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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

April 28, 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
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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 ~~February~~ April 28, 1945. Since that time two final reports have been issued.

Report 17, "The Rupture Test Characteristics of Six Precision Cast and Three Wrought Alloys at 1700° and 1800° F" April 3, 1945.

Report 18, "A Metallurgical Investigation of a Large Forged Disc of (CSA 234-A-5) Alloy" April 25, 1945.

Omit Insert "A"

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. All statements, data and figures in this report are, therefore, tentative and are subject to change as more complete results become available.

A. Evaluation of Properties of Alloys as Rotor Forgings

Samples of 19-9 DL, 234-A-5, Low Carbon N155, S590 and Timken Alloys are being subjected to room temperature tensile tests, tensile, rupture and creep tests at 1200° and 1350° F. The results obtained to date are summarized and compared in tables I, II and III. Descriptive information and rupture data for each disc are included as tables IV through XI and figure 1 shows the stress-rupture time curves.

Briefly these data show the following trends:

1. Room Temperature Yield Strengths (See table I.)

   0.02-percent offset-yield strength of 70,000 psi or higher have been found only for the I-40 forging of Timken Alloy. The as-forged S590 disc and the TC-180[1] forging of Timken alloy had nearly as high yield strengths.

   At 1200° and 1350° F the as-forged S590 disc had the best tensile properties.

   Relatively little improvement in tensile properties resulted from increasing the carbon and hot-cold working 234-A-5 alloy discs.

   Tensile properties for cold-worked 19-9 DL and Low Carbon N155 discs are not yet available, although such processing would probably improve their properties in relation to the Timken alloy forgings.

2. Rupture Strengths at 1200° F (See table II.)

   At 1200° F the best rupture strengths will be shown by the as-forged disc NR66D of Low Carbon N155 alloy with the S590 disc about equally as good.

   The I-40 forging of Timken Alloy has quite good rupture strength, although the TC-180[1] is considerably inferior.

[1]Rim of forging had been machined off. Specimens are from metal midway between center and rim.

The Low Carbon N155 discs, NR66E, made by Crucible Steel Company are considerably inferior to NR66D especially when aged for 24 hours at 1500° F.

The data thus far obtained do not show that high carbon content and hot-cold work appreciably improved the rupture strength of 234-A-5 alloy discs.

The rupture strengths of 19-9 DL, Low Carbon N155 and S590 discs without hot-cold work compare favorably with those for the Timken Alloy discs.

3. Rupture Strengths at 1350° F (See table II.)

Solution-treated S590 discs have the highest rupture strengths and are considerably better than the as-forged disc.

The as-forged disc NR66D of Low Carbon N155 alloy had nearly as good rupture properties, although the NR66E discs were slightly weaker.

19-9 DL and 234-A-5 discs had considerably lower strengths.

4. Total Deformation Characteristics at 1200° F (See table III.)

The deformation characteristics vary for the various alloys and discs both with the stress and the time at which comparisons are made. For instance, the I-40 forging of Timken Alloy will have much poorer creep characteristics than the TG-180 forging even though it had less total deformation up to 100 hours. This is caused by a much higher creep rate for the I-40 specimens. Low Carbon N155 disc NR66E, solution treated and aged at 1350° F, had much better properties than the other two NR66-E discs under 25,000 psi but was much inferior on the basis of 30,000 psi when the yield strength had been exceeded.

The Timken Alloy rotors apparently will have total deformation characteristics similar to the as-forged 19-9 DL and 234-A-5 discs.

A 1500° F aging treatment increased deformation rates for Low Carbon N155 NR66E discs. The NR66D disc was considerably better than the NR66E discs.

The as-forged S590 disc was similar to the Low Carbon N155 disc NR66D. The solution treated and aged S590 material disc was considerably weaker than the as-forged and probably the plain solution treated.

Cold working 234-A-5 discs did not materially improve the total deformation strengths.

TABLE I

TENSILE PROPERTIES OF LARGE DISCS AT ROOM TEMPERATURE, 1200 AND 1350° F
(Available Data for Radial Specimens ~~at Center of Disc~~ ~~4-28-45~~ from 34 Ram, 6-7-45)

Alloy	Discaloy	19-9 DL	234-A-5	234-A-5	234-A-5	Low Carbon N155	S590	S590	S590	Timken	Timken
Disc	NR78[3]	(1)	Low Carbon[2]	High Carbon	High Carbon	NR66D	No.2	No.1-A	No.1-B	TG-180[4]	I-40
Size of disc diameter (in.)	20 1/2	19 3/4	20	20	20	21	18	18	18		
thickness (in.)	19	3 1/4	3 5/16	3 1/2	3 1/2	3 1/4	3 3/8	3	3		
Solution treatment	1 hr at 1950°F A.C.	None	None	2100°F A.C.	2100°F A.C. to 1400°F	None	None	2300°F W.Q.	2300°F W.Q.		
Hot-cold work	None	As-Forged	As-Forged	10% at 1400°F	10% after 24 hr at 1400°F	As-Forged	As-Forged	None	None		
Ageing treatment temperature (°F)	1350°F	1200	1200	1200	1200	1200	1400	None	1400		
time (hr)	20	2	4	4	4	2	16		16		
Room Temperature											
Brinell hardness	291	205	206	241	232	211	267	211	255[5]	223	253 ~~252~~
Tensile strength (psi)	157750	103,500	108,000	115,500	117,500	118,500	130,600	117,500	134,000[5]	112,625	(121,250) ~~120,500~~
Offset yield stress (psi)											
0.02%	76500	40,000	37,500	45,000	46,500	58,000	69,000	37,500	45,000[5]	68,000	72,500 ~~77,000~~
0.1%	97500	50,500	52,000	55,500	62,000	68,000	91,000	53,000	------	78,000	~~86,000~~
0.2%	103500	55,000	57,750	61,000	66,500	72,500	100,000	59,000	------	83,500	~~93,500~~ 91,750
Proportional limit (psi)	48750	26,500	22,500	22,500	30,000	46,000	37,500	22,500	------	47,500	~~55,000~~ 48,750
Elongation in 2 in. (%)	22.5	25.2	34.2	16	17	31.0	9.0	30.5	22.0[5]	23	~~11.0~~ 12.5
Reduction of area (%)	26.0	24.6	37.2	16.3	16.6	50.0	11.5	27.2	18.8[5]	29.2	~~17.0~~ 16.4
1200°F											
Tensile strength (psi)	116200	57,875	52,000	58,375	61,000	83,000	87,875	82,000		72,500	79,000
Offset yield stress (psi)											
0.1%	91500	35,500	37,500	38,500	38,000	47,500	62,500	41,500		51,000	61,000
0.2%	100,000	37,900	40,000	41,000	41,000	49,500	70,000	44,000		56,500	63,500
Proportional limit (psi)	27500	20,000	16,250	17,500	17,500	~~26,000~~ 30,000	22,500	20,000		15,000	37,500
Elongation in 2 in. (%)	4.0	34.0	27.2	29	26	21	16.5	12		30	16
Reduction of area (%)	6.0	47.5	49.4	41.9	33.5	33.6	21.3	17.7		41.3	26.1
1350°F											
Tensile strength (psi)		38,100	39,000			59,750	65,375	71,250			
Offset yield stress (psi)											
0.1%		29,250	32,000			37,500	48,500	41,500			
0.2%		31,100	34,500			40,000	53,000	46,000			
Proportional limit (psi)		15,000	15,000			20,000	17,500	22,500			
Elongation in 2 in. (%)		45.0	40.0			24	31	11			
Reduction of area (%)		69.3	56.0			24.8	45.3	13.0			

[1] See ACR 5C10 (report 15).
[2] ~~Report 18.~~ See Report 18, "A metallurgical Investigation of a Large Forged Disc of 234-A-5 Alloy machined
[3] Data reported by letter dated August 7, 1944
[4] Rim had been ~~marked~~ off. Specimens taken midway between center and rim.
[5] Allegheny-Ludlum data.

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 billet 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.

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Table 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.

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Appendix III
~~Table VI~~

[redacted] 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.

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appendix IV

~~TABLE VII~~

~~DESCRIPTION OF~~ TIMKEN ALLOY DISCS

Chemical Composition

Disc	Heat No.	C	Mn	P	S	Si	Ni	Cr	Mo	N_2
I-40	H-4315	0.10	1.24	0.022	0.022	0.72	25.75	16.56	5.80	0.12
TG-180	H-4174	0.11	1.49	0.023	0.023	0.64	26.25	15.67	6.25	0.111

Processing Procedure

Both discs were forged by Midvale and are in the as-forged condition. The discs were machined to size at the Everett Plant of General Electric.

The I-40 disc was rejected for service and cut up for testing because of a slight internal burst, as shown by x-rays, in the very center of the disc.

The TG-180 disc was rejected for service after x-ray examination because of a defective center. The section being tested was cut so as to avoid most of the defective center. This section represents an approximately 20-22 inch wheel and resulted from machining off 6-8 inches from a 28 inch wheel. It does ~~not~~ represent a full section from center to rim. The rim of the wheel had been cut off so that the diameter of the section submitted was only about 20 inches.

TABLE VIII

RUPTURE TEST CHARACTERISTICS OF LOW CARBON N155 DISCS
(Radial specimens from center of discs at the rim)

Disc	Size of Discs (inches) Diameter	Thickness	Heat Treatment	Test Temperature (° F)	Stress (psi)	Rupture Time (hr)	Elongation in 1 in. (percent)	Reduction of Area (%)
NR66D	21	3 1/4	As Forged + 2 hr at 1200° F	1200	77,000	1.07	9	16.0
					72,000	2.35	26	21.8
					55,000	94.	12	10.9
					50,000	204.	10	9.7
					45,000	502.	7	8.5
					40,000	1461.	12	16.7
NR66E-1	14 3/4	4 3/8	As Forged	1200	55,000	10.	7	12.1
					47,500	40.	10	17.8
					45,000	178.	8	18.9
					40,000	613.	15	17.8
NR66E-2	14 3/4	4 3/8	As Forged + 24 hr at 1500° F	1200	50,000	51.5	35	43.7
					45,000	143.	36	41.8
					40,000	237.	31	24.5
					37,500	504.	19	21.7
NR66E-3	14 3/4	4 3/8	2200° F W.Q. + 24 hr at 1500°	1200	50,000	26.5	15	20.0
					45,000	80.	15	22.3
					40,000	205.	20	24.5
NR66E-4	14 3/4	4 3/8	2200° F W.Q. + 24 hr at 1350°	1200	50,000	11.	13	17.2
					40,000	188.	10	15.6
					35,000	1536.	12	18.9
NR66E-5	14 3/4	4 3/8	2250° F W.Q. + 3% hot-cold work at 1200° F + 24 hr at 1500° F	1200	48,000	61.	23	23.9
					45,000	139.	20	27.7
					40,000	228.	7	24.5
NR66D	21	3 1/4	As Forged + 2 hr at 1200° F	1350	52,000	1.05	29	33.0
					45,000	4.47	12	16.7
					35,000	36.	23	33.0
					30,000	186.	9	11.5
					25,000	432.	10	19.5
					25,000	738.5	7	9.1
					23,000	1734.	5	6.2
					20,000	1336.	5	6.0
NR66E-1	14 3/4	4 3/8	As Forged	1350	30,000	60.	35	30.8
					25,000	239.	34	36.9
					21,500	624	25	45.6
NR66E-4	14 3/4	4 3/8	2200° F W.Q. + 24 hr at 1350°	1350	30,000	96.	24	30.8
					27,500	60	9	14.4
					25,000	392	30	37.2
					23,000	In progress 336 hours (4-28-45)		

TABLE IX

RUPTURE TEST CHARACTERISTICS OF 234-A-5 ALLOY DISCS AT 1200°F.
(Radial Specimens from Center of Disc at Rim)

Disc	Size of Disc (inches)		Heat Treatment	Stress (psi)	Rupture Time (hr)	Elongation in 2 in. (percent)	Reduction of area (percent)
	Diameter	Thickness					
Low Carbon[1]	20	3 5/16	As Forged + 4 hr at 1200° F	48,000	1.09	28	41.8
				45,000	5.0	31	46.5
				35,000	127.	32	48.3
				32,500	196.5	19	51.9
				30,000	974.	18	38.8
				28,500	1596.	13	33.0
High Carbon #5	20	3 1/2	2100° F, A.C. + hot-cold worked approximately 10% from 1420° to 1250° F + 4 hr at 1200° F	40,000	41	34	51.5
				35,000	252	20	35.6
				32,000	495	13	30.8
High Carbon #6	20	3 1/2	Air cooled to 1400° F from 2100° F and held 24 hr + approximately 10% hot-cold work from 1400° to 1250° F + 4 hr at 1200° F	43,000	80	17	25.6
				41,000	90.5	24	46.5
				40,000	534.	15	30.8
				38,000	180	18	29.8
				34,000	In progress 24 hr 4-28-45		

[1]See report number 18.

~~TABLE X~~

Data for

RUPTURE TEST ~~CHARACTERISTICS OF~~ S590 DISCS (18 inch diameter by 3 inch thick)

~~(Radial Specimens from Center of Disc at Rim)~~

Specimen Location

Disc	Size of Disc (inches) Diameter	Thickness	Heat Treatment	Test Temperature (° F)	Stress (psi)	Rupture Time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
#2	~~18~~ 6Y 6Y 6Y 6X	~~3 3/8~~ CRR CRR CRR SER	As Forged + 16 hr at 1400°F	1200	55,000 50,000 45,000 52,500	69.5 150. 372.5 256	21 17 9 15	20.6 21.2 14.4 15.0
#1-A	~~18~~ 14Y 14Y 14Y 14X 14X	~~3~~ CRR CRR CRR SRE SRE	3 3/4 hr at 2300° F, W.Q.	1200	55,000 50,000 52,500 45,000 50,000 55000	59 74 493 14 111 60	4 6 3 6 4 11	7.9 8.5 13.6 7.3 10.9 13.8
#1-B	~~18~~ 8Y 15Y 15Y	~~3~~ CRR CRR CRR	3 3/4 hr at 2300° F, W.Q. + 16 hr at 1400° F	1200	50,000 45,000	153 640	13 8	16.7 10.9
#2	~~18~~ 6Y 6Y 6Y	~~3 3/8~~ CRR CRR CRR	As Forged + 16 hr at 1400°F	1350	30,000 25,000 20,000	60 180 676	12 8 6	14.4 11.5 4.4
#1-A	~~18~~ 14Y 14Y 9Y 9Y	~~3~~ CRR CRR CRR CRR	3 3/4 hr at 2300° F, W.Q.	1350	33,000 30,000 27,000 25,000	86 252 204 ~~In progress 480 hr~~ ~~4 28 45~~ In progress 384 hr 6/7/45	10 11 3	15.6 15.0 8.0
#1-B	~~18~~ 8Y 8Y 8Y 8Y	~~3~~ CRR CRR CRR CRR	3 3/4 hr at 2300° F, W.Q. + 16 hr at 1400° F	1350	35,000 30,000 27000 25000	45.5 ~~In progress 150 hr~~ 198 ~~4 28 45~~ 167 In progress 48 hours 6/7/45	13 12.5 8	17.8 16.0 15.6

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~~TABLE XI~~ Data at 1200°F for as-Forged

RUPTURE TEST ~~CHARACTERISTICS OF~~ TIMKEN ALLOY DISCS ~~AT 1200° F~~

Disc	Specimen ~~Treatment~~ Location	Stress (psi)	Rupture Time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
[1]TG-180	~~As Forged~~	45,000	60	29	34
	2Y radial	40,000	155	26	27.2
	2Y radial	35,000	424	22	26.7
I-40	~~As Forged~~	45,000	88	18	29.8
	8Y CRR	40,000	382	12	16.7
	8Y CRR	37,500	~~In progress 120 hr 4-28-45~~ 612	8	9.7
	8Y CRR	35,000	~~In progress 528 hr 4-28-45~~ 775	10	17.2
	8Y CRR				

[1]Specimens taken midway between rim and center of disc.

CRR Radial specimen from center of disc at rim.

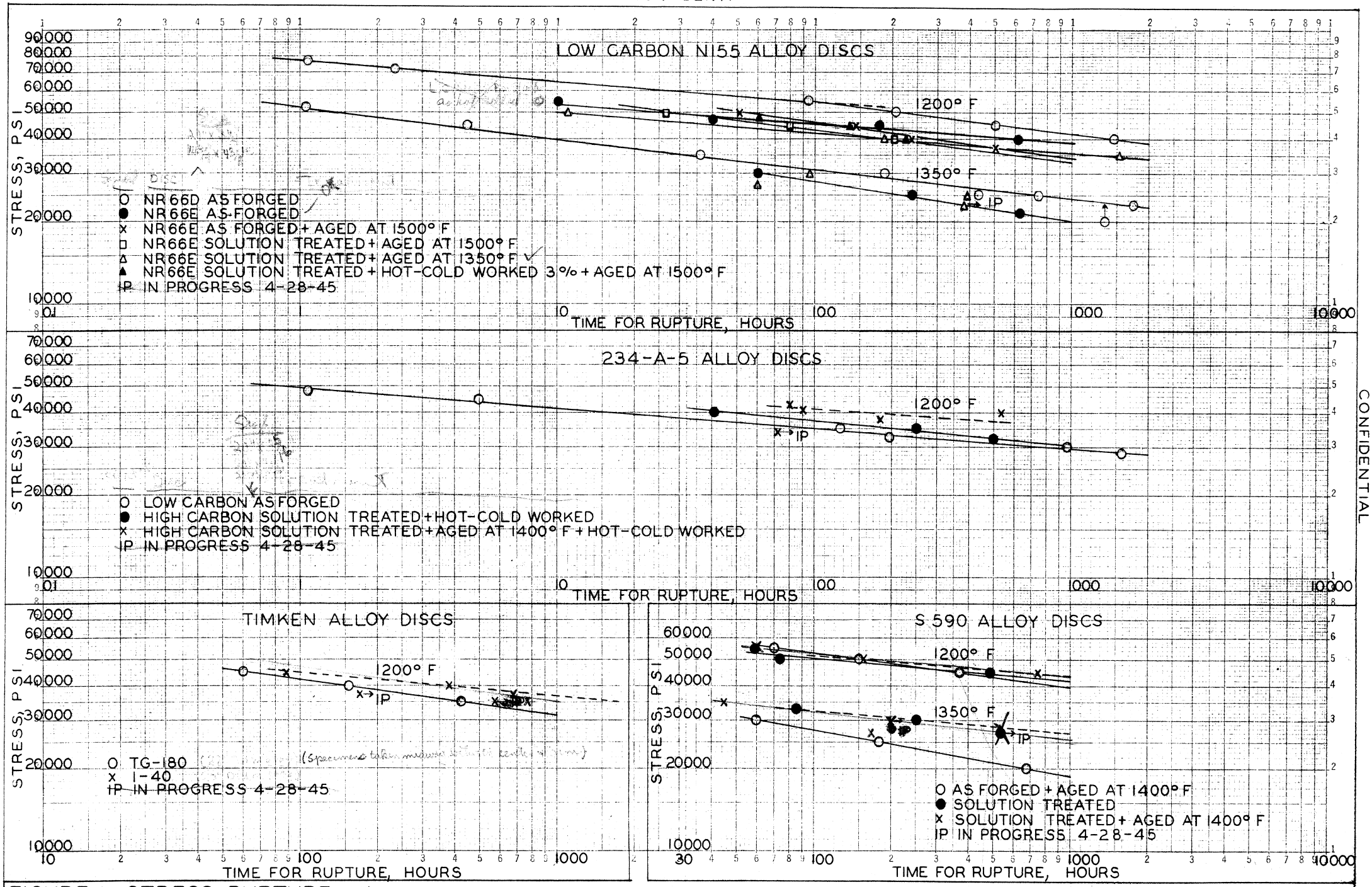

FIGURE 1.- STRESS-RUPTURE TIME CURVES AT 1200° AND 1350° F FOR LARGE GAS TURBINE DISCS OF LOW CARBON N155, 234-A-5, S590, AND TIMKEN ALLOYS.

B. Sheet Alloys at 1700° and 1800° F

An evaluation of the rupture properties at 1700° and 1800° F of several of the better high temperature alloys in sheet form is being carried out to obtain data for the evaluation of these alloys for use as liners in combustion chambers.

Rupture tests are in progress on eight alloys: Inconel, AF-18 (25Cr-20Ni-2Si), Vitallium, S816, 309 (25Cr-12Ni), Co-Cr-Ni, 310 (25Cr-20Ni), and 330 (15Cr-35Ni). As seen from table XII and figure 2, Vitallium has the highest of a wide range of rupture strengths obtained for the alloys tested. Seven other alloys have been submitted and tests are to be conducted on five of these: N155, J837, J838, J839, and J840. Chemical analyses of all the alloys submitted are given in table XIII.

All of the materials for which processing information have been received were in the hot rolled and annealed condition. (See table XIV.)

The rupture specimens being tested are 22" by 1-1/4" by 0.031" to 0.040" in size with a 1" wide 2-3/4" long reduced gage section. The rupture test results obtained to date are given in table XV and plotted as stress-rupture time curves in figure 2.

The rupture strengths were lower than was anticipated on the basis of the strengths of similar alloys tested as round bars.

A study of the effect of heat treatment on the properties of Vitallium or Inconel alloys is to be started as soon as the material is received.

TABLE XII

RUPTURE STRENGTHS OF SHEET ALLOYS AT 1700° AND 1800° F

Stress (psi) for rupture at indicated time periods				
Temperature	1700° F		1800° F	
Alloy	(100 hr)	(1000 hr)	(100 hr)	(1000 hr)
Vitallium	8000	3250	[1]3800	[1]2700
Co-Cr-Ni	5400	3150	[1]3200	(1)
AF-18	[1]4800	[1]3100	[1]3600	(1) 2250
310 25-20 (1%Si)	3900	2300	----	---
S816	[1]3900	[1]2000	[1]2300	(1) 800
309 (25-12)	3150	[1]1850	[1]2000	[1]1400 1500
Inconel	3100	[1]1500	[1]2200	[1]1350
330 (15Cr 35Ni)	[1]1900 2000	(1)	----	----

[1]Data incomplete.

TABLE XIII

CHEMICAL ANALYSES OF SHEET ALLOYS

Alloy	Submitted by	C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	B	N_2
Inconel	General Electric	0.13	1	0.5	13	75	-----	----	----	----	----	----
AF-18	" "	.13		2.	25	20	-----	----	----	----	----	----
Vitallium	" "	.20			27	2.5	Bal.	5.5	----	----	----	----
S816	" "	.35			18	20	45	4	4	3	----	----
309	" "	.12			25	12	-----	-----	----	----	----	----
Co-Cr-Ni	" "	Low			30	15	55	----	----	----	----	----
310	Crucible	.14	1.63	1.09	25.50	21.33	-----	----	----	----	----	----
329	"	.08	.98	.60	23.30	3.17	-----	1.07	----	----	----	----
330	"	.18	1.37	.62	15.77	33.27	-----	----	----	----	----	----
446-N2	"	.22	.48	.39	24.80	0.27	-----	----	----	----	----	0.143
N155	"	.12	1.83	.75	21.80	19.93	20.20	3.00	2.36	1.14	----	.14
N155	Union Carbide and Carbon	.14	1.48	.58	21.24	19.53	20.22	3.10	1.95	1.01	----	.13
J837	" "	.13	1.69	.50	20.27	4.40	20.82	4.35	4.56	----	.34	----
J838	" "	.11	1.46	.51	20.30	14.90	21.14	4.35	4.43	----	.37	----
J839	" "	.12	1.43	.49	21.70	4.40	20.04	4.48	4.40	----	.56	.124
J840	" "	.13	1.38	.58	21.29	15.28	20.98	4.33	4.33	----	.45	.117

TABLE XIV

PROCESSING INFORMATION FOR SHEET ALLOYS

Alloys Submitted by General Electric:

AF-18 Alloy. Made by Allegheny-Ludlum Steel Corporation. Hot rolled to 0.045" gage, furnace temperature 2100°F, annealed 2100-2150°F for six or eight minutes, air cooled, sand blasted and spot ground. Cold rolled to 0.033", annealed 2100-2150°F for six to eight minutes, air cooled, sand blasted and scrubbed, cold rolled one pass and buckled.

S816 Alloy. Made by Allegheny-Ludlum Steel Corporation. Hot rolled to 0.035" gage, furnace temperature 2200-2250°F, returned to furnace and held five minutes at temperature, and air cooled. Sand blasted, scrubbed, two passes on cold rolls and buckled.

Co-Cr-Ni Alloy. Made by Haynes-Stellite Company. Rolling finished at 2100-2125°F. Annealed at 2175-2200°F just long enough for the material to reach furnace temperature, air cooled.

The manufacturing data for Inconel, 309, and Vitallium has not yet been submitted.

Alloys Submitted by the Crucible Steel Company:

Alloy	Heat Number	
310	9R826	Induction melting. 9 X 9" 800-lb. ingot and 13 X 13" 1790-lb. ingot. Hot rolled to 0.031" (cross roll). Annealed 2050°F, air cooled, and pickled.
329	9R1187	Induction melting. 9 X 9" 770-lb. ingot and 13 X 13" 1770-lb. ingot, 14 X 4½" 400-lb. bloom. Hot rolled to 0.031" (cross roll). Annealed 1850-1950°F, air cooled, and sand blasted.

TABLE XIV

PROCESSING INFORMATION FOR SHEET ALLOYS (CONTINUED)

Alloy	Heat Number	
330	8R1445	Induction melting. 9 X 9" 780-lb. ingot and 13 X 13" 1760-lb ingot, 10 X 4" 300-lb bloom. Hot rolled to 0.031" (cross roll). Annealed 1950°F, air cooled, and pickled.
446-N2	8R1077	Induction melting. 10 X 18" 2520-lb ingot, 14 X 3" 273-lb bloom. Hot rolled to 0.031" (cross roll). Annealed 1600°F, water quenched, and sand blasted.
N155	9R835	Induction melting. 9 X 9" 840-lb ingot, 14 X 4½" 300-lb bloom. Hot rolled to 0.031" (cross roll), annealed 1950°F, air cooled, and pickled.

Alloys Submitted by Union Carbide and Carbon Corporation:

Samples 22" X 1½" X 0.040" were fabricated from 30 lb. induction heats by forging and rolling. The ingots were hot-forged, from 2100°F to a finishing temperature near 1500°F, to sheet bars approximately 2" wide by 1" thick. These bars were rolled, from 2000°F to a finishing temperature near 1400°F, to strips from which the 22" long samples were cut. After rolling the samples were annealed in the range 2000-2100°F and air cooled.

TABLE XV

RUPTURE TEST RESULTS AT 1700° AND 1800° F FOR SHEET ALLOYS

Alloy	Temperature (° F)	Stress (psi)	Rupture Time (hours)	Elongation (% in 2 in.)	Reduction of area (percent)
Inconel	1700	12,000	0.20	31.5	35
		4,000	45.5	18.5	18
		3,000	118	27	21
		2,500	177.5	19	14
		2,000	248	36	34
		1,800	~~In progress 72 hours, 4-28-45~~		
Inconel	1800	2,000	152.5	25	15
		1,500	605	44	17
AF-18	1700	5,000	87	7	5
		4,000	~~In progress 216 hours, 4-28-45~~		
		3,000	1124	3.5	3
AF-18	1800	3,500	~~In progress 24 hours, 4-28-45~~		
		3,000	231	5	5
Vitallium	1700	8,000	106	14	19
		6,000	207	14	11
		4,000	599	20	8
Vitallium	1800	4,000	75	15	13
		3,000	472	23	17
S816	1700	3,800	113	16	14
		3,000	256.5	19	24
S816	1800	2,000	136	39	23
		1,500	~~In progress 216 hours, 4-28-45~~		
309	1700	4,000	36	27	35
		3,000	109	21	27
		2,500	277	7	11
309	1800	2,000	93.5	18	17
		1,500	~~In progress 648 hours, 4-28-45~~		
Co-Cr-Ni	1700	6,000	52	2	4
		5,000	140	1.5	1
		4,000	333.5	3	3
Co-Cr-Ni	1800	3,000	132.5	3	4
		2,500	324	2	5
310	1700	4,000	85	20	23
		3,000	285.5	15	16
		2,500	728	10	6
330	1700	4,000	17	28	31
		2,700	46.5	36	31
		2,000	~~In progress 48 hours, 4-28-45~~		
Lc N155	1700	5000	In progress 168 hr (Better than anything except Vitallium)		

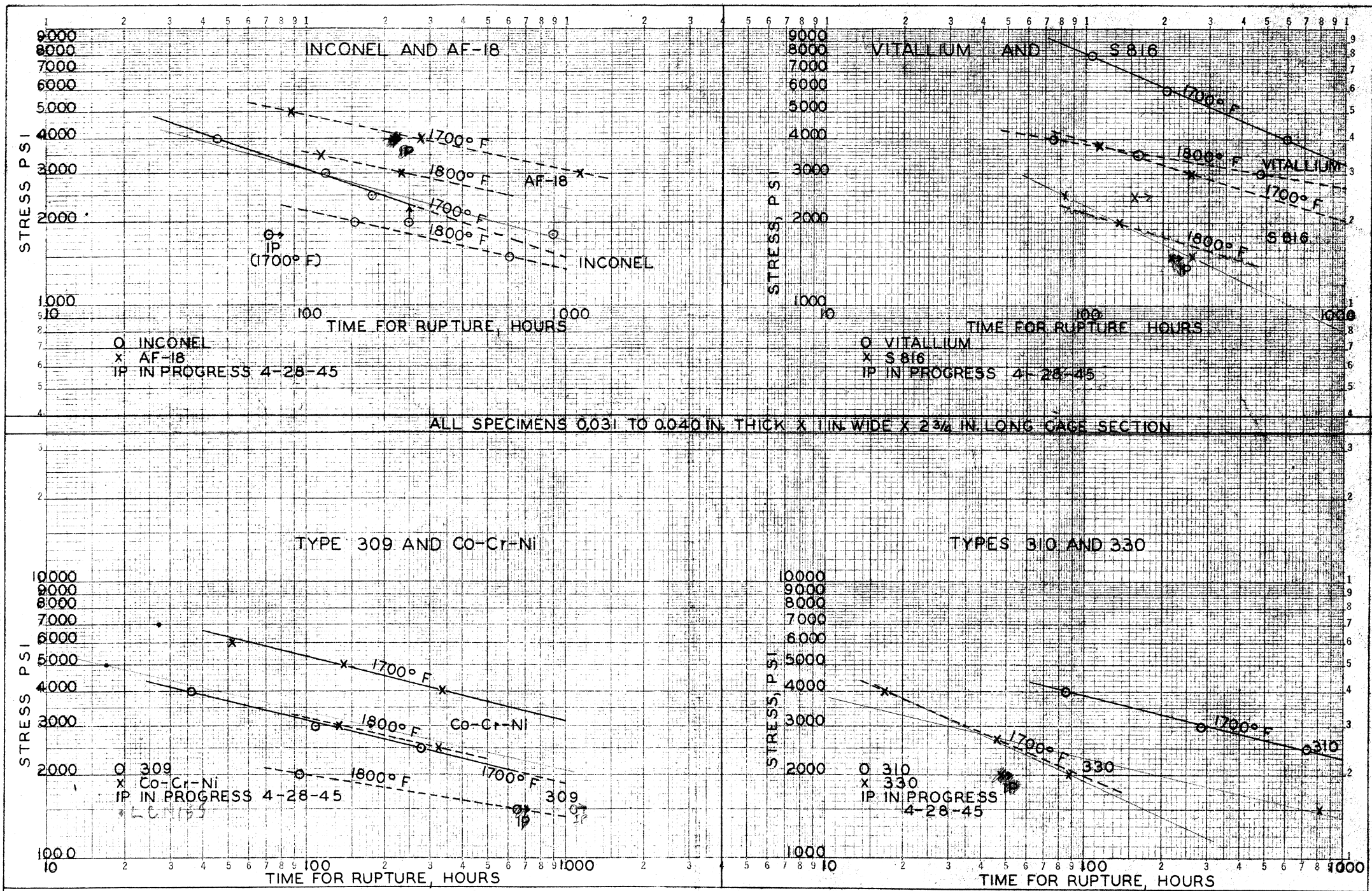

FIGURE 2- STRESS-RUPTURE TIME CURVES AT 1700° AND 1800° F FOR SHEET ALLOYS INCONEL, AF-18, S816, VITALLIUM, 309, Co-Cr-Ni, 310, AND 330.

C. Rupture Tests at 1700° and 1800° F on M.I.T. Alloys

Rupture tests at short time periods were run since the last progress report was issued. All of the data obtained to date are summarized in table XVI and compared graphically in figure 3 with X40, the highest strength alloy previously tested at these temperatures(1). Alloy 97NT-2 gave very erratic results but on an average was somewhat stronger than alloy X-40. At 100 hours NT-2 was equal to X-40 but at longer time periods was weaker.

Samples of both alloys were submitted to Mr. Franks for chemical analyses.

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(1) Taken from report 17.

TABLE XVI

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 128VT2-2	1.13 1.28	23	--	67	6	---	2

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	27,000	1.37	22	18.3
		19,000	88.0	7	11.5
		17,000	134.5	5	8.5
		15,000	412.0	2	3.9
	1800	21,000	1.38	20	34.0
		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	24,000	6.0	20	18.0
		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	20,000	1.33	22	29.0
		12,500	66.5	16	33.0
		11,000	102.0	20	37.0
		9,000	300.0	20	30.9

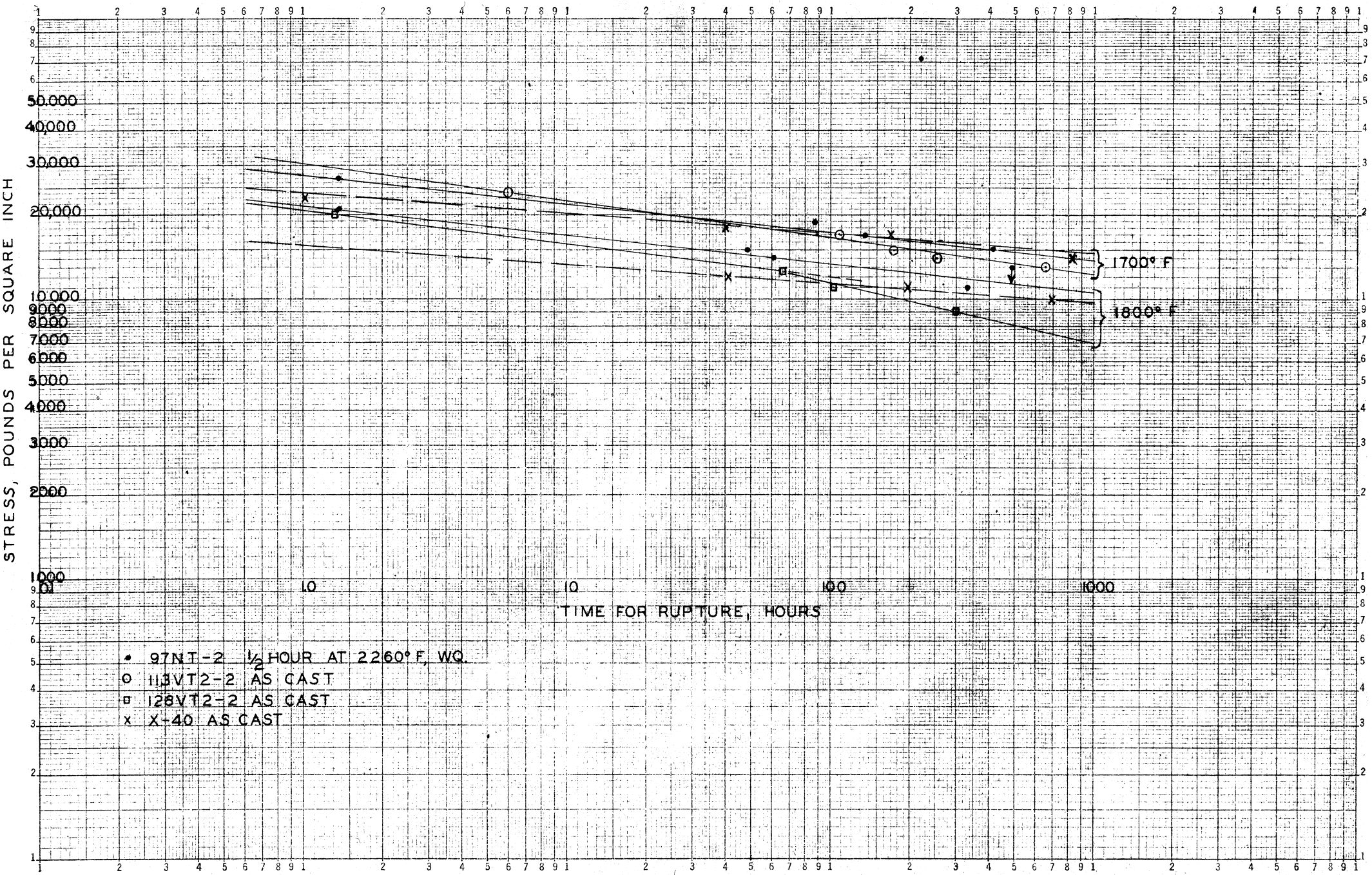

FIGURE 3.- COMPARATIVE STRESS-RUPTURE TIME CURVES FOR ALLOYS 97NT-2, 113 AND 128VT2-2 AND ALLOY X-40 AT 1700° AND 1800° F.

D. Low Carbon N155 + Boron

Three heats of Low Carbon N155 + Boron alloy have been rupture tested at 1200° F. One heat, J597, had about the highest rupture strength yet found for any alloy. The other two heats were inferior to standard Low Carbon N155 alloy. (See table XVII and figure 4.) Rupture tests at 1350° F on the high strength heat J597 gave 100- and 1000-hour strengths of 40,000 and 30,000 psi which are exceptionally high.

A satisfactory explanation of the difference in strength of the heats is not yet available. The excess constituents are more agglomerated in heat J573 than in J597. Samples of J593 were submitted to Mr. Franks for check chemical analysis.

Table I

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									

* Check analysis was reported as 0.58%

Manufacture and Source

Heat J573A was tested in the as-forged condition. Machined 0.160" diameter specimens were submitted by the Union Carbide and Carbon Research Laboratories, Inc.

Heat J597 was tested in the as-forged condition. Two 5-inch by 7/8-inch square bars from a 50 pound experimental heat were 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 was tested in the as-hot rolled condition. ~~From 45 3/4 pound ingot (basic arc melting at Union Carbide and Carbon Research Laboratories, Inc.) heat~~ hammer cogged from 2050°F. to 1750°F. to 2 inch square billet. Billet was rolled from 2080°F. to 1800°F. to 7/8 inch square. One 8-inch by 7/8-inch square bar was submitted by Universal Cyclops Steel Corporation. This bar had been rolled from a 45 3/4 pound ingot cast from a basic arc furnace heat melted by the Union Carbide and Carbon Research Laboratories. The Universal Cyclops Steel Corporation had

~~1200°F. Stress Rupture Results~~ * Table II

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
N175	60,000	8.5	21	23.3
	50,000	114.0	37.5	50.5
	45,000	406.5	47	62.5

1350°F. Stress-Rupture Results

J597	40,000	97.5	33	55.3
	35,000	285.0	28	59.3
	32,000	517.0	21	56.9

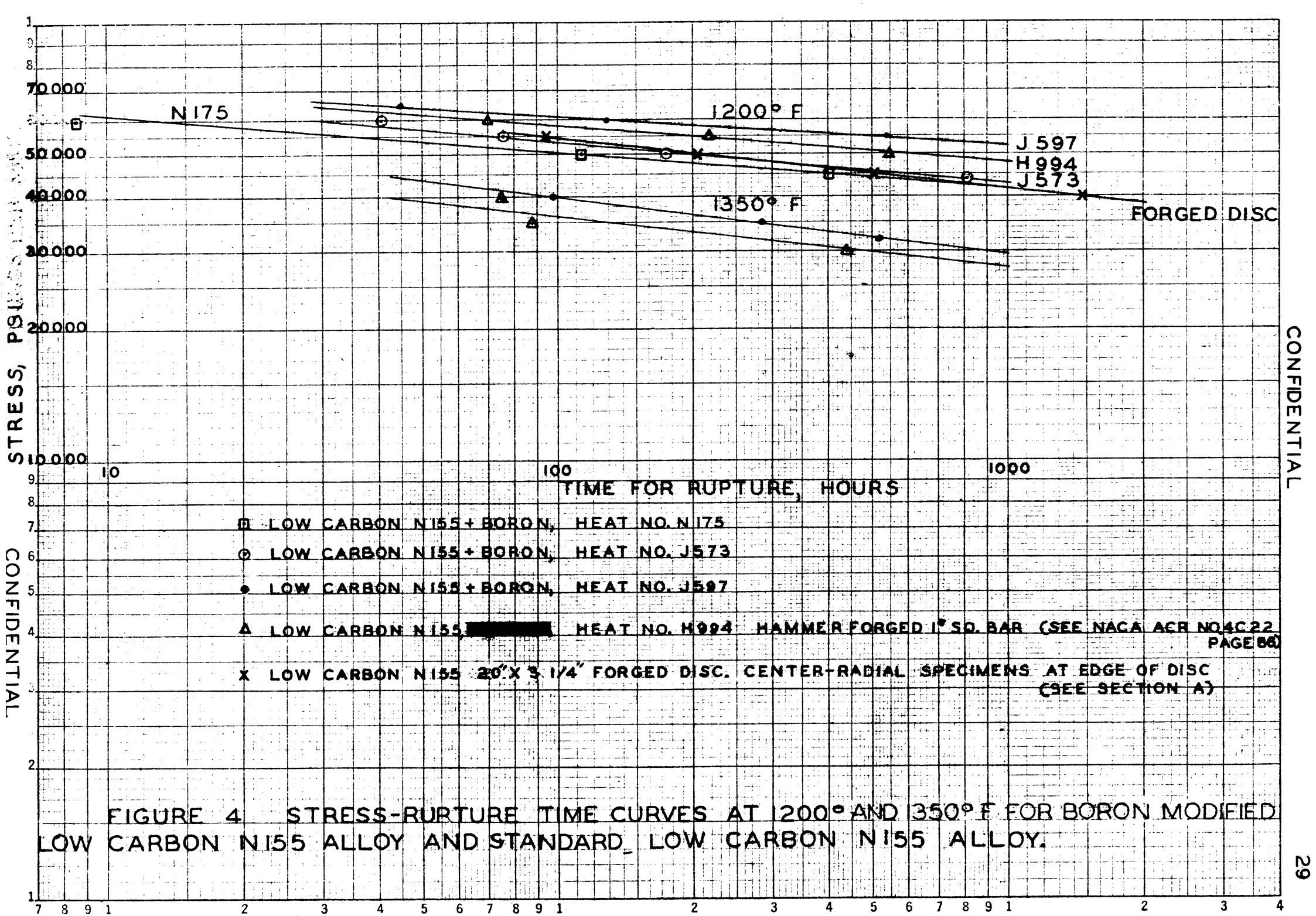

FIGURE 4 STRESS-RUPTURE TIME CURVES AT 1200° AND 1350° F FOR BORON MODIFIED LOW CARBON N155 ALLOY AND STANDARD LOW CARBON N155 ALLOY.

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E. Forged Modifications of 6059 and Low-Carbon N155 Alloys at 1350° F

These two wrought alloys were submitted by Mr. H. C. Cross of National Research Council Project 8 for testing at 1350° F under the NACA program.

The chemical analyses, along with the analyses of normal heats of 6059 and Low Carbon N155, heat treatment, and 1350° F rupture test results are given in table ~~XVIII.~~ X

Incomplete rupture test results, figure 5, indicate that these two alloys have similar rupture strengths. However, in the case of the Low Carbon N155 modification, the rupture strength appears to be lower than that for normal Low Carbon N155. No information is available for normal 6059 in the wrought condition at 1350° F. It is, however, much weaker than cast 6059.

TABLE XVIII

1350° F STRESS-RUPTURE PROPERTIES OF MODIFICATIONS OF 6059 AND N155 ALLOYS

Chemical Analyses:

Alloy	C	Cr	Ni	Co	W	Mo	Cb
NR82 (Mod. 6059)	0.17	24.5	32	32	2	3	1
[1]Standard Cast 6059	0.46	26.17	35	35	-	6.4	-
NR84 (Mod. N155)	0.14	21	25	25	1	4	1
[1]Low Carbon N155 (Heat No. H994)	0.10	20	20	20	2	3	1

Processing Procedure

These two alloys were made from 100 pound basic induction furnace heats by the Union Carbide and Carbon Company. Forging was from 2100° to 1400° F from 3 inch square ingots to 1 inch square bars.

Heat Treatment

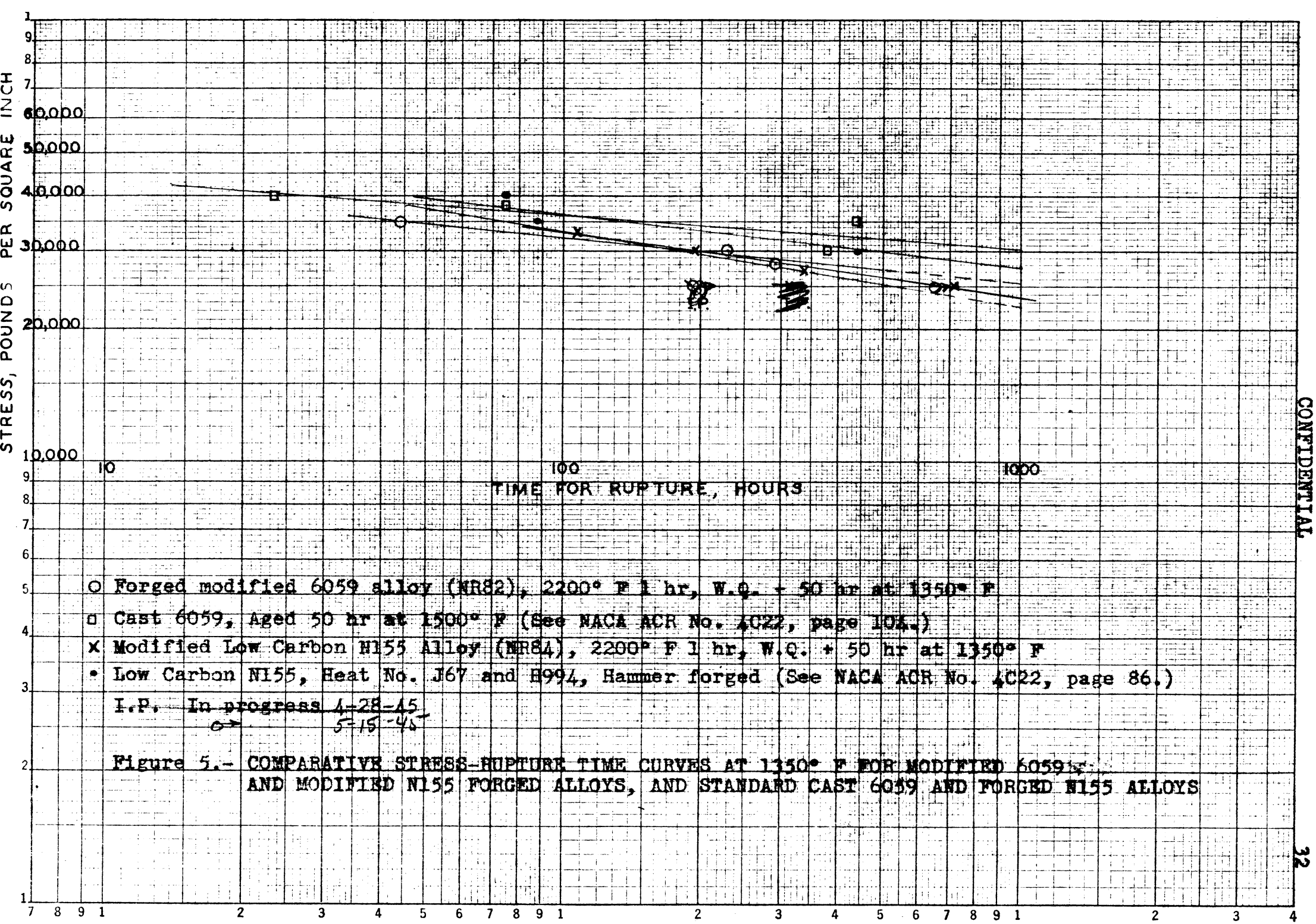
Both of the alloys were solution treated at 2200°F for 1 hour and water quenched followed by ageing 50 hours at 1350° F.

1350° F Rupture Test Results

Alloy	Stress (psi)	Rupture Time (hours)	Elongation (% in 1 in.)	Reduction of Area (percent)
NR82 (Mod. 6059)	35,000	44.5	10	10.5
	30,000	229.0	9	10.9
	28,000	291.5	[2]8	12.5
	25,000	In progress ~~192~~ 648 hours, ~~4-28-45~~ 5-15		
NR84 (Mod. N155)	33,000	106.0	26	26.5
	30,000	196.5	33	39.0
	27,000	338.0 718	[2]30 29	34.2 28.2
	25,000	~~In progress 312 hours, 4-28-45~~		

[1]See NACA ACR No. 4C22.

[2]Broke in gage mark.



○ Forged modified 6059 alloy (NR82), 2200° F 1 hr, W.Q. + 50 hr at 1350° F

□ Cast 6059, Aged 50 hr at 1500° F (See NACA ACR No. 4C22, page 104.)

× Modified Low Carbon N155 Alloy (NR84), 2200° F 1 hr, W.Q. + 50 hr at 1350° F

• Low Carbon N155, Heat No. J67 and H994, Hammer forged (See NACA ACR No. 4C22, page 86.)

I.P. ~~In progress~~ 4-28-45 o→ 5-15-45

Figure 5.- COMPARATIVE STRESS-RUPTURE TIME CURVES AT 1350° F FOR MODIFIED 6059 AND MODIFIED N155 FORGED ALLOYS, AND STANDARD CAST 6059 AND FORGED N155 ALLOYS

F. Chromium Base Alloys at 1350° F

The National Research Council Project 8 has been investigating the properties at 1600° F of cast chromium base alloys developed in connection with the Climax Molybdenum Company. Some of these alloys have shown excellent properties. At the last Subcommittee meeting it was decided that the properties of some of the best of these alloys be investigated at 1350° F under the sponsorship of the NACA.

A 60Cr-30Fe-10Mo alloy, specimen 608, fractured after 38 hours at 1350° F under 50,000 psi. This life is about the same as that of 422-19 alloy, under this same stress. Alloy 422-19 showed the highest rupture strength of any alloy previously tested at 1350° F. (See NACA ACR 4C22.)

A 60Cr-25Fe-15Mo alloy has far better rupture strength. One sample, specimen 612-2, fractured after 484 hours under 50,000 psi. This particular alloy has phenominally high rupture strength at 1350° F, since this compares with about 40 hours as the best previous rupture time at this stress.

Another specimen, 522, carried 45,000 psi for 450 hours before it was overheated through a controller failure. This time, however, was far in excess of the best previous rupture time of 175 hours for 422-19 alloy at 45,000 psi.

TABLE XIX

1350° F RUPTURE TEST RESULTS ON CHROMIUM BASE ALLOYS

Specimen Number	Chemical Analyses					Stress (psi)	Rupture Time (hours)	Elongation, % in 1 in.	Reduction of Area, %
	C	Si	Cr	Fe	Mo				
608	0.03	0.14	61.96	29.14	8.73	50,000	38	40	35
612-2	0.01	0.13	58.86	25.11	15.89	50,000	484	9	9
522	0.05		60	25	15	45,000	Overheated after 450 hr.		

Specimens prepared by melting and centrifugally casting under vacuum, then grinding to a 0.160-inch diameter gage section.

G. Effect of Heat Treatment and Processing on the Properties of Low Carbon N155

Low Carbon N155 alloy has been prepared as bar stock in thirteen different conditions as preliminary work in the study of the effect of processing variables on the 1200° F rupture properties of this alloy. The chemical analysis and manufacturing procedure for the original hot rolled bar stock are given in table XY.

A large range in room temperature tensile properties was found for the alloy in the thirteen different conditions. (See table XXI.) The most pronounced effect resulted from variation in amounts of hot-cold work. Reductions by rolling 10 percent at 1200° F produced yield strength in excess of 90,000 psi, with the as-forged bar stock responding the best. A reduction of 20 percent raised the yield strength to 120,000 psi. A reduction of 5 percent gave a yield strength of 67,000 psi. These values show that the alloy is very responsive to hot-cold work, and that reductions of about 15 percent would produce a yield strength in excess of 100,000 psi.

As soon as equipment is available rupture tests will be started at 1200° F.

TABLE XX

HOT ROLLED LOW CARBON N155 BAR STOCK

Chemical Analysis

C	Cr	Ni	Co	Mo	W	Cb	Mn	Si	N_2	S	P
0.12	21.33	18.88	18.60	3.21	1.97	1.10	1.64	0.39	0.12	0.003	0.026

Manufacture

The melt (Lot 30276) was prepared by the Union Carbide and Carbide Research Laboratories, a 8" X 7" ingot weighing approximately 600 pounds being produced. Hot working was done at Universal Cyclops Steel Corporation. This ingot was hammer cogged without difficulty to 2" square billets with 2050°F. as maximum temperature and 1750°F. as minimum. The 2" square billets were hot rolled to 7/8" square in one heat from 2075°F. to a finishing temperature of 1725°F.

TABLE XXI

ROOM TEMPERATURE TENSILE PROPERTIES OF LOW CARBON N155 ALLOY (LOT 30276) WITH INDICATED TREATMENTS

Heat Treatment					Hot-Cold Work		Brinell Hardness	Tensile Strength (psi)	Proportional Limit (psi)	Yield Stresses (psi)			Elongation (% in 2 in.)	Reduction of area (percent)
Solution Temp. (°F.)	Solution Time (Hours)	Method of Cooling	Ageing Temp. (°F.)	Ageing Time (Hrs.)	Temp. (°F.)	% Reduction				0.02% Offset	0.1% Offset	0.2% Offset		
Hot rolled		----	----	----	----	-----	233	128,500	57,500	72,500	76,500	78,500	40.5	55.7
----	----	----	----	----	1200	10 (10.0)	312	146,750	70,000	98,500	118,000	121,000	25.5	47.0
----	----	----	----	----	1200	20	323	162,500	112,500	134,000	145,000	148,500	19.0	40.7
2050	2	W.Q.	----	----	----	-----	208	117,500	27,500	47,000	56,000	58,500	44.0	62.4
2050	2	W.Q.	----	----	1200	5 (4.5)	249	125,500	42,500	67,000	81,000	84,000	35.5	54.7
2050	2	W.Q.	----	----	1200	10 (10.5)	301	138,750	52,500	90,000	107,500	112,000	28.0	49.2
2050	2	W.Q.	----	----	1200	20 (20.2)	340	154,500	85,000	121,000	134,000	138,000	23.5	49.5
2050	2	W.Q.	1400	24	----	-----	220	118,500	17,500	38,000	53,000	58,500	36.0	41.6
2050	2	W.Q.	1400	24	1200	10 (10.6)	287	134,000	65,000	90,000	105,000	109,000	23.5	37.9
2200	1	W.Q.	----	----	----	-----	205	115,750	25,000	42,000	53,000	57,000	46.5	64.3
2200	1	W.Q.	----	----	1200	10 (10.6)	289	136,500	75,000	90,000	102,500	107,000	31.5	55.7
2200	1	W.Q.	1400	24	----	-----	221	119,250	25,000	48,000	61,000	65,000	32.0	39.8
2200	1	W.Q.	1400	24	1200	10 (10.6)	288	136,250	70,000	98,500	107,500	111,000	22.5	34.7

4. Investigations Completed

A report is being prepared on Low Carbon N155 disc in conjunction with Mr. H. C. Cross for project NRC-8.

The work on the following three programs has been completed and reports are being prepared:

a. S816 and S590 bar stock at 1350° F

b. Vacuum Melted Alloy

c. Ceramic Coated 16-25-6 Alloy

All of the data on these programs was included in the February 8, 1945 progress report.

I. Programs to be Completed

Additional work is to be done on the following programs, although no data have been obtained since the last progress report was issued:

a. 19-9 DL turbosupercharger discs at 1200° and 1350° F.

b. Typical 19-9 DL bar stock.

c. Effect of processing and heat treatment on 19-9 DL. 234-A-5, Timken Alloy and Age-Hardenable Inconel Alloys.