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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

September 4, 1945

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Project Number M478-A

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

Report 19, "High Temperature Properties of Large Forged Discs" June 25, 1945.

Report 20, "A Metallurgical Investigation of S590 and S816 Bar Stock at 1350° F" July 16, 1945.

A joint report with H. C. Cross entitled "A Metallurgical Investigation of a Large Forged Disc of Low-Carbon N155 Alloy" August 4, 1945.

Report Number 18 entitled "A Metallurgical Investigation of a Large Forged Disc of CSA (234-A-5 Alloy" April 25, 1945, is now being duplicated for release as an Advance Restricted Report.

A. Evaluation of Properties of Alloys as Rotor Forgings

A total of 23 discs have been included in the program of evaluation of alloys for service as rotors for gas turbines. These include four Timken, three 19-9 DL, three CSA, one EME, one Discaloy, three S590, two S816 and six Low-Carbon N155 Alloy discs. More than one disc of any one alloy includes different fabrication or heat-treating procedures or different sources.

Complete data for all discs are confined to comparative properties in this report. Otherwise the data are confined to presenting only the data which have been obtained since Report Number 19 entitled "High Temperature Properties of Large Forged Discs" was issued on June 25, 1945. Since this report was written the following additional discs have been received:

Alloy	Type forging	Manufacturer
Timken	TG-180	Midvale
Timken	I-40	Canton Drop Forging & Manufacturing Company
19-9 DL	I-40(worked at 1250° F)	" " " " "
19-9 DL	I-40(worked at 1650° F)	" " " " "
EME	I-40	Midvale
S816	Pancake(as-forged & aged)	Allegheny-Ludlum (NRC-8)

Tensile tests will be run on all discs at room temperature and 1200° F. All discs are being rupture tested at 1200° F. Rupture and tensile data are to be obtained at 1350° F on part of the Low-Carbon N155, and on the S590 and S816 discs. OSRD Project NRC-8 is obtaining creep data at 1350° F and rupture and creep data at 1500° F on discs of these three alloys.

An analysis of the data yields the following information:

1. High yield strengths at room temperature were only developed by hot-cold work at about 1250° F as in the standard I-40 forgings. Discaloy was an exception in that high room-temperature physical properties were obtained by heat treatment. (See table I and figure 1.)

2. The best rupture strengths thus far obtained were shown by the S590 discs and Low-Carbon N155 disc NR66D. (See table II and figures 1, 2A, 2B and 2C.) The Discaloy disc had high rupture strength but low ductility.

   Considerable variation in rupture strength and ductility has been found for discs of the same alloy from different heats or sources and after variation in fabrication procedure or heat treatment.

3. The stress-time for total deformation characteristics are difficult to analyze since relative values for different discs depend on the stress, time period and total deformation considered. (See table III.) In general the S590 discs and Low-Carbon N155 disc NR66D have shown up best in this type of test.

   The four Timken alloy discs have had reasonably similar time-deformation characteristics as is shown by figure 3. They have differed to a considerable extent in the tendency to enter third-stage creep. The curves of stress versus time for total deformation have been steeper for this alloy than for most of the others.

   The two I-40 forgings of 19-9 DL alloy have much better time-deformation characteristics than the first disc tested in the as-forged condition. (See figure 4.) The data thus far obtained indicate that the disc worked at 1250° F will compare favorably with the S590 disc and the Low-Carbon N155 disc NR66D for total deformations of 0.1 and 0.2 percent at 1200° F.

Summary tables for S590, Timken, 19-9 DL, EME and S816 alloys have been prepared to supplement similar data given in Report Number 19 for the other discs considered in this investigation.

Additional tensile and rupture data are given in table IV for S590 discs. The information given in table V includes a description of all the Timken Alloy discs as well as the available tensile and rupture test data. Sketches showing the location of test coupons cut from the various Timken Alloy discs are included as figures 5, 6 and 7. The information for the 19-9 DL discs is included as table VI. Specimens from the I-40 forging were cut as is shown by figure 7.

Tests have not yet been started on the EME and S816 forgings. A description of these two discs have been included as tables VII and VIII.

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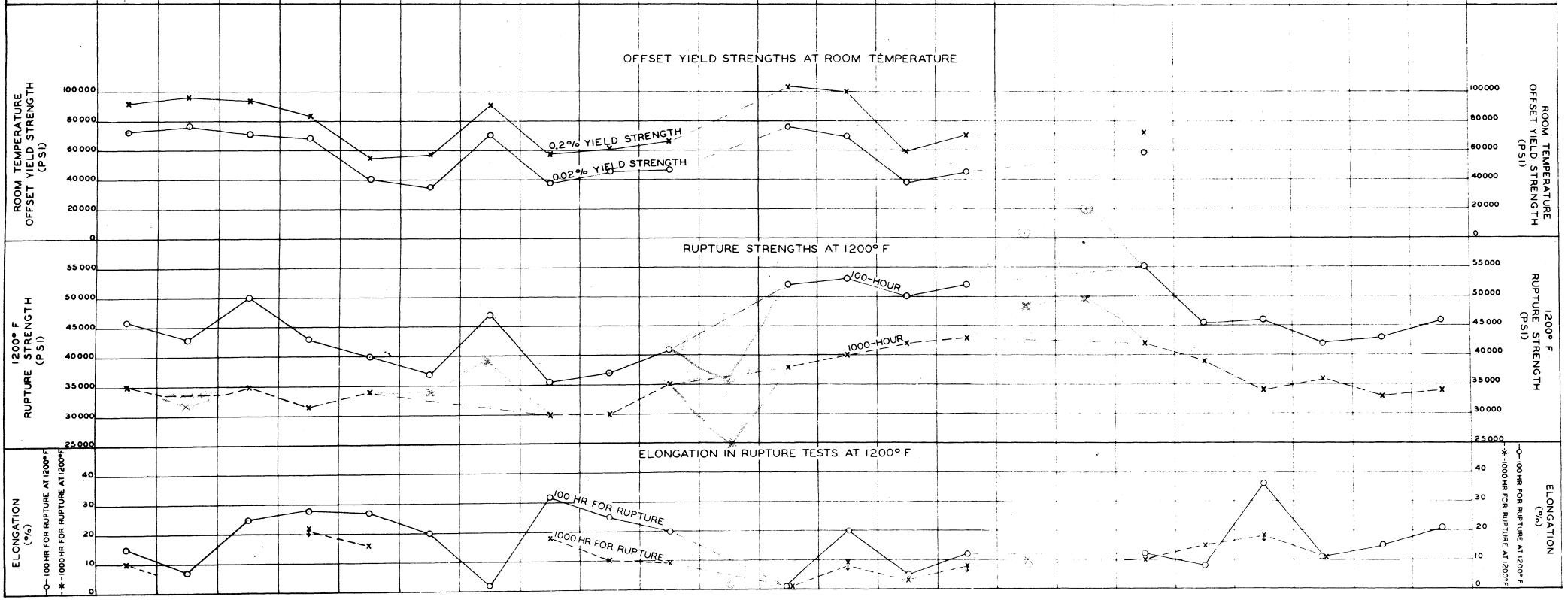
ALLOY	TIMKEN				19-9DL			C S A			EME	DISCALOY	S 590			S 816		LOW-CARBON N 155						ALLOY
DISC	I-40 MIDVALE	I-40 CANTON DROP FORGE	TG-180 MIDVALE	TG-180 MIDVALE	(1)	I-40 CANTON DROP FORGE	I-40 CANTON DROP FORGE	LOW CARBON (2)	HIGH CARBON	HIGH CARBON	I-40 MIDVALE	NR 78 (3)	NO. 2	NO. 1-A	NO. 1-B			NR 66D (4)	NR 66E-1	NR 66E-2	NR 66E-4	NR 66E-3	NR 66E-5	DISC
SIZE OF DISC DIAMETER (IN)	20	20	28	(5)	19 3/4	20	20	20	20	20	20	20 1/2	18	18	18	--	--	21	14 3/4	14 3/4	14 3/4	14 3/4	14 3/4	SIZE OF DISC DIAMETER (IN)
THICKNESS (IN)	---	---	---		3 1/4	---	---	3 5/16	3 1/2	3 1/2	---	3	3 3/8	3	3	3 5/16	3 5/16	3 1/4	4 3/8	4 3/8	4 3/8	4 3/8	4 3/8	THICKNESS (IN)
SOLUTION TREATMENT			NONE		NONE	2150° F W.Q.	2150° F W.Q.	NONE	2100° F A.C.	A.C. TO 1400° F FROM 2100° F	NONE	1950° F A.C. WITH AIR BLAST ON CENTER	NONE	2300° F W. Q.	2300° F W. Q.	NONE		NONE	NONE	NONE	2200° F W.Q.	2200° F W.Q.	2250° F W.Q.	SOLUTION TREATMENT
HOT-COLD WORK			WORKED AT 1275° F		AS-FORGED	WORKED AT 1850° F	WORKED AT 1250° F	AS-FORGED	10% AT 1400° F	10% AFTER 24 HR AT 1400° F	WORKED AT 1240° F	NONE	AS-FORGED	NONE	NONE	AS-FORGED		AS-FORGED	AS-FORGED	AS-FORGED	NONE	NONE	3 %	HOT-COLD WORK
AGEING TREATMENT TEMP (°F)			1200		1200	1200	1200	1200	1200	1200	1200	1350	1400	NONE	1400	1400		1200	NONE	1500	1350	1500	1500	AGEING TREATMENT TEMP (°F)
TIME (HR)			--		2	10	10	4	4	4	4	20	16		16	16		2		24	24	24	24	TIME (HR)



[1] SEE ARR 5C10, "A METALLURGICAL INVESTIGATION OF A LARGE FORGED DISC OF 19-9DL ALLOY."
[2] SEE REPORT 18, "A METALLURGICAL INVESTIGATION OF A LARGE FORGED DISC OF 23-4-5 ALLOY."
[3] SEE LETTER REPORT DATED 8-7-44.
[4] SEE REPORT OF 8-4-45, "A METALLURGICAL INVESTIGATION OF A LARGE FORGED DISC OF LOW-CARBON N 155 ALLOY," BY J.W. FREEMAN AND H.C. CROSS
[5] RIM HAD BEEN MACHINED OFF, SPECIMENS TAKEN MIDWAY BETWEEN CENTER AND RIM.

FIGURE 1.- COMPARISON OF YIELD STRENGTHS AT ROOM TEMPERATURE AND RUPTURE STRENGTHS AND DUCTILITY AT 1200° F FOR ALL FORGED DISCS.

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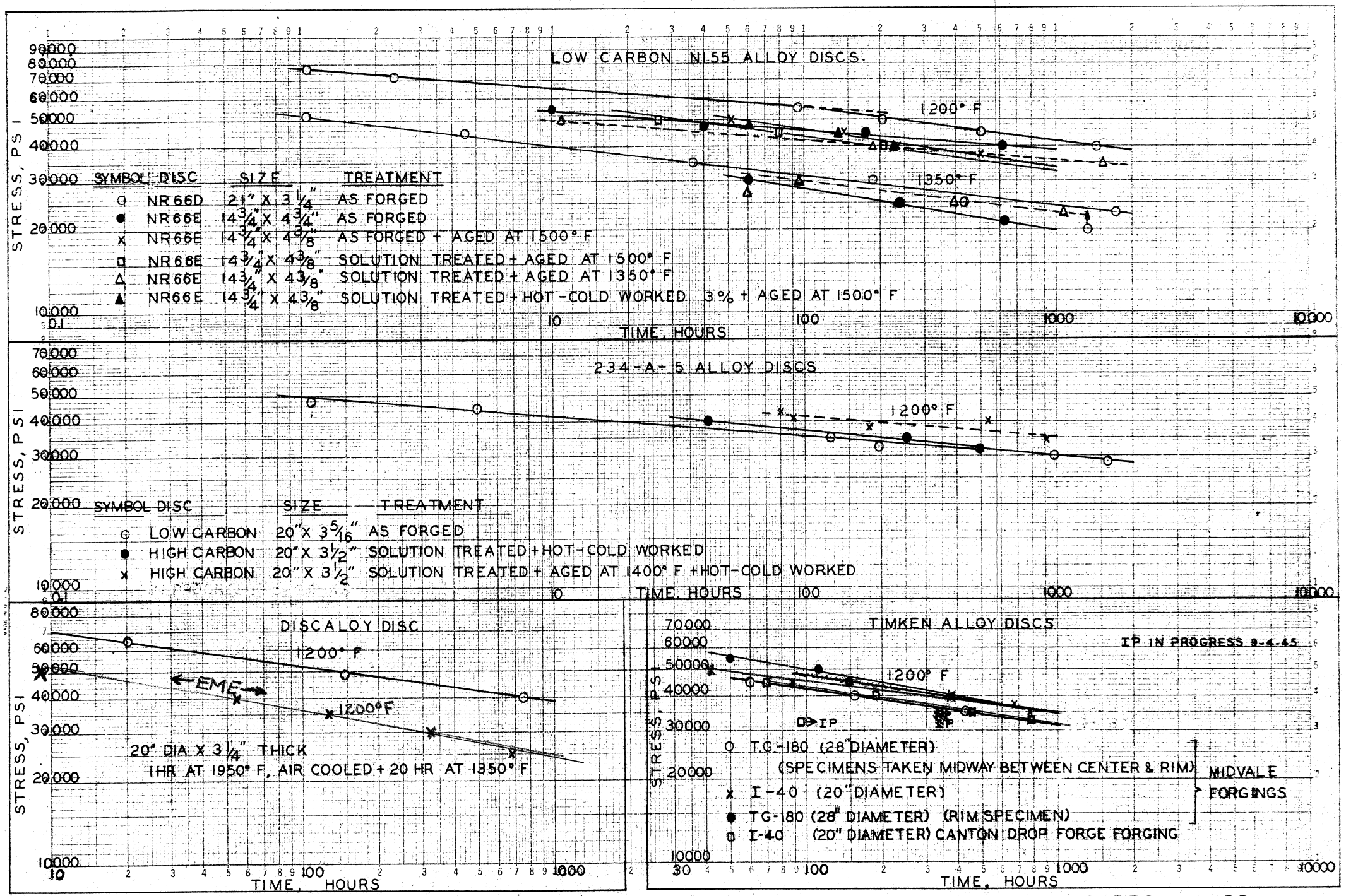
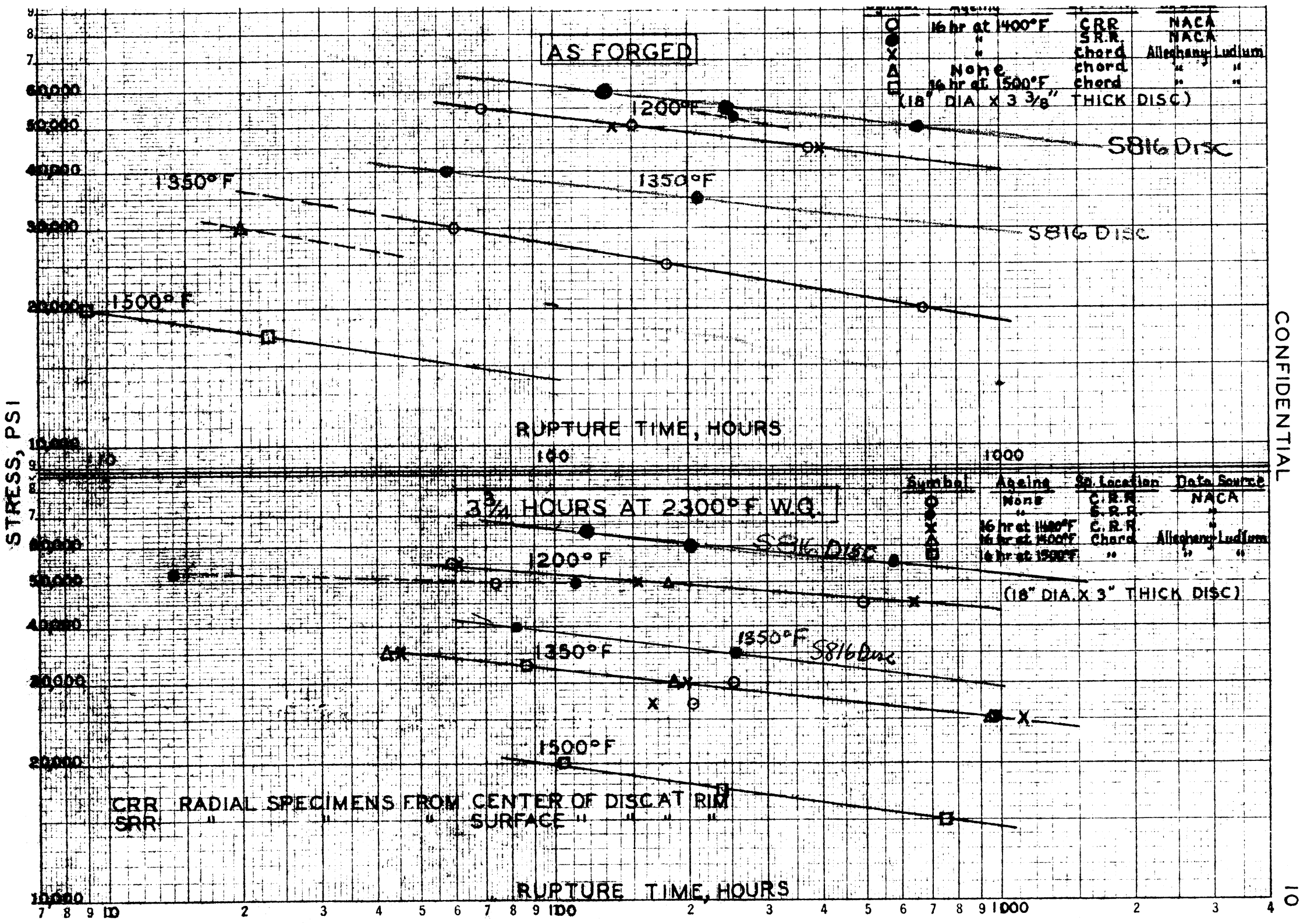


FIGURE 2A-STRESS-RUPTURE TIME CURVES AT 1200° AND 1350° F FOR LARGE DISCS OF LOW-CARBON N155, 234-A-5, DISCALOY AND TIMKEN ALLOYS.


AS FORGED
1200°F
1350°F
1500°F
S816 Disc
(18" DIA X 3 3/8" THICK DISC)
Symbol | Ageing | Sp. Location | Data Source
○ | None | C.R.R. | NACA
● | 16 hr at 1400°F | S.R.R. | "
X | " | C.R.R. | Allegheny Ludlum
△ | None | Chord | "
□ | 16 hr at 1500°F | Chord | "
STRESS, PSI
RUPTURE TIME, HOURS
3¾ HOURS AT 2300°F W.Q.
(18" DIA. X 3" THICK DISC)
CRR RADIAL SPECIMENS FROM CENTER OF DISC AT RIM
SRR " " " " SURFACE " " " "
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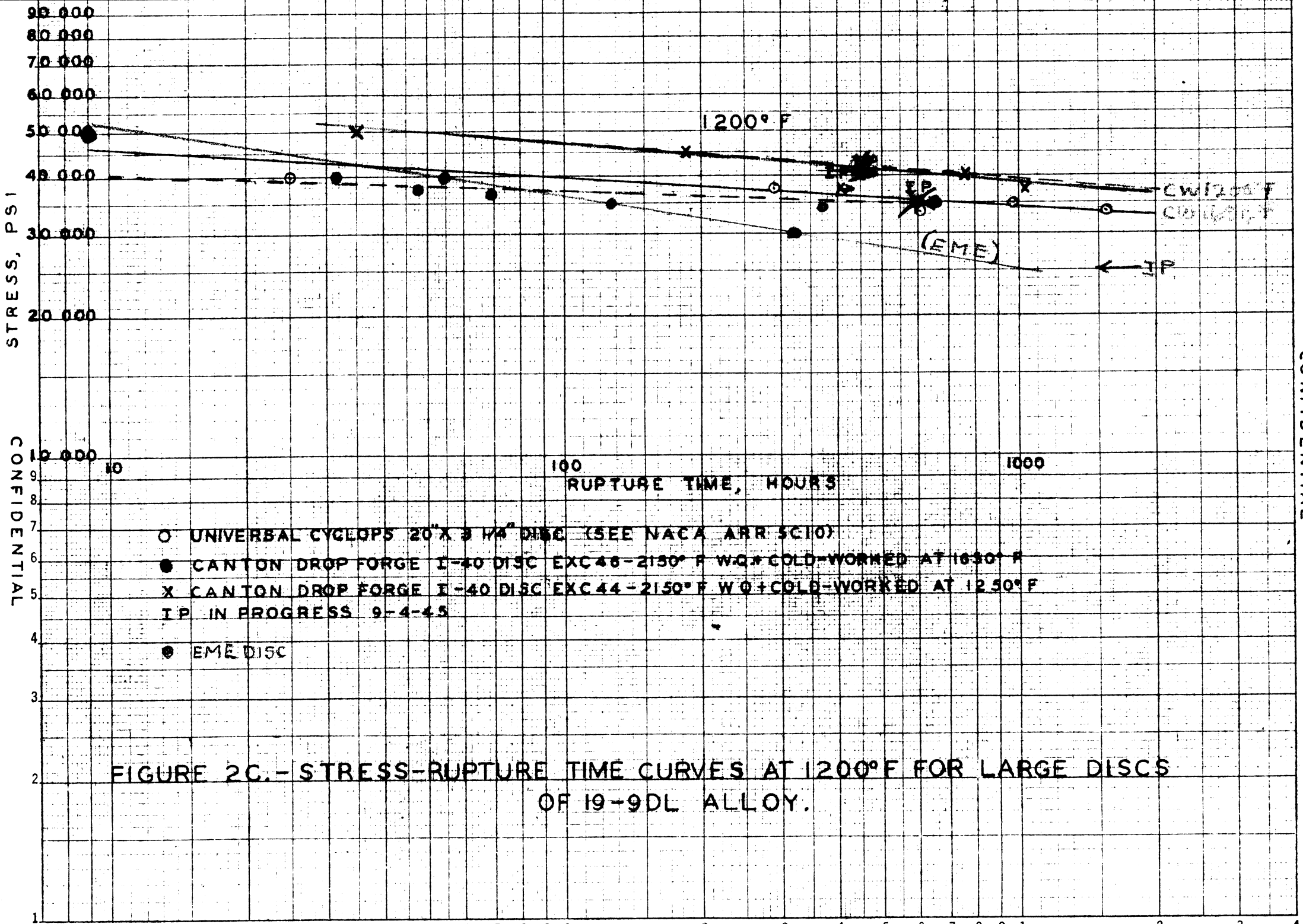

FIGURE 2C.- STRESS-RUPTURE TIME CURVES AT 1200°F FOR LARGE DISCS OF 19-9DL ALLOY.

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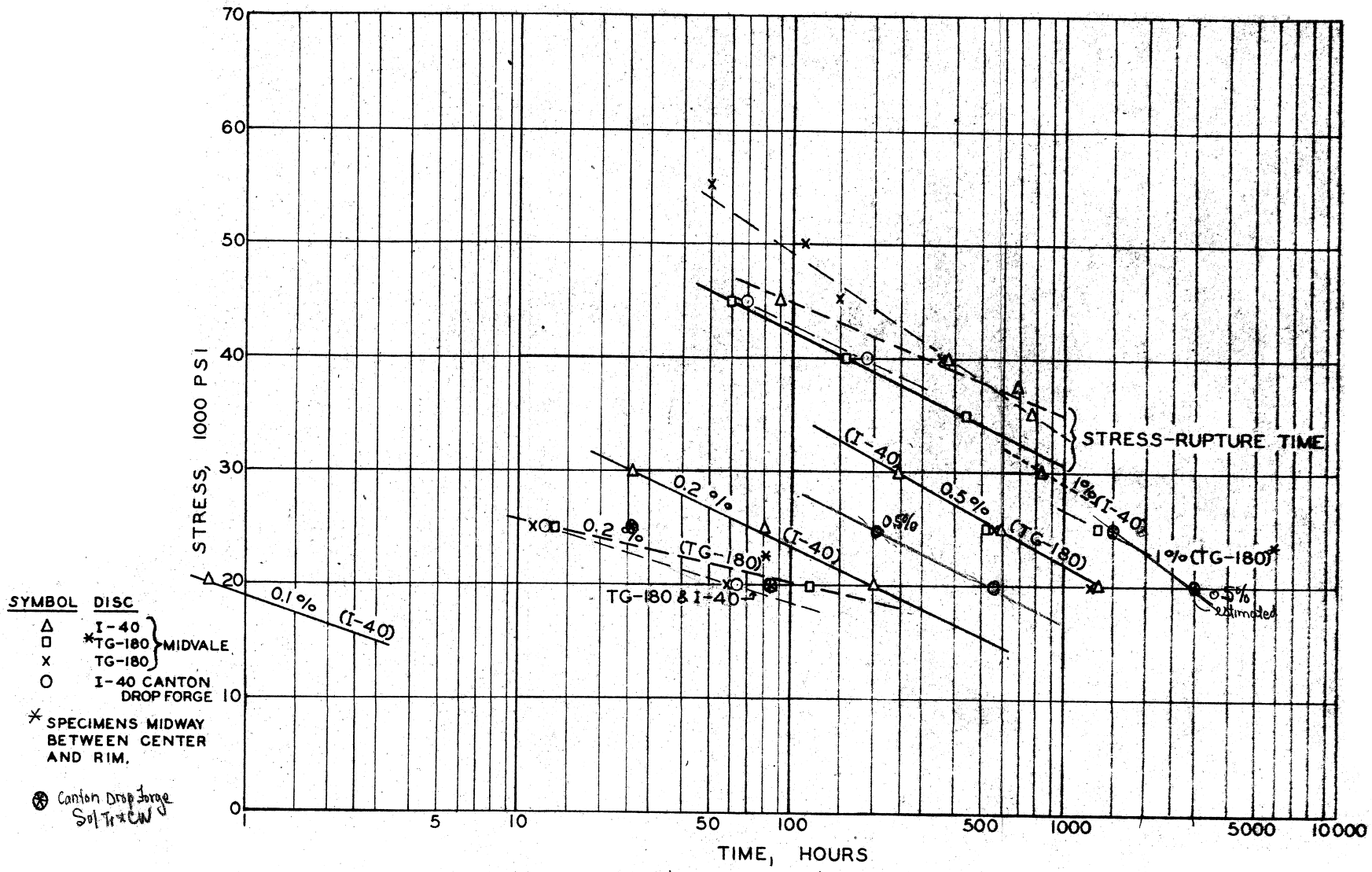

FIGURE 3.- STRESS-TIME FOR TOTAL DEFORMATION CURVES AT 1200° F FOR I-40 AND TG-180 FORGED DISCS OF TIMKEN ALLOY.

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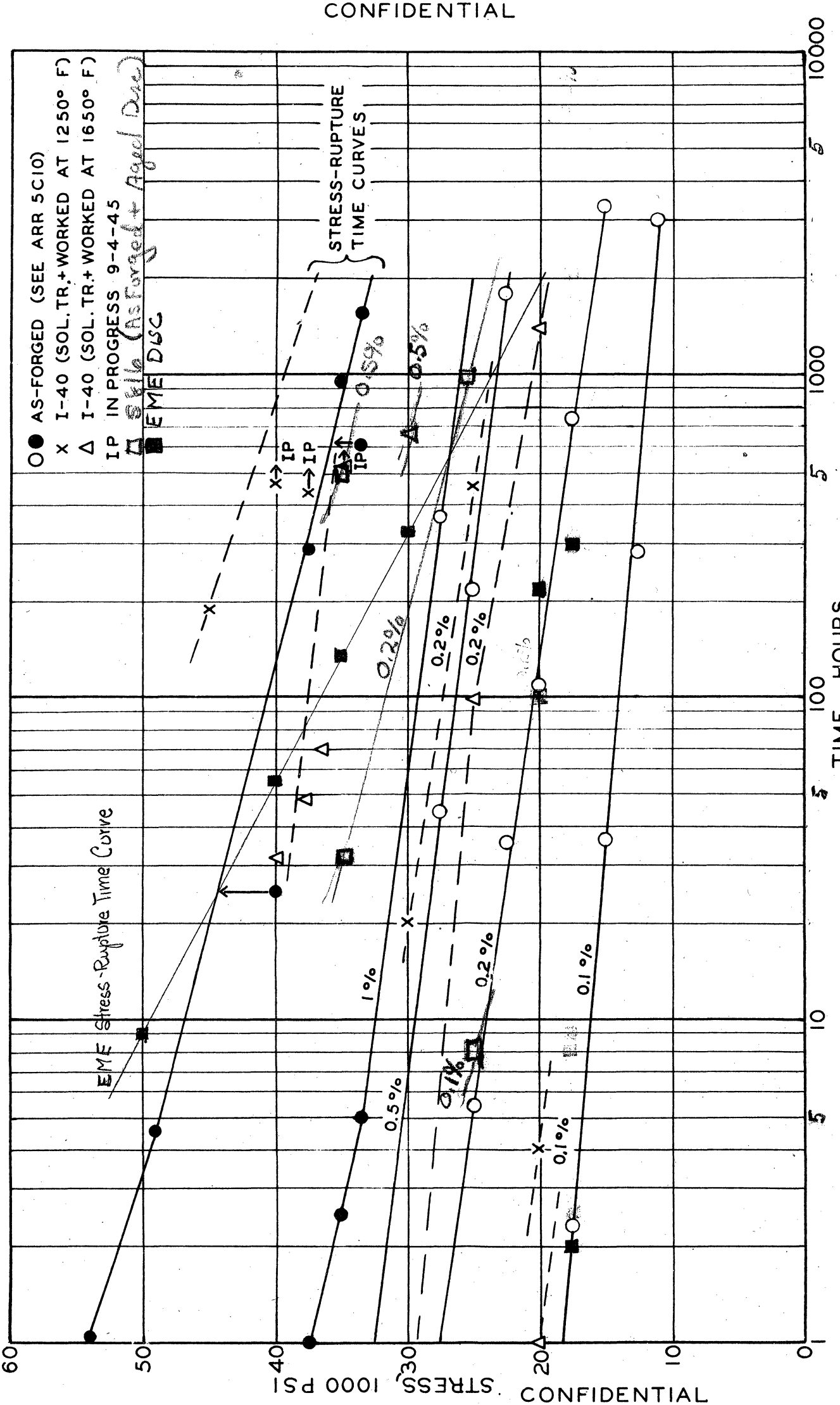

FIGURE 4.- CURVES OF STRESS-TIME FOR INDICATED TOTAL DEFORMATION AT 1200° F FOR 19-9 DL ALLOY DISCS.

TABLE IV

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 University of Michigan.

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

Tensile Properties of S590 Alloy Discs

Specimen	Specimen location	Brinell hardness	Temperature (° F)	Tensile strength (psi)	Offset yield strengths (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)
					0.02%	0.1%	0.2%			
As Forged + Aged 16 Hours at 1400° F										
3Y	CRR	267	Room	130,600	69,000	91,000	100,000	37,500	9	11.5
3X	SRR		Room	127,500	72,500	89,000	96,500	47,500	7	9.2
5Y	CTR	293	Room	137,750	75,000	99,000	108,000	37,500	11.5	23.2
5X	STR		Room	147,000	91,000	111,000	120,000	57,500	10	20.6
1Z	SRR	---	1200	87,900	------	62,500	70,000	22,500	16.5	21.3
2Z	SRR	---	1350	65,375	------	48,500	53,000	17,500	31	45.3
Solution Treated at 2300° F. Water Quenched										
10Y	CRR	211	Room	117,500	37,500	53,000	59,000	22,500	30.5	27.2
12Y	CTR	223	Room	119,000	40,000	53,500	59,000	25,000	38	37.2
12X	STR	---	Room	121,000	30,000	48,500	57,000	17,500	40	39.9
(1)	Chord	229-241	Room	125,000	32,500	------	------	------	39.5	34.3
9Z	SRR	---	1200	82,000	------	41,500	44,000	20,000	12	17.7
10Z	SRR	---	1350	71,250	------	41,500	46,000	22,500	11	13.0
Solution Treated at 2300° F. Water Quenched + 16 Hours at 1400° F										
11Y	CR	259	Room	130,500	45,000	63,500	70,500	25,000	17	18.2
11X	SR	---	1200	81,600	------	46,000	49,000	27,500	27	31.2
8X	SRR	---	1350	65,750	------	43,500	46,000	20,000	25	30.4
(1)	Chord	255	Room	134,000	45,000	------	------	------	22	18.8

CRR Radial specimen from the center third of the disc at the rim.
CTR Tangential specimen from the center third of the disc at the rim.
SRR Radial specimen from the outside third of the disc at the rim.
STR Data supplied by the Allegheny-Ludlum Steel Corporation.
(1) Data supplied by the Allegheny-Ludlum Steel Corporation.
CR Radial specimen from the center third of the disc.
SR Radial specimen from the outside third of the disc.

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TABLE IV (CONTINUED)

Runture Test Data for S590 Discs (18-inch diameter by 3-inch thick discs)

Specimen	Specimen location	Heat treatment	Test temperature (° F)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
6Y	CRR	As Forged + 16 hr at 1400° F	1200	55,000	69.5	21	20.6
6Y	CRR			50,000	150	17	21.2
6Y	CRR			45,000	372.5	9	14.4
6X	SRR			52,500	256	15	15.0
14Y	CRR	3 3/4 hr at 2300° F, W.Q.	1200	55,000	59	4	7.9
14Y	CRR			50,000	74	6	8.5
14Y	CRR			45,000	493	3	7.3
14X	SRR			52,500	14	6	13.6
14X	SRR			50,000	111	4	10.9
8Y	CRR	3 3/4 hr at 2300° F, W.Q	1200	55,000	60	11	13.8
15Y	CRR	+ 16 hr at 1400° F		50,000	153	13	16.7
15Y	CRR			45,000	640	8	10.9
6Y	CRR	As Forged + 16 hr at 1400° F	1350	30,000	60	12	14.4
6Y	CRR			25,000	180	8	11.5
6Y	CRR			20,000	676	6	4.4
14Y	CRR	3 3/4 hr at 2300° F, W.Q.	1350	33,000	86	10	15.6
14Y	CRR			30,000	252	11	15.0
9Y	CRR			27,000	204	8	8.0
9Y	CRR			25,000	951	11	17.8
8Y	CRR	3 3/4 hr at 2300° F, W.Q.	1350	35,000	45.5	13	17.8
8Y	CRR	+ 16 hr at 1400° F		30,000	198	12.5	16.0
8Y	CRR			27,000	167	8	15.6
8Y	CRR			25,000	1121	13	17.8

CRR radial specimen from center of disc at rim.
SRR radial specimen from surface of disc at rim.

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TABLE V

TIMKEN ALLOY DISCS

Chemical Composition

Disc	Forged by	Heat No.	C	Mn	P	S	Si	Ni	Cr	Mo	N_2
I-40	Midvale	H-4315	0.10	1.24	0.022	0.022	0.72	25.75	16.56	5.80	0.12
I-40	Canton Drop Forge	13356	.094	1.90	.024	.012	.70	25.08	16.60	5.86	.141
TG-180	Midvale	H-4174	.11	1.49	.023	.023	.64	26.25	15.67	6.25	.111
TG-180	Midvale	H-4684	.12	1.12	.017	.014	.71	26.20	15.90	6.30	.110

Processing Procedure

Disc and Serial No.	Heat No.	
I-40 S451	H-4315	Forged by Midvale. Machined to size at the Everett Plant of General Electric. 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.
I-40 C0713	13356	This heat was made by Timken and the disc was forged by Canton Drop Forge. Disc weight was 345 pounds.
TG-180 H-4174-7A	H-4174	Forged by Midvale. Machined to size at the Everett Plant of General Electric. 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. The rim of the wheel had been cut off so that the diameter of the section submitted was only about 20 inches.
TG-180 S1509	H-4684	Forging made from Midvale standard 2620-pound 16-inch diameter ingot, bottom poured. The forging was made from the bottom block from the ingot. It was forged at 2000° F, cold worked at 1275° F, and stress relieved at 1200° F. This wheel was gamma ray rejected.

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TABLE V (CONTINUED)

Tensile Properties of Timken Alloy Discs

Specimen	Specimen location	Brinell hardness	Temperature (° F)	Tensile strength (psi)	Offset yield strengths (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)
					0.02%	0.1%	0.2%			
I-40 Forging (Midvale)										
1Y	CRR	252	Room	120,500	77,000	89,000	93,500	55,000	11	17.0
1X	SRR	254	Room	122,000	68,000	83,500	90,000	42,500	14	15.8
9Y	CTR	254	Room	126,250	78,000	92,000	98,000	57,500	18	21.6
3Y	CRR	---	1200	79,000	------	61,000	63,500	37,500	16	26.1
I-40 Forging (Canton Drop Forge)										
3Y	CRR	---	Room	122,400	76,500	91,750	96,250	52,500	17.5	25.4
3X	SRR	---	Room	121,500	75,000	90,000	96,000	47,500		
3Z	SRR	---	1200	77,750	------	58,000	63,000	22,500	21	32.1
[1]TG-180 (Midvale)										
4X	(2)	223	Room	112,625	68,000	78,000	83,500	47,500	23	29.2
1X	(2)	---	1200	72,500	------	51,000	56,500	15,000	30	41.3
TG-180 (Midvale)										
1X	[2]SRR	248	Room	122,000	71,000	88,500	94,500	42,500	19	22.7
3X	[2]STR	267	Room	125,750	72,500	90,000	96,000	37,500	18	26.1
2X	[2]SRR	---	1200	79,000	------	62,000	65,000	37,500	24	32.8

CRR Radial specimen from the center of the forging at the rim.
SRR Radial specimen from the surface of the forging at the rim.
CTR Tangential specimen from the center of the forging at the rim.
STR Tangential specimen from the surface of the forging at the rim.

[1]Specimens taken at a point midway between center and rim of this TG-180 forging.

[2]The TG-180 forgings were too thin to split into thirds. The specimens represent one-half of the thickness.

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TABLE V (CONTINUED)

Rupture Test Data at 1200° F for As-Forged Timken Alloy Discs

Specimen	Specimen location	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
		I-40 Forging (Midvale)			
8Y	CRR	45,000	88	18	29.8
8Y	CRR	40,000	382	12	16.7
8Y	CRR	37,500	672	8	9.7
8Y	CRR	35,000	775	10	17.2
		I-40 Forging (Canton Drop Forge)			
3Y	CRR	45,000	70	7	12.1
3Y	CRR	40,000	188	8 9	13.8 8.5
3Y	CRR	35,000	~~In progress 336 hours 9/4/45~~ 464		
3Y	CRR	32,500	In progress 96 hours 9/4/45		
		[1]TG-180 (Midvale)			
2Y	(2)	45,000	60	29	34
2Y	(2)	40,000	155	26	27.2
2Y	(2)	35,000	424	22	26.7
		TG-180 (Midvale)			
4Y	[2]SRR	55,000	50	21	30.8
4Y	[2]SRR	50,000	112	30	36.9
4Y	[2]SRR	45,000	148	32	40.8
4Y	[2]SRR	40,000	373	33	38.8

CRR Radial specimen from center of forging at rim.
SRR Radial specimen from surface of forging at rim.

[1]Specimens taken midway between rim and center of this TG-180 forging.

[2]The TG-180 forgings were too thin to split into thirds. The specimens represent one-half of the thickness.

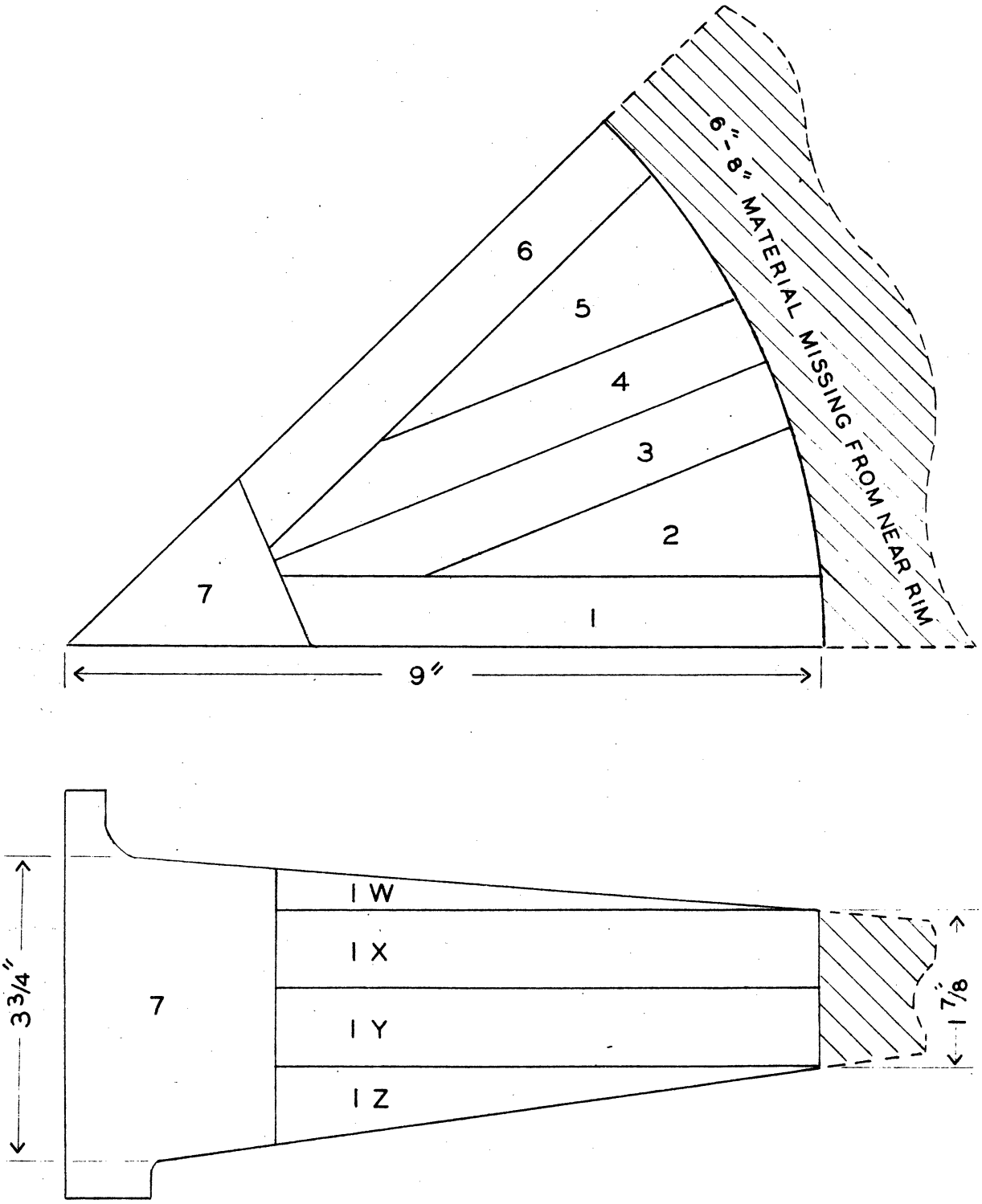
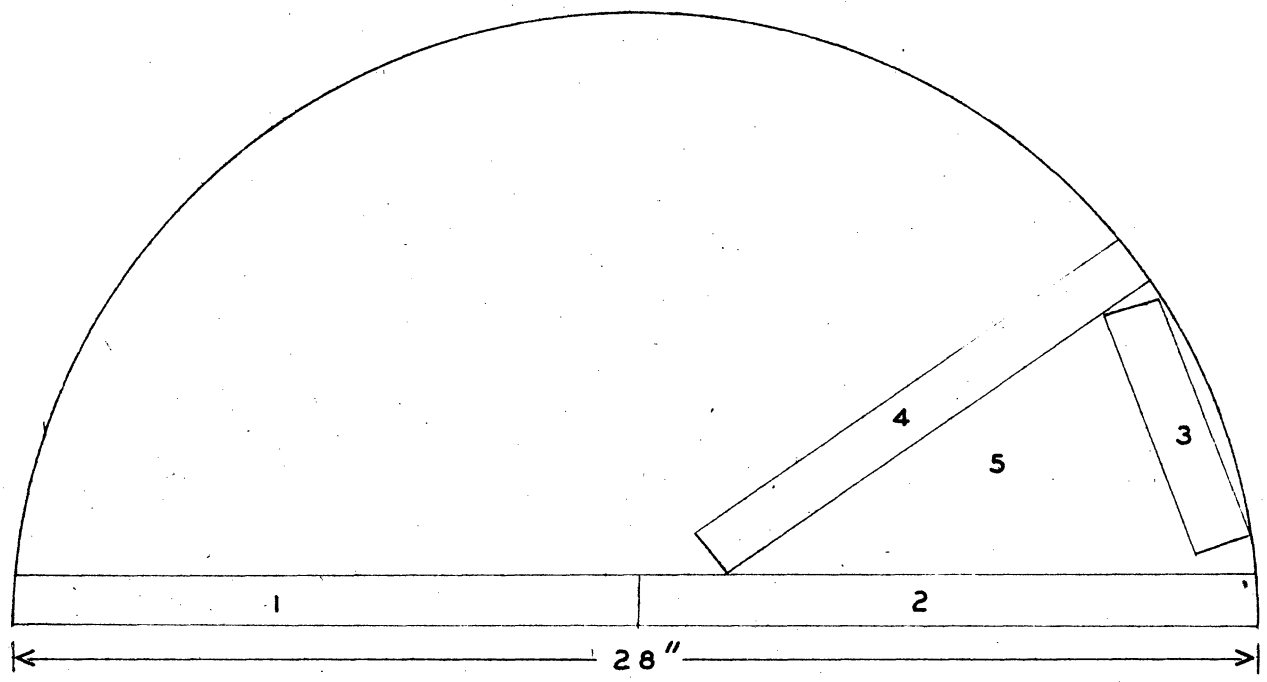


FIGURE 5.-DIAGRAM SHOWING LOCATION OF TEST COUPONS IN AN EIGHTH SECTION OF THE TG-180 (SERIAL NO. H-4174-7A) TIMKEN ALLOY DISC.



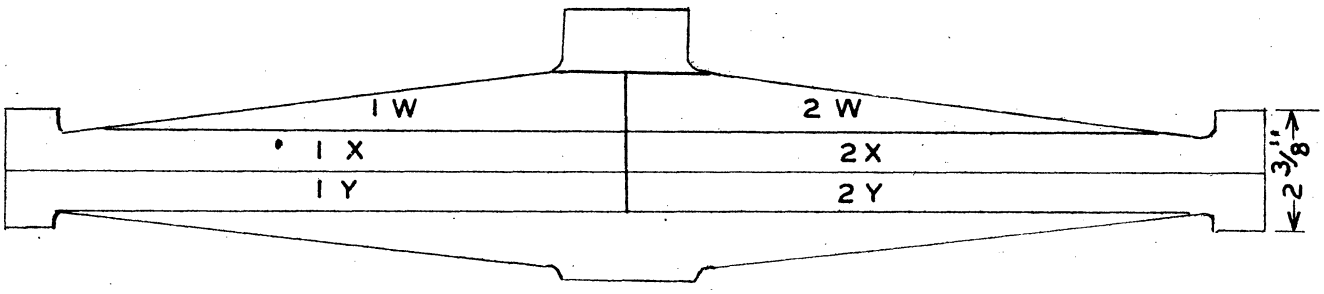


FIGURE 6.- DIAGRAM SHOWING LOCATION OF TEST COUPONS IN A HALF SECTION OF THE TG-180 (SERIAL NO. S1509) TIMKEN ALLOY DISC.

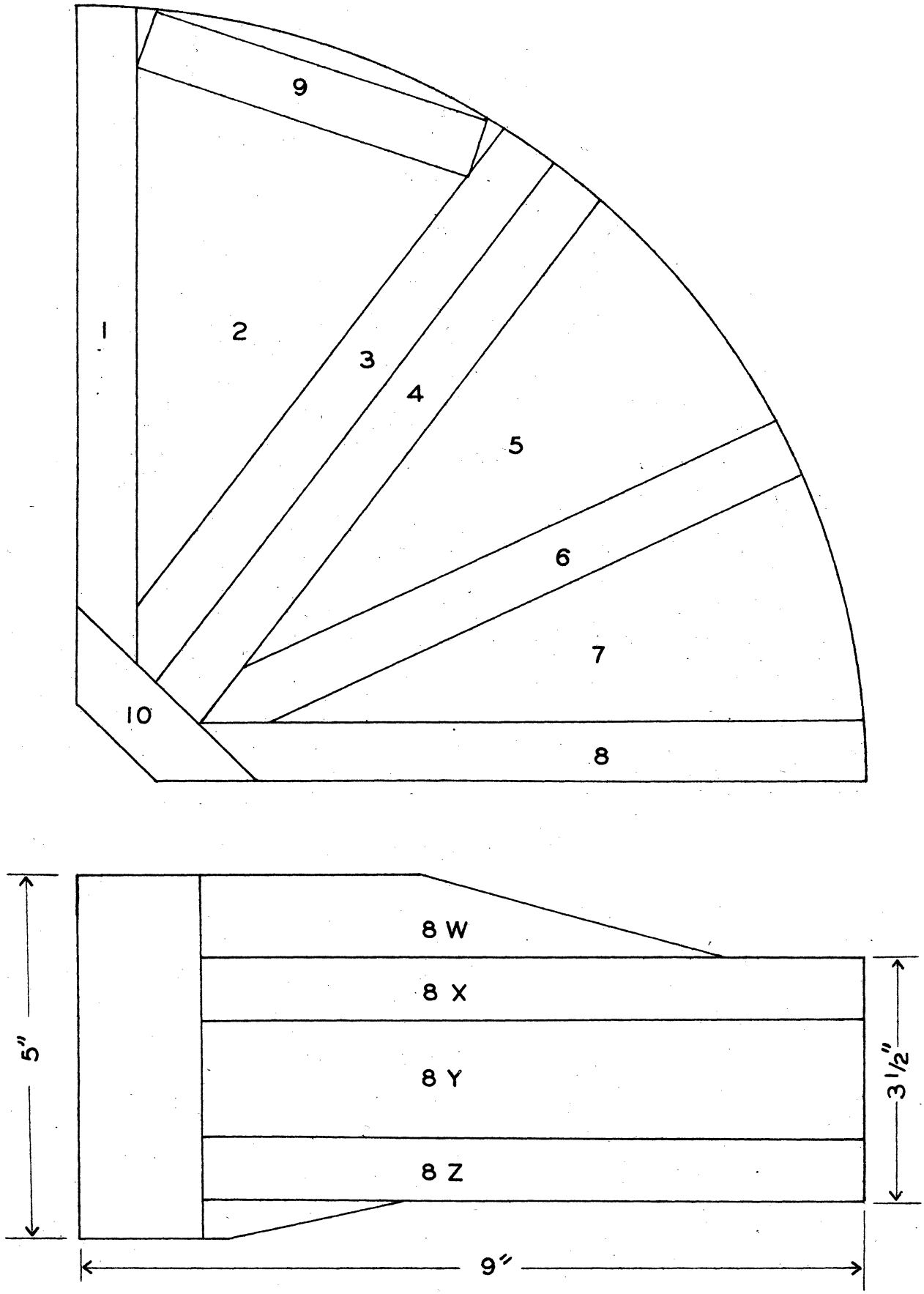


FIGURE 7.-DIAGRAM SHOWING LOCATION OF TEST COUPONS IN QUARTER SECTIONS OF THE I-40 DISCS.

TABLE VI

19-9 DL ALLOY I-40 DISCS

Chemical Composition

Heat No.	C	Mn	P	S	Si	Cr	Ni	W	Mo	Ti	Cb
B-11728	0.29	1.12	0.018	0.010	0.69	19.23	9.03	1.58	1.27	0.43	0.38

Processing Procedure

Both of the 19-9 DL I-40 discs were hot-forged as follows at Canton Drop Forge from a Universal-Cyclops 24,000-pound basic electric arc heat ingot 15½-inch x 15½-inch flat sides x 2600 pounds. 2100° F, 1 3/4-hour, 18 blows from a 25,000-pound hammer using bottle die working, air cooled; 2100° F, 14 hours, first block 9 blows from a 35,000-pound hammer, air cooled; 2100° F, 6½ hours, second block 14 blows from a 35,000-pound hammer, air cooled. Flash was machined off and spot ground after bottle die and second block operations.

Both of the 19-9 DL I-40 discs were solution treated for 2 hours at 2150° F and quenched in warm water.

I-40 disc EXC44 was hot-cold worked after 8 hours at 1250° F by 14 blows from a 35,000-pound hammer. Stress relieved 10 hours at 1200° F and air cooled.

I-40 disc EXC46 was hot-cold worked after 3 hours at 1700° F, dropped to 1650° F for 3/4-hour, by 22 blows from a 35,000-pound hammer. Stress relieved 10 hours at 1200° F and air cooled.

TABLE VI (CONTINUED)

TENSILE PROPERTIES OF 19-9 DL ALLOY I-40 DISCS

Disc	Specimen	Specimen location	Temperature (° F)	Tensile strength (psi)	Offset yield strength (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)
					0.02%	0.1%	0.2%			
EXC46 (cold worked at 1650° F)	3Y	CRR	Room	102,250	31,500	50,000	56,750	12,500	31.5	39.4
	3X	SRR	Room	102,500	38,500	53,000	58,250	20,000	37	42.8
	9Y	CTR	Room	104,750	37,500	53,000	57,500	17,500	32	41.6
EXC44 (cold worked at 1250° F)	3Y	CRR	Room	118,250	70,000	85,500	91,000	47,500	24.5	31.1

CRR Radial specimen from the center third of the forging at the rim.
SRR Radial specimen from the outer third of the forging at the rim.
CTR Tangential specimen from the center third of the forging at the rim.

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TABLE VI (CONTINUED)

PHYSICALS ON 19-9 DL I-40 FORGINGS

MADE BY CANTON DROP FORGING AND MFG. CO.

(from Evans' letter to Johnson 7-20-45)

Tests by Canton:

Serial EXC 44 (Solution treated, cold worked 1250° F)

Sectional Brinell Hardness:

Principal range	255-285
Max. reading	302
Soft spot at center near stub-shaft	217-229
" " " " " pilot hub	202-207

Physicals:	Yield Point	Ultimate Tensile	% Elong.	% Red. in Area
Location 1 (Central, horizontal, near stub-shaft)	89,500	100,000	4	8.5
Location 2 (Central, horizontal)	96,500	117,500	9.5	14.2
Location 3 (Central, horizontal, near pilot hub)	72,500	101,500	19.5	26.2

Serial EXC 46 (Solution treated, cold worked 1650° F)

Sectional Brinell Hardness:

Principal range	207-229
Max. reading	235
Soft spot at center near stub-shaft	192-197
" " " " " pilot hub	179-187

Physicals:	Yield Point	Ultimate Tensile	% Elong.	% Red. in Area
Location 1 (Central, horizontal, near stub-shaft)	60,000	86,000	12.5	18.5
Location 2 (Central, horizontal)	66,200	97,600	14.5	20.4
Location 3 (Central, horizontal, near pilot hub)	59,000	83,000	8.5	14.9

TABLE VI (CONTINUED)

RUPTURE TEST DATA AT 1200° F FOR THE 19-9 DL ALLOY I-40 DISCS

Disc	Specimen	Specimen location	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
EXC46 (solution treated, cold worked at 1650° F)	3Y	CRR	40,000	31.5	25	57.8
	3Y	CRR	37,500	48	17	48.0
	3Y	CRR	36,500	69 661	23 19	51.0 40.8
	3Y	CRR	35,000	~~In progress 600 hr 9/4/45~~		
	4Y 1Y		34 000 32 500	372 In progress	26	49.6
	1Y		50 000	35	3.5	2.3
EXC44 (solution treated, cold worked at 1250° F)	1Y	CRR	45,000	186 764	2	2.3 3.0
	3Y	CRR	40,000	~~In progress 456 hr 9/4/45~~		
	3Y	CRR	37,500	~~In progress 408 hr 9/4/45~~ 1085		

CRR Radial specimen from the center third of the forging at the rim.

TABLE VII

EME ALLOY I-40 DISC

Chemical Composition

Heat No.	C	Mn	P	S	Si	Ni	Cr	W	Cb	N_2
H-4819	0.12	0.48	0.015	0.028	0.73	11.60	19.72	3.38	1.30	0.127

Manufacturing Procedure

The forging was made by Midvale from a 17-inch diameter by 2600-pound ingot cast from an arc type basic electric furnace heat. Hot forging was from 2050°-2100° F finishing at about 1700° F. The ingot was reduced to a $10\frac{1}{4}$-inch diameter billet, upset first under the press and then under the hammer to I-40 dimensions. The forging was cold worked at 1240° F followed stress relief for 4 hours at 1200° F and air cooled.

TABLE VII (CONTINUED)

PHYSICAL PROPERTIES OF A MIDVALE EME ALLOY
I-40 FORGING TESTED BY GENERAL ELECTRIC COMPANY
(reported by letter to the University of Michigan)

Chemical Composition

Heat No.	Analysis by	C	Mn	P	S	Si	Ni	Cr	W	Cb	Mo	N_2	Fe
HF3-15113	Midvale	0.12	0.51	0.019	0.016	0.66	11.92	19.16	3.37	1.23	0.06	0.091	Bal.
	G.E.	.13	.61	.013	.024	.65	10.86	19.45	[1]4.30		.06	.15	Bal.

[1]Reported as total oxides.

Tensile Properties

Bar No.	Bar location	Temperature (° F)	Tensile strength (psi)	Yield strength (psi) 0.0002"/"	Elongation in 2 in. (percent)	Reduction of area (percent)
1	SR	Room	125,000	86,625	24	49.46
2	CR	Room	124,000	82,875	22	44.85
3	CR	Room	125,000	85,500	23.5	41.87
4	CR	Room	125,000	87,000	21	45.73
5	SR	Room	124,000	87,750	21	48.58
6	C	Room	124,500	94,125	9	27.83
7	C	Room	113,500	82,500	8.5	35.99
8	C	Room	108,500	72,750	17	32.78
9	C	Room	116,000	79,125	19	38.81
10	C	Room	124,000	81,000	24	43.67
11	C	Room	120,500	80,250	24	41.57
12	C	Room	104,000	78,375	20	51.12
13	C	Room	112,000	75,750	16.5	29.83
14	C	Room	116,000	79,875	8.5	26.13
15	SR	Room	124,500	85,500	23.5	48.00
16	CR	Room	123,500	84,750	25	44.85
17	CR	Room	124,500	85,125	22	44.55
18	CR	Room	124,000	84,375	20	46.89
19	CR	Room	124,000	84,750	22.5	48.00

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TABLE VII (CONTINUED)

Bar No.	Bar location	Temperature (° F)	Tensile strength (psi)	Yield strength (psi) 0.0002"/"	Elongation in 2 in. (percent)	Reduction of area (percent)
T-1	ST	Room	125,500	91,500	20	45.44
T-2	CT	1200	77,750	62,250	14.5	43.97
T-3	CT	1500	55,750	35,250	20.5	44.26
T-4	ST	1500	54,500	36,000	18.5	50.57
T-5	CT	1200	76,000	53,250	14	44.26
T-6	CT	Room	124,000	93,000	24.5	50.29

SR Radial specimen near surface.
CR Radial specimen away from surface.
C Specimen at center of disc.
ST Tangential specimen at rim near surface.
CT Tangential specimen at rim away from surface.

U of M Data

Specimen	Temp (°F)	Stress (psi)	Rupture Time (hr)	Elongation in 1 in. (%)	Reduction of Area (%)
1Y	1200	50000	9	11	21.7
		40000	54.5	7	9.5
		35000	127.	2.5	2.0
		30000	320.	2.5	6.2
		25000	in progress		

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TABLE VIII

S816 ALLOY WHEEL FORGING

Chemical Composition

Heat No.	C	Mn	Si	Cr	Ni	Co	W	Mo	Cb	Fe
41625	0.38	0.50	0.53	19.80	20.57	42.71	4.76	3.90	3.95	2.87

Manufacturing Procedure

The disc was made by Allegheny-Ludlum Steel Corporation from a 5000-pound electric arc furnace heat which was poured into a 12-inch square ingot. Hammer cogged to 9½-inches square from 2300° F. Upset to 3 5/16-inches thickness from 2250° F. The disc was more nearly octagonal than circular.

The bars cut from the disc were aged 16 hours at 1400° F.

B. Sheet Alloys at 1700° and 1800° F

The properties of 14 alloys in sheet form are being evaluated by rupture tests at 1700° and 1800° F. The data are expected to indicate if there is any relation between rupture strength and service performance as liners in combustion chambers.

The alloys being considered together with their rupture test characteristics are summarized in table IX and are compared graphically in figure 8. Vitallium had the best properties of the alloys considered. The 20Cr-15Ni-20Co-4Mo-4W + Boron alloy J-838 ranked next although a similar material, J-840, except for higher nitrogen, was much weaker. The low oxidation resistance of the J-837 and J-839 heats was surprising, in as much as they differed from J-838 and J-840 only in having 4 percent nickel instead of 15 percent. The ~~S816~~ S590 alloy tested also was surprisingly stronger than the S816 alloy. The Low-Carbon N155 alloy samples had intermediate strength while Inconel was one of the weakest.

The particular fabrication procedure and heat treatments used in producing these strip materials probably had considerable effect on the rupture strengths. This phase of the problem is to be studied by determining the effect of heat treatment on the rupture strength of Vitallium and Inconel sheet.

TABLE IX

RUPTURE TEST CHARACTERISTICS OF SHEET MATERIALS AT 1700° AND 1800° F

Alloy	Type Analysis (%) C	Cr	Ni	Co	Si	Mo	W	Cb	B	1700° F 100 hours Strength (psi)	100 hours Elong (%)	1000 hours Strength (psi)	1000 hours Elong (%)	1800° F 100 hours Strength (psi)	100 hours Elong (%)	1000 hours Strength (psi)	1000 hours Elong (%)
Vitallium	.2	27	--	Bal	-	5	-	-	---	8000	14	3300	20	~~(4000)~~	(15)	~~(2400)~~ 1800	~~(30)~~ (12)
Co-Cr-Ni	--	30	15	55	-	-	-	-	--	5200	2	3100	--	~~(3000)~~ 4000	(4)	(1600)	---
S816	.35	18	20	45	-	4	4	3	---	4000	16	2100	40	2300	37	820	---
S590	.41	20	20	20	-	4	4	4	---	6200	9	3400	(7)	4000	16	(1750)	(10)
[1]Low-Carbon N155	.14	20	20	20	-	3	2	1	---	(4900)	11	(3900)	7	3700	21	(1700)	--
J837	.13	20	4	20	-	4	4	-	.34	Low due to severe oxidation							
J838	.11	20	15	20	-	4	4	-	.37	7300	60	3800	<35	~~(4000)~~ 4100	~~(60)~~ 35	~~(1700)~~ 1500	~~35~~
[1]J839	.12	20	4	20	-	4	4	-	.56	Low due to severe oxidation							
[1]J840	.13	20	15	20	-	4	4	-	.45	(5400)	(25)	~~(2500)~~ (300)	--15	2500	25	~~(1300)~~ 1700	~~28~~
Inconel	.13	13	75	--	-	-	-	-	---	(3200)	22	~~(1750)~~ (?)	57	2200	27	1350	45
Type 330	.18	16	33	--	-	-	-	-	---	(1950)	(25)	(1450)	(60)	----	--	----	--
Type 310	.14	25	20	--	1	-	-	-	---	3800	18	2300	10	----	--	----	--
AF-18	.13	25	20	--	2	-	-	-	---	4800	7	3100	3.5	3600	6	1600	(4)
Type 309	.12	25	12	--	-	-	-	-	---	3200	21	1900	--	2300	15	1500	--

[1]Approximately 0.12% nitrogen also.

(-) Obtained by extrapolation or from incomplete data.

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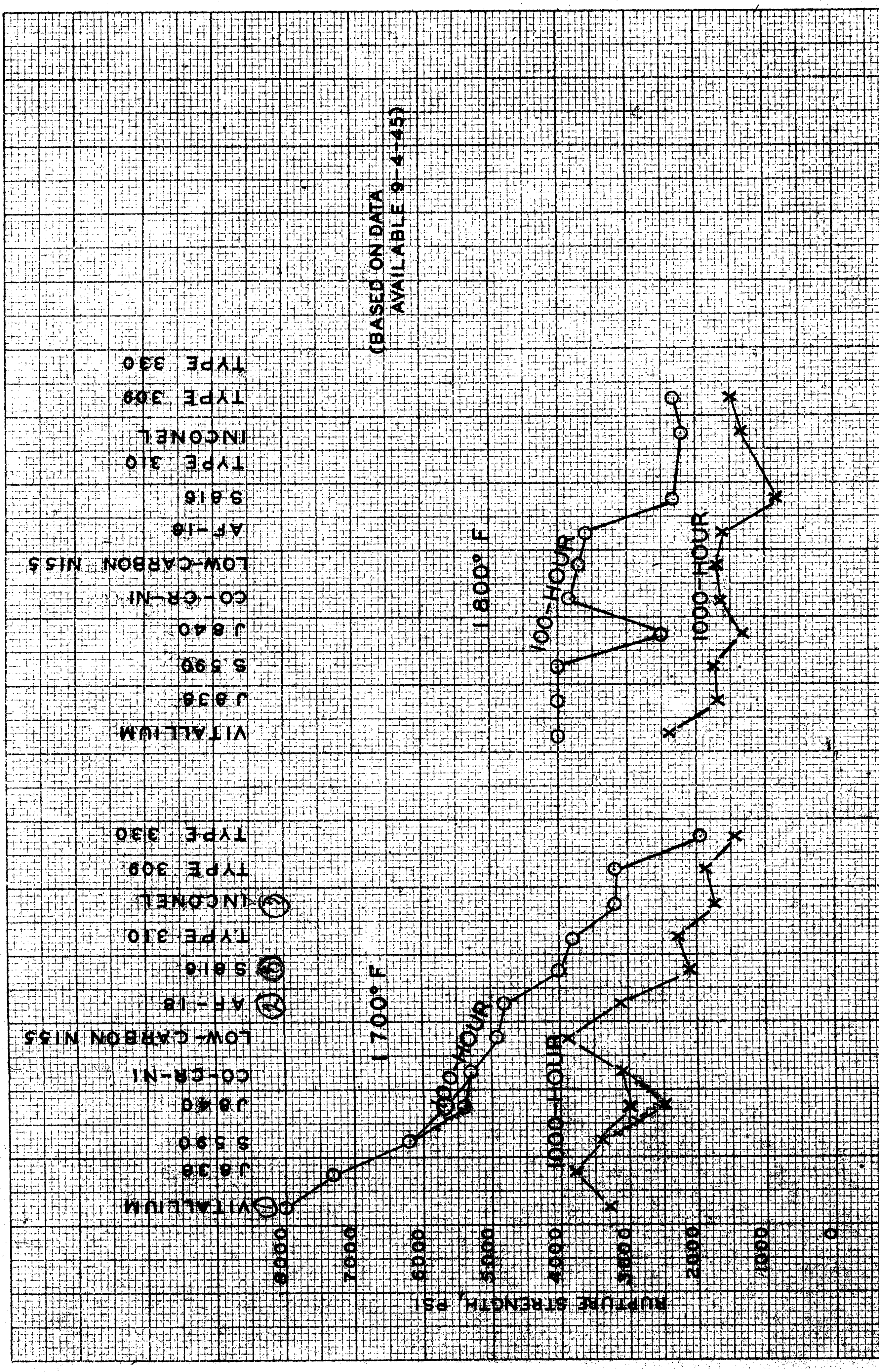

FIGURE 8- COMPARATIVE RUPTURE STRENGTHS FOR SHEET MATERIALS AT 1700° AND 1800° F.

C. 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 X.

The rupture strengths obtained at 1350° F are compared below with those for Cast 6059 and for standard Low-Carbon N155 alloy:

Alloy	Stress for Rupture in Indicated Time Periods (psi)	
	100 Hr	1000 Hr
Modified 6059	32,500	24,000
[1]Cast 6059	36,500	30,500
Modified N155	32,500	24,000
[1]Low-Carbon N155	36,000	27,500

[1]See NACA Report ARR 4C22.

The wrought modified 6059 alloy had rupture strengths considerably below the standard cast alloy and no better than other available wrought alloys of the Low-Carbon N155 type.

The composition modification of the modified N155 alloy did not improve the rupture strength of that type of alloy since the values obtained were somewhat lower than have been obtained for the standard alloy.

TABLE X

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 Runture 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	725.0	9	12.0
NR84 (Mod. N155)	33,000	106.0	26	26.5
	30,000	196.5	33	39.0
	27,000	338.0	[2]30	34.2
	25,000	718.0	[2]29	28.2

[1]See NACA ACR No. 4C22.

[2]Broke in gage mark.

D. Chromium Base Alloys at 1350° F

High rupture strengths at 1600° F shown by chromium base alloys developed by the Climax Molybdenum Company under the sponsorship of Project NRC-8 seemed of sufficient importance to warrant their investigation at 1350° F by the NACA. Accordingly, specimens were obtained for tests as shown in table XI, with the test results thus far obtained.

The rupture time periods at 1350° F under 50,000 psi from 60Cr-25Fe-15Mo are much longer than have been obtained from any other alloy. The ductility in the rupture tests have been good although the alloys are quite brittle at room temperature. Apparently a silicon content of 0.57 percent increases rupture life over that of a 0.13 percent silicon alloy according to the results from specimens 554-2 and 612-2.

The one specimen of 60Cr-30Fe-10Mo, Specimen Number 608, tested was no better than alloy 422-19. Other data for these type alloys indicate that this rupture time was abnormally low.

TABLE XI

1350° F RUPTURE TEST RESULTS ON CHROMIUM BASE ALLOYS

Specimen number	Chemical Analyses C	Si	Cr	Fe	Mo	Condition	Stress (psi)	Rupture time (hours)	Elongation in 1 in. (percent)	Reduction of area (percent)
608	0.03	0.14	61.96	29.14	8.73	As Cast	50,000	38	40	35
612-2	.01	.13	58.86	25.11	15.89	As cast	50,000	484	9	9
522	.05		60	25	15	As cast	45,000	Overheated after 450 hr		
554-2	.04	.57	59.43	24.96	15.00	As cast	50,000	1414	8	6.2
554-3HT						Aged				
634-1	.10	.70	59.09	24.55	15.56	As cast	50,000	~~In progress 672 hr 9/4/45~~ 985	5	5
634-2HT						Aged				
655-1	.02	.19	59.80	25.23	14.76	As cast				
655-2HT						90 hr at 1600° F				
655-3HT						50 hr at 1800° F				
657-1	.08	.19	60.70	24.22	14.81	As cast				
657-2HT						90 hr at 1600° F				

Comparable Data for Best Precision Cast Alloys

Alloy	C	Ni	Cr	Co						
[1]X-40	.48	9.69	25.12	55.2	W 7.23	As cast + 50 hr at 1350° F	50,000	[2]40	--	---
					Mo		45,000	100	31	40.7
[3]422-19	.40	15.92	24.75	Bal.	6.08	As cast + 50 hr at 1500° F	50,000	[2]250	--	---
							45,000	[2]170	[2]25	[2]25

[1]See Section E, page 38.
[2]Obtained by extrapolation.
[3]See NACA Report ARR 4C22.

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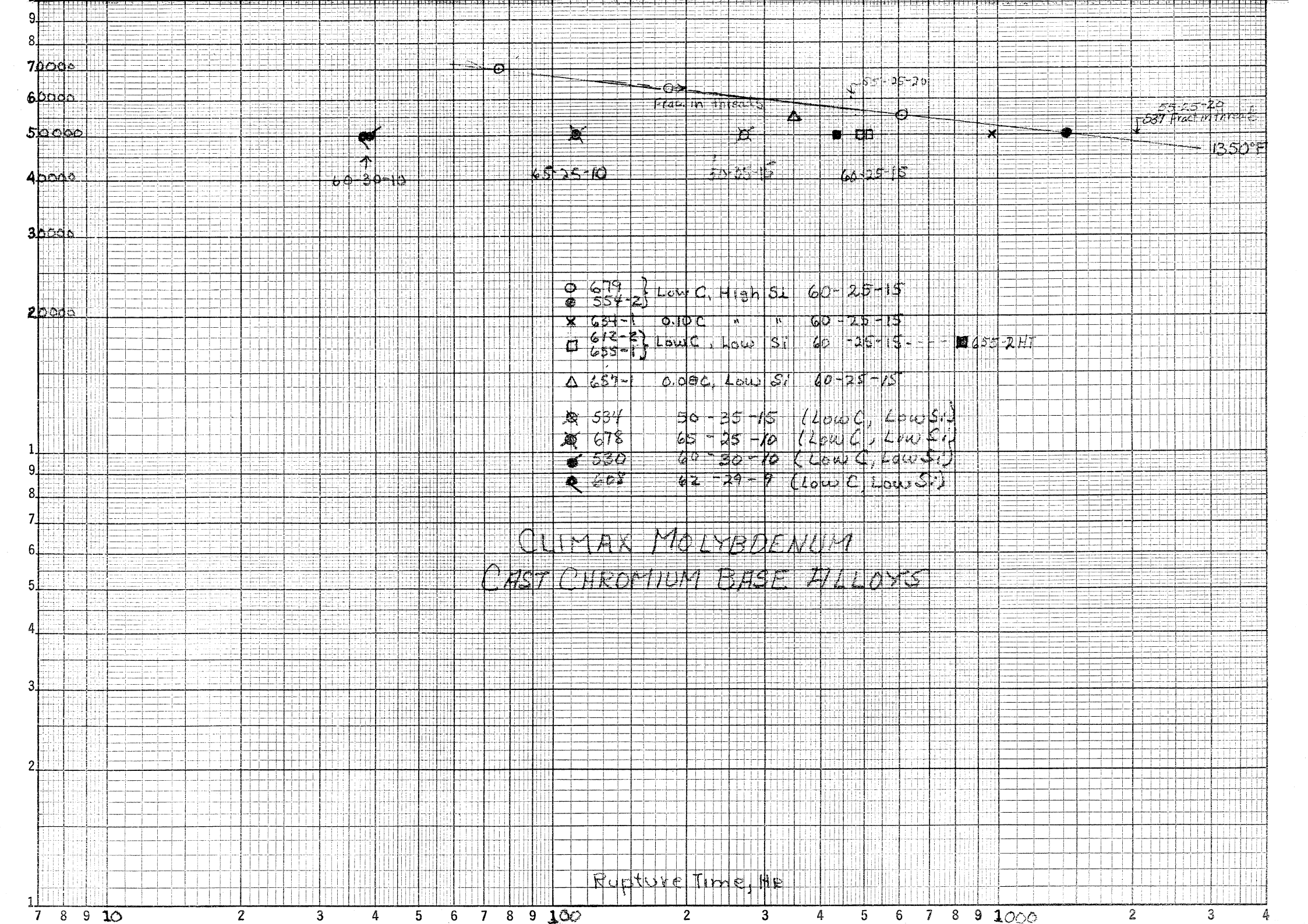
60-30-10
65-25-10
60-25-15
55-25-20
Frac. in threads
55-25-20
537 Fract in Thread
1350°F
679
554-2
Low C, High Si 60-25-15
684-1 0.10C " " 60-25-15
612-2
655-1
Low C, Low Si 60-25-15
655-2HT
657-1 0.08C, Low Si 60-25-15
584 50-35-15 (Low C, Low Si)
678 65-25-10 (Low C, Low Si)
530 60-30-10 (Low C, Low Si)
603 62-29-9 (Low C, Low Si)
CLIMAX MOLYBDENUM
CAST CHROMIUM BASE ALLOYS
Rupture Time, hr

Rupture Test Data at 1350° F for As-Cast Chromium Base Alloys

Heat	C	Si	Cr	Fe	Mo	Stress (psi)	Rupture time (hr)	Elong. (%)	R.A. (%)
522						45000	Interrupted & Broke after 450 hrs		
608	.03	.14	62	29	9	50,000	38	40	35
530-1	.04	.03	60	30	10	50,000	39	48	44
530-2									
678-1	.03	.19	65	25	10	50000	113	13	13
678-2						45000	191	19.5	17
612-2	.01	.13	60	25	15	50,000	484	9	9
655-1	.02	.19	60	25	15	50,000	530	19	17
655-2HT						50,000	434	10	12
655-3HT						Broke in threads while loading			
657-1	.08	.19	60	25	15	55000	347	11.	11.
657-2HT						55000			
554-2	.04	.57	60	25	15	50,000	1414	8	6.2
554-3HT						55000 Broke in threads while loading			
634-1	.10	.70	60	25	15	50000	985	5	5.
634-2HT						50000	Fract in threads at 464 hr	4	4
679-1	.02	.70	60	25	15	63,800	Fractured in threads 182	(5)	
679-2						55000	611	5	6.0
679-3						70000	76	4	6.0
534-1	.02	.11	50	35	15	50000	270.5	10	13.5
534-2						55000	60	16	23
537-1	.03	.06	55	25	20	50000	Fract in threads at 2040 hr.	(3)	2.5
537-2						60000	468	6	5

→ Parke has another casting which has not been machined.

E. X-40, NR-87 and NR-90 AT 1350° F

Rupture tests were authorized at the last Subcommittee meeting on the three cast alloys which had shown very high rupture strength at 1500° F in the Project NRC-8 work. These alloys, designated X-40 (NR-71), NR-87 and NR-90 by Project NRC-8, are described in table XII, together with the rupture test results obtained to date. Stress-rupture time curves are included as figure 9 together with the curve for alloy 422-19, the best alloy previously tested at 1350° F.

The comparative rupture strengths tabulated below show that the three new alloys are no better than alloy 422-19, although there isn't a great deal of difference between any of them:

Alloy	Rupture strengths at 1350° F (psi)	
	100 hr	1000 hr
X-40	45,000	34,000
NR-87	44,000	36,000
NR-90	41,500	34,000
422-19	47,000	36,000

TABLE XII

1350° F STRESS-RUPTURE PROPERTIES OF NR71 (X-40), NR87, AND NR90 ALLOYS

Chemical Analyses

Alloy	C	Si	Mn	Cr	Ni	Mo	W	Fe	Co
NR71(X-40)	0.48	0.72	0.64	25.12	9.69	----	7.23	0.55	55.23
NR87	.52	.69	.70	22.54	19.17	9.09	----	.90	Bal.
NR90	.44	.71	.76	22.60	18.23	5.09	5.18	.80	Bal.

Processing Procedure

All three of these alloys were cast plus aged 50 hours at 1350° F.

Rupture tests are being conducted on 0.250-inch diameter, one-inch reduced section length specimens.

1350° F Rupture Test Results

Alloy	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
NR71(X-40)	45,000	100	31	40.7
	40,000	232	18	37.7
	35,000	816 1189	27 41	35.0
	32,500	~~In progress 168 hr 9/4/45~~		45.8
NR87	45,000	84	20	27.0
	40,000	378	17	27.4
	37,000	775 918	22 18	31.8
	35,000	~~In progress 168 hr 9/4/45~~		33.1
	34 000	1980	13	35.0
NR90	45,000	53	1 23	20.7
	40,000	84	8.5	7.0
	37,500	542	11	13.3
	35,000	639 960	15 8	16.5
	34,000	~~In progress 72 hr 9/4/45~~		10.2
	32 500	1630	7	6.4

[1]Broke in gage mark.

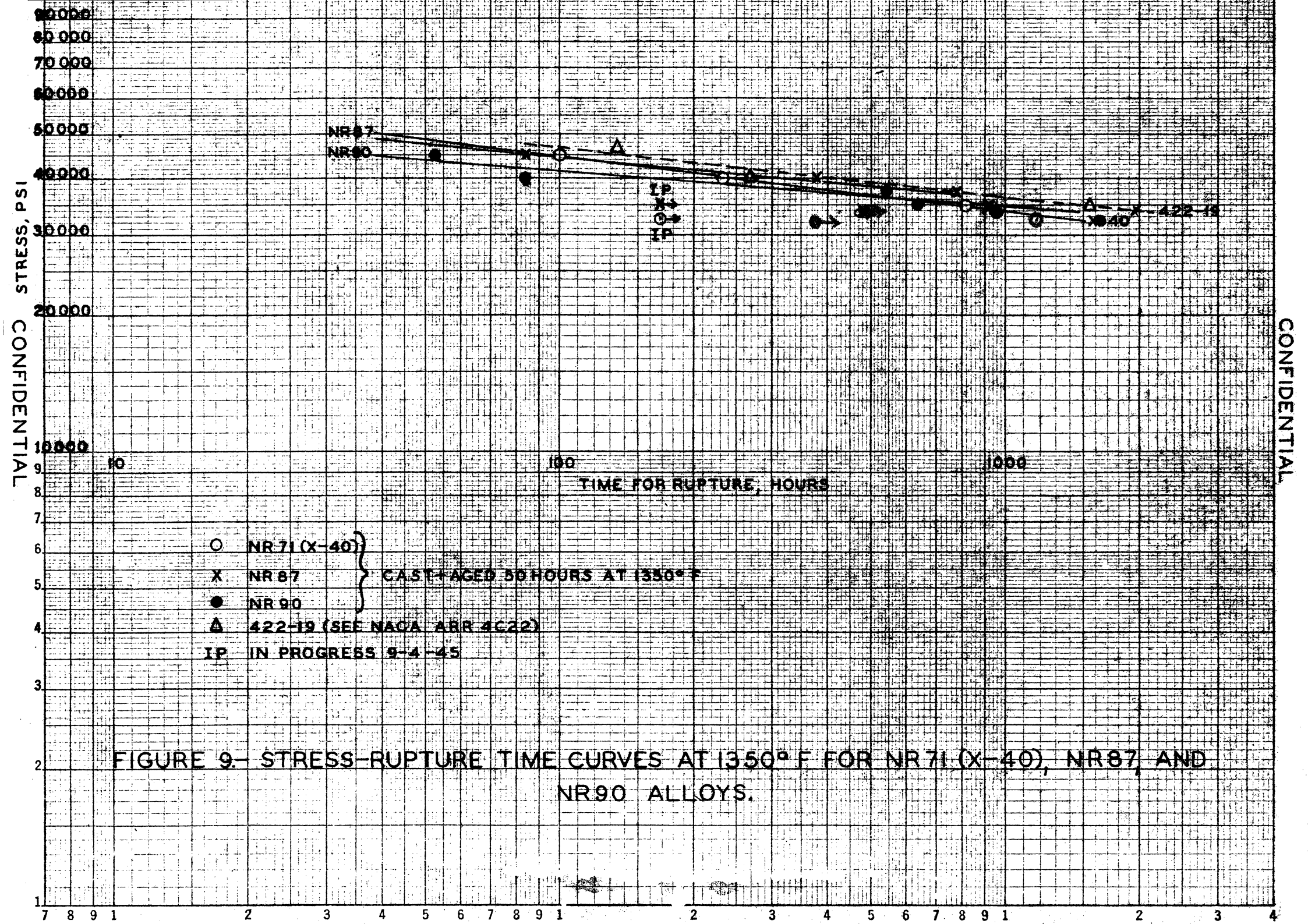

FIGURE 9.- STRESS-RUPTURE TIME CURVES AT 1350° F FOR NR 71 (X-40), NR87, AND NR90 ALLOYS.

F. Driver-Harris Cast Alloy at 1350° F

Data obtained by the Driver-Harris Company on a sand-cast 35Ni-15Cr alloy carrying 2.5 percent titanium at higher temperatures indicated that the alloy might have useful properties at 1350° F. Accordingly specimens were obtained for rupture tests at 1350° F. The results obtained and a description of the specimens are given in table XIII.

The rupture strengths were quite low for the alloy in the as-cast condition. At the present time no further tests are planned.

TABLE XIII

1350° F STRESS-RUPTURE PROPERTIES OF DRIVER-HARRIS CAST ALLOY

Chemical Analysis (average for 8 heats)

Heat No.	C	Mn	Si	Ni	Cr	Mo	Ti
12345 to 13045	0.52	1.11	1.34	35.69	16.27	1.17	2.48

Manufacture

This alloy was prepared by Driver-Harris Company. The metal was melted in a 15-pound Ajax induction furnace. One heat was used for each test bar. In melting the heats the order of charging was as follows: iron, low carbon ferrochrome, 50% of the nickel charge. When this was about 2/3 melted the following ingredients were charged; ferromolybdenum, high carbon ferrochrome, and the balance of the nickel. When this charge was about 2/3 melted a small amount of slag forming material, made up of equal parts of CaO and SiO_2, was added. When the bath was completely melted the slag was skimmed off. The bath was then cleaned with FeSi. FeTi was then added and when completely melted, the bath was again skimmed and deoxidized with Mn-Si-Zr, and CaSi, according to a patent held by Driver-Harris Company.

The heat was poured directly from the furnace into dried sand molds. The temperature of pouring was approximately 2875° F. The cast bars, 1 1/16-inch in diameter by 11-inches long, were poured through a heavy gate at the center of the bar. The samples were radium tested for soundness.

Tests were made on 0.505-inch diameter, 2-inch reduced section length specimens machined from the as cast bars.

1350° F Rupture Test Results

Heat No.	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)
12345	30,000	18.5	21	48.0
12545	22,500	50	25	42.5
12645	18,000	146	28	55.7

G. Effect of Processing and Heat Treatment on 19-9 DL, 234-A-5 (CSA), Timken, Age-Hardenable Inconel and Low-Carbon N155 Alloys

The data previously obtained on this program was given in Report Number 9, the May 9, 1944 progress report, and the April 28, 1945 progress report. The data obtained since may be summarized as follows: 3-1-46

1. 19-9 DL - no additional data have been obtained. ditto

2. 234-A-5 (CSA) - one or two rupture tests at 1200° F have been completed on samples to show the effect of 5, 10 and 20 percent reduction by rolling at 1200° F on 2050° F solution-treated bar stock; the effect of temperature of rolling up to 1600° F; and the effect of ageing for 24 hours at 1200°, 1300°, 1400° and 1500° F on bar stock rolled 10 percent at 1200° F. Due to the curves being incomplete this data is not included at this time. completed

3. Timken - The status of the Timken Alloy program is the same as that of the 234-A-5 (CSA) alloy program given above. completed

4. Age-Hardenable Inconel - no additional data have been obtained. ditto

5. Low-Carbon N155 - The rupture test characteristics at 1200° F for several variables are summarized in table XIV. Rupture strengths varying from 42,500 to 61,000 psi for fracture in 100 hours have been obtained. Corresponding values at 1000 hours range from 35,000 to 51,000 psi.

   Solution treating alone has reduced 100-hour rupture strength with very little effect on the 1000-hour strength at 1200° F. Apparently ageing 2200° F solu-treated samples at 1400° F for 24 hours is far more effective in improving rupture strength at 1200° F than ageing for 50 hours at 1350° F.

   Hot-cold working increased the rupture strength to an appreciable extent. As-rolled stock thus treated had high 100-hour strengths with good ductility. A solution treatment prior to hot-cold work resulted in high 1000-hour strengths but low ductility.

TABLE XIV. EFFECT OF HEAT TREATMENT AND HOT-COLD WORK ON THE RUPTURE-TEST CHARACTERISTICS OF LOW-CARBON N155 ALLOY AT 1200° F

Variable	Treatment: Solution treatment Temp. (° F)	Time (hr)	Cooling	Ageing treatment Temp. (° F)	Time (hr)	Hot-Cold Work Reduction (%)	Temp. (° F)	Stress Relief Temp. (° F)	Time (hr)	Rupture-Test Properties at 1200°F: 100 Hours Strength (psi)	Elong. (%)	1000 Hours Strength (psi)	Elong. (%)
Solution treatment	As rolled									49,000	17	(38,000)	(35)
	2050	2	W.Q.							(43,000)	(10)	(39,000)	(20)
	2200	1	W.Q.							42,500	5	(35,500)	(6)
Ageing treatment	2050	2	W.Q.							(43,000)	(10)	(39,000)	(20)
	2050	2	W.Q.	1400	24					52,000	38	(35,000)	(45)
Ageing treatment	2200	1	W.Q.							42,500	5	(37,000)	(6)
	2200	1	W.Q.	1400	24					51,000	14	(42,000)	(25)
	2200	1	W.Q.	1350	50					47,000	11	37,000	15
Hot-cold work	As rolled									49,000	17	38,000	(35)
	As rolled					10	1200	1200	1	62,000	16	47,000	(12)
	As rolled					20	1200	1200	1	61,000	10	46,000	(14)
Hot-cold work	2050	2	W.Q.							(43,000)	(10)	(39,000)	(20)
	2050	2	W.Q.			5	1200	1200	1	(53,000)	(3)	(44,000)	(18)
	2050	2	W.Q.			10	1200	1200	1	(59,000)	(2)	(51,000)	(8)
	2050	2	W.Q.	1400	24	10	1200	1200	1	(54,500)	22	(42,000)	(18)
Hot-cold work	2200	1	W.Q.	1400	24	10	1200	1200	1	All specimens broke in threads 54,500	12	(48,000)	(15)
										(60000)	(2)	(55000)	(3)

(1) indicates incomplete test data.

H. Typical Bar Stock of 19-9 DL and Low-Carbon N155 Alloy

Under this program complete tensile, rupture and time-deformation data at 1200°F were requested for 19-9 DL alloy bar stock in the following conditions:

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

The program was later enlarged to include Low-Carbon N155 at 1200° and 1350° F.

Tensile data were given for the 19-9 DL samples in the February 8, 1945 status report and for Low-Carbon N155 bar stock in the April 28, 1945 status report.

The rupture strengths and ductilities of the two alloys are summarized in table XV. The stress-rupture time curves for the Low-Carbon N155 alloy are shown in figure 10. The rupture strengths of the Low-Carbon N155 stock are quite low in comparison to what has ordinarily been obtained in previous investigations. The 19-9 DL values appear to be reasonably typical.

The available time-deformation data for 19-9 DL bar stock is summarized in table XVI and figure 11. Hot-cold work by rolling at 1200° F improved the deformation characteristics at 1200° F. The solution-treated material was weakest in this

test, at least for the time periods considered. In all tests the rate of deformation was still decreasing at 1000 hours.

The time-deformation data for the Low-Carbon N155 bar stock is given in table XVII and figure 12. Both the as-rolled condition and the solution-treated material are much weaker than have been obtained from creep tests on large discs. (See report number 19.)

TABLE XV

RUPTURE TEST CHARACTERISTICS OF TYPICAL 19-9 DL AND LOW-CARBON N155 ALLOY BAR STOCK AT 1200° AND 1350° F

Alloy	Heat Number	Treatment	Temp. (° F)	Rupture Test Properties			
				100 hours		1000 hours	
				Strength (psi)	Elong. (%)	Strength (psi)	Elong. (%)
19-9DL	[1]N163	Hot-rolled + stress relieved	1200	48,000	16	37,000	14
19-9DL	B10429	Hot-rolled + rolled to 20% reduction at 1200° F + stress relief	1200	55,000	2	37,500	3.5
19-9DL	B10429	2100° F, 1 hr. A.C. + 1 hr at 1200° F	1200	42,000	12	35,000	>10
Low-Carbon N155	30276	Hot rolled	1200	49,000	17	38,000	35
Low-Carbon N155	30276	As hot-rolled + 20% reduction at 1200° F + stress relief	1200	61,000	10	46,000	14
Low-Carbon N155	30276	2200° F W.Q. + 50 hr at 1350° F	1200	47,000	11	37,000	15
Low-Carbon N155	30276	Hot-rolled + 50 hr at 1350° F	1350	26,000	45	17,500	<35
Low-Carbon N155	30276	W.Q. 2200° F + 50 hr at 1350° F	1350	30,000	26	22,500	25

[1]Universal-Cyclops data.

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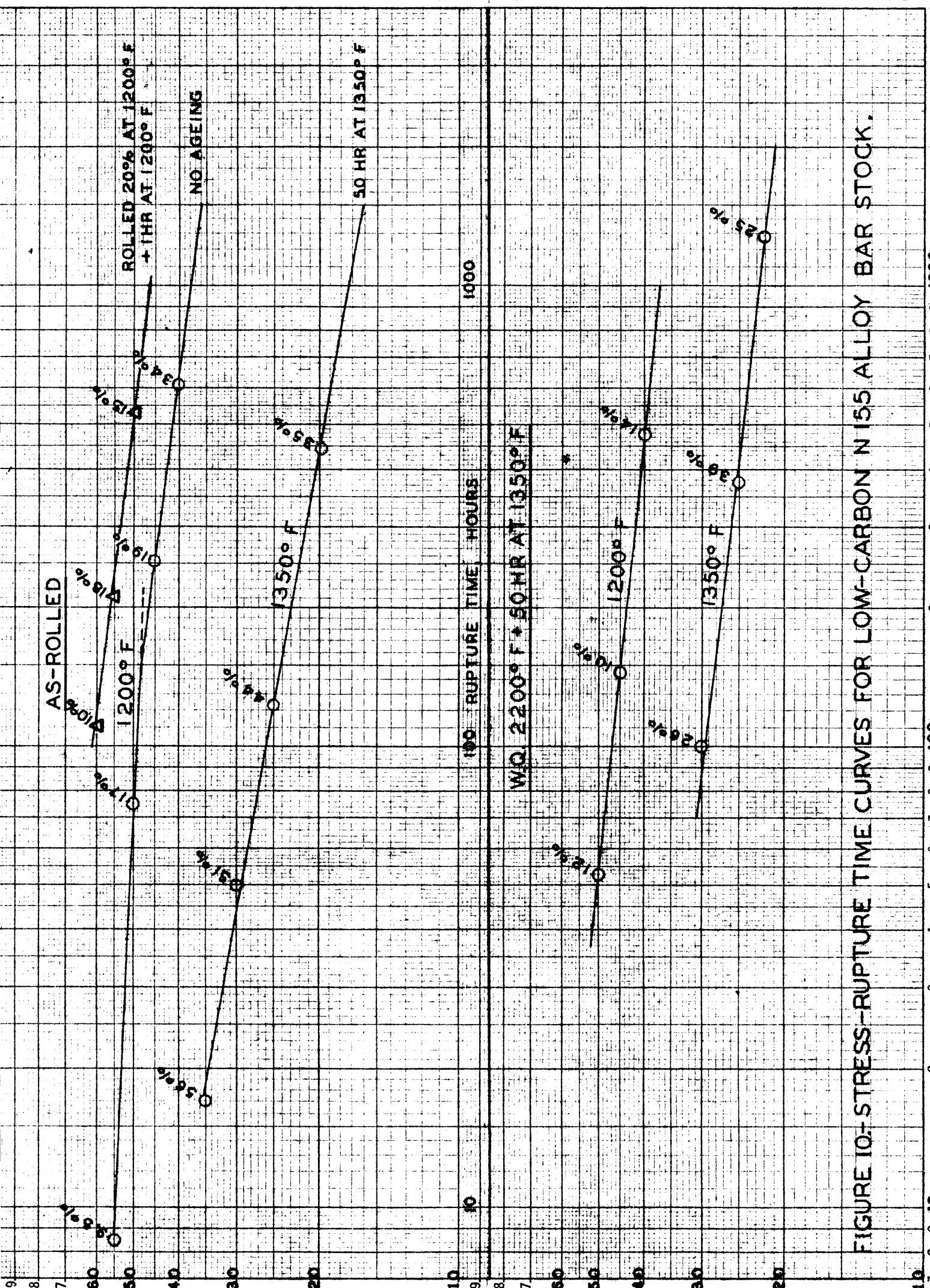

FIGURE 10.- STRESS-RUPTURE TIME CURVES FOR LOW-CARBON N 155 ALLOY BAR STOCK.

TABLE XVI

TIME-TOTAL DEFORMATION CHARACTERISTICS AT 1200° F FOR TYPICAL 19-9 DL BAR STOCK

Heat Number	Treatment	Stress (psi)	Time for indicated total deformation (hours)				Creep Rate at 1000 hours (% per hr)
			0.1%	0.2%	0.5%	1.0%	
N163	As-rolled + stress relieved	10,000	(7000)[1]	----	----		0.000011
		11,000	(2930)[1]	----	----		.000015
		12,000	230	(4500)[1]	----		.000021
		15,000	26	(1750)[1]	----		.000040
		17,500	3	285	----		-------
		20,000	----	180	(3800)[2]		.000074
B10429	As-rolled + 20% reduction by rolling at 1200° F + stress relieved 1200° F	20,000	----	400	----		.00006
		25,000	----	80	----		.000115
		30,000	----	4	650		.00069
		11 000					^2
		15 000					
B10429	1 hr 2100° F, A.C. + stress relieved 1200° F	17,500	----	245	----		.00013
		20,000	----	17	330		.00016
		15 000					
		12, 000	425	(1550)			.000086

[1]Extrapolated from creep rates.

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TABLE XVII

TIME-TOTAL DEFORMATION DATA AT 1200° F FOR LOW-CARBON N155 ALLOY BAR STOCK
(Lot 30276)

Treatment	Stress (psi)	Time for Indicated Total Deformation (hours)				Creep Rate at 1000 hr (% per hr)
		0.1%	0.2%	0.5%	1.0%	
As Rolled	20,000	----	94	937	(1130)[1]	0.00027
	22,500	----	37	345		.00056
	25,000	----	24	240	765	.00104
W.Q. 2200° F + 50 hr at 1350° F	20,000	----	470	----	----	.00010
	25,000	----	73	1045	----	.00022
	30,000	----	23	190	600	.00088

[1]Extrapolated from creep rate.

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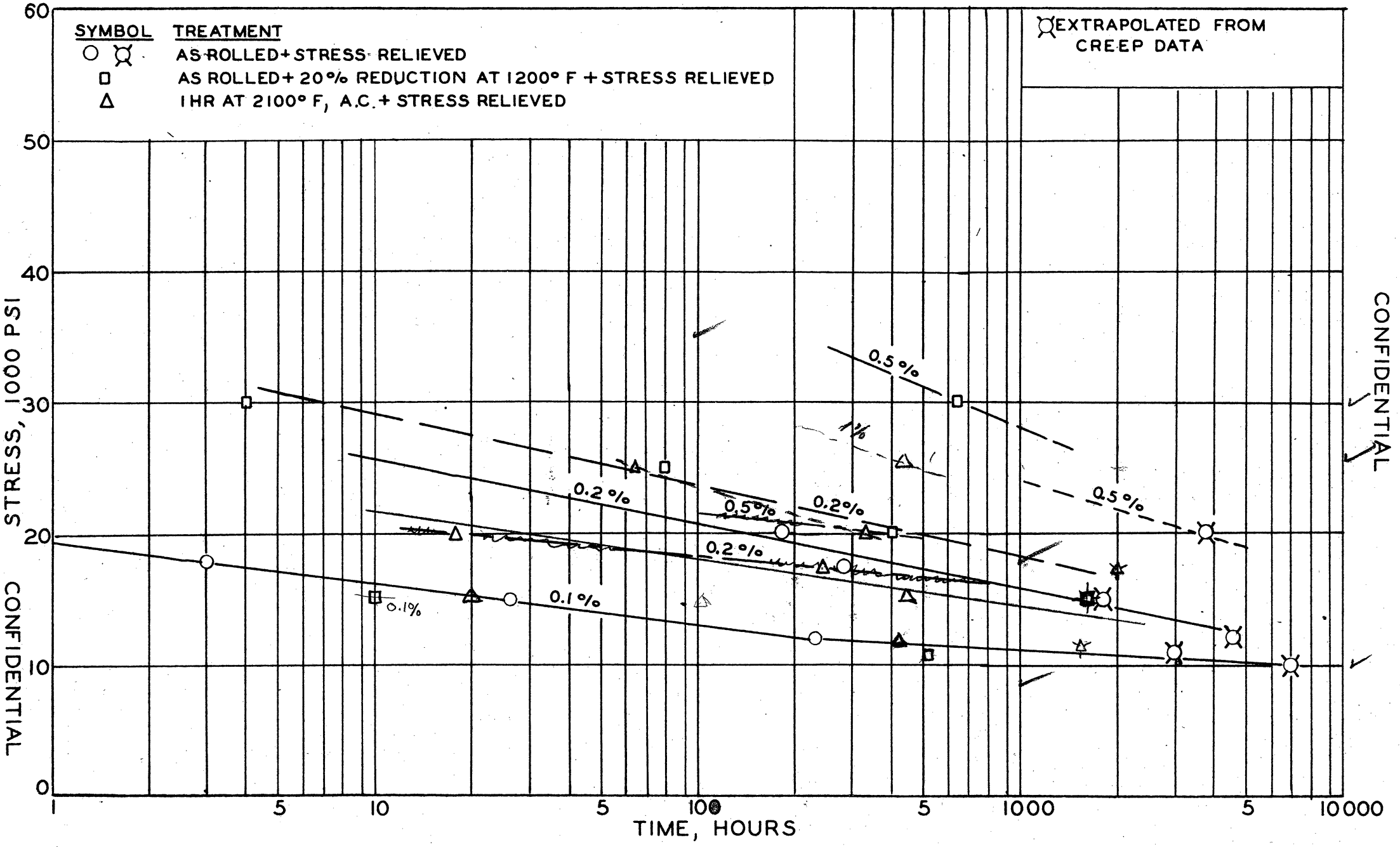

FIGURE 11.- CURVES OF STRESS VS. TIME FOR INDICATED TOTAL DEFORMATIONS AT 1200° F FOR TYPICAL 19-9DL ALLOY BAR STOCK.

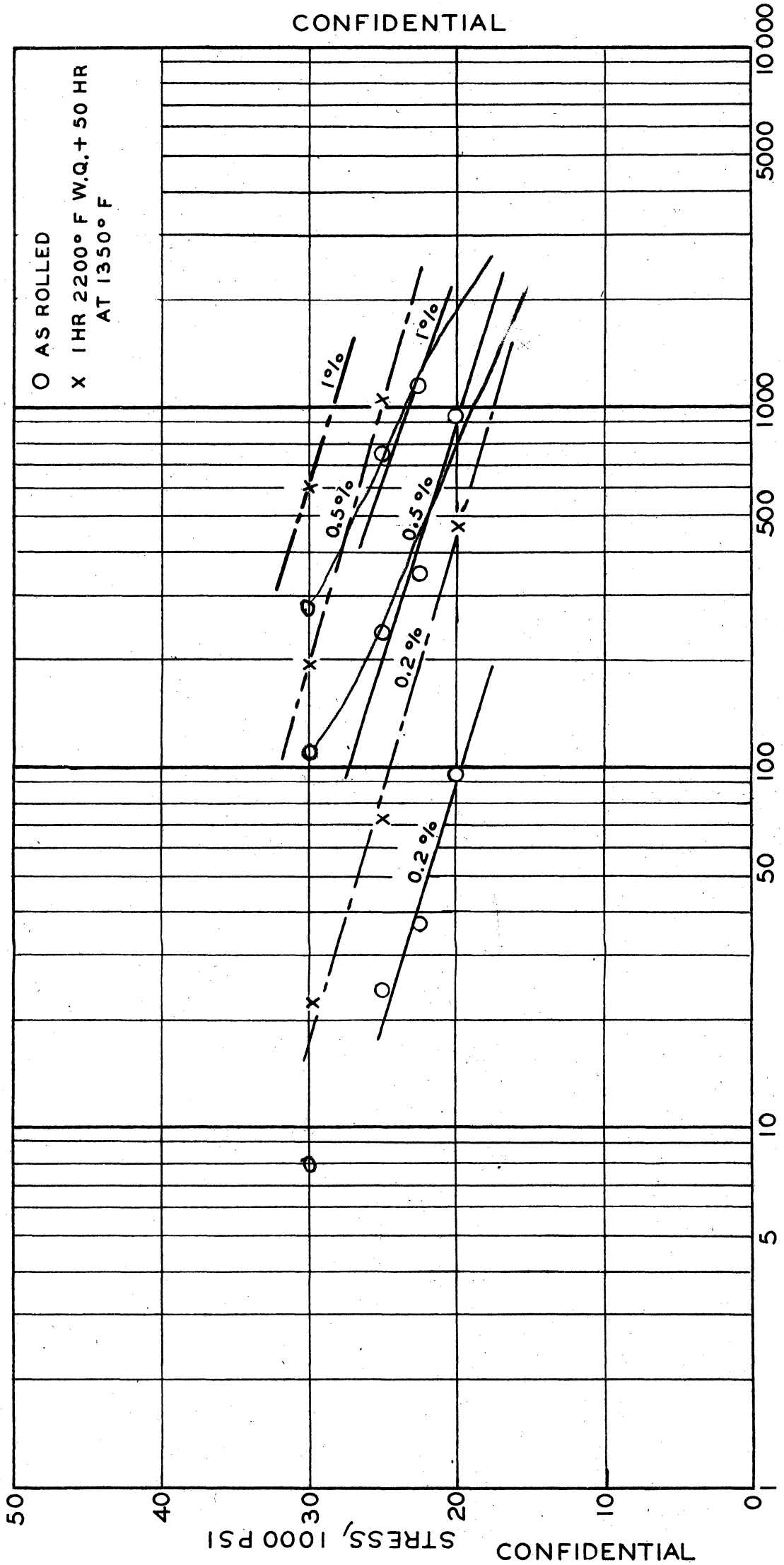

FIGURE 12.- STRESS-TIME FOR TOTAL DEFORMATION CURVES AT 1200° F FOR LOW-CARBON N 155 ALLOY BAR STOCK.

I. Programs Completed

Reports are to be prepared covering the following additional investigations which have previously been completed:

1. Vacuum melting of heat-resistant alloys ✓ Submitted
2. Ceramic coated Timken Alloy —
3. M.I.T. alloys at 1700° and 1800° F rough draft
4. Low-Carbon N155 + Boron — Being Prepared
5. Joint reports are to be prepared with Project NRC-8 covering the results from the Low-Carbon N155 discs NR-66E and the S590 discs.

The data from the above work have been included in the February 8, 1945 or April 28, 1945 status reports or in U. of M. Report Number 19.