FOURTH PROGRESS REPORT

TO

MATERIALS LABORATORY, WRIGHT AIR DEVELOPMENT CENTER

DEPARTMENT OF THE AIR FORCE

ON

FOUR LOW-ALLOY STEELS FOR ROTOR DISKS OF GAS TURBINES IN JET ENGINES

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IN JET ENGINES

SUMMARY

This report is the Fourth Progress Report on an investigation being carried out for the Materials Laboratory, Wright Air Development Center, Department of the Air Force, under Air Force Contract Number: AF33(038)-13496 (Expenditure Order Number: 605-227 SR-7).

A study of the high-temperature properties of four low-alloy steels, 4340, 17-22A(S), H-40, and C-422, in the form of forged J-33 jet engine disks is being carried out. A concurrent investigation of the high-temperature properties of the products of isothermal transformation is being made utilizing bar stock. The results of the structural studies are to be correlated with the results to be obtained from the disks.

The study of the properties of the products of isothermal transformation as outlined in the First Progress Report is virtually complete. The results obtained indicate that the normalized and tempered structures of 17-22A(S), H-40, and C-422 possess superior high-temperature properties at 1100°F as compared to any of the other structures developed to date. (The criterion used for comparison was the stress to cause 1-percent total deformation in 1000 hours.) For 4340, the upper-bainitic structure proved to be superior to the normalized and tempered structure both at 1000°F and 1100°F.

The time-temperature-transformation curve for C-422 steel has been outlined.

All three H-40 disks (normalized, oil quenched, and interrupted-quenched) and the normalized 17-22A(S) disk have been split and the center slabs cut out. These slabs have been magnafluxed and macroetched and found to be sound. Also, a hardness survey has been made on each slab.

The C-422 disks were re-heat treated by the Crucible Steel Company of America to eliminate the problem of hard spots encountered in the disks as originally heat treated.

Room temperature tensile tests have been made on specimens cut from the center slabs of the oil-quenched and interrupted-quenched 4340 disks, each of the 17-22A(S) disks, and the oil-quenched H-40 disk, as outlined in the Third Progress Report.

The initial sorting survey at 1100°F to establish the rim properties of each heat treated disk has been started.

Because of the results obtained to date, a modified testing program for the disks has been suggested and is shown in the Procedure and Proposed Testing Conditions below.

INTRODUCTION

This report covers the progress made between 1 October 1951 and 31 December 1951 on an investigation of the high-temperature properties of four ferritic alloys, 4340, 17-22A(S), H-40, and C-422, in the form of forged rotor disks for gas turbines in jet engines.

The objectives of this investigation are to determine the effect of heat treatment upon the high temperature properties of each of these four steels and to obtain design data for the heat treated disk showing the best properties.

As a further clarification of the effect of heat treatment upon the high-temperature properties of these steels, a concurrent study of the creep-rupture properties of the products of isothermal transformation is being carried out, utilizing bar stock.

PROCEDURE AND PROPOSED TESTING CONDITIONS

The high-temperature testing program for the disks as originally outlined was as follows:

(a) Establish stress-rupture time and stress-time for 1-percent total deformation curves out to 1000 hours at 1100°F for every disk.

(b) On the basis of results of (a), select the best disk of each alloy and:

(1) Establish at each of three temperatures out to 1000 hours curves of stress-rupture time, start of third stage creep, and time for total deformations of 1, 0.5, 0.2, and 0.1 percent, using specimens taken radially at the rim.

(2) Survey by limited tests the variation in high-temperature properties of specimens taken tangentially at the rim and at the center of the disks.

(3) Establish tensile properties at each elevated temperature.

Because interest in ferritic disk materials seems to be mainly focused at 1100°F for regular jet engine service and because of results obtained to date in this investigation, it is suggested that the testing program be modified as follows:

(a) For 4340 steel, survey all three disks at 950°F, the highest temperature for which long time properties appear to remain high enough to be of interest. At 1100°F and 1200°F, establish

stress-rupture curves out to 100 hours for the heat-treated disk showing the best properties at 950°F.

(b) For 17-22A(S), H-40, and C-422, limit the design curves to 1100°F, the temperature of major interest at the moment. Using the heat-treated disk of each alloy showing the best properties at 1100°F, establish curves of stress versus time for fracture and stress versus time for a total deformation of 1 percent out to 1000 hours at 1000°F, and a stress-rupture curve out to 100 hours at 1200°F.

RESULTS

The results obtained to date are presented separately for each steel under (1) disk investigation and (2) investigation of the properties of the products of isothermal transformation.

Disk Investigation

4340 STEEL

The room temperature tensile properties at the centers of the oil-quenched and interrupted-quenched disks have been determined and are presented in Table I. The interrupted-quenched specimens, which were about 20 Brinell points harder than the oil-quenched specimens, showed higher tensile strength and lower ductility as compared to the oil-quenched specimens. For specimens 2W-2Z taken directly from the center of the disks, the interrupted-quenched disk had an average tensile strength of 137,400 psi as compared to 124,000 psi for the oil-quenched disk, and showed an average elongation of 12 percent as compared to 17 percent for the oil-quenched disk. The 0.2 percent offset yield strengths averaged 96,000 psi for the oil-quenched specimens and 105,000 psi for the interrupted-quenched specimens.

The rupture properties for rim material of both disks are determined out to 200 hours at 1100°F and are shown in Table IV. The stresses to cause rupture in 100 hours were 18,500 psi for the interrupted-quenched disk and 15,000 psi for the oil-quenched disk.

17-22A(S) STEEL

The center slab of the normalized and tempered disk was cut out, magnafluxed and macroetched, and found to be sound. A Brinell hardness survey was taken and is shown in figure 1. The slab had a Brinell hardness range of 235 to 330. The principal ranges were 235 to 270 at the center and 300 to 330 around the edges. The low hardnesses at the center of the disk seem to indicate incomplete hardening upon normalizing.

The room temperature tensile properties for all three disks are summarized in Table III. Results from specimens 2W-2Z, taken directly from the center of each disk, show that the interrupted-quenched disk was slightly harder than the oil-quenched disk and had slightly higher tensile properties and tended to have much lower ductility. The normalized disk, which was much softer at the center than either of the other two disks, had much lower tensile properties than either the oil-quenched or interrupted-quenched disks and slightly better ductility.

The survey of the high-temperature properties of the three 17-22A(S) disks is now in progress and the results obtained to date are shown in Table V and in figures 2-4.

The rupture strengths and 1-percent total deformation strengths at 1100°F are as follows:

Disk Number	100 Hour Rupture Strength (psi)	1000 Hour Rupture Strength (psi)	Stress to Cause 1% Total Deformation in 1000 hours (psi)
1 (N.)	35,000	14,500	13,500
3 (O.Q.)	39,500	18,500	18,250
4 (I.Q.)	40,000	21,500	20,500

H-40 STEEL

The center slabs have been cut from all three H-40 disks. All the slabs have been magnafluxed and macroetched and found to be sound. Brinell hardness surveys have been taken on all three slabs and are shown in figures 5-7. All three disks are harder than the specified hardness range of 280-320 Brinell and the oil-quenched disk showed one very hard area of 365-390 Brinell. The variation in hardness tended to be erratic rather than localized at specific locations in the disks. The Brinell hardness ranges for the disks were as follows:

(1) Normalized + tempered, 315-380

(2) Oil quenched + tempered, 315-390

(3) Interrupted quenched + tempered, 327-393

The room temperature tensile properties of the oil-quenched disk are shown in Table II. The average hardness for the test specimens was 357 Brinell, the average tensile strength 177,000 psi, and the 0.2-percent offset yield strength 162,000 psi. The elongation at the rim averaged 10 percent and at the center 4.5 percent.

The survey of the high-temperature properties of the three H-40 disks is now in progress and the results obtained to date are shown in Table VI. These data indicate that all three disks are brittle, showing low elongation at fracture in the rupture tests.

C-422 STEEL

The C-422 disks were re-heat treated by the Crucible Steel Company of America to eliminate the problem of hard spots encountered in the disks as originally heat treated. The original heat treatments and those carried out by the Crucible Company are as follows:

(a) Original Heat Treatment

Disk #1. N. 1900°F + tempered at 1200°F.

Disk #3. As forged.

Disk #4. O.Q. from 1900°F + tempered at 1200°F.

(b) Crucible Company Heat Treatment

Disk #1. Full annealed at 1600°F for 6 hours and furnace cooled.
N. 1900°F + double temper at 1200°F for 2 plus 2 hours.

Disk #3. Full annealed at 1600°F for 6 hours and furnace cooled.

Disk #4. Full annealed at 1600°F for 6 hours and furnace cooled.
O.Q. from 1900°F + double temper at 1200°F for 2 + 2 hours.

The survey of the high-temperature properties of the normalized and tempered C-422 disk is now in progress and the results obtained to date are shown in Table VII.

Investigation of the Properties of the Products of Isothermal Transformation

4340 STEEL

All creep testing of isothermal structures as outlined in the First Progress Report has been completed. Creep data obtained in addition to that shown in Table I of the Third Progress Report is shown in Table VIII.

Using the stress to cause 1-percent total deformation in 1000 hours as a basis for comparison, the normalized and tempered structure was superior at both 1000°F and 1100°F to all structures developed except the upper bainitic structure. The stress to cause 1-percent total deformation in 1000 hours at 1000°F was 13,300 psi for the normalized and tempered structure, and 17,300 psi for the upper bainitic structure.

17-22A(S) STEEL

All creep testing of isothermal structures as outlined in the First Progress Report has been completed at 1100°F except for one test now in progress on the upper bainitic structure. Creep data obtained in addition to that shown in Table II of the Third Progress Report is shown in Table VIII.

The results obtained to date from creep-rupture tests at 1100°F are as follows:

Structure	BHN	Stress to Cause 1% Total Deformation in 1000 Hours (psi)
Norm. + T. 10 Hrs. at 1200°F	291/317	19,000
O.Q. + T. 1 Hr. at 1300°F	302/306	15,000
Aust. 1750°F + 1½ Hrs. at 1350°F	309/313	16,000
Aust. 1750°F + 10 Hrs. at 1150°F + T. 12 Hrs. at 1200°F	291/313	less than 15,000
Aust. 1750°F + 2 Hrs. at 900°F + T. 16 Hrs. at 1200°F	317/327	approximately 16,000
Aust. 1750°F + 5 Min. at 700°F + T. 12 Hrs.	302/303	15,500

Using the stress to cause 1-percent total deformation in 1000 hours as a basis of comparison, it can be seen from the above data that the normalized and tempered structure is superior to any of the other structures developed.

H-40 STEEL

The isothermal transformation data for the H-40 steel has been re-examined and corrected and the time-temperature curve has been redrawn and is shown in figure 8. This diagram shows that the only isothermal structure which can be developed is a bainitic structure between 700°F and 800°F. All creep testing at 1100°F has been completed except for one test now in progress on the bainitic structure. Creep data obtained in addition to that shown in Table III of the Third Progress Report is shown in Table VIII.

The results obtained to date are as follows:

Structure	BHN	Stress to Cause 1% Total Deformation in 1000 Hours (psi)
Norm. + T. 18 Hrs. at 1200°F	312/320	27,800
O.Q. + T. 12 Hrs. at 1200°F	321/323	23,300
Aust. 1950°F + 10 Hrs. at 750°F + T. 1 Hr. at 1300°F (Bainite)	308/312	approximately 23,000

C-422 STEEL

The time-temperature-transformation curve has been outlined and is shown in figure 9. The only signs of austenite transformation appear above 1100°F. Holding above 1100°F out to time periods of 24 hours results first in the appearance of a dark etching material in the grain boundaries, similar to that which was obtained with the H-40 steel. Holding for the longer time periods also produced throughout the matrix what appeared to be carbide particles.

Creep testing of the normalized and tempered and oil-quenched and tempered structures at 1100°F has been completed. The results obtained are as follows:

Structure	BHN	Stress to Cause 1% Total Deformation in 1000 Hours (psi)
Norm. + T. 24 Hrs. at 1200°F	299/306	28,700
O.Q. + T. 4 Hrs. at 1200°F	307	30,000

Creep data obtained in addition to that shown in Table III of the Third Progress Report is shown in Table VIII.

FUTURE WORK

Early in the next period, the initial survey tests on the disks will be completed. The data should then be analyzed and a choice made of the disks

to be used for design data. In this connection, attention is directed to the extreme brittleness of all three H-40 disks in the rupture test with the probable conclusion that all three are unsuitable for use at 1100°F.

Likewise the initial surveys of isothermally-treated specimens is nearing completion, requiring analysis of the data and decision as to future work. In view of the tests on disks it appears that the isothermal transformation survey ought to be extended to include rupture tests as well as total deformation characteristics.

A correlative study of the microstructures of the disks and isothermally transformed structures of bar stock should be carried out.

TABLE I

ROOM TEMPERATURE TENSILE PROPERTIES AT THE CENTER OF THE 4340 DISKS

Disk #3 - Heat Treatment: First treatment - O.Q. from 1750°F + 8 Hrs. at 1200°F
Second treatment - O.Q. from 1550°F + tempered at 1050°F

Specimen Number	Specimen Location (a)	Tensile Strength (psi)	Offset Yield Strengths (psi)			Proportional Limit (psi)	Elongation in 2 in. (%)	Reduction of Area (%)	Brinell Hardness
			0.02%	0.1%	0.2%				
1W	SRR	136,500	112,500	115,800	116,000	73,000	18.5	62.2	280
1X	CRR	129,000	106,900	109,200	110,700	78,000	17.0	58.3	273
2W	SRC	125,500	96,700	98,700	99,200	79,000	15.5	39.2	260
2X	CRC	123,800	91,700	94,700	95,200	82,000	17.0	44.6	255
2Y	CRC	122,800	89,800	94,100	94,600	74,500	18.0	48.6	255
2Z	SRC	123,800	92,500	95,800	96,200	74,500	18.5	47.7	260
	Disk #4 - Heat Treatment: Interrupted-quenched from 1750°F + 2 Hrs. at 1200°F								
1W	SRR	141,200	90,600	104,700	109,200	64,500	17.0	49.5	288
1X	CRR	140,200	87,000	101,200	106,300	63,000	17.0	48.8	289
2W	SRC	137,900	79,000	97,400	103,700	47,000	11.0	23.4	290
2X	CRC	137,800	86,300	99,500	105,300	65,000	12.0	29.8	292
2Y	CRC	137,800	91,200	102,300	106,600	68,000	14.0	26.1	286
2Z	SRC	136,200	85,700	98,600	103,300	60,500	12.0	31.7	287

(a) SRR Surface plane radial specimen near rim of disk
CRR Center plane radial specimen near rim of disk
SRC Surface plane radial specimen at center of disk
CRC Center plane radial specimen at center of disk

TABLE II

ROOM TEMPERATURE PROPERTIES AT THE CENTER OF THE OIL-QUENCHED H-40 DISK

Disk #3 - Heat Treatment: First treatment - O.Q. from 1950°F + 8 Hrs. at 1200°F
Second treatment - Retempered at 1200°F

Specimen Number	Specimen Location (a)	Tensile Strength (psi)	Offset Yield Strengths (psi)			Proportional Limit (psi)	Elongation in 2 in. (%)	Reduction of Area (%)	Brinell Hardness
			0.02%	0.1%	0.2%				
1W	SRR	182,000	139,200	160,700	166,000	113,000	9.5	23.5	364
1X	CRR	183,500	137,000	158,500	164,200	108,000	10.0	23.7	364
2W	SRC	175,200	131,000	155,700	163,800	104,000	2.0	2.8	362
2X	CRC	172,500	124,000	150,200	159,700	95,000	2.0	2.8	365
2Y	CRC	177,000	125,500	150,800	159,400	96,000	5.0	7.8	346
2Z	SRC	178,800	127,800	150,400	159,800	99,000	8.5	16.0	341

(a) SRR Surface plane radial specimen near rim of disk
CRR Center plane radial specimen near rim of disk
SRC Surface plane radial specimen at center of disk
CRC Center plane radial specimen at center of disk

TABLE III

ROOM TEMPERATURE TENSILE PROPERTIES AT THE CENTER OF THE 17-22A(S) DISKS

Specimen Number	Specimen Location (a)	Tensile Strength (psi)	Offset Yield Strengths (psi) 0.02%	0.1%	0.2%	Proportional Limit (psi)	Elongation in 2 in. (%)	Reduction of Area (%)	Brinell Hardness
Disk #1 - Heat Treatment: N. 1750°F + 2 Hrs. at 1200°F									
1W	SRR	142,800	98,500	109,400	114,700	76,500	15.0	50.3	314
1X	CRR	137,200	98,200	107,000	111,300	89,000	14.5	47.1	282
2W	SRC	117,000	71,800	79,400	81,000	47,000	9.0	13.4	242
2X	CRC	116,000	73,400	78,500	79,800	66,000	15.5	38.5	238
2Y	CRC	117,000	73,600	77,200	79,200	62,500	20.5	48.9	238
2Z	SRC	119,000	74,000	79,600	81,700	61,000	19.0	48.0	241
Disk #3 - Heat Treatment: O.Q. from 1750°F + 8 Hrs. at 1200°F									
1W	SRR	150,900	123,000	132,200	133,800	93,000	18.0	56.4	326
1X	CRR	145,000	123,400	130,500	132,800	94,000	16.5	50.9	313
2W	SRC	144,800	121,800	126,400	128,300	109,500	11.0	23.8	313
2X	CRC	145,000	120,600	126,200	128,200	103,000	12.0	29.2	311
2Y	CRC	145,000	119,000	125,500	128,000	99,500	17.5	46.6	295
2Z	SRC	145,800	121,000	126,700	129,000	106,300	15.0	40.7	294
Disk #4 - Heat Treatment: Interrupted-quenched from 1750°F + 2 Hrs. at 1200°F									
1W	SRR	158,800	137,400	142,400	143,700	126,000	16.0	51.1	332
1X	CRR	155,500	125,600	135,300	137,800	93,000	16.5	49.8	321
2W	SRC	148,500	121,000	131,200	134,000	98,000	5.0	6.4	320
2X	CRC	149,000	124,300	130,300	132,800	104,000	8.0	9.3	317
2Y	CRC	149,000	119,300	128,200	131,600	101,000	15.0	41.0	318
2Z	SRC	149,800	124,200	131,200	133,200	108,000	15.5	41.9	312

(a) SRR Surface plane radial specimen near rim of disk
CRR Center plane radial specimen near rim of disk
SRC Surface plane radial specimen at center of disk
CRC Center plane radial specimen at center of disk

TABLE IV

RUPTURE DATA FOR 4340 DISKS AT 1100°F

Disk #3 - Heat Treatment: First treatment - O.Q. from 1750°F + 8 Hrs. at 1200°F
Second treatment - O.Q. from 1550°F + tempered at 1050°F

Specimen Number	Specimen Location (a)	Stress (psi)	Rupture Time (Hours)	Elongation (%)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (Hours)
4W	SRR	25,000	17	20.5(b)	39.1	2.0(c)
4X	CRR	20,000	31	23.0(b)	34.4	2.6(c)
4Y	CRR	13,000	212	57.0(b)	41.0	20
Disk #4 - Heat Treatment: Interrupted-quenched from 1750°F + 2 Hrs. at 1200°F						
4X	CRR	30,000	17	3.5(d)	8.1	4
4W	SRR	25,000	29	4.7(d)	5.9	11.2
4Y	CRR	16,000	199	5.6(d)	7.0	84

(a) SRR Surface plane radial specimen at rim
CRR Central plane radial specimen at rim
(b) Elongation in 2 inches
(c) Extrapolated value
(d) Approximate elongation

TABLE V

RUPTURE DATA FOR 17-22A(S) DISKS AT 1100°F

Specimen Number	Specimen Location (a)	Stress (psi)	Rupture Time (Hours)	Elongation (%) (b)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (Hours)
Disk #1 - Heat Treatment: N. 1750°F + 2 Hrs. at 1200°F						
4W	SRR	50,000	26	12.3	7.0	6
4X	CRR	45,000	36	5.7	3.9	13
4Y	CRR	40,000	60	5.6	7.0	24(c)
4Z	SRR	30,000	175	1.7	0.8	134
6W	SRR	20,000	519	2.6	2.8	406
Disk #3 - Heat Treatment: O.Q. from 1750°F + 8 Hrs. at 1200°F						
4Z	SRR	47,500	51	2.6	5.1	29
4X	CRR	42,500	94	3.5	8.2	47
4W	SRR	38,500	86(d)	3.0	3.5	45
4Y	CRR	32,500	219	3.0	1.6	156
6W	SRR	25,000	489	2.6	3.2	402
6X	CRR	20,500	792	2.1	2.4	774
Disk #4 - Heat Treatment: Interrupted-quenched from 1750°F + 2 Hrs. at 1200°F						
4X	CRR	45,000	69	2.3	4.0	36
4W	SRR	37,500	151	4.0	1.6	79
4Y	CRR	32,500	287(d)	3.0	2.0	186
4Z	SRR	26,000	479	3.9	1.6	337
6W	SRR	20,500	1233	3.0	3.6	964

(a) SRR Surface plane radial specimen at rim
CRR Central plane radial specimen at rim
(b) Approximate elongation
(c) Extrapolated value
(d) Broke in gage mark

TABLE VI

RUPTURE DATA FOR H-40 DISKS AT 1100°F

Disk #1 - Heat Treatment: First treatment - N. 1950°F + 2 Hrs. at 1200°F
Second treatment - Retempered at 1200°F

Specimen Number	Specimen Location (a)	Stress (psi)	Rupture Time (Hours)	Elongation (%) (f)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (Hours)
4W	SRR	55,000	28(b)	--	--	--
4X	CRR	55,000	48.5(c)	1.2	1.3	40(d)
4Y	CRR	45,000	164(b)	--	--	--
Disk #3 - Heat Treatment: First treatment - O.Q. from 1950°F + 8 Hrs. at 1200°F Second treatment - Retempered at 1200°F						
6W	SRR	60,000	35.5	2.2	2.8	26(d)
4Y	CRR	50,000	136	1.8	3.9	106(d)
4W	SRR	45,000	298	1.8	3.9	262(d)
4Z	SRR	39,000	(e)	--	--	--
Disk #4 - Heat Treatment: First treatment - Interrupted-quenched from 1950°F Second treatment - Retempered at 1200°F						
4X	CRR	60,000	34(b)	--	--	28
4W	SRR	50,000	108	2.6	8.1	73
4Y	CRR	45,000	243(b)	--	--	228
4Z	SRR	39,000	(e)	--	--	--

(a) SRR Surface plane radial specimen at rim
CRR Central plane radial specimen at rim
(b) Broke in threads
(c) Broke in shoulder
(d) Extrapolated value
(e) Test in progress
(f) Approximate elongation

TABLE VII

RUPTURE DATA FOR C-422 DISKS AT 1100°F

Disk #1 - Heat Treatment: First treatment - N. 1900°F + 2 Hrs. at 1200°F
Second treatment - Full anneal 6 Hrs. at 1600°F and furnace cooled. N. 1900°F + double temper at 1200°F for two plus two hours.

Specimen Number	Specimen Location (a)	Stress (psi)	Rupture Time (Hours)	Elongation in 2 inches (%)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (Hours)
4W	SRR	55,000	1.7	26.0	69.5	--
4X	CRR	45,000	14.7	23.0	73.0	0.9
4Y	CRR	35,000	318	15.0	36.3	26
4Z	SRR	32,000	(b)	--	--	--

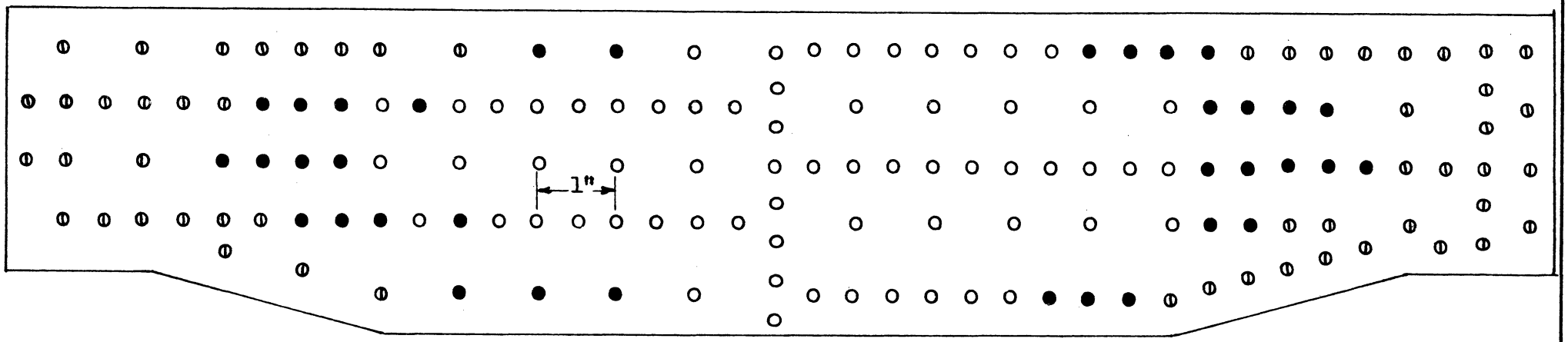
(a) SRR Surface plane radial specimen at rim
CRR Central plane radial specimen at rim
(b) Test in progress

TABLE VIII

CREEP PROPERTIES OF 4340, 17-22A(S), H-40, AND C-422 STEELS

Steel	Heat Treatment	BHN	Test Temp. (°F)	Stress (psi)	Time in Progress (Hours)	Minimum Creep Rate (%/1000 Hrs.)	Percent Total Deformation at Indicated Time Periods			Time in Hours for Specified Total Deformations			
							300 Hrs.	500 Hrs.	1000 Hrs.	0.1%	0.2%	0.5%	1.0%
4340	Aust. 1750°F + 111 Hrs. at 1050°F - (Lower Pearlite)	275	1100	4,250	1007(a)	3.9	1.37	2.32	5.2	9	21	90	217
	" " " "	270	1000	13,000	848(b)	5.4	2.0	4.2	--	2	6	46	141
	Aust. 1750°F + 28 Hrs. at 850°F - (Upper Bainite)	325	1000	15,500	1005(a)	0.42	0.41	0.51	0.75	1	18	470	1595(c)
	Aust. 1750°F + 1½ Hrs. at 650°F + T. 1¼ Hrs. at 1100°F (Lower Bainite)	294	1000	13,000	1032(a)	0.53	0.5	0.64	0.94	2	32	300	1104(c)
17-22A(S)	Aust. 1750°F + 1½ Hrs. at 1350°F	309	1100	19,000	565(b)	2.04	0.88	2.04	--	1	17	159	336
	" " " "	313	1100	15,000	1076(a)	0.59	0.32	0.44	0.74	14	108	622	1465(c)
	Aust. 1750°F + 10 Hrs. at 1150°F + T. 12 Hrs. at 1200°F	313	1100	19,000	550(b)	--	1.78	--	--	(d)	10	79	194
	" " " "	291	1100	15,000	652(b)	--	1.55	3.69	--	24	54	107	218
	Aust. 1750°F + 2 Hrs. at 900°F + T. 16 Hrs. at 1200°F	327	1100	19,000	796(b)	1.43	0.7	1.1	--	(d)	8	177	477
	" " " "	317	1100	15,500	320	--	0.41	--	--	.5	65	--	--
	Aust. 1750°F + 5 Min. at 700°F + T. 12 Hrs. at 1200°F	303	1100	14,000	1032(a)	0.43	0.35	0.45	0.7	22	67	621	1698(c)
H-40	O.Q. + T. 12 Hrs. at 1200°F	323	1100	24,000	1036(a)	0.83	0.5	0.66	1.14	(d)	23	300	862
	Aust. 1950°F + 10 Hrs. at 750°F + T. 1 Hr. at 1300°F (Bainite)	308	1100	28,000	1004(a)	1.37	0.73	1.05	2.16	(d)	1	131	470
	" " " "	312	1100	23,000	660	--	0.43	0.62	--	(d)	37	393	--
C-422	Norm. 1900°F + T. 24 Hrs. at 1200°F	306	1100	30,000	1120(a)	0.88	0.67	0.82	1.34	(d)	3	112	690
	O.Q. + T. 4 Hrs. at 1200°F	307	1100	30,000	1003(a)	0.49	0.64	0.75	1.01	(d)	1	133	970

(a) Completed test
(b) Test fractured at this time
(c) Extrapolated value
(d) Test reached this deformation on loading



○ = 235 - 270 Brinell Hardness
● = 271 - 300 " "
◍ = 301 - 330 " "

Heat Treatment: Normalized at 1750°F. + tempered 2 Hrs. at 1200°F.

Figure 1. Brinell Hardness Survey on Center Section (1,2,3) of Disk #1 of 17-22 A(S) Steel

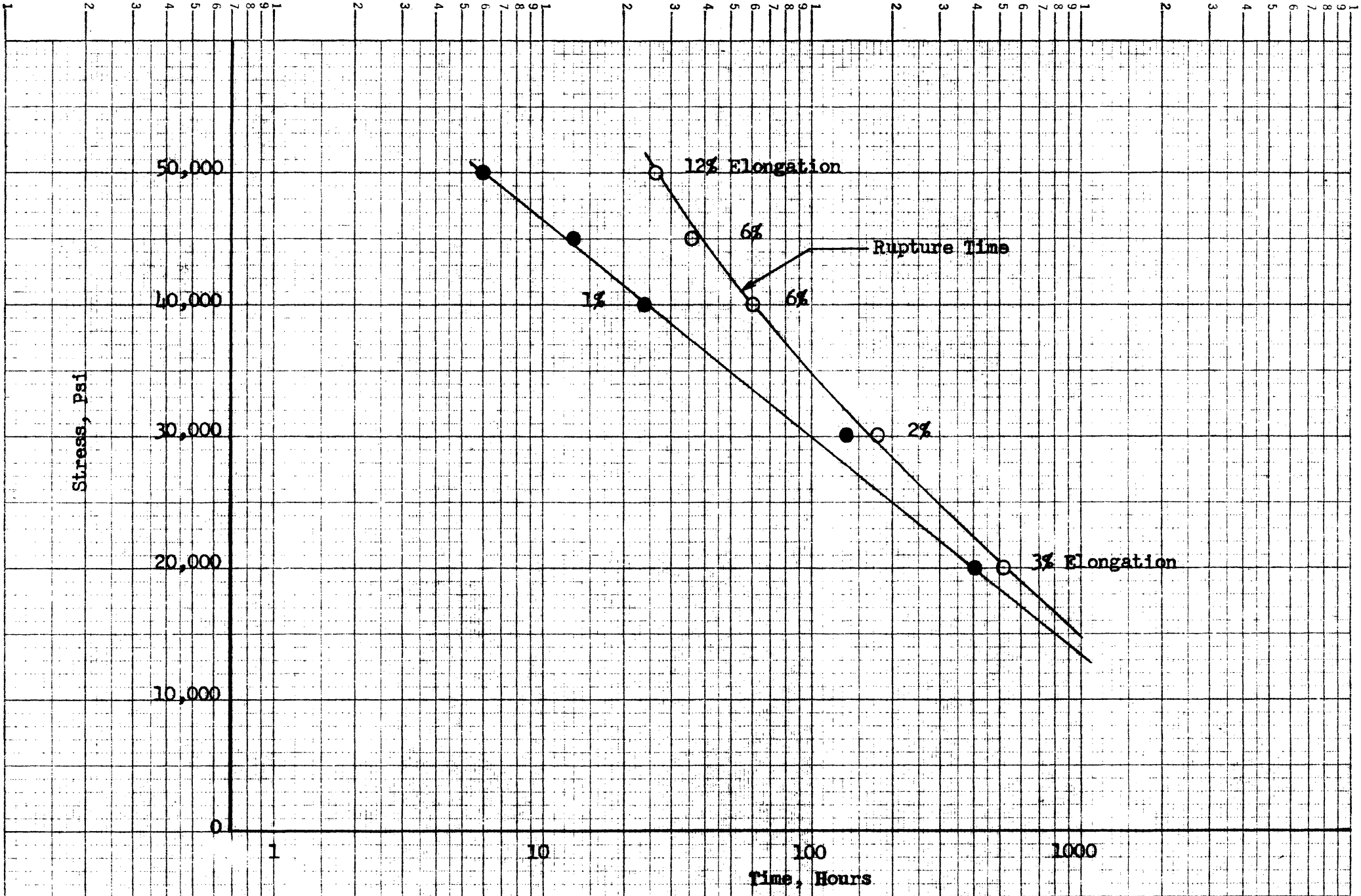


Figure 2. Curves of Stress Against Time for Rupture and 1-Percent Total Deformation for Disk #1 of 17-22A(S) Steel. Heat Treatment: N. 1750°F + 2 Hrs. at 1200°F.

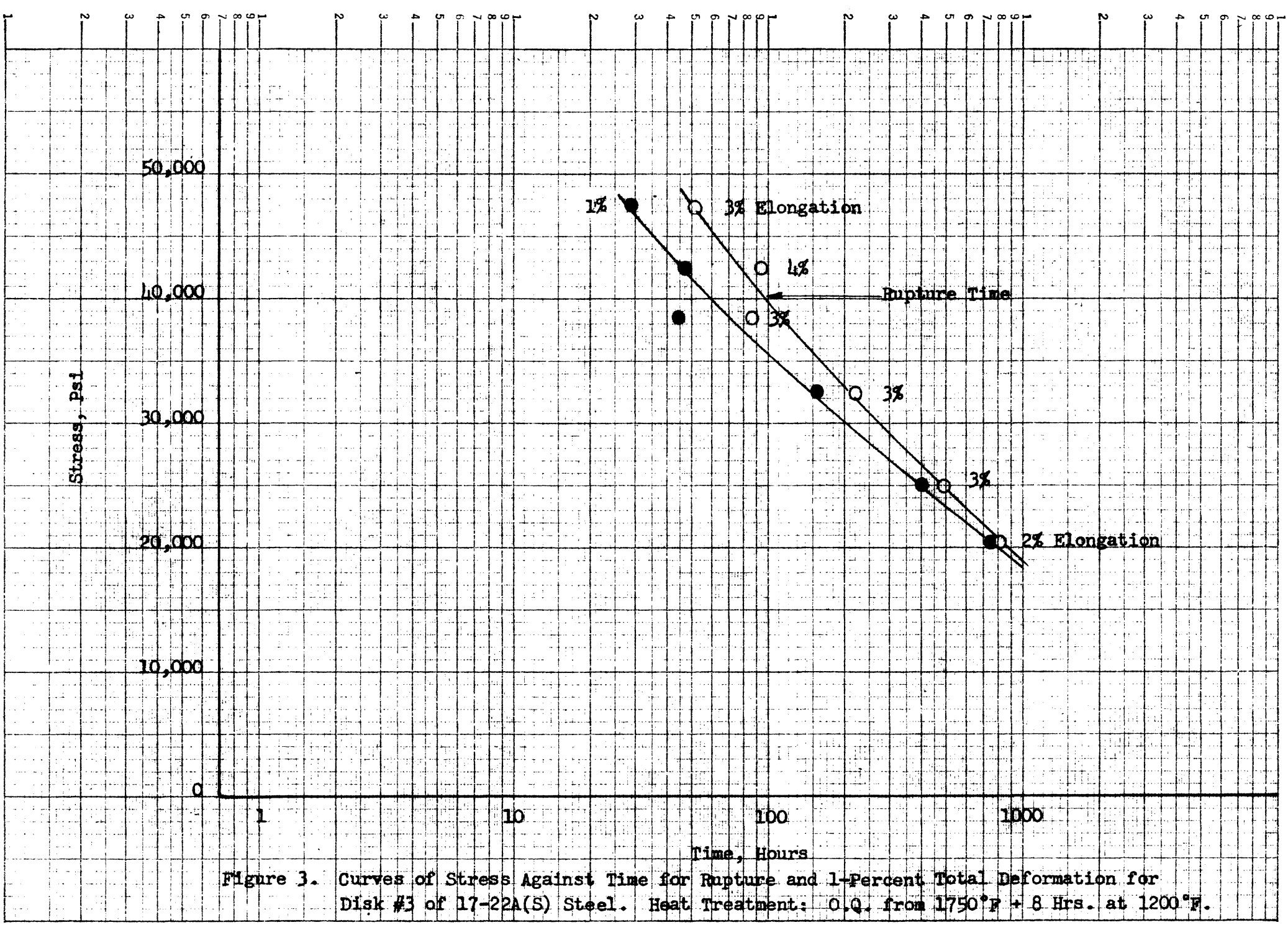


Figure 3. Curves of Stress Against Time for Rupture and 1-Percent Total Deformation for Disk #3 of 17-22A(S) Steel. Heat Treatment: O.Q. from 1750°F + 8 Hrs. at 1200°F.

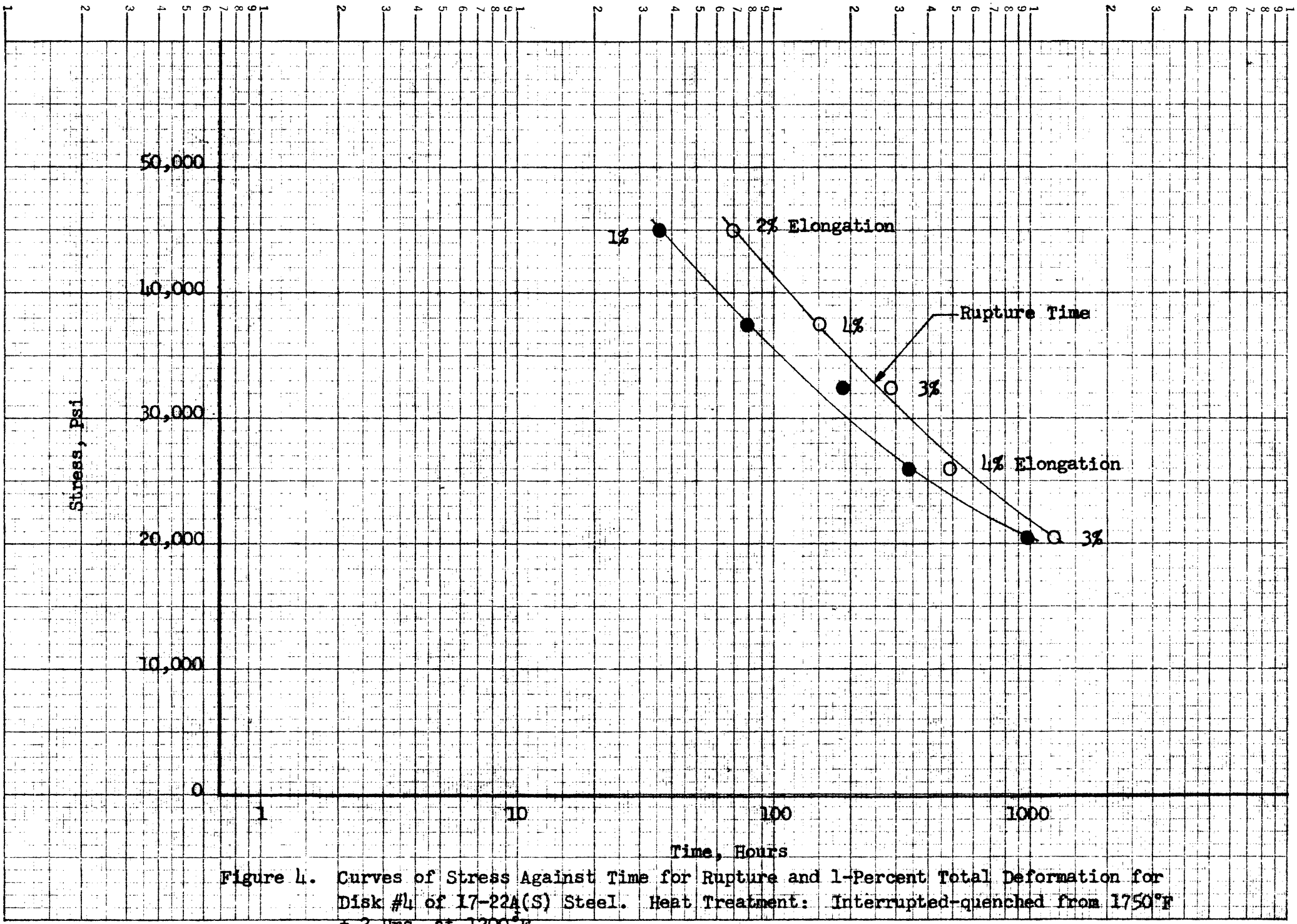
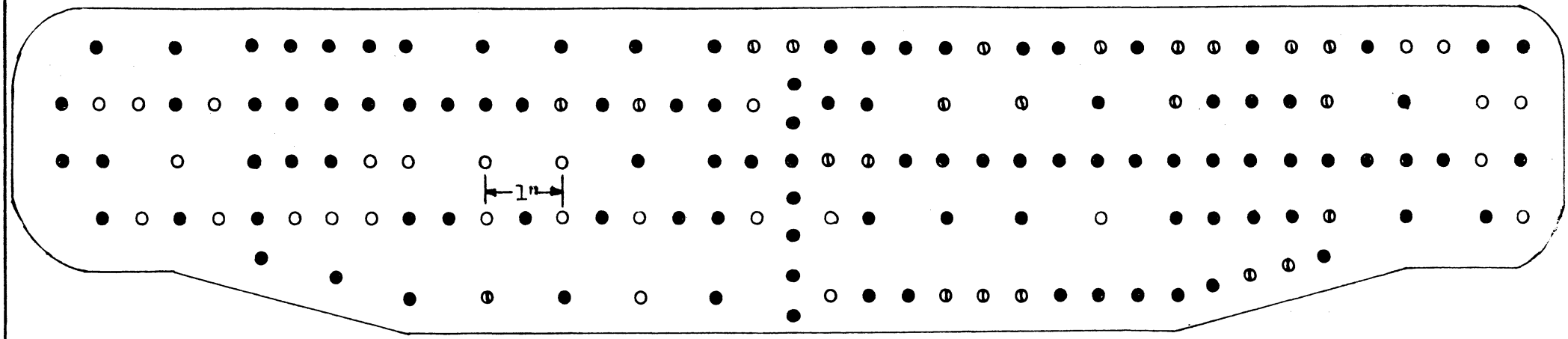


Figure 4. Curves of Stress Against Time for Rupture and 1-Percent Total Deformation for Disk #4 of 17-22A(S) Steel. Heat Treatment: Interrupted-quenched from 1750°F + 2 Hrs. at 1200°F.



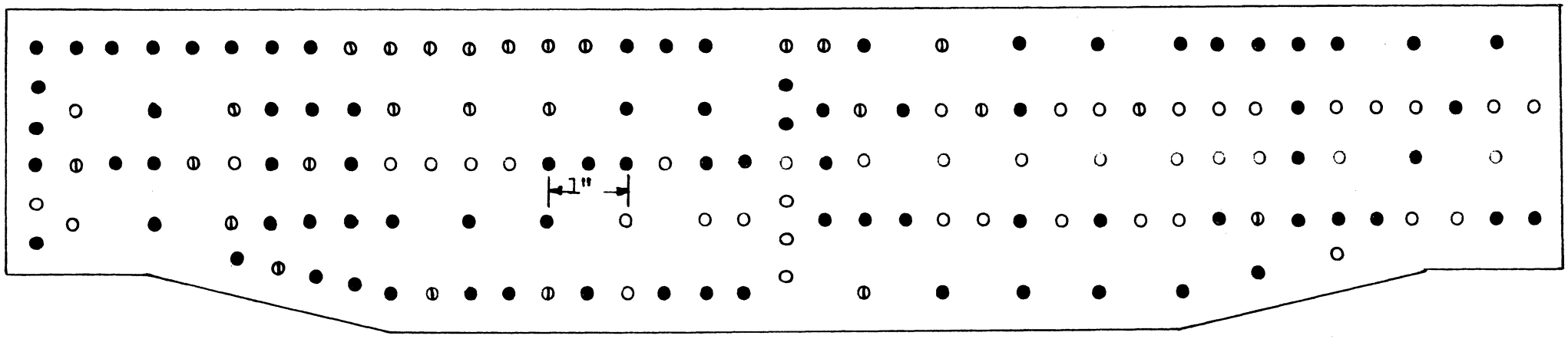
○ = 315-340 Brinell Hardness

● = 341-365 " "

Ⓓ = 366-380 " "

Heat Treatment: First treatment - N. 1950°F + temper 2 Hrs. at 1200°F
Second treatment - Retempered at 1200°F

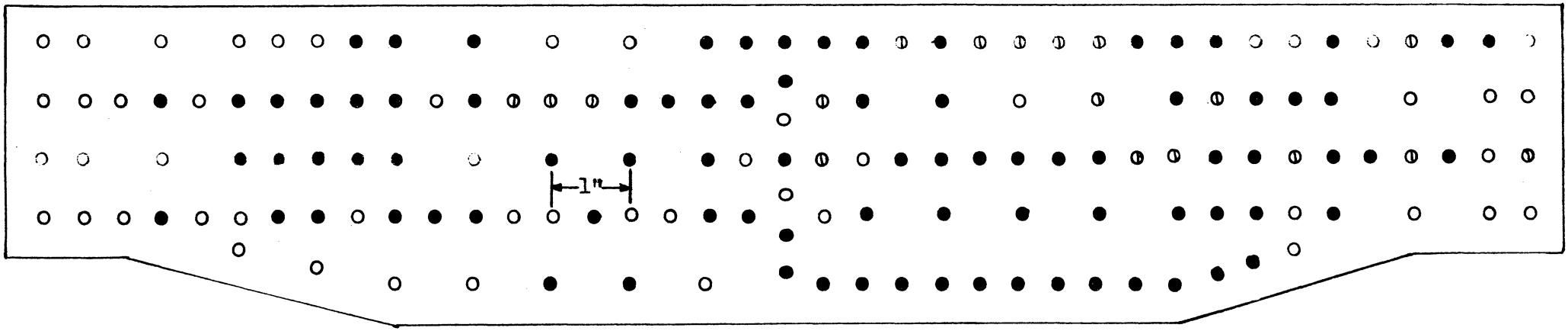
Figure 5. Brinell Hardness Survey on Center Section (1-2-3) of Disk #1 of H-40 Steel.



○ = 315 - 340 Brinell Hardness
● = 341 - 365 " "
◐ = 366 - 390 " "

Heat Treatment: First treatment - O.Q. from 1950°F. + 8 Hrs. at 1200°F.
Second treatment - Retempered at 1200°F.

Figure 6. Brinell Hardness Survey on Center Section (1,2,3) of Disk #3 of H-40 Steel.



○ = 327-350 Brinell Hardness

● = 351-375 " "

◑ = 376-393 " "

Heat Treatment: First treatment - Water quench from 1950°F until black, then withdrawn until glow returned. This was repeated until the glow did not return upon withdrawal. Transferred to furnace at 700°F for 8 hrs. + temper 2 hrs. at 1200°F.

Second treatment - Retempered at 1200°F.

Figure 7. Brinell Hardness Survey on Center Section (1-2-3) of Disk #4 of H-40 Steel.

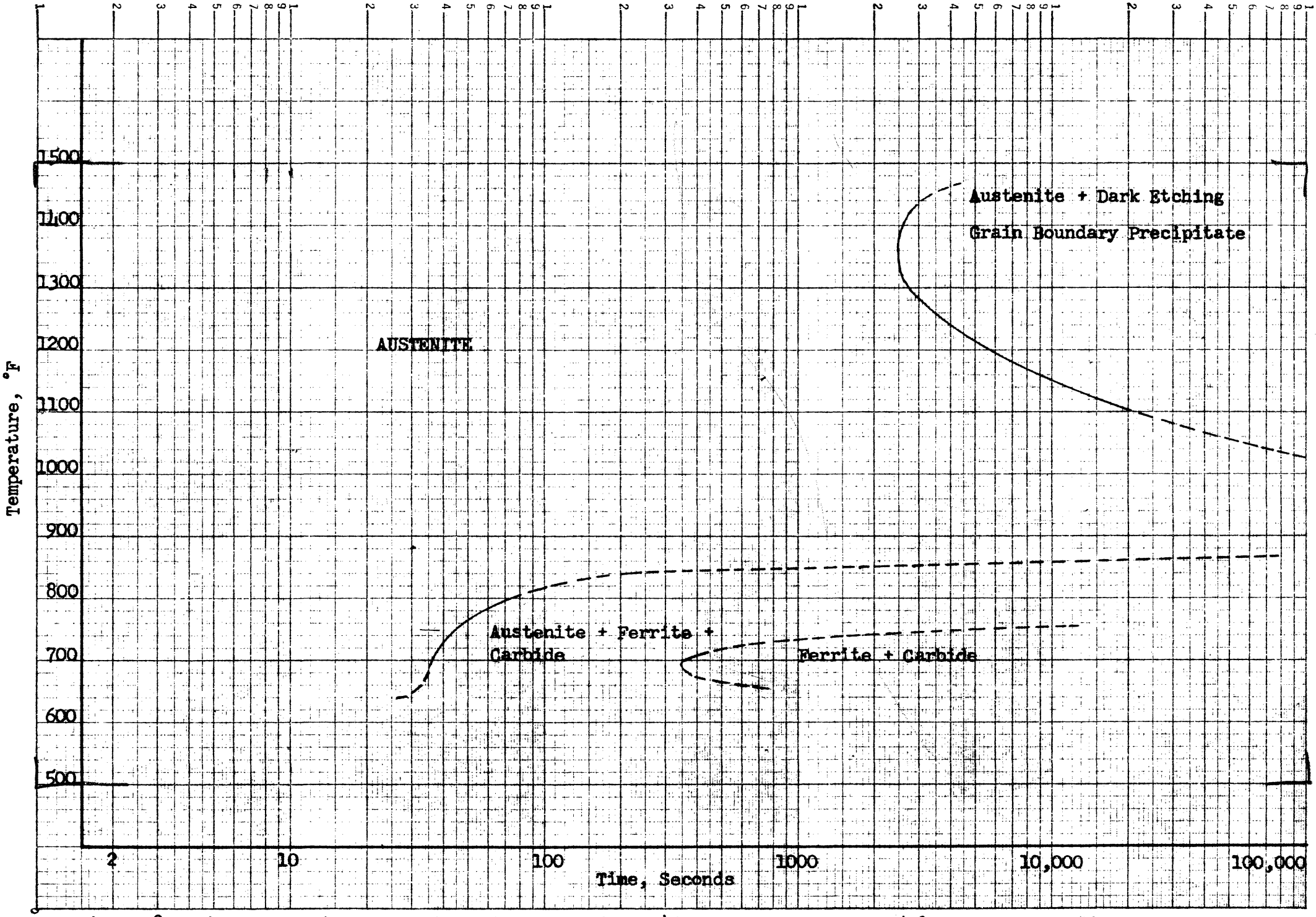


Figure 8. Time-Temperature-Transformation Curve for H-40, Austenitized at 1950°F, Grain Size #6-7.

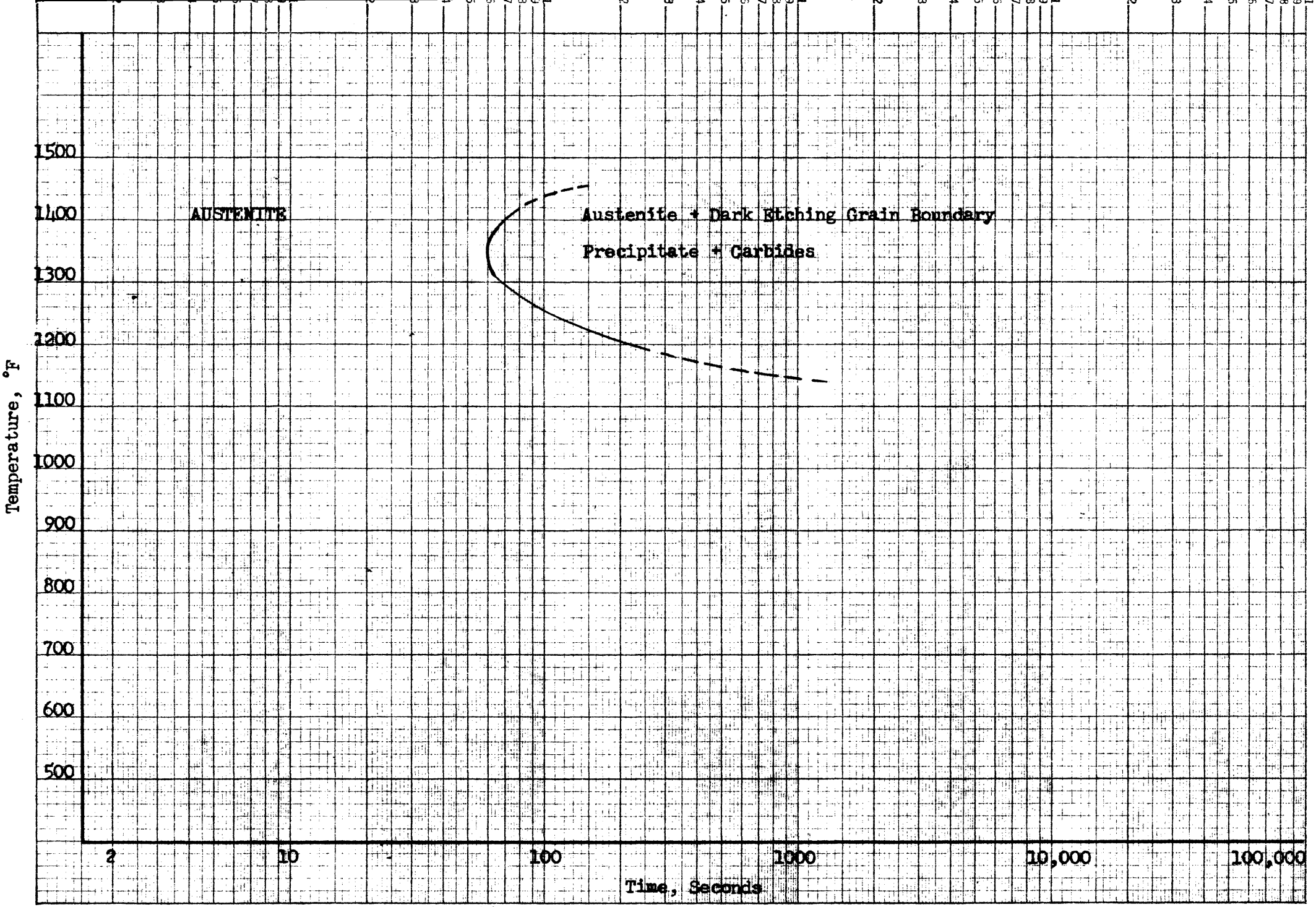


Figure 9. Time-Temperature-Transformation Curve for C-422, Austenitized at 1900°F, Grain Size #6.