FIFTH 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

By

A. Zonder

J. W. Freeman

PROJEC

AIR FORCE CONTRACT NUMBER: AF33(038)-13496
EXPENDITURE ORDER NUMBER: 605-227 SR-7

March 31, 1952

FIFTH PROGRESS REPORT

ON

FOUR LOW-ALLOY STEELS FOR ROTOR DISKS OF GAS TURBINES

IN JET ENGINES

SUMMARY

This report is the Fifth 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).

The purpose of this investigation is to study 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. A concurrent study of the high-temperature properties of the products of isothermal transformation of these four steels is being carried out, utilizing bar stock.

Using the stress to cause 1-percent total deformation in 1000 hours at 1100°F as a basis for comparison, the following isothermal structures had the best high-temperature properties:

Steel	Heat Treatment	BHN	Stress to Cause 1% Total Deformation in 1000 Hours at 1100°F (psi)
4340	Aust. 1750°F + 28 Hrs. at 850°F (Upper Bainite + Martensite)	319	greater than 4,250
"17-22A"S	N. 1750°F + T. 10 Hrs. at 1200°F	291/317	19,000
H-40	N. 1950°F + T. 18 Hrs. at 1200°F	312/320	27,800
C-422	O.Q. 1900°F + T. 4 Hrs. at 1200°F	307	30,000

The normalized 4340 disk and both the normalized and oil-quenched C-422 disks have been split and the center slabs cut out. These slabs have been magnafluxed and macroetched. The normalized C-422 slab showed two small indications of defects near the center on magnafluxing. These same indications appeared on macroetching. A Brinell hardness survey was made on each slab.

Room temperature tensile tests have been made on specimens cut from the center slabs of the normalized 4340 disk, the normalized and interrupted-quench H-40 disks, and the normalized and oil-quenched C-422 disks.

The original testing program for the disks has been modified, the finally established procedure is detailed in the section on Procedure and Proposed Testing Conditions.

The initial sorting survey at 1100°F to establish the rim properties of each heat-treated disk has been completed, and the following disks have been selected for further testing at 1000°, 1100°, and 1200°F:

(a) 4340 - To be decided by Materials Laboratory

(b) "17-22A"S - Disk #3 (Oil-quenched and tempered)

(c) C-422 - Disk #4 (Oil-quenched and tempered)

No further testing of any of the H-40 disks has been planned for the immediate future because of their high hardness and their low and erratic ductility values in the rupture test.

An analysis of the microstructures involved in this investigation is now in progress. This analysis is to be used to correlate the results obtained from the isothermal transformation study with the results obtained from the disk study.

INTRODUCTION

This report covers the progress made between 1 January 1952 and 31 March 1952 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.

This investigation may be divided into two phases, namely:

A. Disk Investigation

1. Determination of the effect of heat treatment upon the high-temperature properties of four ferritic alloys.

2. Determination of design data at 1000°, 1100°, and 1200°F for that heat-treated disk of each steel which has the best practical properties.

B. Isothermal Transformation Investigation

1. Determination of the creep and rupture characteristics of the products of isothermal transformation of the four steels. This work is being done on bar stock to help explain the properties of the disks after various heat treatments.

PROCEDURE AND PROPOSED TESTING CONDITIONS

The following modified testing program has been approved:

1. 4340 Steel

   (a) Establish stress-rupture curves out to 1000 hours at 1000°F for all three disks.

   (b) Establish curves of stress versus time for 1-percent total deformation at 1000°F out to 1000 hours.

   (c) Establish stress-rupture curves and stress-time for 1-percent total deformation curves out to 100 hours at 1100° and 1200°F for the heat-treated disk showing the best properties at 1000°F.

2. "17-22A"S, H-40, and C-422 Steels

   (a) Establish complete design curves for these materials only at 1100°F for that heat-treated disk of each steel showing the best rupture properties at 1100°F.

   (b) Establish stress-rupture and stress-time for 1-percent total deformation curves out to 1000 hours at 1000°F and out to 100 hours at 1200°F for that heat-treated disk of each steel showing the best properties at 1100°F.

3. Continue the isothermal studies on 4340, "17-22A"S, H-40, and C-422 steels.

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 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 over-all hardness range of the slab was 297 to 345 Brinell. The principal ranges were 297 to 320 Brinell at the center and 320 to 345 Brinell around the edges. The room temperature tensile properties were determined from specimens taken from this slab and are presented in Table I. Also included in Table I are the average tensile properties of the oil-quenched and interrupted-quench disks.

The normalized specimens were from 10 to 40 points Brinell harder than the interrupted-quench specimens, and 50 to 75 points harder than the oil-quenched specimens, with correspondingly higher tensile strengths and lower ductility values. The average proportional limit for the normalized specimens (42,750 psi) was much lower than the proportional limit of either the oil-quenched (76,500 psi) or interrupted-quench (61,750 psi) specimens. One center specimen had only 6.5-percent elongation and 9.3-percent reduction of area.

Rupture testing of specimens taken from the rim material of the disks is now in progress at 1000°F, and the results obtained to date are shown in Table II and figures 2 and 3. Also included in figures 2 and 3 are rupture data and total deformation data obtained at 1100°F, which were reported in the Fourth Progress Report dated 31 December 1951. Table III shows the high-temperature strengths of the three 4340 disks at 1000° and 1100°F and the results obtained in the

isothermal transformation study. A study of the microstructures involved is now in progress in order to try to explain the results obtained.

Selection of one of the 4340 disks for further testing at 1200°F has been withheld pending a decision of representatives of the Materials Laboratory on this question, after consideration of the data obtained to date. The following facts should be noted:

(1) Disk #3 (O.Q. + T.) had poor high-temperature properties at 1000° and 1100°F.

(2) Disk #4 (I.Q. + T.) and disk #1 (N.) had similar high-temperature properties at 1000° and 1100°F.

(3) Disk #1 (N.) had not been tempered.

(4) The practicability of the heat treatment used on disk #4 (I.Q. + T.) has made the value of additional data on this disk questionable.

"17-22A"S STEEL

The results of the survey at 1100°F of the high-temperature properties of the three "17-22A"S disks have been reported in the Fourth Progress Report. The 1000-hour rupture strengths were as follows:

Disk Number	1000-Hour Rupture Strengths (psi)
1 (N.)	14,500
3 (O.Q.)	18,500
4 (I.Q.)	21,500

Although the interrupted-quench disk had slightly better properties than the oil-quenched disk, the difference was not great enough to warrant further testing of that disk, considering the practical aspects of the heat treatments involved. Therefore, the oil-quenched disk was selected for further testing at 1000°, 1100°, and 1200°F.

The low strength of the normalized disk was due to the fact that the disk did not harden upon normalizing. Metallographic examination of a section

3/4-inch from the surface of the disk and of a completed rupture test specimen showed large amounts of ferrite and pearlite present, plus a tempered constituent (either bainite or martensite).

The design data obtained to date at 1100°F for the oil-quenched disk are shown in Table IV and figure 4. To date, no results have been obtained at either 1000° or 1200°F.

Table V shows the high-temperature strengths at 1100°F for the three "17-22A"S disks and the results obtained in the isothermal transformation study. A study of the microstructures involved is now in progress in order to try to explain the results obtained.

H-40 STEEL

The room temperature tensile properties of the normalized and interrupted-quench disks are shown in Table VI. Also included are the average tensile properties of the oil-quenched disk which were reported in the Fourth Progress Report. All three materials had hardnesses of about 350 to 360 Brinell with correspondingly high tensile strengths and low ductility values. The specimens taken directly from the center average about 4-percent elongation for all three materials, although values as low as 1- to 2-percent were obtained in each.

The survey at 1100°F of the three disks has been completed and the results are shown in Table VII and figure 5. All three disks had similar high-temperature strengths. They all had high Brinell hardnesses, and they all showed low, erratic ductility values in the rupture test. Because of these facts, no further testing is planned in the immediate future for any of the three disks.

The stresses to cause 1-percent total deformation in 1000 hours at 1100°F for the bar stock and disk material are as follows:

Material	Stress to Cause 1% Total Deformation in 1000 Hours at 1100°F (psi)
Disk #1 (N. + T.)	29,500
Bar Stock - N. 1950°F + T. 18 Hrs. at 1200°F	27,750
Disk #3 (O.Q. + T.)	35,250
Bar Stock - O.Q. 1950°F + T. 12 Hrs. at 1200°F	23,300
Disk #4 (I.Q. + T.)	32,200
Bar Stock - Aust. 1950°F + 10 Hrs. at 750°F + T. 1 Hr. at 1300°F	21,500

A study of the microstructures involved is now in progress in order to try to explain the results obtained.

C-422 STEEL

The normalized and tempered and oil-quenched and tempered disks have been split and the center slabs cut out. These slabs have been magnafluxed and macroetched. The normalized and tempered disk showed two small indications of defects on magnafluxing. These indications also appeared on macroetching. The slab cut from the oil-quenched and tempered disk was found to be sound. Brinell hardness surveys were taken on the slabs from both disks and these are shown in figures 6 and 7. Both disks showed a hardness range of about 280 to 320. The oil-quenched and tempered disk showed one small hard area near the surface where the hardness ranged from 320 to 350 Brinell.

The room temperature tensile properties of both disks were determined from specimens cut from the center slabs, and these properties are shown in Table VIII. Both disks exhibited similar room temperature tensile properties. All four specimens taken from the center of the normalized disk and two of those from the oil-quenched disk had low ductility.

The results of the survey of rupture properties at 1100°F are shown in figure 8 and Table IX. The oil-quenched and tempered disk had somewhat better properties and was selected for further testing at 1000°, 1100°, and 1200°F.

Design data obtained to date at 1000°, 1100°, and 1200°F for the oil-quenched and tempered disk are shown in figure 9 and Tables IX and X. Also included in Table X are data obtained for the normalized and tempered disk at 1100°F and results obtained from tests on similarly treated bar stock.

The data obtained from the bar stock shows reasonable agreement with the data obtained from the disk study. A study of the microstructures involved is now in progress to try to explain the results obtained.

Investigation of the Properties of the Products of Isothermal Transformation

All creep testing at 1100°F of isothermal structures of 4340, "17-22A"S, H-40, and C-422 steels as outlined in the First Progress Report has been completed. The microstructures of the isothermally transformed materials are being examined metallographically in conjunction with the disk materials in an attempt to correlate the data obtained by creep and rupture testing.

4340 STEEL AND C-422 STEEL

The creep test results obtained at 1000° and 1100°F for 4340 and at 1100°F for C-422 have been reported in the Third and Fourth Progress Reports.

"17-22A"S STEEL

The last creep test at 1100°F and 15,500 psi on an intermediate structure developed by isothermally transforming for 2 hours at 900°F and then tempering at 1200°F for 16 hours, with a Brinell hardness of 317, has been completed with the following results:

Minimum Creep Rate (%/1000 Hrs.)	Total Deformation in 1000 Hours (%)	Time for 1% Total Deformation (Hours)
0.94	1.34	798

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

Heat Treatment	BHN	Stress to Cause 1% Total Deformation in 1000 Hours (psi)
N. 1750°F + T. 10 Hrs. at 1200°F	291/317	19,000
O.Q. 1750°F + 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	14,000
Aust. 1750°F + 5 Min. at 700°F + T. 12 Hrs. at 1200°F	302/303	15,500

H-40 STEEL

The last creep test at 1100°F and 23,000 psi on an intermediate or bainitic-type structure with a Brinell hardness of 312 has been completed with the following results:

Minimum Creep Rate (%/1000 Hrs.)	Total Deformation in 1000 Hours (%)	Time for 1% Total Deformation (Hours)
0.76	1.23	843

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

Heat Treatment	BHN	Stress to Cause 1% Total Deformation in 1000 Hours (psi)
N. 1950°F + T. 18 Hrs. at 1200°F	312/320	27,800
O.Q. 1950°F + 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	21,500

FUTURE WORK

Creep-rupture testing of "17-22A"S disk #3 (O.Q.) and C-422 disk #4 (O.Q.) will be continued in order to accumulate additional design data. No further testing is planned in the immediate future for any of the H-40 disks because of their high hardness and low, erratic ductility in the rupture test. Further testing of the 4340 disk material at 1200°F will not be undertaken pending the decision of the Materials Laboratory on this matter.

A correlative study of the microstructures of the disks and isothermally transformed structures of bar stock is now in progress and should be finished in the next period. A limited amount of rupture testing of the isothermally transformed structures is planned to aid in this correlative study.

TABLE I

ROOM TEMPERATURE TENSILE PROPERTIES AT THE CENTER OF THE 4340 DISKS

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%				
	Disk #1 - Heat Treatment: First treatment - N. 1750°F + T. 2 Hrs. at 1200°F Second treatment - N. 1750°F								
1W	SRR	163,500	69,500	97,000	112,000	46,000	15.0	45.5	328
1X	CRR	163,500	72,000	102,500	119,000	43,000	12.5	40.3	331
2W	SRC	156,500	62,000	92,000	106,500	37,000	6.5	9.3	316
2X	CRC	155,000	58,500	87,000	101,500	40,000	10.5	25.5	316
2Y	CRC	155,250	70,500	96,500	110,000	46,000	12.0	32.8	308
2Z	SRC	151,000	65,250	92,500	105,500	44,000	11.5	30.2	304
	Disk #3 - Heat Treatment: First treatment - O.Q. from 1750°F + T. 8 Hrs. at 1200°F Second treatment - O.Q. from 1550°F + Tempered at 1050°F								
-	RR	132,750	109,750	112,500	113,250	75,500	17.8	60.3	276
-	RC	124,000	92,500	95,750	96,250	77,500	17.3	45.0	257
	Disk #4 - Heat Treatment: Interrupted-quench from 1750°F + T. 2 Hrs. at 1200°F								
-	RR	140,700	88,750	103,000	107,750	63,750	17.0	49.1	288
-	RC	137,500	85,500	99,500	104,750	60,000	12.2	27.8	289

(a) SRR Surface plane radial specimen near rim of disk
CRR Central plane radial specimen near rim of disk
SRC Surface plane radial specimen near center of disk
CRC Central plane radial specimen near center of disk
RR Radial specimens near rim of disk
RC Radial specimens near center of disk

TABLE II

RUPTURE DATA FOR 4340 DISKS AT 1000°F

Specimen Number	Specimen Location (a)	Stress (psi)	Rupture Time (Hours)	Elongation in 2 in. (%)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (Hours)
Disk #1 - Heat Treatment:			First treatment - N. 1750°F + T. 2 Hrs. at 1200°F Second treatment - N. 1750°F			
4Y	CRR	50,000	88(b)	2.2	1.2	68
6W	SRR	45,000	163	2.8	1.8	118
4Z	SRR	39,000	146	2.7	1.7	122
6Y	CRR	34,000	292	2.3	4.0	250
6Z	SRR	24,000	(c)	-	-	-
Disk #3 - Heat Treatment:			First treatment - O.Q. from 1750°F + T. 8 Hrs. at 1200°F Second treatment - O.Q. from 1550°F + tempered at 1050°F			
4Z	SRR	50,000	23	28.0	48.7	2
6W	SRR	40,000	77	16.5	30.8	8.5
6X	CRR	32,500	247	11.5	14.5	40
6Y	CRR	27,500	372	11.5	17.8	68
6Z	SRR	20,000	(c)	-	-	124
Disk #4 - Heat Treatment:			Interrupted-quench from 1750°F + T. 2 Hrs. at 1200°F			
4Z	SRR	50,000	88	2.2	3.5	81
6W	SRR	40,000	185	3.1	3.5	140
6X	CRR	34,000	278	1.8	2.2	256
6Y	CRR	28,000	377	1.8	2.4	355
6Z	SRR	19,000	(c)	-	-	-

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

TABLE III

COMPARISON OF THE HIGH TEMPERATURE PROPERTIES OF 4340 BAR STOCK AND 4340 DISK MATERIAL

Material	Heat Treatment	Test Temp. (°F)	Rupture Strengths (psi)				Stress to Cause 1-Percent Total Deformation at Indicated Times (psi)				
			1 Hr	10 Hr	100 Hr	1000 Hr	1 Hr	10 Hr	100 Hr	500 Hr	1000 Hr
Disk #1	(a) N. 1750°F + T. 2 Hrs. at 1200°F (b) N. 1750°F	1000	-	-	48,000	-	-	-	44,500	27,500	21,500*
Disk #1	(a) N. 1750°F + T. 2 Hrs. at 1200°F (b) N. 1750°F	1100	-	36,000	18,500	-	-	26,500	13,000	-	-
Bar Stock	N. 1750°F + T. 1 Hr. at 1100°F	1000	-	-	-	-	-	-	18,500	15,500	13,300
Bar Stock	N. 1750°F + T. 1 Hr. at 1100°F	1100	-	-	-	-	-	-	7,400	5,250	4,250
Disk #3	(a) O.Q. 1750°F + T. 8 Hrs. at 1200°F (b) O.Q. 1550°F + tempered 1050°F	1000	-	58,000	38,000	-	54,500	39,500	24,500	14,250	9,750
Disk #3	(a) O.Q. 1750°F + T. 8 Hrs. at 1200°F (b) O.Q. 1550°F + tempered 1050°F	1100	-	28,000	15,500	-	29,500	15,750	8,400	-	-
Bar Stock	O.Q. 1750°F + T. 10 Hrs. at 1100°F	1000	-	-	-	-	-	-	-	-	~~<13,000~~
Bar Stock	O.Q. 1750°F + T. 10 Hrs. at 1100°F	1100	-	-	-	-	-	-	-	-	4,250
Disk #4	Int.-quench 1750°F + T. 2 Hrs. at 1200°F	1000	-	-	48,000	-	-	-	46,250	24,500	18,250*
Disk #4	Int.-quench 1750°F + T. 2 Hrs. at 1200°F	1100	-	33,500	19,000	-	41,000	25,250	15,500	-	-
Bar Stock	Aust. 1750°F + 28 Hrs. at 850°F (Upper Bainite)	1000	-	-	-	-	-	-	-	20,500	17,300
Bar Stock	Aust. 1750°F + 28 Hrs. at 850°F (Upper Bainite)	1100	-	-	-	-	-	-	-	-	>4,250
Bar Stock	Aust. 1750°F + 1-1/2 Hrs. at 650°F + T. 1-1/4 Hrs. at 1100°F (Lower Bainite)	1000	-	-	-	-	-	-	-	-	13,000
Bar Stock	Aust. 1750°F + 1-1/2 Hrs. at 650°F + T. 1-1/4 Hrs. at 1100°F (Lower Bainite)	1100	-	-	-	-	-	-	-	-	<4,500

* Extrapolation based on data obtained to date.

TABLE IV

CREEP-RUPTURE DATA FOR DISK #3 OF "17-22A"S STEEL AT 1100°F

Heat Treatment: O.Q. 1750°F + T. 8 Hrs. at 1200°F

Specimen Number	Specimen Location (a)	Stress (psi)	Time to Fracture (Hours)	Reduction of Area (%)	Elongation in 2 in. (%)	Time to Reach Specified Total Deformations (Hours)				Time at Start of Third Stage Creep (Hours)
						0.1%	0.2%	0.5%	1.0%	
4Z	SRR	47,500	51	5.1	2.6	(b)	(b)	6	29	20
4X	CRR	42,500	94	8.2	3.5	(b)	(b)	10	47	48
4W	SRR	38,500	86(c)	3.5	3.0	(b)	1	19	45	-
4Y	CRR	32,500	219	1.6	3.0	(b)	2	49	156	116
6W	SRR	25,000	489	3.2	2.6	(b)	21	199	402	280
6X	CRR	20,500	792	2.8	1.7	3	57	441	774	575
6Y	CRR	15,500	(d)	-	-	5	109	-	-	-
6Z	SRR	12,500	(d)	-	-	26	-	-	-	-

(a) SRR Surface plane radial specimen near rim
CRR Central plane radial specimen near rim
(b) Test specimens reached this deformation on loading
(c) Broke in gage mark
(d) Creep tests in progress

TABLE V

COMPARISON OF THE HIGH TEMPERATURE PROPERTIES OF "17-22A"S BAR STOCK AND "17-22A"S DISK MATERIAL AT 1100°F

Material	Heat Treatment	Rupture Strengths (psi)				Stress to Cause 1-Percent Total Deformation at Indicated Times (psi)				
		1 Hr	10 Hr	100 Hr	1000 Hr	1 Hr	10 Hr	100 Hr	500 Hr	1000 Hr
Disk #1	N. 1750°F + T. 2 Hrs. at 1200°F	-	63,000	34,500	14,500	68,000	47,000	31,750	18,250	14,000
Bar Stock	N. 1750°F + T. 10 Hrs. at 1200°F	-	-	-	19,500*	-	-	24,000*	20,500	19,000
Disk #3	O.Q. 1750°F + T. 8 Hrs. at 1200°F	-	70,000	40,000	19,500	-	59,500	35,500	23,250	19,000
Bar Stock	O.Q. 1750°F + T. 1 Hr. at 1300°F	-	-	-	18,000*	-	-	24,500*	18,250	15,000
Disk #4	I.Q. 1750°F + T. 2 Hrs. at 1200°F	-	76,000	41,500	22,500	-	56,000	36,000	24,750	20,500
Bar Stock	Aust. 1750°F + 5 Min. at 700°F + T. 12 Hrs. at 1200°F (Lower Bainite)	-	-	-	-	-	-	21,500*	17,500	15,500
Bar Stock	Aust. 1750°F + 2 Hrs. at 900°F + T. 16 Hrs. at 1200°F (Upper Bainite)	-	-	-	18,000*	-	-	24,750*	17,500	14,000

* Estimated values

TABLE VI

ROOM TEMPERATURE TENSILE PROPERTIES AT THE CENTER OF THE H-40 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: First treatment - N. 1950°F + T. 2 Hrs. at 1200°F Second treatment - Retempered at 1200°F								
1W	SRR	168,500	129,250	147,000	153,500	102,000	12.0	40.5	352
1X	CRR	167,500	128,750	145,500	151,750	104,000	11.0	31.2	350
2W	SRC	163,250	126,500	145,500	154,000	96,000	1.0	4.3	363
2X	CRC	165,500	125,000	144,000	151,750	104,000	1.5	3.9	350
2Y	CRC	169,250	130,500	148,000	154,250	105,000	5.0	9.6	356
2Z	SRC	169,000	129,000	145,750	152,500	104,000	7.0	13.4	345
	Disk #3 - Heat Treatment: First treatment - O.Q. 1950°F + T. 8 Hrs. at 1200°F Second treatment - Retempered at 1200°F								
	RR	182,750	138,000	159,500	165,000	110,500	9.7	23.6	364
	RC	176,000	127,000	151,750	160,500	98,500	4.4	7.4	353
	Disk #4 - Heat Treatment: First treatment - Interrupted-quenched from 1950°F + T. 1200°F Second treatment - Retempered at 1200°F								
1W	SRR	173,000	133,500	150,000	156,500	108,000	10.5	33.7	351
1X	CRR	176,000	130,000	149,250	157,750	101,000	10.0	23.4	361
2W	SRC	169,250	137,000	157,750	164,000	109,500	1.5	1.2	357
2X	CRC	171,500	129,750	150,250	158,250	102,000	2.0	4.7	367
2Y	CRC	174,750	131,000	150,750	158,750	101,000	2.5	7.4	357
2Z	SRC	175,000	129,250	149,000	156,750	102,000	9.0	19.5	355

(a) SRR Surface plane radial specimen near rim of disk
CRR Central plane radial specimen near rim of disk
SRC Surface plane radial specimen at center of disk
CRC Central plane radial specimen at center of disk
RR Radial specimens at rim of disk
RC Radial specimens at center of disk

TABLE VII

RUPTURE DATA FOR H-40 DISKS AT 1100°F

Specimen Number	Specimen Location (a)	Stress (psi)	Rupture Time (Hours)	Elongation in 2 in. (%)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (Hours)
Disk #1 - Heat Treatment: First treatment - N. 1950°F + T. 2 Hrs. at 1200°F Second treatment - Retempered at 1200°F						
4W	SRR	55,000	28(b)	-	-	-
4X	CRR	55,000	48(c)	-	-	40(d)
4Z	SRR	55,000	97	1.4	0.9	93(d)
4Y	CRR	45,000	164(b)	-	-	-
6W	SRR	45,000	242	8.3	14.1	97
6X	CRR	37,000	518	5.0	4.0	336
Disk #3 - Heat Treatment: First treatment - O.Q. 1950°F + T. 8 Hrs. at 1200°F Second treatment - Retempered at 1200°F						
6W	SRR	60,000	35	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	456(c)	-	-	455(d)
6Y	CRR	38,000	189(c)	-	-	188(d)
Disk #4 - Heat Treatment: First treatment - Interrupted-quenched from 1950°F + T. 1200°F Second treatment - Retempered at 1200°F						
4X	CRR	60,000	34(b)	-	-	28
6W	SRR	55,000	67	1.9	5.8	63(d)
4W	SRR	50,000	108	2.6	8.1	73
4Y	CRR	45,000	243(c)	-	-	228
6X	CRR	40,000	457(b)	-	-	451
4Z	SRR	39,000	407(c)	-	-	400(d)
6Y	CRR	35,000	697	2.3	7.0	690

(a) SRR Surface plane radial specimen near rim of disk
CRR Central plane radial specimen near rim of disk
(b) Broke in threads
(c) Broke in fillet
(d) Extrapolated value

TABLE VIII

ROOM TEMPERATURE TENSILE PROPERTIES AT THE CENTER OF THE C-422 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 #4 - Heat Treatment:		First treatment - O.Q. 1900°F + T. 8 Hrs. at 1200°F Second treatment - Full annealed at 1600°F for 6 Hrs. and furnace cooled. O.Q. 1900°F + double temper at 1200°F for 2 plus 2 Hrs.							
1W	SRR	141,500	98,500	108,500	113,000	83,000	16.0	40.1	291
1X	CRR	141,000	96,500	107,500	112,500	82,500	16.5	37.9	299
2W	SRC	135,500	94,250	104,000	108,750	80,000	7.5	8.9	294
2X	CRC	133,000	89,750	101,000	106,000	69,000	7.5	13.0	287
2Y	CRC	132,500	91,000	101,500	105,500	71,000	12.5	30.2	285
2Z	SRC	130,750	86,000	100,000	104,500	66,000	17.0	41.8	282
Disk #1 - Heat Treatment:		First treatment - N. 1900°F + T. 2 Hrs. at 1200°F Second treatment - Full annealed at 1600°F for 6 Hrs. and furnace cooled. N. 1900°F + double temper at 1200°F for 2 plus 2 Hrs.							
1W	SRR	145,500	105,500	117,250	122,750	87,500	16.0	35.0	301
1X	CRR	145,500	95,000	112,500	118,250	67,000	16.0	33.8	308
2W	SRC	133,500	88,500	102,500	107,250	70,500	5.5	7.4	300
2X	CRC	133,250	92,250	102,250	107,000	77,000	5.5	8.1	295
2Y	CRC	135,250	93,250	104,750	110,250	77,000	8.0	12.2	288
2Z	SRC	134,000	94,000	105,250	109,500	75,500	7.5	22.7	294

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

TABLE IX

HIGH TEMPERATURE RUPTURE PROPERTIES OF DISKS #1 AND #4 OF C-422 STEEL

Specimen Number	Specimen Location (a)	Stress (psi)	Rupture Time (Hours)	Elongation in 2 in. (%)	Reduction of Area (%)	Time to Reach Specified Total Deformations (Hours) 0.1%	0.2%	0.5%	1.0%
A. Creep-Rupture Properties of the C-422 Disks at 1100°F									
Disk #1 - Heat Treatment: First treatment - N. 1900°F + T. 2 Hrs. at 1200°F Second treatment - Full anneal 6 Hrs. at 1600°F, furnace cooled. N. 1900°F + double temper at 1200°F for 2 plus 2 Hrs.									
4W	SRR	55,000	2	26.5	69.5	(b)	(b)	(b)	-
4X	CRR	45,000	15	23.5	73.0	(b)	(b)	(b)	1
4Y	CRR	35,000	318	15.0	36.3	(b)	(b)	4	26
4Z	SRR	32,000	1055	9.5	20.4	(b)	1	45	225
Disk #4 - Heat Treatment: First treatment - O.Q. 1900°F + T. 8 Hrs. at 1200°F Second treatment - Full anneal 6 Hrs. at 1600°F, furnace cooled. O.Q. 1900°F + double temper at 1200°F of 2 plus 2 Hrs.									
4W	SRR	50,000	14	36.0	80.5	(b)	(b)	0.2	1.1
4Z	SRR	44,000	81	28.0	77.0	-	-	-	-
4X	CRR	40,000	399	29.5	69.3	(b)	(b)	2	19
4Y	CRR	35,000	1001	14.5	56.9	(b)	1	16	234
10W	SRR	28,000	(c)	-	-	(b)	4	-	-
6X	CRR	22,000	(c)	-	-	1	58	-	-

Continued on next page

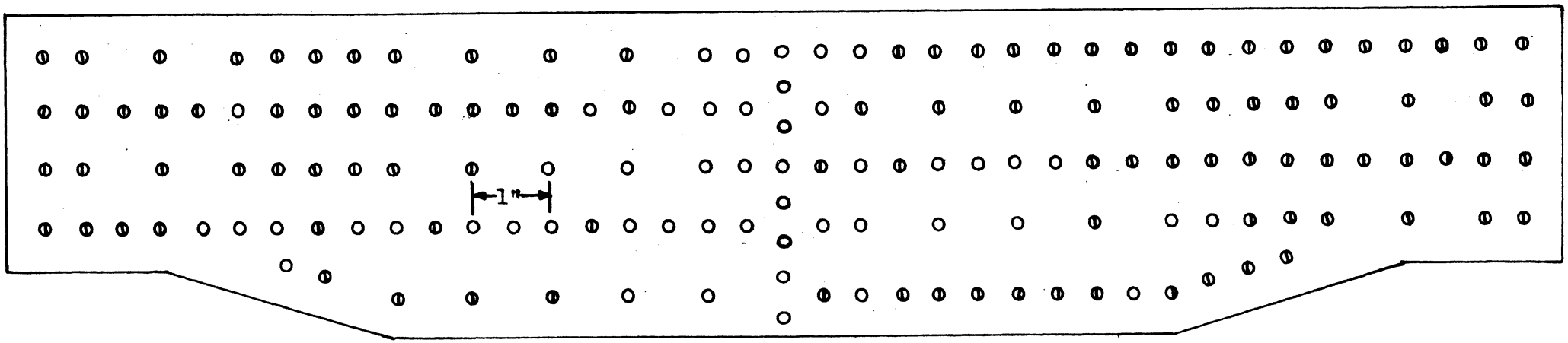
Specimen Number	Specimen Location (a)	Stress (psi)	Rupture Time (Hours)	Elongation in 2 in. (%)	Reduction of Area (%)	Time to Reach Specified Total Deformations (Hours) 0.1%	0.2%	0.5%	1.0%
		B. Creep-Rupture Properties of C-422 Disk #4 at 1000°F							
9W	SRR	67,500	12	26.0	70.4	(b)	(b)	0.2	1.1
9X	CRR	62,000	72	15.0	64.0	(b)	(b)	-	-
9Y	CRR	58,000	116	21.5	68.5	(b)	(b)	1	8
10X	CRR	54,000	(d)	-	-	(b)	(b)	8	208
		C. Creep-Rupture Properties of C-422 Disk #4 at 1200°F							
6Y	CRR	45,000	0.2	31.5	81.0	(b)	(b)	(b)	-
6Z	SRR	30,000	15	26.0	74.3	(b)	(b)	0.9	4.2
9W	SRR	25,000	53	28.5	77.0	(b)	0.3	8.4	19.6
9Z	SRR	20,000	134	18.0	65.8	(b)	5	25	50

(a) SRR Surface plane radial specimen near rim of disk
CRR Central plane radial specimen near rim of disk
(b) Test specimens reached this deformation on loading
(c) Creep tests in progress
(d) Rupture test in progress

TABLE X

HIGH TEMPERATURE CREEP-RUPTURE PROPERTIES OF C-422 DISK MATERIAL AND BAR STOCK AT 1100°F

Material	Heat Treatment	Stress to Cause Rupture at Indicated Times (psi)				Stress to Cause 1-Percent Total Deformation at Indicated Times (psi)				
		1 Hr	10 Hr	100 Hr	1000 Hr	1 Hr	10 Hr	100 Hr	500 Hr	1000 Hr
Disk #1	N. 1900°F + T. 2 Hrs. at 1200°F. Full anneal 6 Hrs. at 1600°F, N. 1900°F + T. 1200°F for 2 + 2 Hrs.	57,500	47,000	38,750	32,000	44,500	38,750	33,500	30,500	29,000
Bar Stock	N. 1900°F + T. 24 Hrs. at 1200°F	-	-	-	34,000	-	-	36,500	31,000	28,750
Disk #4	O.Q. 1900°F + T. 8 Hrs. at 1200°F. Full anneal 6 Hrs. at 1600°F, O.Q. 1900°F + T. 1200°F for 2 + 2 Hrs.	-	50,500	43,750	35,000	49,500	42,500	36,750	33,000	32,000
Bar Stock	O.Q. 1900°F + T. 4 Hrs. at 1200°F	-	-	-	-	-	-	-	-	30,000



○ = 297-320 Brinell Hardness

◐ = 321-345 " "

Heat Treatment: First treatment - N. 1750°F + 2 Hrs. at 1200°F
Second treatment - N. 1750°F

Figure 1. Brinell Hardness Survey on Center Section (1-2-3) of Disk #1 of 4340 Steel.

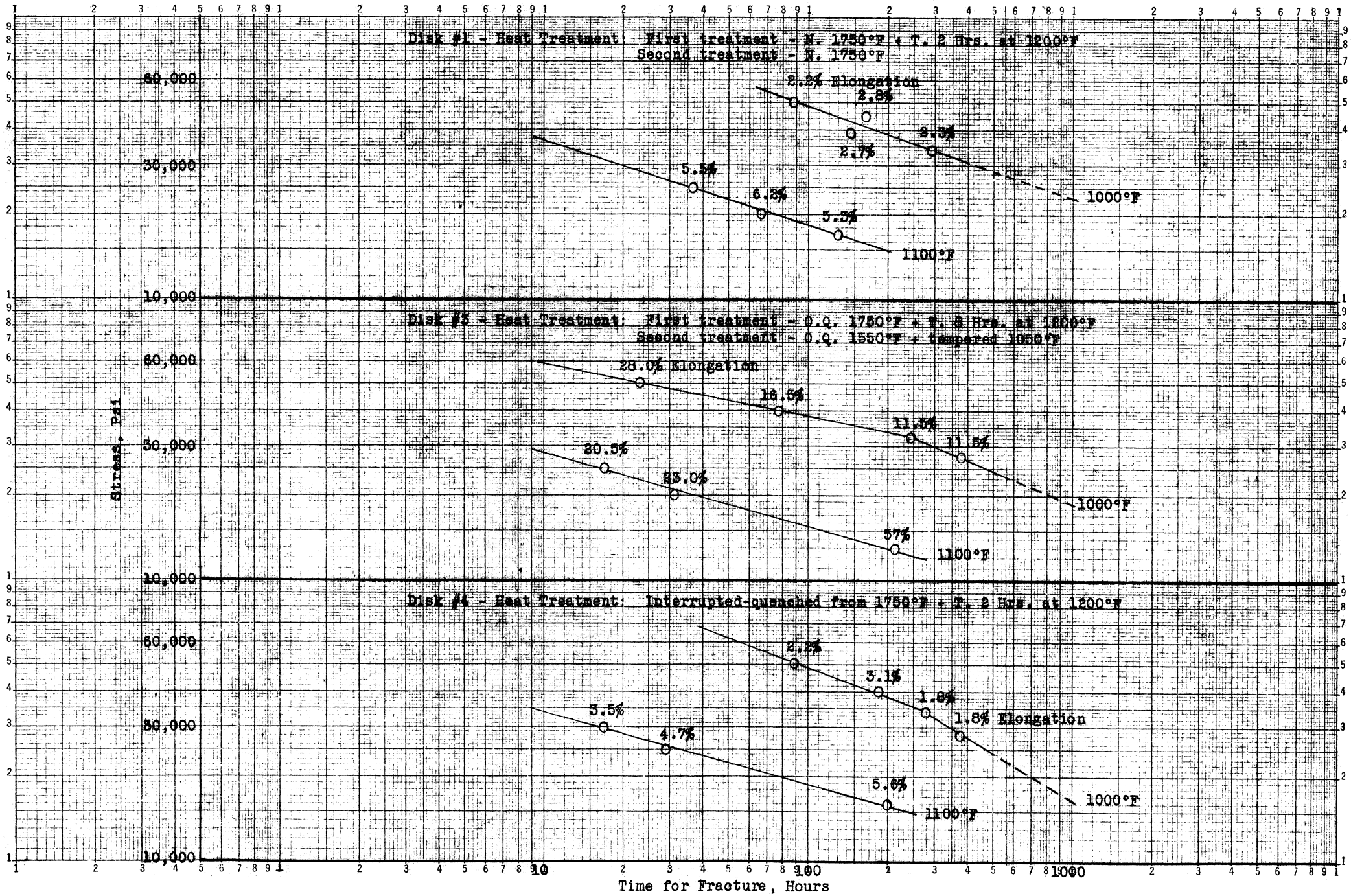


Figure 2. - Stress Versus Time for Fracture at 1000°F and 1100°F for Disks #1, #3, and #4 of 4340 Steel.

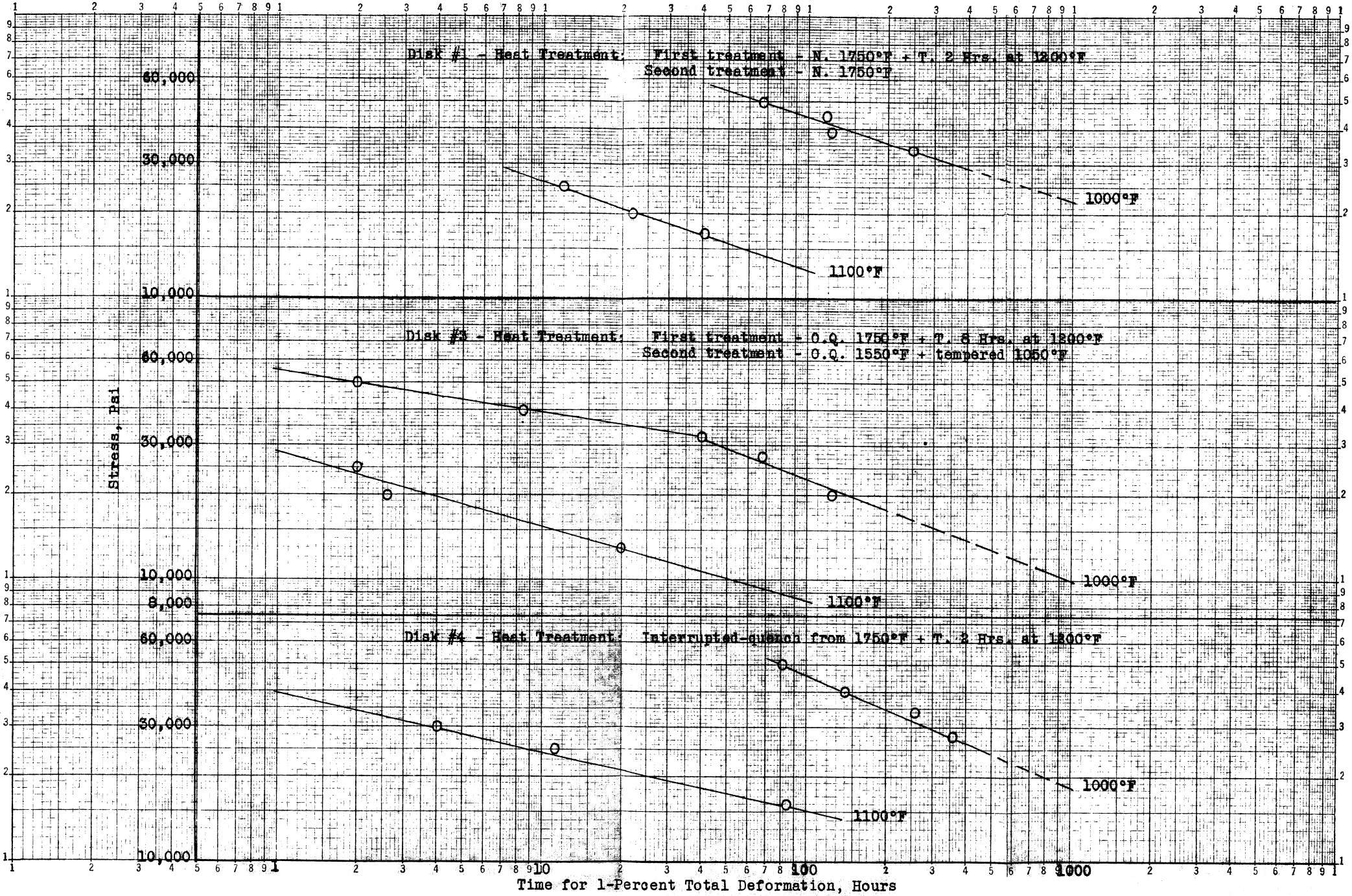


Figure 3. - Stress Versus Time for 1-Percent Total Deformation at 1000°F and 1100°F for Disks #1, #3, and #4 of 4340 Steel.

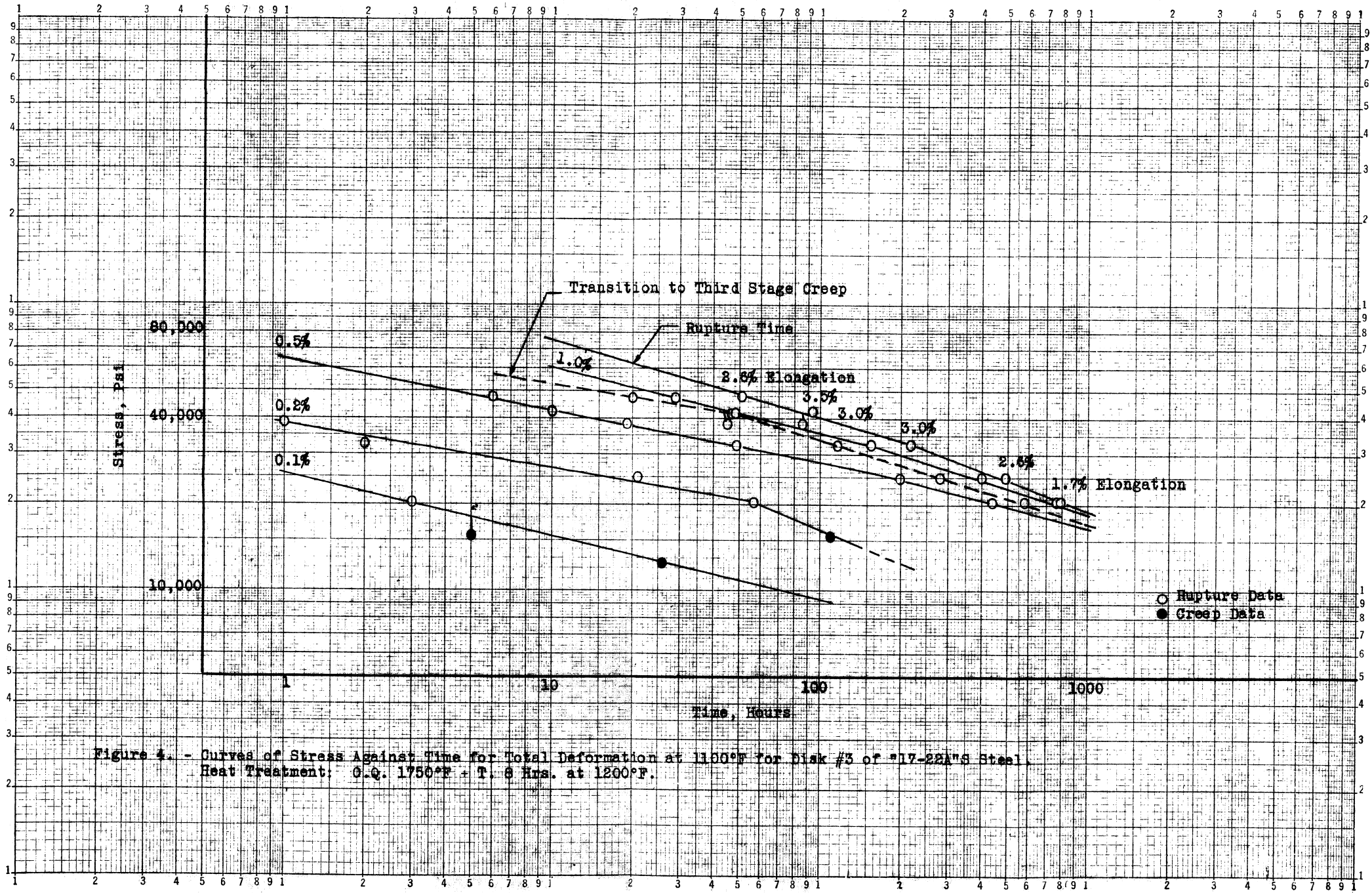


Figure 4. - Curves of Stress Against Time for Total Deformation at 1100°F for Disk #3 of "17-22A"S Steel.
Heat Treatment: O.Q. 1750°F + T. 8 Hrs. at 1200°F.

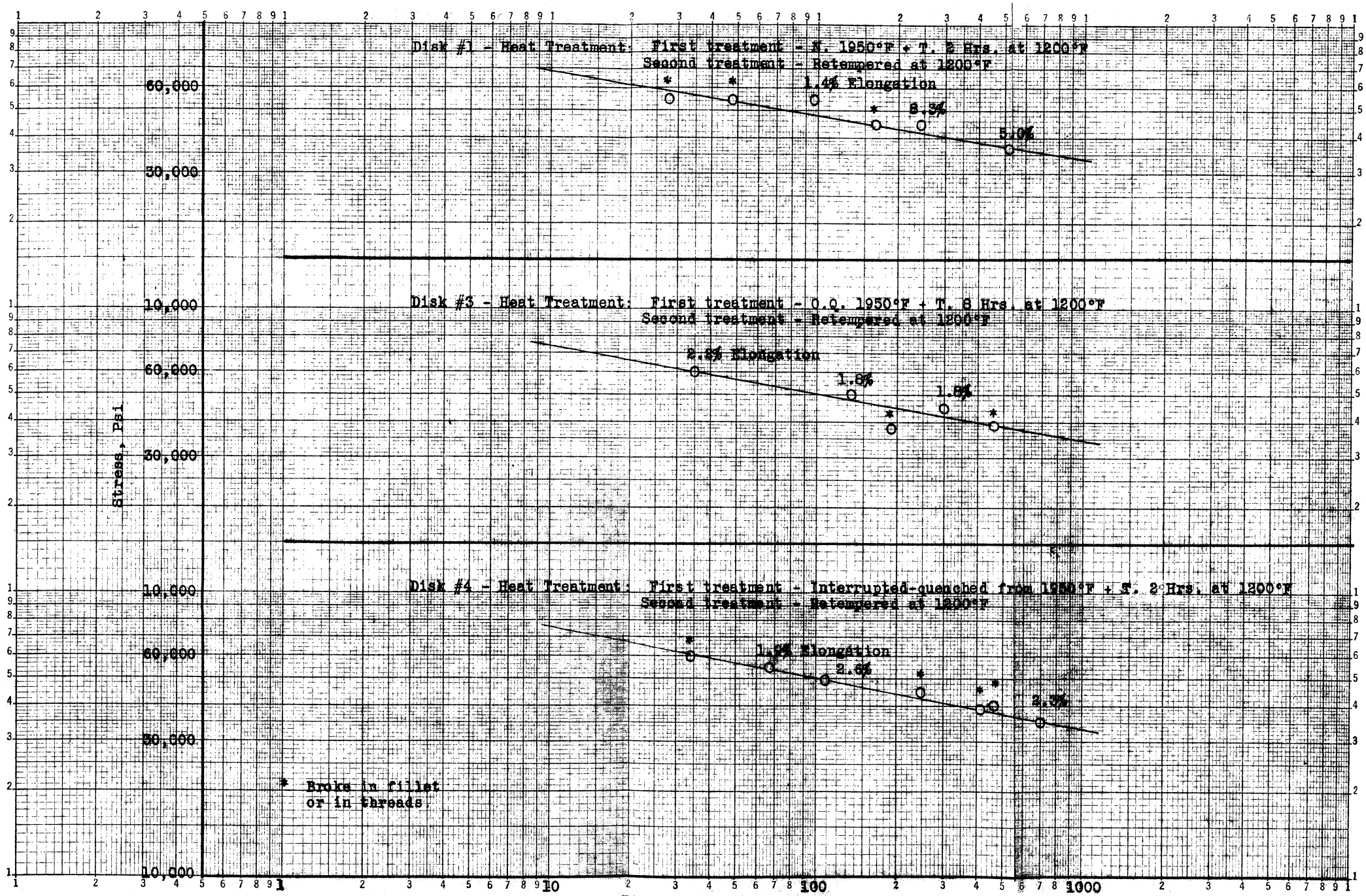
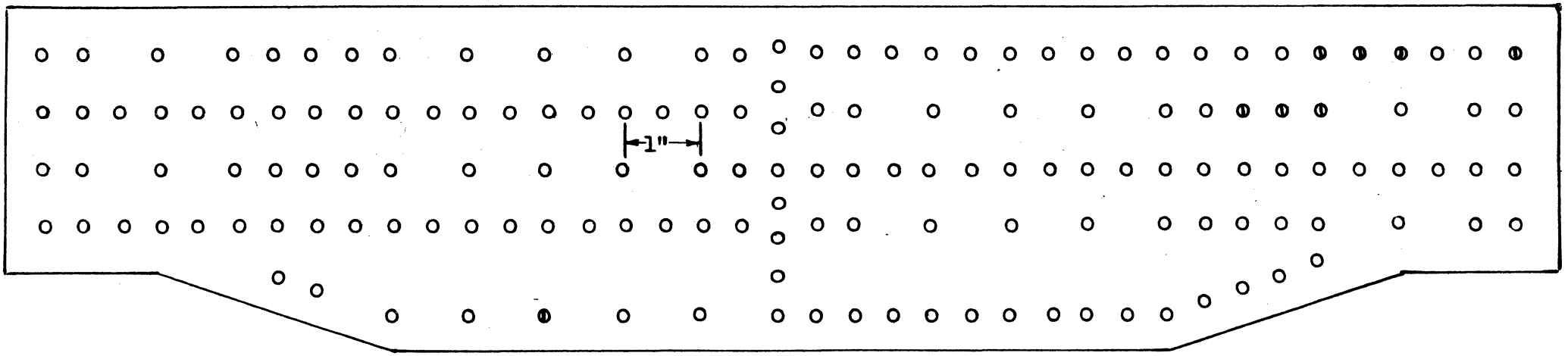


Figure 5. - Stress-Rupture Curves at 1100°F for Disks #1, #3, and #4 of H-40 Steel.

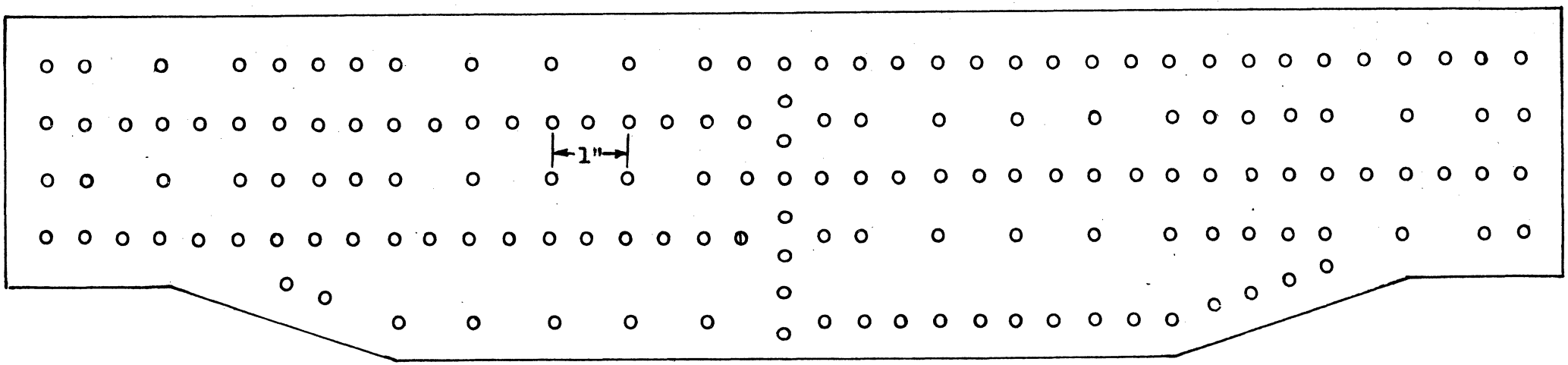


o = 275-320 Brinell Hardness

◐ = 321-352 " "

Heat Treatment: First treatment - O.Q. 1900°F + 8 Hrs. at 1200°F
Second treatment - Full anneal 6 Hrs. at 1600°F, furnace cool.
O.Q. 1900°F + double temper at 1200°F for 2 + 2 Hrs.

Figure 6. - Brinell Hardness Survey on Center Section (1-2-3) of Disk #4 of C-422 Steel.



⊙ = 266 Brinell Hardness

o = 283-323 Brinell Hardness

Heat Treatment: First treatment - N. 1900°F + 2 Hrs. at 1200°F
Second treatment - Full anneal 6 Hrs. at 1600°F, furnace cool.
N. 1900°F + double temper at 1200°F for 2 + 2 Hrs.

Figure 7. - Brinell Hardness Survey on Center Section (1-2-3) of Disk #1 of C-422 Steel.

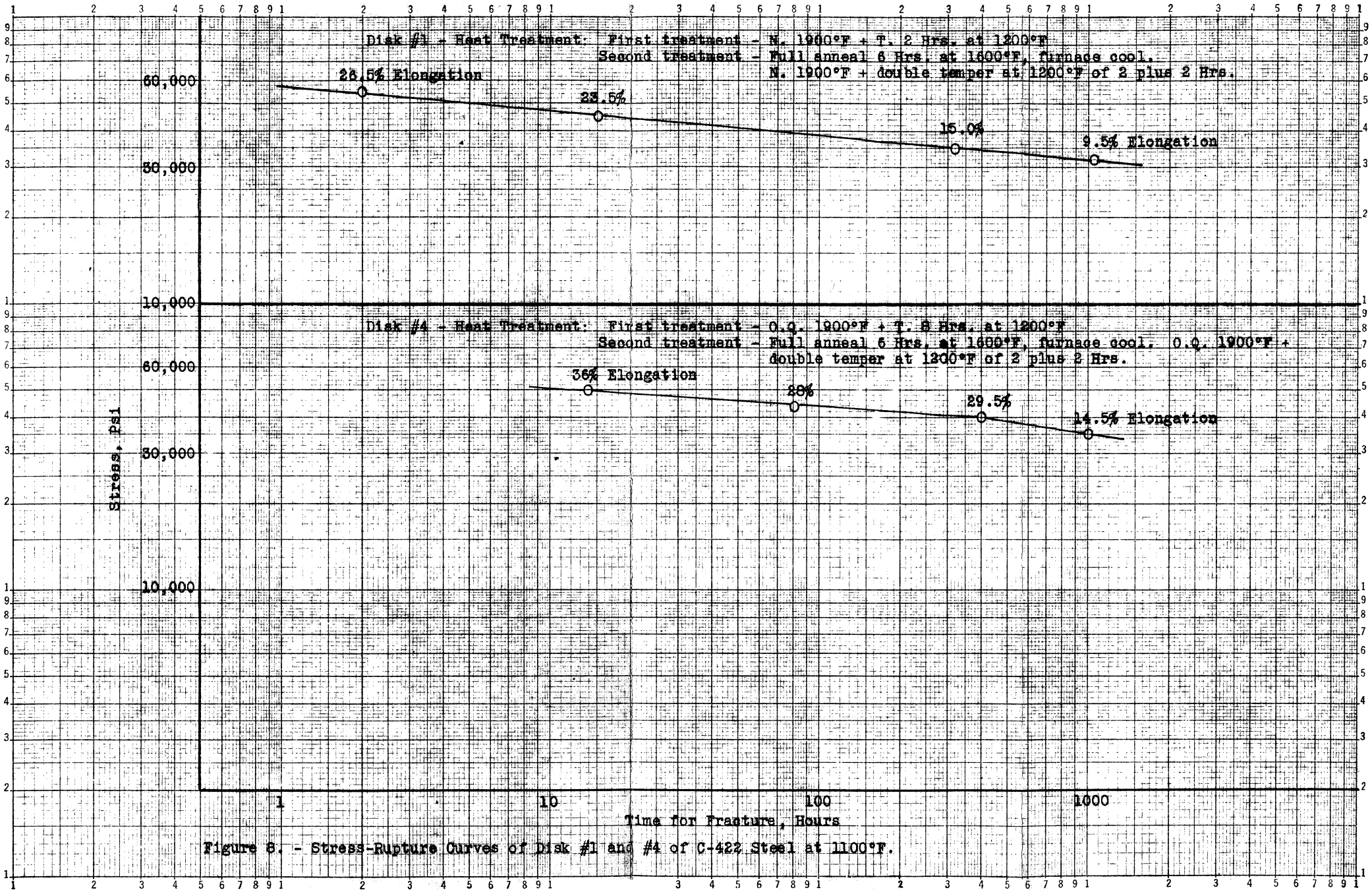


Figure 8. - Stress-Rupture Curves of Disk #1 and #4 of C-422 Steel at 1100°F.

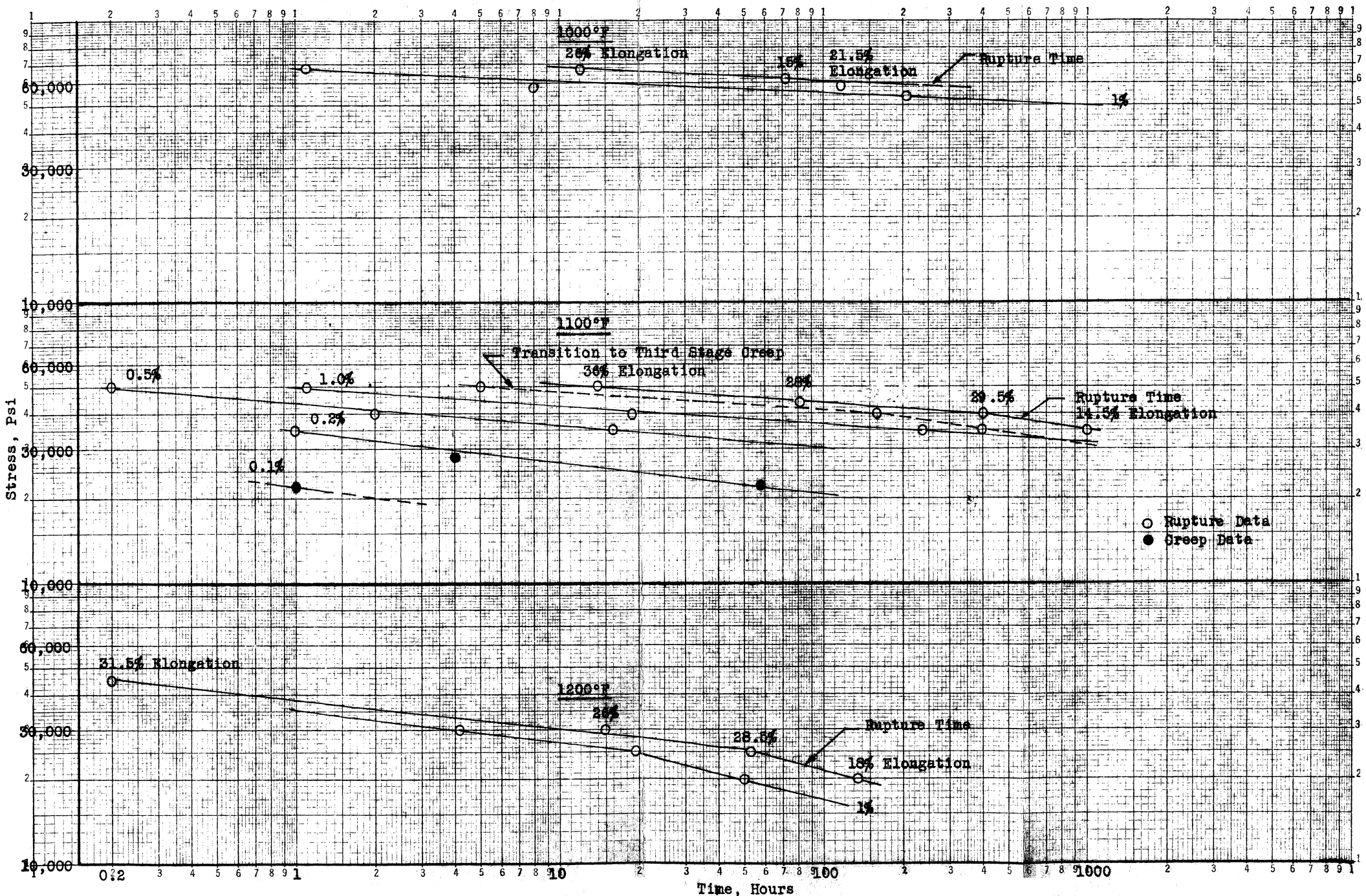


Figure 9. - Curves of Stress Against Time for Total Deformation at 1000°F, 1100°F, and 1200°F for Disk #4 of C-422 Steel. Heat Treatment: First treatment - O.Q. 1900°F + T. 8 Hrs. at 1200°F. Second treatment - Full anneal 6 Hrs. at 1600°F, furnace cool. O.Q. 1900°F + double temper at 1200°F for 2 plus 2 Hrs.