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THE UNIVERSITY OF MICHIGAN
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REPORT
ON
RUPTURE AND TOTAL-DEFORMATION CHARACTERISTICS OF
M252 (VM), UDIMET 500, INCONEL 700, INCONEL 713
AND STELLITE 31 ALLOY
(PHASE VII)

by

K. P. MacKay
J. W. Freeman

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RUPTURE AND TOTAL-DEFORMATION CHARACTERISTICS OF
M252 (VM), UDIMET 500, INCONEL 700, INCONEL 713
AND STELLITE 31 ALLOYS
(PHASE VII)

The objective of the investigation was to establish rupture and total deformation strengths for representative samples from production heats of five alloys considered for turbine blade applications by the Wright Aeronautical Division. The properties were evaluated at temperatures considered to be of main interest for each particular alloy for the application. These temperatures were 1350° and 1550°F for the M252 (vacuum melted), 1350° and 1640°F for Udimet 500 and Inconel 700 alloys, 1550° and 1700°F for Inconel 713 alloy, and 1650°F for Stellite 31 alloy. Evaluation of properties were based on the rupture strengths and stresses for total deformations of 1.0, 0.5, 0.2 and 0.1 percent in 30, 100 and 300 hours.

SUMMARY

The rupture and total deformation characteristics were within expected ranges in properties for the individual alloys, except for Inconel 713 alloy. Only limited data were developed for Inconel 713 because further testing was cancelled when the initial tests indicated that the strength of the specimens submitted was far below that considered characteristic of the alloy.

The ductility of the Udimet 500 and Inconel 700 specimens were very low at 1350°F.

The strengths for a total deformation of 0.1 percent are sparse and limited to short-time periods. The same limitation applied to a lesser extent to the values for 0.2 percent total deformation. The incompleteness of these small deformation strengths resulted from a number of causes as the investigation developed.

EXPERIMENTAL MATERIALS

The reported chemical compositions available for the particular heats of material investigated are given in Table I. Errors were found for the reported analyses in one case and there is, therefore, doubt concerning the analyses given in Table I.

The specimens used were 0.250-inch in diameter by 1-inch long at the gage section. These were supplied as machined specimens except for the Inconel 713 and Stellite 31. Specimens of the Inconel 713 alloy were machined at the University from the cast bars submitted. Investment cast specimens of Stellite 31 were furnished. Additional descriptive information supplied was as follows:

M252 Alloy

The specimens had been machined from 2 1/32-inch bar stock from vacuum melted Heat KA223. Only trace amounts of silicon and manganese were present in the heat. The stock had been heated 4 hours at 1950°F, air cooled and aged 15 hours at 1400°F. The stock was fully heat treated before machining. Eighteen specimens coded A1 through A18 were furnished.

Udimet 500 Alloy

The stock used was from Utica Drop Forge and Tool Corporation Heat 4131, a vacuum melted heat which contained normal amounts of silicon and manganese. The heat treatment consisted of solution for 4 hours at 1975°F, air cooled, and double aged at 1550°F for 24 hours plus 1400°F for 15 hours. Specimens were machined after full heat treatment. Eighteen specimens coded E1 through E18 were supplied.

Inconel 700 Alloy

The stock was solution treated at 2160°F for 2 hours, air cooled and aged at 1600°F for 4 hours to WAD 7827. The specimens, coded C1 through C9, were apparently from Heat Y7952.

Inconel 713 Alloy

Specimens were machined from investment cast bars. The castings were made by the Wright Aeronautical Division in three heat lots, 78, 79 and 80, from a single lot of master alloy furnished by The International Nickel Company. The casting conditions were reported to be as follows:

<u>Heat</u>	<u>Casting Temp. (°F)</u>	<u>Mold Temp. (°F)</u>
78	2650	1900
79	2700	1900
80	2740	1900

The castings were very coarse grained. As is shown later in the report, the stock was much weaker than is considered characteristic of the alloy. The reasons for this were not established, although it was indicated orally by WAD representative that the actual analysis after remelting for casting was off.

Stellite 31 Alloy

As-cast investment cast specimens made by Haynes Stellite were used for the tests. Chemical analysis for the stock was not available. The material was indicated to be in accordance with AMS 5382 and the specimens furnished were coded S1 through S7.

General Comment

It should be noted that the chemical analyses and heat numbers for the materials were submitted at a date considerably later than the specimens. Actual errors were found in this information. For instance, the composition reported for Stellite 31 was obviously wrong. There is, therefore, doubt that the others are entirely correct. The only definitely correct identification available is the coding marks.

PROCEDURE

The temperatures at which the properties of the alloys investigated were to be established had been determined during preliminary discussion with representatives of the Wright Aeronautical Division. At the same time it had been decided that the required data would be curves of stress versus time over the range of 30 to 300 hours for rupture and total deformations of 1.0, 0.5, 0.2 and 0.1 percent. Total deformation was defined as all deformation including the elastic and plastic deformation during loading.

The stress-rupture time curves were first established. Creep data were taken during the rupture tests and supplemented with sufficient additional creep tests to establish the total deformation curves.

The tests were conducted in single specimen units with the load applied through a simple beam. Temperatures variations along the gage length and during the tests were automatically maintained at $\pm 3^\circ\text{F}$ of the nominal indicated temperature. In conducting the tests, about 16 hours were used for temperature adjustment before the load was applied. Creep was measured by a modified Martens type optical extensometer with the extension rods attached to collars threaded on the specimens ahead of the pull rods. The measured deformation was corrected for the fillets and shoulder sections of the specimens on the basis of well established correction factors for the test conditions. Elongations after rupture were based on changes in the overall dimensions of the gage length and not on a punch marked gage length.

RESULTS

The results of the investigation provide the following information:

1. A table for each alloy which gives the following:

- (a) Stress-rupture time data and the elongation and reduction of area values for the rupture tests.
- (b) Time at which creep tests were discontinued.
- (c) Deformation during loading of each test.
- (d) Time to reach deformations of 1.0, 0.5, 0.2 or 0.1 percent during the rupture and creep tests. The values were read from time-elongation curves plotted from the original creep data.

2. Curves of stress versus time for rupture and time for the total deformations plotted from the data described in "1". The values of elongation after rupture are shown on the figures near the rupture time points.

3. Values of stress for rupture and total deformations of 1.0, 0.5, 0.2 and 0.1 percent in 30, 100 and 300 hours were interpolated from the figures and included in the tables.

The stress versus time for total deformation curves for the smaller deformations are extrapolated back to short-time periods asymptotic to the stress which gave the deformation during loading. The tests generally did not attain the larger deformation during loading. The values for total deformations of 0.1 percent are generally few and limited to short-time periods. The curves were not completely established for the smaller deformations because the specimens supplied were too few, results as they were obtained did not justify the additional testing, or because review of the data with WAD representatives indicated further testing was not necessary.

The following comments apply to the data for the individual alloys investigated.

M252 Alloy (vacuum melted)

The results obtained indicated a high level of rupture strength and ductility for the alloy at both 1350° and 1550°F (Table II and Fig. 1).

At 1350°F, the stress versus time curves for total deformations of 1.0 and 0.5 percent were close to the rupture curve, while the curves for 0.2 and 0.1 percent were at considerably lower stress levels. The larger percentage of deformation during loading involved in the total deformations was responsible for this distribution. At 1550°F when creep was a more predominant factor in total deformation, there was not as wide a separation in the curves and it was not necessary to stress specimens so near to the rupture strength to obtain total deformations of 1.0 and 0.5 percent.

Udimet 500 Alloy

The Udimet 500 material investigated had a high level of rupture strength and ductility at 1640°F (Table III and Fig. 2). Ductility in the rupture tests was, however, very low at 1350°F. Because the deformation during loading was the predominant factor in the total deformation values at 1350°F the stress for a given deformation was only slightly lowered by increasing time. Data for total deformations of 0.2 and 0.1 percent were not established because creep was a relatively very small factor for these deformations at 1350°F.

Inconel 700 Alloy

The properties of the material tested was reasonable for the alloy at 1640°F (Table IV and Fig. 3). The specimens were, however, quite brittle at 1350°F. Due to this brittleness and high resistance to creep at 1350°F only a few tests were conducted.

Cast Inconel 713 Alloy

The rupture strengths of the specimens provided (Table V and Fig. 4) proved to be much lower than is considered characteristic of the alloy at 1550° and 1700°F. When limited tests established this fact and it was brought to the attention of representatives of WAD further testing was cancelled.

Cast Stellite 31 Alloy

Evaluation of properties were limited to 1650°F (Table VI and Fig. 5). The results appeared to be reasonable for the alloy at this temperature.

DISCUSSION

The choice of materials used for the investigation was intended to give representative samples of the alloys as they would be supplied for production purposes. It was quite evident that this was not achieved in the case of Cast Inconel 713 alloy. The results in the other cases appeared to be reasonable for the alloys.

There are two main limitations to the results. The number of specimens tested were too few in several cases for complete establishment of the curves. It is far more important to recognize, however, that there can be variations in properties between heats of a given alloy. Thus the values established do not define the ranges in properties which would be expected.

It should be recognized that the M252 material was vacuum melted with only traces of silicon and manganese. This alloy is often made with normal amounts of these two elements.

TABLE I

CHEMICAL COMPOSITION OF FIVE ALLOYS INVESTIGATED

Alloy	M252 vacuum melted	Udimet 500 vacuum melted	Inconel 700	Inconel 713	Stellite 31
Heat No.	KA223	4131	Y7952	78, 79, 80	
Chemical Composition (percent)					
C	0.13	0.08	0.12	0.1	
Cr	19.13	18.7	15.7	14.5	
Co	9.90	13.8	28.69	--	
Ni	56.55	--	46.25	Bal.	
Mo	10.0	4.15	3.08	4.95	
Fe	0.88	1.02	0.65	3.14	
Mn	Trace	0.1	0.07	0.15	
Ti	2.68	2.92	2.02	0.75	
Al	1.05	2.9	3.13	5.5	
Mg	--	0.01	--	--	
Cb + Ta	--	--	--	2.78	
Cu	--	0.1	0.02	--	
Si	Trace	0.35	0.24	0.71	
S	0.011	0.006	0.007	0.008	
P	0.01	--	--	0.01	
					not available

TABLE II

CREEP-RUPTURE DATA FOR M252 ALLOY

Original Data						
Stress (psi)	Rupture Time (hours)	Elongation (%)	Reduction of Area (%)	Deformation on Loading (%)	Time to Reach Specified Total Deformation in %	
					0.1	0.5
1350°F						
90,000	15.0	18	18	0.426	a	0.8
82,000	31.5	20	12	0.388	a	5.4
73,000	92.7	24	23	0.344	a	13.3
60,000	222.3	12	15	0.284	a	71.0
53,000	934.9	24	22	0.250	a	208.0
37,500	963.4	discontinued	discontinued	0.176	a	4500.0(1)
19,000	987.3	discontinued	discontinued	0.088	8.0	b
1550°F						
37,000	39.0	37	34	0.197	a	7.5
30,000	113.3	32	37	0.160	a	27.6
25,000	247.3	45	35	0.133	a	57.5
22,500	428.5	27	30	0.120	a	87.0
17,500	907.0	discontinued	discontinued	0.093	5.0	350.0
15,000	987.1	discontinued	discontinued	0.080	17.5	910.0
Interpolated Data						
Time (hr)	Test Temp (°F)	Strength for Rupture or Specified Total Deformations in Specified Time (in 1000 psi)				
		Rupture	0.1	0.2	0.5	1.0
30	1350	83	--	32	67	74
	1550	(39)	(14)	22	29	32
100	1350	71	--	27	58	64
	1550	31	--	18	23	25
300	1350	61	--	22	51	55
	1550	24	--	(15)	18	20

(1) Extrapolated by creep rates.
(2) Contraction occurred during early stages of test.
a Deformation exceeded during loading.
b Deformation less than indicated value when rupture occurred or the test was discontinued.
() Extrapolated.

CREEP-RUPTURE DATA FOR UDIMET 500 ALLOY

Original Data

Stress (psi)	Rupture Time (hours)	Elongation (%)	Reduction of Area (%)	Deformation on Loading (%)	Time to Reach Specified Total Deformation in %		
					0.1	0.2	0.5
1350°F							
80,000	25.3	5	4	0.385	a	a	1.9
75,000	33.0	1	4	0.362	a	a	3.5
64,000	132.9	1	4	0.309	a	a	34.0
57,000	367.2	1	3	0.275	a	a	114.5
50,000	1422.2	discontinued	discontinued	0.242	a	a	483.0
40,000	1180.0(2)	discontinued	discontinued	0.193	a	b	b
19,000	940.0(2)	discontinued	discontinued	0.091	b	b	b
1640°F							
30,000	18.7	11	10	0.166	a	0.5	3.6
25,000	61.0	18	16	0.138	a	3.5	17.0
21,000	114.6	10	12	0.116	a	6.4	30.2
18,000	281.9	19	17	0.100	0	18.0	85.0
15,000	598.2	29	27	0.083	5.5	32.5	139.0
10,000	598.9	discontinued	discontinued	0.055	14.5	97.5	500.0

Interpolated Data

Time (hr)	Temp (°F)	Strength for Rupture or Specified Total Deformations in Specified Time (in 1000 psi)		
		Rupture	0.1	0.2
30	1350	75	--	64
	1640	28	(7)	21
100	1350	65	--	58
	1640	22	--	17
300	1350	58	--	52
	1640	18	(7)	12

(2) Contraction occurred during early stages of test.
a Deformation exceeded during loading.
b Deformation less than indicated value when rupture occurred or the test was discontinued.
() Extrapolated.

CREEP-RUPTURE DATA FOR INCO 700 ALLOY

Original Data

Stress (psi)	Rupture Time (hours)	Elongation (%)	Reduction of Area (%)	Deformation on Loading (%)	Time to Reach Specified Total Deformation in %		
					0.1	0.2	0.5
1350°F							
72,000	11.1	2	1	0.325	a	a	0.5
65,000	> 50.2(3)	--	--	0.295	a	a	29.0
55,000	> 216.2(4)	<1	<1	0.250	a	a	--
48,000	> 93.0(5)(2)	--	--	0.220	a	a	--
45,000	845.2(2)	--	discontinued	0.205	a	a	b
1640°F							
30,000	22.5	12	14	0.143	a	0.7	4.7
24,000	109.3	9	12	0.114	a	20.0	47.2
20,000	203.7(2)	8 (6)	11	0.096	<0.05	5.0	75.0
15,000	704.0(2)	8	8	0.072	190.0	282.0	410.0

Interpolated Data

Time (hr)	Test Temp (°F)	Strength for Rupture or Specified Total Deformations in Specified Time (in 1000 psi)			Deformation on Loading (%)	Reduction of Area (%)	Elongation (%)	Rupture Time (hours)	Stress (psi)	Notes
		0.1	0.2	0.5						
30	1350	--	--	--	0.325	2	11.1	72,000	(2) Contraction occurred during early stages of test	
	1640	67	22	(64)	0.114	9	109.3	24,000	(3) Fractured in threads at 50.2 hours	
100	1350	29	22	24	0.096	8 (6)	203.7(2)	20,000	(4) Test interrupted at 145.3 hours by thread failure	
	1640	61	--	--	0.220	--	> 93.0(5)(2)	48,000	(5) Fractured in threads at 93.0 hours	
300	1350	24	18	20	0.205	--	845.2(2)	45,000	(6) Fracture damaged in removal from furnace	
	1640	(55)	--	--	0.072	8	704.0(2)	15,000	a Deformation exceeded during loading	
		18	(15)	16					b Deformation less than indicated value when rupture occurred or the test was discontinued	
		17	--	--					() Extrapolated	

TABLE V

CREEP-RUPTURE DATA FOR INCO 713 ALLOY

Original Data									
Stress (psi)	Rupture Time (hours)	Elongation (%)	Reduction of Area (%)	Deformation on Loading (%)	Time to Reach Specified Total Deformation in % (hours)	Time to Reach Specified Total Deformation in % (hours)			
						0.1	0.2	0.5	1.0
<u>1550°F</u>									
50,000	7.6	11	<1	0.310	a	a	2.3	--	--
35,000	59.1	8	1	0.195	a	0.3	42.0	--	--
25,000	491.9	1	<1	0.140	a	10.0	403.0	--	--
<u>1700°F</u>									
27,000	13.6	4	1	0.240	a	a	4.9	--	--
20,000	49.2	4	1	0.150	a	0.3	42.0	--	--
Interpolated Data									
Time (hr)	Test Temp (°F)	Strength for Rupture or Specified Total Deformations in Specified Time (in 1000 psi)							
		Rupture	0.1	0.2	0.5	1.0	0.5	1.0	1.0
30	1550	39	--	(23)	36	--	--	--	--
	1700	23	--	--	21	--	--	--	--
100	1550	32	--	--	30	--	--	--	--
	1700	(27)	--	--	--	--	--	--	--
300	1550	27	--	--	26	--	--	--	--
	1700	--	--	--	--	--	--	--	--

a Deformation exceeded during loading.

TABLE VI

CREEP-RUPTURE DATA FOR STELLITE 31 ALLOY

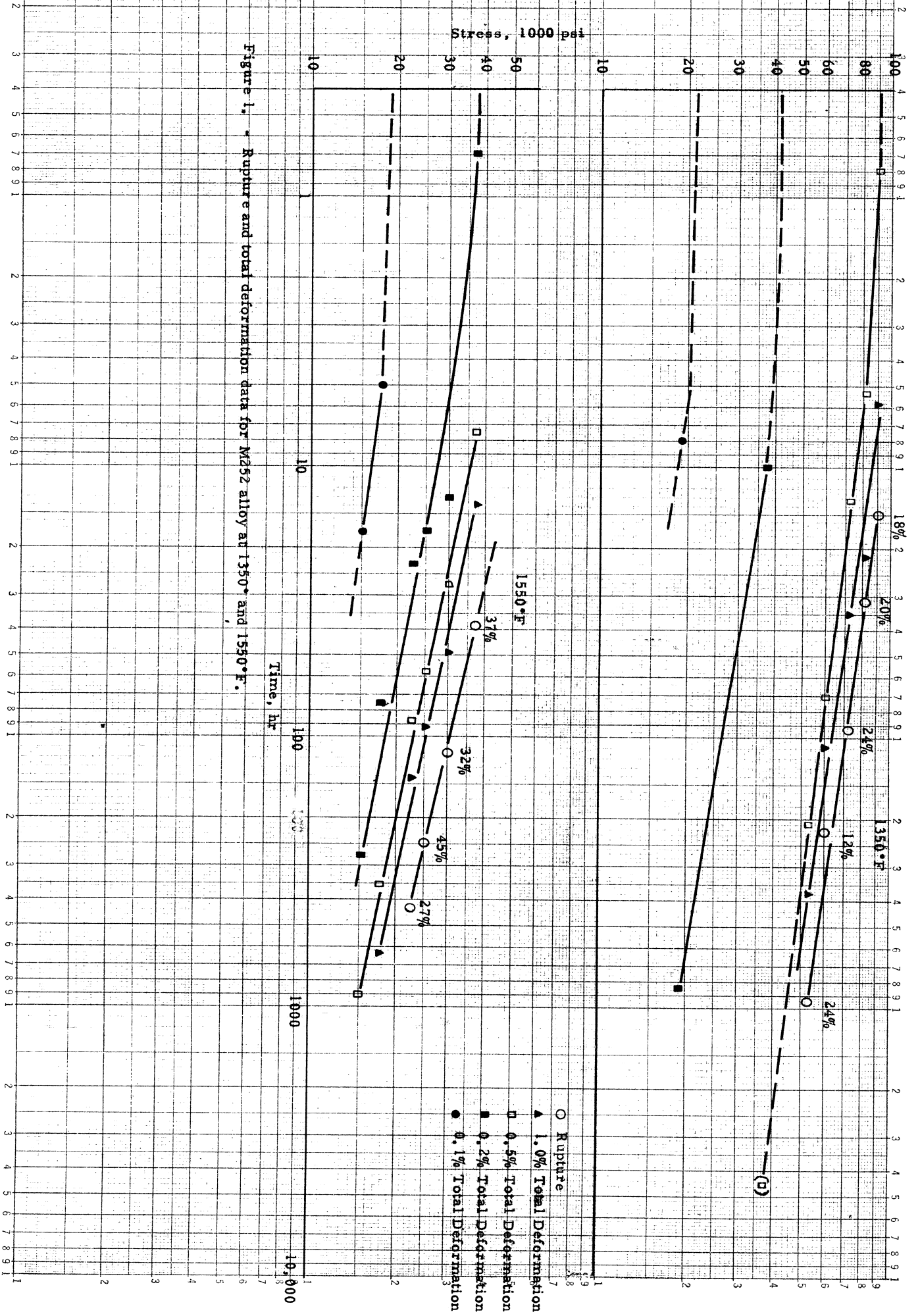
<u>Original Data</u>				<u>Time to Reach Specified Total Deformation in %</u>	
<u>Stress (psi)</u>	<u>Rupture Time (hours)</u>	<u>Elongation (%)</u>	<u>Reduction of Area (%)</u>	<u>Deformation on Loading (%)</u>	<u>(hours)</u>
<u>1650°F</u>					
20,000	20.8	10	19	0.122	0.03
18,000	70.2	10	21	0.108	0.1
16,000	124.4	13	17	0.089	0.05
13,500	386.2	7	6	0.071	0.05
8,000	1445.0		discontinued	0.042	3.0
6,500	2448.0		discontinued	0.034	7.0
5,500	601.5		discontinued	0.028	9.0
					0.2
					0.5
					1.0
					0.2
					0.6
					0.6
					2.1
					b
					2100.0
					b
					b
					0.8
					2.3
					3.4
					11.5
					b
					b
					b

Interpolated Data

<u>Time (hr)</u>	<u>Test Temp (°F)</u>	<u>Strength for Rupture or Specified Total Deformations in Specified Time (in 1000 psi)</u>		
		<u>Rupture</u>	<u>0.1</u>	<u>0.5</u>
30	1650	20	(5.0)	11 (13)
100	1650	16	--	9.2 (11)
300	1650	14	--	8 --
				1.0

a Deformation exceeded during loading

b Deformation less than indicated value when rupture occurred or the test was discontinued



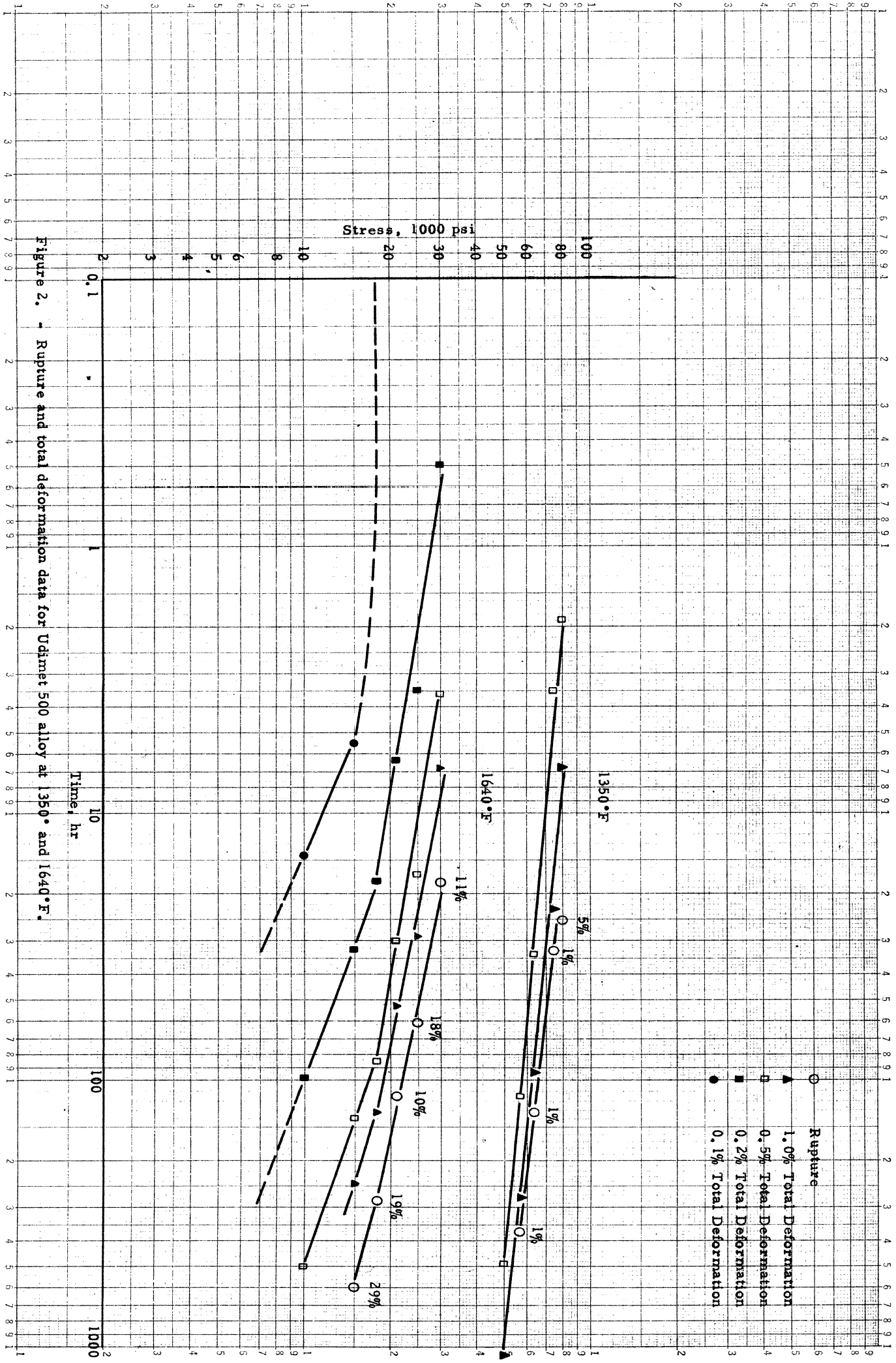


Figure 2. - Rupture and total deformation data for Udimet 500 alloy at 1350° and 1640°F.

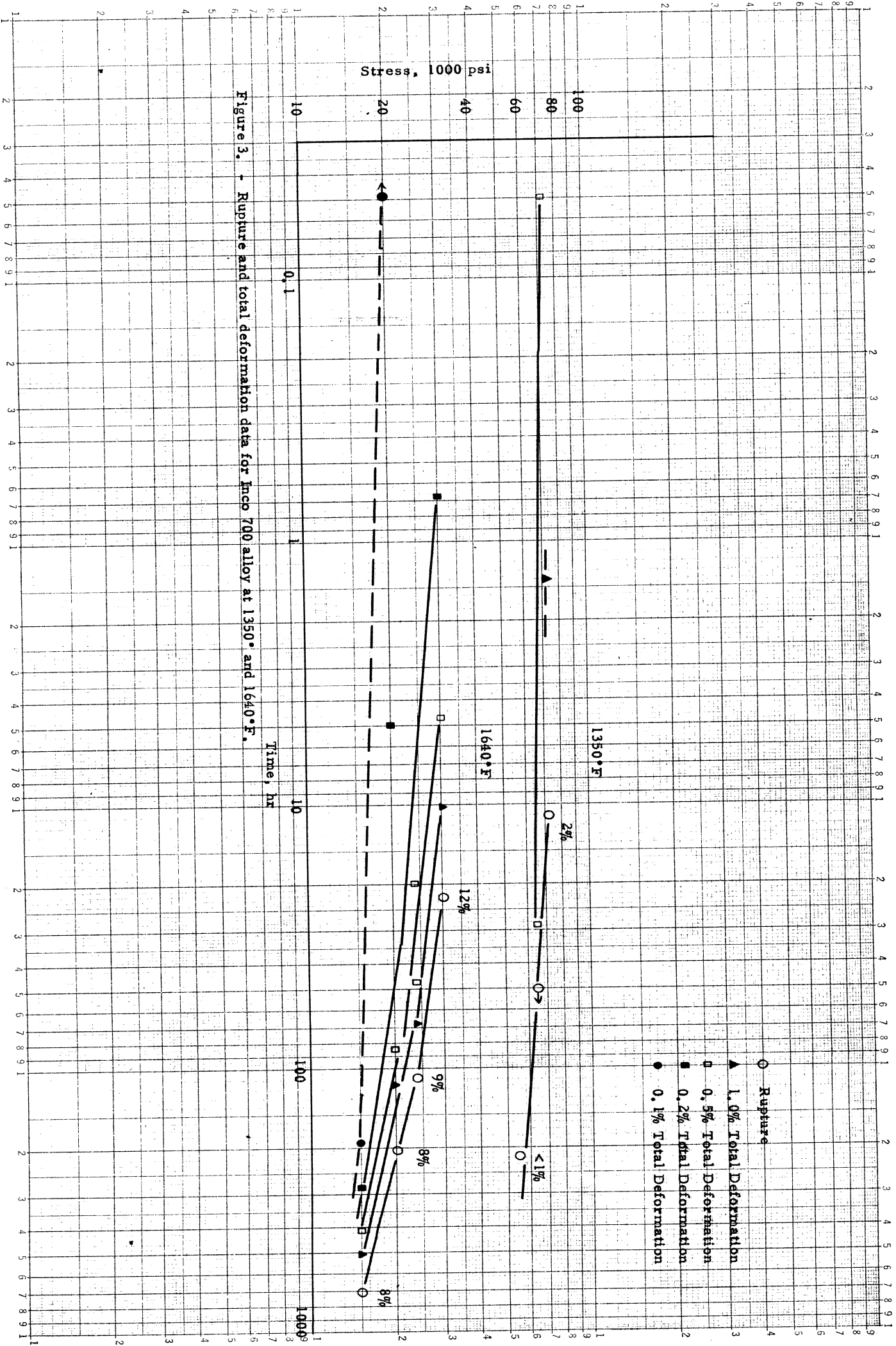


Figure 3. - Rupture and total deformation data for Inco 700 alloy at 1350° and 1640°F.

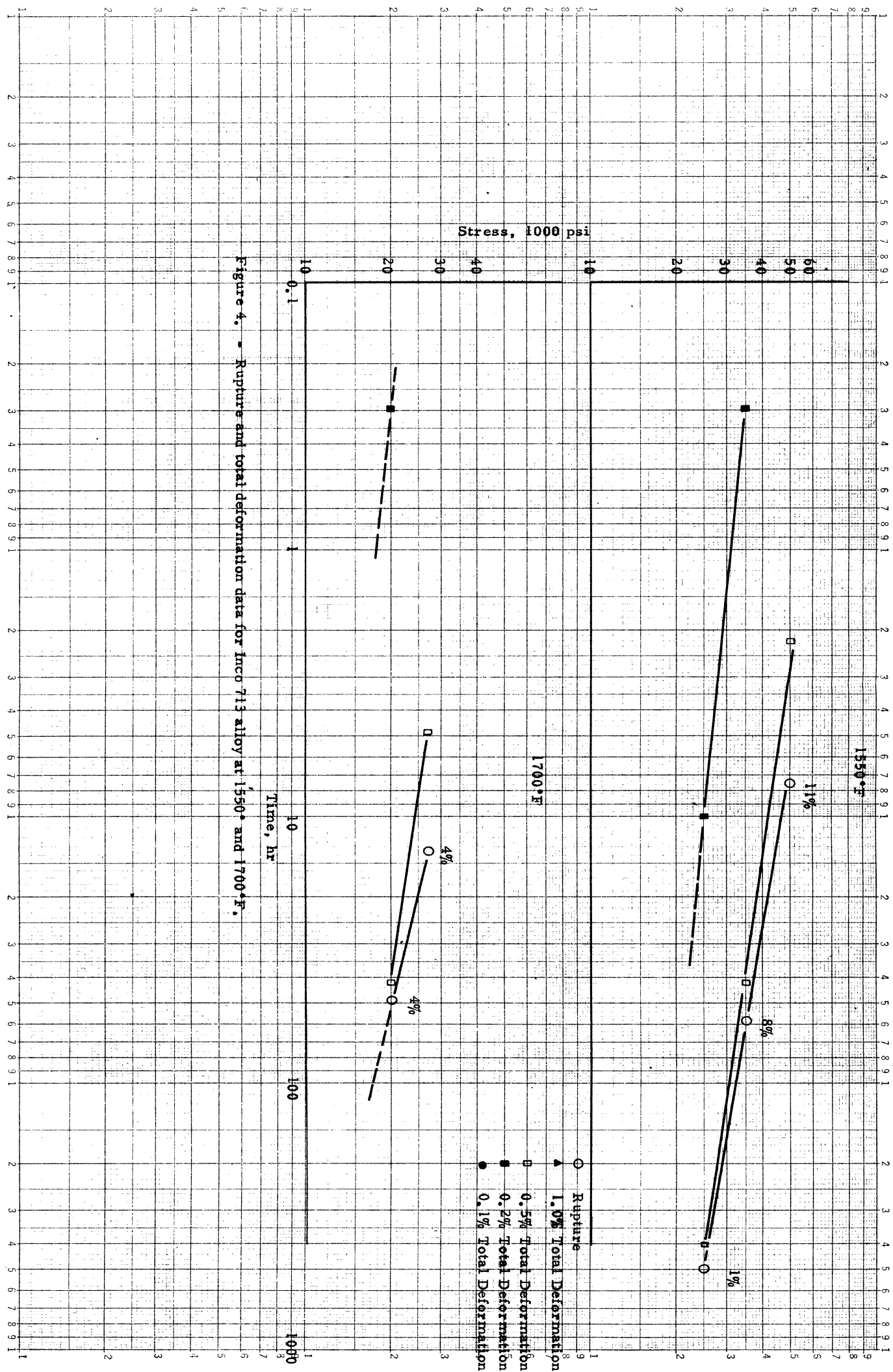


Figure 4. Rupture and total deformation data for Inco 713 alloy at 1550°F and 1700°F.

Stress, 1000 psi

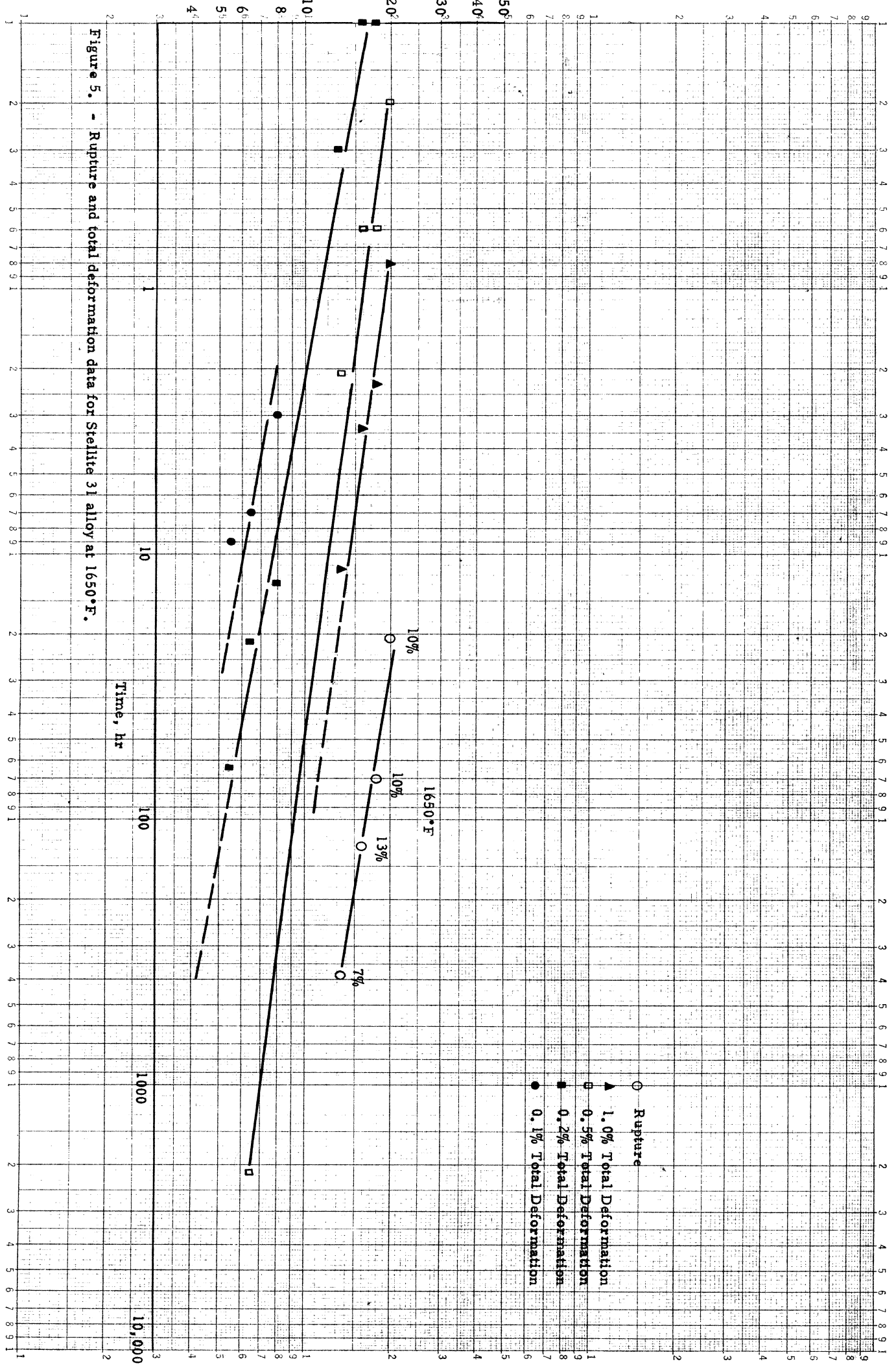


Figure 5. - Rupture and total deformation data for Stellite 31 alloy at 1650°F.

