UNIVERSITY OF MICHIGAN

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STATUS

OF

VARIOUS INVESTIGATIONS IN PROGRESS AT THE UNIVERSITY OF MICHIGAN FOR THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

November 10, 1944

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Project Number M478-A
November 10, 1944

TABLE OF CONTENTS

STATUS OF VARIOUS INVESTIGATIONS IN PROGRESS AT THE UNIVERSITY OF MICHIGAN FOR THE NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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A. Large Disc Forgings of 19-9 DL, 234-A-5, Low Carbon N155 and Discaloy

Rupture test characteristics and time-deformation curves are being determined at 1200 and 1350°F. for several large disc forgings. A considerable portion of the data have been obtained on one forging of each type, as summarized in Tables I through VII and Figures 1 through 5. In addition to these forged discs a limited investigation has been started on several Low Carbon N155 discs from the Crucible Steel Company described in Table IA. The purpose of checking these Low Carbon N155 discs is to obtain an indication of the probable variation between heats and between sources, as well as to study the effects of heat treatments.

The investigation of the 19-9 DL disc is nearly complete and considerable data are available for the Low Carbon N155 and 234-A-5 discs. Further work on the Discalloy disc has been held up pending information from Westinghouse concerning this alloy. As decided at the September 21, 1944 meeting of the Special Subcommittee no further work will be undertaken at 1350°F. on 19-9 DL and 234-A-5 alloys beyond the completion of the tests then in progress.

The properties of the four discs which have been investigated are compared as follows:

1. Tensile Properties

Discaloy has outstanding tensile strengths at room temperature and 1200°F.; Low Carbon N155 is intermediate, and 19-9 DL and 234-A-5 are quite similar.

2. Rupture Test Properties

Low Carbon N155 has the highest strengths at both 1200 and 1350°F. Discaloy has high strength at 1200°F. particularly at the shorter time periods, but has very low elongation and reduction to fracture. The strength of 19-9 DL is somewhat higher than 234-A-5.

3. Time-Deformation Characteristics

The data for 19-9 DL are nearly complete, but only partial values are available for 234-A-5 and Low Carbon N155. The Low Carbon N155 is superior to the other two alloys in this test. The results on 234-A-5 indicate that it will also be similar to 19-9 DL in this test. No tests of this nature have yet been started on Discaloy.

Figure 3 shows that 19-9 DL in this form cannot carry high loads at 1350°F. when the permissible deformation is limited. The transition curve shows that third stage creep is encountered in less than 2000 hours under a stress of only 5000 pounds per square inch.

<u>Note</u>: Three of the creep tests on 19-9 DL and the two tests on Low Carbon N155 at 1350°F. were reported by Mr. H. C. Cross from NRC - Project 8 data.

4. Source of Materials

19-9 DL Disc - Heat B-10429, Universal Cyclops Steel Corporation. Supplied to University of Michigan by NRC Project 8 under specimen designation NR46-B.

234-A-5 Disc - Induction Heat 1X2218, Crucible Steel Company of America.

Low Carbon N155 Disc	- Universal Cyclops Steel Corporation. Supplied to University of Michigan by NRC Project 8 under specimen designation NR-66D.
Discaloy Disc	- Westinghouse alloy. Supplied to University of Michigan by NRC Project 8 under specimen designation NR-78.
Low Carbon N155 Disc	- Crucible Steel Company of America. Supplied to University of Michigan by NRC Project 8 under specimen designation NR-66E.

Table I

CHEMICAL COMPOSITION AND PROCESSING PROCEDURES FOR FOUR FORGED DISCS

Chemical Composition

Alloy	C	Mn	Si	Cr	Ni	Co	Mo	W	Ti	Cb	N_2	S	P	Al
19-9 DL	.33	1.44	.65	19.10	9.05	-----	1.35	1.14	0.16	0.35	---	.015	.016	--
234-A-5	.25	4.14	.25	18.32	5.76	-----	1.46	1.51	----	.95	---	.023	.017	--
Low Carbon N155	.15	1.74	.37	21.66	19.40	19.02	2.76	1.90	----	.79	.14	.021	.018	--
Discaloy	.10	----	---	13	25	-----	----	----	2.25	----	---	----	----	.6

Processing Procedures

19-9 DL — The disc was made from a billet from 10,000 pound arc furnace Heat No. B10429 by the Universal Cyclops Steel Corporation. The billet was directly up-set to produce the disc and finished at 1640°F. to 19-3/4-inches in diameter by 3-1/4-inches in thickness. The finished disc was stress relieved two hours at 1200°F.

234-A-5 — Induction Heat No. 1X2218 by Crucible Steel Company of America. Forged to 20-1/8-inches in diameter by 3-5/16-inches thick. Finishing temperature, 1400°F. Stress relieved four hours at 1200°F.

Low Carbon N155 — Forged to 20-inches in diameter by 3-1/4-inches thick. Finishing temperature, 1630°F. Stress relieved two hours at 1200°F.

Discaloy — Forged to approximately 20-inches diameter by 3-1/4-inches thick. Disc solution heat treated at 1950°F. for one hour and air cooled by air blasts directed at the center of each face. Bars cut from disc were aged 20 hours at 1350°F.

Table IA

Description of Low Carbon N155 Discs from the Crucible Steel Company

1. 14-3/4-inch x 4-3/8-inch discs were made from Crucible Heat Number 1X2232 which was reported to have the following analysis:

C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	N	P	S
.07	1.68	.60	20.80	20.60	20.07	2.94	2.67	1.05	.125	.015	.012

2. Three discs were forged and each was cut in half for final treatment to provide the following representative conditions:

<u>As Forged</u>: One-half of disc No. 1.

<u>As Forged + Aged at 1500°F</u>: One-half of disc No. 1 was heated from the as-forged condition to 1500°F., held 24 hours and then air cooled.

<u>Solution Treated + Aged at 1500°F.</u>: Disc No. 2 was heated to 2200°F. and quenched in water. One-half was reheated to 1500°F. and held for 24 hours and then air cooled.

<u>Solution Treated + Aged at 1350°F.</u>: The other half of disc No. 2 after water quenching from 2200°F. was reheated at 1350°F. for 24 hours and air cooled.

<u>"Hot-Cold" Worked + Aged at 1500°F.</u>: Disc No. 3 was left about 1/8-inch oversize in the upsetting operation. It was then heated to 2250°F. and water quenched, reheated to 1500°F., held 3 hours and then reduced under the hammer approximately 1/8-inch in thickness (approximately 3% reduction), the finishing temperature being about 1200°F. It was finally "stress-relieved" for 24 hours at 1500°F.

3. <u>Manufacturing Procedure</u>: The discs were made from a one-ton induction heat. One ingot was cast 15-inches square by 2200 pounds. This ingot was heated to 2100-2150°F. and cogged on a 7-ton hammer to a 9-inch square billet. Four reductions and three reheatings were required for this operation. The billet was ground, pickled, chipped and cut into slugs weighing 225 pounds.

   The slugs were reheated to 2100-2150°F. and upset to discs 14-3/4-inches in diameter x 4-3/8-inches thick on a 2800 pound hammer, the finishing temperature being approximately 1500°F.

Table IX

COMPARATIVE TENSILE PROPERTIES FOR FOUR FORGED DISCS

(Radial Specimens from 20" Diameter x 3¼" Thick Discs)

Alloy	Temp. °F.	Tensile Strength Lb./Sq.In.	Offset Yield Stress Lb./Sq.In. 0.02%	0.1%	0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %	Brinell Hardness
19-9 DL	Room	103,250	40,600	50,500	55,000	29,000	25.0	23.7	202
		103,500	39,500	50,000	55,000	24,000	25.5	25.6	208
234-A-5 As Forged Heat 1X2218	Room	108,800	37,500	53,000	59,000	22,500	33.0	33.8	209
		106,900	37,500	50,500	56,000	22,500	35.5	40.7	204
Low Carbon N155 As Forged NR66D	Room	117,600	58,000	67,000	71,500	47,500	30.0	48.1	211
		119,500	58,000	69,000	73,500	45,000	32.0	52.2	211
Discalloy*	Room	157,750	76,000	98,000	104,000	50,000	23.0	26.1	291
		157,750	77,000	97,000	103,000	47,500	22.0	25.8	---
19-9 DL	1200	57,875		35,400	37,900	20,000	34.0	47.5	---
234-A-5 As Forged Heat 1X2218	1200	51,000		38,000	40,500	15,000	27.0	53.2	---
		52,750		37,000	39,000	17,500	27.5	45.8	---
Low Carbon N155 As Forged NR66D	1200	83,000		48,000	50,000	27,500	17.0	33.8	---
		83,000		47,000	49,000	25,000	25.0	33.4	---
Discalloy	1200	116,200		91,500	100,000	27,500	4.0	6.0	---
19-9 DL	1350	38,100		29,300	31,000	15,000	45.0	69.3	---
234-A-5 As Forged Heat 1X2218	1350	39,700		32,000	34,500	15,000	40.0	55.7	---
		38,500		32,000	34,000	12,500	40.0	56.0	---
Low Carbon N155 As Forged NR66D	1350	59,750		37,500	40,000	20,000	24.0	24.8	---

*Discalloy cooled by air blasts after 1 hour at 1950°F. Aged 20 hours at 1350°F.
Other discs as forged and stress relieved at 1200°F.

Insert attached page

Table III

RUPTURE TEST CHARACTERISTICS OF A 19-9 DL FORGED DISC
(Radial Specimens at Edge of 20" Diameter x $3\frac{1}{4}$" Thick Disc)

Temperature °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
1200	54,000	1.02	32	43.7
	49,000	4.43	37	51.0
	40,000	25.0	11	25.6
	37,500	290.0	39	53.6
	35,000	966.5	16	29.8
	33,500	604.5	9	28.8
	33,500	1565.0	15	46.5
1350	36,000	0.68	38	62.5
	30,000	4.55	42	70.4
	25,000	36.0	31	55.3
	22,500	135.0	34	64.7
	20,000	277.0	30	67.6
	17,500	663.5	24	38.0
	14,500	1404.0	23	32.0

Table ~~IV~~

RUPTURE TEST CHARACTERISTICS OF ~~A~~ 234-A-5 FORGED DISCS
(Radial Specimens, ~~at Edge~~ (from center of 20" ~~Diameter x $3\frac{1}{4}$" Thick Disc~~ Discs) at Edge

Temperature °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
A.	As Forged Disc	from Heat 1X2218		
1200	48,000	1.09	28	41.8
	45,000	5.0	31	46.5
	35,000	127.0	32	48.3
	32,500	196.5	19	51.9
	30,000	974.0	18	38.8
	28,500	1596. ~~In progress 1224 hours 11-10-44~~	13	33.0
1350	32,000	1.65	38	50.5
	20,000	71.5	39	48.3
	17,500	216.0	25	46.5
	15,000	420.0	15	22.3
	12,500	1080.0	13.5	12.2

As Forged + "Hot-Cold" Worked Disc #5 from Heat 1X2280

1200

Solution Treated + Aged at 1400°F + "Hot-Cold" Worked Disc #6 from Heat 1X2280

1200

Table V

RUPTURE TEST CHARACTERISTICS OF ~~A~~ LOW CARBON N155 FORGED DISCS
(Radial Specimens at Edge ~~of 20" Diameter x 3¼" Thick Disc~~)
from Center of Discs

Temperature °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
	Universal-Cyclops As-Forged Disc, 20" Diameter x 3 5/16" Thick (NR66D)			
1200	77,000	1.07	9	16.0
	72,000	2.35	26	21.8
	55,000	94.0	12	10.9
	50,000	204.0	10	9.7
	45,000	502.5	7	8.5
	40,000	1461.0	12	16.7
1350	52,000	1.05	29	33.0
	45,000	4.47	12	16.7
	35,000	36.0	23	33.0
	30,000	186.0	9	11.5
	25,000	432.0	10	19.5
	23,000	1734.0	5	6.2
	20,000	1336.0	5	6.0
	25,000	(Check test in progress 24 hrs, 11-10-44)		

Table VI

RUPTURE TEST CHARACTERISTICS OF DISCALOY FORGED DISC
(Radial Specimens at Edge of 20" Diameter x 3¼" Thick Disc)

Temperature °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
1200	65,000	20.0	1	3.0
	48,866	145.0	1	2.3
	40,000	750.0	2	0

Crucible As-Forged Disc, 15" Diameter x 4 3/8" thick.

1200

Table VII

COMPARATIVE RUPTURE STRENGTHS FOR FOUR FORGED DISCS AT 1200 AND 1350°F.
(Radial Specimens at Edge of 20" Diameter x $3\frac{1}{4}$" Thick Disc)

Alloy	Temp. °F.	Stress, Lb./Sq.In. for Rupture at Indicated Time Periods, Hours 1	10	100	1000	2000
19-9 DL	1200	54,000	46,000	40,000	34,000	33,000
234-A-5	1200	49,000	42,000	35,500	30,000	28,500
Low Carbon N155	1200	77,000	65,000	55,000	42,000	39,000
Discaloy	1200	------	71,000	52,000	39,000	35,000
19-9 DL	1350	34,500	28,000	23,000	15,500	13,500
234-A-5	1350	33,500	25,000	19,000	12,500	11,000
Low Carbon N155	1350	52,000	40,000	31,000	(24,500)*	*

*Data incomplete.
(1) 19-9DL, 234-A-5, N155 discs as-forged and stress relieved.
(2) Discaloy disc solution treated and aged.
(3) 19-9 DL data previously presented in Report No. 10.
(4) Discaloy data reported by letter on August 7, 1944.

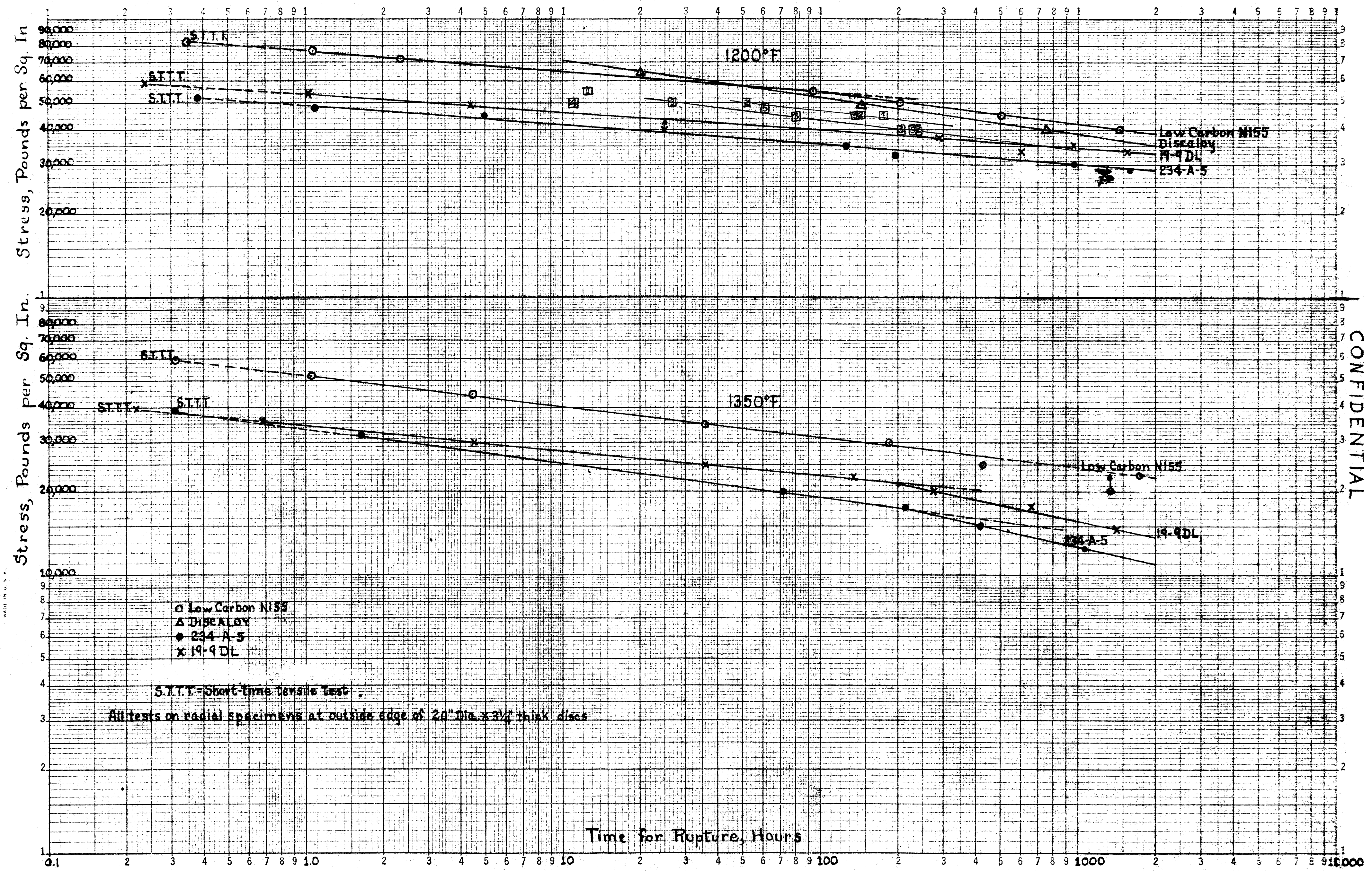

Figure 1. STRESS-RUPTURE TIME CURVES AT 1200 AND 1350°F. FOR LARGE FORGED DISCS OF LOW CARBON N155, DISCALOY, 234-A-5 AND 19-9DL ALLOYS

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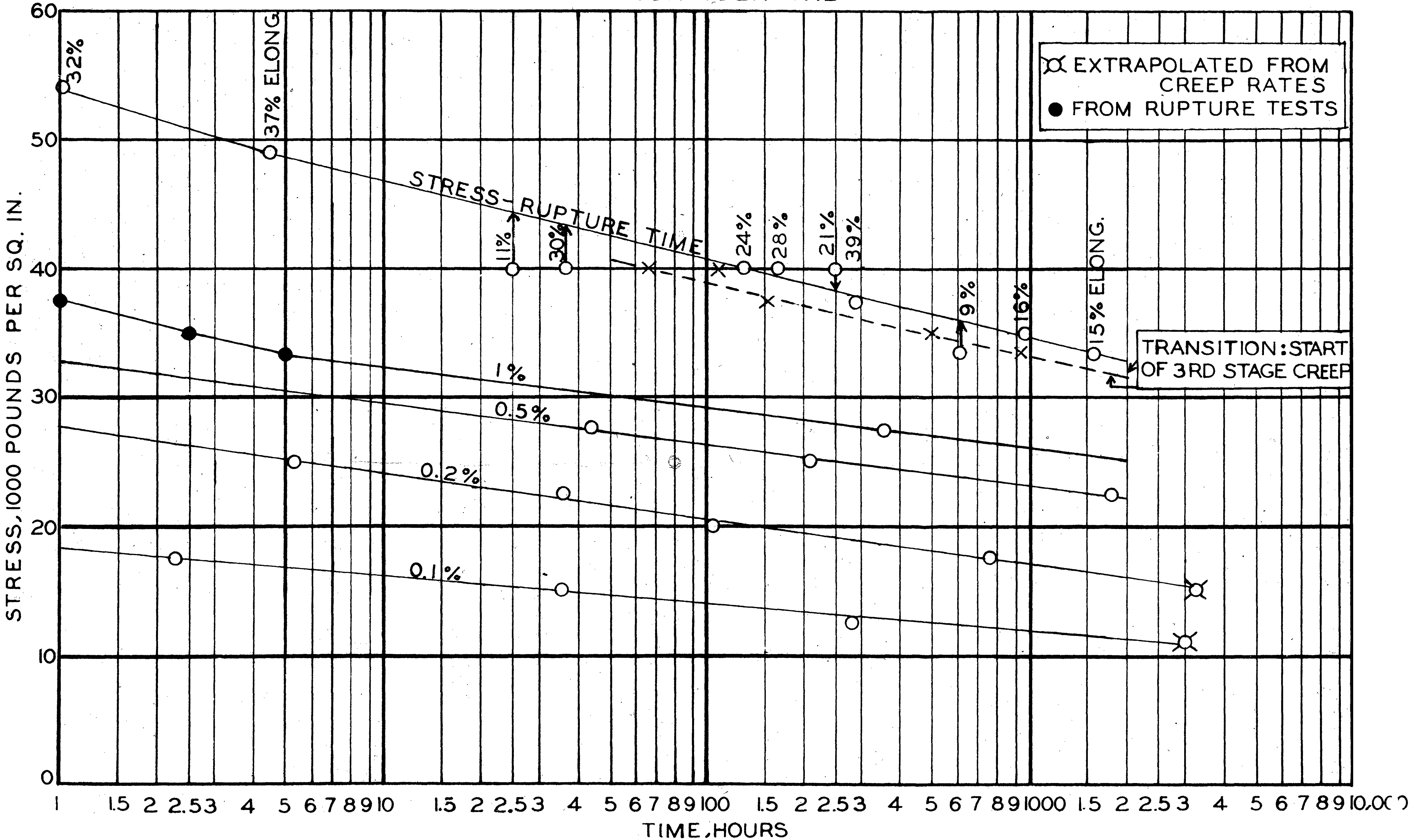

FIGURE 2. CURVES OF STRESS VS. TIME FOR INDICATED TOTAL DEFORMATIONS FOR 19-9 DL STEEL FORGED DISC AT 1200°F.

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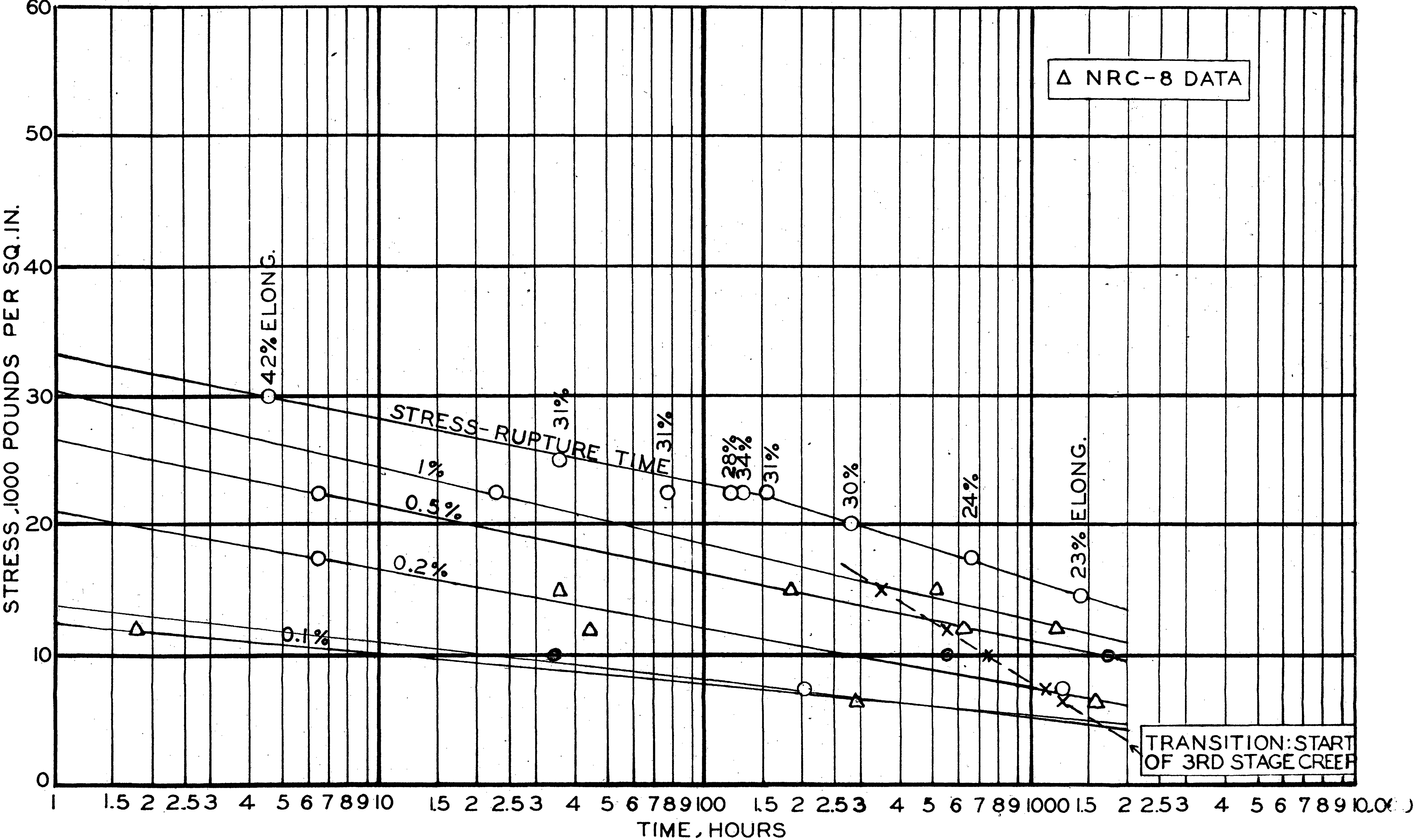

FIGURE 3. CURVES OF STRESS VS. TIME FOR INDICATED TOTAL DEFORMATIONS FOR 19-9DL STEEL FORGED DISC AT 1350°F.

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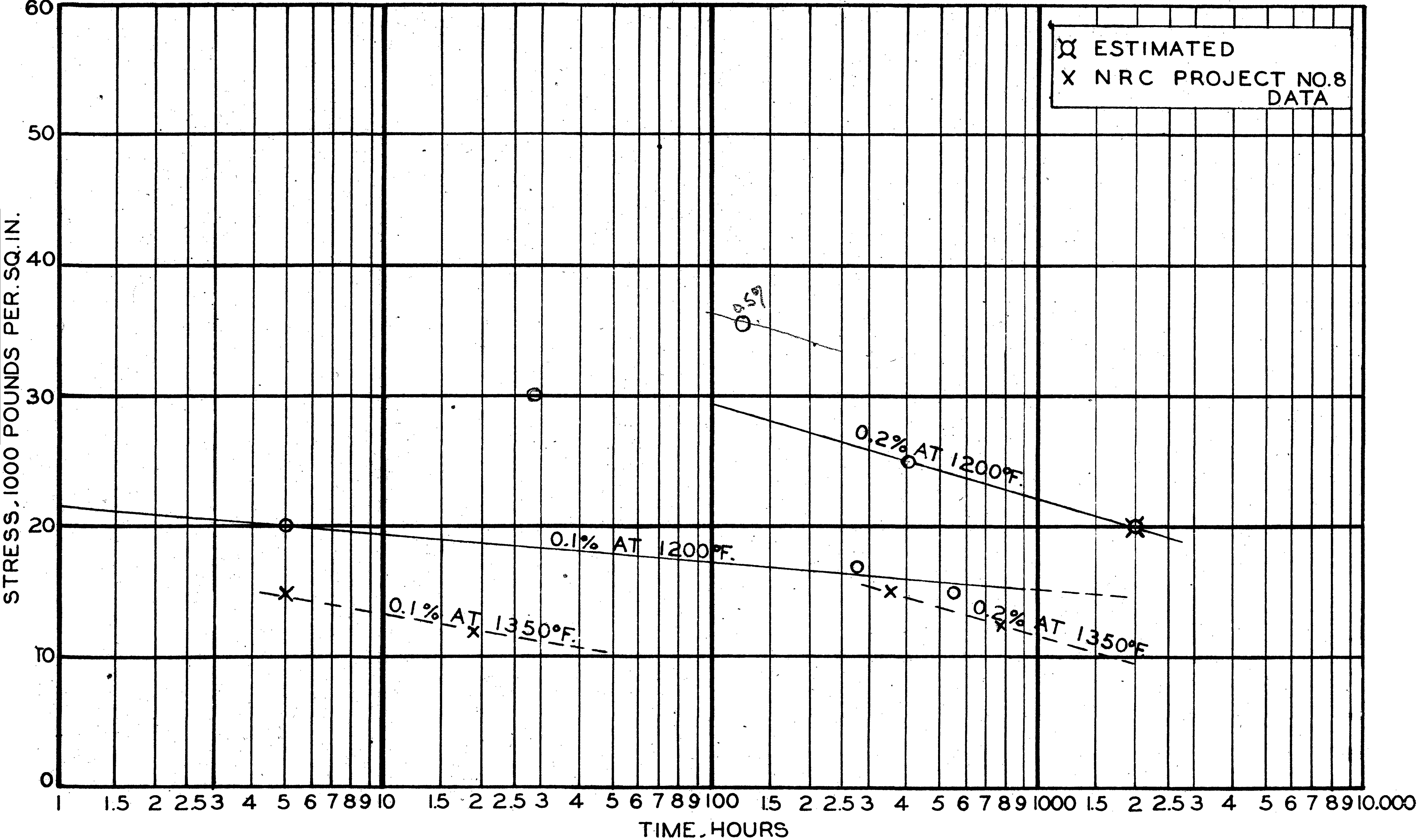

FIGURE 4. CURVES OF STRESS VS. TIME FOR INDICATED TOTAL DEFORMATIONS FOR LOW CARBON N155 ALLOY FORGED DISC AT 1200° AND 1350°F.

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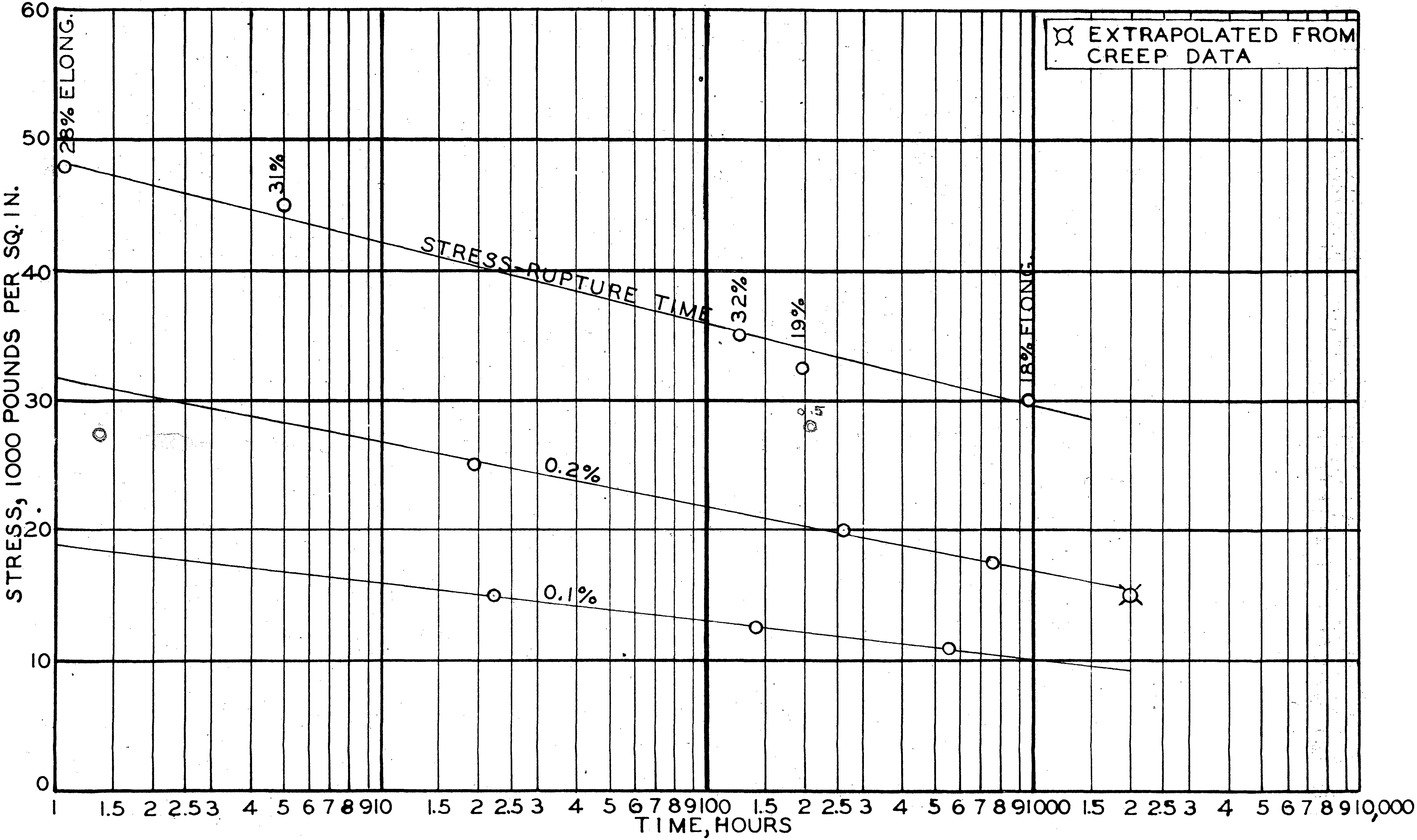

FIGURL 5. CURVES OF STRESS VS. TIME FOR INDICATED TOTAL DEFORMATION FOR 234-A-5 DISC AT 1200°F.

B. <u>19-9 DL Turbosupercharger Discs at 1200 and 1350°F.</u>

The investigation of these discs was originally undertaken to establish 2000 hour rupture strengths for "hot-cold" worked 19-9 DL steel at 1350°F. However, at the September 21, 1944 Subcommittee meeting it was requested that further work at 1350°F. be stopped and that data be obtained at 1200°F. for comparison with the large disc (~~See Section A~~ Report 15) and typical bar stock (See Section C) from the same heat.

The discs are described and the available test data are presented in Table VIII. The rupture test data are compared with those for the other conditions in Figure 6. The data at 1200°F. are as yet too incomplete to permit drawing conclusions. At 1350°F. the "hot-cold" worked discs have rupture strengths similar to the large forging up to about 100 hours. At longer time periods they were somewhat weaker. Their extension to fracture was considerably less than that of the large disc. The solution heat-treatment of disc VD-1957 prior to "hot-cold" work did not appreciably change the rupture test characteristics over that of the forged and "hot-cold" worked disc VD-1952.

Table VIII
19-9 DL TURBOSUPERCHARGER WHEEL BLANKS

Heat Number: B-10429

Chemical Composition

C	Mn	Si	Cr	Ni	Mo	W	Cb	Ti	S	P
.33	1.44	.65	19.10	9.05	1.35	1.14	.35	.16	.015	.016

Manufacture

The heat was a 10,000 pound arc furnace heat. Type "B" supercharger wheels were made from billets by the Steel Improvement and Forge Company.

Section VD-1952 was forged with the regular Steel Improvement and Forge Company practice. A contour forging is made from billet stock at 2100°F. by upsetting in a die with a finishing temperature of about 1800°F. The forgings are allowed to cool to room temperature, inspected and conditioned for "hot-cold" work. The blanks are then reheated to 1300°F. and struck about 10 times in a die with a hammer so as to produce a Brinell hardness of 270 to 300.

Section VD-1957 was manufactured in a similar manner except that the hot forged blank was solution treated at 2100°F. for one hour and air cooled prior to "hot-cold" work.

Heat Treatment

Stress-relief annealed by heating at 1200°F. for five hours.

Rupture Test Data

Section	Temp. °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area, %
VD-1952	1200	50,000	141	1.5	3.7
(no solution		45,000	289	1.0	1.2
treatment)		40,000	282.5	1.0	1.2
		37,500			
	1350	22,500	152.0	2.0	3.7
		20,000	235.0	3.0	4.0
		15,000	601.0	0.0	0.0
VD-1957	1200	40,000	In progress 96 hours		11-10-44
(solution		35,000	In progress 696 hours		
treated)	1350	25,000	62.0	2.0	3.7
		20,000	172.0	4.0	3.1
		17,000	348.0	2.0	2.3

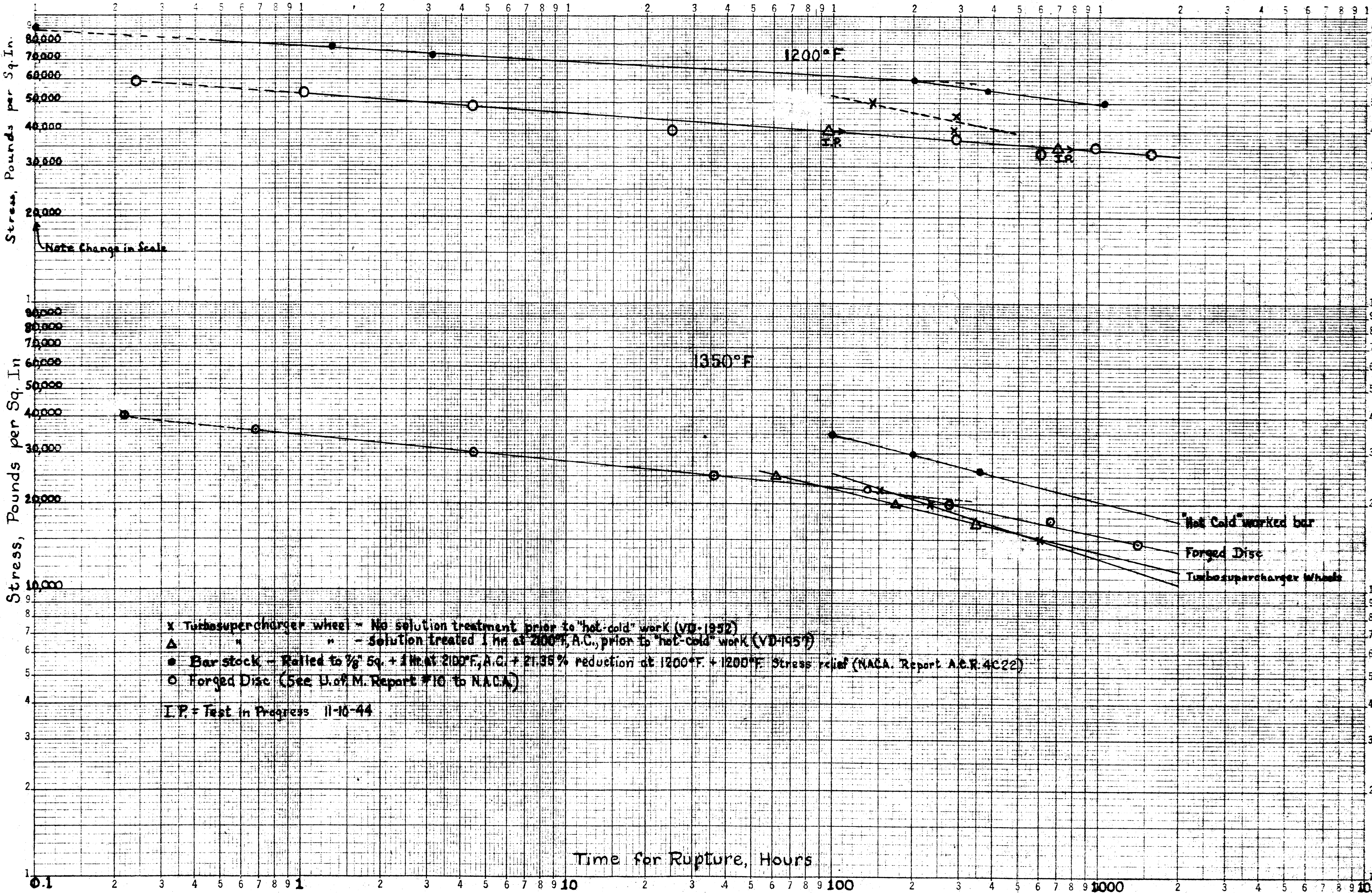

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Figure 6. COMPARATIVE STRESS-RUPTURE TIME CURVES [redacted] FOR 19-9 DL STEEL TURBOSUPERCHARGER WHEELS, BAR STOCK AND LARGE FORGED DISC AT 1200 AND 1350°F.

C. <u>Typical 19-9 DL Bar Stock</u>

Complete tensile, rupture and time-deformation data at 1200°F. have been requested for 19-9 DL steel bar stock in the following conditions:

1. Hot rolled and stress relieved
2. Hot rolled + "hot-cold" work + stress relieved
3. Annealed (solution treated)

The request originally included similar information at 1350°F. The low strength of this alloy at 1350°F., however, led the Subcommittee to request that further work at 1350°F. be stopped when the tests in progress on September 21 were completed.

The test materials are described in Table IX together with the available tensile and rupture test data. The stress-rupture time curves are shown in Figure 7 and time-deformation curves in Figures 8 and 9.

The 1200°F. rupture and deformation data for hot-rolled stock, Heat N163, has been largely taken from Universal-Cyclops data. Only partial results are available for the other two conditions.

According to Figure 5, the 1200°F. rupture strength of the hot-rolled bar is higher than that of the large disc reported in Section A and lower than the "hot-cold" worked bar. The latter. however, is weaker than the original "hot-cold" worked induction heat of 19-9 DL steel. The solution-treated bar stock will apparently have rupture test characteristics similar to the large as-forged disc.

The time-deformation curves show somewhat greater strength at 1200°F. for the hot-worked bar stock than for the large disc. At 1350°F., however, this material is even weaker than the large disc as may be seen by comparing Figures 9 and 3.

Table IX
TYPICAL 19-9 DL BAR STOCK

Type Material

Hot-rolled bar stock	N163 at 1200°F. and B-10429 (Bar #2) at 1350°F.
Hot-cold worked bar stock	B-10429 (Bar #3)
Solution-treated bar stock	B-10429 (Bar #1)

Chemical Analyses

Heat No.	C	Mn	Si	Cr	Ni	Mo	W	Cb	Ti	N_2
N163	.30	.85	.57	18.88	9.31	1.25	1.18	.33	.19	.025
B-10429	.33	1.44	.65	19.10	9.05	1.35	1.14	.35	.16	----

Manufacture

N163: - Hot-rolled 3/4-inch round cornered square bar stock.
B-10429, Bar #1: - Finished in the mill at about 1900°F. as 7/8-inch bar stock.
B-10429, Bar #2: - Finished in the mill at 1650°F. as 7/8-inch square bar stock.
B-10429, Bar #3: - Normally processed hot-rolled 7/8" square bar.

Treatment

N163 and B-10429, Bar #2: - Stress relieved at 1200°F.
B-10429, Bar #3 - Rolled to 20% reduction in area at 1200°F. and stress relieved at 1200°F. for 1 hour.
B-10429, Bar #1 - Heated 1 hour at 2100°F., air cooled, and stress relieved at 1200°F. for one hour.

Table IX (Continued)

Room Temperature Tensile Properties of Typical 19-9 DL Bar Stock

Heat No.	Condition	Tensile Strength Lb./Sq.In.	Offset Yield Strengths Lb./Sq.In. .02%	0.1%	0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area, %	Brinell Hardness
N163	Hot rolled	118,250	55,500	66,000	69,000	44,000	58.0	54.7	216
		116,750	54,000	63,500	66,500	37,500	54.5	56.8	214
B-10429 Bar #3	"Hot-Cold" Rolled 20%	152,500	97,500	118,500	121,000	72,500	24.5	44.0	321
		155,900	103,000	123,000	129,000	75,000	24.0	43.5	335

1200°F. Rupture Test Results for Typical 19-9 DL Bar Stock

Heat No.	Condition	Stress Lb./Sq.In.	Rupture Time Hours	Elongation %	Reduction in Area, %
N163*	Hot rolled	48,000	68.0	17.0	18.8
		45,000	199.5	15.0	28.0
		40,000	498.0	11.5	19.0
		37,000	1111.0	14.0	29.5
B-10429	"Hot-Cold" Rolled 20% at 1200°F.	60,000	36.0	2.0	1.2
		55,000	123.0	2.0	2.0
		50,000	157.0	2.0	4.0
		46,000	420.0	2.0	2.7
		40,000	843.5	2.5	4.2
		36,000	In progress 216 hours 11-10-44		
B-10429	Solution treated 1 hour at 2100°F., A.C. + 1 hour at 1200°F.	45,000	60.0	10.0	14.0
		40,000	180.0	19.0	25.6
		36,000	~~In progress 552 hours 11-10-44~~ 693.0	30.0	33.5

*Universal-Cyclops data.

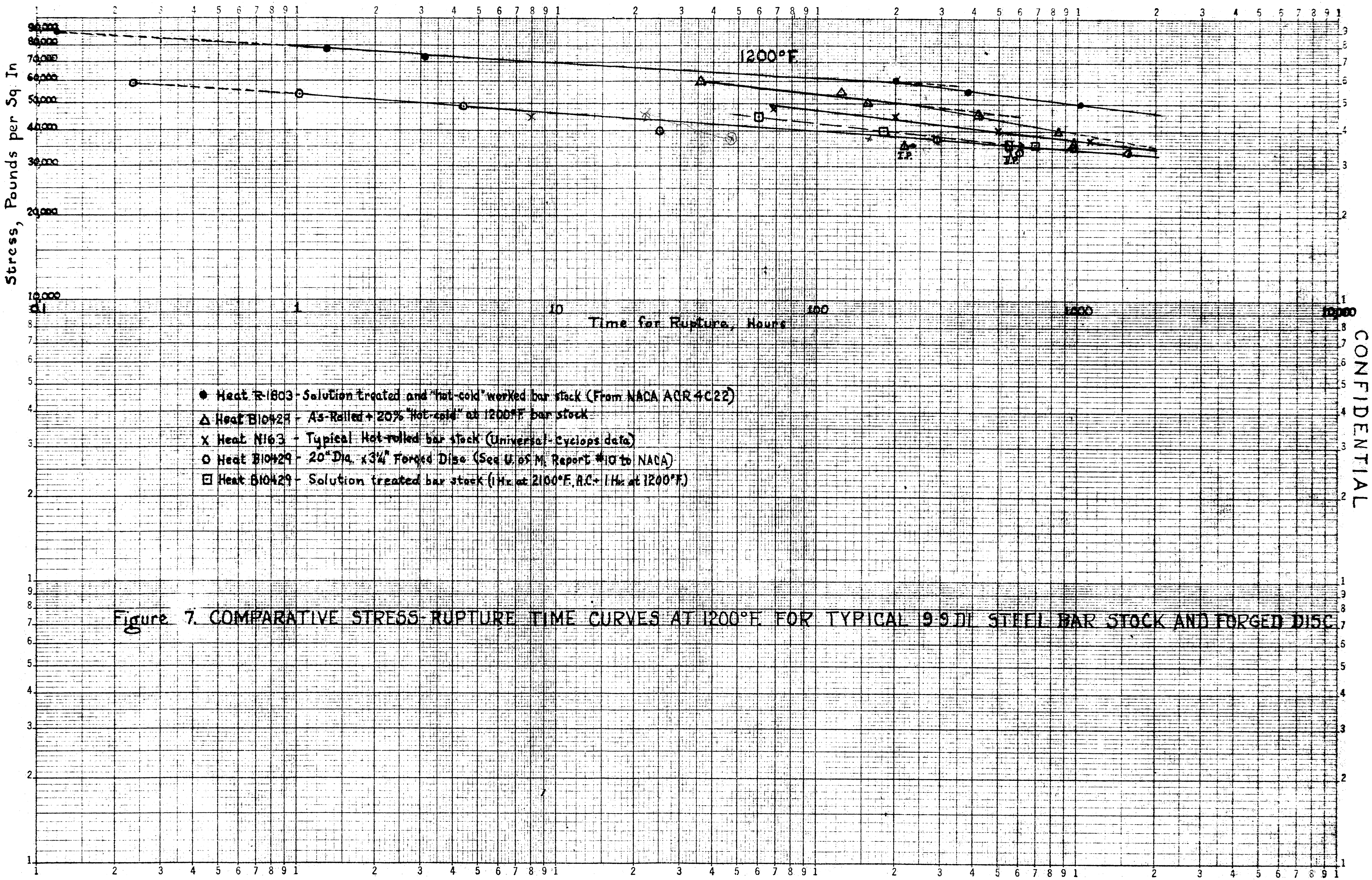

Figure 7. COMPARATIVE STRESS-RUPTURE TIME CURVES AT 1200°F FOR TYPICAL 19-9 DL STEEL BAR STOCK AND FORGED DISC

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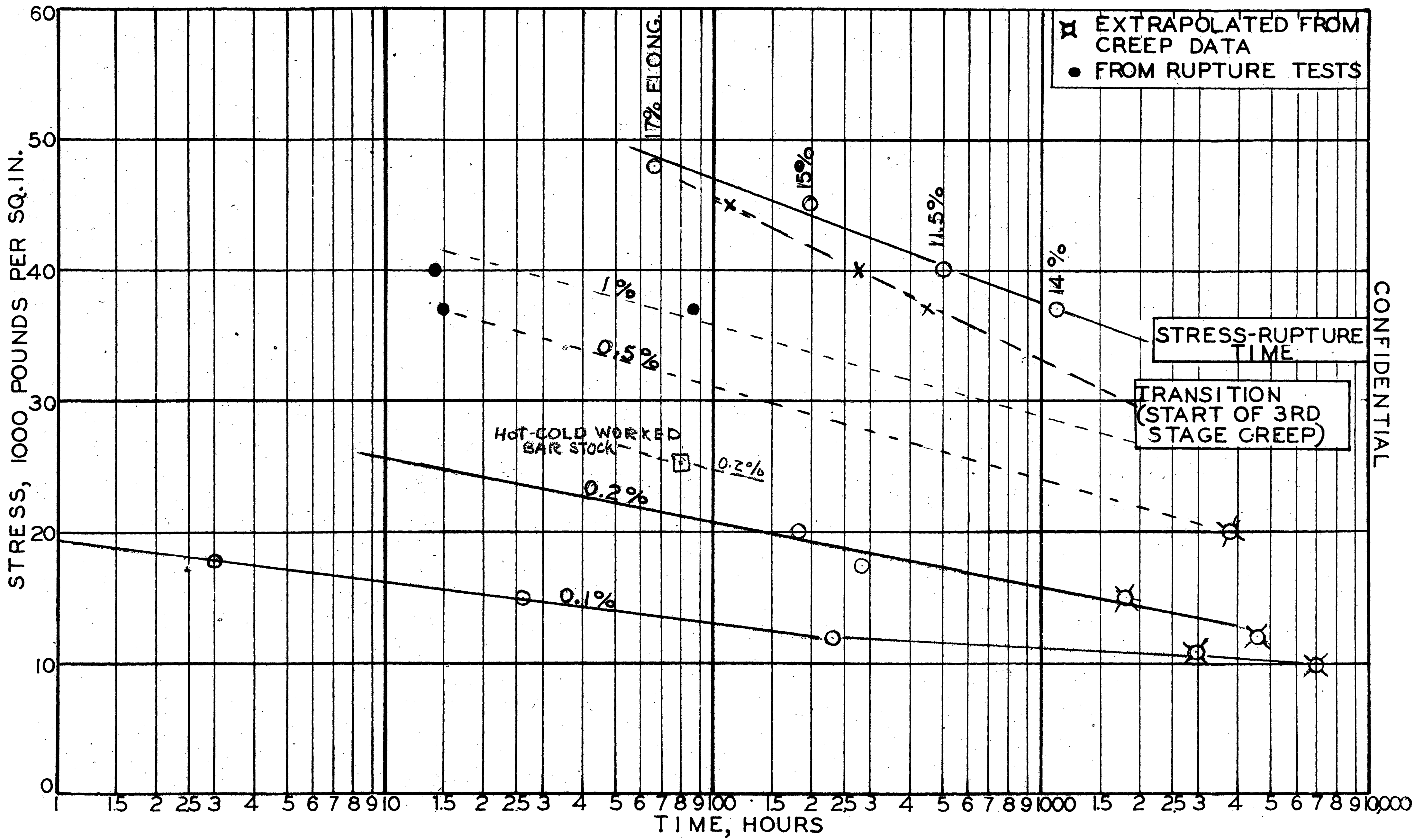

FIGURE 8. CURVES OF STRESS VS. TIME FO.. INDICATED TOTAL DEFORMATIONS AT 1200°F. FOR TYPICAL HOT-ROLLED 19-9 DL STEEL (HEAT N163 HOT-ROLLED + STRESS-RELIEVED AT 1200°F.)

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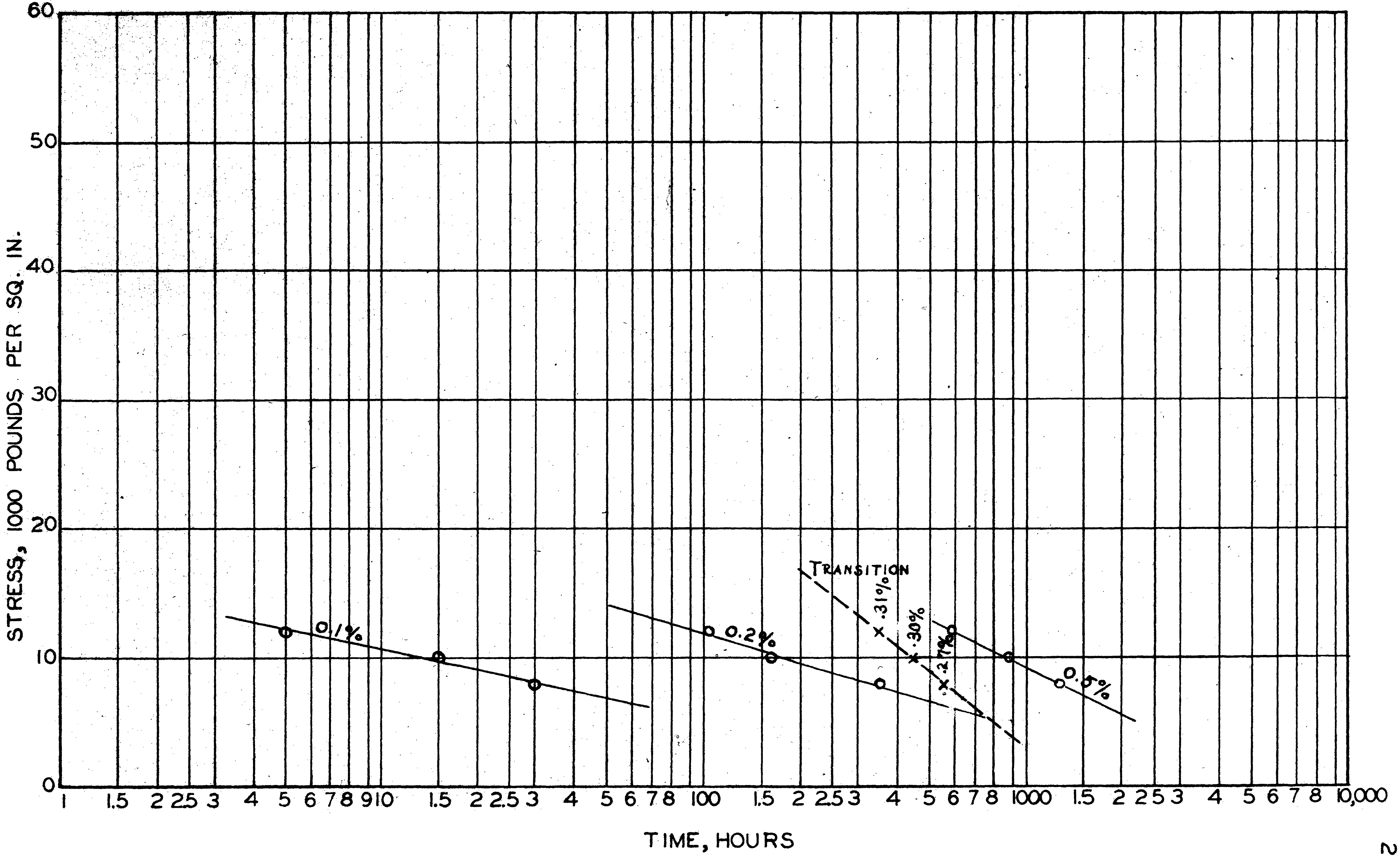

FIGURE CURVES OF STRESS VS. TIME FOR [illegible]DICATED TOTAL DEFORMATIONS AT 13[illegible]° F FOR HOT ROLLED 19-9DL STEEL BAR STOCK

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D. <u>S816 and S590 at 1350°F.</u>

In view of the exceptionally high strength of these two alloys in induction heats, further investigation of the rupture test properties of 800 pound heats is in progress. The available information for the two type heats is summarized in Table X and the stress-rupture time relationships are shown graphically in Figure 10.

As agreed at the May 11, 1944 subcommittee meeting the solution temperature of S816 was reduced to 2300°F. for the 800 pound heat. The S590 material cracked on quenching from 2300°F. and it was necessary to reduce the temperature to 2270°F.

The data indicate that the large heat of S590 has slightly better strength and elongation in the rupture test than did the induction heat. At time periods up to about 1000 hours the reverse was true in the case of alloy S816. This may be due in part to the lower solution temperature used for the large heat specimens. The S816 samples, however, still had considerably higher strength than the S590.

The following tabulation compares these alloys with other alloys under investigation on the basis of 1350°F. rupture strengths:

Alloy	Stress for Rupture in Indicated Time Periods 100 Hours	1000 Hours
S816 (Induction Heat)	44,000	31,500
S816 (800# Heat)	35,000	30,000
S590 (Induction Heat)	31,000	24,000
S590 (800# Heat)	32,500	26,000
Low Carbon N155 Bar Stock(1)	36,000	27,500
Low Carbon N155 disc	31,000	24,500*
19-9 DL Bar Stock(1)	35,000	20,500
19-9 DL Disc	23,000	15,500
234-A-5 Bar Stock(1)	22,500	12,500
234-A-5 Disc	19,000	12,500

*Data incomplete.
(1) ACR No. 4C22.

These strength values definitely indicate that consideration should be given to both S590 and S816 alloys for 1350°F. service. The bar stock data are promising enough to warrent investigation of manufacturing characteristics and properties of large discs.

Table X

ALLEGHENY LUDLUM ALLOYS S590 AND S816

Chemical Analyses

	Alloy	C	Si	Mn	Cr	Ni	Co	Mo	W	Cb	Fe
Induction Heats	S590	.49	.21	.60	19.50	19.78	19.35	3.95	4.15	4.04	Bal.
	S816	.47	.54	.58	19.50	20.23	43.70	3.93	3.45	4.06	2.95
800 pound Heats	S590	.47	.71	.94	20.28	20.55	20.00	4.08	4.22	4.72	Bal.
	S816	.38	.25	.82	18.87	19.70	45.64	4.04	4.71	3.43	2.94

Manufacture

Induction Heats - 17-pound induction furnace ingots were forged to about 1-inch square bars and then rolled to 1/2-inch rounds. The hot working temperature for S590 was 2200°F. and 2250°F. for S816.

800 Pound Heats -

S590 - 7/8-inch round bar processed from 850 pound arc furnace Heat 50254.

S816 - 3/4-inch round bar processed from a 4-inch ingot cast from 800-pound arc furnace Heat 50257. The ingot was forged from 2300°F. to a 2-inch square and rolled from 2250°F. to size.

Heat Treatment

Induction Heats -

S590 - Solution treated one hour at 2300°F. and water quenched by Allegheny-Ludlum. Aged 16 hours at 1400°F. at Michigan.

S816 - Solution treated one hour at 2350°F., water quenched. Aged 16 hours at 1400°F.

800 Pound Heats -

S590 - Solution treated at 2270°F. one hour, water quenched. Aged 16 hours at 1400°F.

S816 - Solution treated at 2300°F. one hour, water quenched. Aged 16 hours at 1400°F.

Table X (Continued)

Tensile Properties of S590 and S816 (800 Pound Heats)

Alloy	Temp. °F.	Tensile Strength Lb./Sq.In.	Offset Yield Strengths Lb./Sq.In. .02%	.10%	.20%	Proportional Limit Lb./Sq.In.	Elongation % in 2 Inches	Reduction of Area,%	Brinell Hardness
S590	Room	160,500	58,500	82,000	89,500	30,000	10.0*	10.5	298
	Room	158,500	55,000	77,500	87,000	30,000	8.5*	7.7	302
S590	1350	66,875	42,500	53,500	58,500	22,500	27.0	33.0	---
	1350	64,875	38,000	51,500	56,500	17,500	29.0	36.3	---
S816	Room	157,500	65,000	81,000	87,500	45,000	31.5	31.0	272
	Room	159,900	72,500	89,500	96,000	47,500	23.5*	20.9	309
S816	1350	89,250	55,000	66,500	70,000	32,500	16.0	16.0	---

*Broke in gage mark.

1350°F. Rupture Test Results

Specimen and Treatment	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
S590 (Induction heat,	30,000	142.0	5.0	13.0
1 hr. 2300°F. W.Q.	27,000	355.0	15.0	21.8
+ 16 hr. 1400°F.)				
S816 (Induction heat,	40,000	182.0	14.0	13.1
1 hr. 2350°F. W.Q.	37,000	307.0	11.0	15.4
+ 16 hr. 1400°F.)				
S590 (800 lb. heat,	33,000	73.0	35.0	55.9
1 hr. 2270°F. W.Q.	30,000	212.5	24.0	56.5
+ 16 hr. 1400°F.)	26,000	940.0	39.0	59.6
S816 (800 lb. heat				
1 hr. 2300°F. W.Q.	35,000	113.0	4.0	6.4
+ 16 hr. 1400°F.)	32,500	288.0	4.0	5.2
	31,000	254.0	4.0	10.2
	30,000	910.5	6.0	10.2

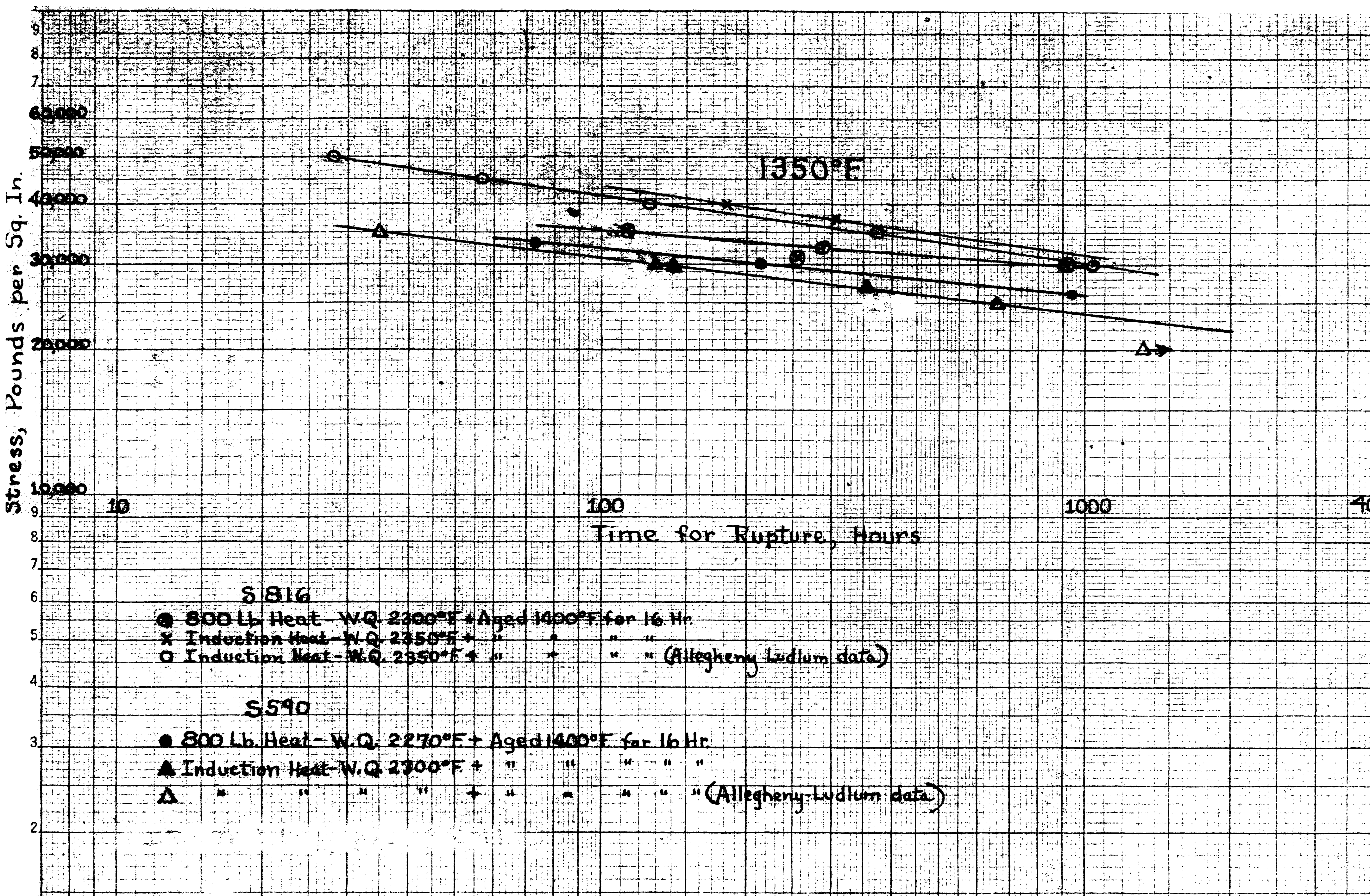

Figure 10. STRESS-RUPTURE TIME CURVES AT 1350°F. FOR S816 AND S590 ALLOYS

E. Modifications of 19-9 DL, Low Carbon N155 and N155 Alloys

The chemical compositions of the twelve heats, as reported by Universal-Cyclops Steel Corporation, are given in Table XI. All test samples were obtained from hammer forged 7/8-inch square bars from 33 pound induction heats. The bars were in the hot worked and stress relieved at 1200°F. condition.

The chemical analyses show considerable variation from the intended values particularly in regard to tungsten, columbium, titanium and nitrogen. In particular the low titanium recovery in the Low Carbon N155 alloys yielded alloys considerably off from the nominal compositions. Tungsten was omitted from Heat R-3188 and is high in Heat R-3190. Not only are the nitrogen contents erratic, but intended differences were not obtained for 19-9 DL steel.

All work on this investigation, except the preparation of the report, has been completed. As a summary of the results the stress-rupture time curves are shown as Figures 11 and 12. Table XII has been prepared to compare the rupture strengths and elongations at 100 hours. The extrapolated 1000-hour rupture strengths are also given, but not elongations since few of the tests were longer than 400 hours. Comparative values from other investigations have not been included since the standard alloy in each series was made and tested as a reference point for similarly processed materials. Briefly these results indicate the following general conclusions:

1. Hammer forged induction heats give erratic results.

2. The data in general do not reflect the differences in chemical composition. For instance, there is nothing in the compositions of Heats R-3157 and R-3234 to account for the difference in rupture strengths.

3. Both of the above conclusions emphasize that other variations than chemical composition have a greater influence on high temperature strength. Past considerations of this finding have indicated that variations encountered in processing the metal are the most probable cause.

Metallographic examination of the original materials indicate, likewise, that structural variations are present which cannot be attributed to chemical composition alone.

The rupture test characteristics of the 19-9 DL series of alloys are generally lower than has been generally found for this alloy. Apparently titanium has little or no effect on Alloy N155, although all of the strength values are somewhat below those previously obtained. The rupture data on Low Carbon N155 alloys indicate that small additions of titanium are beneficial. However, other hot-worked materials previously tested had higher rupture strengths, particularly at 1350°F., than Heat R-3268. In fact, the previous data have been almost identical to the titanium-bearing heats.

Table XI

CHEMICAL ANALYSES OF MODIFIED 19-9 DL, N155 AND LOW CARBON N155 ALLOYS

Grade	Heat No.	C	Mn	Si	Cr	Ni	Co	W	Mo	Cb	Ti	N_2	S	P
19-9 DL	R-3157	.31	.71	.49	18.46	9.40	-----	1.00	1.12	.20	.29	.12	.025	.022
19-9 DL + 10% Co	R-3188	.30	.81	.52	18.95	9.24	9.76	----	1.29	.37	.34	.04	----	----
19-9 DL + 20% Co	R-3233	.29	.90	.51	19.20	8.57	21.07	1.38	1.35	.38	.23	.02	.027	----
19-9 DL + 1% Cb (0% Ti)	R-3232	.29	.80	.40	18.50	9.41	-----	1.47	1.39	1.33	.04	.04	----	----
Low Carbon 19-9 DL + N_2	R-3190	.22	.81	.46	18.10	9.16	-----	2.15	1.37	.36	.40	.16	----	----
19-9 DL + N_2	R-3234	.35	.82	.47	19.34	9.49	-----	1.34	1.39	.35	.11	.12	----	----
N155	R-3235	.30	1.47	.48	22.46	20.29	19.77	2.05	3.10	1.05	---	.20	----	----
N155 + 0.5 Ti	R-3236	.28	1.56	.55	22.88	19.87	20.41	2.00	2.98	1.40	.50	.12	----	----
N155 + 1.0 Ti	R-3237	.29	1.49	.57	23.14	20.37	20.50	2.03	3.14	1.08	.88	.22	----	----
Low Carbon N155	R-3268	.13	1.37	.44	22.80	18.70	20.66	1.64	3.16	1.11	---	.13	----	---
Low Carbon N155 + 0.5 Ti	R-3271	.14	1.53	.49	23.06	18.77	20.88	1.89	3.22	1.25	.20	.18	----	---
Low Carbon N155 + 1.0 Ti	R-3272	.14	1.52	.67	23.30	18.09	18.82	1.94	4.28	1.11	.38	.12	----	----

Table ~~XII~~ IV

COMPARATIVE RUPTURE TEST CHARACTERISTICS OF MODIFIED 19-9 DL, N155 AND LOW CARBON N155 ALLOYS AT 1200 AND 1350°F.

Alloy	100-Hour Rupture Test Properties Temp. °F.	Rupture Strength Lb./Sq.In.	Elongation % in 1 In.	1000-Hour Rupture Strength Lb./Sq.In.
19-9 DL (.12% N_2)	1200	40,000	25	29,000
19-9 DL + 10% Co (0% W)	1200	42,000	25	37,000
19-9 DL + 20% Co	1200	42,000	15	36,000
19-9 DL + 1% Cb (0% Ti)	1200	46,000	15	36,000
Low Carbon 19-9 DL + N_2	1200	51,000	14	42,000
19-9 DL + N_2 (.12% N_2)	1200	50,000	16	37,000
N155	1200	51,000	11	37,000
N155 + 0.5% Ti	1200	50,000	25	36,000
N155 + 1% Ti	1200	48,000	20	39,000
Low Carbon N155	1200	53,000	13	44,000
Low Carbon N155 + 0.2% Ti	1200	58,000	15	48,000
Low Carbon N155 + 0.38% Ti	1200	62,000	28	48,000
19-9 DL (.12% N_2)	1350	20,000	27	12,000
19-9 DL + 10% Co (0% W)	1350	20,000	30	10,500
19-9 DL + 20% Co	1350	18,000	28	11,000
19-9 DL + 1% Cb (0% Ti)	1350	22,500	25	13,500
Low Carbon 19-9 DL + N_2	1350	28,000	10	13,000
19-9 DL + N_2 (.12% N_2)	1350	25,000	12	17,500
N155	1350	23,000	11	15,000
N155 + 0.5% Ti	1350	27,000	21	15,000
N155 + 1% Ti	1350	21,500	19	13,000
Low Carbon N155	1350	25,000	9	15,000
Low Carbon N155 + 0.2% Ti	1350	34,000	24	21,000
Low Carbon N155 + 0.38% Ti	1350	38,000	25	23,500

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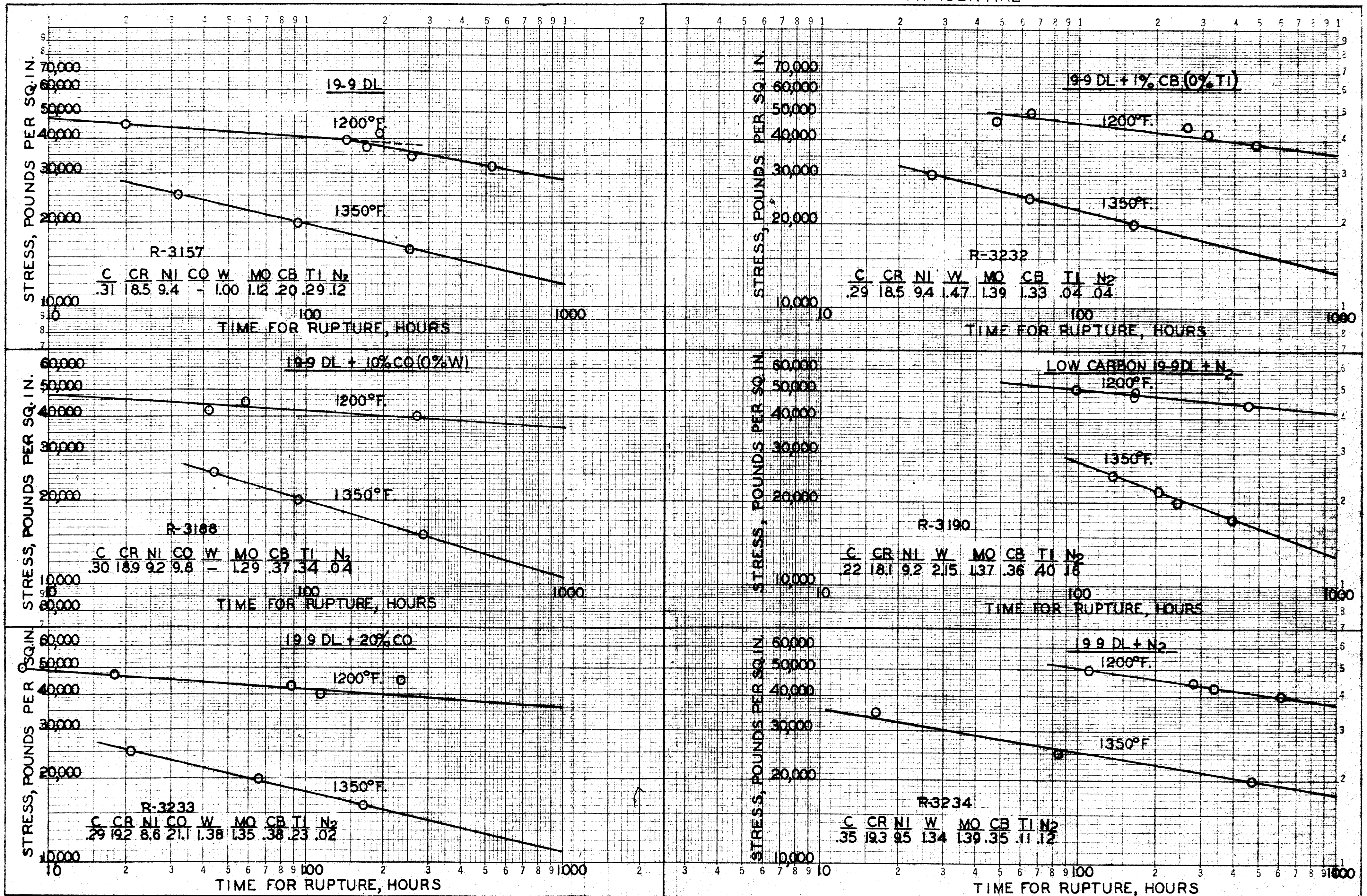

FIGURE 11. STRESS-RUPTURE TIME CURVES AT 1200 AND 1350°F. FOR INDUCTION HEATS OF 19-9 DL TYPE ALLOYS IN THE AS-FORGED CONDITION.

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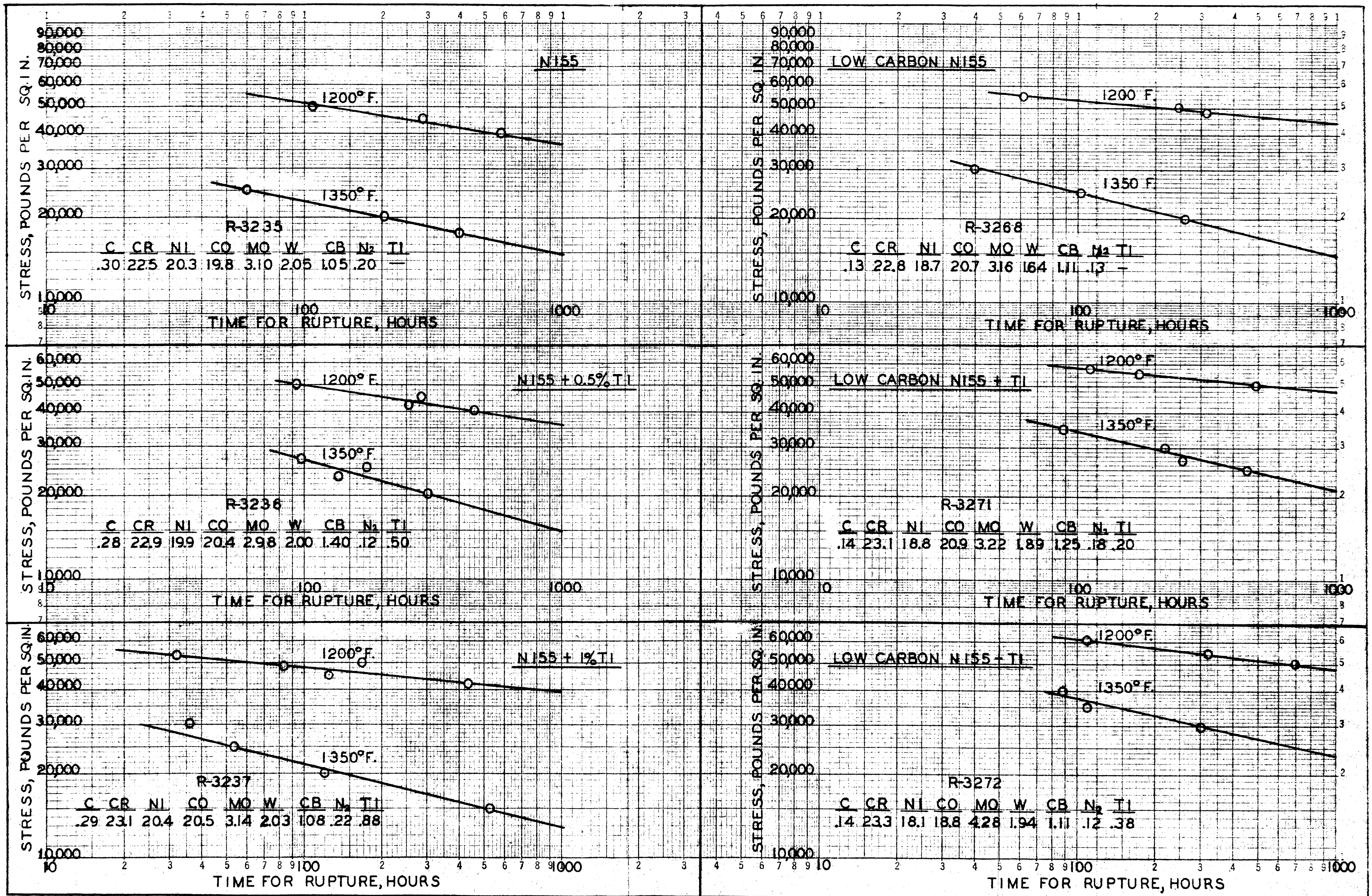

FIGURE 12. STRESS-RUPTURE TIME CURVES AT 1200 AND 1350°F FOR INDUCTION HEATS OF N155 TYPE ALLOYS IN THE AS-FORGED CONDITION.

F. Vacuum Melting

Comparison heats of vacuum and air melted Low Carbon N155 and Age Hardenable Inconel alloys were supplied by The Union Carbide and Carbon Research Laboratories, Inc. These test materials together with the rupture test data obtained at 1200°F. are given in Tables XIII and XIV.

In the case of the Low Carbon N155 heats, erratic stress-rupture time data gives a somewhat higher average curve in Figure 13 for vacuum melted alloys than for the air melted. Both heats, however, are below the original heat of this alloy.

The data for the Age-Hardenable Inconel does not show a difference between the two methods of melting. There is a slight tendency for a somewhat flatter curve in Figure 14 than was obtained for the original heat of this alloy.

Table XIII
VACUUM AND AIR MELTED LOW CARBON N155

Chemical Analyses

Type Melting	Heat No.	Cr	Ni	Co	Mo	W	Cb	N_2	C	Mn	Si
Vacuum	J-582	21.5	19.5	19.5	3.0	2.0	1.0	0.10	0.18	1.50	0.40
Air	J-585	21.5	19.5	19.5	3.0	2.0	1.0	0.14	0.20	1.50	0.40

Treatment

Samples were submitted as hot worked by Union Carbide and Carbon Research Laboratories, Inc.

Room Temperature Tensile Properties

Sample	Tensile Strength Lb./Sq.In.	Offset Yield Strength Lb./Sq.In. 0.02%	0.1%	0.2%	Prop. Limit Lb./Sq.In.	Elongation, % in 2 In.	Reduction of Area, %	Brinell Hardness
J582	120,900	48,500	62,000	67,500	32,500	22.0	39.4	211
	120,500	51,500	63,000	67,500	37,500	21.5*	24.1	215
J585	126,150	54,000	65,000	69,500	40,000	33.5	33.8	227
	128,150	58,500	68,500	74,000	45,000	20.5*	22.3	233

*Broke in gage mark.

1200°F. Stress-Rupture Results

Sample	Stress Lb./Sq.In.	Rupture Time Hours	Elongation %	Reduction in Area, %
J582	55,000	98.5	20.0	34.0
	50,000	244.5	11.0	12.1
	45,000	187.0	25.0	31.9
	45,000	220.0	17.0	8.5
	42,500	630.0	12.0	25.6
J585	55,000	43.0	7.0	10.2
	50,000	78.0	7.0	10.9
	42,500	235.0	7.0	9.1
	35,000	1788.0	11.0	13.3

Table XIV

VACUUM AND AIR MELTED AGE HARDENABLE INCONEL

Chemical Analyses

Type Melting	Heat No.	Cr	Ni	Al	Ti	Mn	Si	C
Vacuum	J-608	15.16	69.78	.37	3.29	.78	1.63	.08
Air	J-598	15.16	72.68	.52	3.45	.28	1.08	.07

Treatment

The vacuum heat (J-608) was melted in air at a pressure of 4 mm of Hg. Heat J-598 was melted in air at atmospheric pressure.

10-pound induction heats were cast into 2-inch square ingots and forged into one-inch square bars.

The bars were heated at 1950°F. for 2 hours and quenched in water. Ageing consisted of heating 16 hours at 1300°F. and air cooling.

1200°F. Rupture Test Characteristics

Sample	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
Vacuum melted (Heat J-608)	60,000	96	1.5	7.8
	55,000	132	2	3.9
	50,000	300	4	3.3
Air melted (Heat J-598)	60,000	60	1	6.4
	55,000	156	4	4.4
	50,000	255	1	2.6
	45,000	~~In progress 240 hours~~ 404	2	2.3

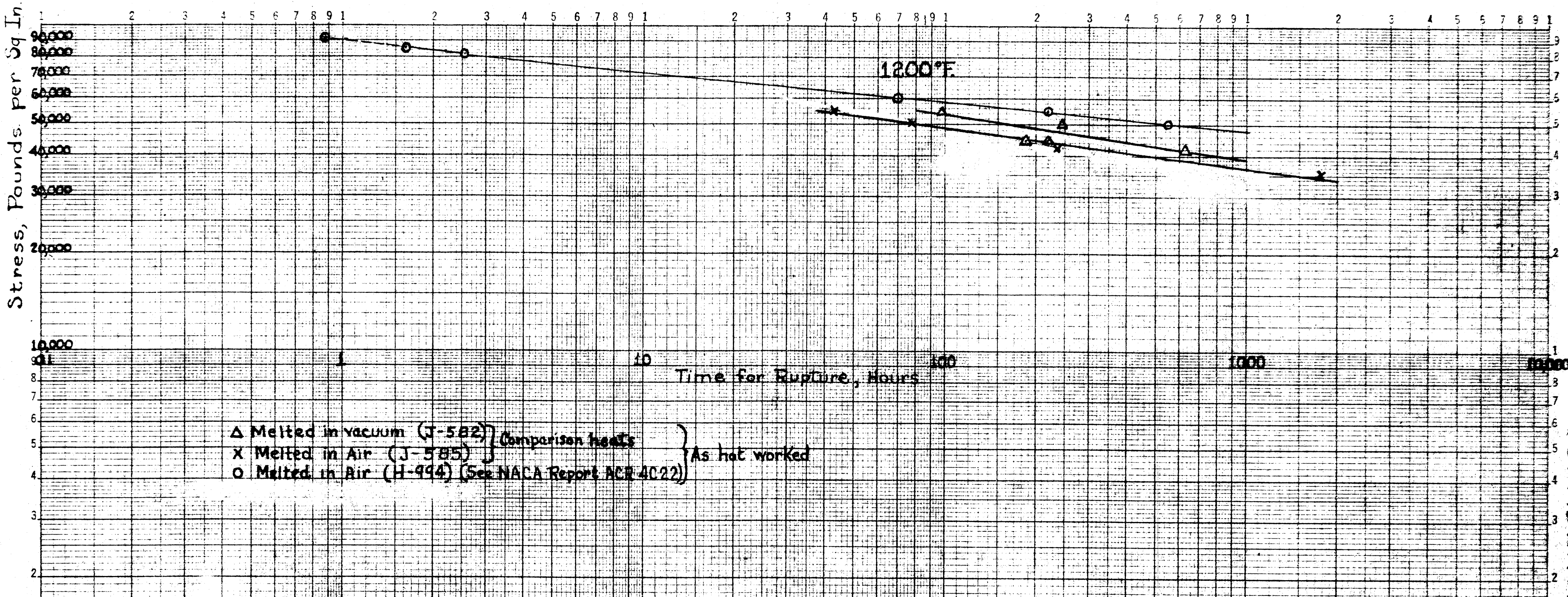

Figure 13. EFFECT OF VACUUM MELTING ON THE 1200°F RUPTURE STRENGTH OF LOW CARBON N155 ALLOY

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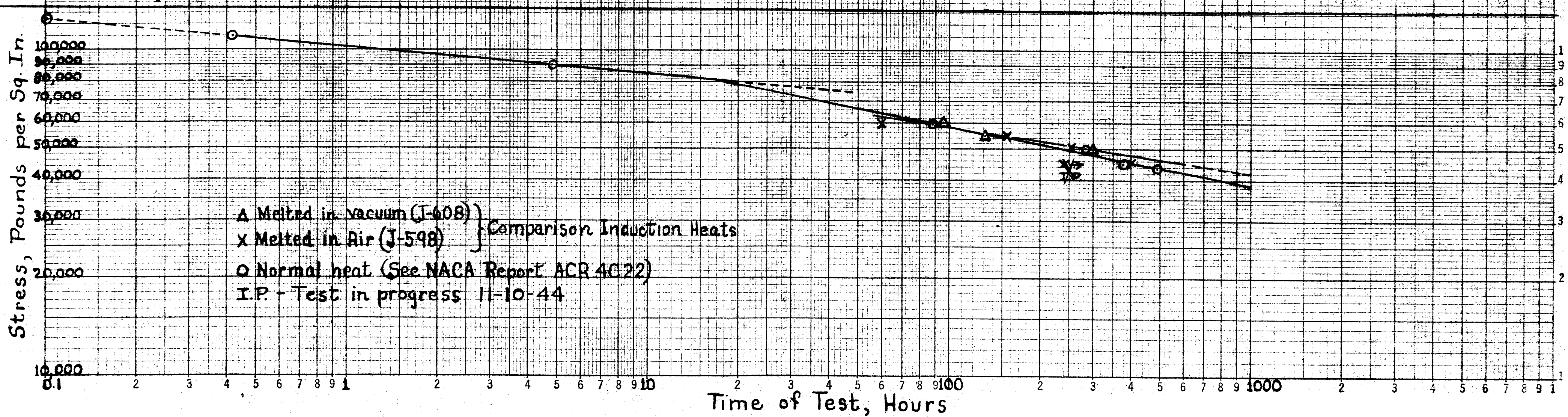

Figure 14. EFFECT OF VACUUM MELTING ON THE 1200°F. RUPTURE STRENGTH OF AGE HARDENABLE INCONEL ALLOY

G. Alloys for Service at 1700 and 1800°F.

Rupture tests up to about 400 hours duration are being conducted at 1700 and 1800°F. on several wrought and precision cast alloys which were considered to have promise for service at these temperatures. The rupture strengths which have been determined are given in Table XV and are compared graphically as Figure 15.

The information for the wrought alloys is summarized in Table XVI and for the cast alloys in Table XVII. The stress-rupture time curves are shown as Figure 16 through 27.

The rupture strengths point to the following conclusions:

1. Possible 100-hour rupture strengths at 1700°F. are as follows:

   a. Precision Castings

      Rupture strengths up to 17,000 pounds per square inch with X-40, X-50, 422-19 and S816 having somewhat the highest strengths.

   b. Wrought Alloys

      Rupture strengths up to 10,000 pounds per square inch with S816 and S590 having the highest values. Solution treating Low Carbon N155 alloy resulted in a material increase in strength.

2. Possible 1000-hour rupture strengths at 1700°F. are as follows:

   a. Precision Castings

      Rupture strengths up to 14,500 pounds per square inch with X-40 and X-50 showing the highest strengths.

b. Wrought Alloys

Rupture strengths up to 5600 pounds per square inch with S816 having the highest strength.

3. Possible 100-hour rupture strengths at 1800°F. are as follows:

a. Precision Castings

Rupture strengths up to 11,000 pounds per square inch with X-40 and S816 somewhat the strongest.

b. Wrought Alloys

Two values have been obtained, 5300 and 4900 pounds per square inch for solution treated S816 and Low Carbon N155, respectively.

4. Possible 1000-hour rupture strengths at 1800°F. are as follows:

a. Precision Castings

Up to 9800 pounds per square inch with X-40 the outstanding alloy.

b. Wrought Alloys

One value, 3000 pounds per square inch, has been obtained for Alloy S816.

5. Precision Castings vs. Wrought Alloys.

The available data on this subject indicates that in the case of Alloy S816 the cast specimens were about 50 per cent stronger than the wrought samples at 1700°F. and about twice as strong at 1800°F. There was, however, relatively little difference between the wrought and cast specimens of S590. Since as a general rule cast materials are stronger in this test than wrought materials, the results for cast S590 may be abnormally low. The data on Low Carbon N155 definitely indicate that a high temperature solution treatment is necessary for wrought alloys if high strength is to be obtained at these temperatures.

6. Elongation values as low as 4 per cent in one inch and as high as 23 per cent were obtained for the tests lasting about 400 hours. In no case, however, was extremely low extension to fracture encountered.

Table ~~XV~~ 14

RUPTURE STRENGTHS OF CAST AND WROUGHT ALLOYS AT 1700 AND 1800°F.

Alloy	Temp. °F.	Stress for Rupture in Indicated Time Periods 1 Hr.	10 Hr.	100 Hr.	400 Hr.	1000 Hr.
		PRECISION CASTINGS				
X-40	1700	24,000	20,000	17,000	15,500	14,500
X-50	1700	22*000	19,000	16,000	15,000	14,000
422-19	1700	25,000	19,000	15,000	12,500	11,500
S816	1700	24,000	19,000	14,500	12,500	11,500
61	1700	21,000	17,000	14,000	12,500	11,500
Vitallium	1700	22,500	17,000	13,000	11,000	10,000
6059	1700	20,500	16,000	12,000	10,000	8,600
S590	1700	~~20,000~~ 19,500	14,500	11,000	9,400	8,400
		WROUGHT ALLOYS				
S816	1700	23*000	15*000	~~10,000~~ 9500	7,000 (3)	~~5,600~~ 6100
S590	1700	18*500	13,600	9,400	7*600	6*600
Sol.Treated L.C. N155	1700	20,000	12,500	7,600	5,800	4,800
Hot Rolled L.C. N155	1700	16,000	10,000	5,000	3,300	2,500
		PRECISION CASTINGS				
X-40	1800	15,500	13,000	11,300	10,300	9,800
X-50	1800	18*000	13*500	10,000	8,600	7,700
422-19	1800	19,000	14,000	10,000	8,000	7,100
S816	1800	20,000	14,500	10,500	9,000	7,800
61	1800	16,500	12,500	8,600	6,500	5,400
Vitallium	1800	16,500	12,500	9,400	7,900*	7,000*
6059	1800	17,000	12,500	9,300	7,700	6,800
S590	1800	16,000	11,500	8,000	6,600	5,800
		WROUGHT ALLOYS				
S816	1800	17*500	9*600	5,300	3,800 (5)	3,000
S590	1800	15*000	9*200	5*600	4200	3500
Sol.Treated L.C. N155	1800	15,500	8,700	4,900	3,500	2*800

~~*Tests incomplete.~~

Table XVI

1700 AND 1800°F. STRESS-RUPTURE PROPERTIES OF FOUR WROUGHT ALLOYS

Chemical Analyses

Alloy	Heat No.	C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Fe	N_2
Low Carbon N155	A11534	.15	1.74	.37	21.66	19.40	20.48	2.76	1.90	0.79	----	.14
*Low Carbon N155 (Welding Rod)	------	.13	----	---	21.50	19.00	19.00	3.10	2.10	1.05	----	--
S590	41572	.47	1.35	.82	19.40	19.07	19.26	4.03	4.00	3.87	----	--
S816	50757	.38	.82	.25	18.87	19.70	45.64	4.04	4.71	3.43	2.94	--

*Approximate analysis.

Manufacture and Heat Treatment

Low Carbon N155 - Hot rolled, Heat No. A11534. Hot rolled to finishing temperature of about 1700°F. Stress relieved at 1200°F., air cooled.

Low Carbon N155 - Solution treated. 1/4-inch welding rod. Heat treated at 1250°C. (2082°F.) for 1/2 hour followed by cooling in still air.

S816 - Heat No. 50757. 800 pound arc heat cast into 4" ingots. Rolled to 1/4-inch round. Solution treated at 2300°F. for one hour and water quenched. Aged 16 hours at 1700°F. for 1700°F. rupture tests. Aged 16 hours at 1800°F. for 1800°F. rupture tests.

S590 - 2-ton electric furnace heat, teemed to 8" ingots and hammer cogged from 2250°F. to 3" square billets. These were hot rolled from 2200°F. to 9/32" round bars which were centerless ground to size. The bars were solution treated at 2270°F. for 1 hour and water quenched, then aged 16 hours at 1700°F. for 1700°F. rupture tests and aged 16 hours at 1800°F. for 1800°F. rupture tests.

Table II
Rupture Test Data at 1700° and 1800°F for Wrought Alloys

~~Table XVI (Continued~~)

~~Rupture Test Data at 1700°F.~~

Alloy	Temp °F	Stress Lb./Sq.In.	Rupture Time Hours	Elongation %	Reduction of Area, %
Low Carbon N155 Hot Rolled	1900	23,000	S.T.T.T.	48.0	61.3
		17,000	0.84	41.5	59.8
		10,000	11.0	28.5	38.2
		8,000	24.5	31.0	34.7
		6,000	49.5	32.0	37.5
		4,500	169.5	25.0	27.5
		3,500	318.0	32.0	28.5
Wrought Low Carbon N155 Solution Treated	1700	23,800	S.T.T.T.	47.0	54.3
		15,000	4.25	53.0	55.3
		8,500	60.0	28.0	26.7
		7,000	134.0	16.0	17.8
		5,500	516.0	10.0	13.3
Wrought S816	1800	31,300	S.T.T.T.	13.0	16.7
		22000	1.18	9	24.7
		12,000	63.0	11.0	13.3
		11,000	64.5	18.0	18.4
		9,000	168.0	8.0	5.0
		7,500	111.0	6.0	5.0
		7,000	390.0	15.0	16.7
Wrought S590		24,100	S.T.T.T.	52.0	56.1
		16,000	2.43	59.0	62.5
		11,833	36.0	40.0	60.9
		9,000	~~Starting~~ 94.5	31.0	44.7
		8000	252.0	28	31.9
		7300	600	14	17.8

~~Rupture Test Data~~ at 1800°F.

Alloy	Temp °F	Stress Lb./Sq.In.	Rupture Time Hours	Elongation %	Reduction of Area, %
Wrought Low Carbon N155 Solution Treated		16,100	S.T.T.T.	67.0	58.6
		11,000	4.12	44.0	44.7
		5,000	108.0	11.0	6.7
		4,000	192.0	9.7	12.0
		3500	415	8	11.5
		3,000	~~In progress 216 hours~~		Broken in threads [illegible]
Wrought S816		22,200	S.T.T.T.	32.0	33.4
		14000	2.51	19	20.2
		6,000	66.5	7.0	14.0
		5,000	119.0	5.0	9.7
		4,000	328.5	7.0	9.1
Wrought S590		18,500	S.T.T.T.	63.0	61.7
		12,000	2.65	53.0	54.3
		7000	36.0	33	38.8
		5000	185.5	23	21.2
		4200	374.	3.5	12.1

Table XVII

1700 AND 1800°F. STRESS-RUPTURE PROPERTIES FOR EIGHT PRECISION CAST ALLOYS

Chemical Analyses

Alloy	Heat No.	C	Cr	Ni	Mo	Fe	Mn	Si	Co	Cb
6059	6437	*0.50	26.85	35.15	5.00	1.04	0.35	0.77	Bal.	
		**0.396	24.61	33.50	5.34	1.00	0.20	0.76	33.55	
Vitallium	V-4705	*0.24	27.60	3.06	5.13	1.76	0.98	0.63	Bal.	
		**0.21	26.66	----	5.57	(Co + Ni 65.56 by difference from 98%)				
422-19	1	*0.48	29.10	13.90	6.20	1.20	0.52	0.63	Bal.	
		**0.54	26.24	10.81	6.21	1.10	0.32	0.63	53.89	
61	6258	*0.44	23.70	0.16	W 5.18	1.04	0.54	0.48	Bal.	
		**0.43	24.49	----	5.15	1.00	0.64	0.58	Co + Ni 69.90	
S590		0.57	20.11	20.64	3.63	W 4.50	0.67	0.63	20.04	4.02
S816		0.41	19.43	19.80	3.61	W 3.42	0.42	0.56	42.81	4.48
X50		0.76	22.57	20.05	W 12.17	----	----	----	40.70	
X40		0.48	25.12	9.69	W 7.23	0.55	0.64	0.72	55.23	

*G.E. River Works analysis.
**Haynes Stellite analysis.

Manufacture

6059, Vitallium, 422-19, 61 - Precision cast 0.160-inch diameter 1-inch gage section stress-rupture specimens.

S590, S816 - Precision cast 0.250-inch diameter 2-inch gage section rupture specimens.

X50, X40 - Precision cast 0.250-inch diameter 1-inch gage section rupture specimens.

(Continued)

~~Table XVII (Continued)~~

~~Rupture Test Data at 1700 and 1800°F.~~

Alloy	Temp. °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation %	Reduction of Area,%
6059	1700	29,300	S.T.T.T.	27.0	40.8
		20,000	1.18	44.0	66.2
		13,000	60.0	20.0	54.3
		11,000	190.0	13.0	31.9
		10,000	362.5	12.0	32.4
6059	1800	22,500	S.T.T.T.	25.0	53.6
		14,000	4.45	30.0	73.1
		10,000	44.0	23.0	45.0
		9,000	156.0	8.0	26.7
		8,000	281.0	19.0	54.3
Vitallium	1700	34,000	S.T.T.T.	19.0	66.2
		25,000	0.43	35.0	52.8
		14,000	35.0	31.0	58.0
		13,000	144.0	8.0	27.7
		10,500	625.0	6.0	21.0
Vitallium	1800	25,200	S.T.T.T.	24.0	54.3
		15,000	2.28	48.0	64.0
		10,000	76.0	17.0	42.2
		9,000	97.5	13.0	27.7
		8,000	132.0	10.0 (50)	16.7 (9.1)
		5,500 (7500)	895.0 (527)	12.0	15.6
		6,800	~~In progress 768 hours 11/10/44~~ (Discontinued after 1244 hours)		
422-19	1700	35,000	S.T.T.T.	18.0	41.8
		21,000	5.2	15.0	39.8
		15,000	47.0	6.0	28.2
		18,000	16.5	13.0	29.0
		14,000	170.0	7.0	16.0
		13,000	346.0	6.0	13.3
422-19	1800	24,700	S.T.T.T.	28.0	45.6
		16,000	3.37	24.0	36.9
		11,000	44.0	12.0	28.8
		10,000	161.0	10.0	17.0
		9,000	204.0	11.0	39.0
		8,000	460.0	4.0	10.9
61	1700	29,800	S.T.T.T.	25.0	51.9
		18,000	7.15	32.0	53.6
		14,000	48.0	4.0	4.4
		13,000	156.0	7.0	9.7
		12,000	717.0	5.0	5.0

(Continued)

Table XVII (Continued)

Alloy	Temp. °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation %	Reduction of Area,%
61	1800	24,200	S.T.T.T.	25.0	47.4
		15,000	2.27	19.0	36.0
		11,000	29.5	19.0	51.9
		10,000	268.0	5.0	8.5
		9,000	100.0	9.0	12.1
		8,000	146.0	7.0	7.5
		7,000	283.5	9.0	6.2
S590	1700	26,450	S.T.T.T.	13.5	29.5
		25,400	S.T.T.T.	16.5	32.2
		16,000	8.6	16.5	40.5
		12,000	29.0	15.5	39.8
		10,000	200.0	14.0	20.5
		9,500	378.5	8.0	13.5
S590	1800	18,600	S.T.T.T.	27.0	40.5
		13,000	4.43	25.5	34.2
		8,000	96.0	14.0	33.0
		7,500	185.0	11.0	22.6
		7,000	137.0	12.0	27.7
		6,500	480.0	5.0	14.6
S816	1700	34,000	S.T.T.T.	13.0	24.8
		21,000	4.31	7.0	21.3
		15,000	60.0	7.0	19.0
		14,500	84.0	14.5	22.0
		14,000	290.5	2.0	5.5
		13,000	327.0	6.0	8.7
S816	1800	25,900	S.T.T.T.	12.0	21.3
		17,000	3.5	16.0	26.6
		11,000	74.0	11.0	17.7
		10,000	156.0	9.0	16.7
		9,000	385.0	7.0	16.2
X40	1700	32,600	S.T.T.T.	38.0	43.4
		23,000	1.03	45.0	55.4
		18,000	40.0	26.0	40.0
		17,000	169.0	20.0	43.2
		14,000	828.0	25.0	43.2
X40	1800	25,950	S.T.T.T.	28.0	45.7
		12,000	41.0	34.0	55.5
		11,000	196.0	19.0	31.9
		10,000	688.0	9.0	17.8

(Continued)

~~Table XVII (Continued)~~

Alloy	Temp. °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation %	Reduction of Area,%
		20,000	8.67	27.0	50.1
X50	1700	18,000	23.0	32.0	34.5
		17,000	52.0	20.0	36.0
		16,000	241.5	5.0	13.4
		16,000	426.0	4.0	2.5
		15,000	227.0	14.0	27.2
		14,000	204.0	13.0	23.6
		14,000	848.0	2.0	5.6
		15,000	5.48	36	30.5
X50	1800	10,000	75.5	17.0	38.4
		9,000	276.0	*	12.2
		8,000	665.0	9.0	9.1

*Part of specimen near fracture missing.

ALLOY	PRECISION CASTINGS X-40	X-50	422-19	S816	61	VITALLIUM	6059	S590	WROUGHT ALLOYS S816	S590	SOL. TREAT LOW CARBON N155	HOT ROLLED LOW CARBON N155
CHEMICAL COMPOSITION, % C	.48	.76	.54	.41	.43	.21	.40	.57	.38	.47	.13	.15
Mn	.64		.32	.42	.64	.98	.20	.67	.82	1.35		1.74
Si	.72		.63	.56	.58	.63	.76	.63	.25	.82		.37
Cr	25.12	22.57	26.24	19.43	24.49	26.66	24.61	20.11	18.87	19.40	21.5	21.66
Ni	9.69	20.05	10.81	19.80		3.06	33.50	20.64	19.70	19.07	19.	19.40
Co	55.23	40.07	53.89	42.81	69.90	61 –	33.55	20.04	45.64	19.26	19	20.48
W	7.23	12.17		3.42	5.15			4.50	4.71	4.00	2.10	1.90
Mo			6.21	3.61		5.57	5.34	3.63	4.04	4.03	3.10	2.76
Cb				4.48				4.02	3.43	3.87	1.05	.79
N_2											.15	.14
Fe	.55	4 –	1.10	5 –	1.00	1.76	1.00	25 –	2.94	27 –	34 –	30 –
HEAT TREATMENT	AS CAST	AS CAST	AS CAST	AS CAST	AS CAST	AS CAST	AS CAST	AS CAST	W.Q. 2300°F 16 HR AGEING AT TEST TEMP	W.Q. 2270°F 16 HR AGEING AT TEST TEMP	1 HR AT 2280°F AIR COOLED	AS HOT ROLLED

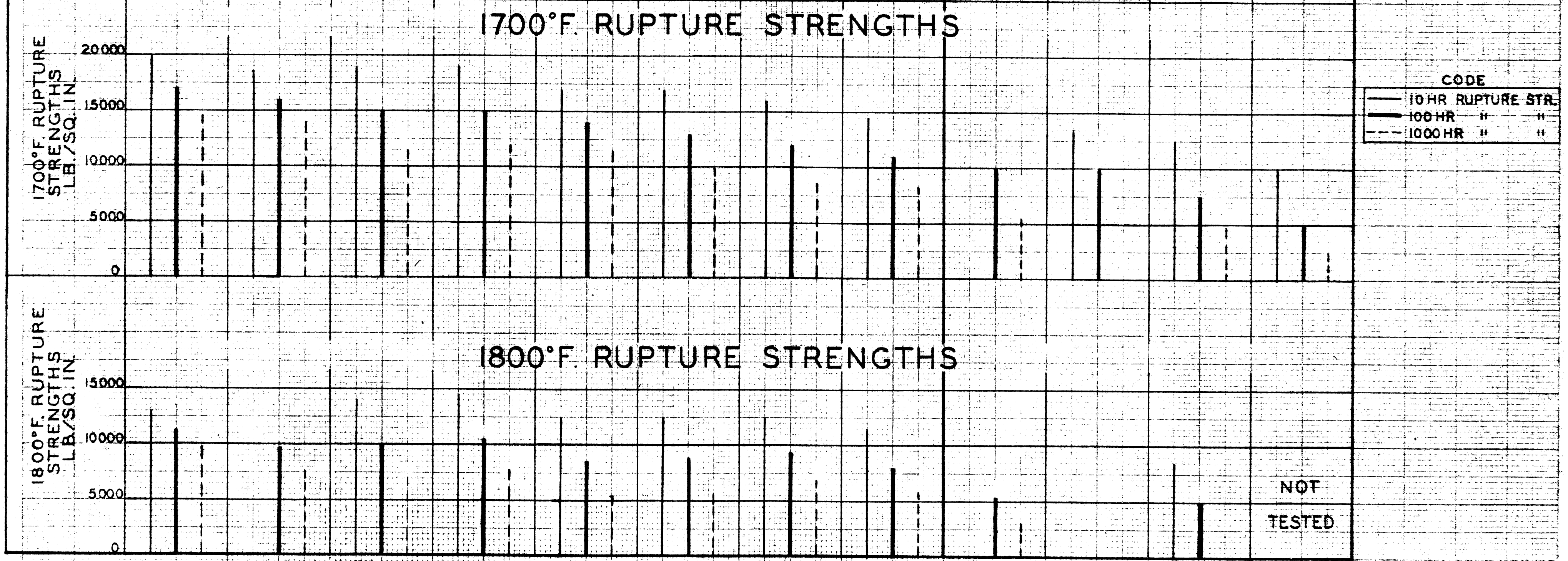

FIGURE 15 COMPARATIVE RUPTURE STRENGTHS AT 1700° AND 1800°F FOR INDICATED ALLOYS

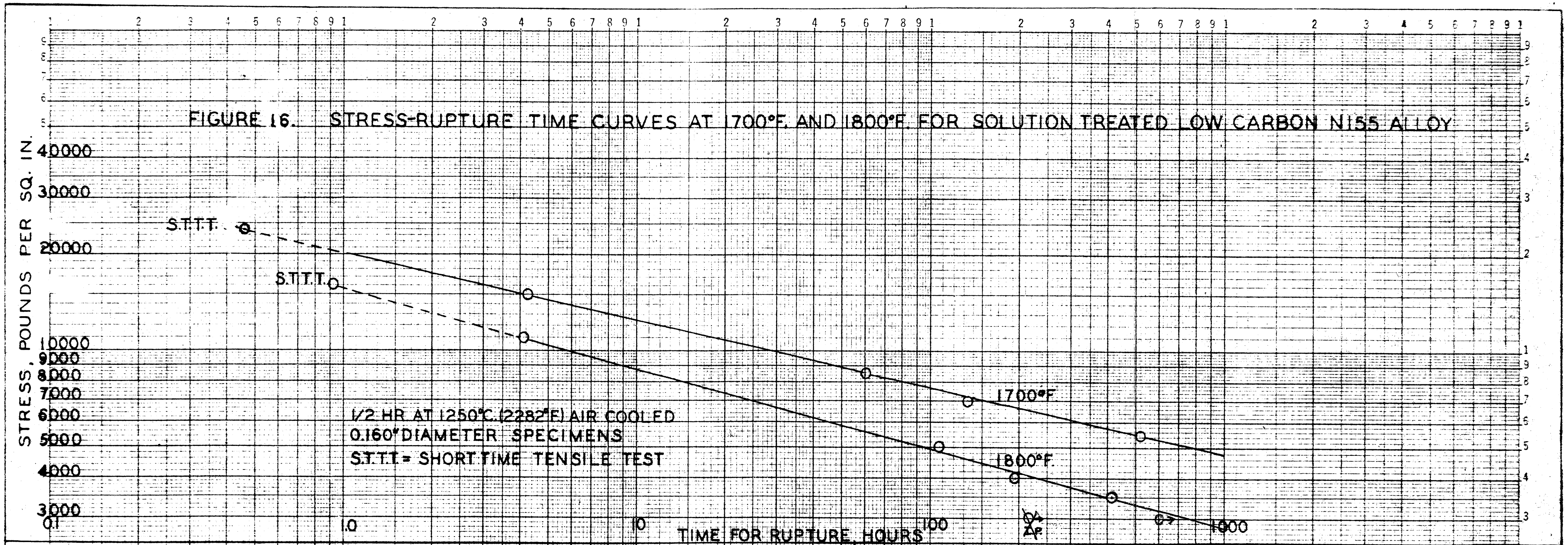

FIGURE 16. STRESS-RUPTURE TIME CURVES AT 1700°F. AND 1800°F. FOR SOLUTION TREATED LOW CARBON N155 ALLOY

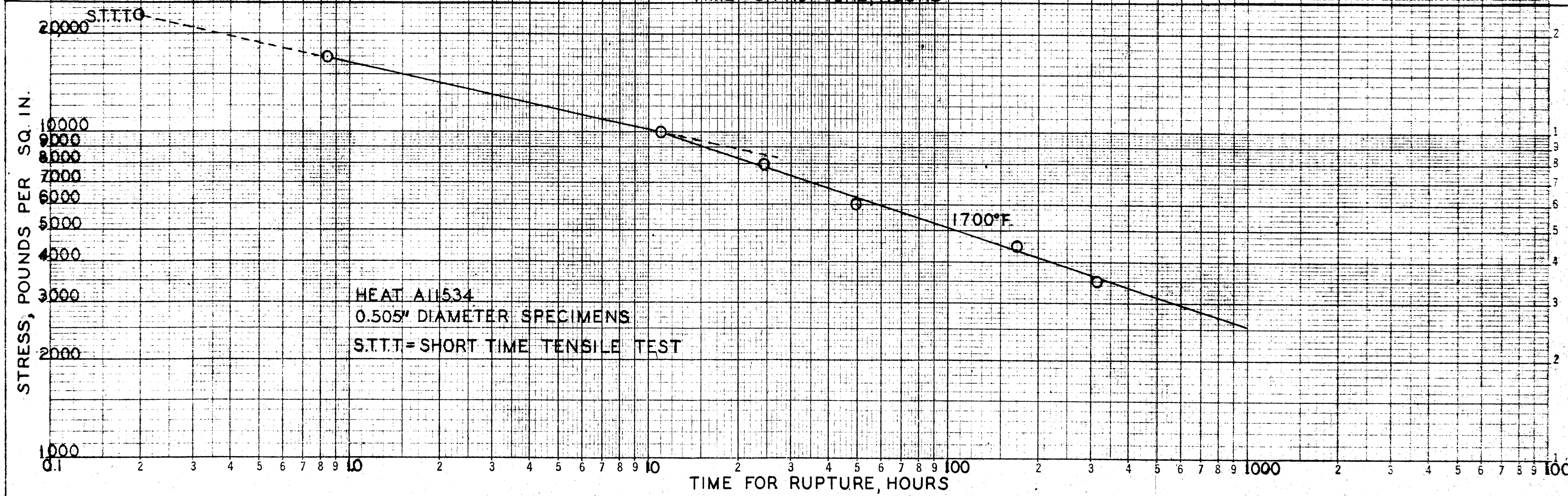

FIGURE 17. STRESS-RUPTURE TIME CURVES AT 1700°F. FOR HOT ROLLED LOW CARBON N155 ALLOY

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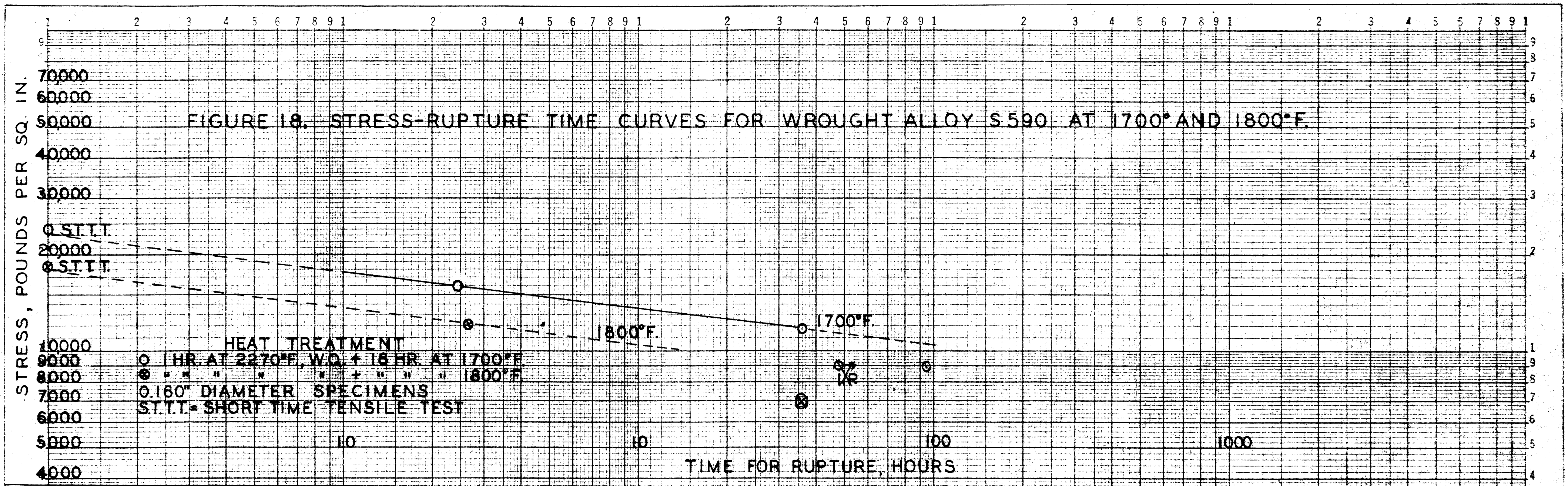

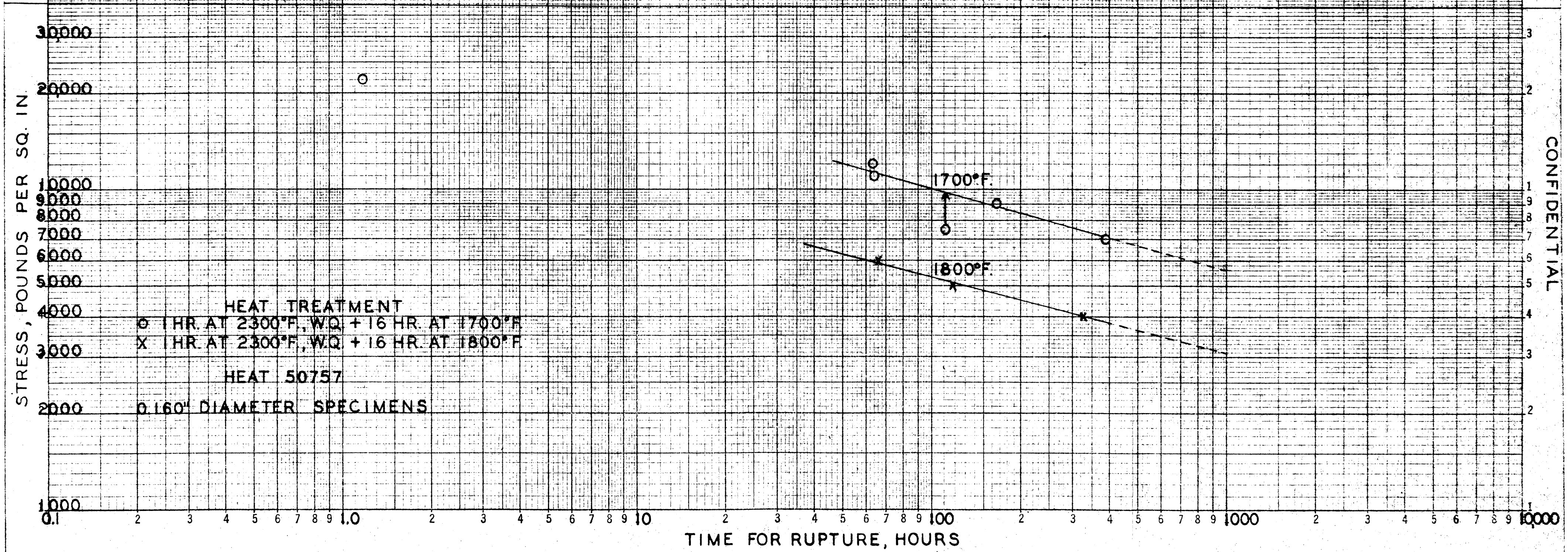

FIGURE 19. STRESS-RUPTURE TIME CURVES FOR WROUGHT ALLOY S816 AT 1700° AND 1800°F.

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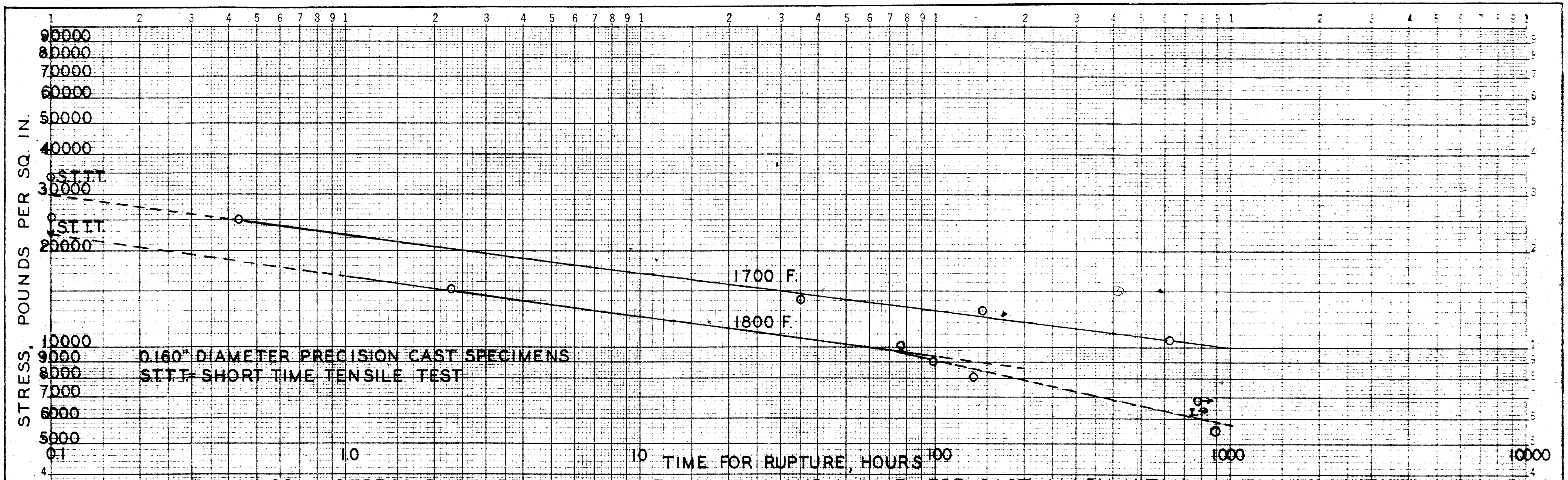

FIGURE 20. STRESS-RUPTURE TIME CURVES AT 1700° AND 1800°F FOR CAST ALLOY VITALLIUM

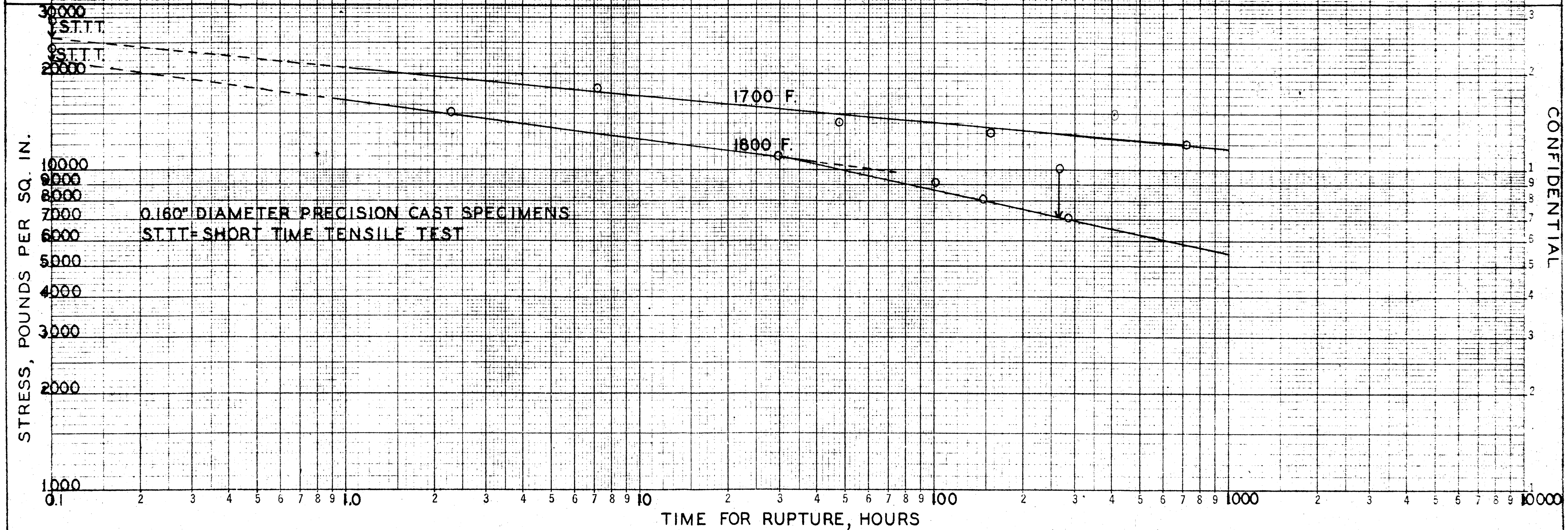

FIGURE 21. STRESS-RUPTURE TIME CURVES AT 1700° AND 1800°F. FOR CAST ALLOY 61

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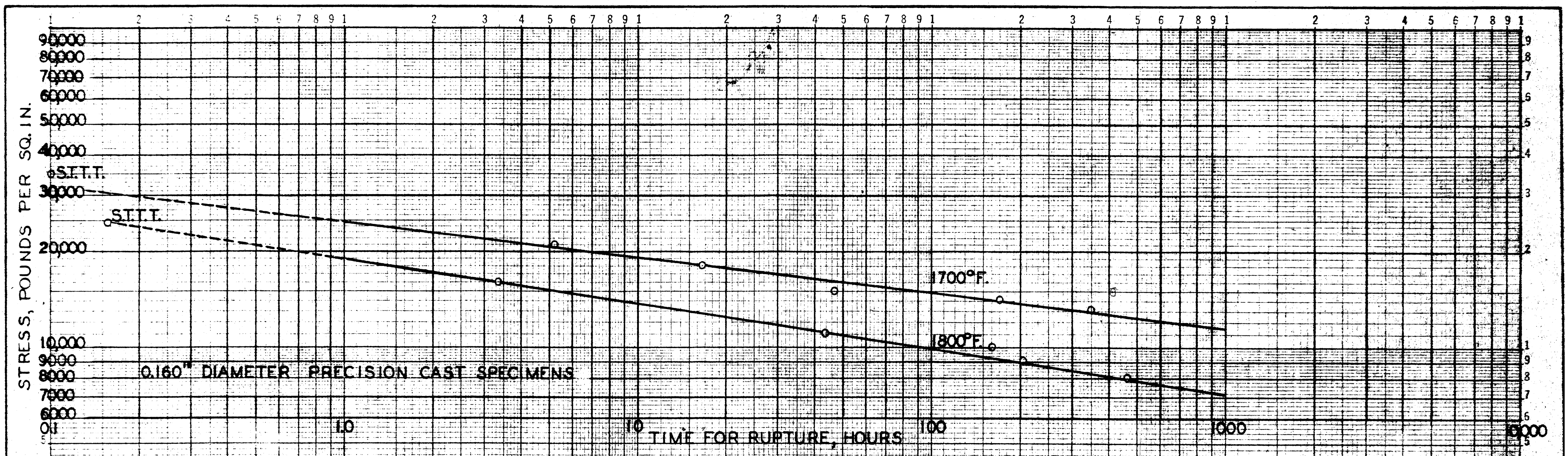

FIGURE 22. STRESS-RUPTURE TIME CURVES AT 1700 AND 1800°F. FOR CAST ALLOY 422-19

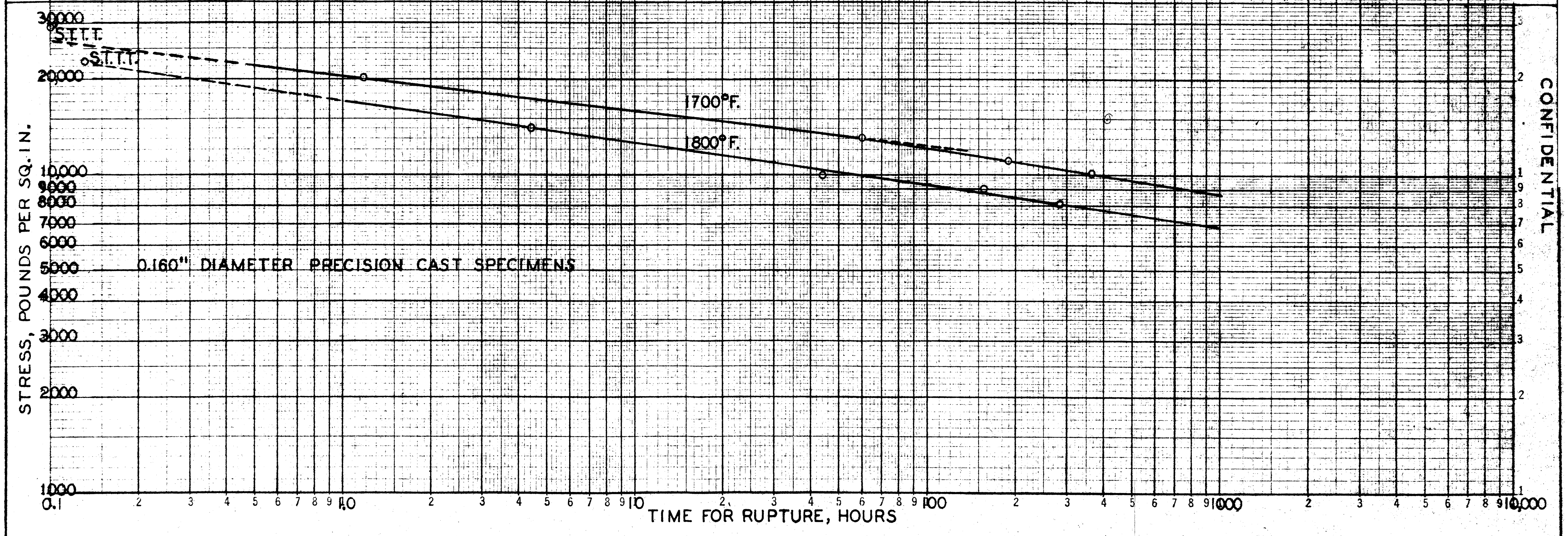

FIGURE 23. STRESS-RUPTURE TIME CURVES AT 1700 AND 1800°F. FOR CAST ALLOY 6059

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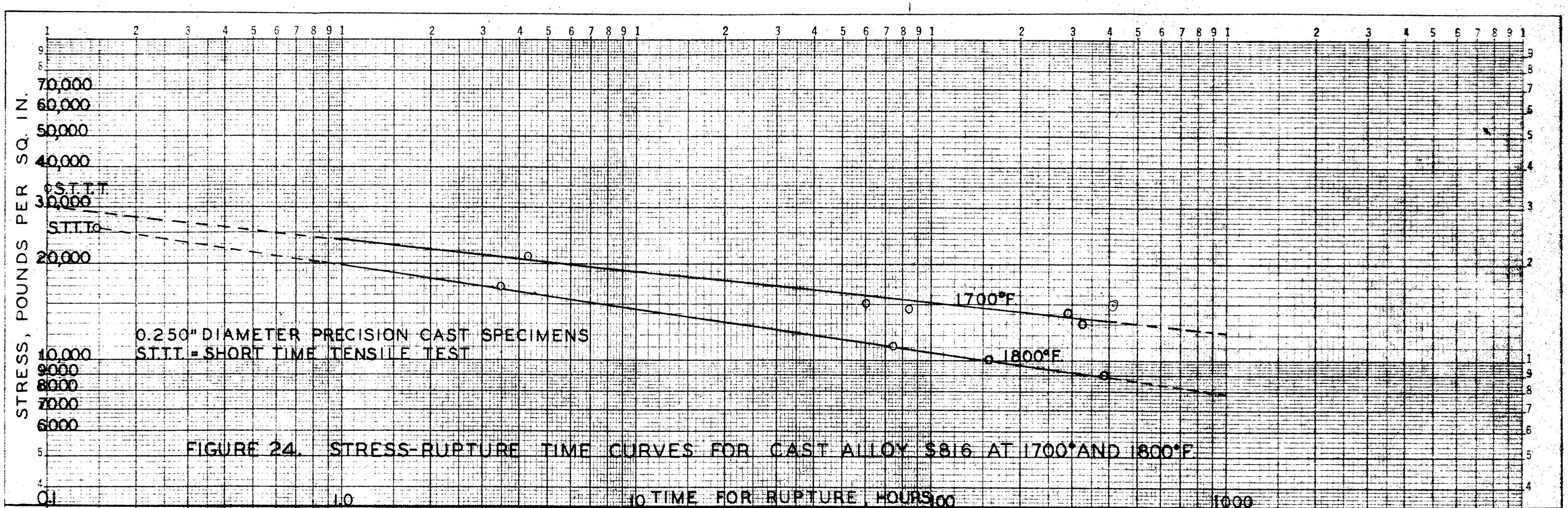

FIGURE 24. STRESS-RUPTURE TIME CURVES FOR CAST ALLOY S816 AT 1700° AND 1800°F.

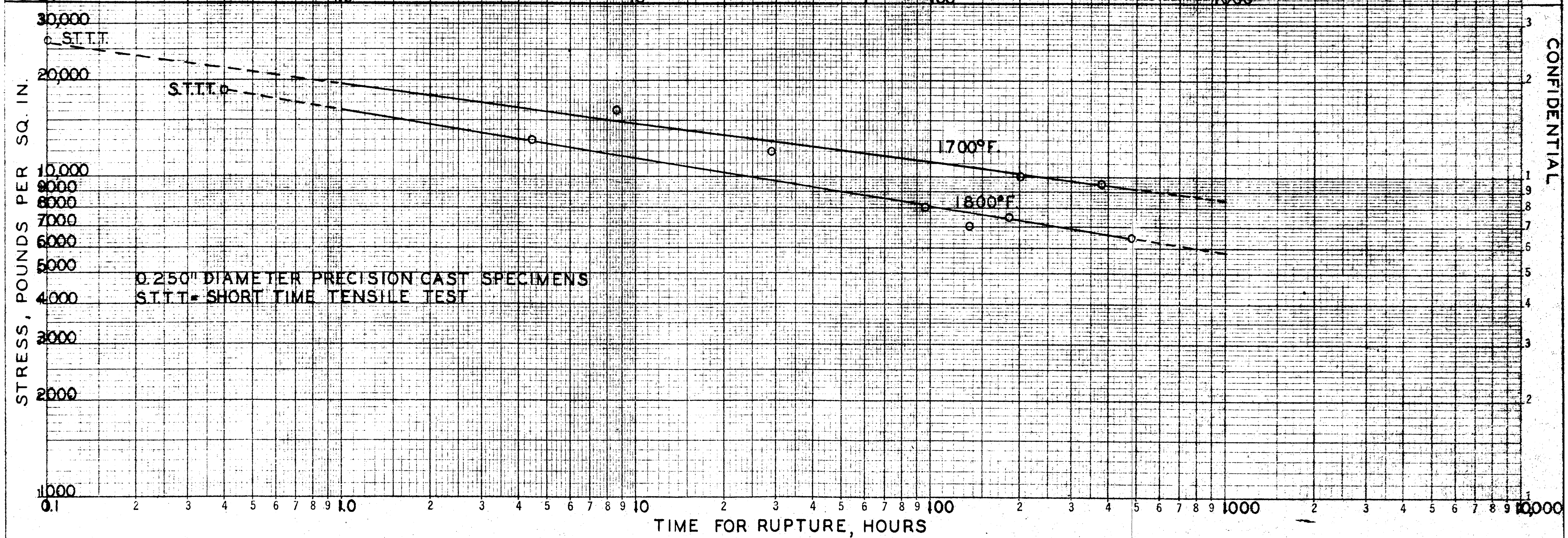

FIGURE 25. STRESS-RUPTURE TIME CURVES FOR CAST ALLOY S590 AT 1700° AND 1800°F.

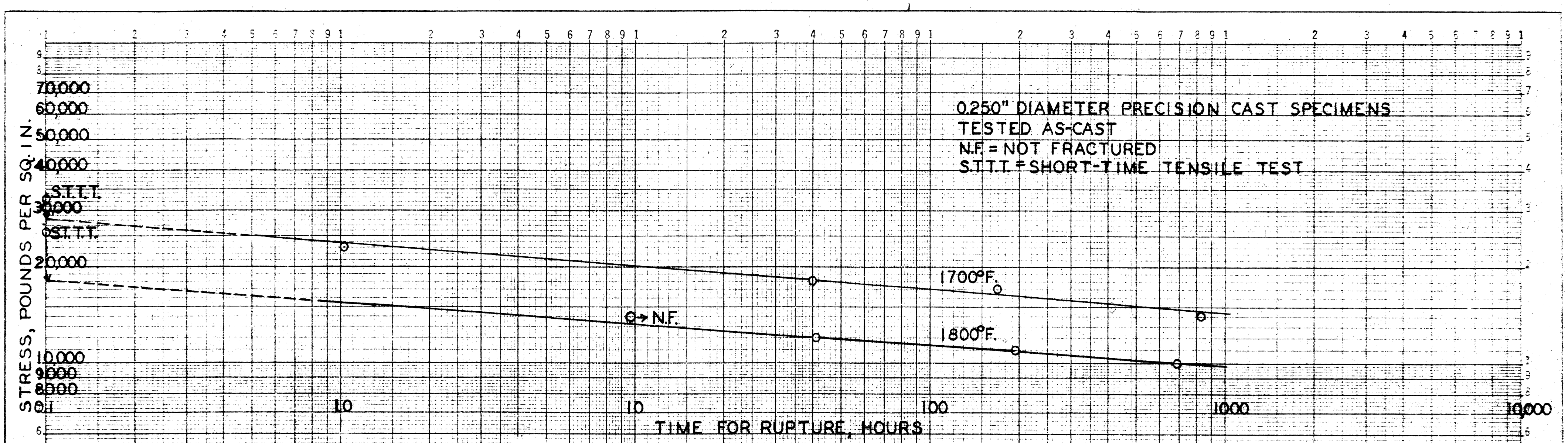

FIGURE 26. STRESS-RUPTURE TIME CURVES FOR ALLOY X-40 AT 1700 AND 1800°F.

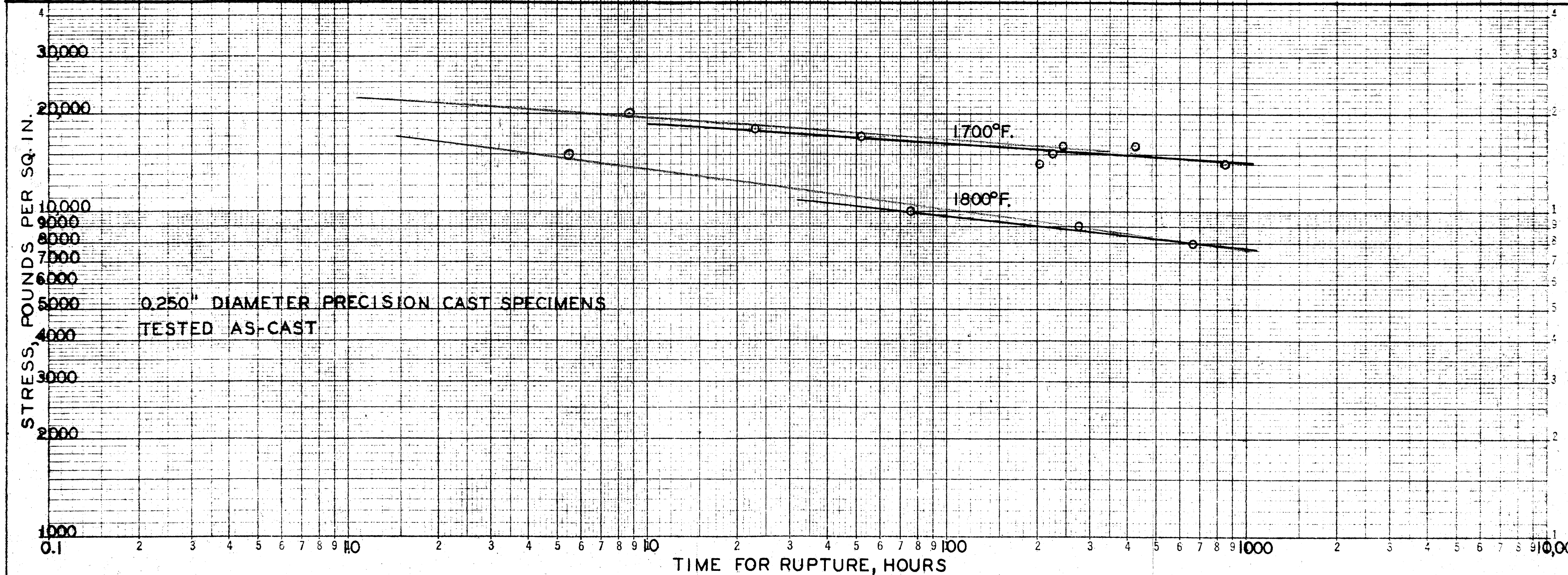

FIGURE 27. STRESS-RUPTURE TIME CURVES FOR ALLOY X-50 AT 1700 AND 1800°F.

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H. Ceramic Coatings

Rupture tests are in progress at 1350°F. on Timken Alloy (16Cr-25Ni-6Mo) specimens coated by the Bureau of Standards with a ceramic material designated as coating A-68f. Since the application of the coating involved heating the specimens to 1650°F., both coated and uncoated specimens are being tested for comparison. The samples are briefly described together with the available rupture test data in Table XVIII and Figure 28.

The rupture test data obtained to date indicate excellent adherence for the coating with high elongation to fracture. As yet comparative data for uncoated specimens is not complete enough to determine if the coating has any effect on the rupture test characteristics although the one test does not indicate an appreciable difference. The 1350°F. rupture tests on Timken Alloy reported in ACR No. 4C22 all indicate higher rupture strength than was found for the coated specimens. This may well have been due to the solution treatment of the former or an inherent difference between heats.

Table XVIII

RUPTURE TEST CHARACTERISTICS OF CERAMIC COATED TIMKEN ALLOY AT 1350°F.

Base Metal

As rolled and stress relieved bar stock from Heat 10446 was machined into the 0.160-inch diameter specimens and supplied to the N.A.C.A. for coating by the Bureau of Standards. The bar stock was the same material which has been used in the investigation of processing variables at the University of Michigan(1)(2). This bar stock was reportedly finished by rolling at 2110°F. to 1865°F. from 2-1/4-inch square bars to 7/8-inch square bars.

Coating

The specimens were cleaned by a light sand blast followed by immersion in a 3% nickel-ammonium sulfate solution at a pH of 5.6 to 6.4 at 65°C. A coating of mix A-68f was sprayed, dried and fired at 1650°F. for 7½ minutes. A second layer was then applied in a similar manner. The resultant coating was approximately 0.0025-inches thick.

A slightly oversize set of specimens was carried through the process without the application of the coating. These have been machined to size and are being tested for comparison with the coated specimens.

1350°F. Rupture Test Data

Samples	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
Coating A-68f	30,000	21.5	59	66.2
	25,000	46.5	57	71.8
	20,000	108.0	54	71.8
	15,000	887.0	32	55.3
Uncoated	20,000 17,500	172.0	53	74.4

Apparently the adherence of the coatings has been very good in all tests.

(1) "A Study of the Effects of Heat Treatment and Hot-Cold Work on the Properties of Four Turbosupercharger Wheel Alloys", Report No. 6 under Project M478 to the National Advisory Committee for Aeronautics from the University of Michigan, November 30, 1943.

(2) "The Effects of Heat Treatment and Hot-Cold Work on the Properties of Five Alloys", Report No. 9 to the National Advisory Committee for Aeronautics from the University of Michigan, February 26, 1944.

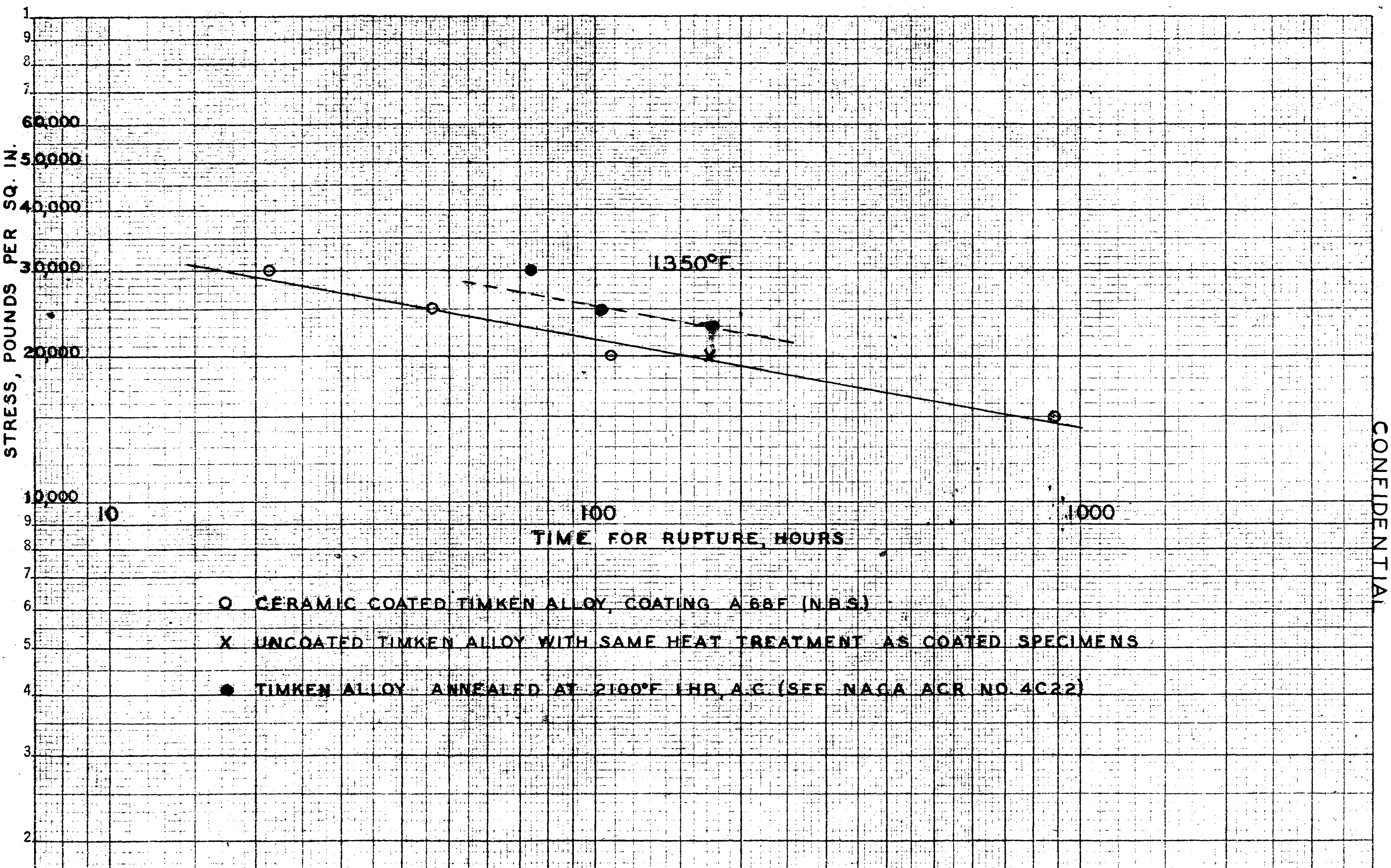

FIGURE 28. STRESS-RUPTURE TIME CURVES AT 1350°F FOR CERAMIC COATED TIMKEN ALLOY

I. Segregations in 234-A-5 Alloy

During the course of fabrication of several large forgings of 234-A-5 alloy, segregations of excess constituents in a 9-inch square billet were observed by the Crucible Steel Company. One of the questions which this brought up was the effect of such segregations on the 1200°F. strength of the alloy. A limited number of rupture tests are being conducted on specimens from the surface and center of the billet to obtain information on this point.

Prior to testing the samples were heated at 2050°F., transferred to a furnace at 1400°F. and held for 24 hours before a cooling in air. The rupture test results obtained to date are as follows:

Samples	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
Surface	40,000	84	17	21.2
	37,500	122	26	40.8
	35,000	640	16	28.8
Center	38,000	52	22	30.8
	36,500	36	30	44.2
	36,500	36	30	50.3
	35,000	384	25	40.0

The stress-rupture time characteristics are graphically compared in Figure 29 with those of the large disc given in Section A of this report. The data indicate:

1. The greater amount of excess constituents in the center specimens resulted in somewhat lower strength and higher elongation than for the surface specimens with less excess constituent. The rupture times were quite erratic, however.
2. The rupture strengths of the billet specimens are apparently equal to or higher than the large disc.

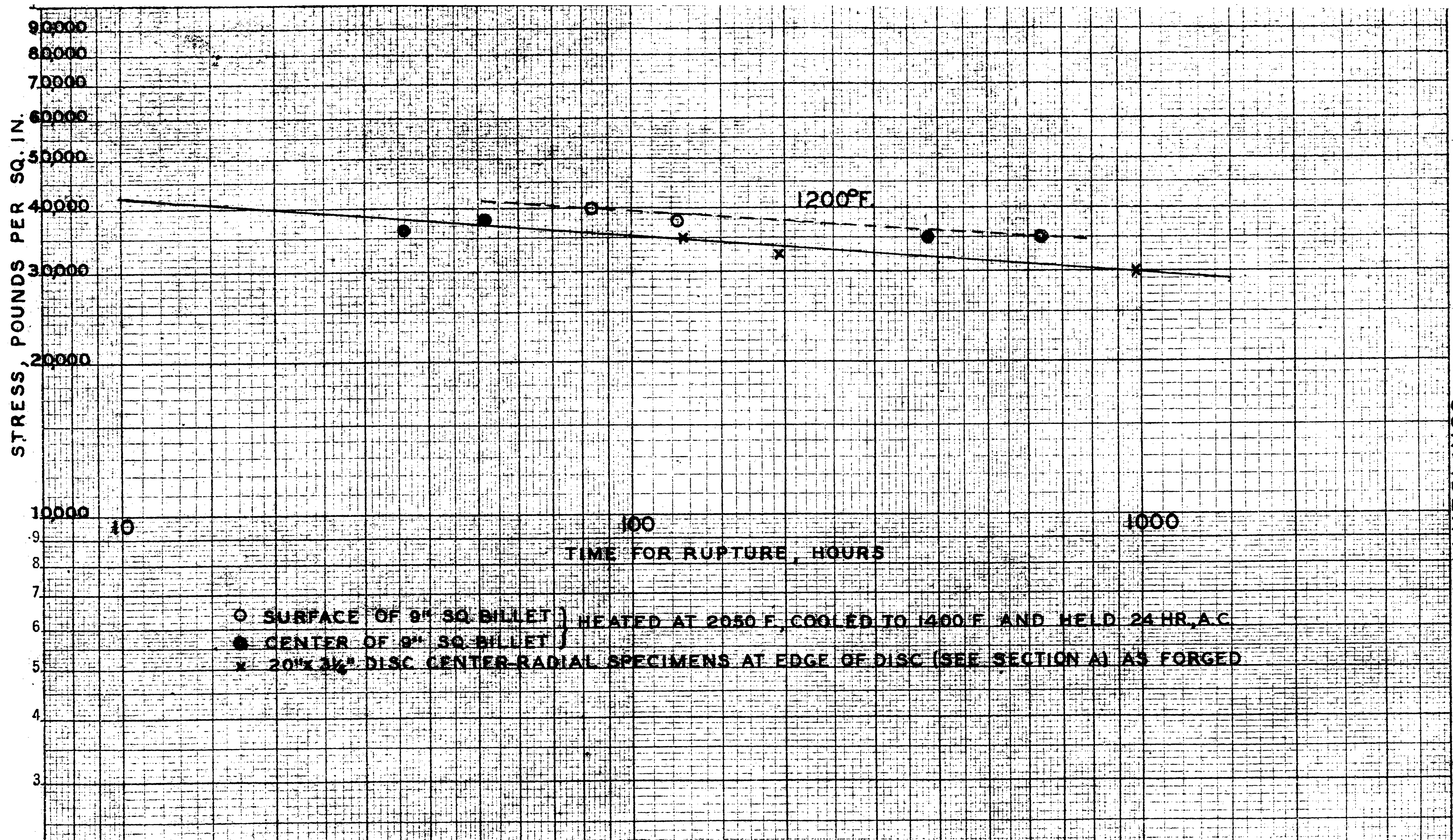

FIGURE 29 EFFECT OF SEGREGATIONS ON THE RUPTURE STRENGTH OF ALLOY 234-A-5 AT 1200°F.

J. Investigations to be Undertaken

1. Boron modified Low Carbon N155 alloy specimens are being supplied by H. C. Cross for rupture tests at 1200 and 1350°F.

2. Precision cast 19-9 DL specimens have not yet been submitted.

3. Specimens of two alloys developed at Massachusetts Institute of Technology for the U.S. Navy have been received for tests at 1700 and 1800°F. This investigation was requested at the September 21, 1944 Subcommittee meeting. The two alloys to be tested are the following:

	Chemical Composition, Per Cent						
Alloy	C	Cr	Ni	Co	Mo	W	Ta
113VT2-2	1.13						
128VT2-2	1.28	23	--	67	6	--	2
97NT-2	0.97	21	30	21	3	2.2	2

Only carbon was actually analyzed with the other elements being aim values, reportedly known to be quite close to actual values.

The 113VT2-2 and 128VT2-2 specimens are being tested "as-cast" and both heats are to be considered as the same material. The 97NT-2 specimens were heat treated at 2260°F. for 1/2-hour and water quenched. Both alloys were melted in a small arc furnace and cast by the Austenal procedure in molds preheated to 1850°F.

4. Notice has been received that the Low Carbon N155 bar stock has been shipped for the investigation of manufacturing variables.