

SIXTH 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

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SUMMARY

This report is the Sixth 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 determine the effect of heat treatment upon 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, and to establish design data for each steel, heat treated to give the best practical properties. A concurrent study of the high temperature properties of the products of isothermal transformation of the four steels is being carried out, utilizing bar stock.

The disks which were selected for determination of design data at 1000°, 1100°, and 1200°F were:

- (a) 4340 - Disk No. 1 (Normalized)
- (b) "17-22A"S - Disk No. 3 (Oil quenched and tempered)
- (c) C-422 - Disk No. 4 (Oil quenched and tempered)

A disk of the H-40 steel has not been selected for further testing at 1000°, 1100°, and 1200°F because all three H-40 disks, in the as-received condition, had high hardness and showed low, erratic ductility values in the rupture test at 1100°F. The Materials Laboratory requested that the disks be retempered to reduce hardness and improve ductility. A survey of the rupture properties of the three disks is to be carried out at 1100°F on the retempered material.

Creep-rupture testing of the 4340, "17-22A"S, and C-422 disks at 1000°, 1100°, and 1200°F has been completed except for one test now in progress on the 4340 material. Included in this testing were check rupture tests run on a tangential specimen and on 0.250-inch diameter specimens taken radially and as near the rim as possible in one case and the center in the other in order to determine the variation in properties. Also, the tensile properties of these disks have been determined at 1000°, 1100°, and 1200°F.

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 investigation.

## INTRODUCTION

This report covers the progress made between 1 April 1952 and 30 June 1952 on an investigation 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.

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 at 1000°, 1100°, and 1200°F for the heat-treated disk showing the best practical 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.

## 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. In each case the data are presented factually without any discussion. Correlation work now in progress will permit proper interpretation of the significance of the data.

### Disk Investigation

#### 4340 STEEL

All creep-rupture testing at 1000°, 1100°, and 1200°F has been completed except for one test now in progress on the normalized disk material. The normalized disk was selected for testing at 1200°F because it exhibited the best practical properties at 1000°F. The rupture data obtained at 1000°, 1100°, and 1200°F for the normalized disk are shown in Table I. Also included are the rupture data obtained at 1000° and 1100°F for the oil-quenched and tempered and interrupted-quench and tempered disks. Figures 1 and 2 show the rupture data and the 1-percent total deformation data obtained at 1000° and 1100°F for the three disks and at 1200°F for the normalized disk.

Table II shows the high temperature strengths of the disks at 1000°, 1100°, and 1200°F and the results obtained in the isothermal transformation study.

The tensile properties of the normalized disk (disk No. 1) at 1000°, 1100°, and 1200°F are shown in Table III. Also included are the average room temperature tensile properties of the normalized material.

Figures 3-6 show a summary of the properties of disk No. 1. Figure 6 also shows the creep rate curves for disks No. 3 and 4 at 1000° and 1100°F.

### "17-22A" S STEEL

The creep-rupture testing of disk No. 3 (oil quenched and tempered) at 1000°, 1100°, and 1200°F has been completed. The data, including the total deformation values, are shown in Table IV and figure 7. The high temperature strengths of disk No. 3 at 1000°, 1100°, and 1200°F are shown in Table V. Also included are the high temperature strengths of disks No. 1 (normalized and tempered) and 4 (interrupted-quench and tempered) at 1100°F, and the results obtained in the isothermal transformation study. Table VI shows the total deformation and creep strengths of "17-22A" S disk No. 3 at 1100°F.

The tensile properties of disk No. 3 have been determined at 1000°, 1100°, and 1200°F and are shown in Table VII. Also included are the average room temperature tensile properties.

Figures 8-11 show a summary of the properties of disk No. 3.

### H-40 STEEL

Because the as-received disks had high hardness and showed low, erratic ductility values in the rupture test at 1100°F, it was decided to retemper material from each disk to a hardness of 300 Brinell and to conduct a survey of the rupture properties of each retempered material at 1100°F.

Material from each disk was retempered for 4 hours at 1250°F with the following resulting hardness values:

<u>Disk No.</u>	<u>Heat Treatment</u>	<u>Brinell Hardness</u>
1	(a) N. 1950°F + T. 2 Hrs. at 1200°F	
	(b) T. at 1200°F	315/380
	(c) T. 4 Hrs. at 1250°F	287/303
3	(a) O. Q. 1950°F + T. 8 Hrs. at 1200°F	
	(b) T. at 1200°F	315/390
	(c) T. 4 Hrs. at 1250°F	295/317

<u>Disk No.</u>	<u>Heat Treatment</u>	<u>Brinell Hardness</u>
4	(a) I. Q. 1950°F + T. 2 Hrs. at 1200°F	
	(b) T. at 1200°F	327/393
	(c) T. 4 Hrs. at 1250°F	287/311

The rupture data obtained to date on the retempered materials are shown in Table VIII.

### C-422 STEEL

The creep-rupture testing of disk No. 4 (oil quenched and tempered) at 1000°, 1100°, and 1200°F has been completed. The data are shown in Table IX and figure 12. The high temperature strengths of C-422 disks No. 1 and 4 are shown in Table X. Also included are data obtained from the isothermal transformation study. Table XI shows the total deformation and creep strengths of C-422 disk No. 4 at 1100°F.

The tensile properties of disk No. 4 have been determined at 1000°, 1100°, and 1200°F and are shown in Table XII. Also included are the average room temperature tensile properties. Figures 13-16 show a summary of the properties of disk No. 4.

### Investigation of the Properties of the Products of Isothermal Transformation

Work on the isothermally transformed bar stock has been confined to examination of the microstructures in conjunction with the microstructures of the disk materials in an attempt to correlate the results of the two investigations.

## FUTURE WORK

The rupture testing of the retempered H-40 materials at 1100°F will be continued in order to determine the properties at the lower hardness levels. The results will be submitted for consideration of the desirability of collecting additional design data at 1000°, 1100°, and 1200°F for the disk with the best properties.

A correlative study of the microstructures of the disk materials and isothermally transformed bar stock materials is now in progress. During the next period correlations involving relative properties of disks and bar stock and the results of the microstructural studies will be developed. It now appears that some additional isothermal work and extension of the test data to include rupture properties of isothermally transformed structures may be desirable.

Attention is directed to the possibility of issuing a factual final report at this time covering the properties of the 4340, "17-22A"S, and C-422 disks. If the Materials Laboratory feels this to be desirable, such a report could be prepared during the next period.

Table I

Rupture Test Data for 4340 Disks at 1000°, 1100° and 1200°F

Spec. No.	Specimen Location (a)	Test Temp. (°F)	Stress (psi)	Rupture Time (hrs.)	Elongation in 2 in. (%)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (hrs.)	Time at Transition to Third Stage Creep (hrs.)	Minimum Creep Rate (%/hour)
10W	SRR	1000	65,000	35	3.5	5.9	13	20	-
4Y	CRR	1000	50,000	88(c)	2.2	1.2	68	63	0.0055
6W	SRR	1000	45,000	163	2.8	1.8	118	95	0.005
4Z	SRR	1000	39,000	146	2.7	1.7	122	98	0.0045
6Y	CRR	1000	34,000	292	2.3	4.0	250	185	0.0025
9Z	SRR	1000	34,000	277	2.2	2.8	213	170	0.0033
7A(b)	SRR	1000	34,000	165(d)	-	-	145(h)	140	0.0045
5A(b)	SRC	1000	34,000	200	4.2	4.0	180	170	0.0037
6Z	SRR	1000	24,000	957	3.3	1.3	683	390	0.00086
14W	STR	1000	24,000	(e)	-	-	-	-	-
9X	CRR	1100	44,000	3.9	6.8	12.0	0.8	-	-
6X	CRR	1100	25,000	37(f)	5.5	7.8	12	5	0.0365
4W	SRR	1100	20,000	67	6.2	7.0	22	17	0.035
4X	CRR	1100	17,000	130	5.3	3.9	41	64	0.0186

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Table I (continued)

Spec. No.	Specimen Location (a)	Test Temp. (°F)	Stress (psi)	Rupture Time (hrs.)	Elongation in 2 in. (%)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (hrs.)	Time at Transition to Third Stage Creep (hrs.)	Minimum Creep Rate (%/hour)
Disk No. 1 (concluded)									
9Y	CRR	1200	20,000	2.5	15.0	19.1	0.25	-	-
10Y	CRR	1200	14,000	12 <sup>(f)</sup>	20.0	14.9	3.3	-	-
10X	CRR	1200	8,000	139	27.5	25.5	14	-	-
10Z	SRR	1200	7,000	157 <sup>(g)</sup>	30.0	-	-	-	-
Disk No. 3. Heat Treatment: First treatment - O.Q. 1750°F + T. 8 Hrs. at 1200°F Second treatment - O.Q. 1550°F + T. at 1050°F									
4Z	SRR	1000	50,000	23	28.0	48.7	2	-	-
6W	SRR	1000	40,000	77	16.5	30.8	8.5	-	-
6X	CRR	1000	32,500	247	11.5	14.5	40	68	0.0194
6Y	CRR	1000	27,500	372	11.5	17.8	68	110	0.0095
6Z	SRR	1000	20,000	604	14.0	26.8	124	120	0.0055
4W	SRR	1100	25,000	17	20.5	39.1	2 <sup>(h)</sup>	-	-
4X	CRR	1100	20,000	31	23.0	34.4	2.6 <sup>(h)</sup>	-	-
4Y	CRR	1100	13,000	212	57.0	41.0	20	73	0.017

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Table I (concluded)

Spec. No.	Specimen Location (a)	Test Temp. (°F)	Stress (psi)	Rupture Time (hrs.)	Elongation in 2 in. (%)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (hrs.)	Time at	
								Transition to Third Stage Creep (hrs.)	Minimum Creep Rate (%/hour)
Disk No. 4. Heat Treatment: Interrupted-quench from 1750°F + T. 2 Hrs. at 1200°F									
4Z	SRR	1000	50,000	88	2.2	3.5	81	63	0.0076
6W	SRR	1000	40,000	185	3.1	3.5	140	120	0.005
6X	CRR	1000	34,000	278	1.8	2.2	256	150	0.0024
6Y	CRR	1000	28,000	377	1.8	2.4	355	210	0.0018
6Z	SRR	1000	19,000	(i)	-	-	1228 <sup>(h)</sup>	960	0.0006
4X	CRR	1100	30,000	17	3.5	5.9	4	-	-
4W	SRR	1100	25,000	29	4.7	8.1	11.2	19	0.066
4Y	CRR	1100	16,000	199	5.6	7.0	84	90	0.011
(a)	SRR	Surface plane radial specimen at rim of disk							
	CRR	Central plane radial specimen at rim of disk							
	SRC	Surface plane radial specimen at center of disk							
	STR	Surface plane tangential specimen at rim of disk							
(b)	0.250-inch diameter specimens								
(c)	Broke in fillet								
(d)	Broke in threads								
(e)	Test in progress								
(f)	Broke in gage mark								
(g)	Badly scaled								
(h)	Extrapolated value								
(i)	Test discontinued at 1150 hours								

Table II

## High Temperature Strengths 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 No. 1	(a) N. 1750°F + T. 2 Hrs. at 1200°F (b) N. 1750°F	1000	-	97,000	48,000	23,500	92,000*	66,000	46,000	26,250	20,500
		1100	71,000	36,000	18,000	-	43,000*	26,000	13,000	-	-
		1200	25,250	14,000	7,800	-	16,500	9,200	3,800	-	-
Bar Stock	N. 1750°F + T. 1 Hr. at 1100°F	1000	-	-	-	-	-	18,500	15,500	13,300	
		1100	-	-	-	-	-	7,400	5,250	4,250	
Disk No. 3	(a) O. Q. 1750°F + T. 8 Hrs. at 1200°F (b) O. Q. 1550°F + T. at 1050°F	1000	-	58,000	38,000	15,500	56,000	39,500	23,000	13,000	10,000
		1100	-	28,000	15,500	-	29,500	15,750	8,400	5,200*	4,400*
Bar Stock	O. Q. 1750°F + T. 10 Hrs. at 1100°F	1000	-	-	-	-	-	-	-	-	11,500
		1100	-	-	-	-	-	-	-	-	< 4,500
Disk No. 4	Int. -quench 1750°F + T. 2 Hrs. at 1200°F	1000	-	90,000	48,000	22,000	-	-	46,250	26,500	21,000
		1100	-	33,750	19,000	-	40,000	25,000	15,500	11,500*	10,000*
Bar Stock	Aust. 1750°F + 28 Hrs. at 850°F (Upper Bainite)	1000	-	-	-	-	-	-	-	20,500	17,300
		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
		1100	-	-	-	-	-	-	-	-	< 4,500

\* Extrapolated value

Table III

## Short Time Tensile Properties of 4340 Disk No. 1

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

Specimen Number	Specimen Location (a)	Test Temp. (°F)	Tensile Strength (psi)	Offset Yield Strengths (psi)			Proportional Limit (psi)	Elongation in 2 in. (%)	Reduction of Area (%)
				0.02%	0.1%	0.2%			
-	RR	Room	163,500	70,750	99,750	115,500	44,500	13.8	42.9
-	RC	Room	154,500	64,000	92,000	106,000	41,750	10.1	24.5
1Y	CRR	1000	99,000	56,500	77,250	86,500	46,000	16.0	48.7
3W	SRR	1000	98,750	65,500	80,250	87,500	48,000	21.0	58.5
14Z	STR	1000	100,000	57,250	77,500	85,750	37,500	16.0	44.8
3X	CRR	1100	71,500	46,750	57,000	64,000	25,000	14.0	35.0
1Z	SRR	1100	64,250	34,000	51,000	57,750	18,500	24.5	56.8
14Y	CTR	1100	72,500	31,000	47,250	58,000	19,500	14.0	26.7
3Z	SRR	1200	38,000	11,750	23,750	29,000	10,000	25.0	41.3
3Y	CRR	1200	38,500	15,500	24,500	31,000	9,000	30.5	37.0
1X	CRR	1200	34,500	15,500	22,750	27,500	8,500	30.5	28.8

(a) RR Radial specimens at rim of disk  
 RC Radial specimens at center of disk  
 CRR Central plane radial specimen at rim of disk  
 SRR Surface plane radial specimen at rim of disk  
 STR Surface plane tangential specimen at rim of disk  
 CTR Central plane tangential specimen at rim of disk

Table IV

Creep-Rupture Properties of "17-22A" S Disk No. 3 at 1000°, 1100°, and 1200°F

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

Spec. No.	Specimen Location (a)	Test Temp. (°F)	Stress (psi)	Time to Fracture (hrs.)	Elongation in 2 in. (%)	Reduction of Area (%)	Time to Reach Specified Total Deformations (hrs.)				Time at Start of Third Stage Creep (hrs.)	Minimum Creep Rate (%/hour)
							0.1%	0.2%	0.5%	1.0%		
7Z	SRR	1000	90,000	1.8	15.0	67.0	(c)	(c)	(c)	0.2	-	-
9Z	SRR	1000	80,000	66	13.1	51.0	(c)	(c)	1	14.5	-	0.030
7W	SRR	1000	70,000	171 <sup>(b)</sup>	5.6	15.4	(c)	(c)	6	60	75	0.009
7Y	CRR	1000	60,000	487	2.5	4.5	(c)	(c)	92	350	270	0.0016
9X	CRR	1100	80,000	0.2	16.0	70.3	(c)	(c)	(c)	-	-	-
4Z	SRR	1100	47,500	51	2.6	5.1	(c)	(c)	6	29	20	0.0172
4X	CRR	1100	42,500	94	3.5	8.2	(c)	(c)	10	47	48	0.0135
4W	SRR	1100	38,500	86 <sup>(b)</sup>	3.0	3.5	(c)	1	19	45	-	0.018
4Y	CRR	1100	32,500	219	3.0	1.6	(c)	2	49	156	116	0.0043
9W	SRR	1100	32,500	165	3.2	3.1	(c)	2	44	97	74	0.0065
7A <sup>(d)</sup>	SRR	1100	32,500	171	3.0	3.2	(c)	(c)	29	98	94	0.0068
5A <sup>(d)</sup>	SRC	1100	32,500	244	3.2	4.7	(c)	(c)	5	82	140	0.0057
6W	SRR	1100	25,000	489	2.6	3.2	(c)	21	199	402	280	0.0015
6X	CRR	1100	20,500	792	1.7	2.8	3	57	441	774	575	0.0008
14Z	STR	1100	19,500	1112	3.6	2.8	1.5	48	374	728	380	0.0009
6Y <sup>(e)</sup>	CRR	1100	15,500	off 1120	-	-	5	109	396	2460 <sup>(f)</sup>	-	0.00032
6Z <sup>(e)</sup>	SRR	1100	12,500	off 1120	-	-	26	227	1210 <sup>(f)</sup>	-	-	0.00032
9Y <sup>(e)</sup>	CRR	1100	7,000	off 1085	-	-	630	1805 <sup>(f)</sup>	-	-	-	0.00009
10W	SRR	1200	35,500	5.2	7.0	8.5	(c)	(c)	0.4	1.9	2	-
10Y	CRR	1200	32,000	6.2	5.5	4.8	(c)	(c)	1	3	3	-
10X	CRR	1200	22,000	33	3.0	6.2	(c)	2	7	16	-	-
10Z	SRR	1200	16,000	73	1.4	4.3	(c)	3	19	38	19	0.016

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

(b) Broke in gage mark

(c) Specimen reached this deformation on loading

(d) 0.250-inch diameter specimen

(e) Creep test

(f) Extrapolated value

Table V

## High Temperature Strengths of "17-22A" S Bar Stock and "17-22A" S Disk Materials

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 No. 1	N. 1730°F + T. 2 Hrs. at 1200°F	1100	-	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	1100	-	-	19,500*	-	-	-	24,000	20,500	19,000	
Disk No. 3	O. Q. 1750°F + T. 8 Hrs. at 1200°F	1000	92,500	85,000	75,000	54,000	87,000	80,500	67,500	58,000	54,000	
		1100	69,000	54,000	41,000	19,500	64,000	51,000	34,500	23,000	19,000	
		1200	50,000	29,000	14,500	-	41,000	24,250	11,500	-	-	
Bar Stock	O. Q. 1750°F + T. 1 Hr. at 1300°F	1100	-	-	-	18,000*	-	-	24,500*	18,250	15,000	
Disk No. 4	I. Q. 1750°F + T. 2 Hrs. at 1200°F	1100	-	69,000	41,500	21,750	-	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)	1100	-	-	-	-	-	-	21,500*	17,500	15,500	
Bar Stock	Aust. 1750°F + 2 Hrs. at 900°F + T. 16 Hrs. at 1200°F (Upper Bainite)	1100	-	-	-	18,000*	-	-	24,750*	17,500	14,000	

\* Estimated values

Table VI

Time-Deformation and Creep Strengths at 1100°F for "17-22A" S Disk No. 3

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

Total Deformation (%)	Stress to Cause Total Deformations at Indicated Times (psi)					Creep Strength (psi)	
	1 hr	10 hr	100 hr	500 hr	1000 hr	0.0001%/hour	0.001%/hour
0.1	22,500	14,750	9,800	7,300	6,500	7,200	21,750
0.2	37,750	27,000	16,000	10,000	8,200		
0.5	59,000	41,500	29,000	18,500	15,000		
1.0	64,000	51,000	34,500	23,000	19,000		
Transition	-	56,000	31,500	21,500	18,000		
Rupture	69,000	54,000	41,000	24,500	19,500		

Table VII

## Short Time Tensile Properties of "17-22A" S Disk No. 3

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

Specimen Number	Specimen Location (a)	Test Temp. (°F)	Tensile Strength (psi)	Offset Yield Strengths (psi)		Proportional Limit (psi)	Elongation in 2 in. (%)	Reduction of Area (%)	
				0.02%	0.1%				0.2%
-	RR	Room	148,000	123,250	131,250	133,500	93,500	17.2	53.6
-	RC	Room	145,250	120,500	126,000	128,500	104,500	13.9	35.1
14X	CTR	1000	97,500	65,000	83,000	90,000	38,500	21.5	71.0
3W	SRR	1000	96,250	64,500	83,250	89,000	45,500	23.0	73.0
3X	CRR	1000	96,500	72,500	84,750	90,000	50,000	26.0	72.5
14Y	CTR	1100	83,500	49,500	68,250	76,000	24,500	27.0	72.5
1Z	SRR	1100	90,500	48,500	65,250	72,000	29,000	29.5	71.6
1Y	CRR	1100	83,200	46,000	67,000	74,250	25,000	23.5	73.5
3Y	CRR	1200	62,500	32,000	46,750	54,000	16,000	24.0	44.8
3Z	SRR	1200	63,000	28,500	44,500	51,000	12,500	22.5	48.3
14W	STR	1200	62,500	33,500	44,000	54,000	19,000	22.0	41.6

(a) RR Radial specimens at rim of disk

RC Radial specimens at center of disk

CTR Central plane tangential specimen at rim of disk

SRR Surface plane radial specimen at rim of disk

CRR Central plane radial specimen at rim of disk

STR Surface plane tangential specimen at rim of disk



Table VIII

## Rupture Data for Retempered H-40 Disk Material at 1100°F

Specimen Number	Specimen Location (a)	Stress (psi)	Rupture Time (hrs.)	Elongation in 2 in. (%)	Reduction of Area (%)	Time to Reach 1-Percent Total Deformation (hrs.)
Disk No. 1. Heat Treatment: First treatment - N, 1950°F + T. 2 Hrs. at 1200°F Second treatment - T. at 1200°F Third treatment - T. 4 Hrs. at 1250°F						
9W	SRR	60,000	2.7	10.5	37.4	0.5
9X	CRR	50,000	43 <sup>(b)</sup>	3.0	7.8	10.7
9Y	CRR	45,000	81	2.7	6.2	53
Disk No. 3. Heat Treatment: First treatment - O. Q. 1950°F + T. 8 Hrs. at 1200°F Second treatment - T. at 1200°F Third treatment - T. 4 Hrs. at 1250°F						
9W	SRR	60,000	10	17.0	50.0	1.4
9Y	CRR	50,000	80	8.0	22.0	23
Disk No. 4. Heat Treatment: First treatment - I. Q. 1950°F + T. 2 Hrs. at 1200°F Second treatment - T. at 1200°F Third treatment - T. 4 Hrs. at 1250°F						
9W	SRR	60,000	2.9	10.5	40.2	0.8
9X	CRR	50,000	70	4.5	8.2	26

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(a) SRR Surface plane radial specimen at rim

CRR Central plane radial specimen at rim

(b) Broke in gage mark

Table IX

## Creep-Rupture Properties of C-422 Disk No. 4 at 1000°, 1100°, and 1200°F

Heat Treatment: First Treatment - O. Q 1900°F + T. 8 Hrs. at 1200°F

Second Treatment - Full anneal 6 Hrs. at 1600°F. O. Q 1900°F + T. at 1200°F for 2 + 2 Hrs.

Spec. No.	Specimen Location (a)	Test Temp. (°F)	Stress (psi)	Time to Fracture (hrs.)	Elongation in 2. in. (%)	Reduction of Area (%)	Time to Reach Indicated Total Deformations (hrs.)				Time at Start of Third Stage Creep (hrs.)	Minimum Creep Rate (%/hour)
							0.1%	0.2%	0.5%	1.0%		
9W	SRR	1000	67,500	12	26.0	70.4	(c)	(c)	0.2	1.1	3.8	-
9X	CRR	1000	62,000	72	15.0	64.0	(c)	(c)	0.5	3	40	-
9Y	CRR	1000	58,000	116	21.5	68.5	(c)	(c)	1	8	-	0.0342
10X	CRR	1000	54,000	off 1150 <sup>(b)</sup>	-	-	(c)	(c)	8	208	-	0.00079
4W	SRR	1100	50,000	14	36.0	80.5	(c)	(c)	0.2	1.1	5	-
4Z	SRR	1100	44,000	81	28.0	77.0	-	-	-	-	-	-
4X	CRR	1100	40,000	399	29.5	69.3	(c)	(c)	2	19	160	0.0055
10Z	SRR	1100	40,000	119	33.8	72.8	(c)	(c)	2.5	16	-	-
7A <sup>(d)</sup>	SRR	1100	40,000	175	27.0	69.5	(c)	(c)	5	15	-	-
5A <sup>(d)</sup>	SRC	1100	40,000	258	20.2	57.0	(c)	(c)	5	23	-	-
4Y	CRR	1100	35,000	1001	14.5	56.9	(c)	0.5	16	234	394	0.0015
14Z	STR	1100	35,000	730	14.5	57.9	(c)	0.5	17	199	448	0.0024
10W <sup>(e)</sup>	SRR	1100	28,000	off 1120	-	-	(c)	4	318	1790 <sup>(f)</sup>	-	0.00033
6X <sup>(e)</sup>	CRR	1100	22,000	off 1104	-	-	1	58	2300 <sup>(f)</sup>	-	-	0.0001
10Y <sup>(e)</sup>	CRR	1100	13,000	off 1085	-	-	40	1090	-	-	-	0.00007
6Y	CRR	1200	45,000	0.2	31.5	81.0	(c)	(c)	(c)	-	-	-
6Z	SRR	1200	30,000	15	26.0	74.3	(c)	(c)	0.9	4.2	6	-
6W	SRR	1200	25,000	53	28.5	77.0	(c)	0.3	8.4	19.6	-	-
9Z	SRR	1200	20,000	134	18.0	65.8	(c)	0.5	25	50	40	0.0146

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

(b) Test discontinued at this time

(c) Specimen reached this deformation on loading

(d) 0.250-inch diameter specimen

(e) Creep test

(f) Extrapolated value

Table X

## High Temperature Strengths of C-422 Bar Stock and C-422 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 No. 1	(a) N. 1900°F + T. 2 Hrs. at 1200°F. (b) Full anneal 6 Hrs. at 1600°F. N. 1900°F + T. at 1200°F for 2 + 2 Hrs.	1100	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	1100	-	-	-	34,000	-	-	36,500	31,000	28,750
Disk No. 4	(a) O. Q. 1900°F + T. 8 Hrs. at 1200°F. (b) Full anneal 6 Hrs. at 1600°F. O. Q. 1900°F + T. at 1200°F for 2 + 2 Hrs.	1000	72,500*	66,500	61,000	55,500	67,000	60,000	54,000	51,000	49,000
		1100	61,500*	51,000	43,000	35,500	50,500	42,000	35,500	31,750	30,000
		1200	37,500	30,250	21,500	-	35,500	27,000	17,500	-	-
Bar Stock	O. Q. 1900°F + T. 4 Hrs. at 1200°F	1100	-	-	-	-	-	-	-	-	30,000

\* Estimated values

Table XI

## Time-Deformation and Creep Strengths at 1100°F for C-422 Disk No. 4

Heat Treatment: First treatment - O.Q. 1900°F + T. 8 Hrs. at 1200°F

Second treatment - Full Anneal 6 Hrs. at 1600°F. O.Q. 1900°F + T. at 1200°F for 2 + 2 Hrs.

Total Deformation (%)	Stress to Cause Total Deformations at Indicated Times (psi)						Creep Strength (psi)	
	1 hr	10 hr	100 hr	500 hr	1000 hr	0.0001%/hour	0.001%/hour	
0.1	22,000	16,000	11,500	-	-	22,000	32,000	
0.2	32,250	26,000	20,250	15,000	13,250			
0.5	44,000	36,500	30,250	26,500	24,750			
1.0	50,500	42,000	35,500	31,750	30,000			
Transition	57,000	47,500	39,500	35,000	33,000			
Rupture	61,500*	51,000	43,000	38,000	35,500			

\* Extrapolated value

Table XII

## Short Time Tensile Properties of C-422 Disk No. 4

Heat Treatment: First treatment - O. Q. 1900°F + T. 8 Hrs. at 1200°F  
 Second treatment - Full Anneal 6 Hrs. at 1600°F. O. Q. 1900°F + T. at 1200°F for 2 + 2 Hrs.

Specimen Number	Specimen Location (a)	Test Temp. (°F)	Tensile Strength (psi)	Offset Yield Strengths (psi)		Proportional Limit (psi)	Elongation in 2 in. (%)	Reduction of Area (%)	
				0.02%	0.1%				
-	RR	Room	141,250	97,500	108,000	112,750	82,750	16.2	39.0
-	RC	Room	133,000	90,250	101,500	106,250	71,500	11.1	23.5
14Y	CTR	1000	83,500	54,500	70,250	75,500	38,500	30.0	70.0
1Y	CRR	1000	84,000	55,500	69,250	74,000	36,000	29.0	66.7
3W	SRR	1000	78,000	52,500	65,750	70,750	38,000	34.5	78.8
1Z	SRR	1100	66,250	45,500	55,500	60,250	35,500	37.0	79.8
14W	STR	1100	64,500	42,500	53,250	58,250	30,500	39.0	81.4
3Y	CRR	1100	67,000	37,500	54,500	60,000	22,000	31.5	76.8
3X	CRR	1200	49,500	28,500	39,250	43,750	13,500	40.5	86.8
14X	CTR	1200	48,500	28,000	36,250	41,500	19,500	39.0	83.8
3Z	SRR	1200	50,000	26,250	39,250	44,250	15,500	45.5	87.5

(a) RR Radial specimens at rim of disk  
 RC Radial specimens at center of disk  
 CTR Central plane tangential specimen at rim of disk  
 CRR Central plane radial specimen at rim of disk  
 SRR Surface plane radial specimen at rim of disk  
 STR Surface plane tangential specimen at rim of disk

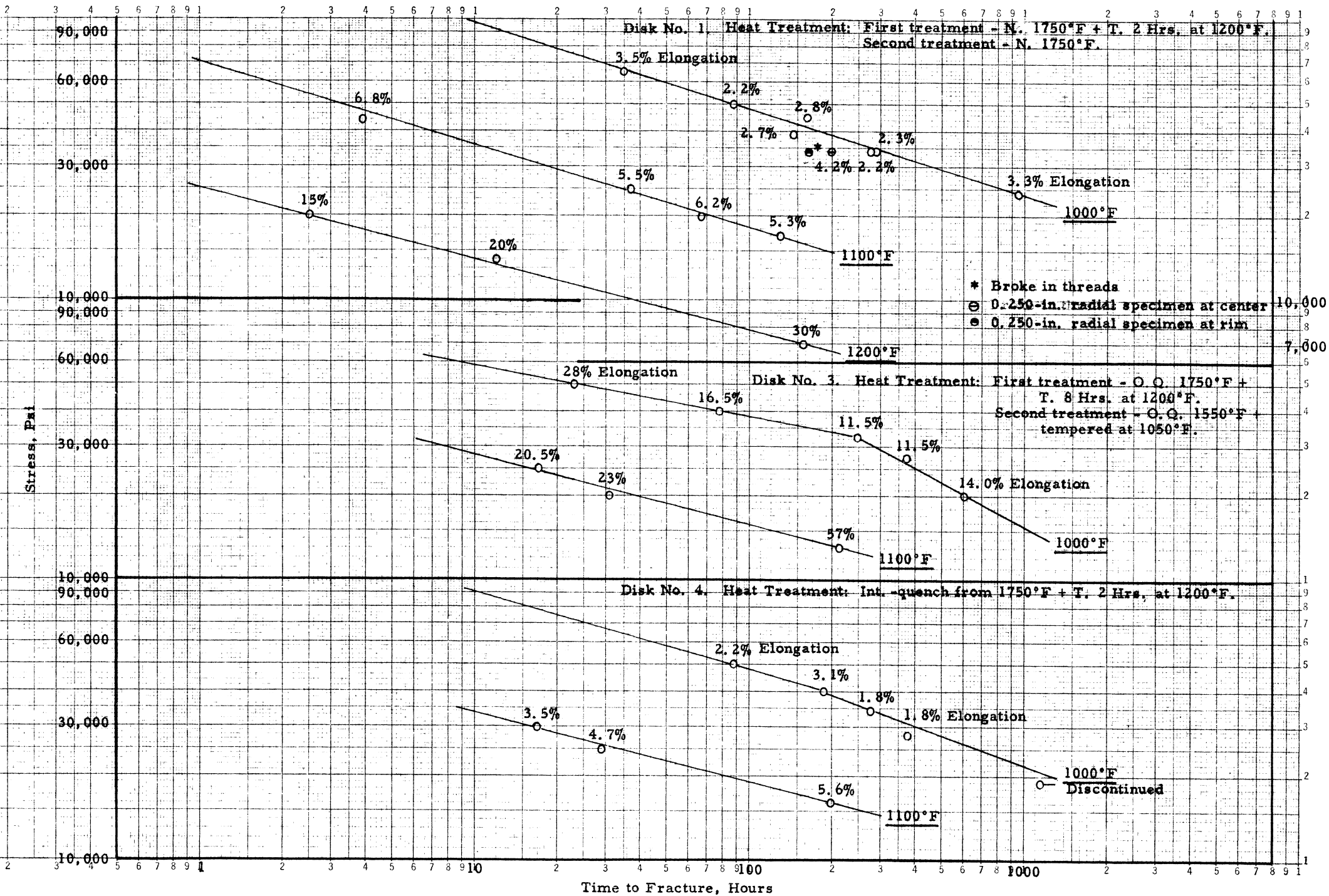


Figure 1. Stress Versus Time to Fracture at 1000°F and 1100°F for 4340 Disks Nos. 1, 3, and 4, and at 1200°F for 4340 Disk No. 1.

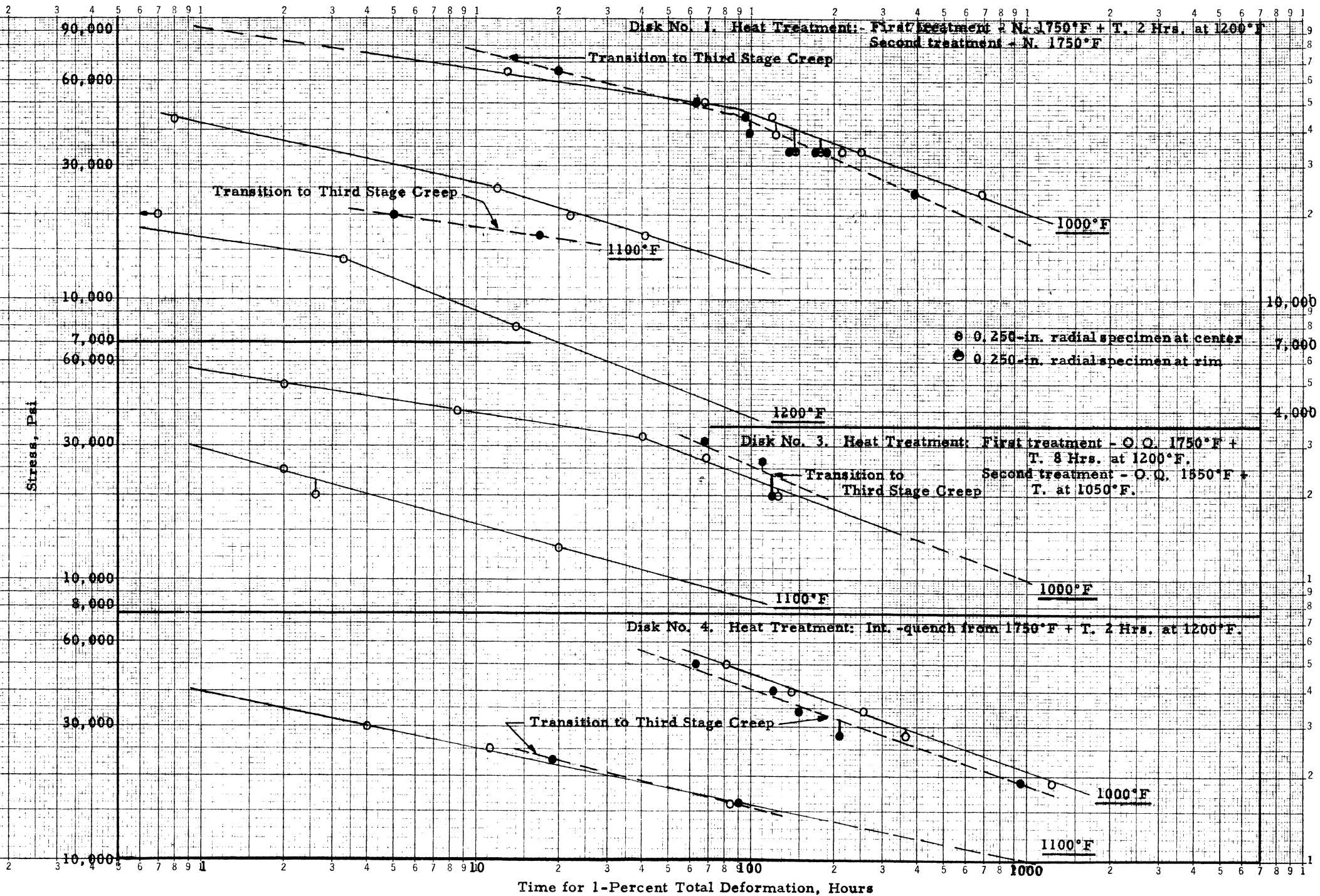


Figure 2. Stress Versus Time for 1-Percent Total Deformation at 1000°F and 1100°F for 4340 Disks Nos. 1, 3, and 4, and at 1200°F for 4340 Disk No. 1.

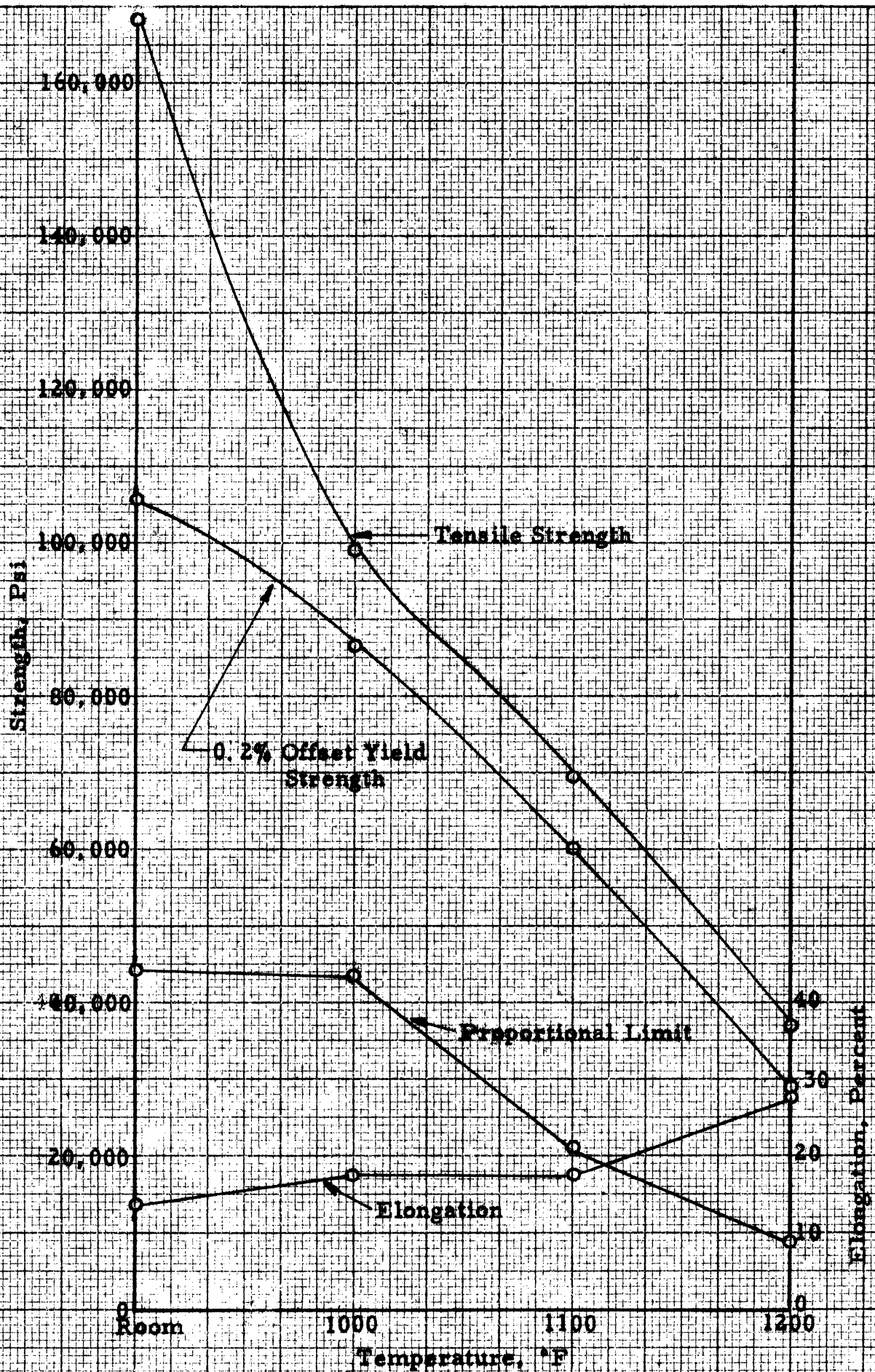


Figure 3. Summary of the Short Time Tensile Properties of 4340 Disk No. 1. Heat Treatment: First treatment - N. 1750°F + T. 2 Hrs. at 1200°F. Second treatment - N. 1750°F.



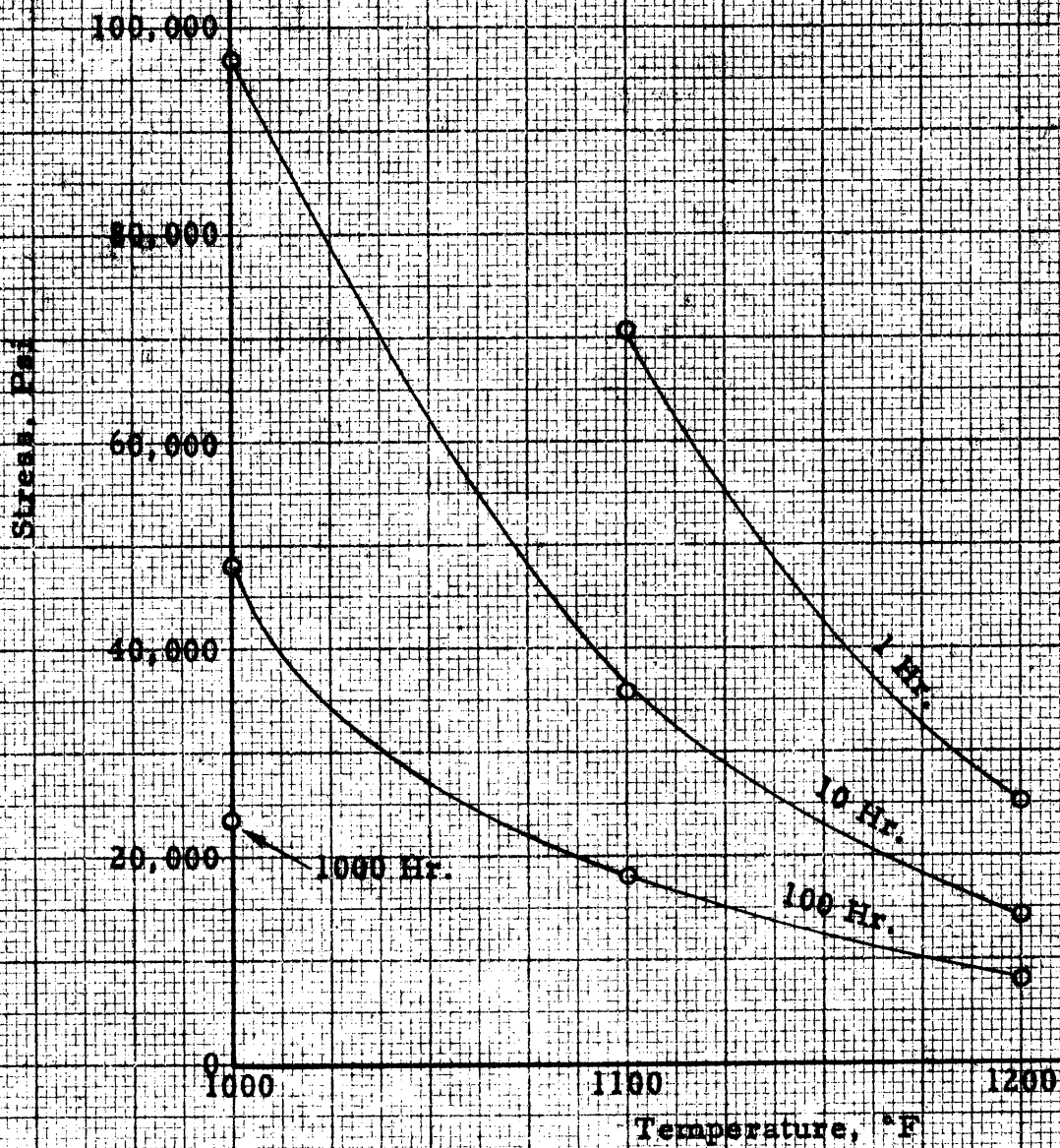


Figure 4. Summary of the Rupture Strengths of 4340 Disk No. 1.  
 Heat Treatment: First treatment - N. 1750°F + T. 2 Hrs.  
 at 1200°F. Second treatment - N. 1750°F.

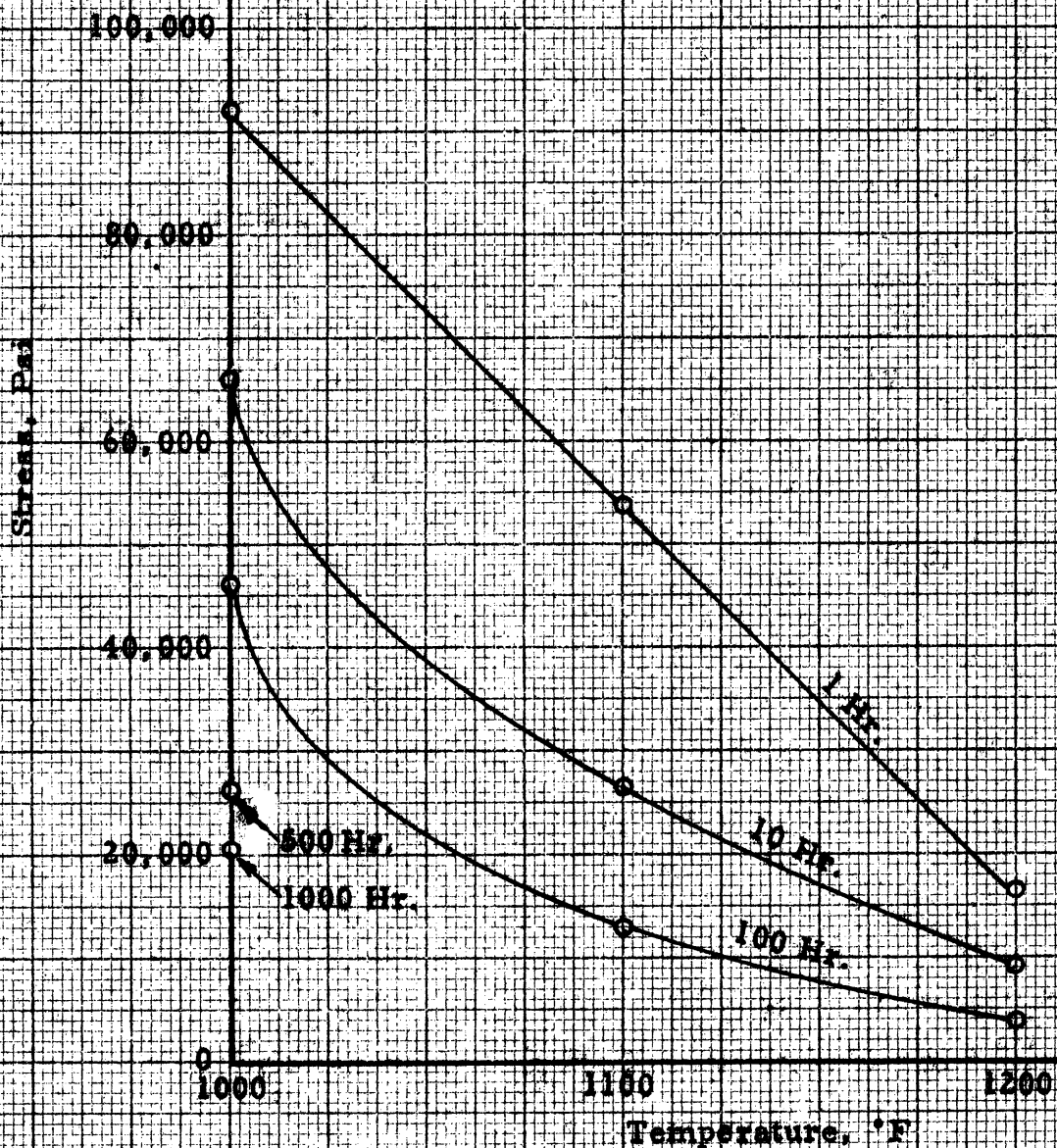


Figure 5. Summary of the 1-Percent Total Deformation Strengths of 4340 Disk No. 1. Heat Treatment: First treatment - N. 1750°F + T. 2 Hrs. at 1200°F. Second treatment - N. 1750°F.

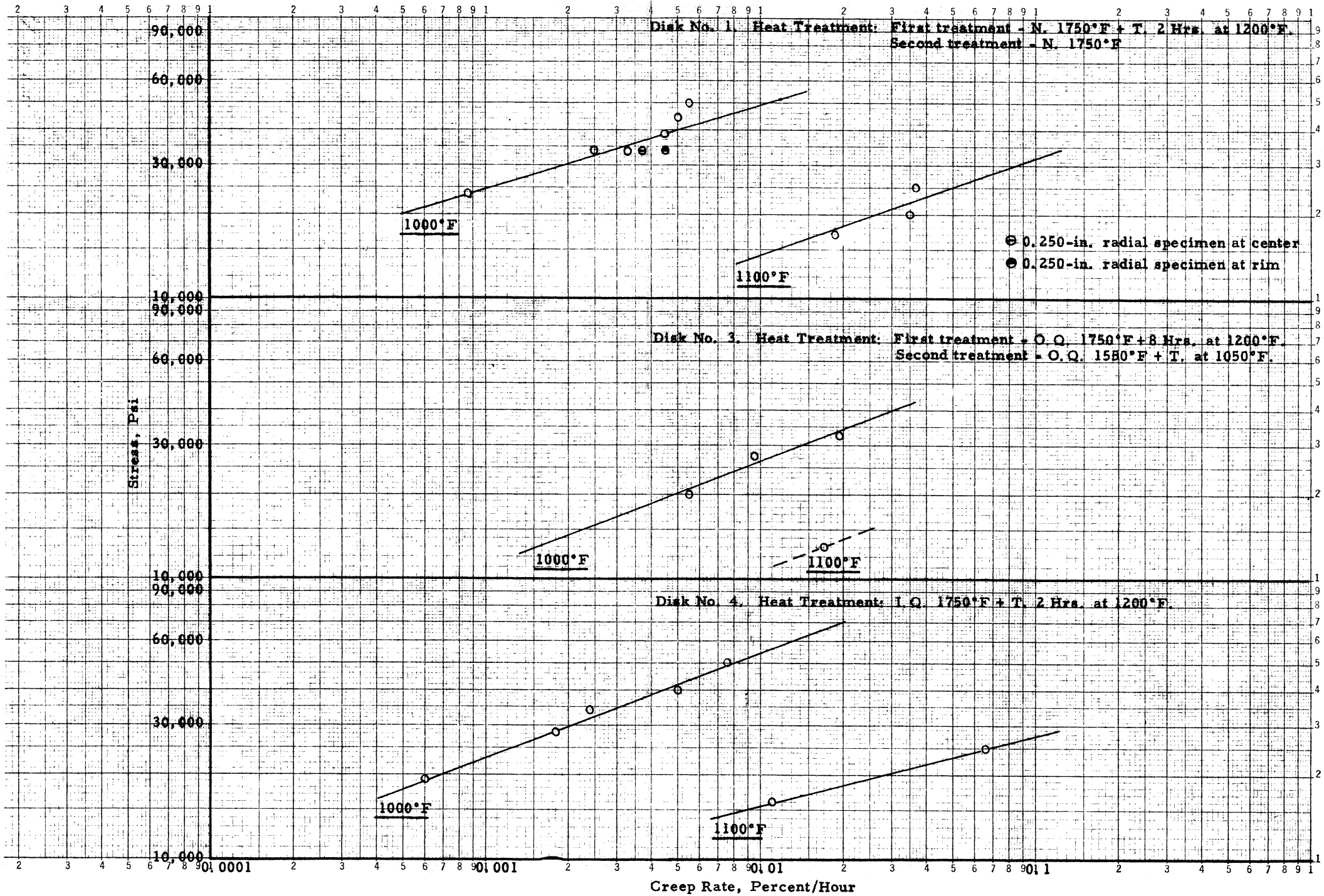


Figure 6. Stress Versus Creep Rate for 4340 Disks Nos. 1, 3, and 4 at 1000°F and 1100°F.

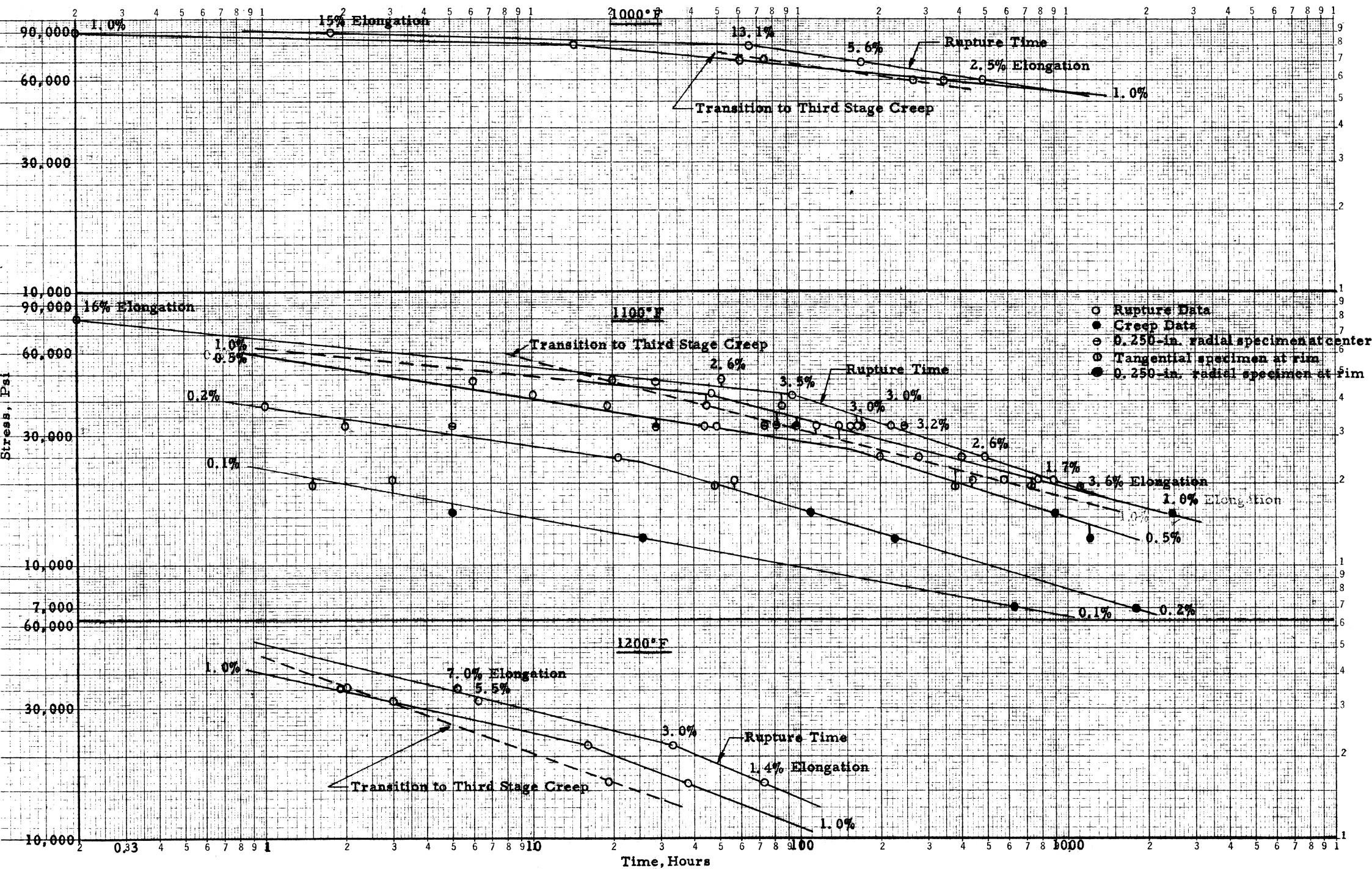


Figure 7. Curves of Stress Against Time for Indicated Total Deformations at 1000°, 1100°, and 1200°F for "17-22A" S Disk No. 3. Heat Treatment: O. Q. 1750°F + 8 Hrs. at 1200°F.

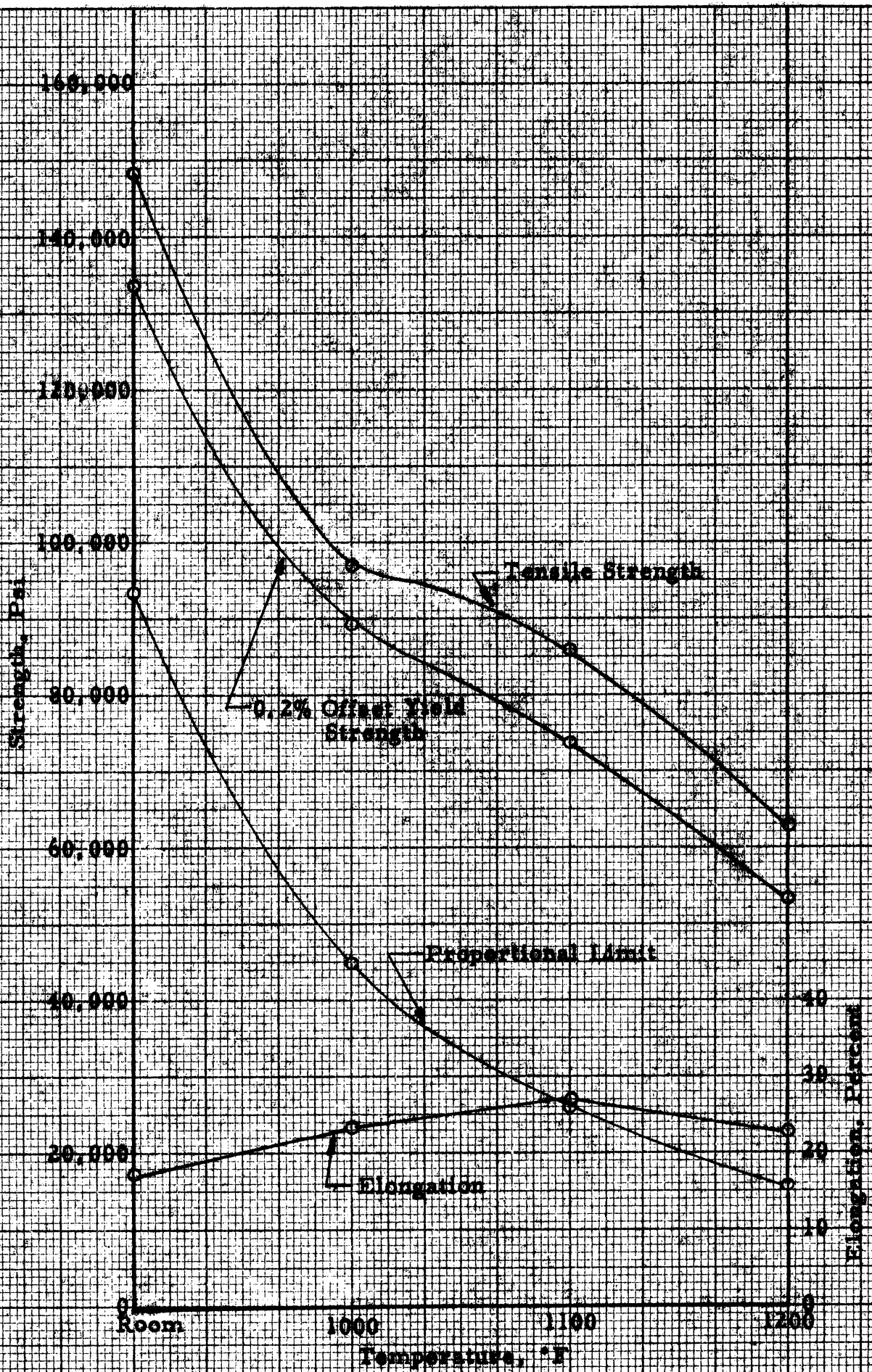


Figure 8. Summary of the Short Time Tensile Properties of n17-22A(S) Disk No. 3, Heat Treatment: O. Q. 1750°F x 1.5 hrs. at 1200°F.

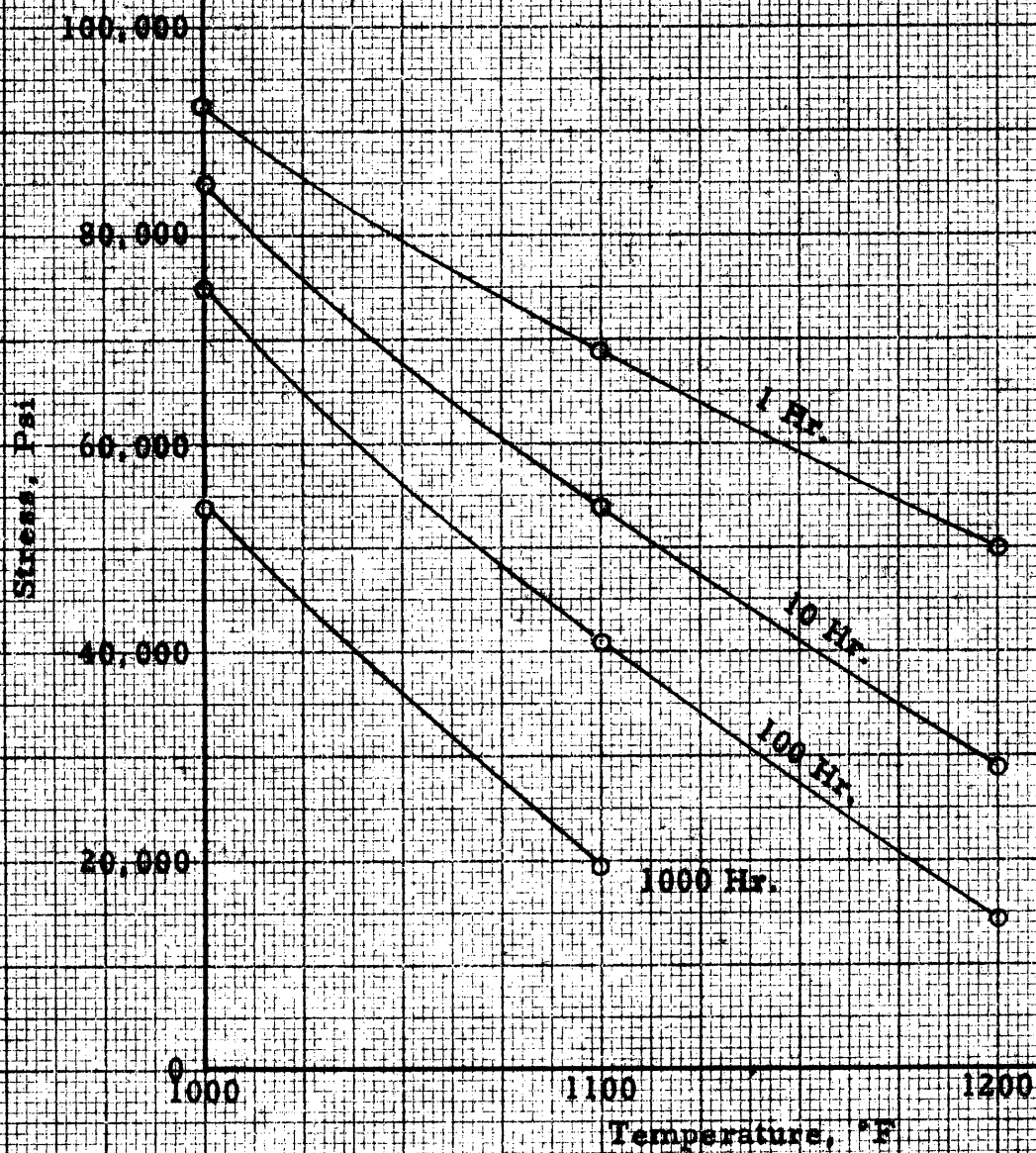


Figure 9. Summary of the Rupture Strengths of 17-22A15 Disk No. 3. Heat Treatment: O. Q. 1750°F + T. 8 Hrs. at 1200°F.

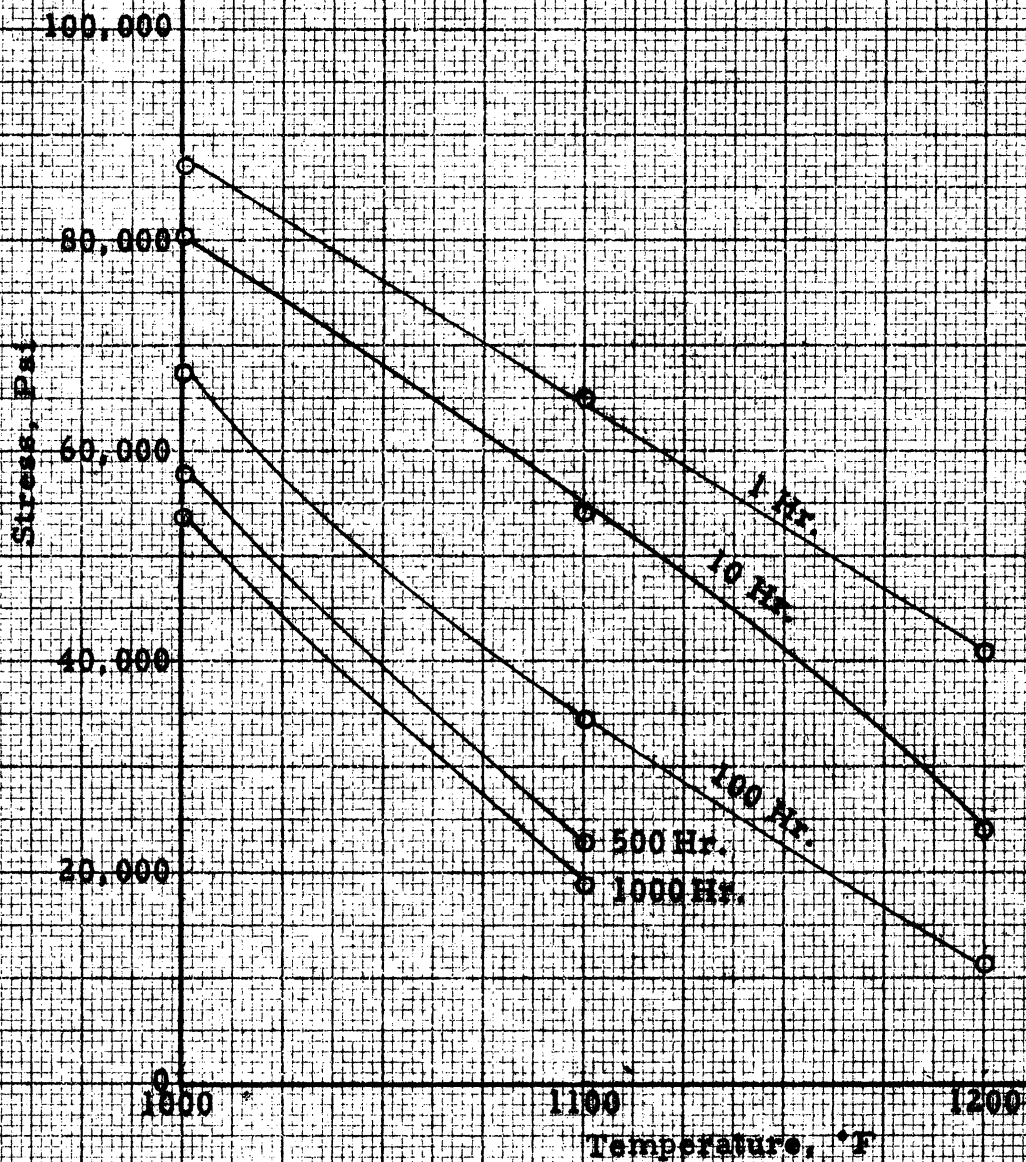


Figure 10. Summary of 1-Percent Total Deformation Strengths of 17-22A's Disk No. 3. Heat Treatment: O. Q. 1750°F + T. 8 Hrs. at 1200°F.

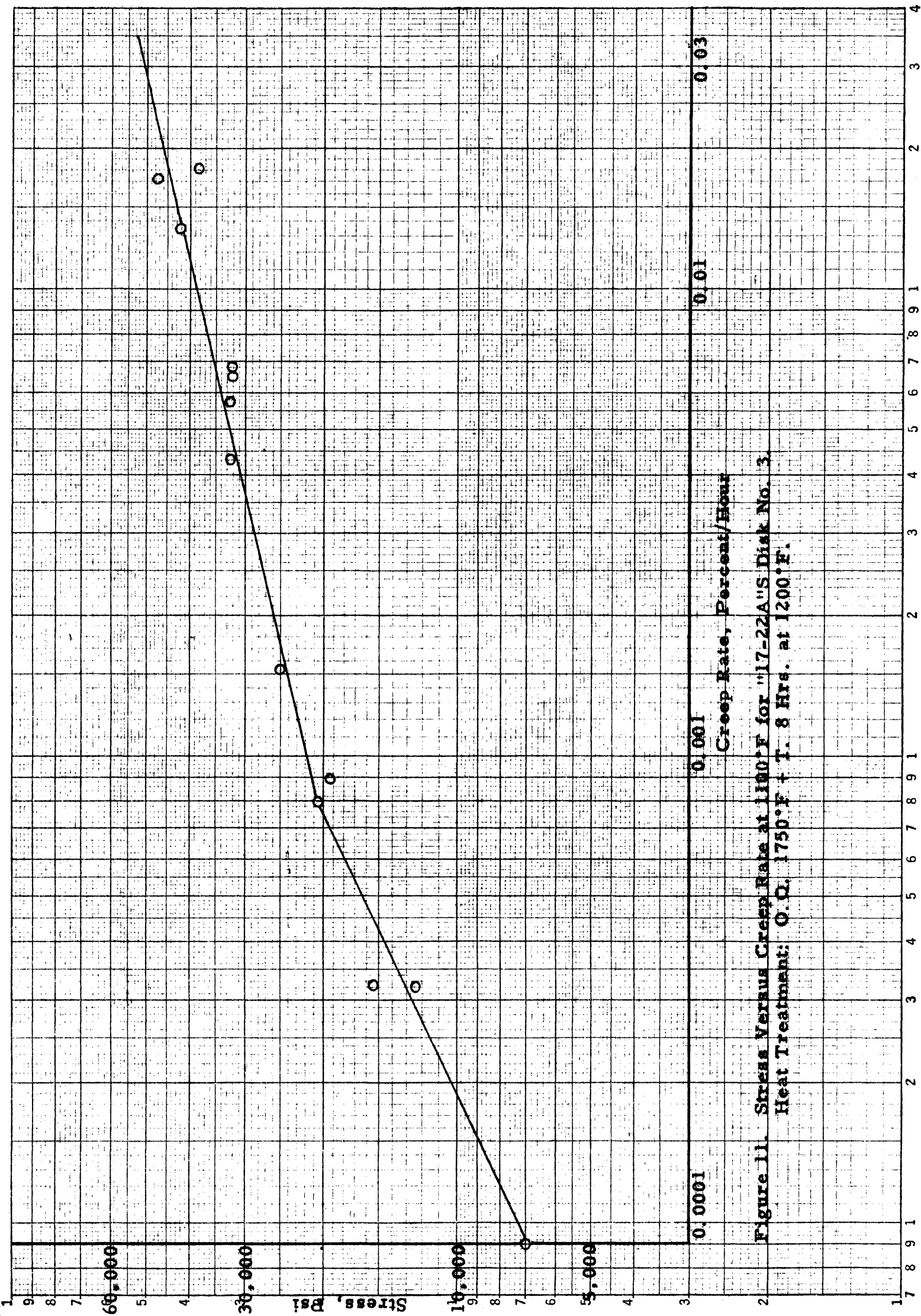


Figure 11. Stress Versus Creep Rate at 1100°F for "17-22A" S Disk No. 3.  
Heat Treatment: O. Q. 1750°F + T. 8 Hrs. at 1200°F.



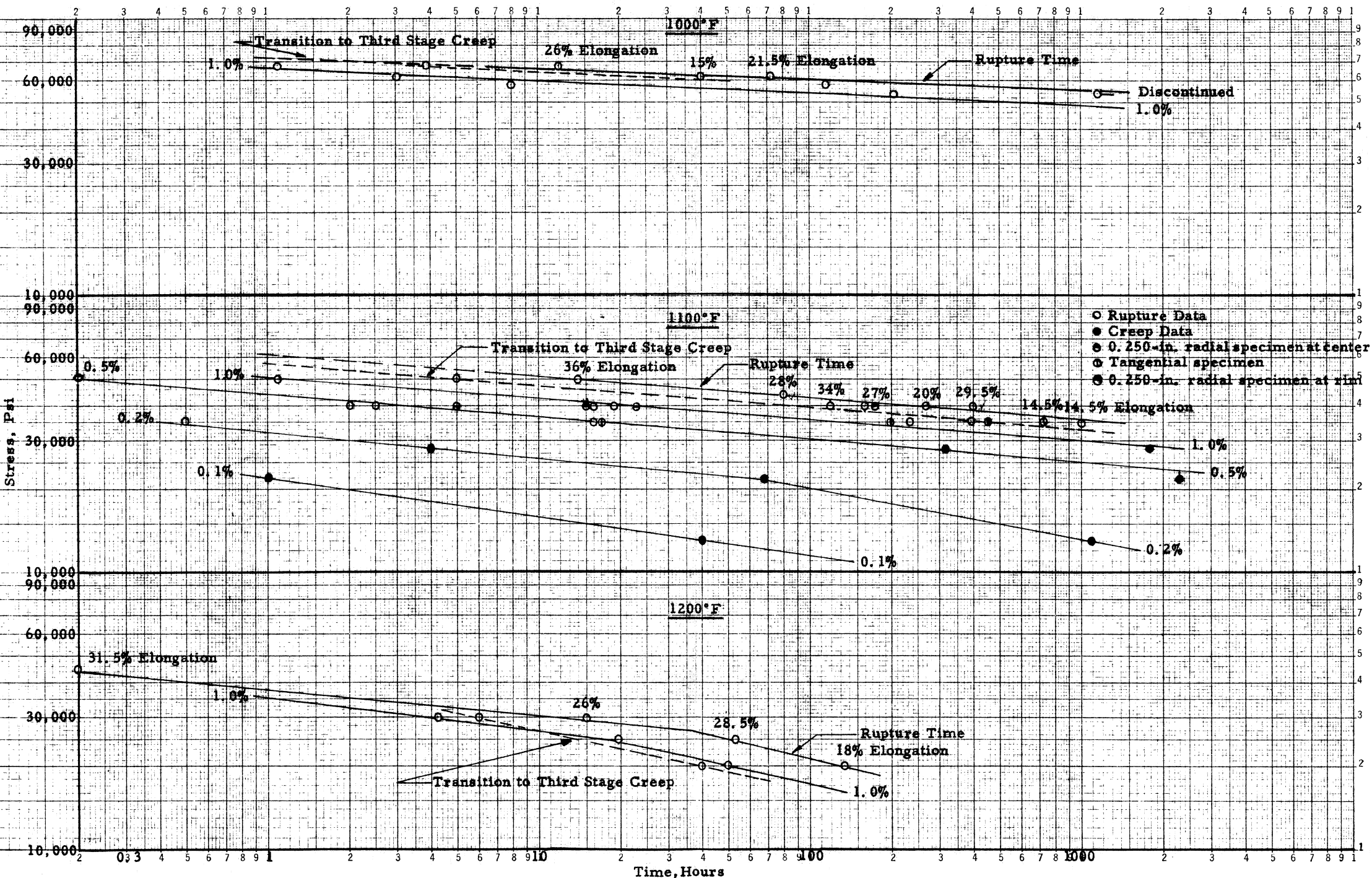


Figure 12. Curves of Stress Against Time for Indicated Total Deformations at 1000°, 1100°, and 1200°F for C-422 Disk No. 4. Heat Treatment: First treatment - O.Q. 1900°F + T. 8 Hrs. at 1200°F. Second treatment - Full Anneal 6 Hrs. at 1600°F. O.Q. 1900°F + T. at 1200°F for 2 + 2 Hrs.

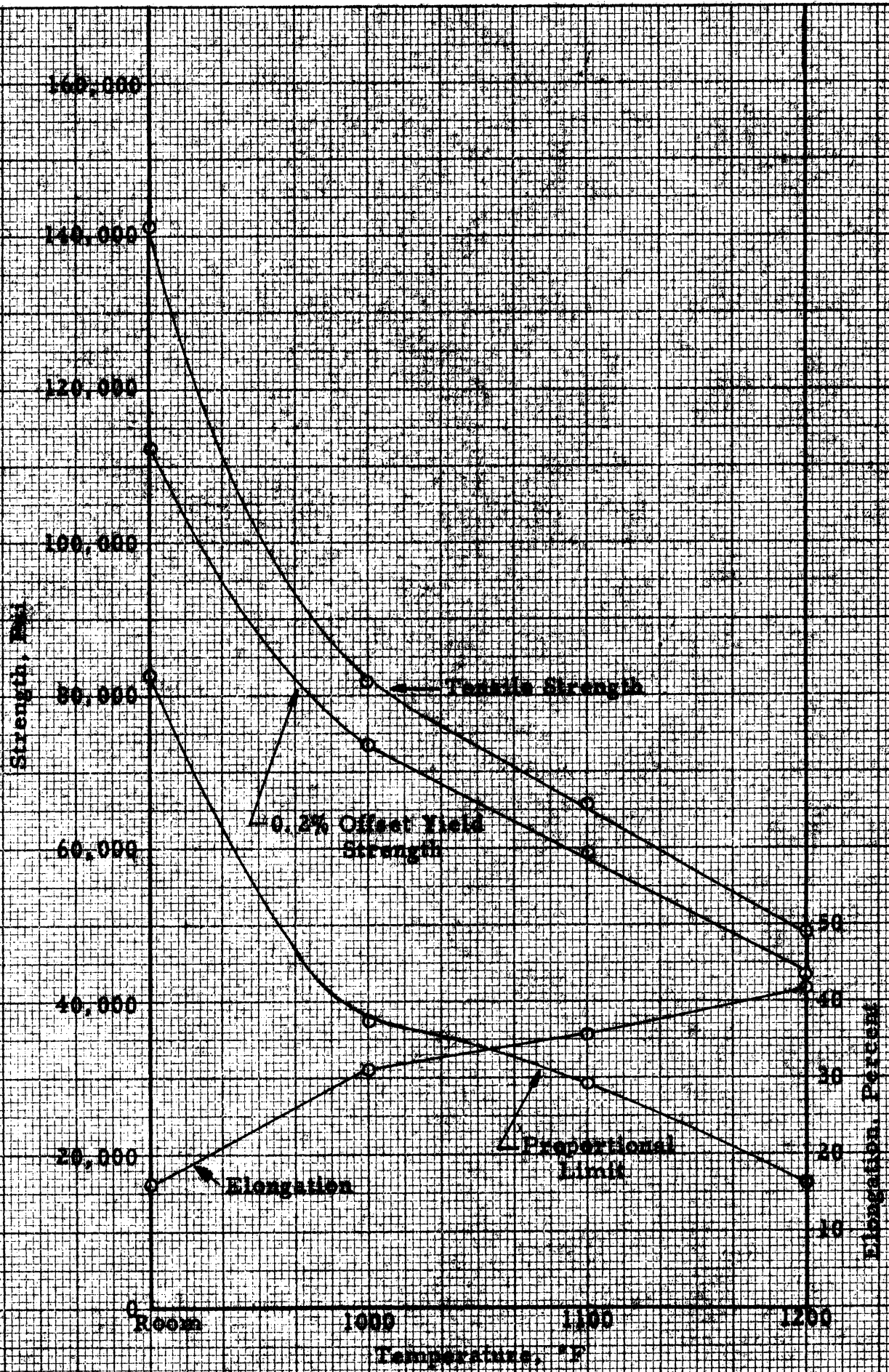


Figure 11. Summary of the Short Time Tensile Properties of C-122 Disk No. 4. Heat Treatment: (a) C. Q. 500°F + T. 8 Hrs. at 1200°F (b) Full Anneal 6 Hrs. at 1500°F. C. Q. 1900°F + T. at 1200°F for 2 + 2 Hrs.

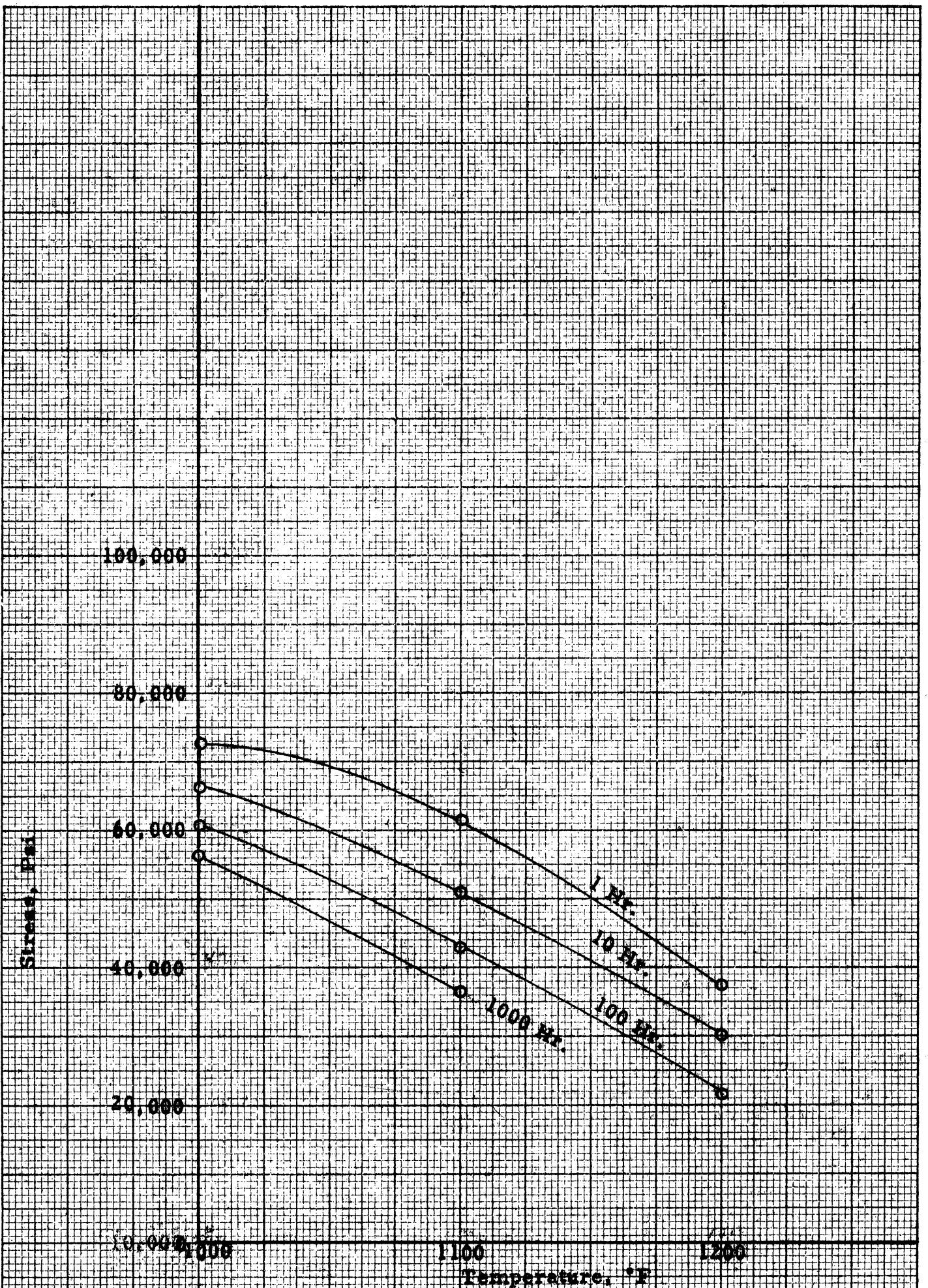


Figure 14. Summary of Rupture Strengths of C-422 Disk No. 4. Heat treatment: (a) O. Q. 1900°F + T. 4 Hrs. at 1200°F. (b) Full Anneal 6 Hrs. at 1600°F. O. Q. 1900°F + T. at 1200°F for 2 + 2 Hrs.

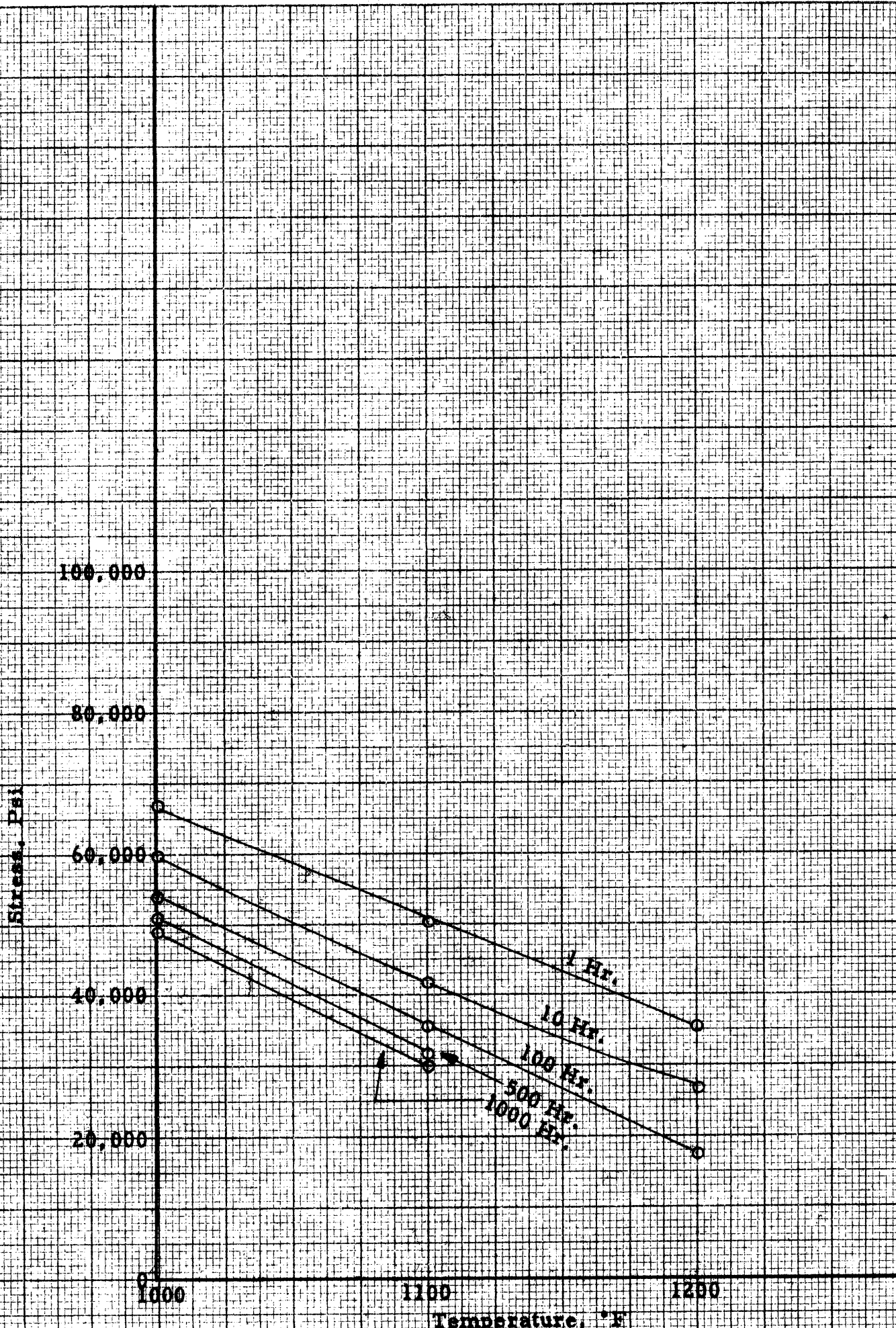


Figure 15. Summary of 1-Percent Total Deformation Strengths of C-422 Disk No. 4. Heat Treatment: (a) O. Q. 1900°F + T. 8 Hrs. at 1200°F. (b) Full Anneal 6 Hrs. at 1600°F. O. Q. 1900°F + T. at 1200°F for 2 + 2 Hrs.

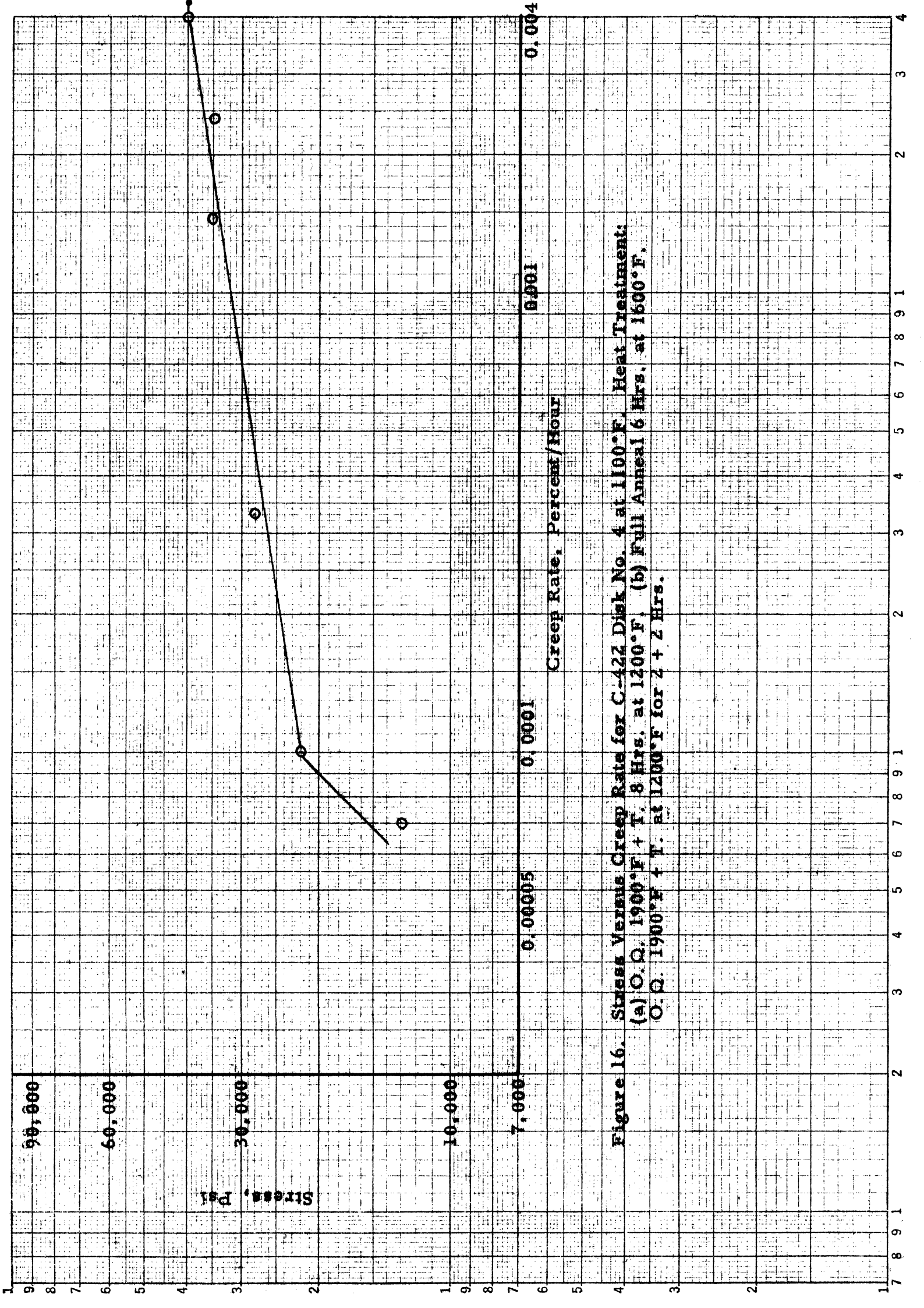


Figure 16. Stress Versus Creep Rate for C-422 Disk No. 4 at 1100°F. Heat Treatment:  
 (a) O.Q. 1900°F + T. 8 Hrs. at 1200°F. (b) Full Anneal 6 Hrs. at 1600°F.  
 O.Q. 1900°F + T. at 1200°F for 2 + 2 Hrs.



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