ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR, MICH.

REPORT

ON

RUPTURE AND TOTAL DEFORMATION PROPERTIES OF INCONEL-W SHEET AT 1200°, 1350°, 1500°, AND 1600°F

by

H. E. Radd
K. P. MacKay
J. W. Freeman

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Curtiss-Wright Corporation
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RUPTURE AND TOTAL-DEFORMATION PROPERTIES OF INCONEL-W SHEET AT 1200°, 1350°, 1500° AND 1600°F

Inconel-W alloy in sheet form has a number of potential applications in aircraft power plants where service temperatures may be in the range of 1200° to 1600°F. The investigation covered by this report was undertaken to define the stress-temperature relationships for rupture and for total deformations of 0.1 to 2 percent up to 300 hours for a typical sample of commercially produced Inconel-W sheet. The resulting information will serve to aid in the selection of material and design of parts to operate within the range of temperatures with varying permissible deformation within 300 hours.

The investigation was conducted as one part of the metallurgical research work authorized by Purchase Order Number FX39962-1 from the Curtiss-Wright Corporation, Wright Aeronautical Division.

SUMMARY

The elevated temperature properties of a 0.075-inch thick sheet of Inconel-W alloy are reported. Stress-rupture characteristic curves were established at 1200°, 1350°, 1500° and 1600°F between 1 and 300 hours. Stress-time for total deformation properties for 0.1, 0.2, 0.5, 1.0 and 2.0 percent deformation as could be obtained from the creep curves for the rupture tests are also included.

Elongations were rather low (<3%) in the rupture tests at 1200° and 1350°F for time periods larger than 100 hours. Deformation during loading of the specimens was a major factor in total deformation strengths at 1200° and 1350°F. At 1500° and 1600°F rapid creep and the early onset of third stage creep caused creep to govern deformation strengths. Rapid overaging apparently occurred above 1350°F to reduce strength.

TEST MATERIALS

The specimens for the investigation were machined by Wright Aeronautical Division from a 0.075-inch thick Inconel-W sheet from Heat 5354W. The analysis of the heat as reported by the manufacturer was as follows:

C	Mn	Fe	S	Si	Cu	Ni	Cr	Al	Ti
0.04	0.49	6.51	0.007	0.26	0.06	74.44	15.31	0.65	2.21

The sheet was manufactured to W.A.D. specification 7840; that is cold rolled, annealed, descaled, aged 16 hours at 1300°F, and air cooled. The tensile properties required by the specification are:

Tensile Strength, psi	140,000 min.
Yield Strength, 0.2% offset	90,000 min.
Elongation, % in 2 in.	20 min.

Strips 1-inch wide and 22 inches long were sheared from the transverse direction of the sheet. A reduced section with a gage length of 2.25 inches by 0.500-inch wide was machined in the center of the 1-inch width. The consecutively numbered specimens were randomized for testing into three equal groups representing the three test temperatures. This procedure was adopted to minimize the effect of specimen location in the sheet from influencing the results at any particular temperature.

PROCEDURE

Sufficient rupture tests were conducted to define the stress-rupture time curves from 1 to 300 hours at 1200°, 1350°, 1500°, and 1600°F. Creep data were taken during the rupture tests and creep curves plotted. The elongation which occurred during loading as well as the subsequent creep was included in the creep curves. As many of the values for total deformations of 0.1, 0.3, 0.5, 1.0 and 2.0 percent as were defined by each creep curve were obtained. These were plotted as stress-time for total deformation curves. In addition, the usual total elongation values after fracture were measured from gage marks.

Under the procedure used, the stress-time for total deformation curves for the smaller amounts of deformation were generally not completed to 300 hours. Additional creep tests at lower stresses would have been necessary to complete the curves. Only the stress-rupture time curves were completely established to 300 hours and the total deformation data was limited to that which could be obtained from the creep curves from the rupture tests.

The stress-rupture tests were conducted in single units of the dead weight-beam loaded type, except when low stresses required the use of a direct load.

The following procedure was used to bring the specimens to temperature:

1. The specimens were set up in the units and the heat turned on at 4:00 p.m. to bring the temperature within 50°F of the desired temperature by 5:00 p.m.

2. The specimens were allowed to stand overnight, the temperature raised to test temperature between 8:00 and 9:00 a.m. the next day.

3. Final adjustments to test temperature and for temperature distribution along the length of the specimen were made so that stress could be applied by 1:00 p.m.

4. Time-elongation data were secured by means of extensometers. Collars were fixed on the upper and lower shoulders of the specimens by means of pins inserted through holes drilled in the specimen shoulder. Extension rods were attached to the collars and extended out of the furnace. Rollers carrying a mirror were inserted between each pair of upper and lower extension rods. As the specimen elongated, the mirrors rotated and the rotation was measured by a scale reflected in the mirrors to a telescope.

The readings on both sides of the specimens were taken and averaged. The sensitivity of the extensometer system was 0.000003 inches per inch in the 2-inch gage length.

Inasmuch as the extensometers were attached to the shoulders, the observed deformation included elongation in the fillets and a portion of the shoulders of the specimen as well as the reduced section. A system of correcting the deformation through a calculated "effective gage length" was used.

RESULTS

The data obtained are summarized in Table I. The stress-rupture time and stress-time for total deformation curves plotted from this data are shown as Figures 1 through 5.

Rupture and total deformation strengths for 1, 5, 10, 25, 50, 100 and 300 hours as defined by the curves of Figures 1 through 5 are summarized in Table II. Due to the limitation of creep data to the rupture tests many of the total deformation strengths do not cover all the time periods listed.

The rupture and total deformation strengths are shown graphically as a function of temperature by Figures 6 through 11.

DISCUSSION

In general there was little difficulty from variation in strength between specimens. Thus, the material in the sheet from which the specimens were taken was quite uniform. Some difficulty was encountered at 1200°F, mainly because the stress-time curves had so little slope that minor variations in specimen strength or testing conditions caused considerable variation in time for rupture or a given total deformation.

Very little data for total deformations of 0.1 and 0.2 percent were obtained at 1200°F. In order to obtain rupture at 1200°F within the required time periods it was necessary to use stresses above the yield strength. Consequently loading deformations exceeded the smaller deformations of interest. Less difficulty of this type was encountered as the temperature was increased.

Elongation in the rupture tests decreased to rather low values (<3%) in the tests at 1200° and 1350°F longer than 100 hours. Such low elongations did not occur at 1500°F and the elongations were very high at 1600°F.

At 1200° and 1350°F, the stress-time for total deformation curves for 0.5 to 2.0 percent deformation were close to the stress-rupture time curves. One reason for this was the necessity to load the specimens above the yield strength and close to the tensile strength to obtain fracture in the specified times. Consequently, a considerable proportion of the total deformation occurred by yielding during loading. A second reason was the rather low deformation at fracture at these temperatures.

The deformations during loading for the tests at all four temperatures are included in Table I and are shown graphically by Figure 12. Many of the total deformations of interest are controlled by the initial deformation. This figure shows that the initial loading deformations were quite consistent. Furthermore, it draws attention to the necessity of recognizing the importance of initial deformation for limited deformation applications, particularly at 1200° and 1350°F.

The change in creep characteristics between 1350° and 1500°F is illustrated by Figure 13. This figure shows the creep curves for tests which ruptured in about 250 hours at 1200°, 1350°, 1500° and 1600°F. It will be noted that there was very little third-stage creep at the two lower temperatures. At 1500° and 1600°F, however, a major portion of the rupture life was in third-stage creep. This accounts for the separation of the total deformation curves from the rupture curves at 1500° and 1600°F while they were close together at 1200° and 1350°F. A large proportion of even 0.5 percent total deformation at 1500° and 1600°F was third-stage creep. Larger amounts of total deformation occurred very rapidly by third-stage creep at these two temperatures.

Presumably the early onset of third-stage creep at 1500° and 1600°F was due to overaging. The small amount of first-stage creep, short duration second-stage creep and extensive third stage creep is characteristic of overaging.

The 100-hour rupture strengths for the sheet were compared with some published values for Inconel-W alloy. It appears that the measured strengths are within the range which might be expected for the alloy.

TABLE I

Stress-Rupture and Stress-Total Deformation Time Data Obtained at 1200°, 1350°, and 1500°F for Inconel-W

(WAD 7840) Sheet Material

Spec. No.	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Deformation on Loading	Time for Specified Total Deformation 0.1	0.2	0.5	1.0	2.0
				1200°F					
9	100,000	b	36.0	--	--	--	--	--	--
15	90,000	0.17	24.0	>2.0	--	--	--	--	--
30	83,000	1.7	14.5	>2.0	--	--	--	--	--
8	65,000	31.8	6.0	(0.278)	a	a	1.4	8.1	13.4
26	64,000	22.6	8.5	(0.273)	--	--	--	--	--
19	60,000	32.7	8.0	0.258	a	a	0.7	3.4	12.7
12	55,000	231.7	2.0	0.237	a	a	92.0	201	R
22	50,000	535.5	3.0	0.216	a	a	153	393	496
13	40,000	1608.(c)	<1.0	0.172	a	6.5	(1000)	(1600)	e
16	21,000	483.5	(d)	0.090	110	e	e	e	e
				1350°F					
24	66,000	1.9	(2)	0.320	a	a	0.19	0.555	0.97
21	52,000	7.9	9.5	0.236	a	a	1.0	2.52	4.27
23	45,000	23.1	5.5	0.205	a	a	3.8	9.8	(19)
31	40,000	49.8	2.5	0.182	a	0.2	15.2	35.0	44.4
28	35,000	129.1	3.0	0.163	a	1.6	70.0	114.	R
17	30,000	249.7	2.0	0.148	a	8.5	132.5	222.5	R
20	25,000	605.3	3.0	0.116	a	24.0	289.	473.	592
				1500°F					
18	36,000	0.9	18.0	0.222	a	a	0.05	0.124	0.257
29	27,000	6.4	10.5	0.145	a	0.12	1.26	2.25	3.18
14	19,000	48.5	13.0	0.097	0.04	3.0	12.0	22.3	30.5
25	17,000	104.6	9.0	0.086	0.15	10.6	35.6	55.0	69.2
10	12,000	259.9	13.5(1)	0.064	4.6	28.8	76.0	117.0	162.0
27	10,000	503.4	11.0	0.053	11.0	50.3	140.0	220.0	320.0
				1600°F(S)					
11	10,000	15.7	34.5	0.068	0.04	0.10	0.3	0.7	1.5
10	7,500	62.4	33.0	0.048	0.4	1.3	4.0	8.4	17.2
12	6,000	131.1	21.0	0.039	2.2	5.0	13.6	24.2	38.3
9	5,000	257.5	40.5	0.032	5.2	12.0	26.9	44.8	74

TABLE I (concluded)

a	Deformation reached on loading.
b	Ruptured on loading.
c	re-started after 1292.8 hours.
d	discontinued at indicated time
R	Ruptured before reaching deformation.
S	Data previously reported.
(1)	Broke in gage mark.
(2)	Broken in two places, piece missing.
( )	Extrapolated value.

TABLE II

Rupture and Total Deformation Strengths Obtained at 1200°, 1350°, 1500° and 1600°F for Inconel-W Sheet Material

Stress for Rupture or Indicated Total Deformation in Specified Time Periods

Temp. (°F)	1	5	10	25	50	100	300
Rupture Strength - 1000 psi							
1200	80	72	68	64	61	58	53.5
1350	72	56.5	51	45	40	36.5	29
1500	37	28	25	21.5	19	17	12
1600	--	--	11	9.4	7.9	6.5	4.85
2% Total Deformation Strength - 1000 psi							
1200	70	66	64	61.5	60	58	55
1350	64	52	48.0	43	39.5	36.5	(29.5)
1500	30.5	24.5	22.0	19.5	17.8	14.8	10.0
1600	10.5	8.7	8.0	6.75	5.6	4.6	3.4
1% Total Deformation Strength - 1000 psi							
1200	67	62	60	58	56	55	51
1350	58.5	49	45.5	41.0	38.0	35.5	28
1500	28	23	21.0	18.7	17.0	13.3	8.5
1600	9.7	8.0	7.3	5.9	4.9	4.0	2.95
0.5% Total Deformation Strength - 1000 psi							
1200	62	59	58	56	55	53	44
1350	52	45	42.0	38.5	36.0	32.0	24.5
1500	26	21	19.6	17.6	14.7	11.1	7.15
1600	8.9	7.3	6.5	5.1	4.3	3.55	--
0.2% Total Deformation Strength - 1000 psi							
1200	--	--	--	--	--	--	--
1350	36	31.5	29.5	24.5	20.5	17.5	13.6
1500	21	18	17.0	12.5	10.0	7.8	(5.4)
1600	7.8	6.0	5.2	4.3	3.7	(3.2)	--
0.1% Total Deformation Strength - 1000 psi							
1200	--	--	--	--	--	--	--
1350	--	less than 22,000 psi for all time periods					
1500	14	11.8	10.3	7.6	6.0	(4.8)	(3.3)
1600	6.7	5.1	4.4	3.6	(3.1)	--	--

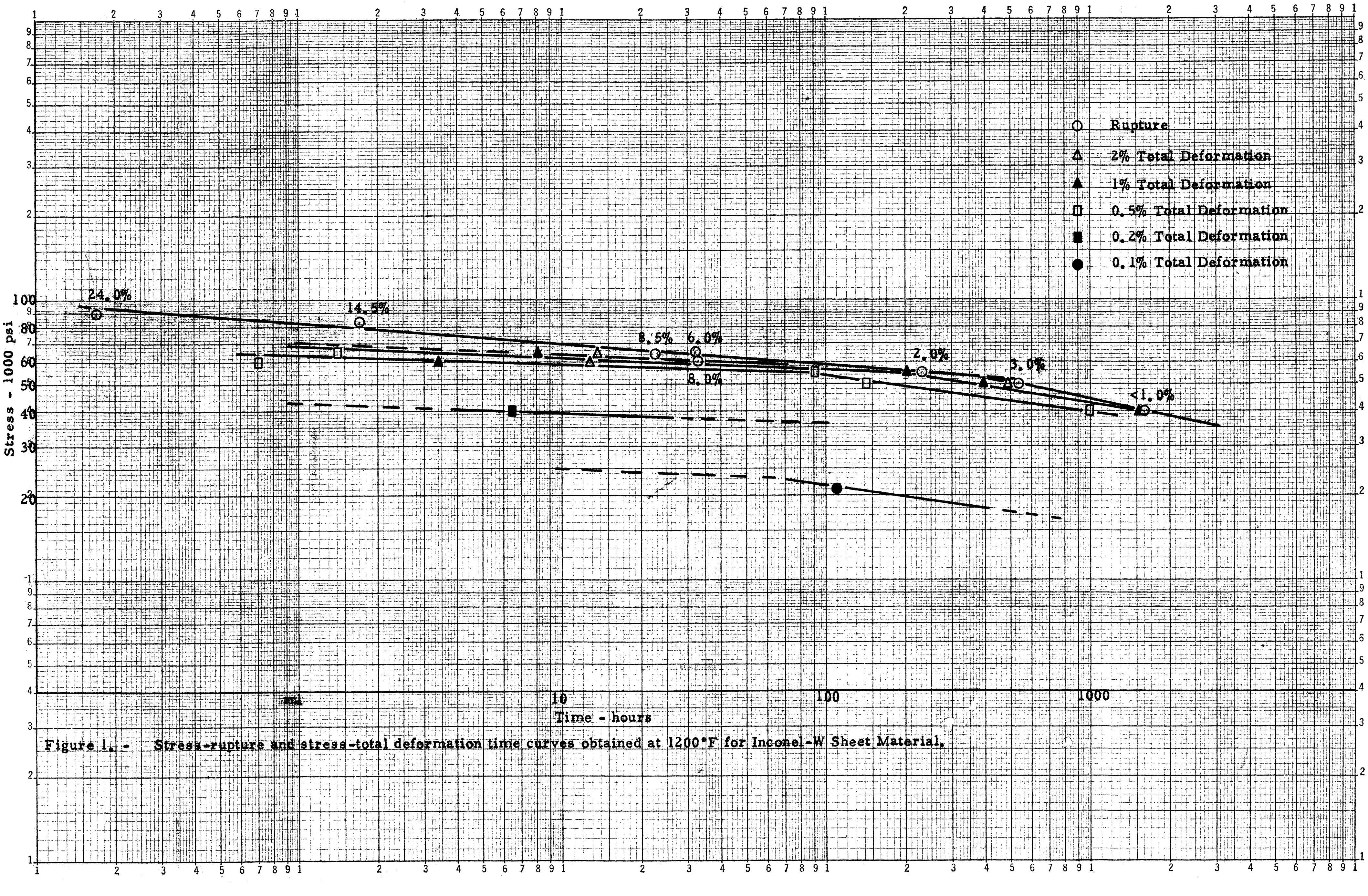

Figure 1. - Stress-rupture and stress-total deformation time curves obtained at 1200°F for Inconel-W Sheet Material.

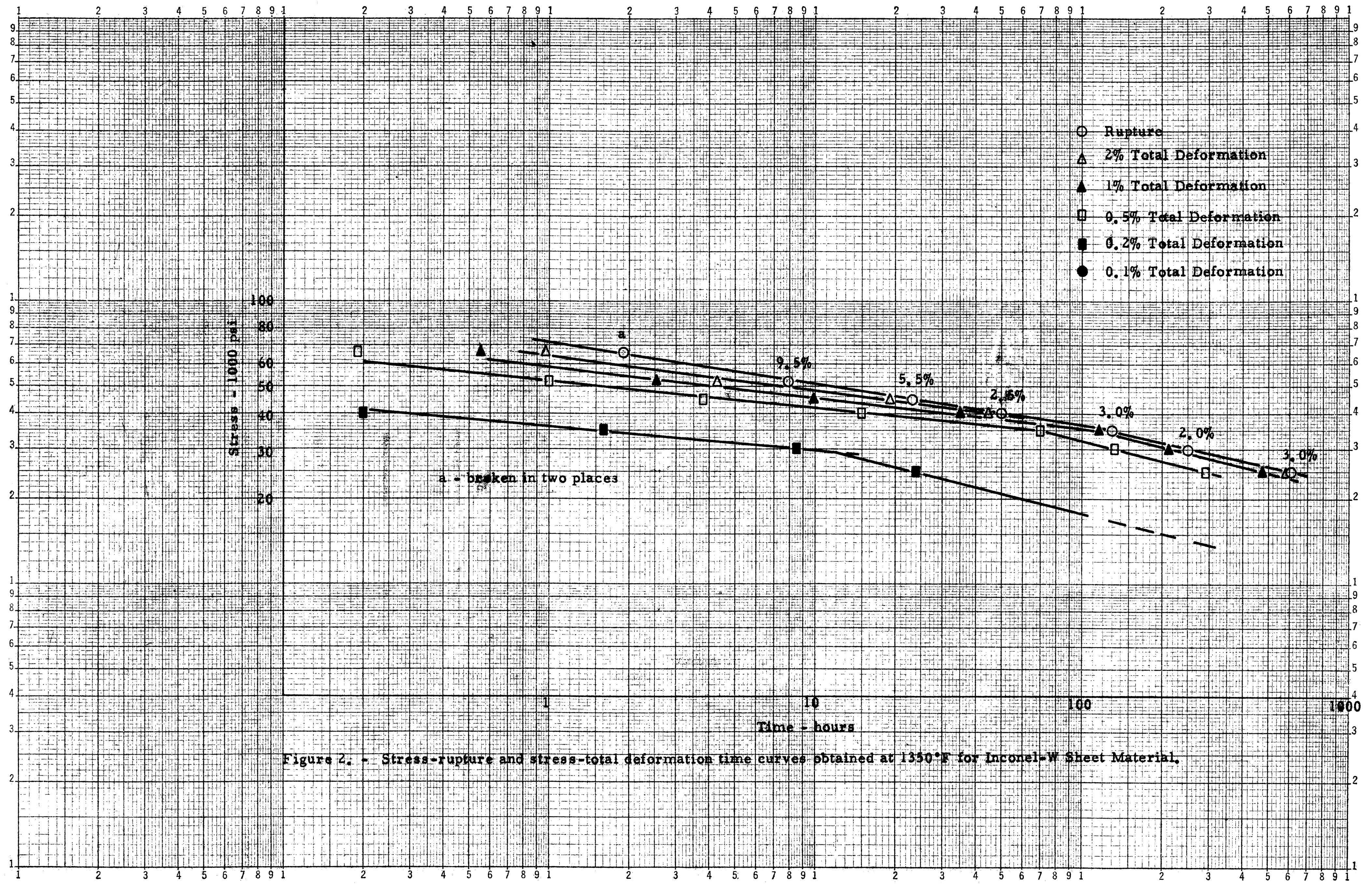

Figure 2. - Stress-rupture and stress-total deformation time curves obtained at 1350°F for Inconel-W Sheet Material.

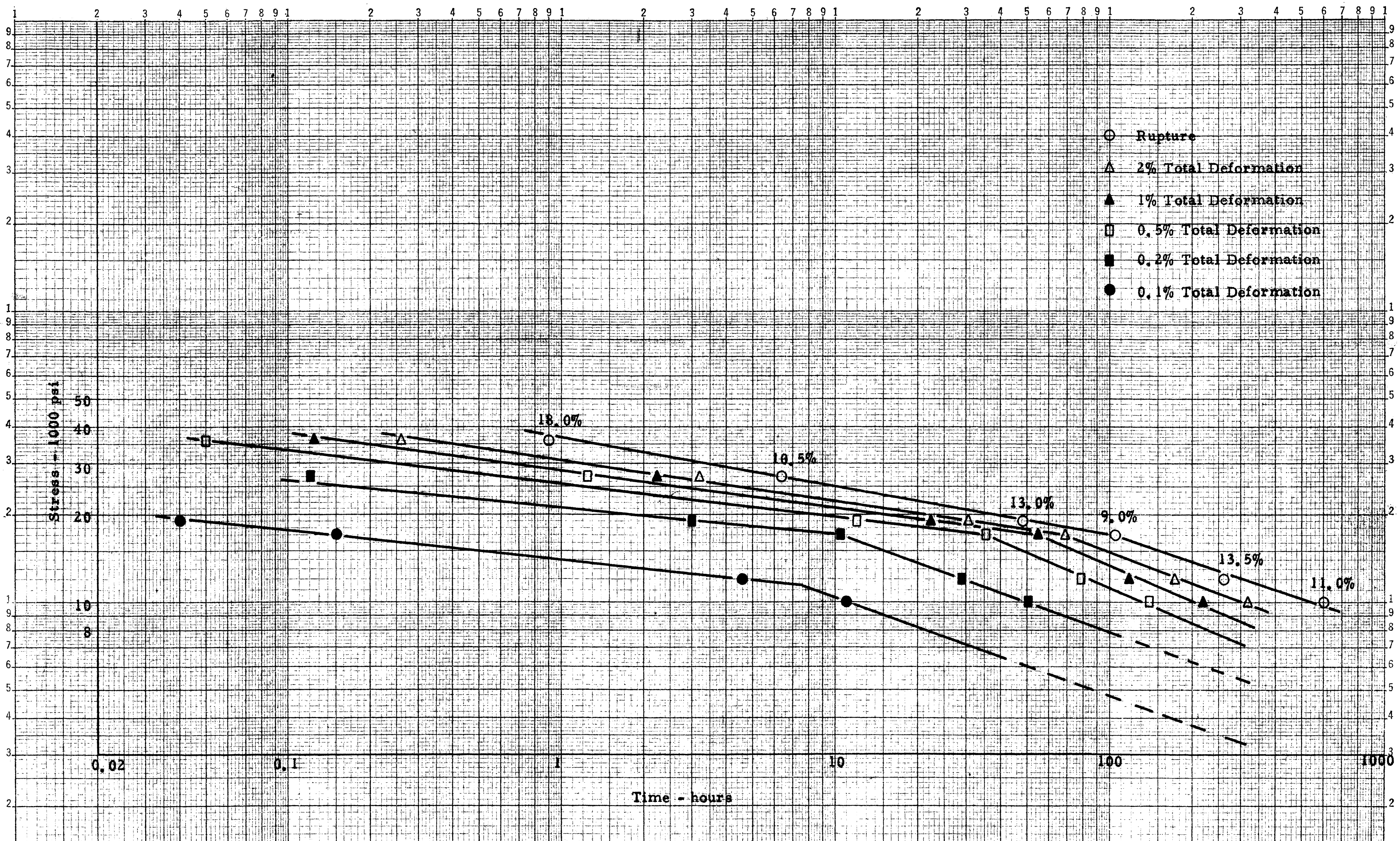

Figure 3.- Stress-rupture and stress-total deformation time curves obtained at 1500°F for Inconel-W Sheet Material.

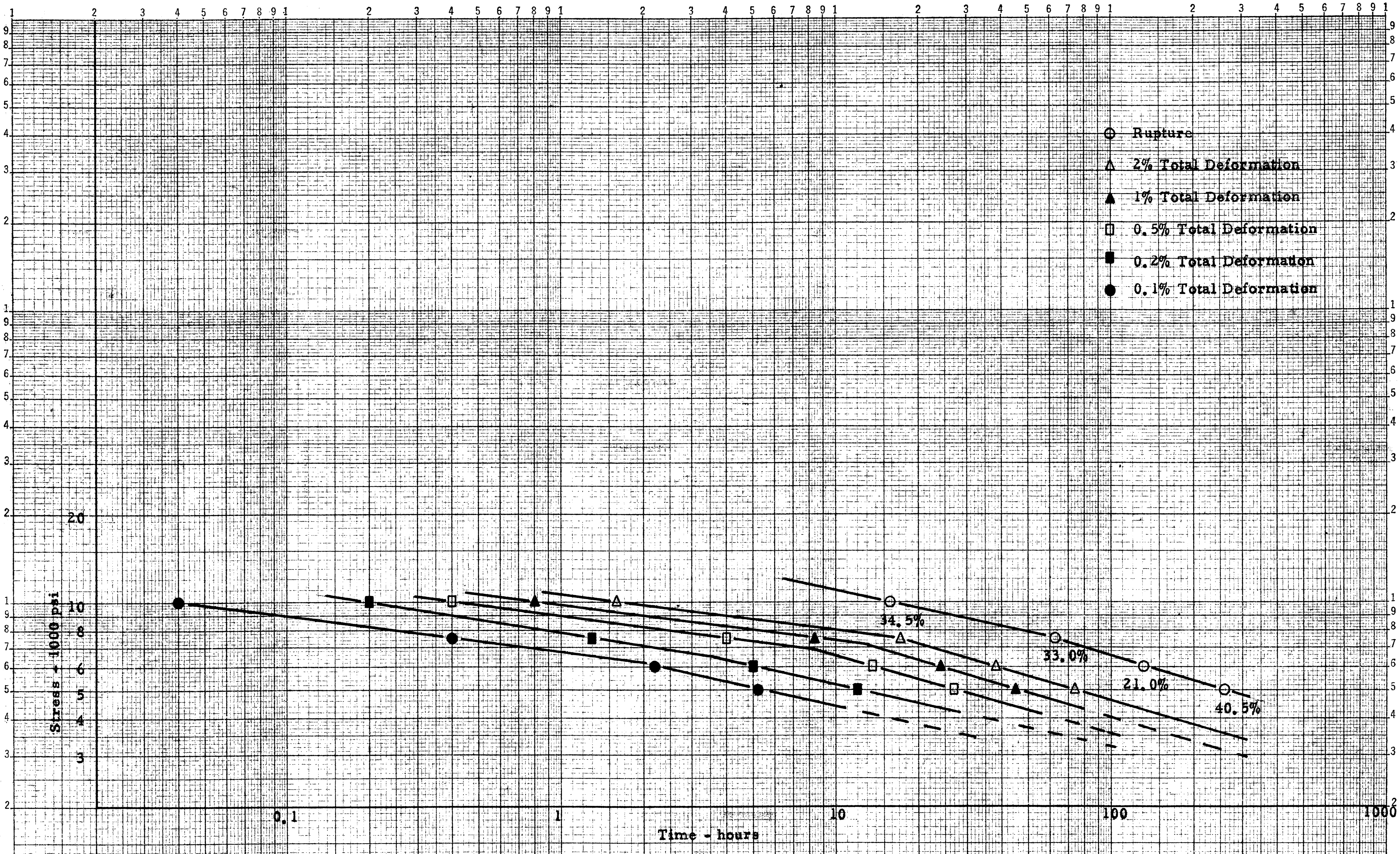

Figure 4. - Stress-rupture and stress-total deformation curves obtained at 1600°F for Inconel-W Sheet Material.

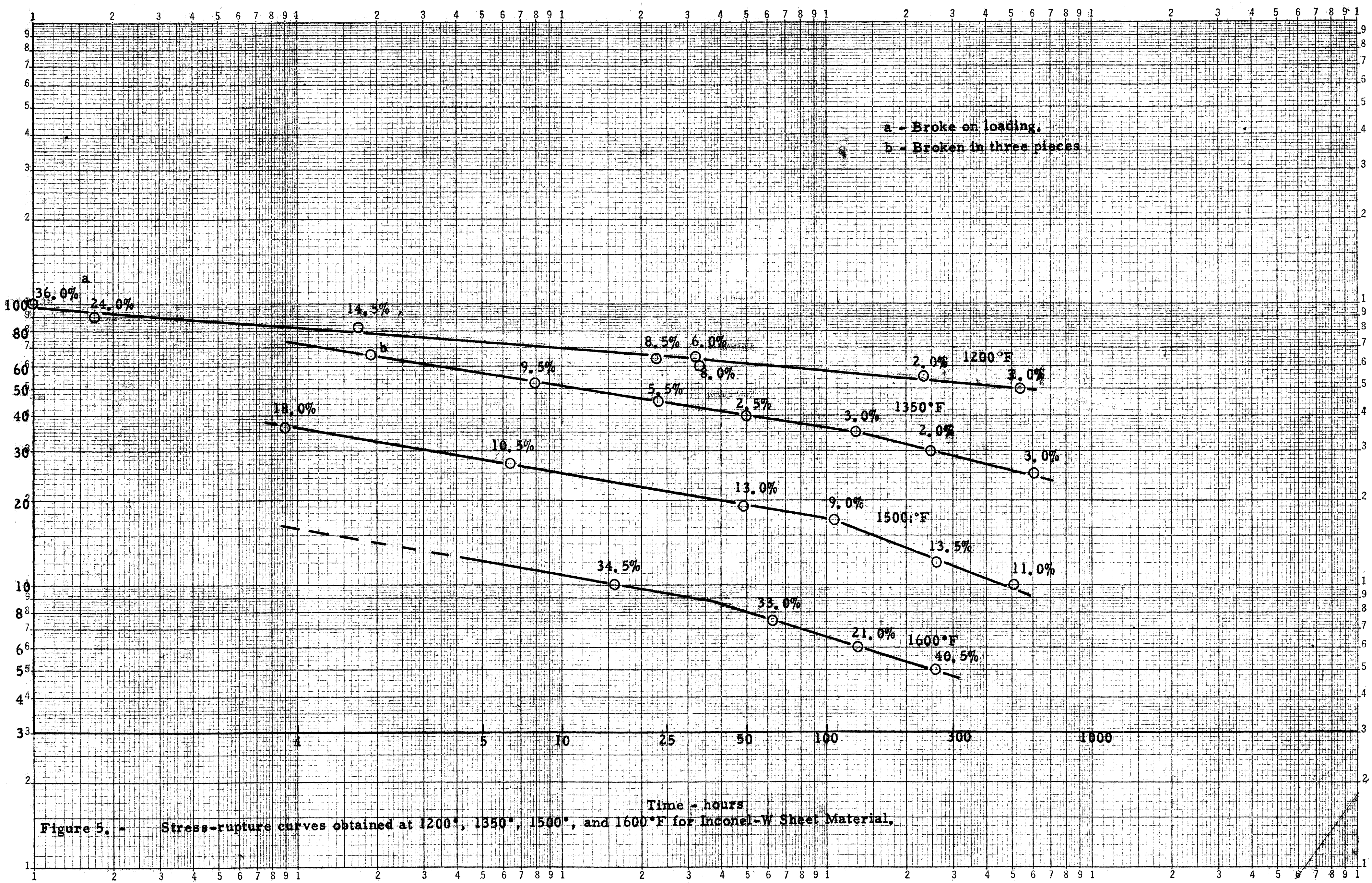

Figure 5. - Stress-rupture curves obtained at 1200°, 1350°, 1500°, and 1600°F for Inconel-W Sheet Material.

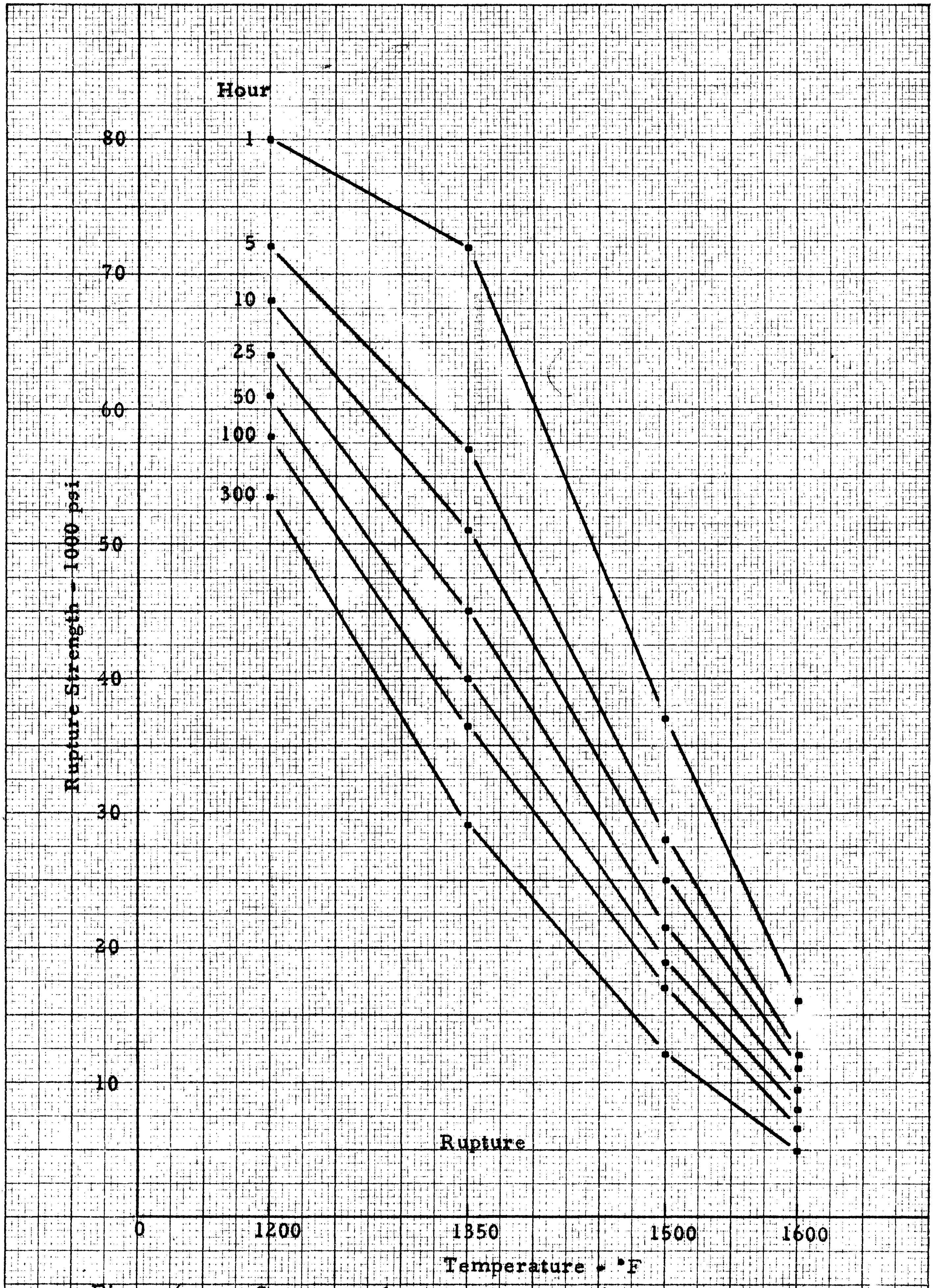

Figure 6. - Summary of rupture strengths for Inconel W (Heat 5354W) sheet material at 1200° to 1600°F for time periods from 1 to 300 hours.

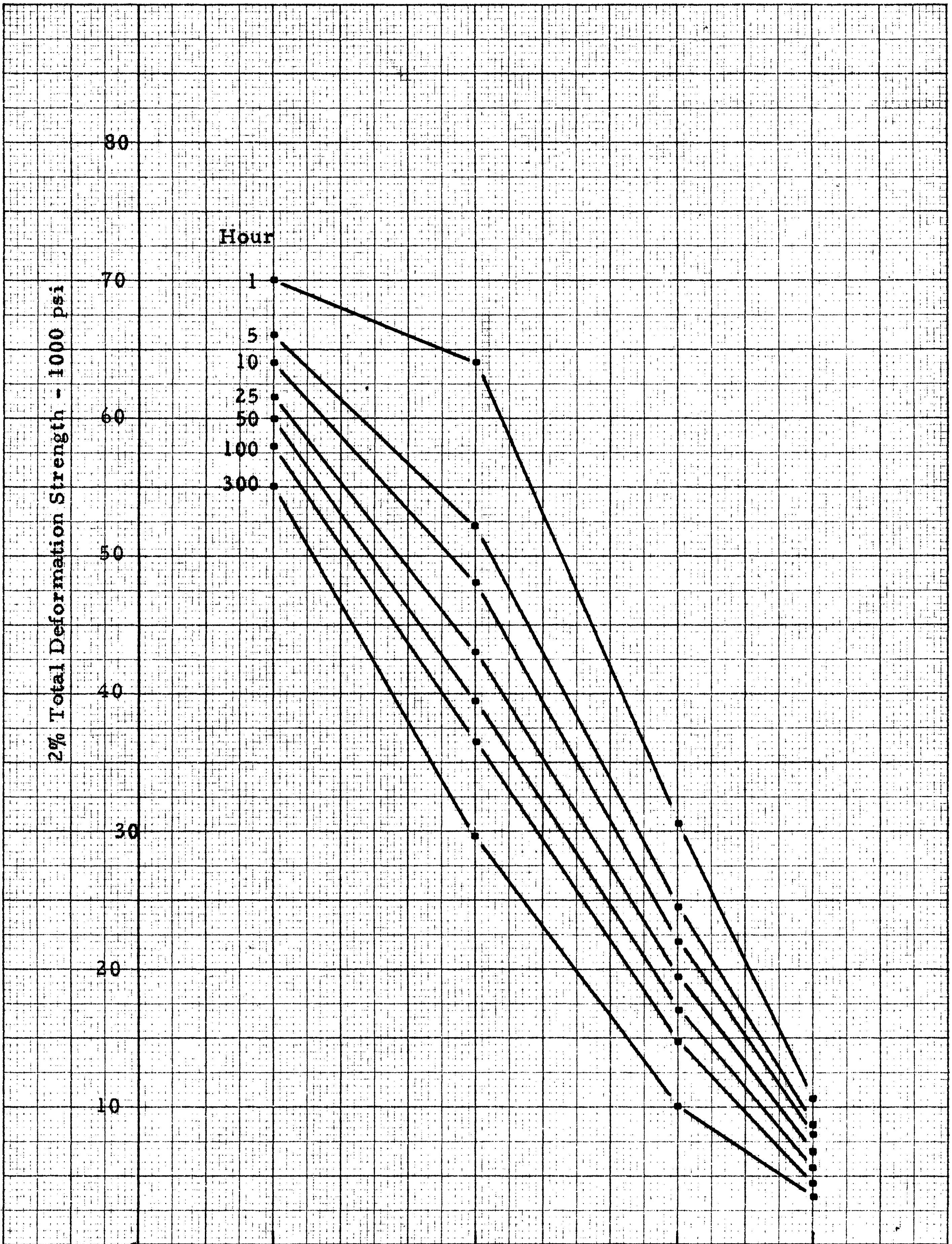

Figure 7. - Summary of 2 percent total deformation strengths for Inconel W (Heat 5354W) sheet material at 1200° to 1600°F for time periods from 1 to 300 hours.

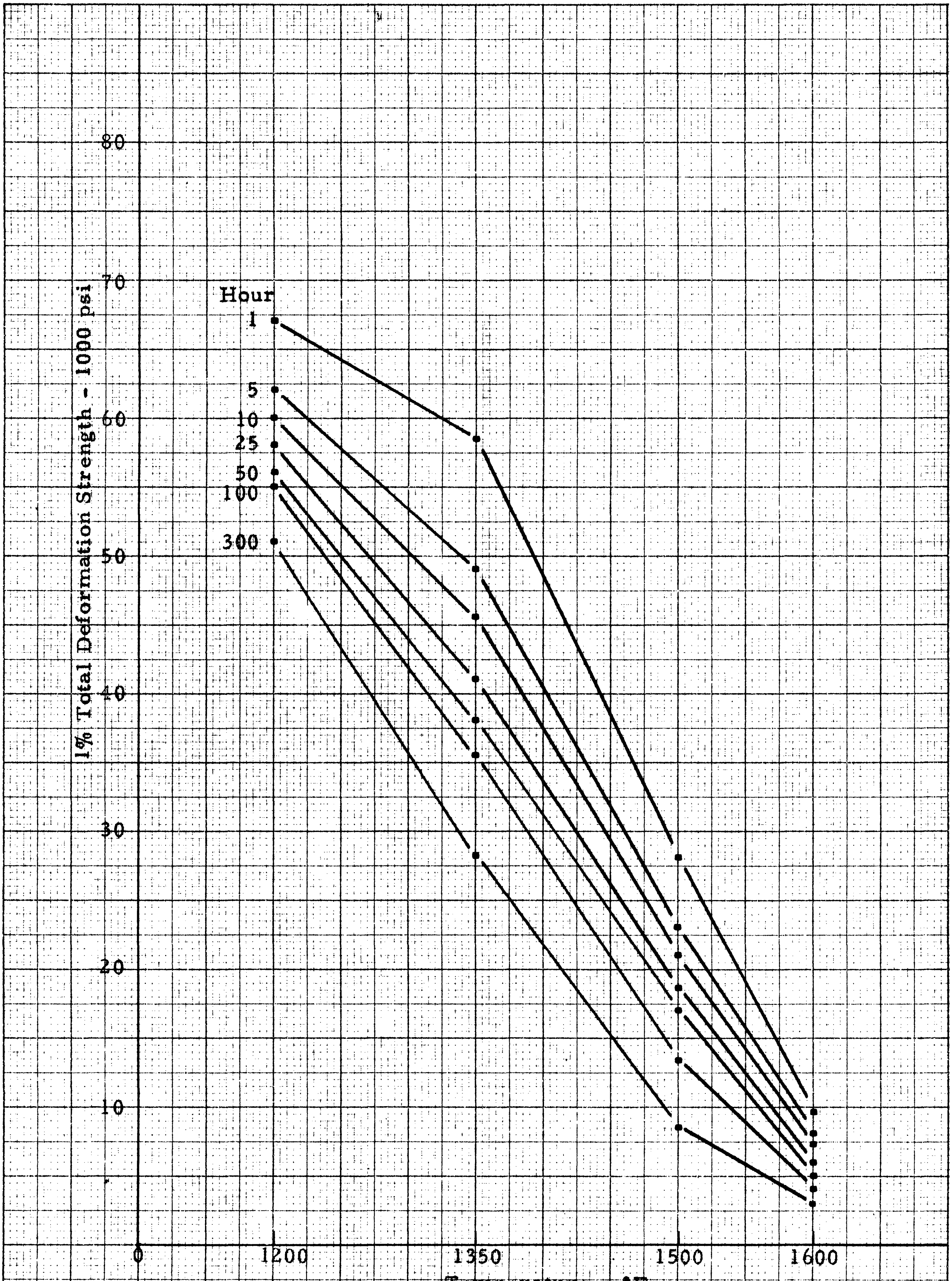

Figure 8. - Summary of 1 percent total deformation strengths for Inconel W (Heat 5354W) sheet material at 1200° to 1600°F for time periods from 1 to 300 hours.

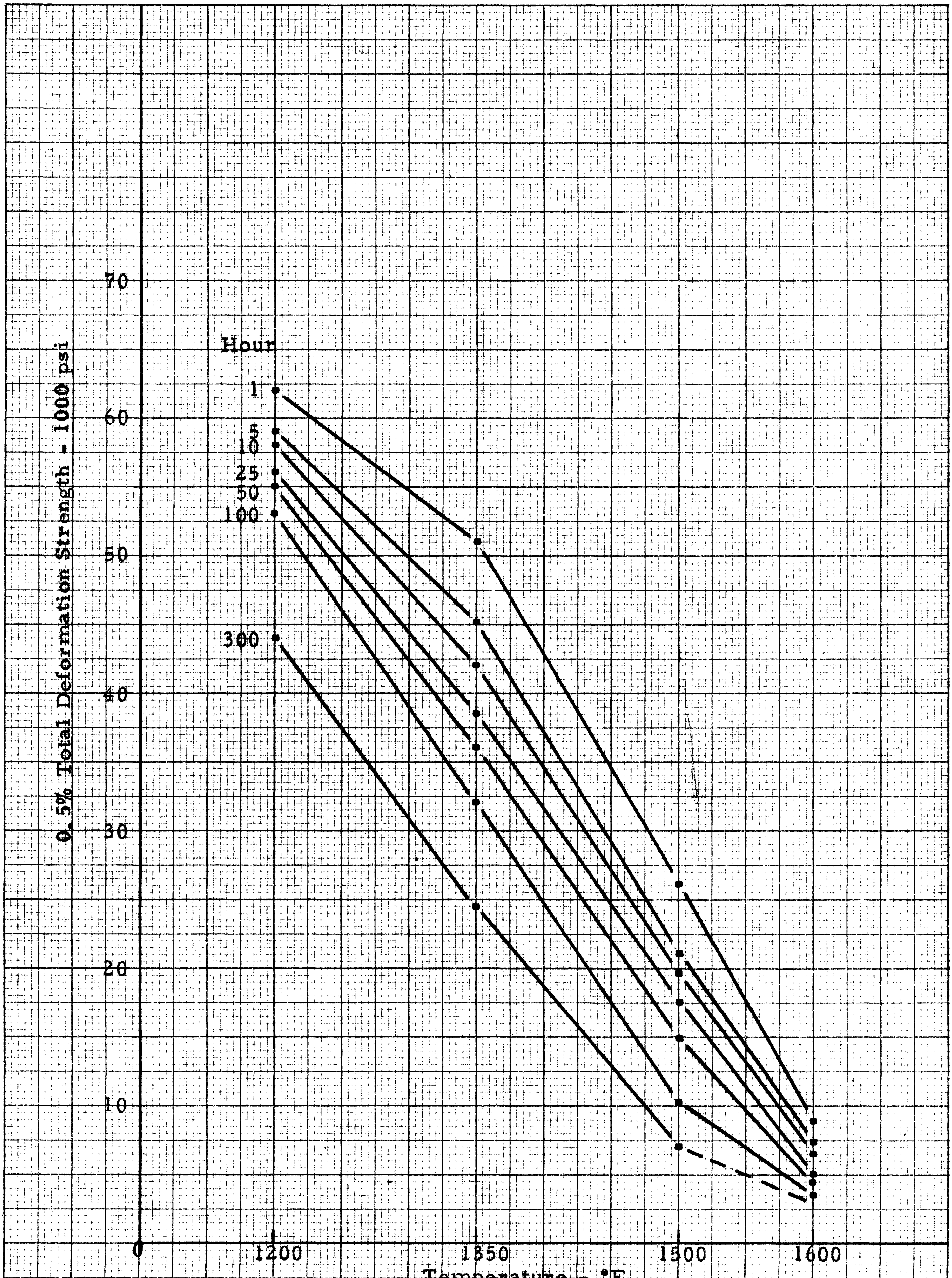

Figure 9. - Summary of 0.5 percent total deformation strengths for Inconel W (Heat 5354W) sheet material at 1200° to 1600°F for time periods from 1 to 300 hours.

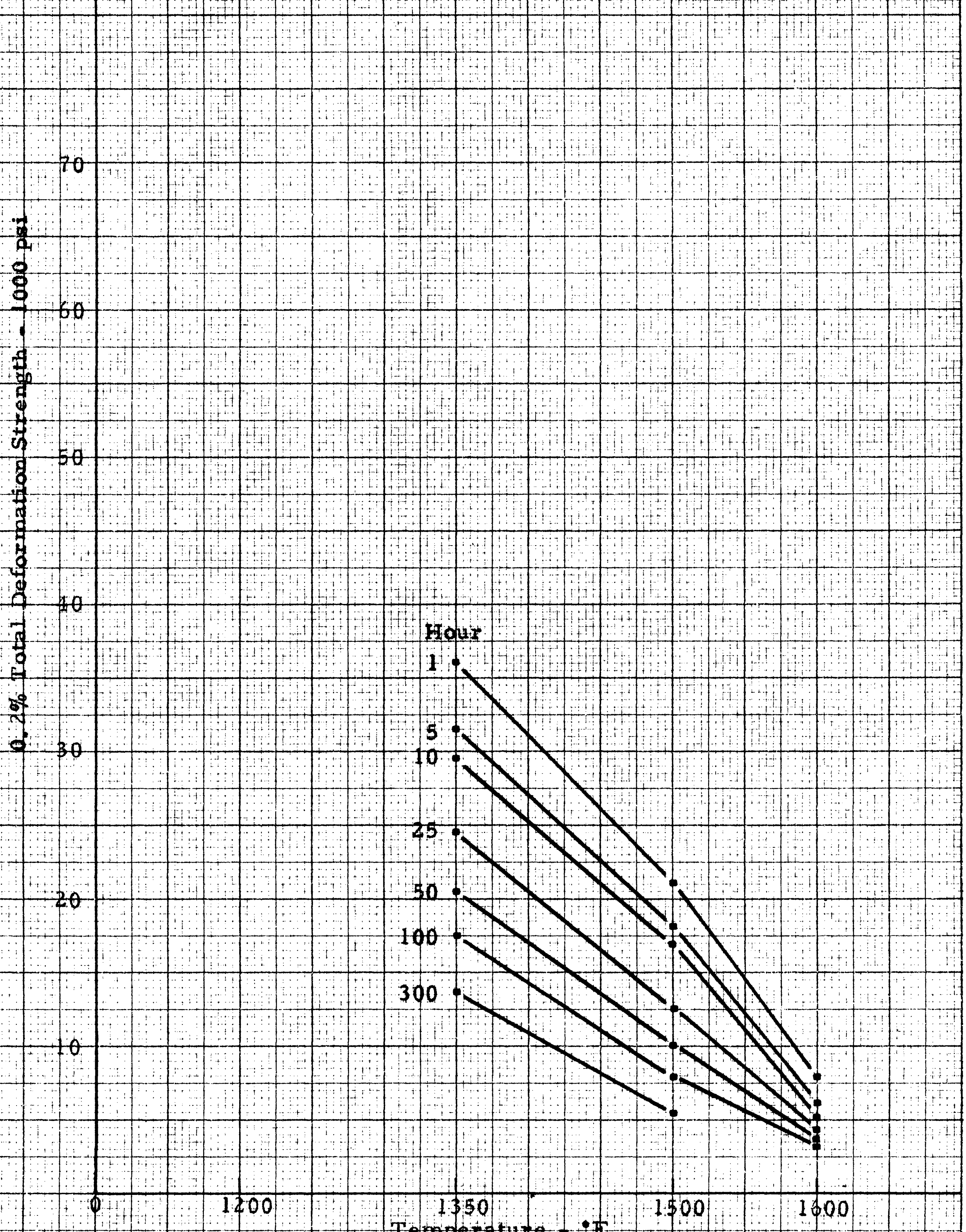

Figure 10. - Summary of 0.2 percent total deformation strengths for Inconel W (Heat 5354) at 1200° to 1600°F for time periods from 1 to 300 hours.

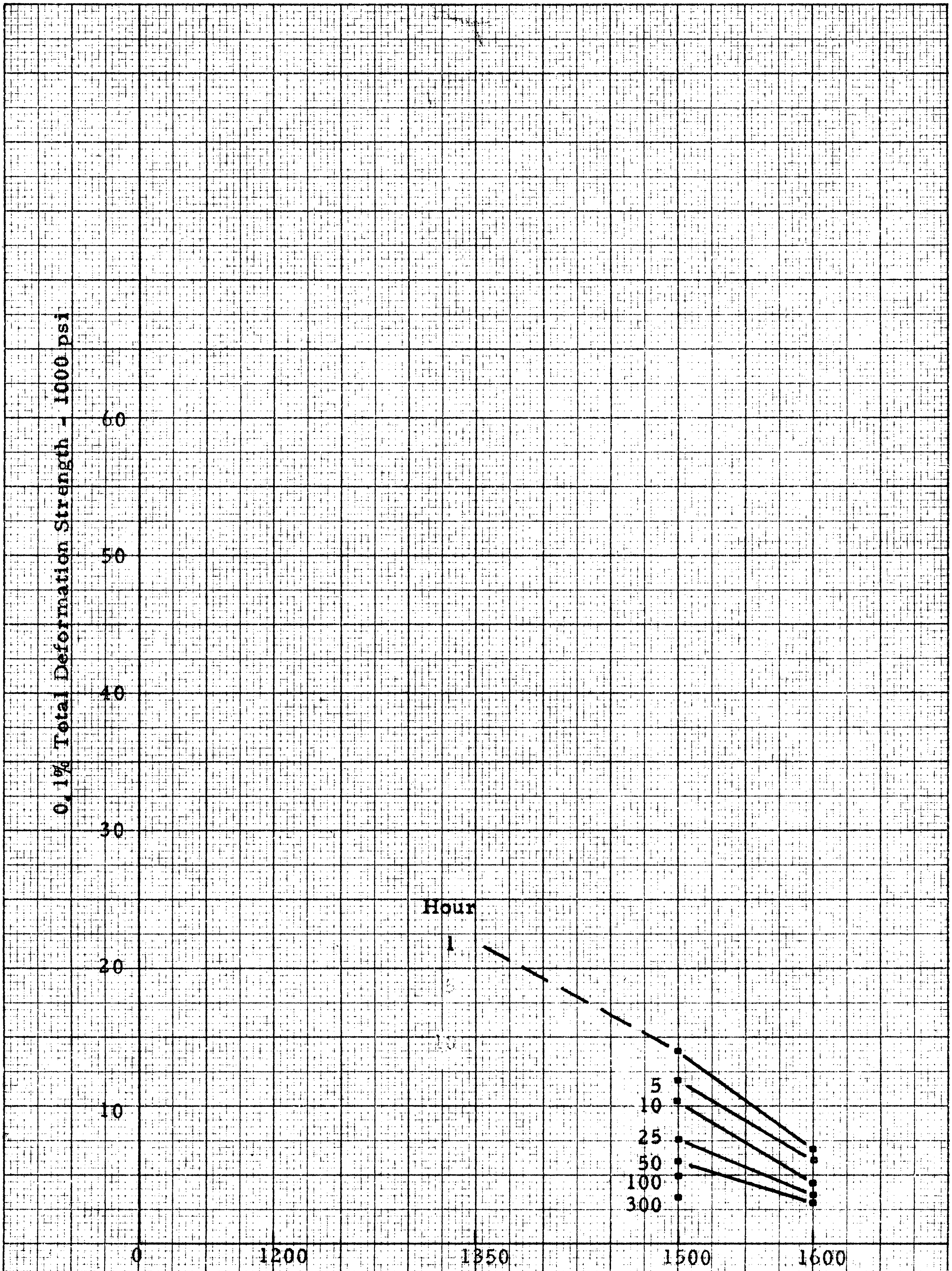

Figure 11. - Summary of 0.1 percent total deformation strengths for Inconel W (Heat 5354W) at 1200° to 1600°F for time periods from 1 to 300 hours.

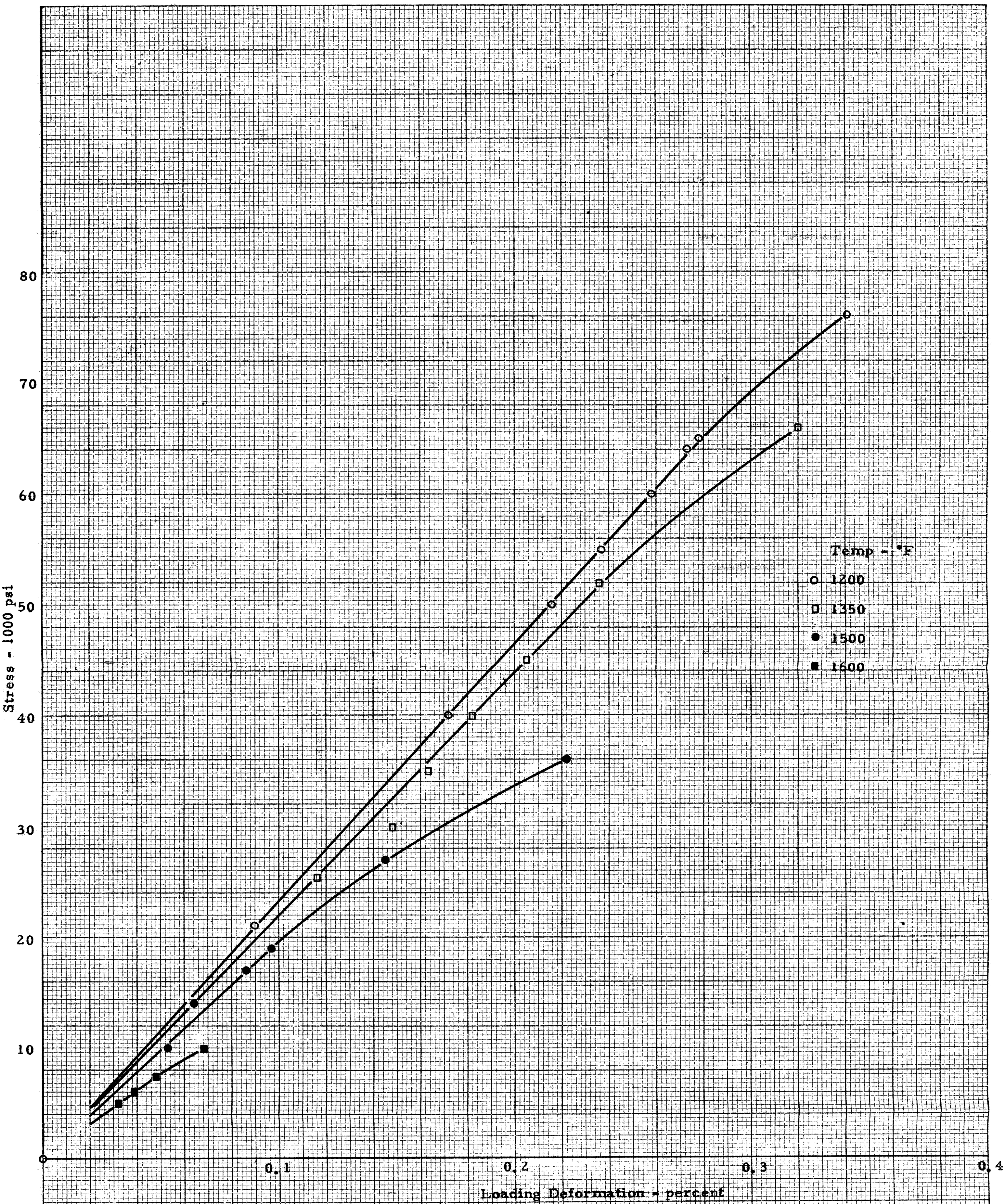

Figure 12. - Stress-loading deformation curves obtained at 1200° to 1600°F for Inconel-W (Heat 5354W) Sheet Material.

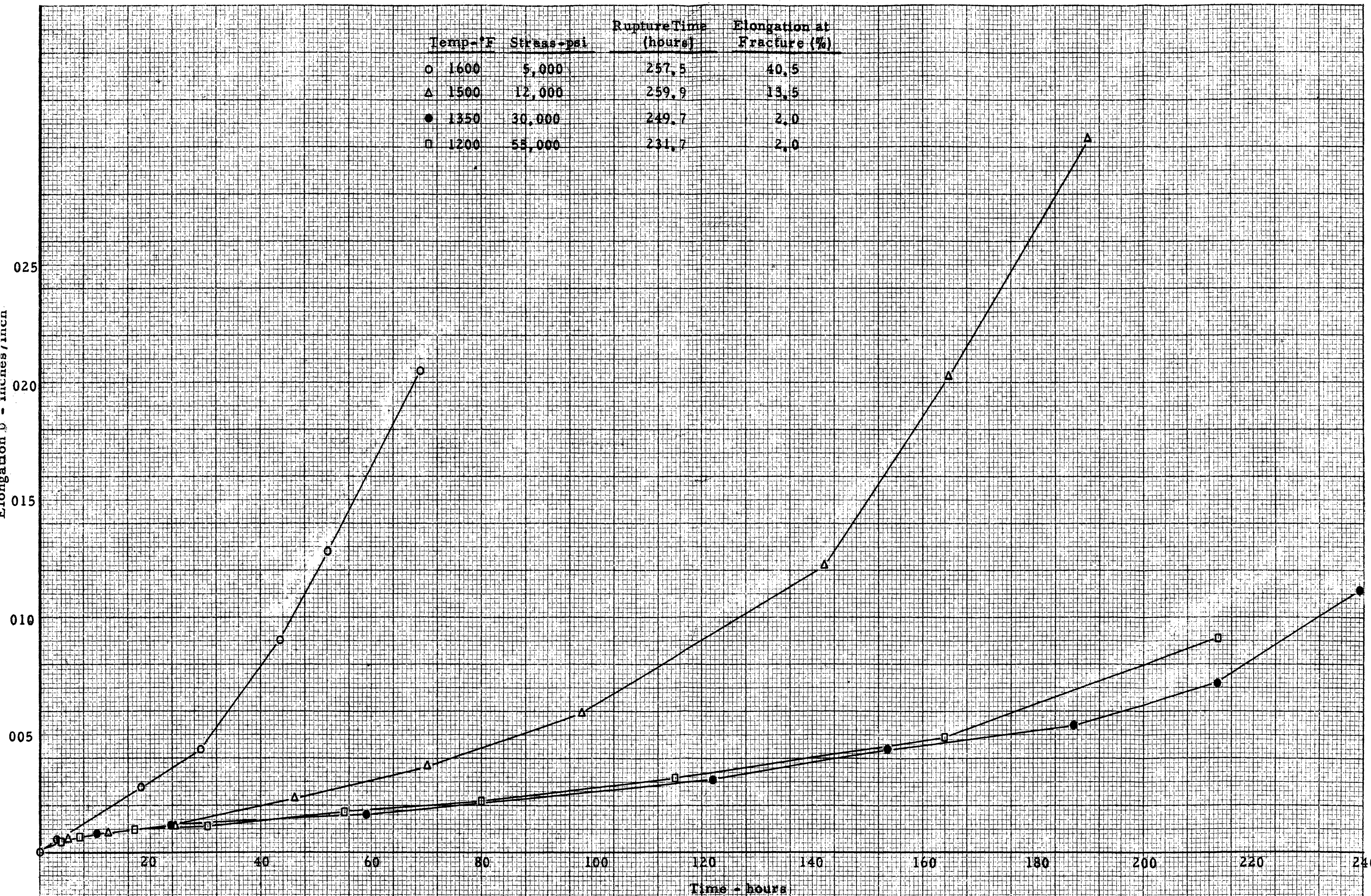

Figure 13. - Time-elongation curves for Inconel-W Sheet Material obtained at 1200° to 1600°F for equal rupture times of 250 hours.