NATIONAL BUREAU OF STANDARDS REPORT

2427

on

Stress-Rupture Tests at 1350°F
on Type 304 Stainless Steel

By

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To

Test Methods Panel of the ASTM-ASME Joint Committee on the Effect of Temperature on the Properties of Metals

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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UNITED STATES DEPARTMENT OF COMMERCE
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National Bureau of Standards

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I. Introduction

Tests were made at the request of the Test Methods Panel to determine the suitability of a heat of 304 stainless steel for use as calibrated specimens for stress-rupture testing. It was requested that the tests be made at 1350°F under a stress to give an average life of 100 hours on specimens selected to evaluate the uniformity of the bars processed from the heat.

II. Material and Testing Procedures

Part of a basic electric heat (No. C-804) of 304 stainless steel was supplied by Universal Cyclops Steel Corporation in the form of 15/16" square (rounded corners) by 10-12' bars (9400 pounds) in the condition as annealed. The heat was cast into 8 ingots, each weighing approximately 3150 pounds and designated 1 to 8, inclusively, in the order of pouring. The bars supplied were processed from ingots 3, 4, 5, and 6. All bars were identified as to ingot, and some were also identified as to the position in the ingot (top, middle, bottom). The bars were annealed by the manufacturer by heating

at 1950-1975°F for 1 hour before quenching in water in three lots (A, B, and C) as follows:

Lot A - all bars from ingot 3; 1/3 of bars from ingot 6.

Lot B - all bars from ingot 4; 1/3 of bars from ingot 6.

Lot C - all bars from ingot 5; 1/3 of bars from ingot 6.

The chemical composition of the heat is given in table 1.

Hardness surveys (Rockwell B) were made at room temperature on cross-sections prepared from some of the annealed bars as received. The values ranged from about Rockwell B 69 to 72 with an average of approximately 71.

A metallographic examination was also made on specimens of the bars, as received, and on specimens after testing in creep at 1350°F. Representative structures are shown in figure 1.

The form and dimensions of the stress-rupture specimens are given in figure 2. These specimens were machined on centers in a lathe to a reduced diameter of approximately 0.002 inch oversize and a slight taper (reduced section approximately 0.001 inch less at the midpoint than at the shoulders) according to a form block attached to the cross-slide of the lathe carriage; light cuts were used to finish the reduced section to these dimensions. The specimens were then finished to size by grinding on centers in a direction parallel to the axis in a specially designed machine; the grinding wheels, 1 1/2 in. dia. x 1/4 in. wide, were made with a soft rubber binder and grinding was dry at a speed of 2400 RPM.

The stress-rupture specimens were machined from the selected identified bars from the positions in the cross-section according to a test program (table 2) that was statistically designed. The axis of specimens from the "a" position in the cross section was the same as the axis of the bars, and that corresponding to the "b" position was 5/16" from the outer surface.

The specimens were heated in air overnight (approximately 16 hr.) to about 1325°F and the temperature was raised, the following morning, to 1350°F. The specimens were held at temperature 1 to 1 1/4 hr. before applying the desired load corresponding to a stress of 13,500 psi. A few exploratory tests were made at stresses ranging from 13,000 to 14,600 psi (table 3). The stress-rupture machines were of a multiple-lever type with motorized jacks to prevent shock loading. Three stress-rupture units were used; each was recently calibrated at room temperature with a proving ring. Autographic strain-time data were obtained from direct-contact follow-up type extensometers attached to shoulders of specially-designed adapters.

The temperature was uniform over the length of the specimen and was maintained at 1350°F ± 4°F throughout the test. The furnace (16" long), the lot of 22-gage Chromel-Alumel thermocouple wire, and the potentiometer used were also calibrated. A hot junction of one thermocouple was attached to the center and the hot junction of another couple to the bottom end of the reduced section of the specimen; new couples were used for each test.

III. Results

The experimental results are summarized in tables 3 to 8 and figures 3 to 6.

IV. Statistical Analysis of Stress-Rupture Data of Table 5

by

William J. Youden

The data for the three ingots 3, 4, and 5 were examined as a group. The average of the 18 tests (using averages where duplicates were available) is 100.3 hours. The averages for each of the three stress-rupture units are

I	II	III
102.8	100.5	97.6

The averages for the three bar positions Aa, Ab, Bb, are

Aa	Ab	Bb
101.6	97.7	101.6

The averages for the three ingots 3, 4, and 5 are

	3	4	5
Unadjusted ave.	108.1	93.1	91.9
Adjusted ave.	105.3	103.0	92.6

The averages for the three positions in an ingot are

	Top	Center	Bottom
Unadjusted ave.	111.5	92.2	97.1
Adjusted ave.	112.9	94.7	93.3

The adjustments are made necessary because top positions were run on only two ingots, and the same was true for center and bottom positions. For example, the center samples were taken from ingots 4 and 5, the weaker ingots.

Statistical analysis showed that test specimens from the same position in the same ingot showed a standard deviation of 11.0 hours. Specimens from different positions chosen from different ingots show a standard deviation of 21.5 hours, just about twice that from specimens from the same part of the same ingot. The material is definitely heterogeneous, but most of this arises from the high values associated with specimens from the tops of ingots.

This heterogeneity within ingots is verified by the data on ingot 6 which gives the following averages (based on three specimens)

Top	Center	Bottom
111.0	102.5	85.8

This ingot, however, shows differences in all three positions. The estimate of error based on the triplicate specimens from the parts of this ingot is 8.0 hours, consistent with the 11.0 hours obtained above.

The analysis of these data show that three different sets of testing equipment could be calibrated so that the results were within three percent of the average for the three sets of equipment. The heterogeneity of the material was avoided by assigning to each test equipment the same number of specimens from each ingot and from each part of an ingot.

The preparation of the specimens is clearly adequate or the good agreement between test equipments would not appear.

Specimens from different bars and from either the corner or center of the cross section of a bar gave results that have a standard deviation of 11 percent provided the bars are from the same part of the same ingot. This standard deviation is doubled if the specimens come from different parts of different ingots. A standard deviation of 20 hours means that two results may easily differ by twice this amount. The four highest and the four lowest results bear out this spread:

129.1;	128.9;	121.8;	114.1
76.3;	77.4;	78.0;	81.0

These eight are the extremes from 30 tests that average close to 100 hours. The evidence shows that it is possible to calibrate the test equipment much closer than the variation shown by this material.

Table 1. Chemical Composition (Percentage by Weight) of the Steel Used, as Furnished by Universal Cyclops Corp.

Ladle analysis

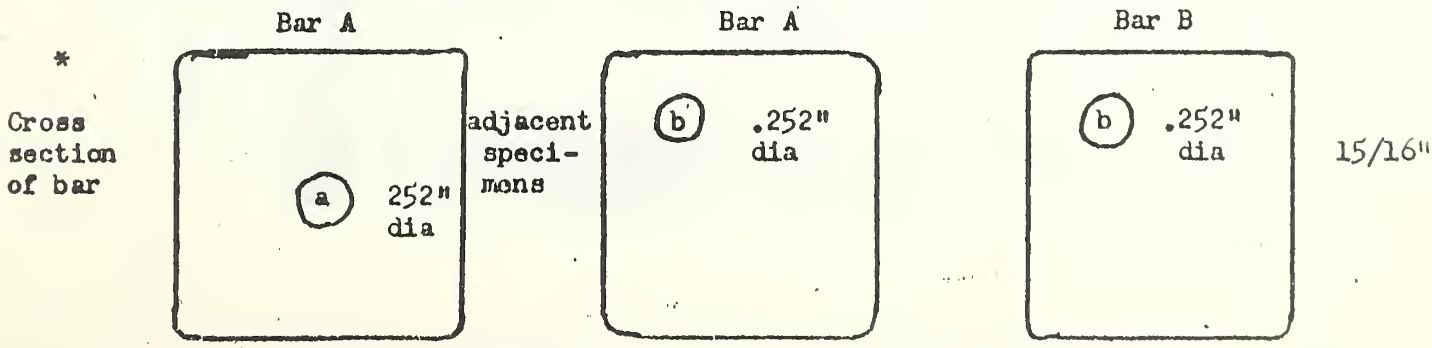
C	0.071	Cr	18.64
Mn	1.76	Ni	10.56
Si	0.57	Mo	0.18
S	0.010	Co	0.12
P	0.023	Cu	0.10

Check analysis on bar product

Ingot No.	4	6
C	0.069	0.069
Mn	1.63	1.67
Si	0.53	0.54
Cr	18.66	18.68
Ni	10.54	10.56

Table 2. Design of the Stress-Rupture Test Program.

Ingot	Position in Ingot	Bar	Specimen Position *	Testing Equipment I	II	III
1	Top	A	a	x		
		A	b		x	
		B	b			x
	Center	A	a			x
		A	b	x		
		B	b		x	
	Bottom	A	a		x	
		A	b			x
		B	b	x		
2	Top	A	a		x	
		A	b			x
		B	b	x		
	Center	A	a		x	
		A	b			x
		B	b	x		
	Bottom	A	a			
		A	b			
		B	b			
3	Top	A	a			x
		A	b	x		
		B	b		x	
	Center	A	a			
		A	b			
		B	b			
	Bottom	A	a			x
		A	b	x		
		B	b		x	
4	Top	A	a			
		A	b			
		B	b			
	Center	A	a	x		
		A	b		x	
		B	b			x
	Bottom	A	a	x		
		A	b		x	
		B	b			x



Position of specimen in cross section of bar

Table 3. Summary of Conditions Used and Results of Exploratory Stress-Rupture Tests. Specimens Tested at 1350°F with Different Stresses.

Specimen Number	Ingot Number	Ingot Position	Position in Bar	Stress Rupture Unit Number	Stress,	Creep Rate, Second Stage	Rupture Time,	Elongation,	Reduction of Area,
					psi	%/hr	hr	% in 1 1/4 in.	%
3CT1B	3	top	surface[1]	1	13,000	0.13	159	34.5	43
3CT2B	3	top	surface	2	13,000	.11	161.5	32	36
3CT1A	3	top	center[2]	3	13,800	.17	127.3	34	37.5
4CF1B	4	middle	surface	2	13,800	.18	73	40	42
3CB1A	3	bottom	center	3	14,000	.36	64.5	39	41
3CB1B	3	bottom	surface	1	14,600	.41	51	32	42
3CB2B	3	bottom	surface	2	14,600	.44	48.9	38.5	40

(1) Position b, table 2

(2) Position a, table 2

Table 4. Summary of Conditions Used and Results of Stress-Rupture Tests. Specimens Tested at 1350°F with a Stress of 13500 psi.

Specimen Number	Ingot Number	Ingot Position	Position in Bar	Stress Rupture Unit Number	Creep Rate, Second Stage	Rupture Time,	Elongation,	Reduction of Area,
					%/hr	hr	% in 1 1/4 in.	%
3T1A	3	top	center	3	0.15	129.1	31	40.5
3T1B	3	top	surface	1	.16	128.9	28	34
3T2B	3	top	surface	2	.18	114.1	32.5	36
3B1A	3	bottom	center	3	.26	84.1	38	42.5
3B1B	3	bottom	surface	1	.24	98.2	36.5	43
3B2B	3	bottom	surface	2	-	94.4	41	43.5
{4CF1A	4	middle	center	1	.24	78	34	36
{4F1A	4	middle	center	1	.24	97.4	38	41.5
4F1B	4	middle	surface	2	.24	76.3	46.5	40.5
4CF2B	4	middle	surface	3	.24	110	37	40
4CB1A	4	bottom	center	1	.22	102.5	36	40.5
4CB1B	4	bottom	surface	2	.22	111.8	39.5	42.5
{4CB2B	4	bottom	surface	3	.25	96.3	40	45
{4B2B	4	bottom	surface	3	.28	87.4	40	49
{5CT1A	5	top	center	2	.21	92.7	39.5	46.5
{5T1A	5	top	center	2	.23	113.8	39	51.5
5CT1B	5	top	surface	3	.25	89.8	36	39
5CT2B	5	top	surface	1	.20	104.1	32	40
5CF1A	5	middle	center	2	.21	103.3	40	44
5CF1B	5	middle	surface	3	.32	81	40	44
5CF2B	5	middle	surface	1	.23	95.2	33	38.5
6T1A	6	top	center	1	.17	121.8	29	35
6T1B	6	top	surface	2	.19	109.6	32	39.5
6T2B	6	top	surface	3	.24	101.7	33	41.5
6F1A	6	middle	center	3	.26	101.1	36	43
6F1B	6	middle	surface	1	.21	110.7	31	42
6F2B	6	middle	surface	2	.21	95.8	34	41
6B1A	6	bottom	center	2	.25	95.8	32	36
6B1B	6	bottom	surface	3	.27	77.4	34	44
6B2B	6	bottom	surface	1	.26	84.3	37	43.5

Ingot	Position in Ingot	Bar	Specimen Position	Testing Equipment No. 1	2	3	Average (Ingot)
6	Top	A	a	121.8			
		A	b		109.6		
		B	b			101.7	
	Middle	A	a			101.1	
		A	b	110.7			99.8
		B	b		95.8		
	Bottom	A	a		95.8		
		A	b			77.4	
		B	b	84.3			
5	Top	A	a		{92.7, 113.8}		
		A	b			89.8	
		B	b	104.1			
	Middle	A	a		103.3		
		A	b			81	96.1
		B	b	95.2			
	Bottom	A	a				
		A	b				
		B	b				
3	Top	A	a			129.1	
		A	b	128.9			
		B	b		114.1		
	Middle	A	a				
		A	b				108.1
		B	b				
	Bottom	A	a			84.1	
		A	b	98.2			
		B	b		94.4		
4	Top	A	a				
		A	b				
		B	b				
	Middle	A	a	{97.4, 78.}			
		A	b		76.3		96.7
		B	b			110	
	Bottom	A	a	102.5			
		A	b		111.8		
		B	b			{87.4, 96.3}	
Average (Testing Equipment)				103.7	100.5	96.2	100.1

Table 5. Effect of conditions used on the rupture time (hours). Specimens tested at 1350°F with stress of 13,500 psi.

Ingot	Position in Ingot	Bar	Specimen Position	Testing Equipment No. 1	2	3	Average (Ingot)
		A	a	0.17			
	Top	A	b		0.19		
		B	b			0.24	
		A	a			.26	
6	Middle	A	b	.21			0.23
		B	b		.21		
		A	a		.25		
	Bottom	A	b			.27	
		B	b	.26			
		A	a		.22*		
	Top	A	b			.25	
		B	b	.20			
		A	a		.21		
5	Middle	A	b			.32	.24
		B	b	.23			
		A	a				
	Bottom	A	b				
		B	b				
		A	a			.15	
	Top	A	b	.16			
		B	b		.18		
		A	a				
3	Middle	A	b				.20
		B	b				
		A	a			.26	
	Bottom	A	b	.24			
		B	b		—		
		A	a				
	Top	A	b				
		B	b				
		A	a	.24*			
4	Middle	A	b		.24		.24
		B	b			.24	
		A	a	.22			
	Bottom	A	b		.22		
		B	b			.26*	
	Average (Testing Equipment)			.21	.22	.25	.23

* Average of 2 tests

Table 6. Effect of conditions used on the second-stage creep rate, percent per hour. Specimens tested at 1350°F with stress of 13,500 psi.

Ingot	Position in Ingot	Bar	Specimen Position	Testing Equipment No.			Average (Ingot)
				1	2	3	
6	Top	A	a	29			
		A	b		32		
		B	b			33	
	Middle	A	a			36	
		A	b	31			33.2
		B	b		34		
	Bottom	A	a		32		
		A	b			34	
		B	b	37			
5	Top	A	a		39*		
		A	b			36	
		B	b	32			
	Middle	A	a		40		
		A	b			40	36.7
		B	b	33			
	Bottom	A	a				
		A	b				
		B	b				
3	Top	A	a			31	
		A	b	28			
		B	b		32.5		
	Middle	A	a				
		A	b				34.5
		B	b				
	Bottom	A	a			38	
		A	b	36.5			
		B	b		41		
4	Top	A	a				
		A	b				
		B	b				
	Middle	A	a	36*			
		A	b		46.5		39.2
		B	b			37	
	Bottom	A	a	36			
		A	b		39.5		
		B	b			40*	
Average (Testing Equipment)				33	37.4	36.1	35.5

* Average of 2 tests.

Table 7. Effect of conditions used on the elongation values (% in 1 1/4 inch). Specimens tested at 1350°F with stress of 13,500 psi.

Ingot	Position in Ingot	Bar	Specimen Position	Testing Equipment No. 1	2	3	Average (Ingot)
		A	a	35			
	Top	A	b		39.5		
		B	b			41.5	
		A	a			43	
6	Middle	A	b	42			41.7
		B	b		41		
		A	a		36		
	Bottom	A	b			44	
		B	b	43.5			
		A	a		49*		
	Top	A	b			39	
		B	b	40			
		A	a		44		
5	Middle	A	b			44	42.4
		B	b	38.5			
		A	a				
	Bottom	A	b				
		B	b				
		A	a			40.5	
	Top	A	b	34			
		B	b		36		
		A	a				
3	Middle	A	b				39.9
		B	b				
		A	a			42.5	
	Bottom	A	b	43			
		B	b		43.5		
		A	a				
	Top	A	b				
		B	b				
		A	a	38.5*			
4	Middle	A	b		40.5		41.5
		B	b			40	
		A	a	40.5			
	Bottom	A	b		42.5		
		B	b			47*	
	Average (Testing Equipment)			39.4	41.3	42.4	41

* Average of 2 tests.

Table 8. Effect of conditions used on the reduction of area values (percent). Specimens tested at 1350°F with stress of 13,500 psi.

Figure 1. Structure of the steel as annealed and after testing at 1350°F to rupture. Longitudinal sections. Etched in 5 parts HCl (conc.) and 2 parts chromic acid (10%).

A. Initial structure, center of specimen. x 100

B. Structure, center of specimen, at time of application of stress. x 100

C. Structure, near fracture, at center of specimen, after rupture in 129.1 hr. x 100

D. Same as C. x 500

E. Structure, near fracture, at center of specimen, after rupture in 76.3 hr. x 100

F. Same as E. x 500

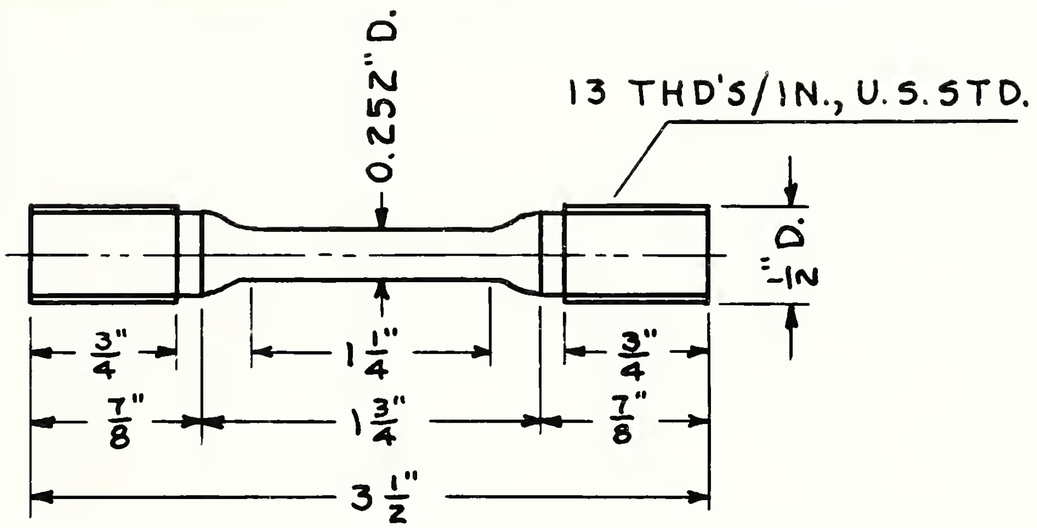


Figure 2. Form and dimensions of stress-rupture specimen.

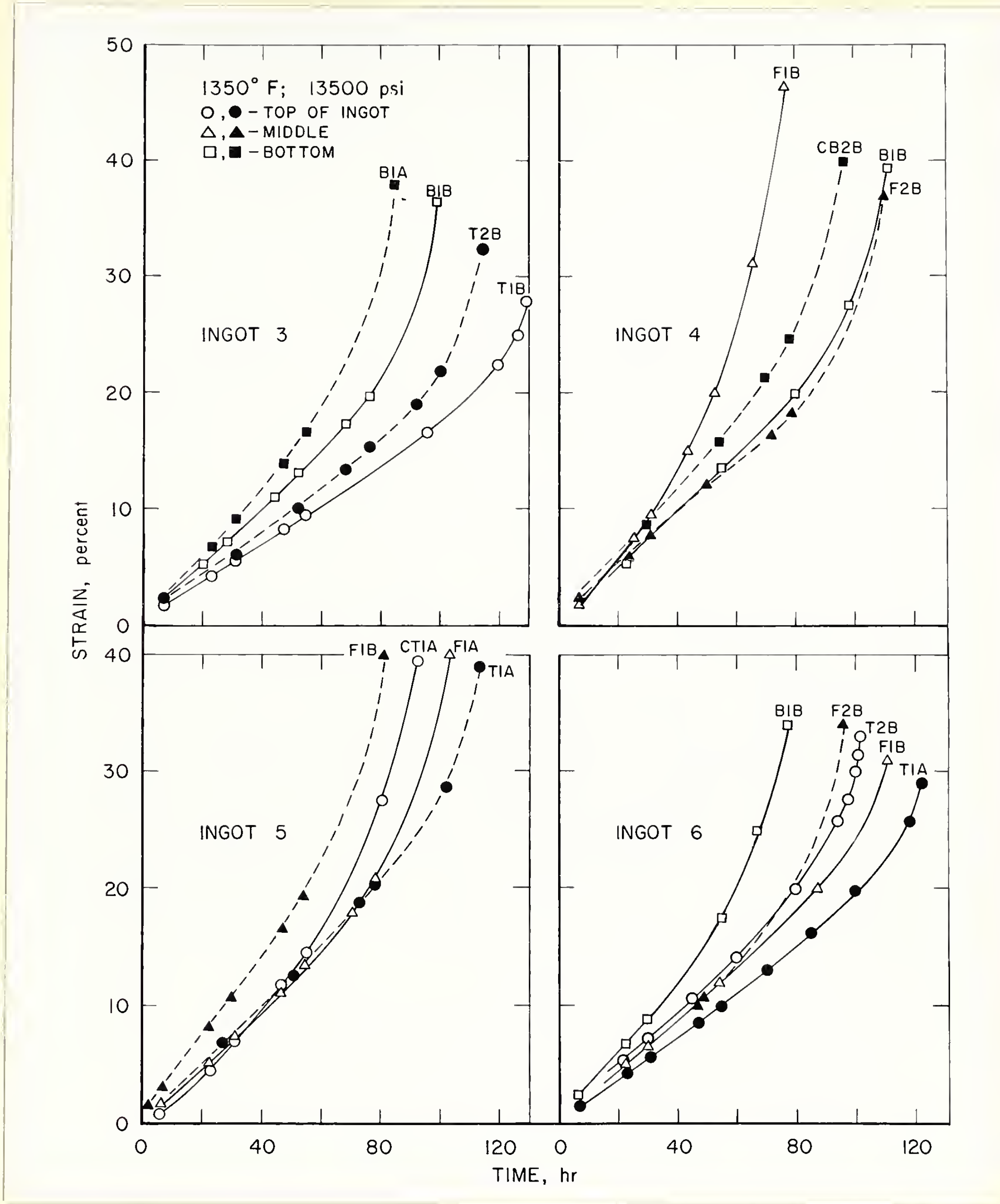


Figure 3. Strain-time curves for specimens tested at 1350°F with a stress of 13,500 psi.

Final point on each curve indicates rupture.

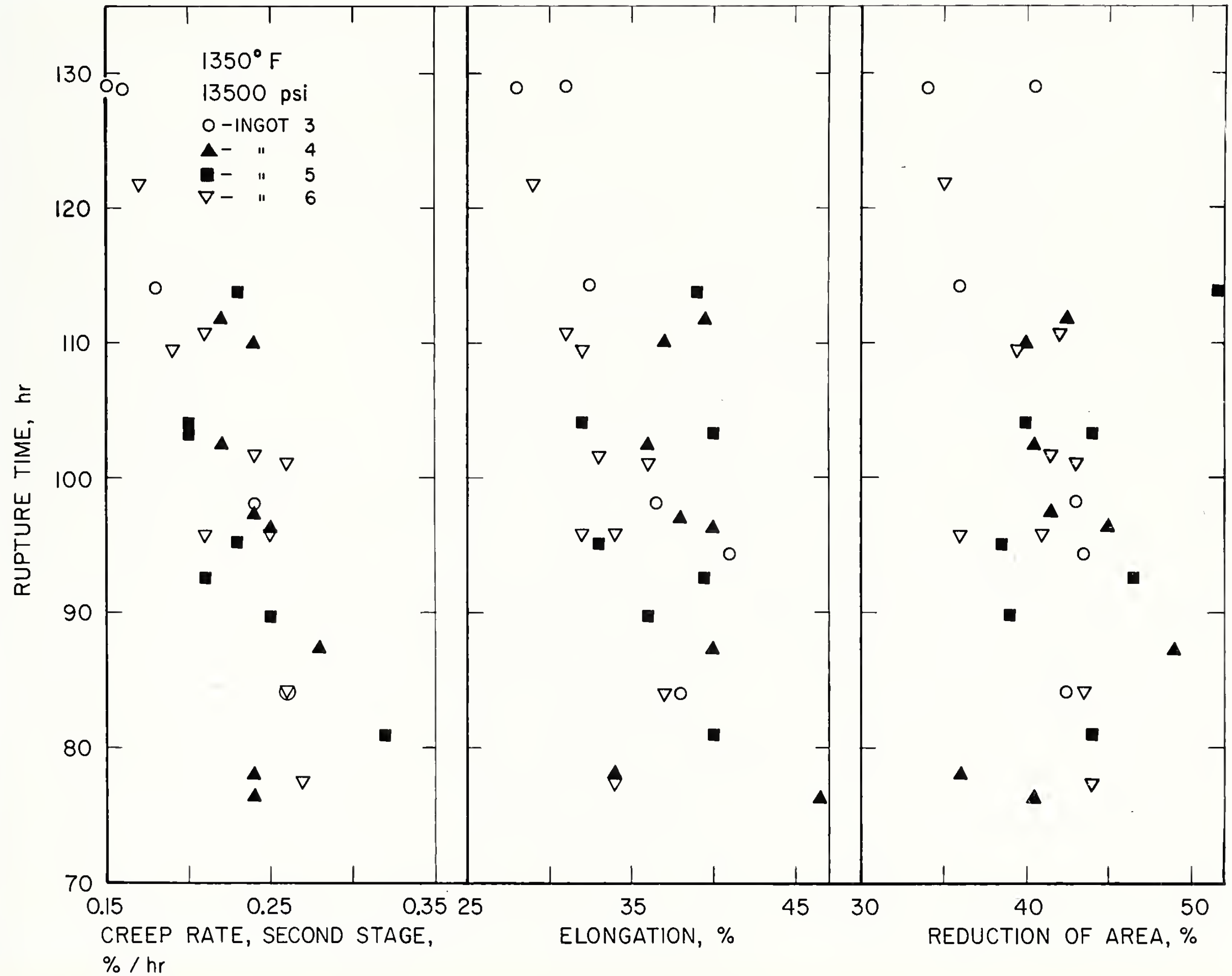


Figure 4. Relation of rupture time to second-stage creep rate, elongation, and reduction of area values for specimens tested at 1350°F with stress of 13,500 psi.

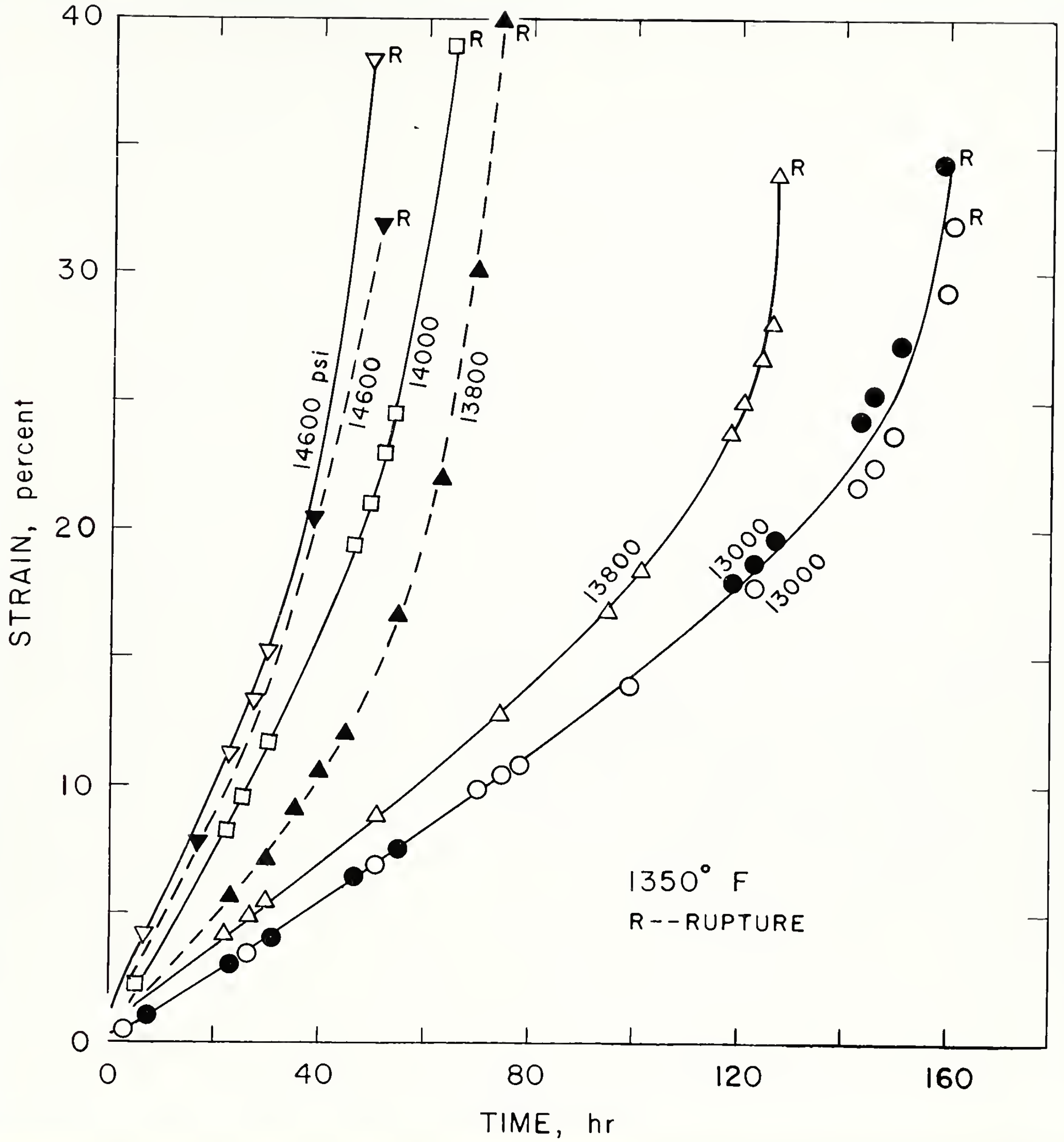


Figure 5. Strain-time curves for specimens tested at 1350°F with different stresses.

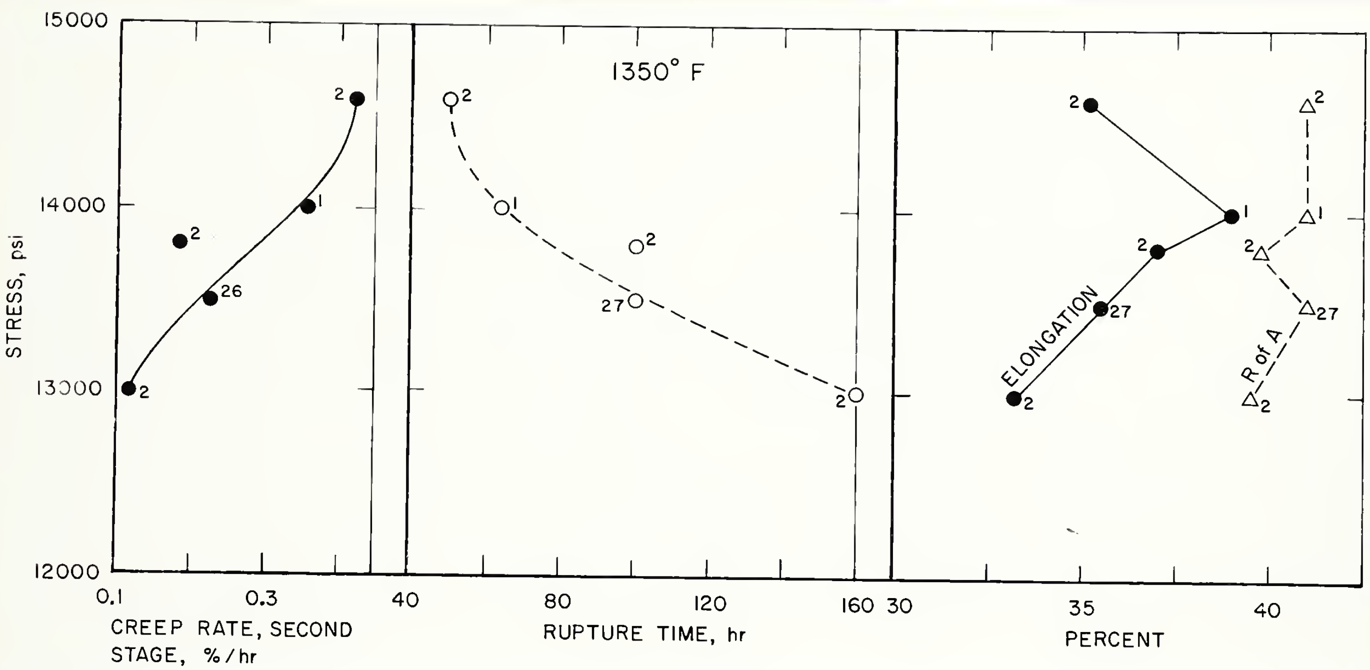


Figure 6. Effect of stress on second-stage creep rate, rupture time and ductility of specimens tested at 1350°F.

Numbers adjacent to points indicate the number of values averaged at this stress.

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