NACA TN No. 1765

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE

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OFFICE OF NAVAL RESEARCH AND NACA METALLURGICAL INVESTIGATION OF A LARGE FORGED DISC OF S-816 ALLOY

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Washington
February 1949

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SUMMARY

This report is one of a series in a cooperative research investigation undertaken to ascertain the properties of the better wrought heat-resisting alloys in the form of large discs required for gas-turbine rotors.

The properties of large discs of S-816 alloy have been determined for both the as-forged and aged condition (disc NR-76B-F) and the heat-treated and aged condition (disc NR-76B-Q) at room temperature and, by means of stress-rupture and creep tests for time periods up to about 2000 hours, at 1200°, 1350°, and 1500° F. Short-time tensile test, impact test, and time-deformation characteristics are included.

INTRODUCTION

This report presents the results of a study of the room-temperature, 1200°, 1350°, and 1500° F properties of a large forged disc of S-816 alloy. One-half of the disc was tested as-forged and aged, and the other half was heat-treated and aged before testing. The halves are referred to herein as two discs, NR-76B-F (forged and aged) and NR-76B-Q (heat-treated and aged).

The primary purpose of this study was to determine the level of properties exhibited by this alloy in the form of large forgings of the type required for rotor wheels of gas turbines and to determine the relative properties of such forgings as-forged and aged and as heat-treated and aged. The results obtained previously from similar investigations of 19-9DL, CSA, Timken alloy, EME, and low-carbon N-155 discs have been published as references 1 to 9. A concurrent and nearly identical investigation of a large forged disc of S-590 alloy has been published as reference 10.

This work is being carried out as part of two correlated programs of research on alloys for gas-turbine applications in progress in this country. The National Advisory Committee for Aeronautics is sponsoring work directed toward the development of improved high-temperature alloys for gas turbines used in aircraft power plants.

A concurrent program, formerly sponsored by the National Defense Research Committee, Office of Scientific Research and Development, and now sponsored by the Office of Naval Research, Navy Department, is being directed to the development of alloys for gas-turbine applications in general and, in particular, for both ship and aircraft propulsion turbines. The work described herein was accomplished with the financial assistance of the National Advisory Committee for Aeronautics and the Office of Naval Research, Navy Department.

This report is being distributed by both the NACA and the Navy. The investigation of these discs for the NACA was conducted at the Engineering Research Institute of the University of Michigan and for the Navy at Battelle Memorial Institute.

TEST MATERIALS

The available information concerning the disc may be summarized as follows:

Manufacturer:

Allegheny-Ludlum Steel Corporation

Heat number:

41625

Chemical composition:

The chemical composition was reported by the manufacturer to be the following percentages:

C	Mn	Si	Cr	Ni	Co	Mo	W	Cb	Fe
0.38	0.50	0.53	19.80	20.57	42.71	3.90	4.76	3.95	2.87

Fabrication procedure:

A 12-inch-square ingot from a 5000-pound electric-arc heat was hammer cogged to $9\frac{1}{2}$ inches square from 2300° F and upset to $3\frac{5}{16}$ inches thick from 2250° F. The resulting disc was more nearly octagonal than circular and measured about 17 inches across.

The disc was cut in half. One half was left as-forged, marked NR-76-F; the other half was heated at 2300° F for $2\frac{1}{2}$ hours and water-quenched, marked NR-76-Q. Test bars from each half were then aged for 16 hours at 1400° F.

Sampling:

The code number assigned to the two halves was NR-76B. They will hereafter be referred to as the two discs, NR-76B-F and NR-76B-Q. Figures 1 and 2 show the locations of the samples cut from the halves and the code system identifying the coupons. The numbers refer to locations on the flat faces of the discs, and the letters refer to the locations through their thicknesses.

EXPERIMENTAL PROCEDURE

The investigation was designed to provide four types of information: (1) The physical properties at room temperature, 1200°, 1350°, and 1500° F which can be expected in large forgings of the S-816 analysis; (2) the effect of heat treatment on these physical properties; (3) the variation in properties which might be present in various locations in such large forgings; and (4) the change in room-temperature properties resulting from exposure to elevated temperatures under stress for prolonged time periods.

The physical-property data obtained from the halves of the large forged disc of S-816 alloy included short-time tensile properties, impact strengths, rupture test characteristics, and design curves of stress against time for total deformations of 0.1, 0.2, 0.5, and 1.0 percent at 1200°, 1350°, and 1500° F. The time - total-deformation data were obtained from time-deformation curves from both stress-rupture and creep tests.

The uniformity of the forging was checked by means of a hardness survey. Hardness, tensile, and impact tests and metallographic examination of specimens after completion of the creep tests were used to estimate the stability of the material during prolonged exposure to temperature and stress.

The testing procedures used for the short-time tensile, stress-rupture, and creep tests were in accordance with the provisions of the A.S.T.M. Recommended Practices E21-43 and E22-41.

RESULTS

The data obtained are compiled as a series of tables and figures, with the principal results from the discs NR-76B-F and NR-76B-Q summarized in figures 3 and 4. The source of the data (NACA or Navy) is indicated in the tables.

Hardness Survey

The Brinell hardness of material cut from the forged and aged disc NR-76B-F ranged from 258 to 311 while the range for the heat-treated and aged disc was from 255 to 280. (See figs. 5 and 6.) The hardness generally increased from the center to the rim of the discs, more so in the case of the forged and aged disc than in the case of the heat-treated and aged disc. However, the minimum value was measured about 2 inches from the center of disc Q on the center plane, while the maximum value was measured at the rim on the forged surface of disc F.

The forged and aged disc showed a higher over-all hardness than the solution-treated and aged disc, in addition to the greater hardness difference from center to rim of the forged and aged disc. The hardness variations encountered from center to rim appear to be relatively small, considering the size of the original disc from which the halves F and Q were cut and the difficulties of forging such a highly alloyed material.

Short-Time Tensile Properties

The results of the short-time tensile tests at room temperature, 1200°, 1350°, and 1500° F are shown in table I. At room temperature, 1200°, and 1350° F, the forged and aged disc NR-76B-F showed slightly higher tensile and yield strengths than the heat-treated and aged disc NR-76B-Q. At 1500° F, the situation was reversed, with the heat-treated and aged disc showing slightly higher strengths than the forged and aged disc. The variation in ductility was small, both between discs F and Q and among the room-temperature and elevated-temperature tests. However, at room temperature and at 1350° F, the average elongation for disc Q was a few percent above that for disc F. The elongations of both discs were higher at room temperature and 1350° F than at 1200° and 1500° F. It should be noted, however, that every specimen tested at 1200° F broke in the gage marks. The average elongation for all the tests on both discs was about 20 percent.

There was a tendency for the specimens from the interior of the discs to have lower strength at room temperature and, in disc Q, lower ductility.

Charpy Impact Resistance

Charpy impact resistance (V-notch) was determined on specimens from the two discs F and Q at room temperature, 1200°, 1350°, and 1500° F after holding at temperature sufficiently long to insure a uniform temperature in the specimens. The data are shown in table II and figures 3 and 4.

The Charpy impact values of the discs F and Q were nearly identical at 1200° and 1500° F, but at room temperature and at 1350° F the impact strength of the forged and aged disc was higher than that of the heat-treated and aged disc. For both the discs F and Q, the impact strength at the elevated temperatures was nearly twice that at room temperature and did not change significantly from 1200° to 1500° F.

The average of the impact strengths of the specimens from the surface of the discs was about 20 percent higher than that of the interior specimens for both discs F and Q at all temperatures.

Rupture Test Characteristics

The stress-rupture data for the tests at 1200°, 1350°, and 1500° F are shown in table III, and the rupture-strength values obtained from the curves of stress against rupture time in figures 7 to 13 are shown at the bottom of table III. All stress-rupture tests were run on 1/4-inch-diameter specimens which were cut from the discs in either a radial direction or less than 45° from radial.

At 1200° F, the stress-rupture strength of the heat-treated and aged disc Q was slightly superior to that of the forged and aged disc F. The 100-hour and 1000-hour rupture strengths of disc Q were 66,000 and 52,000 psi, respectively, and of disc F 62,000 and 50,000 psi, respectively.

At 1350° F, the rupture strengths of the forged and aged disc and quenched and aged disc were nearly identical; the 100-hour and 1000-hour strengths were about 38,000 and 29,000 psi, respectively.

At 1500° F, the 100-hour and 1000-hour rupture strengths of disc Q were again slightly higher than those of disc F. The 100-hour and 1000-hour strengths of disc Q were 23,000 and 17,500 psi, respectively, and of disc F 21,000 and 13,500 psi, respectively.

Inspection of the curves of stress against rupture time (fig. 7) shows some increase in slope with increasing test temperature for disc F and hardly any change in slope with increasing test temperature for disc Q. At 1200° and 1350° F, the slopes of the stress-rupture curves are about the same for both discs. The comparative slope changes between discs at 1500° F indicate that for service at this temperature, the heat-treated and aged disc was superior to the forged and aged.

Ductilities of the stress-rupture specimens measured after fracture varied from fair to good. Elongations for the 1500° F tests were mostly only fair, ranging from 2 to 8 percent, while those for the 1200° and 1350° F tests were better, ranging from 6 to 15 percent, with one low value, 3 percent, reported at 1350° F (disc NR-76B-F).

Time-Deformation Characteristics

A convenient method of describing the high-temperature strength of a material is by curves of stress against time required for various total deformations. Data from both stress-rupture and creep tests are used to prepare such design curves. Such information, along with the curves of stress against rupture time, gives design engineers a complete picture of the expected performance of an alloy under constant tensile stress. This information is presented in figures 8 to 13 for deformations of 0.1, 0.2, 0.5, and 1.0 percent at 1200°, 1350°, and 1500° F for time periods up to 2000 hours. Curves showing the time of transition from a minimum creep rate to the increasing rate of third-stage creep have been added so as to show when rapid elongation preceding failure starts.

The curves of stress against time for total deformation were plotted from the data in tables III to VI. The data were taken from the time-deformation curves of the stress-rupture and creep tests. The time-deformation curves for the creep tests and stress-rupture tests have not been included in this report.

Tables IV, V, and VI also show data scaled from the design curves in figures 8 to 13 and show the stresses to cause various total deformations from 0.1 to 1.0 percent in definite time periods of 1, 10, 100, 1000, and 2000 hours. For ease of comparison, these data and similar data for the S-590 discs NR-74B and for the N-155 disc NR-66D are shown together in table VII. Also included for comparison are impact and tensile data at room temperature, 1200°, 1350°, and 1500° F for these materials and residual room-temperature impact and tensile data for specimens after creep testing of the various materials (after 1000 to 2000 hr under stress at test temperature).

Creep Strengths

Many engineers are accustomed to basing designs on creep rates, especially for long periods of service. For this reason, the creep rate data have been collected from the time-deformation curves and are shown in table VIII, and the logarithmic curves of stress against creep rate for the tests at 1200°, 1350°, and 1500° F on the two discs F and Q are shown in figure 14. The creep rates used were either minimum or final rates from 1000-hour tests at 1200° F and from 2000-hour tests at 1350° and 1500° F. The creep strengths obtained from figure 14 are shown in tables IV, V, and VI and for ease of comparison are tabulated as follows:

Disc	Temperature ($^{\circ}$F)	Stress (psi) for creep rates of –	
		0.0001 percent/hr	0.00001 percent/hr
NR-76B-F	1200	28,000	[a]18,000
NR-76B-Q		28,000	[a]16,000
NR-76B-F	1350	20,000	13,000
NR-76B-Q		19,000	10,500
NR-76B-F	1500	11,000	8,500
NR-76B-Q		13,500	7,500

[a]Estimated.

These creep strengths can be compared with the deformation strengths in tables IV, V, and VI. The creep strengths for a rate of 0.0001 percent per hour at 1200° F are apparently safe for use for time periods up to 10,000 hours since extrapolation of the transition-point curves (stage-two to stage-three creep rate) in figures 8 and 9 out to 10,000 hours indicates that at the stresses listed second-stage creep would still prevail.

For the tests at 1350° F, the situation is quite different. Extrapolation of the 1350° F transition curves in figures 10 and 11 shows that at the stresses for a creep rate of 0.0001 percent per hour increasing creep rates will occur in about 14,000 hours for disc F and 7000 hours for disc Q. At the lower stresses producing a creep rate of 0.00001 percent per hour, third-stage creep would not occur for considerably longer time periods.

Extrapolation of the 1500° F transition curves (figs. 12 and 13) shows that at the stresses for a creep rate of 0.0001 percent per hour, increasing creep rates will occur in 1500 hours for disc F and in 3700 hours for disc Q. Even at the stress for a creep rate of 0.00001 percent per hour, extrapolation indicates an increasing creep rate for disc F in 4000 hours and for disc Q at about 25,000 hours.

Comparison of the extrapolated rupture strengths with the creep strengths indicates that the estimated stresses for fracture in 10,000 hours are well above the 0.0001-percent-per-hour creep strengths at 1200° F. The rupture strength (10,000 hr) is only slightly higher than the creep strength (0.0001 percent/hr) at 1350° F. At 1500° F, the creep strength of disc F is above the estimated rupture strength, while for the disc Q the two are equal.

The scatter of the creep-rate data and the change in slope downward of the curve of stress against creep rate at low stresses producing rates less than 0.0001 percent per hour make unwise the large extrapolations necessary in both creep and rupture data for comparisons of the creep rate for 0.00001 percent per hour with the 100,000-hour rupture strengths.

In all cases, caution should be observed since extended service periods of several times the maximum test period used here (about 2000 hr) may magnify such effects as surface and structural instability, which were overshadowed by other variables during the short test periods.

Stability Characteristics

Some of the test specimens from each of the two discs were subjected to tensile, impact, and hardness tests at room temperature after creep testing at 1200°, 1350°, and 1500° F with the results shown in table IX.

The considerable decreases in impact strength and tensile test ductility at room temperature were the most significant changes observed.

The hardness of disc F increased somewhat after creep testing at 1200° F, but did not change after testing at 1350° F and seemed to decrease slightly after testing at 1500° F.

For the forged and aged disc F, the proportional limit and 0.1- and 0.2-percent yield strengths were slightly higher after creep testing at 1200° and 1350° F (except for the 0.1-percent yield strength after 1200° F which remained unchanged), but were lower after testing at 1500° F. The tensile strength was lower after creep testing at all three temperatures, and the 0.02-percent yield strength did not change significantly after testing at 1200° and 1350° F but decreased after testing at 1500° F.

The yield strengths of the heat-treated and aged disc Q were higher after creep testing at 1200° and 1350° F and lower after testing at 1500° F. The tensile strength was lower after creep testing at all three temperatures.

The microstructure showed less breakdown of the dendritic pattern at the center of the disc than near the rim, and the grains were coarser at the center. The structure near the rim was, however, more typical of that of the test specimens. Original microstructures of the center and rim portions of the forged and aged disc are shown at magnifications of 100X and 1000X in figure 15. The microstructure of the rim portion of the heat-treated and aged disc is also shown at 100X and 1000X in figure 15.

The grain-size range was about 5 to 7 near the rim of the forged and aged disc and about 4 to 7 at the center. The grain-size range near the rim of the heat-treated and aged disc was about 4 to 6. Thus the heat-treated and aged disc was slightly coarser grained (by one A.S.T.M. grain-size number) than the forged and aged disc.

Precipitation within the grains is not evident in the original microstructures or in those of the creep-tested specimens. Some precipitation is evident in the microstructures at 1000X of specimens 10A, Q12F, and Q12E (figs. 16 and 17), which were tested in stress rupture, the first two at 1350° and the last at 1200° F. No explanation can be offered for the apparent absence of precipitation in the photomicrographs of the original structures and of the structures of all the tested creep specimens and 1500° F stress-rupture specimens. The photomicrographs of figure 15 show the original structures at magnifications of 100X and 1000X of the forged and aged and heat-treated and aged discs. Those of figures 18 and 19 show the structures at 100X and 1000X of the two discs, F and Q, after creep testing at 1200°, 1350°, and 1500° F. The photomicrographs of figures 16 and 17 show the fractures at 100X and internal microstructures at 1000X of the specimens of the two discs after stress-rupture tests at 1200°, 1350°, and 1500° F. The fracture of specimen Q12E, which was tested for 1699 hours at 1200° F, appears to be transcrystalline. The fractures of the specimens tested at 1350° (F10A and Q12F) and 1500° F (F11D and Q14D), and the fracture of specimen F9A (2618 hr at 1200° F) were all intergranular. The longer time of exposure to high temperature and lower stress may have caused specimen F9A to break with an intergranular fracture at 1200° F, while the corresponding specimen Q12E from the quenched and aged disc broke with a transcrystalline fracture. Specimens tested in stress rupture at 1350° and 1500° F (F10A, Q12F, F11D, and Q14D) showed considerable intergranular cracking adjacent to the fracture.

DISCUSSION OF RESULTS

The tensile, stress-rupture, creep, and time-deformation data provide as nearly complete design information for the S-816 discs, NR-76B-F and NR-76B-Q, as can be obtained in the laboratory from tests under constant tensile stress.

The test data contained in this report apply only to the particular discs tested and fabricated and heat-treated in the manner indicated. Considerable experience indicates that the properties depend on the particular manufacturing process used in the production of the discs. It should not be assumed that the properties herein reported apply to discs of a similar composition produced by another fabricator or necessarily to similar discs produced by the same fabricator.

SUMMARY OF RESULTS

The principal results obtained from the 17-inch-diameter by $3\frac{5}{16}$-inch-thick discs may be summarized as follows:

	Forged and aged disc, NR-76B-F	Heat-treated and aged disc, NR-76B-Q
1. Brinell hardness range:		
On center plane at rim	300	280
On center plane at center	270	260
2. Offset yield strengths:		
0.2-percent-offset yield strength, psi, at –		
Room temperature	85,600	76,500
1200° F	67,000	58,000
1350° F	59,000	54,500
1500° F	49,000	51,000
3. Rupture test characteristics:		
Stress, psi, to cause rupture at 1200° F in –		
10 hours	78,000	80,000
100 hours	62,000	66,000
1000 hours	50,000	52,000
Stress, psi, to cause rupture at 1350° F in –		
10 hours	52,000	52,000
100 hours	38,000	39,000
1000 hours	29,000	29,000
Stress, psi, to cause rupture at 1500° F in –		
10 hours	30,000	29,000
100 hours	21,000	23,000
1000 hours	13,500	17,500

The elongations and reductions of area of the fractured rupture test specimens were generally satisfactory with the exception of some specimens of the forged and aged disc, NR-76B-F, tested at 1500° F. Increased rupture time did not produce a significant change in ductility.

4. Total-deformation characteristics under stress:

The data for the two discs are shown elsewhere in this report and will not be repeated here. Briefly, the heat-treated and aged disc was generally superior at 1200° F, although extrapolation of the data obtained indicated that for long times at low stresses (0.1- and 0.2-percent total deformation) the forged and aged disc might be superior. The forged and aged disc was superior at 1350° F, and at 1500° F the solution-treated and aged disc was superior except at low stresses (0.1-percent total deformation). No explanation has been found for the fact that the forged and aged disc was quite definitely superior at 1350° F, while the heat-treated and aged disc was superior at both 1200° and 1500° F.

For very long time service, the order of superiority described might be changed somewhat. This is evidenced by the fact that the creep strengths (0.0001 percent per hour and 0.00001 percent per hour) of the forged and aged disc were equal or superior to those of the heat-treated and aged disc at all three test temperatures, except for the 0.0001-percent-per-hour creep strength at 1500° F where the heat-treated and aged disc had the higher strength.

5. Uniformity:

The properties of the discs were quite uniform in view of the size of the forging and the characteristics of the alloy.

6. Stability:

The impact strength and ductility decreased after creep testing at 1200°, 1350°, and 1500° F. The ultimate-strength values from tensile tests decreased after creep testing at all three temperatures. The yield strengths of the forged and aged disc changed very little after creep testing at 1200° and 1350° F and decreased after testing at 1500° F. The yield strengths of the heat-treated and aged disc increased after creep testing at 1200° and 1350° F and decreased after creep testing at 1500° F.

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TABLE I.– SHORT-TIME TENSILE PROPERTIES OF S-816 ALLOY DISCS NR-76B

[Pulled at 0.02 in./min through yield strengths, then 0.06 in./min to rupture]

Disc (a)	Specimen number	Specimen location	Test temperature (°F)	Tensile strength (psi)	Offset yield strengths (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Modulus of elasticity
					0.02 percent	0.1 percent	0.2 percent				
NR-76B-F (forged)	[b]F17X	Surface	Room	153,000	66,800	84,000	91,000	48,600	20.5	19.9	30.4×10^6
	[b]F18X	Surface	Room	150,300	67,400	82,500	89,000	47,400	18.9	19.5	34.0
	[b]F17Y	Interior	Room	149,400	60,000	75,000	81,200	43,600	23.0	23.4	32.5
	[b]F18Y	Interior	Room	147,100	58,000	74,500	81,000	37,400	19.5	19.2	33.5
	[c]F4X	Surface	1200	117,500	53,000	63,000	67,000	41,500	[d]14.5	14.1	26.5
	[c]F6Z	Surface	1200	121,750	51,800	63,500	67,000	42,000	[d]17	15.9	25.0
	[c]F6X	Surface	1350	94,000	53,700	61,600	66,000	39,000	23.5	24.4	25.0
	[c]F6Y	Interior	1350	83,250	44,400	50,000	52,800	36,000	22.5	22.0	23.8
	[b]F5X	Surface	1500	57,500	35,200	44,000	46,800	27,000	----	----	24.1
	[b]F5Y	Interior	1500	60,400	40,500	48,500	51,000	31,000	16.5	19.9	24.0
NR-76B-Q (quenched)	[b]Q2X	Surface	Room	149,500	58,800	71,800	77,800	35,900	32.5	25.9	35.2
	[b]Q3X	Surface	Room	149,000	55,900	71,400	77,400	34,400	33.0	29.0	33.3
	[b]Q2Y	Interior	Room	140,300	55,000	68,800	74,400	30,000	18.5	16.9	32.1
	[b]Q3Y	Interior	Room	138,400	56,400	70,400	76,400	32,900	16.2	15.7	32.5
	[c]Q7X	Surface	1200	107,750	48,500	54,300	57,000	37,500	[d]13	14.8	27.2
	[c]Q8Y	Interior	1200	105,500	50,000	56,700	60,000	37,500	[d]12	13.4	25.8
	[c]Q6X	Surface	1350	84,000	44,500	50,000	52,600	35,000	25.5	22.7	25.0
	[c]Q8Z	Surface	1350	83,000	48,500	54,200	56,800	40,000	23	21.6	24.0
	[b]Q9X	Surface	1500	58,500	44,400	48,500	50,200	40,000	19.6	23.0	29.5
	[b]Q9Y	Interior	1500	63,200	42,400	50,000	51,500	34,900	16.0	16.2	17.0

[a]Heat treatments:

NR-76B-F: As-forged and aged; 16 hr at 1400° F, air-cool.

NR-76B-Q: Heat-treated and aged; 2300° F, $2\frac{1}{2}$ hr water-quenched; 16 hr at 1400° F, air-cool.

[b]Navy data.

[c]NACA data.

[d]Broke in gage mark.

NACA

TABLE II.- CHARPY NOTCHED-BAR IMPACT RESISTANCE AT ROOM TEMPERATURE 1200°, 1350°, AND 1500° F FOR S-816 ALLOY DISCS NR-76B

[Navy data: 0.394-in. square specimens with a 0.079-in.-deep V-notch]

Disc (1)	Specimen number	Specimen location	Test temperature (°F)	Charpy impact strength (ft-lb)	Average Charpy impact strength (ft-lb)
NR-76B-F (forged)	8D	Interior	Room	15	
	14X6	Interior	Room	27	23
	15X4	Interior	Room	27	
	7A	Surface	Room	22	
	15X1	Surface	Room	27	28
	14Z1	Surface	Room	36	
	7D	Interior	1200	31	
	14Z6	Interior	1200	47	40
	15X6	Interior	1200	43	
	8F	Surface	1200	43	
	14X3	Surface	1200	54	45
	15X2	Surface	1200	39	
	14X4	Interior	1350	41	
	14X5	Interior	1350	42	41
	15X5	Interior	1350	39	
	14X1	Surface	1350	45	
	14Z2	Surface	1350	61	53
	15X3	Surface	1350	54	
	7C	Interior	1500	31	
	14Z4	Interior	1500	50	43
	14Z5	Interior	1500	48	
	7F	Surface	1500	48	
	14X2	Surface	1500	34	44
	14Z3	Surface	1500	50	
NR-76B-Q (quenched)	15D	Interior	Room	18	
	16C	Interior	Room	16	17
	18B	Interior	Room	18	
	8X1	Surface	Room	21	22
	18F	Surface	Room	24	
	15B	Interior	1200	42	
	17C	Interior	1200	39	40
	19D	Interior	1200	38	
	15A	Surface	1200	47	
	17F	Surface	1200	50	46
	18A	Surface	1200	42	
	15C	Interior	1350	38	
	16D	Interior	1350	35	37
	18D	Interior	1350	38	
	8X2	Surface	1350	37	
	16F	Surface	1350	51	44
	19A	Surface	1350	43	
	17D	Interior	1500	40	
	18C	Interior	1500	34	37
	19C	Interior	1500	36	
	15F	Surface	1500	51	
	17A	Surface	1500	48	49
	19F	Surface	1500	50	

[1]Heat treatments:
NR-76B-F: As-forged and aged; 16 hr at 1400° F, air-cool.
NR-76B-Q: Heat-treated and aged; 2300° F, $2\frac{1}{2}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

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TABLE III.– RUPTURE TEST DATA AT 1200°, 1350°, AND 1500° F

FOR S-816 ALLOY DISCS NR-76B

Disc (a)	Specimen number	Specimen location	Test temperature (°F)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)	Minimum creep rate (percent/hr)
NR-76B-F (forged)	[b]F9E	Interior	1200	60,000	130	[c]8	9	0.050
	[b]F9C	Interior	1200	55,000	246	[c]11	10.5	.034
	[b]F10E	Interior	1200	55,000	638	13	13.8	.015
	[b]F9B	Interior	1200	50,000	658	[c]10	9.4	.0068
	[b]F9A	Surface	1200	45,000	2618	[c]7	6.4	.0012
	[b]F9D	Interior	1350	60,000	3.5	[c]15	16.2	------
	[b]F10C	Interior	1350	40,000	58	[c]11	12.1	------
	[b]F10B	Interior	1350	35,000	212	[c]10	10.2	.028
	[b]F10F	Surface	1350	35,000	275	8	8.6	.018
	[b]F10D	Interior	1350	30,000	565	14	12.5	.0145
	[b]F10A	Surface	1350	27,000	1894	[c]3	4.7	.0009
	[d]F11A	Surface	1500	25,000	33	2	2.4	.0175
	[d]F11B	Interior	1500	21,000	81	3	5.5	.0137
	[d]F11E	Interior	1500	18,000	236	8	5.6	.010
	[d]F11C	Interior	1500	16,500	362	2	.8	.0015
	[d]F11D	Interior	1500	13,500	1132	4	2.3	.0014
NR-76B-Q (quenched)	[b]Q12A	Surface	1200	65,000	118	[c]7	10.2	------
	[b]Q12B	Interior	1200	60,000	203	[c]6	4.8	.025
	[b]Q12D	Interior	1200	55,000	683	[c]7	7.1	.0075
	[b]Q12E	Interior	1200	50,000	1699	[c]7	4.5	.0026
	[b]Q13A	Surface	1350	40,000	82	[c]11	14.7	------
	[b]Q13B	Interior	1350	35,000	253	[c]14	9.8	.030
	[b]Q12C	Interior	1350	30,000	868	10	9.8	.0047
	[b]Q12F	Surface	1350	27,500	1286	8	10.2	.0023
	[d]Q14A	Surface	1500	25,000	45	7	7.0	.046
	[d]Q14B	Interior	1500	22,000	136	7.5	7.8	.012
	[d]Q14C	Interior	1500	19,500	443	5	4.7	.0026
	[d]Q14D	Interior	1500	17,500	928	4	3.2	.0015
	[d]Q14F	Surface	1500	16,000	(e)	-----	----	------

Rupture strength

Disc	Temperature (°F)	Stress (psi) for rupture in –			
		10 hr	100 hr	1000 hr	2000 hr
NR-76B-F (forged)	1200	[f]75,000	62,000	50,000	47,000
	1350	52,000	38,000	29,000	26,500
	1500	[f]30,000	21,000	13,500	[f]12,000
NR-76B-Q (quenched)	1200	[f]80,000	66,000	52,000	49,000
	1350	[f]52,000	39,000	29,000	[f]26,000
	1500	[f]29,000	23,000	17,500	[f]16,000

[a]Heat treatments:
NR-76B-F: As-forged and aged; 16 hr at 1400° F, air-cool.
NR-76B-Q: Heat-treated and aged; 2300° F, $2\frac{1}{2}$ hr, water-quenched; 16 hr at 1400° F, air-cool.
[b]NACA data; 0.250-in.-diameter specimens with a 1-in. gage length.
[c]Broke in gage mark.
[d]Navy data; 0.250-in.-diameter specimens with a 1.3-in. gage length.
[e]The extensometer was insecure during this test and deformation readings after 50 hr were in error because of rupture of adjacent units. The test was discontinued at 527 hr. Measurement of the specimen after removal from test showed 1.0-percent elongation and 2.4-percent reduction of area.
[f]Estimated values extrapolated from figs. 7 to 13.

TABLE IV.– DATA FOR STRESS AND TIME FOR TOTAL DEFORMATION AT 1200° F FOR S-816 ALLOY DISCS NR-76B

[NACA data]

Disc (a)	Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of –						Transition to third-stage creep	
				0.1 percent	0.2 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
NR-76B-F (forged)	[b]F2Y	25,000	0.087	8	875	----	-----	---	----	----	---
	[b]F2Z	35,000	.133	--	30	503	[c]1850	---	----	----	---
	[d]F9A	45,000	.196	--	1	100	380	970	----	1840	3.2
	[d]F9B	50,000	.210	--	----	11	33	92	347	625	7.4
	[d]F9C	55,000	.250	--	----	4	19	52	139	160	5.7
	[d]F10E	55,000	.365	--	----	7	24	58	208	400	7.8
	[d]F9E	60,000	.300	--	----	[c]1	4	17	68	120	7.1
NR-76B-Q (quenched)	[b]Q6Z	24,000	.088	25	1480	----	-----	---	----	----	---
	[b]Q6Y	35,000	.133	--	85	1030	-----	---	----	----	---
	[d]Q12E	50,000	.276	--	----	44	163	415	1480	1630	5.4
	[d]Q12D	55,000	.351	--	----	14	85	182	550	450	4.0
	[d]Q12B	60,000	.440	--	----	[c]3	15	44	168	----	---
	[d]Q12A	65,000	.650	--	----	----	4	17	72	----	---

Disc (a)	Total deformation (percent)	Stress (psi) to cause total deformation in –				
		1 hr	10 hr	100 hr	1000 hr	2000 hr
NR-76B-F (forged)	0.1	-------	[c]24,500	-------	-------	-------
	.2	45,000	38,000	31,500	24,500	[c]22,500
	.5	61,000	52,000	43,000	33,500	30,500
	1.0	-------	57,000	48,000	38,000	35,500
	Transition	-------	-------	59,500	48,000	44,500
NR-76B-Q (quenched)	.1	-------	[c]27,000	[c]19,500	-------	-------
	.2	-------	[c]43,000	34,500	25,500	[c]23,000
	.5	[c]65,000	55,500	46,000	36,000	[c]33,000
	1.0	[c]71,000	62,000	52,500	[c]43,000	[c]40,000
	Transition	-------	-------	[c]64,000	52,000	48,000

Disc (a)	Creep strength (psi) at 1000 hr for creep rates of –	
	0.0001 percent/hr	0.00001 percent/hr
NR-76B-F (forged)	28,000	[c]18,000
NR-76B-Q (quenched)	28,000	[c]16,000

[a]Heat treatments:
NR-76B-F: As-forged and aged; 16 hr at 1400° F, air-cool.
NR-76B-Q: Heat-treated and aged; 2300° F, $2\frac{1}{2}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

[b]Creep tests; 0.505-in.-diameter specimens with a 2-in. gage length.

[c]Estimated values.

[d]Stress-rupture tests; 0.250-in.-diameter specimens with a 1-in. gage length.

TABLE V.– DATA FOR STRESS AND TIME FOR TOTAL DEFORMATION AT 1350° F FOR S-816 ALLOY DISCS NR-76B

Disc (a)	Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of –						Transition to third-stage creep	
				0.1 percent	0.2 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
NR-76B-F (forged)	[b]F13X	12,000	0.057	400	-------	-----	-----	----	---	----	---
	[b]F2X	15,000	.072	15	1075	-----	-----	----	---	----	---
	[b]F3X	20,000	.080	4	160	-----	-----	----	---	----	---
	[b]F13Z	25,000	.094	1	110	1875	-----	----	---	----	---
	[c]F10A	27,000	.113	---	9	185	800	1695	---	1600	1.8
	[c]F10D	30,000	.125	---	1.5	10	31	86	300	300	5.2
	[c]F10B	35,000	.145	---	[d].5	5	16	47	144	100	3.5
	[c]F10F	35,000	.164	---	.5	12	40	100	245	130	2.5
	[c]F10C	40,000	.170	---	-------	[d]1	[d]2.5	6	20	----	---
NR-76B-Q (quenched)	[b]Q4Z	12,000	.057	175	[d]3000	-----	-----	----	---	----	---
	[b]Q9Z	12,000	.053	225	[d]8000	-----	-----	----	---	----	---
	[b]Q4X	15,000	.072	28	580	-----	-----	----	---	----	---
	[b]Q1Y	18,000	.078	8	132	[d]3800	-----	----	---	----	---
	[b]Q4Y	21,840	.096	1	50	890	-----	----	---	----	---
	[c]Q12F	27,500	.115	---	5	58	243	688	---	820	2.3
	[c]Q12C	30,000	.126	---	2.5	33	124	343	845	440	2.5
	[c]Q13B	35,000	.140	---	-------	[d]2	8	36	125	100	4.0
	[c]Q13A	40,000	.165	---	-------	<1	4	10	38	45	6.0

Disc (a)	Total deformation (percent)	Stress (psi) to cause total deformation in –				
		1 hr	10 hr	100 hr	1000 hr	2000 hr
NR-76B-F (forged)	0.1	24,000	17,000	13,000	[d]10,000	[d]9,500
	.2	33,000	27,500	22,000	16,500	[d]15,000
	.5	39,000	33,000	28,000	24,500	23,000
	1.0	43,000	37,000	31,000	[d]26,500	[d]25,000
	Transition	-------	------	35,500	28,000	[d]26,000
NR-76B-Q (quenched)	.1	21,000	17,000	13,000	[d]9,000	[d]8,000
	.2	[d]30,000	25,000	20,000	15,000	13,500
	.5	38,500	33,000	27,000	21,500	19,500
	1.0	[d]43,000	36,500	30,000	[d]23,500	[d]21,500
	Transition	-------	------	36,000	27,000	[d]24,000

Disc (a)	Creep strength (psi) at 1000 hr for creep rates of –	
	0.0001 percent/hr	0.00001 percent/hr
NR-76B-F (forged)	20,000	13,000
NR-76B-Q (quenched)	19,000	10,500

[a]Heat treatments:
NR-76B-F: As-forged and aged; 16 hr at 1400° F, air-cool.
NR-76B-Q: Heat-treated and aged; 2300° F, $2\frac{1}{2}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

[b]Navy data from creep tests; 0.505-in.-diameter specimens with a 2-in. gage length.
[c]NACA data from stress-rupture tests; 0.250-in.-diameter specimens with a 1-in. gage length.
[d]Estimated values.

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TABLE VI.– DATA FOR STRESS AND TIME FOR TOTAL DEFORMATION AT 1500° F FOR S-816 ALLOY DISCS NR-76B

[Navy data]

Disc (a)	Specimen number	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of –						Transition to third-stage creep	
				0.1 percent	0.2 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
NR-76B-F (forged)	[b]F1Y	8,000	0.033	235	-------	----	---	---	--	----	---
	[b]F13Y	10,000	.052	55	900	----	---	---	--	----	---
	[b]F1Z	10,000	.044	175	[c]2150	----	---	---	--	----	---
	[b]F5Z	13,000	.080	8	155	1325	---	---	--	1140	4.5
	[d]F11D	13,500	-----	4	30	210	535	970	--	500	.9
	[d]F11C	16,500	-----	1	43	230	---	---	--	170	.4
	[d]F11E	18,000	-----	---	2	20	68	145	--	100	1.4
	[d]F11B	21,000	-----	---	2	23	51	77	--	25	.5
	[d]F11A	25,000	-----	---	.5	14	30	---	--	10	.4
NR-76B-Q (quenched)	[b]Q5Y	8,000	.045	210	-------	----	---	---	--	----	---
	[b]Q5X	10,000	.052	20	885	----	---	---	--	----	---
	[b]Q5Z	13,000	.072	20	205	----	---	---	--	----	---
	[d]Q14D	17,500	-----	---	15	190	510	806	--	540	1.0
	[d]Q14C	19,500	-----	---	4	96	218	340	--	130	.6
	[d]Q14B	22,000	-----	---	1	19	44	76	--	21	.5
	[d]Q14A	25,000	-----	---	-------	6	17	30	--	16	1.0

Disc (a)	Total deformation (percent)	Stress (psi) to cause total deformation in –				
		1 hr	10 hr	100 hr	1000 hr	2000 hr
NR-76B-F (forged)	0.1	16,200	12,500	9,000	[c]5,500	[c]4,500
	.2	22,000	18,000	13,800	9,600	8,500
	.5	-------	23,000	17,000	11,200	[c]9,500
	1.0	-------	[c]25,000	18,500	12,000	[c]10,200
	Transition	-------	24,000	18,000	12,000	[c]10,300
NR-76B-Q (quenched)	.1	------	[c]12,500	9,000	[c]5,500	-------
	.2	22,000	18,000	14,000	10,000	[c]8,800
	.5	[c]28,000	23,500	19,000	[c]14,700	[c]13,400
	1.0	-------	[c]25,800	21,000	[c]16,000	[c]14,500
	Transition	-------	[c]24,500	20,200	[c]16,000	[c]14,500

Disc (a)	Creep strength (psi) at 1000 hr for creep rates of –	
	0.0001 percent/hr	0.00001 percent/hr
NR-76B-F (forged)	11,000	8,500
NR-76B-Q (quenched)	13,500	7,500

[a]Heat treatments:
NR-76B-F: As-forged and aged; 16 hr at 1400° F, air-cool.
NR-76B-Q: Heat-treated and aged; 2300° F, $2\frac{1}{2}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

[b]Data from creep tests; 0.505-in.-diameter specimens with a 2-in. gage length.

[c]Estimated values.

[d]Data from stress-rupture tests; 0.250-in.-diameter specimens with a 1-in. gage length.

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TABLE VII.- COMPARISON OF ROOM-TEMPERATURE AND HIGH-TEMPERATURE PROPERTIES OF SEVERAL LARGE FORGED DISCS OF LOW-CARBON N-155, S-590, AND S-816 ALLOYS

Test temperature, °F	Room temperature					1200				
Alloy	Low-carbon N-155 (b)	S-590 (c)		S-816		Low-carbon N-155 (b)	S-590 (c)		S-816	
Disc number[a]	NR-66D	NR-74B-F	NR-74B-QA	NR-76B-F	NR-76B-Q	NR-66D	NR-74B-F	NR-74B-QA	NR-76B-F	NR-76B-Q
Short-time properties:										
Charpy impact strength, foot-pounds	52	5	9	25	19	51	9	15	43	43
Izod impact strength, foot-pounds	56	6	7	18	19	-------	-------	-------	-------	-------
Tensile strength, psi	118,000	129,050	130,500	150,000	144,000	83,000	88,700	81,600	120,000	106,000
0.1-percent-offset yield strength, psi	69,000	90,000	63,500	79,000	70,000	47,500	66,250	46,000	63,000	56,000
0.2-percent-offset yield strength, psi	72,500	98,250	70,500	85,000	76,000	50,000	71,750	49,000	67,000	58,000
Elongation, percent	35.4	8	17	21	30	21	15	27	16	12
Rupture strengths, psi:										
10-hr	-------	-------	-------	-------	-------	65,000	[d]69,000	[d]66,000	[d]78,000	[d]84,000
100-hr	-------	-------	-------	-------	-------	55,000	52,500	52,000	62,000	66,000
1000-hr	-------	-------	-------	-------	-------	42,000	40,000	42,000	50,000	53,000
Creep strengths, psi:										
0.0001 percent/hr	-------	-------	-------	-------	-------	28,000	27,500	23,000	28,000	28,000
0.00001 percent/hr	-------	-------	-------	-------	-------	15,000	-------	-------	[d]18,000	[d]16,000
100-hr deformation strengths, psi:										
0.1-percent deformation	-------	-------	-------	-------	-------	17,500	-------	-------	-------	[d]19,500
0.2-percent deformation	-------	-------	-------	-------	-------	28,000	28,500	26,000	31,500	34,500
0.5-percent deformation	-------	-------	-------	-------	-------	35,000	38,000	33,800	43,000	46,000
1.0-percent deformation	-------	-------	-------	-------	-------	40,000	42,000	39,500	48,000	52,500
Transition	-------	-------	-------	-------	-------	51,500	47,000	49,000	59,500	[d]64,000
1000-hr deformation strengths, psi:										
0.1-percent deformation	-------	-------	-------	-------	-------	14,500	-------	-------	-------	-------
0.2-percent deformation	-------	-------	-------	-------	-------	24,000	22,000	[d]18,500	24,500	25,500
0.5-percent deformation	-------	-------	-------	-------	-------	30,000	32,000	27,000	33,500	37,000
1.0-percent deformation	-------	-------	-------	-------	-------	35,000	34,300	33,000	38,000	[d]43,000
Transition	-------	-------	-------	-------	-------	39,500	39,000	39,000	48,000	52,000
						After creep testing at 1200° F				
Residual room-temperature properties:										
Izod impact strength, foot-pounds	-------	-------	-------	-------	-------	17.5	-------	-------	11	5.5
Tensile strength, psi	-------	-------	-------	-------	-------	118,750	127,000	131,000	139,000	138,000
0.1-percent-offset yield strength, psi	-------	-------	-------	-------	-------	72,500	85,000	78,000	79,000	81,000
0.2-percent-offset yield strength, psi	-------	-------	-------	-------	-------	76,250	94,500	85,000	87,000	88,000
Elongation, percent	-------	-------	-------	-------	-------	25	6	6	8.0	8.5

[a]Heat treatments:

NR-66D: Forged disc; stress-relieved by heating to 1200° F for 2 hr and cooling in air.

NR-74B-F: As-forged disc; aged 16 hr at 1400° F, air-cool.

NR-74B-QA: Heat-treated and aged disc; 2300° F, $3\frac{1}{4}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

NR-76B-F: As-forged and aged disc; 16 hr at 1400° F, air-cool.

NR-76B-Q: Heat-treated and aged disc; 2300° F, $2\frac{1}{2}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

[b]Data from reference 3.

[c]Data from reference 10.

[d]Estimated values.

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TABLE VII.- COMPARISON OF ROOM-TEMPERATURE AND HIGH-TEMPERATURE PROPERTIES - Concluded

Test temperature, °F	1350					1500				
Alloy	Low-carbon N-155 (b)	S-590 (c)		S-816		Low-carbon N-155 (b)	S-590 (c)		S-816	
Disc number[a]	NR-66D	NR-74B-F	NR-74B-QA	NR-76B-F	NR-76B-Q	NR-66D	NR-74B-F	NR-74B-QA	NR-76B-F	NR-76B-Q
Short-time properties:										
Charpy impact strength, foot-pounds	50	11	17	47	40	46	13	20	43	43
Izod impact strength, foot-pounds	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Tensile strength, psi	60,000	64,625	65,750	88,000	83,000	40,500	43,125	44,400	59,000	60,000
0.1-percent-offset yield strength, psi	42,000	50,750	43,500	56,000	52,000	33,000	31,350	35,050	46,000	49,000
0.2-percent-offset yield strength, psi	44,500	55,000	46,000	59,000	55,000	34,000	35,900	37,850	49,000	51,000
Elongation, percent	24.2	29	25	23	28	30.5	25	18	17	17
Rupture strengths, psi:										
10-hr	40,000	[d]42,000	[d]41,000	52,000	[d]53,000	[d]27,300	[d]29,000	-------	[d]31,000	[d]29,500
100-hr	31,000	27,500	32,000	37,500	39,000	20,000	13,100	20,000	20,500	22,800
1000-hr	24,000	18,000	25,000	27,000	29,000	14,200	6,000	15,000	13,700	17,500
Creep strengths, psi:										
0.0001 percent/hr	16,000	10,600	16,400	19,500	19,000	8,700	[d]2,800	10,000	11,000	13,500
0.00001 percent/hr	7,900	-------	12,100	13,000	10,500	[d]5,000	-------	7,100	8,500	7,500
100-hr deformation strengths, psi:										
0.1-percent deformation	11,000	-------	-------	13,000	13,000	7,700	-------	9,400	9,000	9,000
0.2-percent deformation	16,700	13,100	14,700	22,000	20,000	11,000	-------	11,000	13,800	14,000
0.5-percent deformation	22,000	17,000	21,400	28,000	27,000	15,500	6,500	14,800	17,000	19,000
1.0-percent deformation	25,000	20,500	24,100	31,000	30,000	17,400	9,000	17,200	18,500	21,000
Transition	24,000	24,500	29,000	35,500	36,000	16,400	9,300	16,700	18,000	20,200
1000-hr deformation strengths, psi:										
0.1-percent deformation	8,000	-------	-------	[d]10,000	[d]9,000	[d]5,300	-------	[d]7,300	[d]5,500	[d]5,500
0.2-percent deformation	12,000	[d]8,000	8,700	16,500	15,000	6,800	-------	9,200	9,600	10,000
0.5-percent deformation	17,200	13,000	17,000	24,500	21,500	10,500	-------	11,600	11,200	[d]14,700
1.0-percent deformation	19,500	15,500	20,800	[d]26,500	[d]23,500	12,000	[d]4,000	13,600	12,000	[d]16,000
Transition	18,000	14,500	22,500	28,000	27,000	11,200	[d]4,200	12,800	12,000	[d]16,000
Residual room-temperature properties:	After creep testing at 1350° F					After creep testing at 1500° F				
Izod impact strength, foot-pounds	4.6	2	4	7	7.8	4.5	-------	2	5.5	4.8
Tensile strength, psi	126,500	110,500	132,500	136,500	133,500	114,000	105,000	116,000	123,000	119,000
0.1-percent-offset yield strength, psi	65,500	76,000	72,000	82,000	75,500	50,500	71,200	55,000	67,000	65,000
0.2-percent-offset yield strength, psi	69,500	85,000	79,000	89,000	81,000	54,500	80,800	62,500	75,500	71,500
Elongation, percent	13	1	3	9.0	10.7	15	1.5	5	7.4	7.0

[a]Heat treatments:

NR-66D: Forged disc; stress-relieved by heating to 1200° F for 2 hr and cooling in air.

NR-74B-F: As-forged disc; aged 16 hr at 1400° F, air-cool.

NR-74B-QA: Heat-treated and aged disc; 2300° F, $3\frac{1}{4}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

NR-76B-F: As-forged and aged disc; 16 hr at 1400° F, air-cool.

NR-76B-Q: Heat-treated and aged disc; 2300° F, $2\frac{1}{2}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

[b]Data from reference 3.

[c]Data from reference 10.

[d]Estimated values.

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TABLE VIII.– CREEP TEST DATA AT 1200°, 1350°, AND 1500° F FOR S-816 ALLOY DISCS NR-76B

[All specimens were 0.505-in. in diameter with a 2-in. gage length]

Disc (a)	Specimen number	Test temperature (°F)	Stress (psi)	Duration (hr)	Initial deformation (percent)	Creep rate (percent/hr) at –				Total deformation (percent) at –			
						500 hr	1000 hr	1500 hr	2000 hr	500 hr	1000 hr	1500 hr	2000 hr
NR-76B-F (forged)	[b]F2Y	1200	25,000	1124	0.087	0.000083	0.000050	--------	--------	0.172	0.205	-----	-----
	[b]F2Z	1200	35,000	1124	.133	.000415	.000372	--------	--------	.498	.688	-----	-----
	[c]F13X	1350	12,000	2065	.057	.000050	.000040	0.000020	0.000012	.105	.126	0.137	0.145
	[c]F2X	1350	15,000	2016	.072	.000076	.000046	.000033	.000032	.168	.195	.218	.235
	[c]F3Z	1350	20,000	1344	.080	.000172	.000116	[d].00010	--------	.270	.336	[d].370	-----
	[c]F13Z	1350	25,000	2015	.094	.000195	.000155	.000130	.000130	.296	.382	.450	.517
	[c]F1Y	1500	8,000	2490	.033	.000065	.000045	.000022	.000020	.125	.146	.160	.167
	[c]F13Y	1500	10,000	1995	.052	.000105	.000065	.000043	.000038	.170	.210	.231	.246
	[c]F1Z	1500	10,000	2010	.044	.000055	.000055	.000032	.000017	.129	.160	.182	.194
	[c]F5Z	1500	13,000	1956	.080	.000240	.000200	.000250	.000305	.307	.420	.545	.675
NR-76B-Q (quenched)	[b]Q6Z	1200	24,000	1008	.088	.000065	.000050	--------	--------	.148	.176	-----	-----
	[b]Q6Y	1200	35,000	1008	.133	.000290	.000270	--------	--------	.352	.490	-----	-----
	[c] [e]Q4Z	1350	12,000	2012	.057	.000065	.000030	.000022	.000022	.129	.154	.167	.178
	[c]Q9Z	1350	12,000	2040	.053	.000030	.000020	.000015	.000012	.101	.113	.123	.128
	[c]Q4X	1350	15,000	2213	.072	.000095	.000040	.000024	.000030	.194	.223	.233	.258
	[c]Q1Y	1350	18,000	2120	.078	.000175	.000080	.000062	.000060	.281	.337	.373	.400
	[c]Q4Y	1350	21,840	942	.096	.000305	[f].000285	--------	--------	.391	[f].515	-----	-----
	[c]Q5Y	1500	8,000	1963	.045	.000055	.000027	.000015	.000015	.118	.141	.151	.157
	[c]Q5X	1500	10,000	2137	.052	.000075	.000046	.000027	.000027	.182	.208	.224	.243
	[c]Q5Z	1500	13,000	2002	.072	.00019	.00012	.000094	.000094	.262	.332	.383	.433

[a]Heat treatments:

NR-76B-F: As-forged and aged; 16 hr at 1400° F, air-cool.

NR-76B-Q: Heat-treated and aged; 2300° F, $2\frac{1}{2}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

[b]NACA data.

[c]Navy data.

[d]At 1344 hr, when test was discontinued.

[e]Because of controller failures, the temperature was high at 585 hr for 1 hr, maximum 1420° F; and at 650 hr for $3\frac{1}{2}$ hr, maximum 1470° F. The creep rates and deformations may have been increased by these temperature rises.

[f]Values at 942 hr, when test was discontinued.

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TABLE IX.– EFFECT OF CREEP TESTING AT 1200°, 1350°, AND 1500° F ON THE ROOM-TEMPERATURE

PHYSICAL PROPERTIES OF S-816 ALLOY DISCS NR-76B

Disc (a)	Specimen	Prior testing conditions			Residual room-temperature properties									
		Temperature (°F)	Stress (psi)	Time (hr)	Tensile strength (psi)	Offset yield strength (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Izod impact strength (ft-lb)		Vickers hardness
						0.02 percent	0.1 percent	0.2 percent				Navy	NACA	
NR-76B-F (forged)	bF4Y	(c)	(c)	(c)	-------	------	------	------	------	----	----	--------	18, 18	292
	(d) (e)	(c)	(c)	(c)	150,000	63,000	79,000	85,600	44,200	20.5	20.5	f17.8	------	f320
	bF2Z	1200	35,000	1124	-------	------	------	------	------	----	----	--------	10, 12	335
	bF2Y	1200	25,000	1124	139,000	62,500	79,000	87,000	45,000	8	8.7	--------	------	----
	dF2X	1350	15,000	2016	-------	------	------	------	------	----	----	7.0, 7.0	------	334
	dF13X	1350	12,000	2065	136,500	64,000	82,000	89,000	45,000	9.0	6.2	--------	------	----
	dF13Y	1500	10,000	1995	-------	------	------	------	------	----	----	5.0, 6.0	------	323
	dF1Y	1500	8,000	2490	123,000	53,000	67,000	75,500	36,000	7.4	8.2	--------	------	----
NR-76B-Q (quenched)	bQ7Y	(c)	(c)	(c)	-------	------	------	------	------	----	----	--------	10, 10	293
	(d) (e)	(c)	(c)	(c)	144,000	56,500	70,600	76,500	33,300	25.0	21.9	g19.0	------	g326
	bQ6Y	1200	35,000	1008	-------	------	------	------	------	----	----	--------	6, 5	320
	bQ6Z	1200	24,000	1008	138,000	62,000	81,000	88,000	30,000	8.5	8.7	--------	------	----
	dQ9Z	1350	12,000	2040	-------	------	------	------	------	----	----	7.0, 8.5	------	319
	dQ1Y	1350	18,000	2120	133,500	63,500	75,500	81,000	48,000	10.7	11.9	--------	------	----
	dQ5X	1500	10,000	2137	-------	------	------	------	------	----	----	3.5, 6.0	------	312
	dQ5Y	1500	8,000	1965	119,000	50,500	65,000	71,500	31,500	7.0	7.9	--------	------	----

[a] Heat treatments:
NR-76B-F: As-forged and aged; 16 hr at 1400° F, air-cool.
NR-76B-Q: Heat-treated and aged; 2300° F, $2\frac{1}{2}$ hr, water-quenched; 16 hr at 1400° F, air-cool.

[b] NACA data (0.365-in.-square impact specimen with a 0.050-in.-deep V-notch).
[c] Original condition.
[d] Navy data (0.450-in.-diameter impact specimen with a V-notch).
[e] Tensile data from average of four tests on center- and surface-plane radial specimens at rim of disc.
[f] Impact value is average of values from four tests (F17Z – 21.0, 15.0; F18Z – 14.0, 21.0); Vickers hardness value is average of several impressions from each of two specimens (F17Z, F18Z), taken about 1/2 to 1 in. in from the worked surface of the disc.
[g] Impact value is average of values from three tests (Q11Y – 14.3, Q2Z – 22.8, Q3Z – 20.0); Vickers hardness value is average of several impressions from each of two specimens (Q11Y and a specimen from an unidentified location).

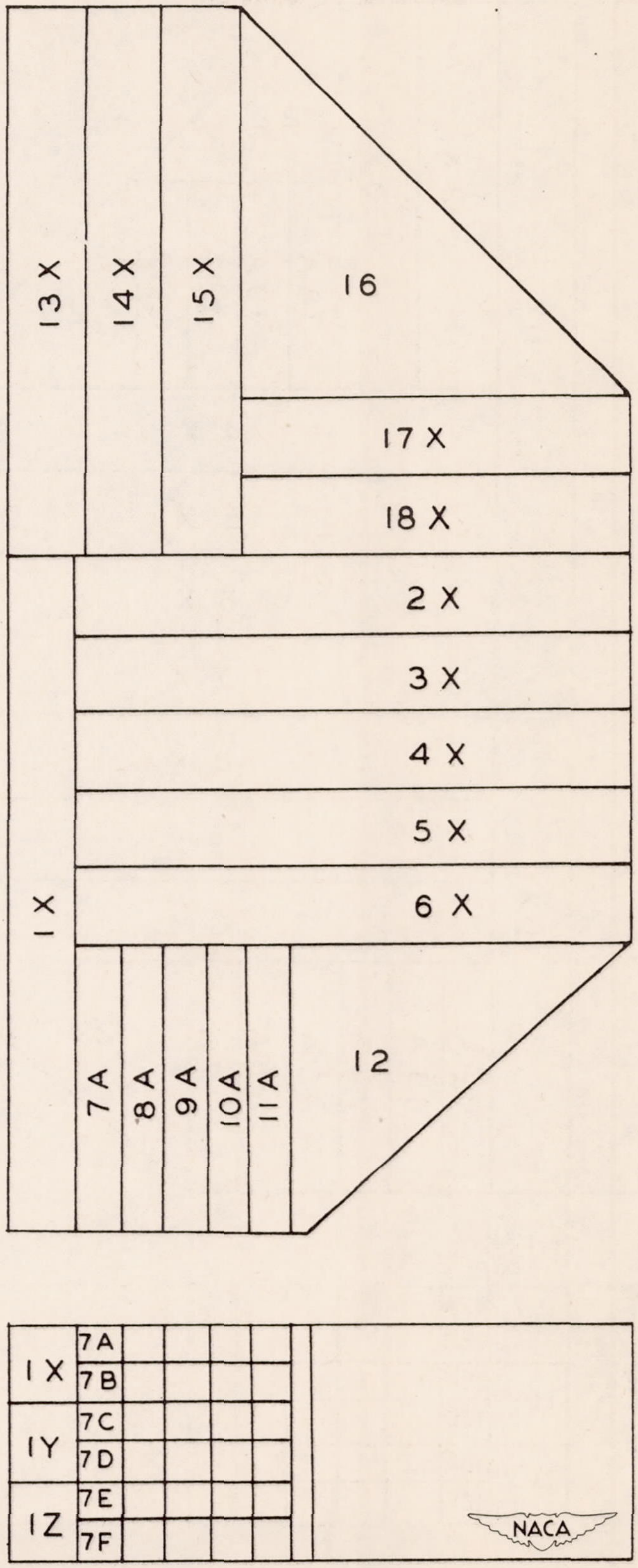


Figure 1.- Location of test coupons from as-forged and aged S-816 alloy disc NR-76B-F.

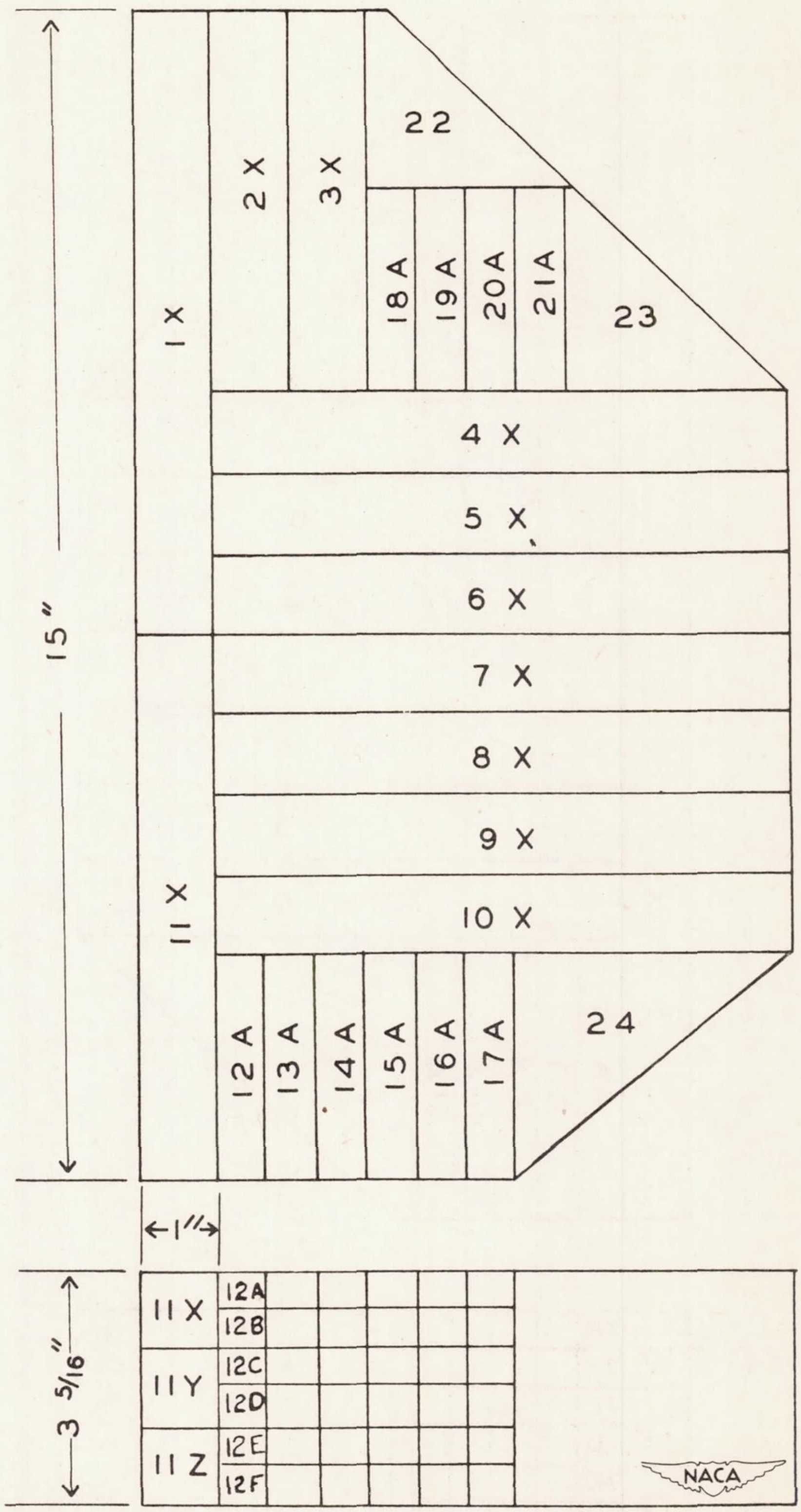


Figure 2.- Location of test coupons from solution-treated and aged S-816 alloy disc NR-76B-Q.

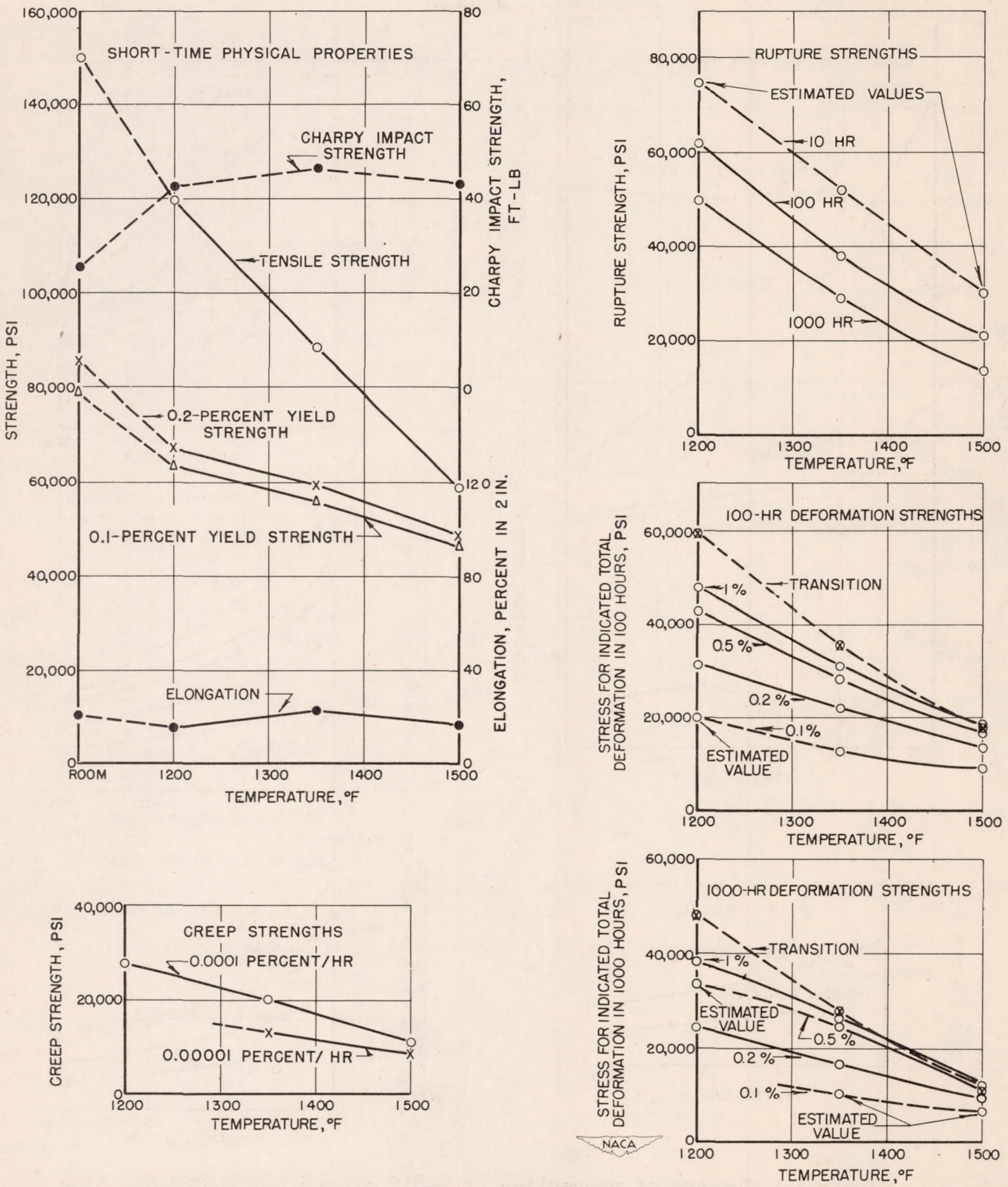


Figure 3.- Summary of properties of S-816 alloy disc NR-76B-F. Disc treatment: As-forged and aged for 16 hours at 1400° F.

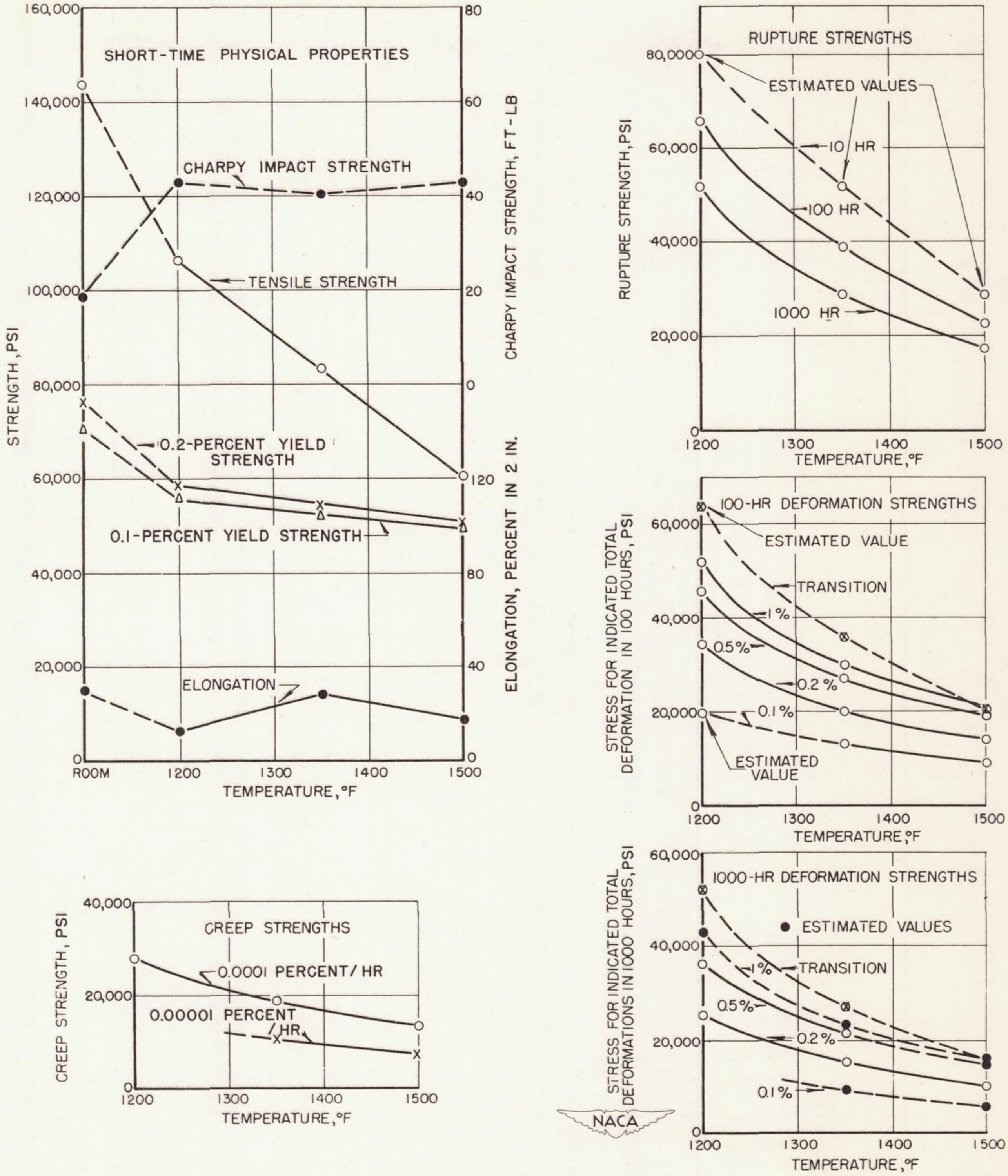


Figure 4.- Summary of properties of S-816 alloy disc NR-76B-Q. Disc treatment: As-forged, water-quenched after $2\frac{1}{2}$ hours at 2300° F, and aged for 16 hours at 1400° F.

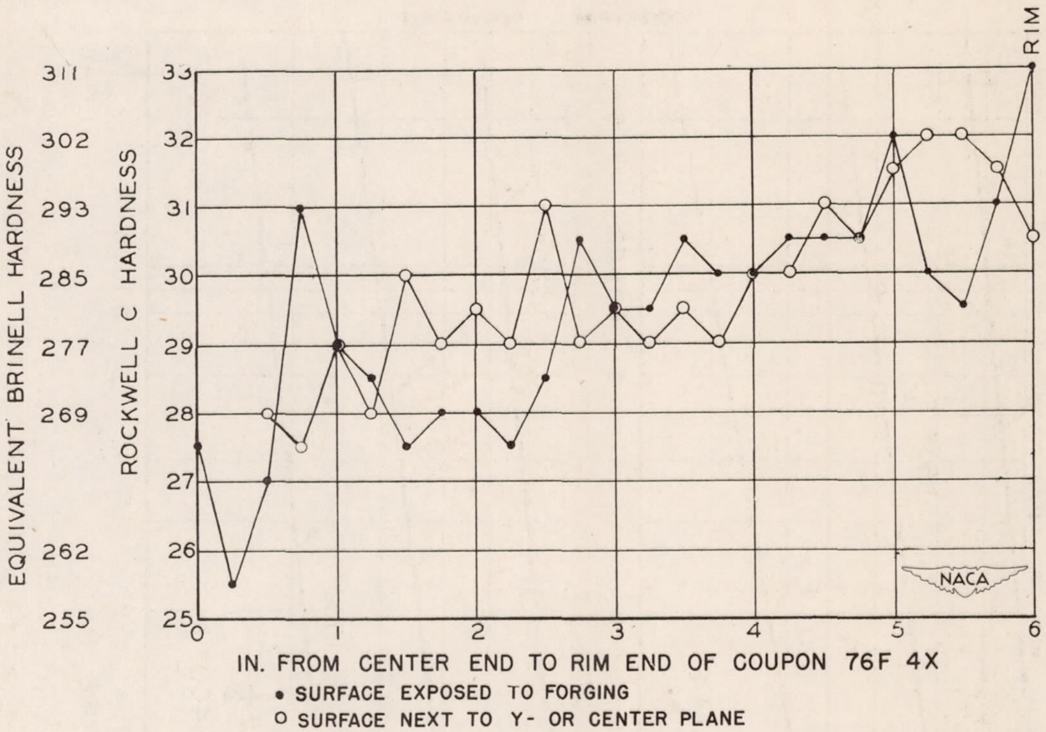


Figure 5.- Variation in hardness from center to rim of as-forged and aged S-816 alloy disc NR-76B-F.

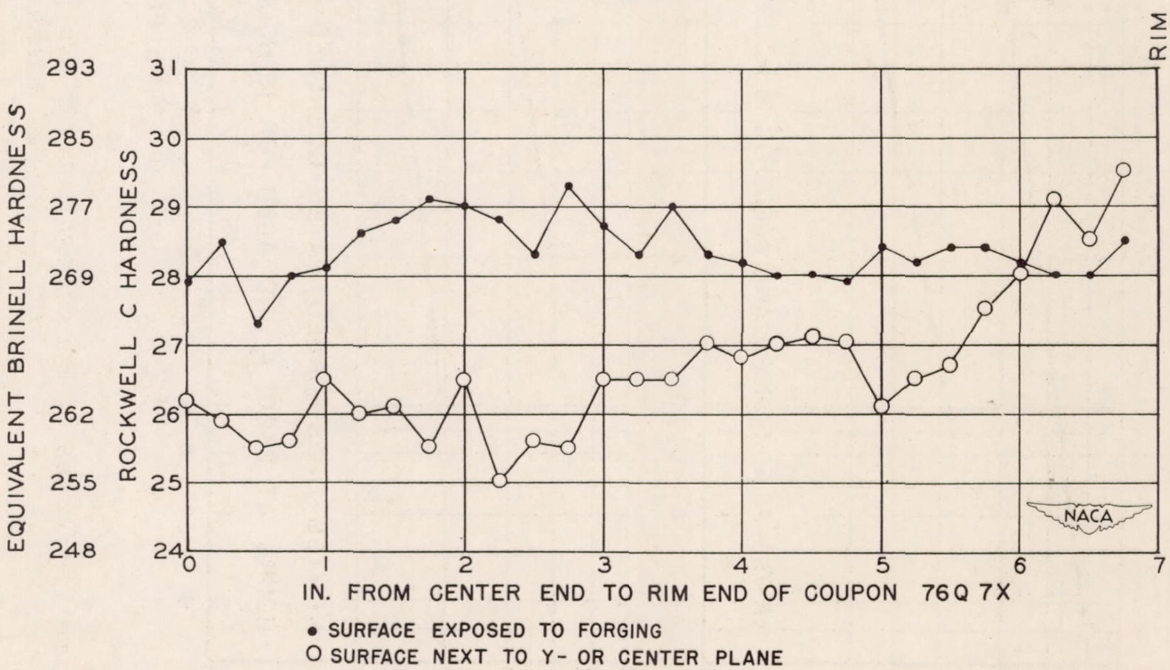


Figure 6.- Variation in hardness from center to rim of solution-treated and aged S-816 disc NR-76B-Q.

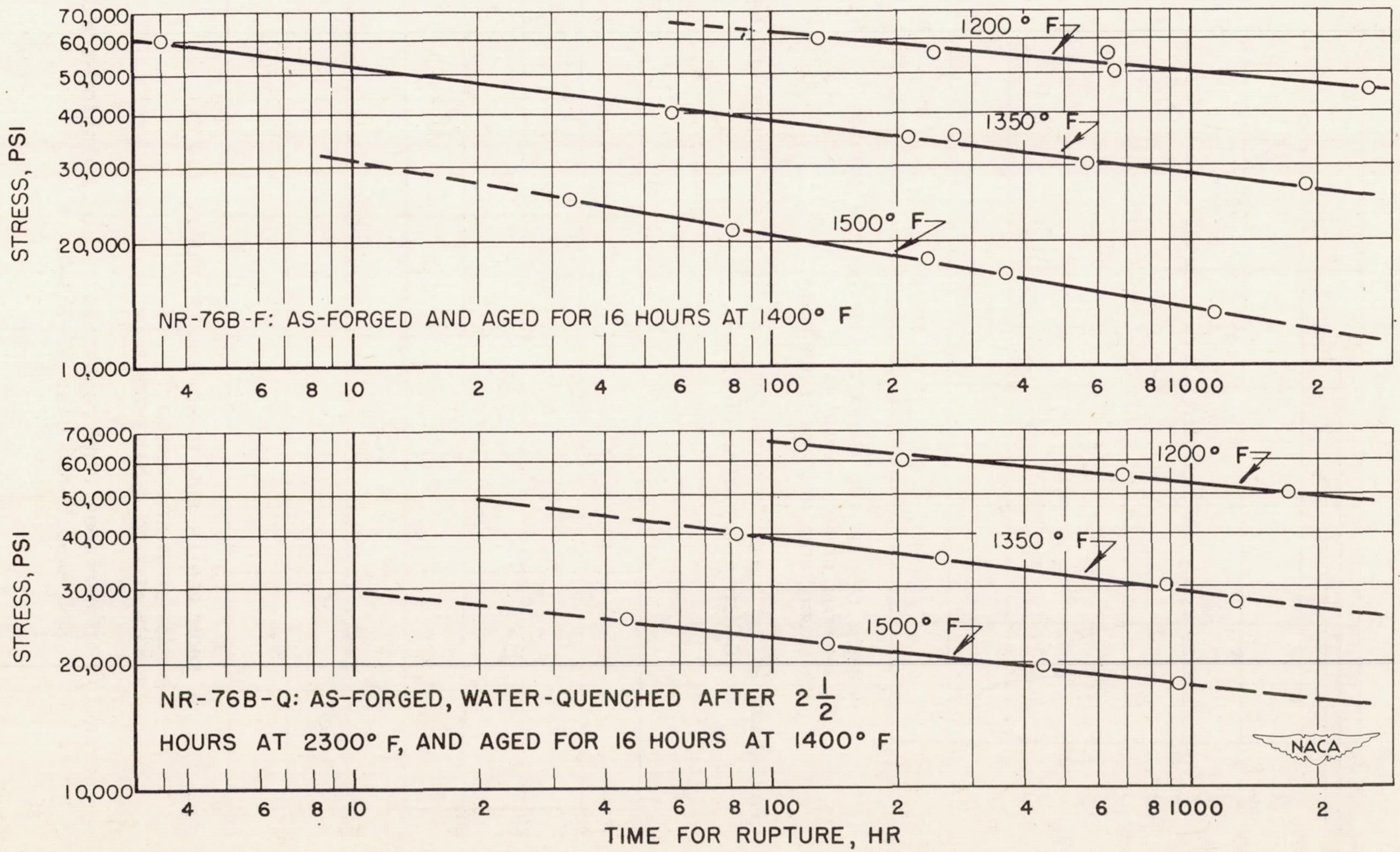


Figure 7.- Curves of stress against rupture time at 1200°, 1350°, and 1500° F for S-816 alloy discs NR-76B.

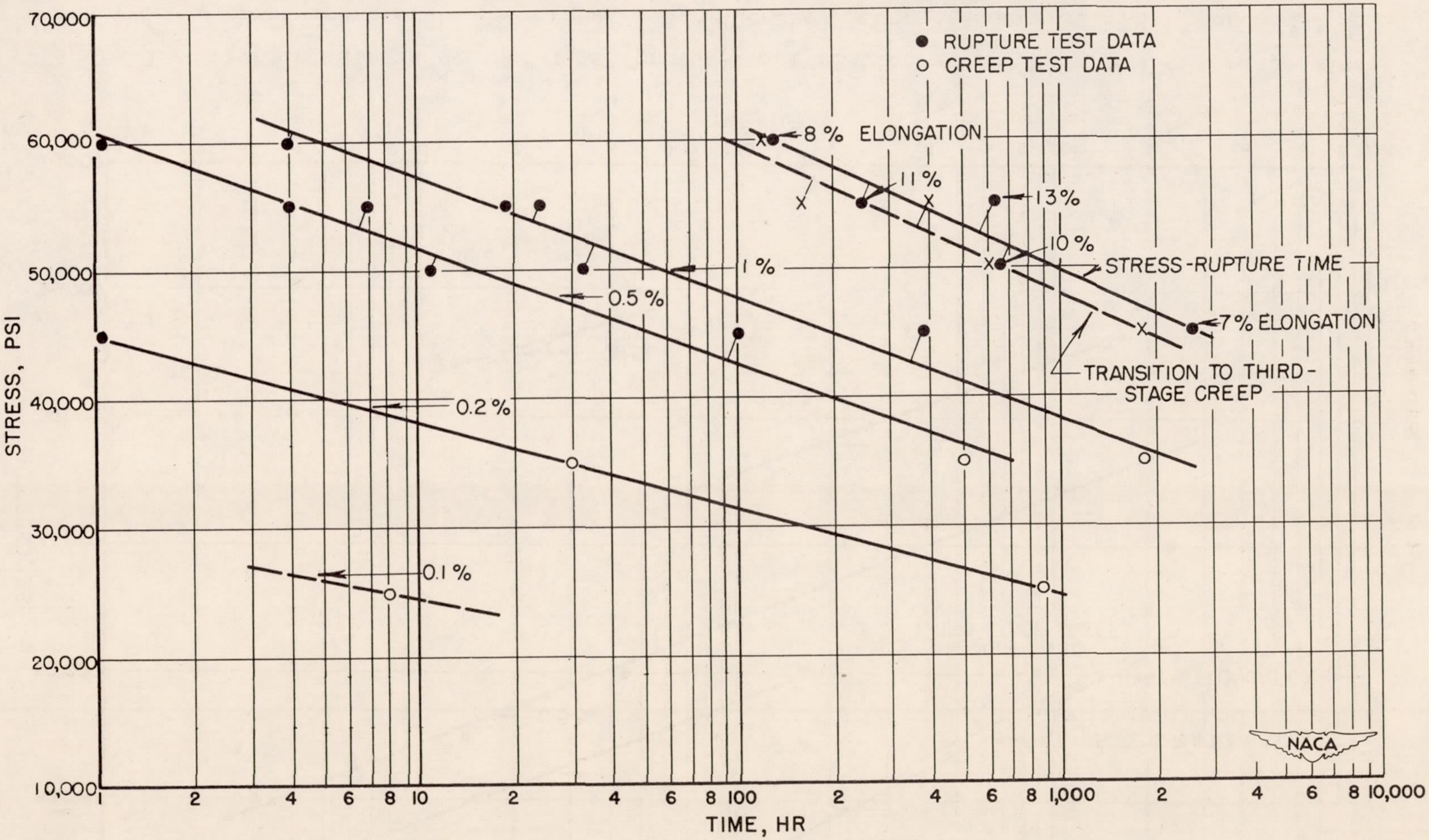


Figure 8.- Curves of stress against time for total deformation at 1200° F for S-816 alloy disc NR-76B-F. Heat treatment: As-forged and aged for 16 hours at 1400° F.

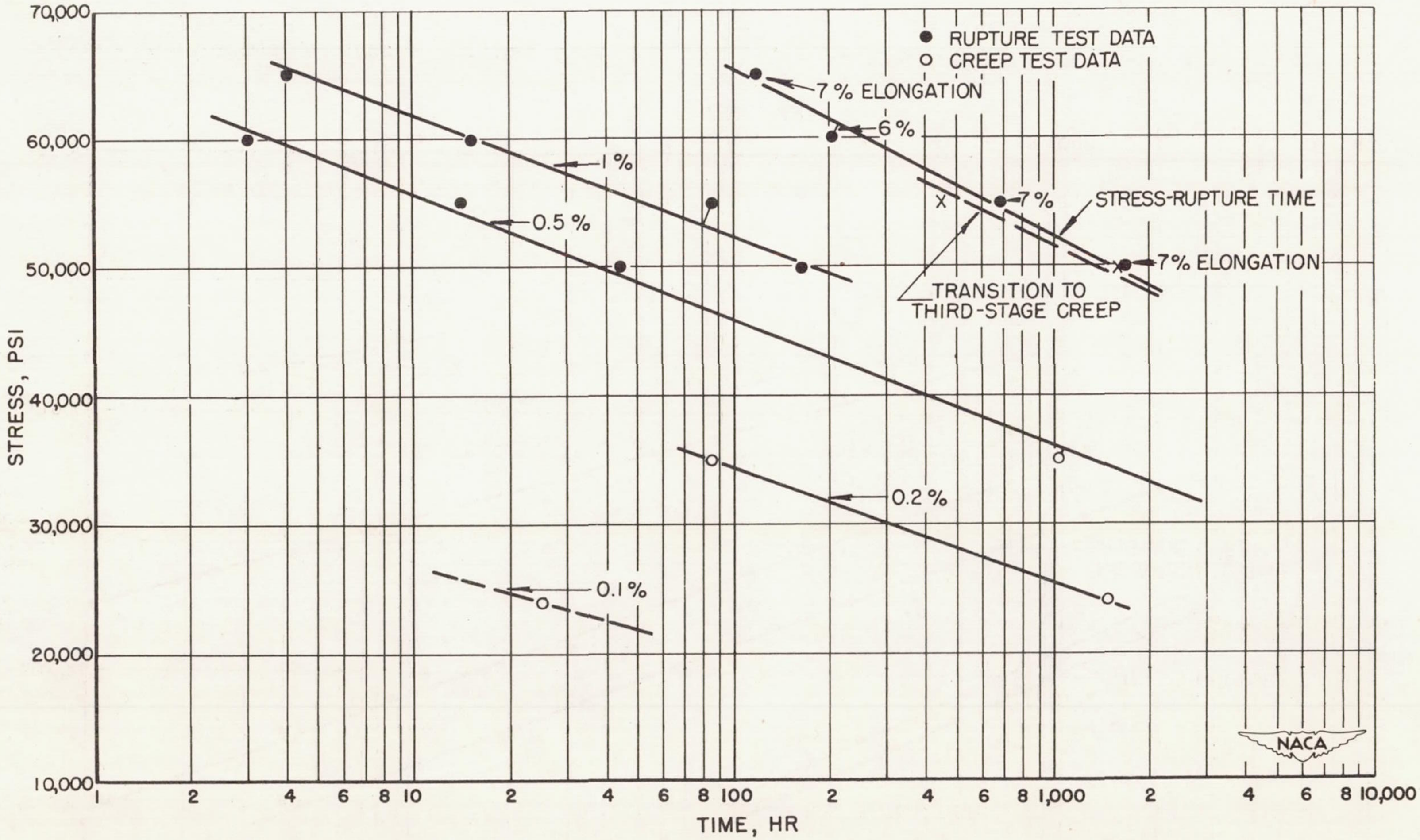


Figure 9.- Curves of stress against time for total deformation at 1200° F for S-816 alloy disc NR-76B-Q. Heat treatment: As-forged, water-quenched after $2\frac{1}{2}$ hours at 2300° F and aged for 16 hours at 1400° F.

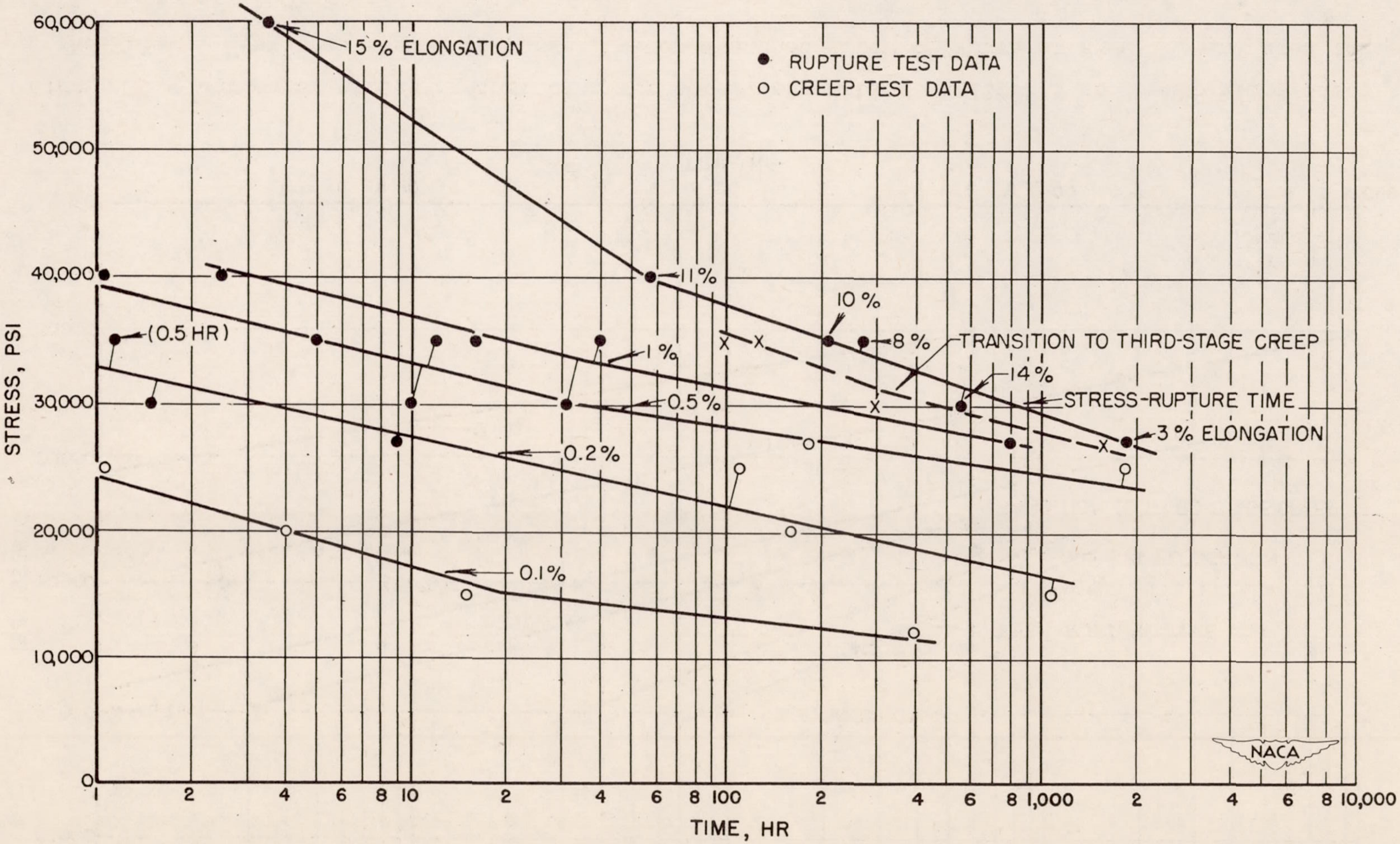


Figure 10.– Curves of stress against time for total deformation at 1350° F for S-816 alloy disc NR-76B-F. Heat treatment: As-forged and aged for 16 hours at 1400° F.

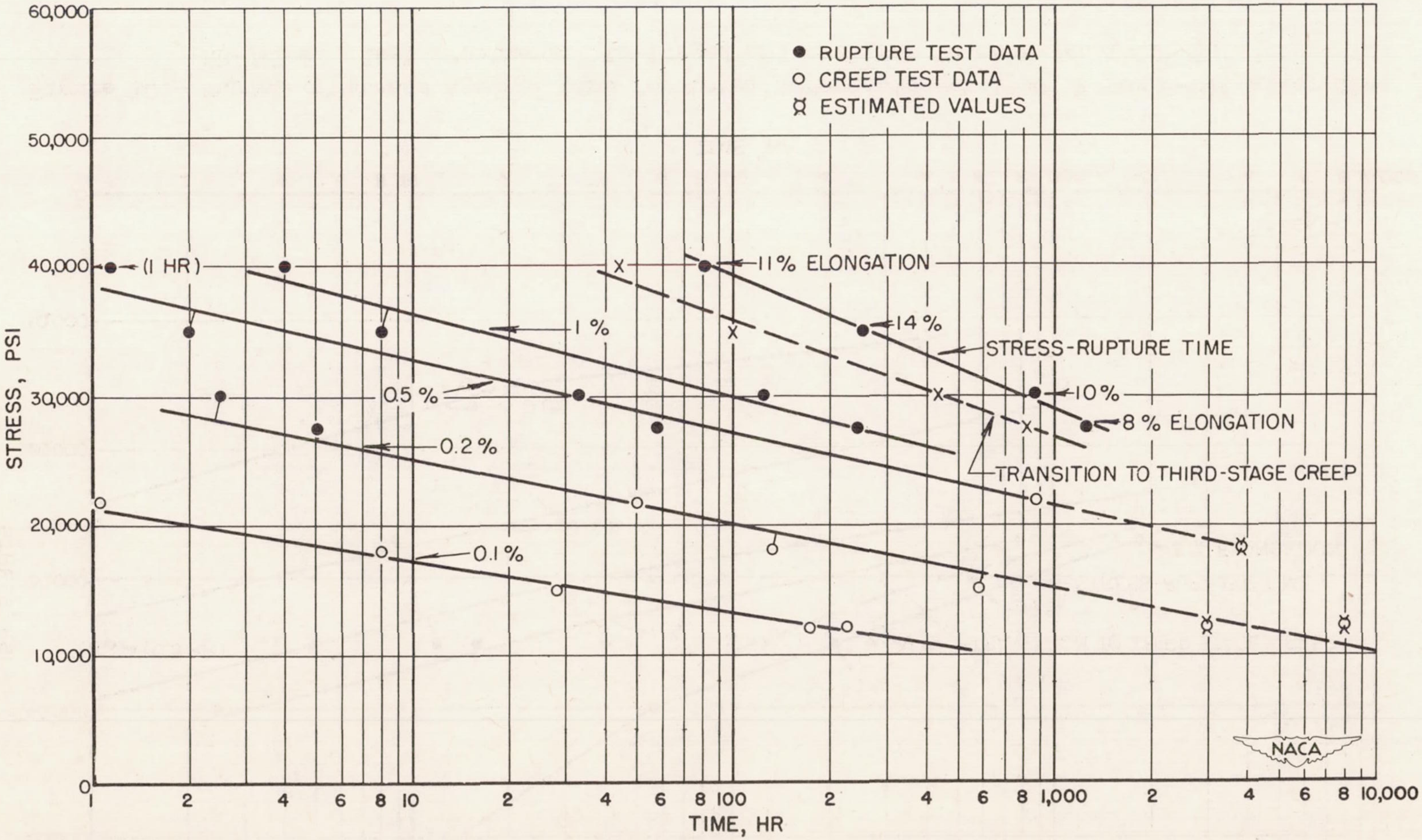


Figure 11.- Curves of stress against time for total deformation at 1350° F for S-816 alloy disc NR-76B-Q. Heat treatment: As-forged, water-quenched after $2\frac{1}{2}$ hours at 2300° F, and aged for 16 hours at 1400° F.

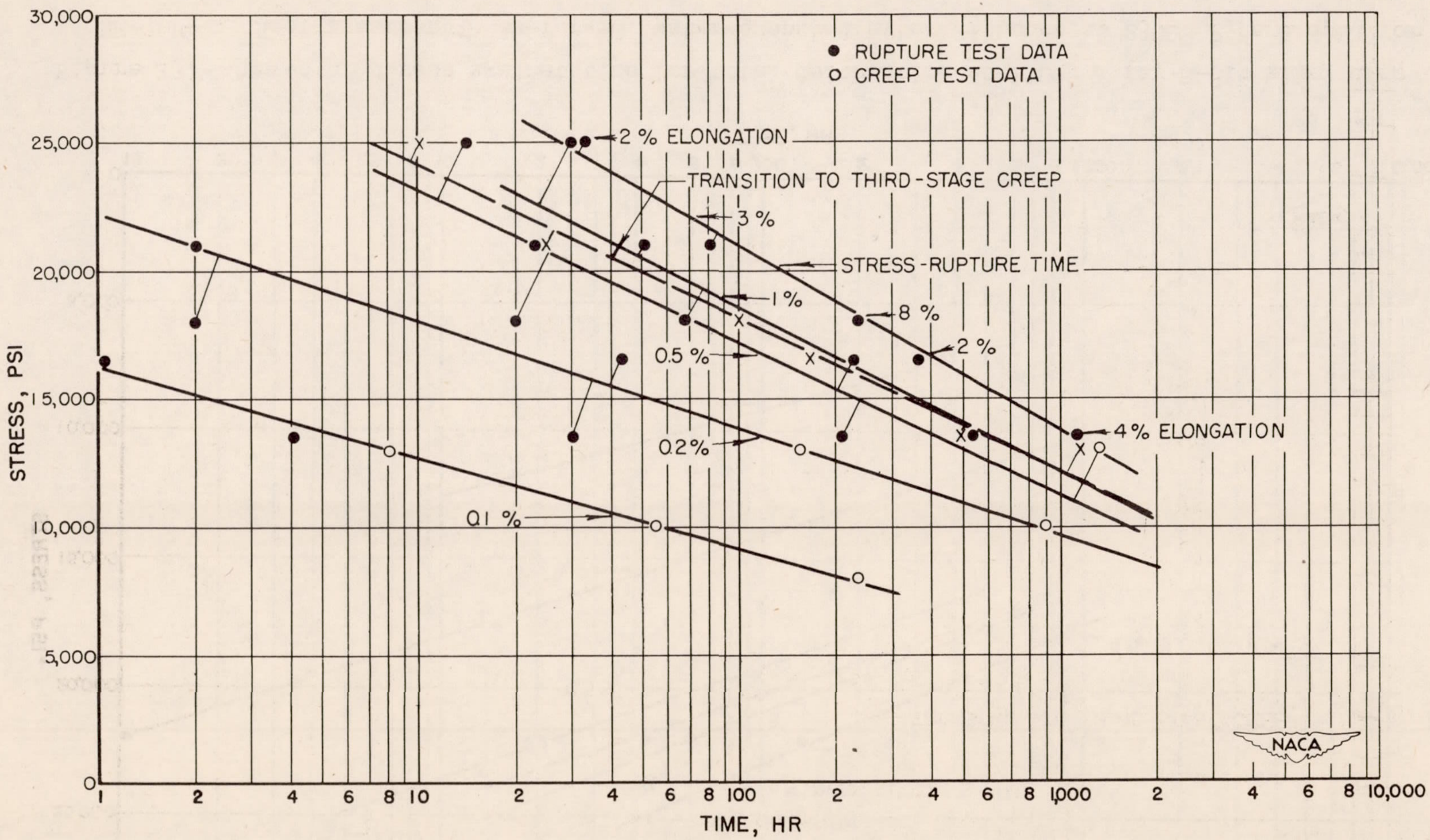


Figure 12.- Curves of stress against time for total deformation at 1500° F for S-816 alloy disc NR-76B-F. Heat treatment: As-forged and aged for 16 hours at 1400° F.

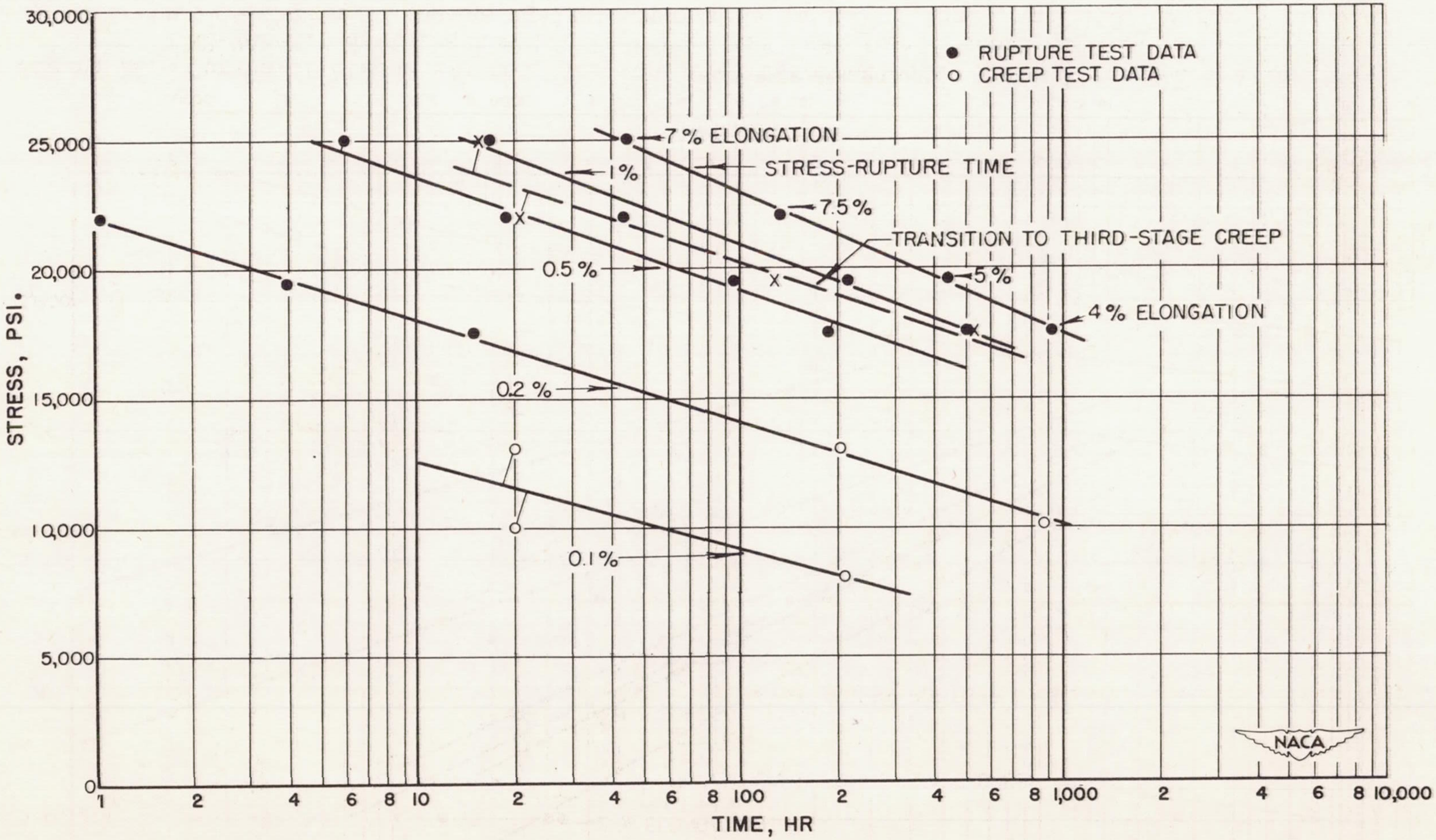


Figure 13.– Curves of stress against time for total deformation at 1500° F for S–816 alloy disc NR–76B–Q. Heat treatment: As–forged, water–quenched after $2\frac{1}{2}$ hours at 2300° F, and aged for 16 hours at 1400° F.

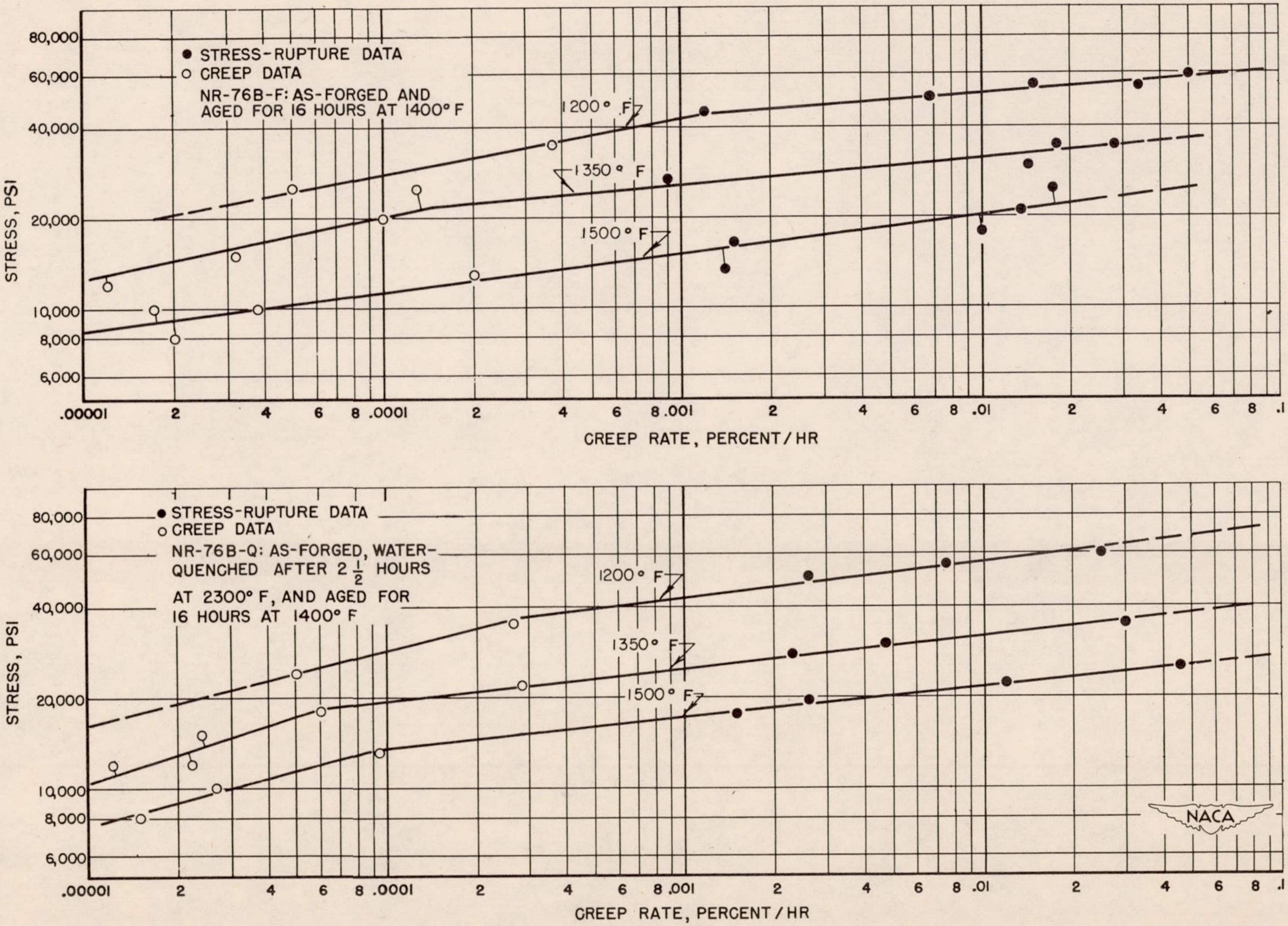
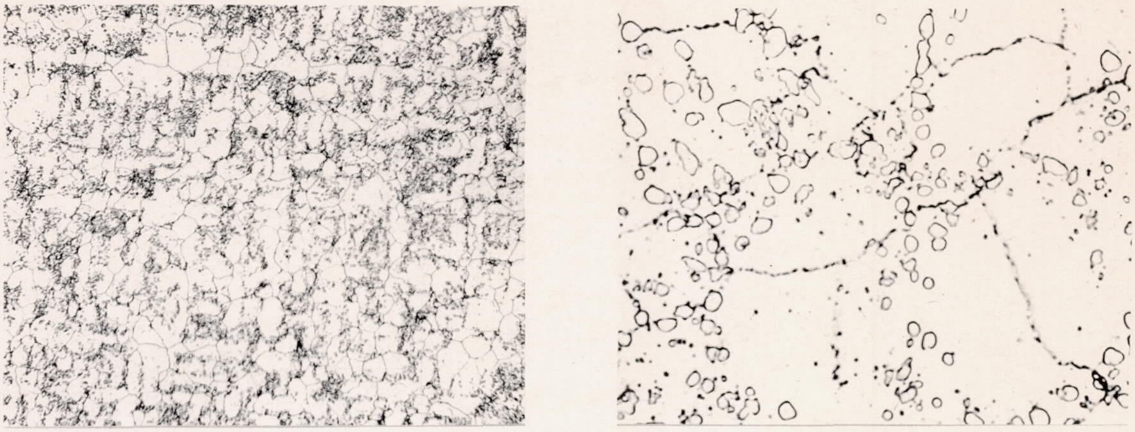
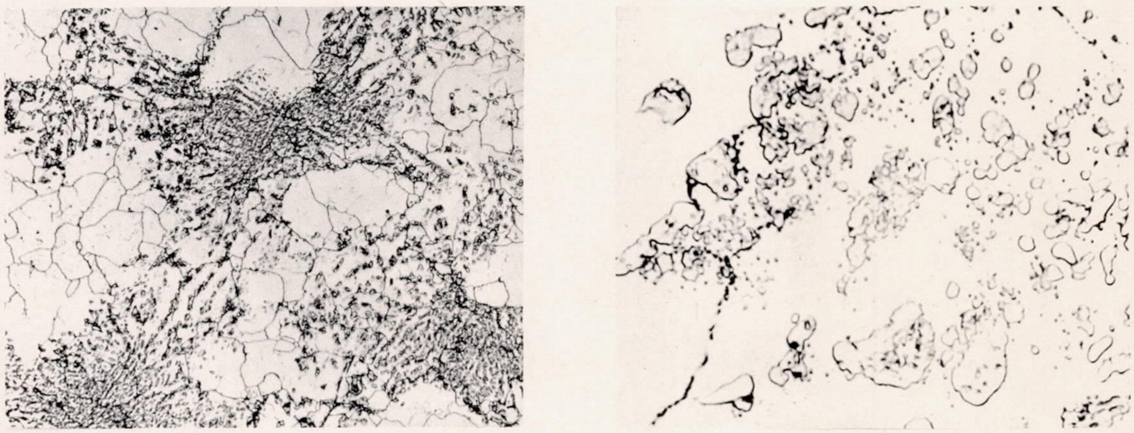


Figure 14.- Curves of stress against creep rate at 1200°, 1350°, and 1500° F for S-816 alloy discs NR-76B.



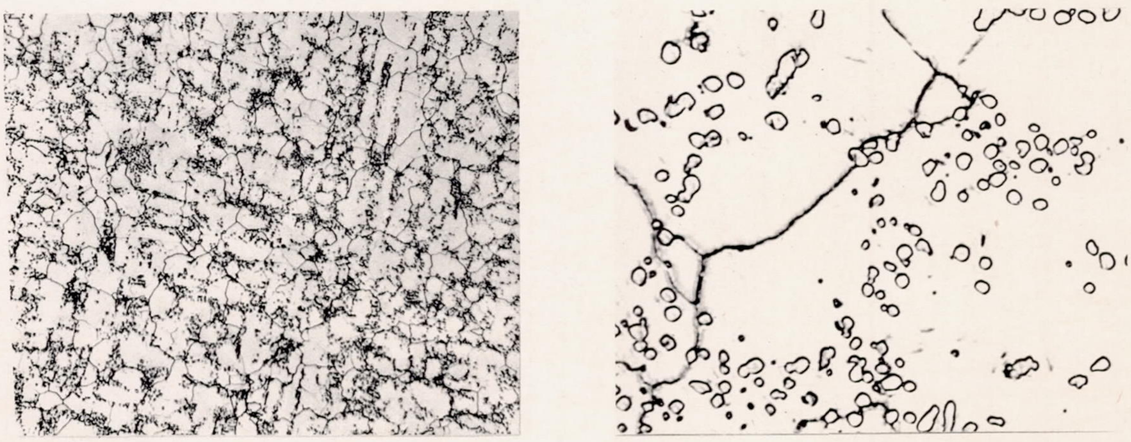
100X 1000X

(a) Disc NR-76B-F; as-forged and aged. Radial section of Y-specimen near rim.



100X 1000X

(b) Disc NR-76B-F; as-forged and aged. Radial section of Y-specimen near center.



100X 1000X

(c) Disc NR-76B-Q; heat-treated and aged. Radial section of Y-specimen near rim.

Figure 15.- Original microstructures of S-816 alloy discs NR-76B-F and NR-76B-Q. Electrolytic chromic acid etch.

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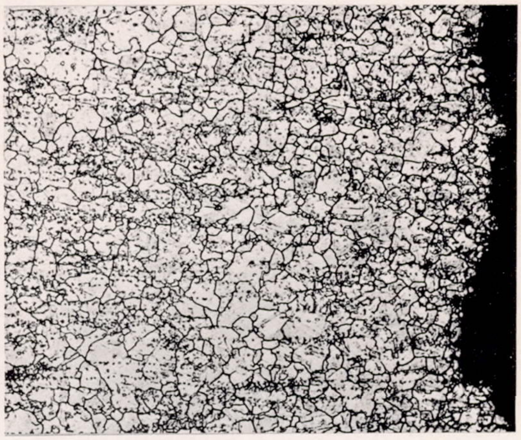
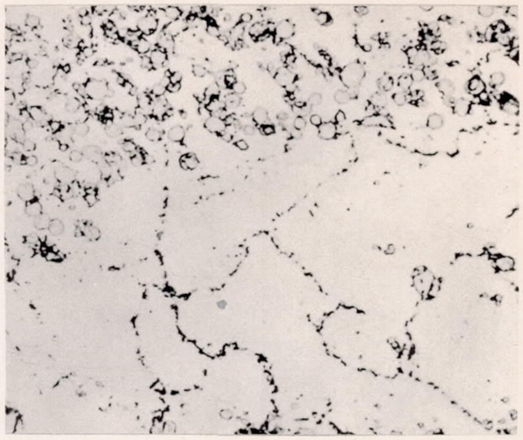
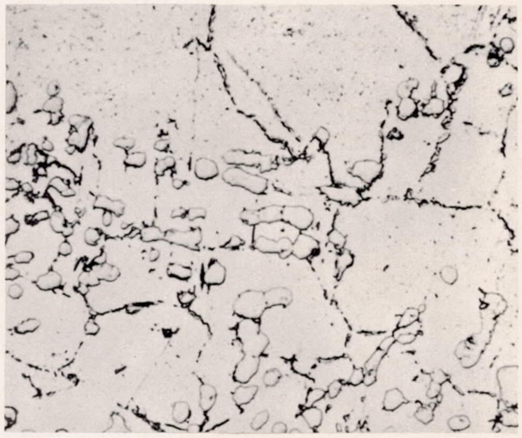




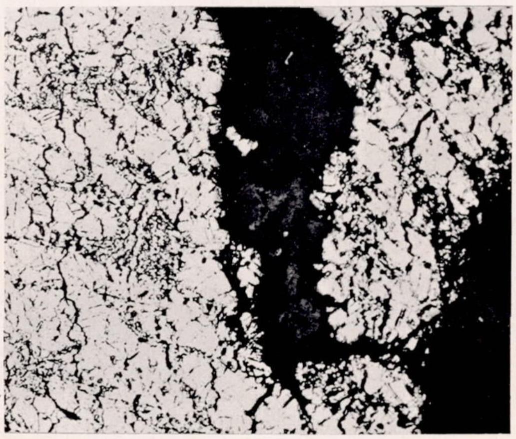
100X 1000X

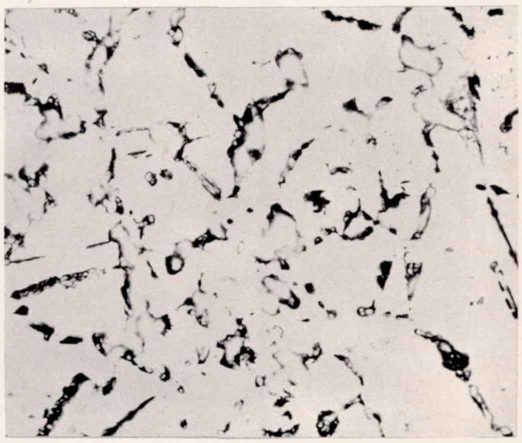
(a) Specimen F9A; 2618 hours for rupture at 1200° F and 45,000 psi.



100X 1000X

(b) Specimen F10A; 1894 hours for rupture at 1350° F and 27,000 psi.





100X 1000X

(c) Specimen F11D; 1132 hours for rupture at 1500° F and 13,500 psi.

Figure 16.- Microstructures of specimens of S-816 alloy disc NR-76B-F after stress-rupture tests. Disc treatment: As-forged and aged for 16 hours at 1400° F. Electrolytic chromic acid etch.

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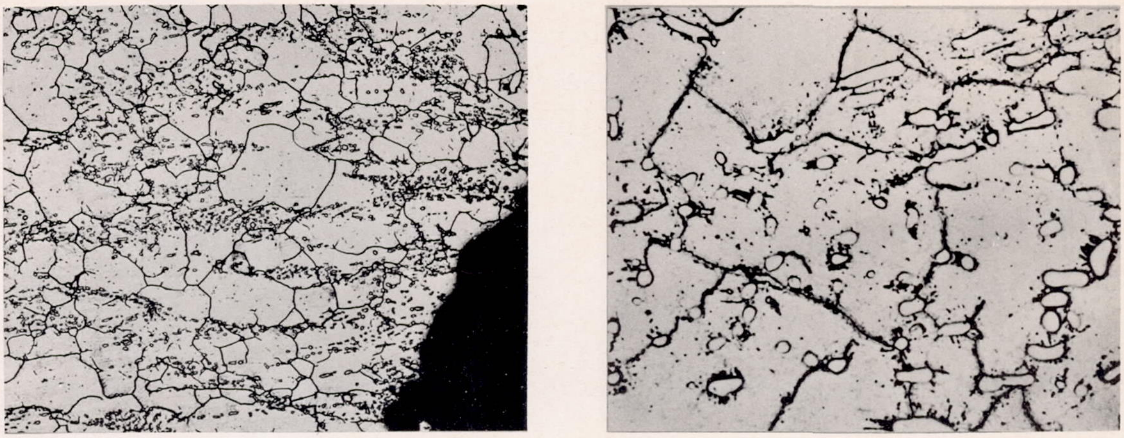
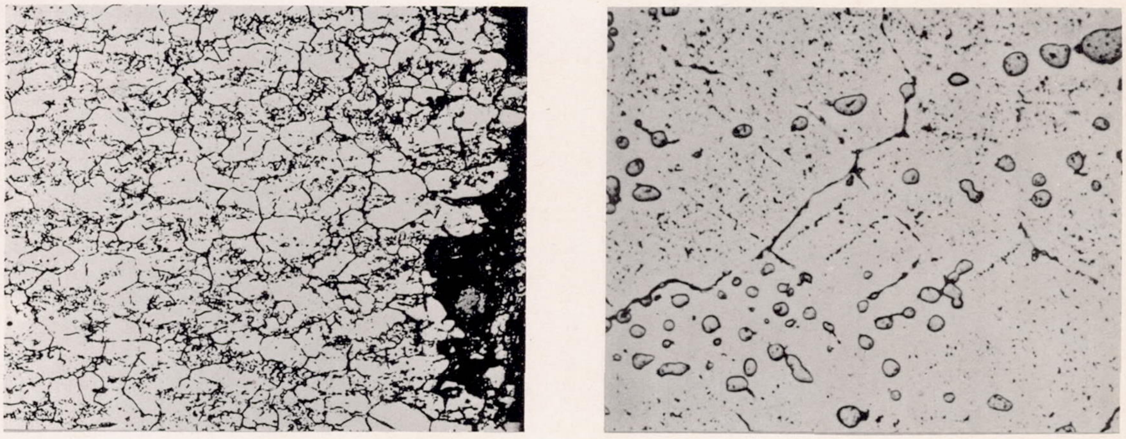


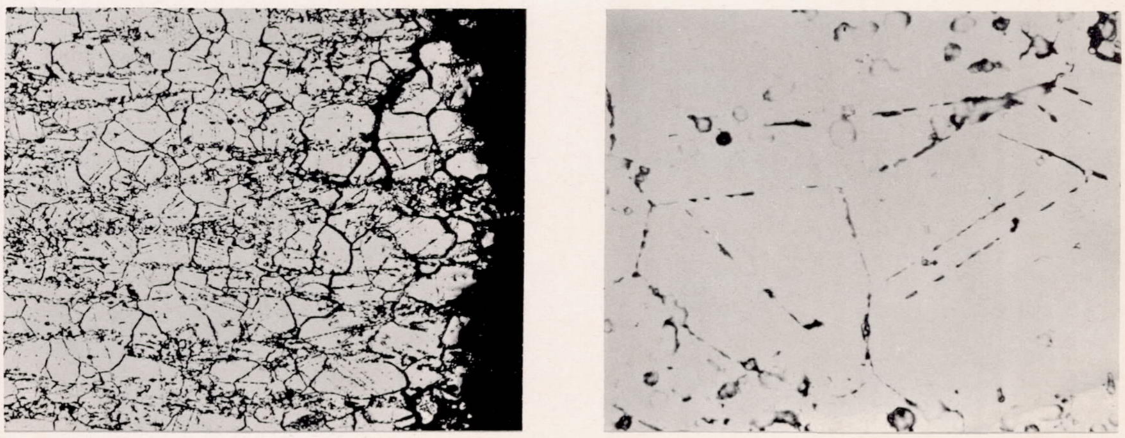
100X 1000X

(a) Specimen Q12E; 1699 hours for rupture at 1200° F and 50,000 psi.



100X 1000X

(b) Specimen Q12F; 1286 hours for rupture at 1350° F and 27,500 psi.



100X 1000X

(c) Specimen Q14D; 928 hours for rupture at 1500° F and 17,500 psi.

Figure 17.– Microstructures of specimens of S-816 alloy disc NR-76B-Q after stress-rupture tests. Disc treatment: As-forged, water-quenched after $2\frac{1}{2}$ hours at 2300° F, and aged for 16 hours at 1400° F. Electrolytic chromic acid etch.

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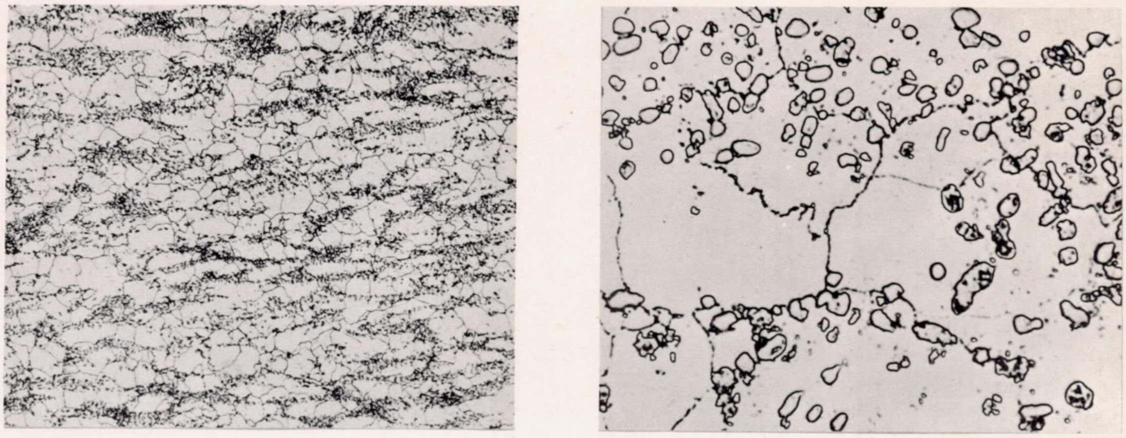
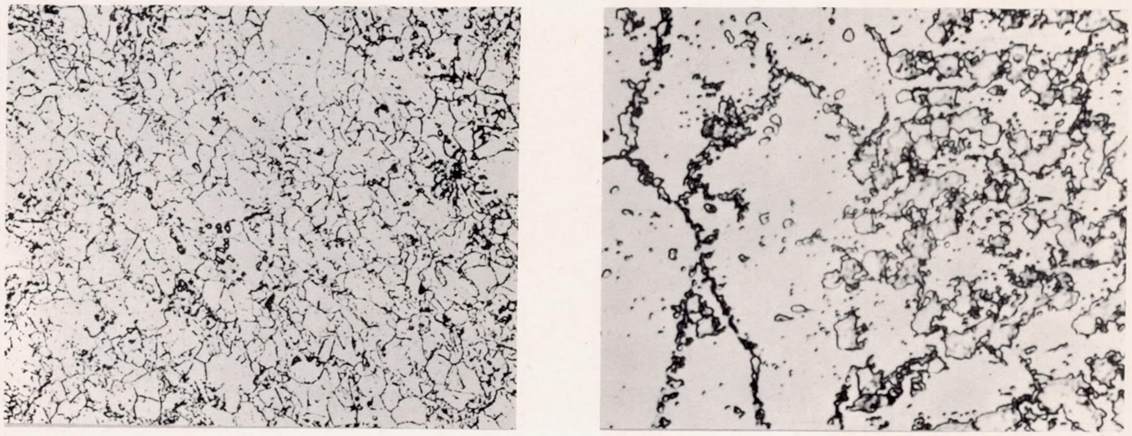


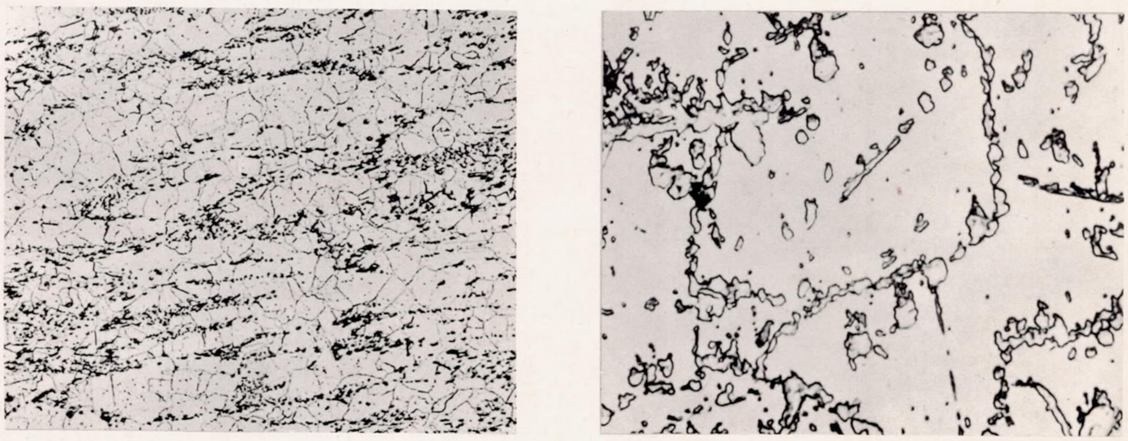
100X 1000X

(a) Specimen F2Z; 1124 hours at 1200° F and 35,000 psi.



100X 1000X

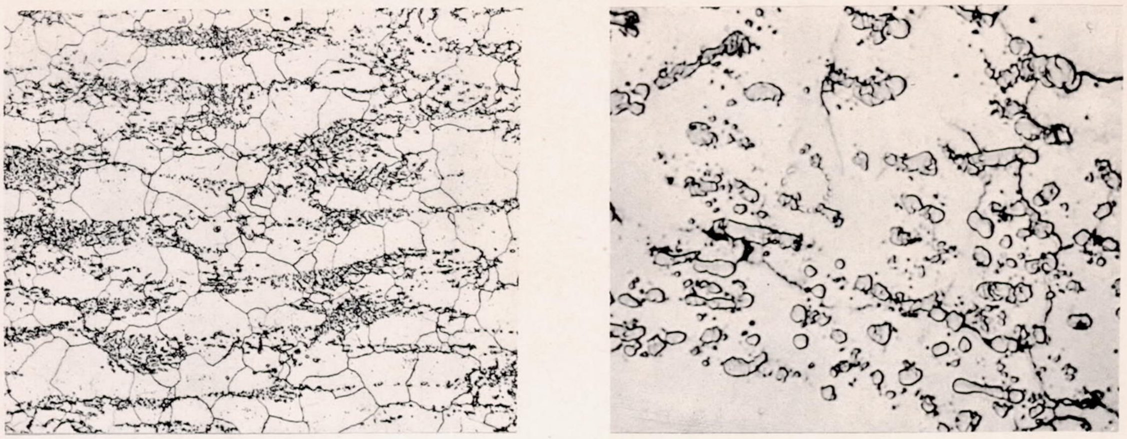
(b) Specimen F2X; 2016 hours at 1350° F and 15,000 psi.



100X 1000X

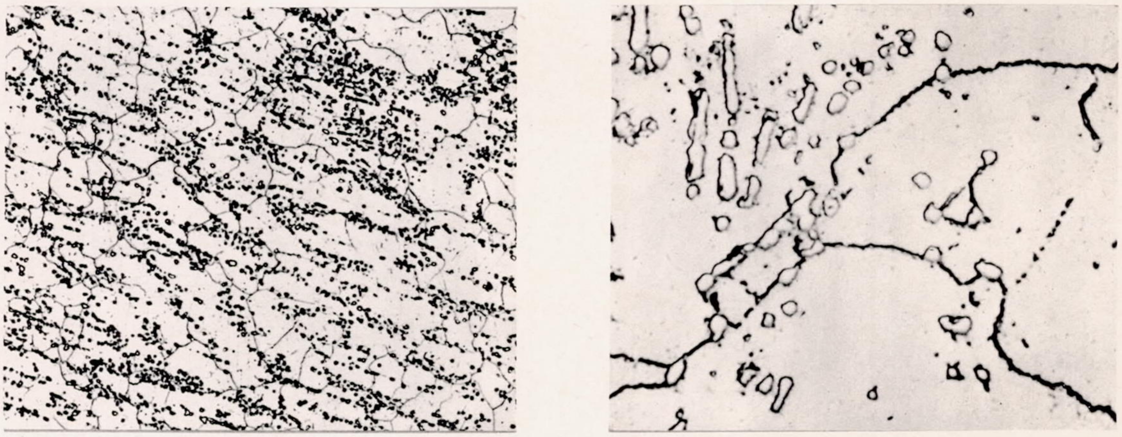
(c) Specimen F13Y; 1995 hours at 1500° F and 10,000 psi.

Figure 18.- Microstructures of specimens of S-816 alloy disc NR-76B-F after creep tests. Disc treatment: As-forged and aged for 16 hours at 1400° F. Electrolytic chromic acid etch.



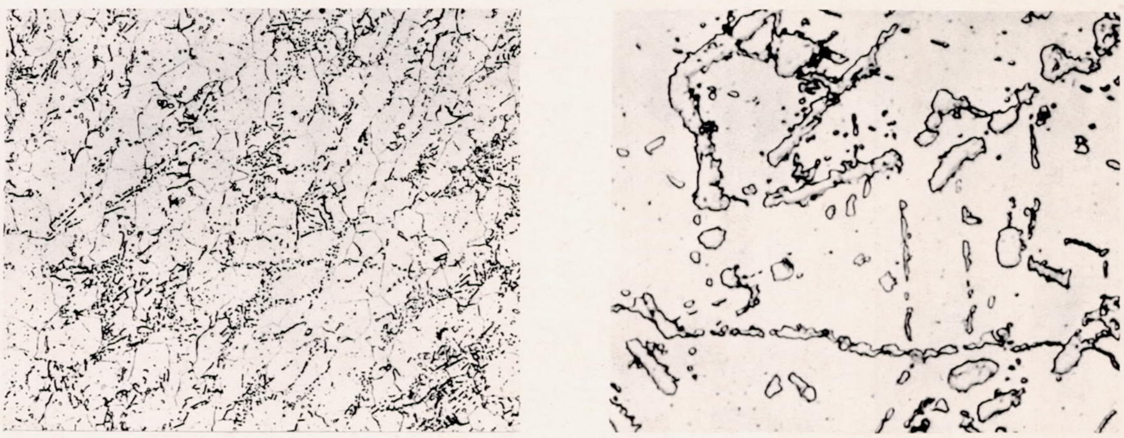
100X 1000X

(a) Specimen Q6Y; 1008 hours at 1200° F and 35,000 psi.



100X 1000X

(b) Specimen Q9Z; 2040 hours at 1350° F and 12,000 psi.



100X 1000X

(c) Specimen Q5X; 2137 hours at 1500° F and 10,000 psi.

Figure 19.- Microstructures of specimens of S-816 alloy disc NR-76B-Q after creep tests. Disc treatment: As-forged, water-quenched after $2\frac{1}{2}$ hours at 2300° F, and aged for 16 hours at 1400° F. Electrolytic chromic acid etch.

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