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OFFICE OF NAVAL RESEARCH AND NACA METALLURGICAL INVESTIGATION OF A LARGE FORGED DISC OF INCONEL X ALLOY

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SUMMARY

The properties of a large forged disc of Inconel X alloy at room temperature, 1200°, 1350°, and 1500° F were studied in order to determine the level of properties obtainable in a forging of the type required for the rotor discs of gas turbines. The disc was tested in the solution-treated and aged condition. The first tests were made on the alloy given a single aging treatment at 1300° F, but it was found that the alloy possessed better properties when given a double aging treatment, first at 1550° F, and then at 1300° F. Most of the test data reported herein were obtained on the alloy given the double aging treatment. The data reported include the results of tensile, impact, rupture, time-deformation, creep, and structural-stability tests.

In general, the Inconel X disc for time periods up to 1000 hours had as high, or higher, properties than other heat-resisting alloys tested at 1200° F. Its superiority decreased with test temperature so that there was relatively little difference between it and other alloys at 1500° F.

It was unusual in that third-stage creep occurred early in all tests, but particularly at 1350° and 1500° F. The disc also retained high ductility at room temperature after prolonged exposure to stress at high temperatures.

INTRODUCTION

This report presents the results of a study of the room-temperature, 1200°, 1350°, and 1500° F properties of a large disc of Inconel X alloy tested in the solution-treated and aged condition.

The purpose of this study was to determine the level of properties exhibited by Inconel X alloy in the form of large forgings of the type required for rotor discs of gas turbines. The results obtained previously from investigations on Timken, CSA, EME, 19-9DL, low-carbon N-155, S-590, and S-816 discs of similar size are contained in reports listed as references 1 through 12.

The work on the disc materials 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. The work herein was performed with the financial assistance of the National Advisory Committee for Aeronautics and the Office of Naval Research, Navy Department.

This report is based on the joint effort of the cooperating research programs. 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 describing the disc may be summarized as follows:

Manufacturer:

International Nickel Company, Inc.

Heat number:

Y-2848-X

Chemical composition:

C	Mn	S	Si	Cr	Ni	Cb	Ti	Al	Fe	Cu
0.05	0.51	0.007	0.39	14.61	73.42	1.04	2.33	0.67	6.90	0.04

Fabrication procedure:

A 4800-pound heat was made in a 6200-pound induction furnace and teemed into an 18- by 18- by 40-inch ingot. This ingot was forged at 2225° F to a $9\frac{1}{2}$-inch-diameter billet, which was then turned to a $8\frac{1}{2}$-inch diameter and cut to a 25-inch length.

This billet was upset by the General Electric Company on a 12,000-pound open frame hammer. Using temperatures between 2225° and 1800° F, the billet was upset in five heats to a disc of 22-inch diameter by $3\frac{1}{2}$ inches thick.

The solution treatment performed on the as-forged disc by the General Electric Company consisted of heating for 4 hours at 2100° F followed by water-quenching. The disc was sectioned and the various test specimens rough machined prior to aging. At the time that tests on this Inconel X disc were first begun, the recommended aging was a single treatment of 40 hours at 1300° F. Subsequently, low ductility was observed in some of the tests at 1200° and 1350° F on the single-aged material, and additional tests were made on material given a double aging treatment as follows:

1550° F, 24 hours, air-cooled

1300° F, 20 hours, air-cooled

Sampling:

The code number assigned to the disc was NR-99. Figure 1 shows the location of the samples cut from the disc and the code system identifying the coupons. The numerals refer to locations on the flat face of the disc, and the letters refer to the locations through the thickness of the disc.

EXPERIMENTAL PROCEDURE

The investigation was designed to provide the following information: (1) The physical properties at room temperature, 1200°, 1350°, and 1500° F which can be expected in large forgings of the Inconel X analysis; (2) the effect of aging treatments 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 for this large forged disc of Inconel X 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. Creep characteristics were also obtained at 1200°, 1350°, and 1500° F. The data from which the design curves were plotted came from the time-deformation curves of both rupture and creep tests.

The uniformity of the disc was checked by means of a hardness survey, short-time tensile tests, and, to a limited extent, by rupture tests on coupons from representative locations throughout the disc.

The testing procedures used for the short-time tension, 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 from the Inconel X disc are presented as a series of tables and figures which show the hardness, impact, tensile, rupture, time-deformation, creep, and stability characteristics. The principal results are summarized in figure 2.

Hardness Survey

Results of the hardness tests on the solution-treated disc after both the first and second steps in the double aging treatment are given in figure 3.

The Brinell hardness as-solution-treated was about 150. The first aging at 1550° F increased the hardness to about 210 and the second aging, to about 285. The surface hardness of the aged disc was slightly higher than for the interior, but the hardness changed little from near the center to the rim.

Short-Time Tensile Properties

The results of the short-time tensile tests at room temperature, 1200°, 1350°, and 1500° F are summarized in table I.

Room-temperature tests were made on both 0.505- and 0.250-inch-diameter radial specimens. The 0.250-inch-diameter specimens gave slightly lower tensile strengths than the 0.505-inch bars, but had slightly higher ductility. The results from both types of specimens indicated good uniformity in the disc.

At 1200° and 1350° F, specimens from the center of the disc gave lower strength values than did radial specimens taken from near the rim. They also tended to have a greater scatter of values. At 1500° F, center and rim specimens gave comparable properties.

The average tensile properties of the radial rim specimens as plotted in figure 2 are as follows:

Temperature (°F)	Tensile strength (psi)	0.2-percent-offset yield strength (psi)	Elongation (percent)
75	154,000	97,000	20
1200	117,000	84,500	10
1350	95,500	77,000	7
1500	46,500	43,000	37

Charpy Impact Resistance

Charpy impact resistance (V-notch) was determined on specimens taken near the rim of the disc. Data are shown in table II and figure 2 for tests at room temperature, 1200°, 1350°, and 1500° F after holding at temperature for a time period sufficiently long to insure a uniform temperature in the specimen.

The Charpy impact resistance increased from about 29 foot-pounds at room temperature to about 60 foot-pounds at 1500° F.

Rupture Test Characteristics

The stress-rupture data for the tests at 1200°, 1350°, and 1500° F are shown in table III, and the rupture strengths obtained from the curves of stress against rupture time in figure 4 are summarized at the bottom of table III.

All the stress-rupture tests were made on 0.250-inch-diameter radial specimens taken from near the rim of the disc. There was no apparent difference in test results from surface and center specimens taken from near the rim.

The rupture strengths at 1200° F for rupture in 100 and 1000 hours were 81,500 and 66,500 psi, respectively. These values are very close to those reported by the International Nickel Company for Inconel X bar stock.

At 1350° F the stresses to produce rupture in 100 and 1000 hours were 53,500 and 37,000 psi, respectively, and at 1500° F, 23,200 and 15,000 psi, respectively. These values are somewhat below those reported by the Nickel Company for bar stock.

Rupture test ductilities were low at 1200° F. The elongation for rupture in 1000 hours was estimated to be about 3 percent. The ductility values at 1350° F were high and held up well as the time to rupture increased. At 1500° F the elongation decreased from 50 percent for rupture in 4.5 hours to 6.9 percent for rupture in 604.2 hours.

Time-Deformation Characteristics

A convenient method of describing the high-temperature strength of a material is curves of stress against the time required for various total deformations. Such information with the curves of stress against rupture time (and the curves of stress against creep rate) gives design engineers a complete picture of the expected performance of an alloy under conditions of constant tensile stress. The time-deformation data obtained on the Inconel X disc are plotted on semilogarithmic coordinates in figures 5, 6, and 7 for total deformations of 0.1, 0.2, (0.3 at 1200° F) 0.5, and 1.0 percent at 1200°, 1350°, and 1500° F for time periods up to about 2000 hours. Additional 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 to failure starts.

At 1200° and 1350° F, and to a lesser extent at 1500° F, the curves for the lower total deformations are controlled largely by the proportional limit. In figures 5, 6, and 7 where this is true the curves are dashed to indicate that their location is somewhat variable. It should be emphasized that, in tests at stresses approaching or exceeding the proportional limit of a material, wide differences in initial deformation can be expected because of variations in the proportional limit.

The curves of stress against time for total deformation were plotted from the data in table IV, which also includes the times for total deformations of 2 and 5 percent. The stresses to cause various total deformations in 1, 10, 100, 1000, and 2000 hours, as obtained from figures 5, 6, and 7, are given in table V. These "deformation strengths" are useful numerical ratings of the deformation characteristics and, with the exception of the estimated strengths for 1 hour, are plotted in summary figure 2.

The steepness of the transition-point curves is a danger signal. This material should be watched closely if used at times and stresses beyond the transition-point curve.

Creep Strengths

Creep rate data, used by many engineers in designs for long periods of service, have been collected from the time-deformation curves of both the stress-rupture and creep tests. Minimum creep rates measured in the rupture tests are included in table III. The detailed creep test data are shown in table VI. The logarithmic curves of stress against creep rate for the rupture and creep tests at 1200°, 1350°, and 1500° F for the Inconel X disc are shown in figure 4.

The creep rates plotted were the minimum rates measured in both the rupture and the creep tests. In the creep tests on this material at 1200° F, in the stress range 45,000 to 50,000 psi, the minimum creep rates measured were also the final rates at the end of test periods in the range 1500 to 2000 hours. Differing from this behavior, in the creep tests at 1350° and 1500° F, the minimum rates of creep occurred either at the start of the test or during the first 500 hours of the testing period. Following this initial period, increasing rates were observed.

The creep strengths obtained from figure 4 were as follows, and for convenience of comparison the 1000-hour and the extrapolated 10,000-hour rupture strengths are shown here also:

Temperature (°F)	Stress (psi) for indicated properties			
	1000-hr rupture strength	0.0001-percent/ hr creep rate	Estimated 10,000-hr rupture strength	0.00001-percent/ hr creep rate
1200	66,500	61,000	54,000	49,000
1350	37,000	31,100	20,000	25,000
1500	15,000	15,800	9,700	13,900

Inconel X behaves differently from many of the other types of heat-resisting alloys included in this program of tests on large discs. The following specific comments should be carefully considered before using creep data for design:

(1) Inconel X is a strong material and minimum creep rates are low at very high stresses. These minimum creep rates cannot, however, be extrapolated with accuracy on the assumption that a rate of 0.0001 or 0.00001 percent per hour is equivalent to 1 percent in 10,000 and 100,000 hours.

(2) At 1200° F, very little first-stage creep was observed. At stresses of 70,000 psi and higher, however, the tests immediately entered third-stage creep. The time for entrance to third-stage creep increased at lower stresses. It is important to note, however, that third-stage creep was observed in as short a time period as 840 hours at 55,000 psi when the creep rate was only 0.000035 percent per hour. In fact, figure 5 indicates that third-stage creep would occur under the stress corresponding to a minimum rate of 0.00001 percent per hour in only 2000 hours.

(3) Not only third-stage creep can be anticipated prematurely but also premature rupture. The comparative 10,000-hour rupture strengths given with the previous tabulations of creep strength were well below the creep strengths for 0.0001 percent per hour and indicate that fracture would occur at time periods much less than 10,000 hours under stresses corresponding to the creep strengths.

Stability Characteristics

Some of the completed-test specimens 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 VII.

After creep testing at 1200° F for 1804 hours, the strength and ductility values measured at room temperature were slightly increased as compared with the values for the material in the original heat-treated condition.

Creep testing for slightly over 2000 hours at 1350° and 1500° F produced a considerable reduction in yield and tensile strengths, with the greatest change at the higher test temperature. Ductility values were somewhat higher after creep testing at 1350° F and practically unchanged after testing at 1500° F. Differing from some other types of alloys, Inconel X consistently maintained a good level of room-temperature tensile ductility and Izod impact strength after long-time creep testing.

Photomicrographs of the Inconel X alloy in the solution-treated and in the solution-treated and aged conditions are shown in figure 8. The very fine precipitate in the aged material is clearly evident.

Figure 9 shows photomicrographs of the structures of creep specimens tested at 1200° and 1350° F. The structures show no significant difference from the as-heat-treated alloy even though tensile properties are somewhat reduced after testing at 1350° F.

The photomicrographs shown in figure 10 for two rupture and creep test specimens tested for 604 and 2160 hours at 1500° F, respectively, definitely indicate a marked change in structure as a result of long-time exposure at this temperature. Appreciable agglomeration of the precipitated phase has occurred and there is a significant difference in structure and degree of agglomeration between the specimens tested for 604 and 2160 hours at 1500° F. This difference in structure accounts for the decrease in room-temperature strength as a result of testing at 1500° F. Because of this lack of structural stability at 1500° F, the use of this alloy at 1500° F should preferably be restricted to service periods over which test data are available and for which the data have shown the deformation at the design loads not to be excessive.

Comparison of Properties of Inconel X with Single and Double Aging Treatments

The first tests on material cut from this Inconel X disc were made on material given a single aging treatment of 40 hours at 1300° F, and this aging treatment was thought to be best. Later, both experimental work by the International Nickel Company and the results of rupture tests at 1200° and 1350° F in the present test program indicated that low ductility and low rupture strengths resulted from the use of this single aging treatment. Upon recommendation of the International Nickel Company, a double aging treatment of 24 hours at 1550° F followed by 20 hours at 1300° F was adopted, and most of the tests herein reported were made on the alloy given this double aging treatment. It was thought of interest, however, to indicate some of the results obtained using the single aging treatment for comparison with the data obtained with the double aging treatment.

The data obtained have been summarized and the strengths for Inconel X with both aging treatments are compared in table VIII. It is indicated that Inconel X shows superior rupture strengths and better ductility at 1200° and 1350° F in the double-aged condition. However, at 1500° F the rupture strength of the single-aged material is slightly higher.

Creep strengths for 0.0001 and 0.00001 percent per hour are higher at 1200° and 1350° F for the single-aged material, but the double-aged material shows the better creep strength at 1500° F.

The trend is for superior 100- and 1000-hour deformation strengths at 1200° and 1350° F for double-aged material. At 1500° F, the single-aged material shows the better 100-hour deformation strengths, while for the longer time or 1000-hour strengths up to 1-percent total deformation the double-aged material maintains a slight superiority. These results together with the better ductility indicate that the double aging treatment is the better of the two treatments.

CONCLUDING REMARKS

The Inconel X disc material developed high tensile and yield strengths when properly solution-treated and aged. Rupture strengths at 1200° and 1350° F were also high. Strengths for total-deformation values in the range of 0.2 to 0.4 percent at 1200° F are largely controlled by minor variations in proportional limit. In tests at all three temperatures of 1200°, 1350°, and 1500° F, the transition to third-stage creep occurred at relatively low deformations and early in the test period. However, Inconel X is such a strong alloy at 1200° and 1350° F that appreciable stresses can be sustained with very low deformations.

Compared with material cut from discs of low-carbon N-155, S-590, and S-816 alloys and tested in various conditions of forging and heat treatment, Inconel X shows generally superior properties at 1200° and 1350° F for time periods up to 1000 hours, which is the extent of the test period for which detailed comparisons can be made. The early transition to third-stage creep for Inconel X suggests extreme caution in extrapolation to longer periods than those for which actual test data are available.

At 1500° F, Inconel X is about equal to or better than any of the other three alloys mentioned for deformations of up to 0.5 percent and time periods up to 1000 hours. Better strengths at 1500° F than those of Inconel X are shown by solution-treated and aged alloy S-816 for a total deformation of 1 percent or more. The observed structural instability of Inconel X at 1500° F and the early transition to third-stage creep are warnings against use of the test data for extrapolation beyond the actual test period.

The high ductility of Inconel X after exposure at high temperature under stress is an unusual and probably desirable characteristic of this material.

Compared with the properties of bar stock of Inconel X given the double aging treatment, the disc material shows slightly lower short-time tensile properties at room temperature and at 1500° F, and slightly lower rupture and creep strengths at 1350° and 1500° F.

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TABLE I.- SHORT-TIME TENSILE PROPERTIES OF INCONEL X DISC

Specimen number (a)	Specimen location (b)	Temperature (°F)	Tensile strength (psi)	Proportional limit (psi)	Offset yield strength (psi)		Elongation in 2 in. (percent)	Reduction of area (percent)	Rockwell B hardness	Modulus of elasticity (psi)
					0.1 percent	0.2 percent				
[c] [d]RR-99-26A	SRR	75	152,800	------	------	------	25.0	24.4	106	--------
[c] [d]26E	SRR	75	152,000	------	------	------	27.0	25.9	106	--------
[c] [d]250	CRR	75	150,200	------	------	------	27.0	21.3	106	--------
[c] [d]25D	CRR	75	151,200	------	------	------	27.0	23.9	---	--------
[c]33X	SRR	75	155,400	75,000	95,400	97,800	19.0	17.0	---	30 × 10⁶
[c]33Z	SRR	75	152,600	75,000	91,800	97,400	17.5	15.6	---	30
[c]33Y	CRR	75	155,600	72,000	93,000	95,900	21.0	19.2	---	32
[c]18Y	CRR	75	153,400	78,000	94,400	97,400	23.2	18.4	---	32
[c]39X	SRR	1200	118,500	54,000	79,600	83,600	9.7	14.1	---	28
[c]39Z	SRR	1200	119,500	61,000	83,000	86,500	9.2	10.0	---	25
[c]39Y	CRR	1200	116,000	-------	81,800	84,900	9.2	11.1	---	29
[c]40Y	CRR	1200	114,100	60,000	80,900	84,400	8.0	11.9	---	29
[e]11Z	SRR	1200	117,750	55,000	79,000	------	8.5	13.0	---	26
[e]34Y	CRR	1200	113,000	52,000	79,500	82,500	12.5	14.8	---	26
[c]6X	SC	1200	102,100	60,000	73,800	76,400	11.5	15.2	104	22
[c]6Z	SC	1200	99,000	55,000	71,400	73,300	11.7	18.4	104	22
[c]7Y	CC	1200	112,800	37,400	69,000	73,100	14.3	15.6	103	25
[c]8Y	CC	1200	93,000	46,400	73,050	75,800	8.0	15.2	103	28
[c]40X	SRR	1350	86,200	43,000	71,900	75,400	7.0	7.3	---	23
[c]40Z	SRR	1350	89,800	47,000	73,900	76,600	6.1	10.0	---	26
[e]11X	SRR	1350	106,000	47,500	76,000	78,300	7.5	11.6	---	24
[e]35Y	CRR	1350	100,000	52,500	75,000	77,500	6.5	10.3	---	23
[c]7X	SC	1350	76,600	36,000	66,800	68,800	3.0	8.1	---	--------
[c]7Z	SC	1350	81,000	47,000	68,500	70,600	4.0	13.0	---	27
[c]41X	SRR	1500	46,700	22,000	38,000	40,200	37.5	38.5	---	20
[c]41Z	SRR	1500	46,600	32,000	39,400	40,500	39.5	44.6	---	17
[c]8X	SC	1500	51,200	29,000	44,200	45,900	22.3	26.1	---	--------
[c]8Z	SC	1500	46,400	23,200	36,000	39,400	43.5	45.5	---	23

[a] Heat treatment: 2100° F 4 hr water-quenched; 1550° F 24 hr; and 1300° F 20 hr.

[b] SRR surface-plane radial specimen near rim of disc.
CRR center-plane radial specimen near rim of disc.
SC surface plane near center of disc.
CC center plane near center of disc.

[c] Navy data.

[d] 0.250-in.-diameter specimen; all others 0.505-in.-diameter specimens.

[e] NACA data.

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TABLE II.– CHARPY NOTCHED-BAR IMPACT RESISTANCE

AT ROOM TEMPERATURE, 1200°, 1350°,

AND 1500° F FOR INCONEL X DISC

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

Specimen number (1)	Specimen location	Test temperature (°F)	Charpy impact strength (ft-lb)
NR-99-9YD	Interior	75	29
9YE	Interior	75	28
9YF	Interior	75	32
1ZK	Interior	75	33
1ZC	Surface	75	22
NR-99-1ZG	Interior	1200	38
1ZH	Interior	1200	37
1ZA	Surface	1200	37
1ZB	Surface	1200	39
NR-99-1ZI	Interior	1350	45
1ZJ	Interior	1350	47
1ZD	Surface	1350	43
1ZE	Surface	1350	44
NR-99-1ZL	Interior	1500	59
9YA	Interior	1500	54
9YB	Interior	1500	60
9YC	Interior	1500	65
1ZF	Surface	1500	62

[1] Heat treatment: 2100° F 4 hr water-quenched; 1550° F 24 hr; and 1300° F 20 hr.

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TABLE III.– RUPTURE TEST DATA AT 1200°, 1350°, AND 1500° F FOR INCONEL X DISC

Specimen number (a)	Specimen location (b)	Test temperature (°F)	Stress (psi)	Rupture time (hr)	Elongation in 1 in. (percent)	Reduction of area (percent)	Minimum creep rate (percent/hr)
[c]NR-99-27A	SRR	1200	90,000	36	3	8.7	--------
[c]27C	CRR		80,000	136	4	4.1	0.0085
[c]28A	SRR		70,000	418	4	3.0	.0020
[c]27D	CRR		65,000	1825	4	4.0	.00018
[c]28D	CRR		60,000	2672	2	3.3	.00007
[c]NR-99-28C	CRR	1350	55,000	86	17	20.5	--------
[c]27E	SRR		49,000	143	19	26.8	--------
[c]28B	CRR		45,000	389	16	18.3	.0060
[c]28E	SRR		40,000	751	21	24.0	.0012
[c]11Z-2	SRR		35,000	1177	12	12.5	.00028
[d]NR-99-24A	SRR	1500	30,000	4.5	50.0	54.3	--------
[d]26B	CRR		25,000	73.6	32.1	34.7	[e].10
[d]24B	CRR		20,000	199.6	18.5	28.1	.008
[d]25A	SRR		16,500	604.2	6.9	14.6	.00045

Rupture strength

Temperature (°F)	Stress (psi) for rupture in –			
	10 hr	100 hr	1000 hr	2000 hr
1200	------	81,500	66,500	63,000
1350	------	53,500	37,000	30,500
1500	28,400	23,200	15,000	------

[a] Heat treatment: 2100° F 4 hr water-quenched; 1550° F 24 hr; and 1300° F 20 hr.

[b] CRR center-plane radial specimen near rim of disc.
SRR surface-plane radial specimen near rim of disc.

[c] NACA data.

[d] Navy data.

[e] Estimated.

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TABLE IV.– DATA FOR STRESS AND TIME FOR TOTAL DEFORMATION AT 1200°, 1350°, AND 1500° F FOR INCONEL X DISC

Specimen number (a)	Temperature (°F)	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of –							Transition to third-stage creep	
				0.1 percent	0.2 percent	0.3 percent	0.5 percent	1 percent	2 percent	5 percent	Time (hr)	Deformation (percent)
[b]NR-99-10X	1200	45,000	0.179	----	[c]3800	----	----	----	----	----	---	-----
[b]10Z		47,000	.187	----	[d]1850	----	----	----	----	----	---	-----
[b]11Y		50,000	.200	----	-----	----	----	----	----	----	---	-----
[b]10Y		55,000	.220	----	-----	1085	----	----	----	----	860	0.287
[b]28D		60,000	.242	----	-----	250	1425	2250	----	----	450	.31
[b]27D		65,000	.267	----	-----	170	885	1510	----	----	230	.31
[b]28A		70,000	.300	----	-----	----	99	265	----	----	46	.40
[b]27C		80,000	.420	-----	-----	----	7	72	----	----	---	-----
[b]27A		90,000	-----	----	-----	----	----	----	----	----	---	-----
[e]NR-99-9X	1350	25,000	.113	----	1500	1915	----	----	----	----	500	.116
[e]12Z		30,000	.153	----	505	1570	1000	1240	1490	1720	325	.168
[b]11Z-2		35,000	.156	----	126	331	473	635	790	----	190	.215
[b]28E		40,000	.162	----	8	80	175	266	356	486	100	.32
[b]28B		45,000	.182	----	-----	----	77	128	172	247	---	-----
[b]27E		49,000	.192	----	-----	----	32	50	68	96	---	-----
[b]28C		55,000	.227	----	-----	----	10	23	35	50	---	-----
[e]NR-99-9Z	1500	10,000	.050	1515	-----	----	----	----	----	----	615	.050
[e]12X		12,000	.062	775	1700	----	----	----	----	----	400	.070
[e]25A		16,500	.104	----	125	----	345	440	510	595	170	.22
[e]24B		20,000	.119	----	12	----	50	80	86	104	75	.68
[e]26B		25,000	.168	----	-----	----	3	7	16	29	25	3.0
[e]24A		30,000	.238	----	-----	----	----	----	----	----	---	-----

[a] Heat treatment: 2100° F 4 hr water-quenched; 1550° F 24 hr; and 1300° F 20 hr.
[b] NACA data.
[c] Estimated by extrapolation of time-deformation curve from 1800 hr.
[d] Estimated by extrapolation of time-deformation curve from 1671-hr.
[e] Navy data.

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TABLE V.– TIME-DEFORMATION AND CREEP STRENGTHS AT 1200°, 1350°, and 1500° F FOR INCONEL X DISC[a]

Temperature (°F)	Total deformation (percent)	Stress (psi) to cause total deformation in –					Creep strength (based on minimum creep rates) (psi)	
		1 hr	10 hr	100 hr	1000 hr	2000 hr	0.00010 percent/hr	0.00001 percent/hr
[b]1200	0.2	[c]50,000	[c]49,000	[c]48,300	[c]47,200	[c]46,000	61,000	49,000
	.3	[c]70,000	[c]68,300	63,300	55,000	-------		
	.5	[c]87,300	78,700	70,000	61,200	58,600		
	1.0	-------	-------	77,700	64,500	60,500		
	Transition			67,500	53,500	-------		
[b] [d]1350	.2	[c]44,000	39,800	35,300	27,000	-------	31,100	25,000
	.5	-------	55,300	42,700	30,000	-------		
	1.0	-------	60,000	45,700	31,200	-------		
	Transition	[c]45,000	[c]43,100	40,000	-------	-------		
[d]1500	.1	-------	[c]14,500	[c]13,100	11,100	-------	15,800	13,900
	.2	[c]24,500	20,600	16,700	12,900	11,700		
	.5	[c]27,000	22,800	18,700	[c]14,500	-------		
	1.0	[c]29,000	24,200	19,500	[c]14,800	-------		
	Transition	-------	-------	18,700	[c]8,000	-------		

[a] Heat treatment: 2100° F 4 hr water-quenched; 1550° F 24 hr; and 1300° F 20 hr.
[b] NACA data.
[c] Estimated.
[d] Navy data.

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TABLE VI.– CREEP TEST DATA AT 1200°, 1350°, AND 1500° F FOR INCONEL X DISC

Specimen number (a)	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
[b]NR-99-10X	1200	45,000	1804	0.179	0.000010	0.000008	0.000004	-------	0.182	0.187	0.200	-----
[b]10Z		47,000	1671	.187	.000011	.000010	.000010	-------	.188	.190	.197	-----
[b]11Y		50,000	1537	.200	.000017	.000018	.000016	-------	.213	.223	.231	-----
[b]10Y		55,000	1655	.220	.000035	.000055	.000095	-------	.273	.295	.330	-----
[c]NR-99-9X	1350	25,000	2095	.113	.000010	.00009	.00014	0.00028	.115	.135	.188	0.295
[c]12Z		30,000	[d]2193	.153	[e].00022	.0012	.0090	-------	.198	.505	2.16	-----
[c]NR-99-9Z	1500	10,000	2160	.050	Nil	.000050	.000085	.000046	.048	.070	.099	.130
[c]12X		12,000	2152	.062	[f].000068	.000068	.000100	.000135	.078	.117	.160	.235

[a] Heat treatment: 2100° F 4 hr water-quenched; 1550° F 24 hr; and 1300° F 20 hr.
[b] NACA data.
[c] Navy data.
[d] Ruptured, 21.9-percent elongation, 20.9-percent reduction of area.
[e] Minimum creep rate 0.00005 percent/hr up to 325 hr.
[f] Minimum creep rate nil up to 400 hr.

TABLE VII.- EFFECT OF CREEP TESTING ON ROOM-TEMPERATURE PHYSICAL PROPERTIES OF INCONEL X DISC

Specimen number (1)	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
					0.1 percent	0.2 percent					
NR-99-33X	(2)	(2)	(2)	155,400	95,400	97,800	75,000	19.0	17.0	71	306
33Z	(2)	(2)	(2)	152,600	91,800	97,400	75,000	17.5	15.6		---
33Y	(2)	(2)	(2)	155,600	93,000	95,900	72,000	21.0	19.2		---
18Y	(2)	(2)	(2)	153,400	94,400	97,400	78,000	23.2	18.4		---
NR-99-11Y	1200	50,000	1537	--------	--------	--------	------	----	----	--	323
10X	1200	45,000	1804	160,000	102,000	105,000	80,000	14.5	15.8		---
NR-99-9X	1350	25,000	2095	140,000	75,400	77,800	------	34.0	30.2	--	---
NR-99-9Z	1500	10,000	2160	--------	--------	------	------	----	----	67	222
12X	1500	12,000	2152	125,500	56,500	57,800	------	22.0	20.2		---

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[1] Heat treatment: 2100° F 4 hr water-quenched; 1550° F 24 hr; and 1300° F 20 hr.
[2] Original condition. Radial specimen near rim of disc.

TABLE VIII.– COMPARISON OF PROPERTIES OF SINGLE- AND DOUBLE-AGED INCONEL X DISC MATERIAL

Test temperature, °F	Room temperature		1200		1350		1500	
Condition	Single aged (a)	Double aged (b)	Single aged (a)	Double aged (b)	Single aged (a)	Double aged (b)	Single aged (a)	Double aged (b)
Short-time properties:								
Tensile strength, psi	145,000	154,000	----------	-------	-------	------	------	-------
Elongation, percent	20	20	----------	-------	-------	------	------	-------
Reduction of area, percent	19	18	----------	-------	-------	------	------	-------
Rupture strengths, psi:								
100-hr	-------	-------	50,000 to 57,000	81,500	46,000	53,500	25,500	23,200
1000-hr	-------	-------	35,000 to 46,000	66,500	36,000	39,000	16,000	15,000
Creep strengths, psi:								
0.0001 percent/hr	-------	-------	46,000	61,000	[c]30,000	31,100	11,200	15,800
0.00001 percent/hr	-------	-------	39,000	49,000	-------	25,000	7,600	13,900
100-hr deformation strengths, psi:								
0.1-percent deformation	-------	-------	----------	-------	-------	------	14,200	[c]13,100
0.2-percent deformation	-------	-------	[c]55,000	[c]48,300	-------	35,300	19,600	16,700
0.5-percent deformation	-------	-------	[c]58,000	70,000	40,000	42,700	21,300	18,700
1.0-percent deformation	-------	-------	----------	77,700	43,500	45,700	22,200	19,500
Transition	-------	-------	59,000	66,800	[c]45,000	40,000	19,500	18,700
1000-hr deformation strengths, psi:								
0.1-percent deformation	-------	-------	----------	-------	-------	------	10,000	11,100
0.2-percent deformation	-------	-------	----------	[c]47,200	-------	27,000	12,200	12,900
0.5-percent deformation	-------	-------	----------	61,200	37,000	30,000	13,900	[c]14,500
1.0-percent deformation	-------	-------	----------	64,500	-------	31,200	14,500	[c]14,800
Transition	-------	-------	31,000	58,100	34,000	-------	12,800	[c]8,000

[a]2100° F 4 hr water-quenched; 1300° F 40 hr.
[b]2100° F 4 hr water-quenched; 1550° F 24 hr; and 1300° F 20 hr.
[c]Estimated.

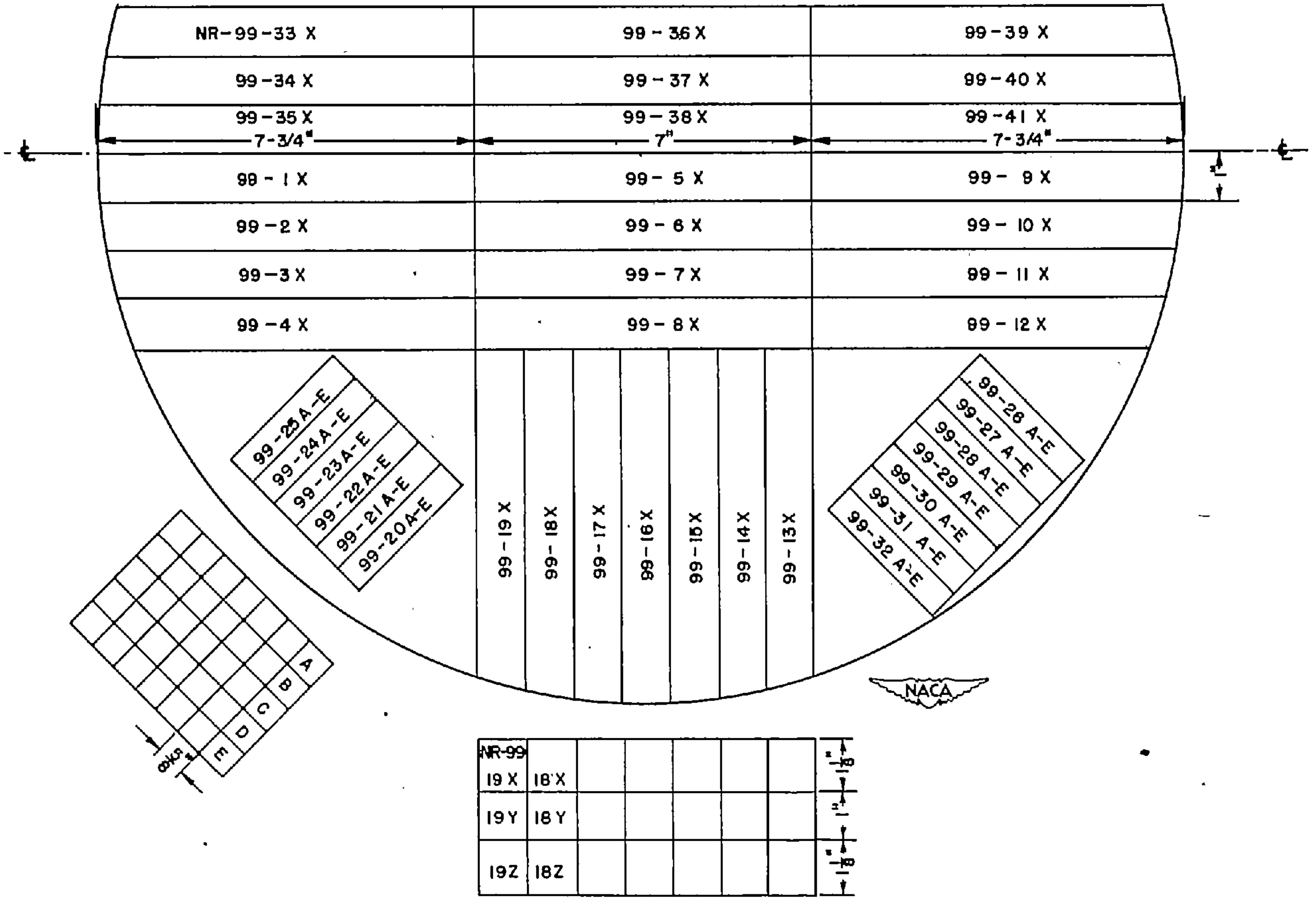


Figure 1.- Location of test coupons in Inconel X disc NR-99.

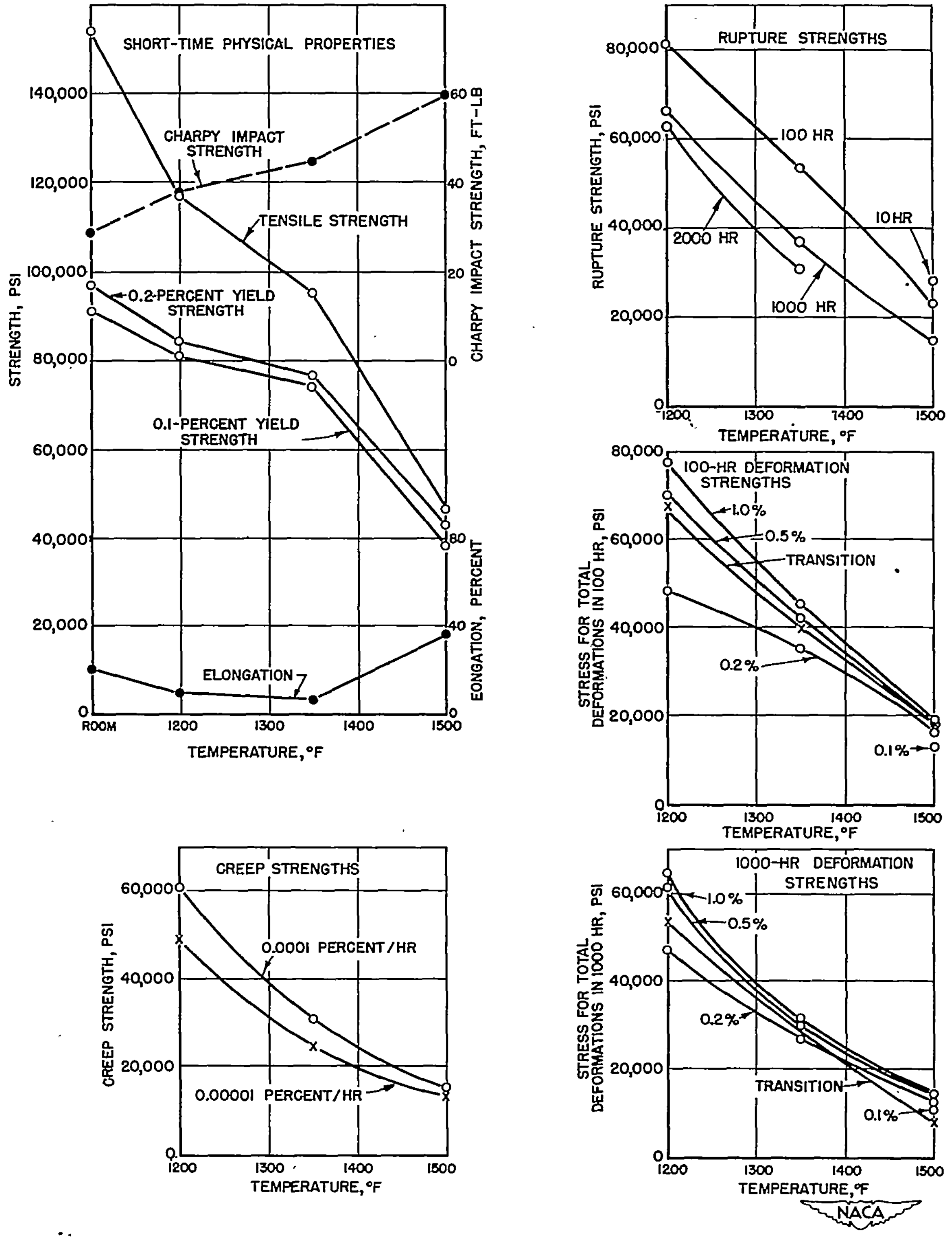


Figure 2.- Summary of properties of the Inconel X disc.

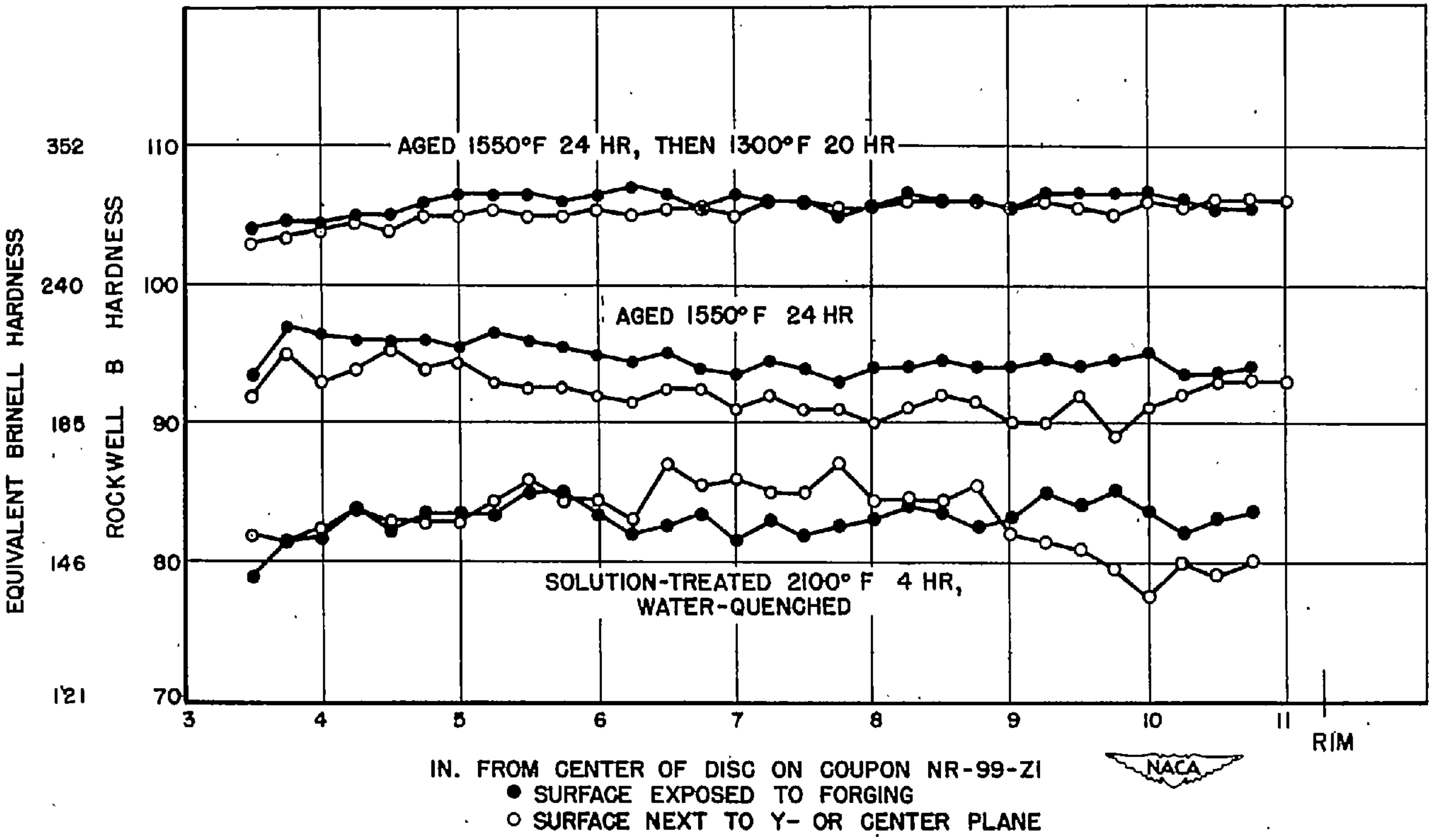


Figure 3.- Variation in hardness from center to rim of Inconel X disc.

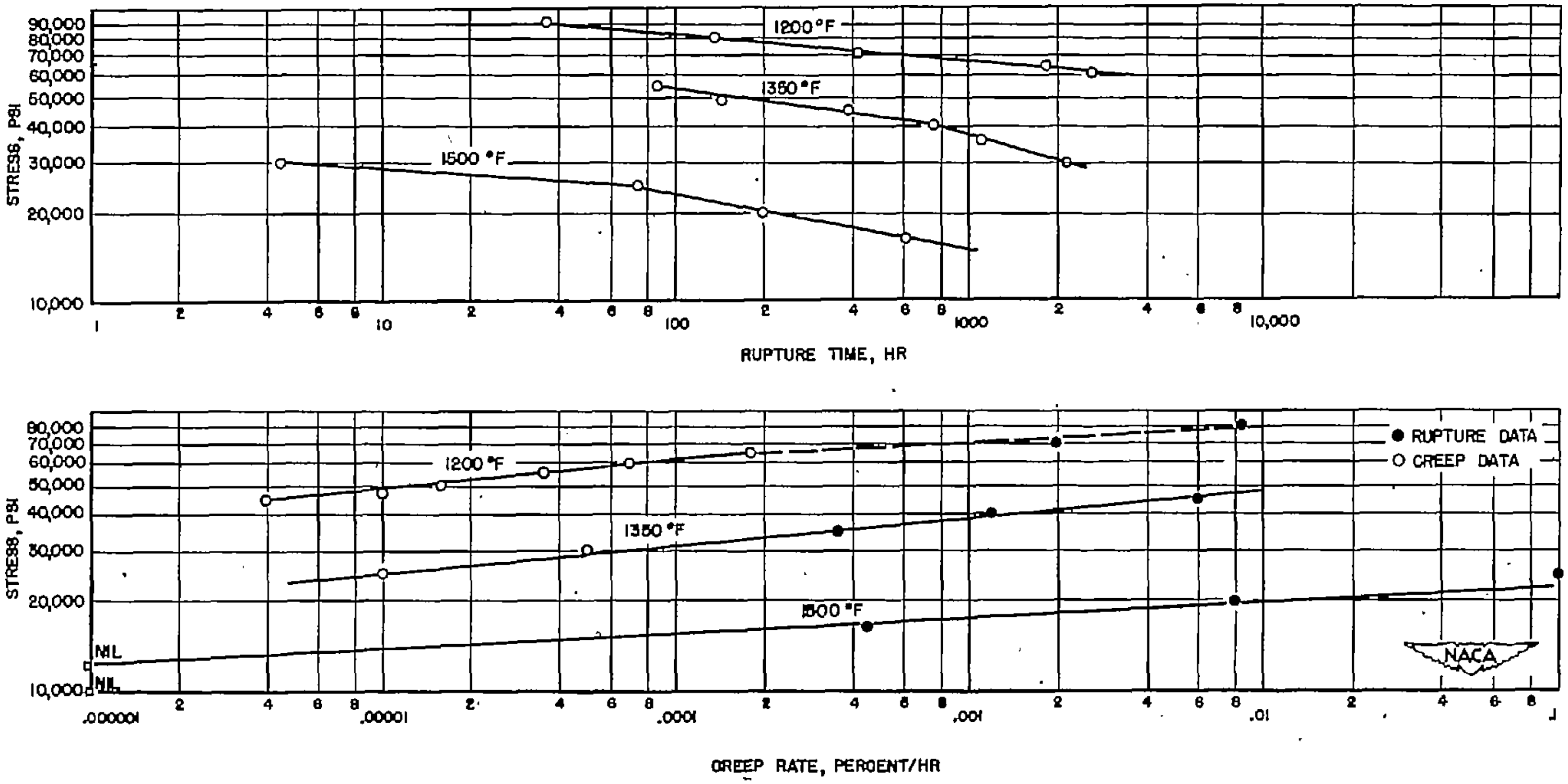


Figure 4.- Curves of stress against rupture time and creep rate at 1200°, 1350°, and 1500° F for Inconel X disc.

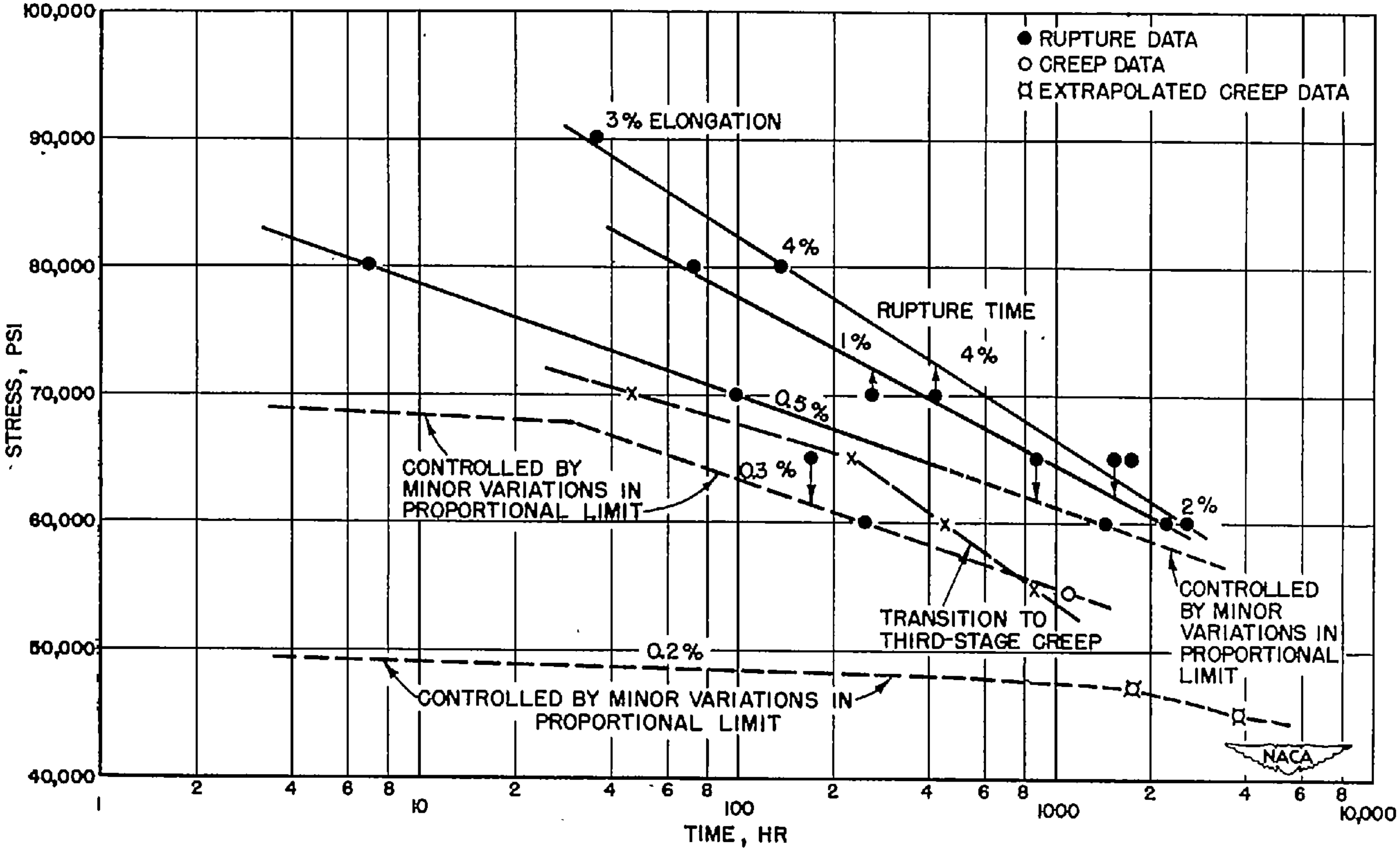


Figure 5.- Curves of stress against time for total deformation at 1200° F for Inconel X disc.

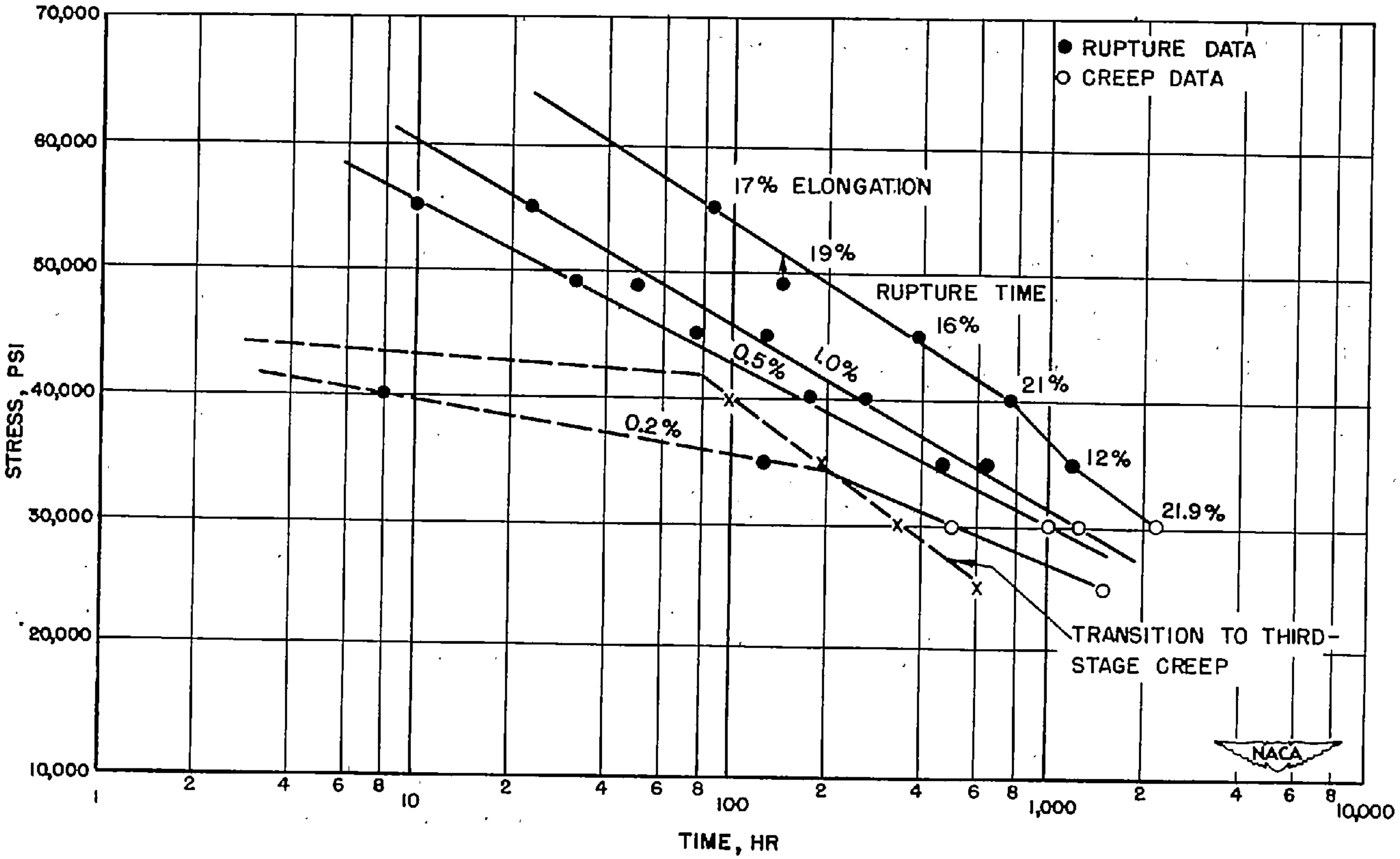


Figure 6.- Curves of stress against time for total deformation at 1350° F for Inconel X disc.

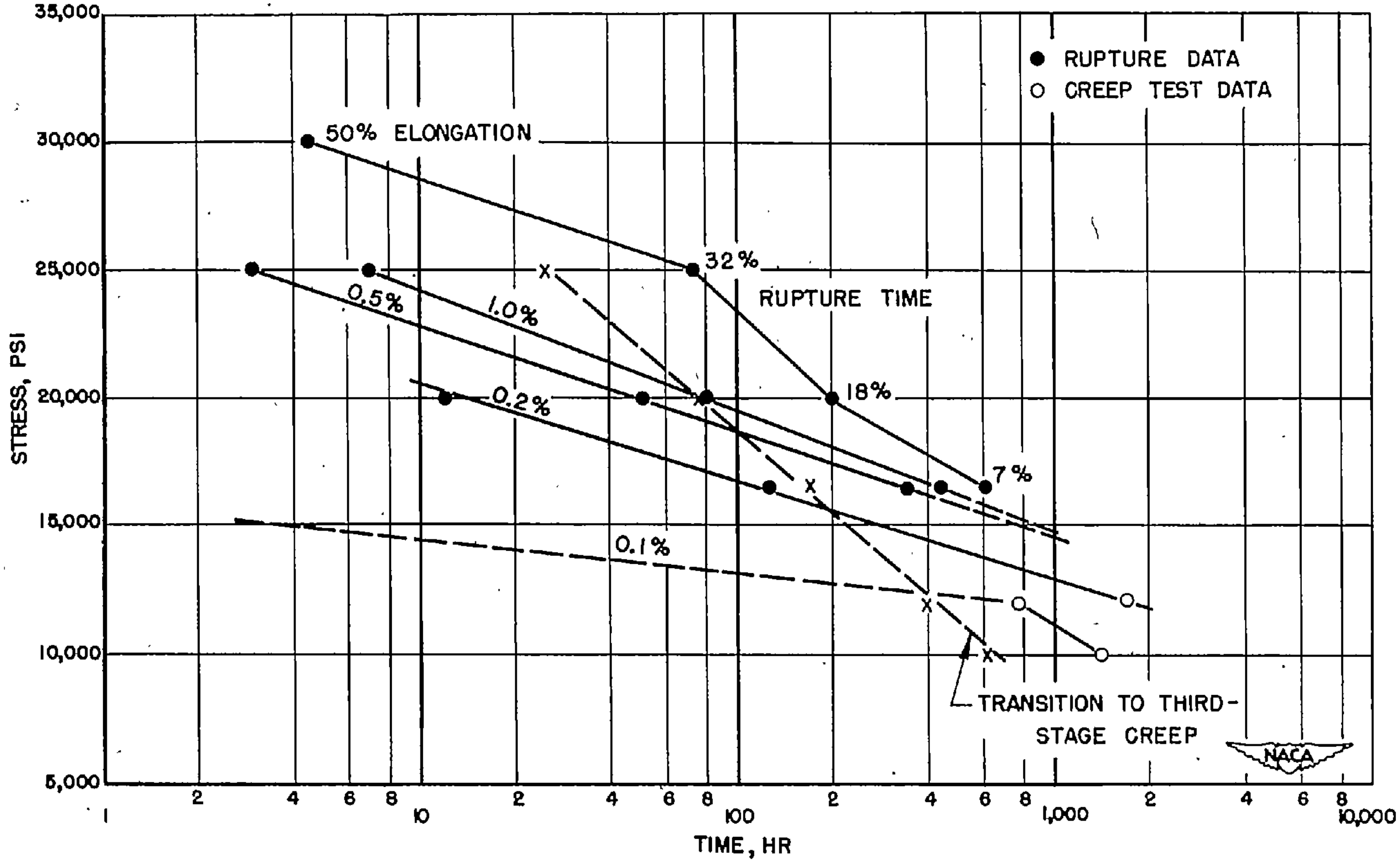
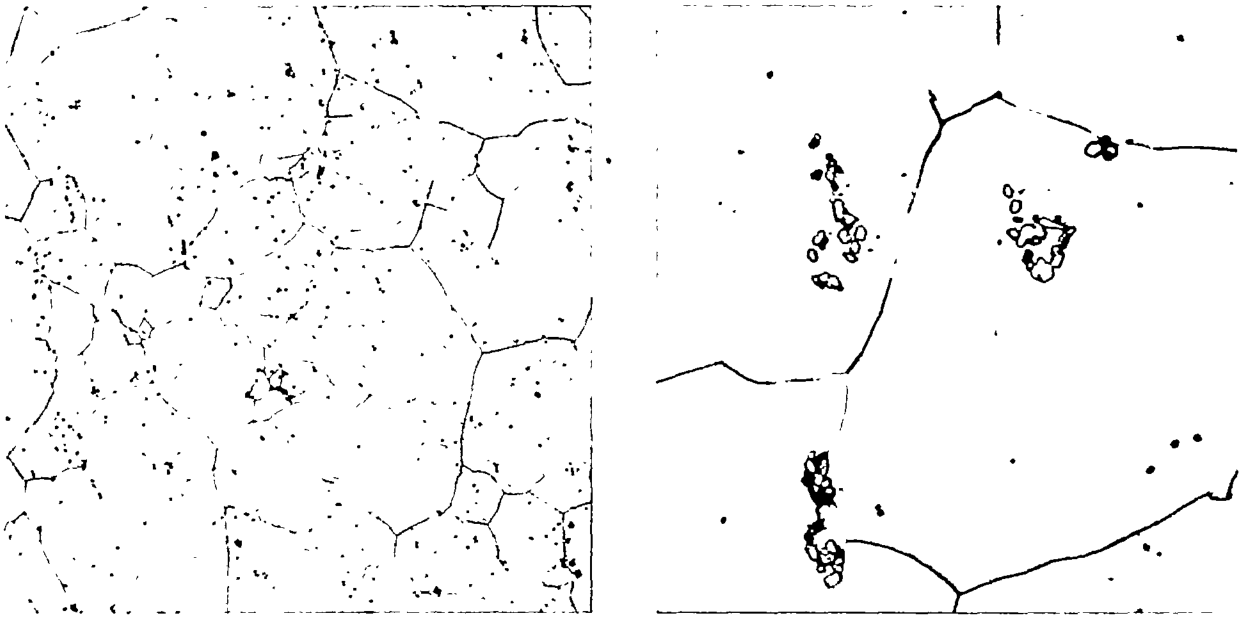


Figure 7.- Curves of stress against time for total deformation at 1500° F for Inconel X disc.



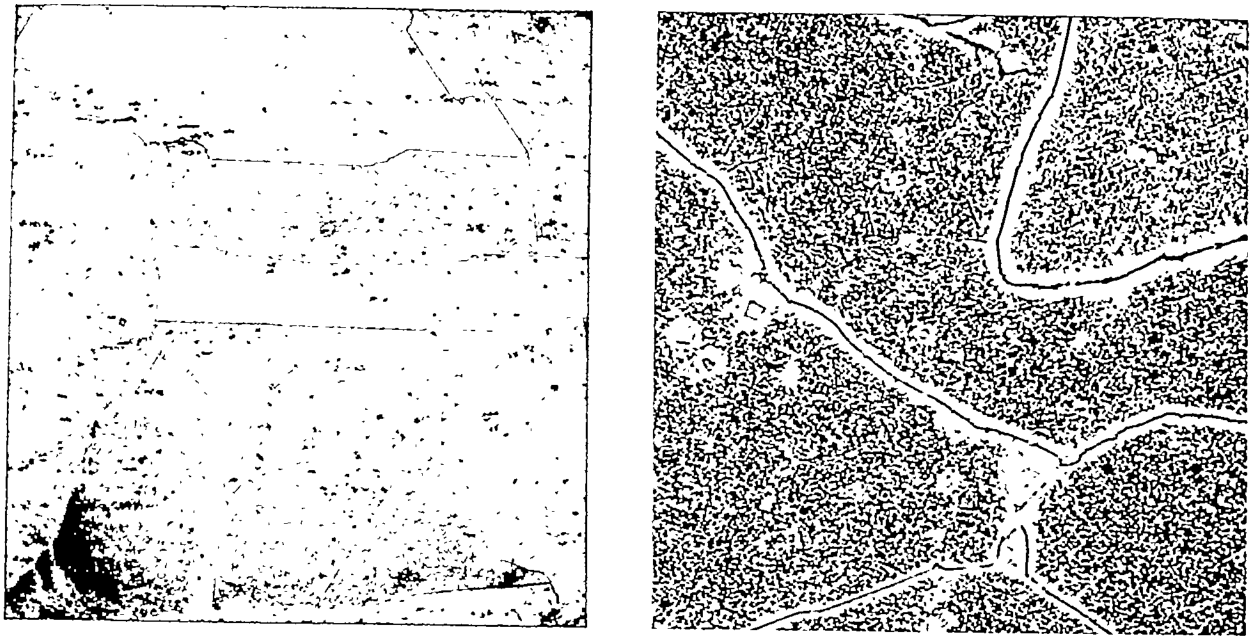
100X 1000X

(a) Solution-treated – heated at 2100° F 4 hours and water-quenched.

100X 1000X

(b) Solution-treated and then aged 24 hours at 1550° F and 20 hours at 1300° F.

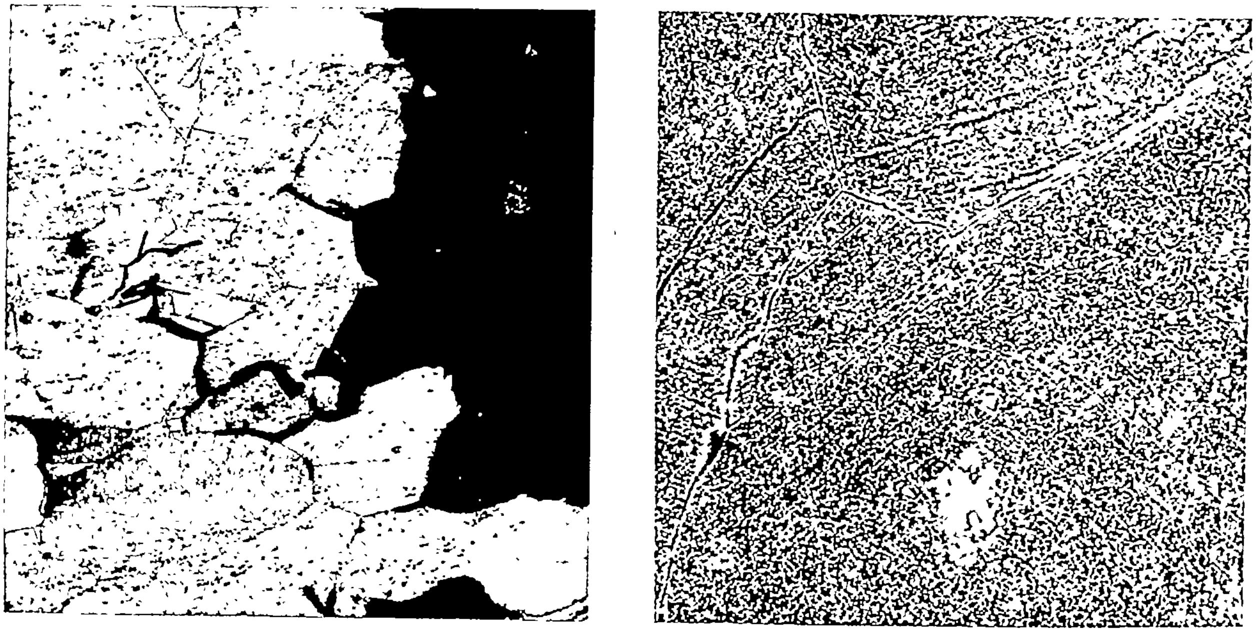
Figure 8.– Original microstructure of Inconel X disc. Aqua regia in glycerine etch.



100X

1000X

(a) Specimen 11Y; 1537 hours at 1200° F under 50,000 psi.

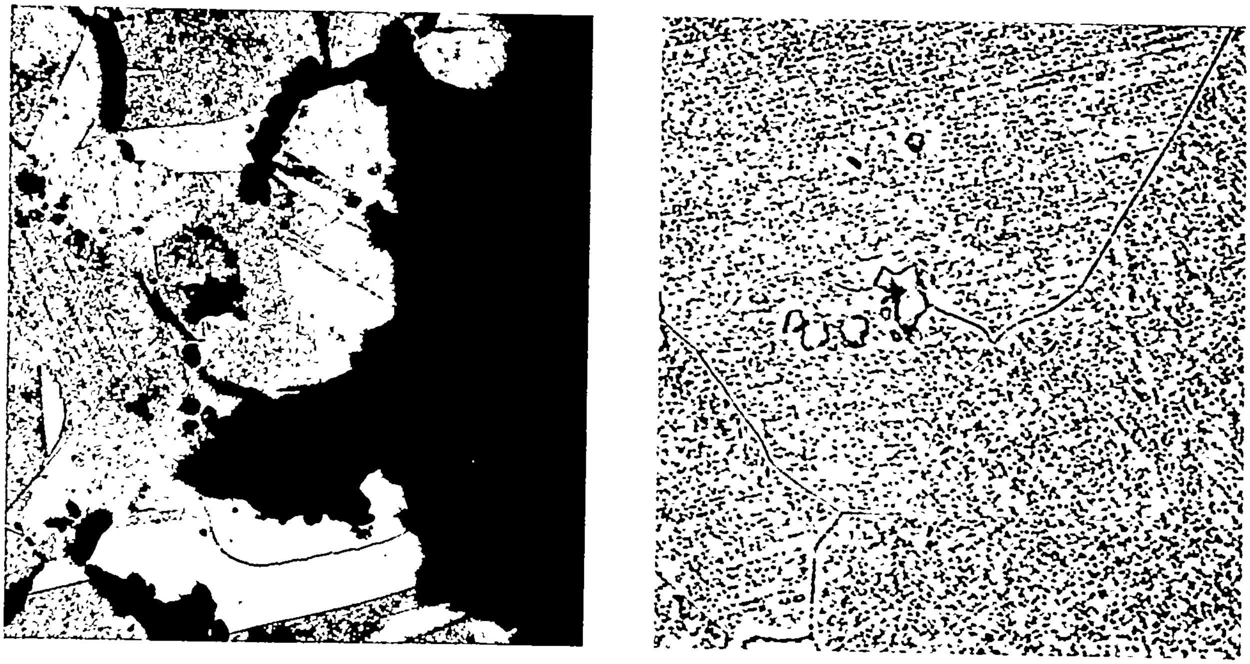


Fracture — 100X

Interior — 1000X

(b) Specimen 28E; 751 hours for rupture at 1350° F under 40,000 psi.

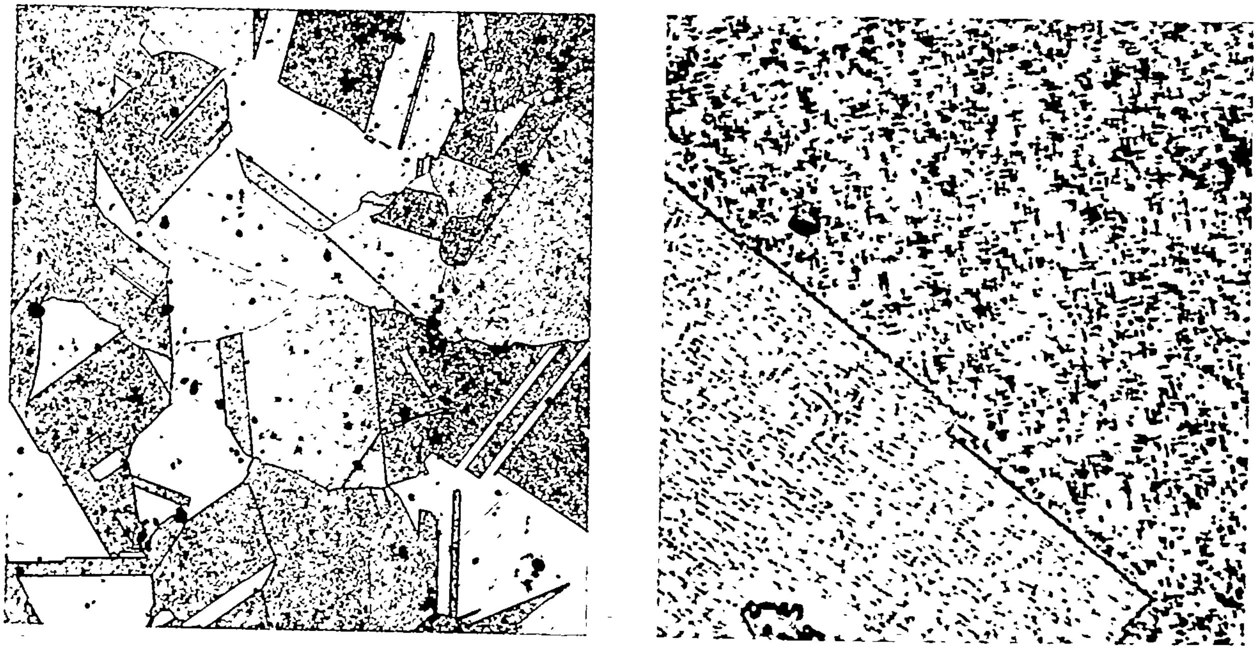
Figure 9.- Microstructures of tested specimens from Inconel X disc.
Aqua regia in glycerine etch.



Fracture – 100X

Interior – 1000X

(a) Specimen 25A; 604 hours for rupture at 1500° F under 16,500 psi.



100X

1000X

(b) Specimen 9Z; 2160 hours at 1500° F under 10,000 psi.

Figure 10.– Microstructures of tested specimens from Inconel X disc. Aqua regia in glycerine etch.