DEPARTMENT OF ENGINEERING RESEARCH

UNIVERSITY OF MICHIGAN

ANN ARBOR

STATUS

OF

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

February 8, 1945

Approved by

A. E. White

Written by

E. E. Reynolds
J. W. Freeman

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

~~February 8~~, April 26, 1945

Several related investigations are in progress at the Department of Engineering Research of the University of Michigan for the National Advisory Committee for Aeronautics under contract NAw 3781 covering a general research program for the development of heat-resisting alloys for aircraft power plants. In view of the long time required for the completion of the investigations a series of "status" reports have been issued prior to meetings of the Subcommittee on Heat-Resisting Alloys, Committee on Power Plants for Aircraft so that the members could be guided by partial results. The last "status" report was issued under date of ~~November 10~~, February 8, 1944. Since that time two final reports have been issued

Report ~~15~~ 17, "A Metallurgical Investigation of a Large Forged Disc of 19-9 DL Alloy" January 12, 1945.

Report ~~16~~ 18, "The Effect of Chemical Composition Modifications on the High Temperature Properties of 19-9 DL, N155 and Low Carbon N155 Alloys" January 25, 1945.

The "status" reports are intended to be brief factual presentation of partial results. The data have not been checked as in the preparation of final reports. Likewise, further data from subsequent work may show that values and trends should be modified. <u>All statements, data and figures in this report are, therefore, tentative and are subject to change as more complete results become available.</u>

A. Large Forgings of Low Carbon N155, 234-A-5 and S590 Alloys

Rupture test characteristics and time-total deformation characteristics are being determined at 1200 and 1350°F. for several large disc forgings of the type intended for use as gas turbine rotors. These properties are being completely determined for one of the Low Carbon N155 discs and one of the 234-A-5 discs. The other discs are to be evaluated by a few rupture tests and by 1000-hour creep tests at 1200°F. under stresses of 25,000 and 35,000 pounds per square inch, in accordance with the action of the subcommittee at the November 28, 1944 meeting. Further investigation of the discs at 1350°F. is planned when time and equipment permit.

1. Low Carbon N155 Discs

Six discs, Table I, representative of various treatments, two sources and two heats are being studied. Complete rupture and deformation studies are being made on the Universal Cyclops disc NR66D. The rupture test data obtained to date, Table II, Table VII and Figure 1 show that the discs from Crucible Steel Co. have lower rupture strength than disc NR66D. There is apparently relatively little difference in strength due to the various treatments.

The comparative time-deformation characteristics, Table VIII and Figure 2 show considerable variation between the treatments given three of the Crucible discs, although all are weaker than NR66D.

2. 234-A-5 Alloy Discs

Three discs, Table III, representing two heats and three treatments are being tested. A further variable is the higher carbon content of the discs from Heat 1X2280. Complete data are being obtained on the disc from Heat 1X2218 at 1200°F. and only partial data on the other two.

The rupture test data obtained to date, Table IV, Table VII, and Figure 1, indicate that the two high carbon discs from Heat 1X2280 will be considerably stronger than the lower carbon disc from Heat 1X2218. Stress-time for deformation curves for the disc from Heat 1X2218, Figure 3, and Table VIII, are nearly complete while no creep tests have yet been started on the other two discs.

3. S590 Discs

Two discs of S590 alloy, Table V, representing one heat and three treatments are included in this program. Relatively little difference in rupture strength at 1200°F. resulted from the three treatments considered, Table VI, Table VII, and Figure 1, although the solution treated samples had lower ductility to fracture. One creep test is in progress on the as forged and aged disc, Table VIII and Figure 2. At 1350°F. the solution treated disc will be stronger than the as-forged and aged disc and equal to bar stock (Section D).

4. Comparative Properties

Of the alloys tested the as-forged and aged S590 disc has the best properties at room temperature, Table IX. As forged Low Carbon N155 disc NR66D and the S590 discs will apparently have the highest rupture strengths and time-deformation characteristics, Tables VII and VIII.

Table IV

Description of Low Carbon N155 Alloy Discs

Chemical Composition

Disc	Heat Number	C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	N_2
NR66D	-----	.15	1.74	.37	21.66	19.40	19.02	2.76	1.90	.79	.14
NR66E	1X2232	.07	1.68	.60	20.80	20.60	20.07	2.94	2.67	1.05	.125

Manufacturing Procedure

Disc NR66D was produced by the Universal-Cyclops Steel Corporation as a 20-inch diameter X 3-5/16 inch thick forging finished at 1630°F. and stress relieved at 1200°F. for two hours.

Three discs were produced from Heat 1X2232 by the Crucible Steel Company. A 15-inch square ingot was made from a one-ton induction furnace heat. A 9-inch square billet was cogged on a 7-ton hammer from the ingot at 2100/2150°F. Three reheatings were required in 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 temperatures being approximately 1500°F.

Five representative conditions were produced by cutting the discs in half and subjecting them to the following treatments:

As Forged: One-half of disc No. 1.

As Forged + Aged at 1500°F: One half of disc No. 1 was heated to 1500°F. for 24 hours.

Solution Treated + Aged at 1500°F: Disc No. 2 was heated to 2200°F. and quenched in water. One half was reheated to 1500°F. for 24 hours.

Solution Treated + Aged at 1350°F: The other half of disc No. 2 was reheated to 1350°F. for 24 hours.

Solution Treated + "Hot-Cold" Worked + Aged at 1500°F: Disc No. 3 was left about 1/8-inch oversize in the upsetting operating, reheated to 2250°F. and water quenched. After reheating to 1500°F. for 3 hours it was reduced approximately 1/8 inch in thickness (approx. 3% reduction), the finishing temperature being about 1200°F. The final treatment was holding at 1500°F. for 24 hours.

Table II

Rupture Test Characteristics of Low Carbon N155 Discs
(Radial Specimens in Center Plane of Discs)

Disc	Temp. °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
As forged 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
		25,000	738.5	7	9.1
		23,000	1734.0	5	6.2
		20,000	1336.0	5	6.0
As forged Heat 1X2232 (14-3/4" Diam. X 4-3/8" Thick)	1200	55,000	10.0	7	12.1
		47,500	40.0	10	17.8
		45,000	178.0	8	18.9
		40,000	613.0	15	17.8
As forged + aged at 1500°F. Heat 1X2232	1200	50,000	51.5	35	43.7
		45,000	143.0	36	41.8
		40,000	237.0	31	24.5
		37,500	504.0	19	21.7
Solution Treated + Aged at 1500°F. Heat 1X2232	1200	50,000	26.5	15	20.0
		45,000	80.0	15	22.3
		40,000	205.0	20	24.5
Solution Treated + Aged at 1350°F. Heat 1X2232	1200	50,000	11.0	13	17.2
		40,000	188.0	10	15.6
		35,000	In progress ~~1128~~ 1416 hrs.		~~2-8-45~~ 2-19-45
Solution Treated "Hot-Cold" Worked + Aged at 1500°F. Heat 1X2232	1200	48,000	61.0	23	23.9
		45,000	139.0	20	27.7
		40,000	228.0	7	24.5

Table ~~III~~ V

Description of 234-A-5 Alloy Discs

Chemical Composition

Disc	Heat No.	C	Mn	Si	Cr	Ni	Mo	W	Cb
----	1X2218	.25	4.14	.25	18.32	5.76	1.46	1.51	.95
#5,#6	1X2280	.42	4.47	.41	18.06	5.20	1.30	1.20	.28

Processing Procedures

The disc from Heat 1X2218 was forged to a 20-inch diameter x 3-5/16-inches thick disc. The finishing temperature was 1400°F. and the finished disc was stress relieved at 1200°F. for 4 hours.

Discs #5 and #6 from Heat 1X2280 were made from a 15-inch square ingot. The ingot was hammer cogged on a 7-ton hammer to a 9-inch square billet. 290-lb. slugs from the billet were heated to 2150°F. and upset and rounded to a 20-inch diameter X 3-7/8-inch thick discsin one heat on a 7-ton hammer. The finishing temperatures were 1650°F.

Disc #5 was air cooled from 2050/2100°F., heated to 1420°F. and "hot-cold" worked on a 7-ton hammer to 3-1/2-inches thick. The estimated finishing temperature was 1250°F. and the disc was stress relieved at 1200°F. for 4 hours.

Disc #6 was heated to 2050/2100°F. and air cooled to 1400°F. and held 24 hours, air cooled. After reheating to 1420°F. it was "hot-cold" worked on a 7-ton hammer to 3-1/2-inches thick. The estimated finishing temperature was 1250°F. and the disc was stress relieved at 1200°F. for 4 hours.

Table IV

Rupture Test Characteristics of 234-A-5 Alloy Discs
(Radial Specimens at Rim in Center Plane of 20" Diameter Discs)

Disc	Temperature °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction in Area %
As Forged 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	1596.0	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
#5 Sol. treated "hot-cold" work Heat 1X2280	1200	40,000	41.0	39	51.5
		35,000	In progress 216 hours 2-8-45		
#6 Sol. treated + aged + "hot-cold" work Heat 1X2280	1200	40,000	In progress 144 hours 2-8-45		

Table V

Description of S590 Alloy Discs

Chemical Composition

C	Si	Mn	Cr	Ni	W	Mo	Cb	Co	P	S
.45	.56	1.44	19.76	19.05	4.08	4.03	3.35	20.20	.015	.018

Manufacturing Procedure

These discs were produced by the Allegheny-Ludlum Steel Corporation. 12-inch ingots were forged from 2250°F. to 9-inch square billets, air cooled and ground. The nine inch billets were upset forged from 2250°F. to rough 4-inch thick discs.

Disc #1 - Reforged to 18-inch diameter 3-inch thick from 2250°F.
#1-A Solution treated at 2300°F. for 3-1/4 hours and water quenched
#1-B Some of Disc #1 was aged 16 hours at 1400°F. at Univ. of Mich.

Disc #2 - Reforged from 2250°F. to 3-3/4-inch thick, cooled, then reforged in one heat to 18-inch diameter 3-3/8-inch thick (10%) from 2000°F. The disc was then aged for 16 hours at 1400°F.

Table VI

Rupture Test Characteristics of S590 Alloy Discs

Disc	Condition	Temp. °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
#2	Forged plus aged at 1400°F.	1200	55,000	69.5	21.0	20.6
			50,000	150.0	17.0	21.2
			45,000	372.5	9.0	14.4
		1350	30,000	60.5	12.0	14.4
			25,000	180.0	8.0	11.5
			20,000	In progress 72 hours 2-8-45		
#1-A	Solution treated	1200	55,000	59.0	4.0	7.9
			50,000	74.0	6.0	8.5
			45,000	493.0	3.0	7.3
		1350	33,000	86.0	10.0	15.6
			30,000	252.0	11.0	15.0
			27,000	Starting 2-8-45		
#1-B	Solution treated plus aged at 1400°F.	1200	50,000	In progress 144 hours 2-8-45		

Table VII

Comparative Rupture Strengths at 1200° and 1350°F. of Low Carbon N155, 234-A-5, and S590 Alloy Discs

Alloy	Treatment	Temp. °F.	Stress, Lb./Sq.In. for Rupture at Indicated Time Periods, Hours 1	10	100	1000	2000
Low Carbon N155 (NR66D)	As forged	1200	77,000	65,000	55,000	42,000	39,000
Low Carbon N155 (NR66E)	As forged	1200	------	55,000	48,000	38,000	------
Low Carbon N155 (NR66E)	Forged + aged at 1500°F.	1200	------	------	46,000	34,000	------
Low Carbon N155 (NR66E)	Solution Treated + Aged at 1500°F.	1200	------	56,000	44,000	34,000	------
Low Carbon N155* (NR66E)	Solution Treated + Aged at 1350°F.	1200	------	50,000	42,000	35,000	------
Low Carbon N155 (NR66E)	"Hot-Cold" Worked + Aged at 1500°F.	1200	------	------	46,000	34,000	------
234-A-5	As forged	1200	49,000	42,000	35,500	30,000	28,500
234-A-5*	Solution Treated + "Hot-Cold" Worked	1200	------	------	37,500	------	------
234-A-5*	Solution Treated + Aged + "Hot-Cold" Worked	1200	------	------	40,000+	------	------
S590	Forged + Aged	1200	------	------	53,000	40,000	------
S590	Solution Treated	1200	------	------	51,000	43,000	------
S590*	Solution Treated	1200	------	------	52,000+	43,000	------
Low Carbon N155 (NR66D)	As forged	1350	52,000	40,000	31,000	24,500	22,500
234-A-5	As forged	1350	33,500	25,000	19,000	12,500	11,000
S590*	Forged + Aged	1350	------	------	27,500	19000	------
S590*	Solution Treated	1350	------	------	32,000	26500	------

*Data incomplete.

Table VIII

Comparative Time-Deformation Data for Discs at 1200°F. Under a Stress of 25,000 Lb./Sq.In.

(Revised February 20, 1945)

Alloy	Treatment	Initial Deformation %	Hours to Reach Indicated Total Deformations 0.2%	0.5%	Total Deformation at Indicated Time Period Hours	%	Creep Rate at 900 Hours o/o/Hour
Low Carbon N155 (NR66D)	As Forged	0.113	435	---	~~575~~ 900	~~0.214~~ 0.257	0.000053
Low Carbon N155 (1X2232)	As Forged ~~+ Aged at 1500°F~~.	0.127	70	~~1100~~ >900	~~575~~ 900	~~0.405~~ 0.473	0.00017
Low Carbon N155 (1X2232)	Sol. Treated + Aged at 1500°F.	0.127	65	600	~~575~~ 900	~~0.49~~ 0.647	0.00048
Low Carbon N155 (1X2232)	Sol. Treated + Aged at 1350°F.	0.143	215	---	~~575~~ 900	~~0.250~~ 0.305	0.00016
234-A-5 (1X2218)	As Forged	0.133	20	---	~~575~~ 900	~~0.387~~ 0.458	0.00022
S590	As Forged + 16 Hrs. at 1400°F	0.102	375	---	~~575~~ 900	~~0.215~~ 0.237	0.00005

Table IX

Comparative Tensile Properties for Forged Discs (Radial Specimens)

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
234-A-5: As Forged	Room	108,800	37,500	53,000	59,000	22,500	33.0	33.8	209
Heat 1X2218		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
S590: As Forged + 16 Hr. at 1400°F	Room	133,500*	72,500	------	------	------	13.0	19.2	302
		130,600	69,000	91,000	100,000	37,500	9.0	11.5	267
S590: Solution Treated	Room	125,500*	32,500	------	------	------	39.5	34.3	229/241
		117,500	37,500	53,000	59,000	22,500	30.5	27.2	211
S590: Solution Treated + Aged 16 Hr. at 1400°F	Room	134,000*	45,000	------	------	------	22.0	18.8	255
234-A-5: As Forged	1200	51,000		38,000	40,500	15,000	27.0	53.2	---
Heat 1X2218		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	---
234-A-5: As Forged	1350	39,700		32,000	34,500	15,000	40.0	55.7	---
Heat 1X2218		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	---

*Allegheny-Ludlum data.

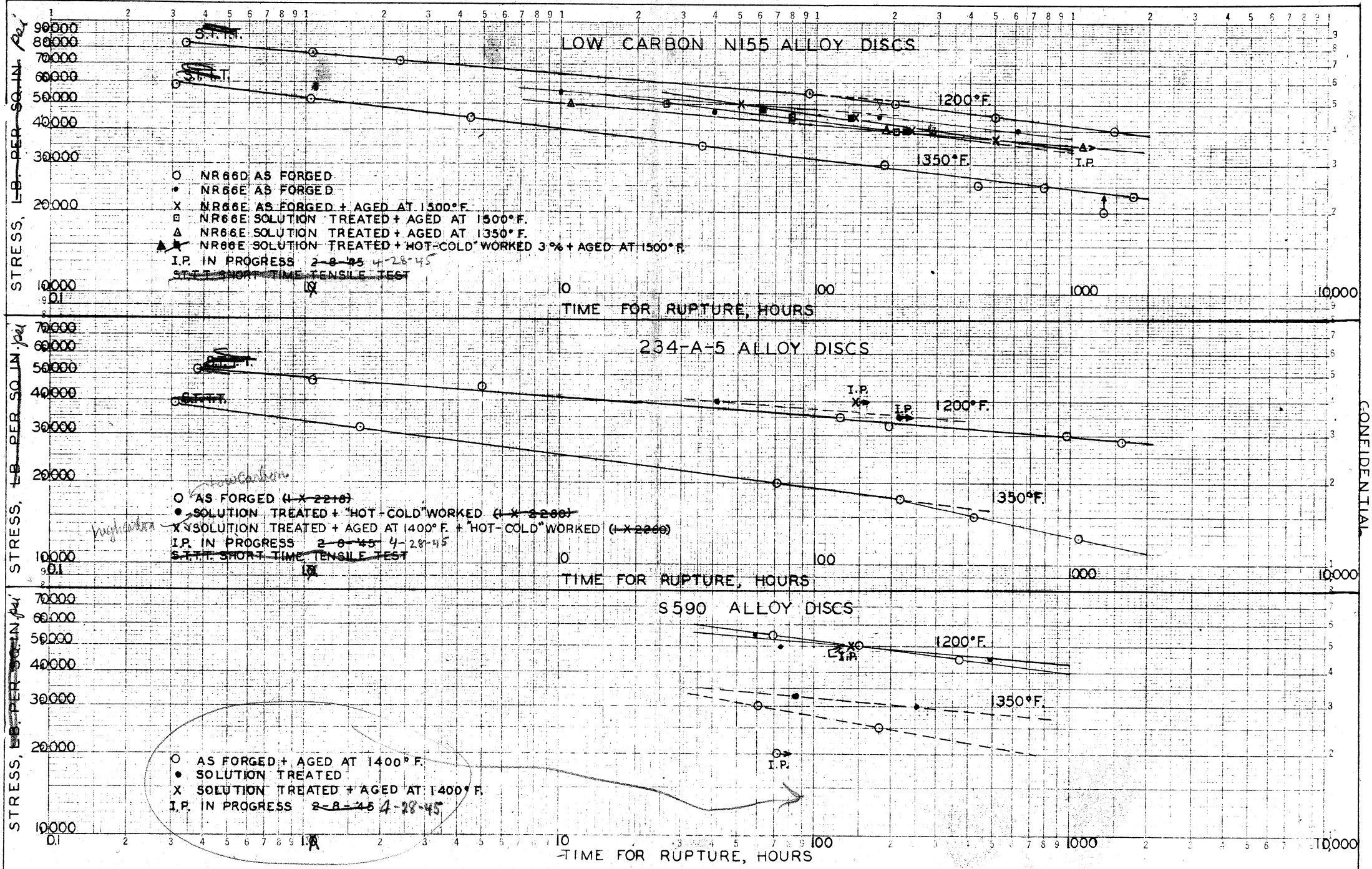

FIGURE 1. STRESS-RUPTURE TIME CURVES AT 1200° AND 1350°F FOR LARGE GAS TURBINE DISCS OF LOW CARBON N155, 234-A-5, AND S590 ALLOYS and Timken Alloys

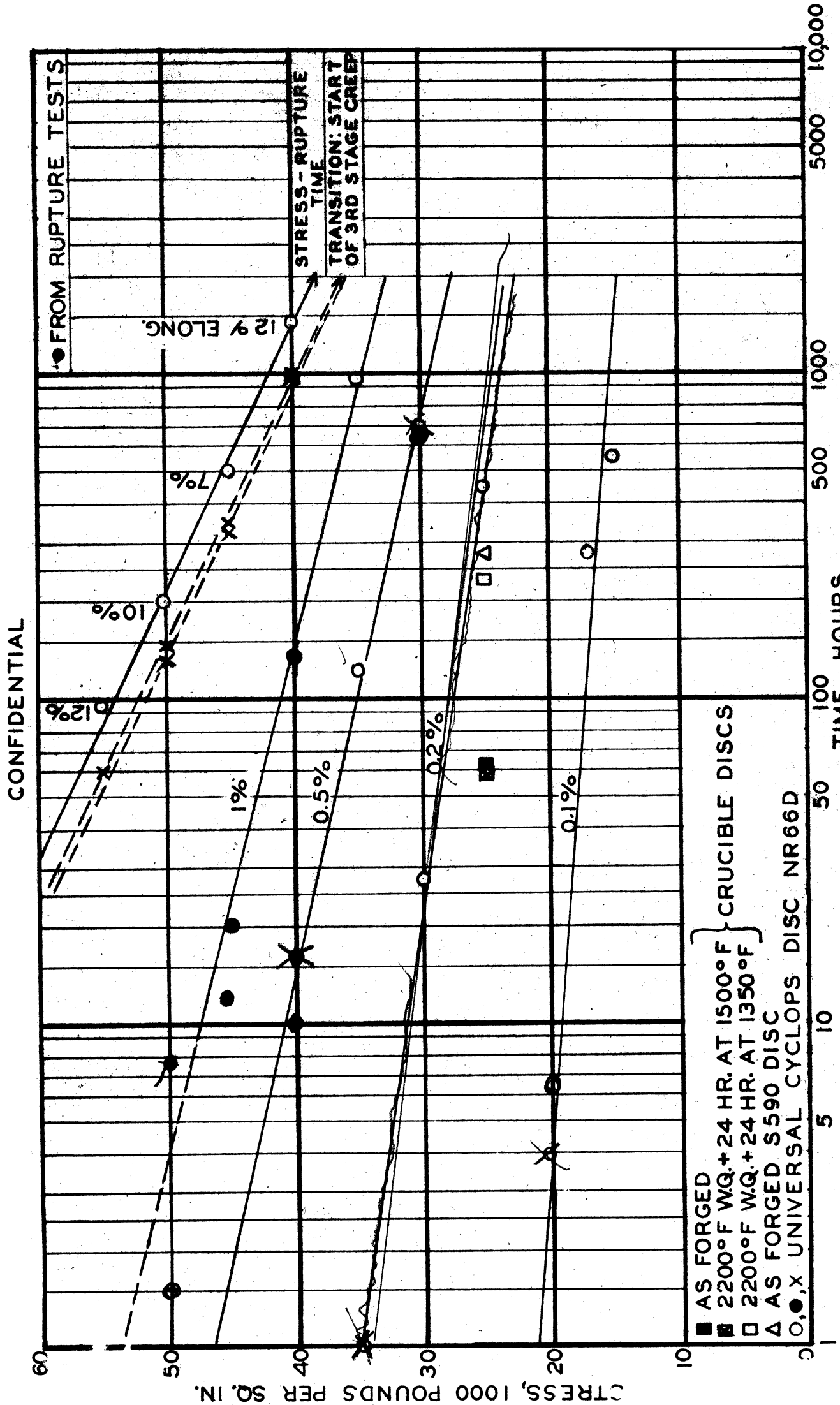

FIGURE 2 STRESS VS. TIME FOR INDICATED TOTAL DEFORMATIONS AT 1200°F FOR LOW CARBON N155 ALLOY DISC NR66D

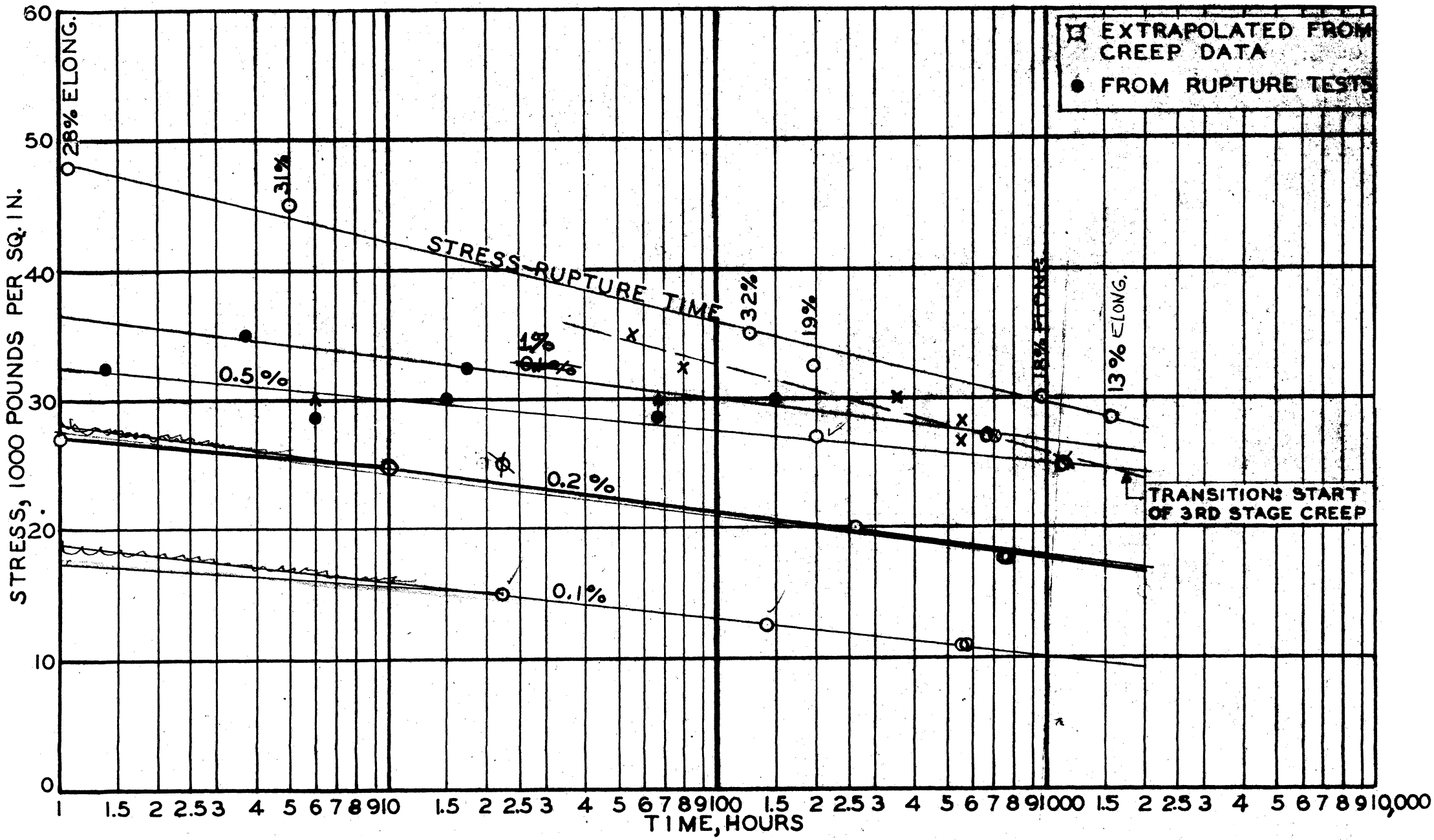

FIGURE 3. CURVES OF STRESS VS. TIME FOR INDICATED TOTAL DEFORMATIONS FOR AS FORGED 234-A-5 DISC AT 1200°F. (HEAT IX 2218)

B. 19-9 DL Turbosupercharger Discs at 1200° and 1350°F.

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 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 X. The rupture test data are compared with those for the other conditions in Figure 4.

There was no appreciable difference in stress-rupture time characteristics at 1200°F. due to the omission or use of a solution treatment prior to "hot-cold" working the discs. Comparative data in Figure 4 for "hot-cold" worked bar stock and a large disc from this same heat show that for time periods up to at least 1000 hours the "hot-cold" work was beneficial to strength. There was no appreciable difference between the discs and the bar stock from Heat B-10429 although the strength of the bar stock from Heat R-1803 was considerably higher.

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 X

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 (no solution treatment)	1200	60,000	26.0	5.0	3.7
		50,000	141.0	1.5	3.7
		45,000	289.0	1.0	1.2
		40,000	282.5	1.0	1.2
		37,500	957.0	2.0	3.2
	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 (solution treated)	1200	55,000	34.0	1.5	3.1
		50,000	212.5	3.5	5.1
		40,000	504.0	1.0	2.3
		35,000	1475.0	2.0	2.4
	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

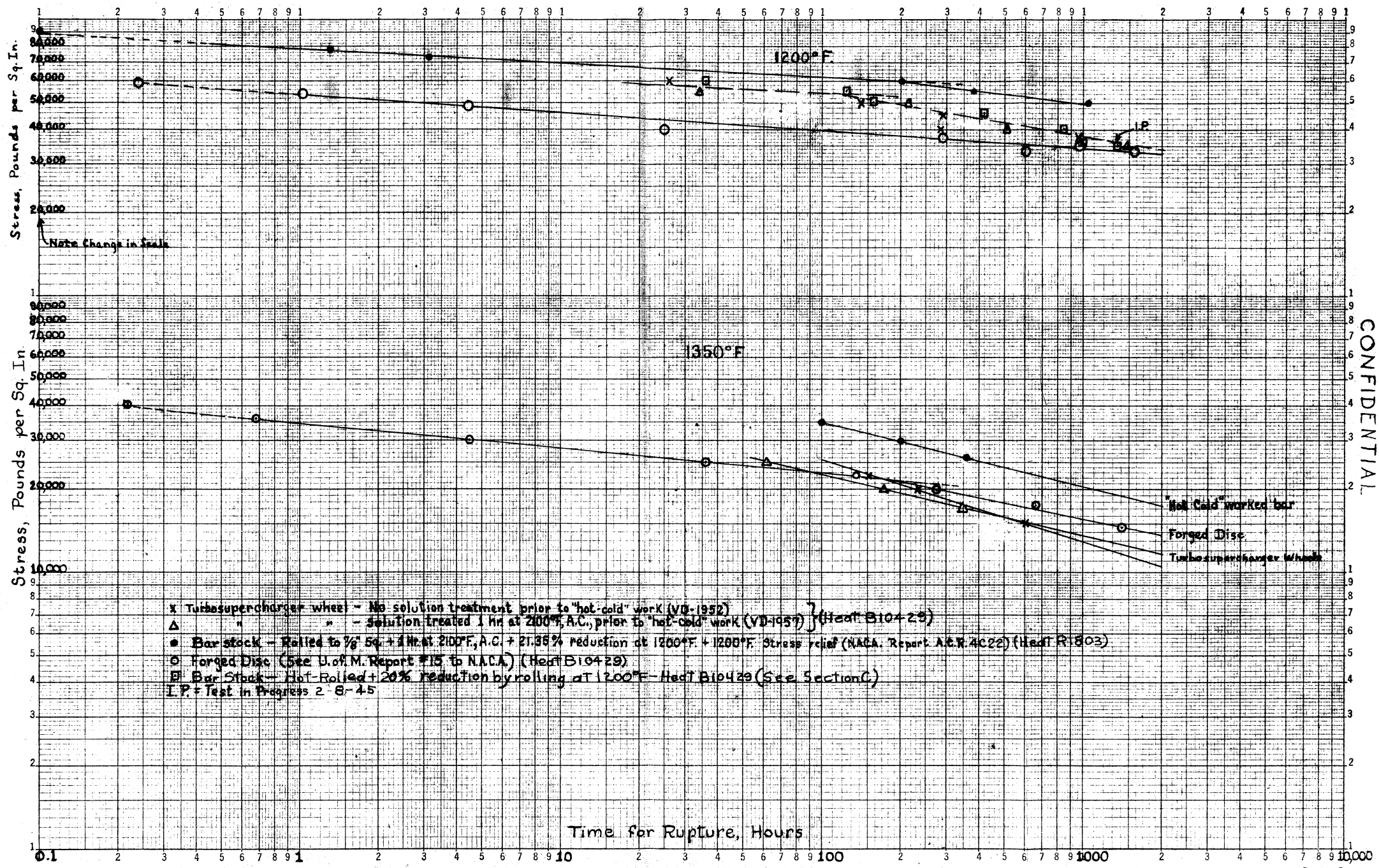

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Figure 4. COMPARATIVE STRESS-RUPTURE TIME CURVES [redacted] FOR 19-9 DL STEEL TURBOSUPERCHARGER WHEELS, BAR STOCK AND LARGE FORGED DISC AT 1200 AND 1350°F.

C. Typical 19-9 DL Bar Stock

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 XI together with the available tensile and rupture test data. The stress-rupture time curves are shown in Figure 5 and time-deformation curves in Figures 6 and 7.

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, Report 15, and lower than the "hot-cold" worked bar. The latter, however, is weaker than the original "hot-cold" worked induction heat R1803 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, Figure 6, than for the large disc, Report 15. The one point available for "hot-cold" worked bar stock shows considerable improvement over the hot-rolled condition. The point for "hot-cold" worked bar stock was obtained from a creep test at 1200°F. of 1000-hours duration. The results from this test may be summarized as follows:

		Large Disc
Stress	25,000 Lb./Sq.In.	
Initial Deformation	0.128%	.132
Time to reach 0.2%	80 hours	5.2
Total Deformation in 1000 hours	0.32%	
Creep Rate at 1000 hours	0.00011% per hour	

At 1350°F. the hot-rolled bar stock was weak as is shown by the early onset of third stage creep and excessive deformations under a stress of only 8000 pounds per square inch, Figure 7.

Table XI
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 XI (Continued)

Tensile Properties of Typical 19-9 DL Bar Stock

Heat No.	Condition	Temp. °F.	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	Room	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% at 1200°F.	Room	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	98,625	64,000	83,500	88,000	32,500	13.5	30.8	
			98,400	64,000	84,000	88,000	30,000	12.0	23.7	
B-10429 Bar #1	Sol. treated 1 hour at 2100°F., A.C. + 1 hour at 1200°F.	Room	101,750	23,000	35,500	41,500	15,000	52.5	58.2	186
			102,950	30,000	38,500	43,000	20,000	54.0	57.6	189
		1200	67,400	19,000	23,000	24,500	7,500	35.5	37.9	
			66,400	19,000	23,000	25,000	7,500	35.0	35.0	

*Universal Cyclops data.

Table XI (Continued)

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

Heat No.	Condition	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of 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
B10429 Bar #3	"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	978.0 1406	3.0 4.0	6.1
		35,000	~~In progress 1344~~ hours 2-8-45		6.2
B10429 Bar #1	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	693.0	30.0	33.5
		32,500	~~In progress 1704 hours 2-8-45~~ 2069	10.0	17.8

*Universal Cyclops data.

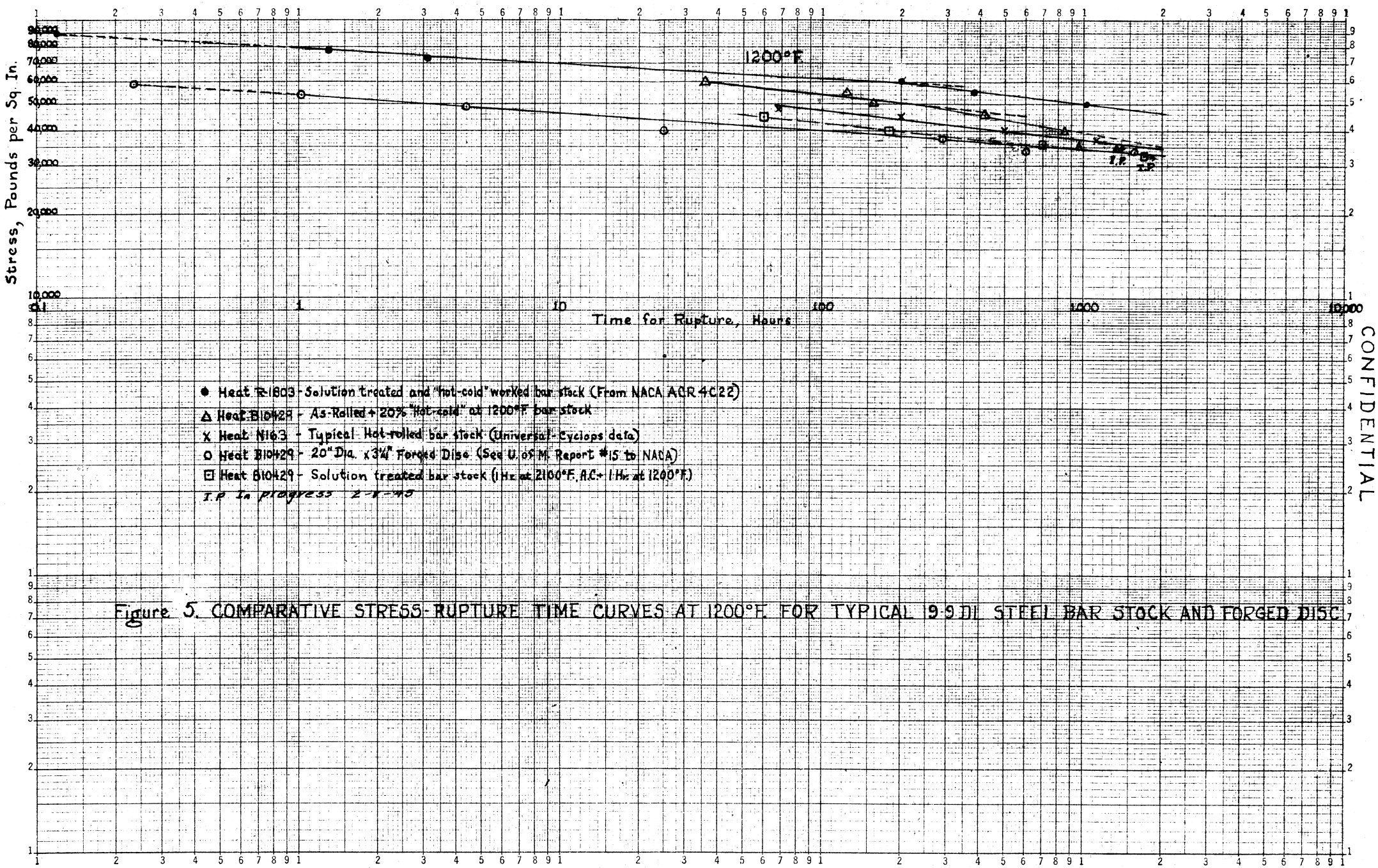

Figure 5. COMPARATIVE STRESS-RUPTURE TIME CURVES AT 1200°F. FOR TYPICAL 9-9 DL STEEL BAR STOCK AND FORGED DISC

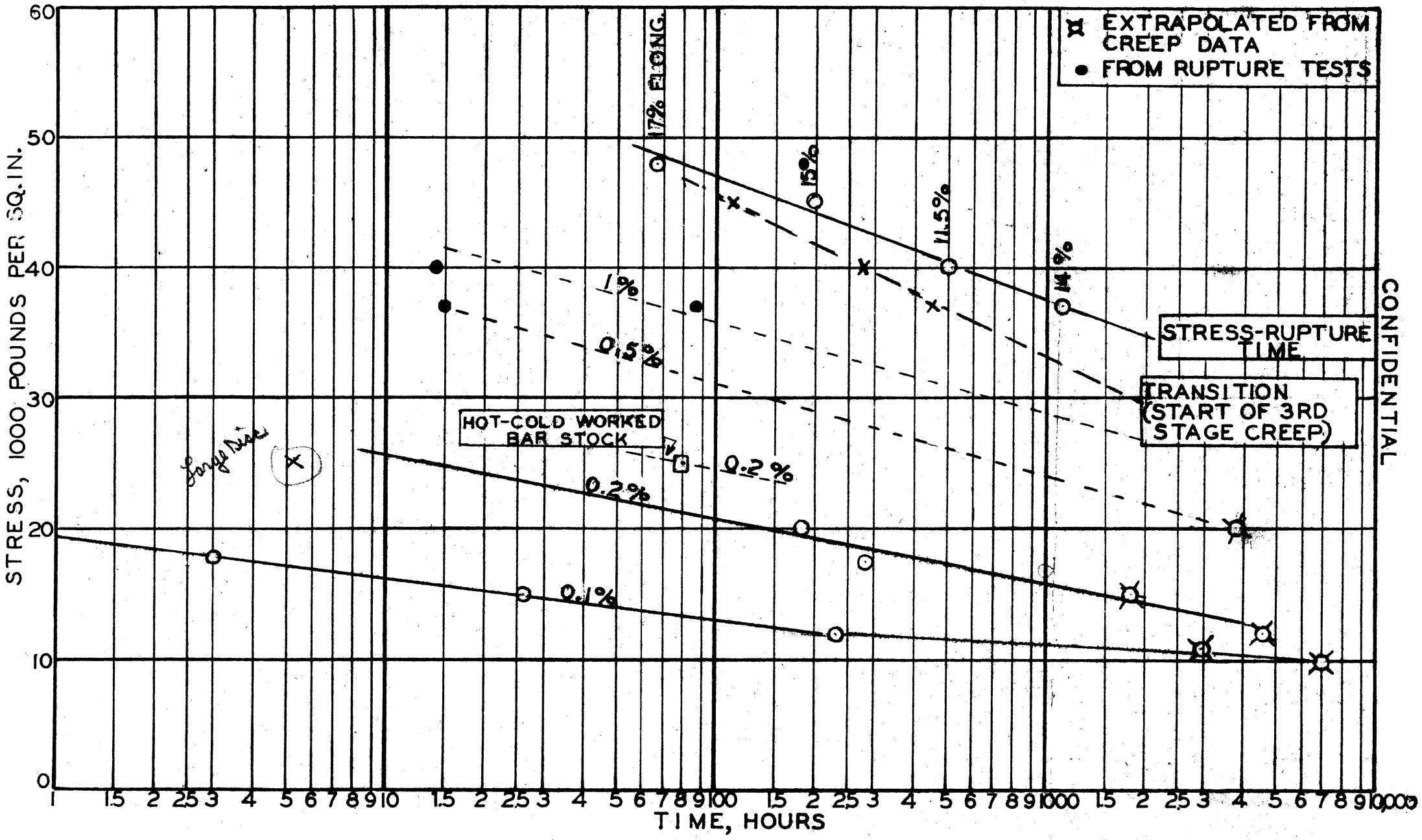

FIGURE 6. CURVES OF STRESS VS. TIME FOR INDICATED TOTAL DEFORMATIONS AT 1200°F. FOR TYPICAL HOT-ROLLED 199DL STEEL (HEAT N163 HOT-ROLLED + STRESS-RELIEVED AT 1200°F.)

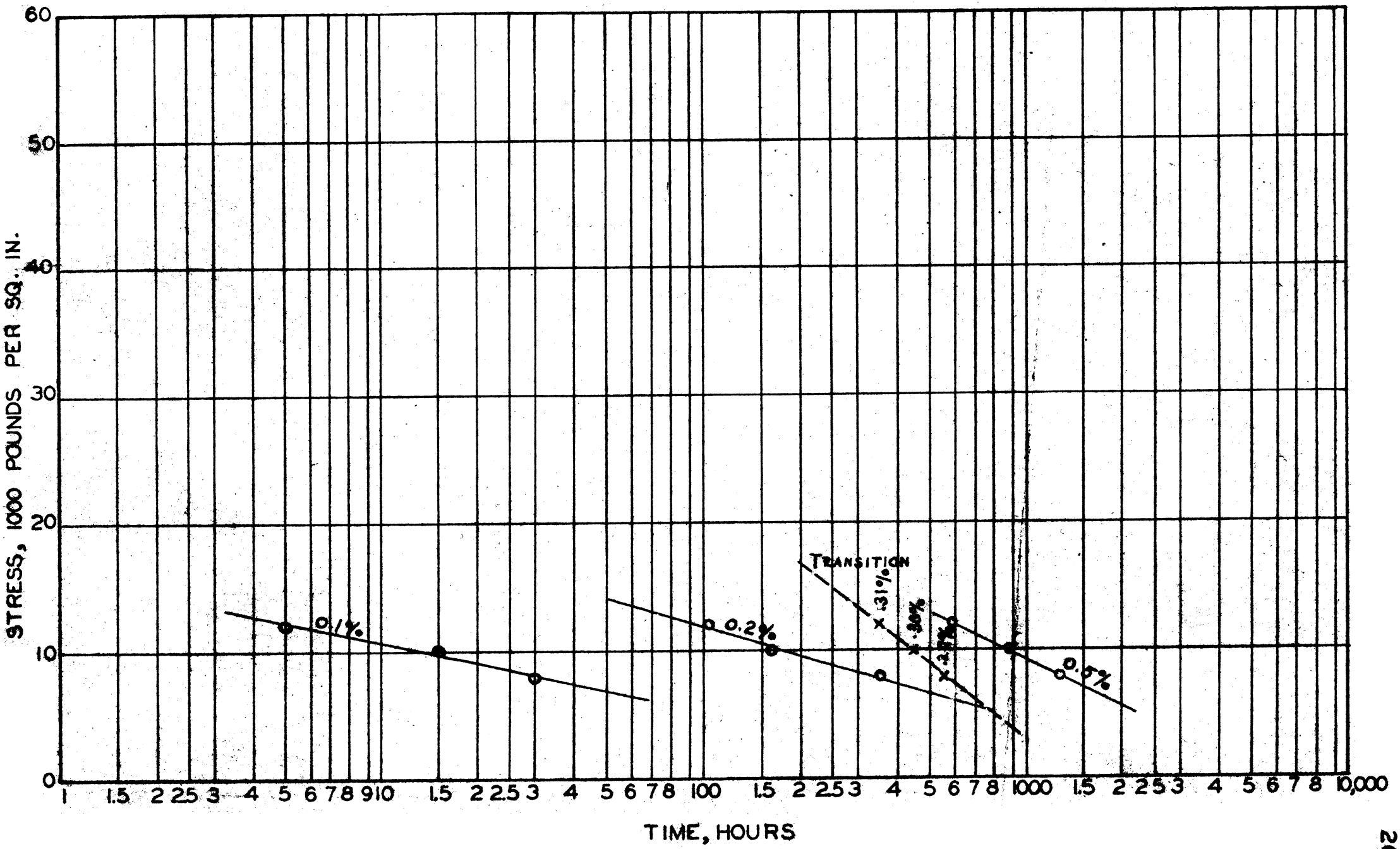

FIGURE 7. CURVES OF STRESS VS. TIME FOR INDICATED TOTAL DEFORMATIONS AT 1350° F FOR HOT ROLLED 19-9DL STEEL BAR STOCK

D. S816 and S590 at 1350°F.

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 XII and the stress-rupture time relationships are shown graphically in Figure 8.

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.

Of the two large discs of S590 being tested, Section A, the solution treated disc has the same rupture strength as the best bar stock, Figure 8 and the following tabulation. The as forged and aged disc, however, is considerably weaker, indicating the desirability of a solution treatment prior to service at 1350°F.

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
S590 Large disc (Forged + Aged)*	27,500	------
S590 Large disc (Solution treated)*	32,000	------
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 (2)	23,000	15,500
234-A-5 Bar Stock(1)	22,500	12,500
234-A-5 Disc*	19,000	12,500

*See Section A.
(1) ACR No. 4C22.
(2) U. of M. Report No. 15 to N.A.C.A.

Table XII

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 XII (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	---
	1350	85,900	54,200	64,600	68,700	28,900	8.0	10.0	---

*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

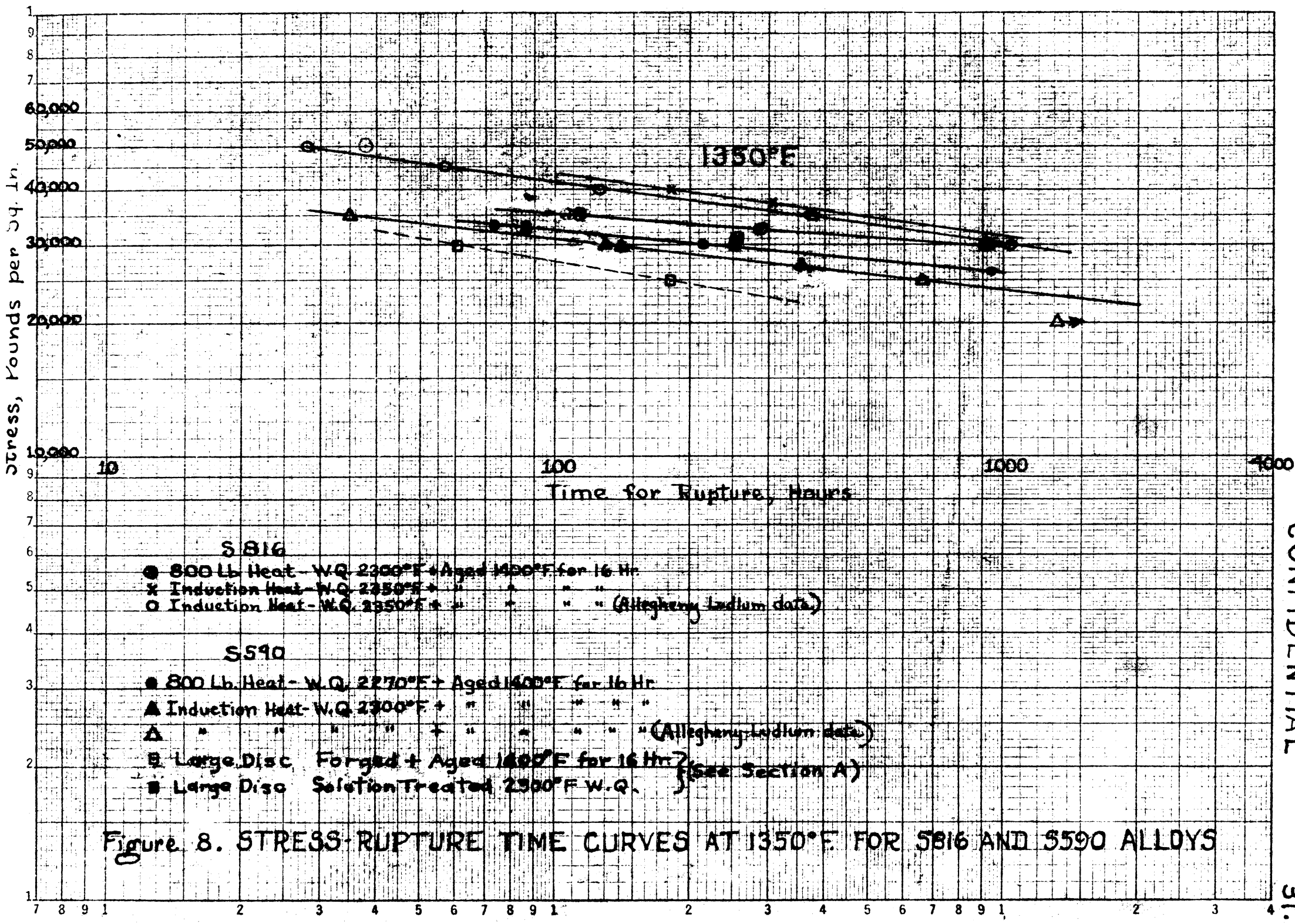

Figure 8. STRESS-RUPTURE TIME CURVES AT 1350°F FOR S816 AND S590 ALLOYS

E. 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 9 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, Figure 10. Likewise there was practically no difference between the present results and those obtained for the original heat of this alloy.

The work on this subject is now completed and a report will be submitted as soon as possible.

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.

Tensile Properties

Sample	Temp. °F.	Tensile Strength Lb./Sq.In.	Offset Yield Strength Lb./Sq.In. 0.02%	0.1%	0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %	Brinell Hardness
Vacuum melted (J-608)	Room	159,125	91,500	100,000	103,400	68,400	25.0	29.8	300
		160,000	89,500	101,500	104,700	65,600	23.0	29.0	302
	1200	119,750	86,600	96,600	99,500	57,900	10.5	13.8	
Air melted (J-598)	Room	175,000	100,000	113,000	117,000	67,500	27.5	40.7	314
		175,000	101,000	113,500	118,000	67,500	26.5	31.4	313
	1200	112,375	84,600	98,800	102,300	60,500	3.5	10.8	

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	404	2	2.3

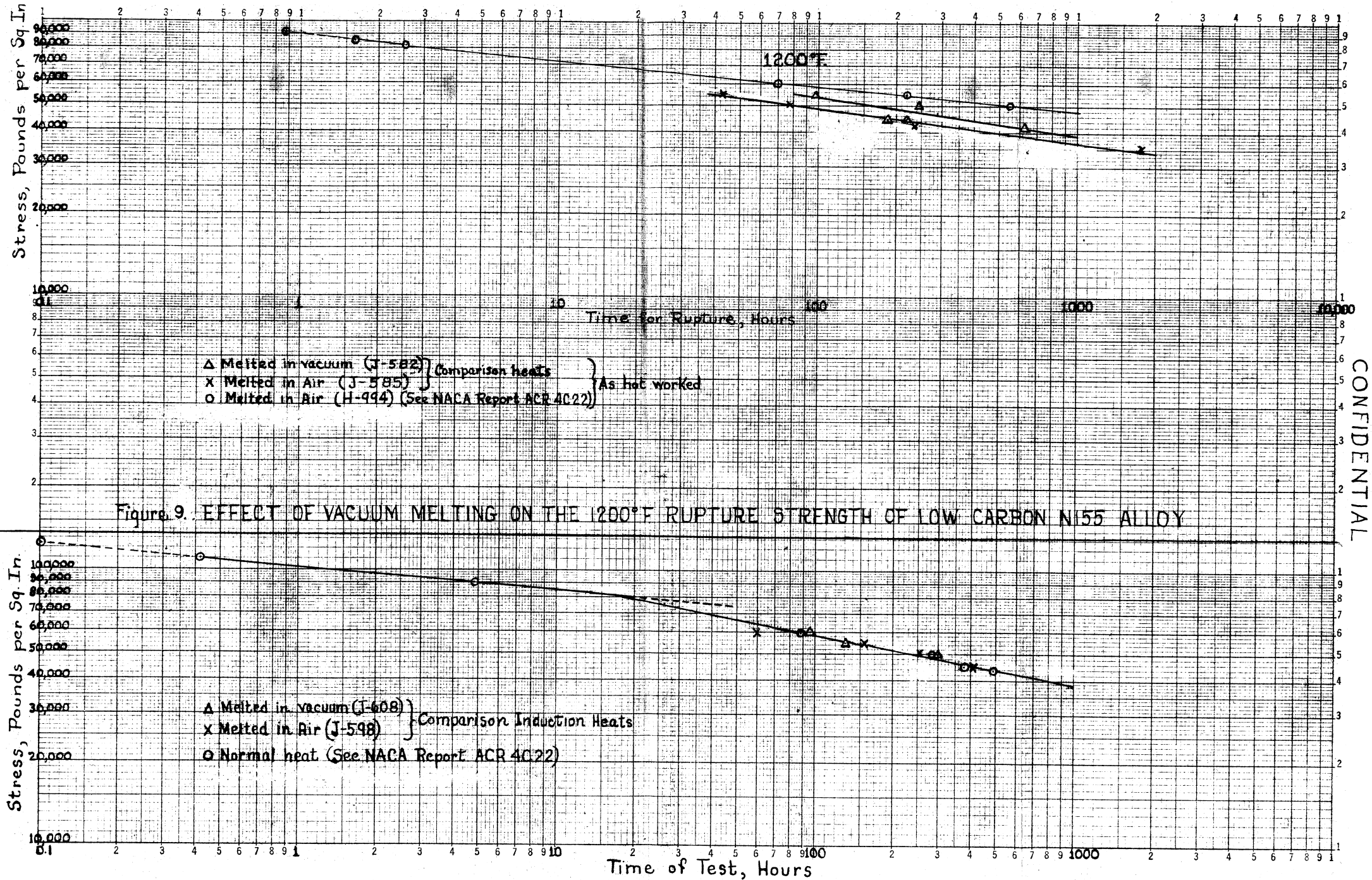

Figure 9. EFFECT OF VACUUM MELTING ON THE 1200°F. RUPTURE STRENGTH OF LOW CARBON N155 ALLOY

Figure 10. EFFECT OF VACUUM MELTING ON THE 1200°F. RUPTURE STRENGTH OF AGE HARDENABLE INCONEL ALLOY

F. Rupture Tests at 1700° and 1800°F.

A report will be distributed in the near future covering the rupture test results from twelve alloys at these two temperatures. Two further phases of this work are still in progress.

1. Two alloys from Massachusetts Institute of Technology (Table XV).
2. Strip specimens (Table XVI).

The investigation of the M.I.T. alloys developed for the U.S. Navy was requested at the September 21, 1944 subcommittee meeting. The two alloys selected represent their better low and high cobalt alloys, Table XV. Alloys 113VT2-2 and 128VT22 were to be considered as the same material, although they were not from the same heat. The rupture test data obtained to date are compared graphically in Figure 11 with X-50, the highest strength alloy previously tested at these temperatures. Alloy 97NT-2 gave very erratic results but on an average was somewhat stronger than alloy X-50. Alloy VT2-2 had a steeper slope with the result that it was equal to X-50 at 100 hours and considerably weaker at the longer time periods.

The critical nature of the need for sheet materials for combustion chambers caused the subcommittee to request that the rupture test characteristics of representative sheet materials be investigated at 1700° and 1800°F. Table XVI lists the sheet materials which are to be submitted. Thus far only three of these have been received, Inconel, Type 309 Stainless and Type 310 Stainless. Actual analyses and conditions of fabrication for these have not

yet been reported. The materials received were 0.031" thick X 1-1/4" wide X 22" long. A gauge section one-inch wide by 2-3/4" long is machined in these before testing.

The results obtained to date, Table XVI and Figure 12, indicate that there is not much difference in strength or ductility between Inconel and Type 309 Stainless steel. Both are considerably weaker than hot-rolled Low Carbon N155 alloy, the weakest bar stock previously investigated.

Table XV

1700° and 1800°F. Rupture Properties for Two Precision Cast Alloys Submitted by M.I.T.

Chemical Analyses (approximate, except carbon)

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

Manufacture and Heat Treatment

Both alloys were melted in a small arc furnace and cast by the Austenal procedure in molds preheated to 1850°F. at the Massachusetts Institute of Technology. The specimens were 0.250-inch in diameter with 1-inch gage section.

113VT2-2 and 128VT2-2 were tested in the as cast condition.

97NT-2 specimens were heat treated at 2260°F. for 1/2-hour and water quenched.

Rupture Test Data at 1700° and 1800°F.

Alloy	Temp. °F.	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
97NT-2	1700	19,000	88.0	7	11.5
		17,000	134.5	5	8.5
		15,000	412.0	2	3.9
	1800	15,000	48.5	8	12.1
		14,000	61.0	3	7.1
		13,000	490.0	3	4.7
		11,000	329.5	4	10.9
113VT2-2	1700	17,000	108.0	14	20.5
		15,000	173.0	19	25.7
		14,000	252.0	12	20.2
		13,000	651.0	9	12.8
128VT2-2	1800	12,500	66.5	16	33.0
		11,000	102.0	20	37.0
		9,000	300.0	20	30.9

Table XVI

Sheet Alloys for Stress-Rupture Tests at 1700° and 1800°F.

Nominal Chemical Analyses

Alloy Type	Source	C	Cr	Ni	Co	Mo	Other
(R)*Inconel	G.E.**	.13	13	75	--	--	Fe-9, Mn-1, Si-0.5
AF-18	"	.13	25	20	--	--	Si-2
Vitallium	"	.20	27	2.5	Bal.	5.5	
S816	"	.35	18	20	45	4	Cb-3, W-4
(R)*309	"	.12	25	12	--	--	
Co-Cr	"	Low	30	15	55	--	
446N2	C.S.C.***	.20	25	--	--	--	N_2-0.15
(R)*310	"	.15	25	20	--	--	
327	"	.15	27	4			
329	"	.10	24	3	--	1.25	Non-Hardening
330	"	.15	15	35	--	--	
327/446	"	.15	25	1	--	--	N_2-.20
446	"	.20	25	--	--	--	
N155	"	.10	21	20	20.5	3	N_2-.12, W-2.5, Cb-1

*(R) - Alloys received by 2-8-45.
**G.E. - General Electric Company.
***C.S.C. - Crucible Steel Company of America.
Samples in the annealed condition.

Rupture Test Data at 1700°F.

Alloy	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 2 In.
Inconel	12,000	0.2	31.5
	4,000	45.5	18.5
	3,000	118.0	27.0
	2,000 2,500	In progress 384 177.5	hours 2-8-45 19.0
309 (25Cr-12Ni)	4,000	36.0	27.0
	3,000	109.0 277	21.5
	2,500	~~In progress 144 hours 2-8-45~~	
310 (25Cr-20Ni)	3,000	285.5 ~~In progress 72 hours 2-8-45~~	15

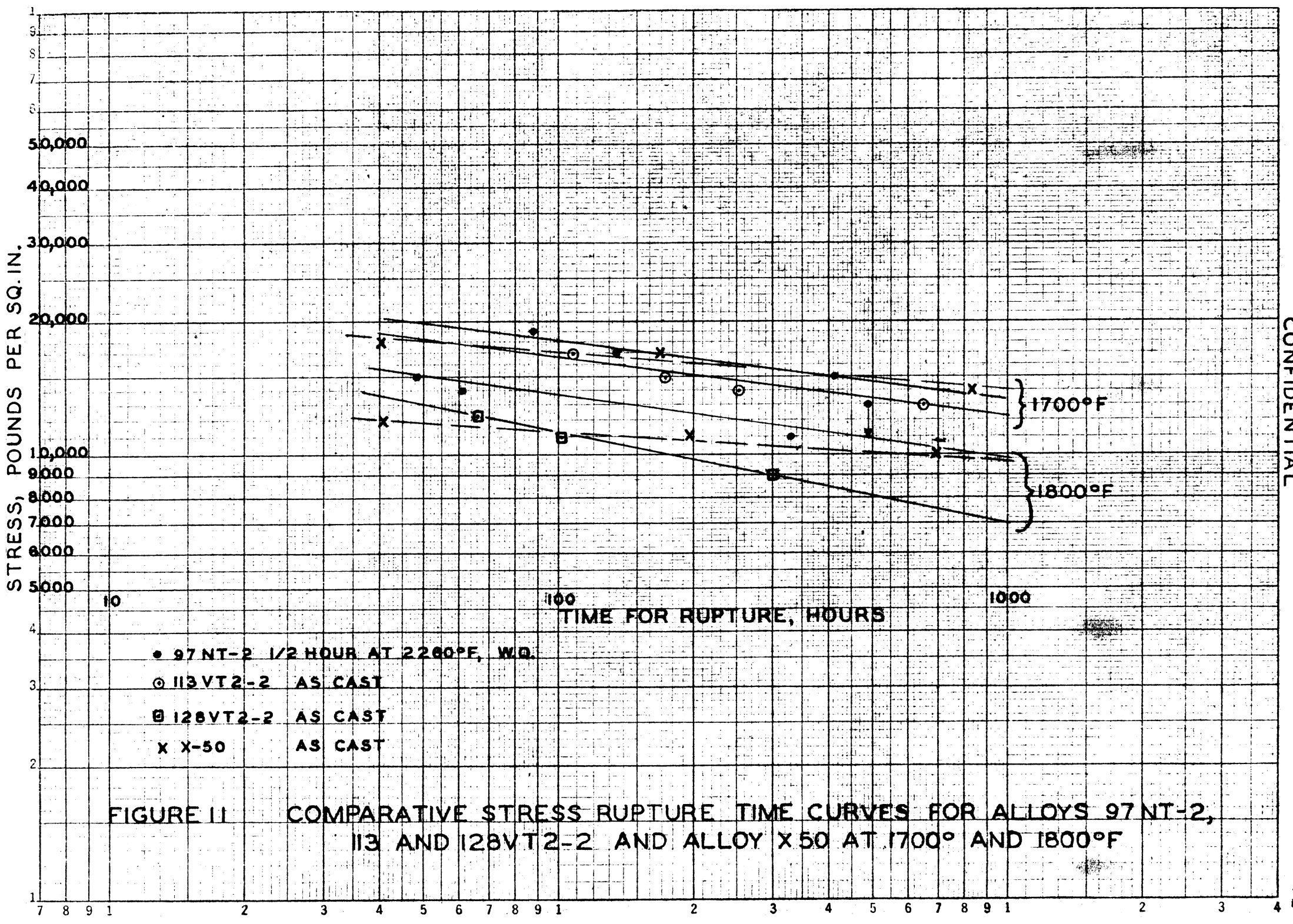

FIGURE 11 COMPARATIVE STRESS RUPTURE TIME CURVES FOR ALLOYS 97 NT-2, 113 AND 128 VT2-2 AND ALLOY X 50 AT 1700° AND 1800°F

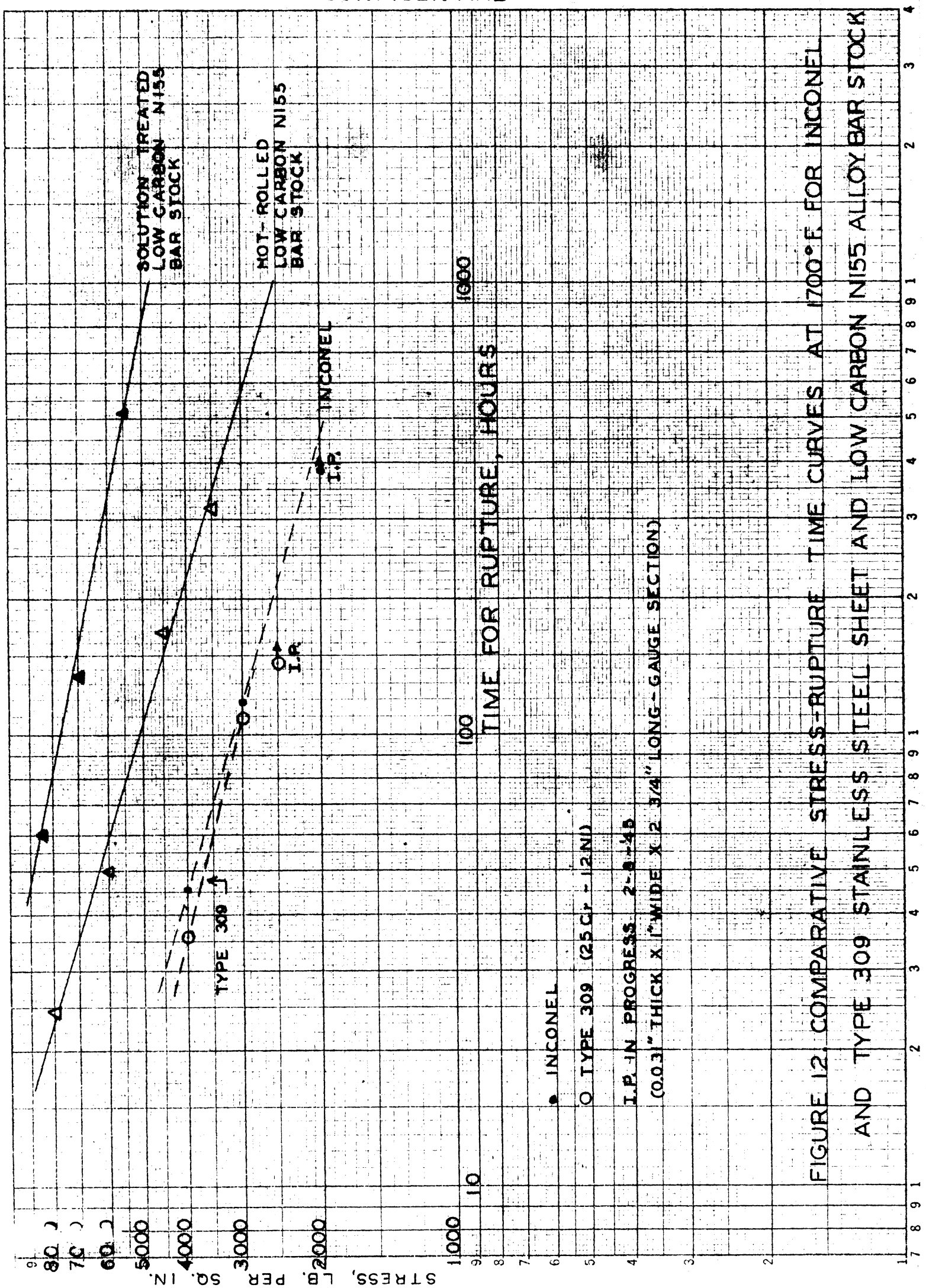

FIGURE 12. COMPARATIVE STRESS-RUPTURE TIME CURVES AT 1700°F. FOR INCONEL AND TYPE 309 STAINLESS STEEL SHEET AND LOW CARBON N155 ALLOY BAR STOCK

G. 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 XVII and Figure 13.

The rupture test data obtained to date indicate excellent adherence for the coating with high elongation to fracture. Comparative data for uncoated specimens shows, if anything, a very slightly higher rupture strength for the uncoated specimens. 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 XVII

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
	17,500	288.0	69.7	71.9
	15,000	887.0	32	55.3
Uncoated	25,000	61.0	64	67.1
	22,000	112.0	51	69.5
	20,000	172.0	53	74.4
	17,500	443.0	67	71.1

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

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(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.

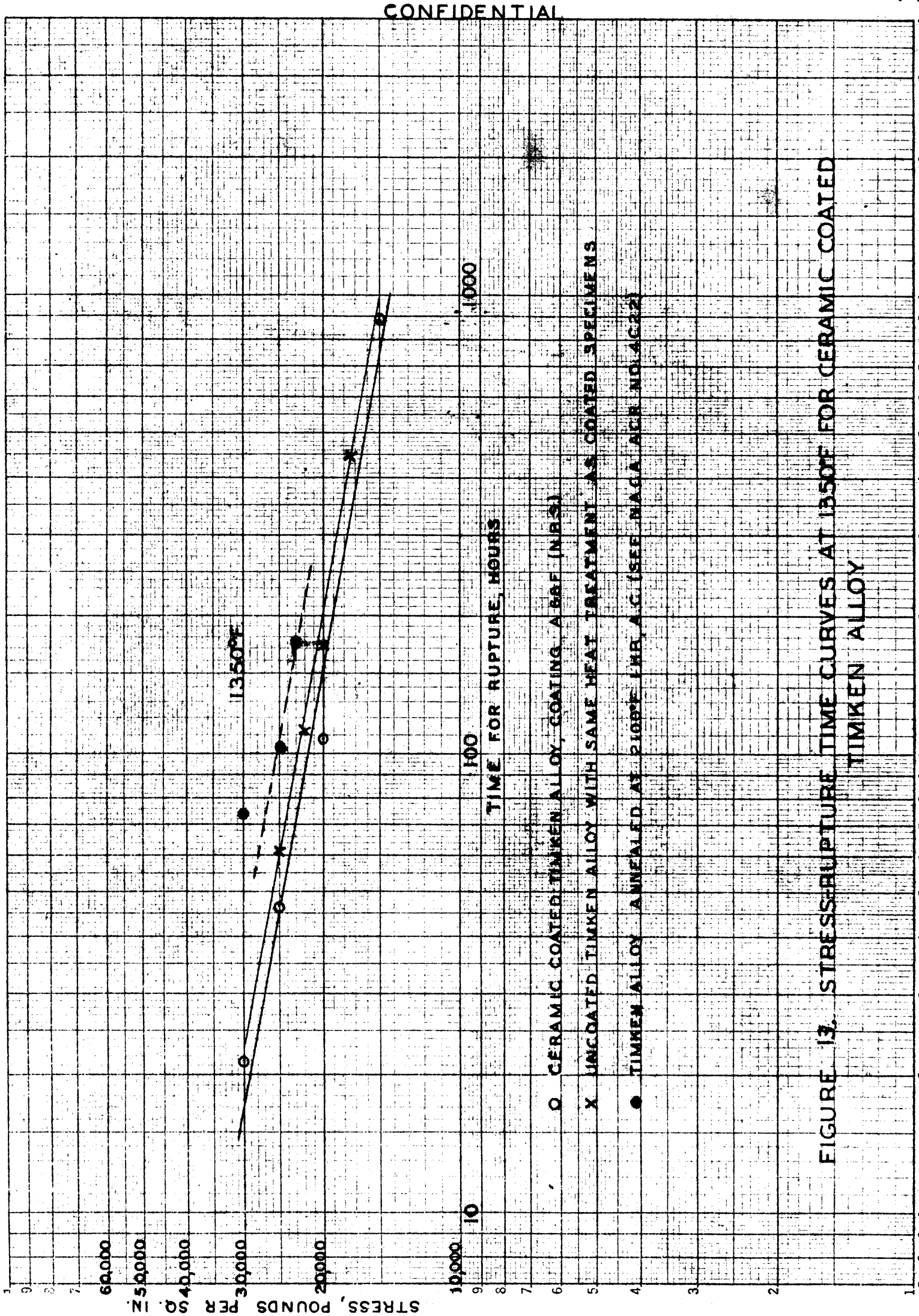

FIGURE 13. STRESS-RUPTURE TIME CURVES AT 1350°F FOR CERAMIC COATED TIMKEN ALLOY

H. Low Carbon N155 + Boron

The improved properties reported by the Union Carbide and Carbon Research Laboratories for their Boron modification of Low Carbon N155 alloy indicated that the alloy had excellent promise for gas turbine applications. Most of the preliminary testing was done at 1500°F. The possibility of it being an improved wheel alloy led to the approval of investigation of the alloy at 1200°F. as bar stock and as a large forged disc.

Two lots of bar stock were received at the same time, J573 and J597, of Table XVIII. Heat J573 was tested first at 1200°F. with surprisingly low strength, Table XVIII and Figure 12. The rupture strength of this heat was considerably lower than had been previously obtained for standard Low Carbon N155 alloy bar stock and was only equal to that of the large disc (Section A). In view of the unexpected nature of the results it was decided to run tests on Heat J597 which was found to have the improved properties claimed for the analysis. The 1000-hour rupture strength of 52,500 pounds per square inch for J597 equals the highest value previously found, Alloy 6MM cold rolled 25% as reported in ACR No. 3D28, April 1943.

As yet no explanation for the difference in rupture strength between the two heats of Low Carbon N155 + Boron is available.

No work has been done on the sample from Heat N175.

Table XVIII

Boron Modified Low Carbon N155 Alloy

Chemical Analyses

Heat No.	Cr	Ni	Co	Mo	W	Si	Mn	B	C	N_2
J573	21.00	20.04	20.88	3.08	2.17	0.45	1.65	0.37	0.20	0.14
J597	21.5	19.5	19.5	3.1	2.0			0.38	0.12	0.12
N175	Analysis not submitted									

Manufacture and Source

Heat J573, in as forged condition. Machined 0.160" diameter specimens submitted by the Union Carbide and Carbon Research Laboratories, Inc.

Heat J597, as forged from 50 pound experimental heat. Two 5-inch by 7/8-inch square bars submitted by Mr. H. C. Cross for Project NRC-8 as supplied to them by the Union Carbide and Carbon Research Laboratories, Inc.

Heat N175, as hot rolled from 45-3/4 pound ingot (basic arc melting at Union Carbide and Carbon Research Laboratories, Inc.) Ingot hammer cogged from 2050°F. to 1750°F. to 2 inch square billet. Billet rolled from 2080°F. to 1800°F. to 7/8 inch square. One 8-inch by 7/8-inch square bar submitted by Universal Cyclops Steel Corporation.

1200°F. Stress-Rupture Results

Specimen	Stress Lb./Sq.In.	Rupture Time Hours	Elongation % in 1 In.	Reduction of Area,%
J573	60,000	40.5	33	39.8
	55,000	75.5	37	46.5
	50,000	174.0	27	36.0
	44,000	810.5	31	56.4
J597	65,000	45.0	22	44.7
	60,000	129.0	24	48.3
	55,000	540.0	20	53.6

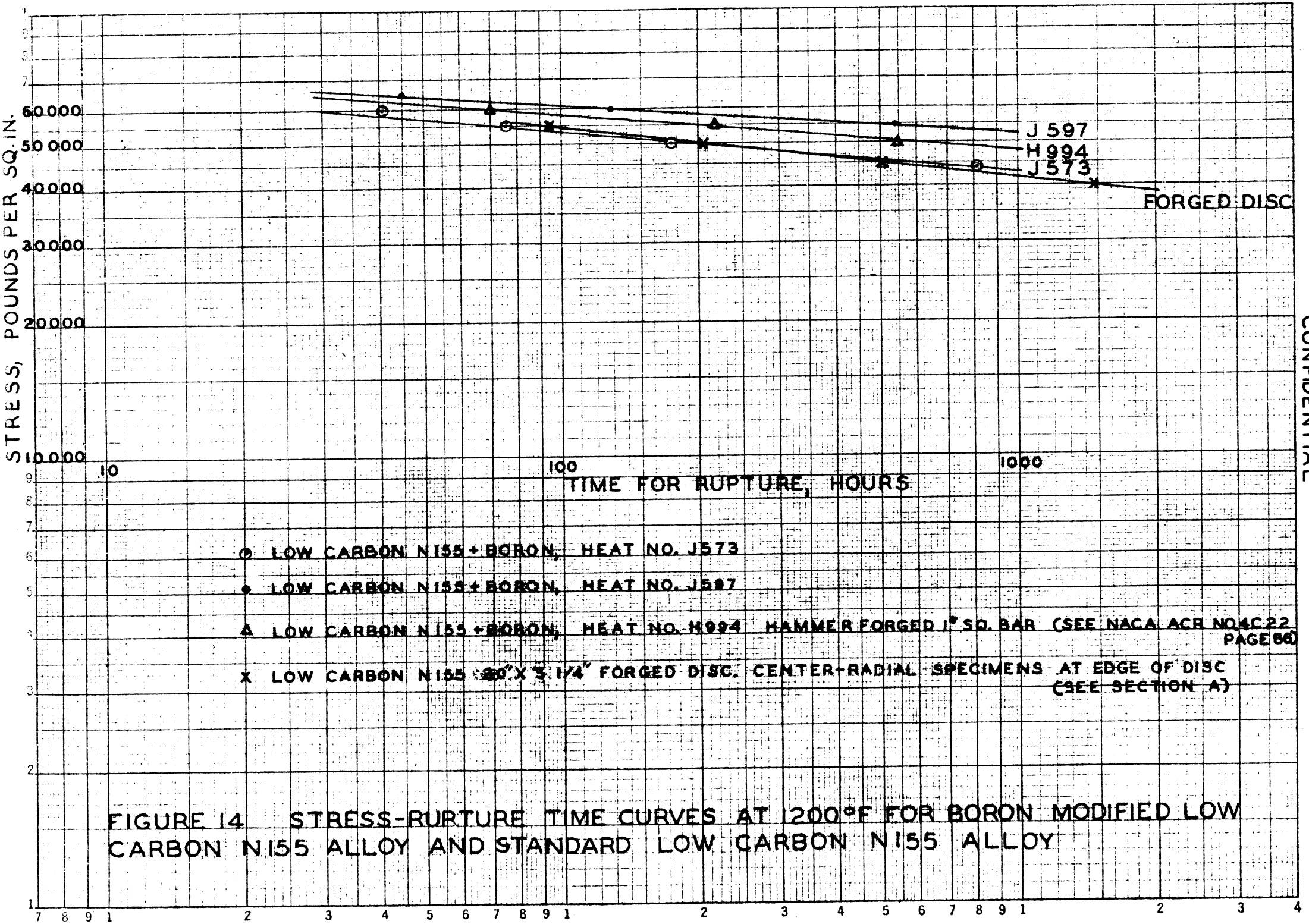

FIGURE 14 STRESS-RUPTURE TIME CURVES AT 1200°F FOR BORON MODIFIED LOW CARBON N155 ALLOY AND STANDARD LOW CARBON N155 ALLOY