	1.33	1.69
	100	0.47*	0.63	1.13*	1.34	1.71
	150		0.61	1.12*	1.32*	1.69
	200		0.59		1.32*	1.70
	500					1.73*

* = Ratio calculated from extrapolated stress values.

TABLE 28

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR C-110M TITANIUM ALLOY SHEET AT ELEVATED TEMPERATURES FOR BEARING HOLE OF 0.125 INCH AND EDGE DISTANCE OF 1.5D

Temp. °F	Time in Hours	Bearing-Tensile Stress Ratios For Bearing Hole Deformation of		
		5.0%	10.0%	Rupture
700	10	1.01	1.30	1.54
	50	0.93	1.25	1.57
	100	0.91	1.23	1.58
	150	0.90	1.21	1.59
	200	0.90*	1.21*	1.64
	500			1.64*
800	10	1.02	1.29	1.76
	50	0.86	1.11	1.63
	100	0.75	1.10*	1.65
	150	0.72	1.12*	1.67
	200	0.70		1.71
	500	0.64*		1.72

* = Ratio calculated from extrapolated stress values.

TABLE 29

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS
FOR A-110AT TITANIUM ALLOY SHEET AT ELEVATED TEMPERATURES
FOR BEARING HOLE OF 0.125 INCH AND EDGE DISTANCE OF 2.0D

Temp. °F	Time in Hours	Bearing-Tensile Stress Ratios For Bearing Hole Deformation of			
		0.5%	10.0%	20.0%	Rupture
800	10			1.90*	2.08*
	50			1.88	2.12
	100			1.88*	2.15
	150				2.17
	200				2.18
	500				2.18*
1000	1	1.23	1.45	1.70*	
	10	1.15	1.51	1.70	2.06
	50		1.38*	1.70	2.16
	100			1.64*	2.18
	150			1.65*	2.21
	200				2.22
	500				2.28

* = Ratio calculated from extrapolated stress values.

TABLE 30

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS FOR NORMALIZED SAE 4130 ALLOY STEEL SHEET AT ELEVATED TEMPERATURES USING VARIOUS EDGE DISTANCES AND A CONSTANT BEARING HOLE OF 0.125 INCH

Temp. °F	Time in Hours	Bearing-Tensile Stress Ratios for Various Edge Distances and Bearing Hole Deformation of							
		2.0%		5.0%		10.0%		Rupture	
		1.5D	2.0D	1.5D	2.0D	1.5D	2.0D	1.5D	2.0D
800	10			1.30	1.46			1.67	2.31
	50			1.30	1.45			1.70	2.32
	100			1.30	1.45			1.71	2.34
	150			1.27	1.46			1.71	2.35
	200				1.45*			1.71*	2.37
	500								2.34*
900	10			1.20	1.35	1.42		1.63	2.27
	50			1.18*	1.23*	1.39		1.62	2.27
	100					1.39*		1.63	2.22
	150					1.40*		1.63	2.25
	200							1.62*	2.25
	500								2.31*
1000	1	0.72		1.25		1.44		1.61	
	10	0.61		1.12		1.37		1.61	
	50	0.60*		1.13*		1.35		1.64	
	100							1.71	
	150							1.71	
	200							1.71	
	500							1.79*	

* = Ratio calculated from extrapolated stress values.

TABLE 31

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS
FOR TYPE 321 STAINLESS STEEL SHEET AT ELEVATED TEMPERATURES
USING VARIOUS EDGE DISTANCES AND A CONSTANT BEARING HOLE OF 0.125 INCH

Temp. °F	Time in Hours	Bearing-Tensile Stress Ratios for Various Edge Distances and Bearing Hole Deformation of									
		1.0%		2.0%		5.0%		10.0%		Rupture	
		1.5D	2.0D	1.5D	2.0D	1.5D	2.0D	1.5D	2.0D	1.5D	2.0D
1200	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							1.40*		1.71	
	200									1.72	
	500									1.75*	
1350	1	0.57	0.91	0.88	1.19	1.25	1.53	1.46	1.82	1.73*	2.38*
	10	0.36	0.76	0.71	1.11	1.10	1.43	1.30	1.71	1.72	2.32
	50			0.59	0.94	1.15*	1.56*	1.46	1.82	1.81	2.40
	100			0.53				1.44*	1.88*	1.87	2.46
	150			0.51				1.47*	1.87*	1.91	2.48
	200			0.49						1.96	2.52
	500									2.00*	

* = Ratio calculated from extrapolated stress values.

TABLE 32

RATIO OF BEARING CREEP STRESS TO TENSILE RUPTURE STRESS
FOR 19-9DX ALLOY SHEET AT ELEVATED TEMPERATURES
FOR BEARING HOLE OF 0.125 INCH AND EDGE DISTANCE OF 2.0D

Temp. °F	Time in Hours	Bearing-Tensile Stress Ratios for Bearing Hole Deformation of					
		2.0%	5.0%	10.0%	20.0%	25.0%	Rupture
1200	1		1.29	1.40	1.67	1.82	2.10*
	10		1.16*	1.49	1.68	1.78	1.97
	50				1.67	1.74	1.88
	100				1.65	1.73	1.88
	150				1.65	1.73	1.79
	200				1.67*	1.72	1.78
	500						1.82*
1350	1	1.00	1.33	1.61	1.83		
	10	0.88	1.28	1.55	1.77		1.98
	50		1.26	1.53	1.71		2.00
	100		1.21	1.55*	1.67		1.97
	150		1.21*	1.59*	1.70		2.00
	200				1.76*		2.05
	500						2.14*

* = Ratio calculated from extrapolated stress values.

APPENDIX II

LIST OF TABLES

TABLE 33

RATIO OF SHEAR CREEP STRESS TO TENSILE RUPTURE STRESS
FOR SHEAR-PIN DEFORMATION AND RUPTURE OF
2024-T3 ALUMINUM ALLOY PLATE AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Shear-Tensile Stress Ratios for Shear-Pin Deformation of 0.002 Inch	0.005 Inch	0.01 Inch	0.02 Inch	Rupture
	1	0.63				0.63
	10	0.58				0.62
	50	0.54*				0.61
300	100					0.60
	150					0.59
	200					0.58
	500					0.62*
	1	0.25	0.33			0.43
	10	0.30	0.37			0.43
	50	0.23	0.39			0.43
450	100	0.20	0.40			0.43
	150	0.20	0.41			0.48
	200	0.20*	0.41			0.48
	500		0.41*			0.48
	1					
	10	0.36	0.42	0.45	0.49	0.51
	50	0.40	0.47	0.51	0.53	0.57
600	100	0.42*	0.49	0.52	0.55	0.58
	150			0.54	0.56	0.59
	200			0.50	0.56	0.59
	500					0.50

* = Ratio calculated from extrapolated stress values.

TABLE 34

RATIO OF SHEAR CREEP STRESS TO TENSILE RUPTURE STRESS
FOR SHEAR-PIN DEFORMATION AND RUPTURE OF
2117-T4 ALUMINUM ALLOY BAR AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Shear-Tensile Stress Ratios for Shear-Pin Deformation of 0.002 Inch	0.005 Inch	0.01 Inch	0.02 Inch	Rupture
300	1					0.67*
	10					0.67
	50					0.66
	100					0.64
	150					0.63
	200					0.62
	500					0.62*
450	1					0.55*
	10		0.50			0.55
	50		0.53			0.54
	100		0.53			0.57
	150		0.50			0.56
	200					0.55
	500					0.56*
600	1	0.49*	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		0.55*	0.59	0.64	0.69
	500			0.60*	0.62*	0.66

* = Ratio calculated from extrapolated stress values.

TABLE 35

RATIO OF SHEAR CREEP STRESS TO TENSILE RUPTURE STRESS
FOR SHEAR-PIN DEFORMATION AND RUPTURE OF
A-110AT TITANIUM ALLOY BAR AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Shear-Tensile Stress Ratios for Shear-Pin Deformation of 0.02 Inch	0.03 Inch	0.04 Inch	Rupture
800	1	0.57*	0.61*	0.66*	
	10	0.57	0.64	0.68	0.72
	50	0.58	0.67	0.70	0.71
	100	0.58	0.65	0.70	0.72
	150	0.59*	0.65	0.70	0.72
	200		0.65	0.70	0.72
	500		0.65*	0.69*	0.71*
1000	1	0.51	0.58*	0.63*	0.68*
	10	0.53	0.64	0.67	0.71
	50	0.51*	0.64	0.70	0.74
	100		0.61*	0.67	0.74
	150			0.66*	0.75
	200				0.75
	500				0.76*

* = Ratio calculated from extrapolated stress values.

TABLE 36

RATIO OF SHEAR CREEP STRESS TO TENSILE RUPTURE STRESS FOR SHEAR-PIN DEFORMATION AND RUPTURE OF MONEL ALLOY BAR AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Shear-Tensile Stress Ratios for Shear-Pin Deformation of 0.01 Inch	0.015 Inch	0.02 Inch	0.03 Inch	Rupture
1000	1		0.51	0.57	0.66	0.71
	10		0.55	0.61	0.65	0.71
	50		0.57	0.61	0.65	0.69
	100		0.60*	0.63	0.67	0.71
	150		0.61*	0.64	0.67	0.71
	200			0.66	0.69	0.72
	500			0.68*	0.69	0.73
1200	1	0.51*		0.58*	0.65*	0.71*
	10	0.47		0.62	0.65	0.69
	50	0.44*		0.56	0.63	0.67
	100			0.55	0.61	0.64
	150			0.55	0.60	0.63
	200			0.56*	0.62	0.64
	500				0.66	0.69

* = Ratio calculated from extrapolated stress values.

TABLE 37

RATIO OF SHEAR CREEP STRESS TO TENSILE RUPTURE STRESS
FOR SHEAR-PIN DEFORMATION AND RUPTURE OF
TYPE 301 STAINLESS STEEL BAR AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Shear-Tensile Stress Ratios for Shear-Pin Deformation of 0.01 Inch	0.02 Inch	0.03 Inch	Rupture
1200	1	0.49*	0.58*	0.65*	0.72*
	10	0.52	0.59	0.66	0.72
	50	0.51	0.61	0.66	0.71
	100	0.50	0.62	0.66	0.70
	150	0.49*	0.62*	0.66	0.69
	200		0.63*	0.67	0.70
	500			0.67*	0.69*
1350	1	0.48	0.57*	0.64*	0.76*
	10	0.53	0.60	0.65	0.72
	50	0.49*	0.64	0.67	0.72
	100		0.64	0.68	0.71
	150		0.62	0.69	0.72
	200		0.61*	0.67	0.71
	500			0.65*	0.68*

* = Ratio calculated from extrapolated stress values.

TABLE 38

RATIO OF SHEAR CREEP STRESS TO TENSILE RUPTURE STRESS FOR SHEAR-PIN DEFORMATION AND RUPTURE OF 19-9DX ALLOY BAR AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Shear-Tensile Stress Ratios for Shear-Pin Deformation of 0.01 Inch	0.02 Inch	0.03 Inch	Rupture
1000	1				0.64*
	10			0.62	0.65
	50			0.61	0.65
	100			0.61	0.63
	150			0.62*	0.64
	200				0.64
	500				0.67*
1200	1	0.38	0.46	0.54	0.63*
	10	0.44	0.50	0.54	0.64
	50	0.45	0.49	0.54	0.55
	100	0.49*	0.54	0.54	0.56
	150		0.53	0.54	0.55
	200		0.53*	0.54	0.54
	500				0.53*
1350	1				
	10	0.32	0.41	0.48	0.53
	50	0.29*	0.44	0.51	0.55
	100		0.42	0.49	0.55
	150		0.41*	0.47	0.55
	200			0.47*	0.54
	500				0.55*

* = Ratio calculated from extrapolated stress values.

TABLE 39

RATIO OF SHEAR CREEP STRESS TO TENSILE RUPTURE STRESS FOR SHEAR-PIN DEFORMATION AND RUPTURE OF HARDENED A-286 ALLOY BAR AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Shear-Tensile Stress Ratios for Shear-Pin Deformation of 0.001 Inch	0.002 Inch	0.003 Inch	Rupture
1000	1		0.46	0.61*	
	10		0.45	0.60	0.65
	50			0.58	0.63
	100			0.57	0.61
	150			0.57*	0.60
	200			0.57*	0.60
	500				0.59*
1200	1		0.41	0.45	0.52
	10		0.41	0.45	0.49
	50		0.43	0.46	0.50
	100		0.44	0.48	0.51
	150		0.46*	0.50	0.52
	200		0.48*	0.53	0.53
	500			0.55*	0.56
1350	1	0.37	0.52		0.63
	10	0.38	0.51		0.63
	50	0.38*	0.47		0.57
	100		0.47		0.54
	150		0.49		0.56
	200		0.51*		0.57
	500				

* = Ratio calculated from extrapolated stress values.

APPENDIX III

LIST OF TABLES

TABLE 40

COMPRESSION-TENSION CREEP STRESS RATIOS FOR 2024-T3 ALUMINUM ALLOY SHEET AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Compression-Tension Stress Ratios for Total Deformation of			
		0.2%	0.3%	0.5%	1.0%
450	1		0.82	0.93	
	10		0.88	0.92	0.94
	50			0.99	0.96
	100			1.07	1.00
	150			1.06	1.01
	200			1.07	1.08
	500				1.25*
600	1	0.75	0.83	0.93	
	10	0.72	0.81	0.89	1.01
	50	0.70*	0.72*	0.85	1.02
	100			0.82	1.03
	150			0.82*	1.02
	200			0.80*	1.00
	500				1.00

* = Ratio calculated from extrapolated stress values.

TABLE 41

COMPRESSION-TENSION CREEP STRESS RATIOS FOR
2024-T3 ALUMINUM ALLOY PLATE AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Compression-Tension Stress Ratios for Total Deformation of 0.2%	0.3%	0.5%	1.0%
450	1		0.92	1.00	0.96*
	10		0.86	0.95	0.96
	50			0.96	0.93
	100			0.93	0.94
	150			0.93*	0.95
	200				0.94
	500				0.92*
600	1	0.85	0.89	0.87*	
	10	0.90	0.89	0.88	0.88
	50	0.94*	0.89	0.92	0.92
	100		0.90*	0.93	0.96
	150			0.94	0.97
	200			0.95	0.97
	500			0.97*	1.00

* = Ratio calculated from extrapolated stress values.

TABLE 42

COMPRESSION-TENSION CREEP STRESS RATIOS FOR
A-70 TITANIUM SHEET AT ELEVATED TEMPERATURE

Temp. °F	Time in Hours	Compression-Tension Stress Ratios for Total Deformation of				
		0.2%	0.3%	0.5%	1.0%	2.0%
	1	1.20*				
	10	0.92	1.05	1.07	1.07	1.04*
800	50		0.84*	0.95	1.15	1.07
	100			0.80*	1.05	1.04
	150				1.02	1.05
	200				0.99*	1.03*

* = Ratio calculated from extrapolated stress values.

TABLE 43

COMPRESSION-TENSION CREEP STRESS RATIOS FOR
C-110M TITANIUM ALLOY SHEET AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Compression-Tension Stress Ratios for Total Deformation of 0.2%	0.3%	0.5%	1.0%	2.0%
700	1				0.87*	
	10				0.87	0.86
	50				0.91	0.92
	100				0.92*	0.95
	150				0.91*	0.97
	200					0.99*
800	1	0.51*	0.77*	0.88	0.86*	
	10		0.85*	1.05	1.00	
	50			0.97	1.05	
	100				1.00	
	150				0.96*	
	200				0.96*	

* = Ratio calculated from extrapolated stress values.

TABLE 44

COMPRESSION-TENSION CREEP STRESS RATIOS FOR
A-110AT TITANIUM ALLOY SHEET AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Compression-Tension Stress Ratios for Total Deformation of			
		0.3%	0.5%	1.0%	2.0%
800	1				
	10				
	50				1.11
	100				1.10
	150				1.09
	200				1.08
	500				1.05*
1000	1	1.12*	1.08	1.01	1.00
	10	1.09	1.08	1.06	1.08
	50	1.21	1.09	1.09	1.11
	100		1.12	1.10	1.13
	150			1.11	1.13*
	200			1.11	1.15*
	500			1.14*	

* = Ratio calculated from extrapolated stress values.

TABLE 45

COMPRESSION-TENSION CREEP STRESS RATIOS FOR NORMALIZED SAE 4130 ALLOY STEEL SHEET AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Compression-Tension Stress Ratios for Total Deformation of 0.3%	0.5%	1.0%	2.0%
	1			0.94	1.03
	10			0.92	1.03
	50			0.98	1.01
800	100			1.00	1.00
	150			1.01	1.00*
	200			1.01*	1.01*
	500			1.03*	1.02*
	1	1.10	0.98	1.00	1.05*
	10	1.17*	1.04	1.03	1.04
	50		1.05*	1.05	1.07
900	100		1.05*	1.05	1.11*
	150			1.05	
	200			1.05	
	500			1.09*	
	1	1.17	1.05	1.03	
	10	1.11*	1.10	1.06	
	50		1.16	1.10	
1000	100		1.20*	1.15	
	150		1.22*	1.19	
	200			1.20	
	500			1.25*	

* = Ratio calculated from extrapolated stress values.

TABLE 46

COMPRESSION-TENSION CREEP STRESS RATIOS FOR TYPE 321 STAINLESS STEEL ALLOY SHEET AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Compression-Tension Stress Ratios for Total Deformation of 0.2%	0.5%	1.0%	2.0%
1200	1	0.99			
	10	1.00	1.00	1.05	
	50	1.03*	1.05	1.09	
	100		1.02	1.05	
	150		0.99*	1.08	
	200			1.04*	
	500			1.02*	
1350	1	0.93	1.13	1.10	1.06*
	10	0.90	1.03	1.02	1.12
	50	0.85	1.00	0.99	1.05
	100		0.95	0.97	1.03
	150		0.93	0.97	1.00*
	200		0.93*	0.96	
	500			0.94*	

* = Ratio calculated from extrapolated stress values.

TABLE 47

COMPRESSION-TENSION CREEP STRESS RATIOS FOR 19-9DX ALLOY SHEET AT ELEVATED TEMPERATURES

Temp. °F	Time in Hours	Compression-Tension Stress Ratios for Total Deformation of				
		0.2%	0.3%	0.5%	1.0%	2.0%
1200	1		0.72	0.66	0.66	0.72*
	10		0.74*	0.70	0.69	0.74
	50			0.76	0.72	0.77
	100			0.76*	0.72	0.79*
	150				0.75	
	200				0.77	
	500				0.81	
1350	1	0.93	0.73	0.70*		
	10	1.14	0.88	0.78	0.76*	
	50	1.46	1.14	0.94	0.82	0.80*
	100	1.56	1.37	1.04	0.94	0.89
	150	1.66	1.47	1.22	1.00	0.97
	200		1.56	1.33	1.06*	1.05*
	500					

* = Ratio calculated from extrapolated stress values.

TABLE 48

COMPRESSION-TENSION CREEP STRESS RATIOS FOR
HARDENED A-286 ALLOY SHEET
AT ELEVATED TEMPERATURE

Temp. °F	Time in Hours	Compression-Tension Stress Ratios for Total Deformation of		
		0.5%	1.0%	2.0%
1350	10	1.15		
	50	1.14	1.23	
	100		1.13	1.25
	150		1.11	1.22
	200		1.09	1.17
	500			1.05