STATUS
OF
VARIOUS INVESTIGATIONS IN PROGRESS ON MAY 9, 1944
FOR THE
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
AT THE UNIVERSITY OF MICHIGAN

Ten separate programs of research are in progress. A short summary of their status constitutes the following sections:

19-9 DL Gas Turbine Disc

Additional rupture test data at 1200 and 1350°F., obtained since Report Number 8 was issued, are summarized in Table I. The stresses and corresponding rupture time periods are shown in Figure 1, which includes the data previously obtained. Spot tests at various locations in the forging show that the forging has quite uniform rupture strengths.

At the last meeting, the investigation was increased to include the determination of curves of stress versus the logarithm of the time for total deformations of 0.1, 0.2, 0.5, and 1.0 per cent for time periods up to 2000 hours. Curves for stress versus the time for the creep rate to increases 10 per cent over the minimum creep rate (transition point); and a curve for the stress-rupture time data are to be included. Since the last meeting, test materials have been obtained from Mr. Cross, one test completed under a stress of 15,000 psi at 1200°F., and

five tests started. This data has also been included in Table I.

234-A-5 Gas Turbine Disc

Notice has been received of the shipment of a forging 20 inches in diameter by 3-1/4 inches thick by the Crucible Steel Company. The chemical analysis was reported as:

C	Mn	P	S	Si	Ni	Cr	Cb	W	Mo
0.25	4.14	.017	.023	.25	5.76	18.32	.95	~~1.31~~ 1.51	1.46

The Brinell hardness was surveyed and reported to vary from 235 to 255 with most readings at 235 and 241.

The disc is to be subjected to the same investigation as the 19-9 DL disc described in the previous section.

Table I

ADDITIONAL RESULTS FOR 19-9 DL FORGED GAS TURBINE DISC (NR46B)
(Supplementing Report Number 8)

1. Stress-Rupture Results at 1200 and 1350°F.:

Specimen	Temp. °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area, %
		Radial Specimens Center Plane			
18Y	1200	33,500	604.5	9.0	28.8
20Y		33,500	In progress 768 hours (5-9-44)		
		Radial at Surface			
18X		40,000	136.0	24.0	57.0
		Tangential in Center			
5Y		40,000	168.5	28.0	58.6
		Tangential at Surface			
5X		40,000	37.5	30.0	63.2
		Radial at Center			
19Y	1350	17,500	663.5	24.0	38.0
		14,500	In progress 1200 hours (5-9-44)		
		Radial at Surface			
18X		22,500	124.5	28.0	63.2
		Tangential in Center			
5Y		22,500	156.0	31.0	66.2
		Tangential at Surface			
5X		22,500	133.5	26.0	68.0

(Continued)

Table I (Continued)

2. Creep Tests at 1200 and 1350°F.

Temp. °F.	Stress Lb./Sq.In.	Initial Deformation Inches/Inch	Time (Hrs.) for Indicated Deformations 0.1%	0.2%	Creep Rate at 700-1200 Hr. % per 1000 Hr.
1200	15,000	0.00095	Approx. 1	1225	0.025
	20,000	In progress 50 hours (5-9-44)			
	12,500	In progress 50 hours (5-9-44)			
	10,000	In progress 50 hours (5-9-44)			
1350	10,000	In progress 50 hours (5-9-44)			
	7,500	In progress 50 hours (5-9-44)			

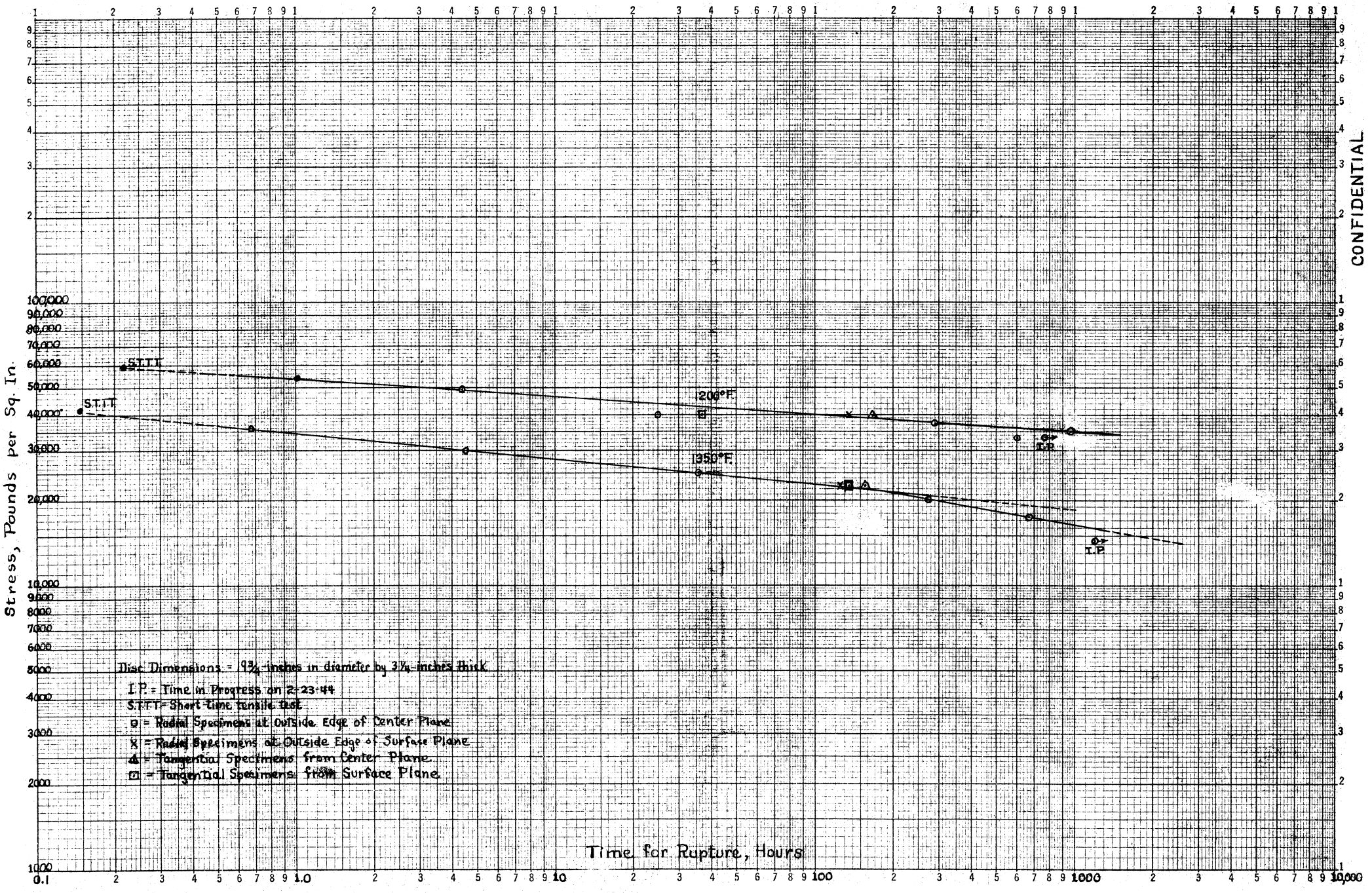

Figure 1. STRESS-RUPTURE TIME CURVES AT 1200 AND 1350°F. FOR FORGED 19-9DL STEEL GAS TURBINE DISC MATERIAL

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Alloys for Service at 1700 and 1800°F.

At the last meeting, this program was initiated by deciding to run rupture tests on five cast alloys and wrought Low Carbon N155 alloy at 1700 and 1800°F. The test materials have been procured and a limited amount of rupture test data have been obtained at 1700°F.

The chemical analyses reported for the test materials are given in Table II. The Vitallium, 422-19, 61, and 6059 alloys were supplied by Mr. Badger. The cast S816 and S590 (modified S497) alloys were prepared by Mr. Browne. Mr. Evans supplied the Low Carbon N155 bar stock. The castings were all "precision" type and are being tested in the as-cast condition. The N155 stock is in the hot-rolled and stress-relieved at 1200°F. condition.

The rupture test data obtained to date and the stress-rupture time relationships are summarized in Table III and Figure 2.

Table II

CHEMICAL ANALYSIS OF CAST ALLOYS AND LOW CARBON N155

Alloy	C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Fe
Vitallium*	.24			28.70	---	Bal.	5.57	---	---	
422-19*	.40		.51	24.75	15.92	Bal.	6.08	---	---	.65
61*	.42			24.07	---	Bal.	---	5.17	---	
6059*	.46			26.17	---	½ Bal.	6.40	---	---	½ Bal.
S816	.41	.42	.56	19.43	19.80	42.81	3.61	3.42	4.48	---
S590	.57	.67	.63	20.11	20.64	20.04	3.63	4.50	4.02	
N155 (Heat A11534)	.15	1.74	.37	21.66	19.40	20.48	2.76	1.90	.79	N .14

*Type analysis only (from Table I, Univ. of Mich. Report 7).

Table III

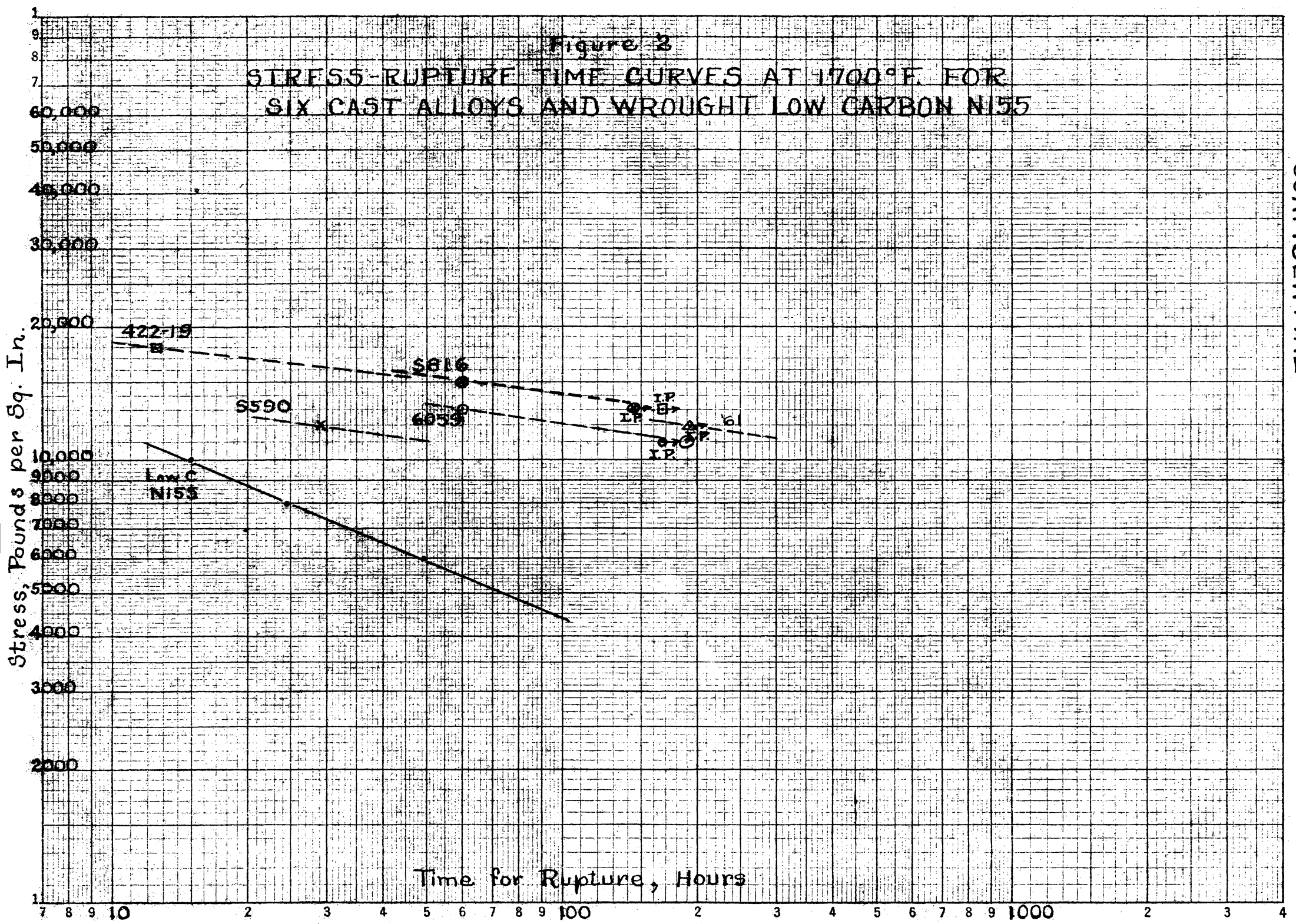
STRESS-RUPTURE TEST DATA AT 1700°F. FOR SIX CAST ALLOYS AND WROUGHT LOW CARBON N155

Material	Treatment	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area %
Vitallium(1)	As cast	No data			
422-19(1)	As cast	18,000	12.5	13.0	29.0
		13,000	In progress 168 hrs. (5-9-44)		
61(1)	As cast	12,000	In progress 192 hrs. (5-9-44)		
6059(1)	As cast	13,000	60.0	20.0	54.3
		11,000	In progress ~~168~~ 190 hrs. (5-9-44)		
S816(2)	As cast	15,000	60.0	7.0	19.0
		13,000	In progress 144 hrs. (5-9-44)		
S590(2)	As cast	12,000	29.0	15.5	39.8
		10,000	In progress 24 hrs. (5-9-44)		
Low Carbon(3) N155	Hot-rolled, 1200°F. stress relief	10,000	15.0	28.5	38.2
		8,000	24.5	31.0	34.7
		6,000	49.5	32.0	37.5

(1) Precision castings, 0.160-inch diameter and one-inch gage length.
(2) Precision castings, 0.250-inch diameter and two-inch gage length.
(3) Machined specimens 0.505-inch diameter and two-inch gage length.

Figure 2

STRESS-RUPTURE TIME CURVES AT 1700°F. FOR SIX CAST ALLOYS AND WROUGHT LOW CARBON N155



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Cast 19-9 DL Steel

The rupture test results obtained to date on cast bars of 19-9 DL steel at 1350°F. are summarized in Table IV, and shown graphically in Figure 3. Room temperature tensile data will be available in the near future.

The 100-hour rupture strengths appear to be the following on the basis of only two completed tests:

Treatment	1350°F. 100-Hour Rupture Strength, Lb./Sq.In.
As Cast + 50 Hr. at 1350°F.	21,000
2250°F. Oil Quenched + 50 Hr. at 1350°F.	23,000

Table IV
1350°F. STRESS-RUPTURE PROPERTIES
OF CAST 19-9 DL STEEL

Specimen	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area, %
NR-46-C-6	25,000	60.0	11.0	34.0
	20,000	250.0	6.0	13.1
	15,000	In progress 888 hours (5-8-44)		
NR-46-C-10	25,000	20.25	22.0	53.8
	20,000	148.0	23.0	62.0
	15,000	In progress 792 hours (5-8-44)		

Tests are being conducted on 0.250-inch diameter specimens of one-inch gage length. The specimens were taken from one-inch diameter cast bars. The following information was supplied by Mr. H. C. Cross of the National Research Council Project 8:

Chemical Analysis:

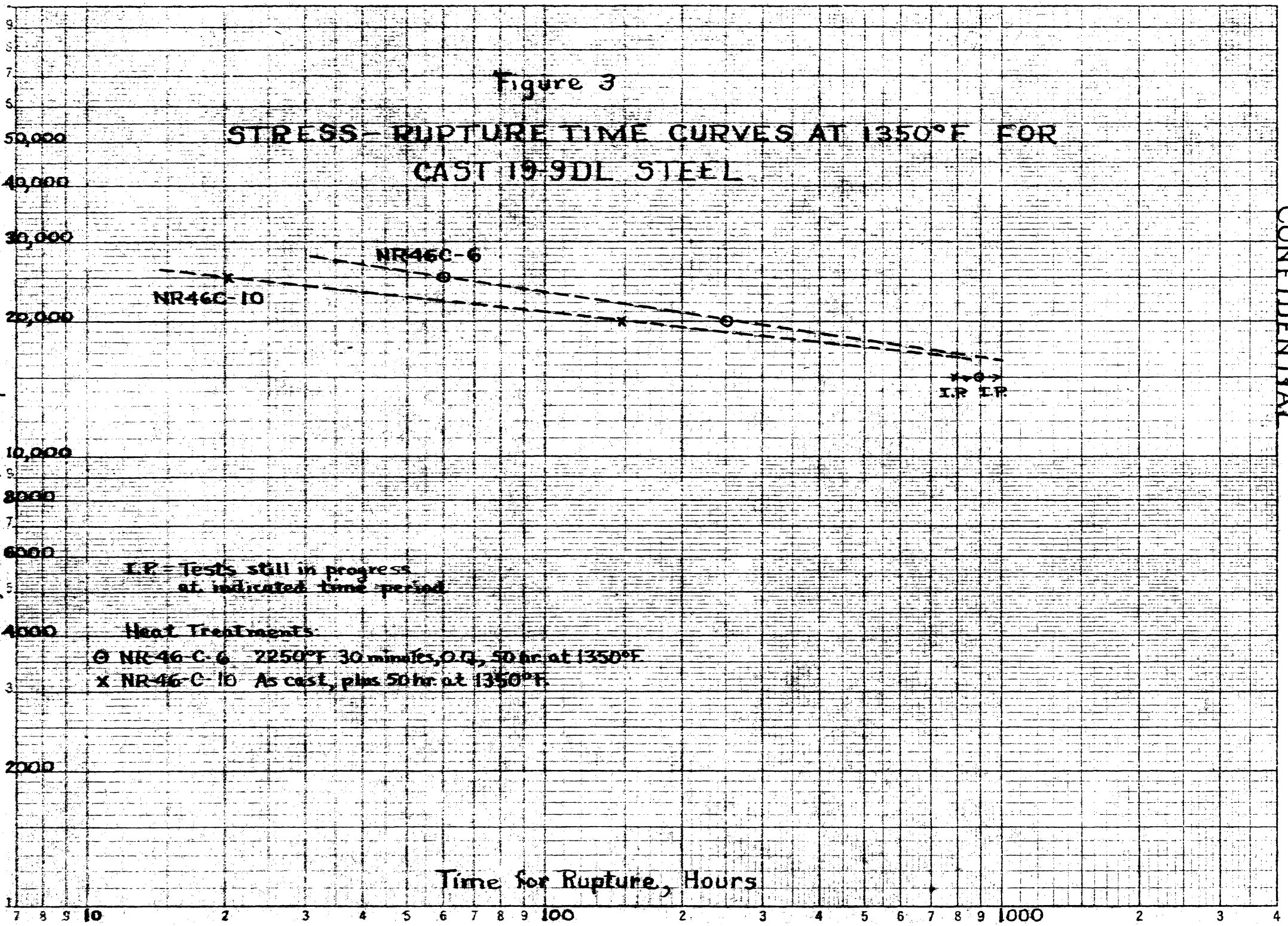
C	Mn	Si	Ni	Cr	Mo	Cb	W	Ti
0.29	0.65	0.79	9.40	18.85	1.33	0.40	1.15	0.16

Heat Treatment:

Specimen	Treatment
NR-46-C-6	2250°F. for 30 minutes, oil quenched, aged 50 hours at 1350°F.
NR-46-C-10	As cast, plus 50 hours at 1350°F.

Figure 3

STRESS-RUPTURE TIME CURVES AT 1350°F FOR CAST 19-9DL STEEL



Design Data for 19-9 DL Steel at 1200 and 1350°F.

At the last meeting it was requested that design data be obtained at 1200 and 1350°F. from tests of 2000 hours duration on 19-9 DL steel bar stock in three representative conditions of treatment. The data was to consist of curves of stress versus the logarithm of time for total deformations of 0.1, 0.2, 0.5 and 1.0 per cent. In addition curves of the time at which the creep rate increased 10 per cent over the minimum rate, and stress-rupture time curves were to be added.

The three conditions selected are:

1. Hot rolled and stress-relieved at 1200°F.
2. Hot rolled and stress-relieved at 1200°F. bar stock hot-cold rolled at 1200°F. to a yield strength (0.02% offset) of 80,000 pounds per square inch.
3. Bar stock solution treated at 2250°F.

The following heats were selected for the testing program:

1. Stock from Heat N-163 will be used at 1200°F. for the hot-rolled condition. This material was selected because nearly complete data will be supplied by Universal-Cyclops and very little additional testing will be required. Considerable data has been accumulated on this heat and reported to the NACA.
2. All other bar stock will be from Heat B10429. This is the same heat as that from which the gas turbine forging was obtained. Also two halves of Type "B" turbosupercharger wheel blanks were supplied from this same heat(1). These blanks were made by the standard practice of the Steel Improvement and Forge Company. One was cold worked without a solution treatment and the other was solution treated at 2100°F. prior to hot-cold working.

(1) The test material requested some time ago in response to Mr. J. B. Johnson's request for 2000 hour rupture tests on cold worked 19-9 DL steel.

The completion of this program should yield design data on laboratory bar stock which can be compared with actual finished commercial product properties on material from the same heat. Thus not only will good design data result, but the relation between laboratory results on bar stock and commercial product properties for all new alloys should be better defined.

Complete investigation of the turbosupercharger wheels is not planned nor is it possible with the amount of test stock available. A few spot tests will be run for comparison.

The Effects of Heat Treatment and Hot-Cold Work on the Properties of Five Alloys.

Additional data, supplementing Report Number 9, have been obtained. Table V summarizes the 1200°F. rupture test results which have been obtained in addition to those given in Report 9.

Samples have been prepared with various amounts of hot-cold work at 1200°F., with hot-cold work at various temperatures, and with various aging treatments after rolling at 1200°F. The schedule of treatments is outlined in Table VI. To date the only tests on these samples have been room temperature tests on 19-9 DL steel, the results of which are given in Table VII.

The amount of work now in progress for other programs will not permit additional work on this program for some time, except for room temperature tensile tests.

Table V
Additional Rupture Test Data at 1200°F.

Material	Heat Treatment					Hot-Cold Work		Stress-Rupture Properties			
	Solution Temp. (°F.)	Solution Time (Hours)	Method of Cooling	Ageing Temp. (°F.)	Ageing Time (Hrs.)	Temp. (°F.)	Per Cent Reduction	Stress Lb./Sq.In.	Time Hours	Elongation % in 1 In.	Reduction of Area %
16-25-6	2200	1	Cool to	1400	24	----	none	35,000	621.0	13.5	40.0
16-25-6	2050	2	W.Q.	none	--	----	none	47,000	24.0	5.0	10.0
								45,000	138.0	18.0	24.5
								43,000	160.0	15.0	28.8
								38.000	406.5	15.0	33.0
16-25-6	2050	2	Cool to	1400	24	1200	10	37,000	355.0	5.0	2.3
234-A-5	2200	1	Cool to	1100	24	----	none	40,000	459.0	4.0	6.2
234-A-5	2200	1	Cool to	1400	24	1200	10	35,000	550.5	2.0	0
234-A-5	2050	2	Cool to	1400	24	1200	10	37,000	436.0	15.0	35.0
234-A-5	2050	2	W.Q.	none	--	----	none	48,000	89.0	12.0	7.0
								43,000	285.0	15.0	15.6
								40,000	492.0	7.1	10.9
234-A-5	2050	2	Cool to	1100	24	----	none	33,000	311.0	34.0	56.9
19-9 DL	2200	1	W.Q.	1100	24	----	none	35,000	612.0	6.0	9.7
19-9 DL	2200	1	Cool to	1100	24	----	none	37,000	348.0	8.0	18.9
19-9 DL	2050	2	W.Q.	none	--	----	none	45,000	36.0	8.0	14.4
								43,000	144.0	12.0	26.7
								40,000	320.0	8.0	22.3
19-9 DL	2050	2	W.Q.	none	--	1200	10	47,000	983.0	4.0	20.0
19-9 DL	2050	2	W.Q.	1400	24	1200	20	43,000	246.0	10.0	27.7
N-153	2050	2	Cool to	1400	24	1200	10	42,000	675.0	2.0	2.0

Table VI
HEAT TREATING AND ROLLING PROGRAM IN PROGRESS ON
TIMKEN ALLOY (16-25-6), 234-A-5, AND 19-9 DL ALLOYS
(Supplementing Report Number 9)

1. Effect of per cent reductions on 2050°F. solution treated material:

    a. 5% reduction at 1200°F.
    b. 20% reduction at 1200°F.

2. Effect of temperature of rolling on 2050°F. solution treated material:

    a. 10% reduction at 1300°F.
    b. 10% reduction at 1400°F.
    c. 10% reduction at 1500°F.
    d. 10% reduction at 1600°F.

3. Effect of aging temperature, after rolling 10% at 1200°F., on 2050°F. solution treated material:

    a. Age 24 hours at 1200°F.
    b. Age 24 hours at 1300°F.
    c. Age 24 hours at 1400°F.

Table VII
Room Temperature Tensile Properties of 19-9 DL Alloy (Heat No. A-10753) with Indicated Treatments

Heat Treatment					Hot-Cold Work			Room Temperature Tensile Properties					
Solution Temp. (°F.)	Solution Time (Hours)	Method of Cooling	Ageing Temp. (°F.)	Ageing Time (Hrs.)	Temp. (°F.)	% Reduction	Brinell Hardness	Tensile Strength Lb./Sq.In.	Proportional Limit Lb./Sq.In.	Yield Stresses 0.02% Offset	Yield Stresses 0.2% Offset	Elongation, % in 2 In.	Reduction of Area, %
2050	1	W.Q.	----	----	1200	5 (5.10)	238	111,500	37,500	65,000	81,000	41.5	58.3
2050	1	W.Q.	----	----	1200	20 (19.5)	299	131,800	45,000	77,500	104,500	30.0	53.3
2050	1	W.Q.	----	----	1300	10 (9.95)	261	119,200	62,500	73,000	91,500	37.0	54.7
2050	1	W.Q.	----	----	1400	10 (10.85)	247	115,350	47,500	63,000	82,000	37.0	53.6
2050	1	W.Q.	----	----	1500	10 (11.70)	230	113,500	40,000	57,500	74,000	39.0	53.6
2050	1	W.Q.	----	----	1600	10 (10.60)	236	109,750	37,500	50,500	67,000	38.5	52.7
2050	1	W.Q.	1200	24 after rolling	1200	10 (9.15)	287	125,600	52,500	71,000	91,500	32.5	51.6
2050	1	W.Q.	1300	24 after rolling	1200	10 (9.30)	269	122,550	40,000	58,000	81,000	31.5	53.6
2050	1	W.Q.	1400	24 after rolling	1200	10 (9.15)	264	118,900	42,500	59,000	75,000	32.0	52.5

Modified 16-25-6 and Modified 17W (General Electric Company)

Rupture tests are in progress at 1200°F. on two alloys which have not been previously investigated. The test materials were supplied by Mr. Badger of the General Electric Company. The information concerning the composition, fabrication, and properties reported for the specimens is given in Table VIII. The rupture test data obtained to date are included as Table IX and the rupture strength curves are shown as Figure 4.

Table VIII
INFORMATION ON M16-25-6, M17W(NCW) AND M17W(CW) SUPPLIED BY GENERAL ELECTRIC COMPANY

1. Chemical Analysis:

Alloy	C	Si	Mn	P	S	Cr	Ni	Mo	W	Cb
Modified 16-25-6	.10	.28	1.70	.017	.018	16.92	24.79	3.12	5.02	---
Modified 17W	.25	.68	.73	---	---	13.25	19.29	1.90	2.17	.54

2. Manufacturing Procedure:

Modified Timken Alloy (16-25-6) - Heat No. 01658

Wheel No. A-714. Material was forged at 2100°F. Solution treated 1/2 hour at 2100°F. and air cooled. Cold worked 12½ percent at 1200°F. Annealed 4 hours at 1200°F. and air cooled. Test bars were cut from wheel blank radially near rim.

Modified 17W (No cold work) - Crucible Steel Co. - Heat No. 4639

Forged as test bars at 2100°F. Solution treated 1 hour at 2100°F., air cooled. Annealed 2 hours at 1200°F., air cooled.

Modified 17W (Cold work) - Crucible Steel Co. - Heat No. 4639

Forged as test bars at 2100°F. Solution treated 1 hour at 2100°F. and air cooled. Cold worked 12½ percent at 1200°F. Annealed 2 hours at 1200°F. and air cooled.

3. Physical Properties (from General Electric Co.):

Specimen	Test Temp.°F.	Tensile Strength Lb./Sq.In.	Yield Strength Lb./Sq.In.	Elongation, Per Cent	Reduction of Area %
M-16-25-6 (Radial at rim)	Room	127,200	87,000	24	45
M16-25-6 (Radial at center)	Room	127,200	88,200	15	16
	1200	86,940		13	23

(continued)

Table VIII (Continued)

Specimen	Test Temp. °F.	Tensile Strength Lb./Sq.In.	Yield Strength Lb./Sq.In.	Elongation %	Reduction of Area, %
M-17W(NCW)	Room	106,000	37,000	46	63
	1200	79,500		27	30
	1500	49,500		20	21
M-17W(CW) (10% Cold Work)	Room	148,000	108,500	21	51
	1200	103,000		9	27
	1500	63,400		7	18
M-17W(CW) (15% Cold Work)	Room	149,000	109,000	22	51
	1200	102,300		12	24
	1500	61,600		8	17

Table IX
1200°F. STRESS-RUPTURE PROPERTIES OF MODIFIED TIMKEN ALLOY (16-25-6), MODIFIED 17W, AND COLD-WORKED MODIFIED 17W

Specimen	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area, %
M-16-25-6	50,000	75.0	3.0	1.2
	45,000	256.0	2.0	1.2
	42,000	In progress 648 hours (5-8-44)		
M-17W (N.C.W.)	45,000	7.0	6.0	10.9
	40,000	16.5	7.0	9.7
	35,000	59.0	5.0	10.3*
	30,000	276.0	3.0	6.6*
M-17W (C.W.)	50,000	4.0	8.0	6.2
	35,000	43.0	2.0	5.2*
	30,000	145.5	1.0	6.6*

*0.150-inch diameter specimens. All other specimens were 0.160-inch diameter, 1 inch gage length.

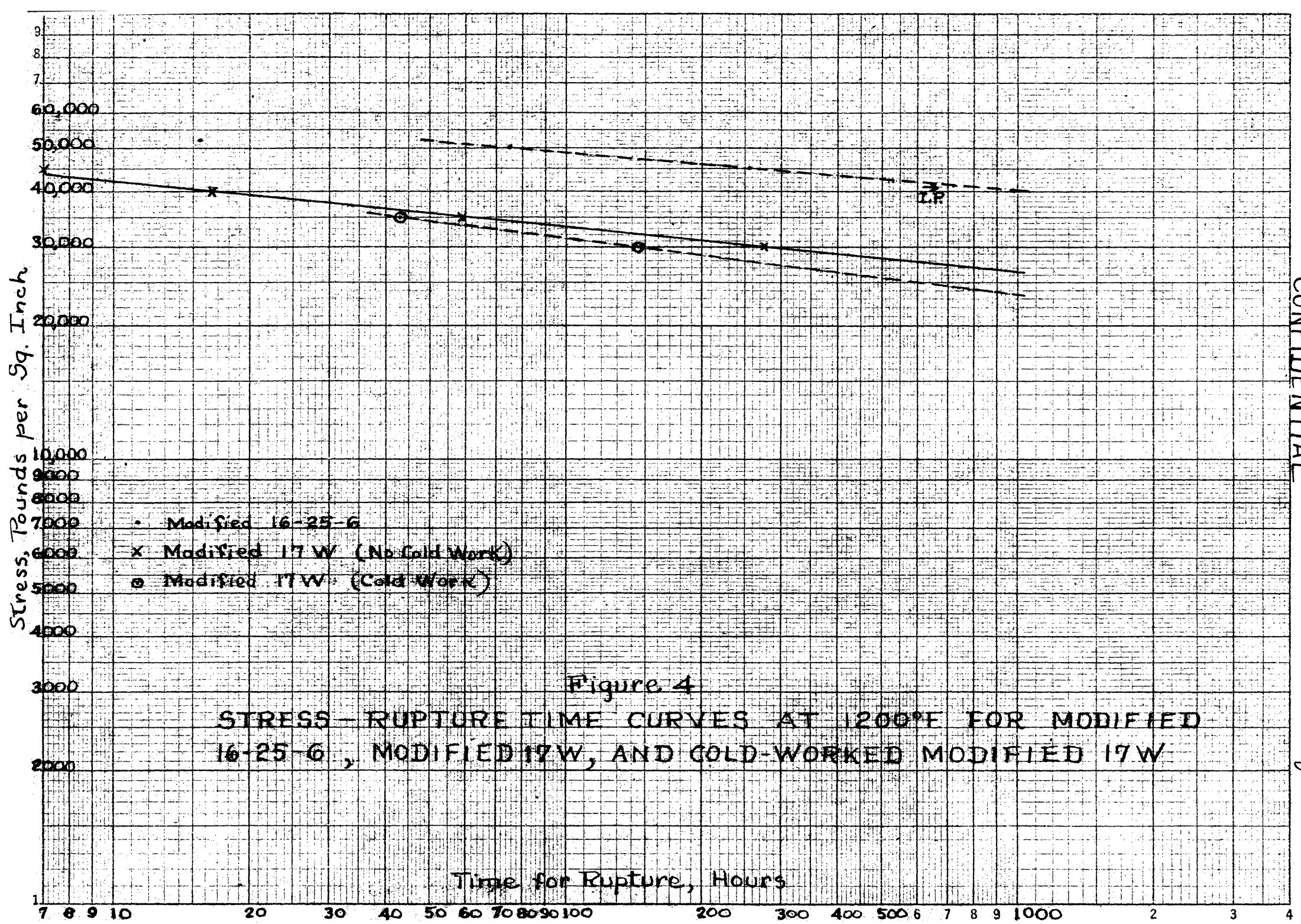


Figure 4

STRESS – RUPTURE TIME CURVES AT 1200°F FOR MODIFIED 16-25-6, MODIFIED 17W, AND COLD-WORKED MODIFIED 17W

CONFIDENTIAL

22

Manganese-Chromium-Cobalt Alloys (Crucible Steel Company)

Test materials were submitted by Mr. Bergen for two new alloys. The analyses and fabrication procedures are given in Table X. Two rupture tests are in progress at 1200°F.

Modified S497 (S590 and S816) Alloys (Allegheny Ludlum Steel Corp.)

Mr. Browne submitted bar stock from induction heats of a high chromium and a high chromium + high cobalt modification of S497 alloy. The description of these materials together with rupture test data obtained by the University of Michigan and by Allegheny Ludlum at 1350°F. are given in Table XI.

The S590 stock for the University of Michigan tests was solution treated by Allegheny Ludlum and aged at Michigan. The S816 stock was both solution treated and aged at Michigan. It was found that 2350°F. was very near the "burning" temperature for S816.

Reference to Table XI and Figure 5 shows that duplicate results were obtained by the two laboratories on S590. The University of Michigan results on S816 were very similar but slightly higher in strength and ductility.

Bar stock from larger heats of both alloys have been submitted, but their investigation has not been authorized.

Table X
RUPTURE TESTS ON CRUCIBLE ALLOYS C-4817 AND C-4818

Chemical Analysis:

Alloy	C	Mn	Si	Ni	Cr	Mo	Cb	W	Co
C-4817	0.32	4.57	0.35	5.94	18.14	1.46	0.67	1.52	12.44
C-4818	0.68	12.77	0.50	----	18.11	1.95	0.28	1.64	12.32

Manufacturing Procedure:

Melted in 30 pound induction furnace. Forged to 7/8 inch square. Initial forging temperature 1950-2000°F., finishing temperature about 1200°F. Stress-relieved one hour at 1200°F.

Rupture Tests in Progress at 1200°F.:

Specimen	Stress Lb./Sq.In.	
C-4817	48,000	In progress 200 hours (5-8-44)
C-4818	50,000	Test starting (5-8-44)

Table XI
1350°F. STRESS-RUPTURE PROPERTIES OF ALLEGHENY LUDLUM ALLOYS S590 AND S816

Tests were run on 0.250" diameter, 1" gage length specimens. Specimens were machined from bars made from 17 pound ingots, which were forged to 1-inch square and rolled to 1/2-inch round. Temperature of hot working was 2200°F. for S590 and 2250°F. for S816. Chemical analysis supplied by Allegheny Ludlum:

	C	Cr	Si	Mn	Ni	Mo	W	Cb	Co	Fe
S590	.49	19.50	.21	.60	19.78	3.95	4.15	4.04	19.35	Bal.
[illegible]	[illegible]	[illegible]	[illegible]	.58	20.23	3.93	3.45	4.06	43.70	2.95

University of Michigan Rupture Test Data at 1350°F.

Specimen and Treatment	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 Hr.	Reduction of Area,%
S590 (1 hr. 2300°F. W.Q. 16 hr. 1400°F.)	30,000	142.0	5.0	13.0
	27,000	355.0	15.0	21.8
S816 (1 hr. 2350°F. W.Q. 16 hr. 1400°F.)	40,000	182.0	14.0	13.1
	37,000	307.0	11.0	15.4

Rupture Test Data Supplied by Allegheny Ludlum Corporation

S590	35,000	35.0	21.0	20.0
	30,000	131.0	19.0	24.0
	25,000	658.0	13.0	20.0
	20,000	1350.0 plus		
S816	50,000	28.0	17.0	15.0
	45,000	57.0	14.0	10.0
	40,000	128.0	6.0	5.0
	35,000	373.0	8.0	9.0
	30,000	1031.0	6.0	6.0

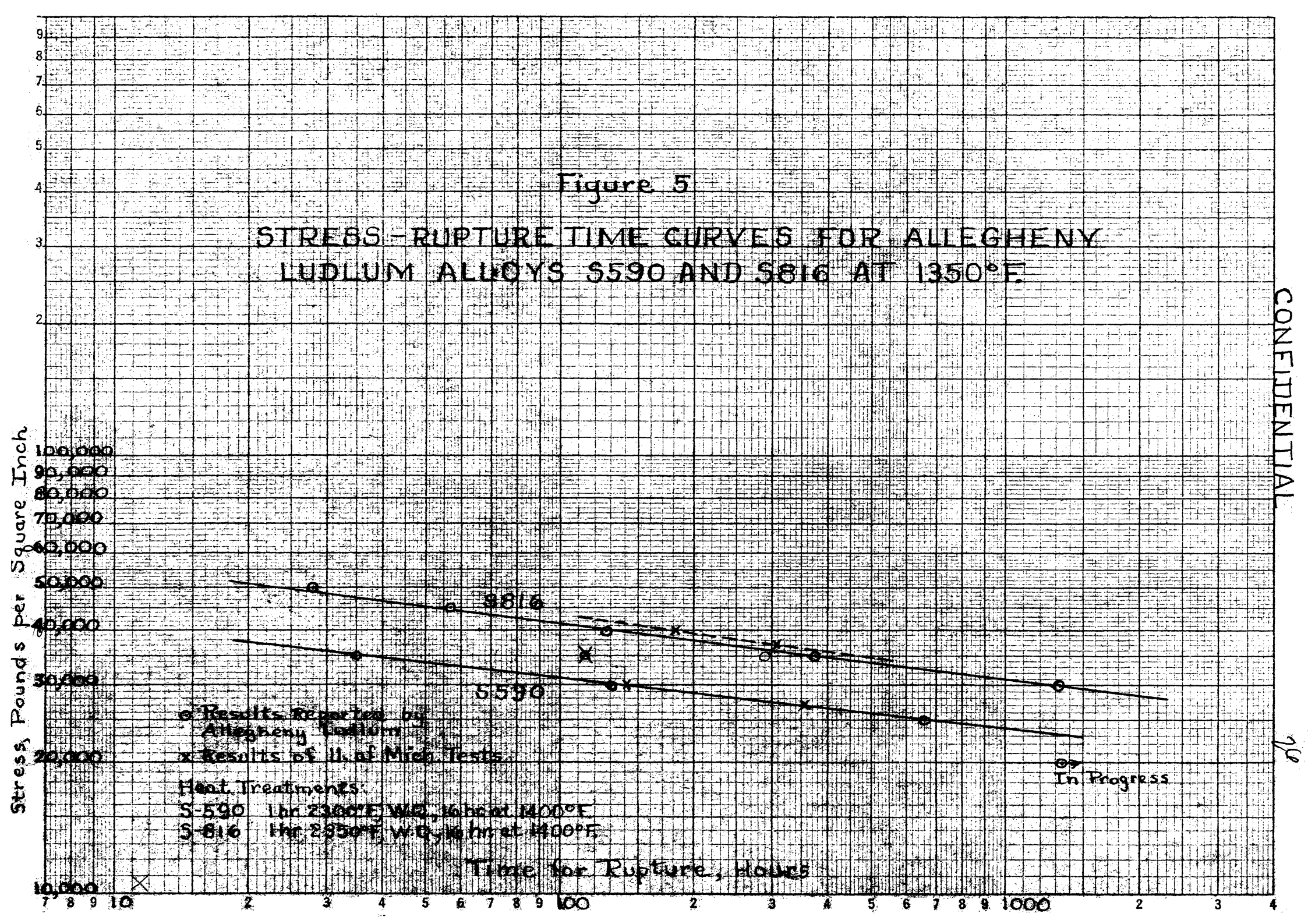


Figure 5
STRESS-RUPTURE TIME CURVES FOR ALLEGHENY LUDLUM ALLOYS S590 AND S816 AT 1350°F.
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Stress, Pounds per Square Inch
100,000
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
S816
S590
o Results Reported by Allegheny Ludlum
x Results of U. of Mich. Tests
In Progress
Heat Treatments:
S-590 1 hr 2300°F, W.Q., 16 hr at 1400°F
S-816 1 hr 2250°F, W.Q., 16 hr at 1400°F
Time for Rupture, Hours
7 8 9 10 2 3 4 5 6 7 8 9 100 2 3 4 5 6 7 8 9 1000 2 3 4
20

Modified 19-9 DL, N155 and Low Carbon N155 Alloys (Universal-Cyclops Steel Corporation).

Bar stock from five induction heats representing new chemical analysis modifications of 19-9 DL steel, two modifications of N155 steel and two for Low Carbon N155 were submitted by Mr. Evans. Control heats of the standard analyses were also included. These heats are described in Table XII together with the room temperature physical properties reported by Mr. Evans.

The 1200°F. rupture test data obtained to date is presented in Table XIII and shown graphically in Figure 6.

Table XII

INFORMATION SUPPLIED BY THE UNIVERSAL-CYCLOPS STEEL CORPORATION ON MODIFIED 19-9 DL AND MODIFIED N155 ALLOYS

1. Manufacturing Procedure:

Heat Number	Grade	Finishing Temp. °F.	Brinell Hardness
R-3157	19-9 DL	1700	277
R-3188	19-9 DL + 10% Co	1675	286
R-3233	19-9 DL + 20% Co	1675	286
R-3232	19-9 DL + 1% Cb (0% Ti)	1700	277
R-3190	Low Carbon 19-9 DL + N	1700	277
R-3234	19-9 DL + N	1675	302
R-3235	High carbon N155	1600	321
R-3236	High carbon N155 + .50 Ti	1575	302
R-3237	High carbon N155 + 1.00 Ti	1600	302
R-3268	Low carbon N155	1600	321
R-3271	Low carbon N155 + .50 Ti	1575	321
R-3272	Low carbon N155 + 1.00 Ti	1600	302

Notes: All bars were hammer forged from 33 lb. induction ingots.
All the 19-9 DL heats were worked at the same time and all the N155 heats were worked at the same time.
All bars were stress-relieved at 1200°F. for 1 hour and air cooled.

Table XII (Continued)

2. Chemical Analysis

	R3157	R3188	R3233	R3232	R3190	R3234	R3235	R3236	R3237	R3268	R3271	R3272
C	.31*	.30*	.29*	.29*	.22*	.35*	.30*	.28*	.29*	.13*	.14*	.14*
Mn	.71*	.81*	1.00	1.00	.81*	1.00	1.47*	1.56*	1.49*	1.37*	1.53*	1.52*
Si	.49*	.52*	.55	.55	.46*	.55	.48*	.55*	.57*	.44*	.49*	.72*
Cr	18.46*	18.95*	19.00	19.00	18.10*	19.00	22.46*	22.88*	23.14*	22.80*	23.06*	23.30*
Ni	9.40*	9.24*	9.00	9.00	9.16*	9.00	20.29*	19.87*	20.37*	18.70*	18.77*	18.09*
Co	----	9.76*	20.00	----	----	----	20.00	20.00	20.00	20.00	20.00	20.00
W	1.00*	1.25	1.25	1.25	1.25	1.25	2.00	2.00	2.00	2.00	2.00	2.00
Mo	1.12*	1.29*	1.25	1.25	1.25	1.25	3.00	3.00	3.00	3.00	3.00	3.00
Cb	.20*	.30	.30	1.00	.30	.30	1.00	1.00	1.00	1.00	1.00	1.00
Ti	.29*	.34*	.25	----	.25	.25	----	.50	1.00	----	.50	1.00
N	----	----	----	----	.16*	.15	.20*	.12*	.22*	.13*	.18*	.12*
S	.025*		.027*									
P	.022*											

*Actual analysis. All other values are type analysis.

Table XII (Continued)

3. Room Temperature Physical Properties

Heat No.	Proof Stress	Yield Stress Lb./Sq.In. 0.2% Offset	Ultimate Tensile Strength, Psi	Elongation, % in 2 In.	Reduction of Area, %
R-3157	65,000	95,000	125,000	30.5	40.1
R-3188	65,500	92,000	130,000	27.0	41.0
R-3233	76,000	98,500	135,500	27.5	34.4
R-3232	76,000	95,500	127,000	27.5	44.6
R-3190	82,500	106,500	131,500	23.0	29.5
R-3234	69,500	105,000	128,000	22.0	45.5
R-3235	86,500	117,500	158,000	19.0	31.5
R-3236	84,000	105,000	141,000	22.0	34.7
R-3237	70,000*	108,000	139,000	12.5	17.0
R-3268	116,000	134,000	161,500	23.5	35.4
R-3271	107,000	123,500	155,000	24.5	43.7
R-3272	106,000	123,500	153,500	24.0	45.2

*Sample showed surface seam at fracture.

Table XIII

STRESS-RUPTURE TEST RESULTS AT 1200°F. FOR MODIFIED 19-9 DL AND MODIFIED N155 ALLOYS

Heat No.	Grade	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area %
R-3157	19-9 DL	45,000	20.0	31.0	64.0
		40,000	143.0	25.0	64.0
		37,500	175.0	24.0	68.4
R-3188	19-9 DL + 10% Co	45,000	58.0	23.0	56.9
		42,000	42.0	12.0	61.7
		40,000	In progress 48 hours (5-8-44)		
R-3233	19-9 DL + 20% Co	50,000	8.0	38.0	57.8
		45,000	235.0	12.0	20.0
R-3232	19-9 DL + 1% Cb (0% Ti)	50,000	66.0	15.0	56.1
		45,000	265.0	13.0	45.6
R-3190	Low C 19-9 DL + N	47,140	164.0	10.0	26.7
		45,000	459.5	13.0	22.3
R-3234	19-9 DL + N	50,000	110.0	16.0	26.7
		45,000	281.0	14.0	26.7
R-3235	High carbon N155	45,000	In progress 144 hours (5-8-44)		
		40,000	578.0	9.0	13.1
R-3236	High carbon N155 + .50 Ti	45,000	285.5	20.0	42.7
R-3237	High carbon N155 + 1.00 Ti				
R-3268	Low carbon N155				
R-3271	Low carbon N155 + .50 Ti	45,000	In progress 264 hours (5-8-44)		
R-3272	Low carbon N155 + 1.00 Ti				

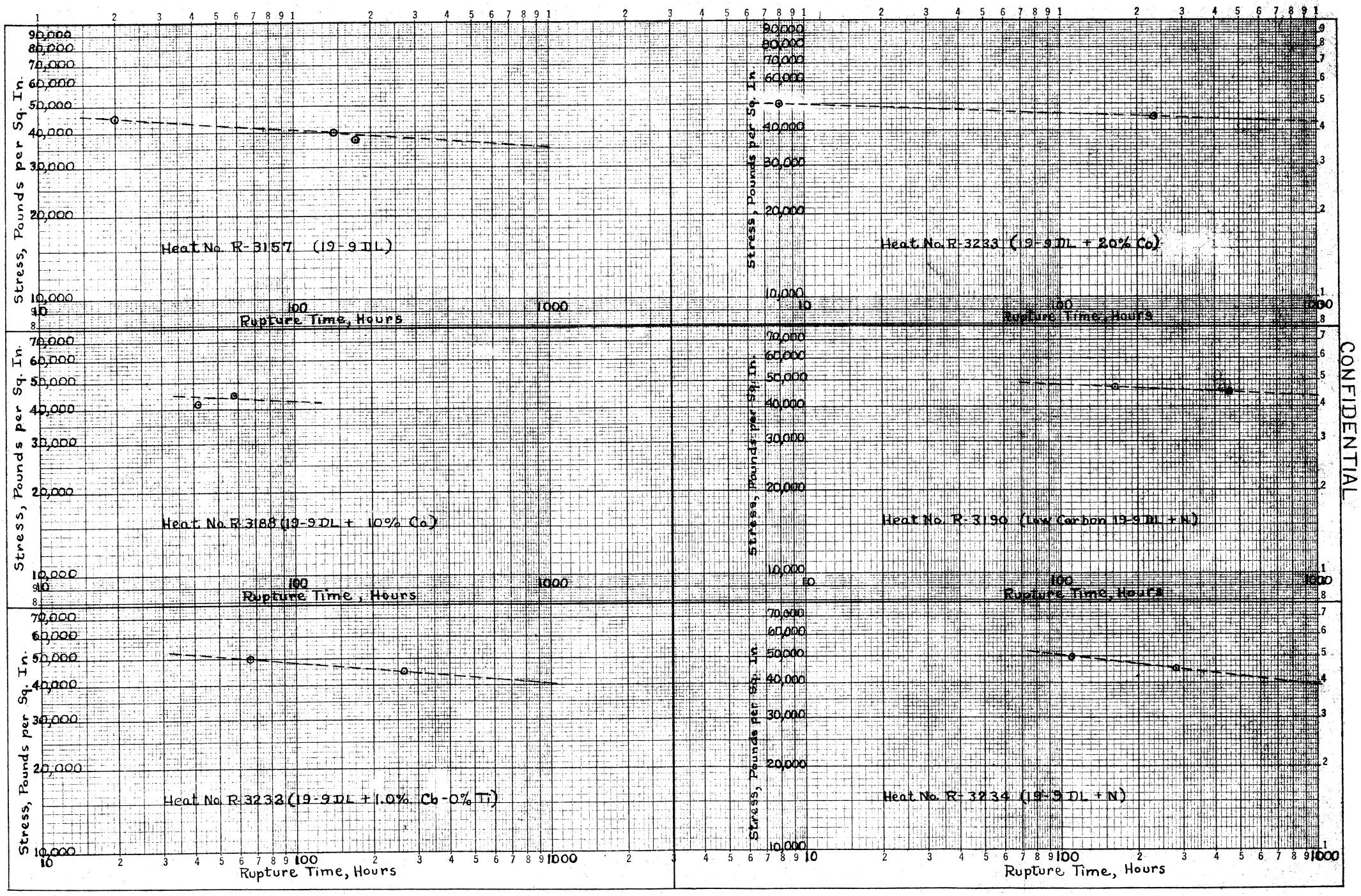

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Figure 6. STRESS - RUPTURE TIME CURVES AT 1200°F FOR 19-9DL AND MODIFICATIONS OF 19-9 DL