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TENSILE AND CREEP RUPTURE PROPERTIES OF (16) UNCOATED AND (2) COATED ENGINEERING ALLOYS AT ELEVATED TEMPERATURES

by

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SUMMARY

Tensile, creep rupture and Poisson's Ratio were generated on a group of sixteen materials supplied by NASA-Lewis Research Center. Two of the materials were additionally tested after a Jocoat* coating was applied.

The tensile and Poisson's Ratio test data are supplied in tabular form - with samples of the load-strain curves. Creep rupture data are presented in tabular and graphical form - the graphs being iso-thermal plots of the rupture life data as well as families of plastic deformation versus time plots.

All such data are grouped according to alloy designations.

*Jocoat is a high temperature oxidation-resistant coating proprietary to Pratt & Whitney Aircraft Corporation applied by an approved source according to Specification PWA A47.

INTRODUCTION

Over the past several years, a considerable amount of high temperature, low cycle fatigue data have been generated at the Lewis Research Center on a variety of alloys. A significant part of this testing was to develop improved methods for predicting high temperature fatigue behavior. Specifically, there was a thrust to ascertain whether fatigue behavior could be predicted from a knowledge of the tensile properties at the various temperatures of interest. No such tensile data existed on the particular heats of the materials which had been evaluated in low cycle fatigue testing, although handbook values existed for some material-temperature combinations.

In order to make a critical evaluation of life prediction approaches, it became imperative to generate the tensile and creep rupture properties on the same heats as were used to generate the fatigue data.

This report represents the culmination of the test effort to collect the necessary tensile and creep rupture data for correlating with existing fatigue data. Material for this evaluation was supplied from the test heats by NASA-Lewis Research Center.

GENERAL BACKGROUND

Materials

The materials and test temperatures in this program are as follows:

	Alloy	T_1 (°C)	T_1 (°F)	T_2 (°C)	T_2 (°F)	T_3 (°C)	T_3 (°F)
1.	7075-T6 Aluminum	121	250	149	300	177	350
2.	Amzirc Copper	482	900	538	1000	593	1100
3.	Titanium-6Al-2Sn-4Zr-2Mo	482	900	538	1000	593	1100
4.	H-13 Tool Steel	538	1000	593	1100	649	1200
5.	D-979	593	1100	649	1200	704	1300
6.	A-286	593	1100	649	1200	704	1300
7.	L-605	593	1100	649	1200	704	1300
8.	304 Stainless Steel	593	1100	649	1200	760	1400
9.	316 Stainless Steel	593	1100	704	1300	816	1500
10.	Udimet 700	760	1400	816	1500	927	1700
11.	TAZ-8A	850	1562	925	1697	1000	1832
12.	IN 100	850	1562	925	1697	1000	1832
13.	IN 100 + Jocoat	850	1562	925	1697	1000	1832
14.	B 1900	850	1562	925	1697	1000	1832
15.	B 1900 + Jocoat	850	1562	925	1697	1000	1832
16.	Mar-M200	871	1600	927	1700	982	1800
17.	Mar-M302	850	1562	925	1697	1000	1832
18.	Rene' 80	850	1562	925	1697	1000	1832

Alloys 1-10 were furnished by the Government in the form of wrought bars -- 0.75 inch diameter by 27 to 36 inches long. Specimens of these alloys were machined as described elsewhere in this report (page 4).

Alloys 11-18 were furnished by the Government as cast remelt stock -- 2-1/2 to 3-1/2 inch diameter by 6 to 43 inches long. Specimens of these alloys were cast to size. The remelt stock was shipped from Metcut to Howmet Corporation-Misco Division, where it was cast into specimen blanks per Figure 1.

The specifics of any heat treatment or coating of the alloys is covered in the segment of this report covering those particular alloys.

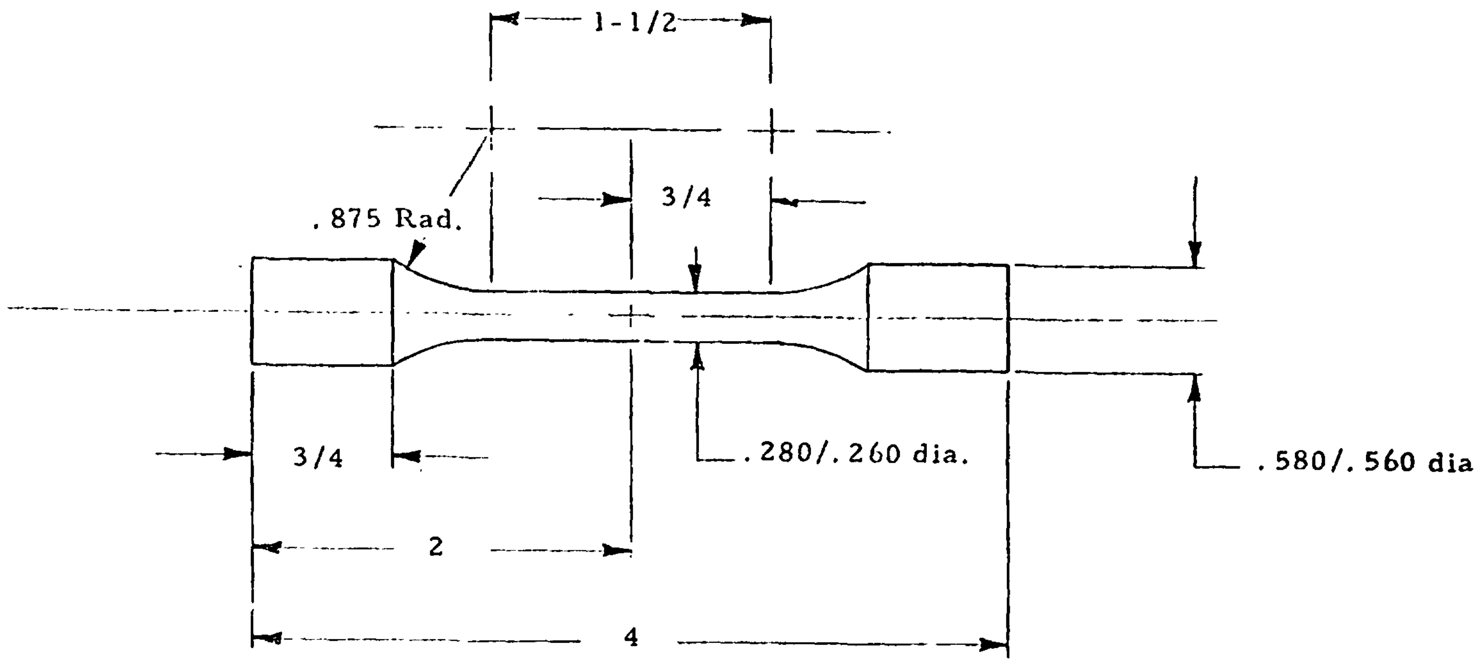


FIGURE 1 CAST BAR SPECIMEN BLANK

(dimensions in inches)

Specimen Preparation

The wrought materials (Alloys 1-10) were cut into appropriate blank sizes for machining into the tensile, creep and Poisson's Ratio test specimens shown in Figures 2, 3, and 4, respectively. On the assumption that the material was uniform from bar to bar, the blanks were cut up without sketching specimen location within the bars. All tensile blanks might be from consecutive positions in one or two bars with the same procedure followed for creep and Poisson's Ratio blanks.

Once the blank was cut to its approximate size, it was faced and centered; thereafter, all machining was performed with reference to these centers. Such practices assure centrality of the finished specimen.

As previously stated, all specimen blanks from the cast materials were supplied to a single configuration. From this blank, the creep, tensile and Poisson's Ratio specimens were machined per Figures 3, 5, and 6, respectively.

All specimens (except the Amzirc Copper) were machined using Metcut's "low stress" grinding techniques to finish the gage section. The Amzirc Copper specimens were turned and polished in the reduced gage section.

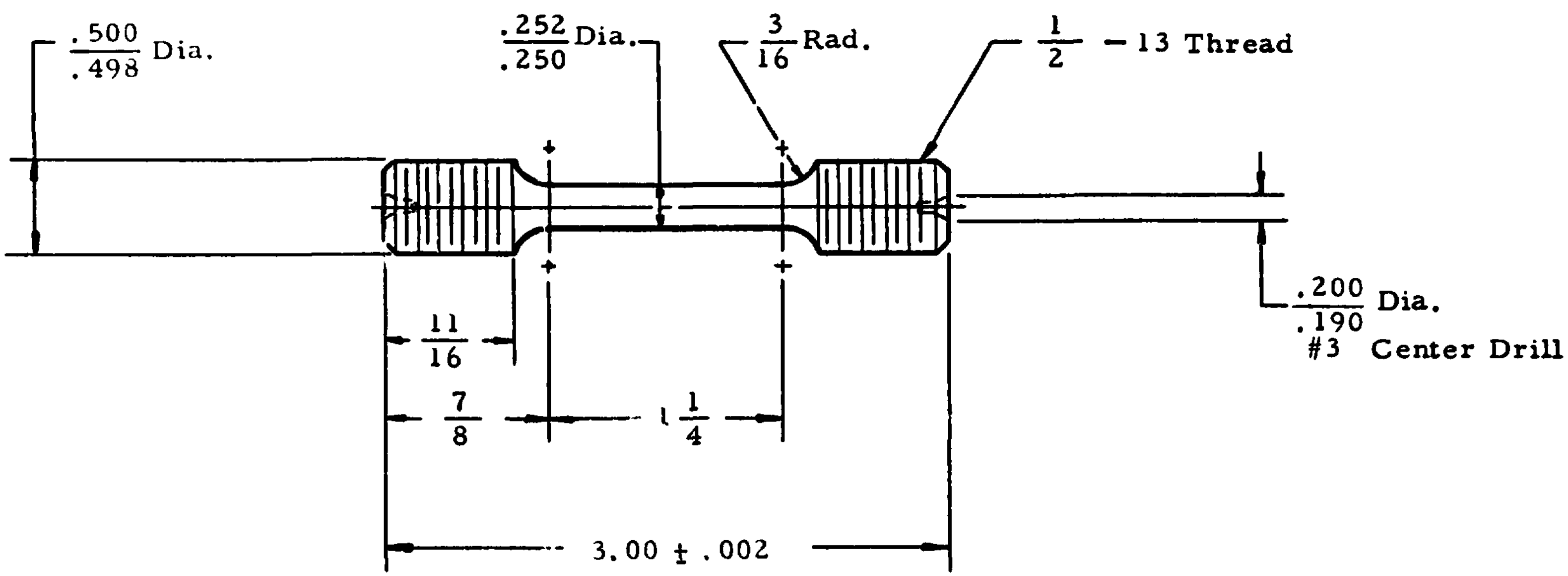


Figure 2 - SPECIMEN FOR TENSILE TESTING OF WROUGHT ALLOYS

(dimensions in inches)

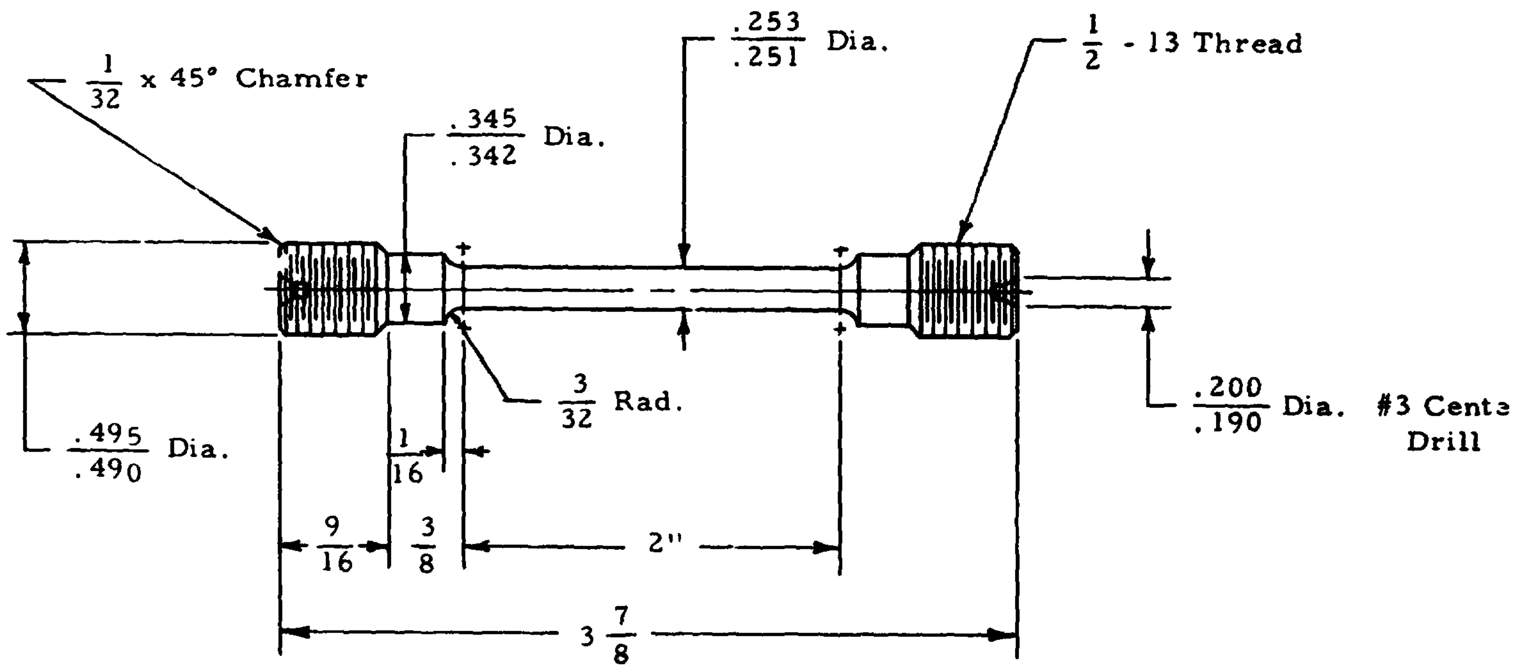


Figure 3 - SPECIMEN FOR CREEP RUPTURE TESTING

(dimensions in inches)

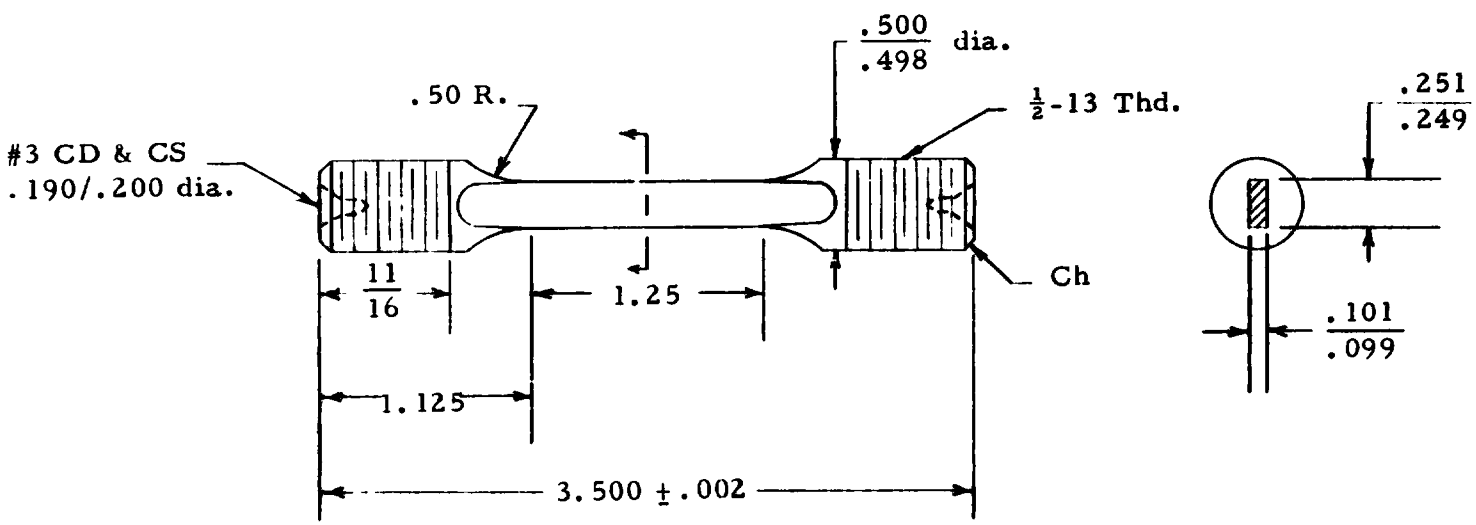


Figure 4 - SPECIMEN FOR DETERMINATION OF POISSON'S RATIO ON WROUGHT BAR ALLOYS

(dimensions in inches)

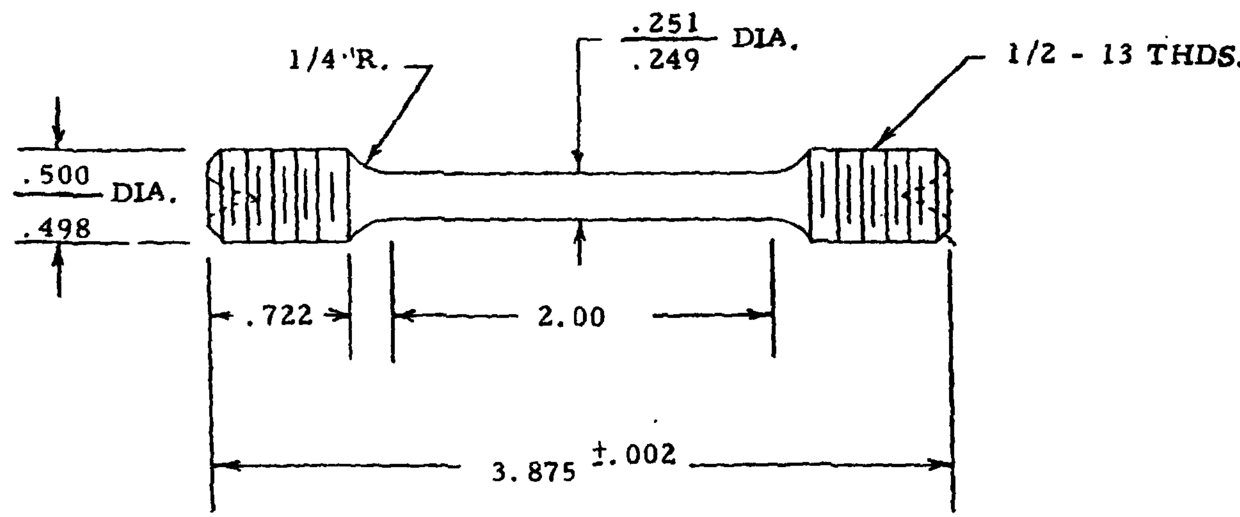


FIGURE 5 TENSILE SPECIMEN FOR CAST MATERIALS

(dimensions in inches)

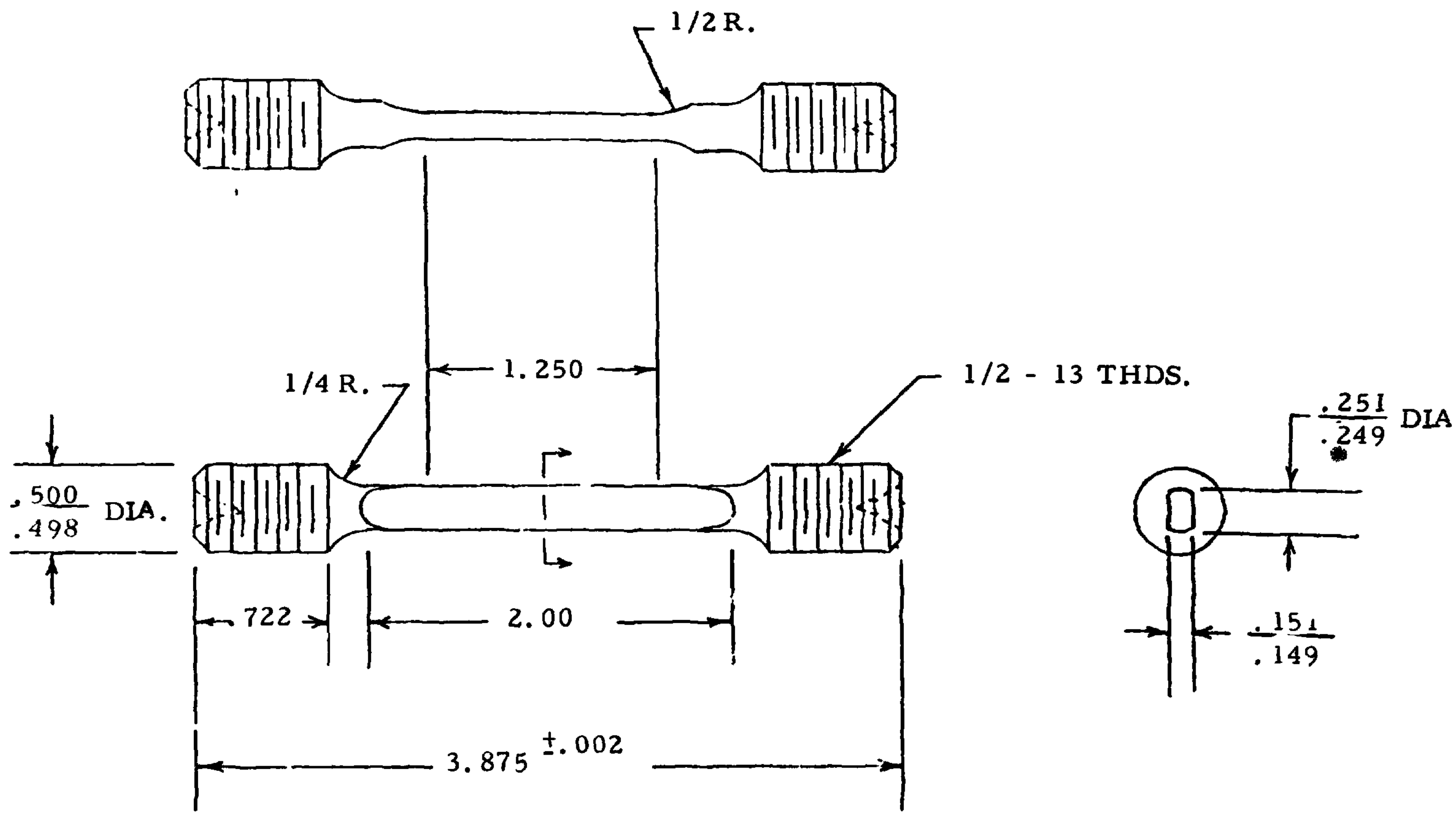


FIGURE 6 POISSON'S RATIO SPECIMEN FOR CAST MATERIALS

(dimensions in inches)

Test Procedures

A. General Test Procedures

All measurements of specimen dimensions were made using micrometers or calipers traceable to the National Bureau of Standards. Specimen diameters were measured to the nearest .0001 in.; specimen lengths were measured using caliper which read to the nearest .001 in. Extension measurements on tensile specimens were made using standard mechanical extensometers. Creep readings were made using both optical and electromechanical extensometers. Poisson's Ratio was determined using bonded strain gages verified per ASTM Method E251. Coated specimen diameters were measured prior to coating. The coating thickness was nominally 0.004 in. The reduction of area calculations were corrected for this thickness.

Elevated temperature tests were conducted in standard wire-wound resistance type furnaces. These furnaces were controlled by means of saturable core reactors which have a capability of maintaining temperatures to within ± 1°C. Temperature measurements on all tests through 871°C were made using type K thermocouple wire. Above this temperature, measurements were made using Pt-13%Rh thermocouple wire. Calibration of the thermocouple wire at Metcut routinely follows the procedures outlined in ASTM E 220.

The tensile machines and stress rupture frames at Metcut are verified to less than one percent error using methods detailed in ASTM Method E74. All test equipment proposed for use in this program is maintained in calibration to standards which are NBS traceable. Calibrations are performed at regularly scheduled intervals.

B. Tensile Test Procedures

Tensile tests to determine ultimate tensile strength, yield strengths (0.02 and 0.2% offset), percent elongation, percent reduction of area, strain hardening exponent, and true fracture strength were performed on a minimum of three (3) specimens at each of four (4) test temperatures -- room and three elevated temperatures.

B. Tensile Test Procedures (continued)

All testing was performed in one of two Baldwin universal hydraulic testing machines. Both machines are equipped with integral strain pacers and autographic load-strain recording systems.

Room temperature strain was monitored using a linear differential transformer extensometer which was clipped directly to the test section. At elevated temperatures, the motion was transferred to an LVDT extensometer through extension arms attached to the specimen gage section.

A strain rate of 0.005 cm/cm/min. was maintained through the 0.2% yield strength; thereafter, a controlled head rate of 0.125 cm/min. was used.

All strength calculations were based on loads and cross-sectional areas measured to the accuracies as described earlier. Ductility values were calculated using initial and final measurements as measured to these accuracies also.

Elongation measurements for the wrought alloys were made between gage marks (1 in. length) in the reduced section. For the cast materials, where such marks could adversely affect the test results, the elongation was measured using the overall specimen length. Percent elongation was then calculated using the adjusted reduced gage section length as described in ASTM E21.

The units of measurement in all cases were the U.S. customary system of units. Measurements were made in inches, loads in pounds and stresses calculated in pounds per inch.^{2} The SI units presented in the report are from conversions using NBS values.

The strain hardening exponent "n" was calucated using the power expression of the form,

$$\sigma = K \epsilon_p^n$$

where σ is true stress, ϵ_p is true plastic strain, K is the stress at $\epsilon_p = 1.0$, and n is the strain hardening exponent. The value of n is most accurately determined from tensile stress-strain data obtained in a tensile test using special high elongation extensometry.

B. Tensile Test Procedures (continued)

The extensometry used in normal stress-strain testing has higher precision, but will not permit measurement of plastic strains larger than a few percent. It is possible, however, to get a good estimate of the strain hardening exponent from load elongation data obtained in normal tensile testing. The limitation is that the true stress versus true plastic strain results occurs only over a limited range of strain. Plotting the available data points on log-log coordinates and taking the slope of the straight line between them yields an estimate of n which is useful for engineering comparisons of strain hardening behavior among various types of materials. This was the procedure used in this report.

The modulus of elasticity is another value which theoretically can be calculated from a stress-strain plot of a tensile test. In reality, however, the load and strain magnifications necessary to produce a complete tensile curve are not necessarily the ranges one would choose for measuring modulus of elasticity. The modulus of elasticity was obtained with the same specimen as that used for tensile testing, by loading several times to loads well below the proportional limit at suitable load and strain magnification ranges.

All tensile data is reported in both SI and the U.S. customary systems of units.

C. Poisson's Ratio

Tension specimens having a rectangular cross-section per Figures 4 and 6 were used for this determination. Strain gages were bonded on the .250 in. wide test surface at mid-span. The gages were 90° rosettes with 0.100 in. grids. Gages were mounted on opposite faces to compensate for any bending which occurred during testing.

Static loads were applied in approximately ten equal steps with the maximum stress on the specimen being held well below the proportional limit. Strain measurements were made at the individual step loads while loading and unloading the specimen. The entire cycle was performed a total of three times on each specimen.

C. Poisson's Ratio (continued)

The loads were applied while the specimen was mounted in a stress rupture frame and were either direct dead weight loaded or lever loaded, depending on the maximum stress to which the specimen was subjected. The load-strain values thus obtained were analyzed numerically to produce the individual and sample mean (average) value for Poisson's Ratio and both 90 and 95 percent confidence limits. The values so analyzed were the individual values as measured. Poisson's Ratio was not determined using the slope of the plotted values.

D. Creep Rupture Procedures

Creep rupture testing was performed using procedures as detailed in ASTM E 139 on specimens having a 2 in. gage length (Figure 3).

Readings were made using optical creep cathetometers for the longer time and higher temperature tests. A mechanical creep system was used to obtain maximum data points for the shorter time tests, since it gave 24 hour per day coverage of these readings.

The data so generated, assisted by the employment of a variety of numerical analysis procedures, yielded the following:

(1) A plotted curve of creep strain versus time

(2) The time to the onset of third-stage creep

(3) The time to achieve 1% creep strain

(4) The minimum creep rate

(5) The time to rupture

(6) The percent elongation at failure

(7) The percent reduction of area at failure

From the minimum of five (5) tests at each of three (3) test temperatures, and using the appropriate isothermal and parametric relationships, the stress levels to produce rupture lives of 100, 300, and 1000 hours were determined.

TEST RESULTS

Material 1: 7075-T6 Aluminum

This high strength, heat treatable aluminum alloy was supplied as fully heat treated, wrought bar stock by NASA-Lewis Research Center. Nominal composition of this alloy is as follows:

Zinc	5.1 - 6.1%
Magnesium	2.1 - 2.9
Copper	1.2 - 2.0
Chromium	0.18 - 0.35
Manganese	0.30 max.
Iron	0.50 max.
Silicon	0.40 max.
Titanium	0.20 max.
Other Impurities, each	0.05 max.
Other Impurities, total	0.15 max.
Aluminum	Balance

Tensile results are presented as Table I with samples of the load-strain curves compiled as Figure 7.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	Confidence Limits 95%
1-P1	-0.3244	±.0018	±.0022
1-P2	-0.3190	±.0030	±.0036
1-P3	-0.3285	±.0021	±.0026

Creep rupture data are presented in Table II. Creep deformation versus time values are plotted in Figures 8, 9, and 10. Isothermal plots of the rupture life data appear as Figure 11.

Material 1: 7075-T6 Aluminum (continued)

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

		Stress to Produce Failure at					
		100 hours		300 hours		1000 hours	
(°C)	(°F)	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
121	250	365.4	53.0	324.1	47.0	298.6	42.0
149	300	255.1	37.0	206.8	30.0	165.5	24.0
177	350	151.7	22.0	124.1	18.0	103.4	15.0

TABLE I
Tensile Properties of 7075-T6 Aluminum

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
1-T1	21	70	561.9	81.5	486.1	70.5	510.9	74.1	----	---	0.06	16	33.7
1-T5			570.9	82.8	461.3	66.9	515.7	74.8	----	---	0.12	16.5	35.7
1-T9			578.5	83.9	470.2	68.2	520.6	75.5	----	---	0.07	16.5	31.4
1-T2	121	250	466.8	67.7	413.0	59.9	448.9	65.1	----	---	0.04	24.5	54.9
1-T6			464.0	67.3	390.2	56.6	437.8	63.5	----	---	0.04	24.5	52.3
1-T10			477.1	69.2	393.0	57.0	452.3	65.6	----	---	0.03	24.5	57.2
1-T3	149	300	415.8	60.3	352.3	51.1	399.9	58.0	----	---	0.04	27.5	56.4
1-T8			413.0	59.9	359.2	52.1	388.9	56.4	----	---	0.03	25	58.1
1-T11			418.5	60.7	365.4	53.0	393.0	57.0	----	---	----	26.8	60.8
1-T4	177	350	372.3	54.0	315.1	45.7	354.4	51.4	----	---	0.03	22	62.5
1-T12			381.3	55.3	284.8	41.3	360.2	52.2	----	---	0.03	25	64.8
1-T13			369.6	53.6	297.2	43.1	357.8	51.9	----	---	----	20.5	59.3

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	72.4	10.5
121	250	70.3	10.2
149	300	64.1	9.3
177	350	63.4	9.2

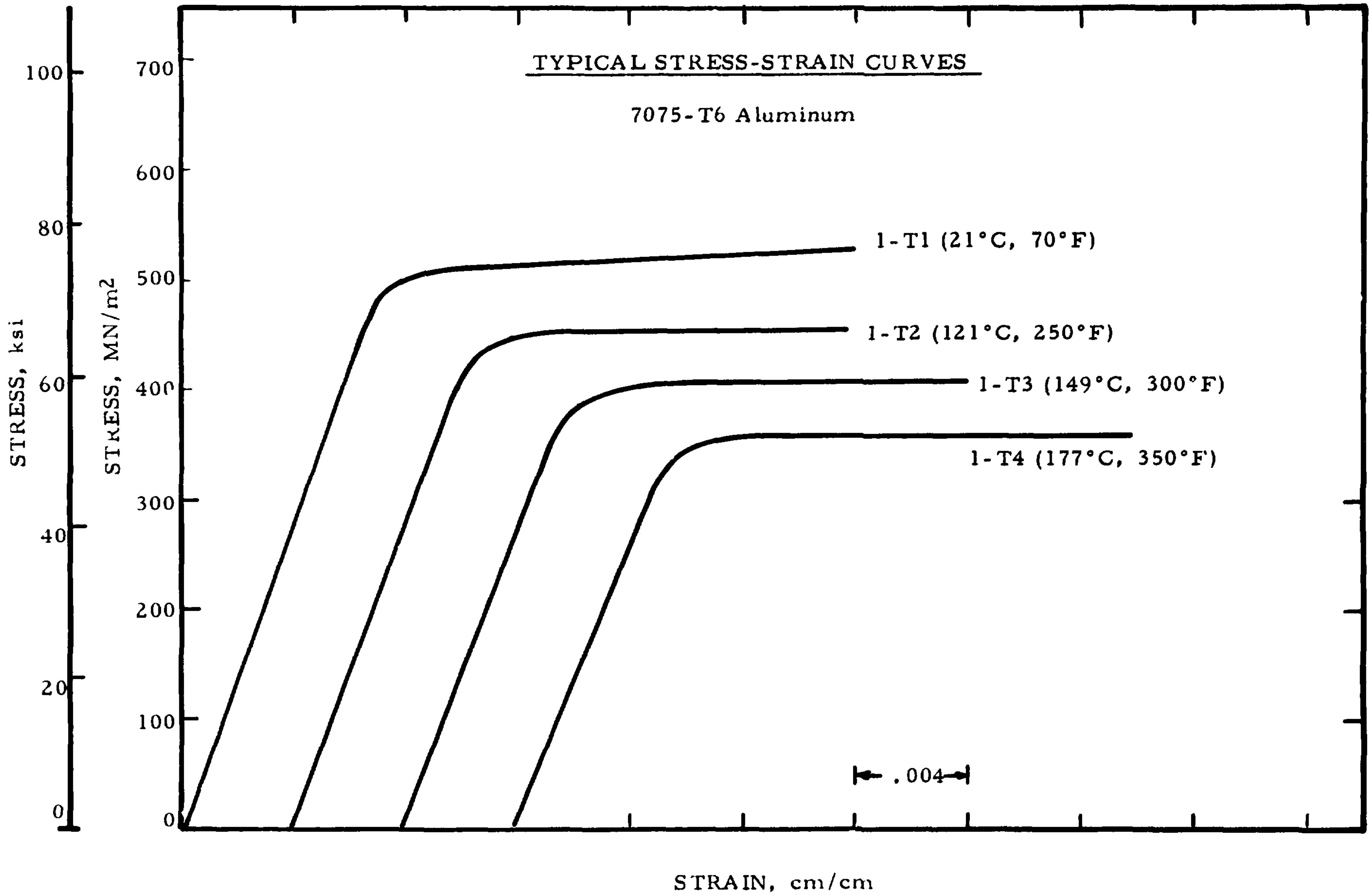

TYPICAL STRESS-STRAIN CURVES
7075-T6 Aluminum
1-T1 (21°C, 70°F)
1-T2 (121°C, 250°F)
1-T3 (149°C, 300°F)
1-T4 (177°C, 350°F)
.004
STRESS, ksi
100
80
60
40
20
0
STRESS, MN/m2
700
600
500
400
300
200
100
0
STRAIN, cm/cm

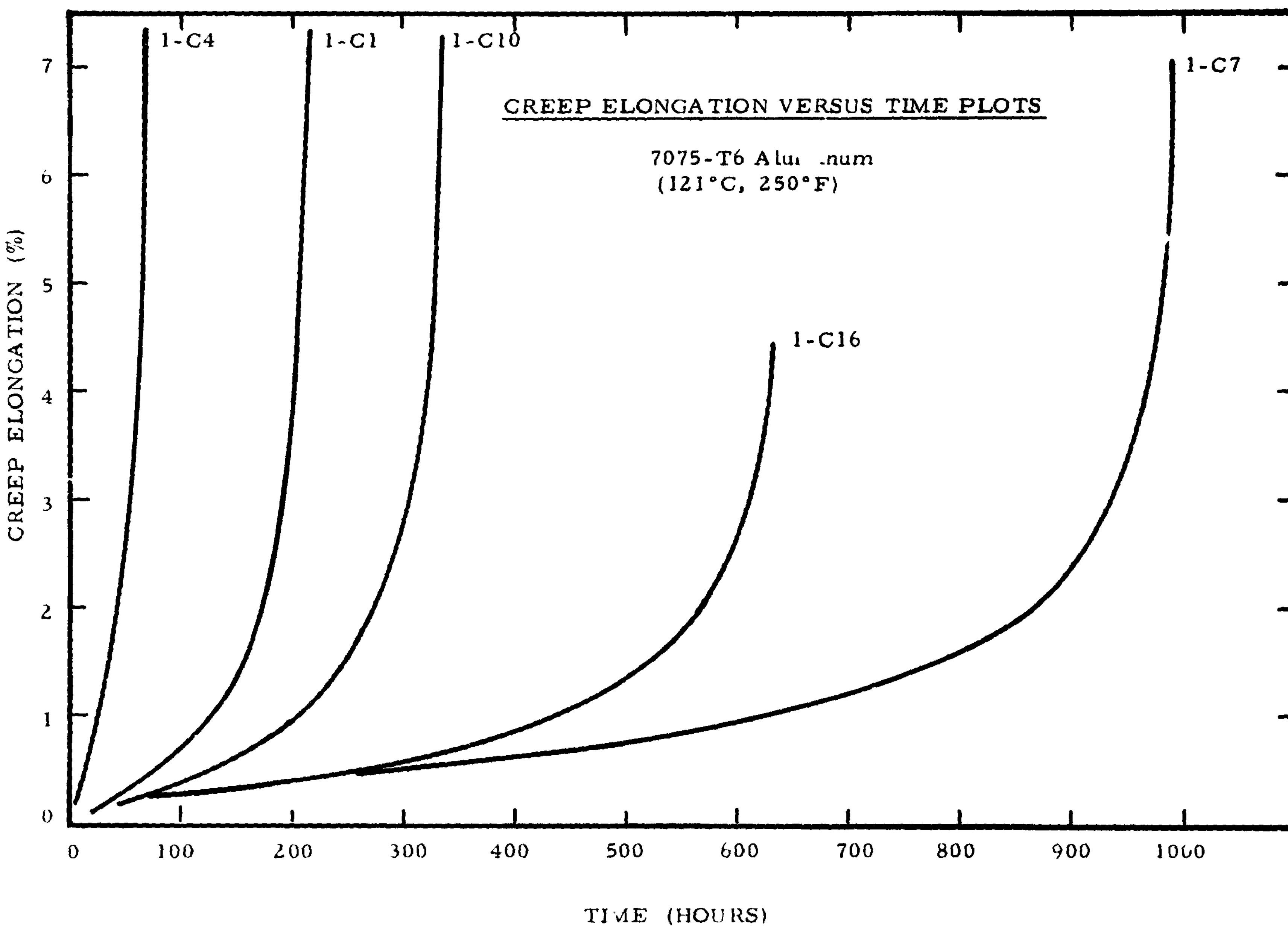
Figure 7

TABLE II

Creep Rupture Properties of 7075-T6 Aluminum

Specimen Number	Temp. °C	Temp. °F	Stress MN/m^2	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
1-C4	121	250	379.2	55.0	.0350	33	25	70.0	12.6	54.8
1-C1			344.7	50.0	.0067	90	124	214.1	11.3	56.4
1-C10			331.0	48.0	.0040	130	200	334.2	11.4	56.8
1-C13			303.4	44.0	--	--	--	(a)	--	--
1-C16			303.4	44.0	.0015	320	440	634.2	8.5	54.1
1-C7			289.6	42.0	.0012	650	640	989.7	11.0	58.1
1-C2	149	300	241.3	35.0	.0048	70	110	136.0	10.3	63.0
1-C5			220.6	32.0	.0040	150	190	239.3	12.0	66.8
1-C8			175.8	25.5	.0012	435	580	695.0	11.6	70.6
1-C11			172.4	25.0	.0010	310	620	734.2	10.6	69.0
1-C14			162.0	23.5	.0009	770	810	1103.3	13.0	71.7
1-C3	177	350	151.7	22.0	.0088	45	75	89.6	14.1	75.0
1-C6			127.6	18.5	.0029	205	247	284.1	23.7	76.2
1-C15			117.2	17.0	.0012	315	375	443.8	14.6	78.5
1-C9			106.9	15.5	.0008	530	680	739.6	14.6	81.1
1-C12			100.0	14.5	.0005	850	1030	1195.0	15.0	81.0

(a) Controller malfunction; specimen to 1600°F



CREEP ELONGATION VERSUS TIME PLOTS
7075-T6 Alu .num
(121°C, 250°F)
1-C4
1-C1
1-C10
1-C16
1-C7
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 8

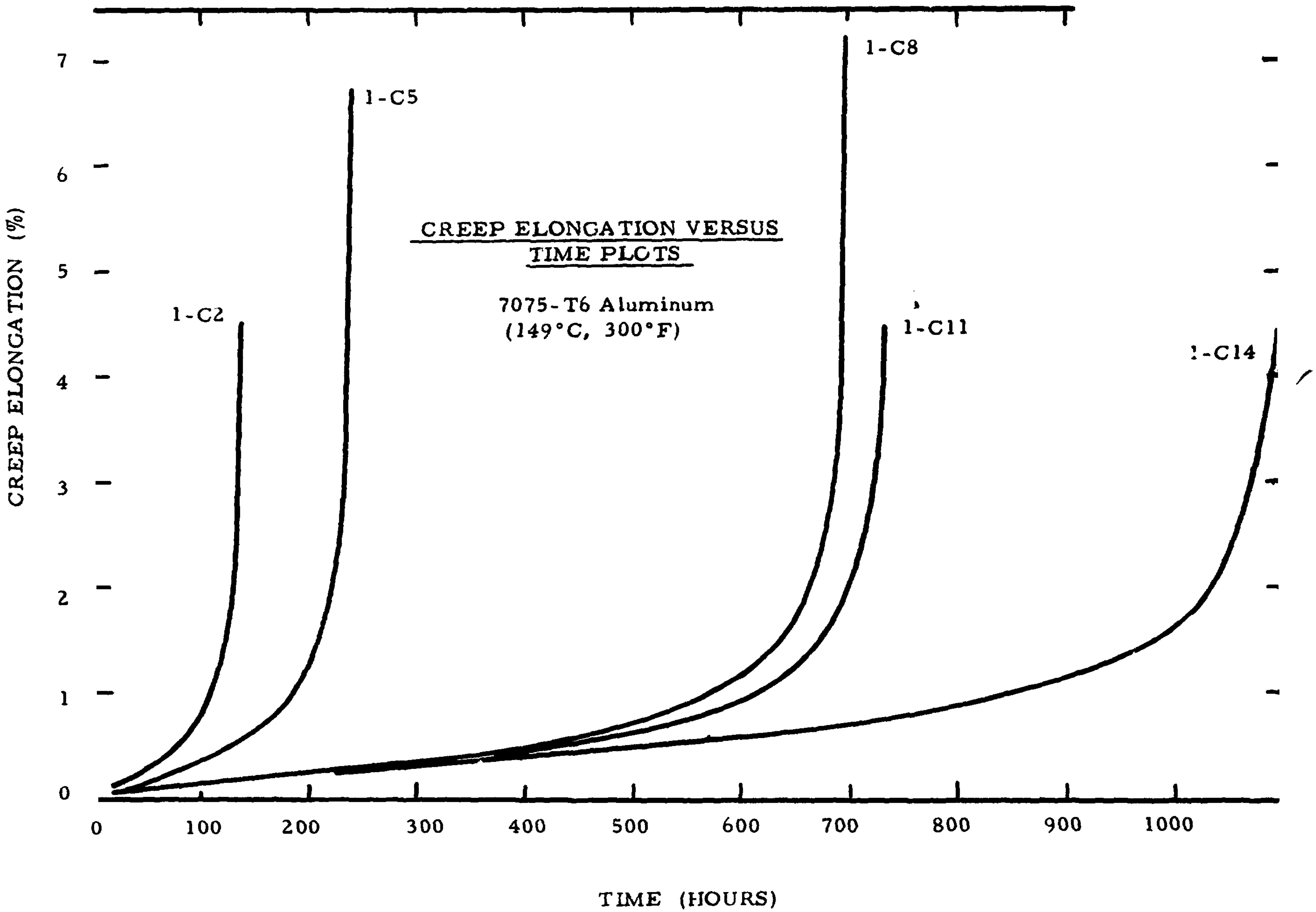

CREEP ELONGATION VERSUS TIME PLOTS
7075-T6 Aluminum
(149°C, 300°F)
1-C2
1-C5
1-C8
1-C11
1-C14
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 9

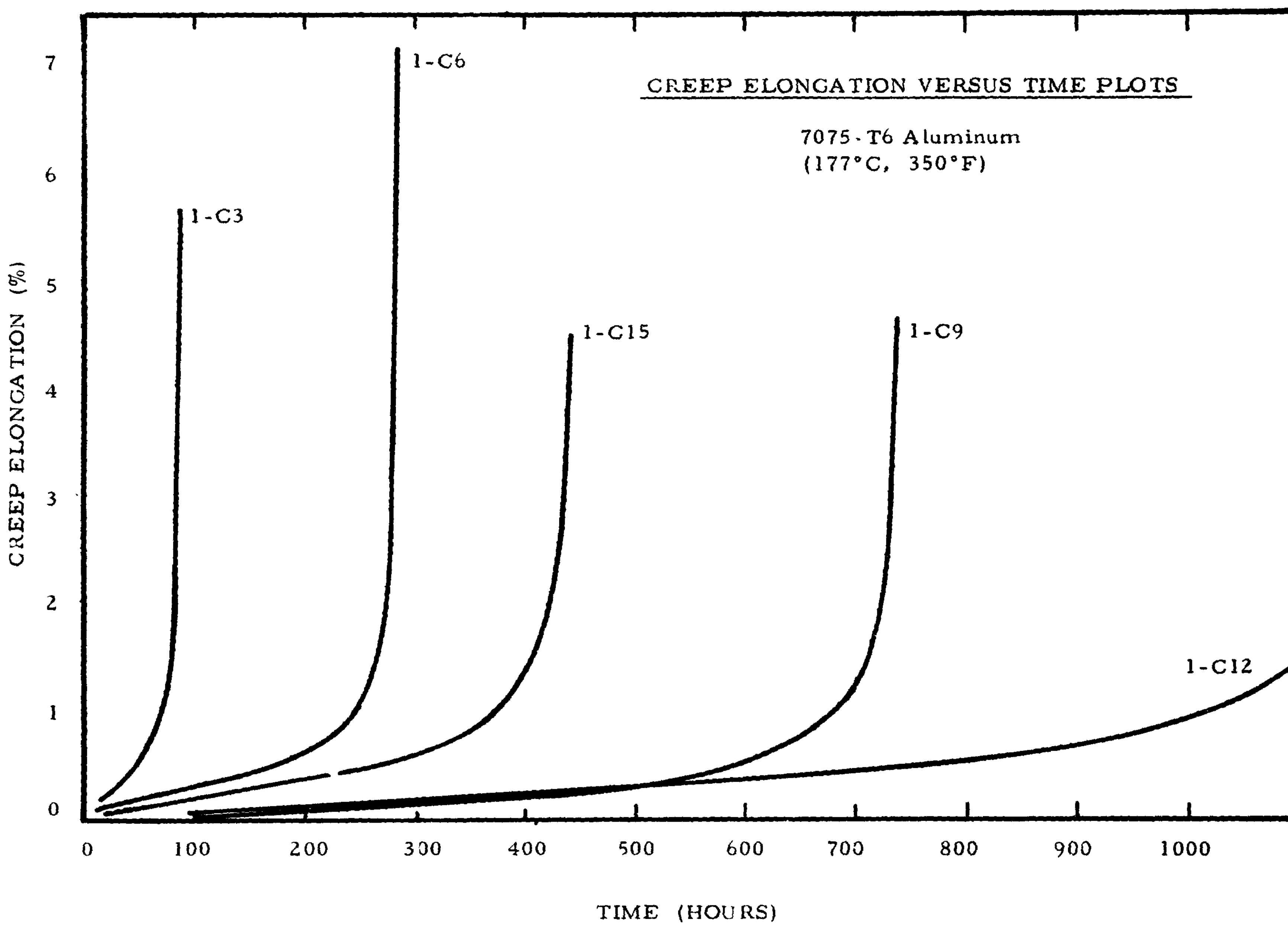
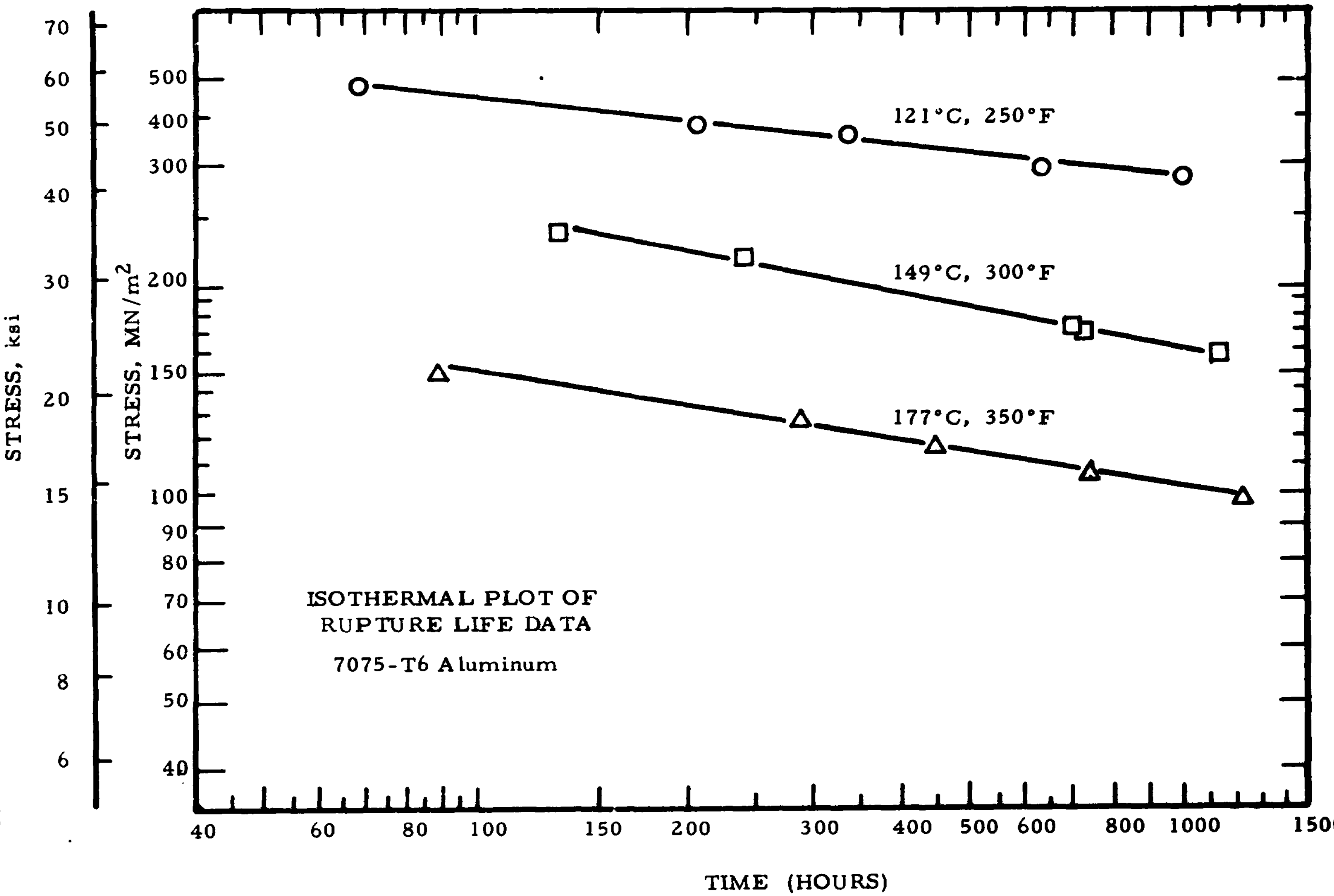

CREEP ELONGATION VERSUS TIME PLOTS
7075-T6 Aluminum
(177°C, 350°F)
1-C3
1-C6
1-C15
1-C9
1-C12
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 10



ISOTHERMAL PLOT OF RUPTURE LIFE DATA
7075-T6 Aluminum
121°C, 250°F
149°C, 300°F
177°C, 350°F
STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
40
60
80
100
150
200
300
400
500
600
800
1000
1500

Figure 11

TEST RESULTS (continued)

Material 2: Amzirc Copper

This copper zirconium alloy, developed to produce good strength levels at high temperature, was supplied as fully processed (half-hard) wrought bar stock by NASA-Lewis Research Center.

Chemical composition of this heat of material (supplied by NASA-Lewis Research Center) is as follows:

Iron	0.002%
Nickel	0.002
Zirconium	0.18
Copper	Balance

Tensile results are presented as Table III with samples of the load-strain curves compiled as Figure 12.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	95%
2-P2	-0.3656	±.0028	±.0034
2-P3	-0.3623	±.0027	±.0032
2-P[illegible]	-0.3570	±.0013	±.0016

Creep rupture data are presented in Table IV. Creep deformation versus time values are plotted in Figures 13, 14, and 15. Isothermal plots of the rupture life data appear as Figure 16.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hrs.		300 hrs.		1000 hrs.	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
482	900	48.3	7.0	37.9	5.5	31.0	4.5
538	1000	29.6	4.3	22.8	3.3	16.5	2.4
593	1100	17.9	2.6	13.8	2.0	10.3	1.5

TABLE III

Tensile Properties of Amzirc Copper

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
2-T1	21	70	352.3	51.1	224.8	32.6	313.7	45.5	--	--	0.06	22.0	78.7
2-T5			357.2	51.8	251.0	36.4	313.7	45.5	--	--	0.04	22.0	81.5
2-T9			351.6	51.0	226.1	32.8	310.0	44.9	--	--	0.05	23.0	80.8
2-T2	482	900	198.6	28.8	155.8	22.6	195.1	28.3	--	--	0.05	21.0	85.6
2-T6			193.1	28.0	126.2	18.3	186.2	27.0	--	--	0.03	22.0	84.4
2-T10			199.3	28.9	128.2	18.6	177.2	25.7	--	--	0.02	25.5	84.5
2-T3	538	1000	122.7	17.8	64.1	9.3	113.1	16.4	--	--	0.03	32.0	89.5
2-T7			120.7	17.5	57.2	8.3	109.6	15.9	--	--	0.03	36.0	92.0
2-T11			113.1	16.4	51.0	7.4	6.5	14.0	--	--	0.04	32.0	91.5
2-T4	593	1100	56.5	8.2	21.4	3.1	26.9	3.9	--	--	0.16	78.7	95.7
2-T8			57.9	8.4	23.4	3.4	31.7	4.6	--	4.4	0.26	72.6	95.4
2-T12			(a)	(a)	--	--	--	--	--	--	--	--	--
2-C20			66.9	9.7	26.9	3.[illegible]	51.0	7.4	--	2.8	0.10	29.9	94.3

(a) Defective test; specimen was losing temperature during test

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	119.3	17.3
482	900	82.0	11.9
538	1000	59.3	8.6
593	1100	50.3	7.3

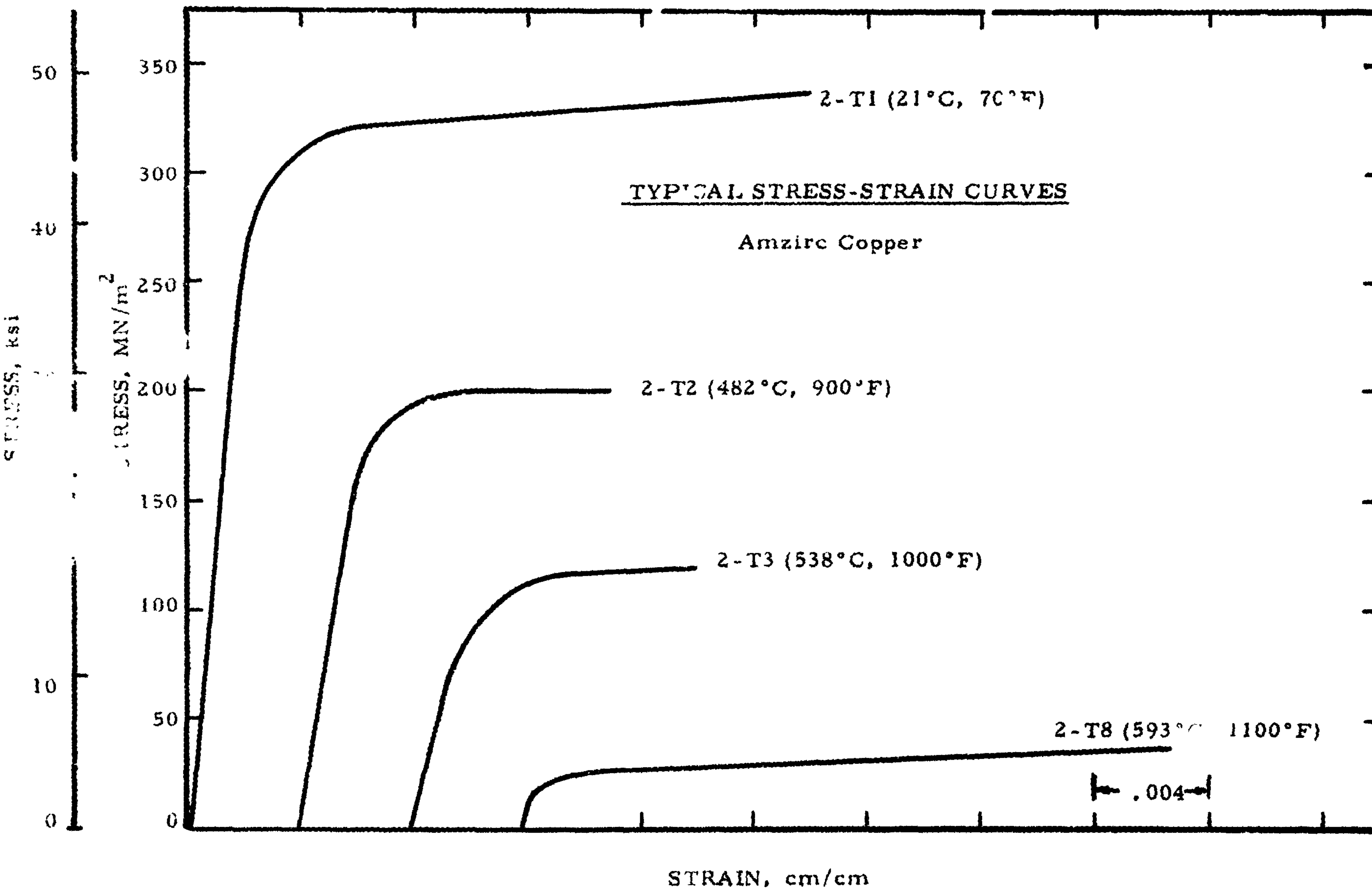

TYPICAL STRESS-STRAIN CURVES
Amzirc Copper
2-T1 (21°C,
2-T2 (482°C, 900°F)
2-T3 (538°C, 1000°F)
2-T8
1100°F)
.004
STRESS, ksi
STRESS, MN/m²
STRAIN, cm/cm
0
10
40
50
50
100
150
200
250
300
350

Figure 12

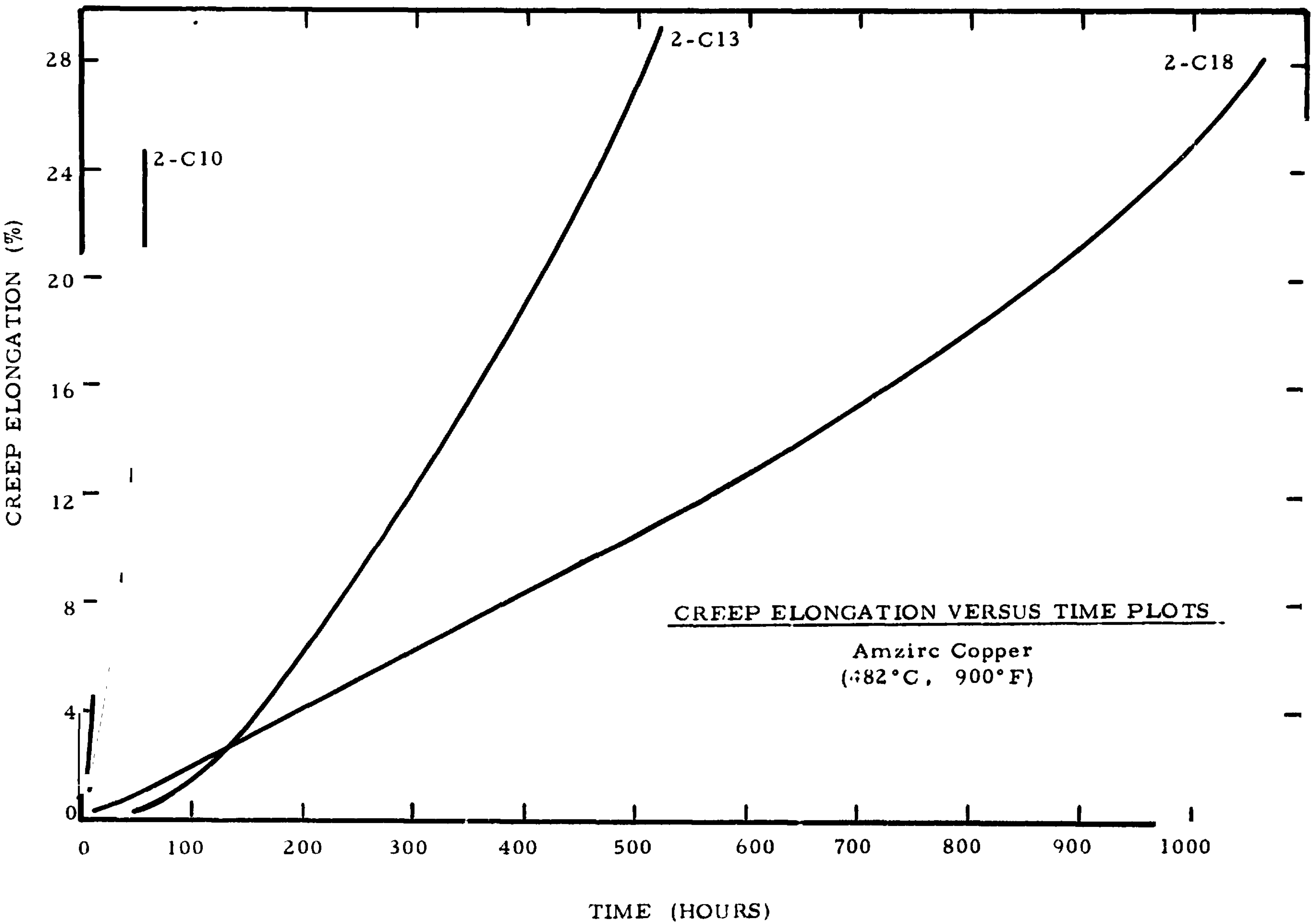
TABLE IV

Creep Rupture Properties of Amzirc Copper

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
2-C1	482	900	172.4	25.0	--	--	0.1	0.2	13.3	83.7
2-C4			124.1	18.0	.205	5.0	4.5	10.9	16.1	80.9
2-C7			82.7	12.0	.195	3.3	4.3	13.2	37.0	87.1
2-C10			55.2	8.0	.110	23.0	8.6	73.5	64.6	81.7
2-C13			34.5	5.0	.009	130.0	93.0	641.8	48.4	47.9
2-C18			29.0	4.2	.021	580.0	79.0	1208.7	43.4	41.6
2-C2	538	1000	82.7	12.0	--	--	--	(a)	57.8	94.3
2-C5			48.3	7.0	1.09	1.2	0.8	21.3	54.0	86.1
2-C8			34.5	5.0	.646	--	2.2	54.0	52.4	66.2
2-C11			27.6	4.0	.240	54.0	1.0	132.0	63.6	56.3
2-C14			20.7	3.0	.066	145.0	14.0	421.6	51.4	40.1
2-C17			16.5	2.4	.024	720.0	34.0	1012.7	32.2	24.8
2-C9	593	1100	19.3	2.8	.317	48.0	1.5	87.6	56.8	51.1
2-C15			16.5	2.4	.168	80.0	5.0	162.4	47.7	43.9
2-C6			13.8	2.0	.109	125.0	8.0	281.2	(b)	--
2-C12			11.7	1.7	--	--	--	(c)	--	--
2-C16			11.7	1.7	.044	270.0	18.0	572.5	42.5	39.5
2-C3			10.3	1.5	.032	650.0	28.0	966.9	37.1	52.1

(a) Specimen failed in loading
(b) Specimen bent while being removed from furnace; cannot measure ductility
(c) Specimen loaded at wrong stress level; test void

Temperature		Stress to Produce Failure at					
		100 hr.		300 hr.		1000 hr.	
°C	°F	MN/m²	ksi	MN/m²	ksi	MN/m²	ksi
482	900	48.3	7.0	37.9	5.5	31.0	4.5
538	1000	29.6	4.3	22.8	3.3	16.5	2.4
593	1100	17.9	2.6	13.8	2.0	10.3	1.5



2-C13
2-C18
2-C10
28
24
20
16
12
8
4
0
CREEP ELONGATION (%)
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)
CREEP ELONGATION VERSUS TIME PLOTS
Amzirc Copper
(482°C, 900°F)

Figure 13

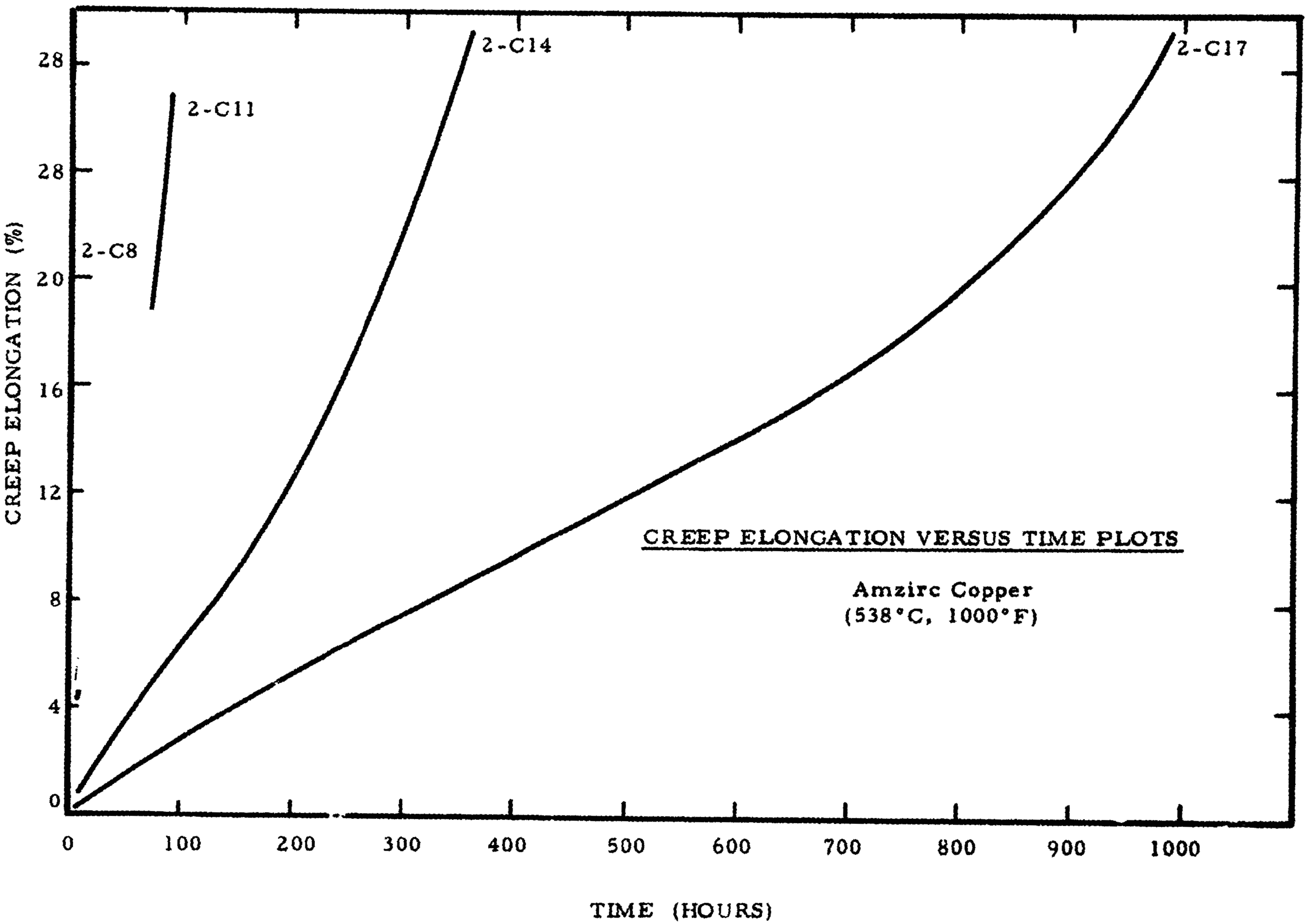

CREEP ELONGATION VERSUS TIME PLOTS
Amzirc Copper
(538°C, 1000°F)
2-C8
2-C11
2-C14
2-C17
CREEP ELONGATION (%)
TIME (HOURS)
0
4
8
12
16
20
28
28
0
100
200
300
400
500
600
700
800
900
1000

Figure 14

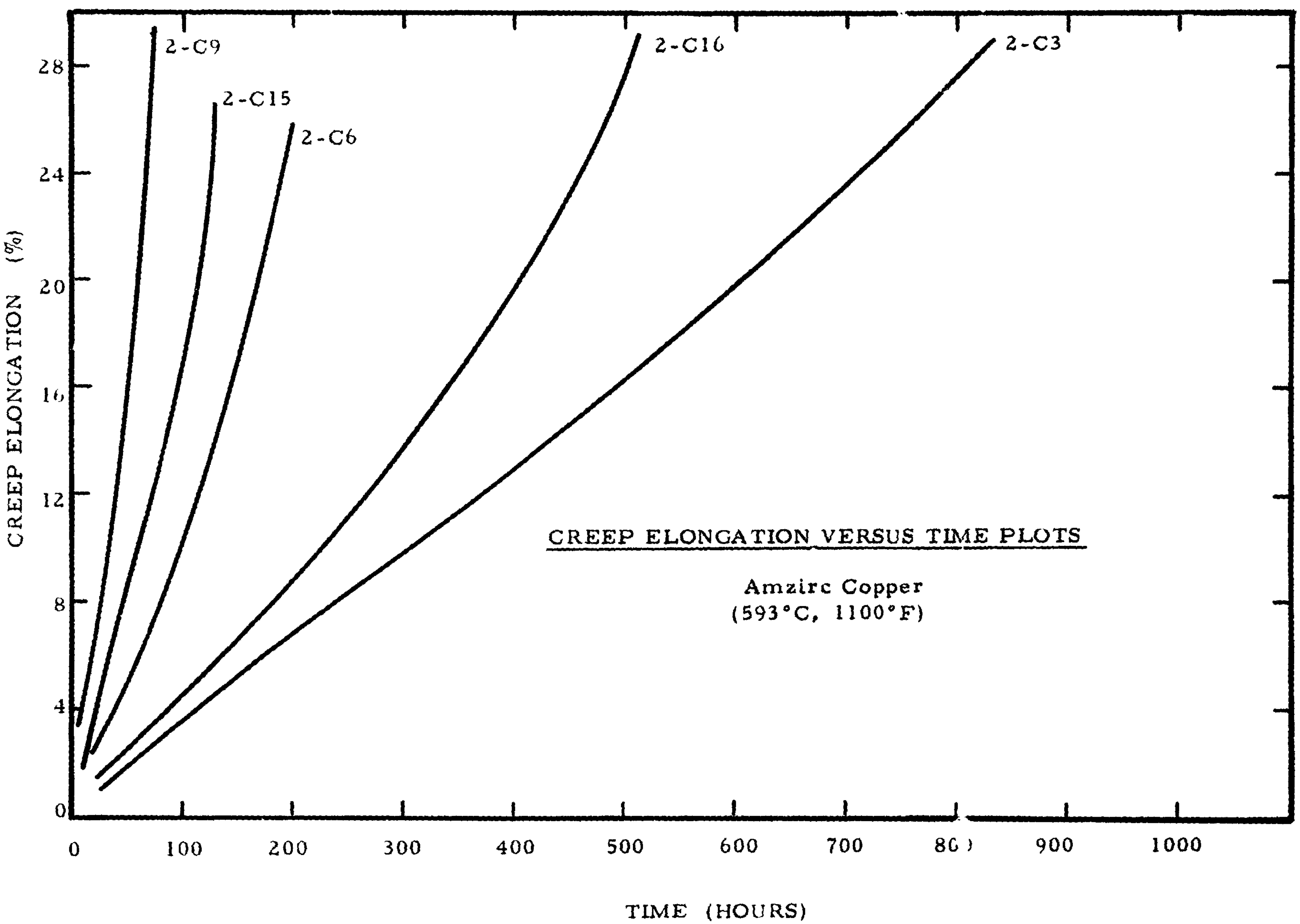

CREEP ELONGATION VERSUS TIME PLOTS
Amzirc Copper
(593°C, 1100°F)
2-C9
2-C15
2-C6
2-C16
2-C3
CREEP ELONGATION (%)
TIME (HOURS)
0
4
8
12
16
20
24
28
100
200
300
400
500
600
700
900
1000

Figure 15

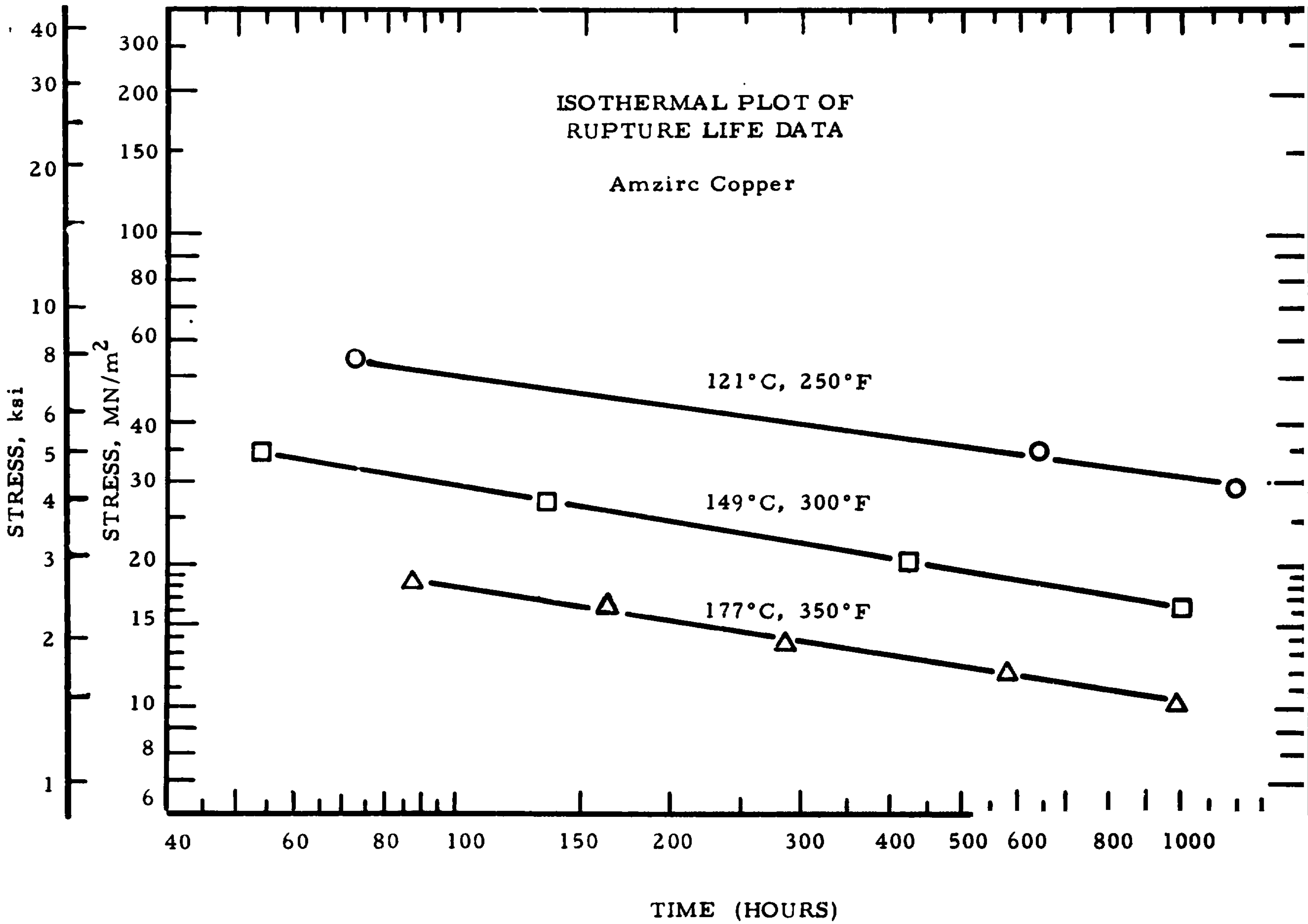

ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
Amzirc Copper
121°C, 250°F
149°C, 300°F
177°C, 350°F
STRESS, ksi
STRESS, MN/m2
TIME (HOURS)
40
30
20
10
8
6
5
4
3
2
1
300
200
150
100
80
60
40
30
20
15
10
8
6
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 16

Material 3: Titanium-6Al-2Sn-4Zr-2Mo

This super-alpha titanium alloy, developed to produce a good combination of tensile, creep, toughness, and stability to 1050°F was supplied as fully processed wrought bar stock by NASA-Lewis Research Center.

Nominal composition of this alloy is as follows:

Aluminum	5.5 - 6.5%
Tin	1.8 - 2.2
Zirconium	3.6 - 4.4
Molybdenum	1.8 - 2.2
Iron	0.25 max.
Carbon	0.05 max.
Nitrogen	0.05 max.
Hydrogen	0.0150 max.
Oxygen	0.12 max.
Titanium	Balance

Tensile results are presented as Table V with samples of the load-strain curves compiled as Figure 17.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	95%
3-P1	-0.3017	±.0012	±.0015
3-P2	-0.3076	±.0026	±.0031
3-P3	-0.3115	±.0016	±.0020

Creep rupture data are presented in Table VI. Creep deformation versus time values are plotted in Figures 18, 19, and 20. Isothermal plots of the rupture life data appear as Figure 21.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

TEST RESULTS (continued)

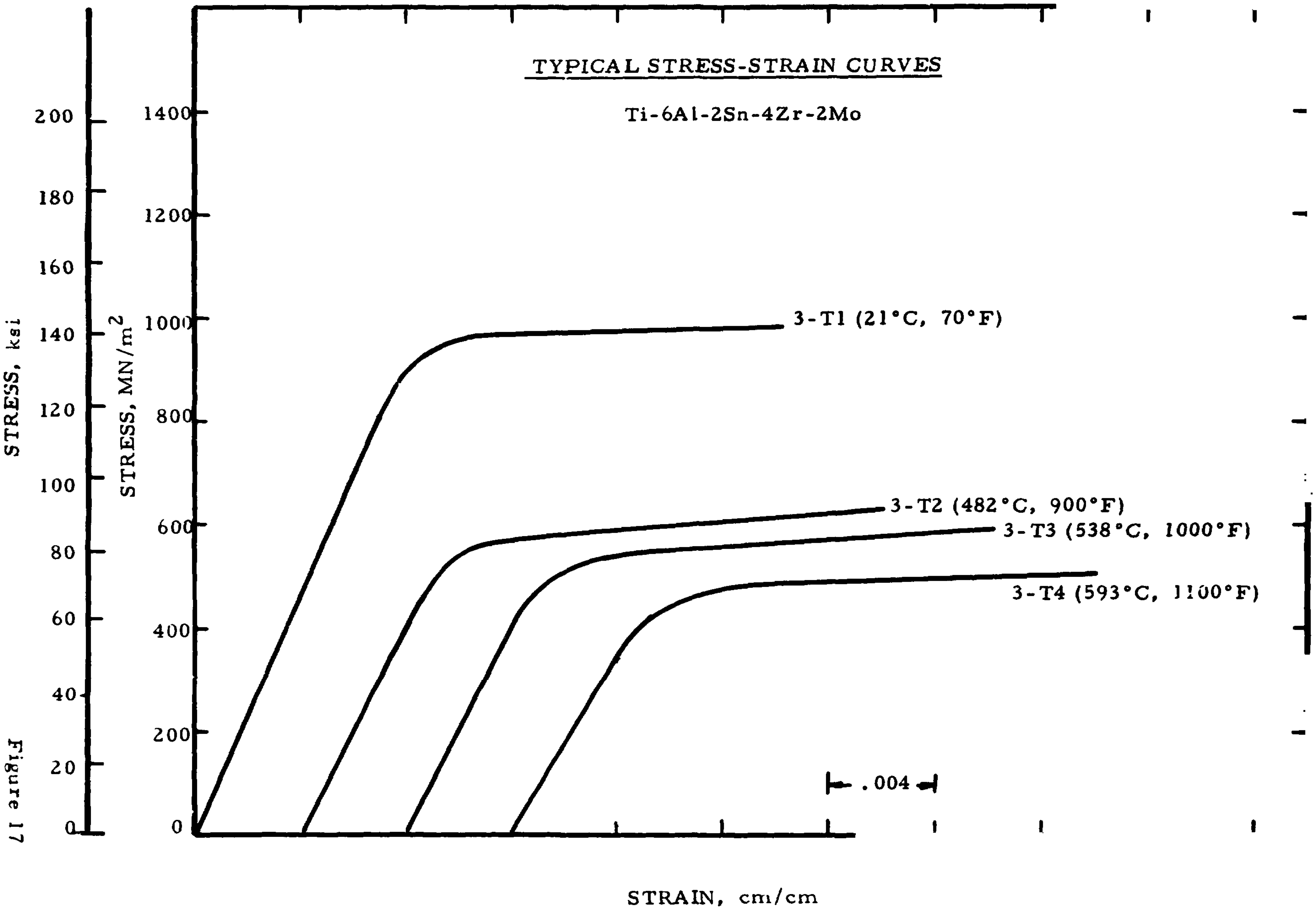
Material 3: Titanium-6Al-2Sn-4Zr-2Mo (continued)

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
482	900	620.5	90.0	579.2	84.0	254.0	76.0
538	1000	399.9	58.0	324.1	47.0	258.6	37.5
593	1100	227.5	33.0	162.0	23.5	113.8	16.5

TABLE V
Tensile Properties of Ti-6Al-2Sn-4Zr-2Mo

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
3-T1	21	70	1014.9	147.2	896.3	130.0	967.3	140.3	----	---	0.03	19	42.7
3-T5			1026.6	148.9	859.8	124.7	957.0	138.8	----	---	0.02	18	41.6
3-T9			1017.0	147.5	815.7	118.3	947.3	137.4	----	---	0.06	20	46.3
3-T2	482	900	738.4	107.1	506.8	73.5	564.0	81.8	----	---	0.13	22	51.7
3-T6			737.1	106.9	478.5	69.4	558.5	81.0	----	---	0.13	21.5	52.2
3-T10			723.3	104.9	437.1	63.4	562.6	81.6	----	---	0.11	24	60.5
3-T3	538	1000	677.1	98.2	428.9	62.2	532.3	77.2	----	---	0.09	29	56.4
3-T7			679.8	98.6	457.8	66.4	535.7	77.7	----	---	0.11	28	60.2
3-T11			666.0	96.6	420.6	61.0	528.1	76.6	----	---	0.11	27.5	65.6
3-T4	593	1100	570.9	82.8	370.3	53.7	472.3	68.5	----	---	0.04	31	65.7
3-T8			586.7	85.1	312.3	45.3	483.3	70.1	----	---	0.08	35	66.5
3-T12			576.4	83.6	337.2	48.9	468.8	68.0	----	---	0.09	34.5	68.2

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	117.9	17.1
482	900	99.3	14.4
538	1000	90.3	13.1
593	1100	84.8	12.3



TYPICAL STRESS-STRAIN CURVES
Ti-6Al-2Sn-4Zr-2Mo
STRESS, ksi
STRESS, MN/m^2
STRAIN, cm/cm
3-T1 (21°C, 70°F)
3-T2 (482°C, 900°F)
3-T3 (538°C, 1000°F)
3-T4 (593°C, 1100°F)
.004
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400

Figure 17

TABLE VI

Creep Rupture Properties of Ti-6Al-2Sn-4Zr-2Mo

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
3-C4	482	900	620.5	90.0	.104	52	(a)	87.4	22.0	57.6
3-C13			606.7	88.0	.0507	87	(a)	186.2	24.2	54.8
3-C10			586.1	85.0	.0215	175	0.3	304.1	22.2	54.1
3-C1			551.6	80.0	.0236	200	12	464.1	28.0	54.6
3-C7			524.0	76.0	.0055	370	70	1070.3	22.8	54.7
3-C2	538	1000	517.1	75.0	.382	8.5	2	24.7	39.8	67.0
3-C5			482.6	70.0	.227	10.5	3.5	37.3	27.9	59.0
3-C8			379.2	55.0	.0292	26	27	137.9	27.6	58.8
3-C11			331.0	48.0	.0201	110	54	349.3	63.4	60.6
3-C14			275.8	40.0	.0088	150	103	539.7	27.8	65.2
3-C16			265.4	38.5	.0068	137	140	899.1	47.6	67.8
3-C3	593	1100	310.3	45.0	.285	6.5	3.5	24.7	39.8	67.0
3-C6			241.3	35.0	.160	(b)	(b)	89.9	40.0	70.5
3-C9			199.9	29.0	.0704	54	14	163.5	71.9	75.2
3-C12			158.6	23.0	.0469	52	24	337.7	72.5	81.1
3-C15			113.8	16.5	.0211	225	45	976.1	82.7	95.6

(a) More than 1.0% plastic deformation occurred on loading

(b) Insufficient data to obtain this value

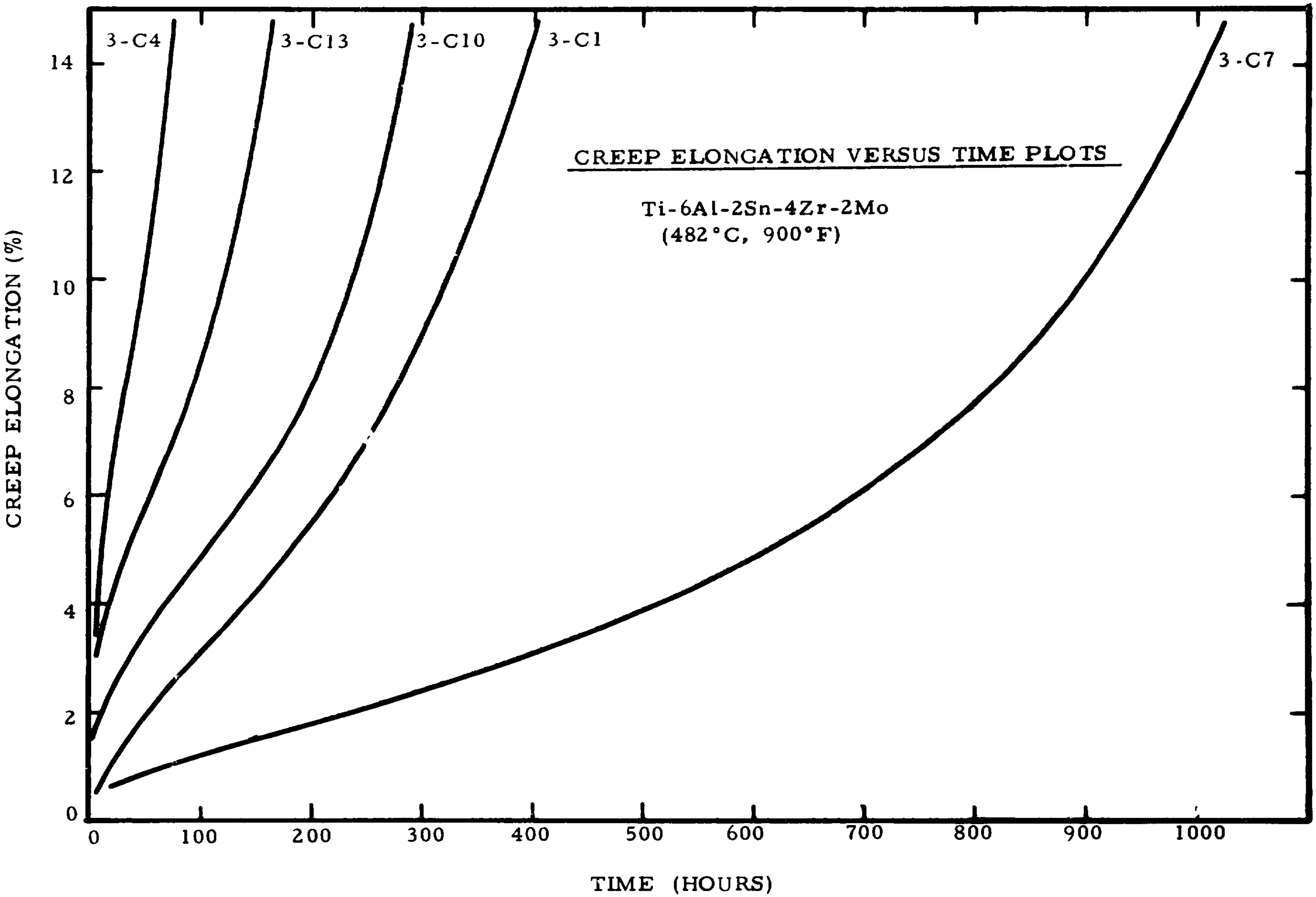

CREEP ELONGATION VERSUS TIME PLOTS
Ti-6Al-2Sn-4Zr-2Mo
(482°C, 900°F)
3-C4
3-C13
3-C10
3-C1
3-C7
CREEP ELONGATION (%)
0
2
4
6
8
10
12
14
TIME (HOURS)
0
100
200
300
400
500
600
700
800
900
1000

Figure 18

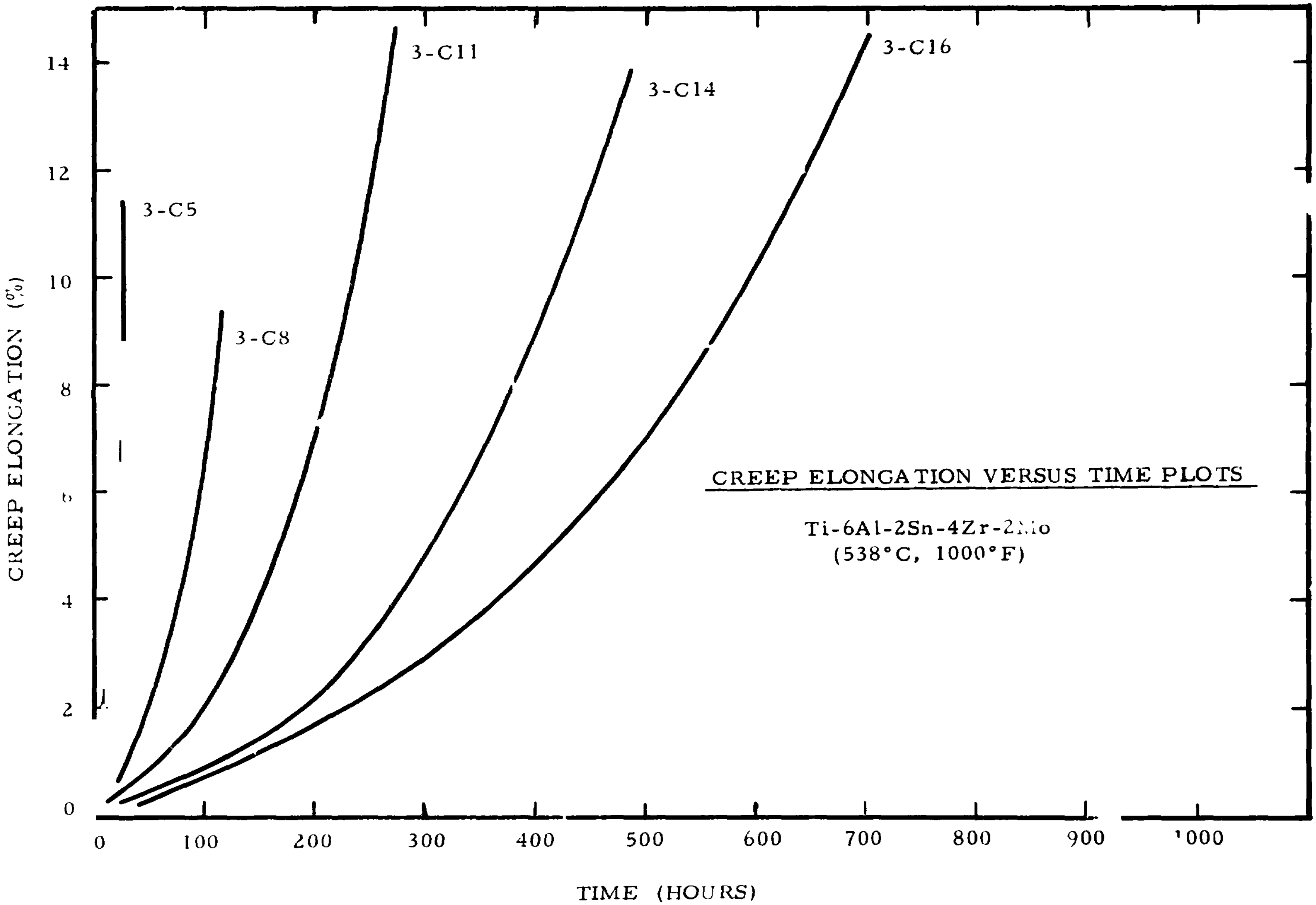

CREEP ELONGATION VERSUS TIME PLOTS
Ti-6Al-2Sn-4Zr-2Mo
(538°C, 1000°F)
3-C5
3-C8
3-C11
3-C14
3-C16
CREEP ELONGATION (%)
TIME (HOURS)
0
2
4
6
8
10
12
14
100
200
300
400
500
600
700
800
900
1000

Figure 19

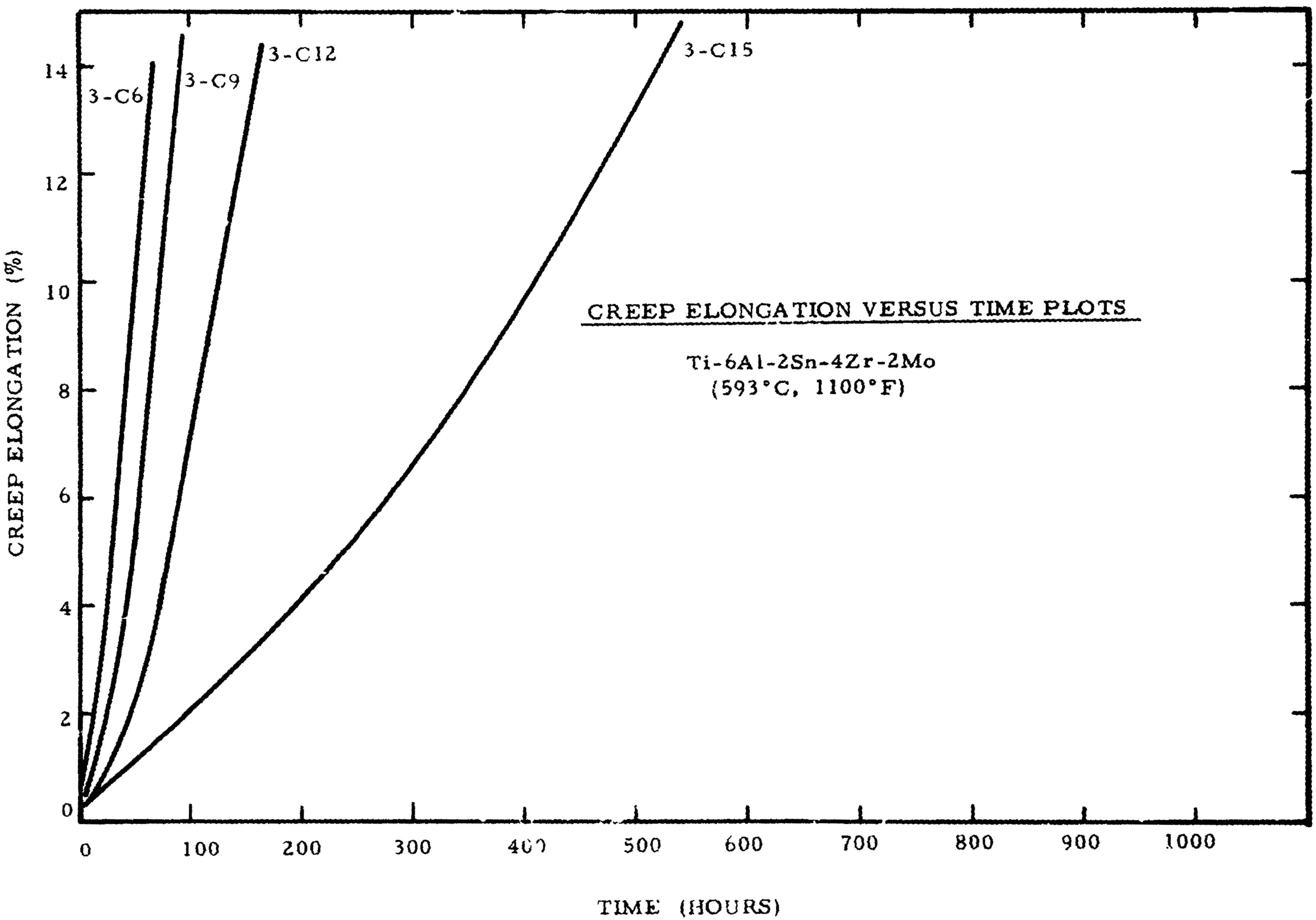

CREEP ELONGATION VERSUS TIME PLOTS
Ti-6Al-2Sn-4Zr-2Mo
(593°C, 1100°F)
3-C6
3-C9
3-C12
3-C15
CREEP ELONGATION (%)
TIME (HOURS)
0
2
4
6
8
10
12
14
100
200
300
400
500
600
700
800
900
1000

Figure 20

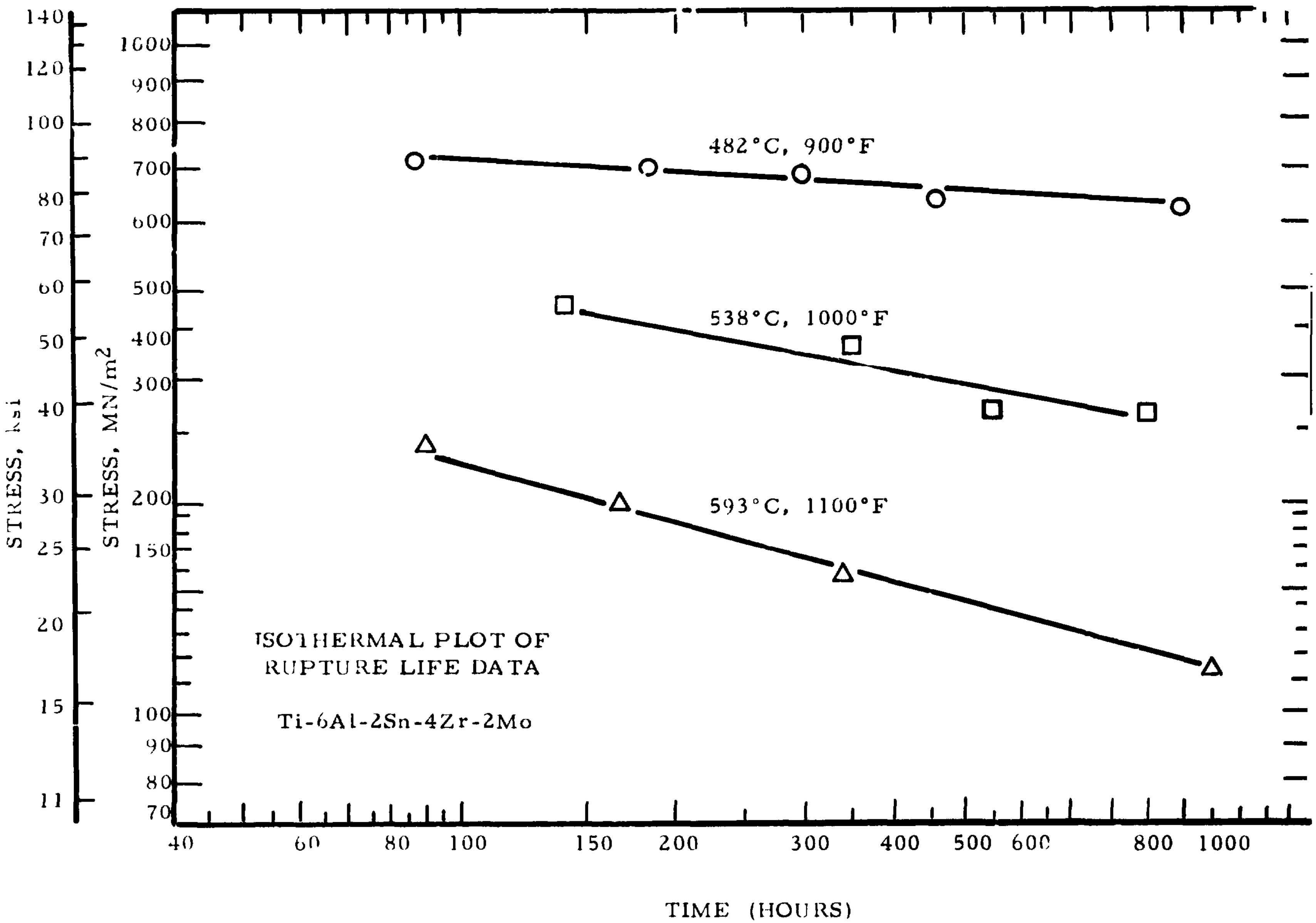

482°C, 900°F
538°C, 1000°F
593°C, 1100°F
ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
Ti-6Al-2Sn-4Zr-2Mo
STRESS, ksi
STRESS, MN/m2
TIME (HOURS)
140
120
100
80
70
60
50
40
30
25
20
15
11
1000
900
800
700
600
500
400
300
200
150
100
90
80
70
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 21

TEST RESULTS (continued)

Material 4: H-13 Tool Steel

This air-hardening, hot work tool and die steel was supplied as bar stock by NASA-Lewis Research Center. Nominal composition of this alloy is as follows:

Carbon	0.35%
Manganese	0.35
Silicon	1.00
Chromium	5.00
Vanadium	1.00
Molybdenum	1.50
Iron	Balance

Prior to finish machining, the material was heat treated at Metcut using the following NASA recommended heat treatment.

> Preheat specimen blanks to 1400°F for 1/2 hour.
> Transfer to 1850°F/1 hour/air cool.
> Double temper at 1200°F for two hours, air cool to room temperature each time.

Tensile results are presented as Table VII with samples of the load-strain curves compiled as Figure 22.

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	95%
4-P1	-0.2746	±.0019	±.0023
4-P2	-0.2786	±.0017	±.0020
4-P3	-0.2758	±.0015	±.0018

Creep rupture data are presented in Table VIII. Creep deformation versus time values are plotted in Figures 23, 24, and 25. Isothermal plots of the rupture life data appear as Figure 26.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Material 4: H-13 Tool Steel (continued)

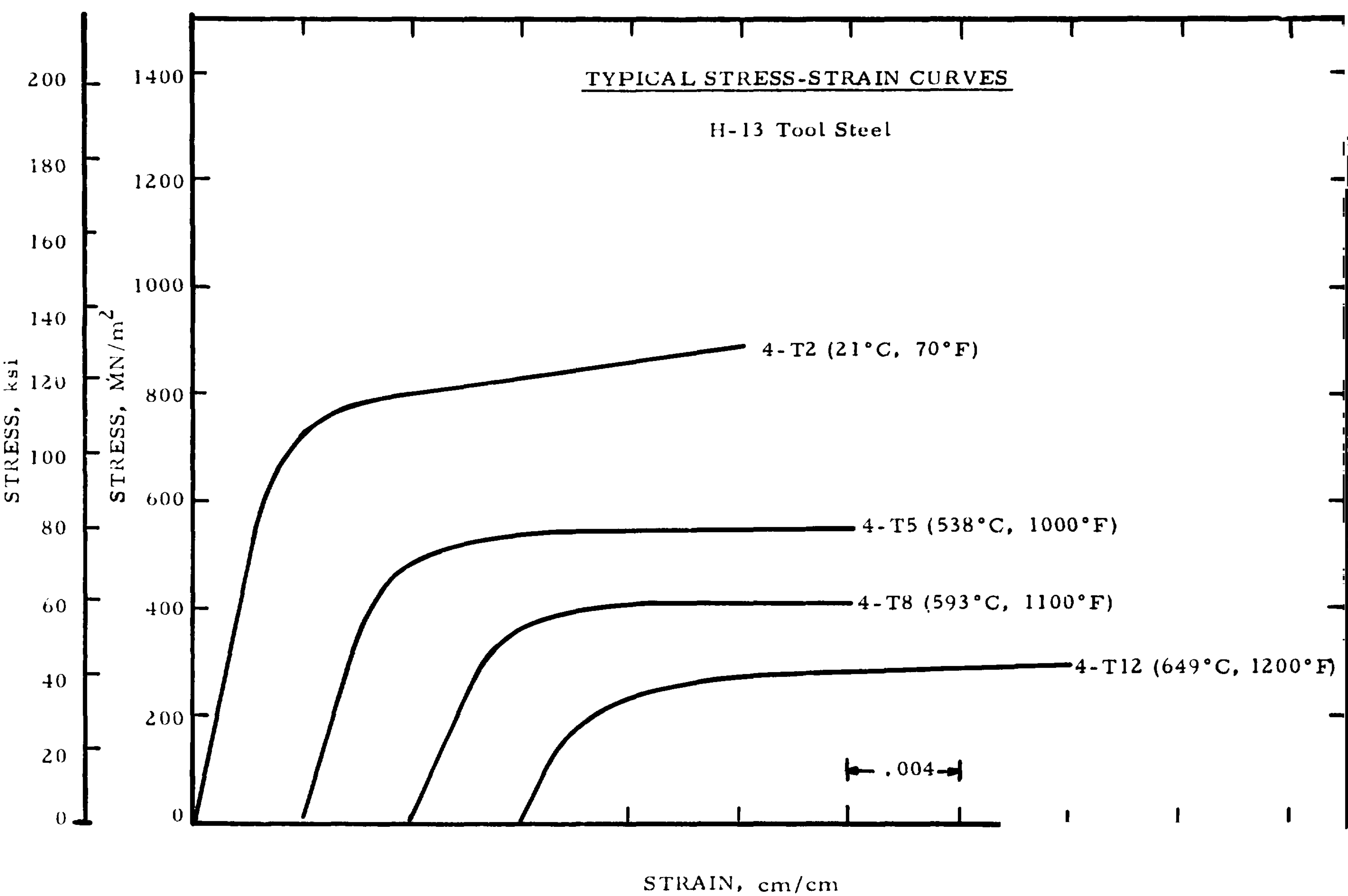
Temp.		Stress to Produce Failure at					
		100 hours		300 hours		1000 hours	
°C	°F	MN/m²	ksi	MN/m²	ksi	MN/m²	ksi
538	1000	282.7	41.0	237.9	34.5	193.0	28.0
593	1100	165.5	24.0	134.4	19.5	106.9	15.5
649	1200	96.5	14.0	79.3	11.5	62.0	9.0

TABLE VII

Tensile Properties of H-13 Tool Steel

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
4-T1	21	70	986.0	143.0	684.0	99.2	788.1	114.3	----	---	0.11	14.1	50.9
4-T2			986.0	143.0	651.6	94.5	768.1	111.4	----	---	0.11	14.9	52.7
4-T3			981.8	142.4	622.6	90.3	759.1	110.1	----	---	0.12	15.7	51.4
4-T4	538	1000	552.3	80.1	410.2	59.5	501.[illegible]	[illegible]2.7	----	---	0.07	27.1	80.8
4-T5			554.3	80.4	356.5	51.7	491.[illegible]	[illegible]1.3	----	---	0.05	26.5	80.4
4-T6			572.3	83.0	366.1	53.1	[illegible].2	74.0	----	---	0.05	25.4	80.1
4-T7	593	1100	426.8	61.9	247.5	35.9	361.3	52.4	----	---	0.05	34.3	88.5
4-T8			461.3	66.9	255.8	37.1	382.0	55.4	----	---	0.04	35.1	88.2
4-T9			416.4	60.4	262.0	38.0	366.1	53.1	----	---	0.04	35.5	89.7
4-T10	649	1200	315.8	45.8	166.2	24.1	239.9	34.8	----	---	0.06	36.6	92.4
4-T11			322.0	46.7	144.1	20.9	226.8	32.9	----	---	----	40.7	93.5
4-T12			306.1	44.4	138.6	20.1	228.2	33.1	----	---	0.04	43.0	92.6

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	226.1	32.8
538	1000	177.9	25.8
593	1100	130.3	18.9
649	1200	125.5	18.2



TYPICAL STRESS-STRAIN CURVES
H-13 Tool Steel
STRESS, ksi
0
20
40
60
80
100
120
140
160
180
200
STRESS, MN/m²
0
200
400
600
800
1000
1200
1400
4-T2 (21°C, 70°F)
4-T5 (538°C, 1000°F)
4-T8 (593°C, 1100°F)
4-T12 (649°C, 1200°F)
.004
STRAIN, cm/cm

Figure 22

TABLE VIII

Creep Rupture Properties of H-13 Tool Steel

Specimen Number	Temp. °C	Temp. °F	Stress MN/m^2	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
4-C1	538	1000	448.2	65.0	--	0.4	0.1	1.0	25.7	76.8
4-C4			413.7	60.0	2.93	1.5	0.2	32.4	24.2	74.8
4-C7			275.8	40.0	.072	45	8	116.8	32.1	80.5
4-C13			241.3	35.0	.030	110	20	285.6	36.9	82.5
4-C10			206.8	30.0	.0119	300	52	797.3	45.5	85.1
4-C16			196.5	28.5	.0106	450	80	914.5	29.2	82.8
4-C2	593	1100	275.8	40.0	2.35	2.5	0.3	4.3	27.9	84.3
4-C5			482.6	30.0	.342	9	0.7	39.7	33.6	88.9
4-C8			158.6	23.0	.0775	50	8.5	142.1	51.0	89.8
4-C11			137.9	20.0	.0498	95	16	209.8	35.6	89.2
4-C14			96.5	14.0	.0074	850	27	1804.8	49.4	89.9
4-C3	649	1200	137.9	20.0	.60	1.5	1	15.8	43.3	94.0
4-C6			106.9	15.5	.333	11	2	45.4	43.0	92.8
4-C15			82.7	12.0	.0623	105	8	263.7	49.9	92.0
4-C9			72.4	10.5	.0327	200	13	500.6	58.7	92.2
4-C12			65.5	9.5	.0192	360	14	761.5	58.9	94.1

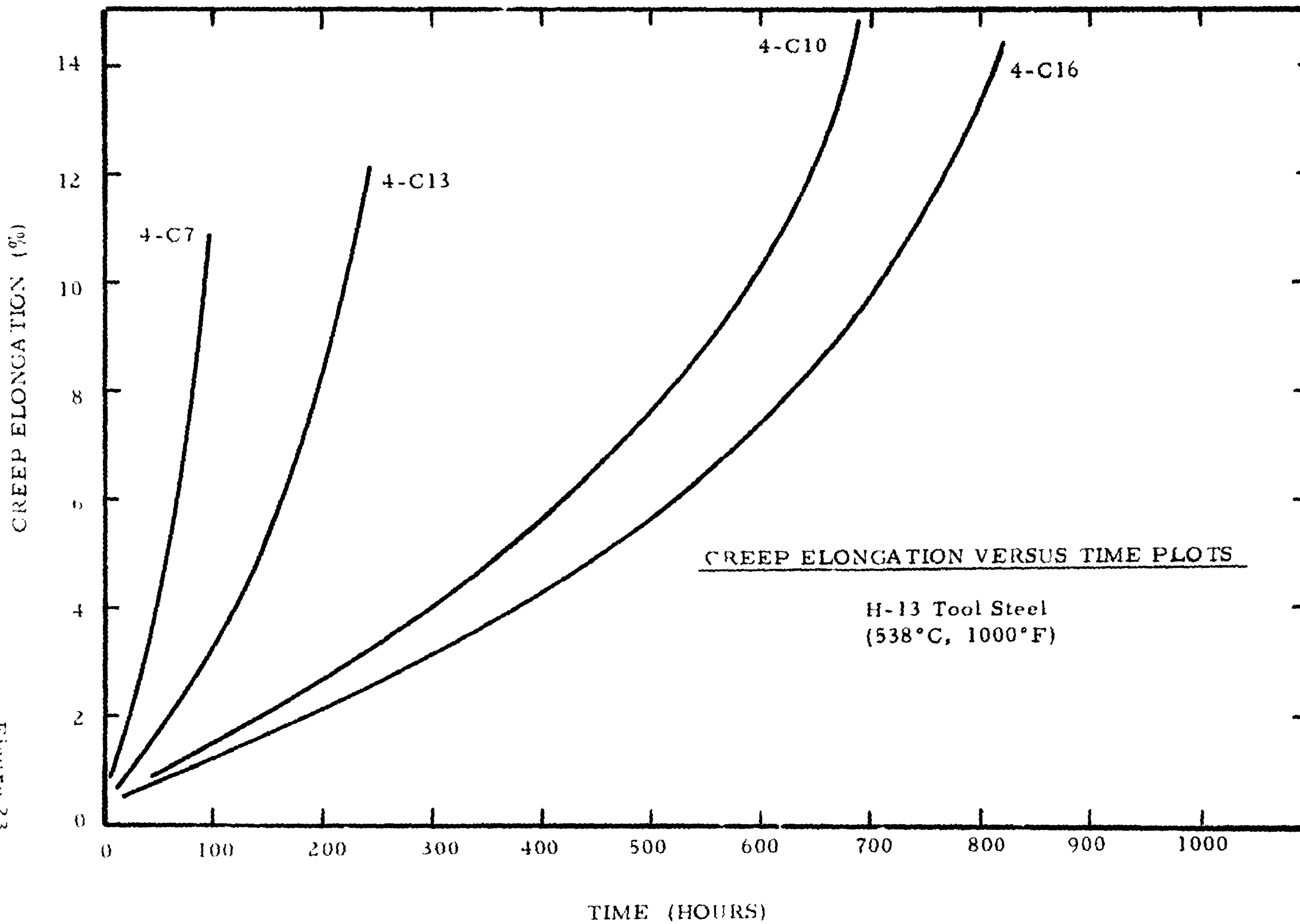

CREEP ELONGATION (%)
14
12
10
8
6
4
2
0
4-C7
4-C13
4-C10
4-C16
CREEP ELONGATION VERSUS TIME PLOTS
H-13 Tool Steel
(538°C, 1000°F)
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 23

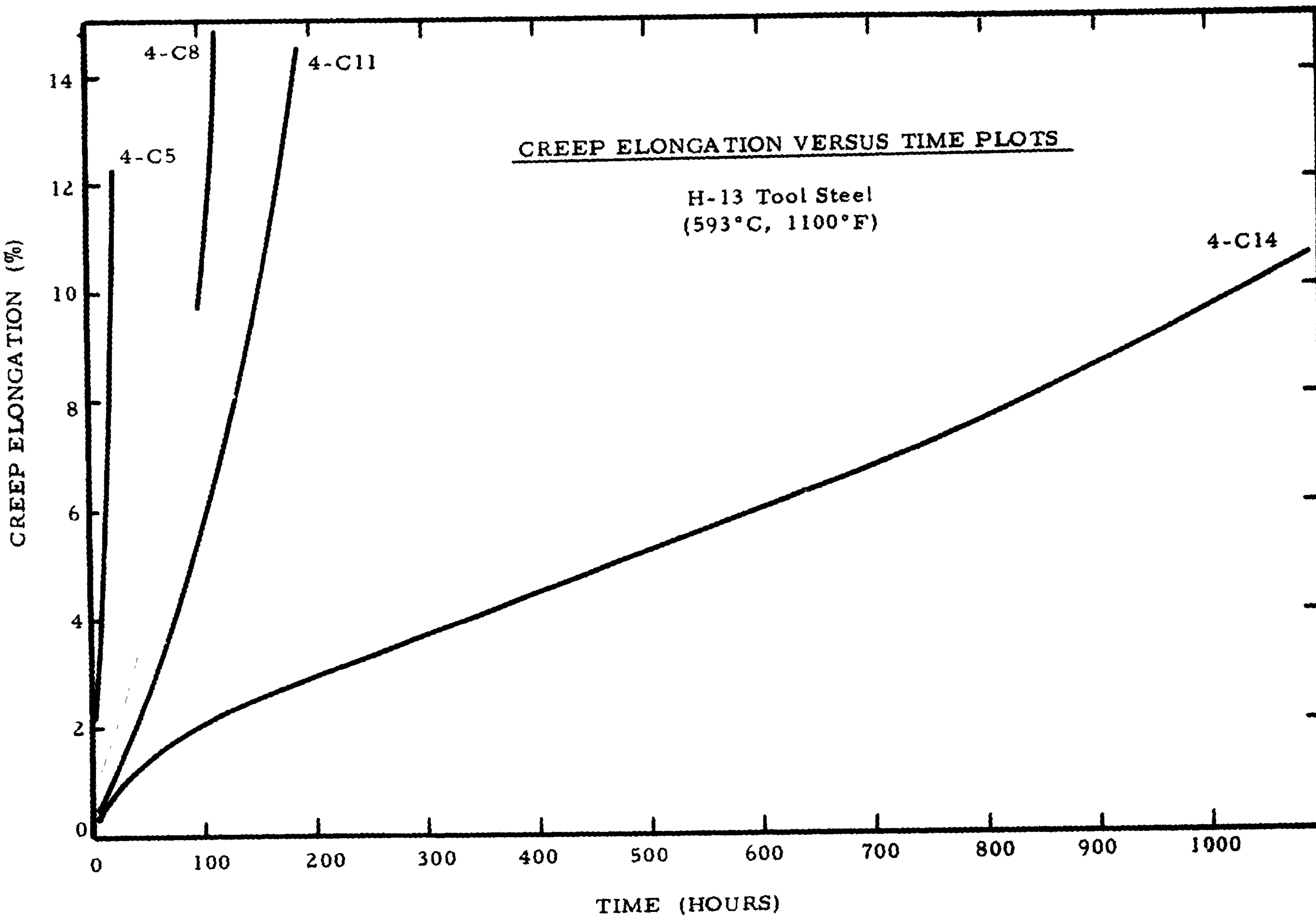

CREEP ELONGATION VERSUS TIME PLOTS
H-13 Tool Steel
(593°C, 1100°F)
4-C5
4-C8
4-C11
4-C14
CREEP ELONGATION (%)
0
2
4
6
8
10
12
14
TIME (HOURS)
0
100
200
300
400
500
600
700
800
900
1000

Figure 24

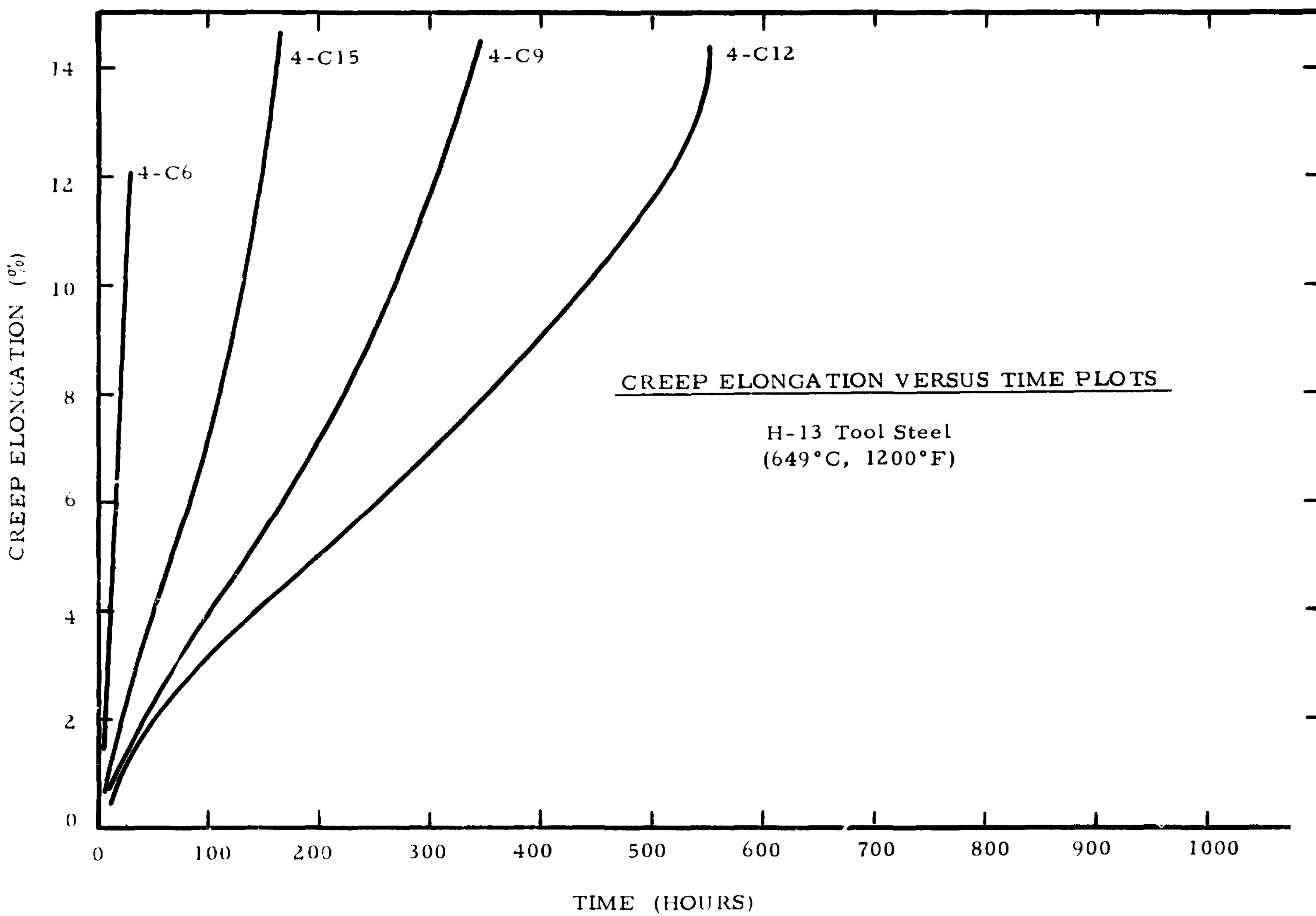

CREEP ELONGATION VERSUS TIME PLOTS
H-13 Tool Steel
(649°C, 1200°F)
4-C6
4-C15
4-C9
4-C12
CREEP ELONGATION (%)
TIME (HOURS)
0
2
4
6
8
10
12
14
100
200
300
400
500
600
700
800
900
1000

Figure 25

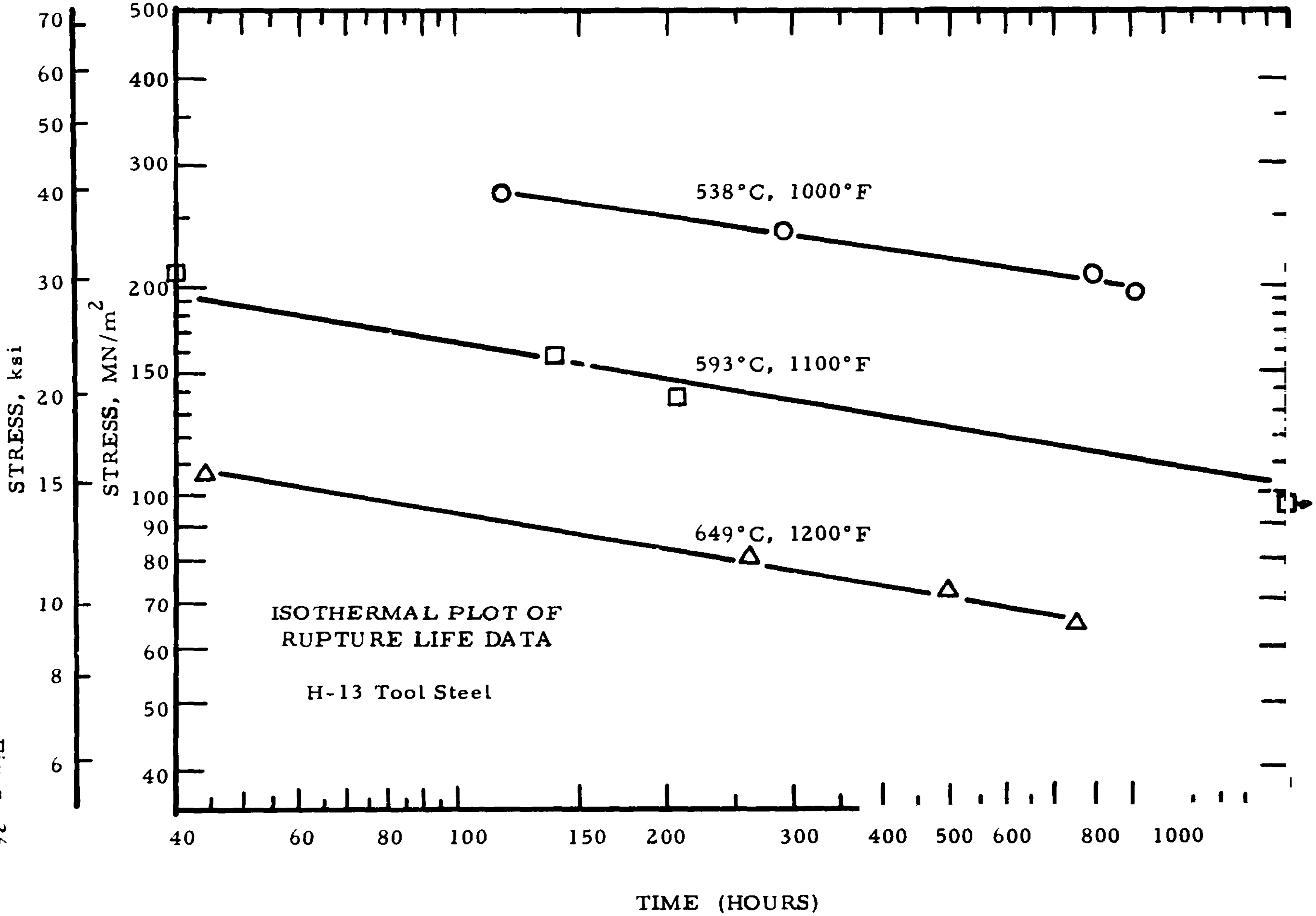

ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
H-13 Tool Steel
538°C, 1000°F
593°C, 1100°F
649°C, 1200°F
STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 26

Material 5: D-979

This precipitation hardening austenitic, high temperature superalloy was supplied as fully processed wrought bar stock by NASA-Lewis Research Center.

Nominal composition of this alloy is as follows:

Carbon	0.08 max.
Manganese	0.75 max.
Silicon	0.75 max.
Phosphorus	0.040 max.
Chromium	14.00 - 16.00
Molybdenum	3.00 - 4.50
Tungsten	3.00 - 4.50
Titanium	2.70 - 3.00
Aluminum	0.75 - 1.30
Boron	0.008 - 0.016
Iron	25.00 - 29.00
Nickel	42.00 - 48.00

Tensile results are presented as Table IX with samples of the load-strain curves compiled as Figure 27.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	Confidence Limits 95%
5-P1	-0.2852	±.0026	±.0031
5-P2	-0.2853	±.0016	±.0020
5-P3	-0.3013	±.0012	±.0014

Creep rupture data are presented in Table X. Creep deformation versus time values are plotted in Figures 28, 29, and 30. Isothermal plots of the rupture life data appear as Figure 31.

Material 5: D-979 (continued)

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at appropriate test temperatures.

Temp.		Stress to Produce to Failure at					
		100 hour		300 hour		1000 hour	
C°	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
593	1100	758.4	110.0	696.4	101.0	627.4	91.0
649	1200	599.8	87.0	537.8	78.0	482.6	70.0
704	1300	468.8	68.0	427.5	62.0	386.1	56.0

TABLE IX
Tensile Properties of D-979

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
5-T5	21	70	1407.2	204.1	877.7	127.3	1010.0	146.5	----	---	0.11	18	27.5
5-T9			1428.6	207.2	844.6	122.5	976.3	141.6	----	---	0.11	19.5	27.2
5-T14			1410.7	204.6	757.7	109.9	954.2	138.4	----	---	----	19	27.7
5-T2	593	1100	1289.3	187.0	743.3	107.8	937.7	136.0	----	---	0.15	16	23.6
5-T6			1276.2	185.1	779.1	113.0	933.6	135.4	----	---	0.09	17	25.8
5-T10			1291.4	187.3	780.5	113.2	932.2	135.2	----	---	0.14	18	26.3
5-T3	649	1200	1136.3	164.8	715.7	103.8	916.3	132.9	----	---	0.07	10.5	13.7
5-T7			1108.7	160.8	734.3	106.5	913.6	132.5	----	---	0.08	11.2	12.7
5-T11			1167.3	169.3	756.4	109.7	923.2	133.9	----	---	0.08	14	15.3
5-T4	704	1300	927.4	134.5	677.1	98.2	821.2	119.1	----	---	0.04	10	11.4
5-T8			960.4	139.3	724.6	105.1	872.2	126.5	----	---	0.03		
5-T12			1012.8	146.9	735.0	106.6	903.2	131.0	----	---	0.04	11	12.2

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	212.4	30.8
593	1100	167.5	24.3
649	1200	165.5	24.0
704	1300	166.2	24.1

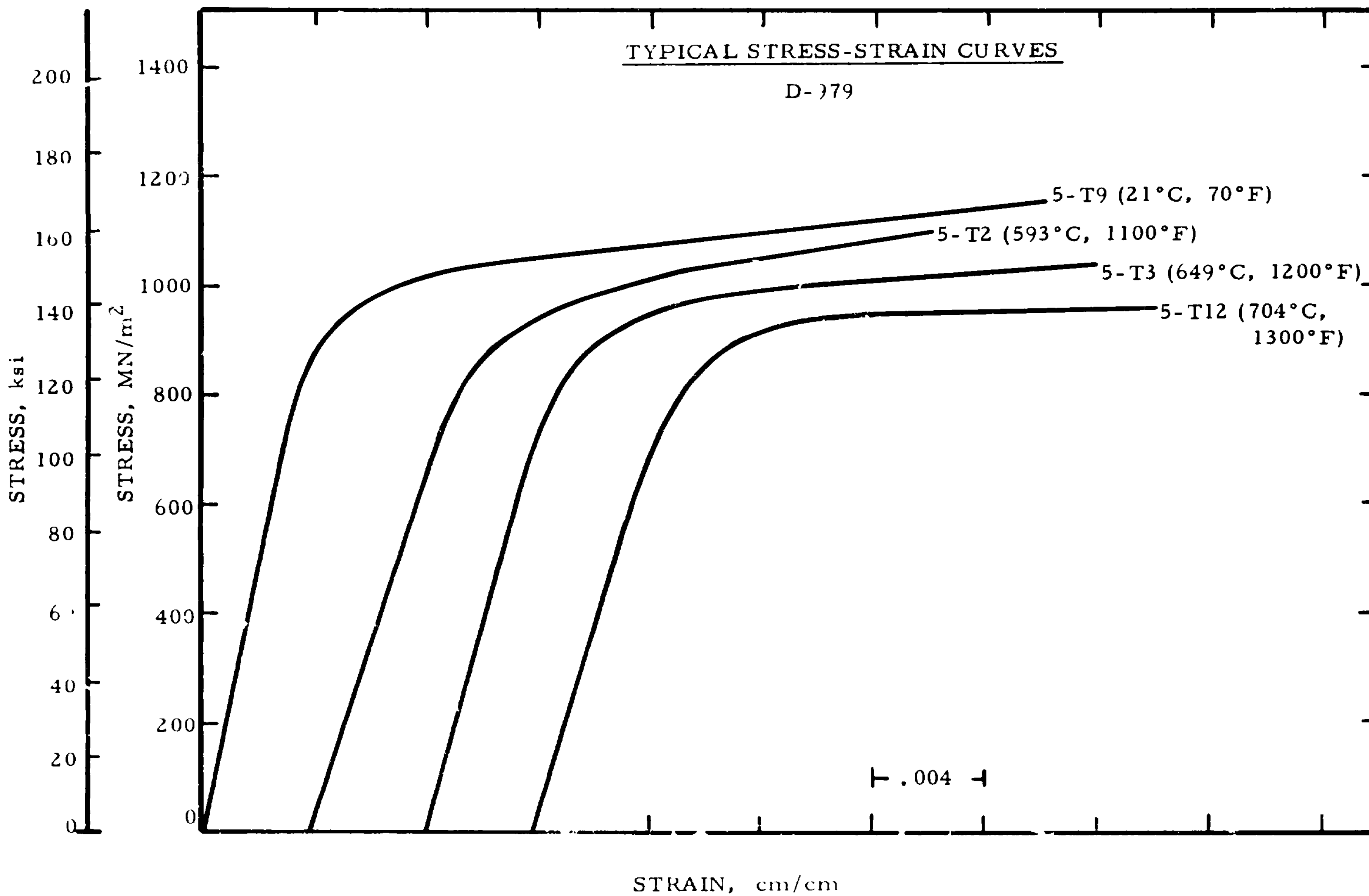

TYPICAL STRESS-STRAIN CURVES
D-979
5-T9 (21°C, 70°F)
5-T2 (593°C, 1100°F)
5-T3 (649°C, 1200°F)
5-T12 (704°C, 1300°F)
STRESS, ksi
STRESS, MN/m²
STRAIN, cm/cm
.004
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400

Figure 27

TABLE X

Creep Rupture Properties of D-979

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
5-C1	593	1100	758.4	110.0	.016	32	53	111.1	3.3	4.7
5-C12			703.3	102.0	.0033	109	213	258.7	1.6	4.7
5-C4			689.5	100.0	.0022	110	265	408.8	2.2	4.0
5-C9			641.2	93.0	.0004	(a)	(a)	724.1	1.1	4.0
5-C15			620.5	90.0	.0003	(a)	(a)	1144.2	0.8	4.4
5-C2	649	1200	620.5	90.0	.016	15	34	61.7	2.9	5.4
5-C5			593.0	86.0	.015	36	52	109.1	3.5	5.3
5-C7			544.7	79.0	.0027	125	242	317.3	2.0	2.4
5-C10			496.4	72.0	.0010	420	730	808.1	1.7	2.5
5-C13			482.6	70.0	.0006	620	(a)	976.0	1.2	2.5
5-C3	704	1300	517.1	75.0	.049	11	16	34.3	4.0	6.4
5-C6			482.6	70.0	.026	24	31	68.4	3.6	5.9
5-C14			441.3	64.0	.0102	59	81	169.9	3.9	6.1
5-C8			413.7	60.0	.0061	120	148	367.8	4.6	6.8
5-C11			386.1	56.0	.0018	295	465	972.6	5.1	7.2

Note: (a) Specimen failed before value was obtained.

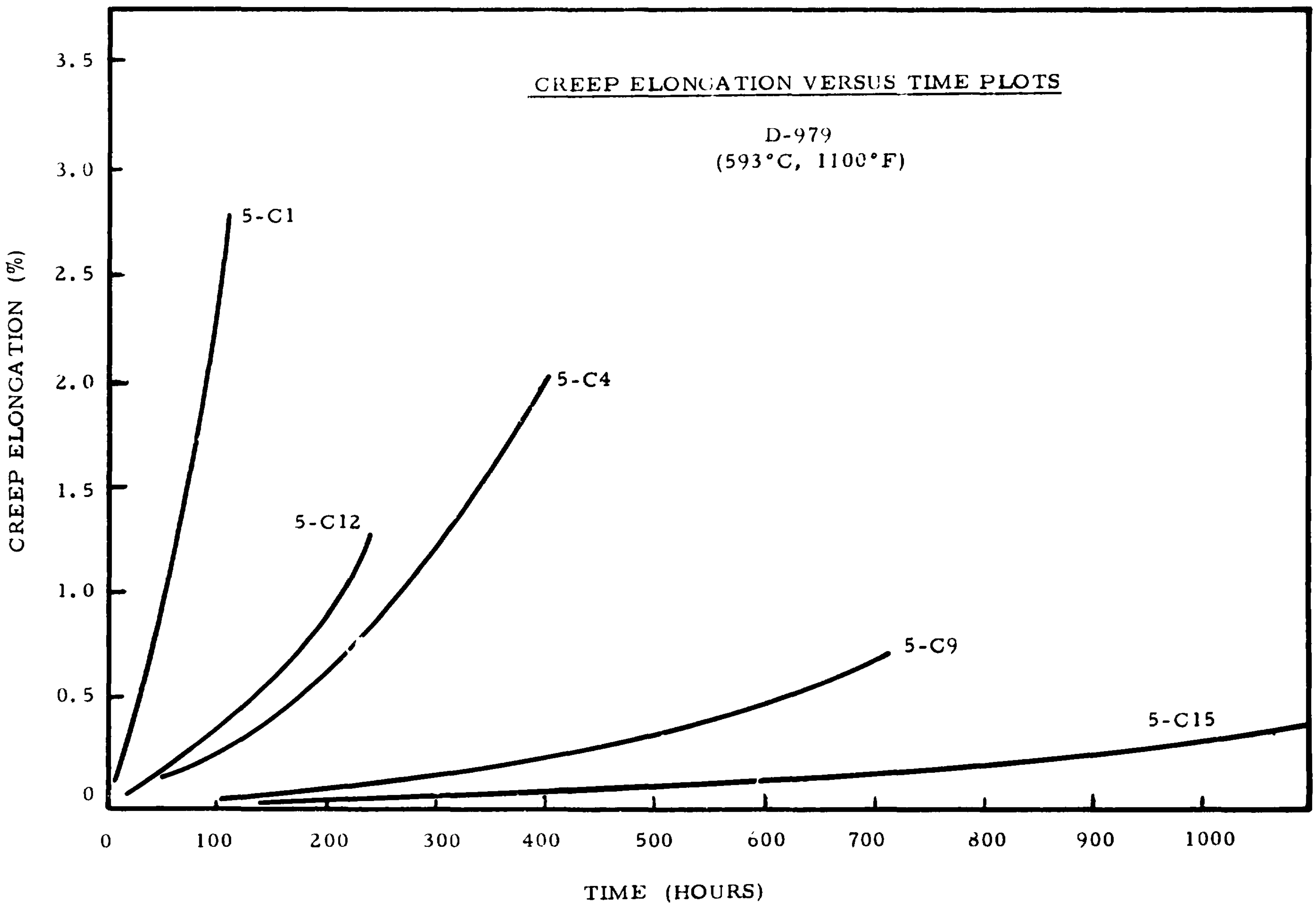

CREEP ELONGATION VERSUS TIME PLOTS
D-979
(593°C, 1100°F)
5-C1
5-C4
5-C12
5-C9
5-C15
CREEP ELONGATION (%)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 28

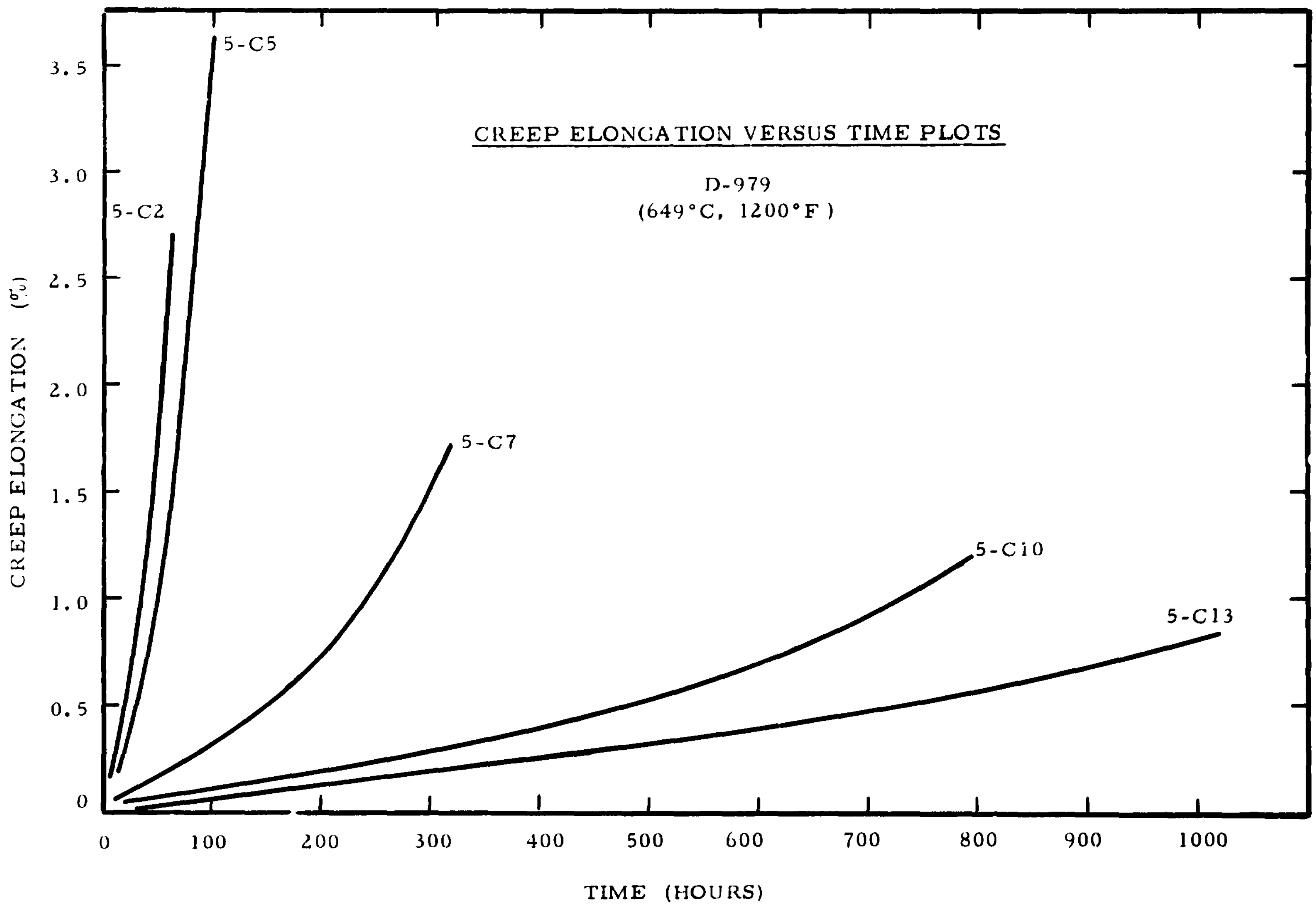

CREEP ELONGATION VERSUS TIME PLOTS
D-979
(649°C, 1200°F)
5-C5
5-C2
5-C7
5-C10
5-C13
CREEP ELONGATION (%)
TIME (HOURS)
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
100
200
300
400
500
600
700
800
900
1000

Figure 29

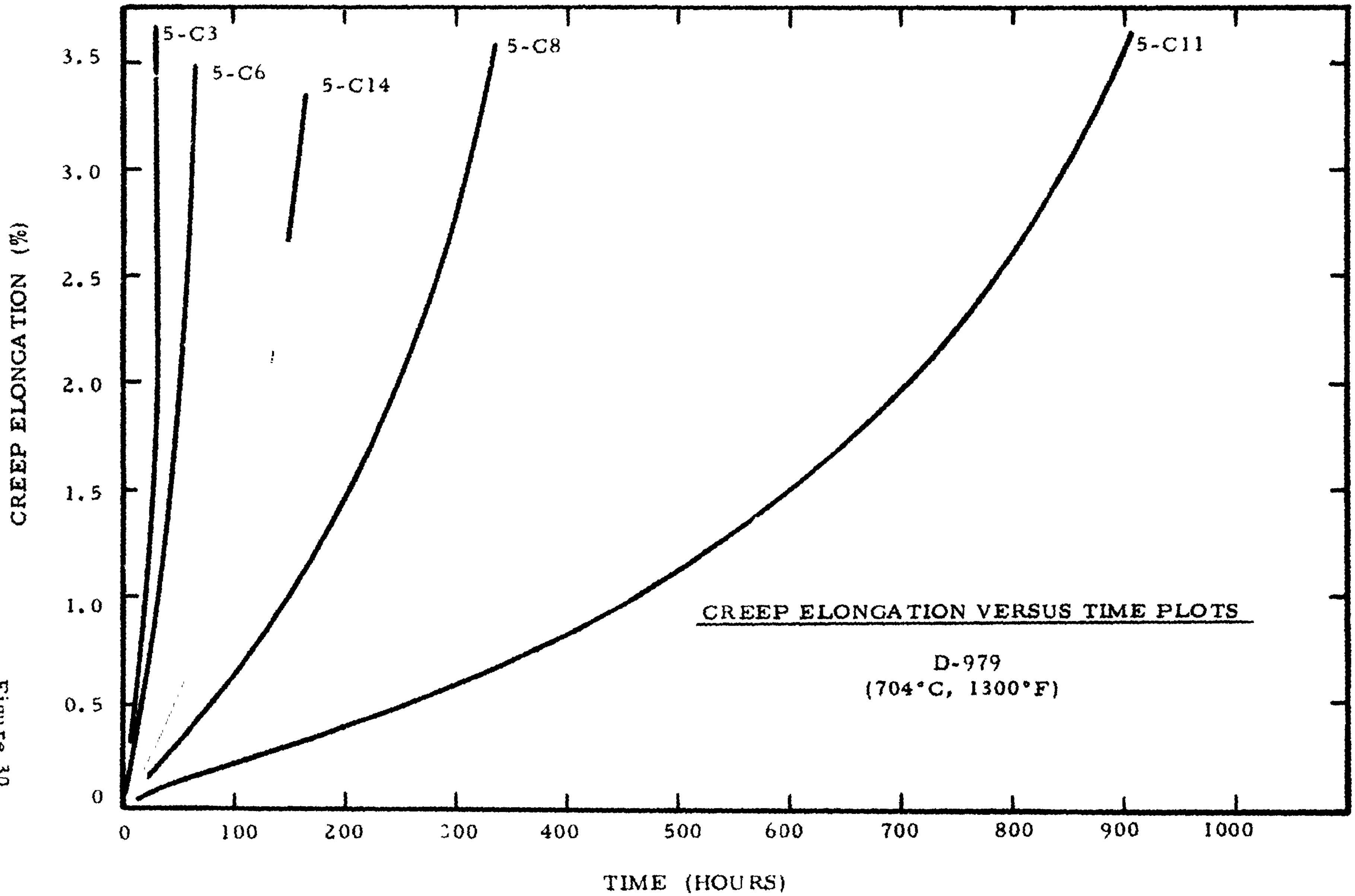

5-C3
5-C6
5-C14
5-C8
5-C11
CREEP ELONGATION (%)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)
CREEP ELONGATION VERSUS TIME PLOTS
D-979
(704°C, 1300°F)

Figure 30

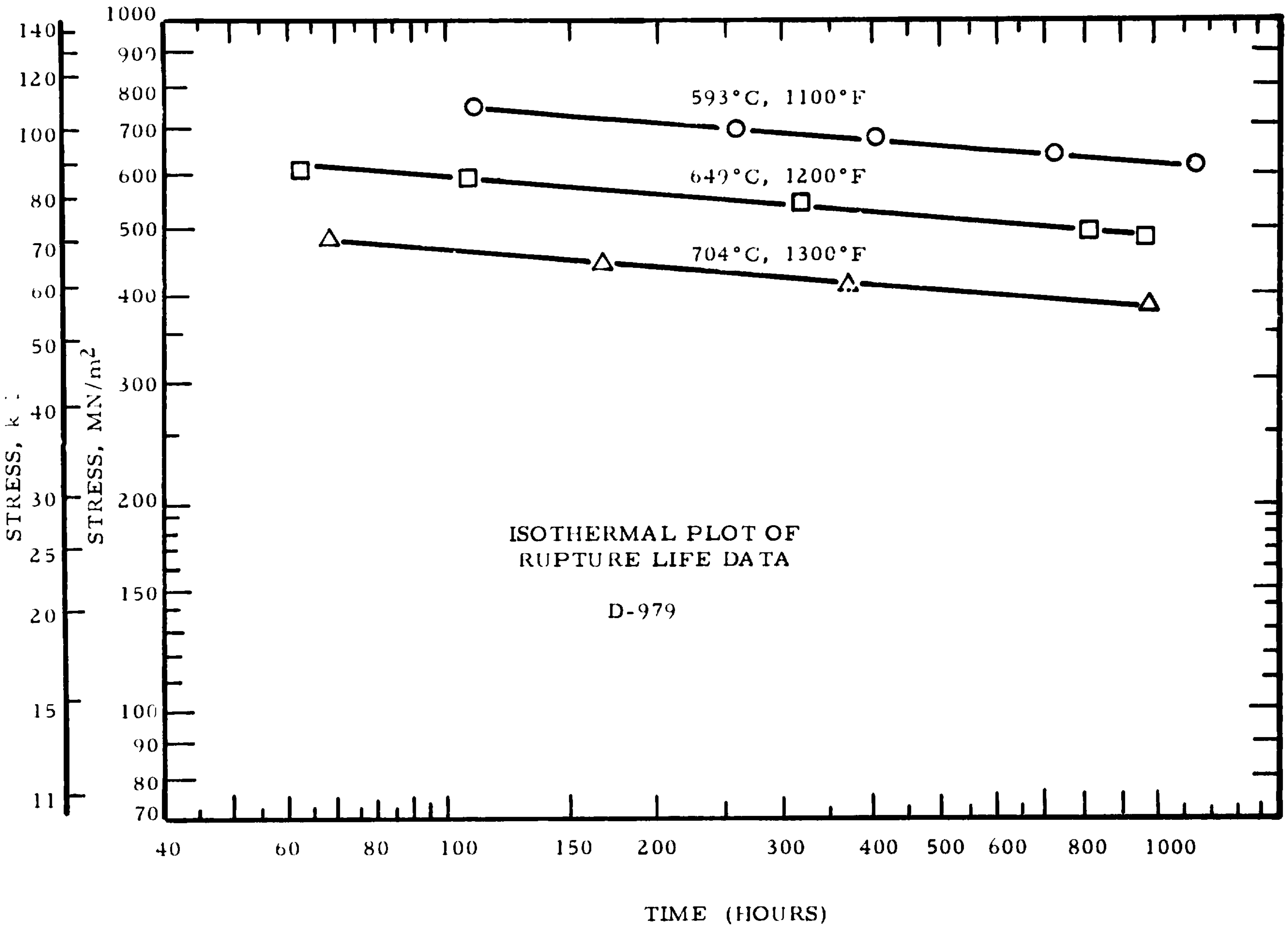

593°C, 1100°F
649°C, 1200°F
704°C, 1300°F
ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
D-979
STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
140
120
100
80
70
60
50
40
30
25
20
15
11
1000
900
800
700
600
500
400
300
200
150
100
90
80
70
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 31

Material 6: A-286

This age hardenable austenitic nickel-chromium steel was supplied as wrought bar stock by NASA-Lewis Research Center. Nominal composition of this alloy is as follows:

Carbon	0.08 max.
Manganese	2.00 max.
Silicon	1.00 max.
Phosphorous	0.025 max.
Sulfur	0.025 max.
Chromium	13.50-16.00
Nickel	24.00-27.00
Molybdenum	1.00-1.50
Titanium	1.90-2.35
Aluminum	0.35 max.
Vanadium	0.10-0.50
Boron	0.003-0.010
Iron	Balance

Prior to finish machining, the material was heat treated at Metcut using the following NASA recommended heat treatment:

Age at 1325°F/16 hours/air cool to room temperature

Tensile results are presented as Table XI with samples of the load-strain curves compiled as Figure 32.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	95%
6-P1	-0.2621	±.0015	±.0018
6-P2	-0.2624	±.0024	±.0029
6-P3	-0.2640	±.0015	±.0018

Creep rupture data are presented in Table XII. Creep deformation versus time values are plotted in Figures 33, 34, and 35. Isothermal plots of the rupture life data appear as Figure 36.

Material 6: A-286 (continued)

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to produce failure at					
		100 hours		300 hours		1000 hours	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
593	1100	703.3	102.0	648.1	94.0	593.0	86.0
649	1200	524.0	76.0	437.8	63.5	358.5	52.0
704	1300	303.4	44.0	217.2	31.5	148.2	21.5

TABLE XI
Tensile Properties of A-286

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m^2	Ultimate Strength ksi	0.02% Yield Strength MN/m^2	0.02% Yield Strength ksi	0.2% Yield Strength MN/m^2	0.2% Yield Strength ksi	Fracture Strength MN/m^2	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R. A. (%)
6-T1	21	70	1336.9	193.9	912.9	132.4	1174.2	170.3	----	---	0.06	15	35.8
6-T2			1341.0	194.5	891.5	129.3	1139.0	165.2	----	---	0.06	15.5	37.5
6-T3			1339.7	194.3	891.5	129.3	1165.2	169.0	----	---	0.07	14	36.0
6-T4		1100	990.1	143.6	639.1	92.7	903.2	131.0	----	---	0.04	17	44.9
6-T5			1000.4	145.1	735.7	106.7	904.6	131.2	----	---	0.04	16.5	44.5
6-T6			983.2	142.6	640.5	92.9	843.2	122.3	----	---	0.05	19	45.8
6-T7	649	1200	840.5	121.9	556.4	80.7	786.0	114.0	----	---	0.05	24	54.0
6-T8			870.8	126.3	581.2	84.3	772.2	112.0	----	---	0.05	24	54.2
6-T9			853.6	123.8	623.3	90.4	779.1	113.0	----	---	0.04	27	54.1
6-T10	704	1300	728.8	105.7	370.9	53.8	639.1	92.7	----	---	0.02	34	63.2
6-T11			743.9	107.9	421.3	61.1	-----	-----	----	---	----	36	63.5
6-T12			739.1	107.2	477.8	69.3	690.9	100.2	----	---	0.03	32	62.7

Temp. °C	Temp. °F	Modulus of Elasticity GN/m^2	Modulus of Elasticity 10^6 psi
21	70	226.1	32.8
593	1100	166.9	24.2
649	1200	145.5	21.1
704	1300	144.8	21.0

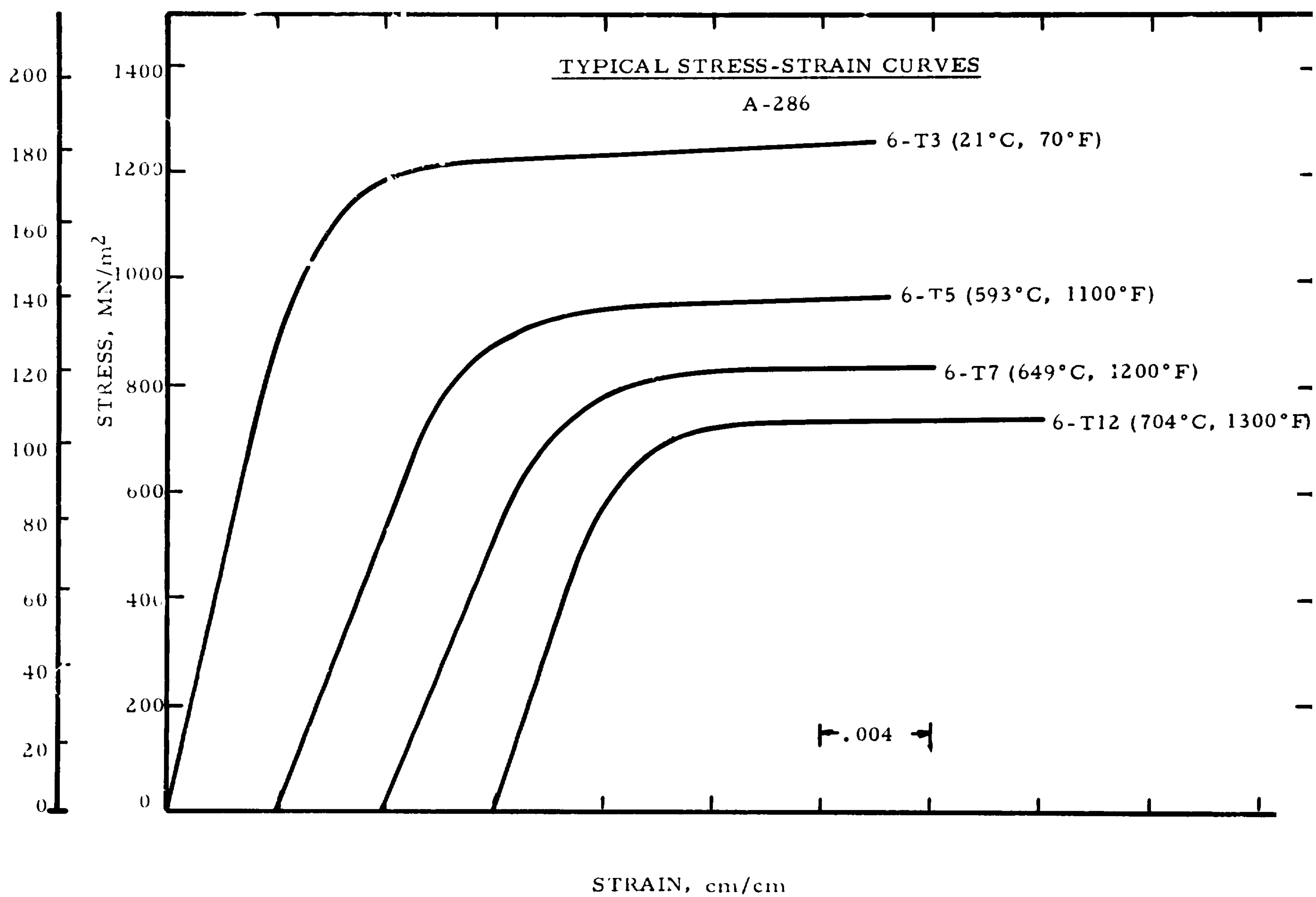

TYPICAL STRESS-STRAIN CURVES
A-286
6-T3 (21°C, 70°F)
6-T5 (593°C, 1100°F)
6-T7 (649°C, 1200°F)
6-T12 (704°C, 1300°F)
.004
STRESS, ksi
STRESS, MN/m²
STRAIN, cm/cm
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400

Figure 32

TABLE XII

Creep Rupture Properties of A-286

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
6-C4	593	1100	758.4	110.0	.154	7	7	29.0	22.0	47.7
6-C7			689.5	100.0	.011	25	42	93.9	17.9	50.9
6-C10			655.0	95.0	.0062	95	126	270.6	15.3	50.3
6-C13			634.3	92.0	.0043	82	122	257.3	14.5	52.1
6-C1			586.1	85.0	.0008	400	865	1462.5	15.1	47.2
6-C5	649	1200	551.6	80.0	.035	21	27	54.3	18.4	59.6
6-C8			496.4	72.0	.0076	56	89	176.4	22.3	59.8
6-C2			448.2	65.0	.0033	52	106	244.2	13.6	59.5
6-C11			386.1	56.0	.0022	190	307	666.4	14.8	60.7
6-C14			365.4	53.0	.0019	190	345	887.1	34.0	57.8
6-C3	704	1300	324.1	47.0	---	---	---	(a)	--	--
6-C6			324.1	47.0	.029	20	25	81.5	32.5	66.5
6-C			275.8	40.0	.020	26	42	145.9	23.7	64.9
6-C 2			227.5	33.0	.012	60	78	272.8	36.7	61.0
6-C15			165.5	24.0	.0051	120	172	688.8	47.1	57.5
6-C16			137.9	20.0	.0027	200	315	1271.1	37.5	59.1

Note: (a) Specimen over-temperature prior to test; void test.

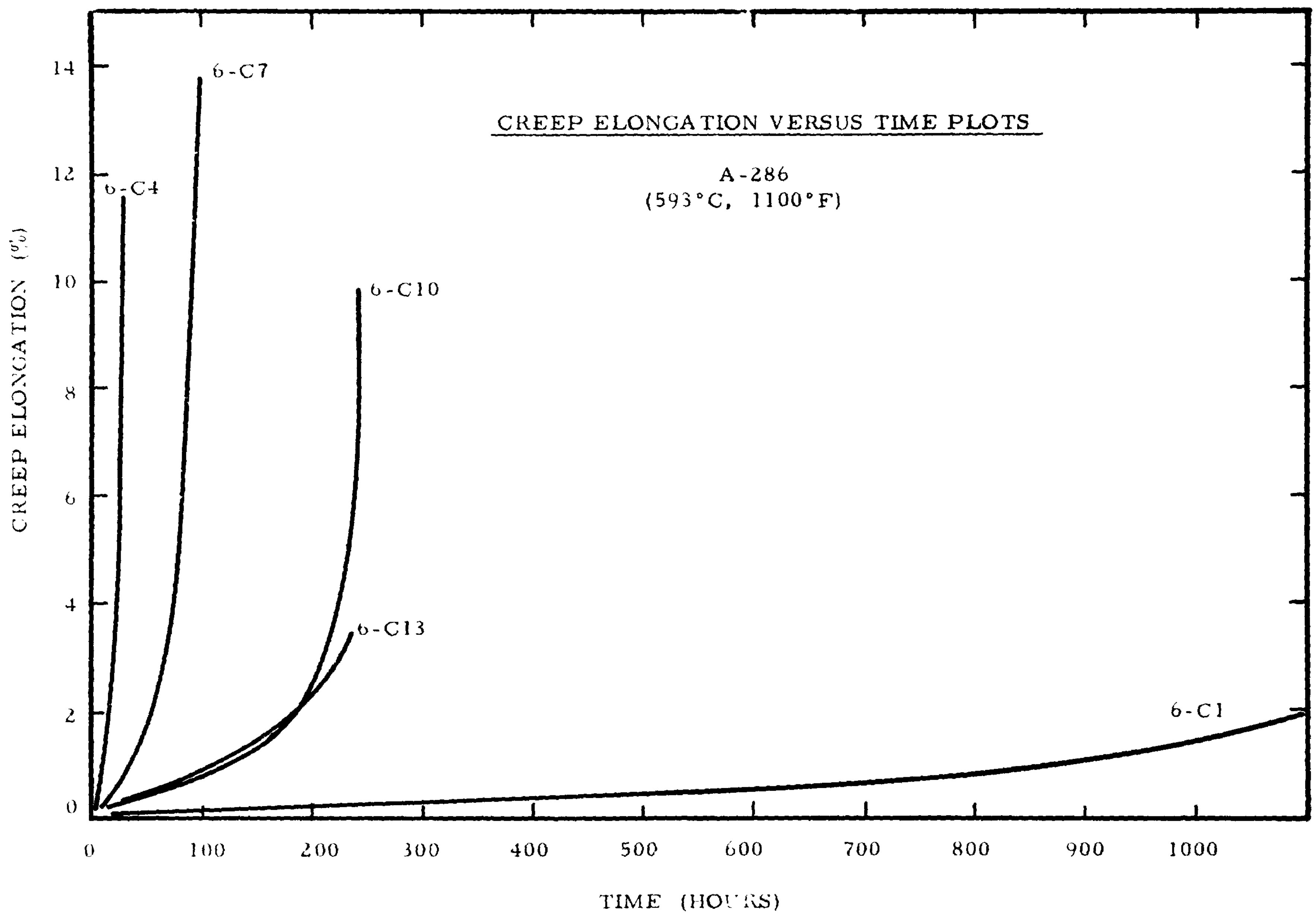

CREEP ELONGATION VERSUS TIME PLOTS
A-286
(593°C, 1100°F)
6-C7
6-C4
6-C10
6-C13
6-C1
CREEP ELONGATION (%)
TIME (HOURS)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
900
1000

Figure 33

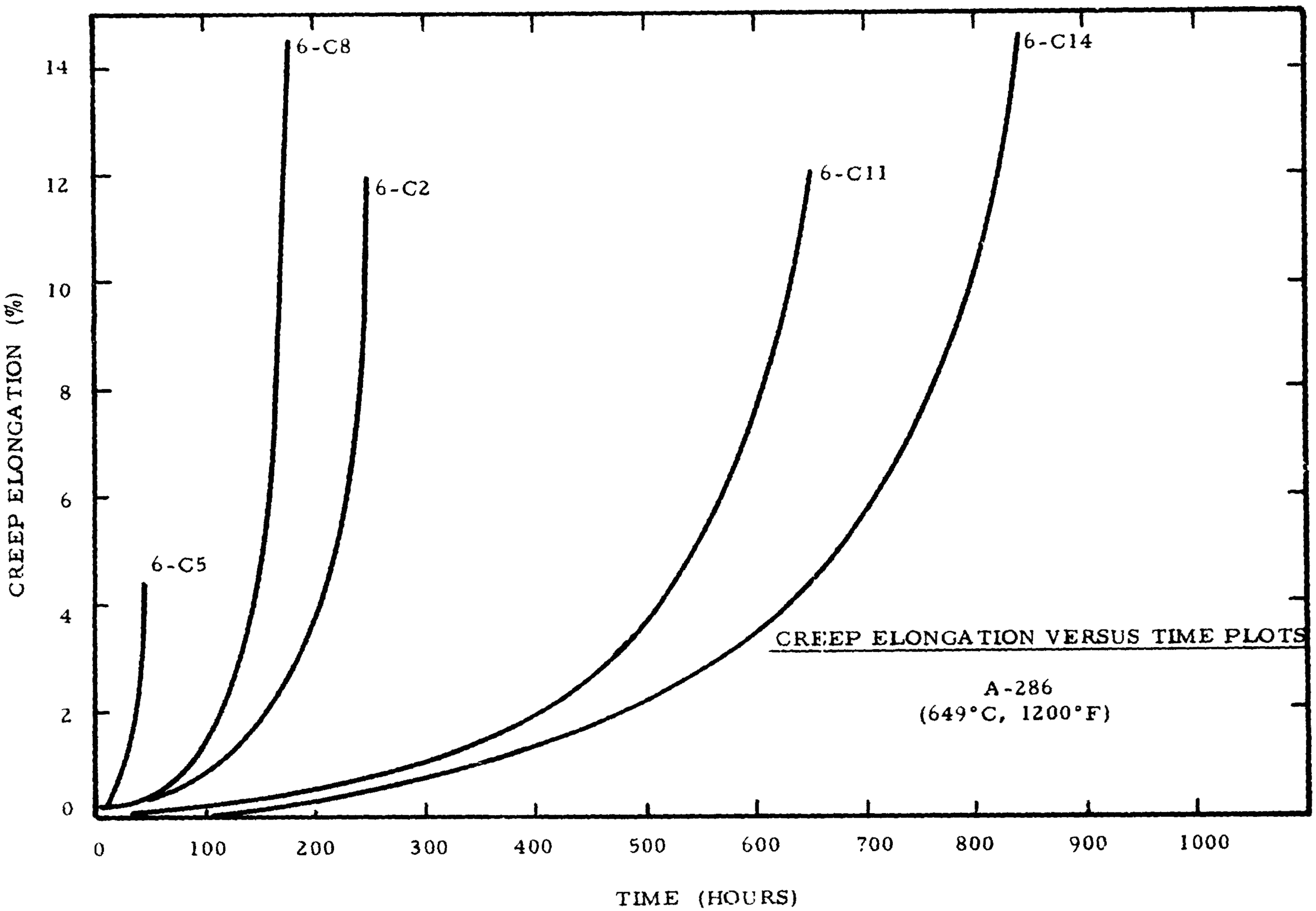

6-C8
6-C2
6-C5
6-C11
6-C14
CREEP ELONGATION (%)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)
CREEP ELONGATION VERSUS TIME PLOTS
A-286
(649°C, 1200°F)

Figure 34

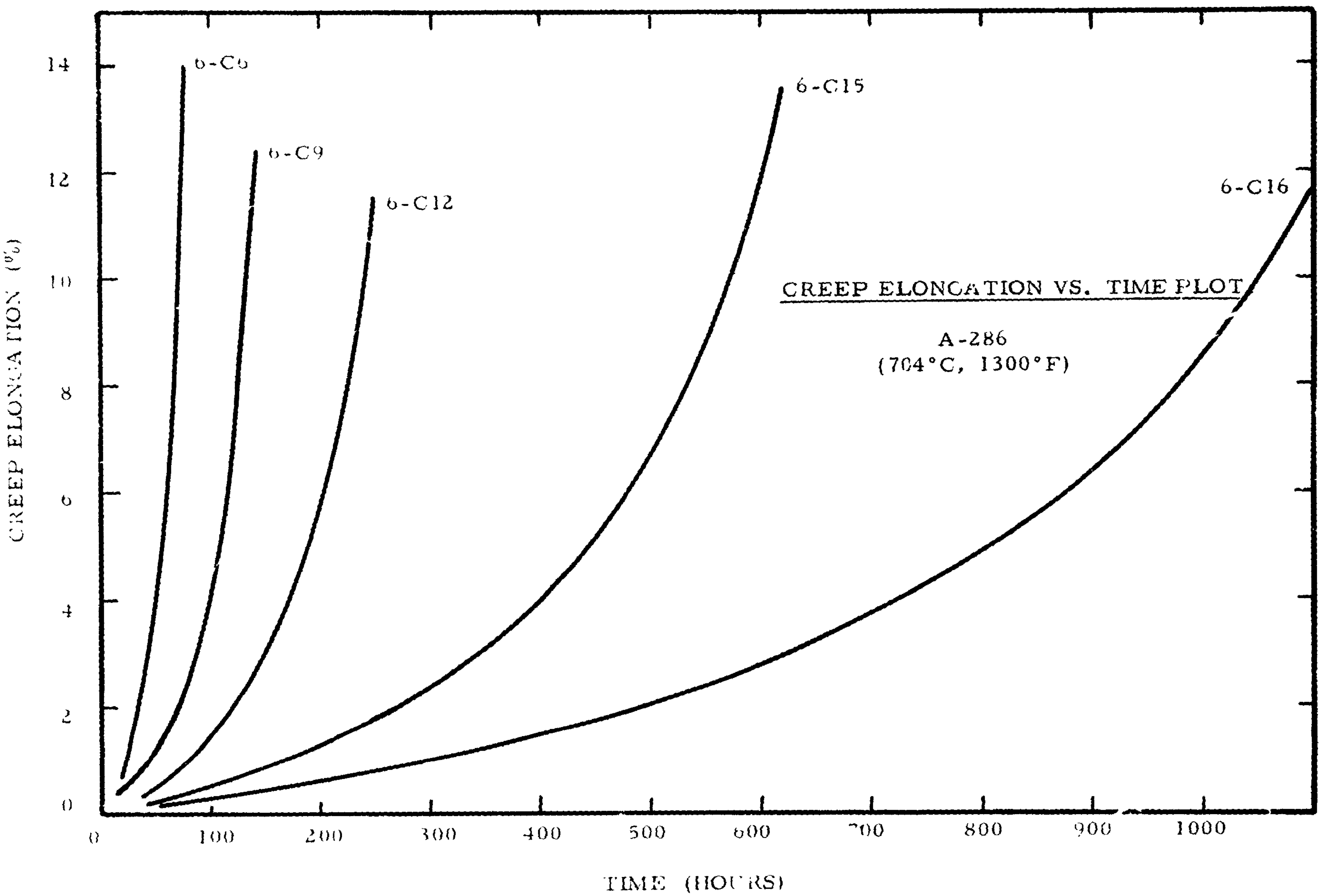

CREEP ELONGATION VS. TIME PLOT
A-286
(704°C, 1300°F)
6-C6
6-C9
6-C12
6-C15
6-C16
CREEP ELONGATION (%)
TIME (HOURS)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
900
1000

FIGURE 35

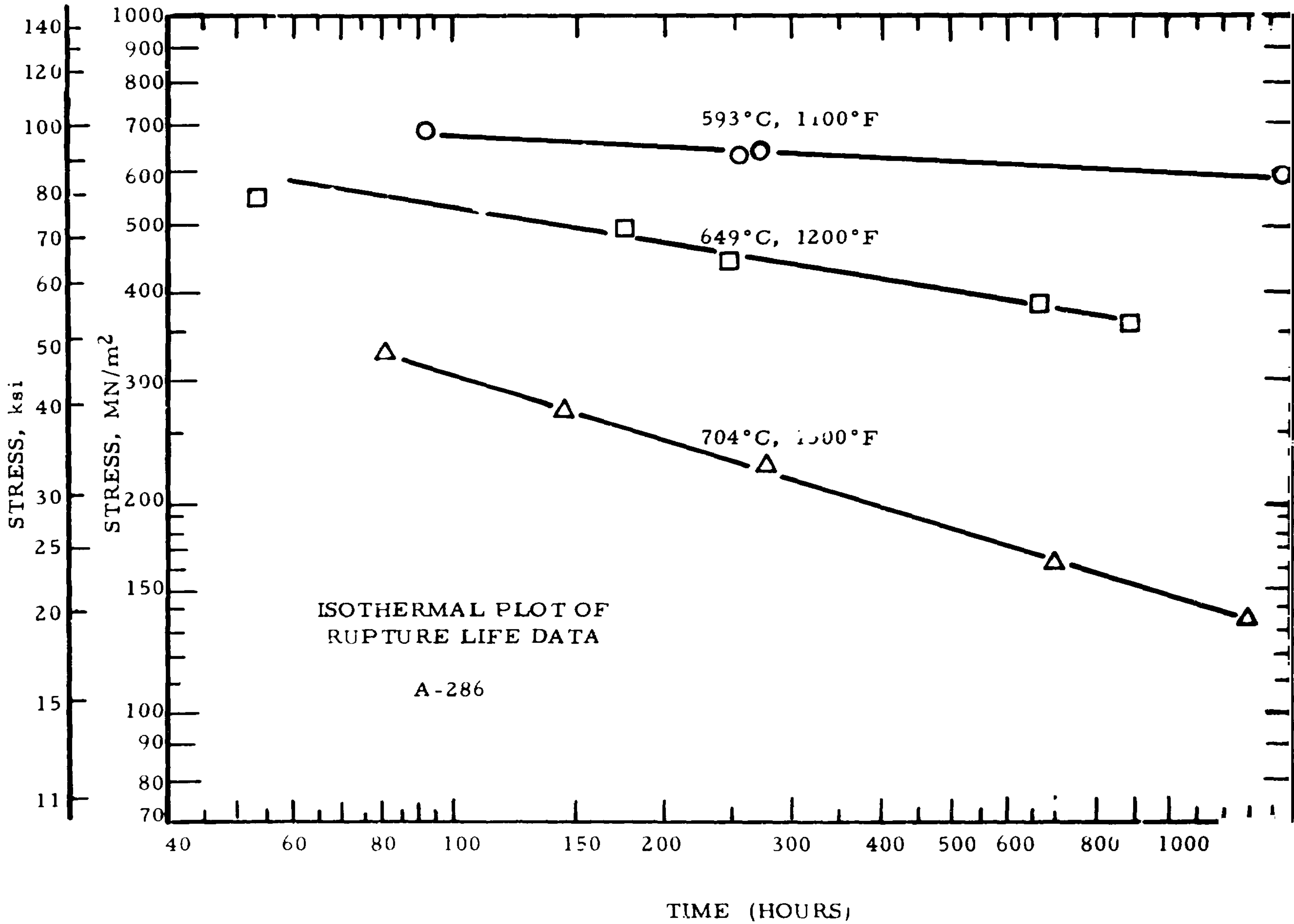

STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
593°C, 1100°F
649°C, 1200°F
704°C, 1300°F
ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
A-286
140
120
100
80
70
60
50
40
30
25
20
15
11
1000
900
800
700
600
500
400
300
200
150
100
90
80
70
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 36

Material 7: L-605

This alloy, a cobalt-base alloy, was supplied as fully processed wrought bar stock by NASA-Lewis Research Center. Nominal composition of this alloy is as follows:

Carbon	0.05-0.15
Manganese	1.00-2.00
Silicon	0.040 max.
Phosphorous	0.040 max.
Sulfur	0.030 max.
Chromium	19.00-21.00
Nickel	9.00-11.00
Tungsten	14.00-16.00
Iron	3.00 max.
Cobalt	Balance

Tensile results are presented in Table XIII with samples of the load-strain curves compiled as Figure 37.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	Confidence Limits 95%
7-P1	-0.2924	±.0016	±.0020
7-P2	-0.2935	±.0015	±.0018
7-P3	-0.2874	±.0012	±.0015

Creep rupture data are presented in Table XIV. Creep deformation versus time values are plotted in Figures 38, 39, and 40. Isothermal plots of the rupture life data appear as Figure 41.

.aterial 7: L-605 (continued)

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to produce failure at 100 hours		300 hours		1000 hours	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
593	1100	551.6	80.0	496.4	72.0	448.2	65.0
649	1200	399.9	58.0	351.6	51.0	299.9	43.5
704	1300	303.4	44.0	275.8	40.0	244.8	35.5

TABLE XIII
Tensile Properties of L-605

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
7-T1	21	70	1032.2	149.7	439.2	63.7	477.1	69.2	----	---	0.07	60	43.4
7-T5			1036.3	150.3	424.0	61.5	477.1	69.2	----	---	0.09	61	42.3
7-T9			1036.3	150.3	375.1	54.4	452.3	65.6	----	---	0.09	61	42.9
7-T2	592	1100	777.0	112.7	208.9	30.3	229.6	33.3	----	---	0.13	70	48.7
7-T6			793.6	115.1	204.8	29.7	231.0	33.5	----	---	0.11	68	48.0
7-T10			789.5	114.5	224.1	32.5	232.4	33.7	----	---	0.10	71	48.3
7-T3	649	1200	669.5	97.1	205.5	29.8	216.5	31.4	----	---	0.11	40.5	35.1
7-T7			666.7	96.7	197.2	28.6	208.9	30.3	----	---	0.18	41	33.7
7-T11			655.7	95.1	186.2	27.0	207.5	30.1	----	---	0.19	39.5	34.4
7-T4	704	1300	568.1	82.4	201.3	29.2	213.7	31.0	----	---	0.07	27	25.9
7-T8			571.6	82.9	188.2	27.3	210.3	30.5	----	---	0.14	26	24.6
7-T12			585.4	84.9	201.3	29.2	219.3	31.8	----	---	0.18	27	25.3

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10⁶ psi
21	70	220.0	32.2
593	1100	190.3	27.6
649	1200	177.2	25.7
704	1300	170.3	24.7

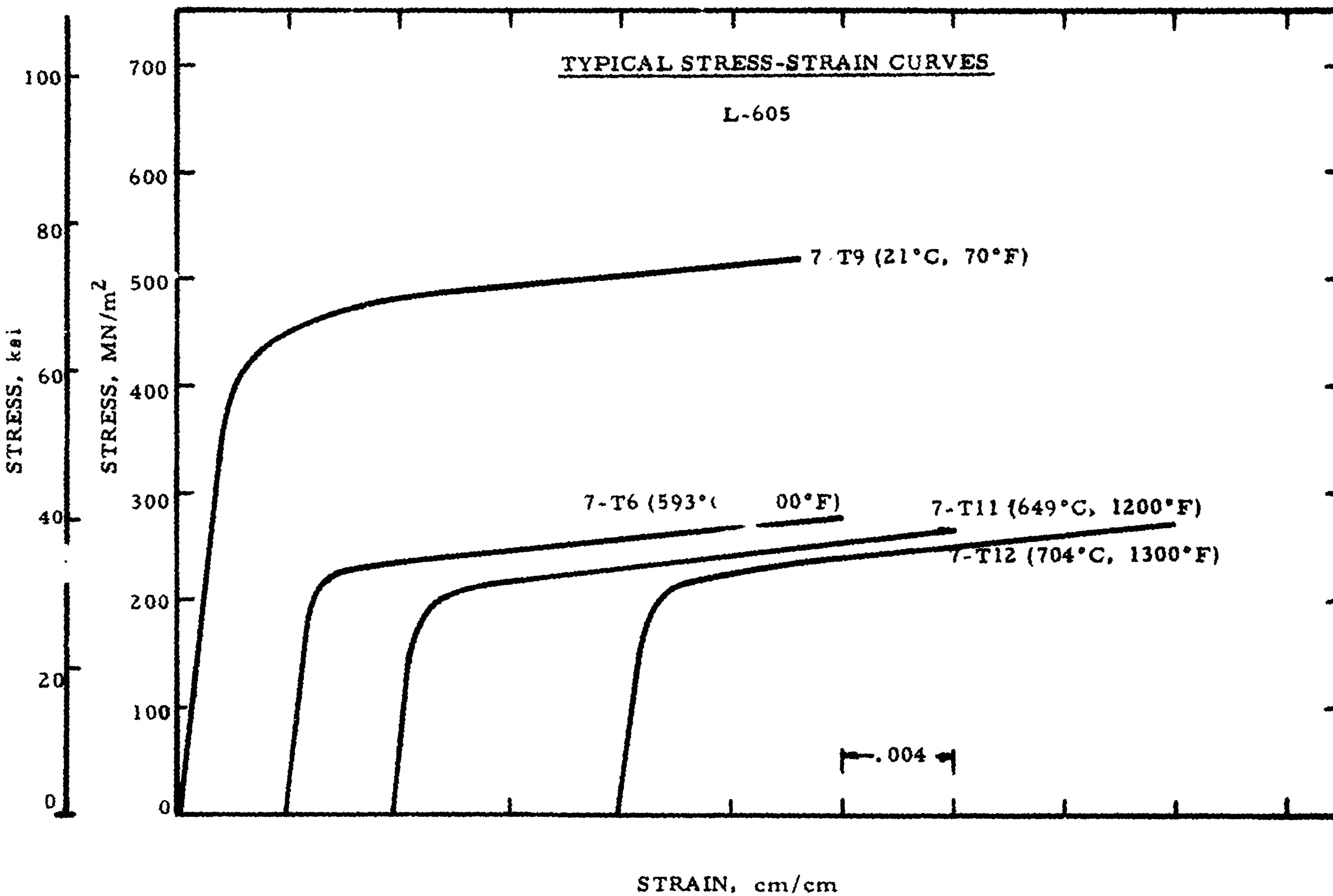

TYPICAL STRESS-STRAIN CURVES
L-605
7-T9 (21°C, 70°F)
7-T6 (593°(00°F)
7-T11 (649°C, 1200°F)
7-T12 (704°C, 1300°F)
.004
STRESS, ksi
STRESS, MN/m²
STRAIN, cm/cm
0
20
40
60
80
100
0
100
200
300
400
500
600
700

Figure 37

TABLE XIV

Creep Rupture Properties of L-605

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
7-C7	593	1100	551.6	80.0	.0074	(a)	(a)	116.2	28.4	27.5
7-C10			517.1	75.0	.0049	(a)	(a)	183.7	27.8	23.8
7-C4			482.6	70.0	.0016	(a)	(a)	525.7	15.3	21.8
7-C13			448.2	65.0	---	---	---	(b)	--	--
7-C15			448.2	65.0	.0009	(a)	(a)	938.6	17.3	21.5
7-C1			413.7	60.0	.0006	(a)	(a)	1976.1	13.7	19.3
7-C5	649	1200	393.0	57.0	.014	(a)	(a)	93.5	12.3	23.2
7-C14			365.4	53.0	.0052	(a)	(a)	263.4	9.1	11.5
7-C2			344.7	50.0	.0044	(c)	(c)	323.4	8.4	11.2
7-C8			324.1	47.0	.0027	(a)	(a)	577.0	6.9	9.1
7-C11			303.4	44.0	.0019	(a)	(a)	905.8	4.2	7.2
7-C16	704	1300	303.4	44.0	.030	80	(d)	97.1	8.0	12.1
7-C6			299.9	43.5	.039	127	(d)	156.8	10.8	10.5
7-C9			268.9	39.0	.012	---	(d)	277.0	5.2	8.9
7-C3			248.2	36.0	.0050	(a)	(a)	637.2	5.7	6.3
7-C12			234.4	34.0	.0026	---	150	(e)	--	--
7-C17			234.4	34.0	.0009	---	117	>1533.1 (f)	--	--

Notes:

(a) Specimen indicated plastic deformation in excess of 1.0% on loading; no third stage creep indicated.
(b) Temperature to 2000° F prior to loading; test void.
(c) Extensometer erratic; data not available
(d) Value obtained on loading.
(e) Temperature 80°F over at 691.1 hours; specimen unloaded.
(f) Specimen unloaded without failure at time shown.

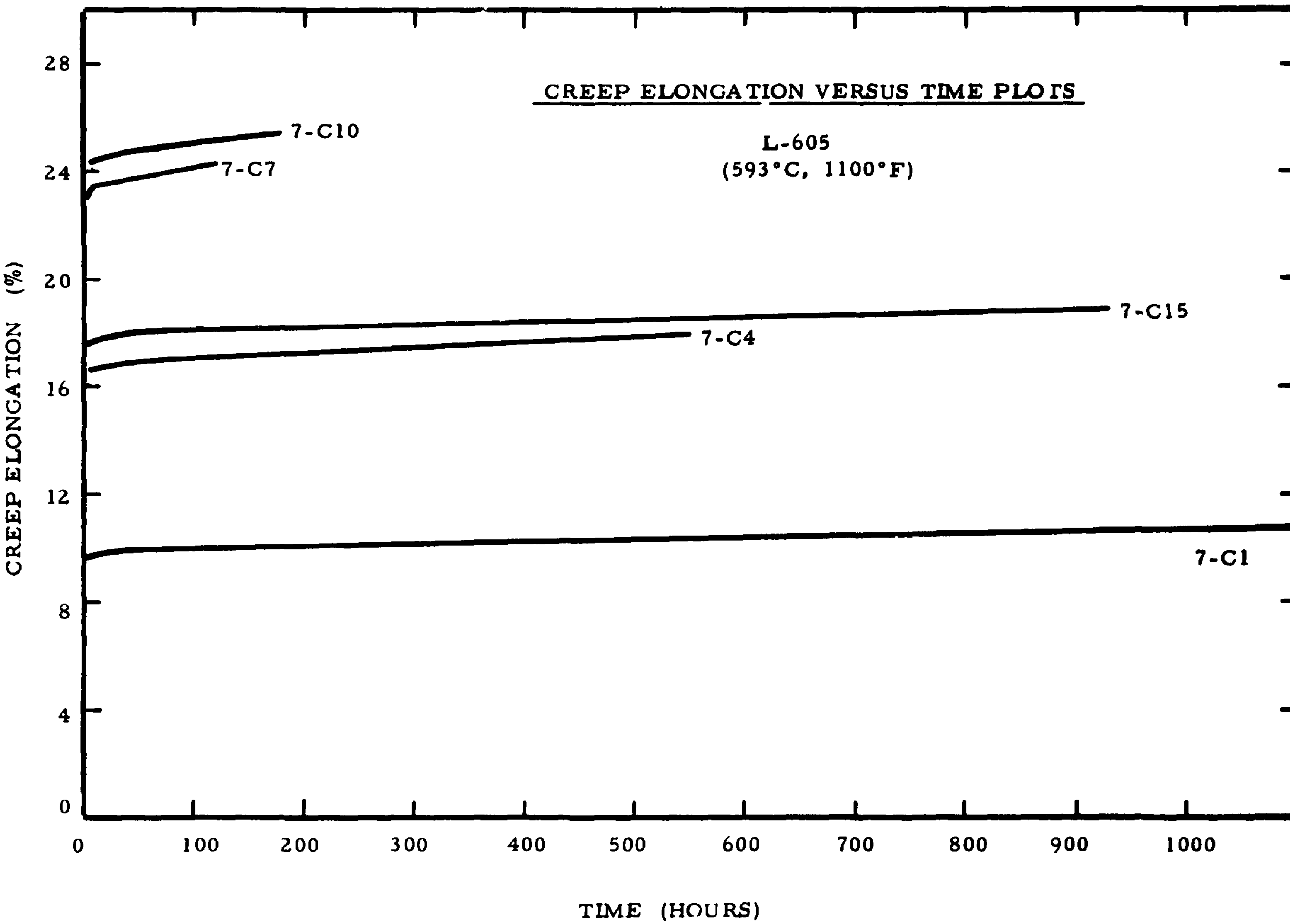
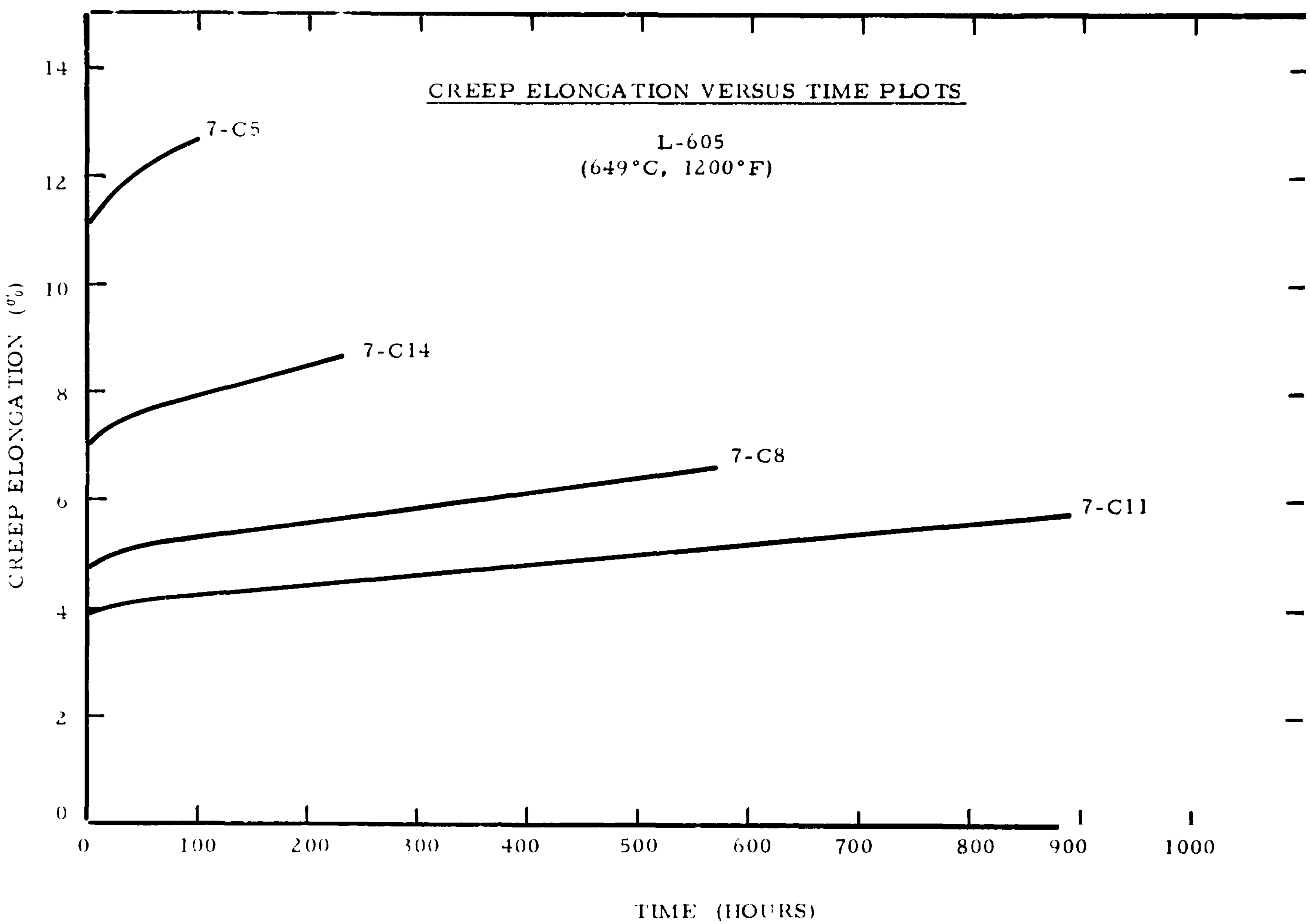

CREEP ELONGATION VERSUS TIME PLOTS
L-605
(593°C, 1100°F)
7-C10
7-C7
7-C15
7-C4
7-C1
CREEP ELONGATION (%)
0
4
8
12
16
20
24
28
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 38



CREEP ELONGATION VERSUS TIME PLOTS
L-605
(649°C, 1200°F)
7-C5
7-C14
7-C8
7-C11
CREEP ELONGATION (%)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 3.

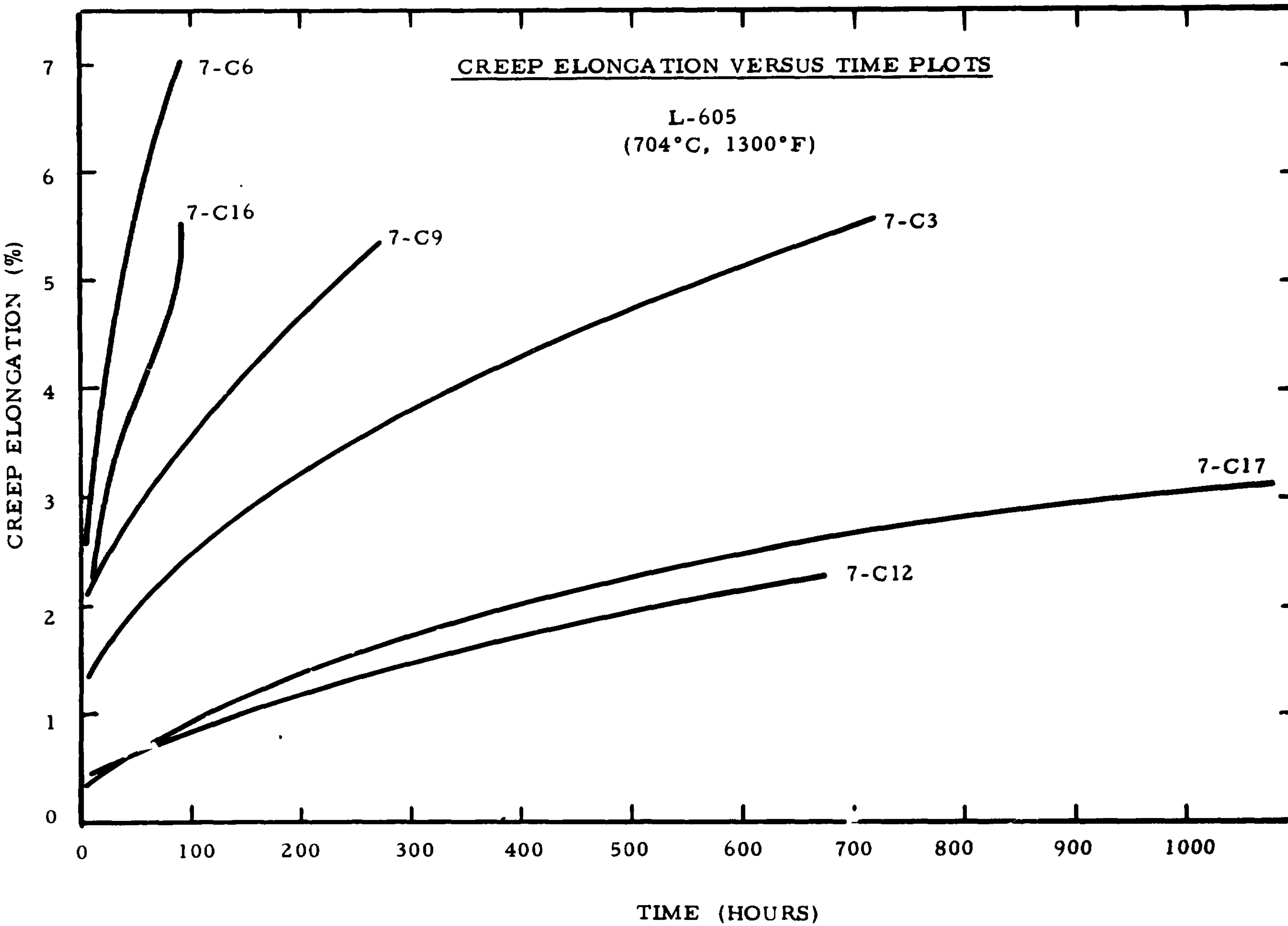

CREEP ELONGATION VERSUS TIME PLOTS
L-605
(704°C, 1300°F)
7-C6
7-C16
7-C9
7-C3
7-C17
7-C12
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 40

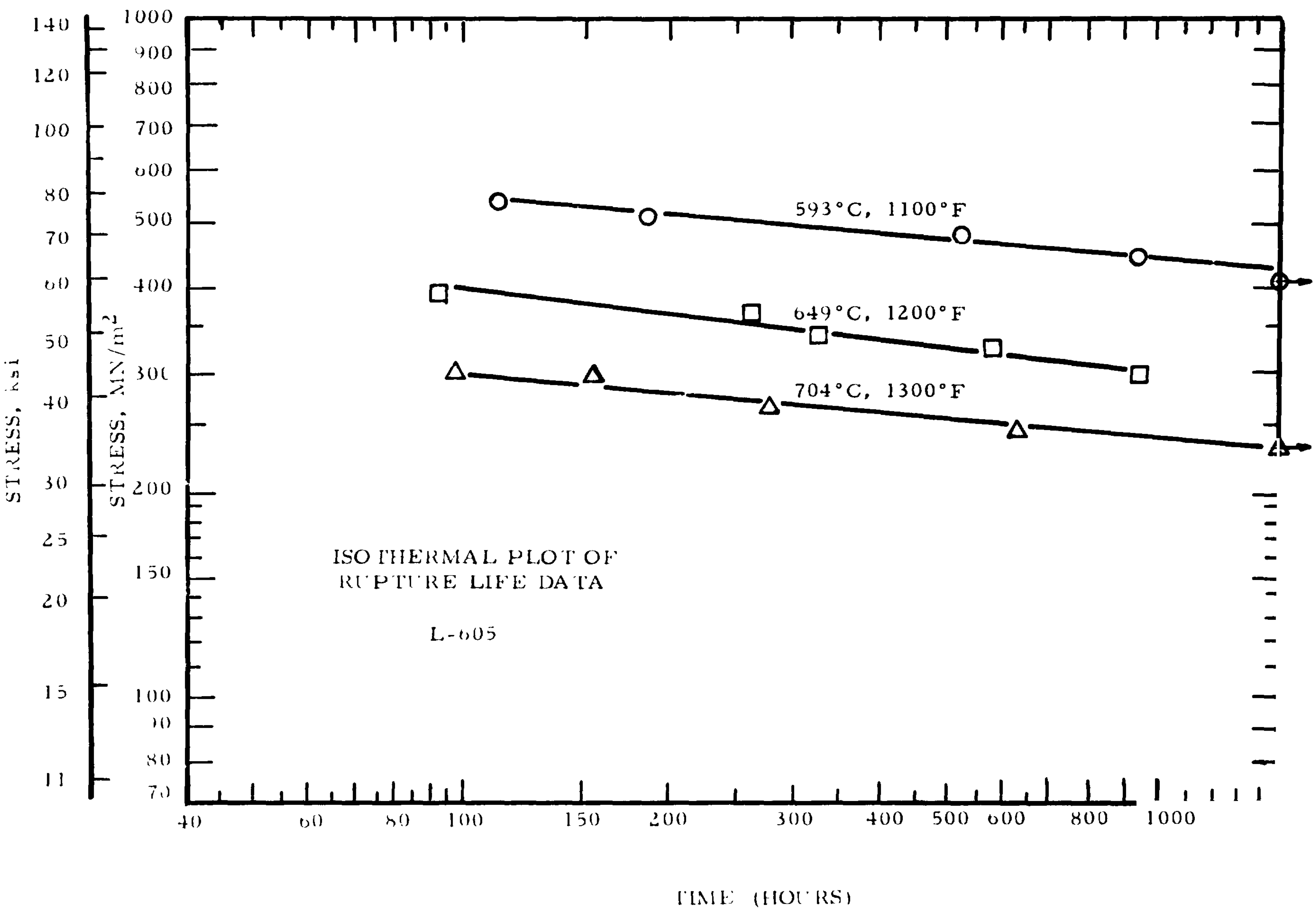

ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
L-605
593°C, 1100°F
649°C, 1200°F
704°C, 1300°F
STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
140
120
100
80
70
60
50
40
30
25
20
15
11
1000
900
800
700
600
500
400
300
200
150
100
90
80
70
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 41

TEST RESULTS (continued)

Material 8: 304 Stainless Steel

This alloy, a low carbon member of the austenitic stainless steel family, was supplied as fully processed bar stock by NASA-Lewis Research Center.

Nominal composition of this alloy is as follows:

Carbon	0.08 max.
Manganese	2.00 max.
Silicon	1.00 max.
Phosphorus	0.045 max.
Sulfur	0.030 max.
Chromium	18.00 - 20.00
Nickel	8.00 - 10.50
Iron	Balance

Tensile results are presented as Table XV with samples of the load-strain curves compiled as Figure 42.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	Confidence Limits 95%
8-P4	-0.2609	±.0039	±.0046
8-P5	-0.2458	±.0040	±.0048
8-P6	-0.2617	±.0047	±.0057

Creep rupture data are presented in Table XVI. Creep deformation versus time values are plotted in Figures 43, 44, and 45. Isothermal plots of the rupture life data appear as Figure 46.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Material 8: 304 Stainless Steel (continued)

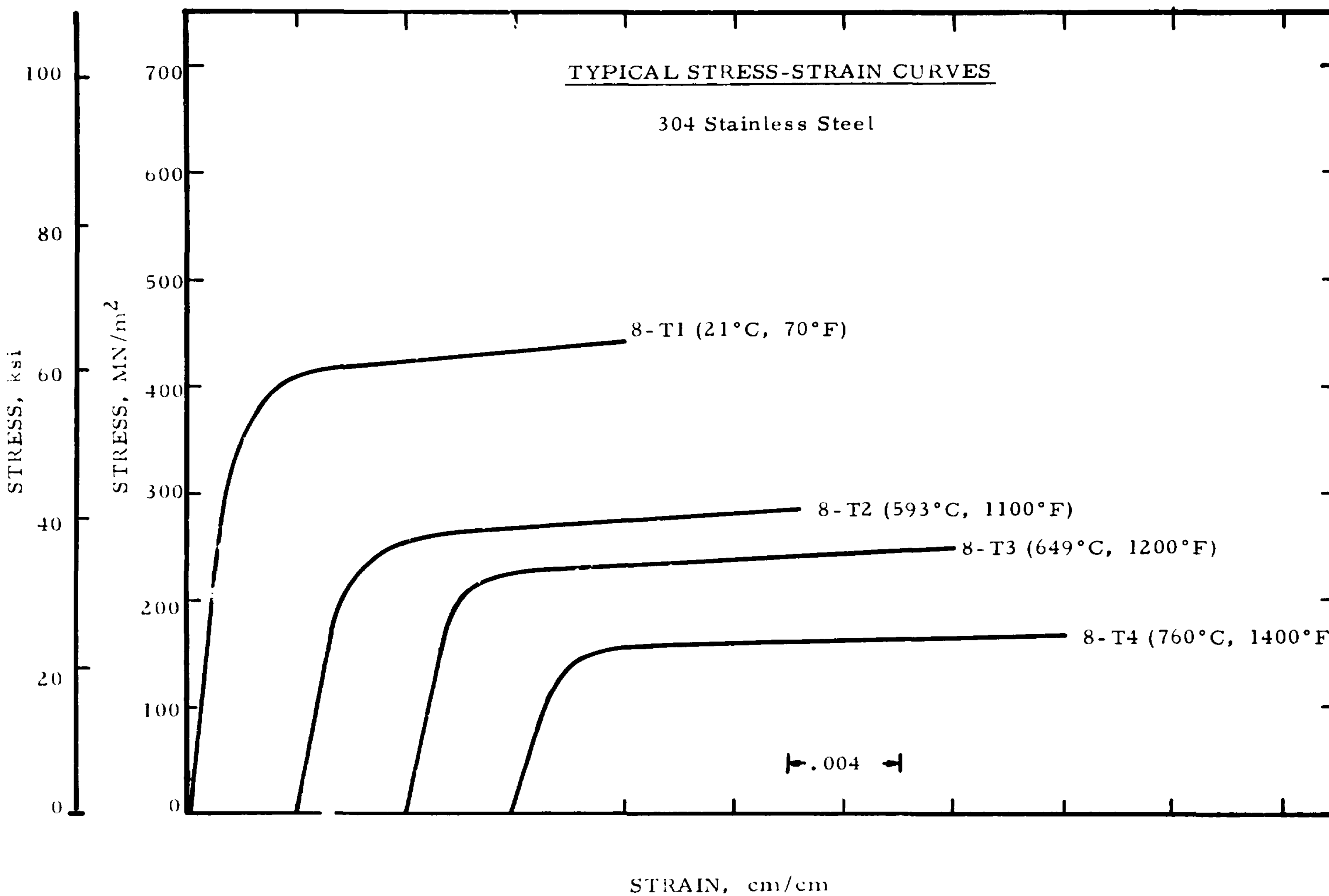
Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m²	ksi	MN/m²	ksi	MN/m²	ksi
593	1100	237.9	34.5	206.8	30.0	179.3	26.0
649	1200	162.0	23.5	134.4	19.5	106.9	15.5
760	1400	68.9	10.0	59.3	8.6	50.3	7.3

TABLE XV

Tensile Properties of 304 Stainless Steel

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m^2	Ultimate Strength ksi	0.02% Yield Strength MN/m^2	0.02% Yield Strength ksi	0.2% Yield Strength MN/m^2	0.2% Yield Strength ksi	Fracture Strength MN/m^2	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
8-T1	21	70	639.1	92.7	286.1	41.5	404.7	58.7	----	---	0.07	65	79.9
8-T5			641.9	93.1	257.9	37.4	393.7	57.1	----	---	----	63	79.9
8-T9			588.8	85.4	183.4	26.6	203.4	29.5	----	---	0.05	81	84.1
8-T2	593	1100	357.2	51.8	193.1	28.0	247.5	35.9	----	---	0.07	36	57.4
8-T6			357.8	51.9	180.0	26.1	252.3	36.6	----	---	0.09	31.5	59.9
8-T10			325.4	47.2	88.3	12.8	102.7	14.9	----	---	0.21	43.5	71.3
8-T3	649	1200	299.2	43.4	177.2	25.7	219.3	31.8	----	---	0.10	44.5	52.3
8-T7			297.9	43.2	184.1	26.7	224.1	32.5	----	---	0.12	40.5	51.5
8-T11			275.1	39.9	65.5	9.5	88.9	12.9	----	---	0.14	55.0	68.2
8-T4	760	1400	180.6	26.2	115.8	16.8	153.8	22.3	----	---	0.06	47	56.2
8-T8			183.4	26.6	119.3	17.3	153.8	22.3	----	---	0.06	58	52.9
8-T12			173.7	25.2	76.5	11.1	91.7	13.3	----	---	0.13	95	87.6

Temp. °C	Temp. °F	Modulus of Elasticity GN/m^2	Modulus of Elasticity 10^6 psi
21	70	197.9	28.7
593	1100	153.8	22.3
649	1200	141.3	20.5
760	1400	111.7	16.2



TYPICAL STRESS-STRAIN CURVES
304 Stainless Steel
STRESS, ksi
100
80
60
40
20
0
STRESS, MN/m2
700
600
500
400
300
200
100
0
8-T1 (21°C, 70°F)
8-T2 (593°C, 1100°F)
8-T3 (649°C, 1200°F)
8-T4 (760°C, 1400°F)
.004
STRAIN, cm/cm

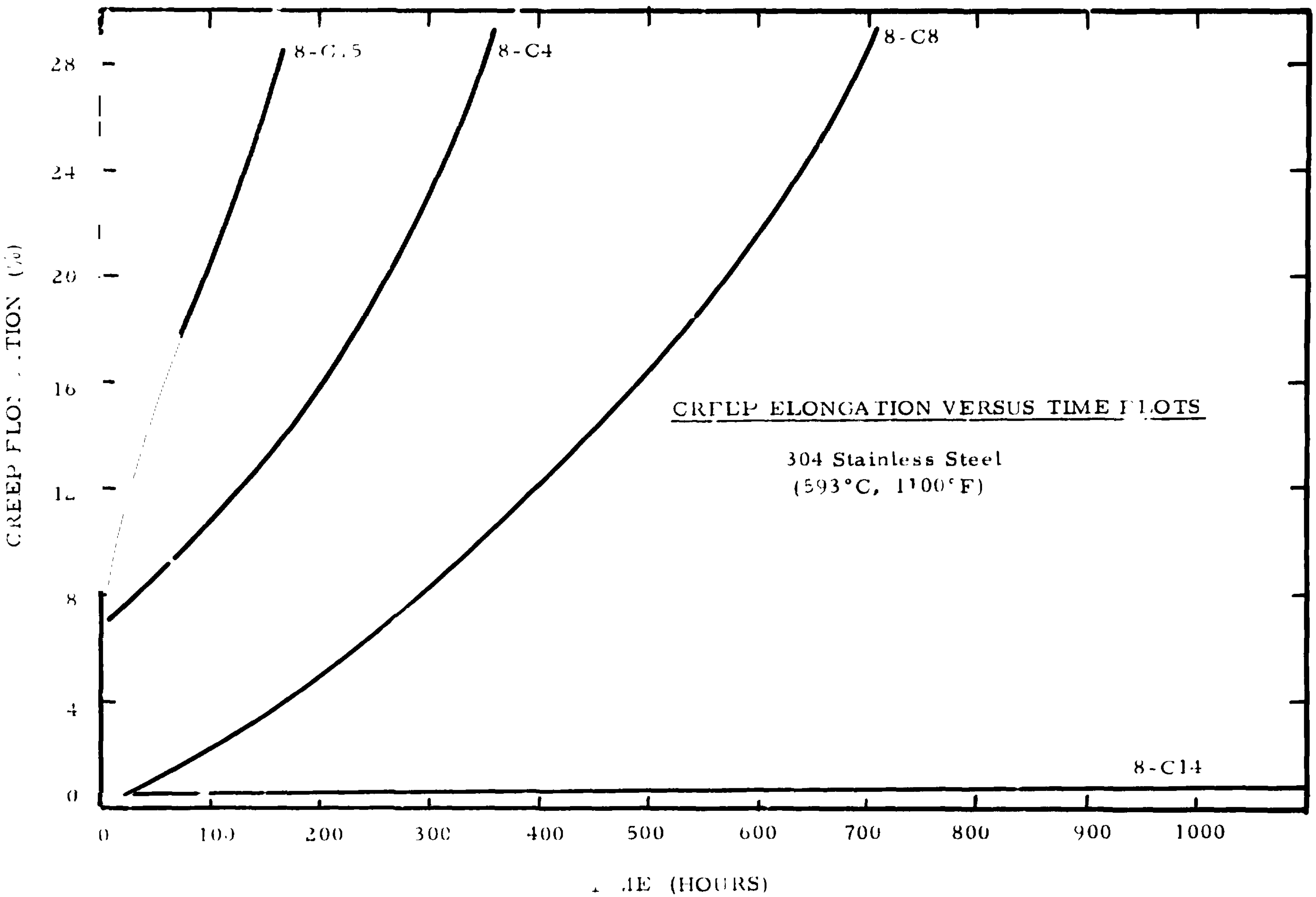
Figure 42

TABLE XVI

Creep Rupture Properties of 304 Stainless Steel

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
8-C1	593	1100	234.4	34.0	.41	(a)	(b)	70.5	49.3	79.8
8-C11			220.6	32.0	--	--	--	(c)	--	--
8-C15			220.6	32.0	.10	148	(b)	193.5	47.6	72.4
8-C4			206.8	30.0	.042	175	(b)	410.2	47.7	75.5
8-C8			179.3	26.0	.030	270	47	804.2	46.3	48.0
8-C14			106.9	15.5	.0002	--	--	1750.6 (d)	--	--
8-C18	649	1200	162.0	23.5	--	--	--	(e)	--	--
8-C2			158.6	23.0	.45	31	(b)	125.1	46.8	83.7
8-C7			137.9	20.0	.11	95	12	242.6	50.6	46.7
8-C17			124.1	18.0	.0011	--	(b)	1274.6 (d)	--	--
8-C12			110.3	16.0	.016	335	80	857.6	33.5	32.8
8-C9	760	1400	75.8	11.0	.15	10	7	45.7	23.2	26.4
8-C3			65.5	9.5	.31	--	0.8	151.3	100.6	90.4
8-C10			58.6	8.5	--	--	--	(f)	--	--
8-C13			58.6	8.5	.103	22	2.2	406.8	104.8	85.8
8-C6			55.2	8.0	.068	3.	3	594.2	97.3	85.2
8-C5			44.8	6.5	.017	1(	11	2040.2	105.6	64.2

(a) Insufficient data to obtain value
(b) Over 1% plastic strain on loading
(c) Specimen over temperature prior to loading; test void
(d) Specimen unloaded without failing at time shown
(e) Controller malfunction at 71.7 hours; test void
(f) Test run in error at 1300°F; test void



CREEP ELONGATION VERSUS TIME PLOTS
304 Stainless Steel
(593°C, 1100°F)
8-C4
8-C8
8-C14
CREEP ELONGATION (%)
28
24
20
16
8
4
0
0
200
300
400
500
600
700
800
900
1000
(HOURS)

Figure 43

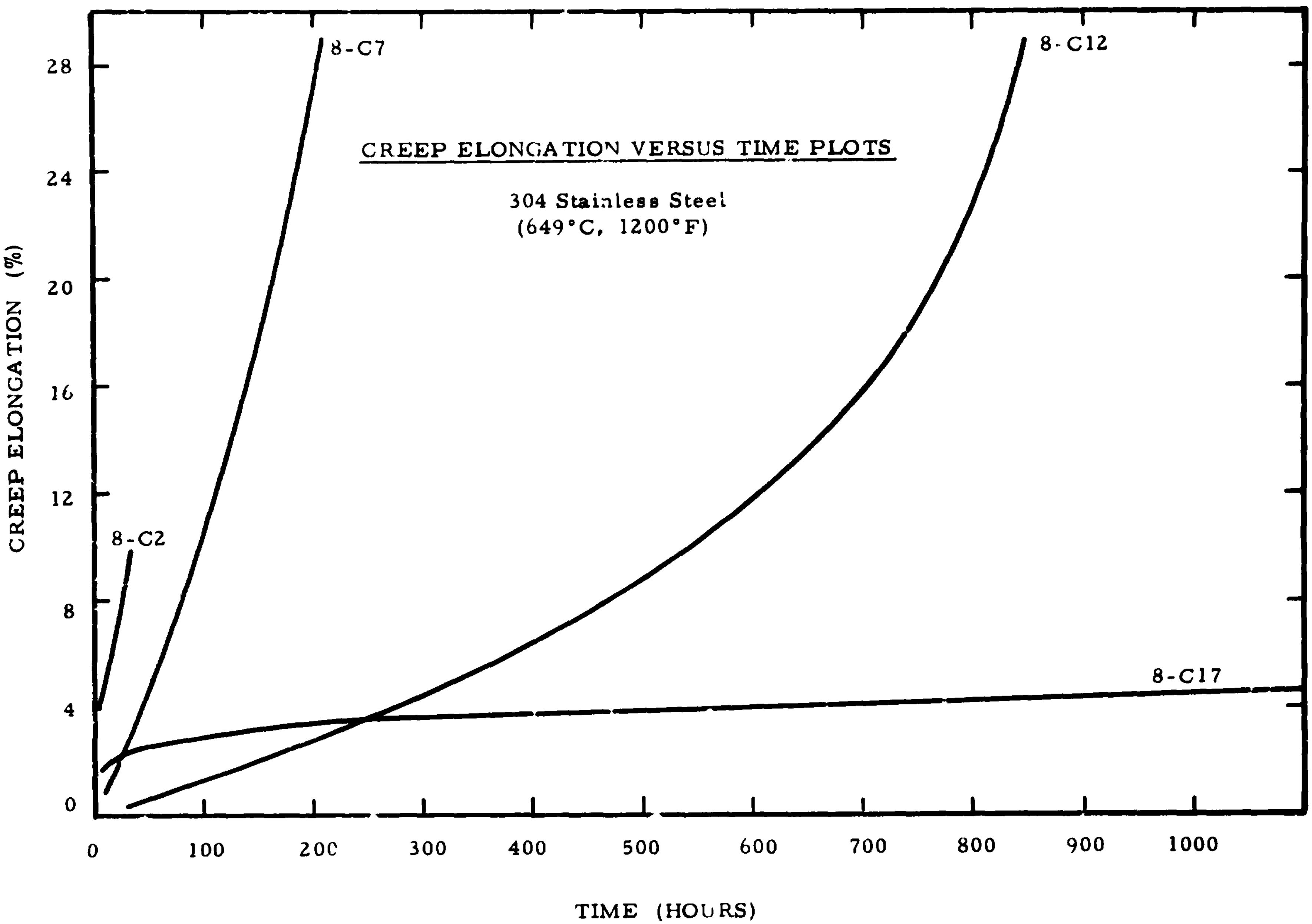

CREEP ELONGATION VERSUS TIME PLOTS
304 Stainless Steel
(649°C, 1200°F)
8-C7
8-C12
8-C2
8-C17
CREEP ELONGATION (%)
28
24
20
16
12
8
4
0
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 44

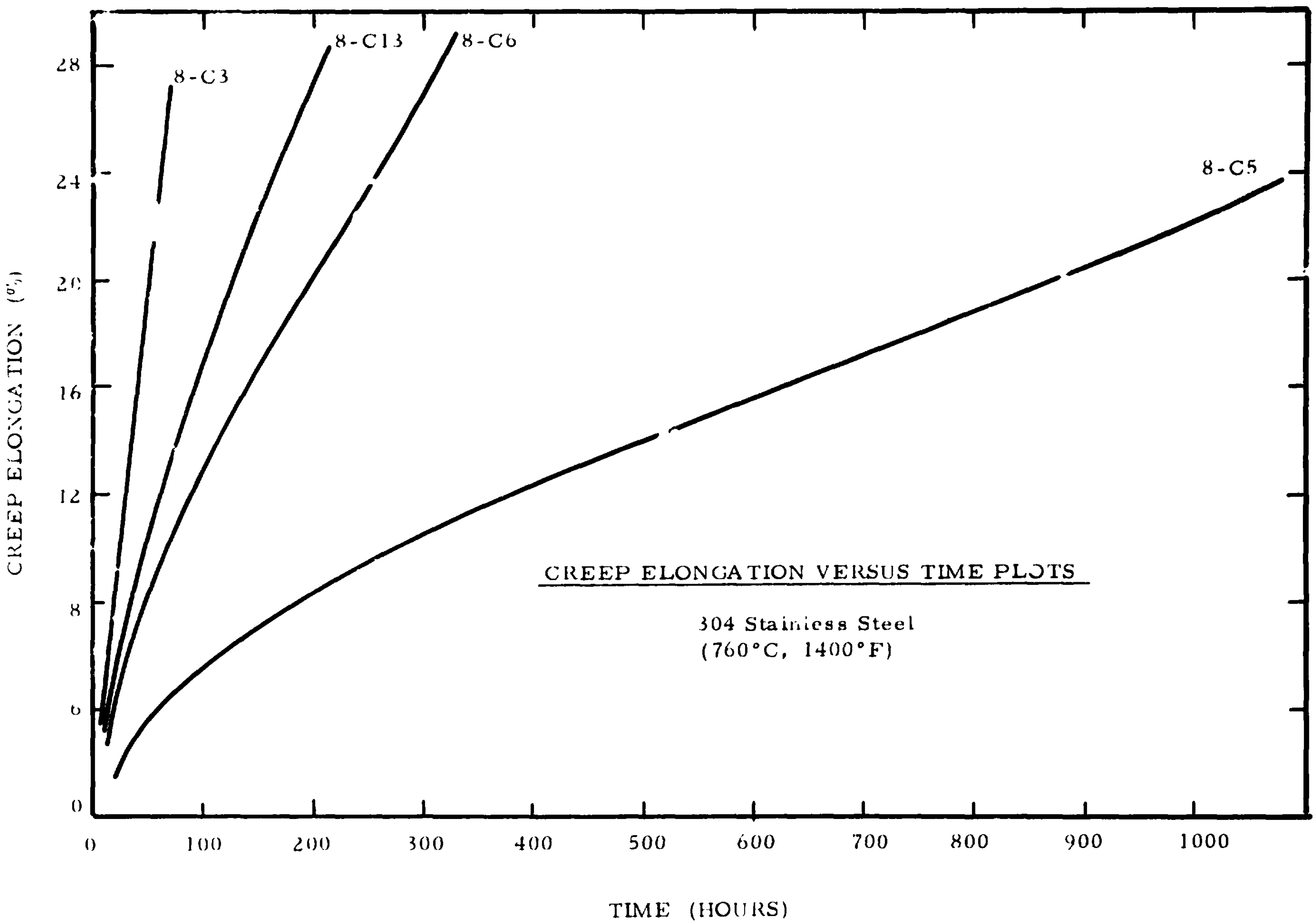
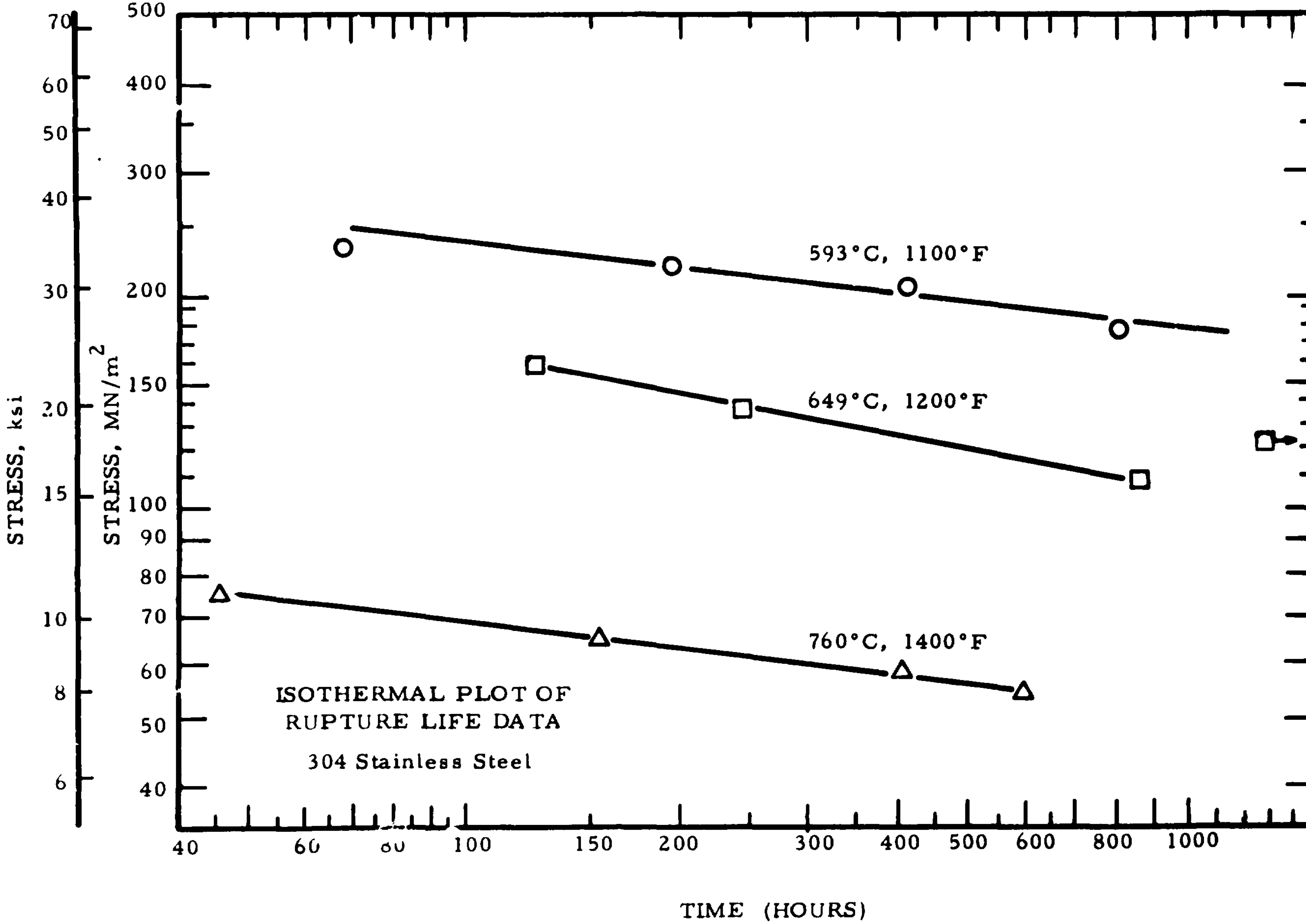

CREEP ELONGATION VERSUS TIME PLOTS
304 Stainless Steel
(760°C, 1400°F)
8-C3
8-C13
8-C6
8-C5
CREEP ELONGATION (%)
TIME (HOURS)
0
100
200
300
400
500
600
700
800
900
1000
4
8
12
16
20
24
28

Figure 45



ISOTHERMAL PLOT OF RUPTURE LIFE DATA
304 Stainless Steel
593°C, 1100°F
649°C, 1200°F
760°C, 1400°F
STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 46

TEST RESULTS (continued)

Material 9: 316 Stainless Steel

This molybdenum bearing grade of austenitic stainless, which can be hardened only by cold working, was supplied as fully processed wrought bar stock by NASA-Lewis Research Center.

The nominal composition of this alloy is as follows:

Carbon	0.08 max.
Manganese	2.00 max.
Silicon	1.00 max.
Phosphorus	0.045 max.
Sulfur	0.030 max.
Chromium	17.00 - 19.00
Nickel	9.00 - 12.00
Titanium	5XC min.
Iron	Balance

Tensile results are presented as Table XVII with samples of the load-strain curves compiled as Figure 47.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	95%
9-P4	-0.2881	±.0028	±.0033
9-P5	-0.2846	±.0023	±.0027
9-P6	-0.2928	±.0035	±.0043

Creep rupture data are presented in Table XVIII. Creep deformation versus time values are plotted in Figures 48, 49, and 50. Isothermal plots of the rupture life data appear as Figure 51.

TEST RESULTS (continued)

Material 9: 316 Stainless Steel (continued)

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
[illegible]	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
[illegible]	1100	303.4	44.0	282.7	41.0	255.1	37.0
704	1300	134.4	19.5	113.8	16.5	93.1	13.5
816	1500	64.1	9.3	51.7	7.5	40.7	5.9

TABLE XVII

Tensile Properties of 316 Stainless Steel

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m^2	Ultimate Strength ksi	0.02% Yield Strength MN/m^2	0.02% Yield Strength ksi	0.2% Yield Strength MN/m^2	0.2% Yield Strength ksi	Fracture Strength MN/m^2	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
9-T1	21	70	629.5	91.3	175.1	25.4	240.6	34.9	----	---	0.15	79	82.0
9-T5			632.3	91.7	153.1	22.2	245.5	35.6	----	---	0.14	79	82.0
9-T9			618.5	89.7	151.0	21.9	225.5	32.7	----	---	0.14	80	82.1
9-T2	593	1100	441.3	64.0	82.0	11.9	111.7	16.2	----	---	0.22	53	71.3
9-T6			444.0	64.4	68.3	9.9	100.7	14.6	----	---	0.16	53	70.7
9-T10			442.0	64.1	71.7	10.4	106.2	15.4	----	---	0.24	56	70.8
9-T3	704	1300	266.1	38.6	71.7	10.4	103.4	15.0	----	---	0.21	67	66.1
9-T7			273.0	39.6	80.0	11.6	112.4	16.3	----	---	0.29	67.5	64.1
9-T11			269.0	39.1	77.9	11.3	106.2	15.4	----	---	0.21	61	62.3
9-T4	816	1500	161.3	23.4	75.2	10.9	100.7	14.6	----	---	0.21	105	85.5
9-T8			155.1	22.5	71.7	10.4	99.3	14.4	----	---	0.18	97	97.0
9-T12			157.9	22.9	73.1	10.6	98.6	14.3	----	---	0.19	65.5	79.5

Temp. °C	Temp. °F	Modulus of Elasticity GN/m^2	Modulus of Elasticity 10^6 psi
21	70	177.9	25.8
593	1100	149.6	21.7
704	1300	141.3	20.5
816	1500	105.5	15.3

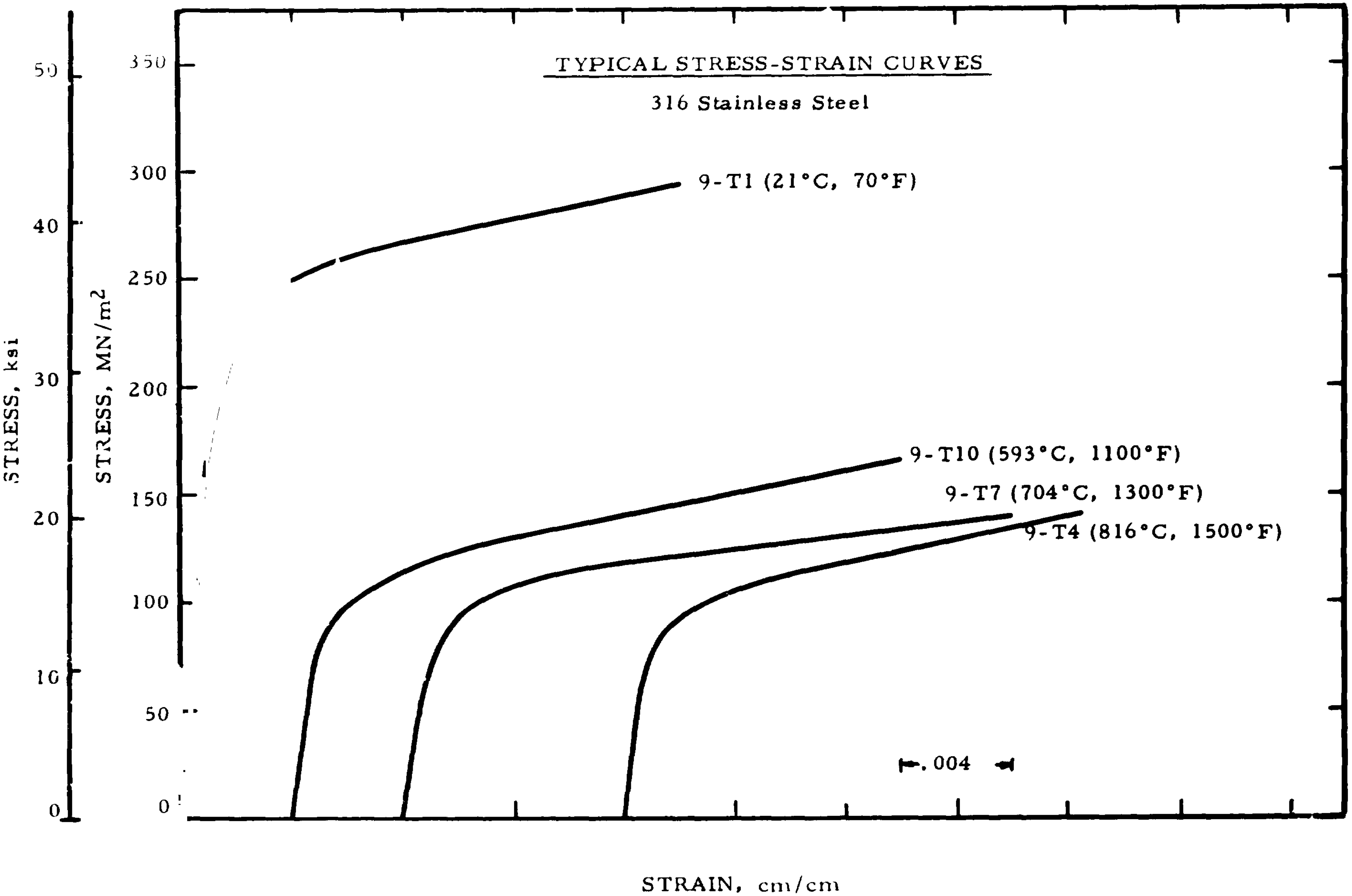

TYPICAL STRESS-STRAIN CURVES
316 Stainless Steel
9-T1 (21°C, 70°F)
9-T10 (593°C, 1100°F)
9-T7 (704°C, 1300°F)
9-T4 (816°C, 1500°F)
.004
STRESS, ksi
0
10
20
30
40
50
STRESS, MN/m²
0
50
100
150
200
250
300
350
STRAIN, cm/cm

Figure 47

TABLE XVIII

Creep Rupture Properties of 316 Stainless Steel

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
9-C1	593	1100	317.2	46.0	.105	(a)	(b)	60.6	22.1	28.7
9-C7			310.3	45.0	.044	52	(b)	80.8	28.5	32.9
9-C4			289.6	42.0	.036	120	(b)	249.7	35.4	42.0
9-C13			268.9	39.0	.022	380	(b)	660.7	33.8	40.9
9-C10			241.3	35.0	.004	980	(b)	2118.1	30.2	40.8
9-C2	704	1300	172.7	25.0	1.06	9	(b)	22.5	62.5	80.0
9-C5			144.8	21.0	--	14	(b)	62.9	78.4	80.9
9-C8			124.1	18.0	.169	55	0.8	169.7	81.3	83.2
9-C14			106.9	15.5	.052	73	15.5	387.1	70.4	68.7
9-C11			96.5	14.0	.031	300	25	844.7	73.8	72.3
9-C3	816	1500	82.7	12.0	1.99	(a)	0.3	26.5	84.4	81.8
9-C6			68.9	10.0	.653	(a)	1.3	93.1	54.7	73.8
9-C9			58.6	8.5	.165	(a)	3.5	177.8	88.1	73.7
9-C12			51.7	7.5	.112	140	7.5	274.4	68.8	67.4
9-C15			41.4	6.0	.020	370	35	938.2	45.4	48.5

(a) Insufficient data points to determine this value
(b) Specimen exceeded 1% plastic deformation on loading

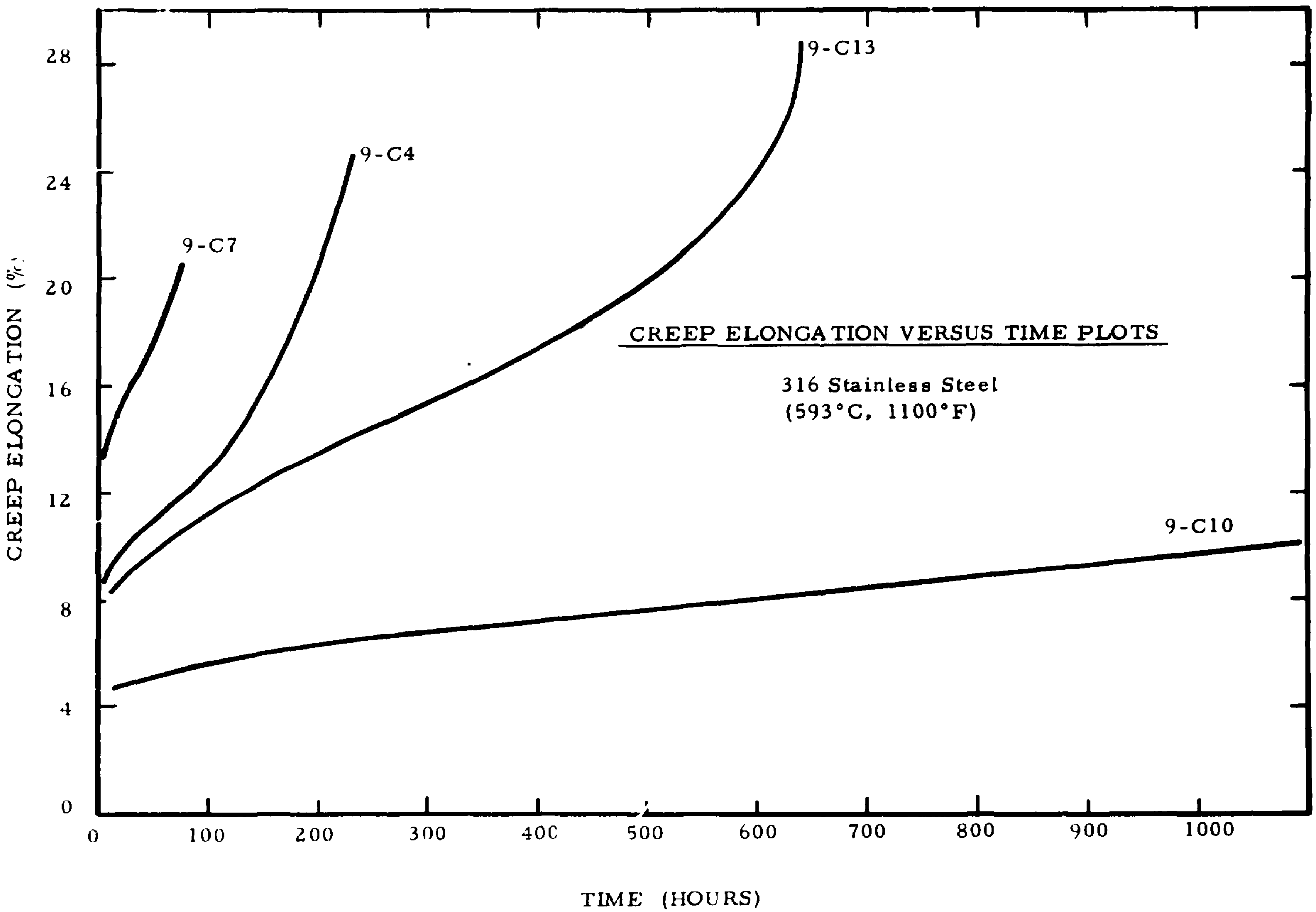

CREEP ELONGATION VERSUS TIME PLOTS
316 Stainless Steel
(593°C, 1100°F)
9-C13
9-C4
9-C7
9-C10
CREEP ELONGATION (%)
TIME (HOURS)
0
4
8
12
16
20
24
28
0
100
200
300
400
500
600
700
800
900
1000

Figure 48

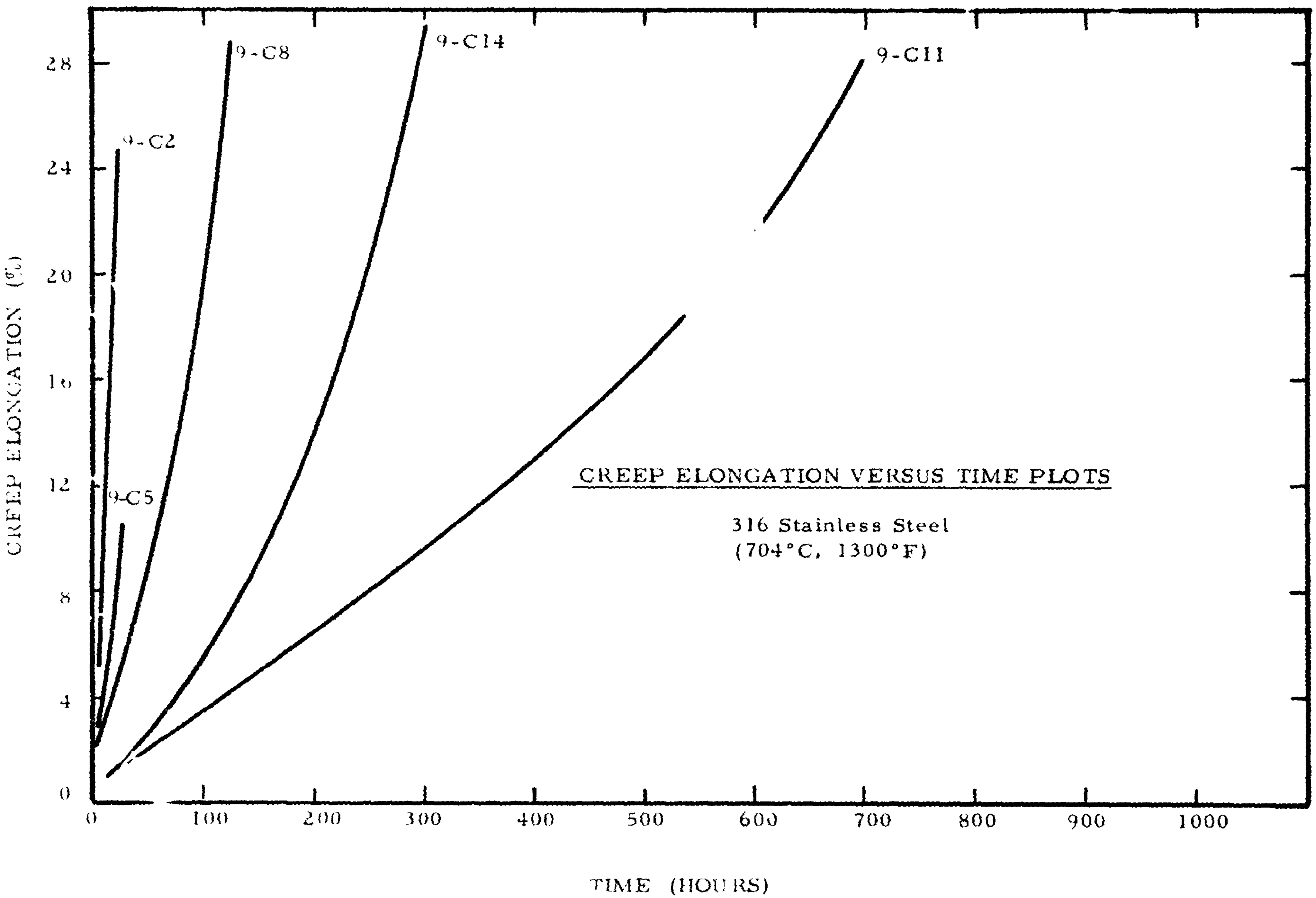

CREEP ELONGATION VERSUS TIME PLOTS
316 Stainless Steel
(704°C, 1300°F)
9-C8
9-C14
9-C11
9-C2
9-C5
CREEP ELONGATION (%)
TIME (HOURS)
0
4
8
12
16
20
24
28
100
200
300
400
500
600
700
800
900
1000

Figure 49

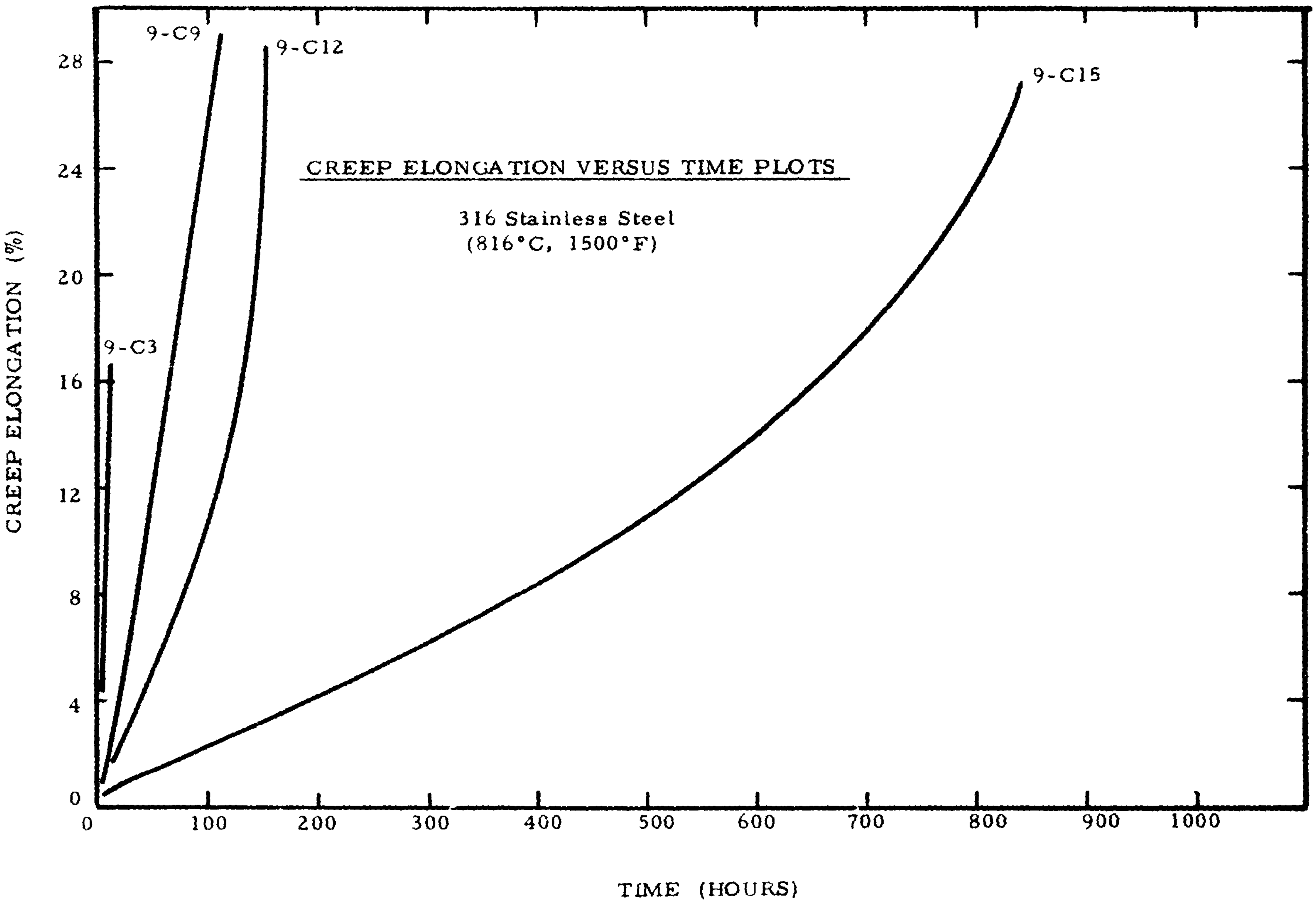

CREEP ELONGATION VERSUS TIME PLOTS
316 Stainless Steel
(816°C, 1500°F)
9-C9
9-C12
9-C15
9-C3
CREEP ELONGATION (%)
0
4
8
12
16
20
24
28
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 50

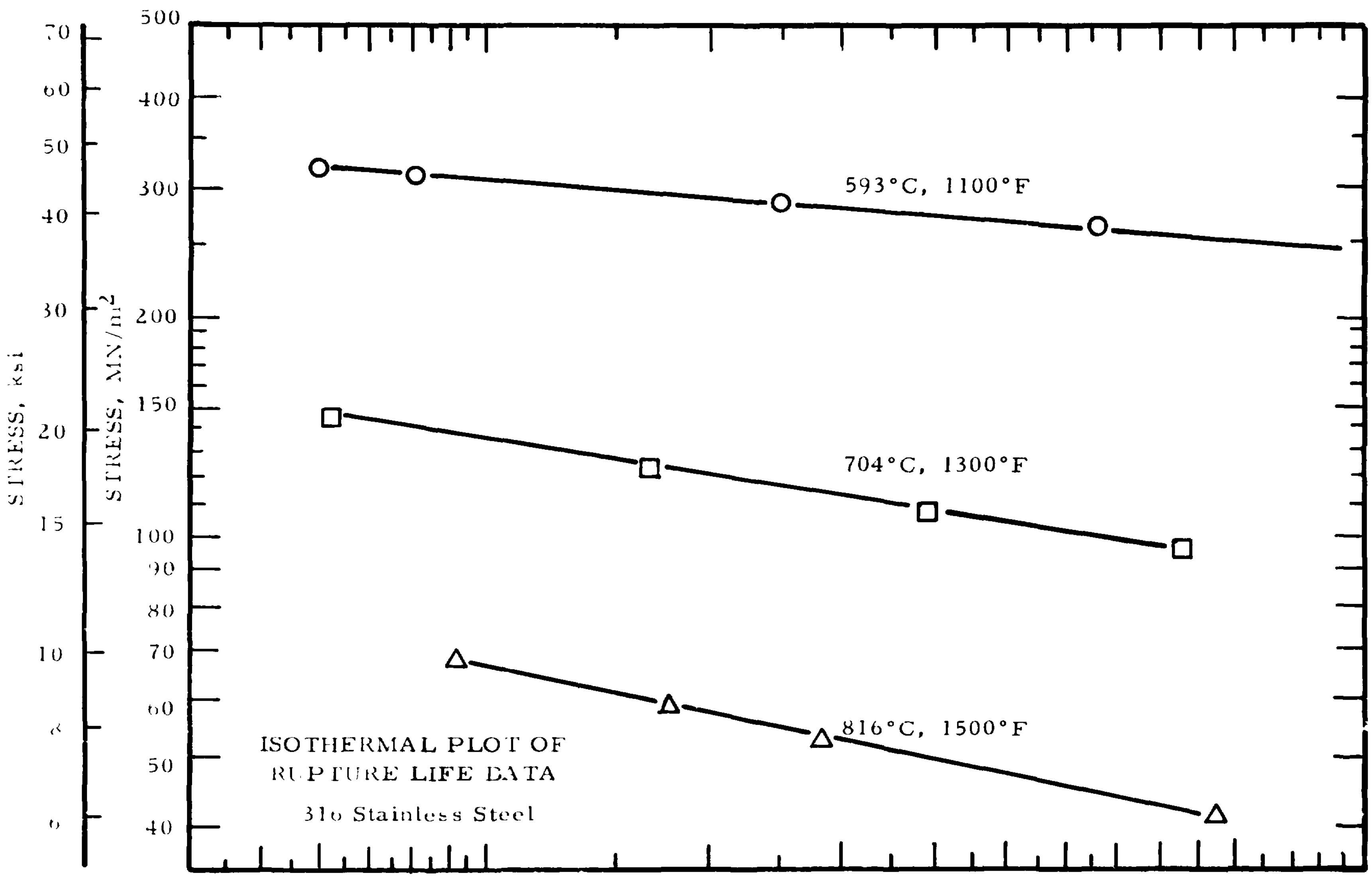

STRESS, ksi
STRESS, MN/m^2
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
593°C, 1100°F
704°C, 1300°F
816°C, 1500°F
ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
316 Stainless Steel

Figure 51

TEST RESULTS (continued)

Material 10: Udimet 700

This nickel-base alloy was developed for high temperature tensile strength, creep resistance and high fatigue strength. Chemical composition of this heat of material (supplied by NASA) is as follows:

Carbon	0.07%
Manganese	<0.10
Silicon	<0.10
Chromium	14.6
Cobalt	19.0
Iron	0.19
Molybdenum	4.85
Boron	0.027
Zirconium	<0.05
Sulfur	0.003
Copper	<0.10
Nickel	Balance

The bar stock supplied by NASA-Lewis Research Center required this recommended heat treatment prior to final machining.

2125°F/4 hours/air cool to room temperature
1975°F/4 hours/air cool to room temperature
1550°F/24 hours/air cool to room temperature
1400°F/16 hours/air cool to room temperature

Tensile results are presented as Table XIX with samples of the load-strain curves compiled as Figure 52.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	95%
10-P1	-0.2903	±.0014	±.0017
10-P2	-0.2926	±.0023	±.0023
10-P3	-0.2862	±.0017	±.0020

TEST RESULTS (continued)

Material 10: Udimet 700 (continued)

Creep rupture data are presented in Table XX. Creep deformation versus time values are plotted in Figures 53, 54, and 55. Isothermal plots of the rupture life data appear as Figure 56.

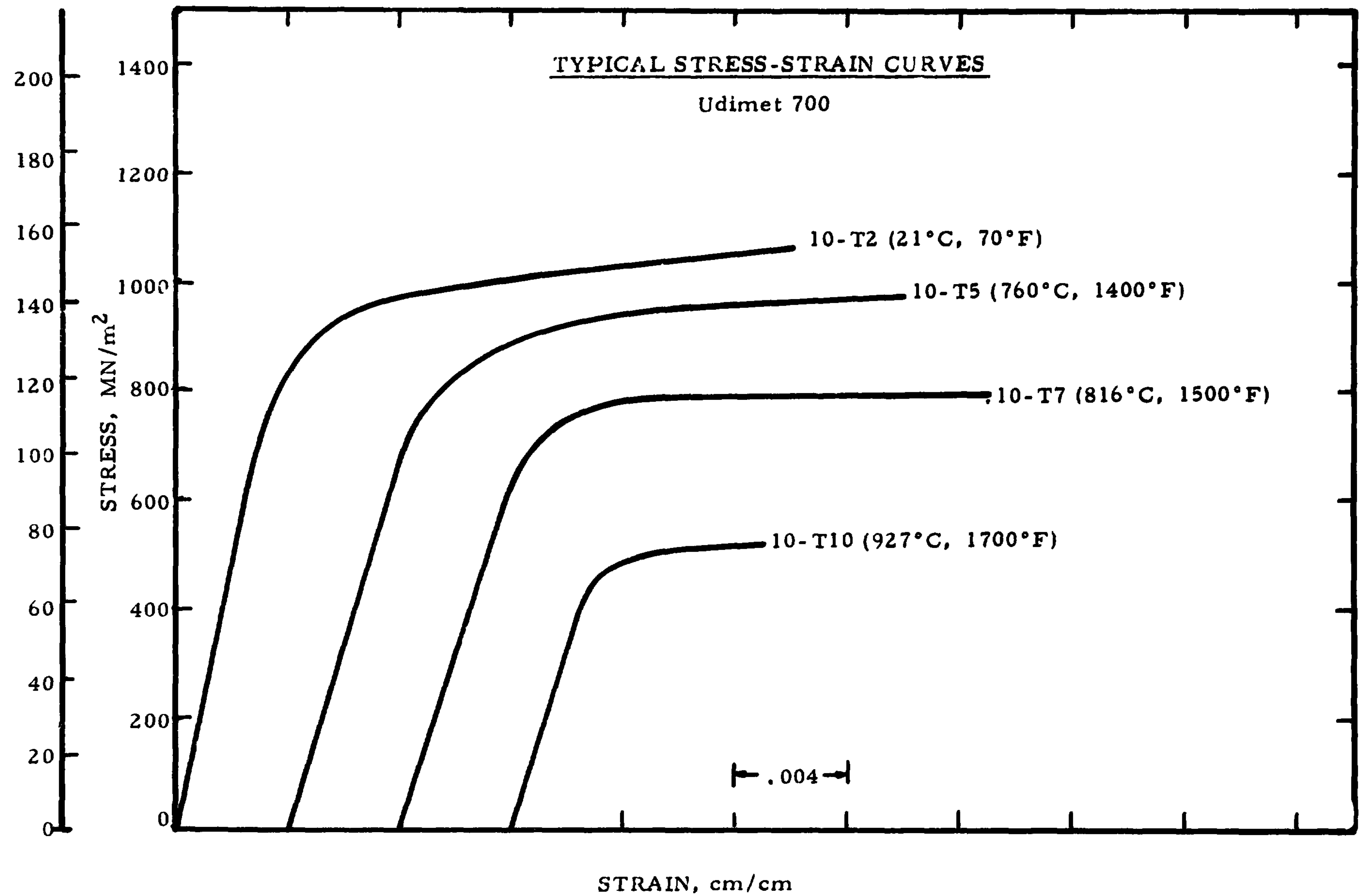
An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
760	1400	482.6	70.0	420.6	61.0	358.5	52.0
816	1500	372.3	54.0	331.0	48.0	289.6	42.0
927	1700	186.2	27.0	151.7	22.0	120.7	17.5

TABLE XIX
Tensile Properties of Udimet 700

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
10-T1	21	70	1373.4	199.2	637.8	92.5	925.3	134.2	----	---	0.07	17.0	15.5
10-T2			1370.7	198.8	711.5	103.2	924.6	134.1	----	---	0.12	15.5	16.4
10-T3			1374.8	199.4	799.8	116.0	938.4	136.1	----	---	0.11	16.3	15.8
10-T4	760	1400	1039.0	150.7	688.1	99.8	870.8	126.3	974.9	141.4	0.11	14.5	14.9
10-T5			1029.4	149.3	699.1	101.4	864.6	125.4	948.7	137.6	0.08	16.0	19.9
10-T6			1010.1	146.5	675.7	98.0	854.3	123.9	924.6	134.1	0.08	16.5	17.2
10-T7	816	1500	886.0	128.5	595.0	86.3	771.5	111.9	721.9	104.7	0.03	14.5	19.3
10-T8			857.7	124.2	633.6	91.9	783.2	113.6	699.8	101.5	0.04	15	18.6
10-T9			902.5	130.9	599.8	87.0	795.7	115.4	735.7	106.7	0.04	18	18.1
10-T10	927	1700	540.6	78.4	447.5	64.9	510.9	74.1	224.8	32.6	0.02	14	16.9
10-T11			559.2	81.1	462.6	67.1	535.0	77.6	202.7	29.4	0.03	12	14.6
10-T12			541.2	78.5	434.4	63.0	524.0	76.0	1.4	0.2	0.02	12.5	15.2

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	228.2	33.1
760	1400	190.3	27.6
816	1500	171.7	24.9
927	1700	158.6	23.0



TYPICAL STRESS-STRAIN CURVES
Udimet 700
STRESS, ksi
STRESS, MN/m²
STRAIN, cm/cm
10-T2 (21°C, 70°F)
10-T5 (760°C, 1400°F)
10-T7 (816°C, 1500°F)
10-T10 (927°C, 1700°F)
.004
0
20
40
60
80
100
120
140
160
180
200
200
400
600
800
1000
1200
1400

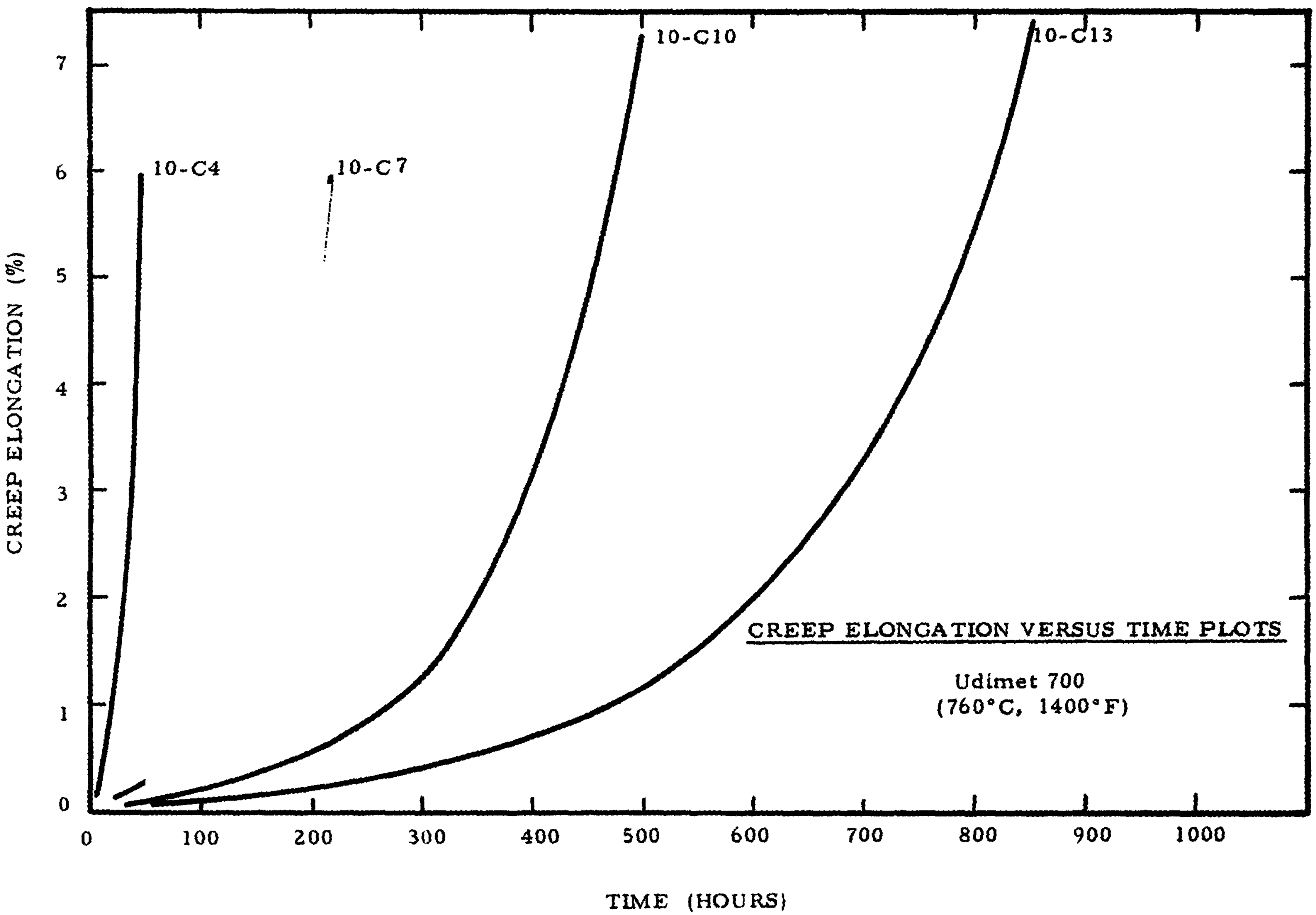
Figure 52

TABLE XX

Creep Rupture Properties of Udimet 700

Specimen Number	Temp. °C	Temp. °F	Stress MN/m^2	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
10-C1	760	1400	586.1	85.0	--	(a)	(a)	26.3	5.5	9.6
10-C4			537.8	78.0	.044	13	19	43.9	5.5	10.1
10-C7			434.4	63.0	.0060	78	113	243.0	12.1	16.8
10-C10			393.0	57.0	.0018	150	275	551.2	13.6	18.7
10-C13			365.4	53.0	.0015	320	480	955.5	18.2	23.5
10-C2	816	1500	448.2	65.0	--	(a)	(a)	17.7	5.9	8.6
10-C5			413.7	60.0	.052	11	15	39.8	7.5	10.7
10-C11			344.7	50.0	.0078	55	89	164.5	10.2	15.5
10-C8			310.3	45.0	.0028	195	282	613.6	13.5	21.2
10-C14			289.6	42.0	.0014	250	420	971.6	13.1	17.5
10-C16	927	1700	186.2	27.0	.025	29	37	107.8	12.9	19.0
10-C3			172.4	25.0	.027	73	40	141.1	10.4	13.4
10-C6			158.6	23.0	--	--	--	(b)	--	--
10-C9			158.6	23.0	.0092	75	101	242.1	10.5	14.4
10-C12			131.0	19.0	--	(c)	(c)	320.2	11.0	15.7
10-C15			117.2	17.0	.0017	250	475	1187.3	17.0	19.9

(a) Insufficient data available to obtain value
(b) Specimen to 2000°F prior to loading; no test
(c) Data is erratic; cannot determine values



CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
100
200
300
400
500
600
700
800
900
1000
10-C4
10-C7
10-C10
10-C13
CREEP ELONGATION VERSUS TIME PLOTS
Udimet 700
(760°C, 1400°F)

Figure 53

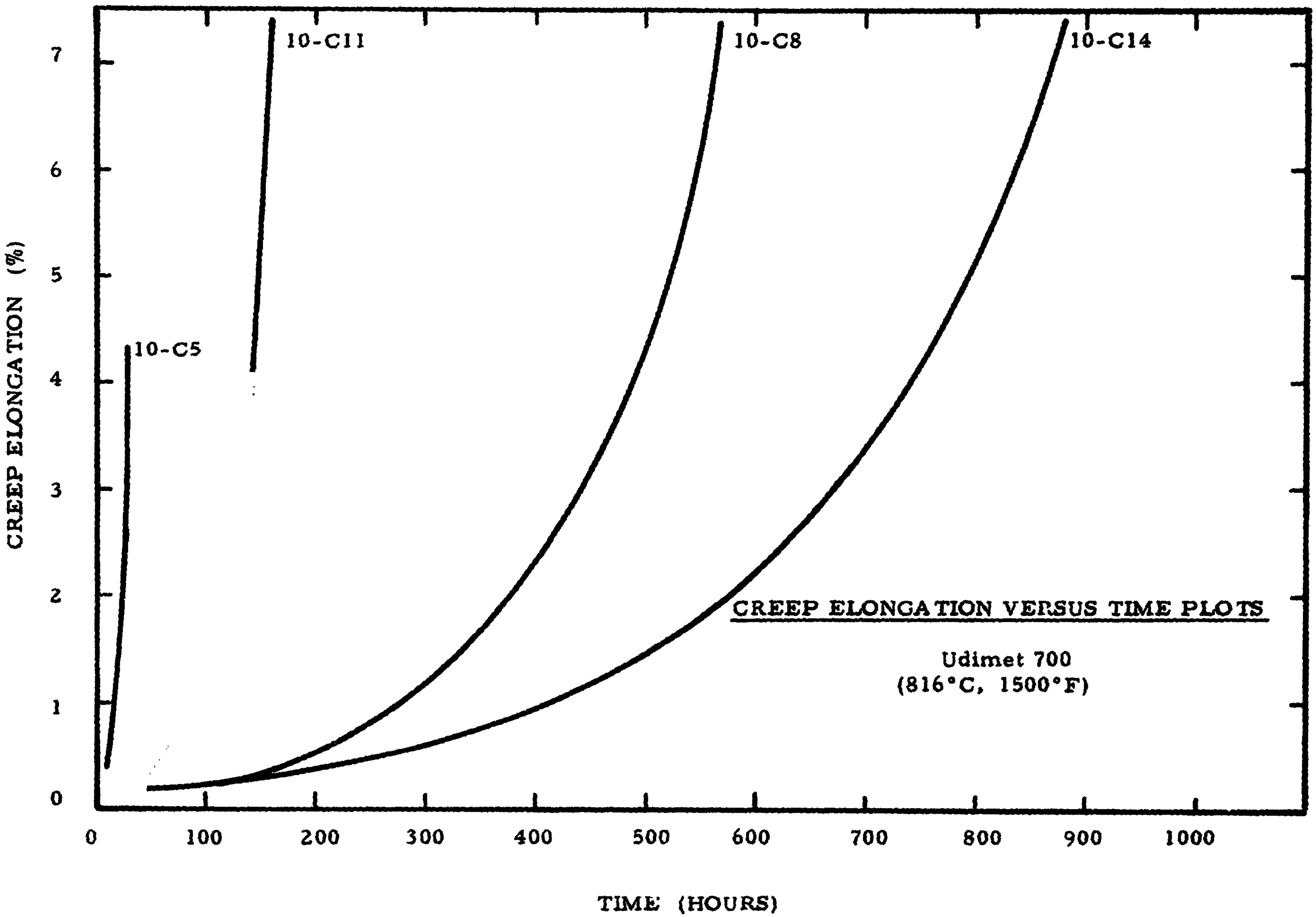

CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
10-C5
10-C11
10-C8
10-C14
CREEP ELONGATION VERSUS TIME PLOTS
Udimet 700
(816°C, 1500°F)
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 54

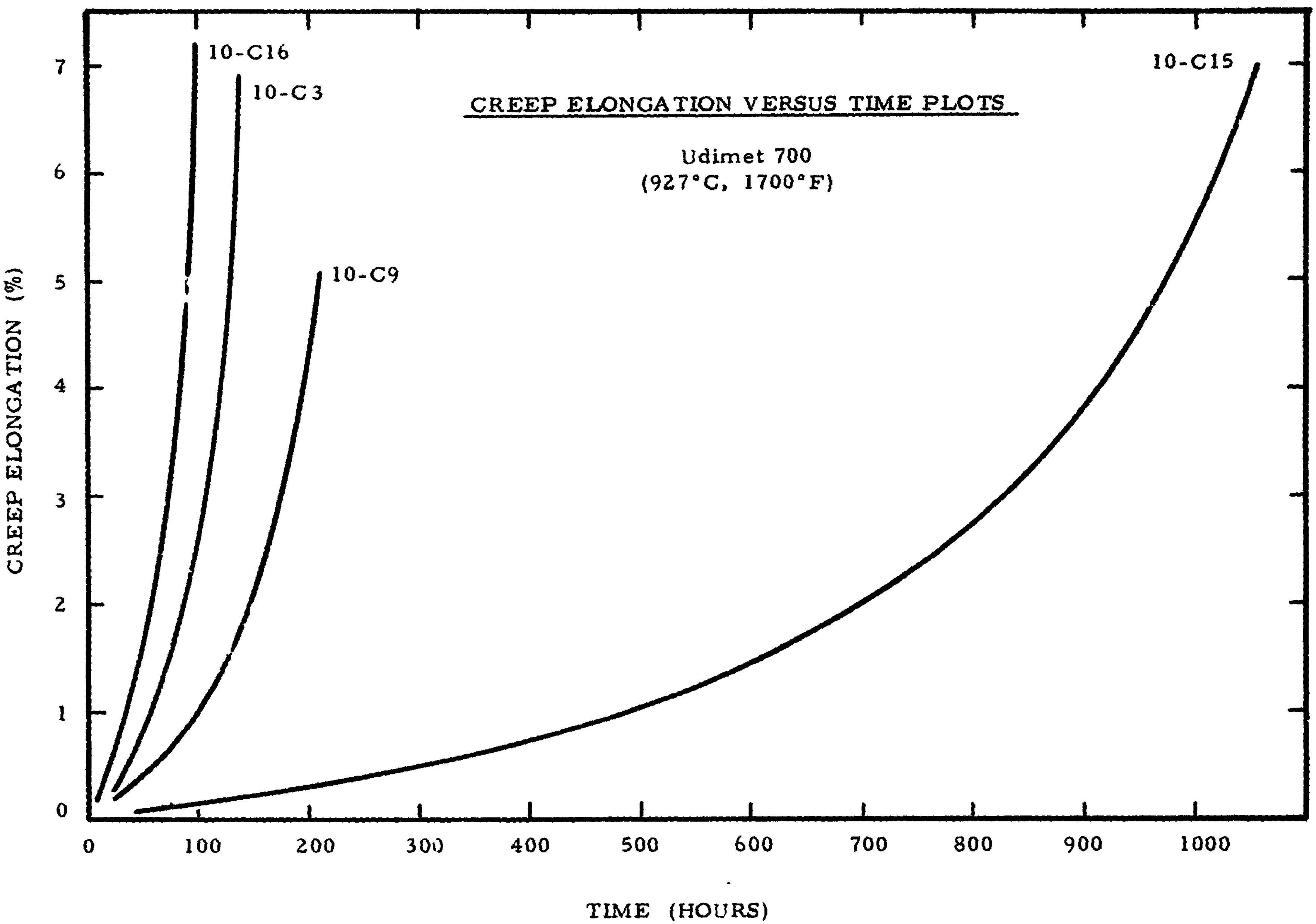

CREEP ELONGATION VERSUS TIME PLOTS
Udimet 700
(927°C, 1700°F)
10-C16
10-C3
10-C9
10-C15
CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000

Figure 55

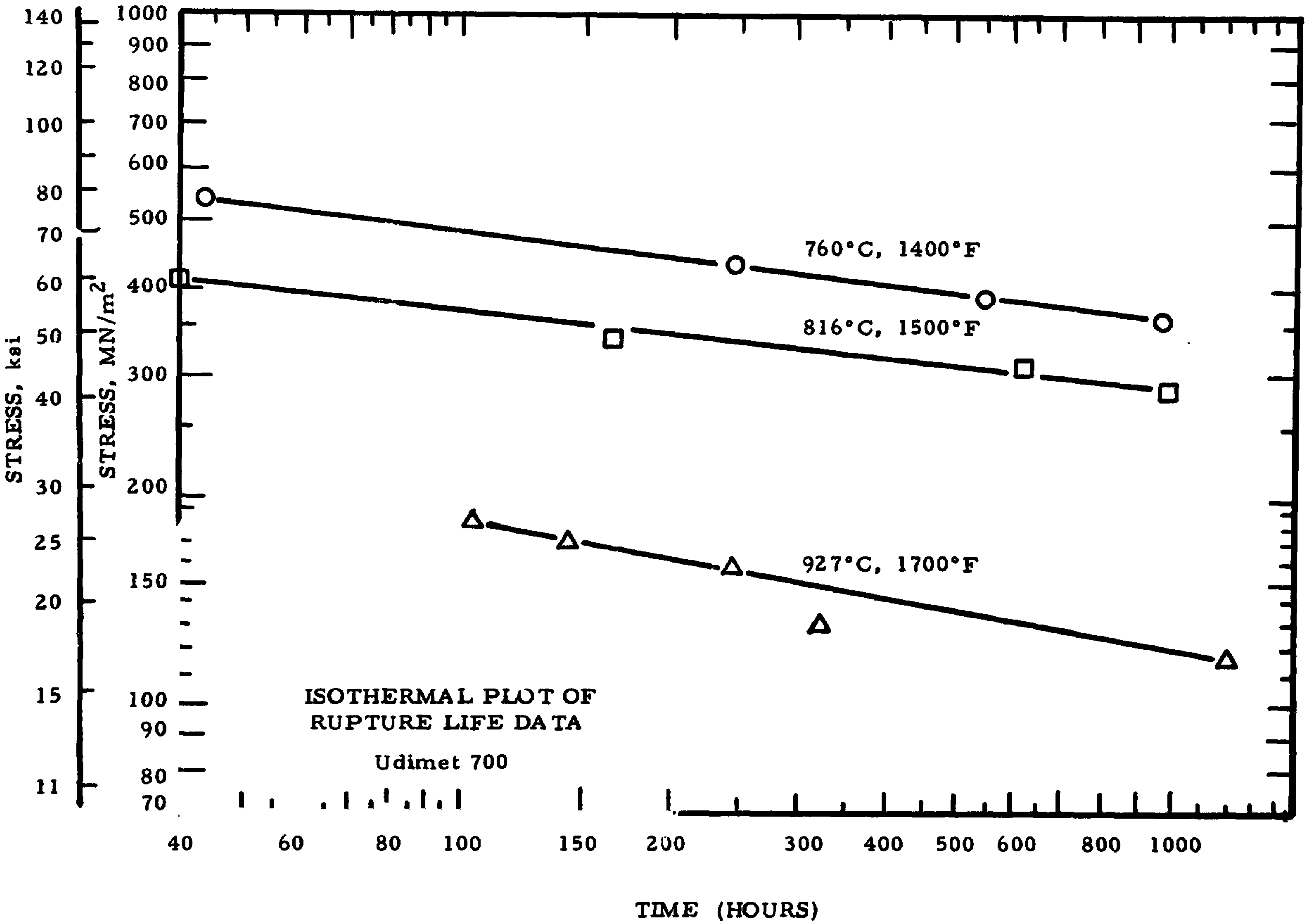

STRESS, ksi
STRESS, MN/m²
140
120
100
80
70
60
50
40
30
25
20
15
11
1000
900
800
700
600
500
400
300
200
150
100
90
80
70
760°C, 1400°F
816°C, 1500°F
927°C, 1700°F
ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
Udimet 700
40
60
80
100
150
200
300
400
500
600
800
1000
TIME (HOURS)

Figure 56

Material 11: TAZ-8A

This alloy was developed by NASA-Lewis Research Center for good elevated temperature strengths and excellent corrosion resistance. The material was supplied as cast remelt stock and was cast into bar specimens by Howmet Corporation-Misco Division. Testing was perfomred on the material in the as-cast condition.

Chemical analysis of this heat of material (supplied by NASA-Lewis Research Center) is as follows:

Carbon	0.13%
Manganese	0.04
Silicon	0.11
Chromium	6.10
Molybdenum	3.90
Tungsten	4.00
Iron	<0.10
Sulfur	0.015
Aluminum	5.78
Columbium	1.81
Tantalum	8.10
Boron	0.005
Zirconium	0.57
Bismuth	<.2 ppm
Lead	<1 ppm
Nickel	Balance

Tensile results are presented as Table XXI with samples of the load-strain curves compiled as Figure 57.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	Confidence Limits 95%
11-P1	-0.3092	±.0067	±.0080
11-P2	-0.3295	±.0024	±.0029
11-P3	-0.3111	±.0084	±.0101

Material 11: TAZ-8A (continued)

Creep rupture data are presented in Table XXII. Creep deformation versus time values are plotted in Figures 58, 59, and 60. Isothermal plots of the rupture life data appear as Figure 61.

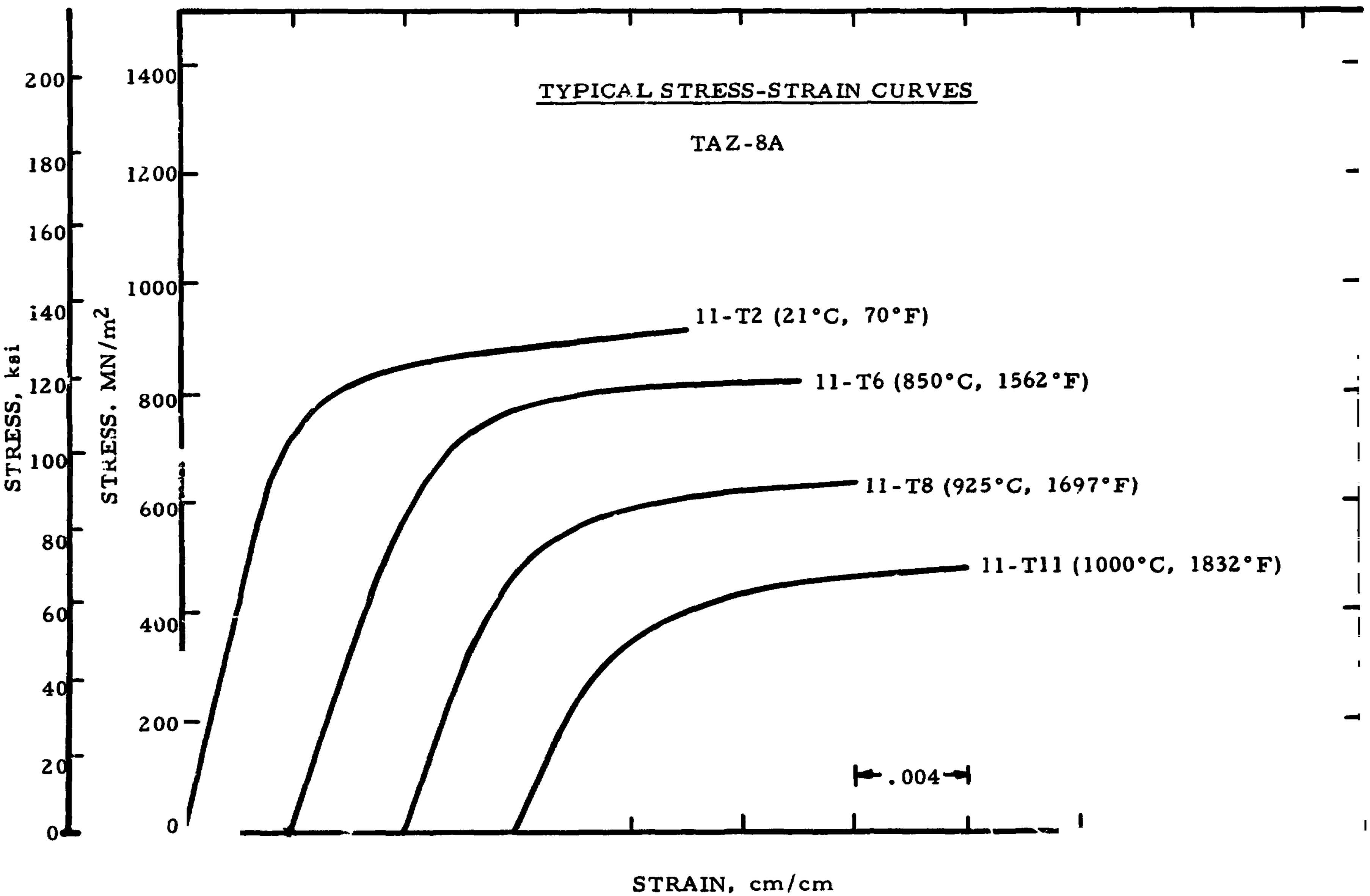
An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
850	1562	417.1	60.5	348.2	50.5	282.7	41.0
925	1697	244.8	35.5	203.4	29.5	166.5	24.0
1000	1832	137.9	20.0	117.2	17.0	96.5	14.0

TABLE XXI
Tensile Properties of TAZ-8A

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
11-T1	21	70	1002.5	145.4	713.6	103.5	826.0	119.8	1077.7	156.3	0.06	4.1	7.3
11-T2			1006.6	146.0	690.9	100.2	816.3	118.4	1033.5	149.9	0.11	3.9	6.4
11-T3			979.1	142.0	670.9	97.3	810.8	117.6	1025.3	148.7	0.07	3.4	4.8
11-T4	850	1562	870.8	126.3	568.1	82.4	761.2	110.4	900.5	130.6	0.06	2.7	5.2
11-T5			850.8	123.4	552.3	80.1	741.9	107.6	880.5	127.7	0.12	3.1	5.4
11-T6			822.5	119.3	499.9	72.5	726.0	105.3	861.9	125.0	0.06	3.2	6.4
11-T7	925	1697	666.0	96.6	329.6	47.8	517.1	75.0	675.0	97.9	0.16	4.5	6.5
11-T8			641.2	93.0	357.2	51.8	518.5	75.2	632.5	91.7	0.09	4.8	7.5
11-T9			644.0	93.4	329.6	47.8	508.1	73.7	595.0	91.9	0.16	4.0	6.1
11-T10	1000	1832	469.5	68.1	242.7	35.2	378.5	54.9	438.5	63.6	0.09	6.8	12.1
11-T11			477.8	69.3	233.0	33.8	368.2	53.4	423.3	61.4	0.09	6.5	11.3
11-T12			468.2	67.9	221.3	32.1	351.6	51.0	446.8	64.8	0.13	6.3	9.9

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	206.8	30.0
850	1562	173.7	25.2
925	1697	147.5	21.4
1000	1832	137.2	19.9



TYPICAL STRESS-STRAIN CURVES
TAZ-8A
11-T2 (21°C, 70°F)
11-T6 (850°C, 1562°F)
11-T8 (925°C, 1697°F)
11-T11 (1000°C, 1832°F)
.004
STRESS, ksi
0
20
40
60
80
100
120
140
160
180
200
STRESS, MN/m2
0
200
400
600
800
1000
1200
1400
STRAIN, cm/cm

Figure 57

TABLE XXII

Creep Rupture Properties of TAZ-8A

Specimen Numb	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
11-C1	850	1562	427.5	62.0	.027	30	32	85.1	5.7	6.3
11-C2			379.2	55.0	--	--	--	(a)	--	--
11-C3			379.2	55.0	.0092	50	86	197.9	3.9	5.6
11-C4			331.0	48.0	.0041	150	192	444.7	3.7	4.4
11-C5			306.8	44.5	.0029	200	285	619.6	4.1	4.4
11-C16			282.7	41.0	.0018	370	500	1017.4	3.5	5.2
11-C8	925	1697	248.2	36.0	.025	27	36	89.5	6.1	9.7
11-C6			227.5	33.0	.0109	55	75	179.7	4.7	6.9
11-C7			206.8	30.0	.0082	85	105	265.5	6.2	7.5
11-C9			182.7	26.5	.0028	215	302	[illegible]8.9	4.6	6.5
11-C10			172.4	25.0	.0025	260	335	705.2	4.7	6.8
11-C12	1000	1832	151.7	22.0	.014	40	53	60.2	3.9	11.7
11-C13			127.6	18.5	.012	90	88	175.0	5.2	9.4
11-C14			113.8	16.5	.0047	210	143	392.9	4.6	7.9
11-C11			103.4	15.0	.0022	320	365	665.1	4.5	11.2
11-C15			96.5	14.0	.0022	340	380	789.2	5.3	11.7

(a) Specimen loaded at 1652°F; test void

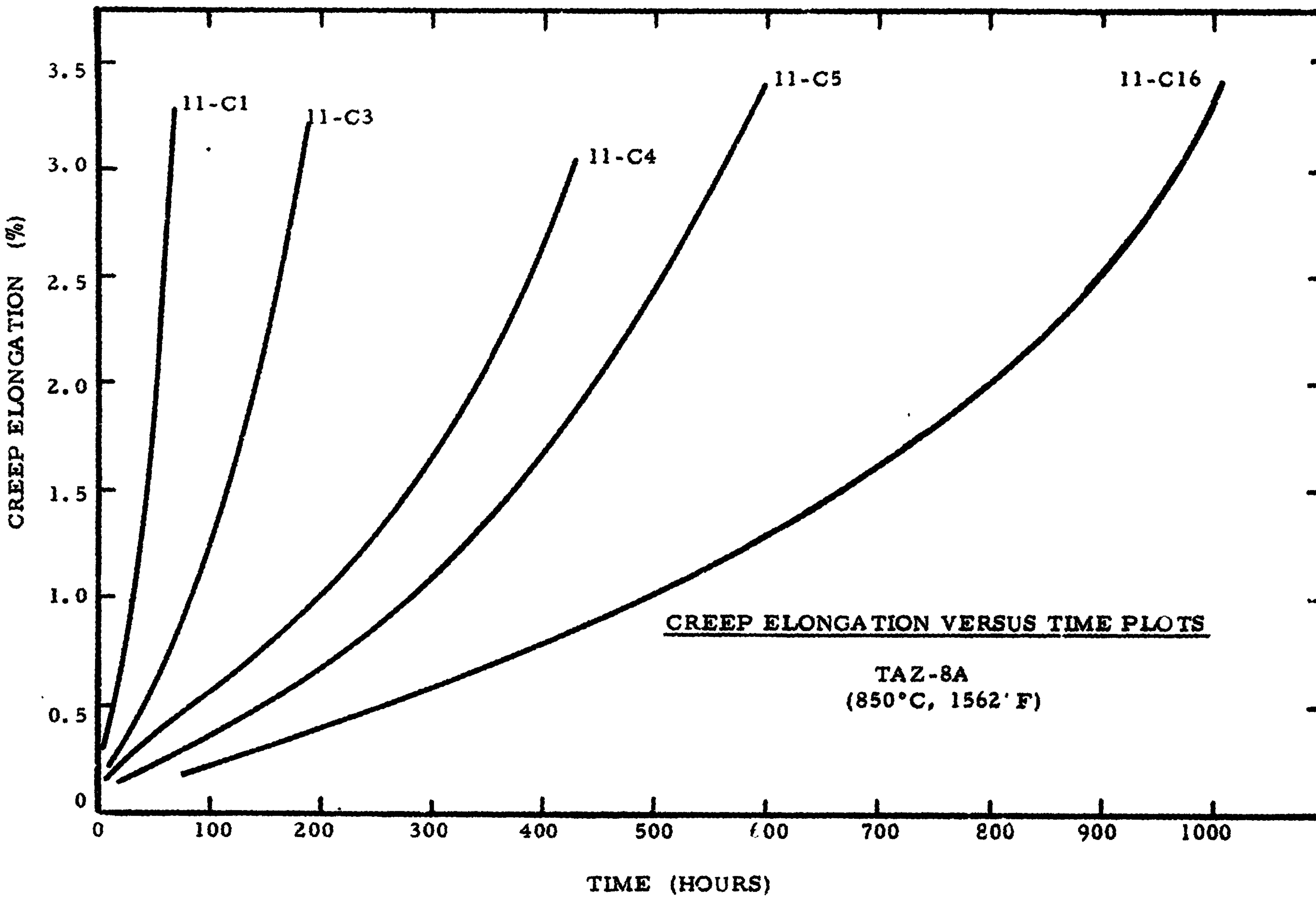

CREEP ELONGATION (%)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)
11-C1
11-C3
11-C4
11-C5
11-C16
CREEP ELONGATION VERSUS TIME PLOTS
TAZ-8A
(850°C, 1562°F)

Figure 58

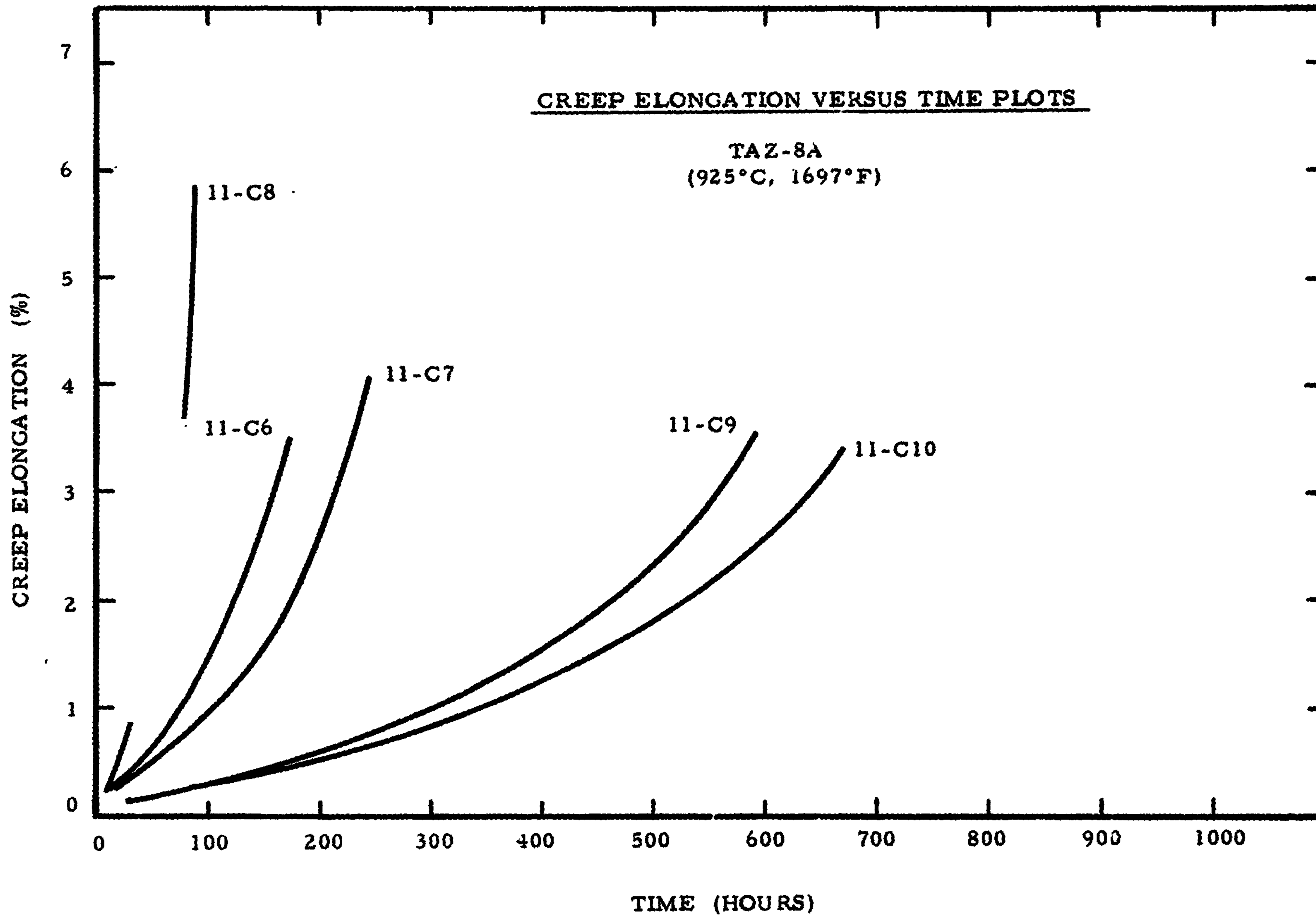

CREEP ELONGATION VERSUS TIME PLOTS
TAZ-8A
(925°C, 1697°F)
11-C8
11-C7
11-C6
11-C9
11-C10
CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000

Figure 59

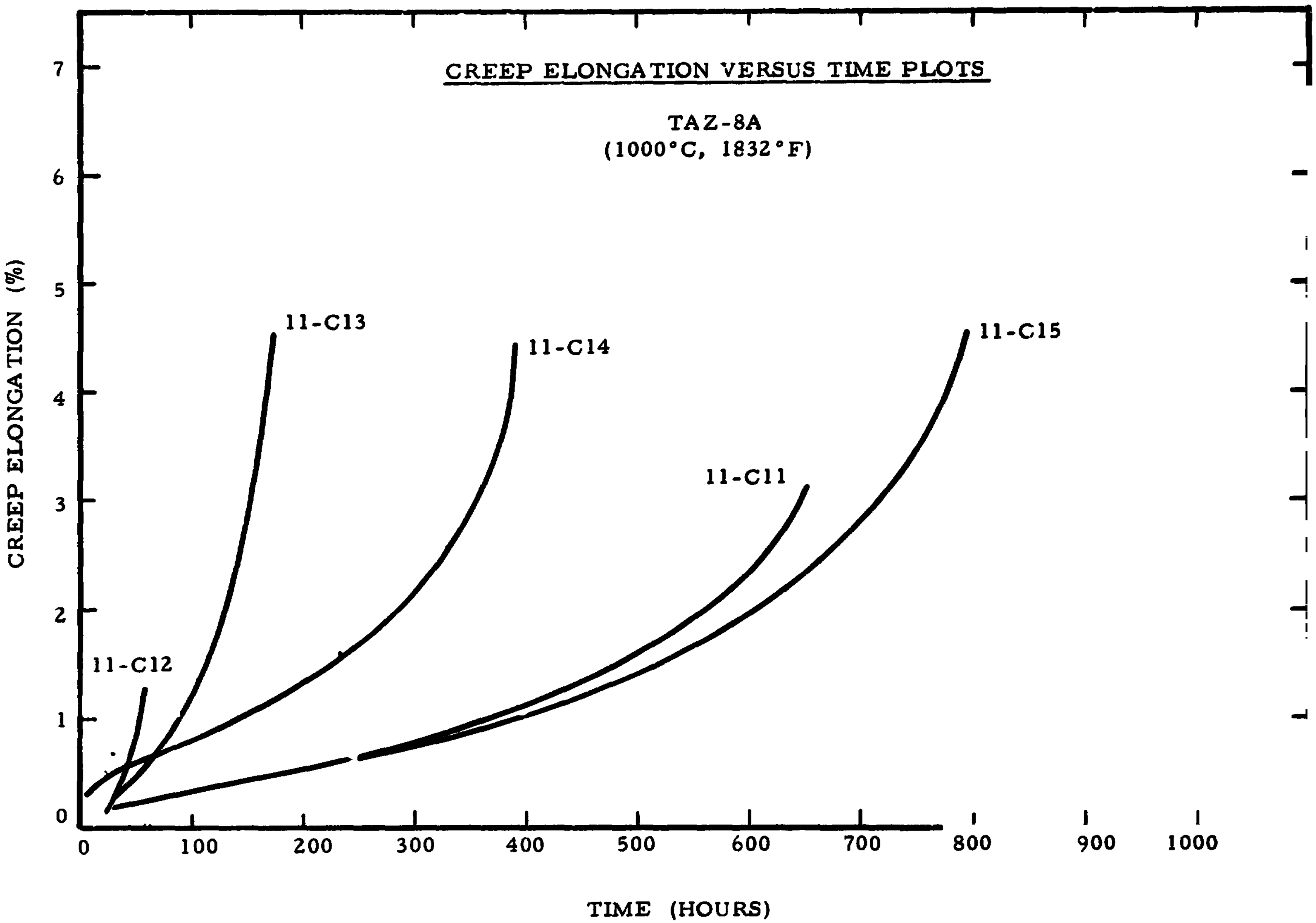

CREEP ELONGATION VERSUS TIME PLOTS
TAZ-8A
(1000°C, 1832°F)
CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
11-C12
11-C13
11-C14
11-C11
11-C15

Figure 60

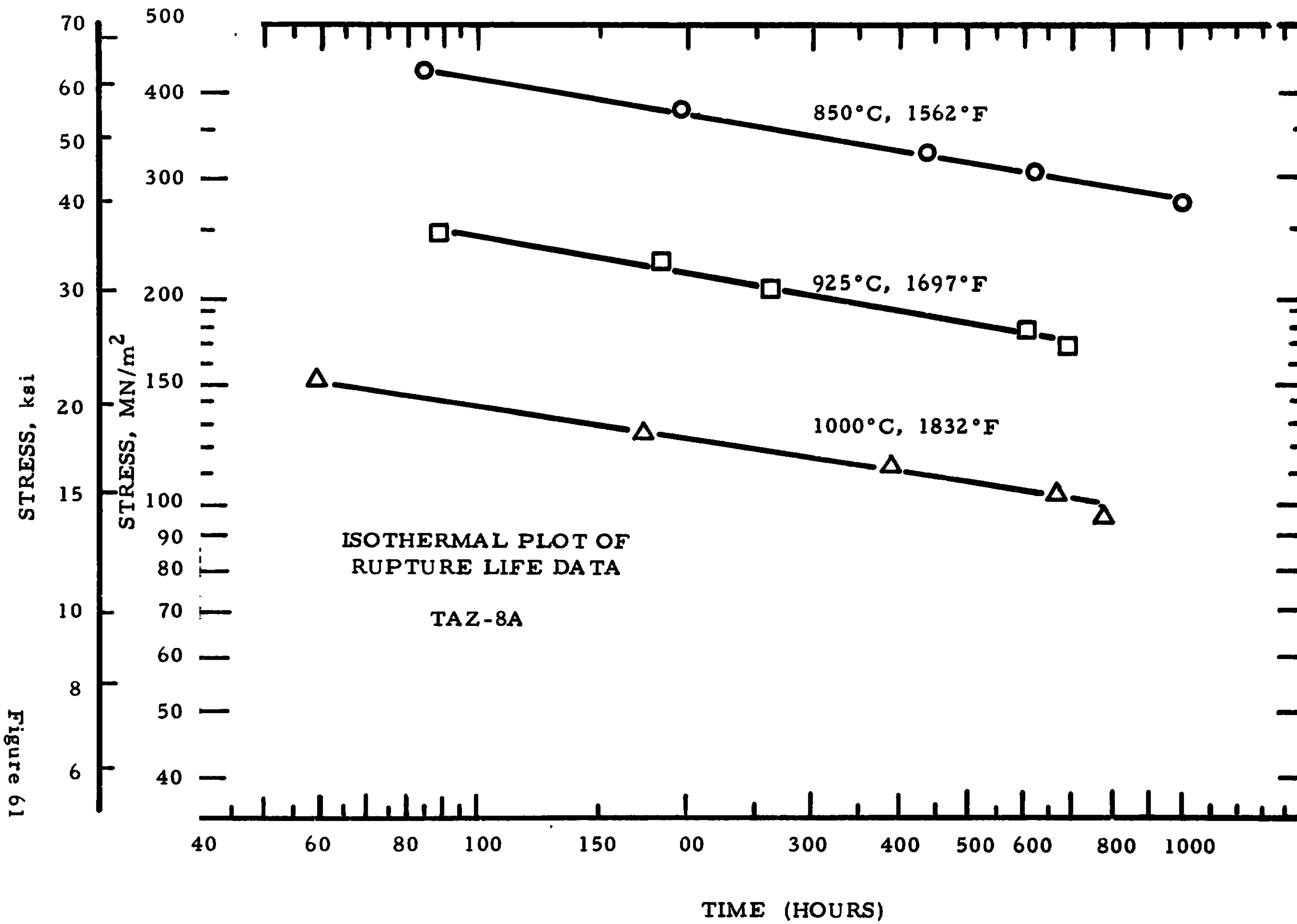

850°C, 1562°F
925°C, 1697°F
1000°C, 1832°F
ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
TAZ-8A
STRESS, ksi
STRESS, MN/m²
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
40
60
80
100
150
00
300
400
500
600
800
1000
TIME (HOURS)

Figure 61

Material 12: IN 100

This nickel-base alloy, developed for high temperature strength, was supplied by NASA-Lewis Research Center as cast remelt stock. Subsequently, it was cast into bar specimens by Howmet Corporation-Misco Division. Testing was performed on the material in the as-cast condition.

Chemical composition of this heat of material (supplied by NASA-Lewis Research Center) is as follows:

Carbon	0.17
Manganese	<0.02
Silicon	0.11
Chromium	10.30
Cobalt	15.10
Molybdenum	2.96
Aluminum	5.45
Titanium	4.76
Zirconium	0.084
Boron	0.016
Iron	0.021
Vanadium	0.97
Nickel	Balance

Tensile results are presented as Table XXIII with samples of the load-strain curves compiled as Figure 62.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	Confidence Limits 95%
12-P1	-0.3038	±.0080	±.0096
12-P2	-0.3188	±.0038	±.0046
12-P3	-0.2717	±.0049	±.0059

Material 12: IN 100 (continued)

Creep rupture data are presented in Table XXIV. Creep deformation versus time values are plotted in Figures 63, 64, and 65. Isothermal plots of the rupture life data appear as Figure 66.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yeidls the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
850	1562	427.5	62.0	358.5	52.0	296.5	43.0
925	1697	262.0	38.0	206.8	30.0	158.6	23.0
1000	1832	137.9	20.0	113.8	16.5	93.1	13.5

TABLE XXIII
Tensile Properties of IN 100

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m^2	Ultimate Strength ksi	0.02% Yield Strength MN/m^2	0.02% Yield Strength ksi	0.2% Yield Strength MN/m^2	0.2% Yield Strength ksi	Fracture Strength MN/m^2	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
12-T1	21	70	1052.1	152.6	775.7	112.5	905.3	131.3	1190.7	172.7	0.08	7.0	9.0
12-T2			1031.5	149.6	715.0	103.7	815.7	118.3	1168.0	169.4	0.10	8.4	14.1
12-T3			1037.7	150.5	754.3	109.4	875.0	126.9	1151.4	167.0	0.07	7.3	13.1
12-T4	850	1562	758.4	110.0	537.8	78.0	617.8	89.6	860.5	124.8	0.14	6.0	13.5
12-T5			789.5	114.5	507.5	73.6	652.9	94.7	878.4	127.4	0.10	5.8	10.9
12-T6			796.3	115.5	508.1	73.7	668.1	96.9	858.4	124.5	0.10	5.3	14.1
12-T7	925	1697	654.3	94.9	384.7	55.8	521.9	75.7	642.6	93.2	0.17	5.0	7.7
12-T8			598.5	86.8	308.9	44.8	436.4	63.3	580.0	84.1	0.12	4.4	9.1
12-T9			614.3	89.1	312.3	45.3	442.6	64.2	618.5	89.7	0.18	6.5	13.7
12-T10	1000	1832	437.8	63.5	227.5	33.0	328.9	47.7	276.5	40.1	0.14	10.5	15.6
12-T11			432.3	62.7	218.6	31.7	331.0	48.0	433.0	62.8	0.09	8.1	21.7
12-T12			417.1	60.5	186.2	27.0	290.3	42.1	326.8	47.4	0.11	9.6	20.0

Temp. °C	Temp. °F	Modulus of Elasticity GN/m^2	Modulus of Elasticity 10^6 psi
21	70	205.5	29.8
850	1562	150.3	21.8
925	1697	155.1	22.5
1000	1832	132.4	19.2

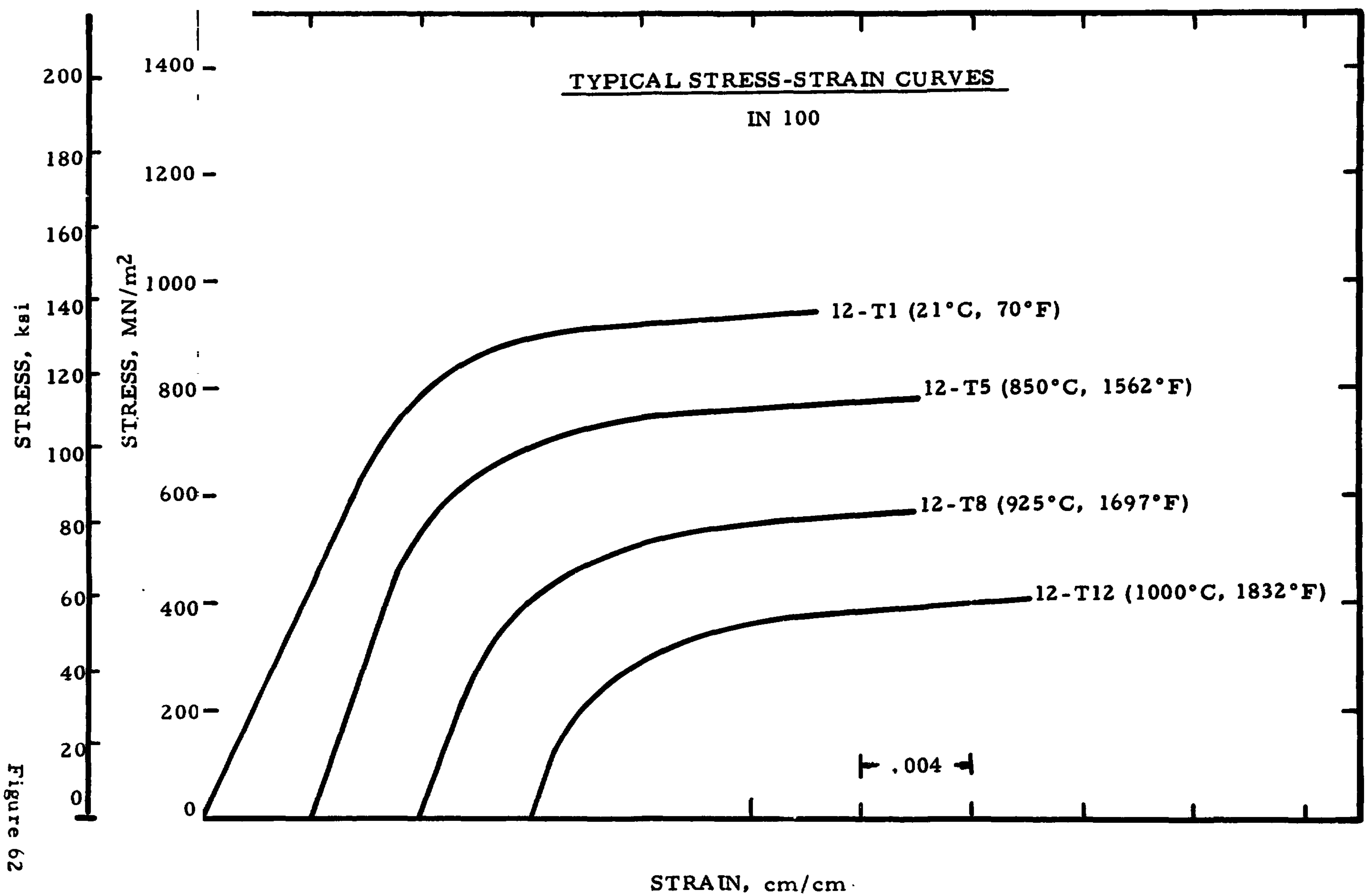

TYPICAL STRESS-STRAIN CURVES
IN 100
STRESS, ksi
STRESS, MN/m²
STRAIN, cm/cm
12-T1 (21°C, 70°F)
12-T5 (850°C, 1562°F)
12-T8 (925°C, 1697°F)
12-T12 (1000°C, 1832°F)
.004
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400

Figure 62

TABLE XXIV

Creep Rupture Properties of IN 100

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
12-C1	850	1562	434.4	63.0	.027	32	33	83.9	3.9	9.6
12-C2			372.3	54.0	.0069	103	127	261.3	3.6	10.1
12-C3			331.0	48.0	.0031	195	260	512.2	4.2	9.2
12-C4			296.5	43.0	.0018	315	483	801.7	5.0	9.5
12-C5			286.1	41.5	.0009	510	800	1211.4	3.3	6.7
12-C6	925	1697	262.0	38.0	.0129	26	48	114.2	7.7	11.5
12-C7			220.6	32.0	.0069	75	102	209.9	5.9	13.7
12-C9			186.2	27.0	.0031	130	225	429.4	5.4	6.9
12-C10			172.4	25.0	.0017	180	375	708.9	8.1	9.5
12-C8			158.6	23.0	.0012	490	745	1163.7	5.9	10.1
12-C11	1000	1832	151.7	22.0	.039	25	25	59.3	8.6	13.9
12-C12			117.2	17.0	.0067	110	136	263.8	7.4	14.0
12-C14			103.4	15.0	.0026	195	280	415.0	5.1	22.0
12-C15			96.5	14.0	.0021	310	377	590.9	4.6	16.9
12-C13			93.1	13.5	.0010	(a)	(a)	1035.7	5.4	15.0

(a) Extensometer malfunction; data not available

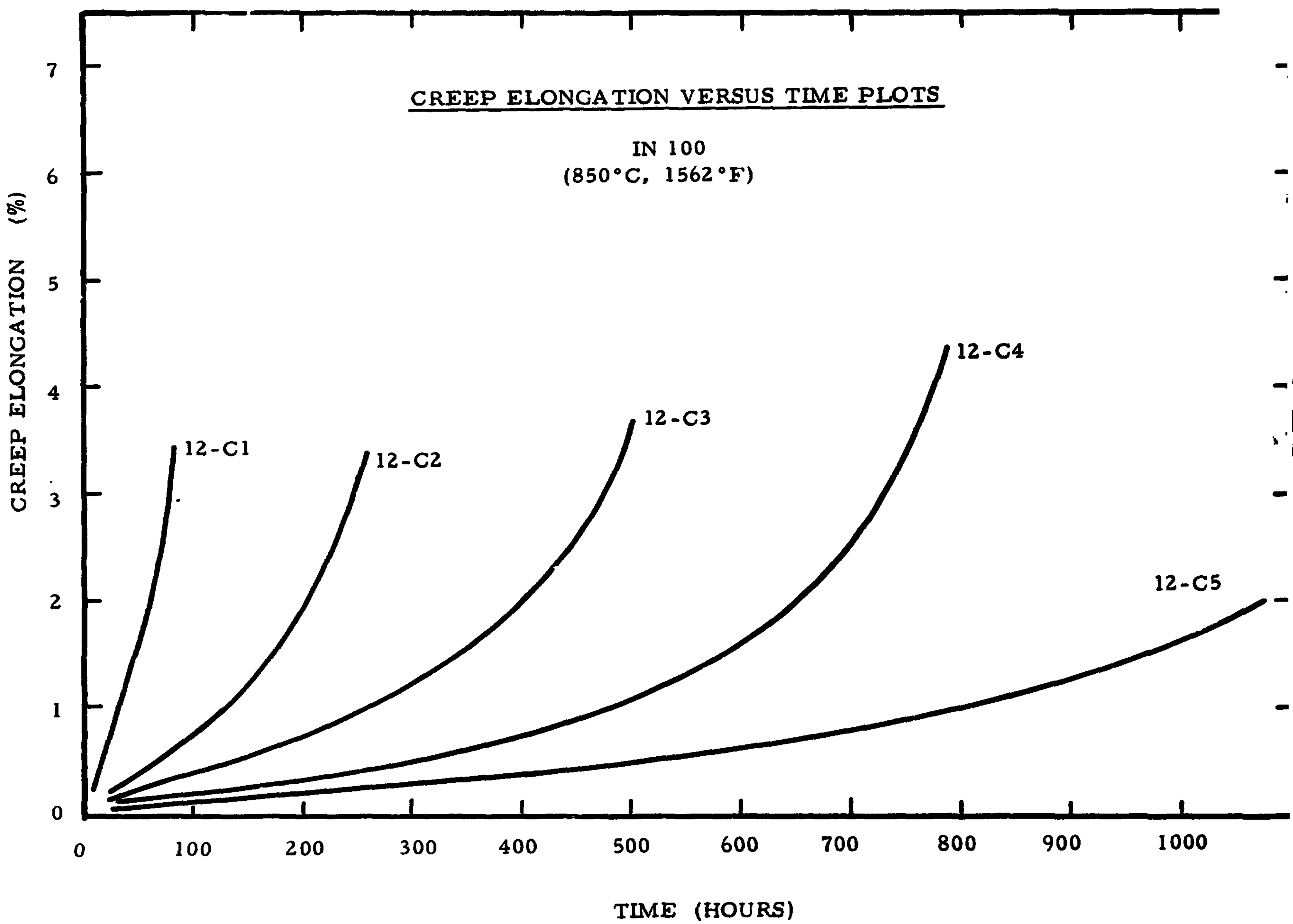

CREEP ELONGATION VERSUS TIME PLOTS
IN 100
(850°C, 1562°F)
CREEP ELONGATION (%)
TIME (HOURS)
12-C1
12-C2
12-C3
12-C4
12-C5
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000

Figure 63

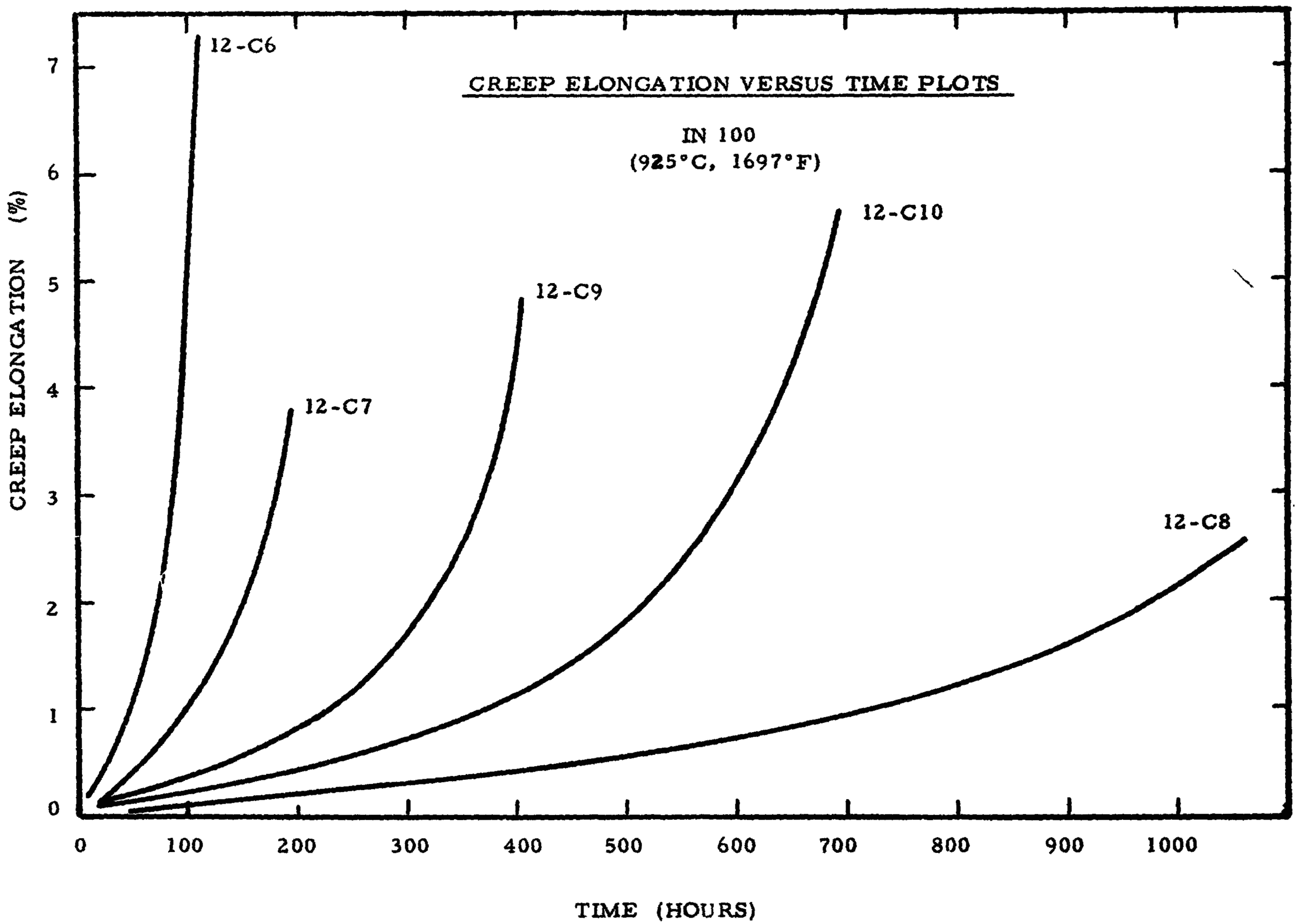

CREEP ELONGATION VERSUS TIME PLOTS
IN 100
(925°C, 1697°F)
CREEP ELONGATION (%)
TIME (HOURS)
12-C6
12-C7
12-C9
12-C10
12-C8
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000

Figure 64

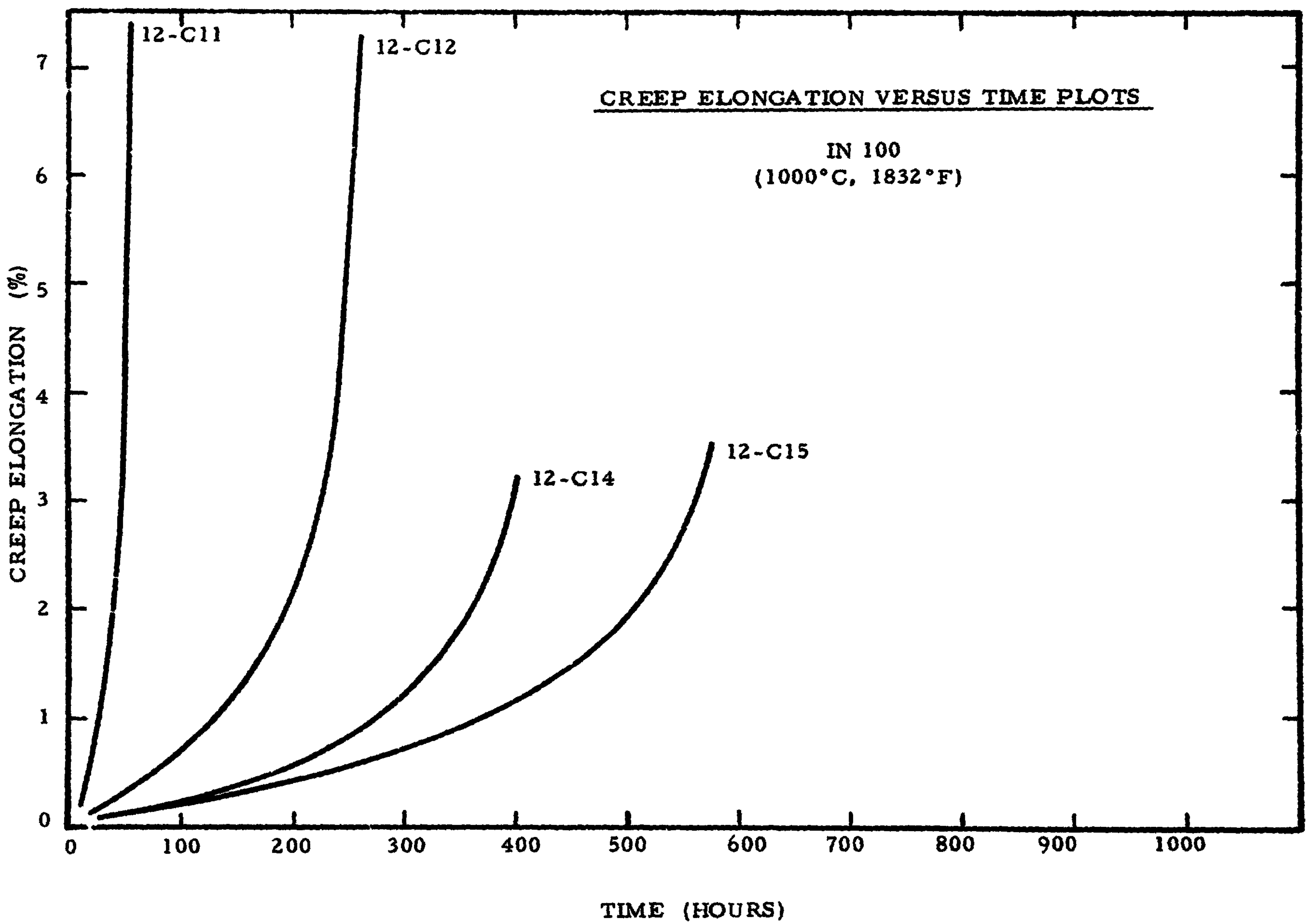

CREEP ELONGATION VERSUS TIME PLOTS
IN 100
(1000°C, 1832°F)
12-C11
12-C12
12-C14
12-C15
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
TIME (HOURS)
0
100
200
300
400
500
600
700
800
900
1000

Figure 65

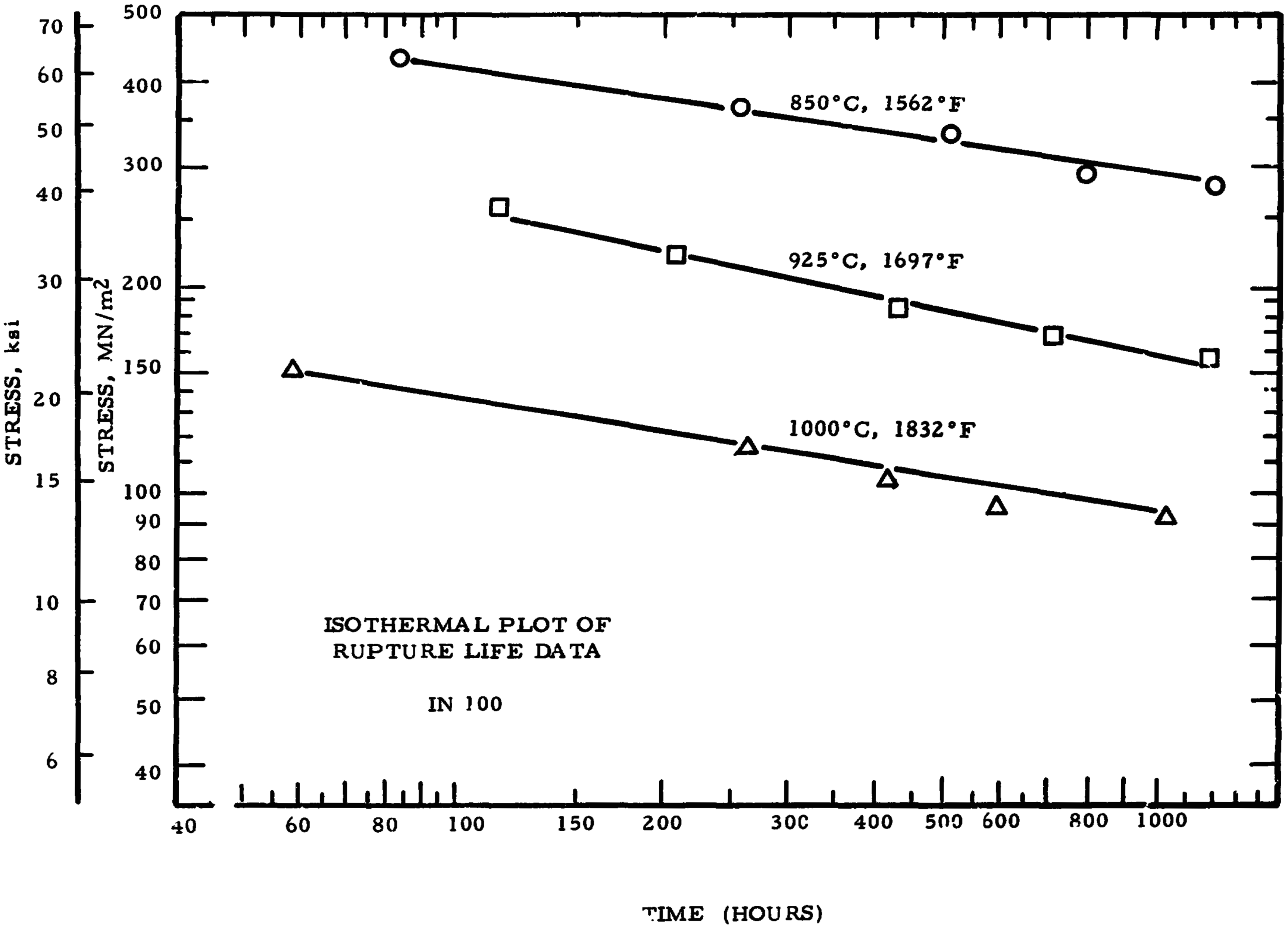

STRESS, ksi
70
60
50
40
30
20
15
10
8
6
STRESS, MN/m2
500
400
300
200
150
100
90
80
70
60
50
40
850°C, 1562°F
925°C, 1697°F
1000°C, 1832°F
ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
IN 100
40
60
80
100
150
200
300
400
500
600
800
1000
TIME (HOURS)

Figure 66

Material 13: IN 100 + Jocoat

Some of the cast IN 100 bars (Material 12) were coated with PWA 47 Jocoat at TRW Inc.-Turbine Components Division. At the end of the coating cycle, the bars were heat treated in vacuum as follows:

1975°F/4 hours/rapid argon quench

Tensile results are presented as Table XXV with samples of the load-strain curves compiled as Figure 67.

Creep rupture data are presented in Table XXVI. Creep deformation versus time values are plotted in Figures 68, 69, and 70. Isothermal plots of the rupture life data appear as Figure 71.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
850	1562	413.7	60.0	344.7	50.0	282.7	41.0
925	1697	244.8	35.5	199.9	29.0	158.6	23.0
1000	1832	137.9	20.0	106.9	15.5	82.7	12.0

TABLE XXV
Tensile Properties of IN 100 + Jocoat

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
13-T1	21	70	957.7	138.9	605.4	87.8	761.2	110.4	1138.3	165.1	0.10	7.9	15.9
13-T2			987.3	143.2	607.4	88.1	743.3	107.8	1122.5	162.8	0.11	7.1	12.6
13-T3			1021.8	148.2	617.8	89.6	783.9	113.7	1179.0	1[illegible]1.0	0.11	8.8	13.8
13-T4	850	1562	760.5	110.3	621.2	90.1	732.2	106.2	777.7	112.8	0.06	5.0	6.1
13-T5			772.2	112.0	579.9	84.1	724.6	105.1	801.9	116.3	0.06	4.1	6.3
13-T6			763.9	110.8	615.0	89.2	[illegible]24.6	105.1	837.7	121.5	0.06	4.6	11.6
13-T7	925	1697	557.8	80.9	315.8	45.8	456.4	66.2	501.3	72.7	0.04	7.5	10.9
13-T8			568.8	82.5	353.7	51.3	446.1	64.7	561.9	81.5	0.04	8.0	13.5
13-T9			574.3	83.3	372.3	54.0	480.6	69.7	577.1	83.7	0.05	7.0	11.6
13-T10	1000	183[illegible]	393.7	57.1	205.5	29.8	295.1	42.8	315.1	45.7	0.05	12.3	19.7
13-T11			383.4	55.6	189.6	27.5	285.4	41.4	122.0	17.7	0.05	11.9	19.5
13-[illegible]			384.0	55.7	199.9	29.0	302.7	43.9	299.2	43.4	0.03	13.3	20.2

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	225.5	32.7
850	1562	157.9	22.9
925	1697	155.8	22.6
1000	1832	128.9	18.7

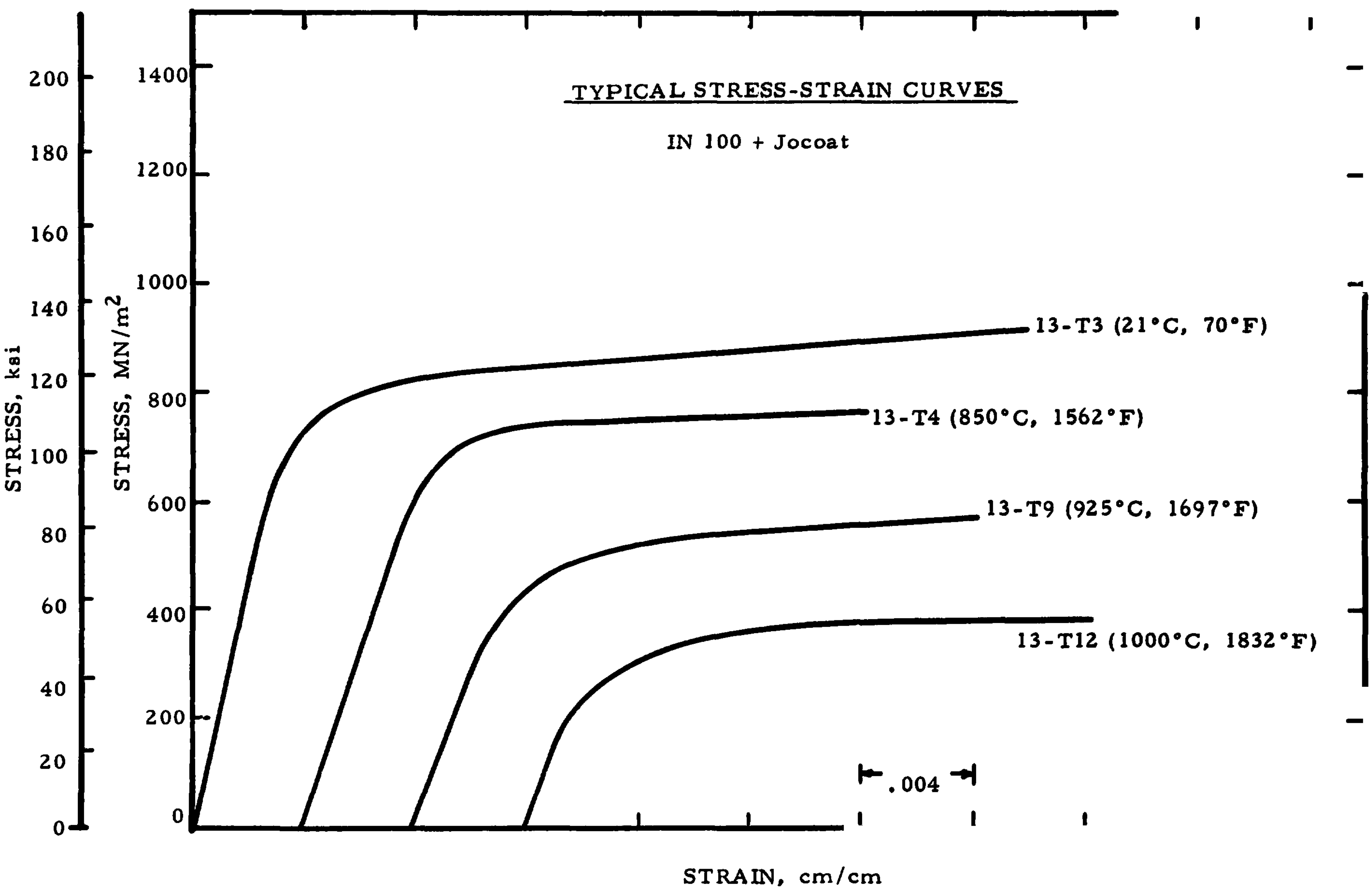

TYPICAL STRESS-STRAIN CURVES
IN 100 + Jocoat
STRESS, ksi
STRESS, MN/m^2
STRAIN, cm/cm
13-T3 (21°C, 70°F)
13-T4 (850°C, 1562°F)
13-T9 (925°C, 1697°F)
13-T12 (1000°C, 1832°F)
.004
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400

Figure 67

TABLE XXVI

Creep Rupture Properties on IN 100 + Jocoat

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
13-C1	850	1562	427.5	62.0	.029	20	29	75.1	6.3	13.3
13-C2			393.0	57.0	.0145	55	67	159.2	5.6	16.6
13-C3			317.2	46.0	.0036	230	272	576.1	5.7	12.7
13-C4			317.2	46.0	.0031	230	277	580.5	5.0	13.8
13-C5			293.0	42.5	.0020	300	420	807.7	4.8	8.5
13-C6	925	1697	248.2	36.0	.0179	26	45	90.7	5.8	18.2
13-C7			220.6	32.0	.0056	65	110	191.1	6.0	17.8
13-C8			186.2	27.0	.0043	130	190	408.0	7.1	14.4
13-C9			179.3	26.0	.0037	170	225	518.6	6.2	16.1
13-C10			168.9	24.5	.0018	310	420	712.0	4.5	12.9
13-C11	1000	1832	144.8	21.0	.027	25	30	60.1	5.0	18.0
13-C2			127.6	18.5	.0106	75	81	178.2	11.2	25.3
13-C13			110.3	16.0	.0035	130	184	302.1	5.9	19.0
13-C14			100.0	14.5	.0035	175	246	399.1	7.1	24.5
13-C15			93.1	13.5	.0017	340	422	634.3	5.2	23.8

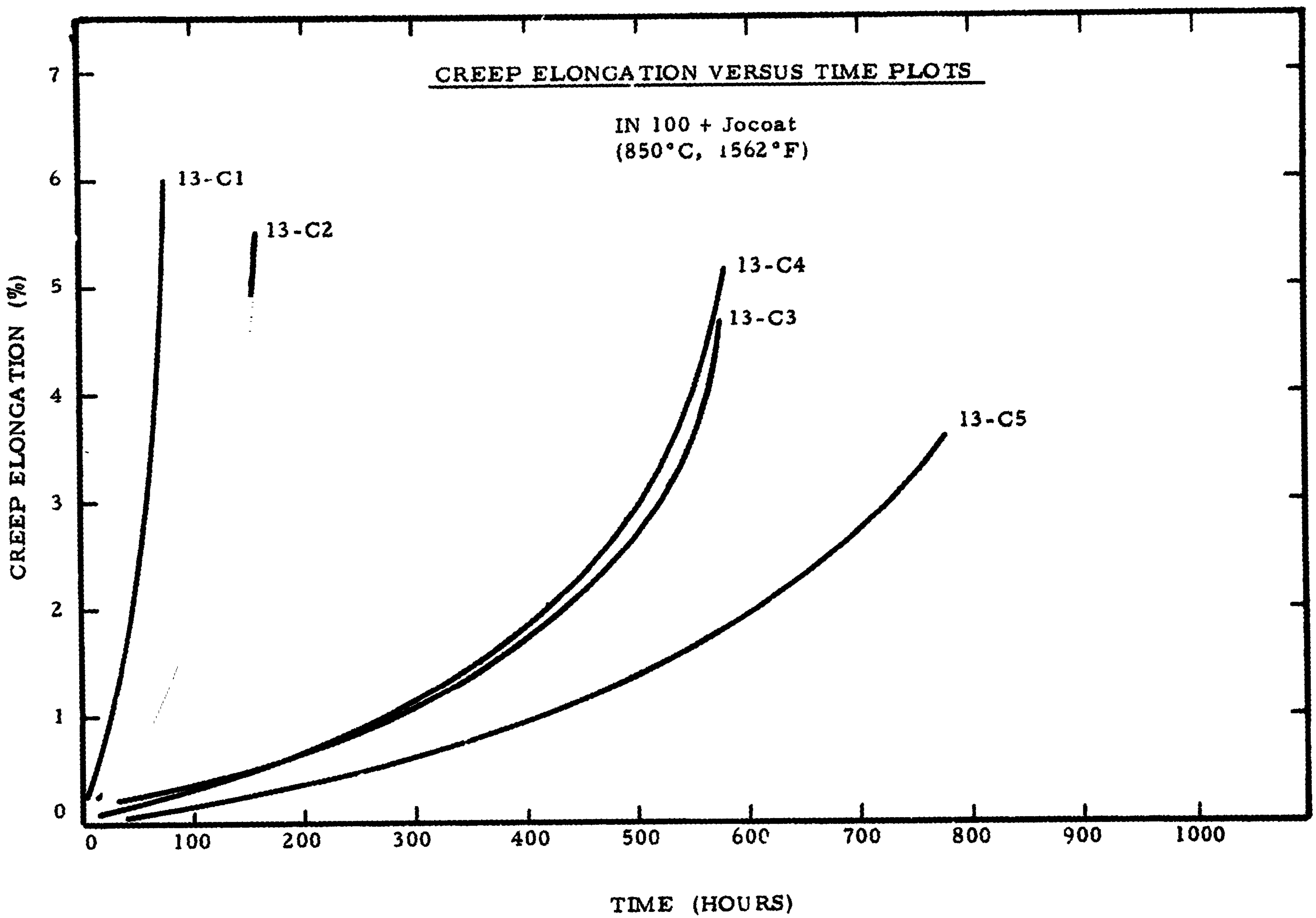
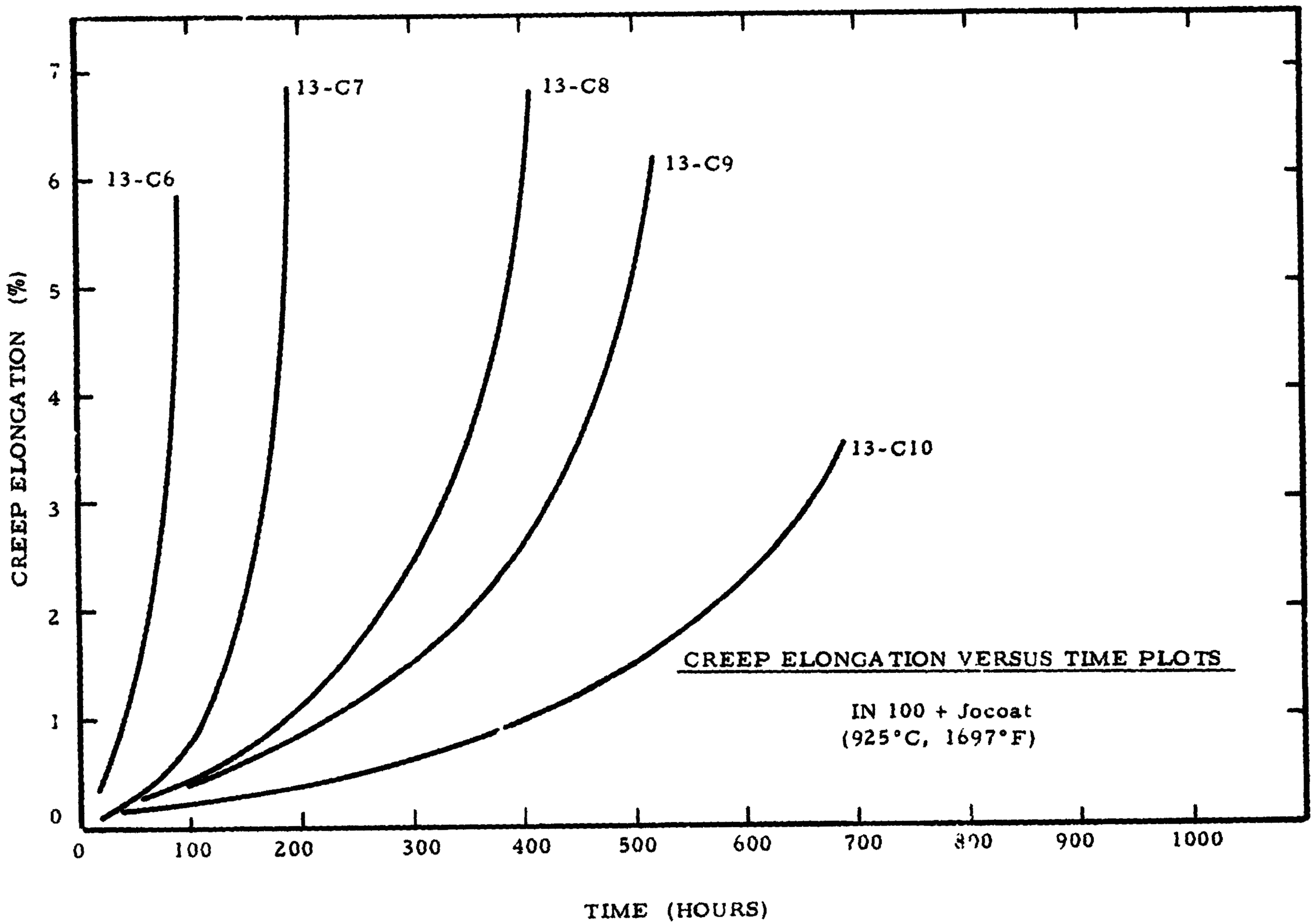

CREEP ELONGATION VERSUS TIME PLOTS
IN 100 + Jocoat
(850°C, 1562°F)
13-C1
13-C2
13-C4
13-C3
13-C5
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 68



CREEP ELONGATION (%)
TIME (HOURS)
13-C6
13-C7
13-C8
13-C9
13-C10
CREEP ELONGATION VERSUS TIME PLOTS
IN 100 + Jocoat
(925°C, 1697°F)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000

Figure 69

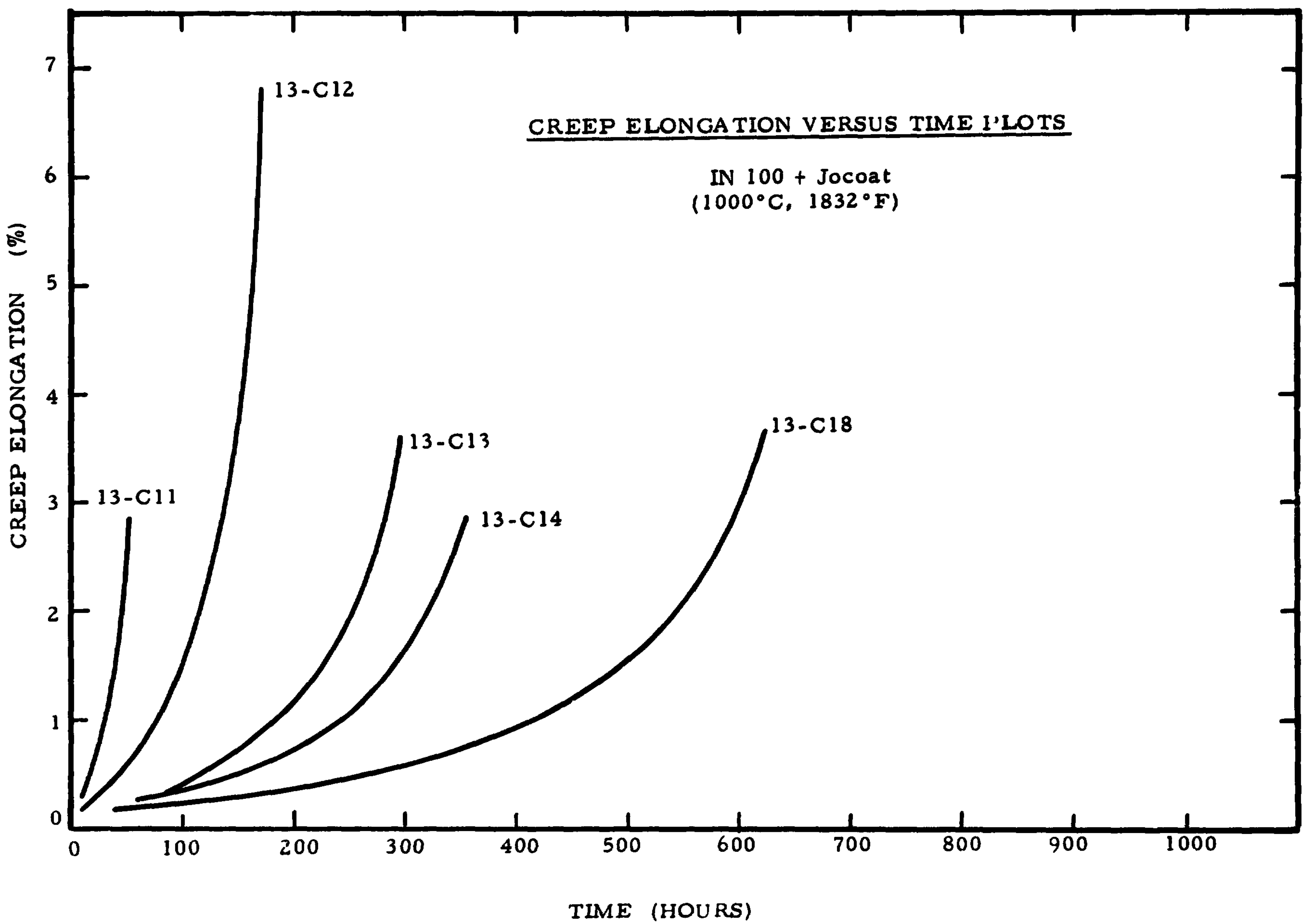

CREEP ELONGATION VERSUS TIME PLOTS
IN 100 + Jocoat
(1000°C, 1832°F)
13-C11
13-C12
13-C13
13-C14
13-C18
CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
100
200
300
400
500
600
700
800
900
1000

Figure 70

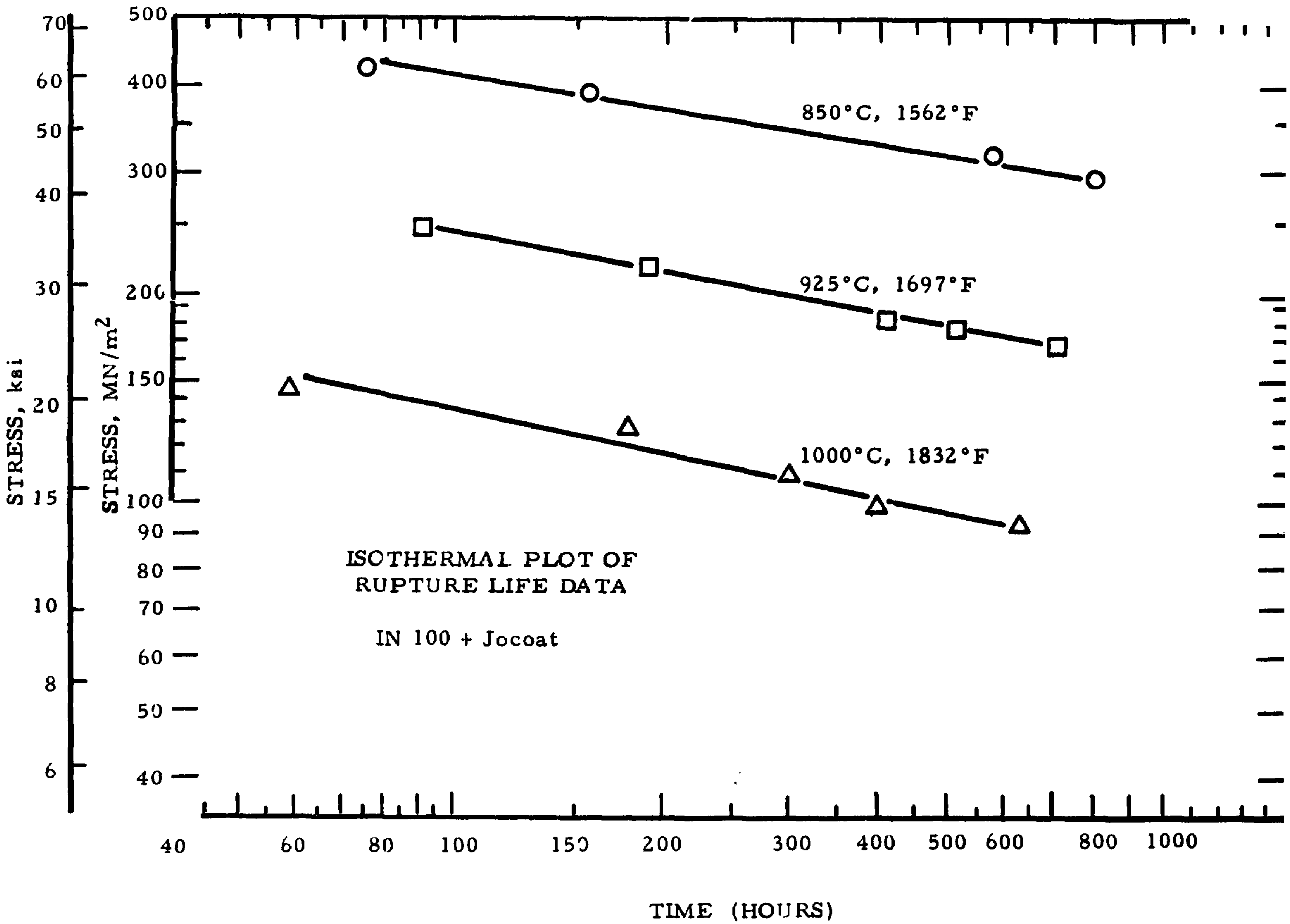

ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
IN 100 + Jocoat
850°C, 1562°F
925°C, 1697°F
1000°C, 1832°F
STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 71

Material 14: B 1900

This nickel-base alloy, developed by Pratt & Whitney Aircraft for turbine applications was supplied by NASA-Lewis Research Center as cast remelt stock. The alloy was cast into specimen blanks by Howmet Corporation-Misco Division.

Chemical composition (supplied by NASA-Lewis Research Center) of this heat of material is as follows:

Carbon	0.10
Manganese	0.10
Silicon	<0.10
Chromium	8.11
Cobalt	10.15
Molybdenum	6.11
Tungsten	<0.10
Aluminum	6.09
Titanium	0.98
Zirconium	0.08
Boron	0.013
Tantalum	4.28
Iron	0.16
Nickel	Balance

Prior to finish machining the specimens were heat treated in air per NASA-Lewis Research Center. Instructions were as follows:

1550°F/24 hours/air cool to room temperature

Tensile results are presented as Table XXVII with samples of the load-strain curves compiled as Figure 72.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	Confidence Limits 95%
14-P1	-0.2176	±0.0028	±0.0033
14-P2	-0.2118	±0.0071	±0.0085
14-P3	-0.3771	±0.0024	±0.0029

Material 14: B 1900 (continued)

Creep rupture data are presented in Table XXVIII. Creep deformation versus time values are plotted in Figures 73, 74, and 75. Isothermal plots of the rupture life data appear as Figure 76.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yeilds the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
850	1562	413.7	60.0	372.3	54.0	324.0	47.0
925	1697	248.2	36.0	210.3	30.5	172.4	25.0
1000	1832	148.2	21.5	120.7	17.5	96.5	14.0

TABLE XXVII
Tensile Properties of B 1900

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
14-T1	21	70	971.5	140.9	659.8	95.7	781.2	113.3	1076.3	156.1	0.09	6.6	10.9
14-T2			911.5	132.2	655.7	95.1	726.0	105.3	1066.6	154.7	0.07	6.4	15.6
14-T3			940.5	136.4	674.3	97.8	782.6	113.5	1072.8	155.6	0.06	7.2	13.9
14-T4	850	1562	787.4	114.2	476.4	69.1	664.0	96.3	830.8	120.5	0.09	6.8	13.8
14-T5			775.7	112.5	538.5	78.1	669.5	97.1	851.5	123.5	0.07	7.4	15.5
14-T6			755.7	109.6	493.7	71.6	634.3	92.0	843.9	122.4	0.10	4.4	15.7
14-T7	925	1697	601.2	87.2	317.9	46.1	448.2	65.0	677.1	98.2	0.09	6.1	18.9
14-T8			609.5	88.4	344.1	49.9	493.0	71.5	664.0	96.3	0.12	4.5	14.8
14-T9			589.5	85.5	330.3	47.9	466.8	67.7	644.7	93.5	0.08	4.4	14.7
14-T10	1000	1832	439.2	63.7	208.9	30.3	311.6	45.2	382.0	55.4	0.08	8.6	15.5
14-T11			467.5	67.8	212.4	30.8	328.9	47.7	426.8	61.9	----	7.5	12.5
14-T12			419.2	60.8	226.1	32.8	329.6	47.8	316.5	45.9	0.04	6.0	17.3

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	209.6	30.4
850	1562	158.6	23.0
925	1697	157.2	22.8
1000	1832	135.1	19.6

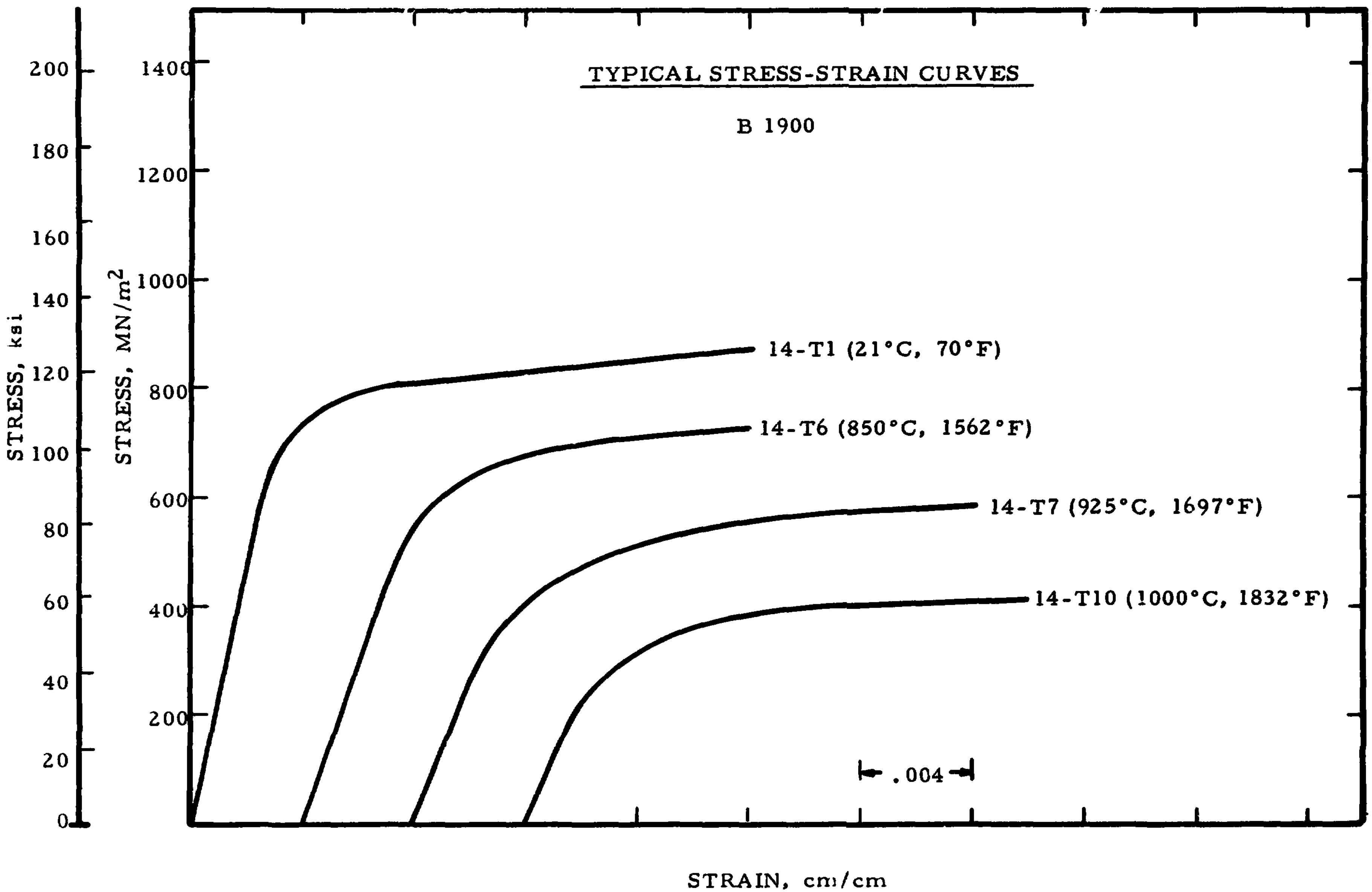

TYPICAL STRESS-STRAIN CURVES
B 1900
14-T1 (21°C, 70°F)
14-T6 (850°C, 1562°F)
14-T7 (925°C, 1697°F)
14-T10 (1000°C, 1832°F)
.004
STRESS, ksi
STRESS, MN/m2
STRAIN, cm/cm
0
20
40
60
80
100
120
140
160
180
200
200
400
600
800
1000
1200
1400

Figure 72

TABLE XXVIII

Creep Rupture Properties of B 1900

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
14-C4	850	1562	448.2	65.0	.044	19	19	51.0	4.7	14.3
14-C1			372.3	54.0	.0069	195	118	307.3	3.9	11.8
14-C2			372.3	54.0	.0066	105	119	250.3	3.9	10.4
14-C3			344.7	50.0	.0032	200	275	583.4	5.2	15.0
14-C5			313.7	45.5	--	(a)	(a)	1156.9	5.9	14.3
14-C7	925	1697	225.1	37.0	.014	50	55	93.2	3.2	10.5
14-C6			220.6	32.0	.0063	70	165	202.4	3.3	12.9
14-C8			199.9	29.0	.0012	225	335	395.5	3.5	14.1
14-C9			186.2	27.0	.0017	305	442	670.7	3.7	15.5
14-C10			172.4	25.0	.0008	510	750	1022.4	4.1	15.2
14-C12	1000	1832	151.7	22.0	.016	50	53	92.9	6.4	23.4
14-C11			124.1	18.0	.0037	150	188	256.5	4.9	27.4
14-C13			113.8	16.5	.0017	315	395	472.9	4.7	24.9
14-C14			103.4	15.0	.0011	(b)	(b)	773.9	3.0	14.1
14-C15			96.5	14.0	.0006	575	795	928.4	5.5	28.4

(a) Extensometer malfunction; data not available

(b) Specimen indicated 0.90% creep at 765.6 hours; time to 1% and start of third stage data was not obtained

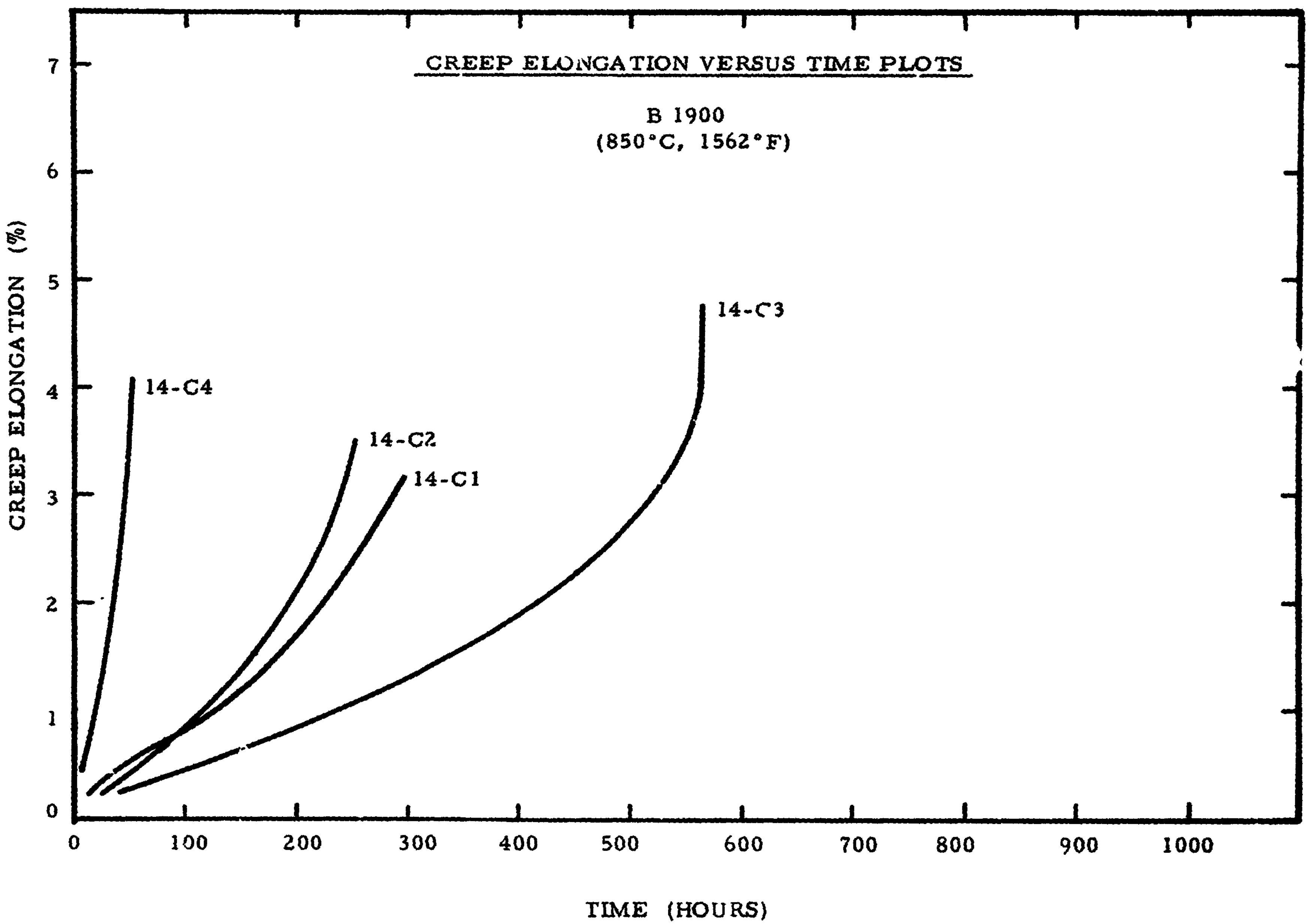

CREEP ELONGATION VERSUS TIME PLOTS
B 1900
(850°C, 1562°F)
14-C4
14-C2
14-C1
14-C3
CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000

Figure 73

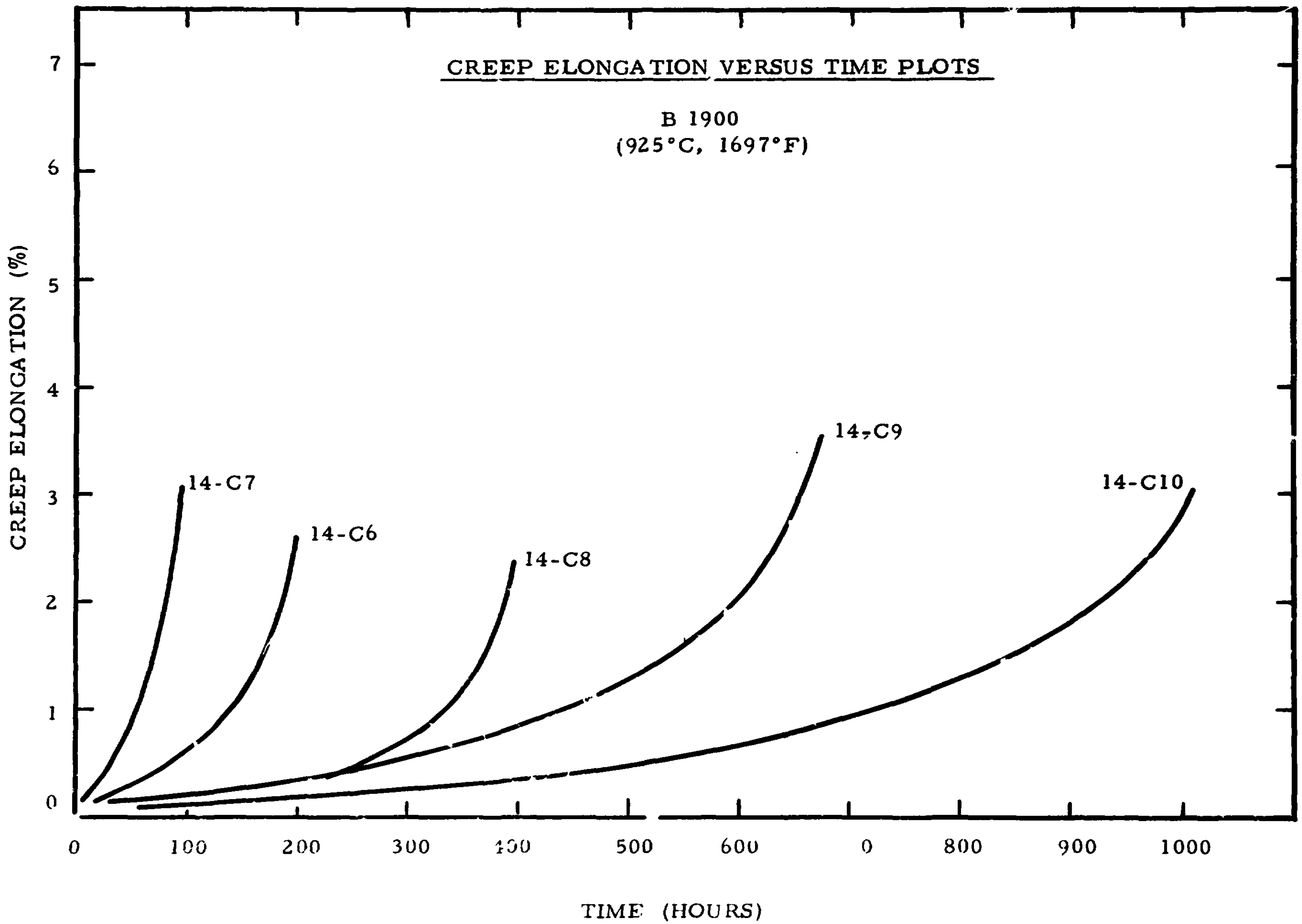
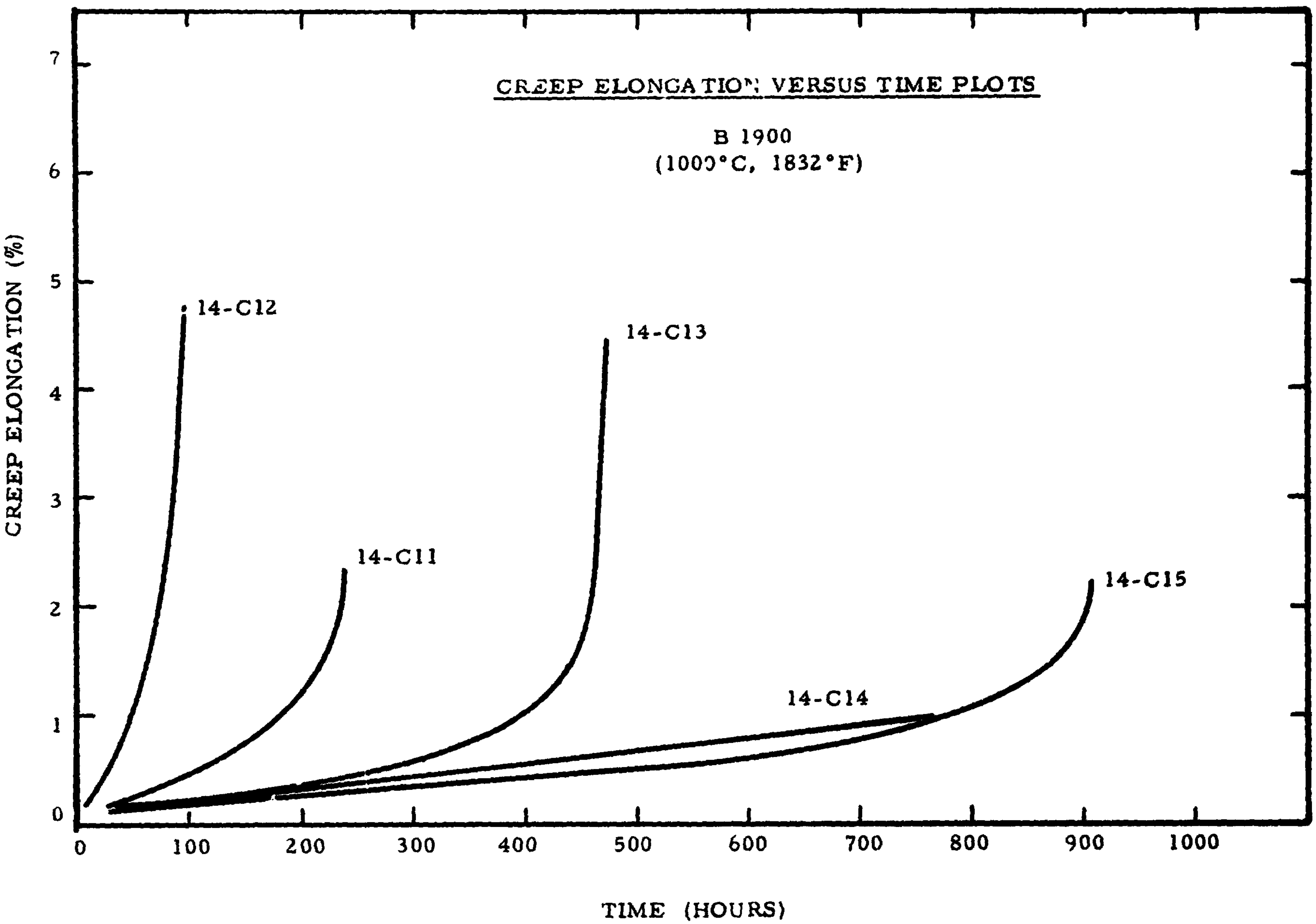

CREEP ELONGATION VERSUS TIME PLOTS
B 1900
(925°C, 1697°F)
14-C7
14-C6
14-C8
14-C9
14-C10
CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
0
100
200
300
500
600
800
900
1000

Figure 74



CREEP ELONGATION VERSUS TIME PLOTS
B 1900
(1000°C, 1832°F)
CREEP ELONGATION (%)
TIME (HOURS)
14-C12
14-C13
14-C11
14-C15
14-C14
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000

Figure 75

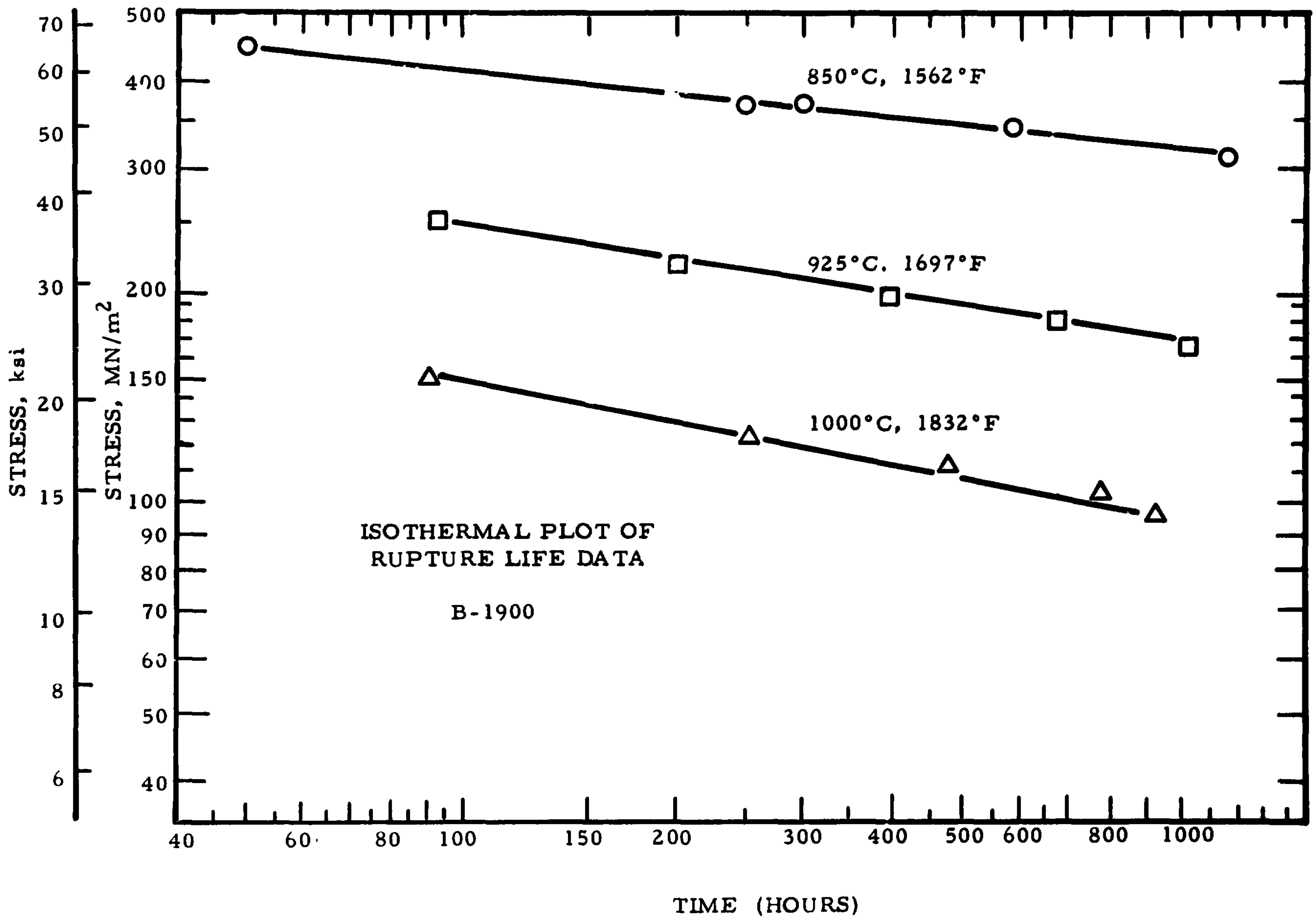

850°C, 1562°F
925°C, 1697°F
1000°C, 1832°F
ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
B-1900
STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 76

Material 15: B 1900 + Jocoat

A number of the machine. nd heat treated cast B 1900 bars (Material 14) were shipped to TRW Inc. - Turbine Components Division to have the PWA A 47 Jocoat applied. During this coating cycle, the bars were vacuum heat treated as follows:

1975°F/4 hours/rapid argon quench

After coating, the specimens were heat treated (at Metcut) in air as follows:

1550°F/24 hours/air cool to room temperature

Tensile results are presented as Table XXIX with samples of the load-strain curves compiled as Figure 77.

Creep rupture data are presented in Table XXX. Creep deformation versus time values are plotted in Figure 78, 79, and 80. Isothermal plots of the rupture life data appear as Figure 81.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
850	1562	393.0	57.0	344.7	50.0	299.9	43.5
925	1697	241.3	35.0	199.9	29.0	165.5	24.0
1000	1832	137.9	20.0	113.8	16.5	93.1	13.5

TABLE XXIX
Tensile Properties of B 1900 + Jocoat

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
15-T1	21	70	941.8	136.6	635.7	92.2	76[illegible]	[illegible]0.4	1026.6	148.9	0.10	6.7	8.5
15-T2			972.9	141.1	678.4	98.4	7[illegible]	[illegible]15.2	1048.7	152.1	0.07	6.6	7.5
15-T3			906.0	313.4	628.8	91.2	[illegible]55.0	109.5	983.9	142.7	0.08	6.3	8.0
15-T4	850	1562	752.9	109.2	466.8	67.7	642.6	93.2	779.1	113.0	0.07	7.0	11.0
15-T5			751.5	109.0	463.3	67.2	660.5	95.8	826.7	119.9	0.06	5.8	11.1
15-T6			770.8	111.8	540.6	78.4	695.7	100.9	795.0	115.3	0.11	1.9	5.3
15-T7	925	1697	627.4	91.0	350.3	50.8	482.6	70.0	715.7	103.8	0.10	6.2	17.4
15-T8			584.0	84.7	351.6	51.0	483.3	70.1	581.2	84.3	0.07	8.8	12.7
15-T9			600.5	87.1	333.0	48.3	484.0	70.2	432.3	62.7	0.16	6.5	19.8
15-T10	1000	1832	399.9	58.0	228.2	33.1	311.6	45.2	374.4	54.3	0.17	8.6	19.5
15-T11			435.1	63.1	204.8	29.7	312.3	45.3	295.1	42.8	0.18	8.5	13.7
15-T12			423.3	61.4	204.8	29.7	322.7	46.8	337.8	49.0	0.24	6.9	14.5

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	217.9	31.6
850	1562	170.3	24.7
925	1697	149.6	21.7
1000	1832	128.2	18.6

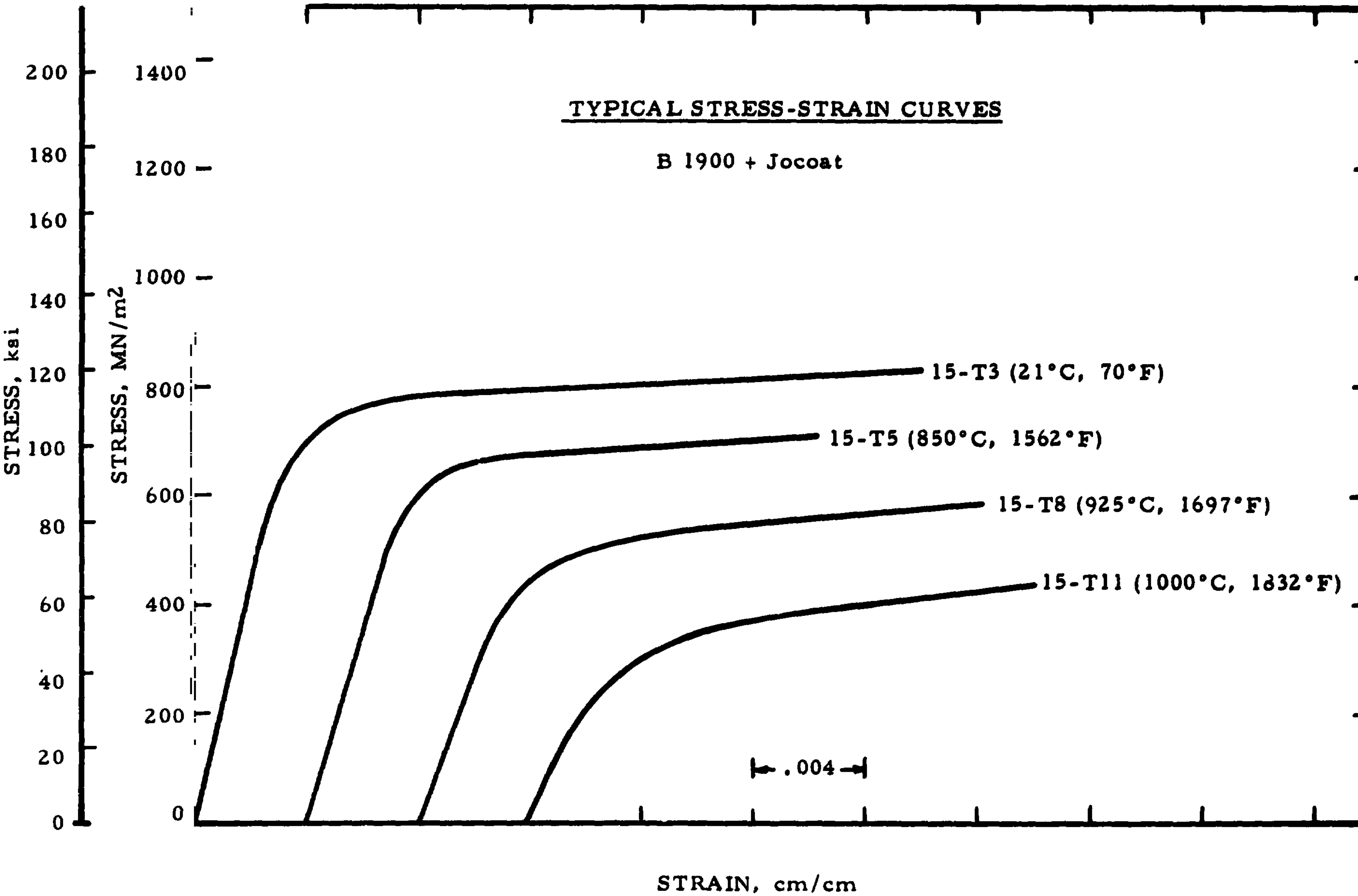

TYPICAL STRESS-STRAIN CURVES
B 1900 + Jocoat
STRESS, ksi
200
180
160
140
120
100
80
60
40
20
0
STRESS, MN/m2
1400
1200
1000
800
600
400
200
0
15-T3 (21°C, 70°F)
15-T5 (850°C, 1562°F)
15-T8 (925°C, 1697°F)
15-T11 (1000°C, 1832°F)
.004
STRAIN, cm/cm

Figure 77

TABLE XXX

Creep Rupture Properties of B 1900 + Jocoat

Specimen Number	Temp. °C	Temp. °F	Stress MN/m^2	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
15-C1	850	1562	434.4	63.0	.061	16	14	41.0	3.8	9.7
15-C2			393.0	57.0	.0211	42	44	98.6	3.4	9.4
15-C3			358.5	52.0	.0077	140	120	288.0	4.7	11.3
15-C4			324.1	47.0	.0029	230	284	503.7	4.6	12.2
15-C5			317.2	46.0	.0031	220	252	549.8	5.4	10.3
15-C6	925	1697	255.1	37.0	.0170	38	51	79.2	3.6	12.9
15-C7			220.6	32.0	.0088	70	100	170.6	4.7	23.6
15-C8			199.9	29.0	.0040	130	189	299.7	4.3	22.0
15-C9			186.2	27.0	.0024	250	300	471.6	4.1	12.0
15-C10			172.4	25.0	.0014	360	485	698.3	4.7	12.2
15-C11	1000	1832	151.7	22.0	.0153	25	32	48.4	3.4	18.3
15-C12			134.4	19.5	.0078	70	92	127.4	3.5	16.7
15-C13			117.2	17.0	.0037	135	197	244.7	3.6	14.1
15-C14			106.9	15.5	.0020	290	374	512.6	4.1	13.1
15-C15			96.5	14.0	.0009	400	650	761.5	5.6	14.0

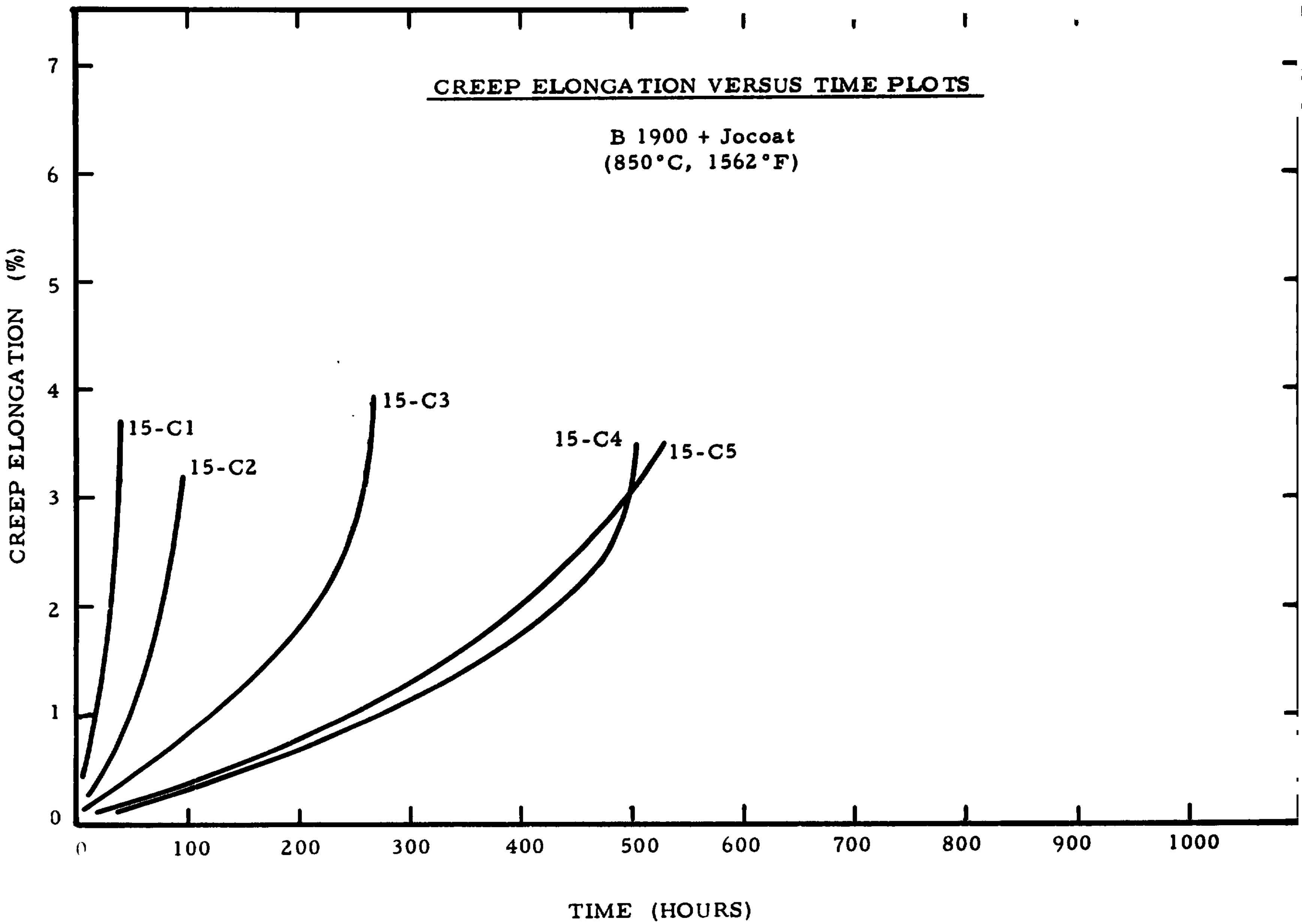

CREEP ELONGATION VERSUS TIME PLOTS
B 1900 + Jocoat
(850°C, 1562°F)
CREEP ELONGATION (%)
TIME (HOURS)
15-C1
15-C2
15-C3
15-C4
15-C5
0
1
2
3
4
5
6
7
100
200
300
400
500
600
700
800
900
1000

Figure 78

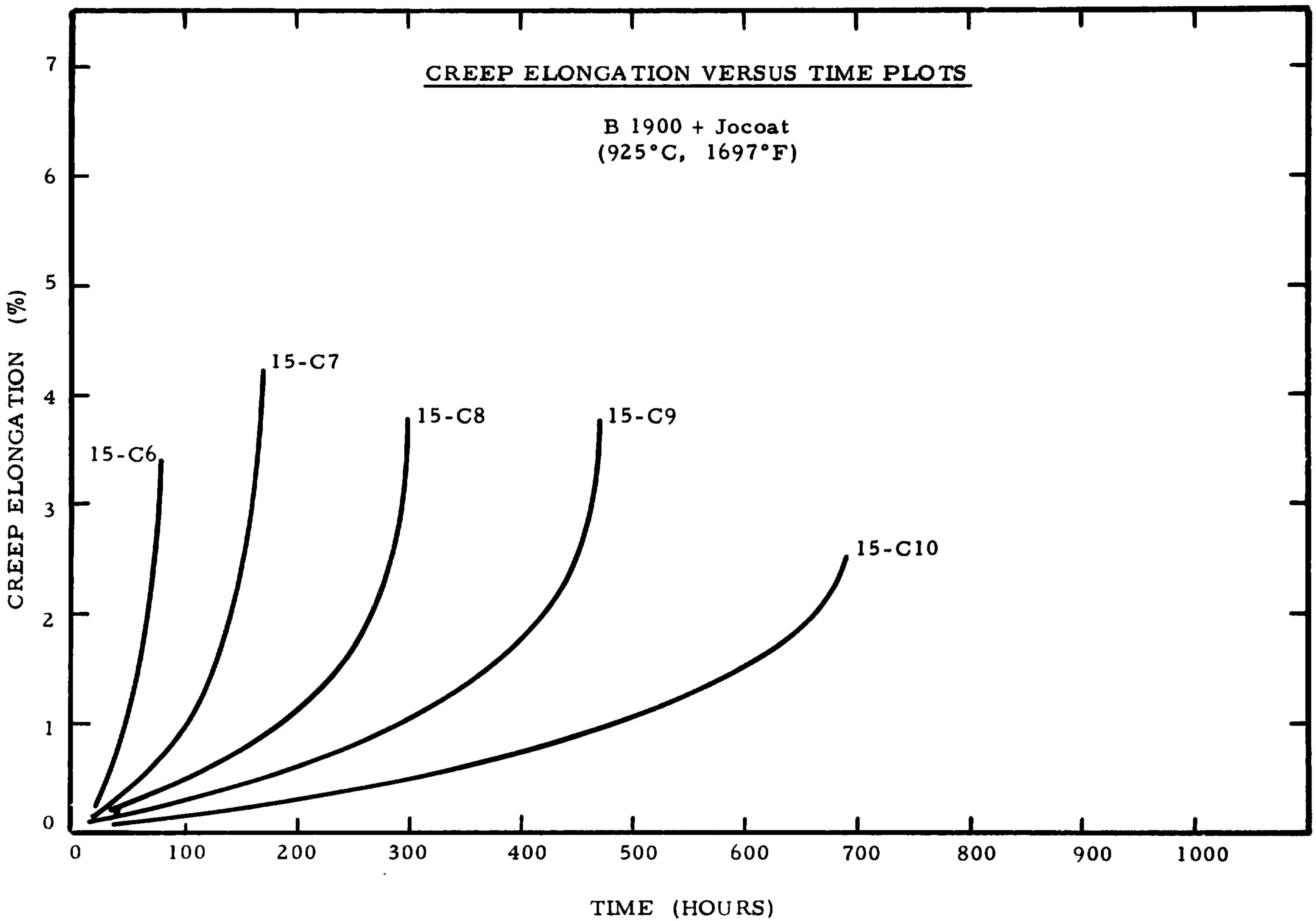

CREEP ELONGATION VERSUS TIME PLOTS
B 1900 + Jocoat
(925°C, 1697°F)
15-C6
15-C7
15-C8
15-C9
15-C10
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 79

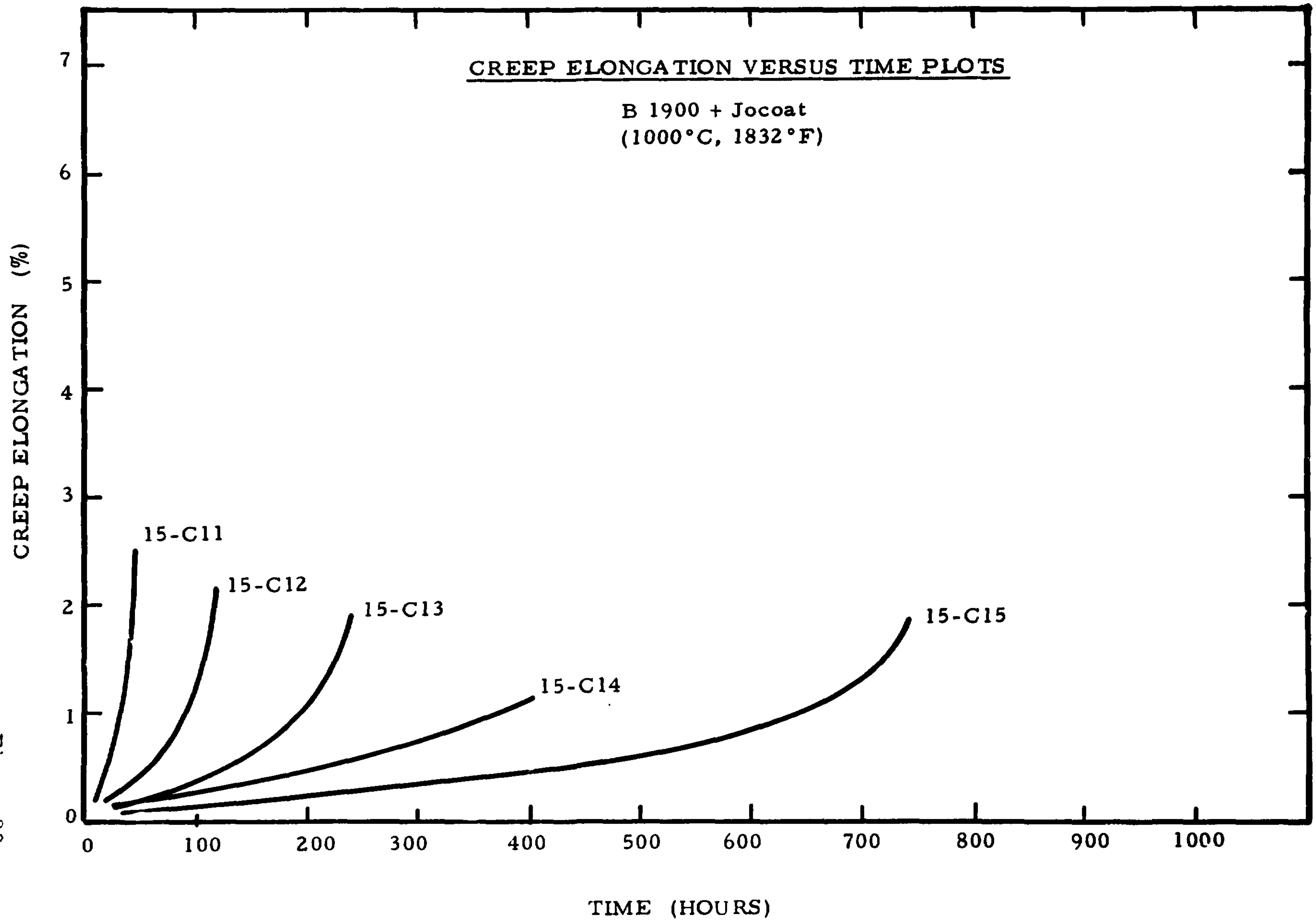

CREEP ELONGATION VERSUS TIME PLOTS
B 1900 + Jocoat
(1000°C, 1832°F)
CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
15-C11
15-C12
15-C13
15-C14
15-C15

Figure 80

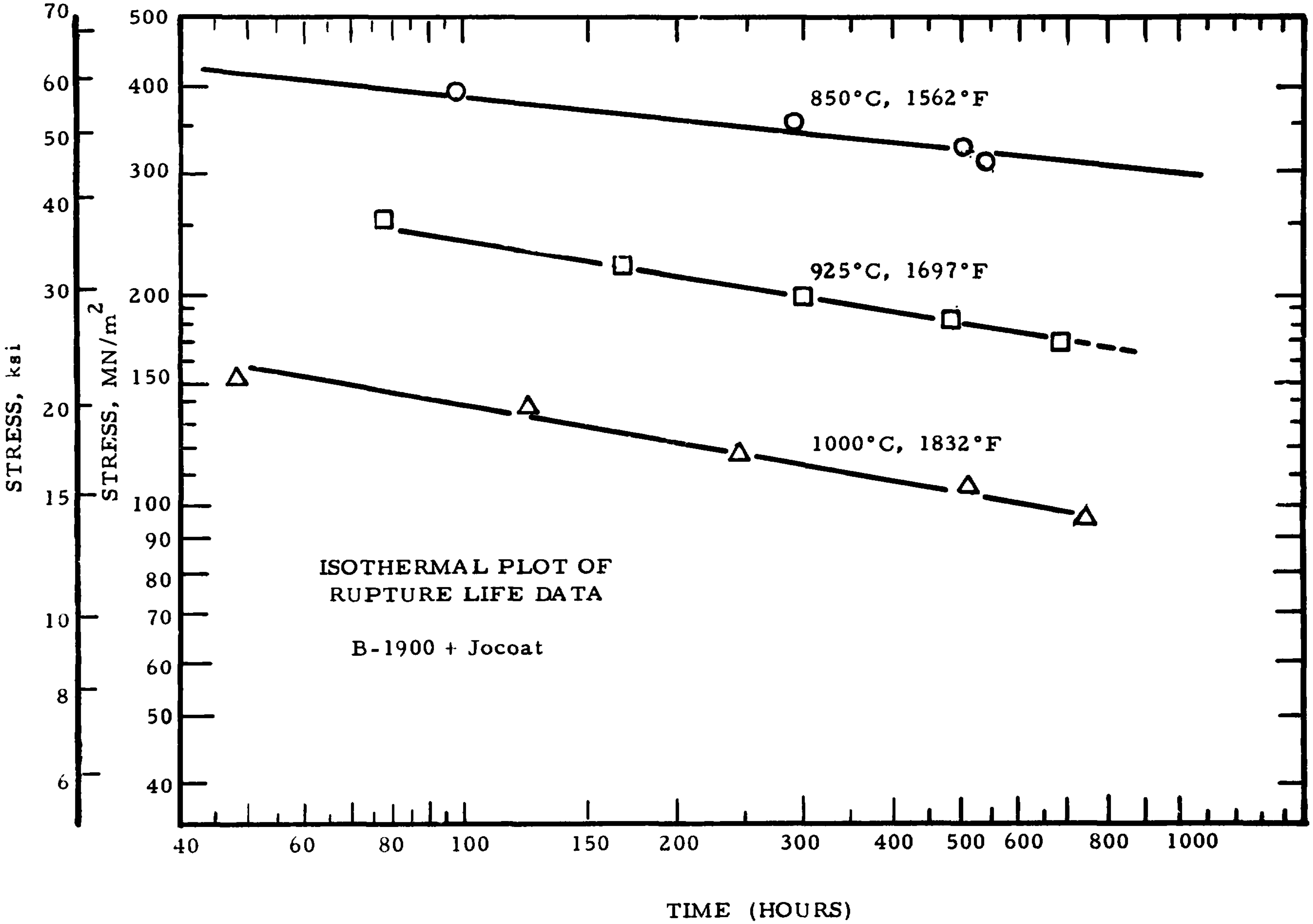

ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
B-1900 + Jocoat
850°C, 1562°F
925°C, 1697°F
1000°C, 1832°F
STRESS, ksi
STRESS, MN/m2
TIME (HOURS)
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 81

TEST RESULTS (continued)

Material 16: Mar-M200

The nickel-base alloy, designed for use as a cast turbine blade material, was supplied as cast remelt stock by NASA-Lewis Research Center. Test specimen blanks were cast by Howmet Corporation-Misco Division. Testing was performed on the material in the as-cast condition.

Chemical composition (supplied by NASA-Lewis Research Center) on this heat of material is as follows:

Carbon	0.15
Manganese	<0.02
Silicon	0.080
Chromium	9.20
Cobalt	10.25
Tungsten	12.55
Aluminum	5.05
Titanium	2.13
Zirconium	0.048
Boron	0.017
Iron	0.36
Columbium	0.96
Vanadium	<0.01
Nickel	Balance

Tensile results are presented as Table XXXI with samples of the load-strain curves compiled as Figure 82.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	Confidence Limits 95%
16-P1	-0.2843	±.0044	±.0053
16-P2	-0.3107	±.0035	±.0042
16-P3	-0.3167	±.0060	±.0072

Material 16: Mar-M200 (continued)

Creep rupture data are presented in Table XXXII. Creep deformation versus time values are plotted in Figures 83, 84, and 85. Isothermal plots of the rupture life data appear as Figure 86.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
871	1600	400.0	58.0	344.7	50.0	296.5	43.0
927	1700	262.0	38.0	217.2	31.5	175.8	25.5
982	1800	165.5	24.0	137.9	20.0	110.3	16.0

TABLE XXXI

Tensile Properties of Mar-M200

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
16-T1	21	70	1049.4	152.2	792.2	114.9	901.8	130.8	1128.7	163.7	0.08	6.0	8.5
16-T2			1074.9	155.9	766.0	111.1	898.4	130.3	1178.3	170.9	0.08	7.5	9.1
16-T3			1006.0	145.9	717.1	104.0	864.6	125.4	1183.8	171.7	0.08	6.7	15.5
16-T4	871	1600	798.4	115.8	575.0	83.4	750.2	108.8	838.4	121.[illegible]	0.14	1.1	4.7
16-T5			812.2	117.8	539.2	78.2	743.9	107.9	831.5	120.6	0.08	1.9	2.8
16-T6			797.8	115.7	559.2	81.1	728.1	105.6	825.3	119.7	0.07	1.5	3.6
16-T7	927	1700	630.2	91.4	411.6	59.7	540.6	78.4	657.8	95.4	0.07	1.6	4.4
16-Y8			659.8	95.7	460.6	66.8	570.9	82.8	682.6	99.0	0.12	2.5	5.0
16-T9			683.7	99.2	428.2	62.1	556.4	80.7	685.3	99.4	0.12	2.3	3.9
16-T10	982	1800	466.8	67.7	308.2	44.7	373.7	54.2	451.6	65.5	0.10	3.6	4.2
16-T11			515.7	74.8	315.8	45.8	408.2	59.2	498.5	72.3	0.09	2.8	4.2
16-T12			540.6	78.4	279.2	40.5	406.1	58.9	553.7	80.3	0.09	4.6	7.8

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	211.0	30.6
871	1600	164.8	23.9
927	1700	156.5	22.7
982	1800	141.4	20.5

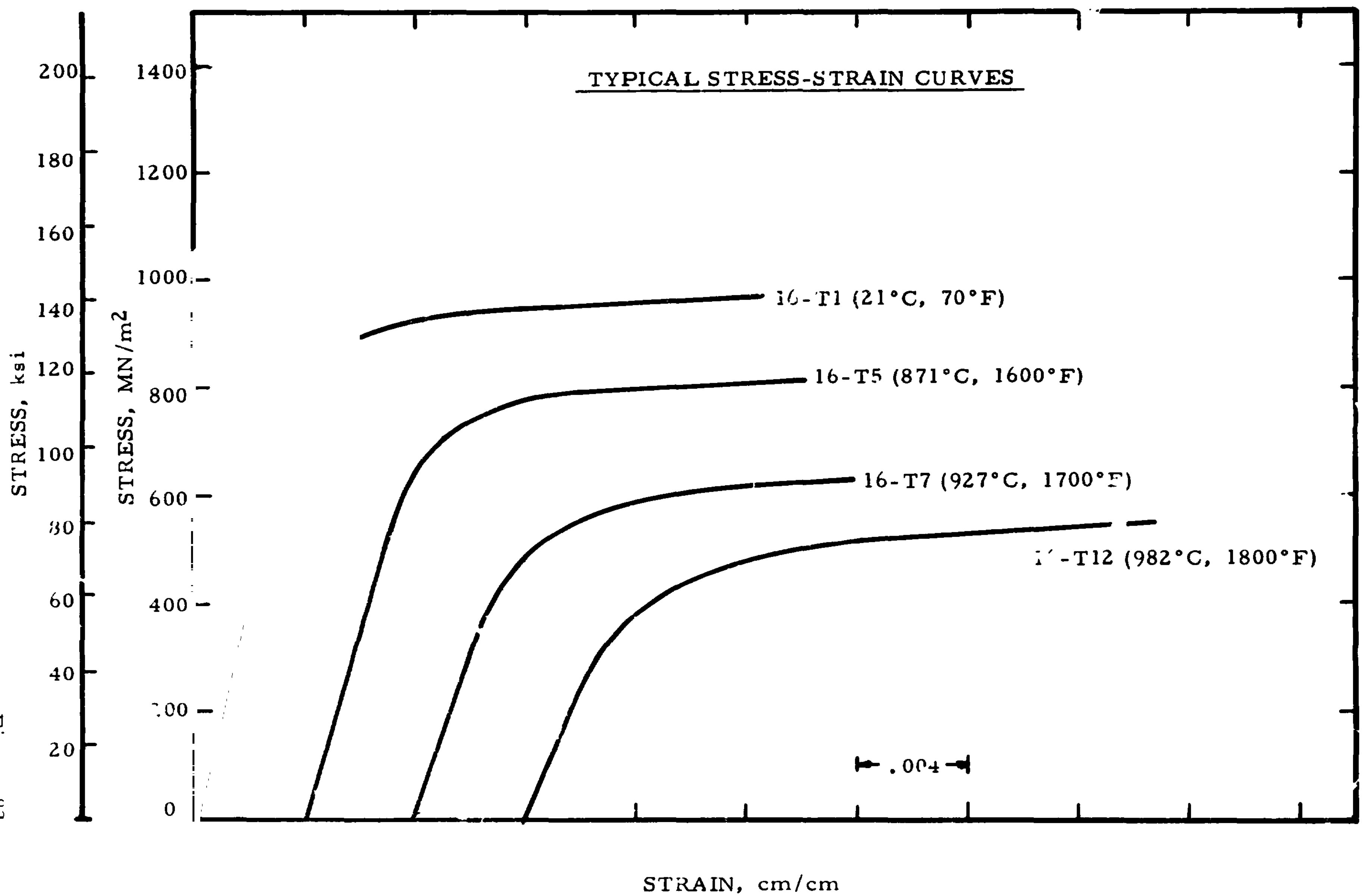

TYPICAL STRESS-STRAIN CURVES
16-T1 (21°C, 70°F)
16-T5 (871°C, 1600°F)
16-T7 (927°C, 1700°F)
-T12 (982°C, 1800°F)
.004
STRESS, ksi
STRESS, MN/m2
STRAIN, cm/cm
200
180
160
140
120
100
80
60
40
20
1400
1200
1000
800
600
400
0

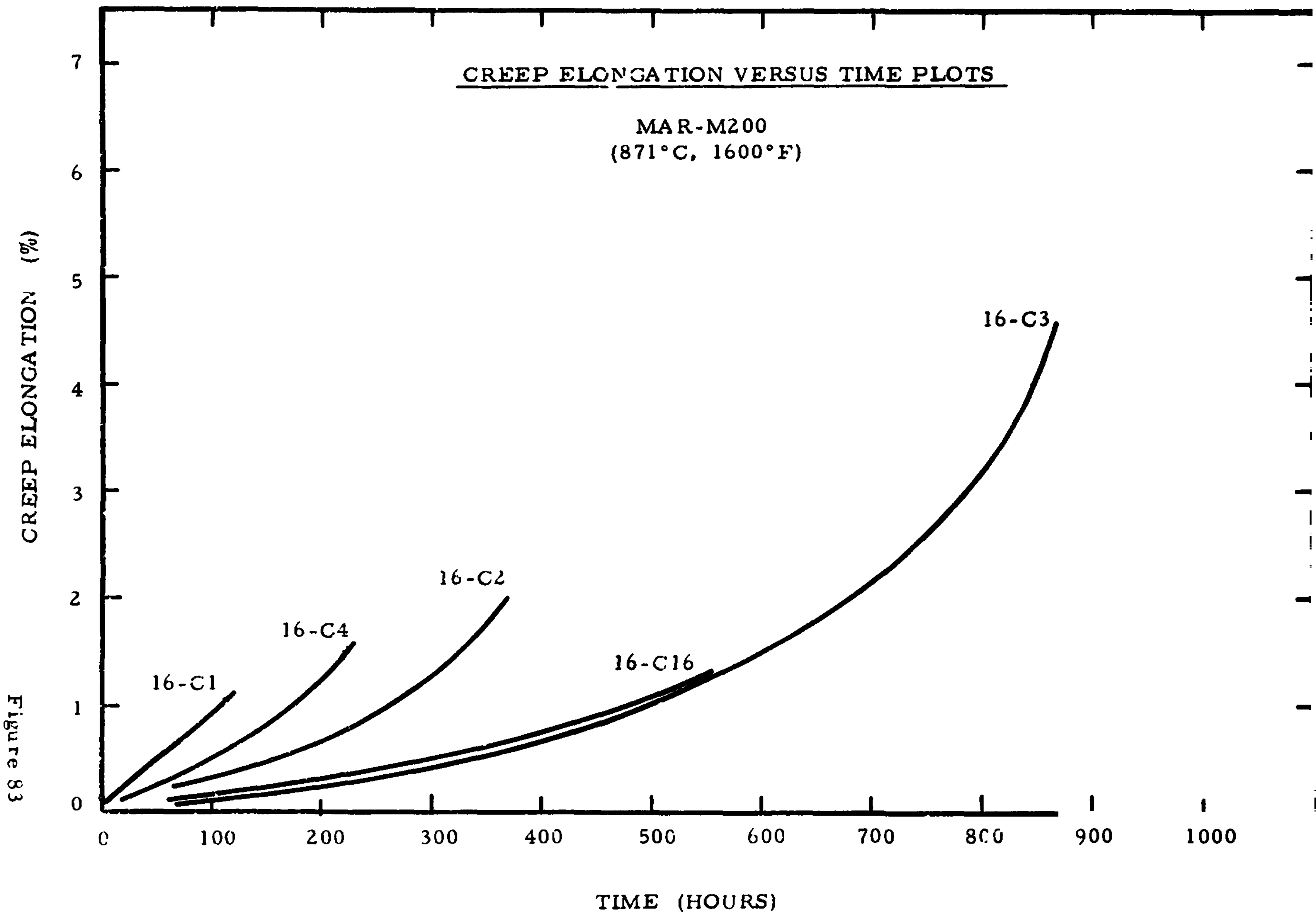
Figure 82

TABLE XXXII

Creep Rupture Properties of Mar-M200

Specimen Number	Temp. °C	Temp. °F	Stress MN/m²	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
16-C1	871	1600	379.2	55.0	.0060	73	110	138.1	1.6	2.2
16-C4			365.4	53.0	.0042	117	177	229.6	1.8	2.0
16-C2			344.7	50.0	.0014	145	265	383.8	2.6	3.4
16-C5			317.2	46.0	--	--	--	(a)	--	--
16-C16			317.2	46.0	.0010	290	480	588.8	2.0	1.5
16-C3			303.4	44.0	.0012	250	498	874.7	5.2	8.1
16-C6	927	1700	255.1	37.0	.0078	73	101	122.2	1.7	1.8
16-C7			227.5	33.0	.0027	165	(b)	227.6	1.1	0.4
16-C8			199.9	29.0	.0012	370	(b)	515.8	1.4	0.4 (c)
16-C10			186.2	27.0	.0011	510	(b)	629.5	0.9	0.4 (c)
16-C9			179.3	26.0	--	--	--	4.8 (d)	6.8	19.4
16-C11	982	1800	172.4	25.0	.0081	73	(b)	101.2	1.3	0.2
16-C12			151.7	22.0	.0057	118	167	198.8	1.7	0.8
16-C13			131.0	19.0	.0025	250	312	322.5	1.4	0.2
16-C14			120.7	17.5	.0007	(b)	(b)	717.9	2.0	nil (c)
16-C15			113.8	16.5	.0008	(b)	(b)	871.4	1.4	1.2 (c)

(a) Over temperature at beginning of test; void
(b) Specimen failed before value was obtained
(c) Failure occurred near radius
(d) Test void; specimen temperature was approximately 60°F higher after one hour at stress



CREEP ELONGATION VERSUS TIME PLOTS
MAR-M200
(871°C, 1600°F)
16-C1
16-C4
16-C2
16-C16
16-C3
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 83

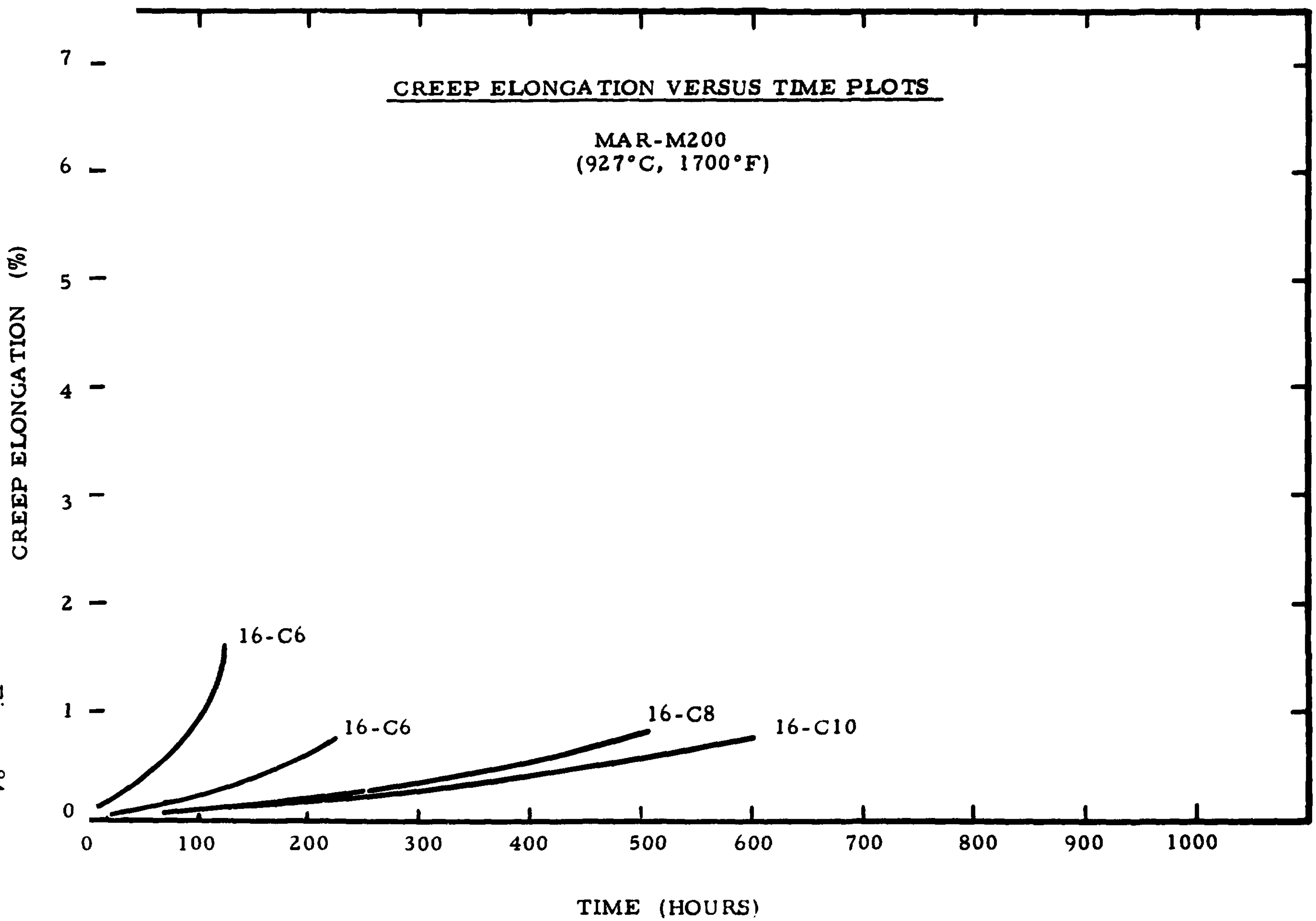

CREEP ELONGATION VERSUS TIME PLOTS
MAR-M200
(927°C, 1700°F)
CREEP ELONGATION (%)
TIME (HOURS)
16-C6
16-C6
16-C8
16-C10
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000

Figure 84

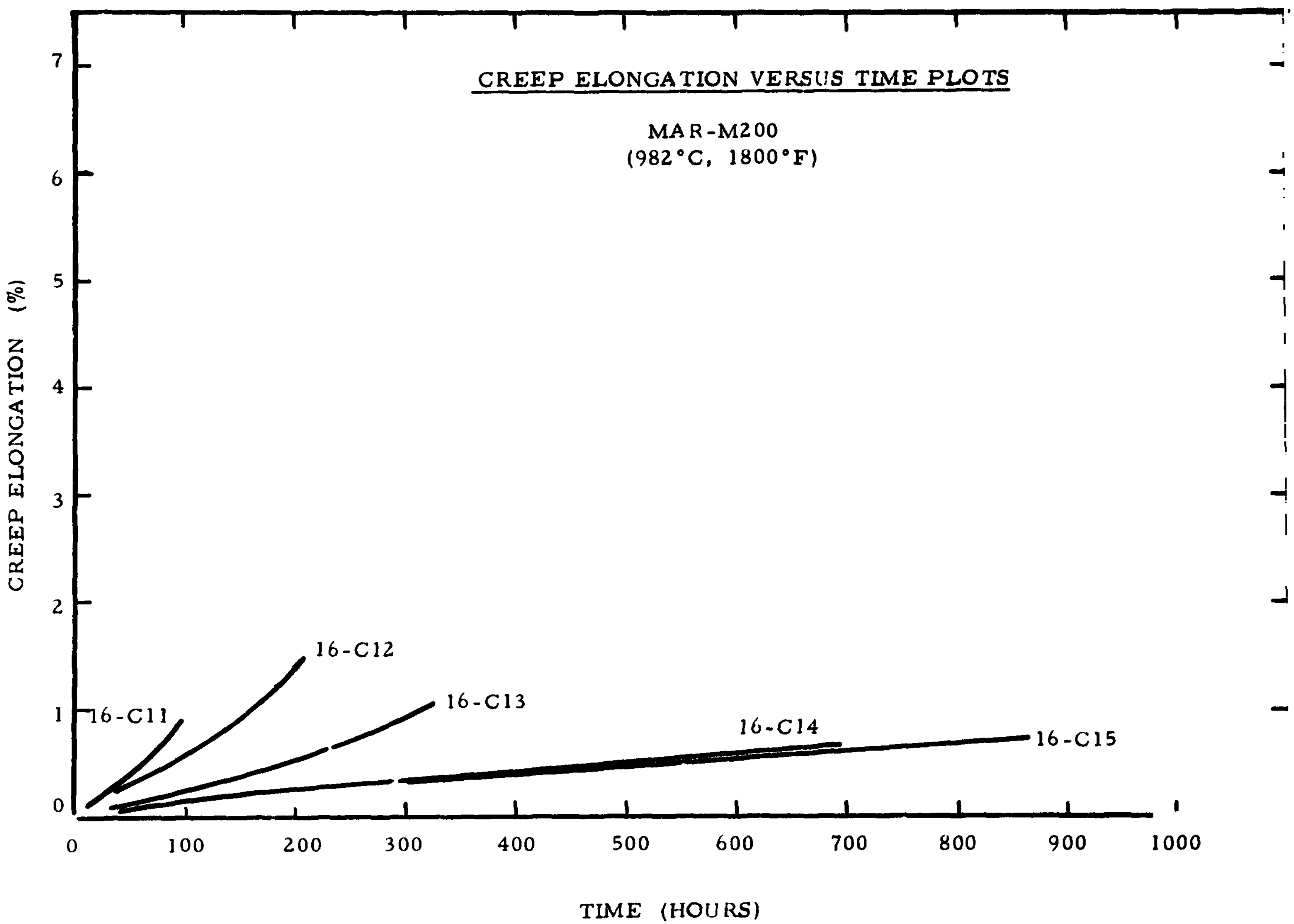
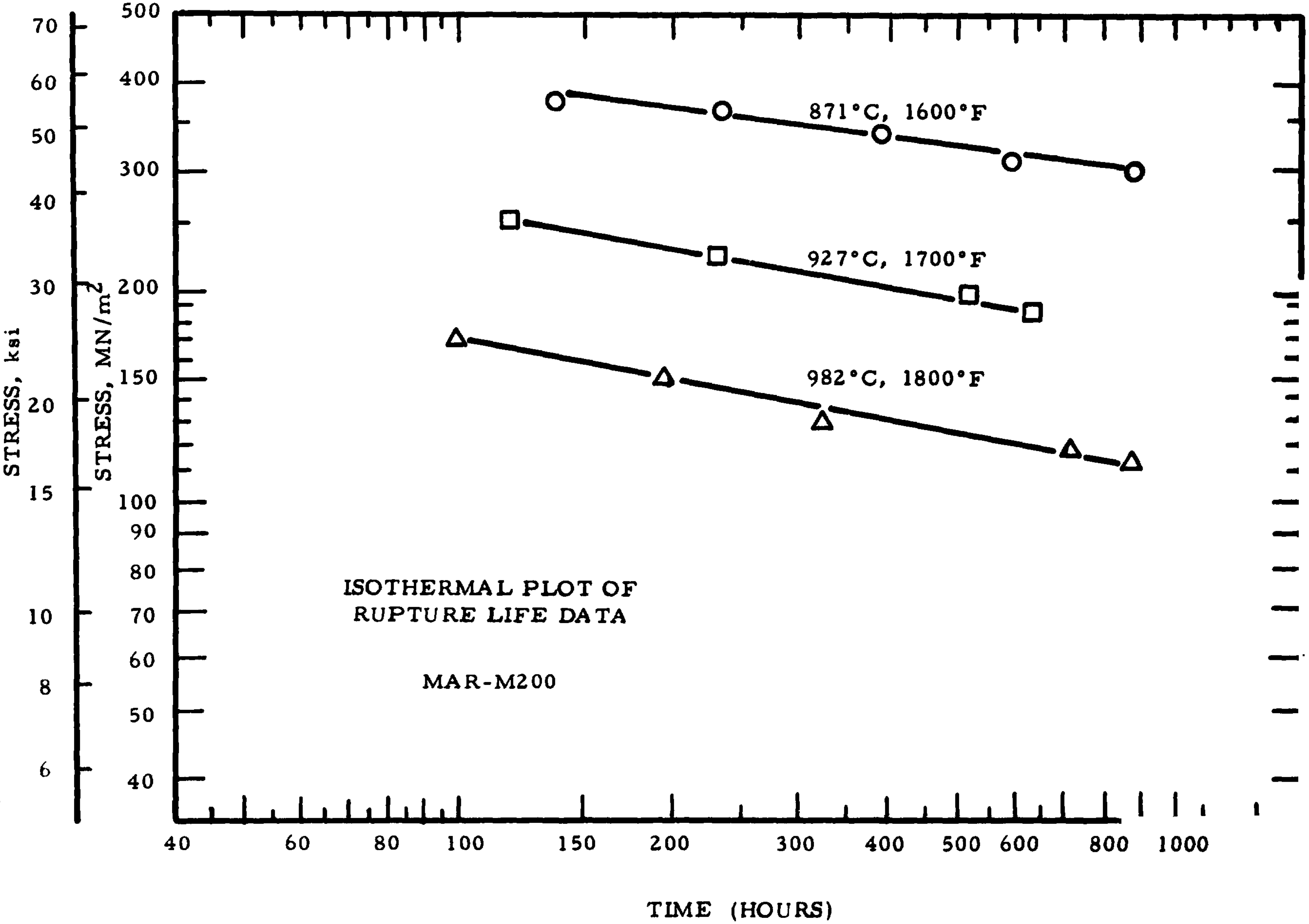

CREEP ELONGATION VERSUS TIME PLOTS
MAR-M200
(982°C, 1800°F)
CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
16-C11
16-C12
16-C13
16-C14
16-C15

Figure 65



ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
MAR-M200
871°C, 1600°F
927°C, 1700°F
982°C, 1800°F
STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 86

Material 17: Mar-M302

This cobalt base alloy, having good oxidation and thermal shock resistance, was supplied as cast remelt stock by NASA-Lewis Research Center. It was subsequently cast into specimens by the Howmet Corporation-Misco Division. All testing was performed on the material in the as-cast condition.

Chemical composition (supplied by NASA-Lewis Research Center) for this heat of material is as follows:

Carbon	0.88
Manganese	<0.10
Silicon	0.22
Chromium	21.9
Nickel	0.49
Molybdenum	< 0.1
Tungsten	9.89
Zirconium	0.24
Boron	<0.01
Tantalum	8.80
Iron	1.11
Cobalt	Balance

Tensile results are presented as Table XXXIII with samples of the load-strain curves compiled as Figure 87.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	95%
17-P1	-0.3001	±.0020	±.0024
17-P2	-0.2906	±.0037	±.0044
17-P3	-0.2907	±.0051	±.0061

TEST RESULTS (continued)

Creep rupture data are presented in Table XXXIV. Creep deformation versus time values are plotted in Figures 88, 89, and 90. Isothermal plots of the rupture life data appear as Figure 91.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
850	1562	217.2	31.5	186.2	27.0	155.1	22.5
925	1697	144.8	21.0	120.7	17.5	98.6	14.3
1000	1832	79.3	11.5	65.5	9.5	51.7	7.5

TABLE XXXIII
Tensile Properties of MAR-M302

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m²	Ultimate Strength ksi	0.02% Yield Strength MN/m²	0.02% Yield Strength ksi	0.2% Yield Strength MN/m²	0.2% Yield Strength ksi	Fracture Strength MN/m²	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
17-T17	21	70	826.0	119.8	402.0	58.3	623.3	90.4	829.4	120.3	0.29	0.8	0.4
17-T2			834.3	121.0	430.9	62.5	602.6	87.[illegible]	845.3	122.6	0.14	0.8	1.6
17-T3			737.1	106.9	387.5	56.2	625.4	90.7	745.3	108.1	0.33	0.9	1.5
17-T4	850	1562	459.9	66.7	253.0	36.7	337.2	48.9	473.7	68.7	0.16	8.2	9.8
17-T5			441.3	64.0	254.4	36.9	334.4	48.5	472.3	68.5	0.14	11.7	12.2
17-T6			437.8	63.5	254.4	36.9	331.0	48.0	489.5	71.0	0.08	11.1	14.9
17-T7	925	1697	326.1	47.3	222.0	32.2	273.7	39.7	348.2	50.5	0.08	10.1	11.5
17-T8			328.2	47.6	225.5	32.7	274.4	39.8	333.7	48.4	0.11	16.0	21.1
17-T9			303.4	44.0	197.8	28.7	248.9	36.1	348.9	50.6	0.08	16.1	18.2
17-T10	1000	1832	222.0	32.2	139.3	20.2	178.6	25.9	54.5	7.9	0.04	12.5	22.0
17-T11			225.5	32.7	125.5	18.2	199.9	29.0	4.1	0.6	0.09	21.5	27.8
17-T12			237.9	34.5	130.3	18.9	174.4	25.3	187.5	27.2	0.10	20.9	26.1

Temp. °C	Temp. °F	Modulus of Elasticity GN/m²	Modulus of Elasticity 10^6 psi
21	70	233.0	33.8
850	1562	144.1	20.9
925	1697	152.4	22.1
1000	1832	121.3	17.6

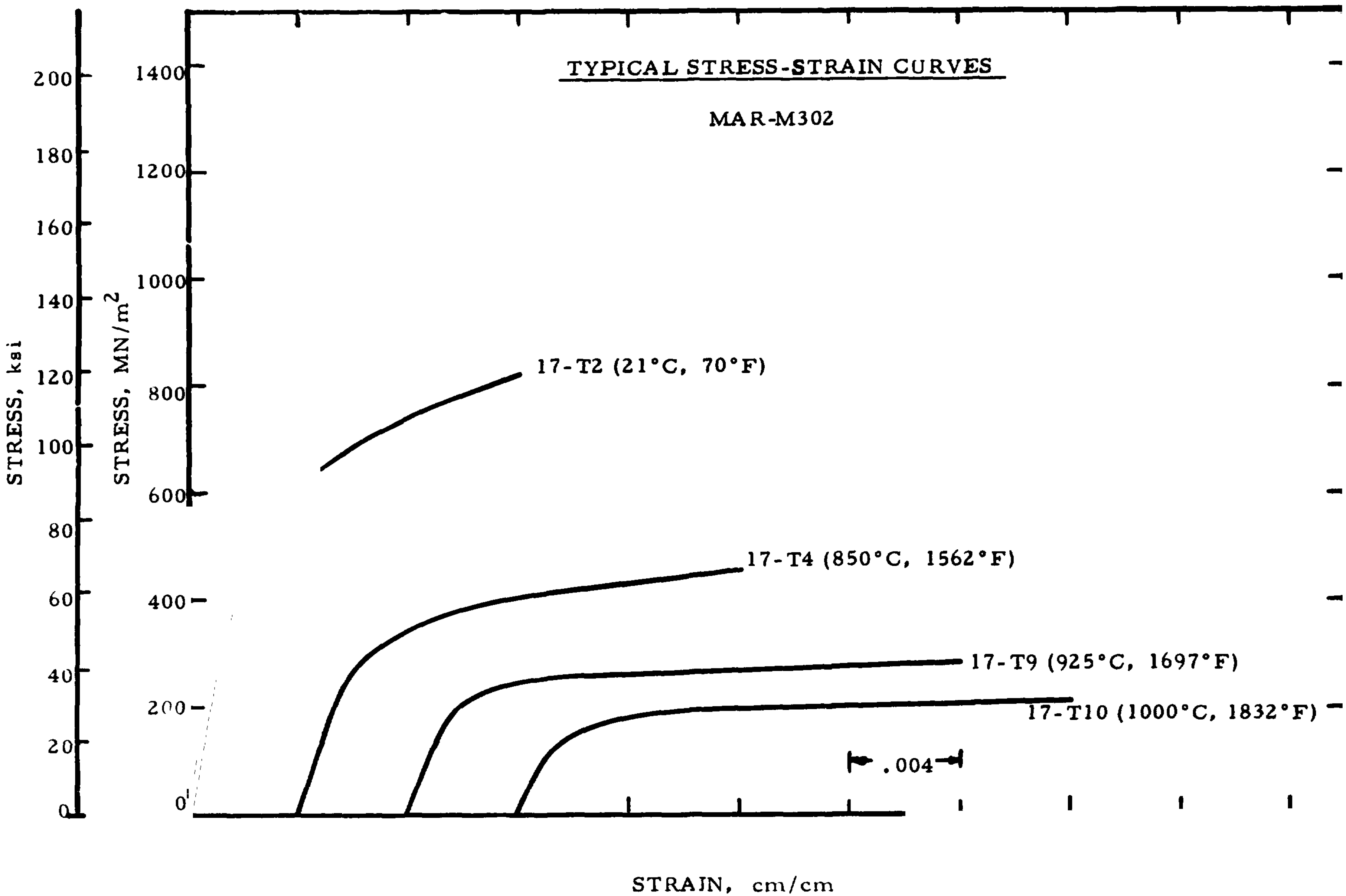

TYPICAL STRESS-STRAIN CURVES
MAR-M302
17-T2 (21°C, 70°F)
17-T4 (850°C, 1562°F)
17-T9 (925°C, 1697°F)
17-T10 (1000°C, 1832°F)
.004
STRESS, ksi
STRESS, MN/m²
STRAIN, cm/cm
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400

Figure 87

TABLE XXXIV

Creep Rupture Properties of Mar-M302

Specimen Number	Temp. °C	Temp. °F	Stress MN/m^2	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
17-C1	850	1562	206.8	30.0	.043	(a)	(a)	139.7	17.4	19.0
17-C2			189.6	27.5	--	--	--	(b)	--	--
17-C3			189.6	27.5	.0184	77	30	254.0	17.4	24.4
17-C4			172.4	25.0	.0113	140	45	509.7	22.3	23.7
17-C5			155.1	22.5	.0036	310	190	924.5	7.7	12.7
17-C8	925	1697	137.9	20.0	.079	49	7.5	130.0	15.0	20.4
17-C6			124.1	18.0	.0257	120	28	246.3	9.0	13.2
17-C9			110.3	16.0	.0036	220	95	532.8	8.9	12.6
17-C7			93.1	13.5	.0025	875	235	1401.4	5.6	7.4
17-C10	1000	1832	103.4	15.0	--	(c)	2.5	24.5	11.9	19.2
17-C11			79.3	11.5	.0492	65	19.5	111.9	8.3	11.7
17-C12			68.9	10.0	.0130	--	74	(d)	--	--
17-C13			68.9	10.0	.0166	175	62	255.2	6.8	7.5
17-C14			62.1	9.0	.0069	250	140	444.4	5.6	8.2
17-C15			55.2	8.0	--	--	--	669.7	(e)	5.7
17-C16			48.3	7.0	.0013	1050	610	1476.5	(e)	1.8

(a) Apparent extensometer malfunction; data not available
(b) Specimen over temperature at 21.3 hours; test unloaded
(c) Insufficient data available to determine this value
(d) Furnace "burned out" at 142.3 hours; test discontinued
(e) Specimen broke at second loadtion while removing from adapter; elongation not available

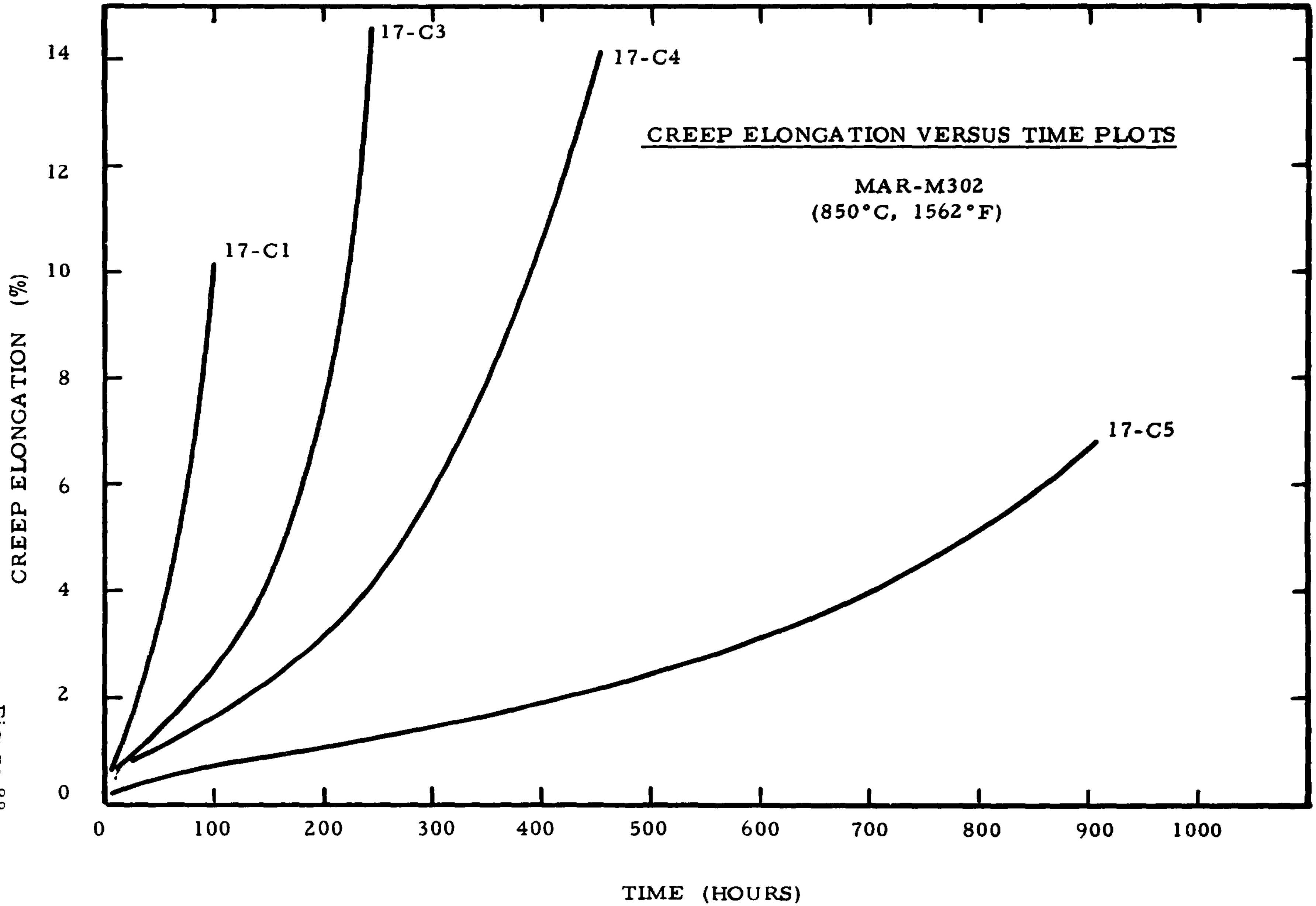

CREEP ELONGATION VERSUS TIME PLOTS
MAR-M302
(850°C, 1562°F)
17-C1
17-C3
17-C4
17-C5
CREEP ELONGATION (%)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 88

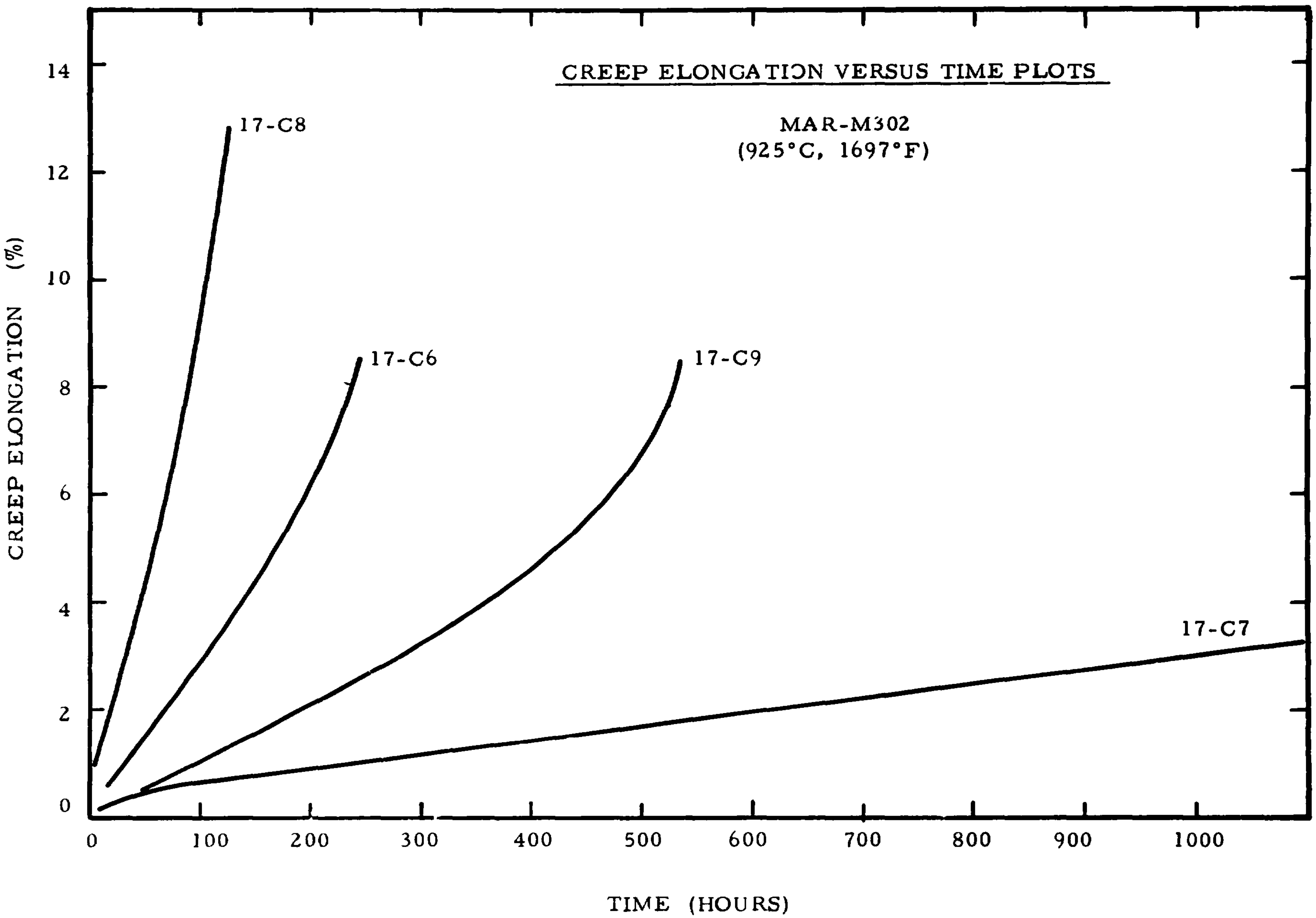

CREEP ELONGATION VERSUS TIME PLOTS
MAR-M302
(925°C, 1697°F)
17-C8
17-C6
17-C9
17-C7
CREEP ELONGATION (%)
0
2
4
6
8
10
12
14
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 89

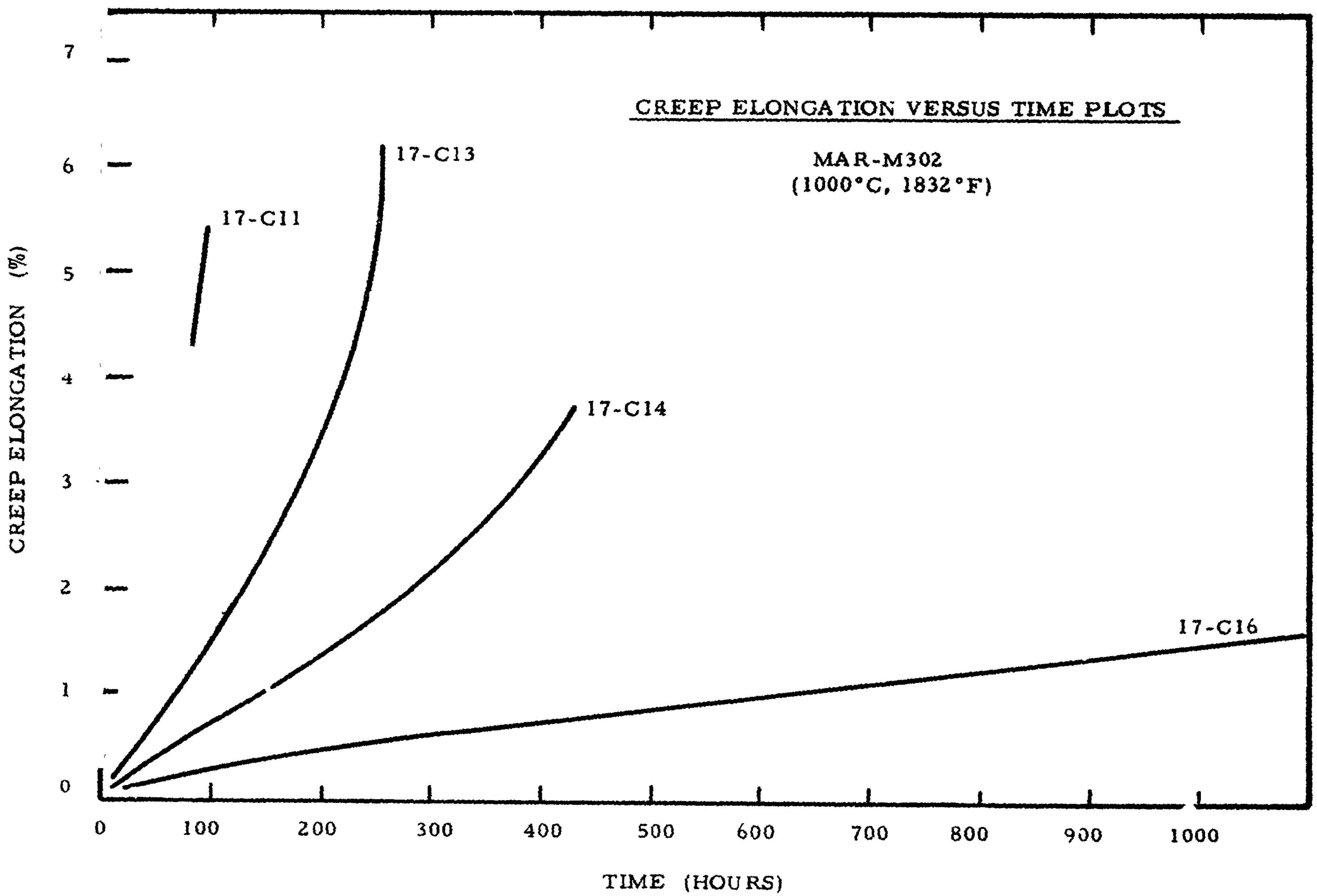
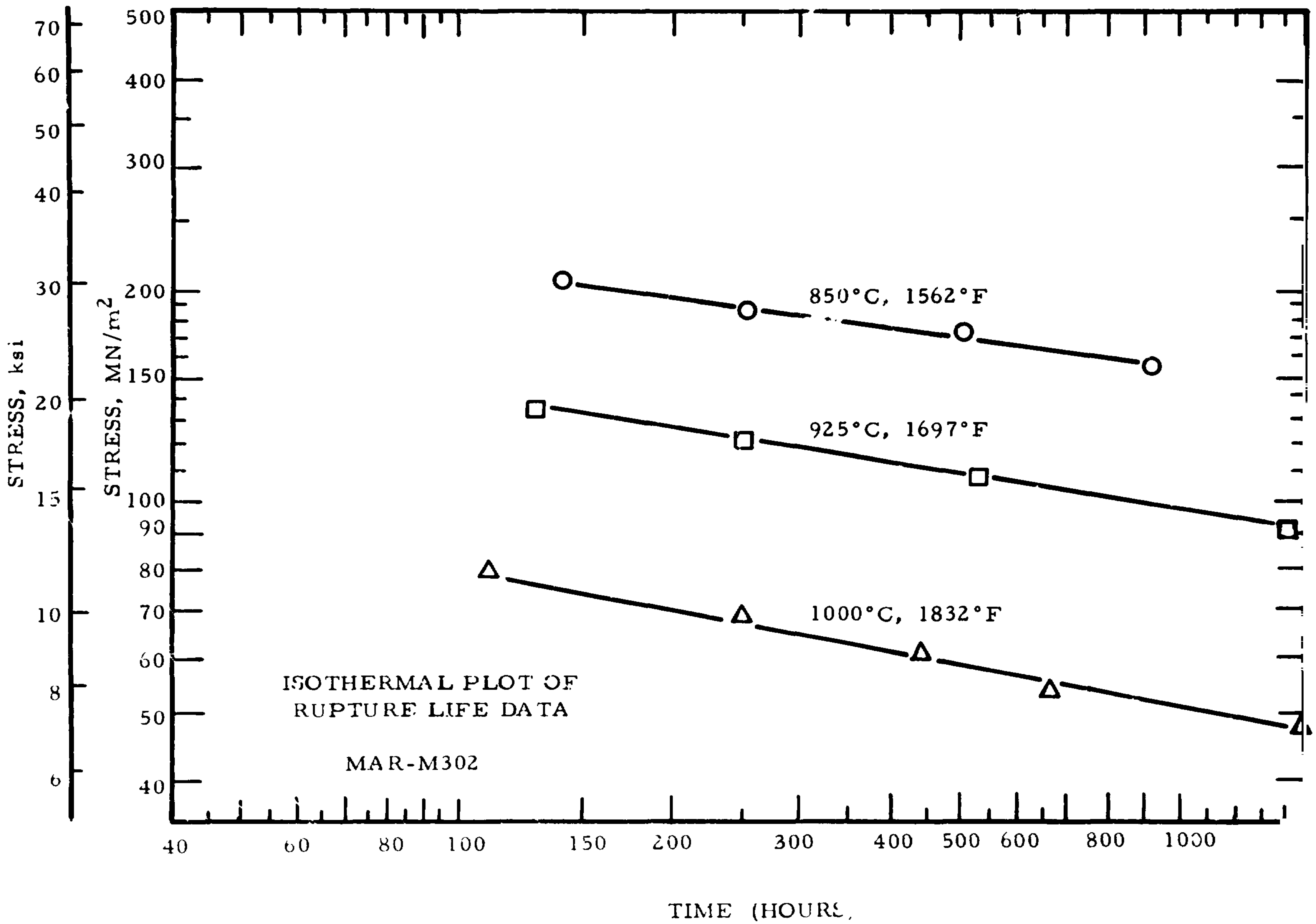

CREEP ELONGATION VERSUS TIME PLOTS
MAR-M302
(1000°C, 1832°F)
17-C11
17-C13
17-C14
17-C16
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 90



850°C, 1562°F
925°C, 1697°F
1000°C, 1832°F
ISOTHERMAL PLOT OF
RUPTURE LIFE DATA
MAR-M302
STRESS, ksi
STRESS, MN/m2
TIME (HOURS)

Figure 91

Material 18: Rene' 80

This nickel-base alloy, developed from high temperature-high strength applications was supplied by NASA-Lewis Research Center as cast remelt stock. Specimen blanks were cast by Howmet Corporation-Misco Division. Subsequently, Misco also heat treated the blanks as follows:

2200°F (vacuum)/2 hours/vacuum cool to 2000°F, gas fan cool
2000°F (vacuum)/4 hours/gas fan cool
1925°F (vacuum)/4 hours/cool to 1200°F in 1 hour - gas fan cool
1550°F (argon)/16 hours/air cool

Chemical composition (supplied by NASA-Lewis Research Center) for this heat of material is as follow

Carbon	0.17
Manganese	<0.02
Silicon	<0.05
Chromium	13.80
Molybdenum	4.11
Iron	0.13
Titanium	4.87
Aluminum	2.99
Cobalt	9.73
Tungsten	3.94
Zirconium	0.043
Boron	0.015
Nickel	Balance

Tensile results are presented as Table XXXV with samples of the load-strain curves compiled as Figure 92.

Poisson's Ratio values are as listed below:

Specimen Number	Average Value Poisson's Ratio	Confidence Limits 90%	95%
18-P1	-0.3039	±.0038	±.0046
18-P2	-0.3312	±.0051	±.0062
18-P3	-0.3199	±.0095	±.0115

TEST RESULTS (continued)

Material 18: Rene' 80 (continued)

Creep rupture data are presented in Table XXXVI. Creep deformation versus time values are plotted in Figures 93, 94, and 95. Isothermal plots of the rupture life data appear as Figure 96.

An analysis of the creep rupture data using parametric plots of the data in conjunction with the isothermal plot yields the following values of the rupture strengths to produce 100, 300, and 1000 hour life data at the appropriate test temperatures.

Temp.		Stress to Produce Failure at					
		100 hour		300 hour		1000 hour	
°C	°F	MN/m^2	ksi	MN/m^2	ksi	MN/m^2	ksi
850	1562	358.5	52.0	313.7	45.5	272.3	39.5
925	1697	227.5	33.0	186.2	27.0	155.1	22.5
1000	1832	127.6	18.5	103.4	15.0	82.7	12.0

TABLE XXXV
Tensile Properties of Rene'80

Spec. No.	Temp. °C	Temp. °F	Ultimate Strength MN/m^2	Ultimate Strength ksi	0.02% Yield Strength MN/m^2	0.02% Yield Strength ksi	0.2% Yield Strength MN/m^2	0.2% Yield Strength ksi	Fracture Strength MN/m^2	Fracture Strength ksi	Strain Hardening Exponent	Elong. (%)	R.A. (%)
18-T1	21	70	979.8	142.1	689.5	100.0	814.3	118.1	1032.8	149.8	0.11	5.3	5.2
18-T2			1005.3	145.8	682.6	99.0	820.5	119.0	1077.7	156.3	0.11	6.0	6.8
18-T3			1001.8	145.3	690.9	100.2	828.1	120.4	1074.2	155.8	0.09	5.8	6.7
18-T4	850	1562	686.7	99.6	435.8	63.2	555.7	80.6	752.9	109.2	0.08	12.5	32.6
18-T5			693.6	100.6	417.1	60.5	515.4	76.2	759.8	110.2	0.08	17.5	28.7
18-T6			668.1	96.9	413.7	60.0	531.6	77.1	737.1	106.9	0.09	20.8	26.9
18-T7	925	1697	523.2	75.9	279.2	40.5	364.7	52.9	501.3	72.7	0.20	20.6	32.0
18-T8			510.2	74.0	284.1	41.2	368.2	53.4	498.5	72.3	0.08	21.2	35.9
18-T9			495.0	71.8	262.0	38.0	344.1	49.6	400.6	58.1	0.19	20.3	31.7
18-T10	1000	1832	329.6	47.8	169.6	24.6	221.3	32.1	257.9	37.4	0.17	17.0	32.9
18-T11			357.2	51.8	177.2	25.7	244.1	35.4	-----	----	0.22	19.9	34.4
18-T12			311.6	45.2	163.4	23.7	223.4	32.4	153.8	22.3	0.19	18.4	30.8

Temp. °C	Temp. °F	Modulus of Elasticity GN/m^2	Modulus of Elasticity 10^6 psi
21	70	198.6	28.8
850	1562	150.3	21.8
925	1697	139.3	20.2
1000	1832	128.2	18.6

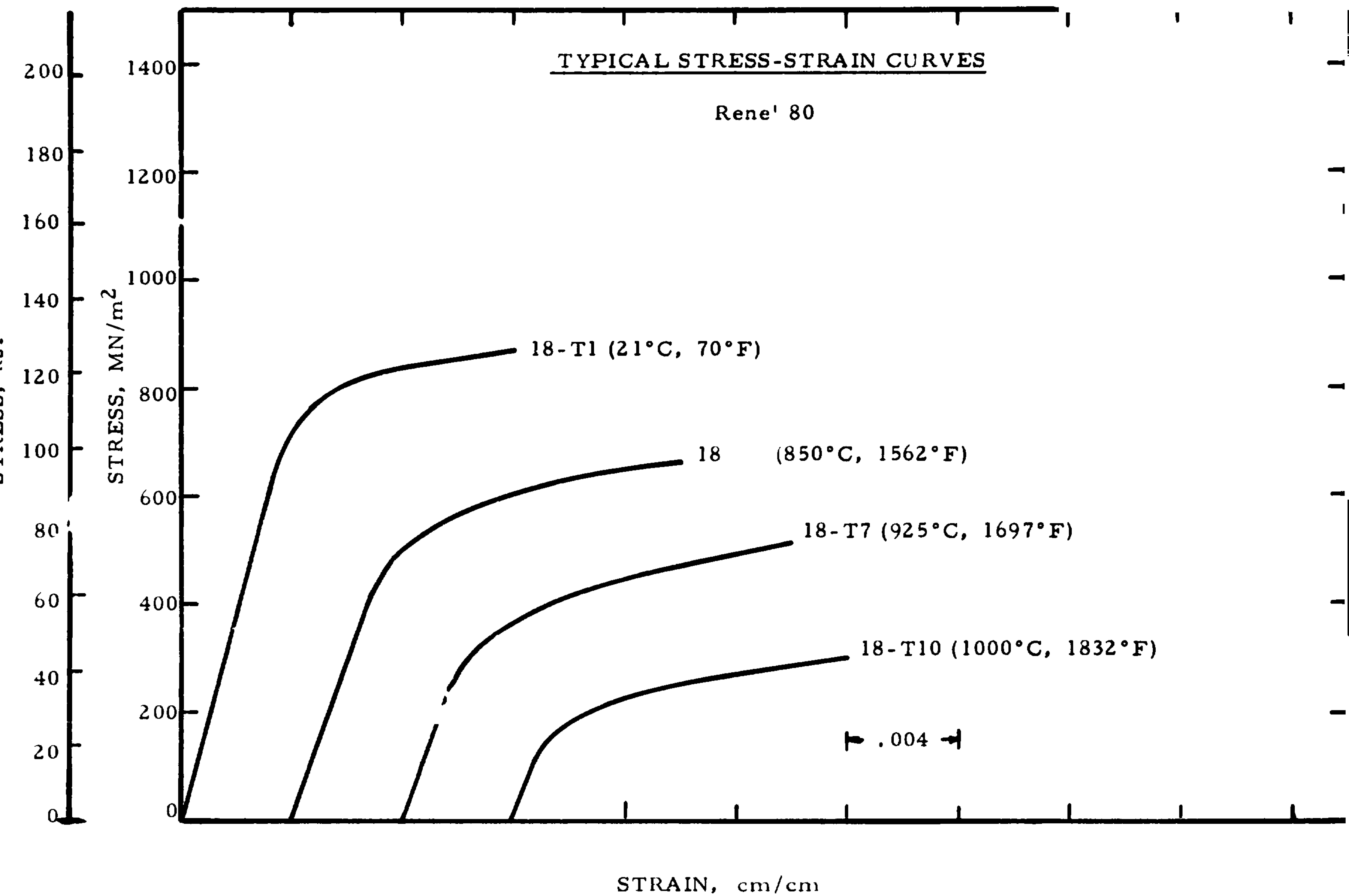

TYPICAL STRESS-STRAIN CURVES
Rene' 80
18-T1 (21°C, 70°F)
18 (850°C, 1562°F)
18-T7 (925°C, 1697°F)
18-T10 (1000°C, 1832°F)
.004
STRESS, ksi
STRESS, MN/m2
STRAIN, cm/cm
0
20
40
60
80
100
120
140
160
180
200
0
200
400
600
800
1000
1200
1400

Figure 92

TABLE XXXVI

Creep Rupture Properties of Rene' 80

Specimen Number	Temp. °C	Temp. °F	Stress MN/m^2	Stress ksi	Min. Creep Rate %/hr.	Time (hrs.) to start of 3rd stage	Time (hrs.) to 1% creep strain	Rupt. Life (hrs.)	Elong. (%)	R.A. (%)
18-C2	850	1562	413.7	60.0	.16	7	5	29.0	14.4	22.9
18-C3			310.3	45.0	.010	125	95	307.0	9.2	14.7
18-C4			289.6	42.0	.0049	205	140	584.1	8.5	10.5
18-C1			275.8	40.0	.0029	295	245	839.5	6.6	8.7
18-C5			265.4	38.5	.0022	575	380	1220.9	6.3	9.7
18-C7	925	1697	206.8	30.0	.0148	50	62	144.8	7.9	16.2
18-C8			189.6	27.5	--	--	--	(a)	--	--
18-C9			189.6	27.5	.0070	145	125	262.1 (b)	6.5	9.2
18-C17			189.6	27.5	.0067	100	115	278.4	8.2	13.3
18-C6			172.4	25.0	.0046	190	175	462.5	7.7	14.7
18-C10			151.7	22.0	.0016	475	510	1210.7	8.1	9.0
18-C11	1000	1832	165.5	24.0	.16	(c)	(c)	21.1	9.7	13.5
18-C12			151.7	22.0	.065	15	14	34.4	8.7	14.8
18-C13			117.2	17.0	.015	50	58	165.7	8.2	11.5
18-C14			100.0	14.5	.0052	160	165	351.7	7.4	9.4
18-C16			93.1	13.5	.0027	275	320	506.1	4.7	13.1
18-C15			86.2	12.5	--	--	--	(d)	--	--

(a) Adapter failure at 136.0 hours; test discontinued
(b) Specimen was 44°F over temperature at failure
(c) Insufficient data to construct creep curve
(d) Controller malfunction prior to loading; specimen melted

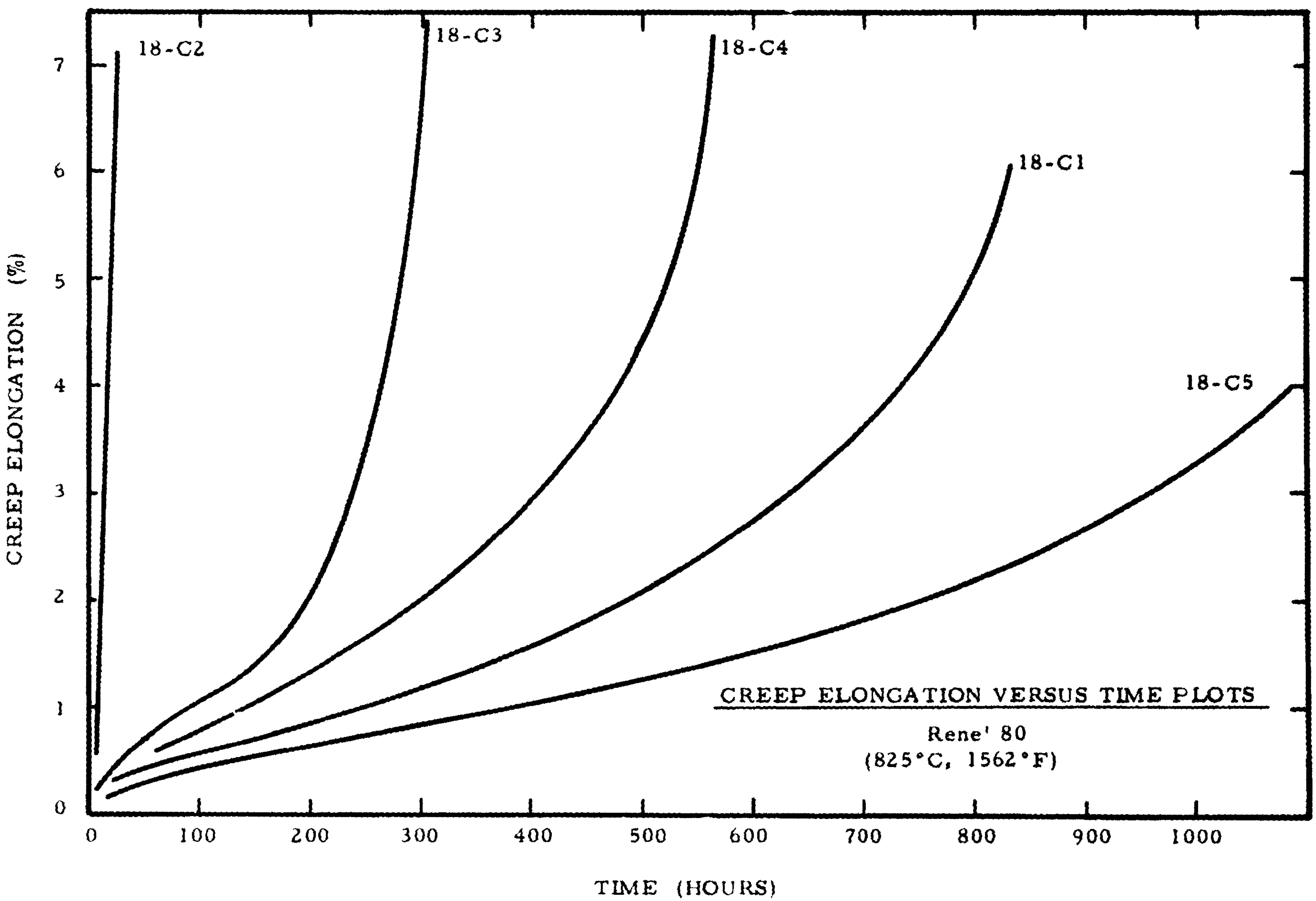

18-C2
18-C3
18-C4
18-C1
18-C5
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)
CREEP ELONGATION VERSUS TIME PLOTS
Rene' 80
(825°C, 1562°F)

Figure 93

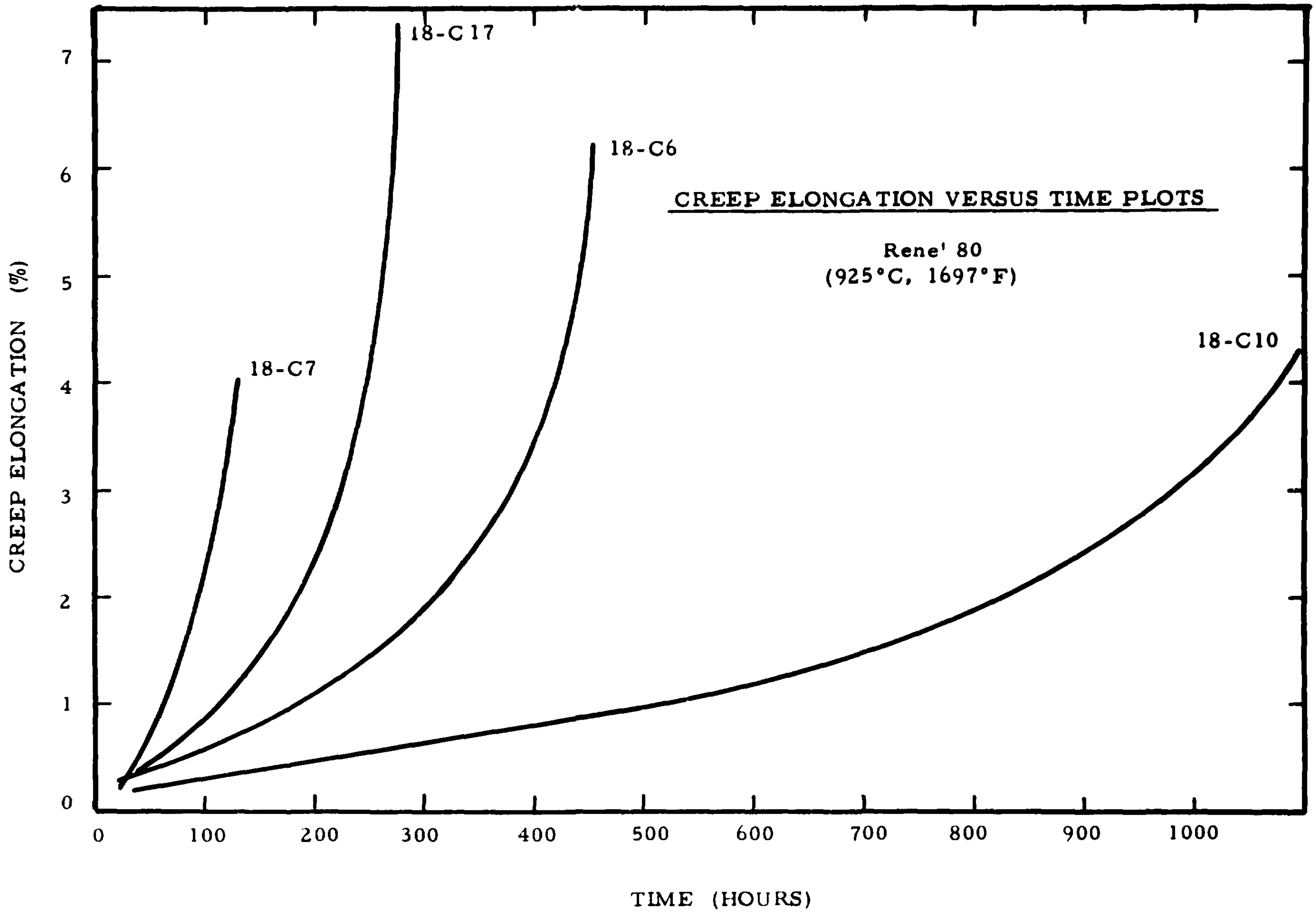

CREEP ELONGATION VERSUS TIME PLOTS
Rene' 80
(925°C, 1697°F)
18-C17
18-C6
18-C7
18-C10
CREEP ELONGATION (%)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000
TIME (HOURS)

Figure 94

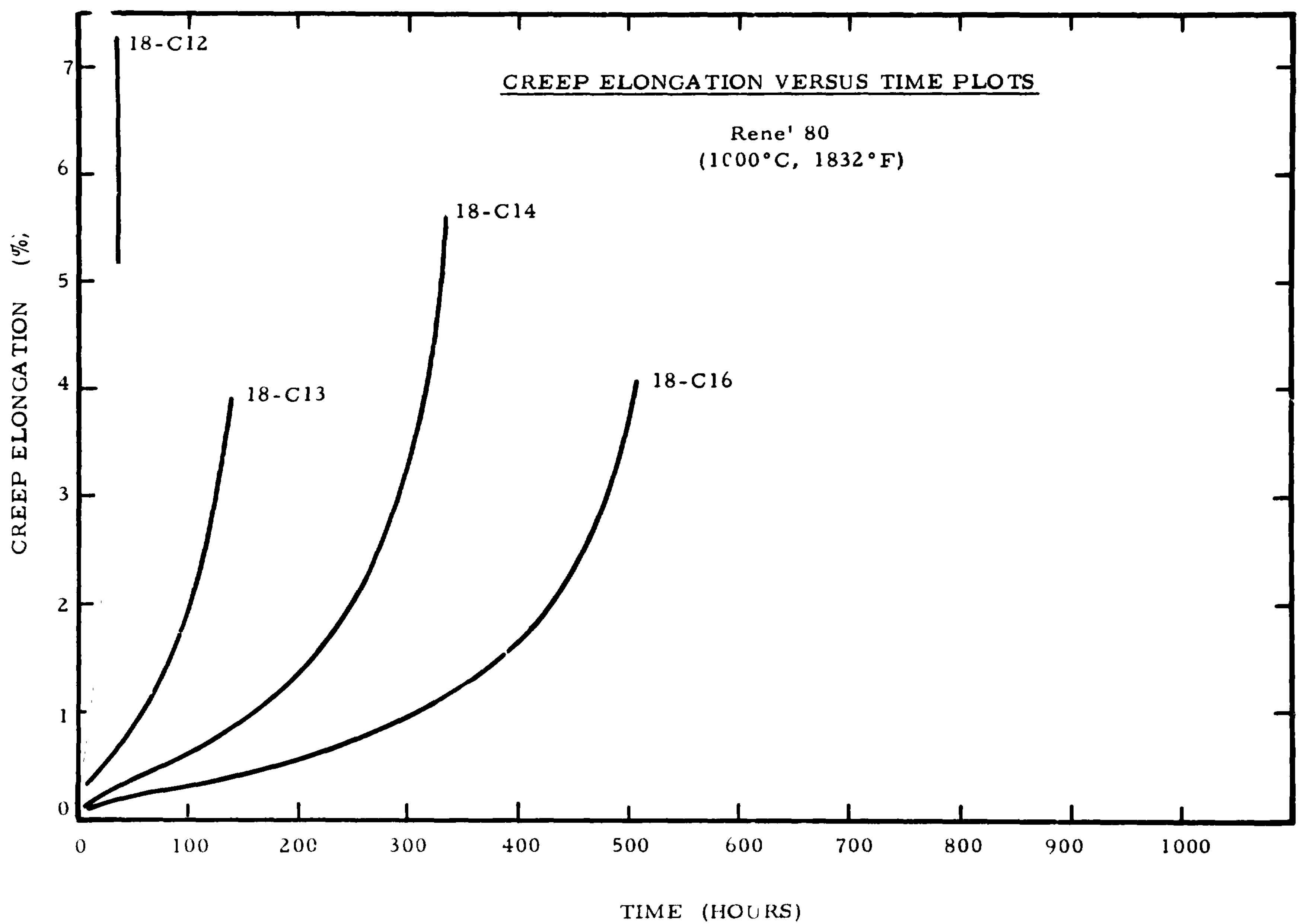
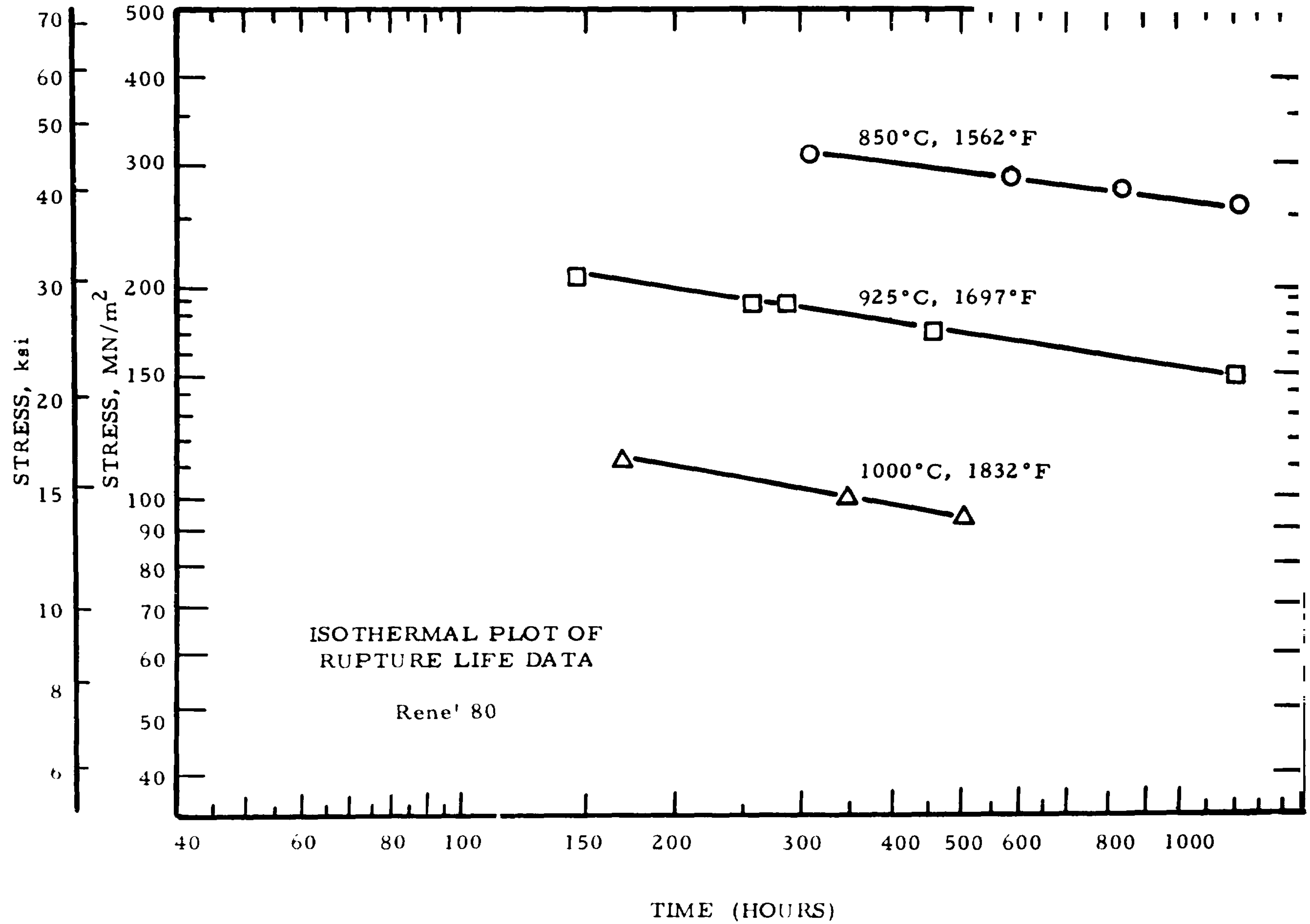

CREEP ELONGATION VERSUS TIME PLOTS
Rene' 80
(1000°C, 1832°F)
18-C12
18-C14
18-C13
18-C16
CREEP ELONGATION (%)
TIME (HOURS)
0
1
2
3
4
5
6
7
0
100
200
300
400
500
600
700
800
900
1000

Figure 15



ISOTHERMAL PLOT OF RUPTURE LIFE DATA
Rene' 80
850°C, 1562°F
925°C, 1697°F
1000°C, 1832°F
STRESS, ksi
STRESS, MN/m²
TIME (HOURS)
70
60
50
40
30
20
15
10
8
6
500
400
300
200
150
100
90
80
70
60
50
40
40
60
80
100
150
200
300
400
500
600
800
1000

Figure 96