REPORT ON PROJECT 17

ACCEPTABILITY TESTS

FOR

HIGH-TEMPERATURE CHARACTERISTICS

TO

JOINT HIGH-TEMPERATURE COMMITTEE, A.S.T.M.-A.S.M.E.

C. L. CLARK

AND

A. E. WHITE

DEPARTMENT OF ENGINEERING RESEARCH

UNIVERSITY OF MICHIGAN

NOVEMBER 30, 1938

REPORT ON PROJECT 17

ACCEPTABILITY TESTS
FOR
HIGH-TEMPERATURE CHARACTERISTICS

TO

JOINT HIGH-TEMPERATURE COMMITTEE, A.S.T.M.-A.S.M.E.

FROM

DEPARTMENT OF ENGINEERING RESEARCH
UNIVERSITY OF MICHIGAN

BY

C. L. CLARK AND A. E. WHITE

NOVEMBER 30, 1938

SUMMARY

This report sets forth results obtained from stress-rupture tests, of approximately 15 hours duration, on four of the steels used by Battelle Memorial Institute in their investigation of the influence of manufacturing variables on the creep resistance of steels.

At each of the temperatures considered, austenitic grain size, as produced by heat-treatment, has the same general influence on the 10 hour rupture strength as on the creep rate as determined in 500 hour tests. For the given heat-treatments, however, the ratio of the creep rates of the fine and coarse austenitic grained steels ranged from 2.41 to 47.33, while the corresponding range in

the ratio of the 10 hour rupture strength of the fine and coarse austenitic grained steels was from 0.65 to 0.90.

These results therefore indicate variations in austenitic grain size to have a more uniform influence on the 10 hour rupture strength than on the 500 hour creep rates. In fact, in the case of the rupture strength, the range in this ratio becomes even less when proper consideration is given to the maximum variation in the austenitic grain size of the steels being compared.

INTRODUCTION

A report[1] was presented before the 1938 Annual Convention of the A.S.T.M. on the effects of manufacturing variables on the creep resistance of steels. The chief variable considered in this study was the austenitic grain size and, on the basis of 500 hour creep tests, it was found that for each of the 13 steels considered the coarse-grained austenitic steels possessed a lower creep rate, that is, a greater creep strength, than the corresponding fine-grained steels at the temperatures employed.

At this same Convention a report[2] was likewise presented which indicated that short-time rupture tests offered a possibility of rapidly classifying steels of the same type with respect to

1. "Study of Effects of Manufacturing Variables on the Creep Resistance of Steels." H. C. Cross and J. G. Lowther.
2. "Acceptability Tests for High Temperature Characteristics." A. E. White and C. L. Clark.

their relative order of creep strength. On the basis of this work, however, too definite conclusions were not permissible as only five steels were considered and, furthermore, the creep resistance of only three of these steels was known.

In order to obtain further information with respect to the relative merits of the short-time rupture test it was believed advisable to subject to this test certain of the steels used in the study of manufacturing variables. Since the creep characteristics of these steels were already known it could thus be determined whether or not the steels would be arranged in the same relative order on the basis of the two tests. The results which have been obtained are contained in the present report.

STEELS INVESTIGATED

The steels used in this investigation were obtained from Battelle Memorial Institute in the form of one inch bars. Information with respect to their chemical composition, melting practice, melting process and McQuaid-Ehn grain size are given in Table I. With one exception, the steels are of the plain carbon type, containing 0.35 to 0.51 per cent carbon. Steel 393 likewise contains 0.18 per cent vanadium.

Table I

Chemical Composition of Steels Used in Acceptability Tests

Steel Designation	C	Mn	P	S	Si	V	Al. Addition, %	Process	McQuaid-Ehn Grain Size
52	0.46	0.54	0.016	0.030	0.23	----	0.105	Basic O.H.	5 to 7
56	0.51	0.75	0.018	0.033	0.21	----	0.10	Basic O.H.	5 to 7
393	0.37	0.70	-----	-----	0.16	0.18	----	---------	8
K-20	0.35	0.55	0.016	0.030	0.19	----	0.06	Basic O.H.	7 to 8

The steels were given the same heat-treatments as employed by Battelle and special care was taken to have all the details in strict accordance with those previously used in order that the resulting grain sizes would be the same. A portion of each steel was heat-treated to produce a fine austenitic grain and this treatment consisted of air cooling from either 1550 or 1600°F. The remaining portion of each steel was heat-treated to produce a coarse austenitic grain. The temperatures for this purpose varied from 1800 to 2000°F.

The microstructures of Charts 1 to 4 show the austenitic grain size for each of the steels in both conditions of heat-treatment and these same results are summarized in Table II.

If the results of Table II be compared with those previously reported by Battelle very good agreement will be found to exist. Slight differences are found in Heat 393 in that the grain size variations in the coarsened steel was previously found to range from 2 to 5, and in the case of K-20, the previous range was from 0 to 3.

Table II

Austenitic Grain Size When Subjected to Designated Treatments

Steel Designation	Heat-Treatment Deg. Fahr.	Austenitic Grain Size
52-1	1550, 45 min.	6 to 8
52-2	1800, 45 min.	2 to 4
56-1	1550, 45 min.	6 to 8
56-2	1850, 45 min.	2 to 4
393-1	1600, 1 hr.	8
393-2	2000, 1 hr.	3 to 5
K-20(1)	1550, 45 min.	8
K-20(2)	1900, 2 hr. & 6 hr.	1 to 3

PROCEDURE

Description of the apparatus and procedure employed in the short-time stress-rupture tests were given in the earlier report.[2] As previously stated the test is relatively simple in that it consists of fracturing a series of specimens at each temperature under fixed loads so chosen that the resulting fracture times vary from a few minutes up to a maximum of 15 hours. The stresses and corresponding fracture times, when plotted to logarithmic coordinates, form an approximately straight-line relationship at each of the temperatures. It is thus possible to determine the stress corresponding to a definite fracture time, such as 10 hours.

In the present investigation, specimens of each of the four steels were given both of the heat-treatments listed in Table

II. In each case the specimens heat-treated at the lower temperature possessed a fine austenitic grain size and those heat-treated at the higher temperature possessed a coarse austenitic grain size. The results obtained will, therefore, indicate the influence of austenitic grain size on the rupture strength.

RESULTS

The results obtained from stress-rupture tests of a maximum of 15 hours duration on these four steels are shown graphically in Figures 1 to 4, inclusive, and likewise given in Tables III through VIII.

The four figures, which are plotted to logarithmic coordinates, clearly show the coarse grained austenitic steels to possess the greater rupture strength at each of the temperatures considered. The difference in strength between the coarse and fine austenitic grained steels appears to be relatively constant for Steels 52, 56 and 393 and of a greater order of magnitude for Steel K-20.

Tables III through VI contain, in addition to the stresse and corresponding fracture times, information with respect to the ductility of the fractured specimens. Even though the testing time periods in these tests are relatively short, the ductility values do give an indication of the influence of time and stress on both the elongation and reduction of area. With all the steels the ductility of the coarse austenitic grain steels is less than that of the fine-grained steels. In the case of Steel 52 the difference is not of a large order of magnitude and both grain sizes would be said to possess ample ductility. With the remaining three steels, however, the ductility of the fine-grained structure is ample but that of the coarse-grained is low, the elongation being below 20 per cent. Especially is this true with Steel 393 at 850°F. and Steel K-20 at 850°F.

Table VII summarizes the results from both the 500 hour creep tests and the stress-rupture tests, while Table VIII shows the comparative influence of austenitic grain size on both the creep and short-time rupture strength. In this table the comparison in the creep strength is made on the ratio of creep rates, and in the stress-rupture strength, on the ratio of the stresses required for fracture in 10 hours.

The values of Table VIII show the ratio of the creep rates to range from 2.41 to 47.33. The large variation in this ratio may be partly due to the fact that the creep rate varies as some power of the stress and likewise because certain of the 500 hour creep tests entered the third stage while others remained in the second stage. In other words, certain of these ratios compare third stage creep rates with second stage creep rates and the range would have been considerably less if the stresses had been so chosen that all the specimens remained in the second stage.

In the case of the rupture strength, the range in the ratio is only from 0.65 to 0.90. Furthermore, this observed range in the ratio is directly proportional to the difference between the extremes of the austenitic grain size considered. For example, in Steels 52 and 56 the fine austenitic grain size had a rating of 6 to 8 and the coarse a rating of 2 to 4 or an average difference of 4 grain size numerals. For both of these steels the range in the ratio was only from 0.84 to 0.90. For Steel K-20, an average difference of 6 grain size numerals existed and the average ratio was lower, being approximately 0.67. In other words, as should be expected, the superiority of the coarse grain structure over the fine grain steel increases as the relative spread between the grain sizes considered increases.

DISCUSSION OF RESULTS

On the basis of these results it is to be concluded that both the 500 hour creep tests and the 15 hour stress-rupture tests show the coarse grained austenitic steels to possess the superior high temperature strength at the temperatures considered. The stress-rupture test, however, shows the influence of the grain size effect to be constant in all four steels and at each of the temperatures considered. On the other hand, the creep tests do not show a consistent degree of improvement in the high temperature strength with increasing grain size.

The stress-rupture test likewise shows that even though increased high temperature strength results from a coarse austenitic grain, full advantage cannot always be taken of this fact because of the low high temperature ductility which results in certain of the steels considered.

Table III

Stress-Rupture Data for Steel 52

Heat Number	Temperature Deg. Fahr.	Stress Lb./Sq.In.	Time Hours	Elongation % in 2 In.	Reduction of Area %
52-1	950	50,250	S.T.T.S.	43.0	81.5
	950	45,000	0.083	41.5	80.3
	950	40,000	0.60	43.0	77.2
	950	36,500	1.40	42.0	76.6
	950	29,000	10.0	43.0	74.5
	850	63,000	S.T.T.S.	40.5	79.9
	850	58,000	0.083	40.5	78.4
	850	49,000	2.88	40.5	76.4
	850	45,000	6.41	39.5	76.3
52-2	950	51,500	S.T.T.S.	35.0	72.3
	950	41,000	0.63	37.5	68.6
	950	35,000	4.5	35.0	69.0
	950	32,000	11.7	35.0	69.5
	850	67,500	S.T.T.S.	33.0	68.4
	850	58,000	0.50	32.0	61.8
	850	50,000	4.27	30.0	55.5
	850	47,000	14.2	28.5	56.5

52-1: 1550°F., 45 min., air cool (6 to 8).
52-2: 1800°F., 45 min., air cool (2 to 4).

Table IV

Stress-Rupture Data for Steel 56

Heat Number	Temperature Deg. Fahr.	Stress Lb./Sq.In.	Time Hours	Elongation % in 2 In.	Reduction of Area %
56-1	950	55,000	S.T.T.S.	40.0	80.9
	950	46,000	0.38	42.0	77.8
	950	41,000	1.45	41.0	74.5
	950	38,000	2.55	40.0	72.3
	950	33,000	12.52	38.5	68.2
	850	69,250	S.T.T.S.	36.0	79.8
	850	60,000	0.37	37.0	78.8
	850	55,000	1.70	40.0	77.0
	850	50,000	9.17	38.0	73.3
56-2	950	62,000	S.T.T.S.	32.0	72.9
	950	52,000	0.32	28.5	64.0
	950	44,000	4.13	26.5	56.0
	950	40,000	10.67	27.0	56.5
	850	77,000	S.T.T.S.	27.0	65.2
	850	68,000	0.37	25.0	54.7
	850	65,000	1.56	21.0	47.2
	850	62,000	5.03	20.0	42.5
	850	60,000	4.32	20.5	43.7
	850	58,000	16.5	19.5	41.6

56-1: 1550°F., 45 min., air cool (6 to 8).
56-2: 1850°F., 45 min., air cool (2 to 4).

Table V

Stress-Rupture Data for Steel S393

Heat Number	Temperature Deg. Fahr.	Stress Lb./Sq.In.	Time Hours	Elongation % in 2 In.	Reduction of Area %
393-1	850	68,125	S.T.T.S.	35.0	73.5
	850	63,000	0.133	36.5	74.9
	850	58,000	4.52	37.0	73.5
	850	56,500	8.12	39.5	74.9
393-2	850	90,000	S.T.T.S.	19.0	43.4
	850	83,000	0.28	17.0	30.2
	850	79,000	1.48	12.0	19.9
	850	76,000	2.45	11.0	17.7
	850	70,000	11.77	7.5	11.5

393-1: 1600°F., 1 Hr., air cool (8).
393-2: 2000°F., 1 Hr., air cool (3 to 5).

Table VI

Stress-Rupture Data for Steel K-20

Heat Number	Temperature Deg. Fahr.	Stress Lb./Sq.In.	Time Hours	Elongation % in 2 In.	Reduction of Area %
K-20(1)	850	45,000	S.T.T.S.	52.5	79.5
	850	40,000	0.40	56.0	79.5
	850	36,000	1.67	56.0	79.5
	850	32,500	8.30	57.5	79.2
	850	31,000	13.92	53.0	78.4
	750	55,500	S.T.T.S.	49.0	76.8
	750	51,000	0.48	49.5	74.5
	750	49,000	1.22	52.5	75.6
	750	45,000	6.33	52.5	75.3
	750	43,000	10.33	55.5	78.9
	750	42,000	21.60	55.5	76.6
K-20(2)	850	62,750	S.T.T.S.	27.0	56.0
	850	55,000	0.90	22.0	38.8
	850	53,000	1.80	20.0	34.7
	850	50,000	5.68	15.5	30.2
	750	76,400	S.T.T.S.	29.5	58.8
	750	69,000	0.95	26.0	49.8
	750	67,000	2.19	24.5	48.9
	750	65,000	7.32	20.5	40.4

K-20 (1): 1550°F., air cooled (8).
K-20 (2): 1900°F., 2 Hr., air cooled; 1900°F., 6 Hr., air cooled (13)

Table VII

Creep and Short-Time Stress-Rupture Characteristics of Designated Steels

Steel Designation	Temperature Deg. Fahr.	Stress Lb./Sq.In.	Creep Rate %/Hr.	Stress for Fracture in 10 Hours
52-1	950	11,000	0.0120	29,000
	850	20,000	0.00910	43,000
52-2	950	11,000	0.00066	32,500
	850	20,000	0.00048	48,000
56-1	950	11,000	0.00313	34,000
	850	20,000	0.00415	49,500
56-2	950	11,000	0.00038	40,000
	850	20,000	0.00019	59,000
393-1	850	15,000	0.000135	56,000
393-2	850	15,000	0.000056	70,000
K-20(1)	850	7,500	0.000120	31,800
	750	28,000	0.00426	43,800
K-20(2)	850	7,500	0.000021	48,800
	750	28,000	0.00009	64,000

52-1: 1550°F., 45 min., air cooled (6 to 8).
52-2: 1800°F., 45 min., air cooled (2 to 4).
56-1: 1550°F., 45 min., air cooled (6 to 8).
56-2: 1850°F., 45 min., air cooled (2 to 4).
393-1: 1600°F., 1 Hr., air cooled (8).
393-2: 2000°F., 1 Hr., air cooled (3 to 5).
K-20(1): 1550°F., air cooled (8).
K-20(2): 1900°F., 2 Hr., air cooled; 1900°F., 6 Hr., air cooled (1 to 3).

Table VIII

Comparative Influence of Austenitic Grain Size on the Creep and Short-Time Stress-Rupture Characteristics

Steel	Temperature	Creep Rate* (F.G.) / Creep Rate (C.G.)	Fracture Stress** (F.G.) / Fracture Stress (C.G.)
52	950	18.18	0.89
52	850	18.95	0.90
56	950	8.24	0.85
56	850	21.84	0.84
393	850	2.41	0.80
K-20	850	5.71	0.65
K-20	750	47.33	0.68

*Results based on Battelle's Creep Stress.
**Comparison based on stress required for fracture in 10 hours.

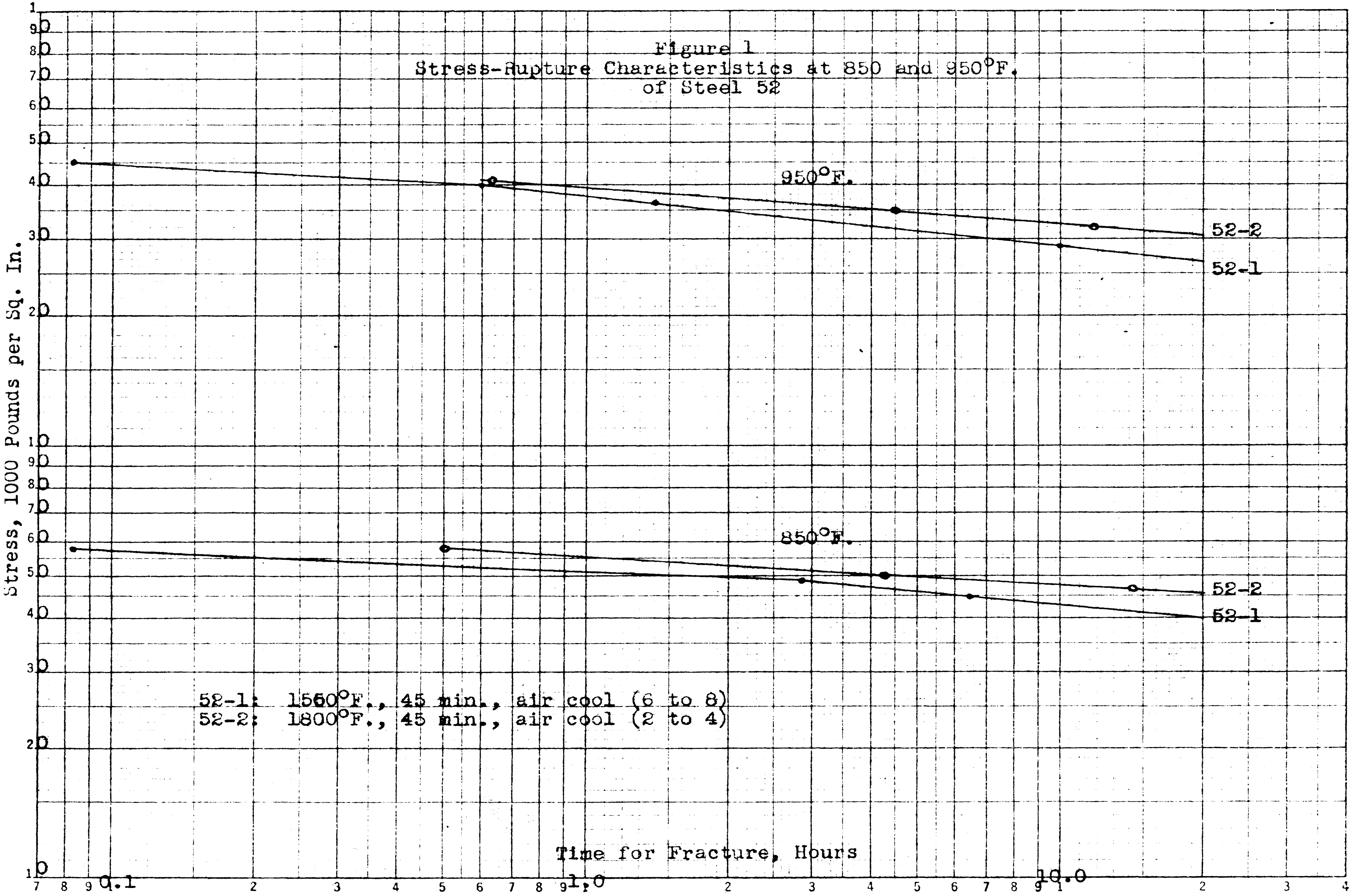


Figure 1
Stress-Rupture Characteristics at 850 and 950°F.
of Steel 52
950°F.
850°F.
52-2
52-1
52-2
52-1
52-1: 1560°F., 45 min., air cool (6 to 8)
52-2: 1800°F., 45 min., air cool (2 to 4)
Stress, 1000 Pounds per Sq. In.
Time for Fracture, Hours
0.1
1.0
10.0

Figure 2
Stress-Rupture Characteristics at 850 and 950°F.
of Steel 56

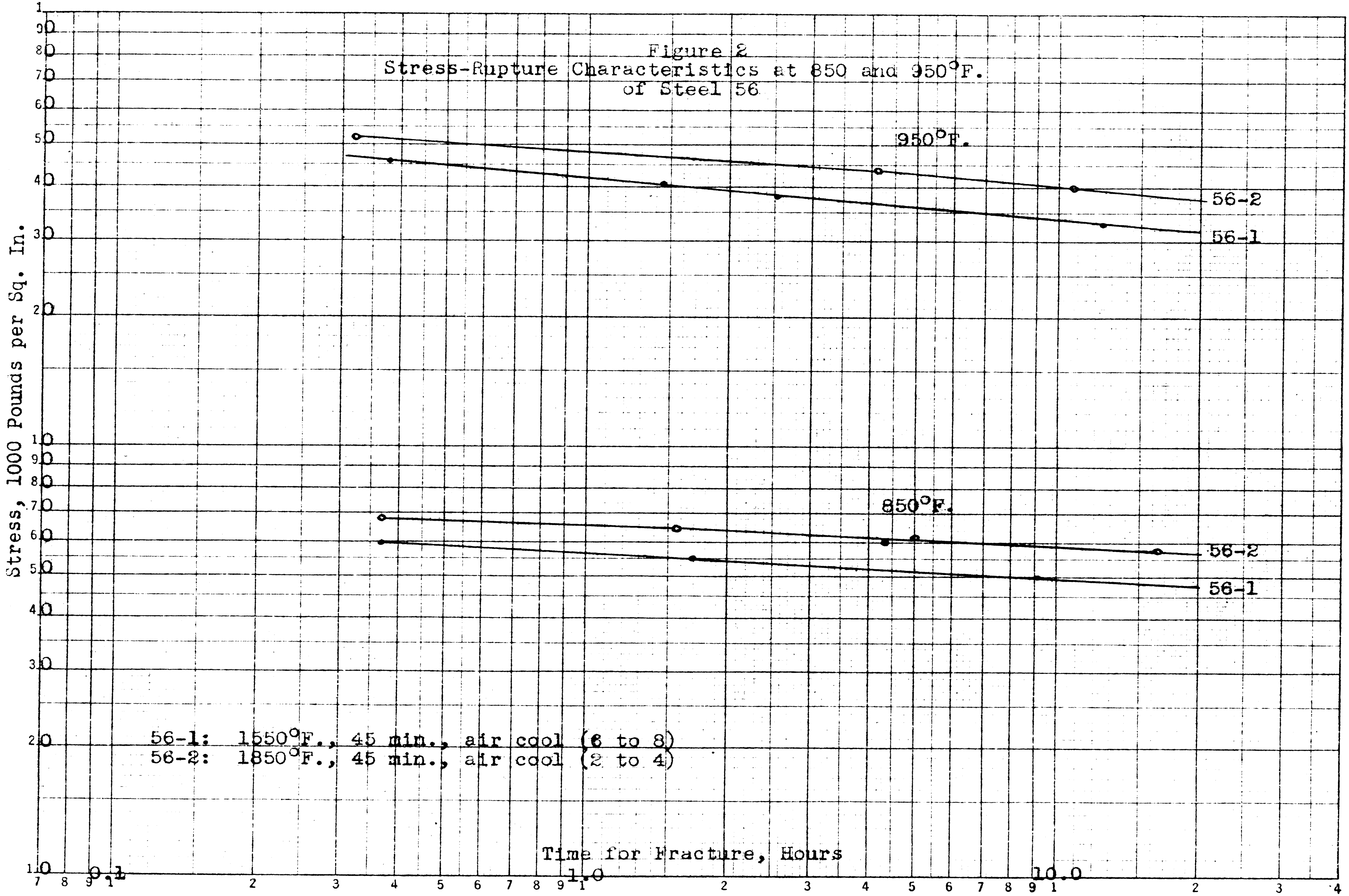
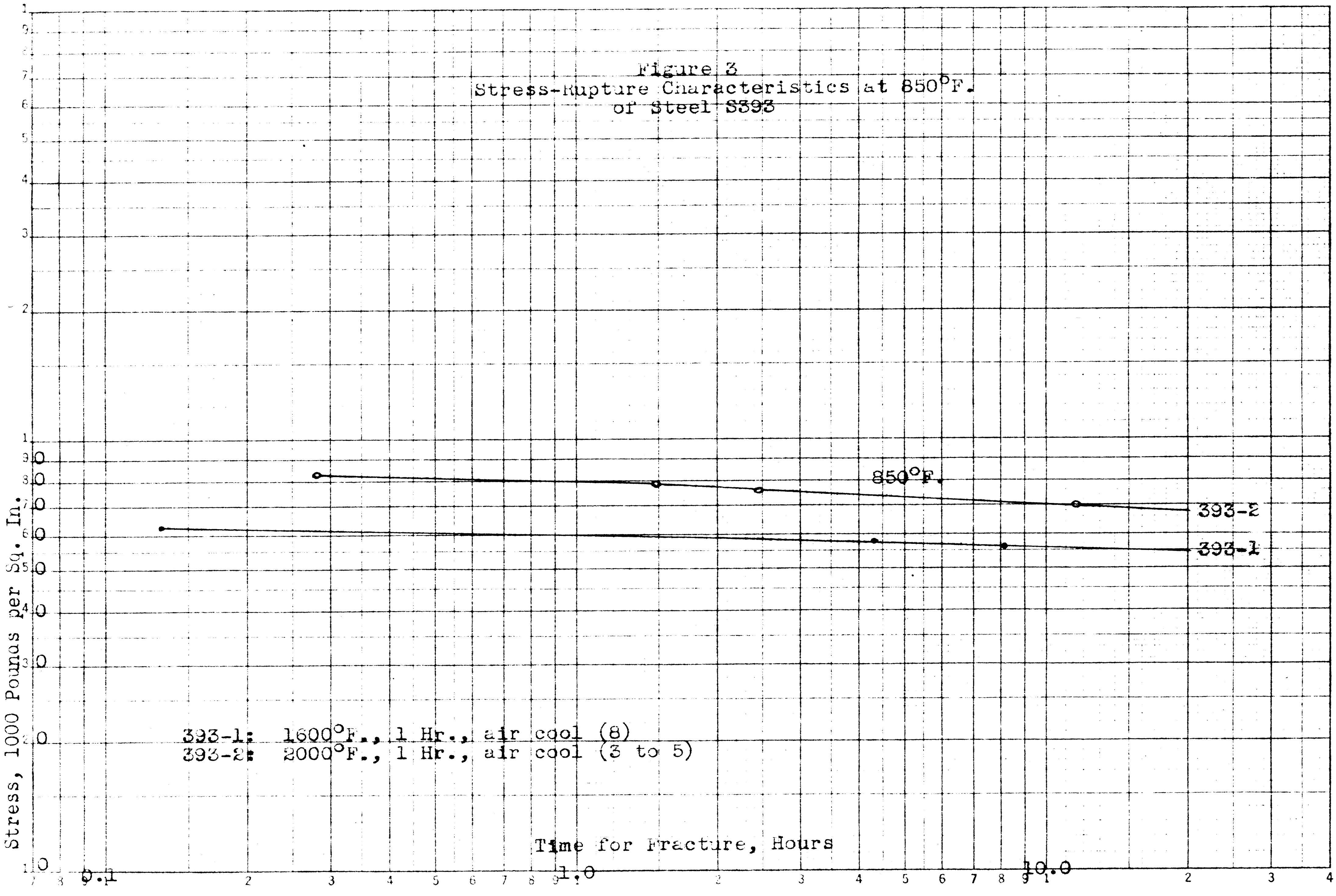


Figure 3
Stress-Rupture Characteristics at 850°F.
of Steel S393



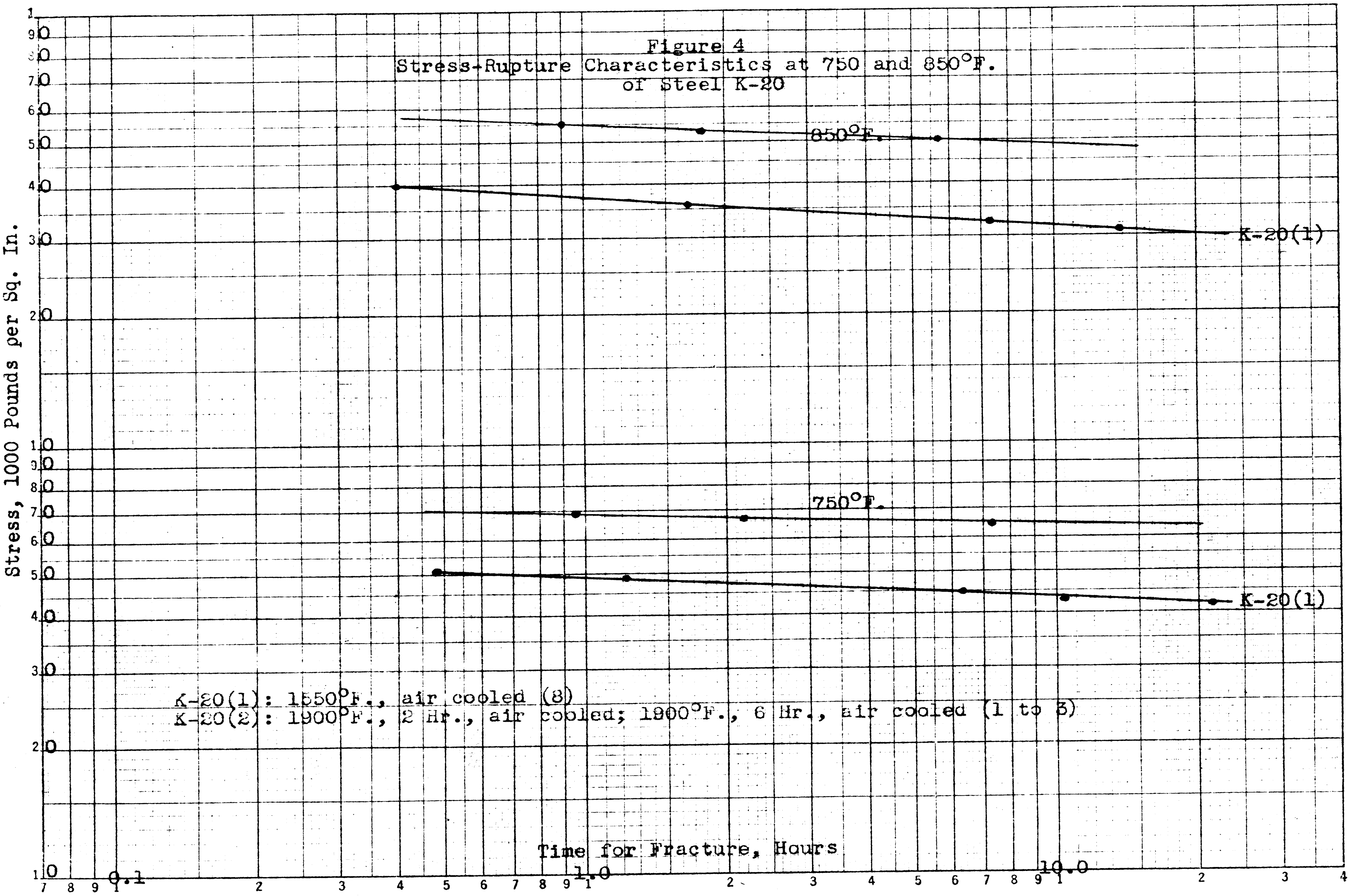


Figure 4
Stress-Rupture Characteristics at 750 and 850°F. of Steel K-20