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TECHNICAL NOTE

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PROPERTIES OF 19-9DL ALLOY BAR STOCK AT 1200° F

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SUMMARY

A test program was conducted to provide data at 1200° F for 19-9DL alloy bar stock in three typical conditions of treatment. These were the hot-rolled, hot-cold-rolled, and solution-treated conditions. A stress relief at 1200° F prior to testing was applied to all samples. The properties reported include tensile data at room temperature and tensile, rupture, creep, total-deformation, and stability test data at 1200° F. The results of three creep tests at 1350° F on hot-rolled stock are also given.

The highest strengths at 1200° F for short time periods and high stresses were shown by the hot-cold-worked stock. The solution treatment was best for long time periods and low stresses. The as-rolled material was intermediate. These findings were normal for the three types of treatment.

Variations in properties can result from varying the conditions of a type of treatment with the result that, under commercial production conditions, such products as forged discs, sheet, or bar stock frequently have properties appreciably lower or higher than those reported. Those treatments which produce maximum strength at high temperatures may not properly develop other properties, such as corrosion resistance or ductility, necessary for certain applications and it may be necessary to sacrifice strength at high temperatures in order to obtain them.

The properties were found to agree with the theory that strength is dependent on the composition, size, and dispersion of precipitated particles together with the strain hardening from cold-work and structural stability. The treatments used in preparing the test stock apparently controlled the properties by changing these characteristics.

INTRODUCTION

The properties of alloys suitable for the components of gas turbines operating at high temperatures vary considerably, depending on their prior treatment and the service conditions. The large number of variables involved usually makes the data from most investigations of such alloys incomplete. For this reason an investigation was undertaken to obtain reasonably complete data for typical bar stock of 19-9DL alloy. The investigation involved considerably more than data collecting because it was intended to, and does, show the relationship between processing of a good heat-resistant alloy and the relative properties as a function of time, stress, strain rate, and total deformation.

The typical conditions of processing of the test material selected were (1) hot-rolled, (2) hot-cold-rolled at 1200° F to a minimum 0.02-percent-offset yield strength of 80,000 psi, and (3) solution-treated. All three materials were stress-relieved at 1200° F. Sufficient data were obtained at 1200° F for design curves in the form of stress against time for total deformation for deformations of 0.1, 0.2, 0.5, and 1 percent for time periods up to 2000 hours. Additional data from tensile, rupture, and creep tests supplemented the design curves. A limited amount of data at 1350° F was also obtained.

The experimental work was conducted at the University of Michigan under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics. The test materials were furnished gratis by the Universal-Cyclops Steel Corporation. In addition, this company contributed a considerable amount of the required data for hot-rolled bar stock from privately sponsored work.

TEST MATERIALS

The bar stock used for tests was from two heats. The description of processing furnished by the manufacturer is summarized as follows:

Manufacturer:

The Universal-Cyclops Steel Corporation

Chemical composition, percent:

Heat number	C	Mn	Si	Cr	Ni	Mo	W	Cb	Ti	N	S	P
N163	0.30	0.85	0.67	18.88	9.31	1.25	1.18	0.33	0.19	0.025	-----	-----
B10429	.33	1.14	.65	19.10	9.05	1.35	1.14	.35	.16	-----	0.015	0.016

Fabrication procedure:

The stock from heat N163 was furnished as hot-rolled $\frac{3}{4}$-inch round-cornered square bars. These had been stress-relieved 1 hour at 1200° F and air-cooled.

Two $\frac{7}{8}$-inch round-cornered square bars from heat B10429 were submitted. Bar 1 was hot-rolled with a finishing temperature of about 1900° F. Bar 2 was finished at 1650° F and stress-relieved for 1 hour at 1200° F.

EXPERIMENTAL PROCEDURE

Bar stock from heat N163 was available as hot-rolled material, and a considerable amount of the required data had been established in work sponsored by the Universal-Cyclops Steel Corporation. This stock, together with their data, was furnished for this investigation.

Bar 1 from heat B10429 was heated to 2100° F for 1 hour, air-cooled, and then reheated to 1200° F for 1 hour to provide samples of solution-treated stock.

The hot-cold-worked bar stock was obtained by rolling bar 2 from heat B10429 at 1200° F. The actual reduction in cross-sectional area was 20.2 percent. These bars were stress-relieved for 1 hour at 1200° F.

The testing program consisted of the following:

(1) Short-time tensile tests at room temperature and 1200° F

(2) Rupture tests up to 2000-hour duration at 1200° F

(3) Sufficient creep tests at 1200° F to provide curves of stress against time for total deformation up to 2000-hour duration and ranging from 0.1-percent total deformation to rupture

Also three creep tests on hot-rolled stock were completed at 1350° F.

RESULTS

Physical Properties

The physical properties, in table I, varied as would be expected for the three types of treatment. The 0.02-percent-offset yield strengths at room temperature varied from 26,500 to 100,000 psi with the solution treatment producing the lowest and hot-cold-work the highest strength.

The hot-rolled stock from heat N163 had intermediate strength properties. It will be noted, however, that the presumably equivalent hot-rolled stock, from heat B10429, used for the hot-cold-worked bar, had considerably higher hardness and strength in the as-rolled condition.

Rupture Test Characteristics

The relative rupture strengths of the bar stocks at 1200° F varied depending on their treatment and the time periods considered. (See table II and fig. 1.) For time periods up to approximately 2000 hours the hot-cold-working treatment developed the highest strength; the hot-rolled material was intermediate; and the solution-treated, weakest. Extrapolation of the curves of stress against rupture time to 10,000 hours indicates that the hot-rolled and solution-treated stock would have equal rupture strengths of about 29,000 psi and the hot-cold-worked material would be about 6000 psi lower.

The hot-rolled stock had the highest elongation and reduction of area in the rupture tests; the hot-cold-worked material was lowest; and the solution-treated stock was intermediate. Although the rupture test ductility after hot-cold-working was low, it increased with time for rupture.

Time-Deformation Characteristics

Curves showing the relationship between stress and time for various total deformations for the three types of bar stock are given in figures 2 to 5. The data for these curves, summarized in tables III to V, were taken from time-elongation curves from creep tests and rupture tests.

The comparative total-deformation characteristics after the three types of treatment are summarized in table VI and figure 6.

In general, the lower the total deformation or the longer the time period considered, the less difference there was between the three conditions. The shorter the time period and the higher the total deformation considered, the greater was the superiority shown by the hot-cold-rolled bar stock. The hot-rolled material was intermediate in this respect. One important reason for this was that these two materials had higher yield strengths and could support higher stresses than the solution-treated stock without excessive yielding.

Because of the wide difference in total-deformation characteristics of the creep and rupture tests, the total-deformation curves for the hot-rolled material are not as complete as would be desirable. This was caused by the rupture test stresses being at or above, while the creep tests were at stresses well below, the proportional limit.

The same situation existed for the tests on the solution-treated stock, except that some of the creep tests were also above the proportional limit. The initial deformation during the rupture tests was so rapid and extensive that the extensometer used could not measure it. The stress-strain curves for the tensile tests indicate, however, that even the 32,500 psi test exceeded 2-percent initial deformation. The total-deformation curves underwent a double inflection between about 70 and 700 hours. (See fig. 4.) This was the result of similar inflections of the time-elongation curves during the creep tests caused by a decrease in specimen length during the early portions of the tests. Presumably the decrease occurred as a result of a volume contraction accompanying precipitation.

The hot-rolled specimens also underwent a volume decrease during creep testing at 1200° F, but the data are not complete enough to show definitely the inflections in the total-deformation curves. This volume decrease was not observed in the hot-cold-worked specimens.

Somewhat erratic results were obtained from the tests on the hot-cold-worked specimens. In addition the rate of creep did not decrease with time to the same degree as the other two conditions, with the result that the total-deformation curves had a steeper slope. Some of the time-elongation curves for rupture tests were discarded because of excessive creep in threads and adapters. The data shown, however, were obtained with precision extensometers and are not subject to error from this source.

Only three creep tests were conducted at 1350° F on the hot-rolled material. The total-deformation strengths were quite low, and third-stage creep occurred at relatively low stresses and short time periods. In fact, the transition time was more dependent on time at 1350° F than on stress. (See fig. 3.)

Creep Characteristics

The creep rates measured from the time-elongation curves of the creep and rupture tests are summarized in table VII. In all the creep tests, except those at 1350° F on the hot-rolled stock, the creep rates decreased with time of testing. Minimum rates and time of transition to third-stage creep are shown for the rupture tests.

The usual logarithmic curves of stress against creep rate are included as figure 7. The creep rates plotted are those at the end of 1000 hours of testing or the minimum rates from rupture tests. The creep strengths for rates of 0.00001 and 0.0001 percent per hour as defined by these curves are compared in table VIII. This table also includes creep strengths for tests of 2000-hour duration, as estimated from the fragmentary data from tests of this duration and the minimum rates from rupture tests.

There was relatively little effect from treatment on the stress for 0.00001-percent-per-hour creep rate. There was only a slight increase in this creep strength as measured by the lower rates at 2000 hours. The indicated 0.0001-percent-per-hour creep strength of the solution-treated stock increased materially with time, so that after 2000 hours of testing there was relatively little difference between the three treatments.

The creep strengths are frequently extrapolated for design purposes on the basis that a rate of 0.00001 percent per hour is equivalent to 1 percent in 100,000 hours and 0.0001 percent per hour is equivalent to 1 percent in 10,000 hours. Comparison of such extrapolations with the extrapolated curves for transition to third-stage creep indicates that only the solution-treated bar-stock creep data can be safely extrapolated. The hot-rolled material would enter third-stage creep under the creep-strength stress before 10,000 or 100,000 hours. Extrapolation of creep strengths of hot-cold-worked material would be even less safe.

The data at 1350° F for hot-rolled stock were incomplete and permitted estimation of only the 0.0001-percent-per-hour creep strength. The curve is of doubtful value for extrapolation purposes because the available data suggest that transition to third-stage creep is more a function of time than stress. Early third-stage creep could be expected under a stress corresponding to the 0.0001-percent-per-hour creep strength.

Stability Characteristics

The hot-cold-worked bar stock tested at 1200° F and the hot-rolled bar tested at 1350° F were the most unstable. The hot-rolled bar tested at 1200° F was intermediate in this respect while the solution-treated bar showed the least change in stability characteristics.

Tensile, impact, hardness, and metallographic tests at room temperature all indicated varying degrees of structural instability during testing of the three types of bar stock. All three materials lost ductility and impact strength, although the data in table IX do not show any excessively low values. The solution-treated material was the only one which did not show an appreciable increase in hardness during testing.

The microstructures of the original test materials and the specimens after testing (figs. 8 to 11) also show structural instability. The most pronounced change occurred in the hot-rolled material subjected to creep tests at 1350° F. Apparently a new constituent, the irregular small clear grains in figure 9(b), formed during testing at 1350° F. Considerable precipitation occurred during testing of the hot-rolled and solution-treated stock at 1200° F. There was practically no change in the appearance of the hot-cold-worked test material during testing at 1200° F.

DISCUSSION OF RESULTS

The objectives of this investigation were twofold. Properties were to be obtained for three typical types of bar stock in order to clarify the relative effects of different types of processing procedures.

Metallurgical studies were to be made so as to develop an understanding of the reasons for the changes in properties when the processing conditions are varied.

Properties of Bar Stock

The properties measured were limited to those commonly used to appraise an alloy for service in gas turbines, particularly for the discs of rotors. Therefore, the data include only the results of tensile tests at room temperature and of tensile, rupture, and creep tests at 1200° F. Time-total-deformation curves plotted from the rupture and creep test data will serve as a guide in design. All the data are applicable to the selection of the proper type of heat treatment and processing conditions for different types of service.

It was recognized in selecting the types of bar stock to test that, from a reproducibility standpoint, hot-rolled material could be quite variable, depending on the rolling conditions. Hot-rolled stock was selected as one of the types and hot-rolled material was hot-cold-worked for another type because these conditions were most representative of those actually used. Insofar as possible, however, stock representative of the usual hot-worked product was selected for the tests.

In general, the data show the trends to be expected from the three types of treatment:

(1) A solution treatment produces the best properties for long service at low strain rates (low stresses)

(2) Hot-cold-working produces high strengths for relatively short time periods at high strain rates (high stresses) with low ductility to fracture in the rupture test

(3) Hot-rolled bar stock has intermediate properties

The data do not show the degree of variation to be expected from normal variations in chemical composition, processing, and heat treatment. In addition to the normal spread in data, additional differences in properties are to be expected when the specified conditions of treatment are changed. Such variations in treatment conditions may lead to considerable alternation of the actual strength of a fabricated part. Forged discs and sheet, or even bar stock, can and frequently do have lower or higher properties than those obtained in the tests for this report because the forging conditions, heat treatments, and degree of hot-cold-work were changed or were not suitably controlled under commercial production conditions. Comparative data for forged discs have been published in references 1 and 2.

The data from this investigation can be used to approximate the time period at which the different types of treatment produce superior properties for various strain rates. Specific cases may differ from those reported, but the general trends are fairly well shown. The hot-cold-worked stock tested probably is the least typical of its type of processing of the three conditions considered because the properties before hot-cold-working indicate that considerable hot-cold-work had occurred during hot-rolling.

From a practical standpoint, it should be recognized that properties other than strength under tension may be of equal or even greater importance for some service conditions. Such factors as corrosion resistance, forming characteristics, thermal shock resistance, and freedom from intergranular precipitation may be of greater importance than strength. It therefore follows that although it may be possible to select a treatment which will give the highest rupture or total-deformation strength such a treatment may introduce other characteristics which would prohibit the use of the material in some applications. In fact, it is conceivable that it might be desirable under some conditions to sacrifice a considerable amount of strength to obtain, for instance, freedom from intergranular precipitation during service by precipitating and agglomerating excess constituents.

The creep data at 1200° F revealed characteristics of 19-9DL alloy which may be important:

(1) The volume tends to decrease in the solution-treated and hot-rolled conditions during the first 200 or 300 hours at 1200° F.

(2) The volume decreases obscure the characteristics of stress against creep rate of tests of short duration at low stresses. Tests of sufficient duration apparently reach the point where secondary creep is the controlling factor, although there appears to be a period when the volume change ceases to be effective where fairly rapid creep occurs.

(3) Solution-treated material has a very long period of decreasing creep (first-stage or primary creep) rate but eventually reaches a point where its creep rates are lower under a given stress than those for hot-rolled or hot-cold-worked conditions. This effect is sufficient to give erroneous, but conservative, creep characteristics from tests of 1000-hour duration; even 2000-hour tests had apparently not established minimum creep rates. The effect of time is not so great under high stresses so that for relatively short-time tests the rupture characteristics may be a better criterion of expected performance of the alloy than the creep rates under low stresses.

Metallurgical Characteristics

Experience with the test properties of 19-9DL and other high-strength alloys seems to indicate that the properties at different time periods and temperatures are apparently a function of the size and dispersion of precipitated particles and of strain hardening. Some possible generalizations, concerned with the influence of these phenomena on properties, are as follows:

(1) An effective solution treatment produces the highest strengths for time periods in excess of 2000 to 10,000 hours at 1200° F. The time period for superiority after this treatment decreases with increasing temperature so that at temperatures above 1350° F the solution-treated condition will give the highest rupture and creep properties except for very short time periods.

The outstanding properties of solution-treated material are apparently the result of the precipitation of the most effective size and dispersion of particles of excess constituents in a stable form during testing.

(2) Any treatment which introduces cold-work results in a structural instability at temperatures of 1200° F and higher. The strengths at short time periods may be high, but the structural instability causes rapid agglomeration of excess constituents and possibly other structural changes which will result in loss in strength.

(3) Hot-worked materials can be quite variable in their characteristics, depending on the conditions of hot-working. An effective solution treatment during heating for hot-working followed by a high finishing temperature with fairly rapid cooling produces a material similar to that of a solution treatment. A low finishing temperature during hot-working will produce properties characteristic of hot-cold-worked material discussed in the next section.

In addition, it is possible that agglomeration of excess constituents can occur when there is considerable reduction at temperatures above about 1400° F. Reheating for hot-working under conditions which do not effectively dissolve precipitated constituents also does the same thing. Such materials are characterized by intermediate to low strength and high ductility in the rupture test.

(4) Hot-cold-work produces a material which combines the effects of cold-work and precipitation. The actual properties depend on the temperature of working, the degree of reduction at these temperatures, and the initial condition of the material before hot-cold-work. A wide range in properties is therefore possible. All the possibilities are not known. It does appear, however, that the following trends are justified:

(a) An effective prior solution treatment together with 15 to 20 percent reduction at 1200° to 1400° F produces the highest possible rupture strengths at 1200° F for time periods up to 2000 to 10,000 hours. Such materials have low elongation in the rupture test.

(b) Hot-cold-working materials with previously precipitated excess constituents will result in lower strengths and higher elongation in the rupture tests. Such conditions can occur when hot-worked material is hot-cold-worked.

(c) The time period over which superior strengths are retained by hot-cold-worked material decreases with increasing temperature above 1200° F so that little or no superiority exists above about 1350° F. This loss in strength is presumably due to the structural instability caused by the cold-work and possibly an unstable size, composition, and dispersion of precipitates.

(d) Apparently the hot-cold-work does not improve strength at low strain rates, even at 1200° F.

The materials studied in this investigation fit into the preceding generalizations in the following manner:

(1) The hot-rolled stock from heat N163 apparently approximated a solution-treated condition with a small amount of hot-cold-work. Consequently the strength at 1200° F was somewhat higher than the solution-treated material and the stability was nearly as good as the solution-treated stock. The ductility in the rupture test was low as a result of the hot-cold-work on effectively solution-treated material.

The hot-rolled material from heat B10429 used for hot-cold-rolling and for the creep tests at 1350° F was similar to that from heat N163 except that it was hot-cold-worked to a considerably greater extent during hot-rolling. Strain hardening from this hot-cold-work probably accounts for the structural instability at 1350° F. The degree of hot-cold-work, as indicated by the properties, seemed to be considerably more than would be anticipated from the reported hot-rolling conditions.

(2) The solution-treated stock tested was normal for a material with an effective solution treatment at a temperature low enough to prevent excessive grain growth.

(3) The hot-cold-worked material is difficult to analyze because it represents a severe degree of hot-cold-work at 1200° F applied to a material already quite severely hot-cold-worked during hot-rolling. The high strength at short time periods at 1200° F, the high yield strengths, and the low ductility in the rupture test are representative of a material severely hot-cold-worked after a fairly effective solution treatment.

The structural changes occurring during the tests cannot be adequately explained. Certainly precipitation and agglomeration of excess constituents occur. In addition, the material creep tested at 1350° F shows evidence of a structural change which has not yet been properly identified. It probably is, however, connected with the formation of ferrite-sigma phases. An alloy with an analysis of the type considered is structurally on the border line for the coexistence of austenite and ferrite-sigma phases.

CONCLUSIONS

From a study of the tensile, rupture, creep, and total-deformation characteristics at 1200° F for hot-rolled, hot-rolled and hot-cold-worked, and solution-treated 19-9DL alloy bar stock, the following conclusions were made:

1. The properties obtained were quite typical for the three types of bar stock in that

a. Hot-cold-work produced the highest strengths in rupture and creep tests under high stresses and the more rapid strain rates considered. This superiority decreased with both time and strain rate so that the hot-rolled and solution-treated materials had better properties at the longer time periods and lower strain rates. The bar stock tested had properties characteristic of effectively solution-treated and hot-cold-worked stock.

b. The solution-treated material had the best strengths at time periods longer than several thousand hours.

c. The hot-rolled material was intermediate in its characteristics. Its properties were characteristic of material effectively solution-treated and slightly hot-cold-worked.

2. The data were analyzed, and it was recognized that, while quite typical, consideration was not given to variations to be expected from normal chemical composition and production conditions. Likewise, the data do not show the greater variation to be expected from deliberately changing the hot-rolling conditions, the temperature and degree of hot-cold-work, or the solution-treating temperatures.

Commercial products such as forged discs, sheet, and bar stock are frequently made under conditions different from those used on the experimental bar stock of this investigation and, consequently, the properties frequently may be lower and less frequently higher than those reported for the "typical" stock tested.

3. The effect of time and strain rate on properties indicates that the optimum treatment for any particular application depends on the service conditions. It is also important to consider the possibility that other properties than load-carrying ability under tension may be of major importance in determining the optimum treatment for the alloy.

4. The data seem to agree with the theory that the strength of the alloy is a function of the size and dispersion of precipitated particles

together with the amount of cold-work. Loss of strength of hot-cold-worked materials at prolonged time periods seems to be caused by structural instability due to cold-work, resulting in agglomeration of excess constituents and possibly other structural changes. This structural instability is increased with increasing temperatures.

University of Michigan
Ann Arbor, Mich., June 30, 1947

REFERENCES

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2. Freeman, J. W., Reynolds, E. E., and White, A. E.: A Metallurgical Investigation of Two Contour-Forged Gas-Turbine Discs of 19-9DL Alloy. NACA TN No. 1532, 1948.

TABLE I

PHYSICAL PROPERTIES OF 19-9DL ALLOY BAR STOCK

Processing and heat treatment	Test temperature (°F)	Tensile strength (psi)	Offset yield strength (psi)			Proportional limit (psi)	Elongation in 2 in. (percent)	Reduction of area (percent)	Brinell hardness	Young's modulus
			0.02 percent	0.10 percent	0.20 percent					
Heat N163 - Hot-rolled and stress-relieved at 1200° F	Room	118,250	55,000	66,000	69,000	44,000	58.0	54.7	216	29.5×10^6
	Room	116,750	54,000	63,500	66,500	37,500	54.5	56.8	215	29.5
	1200	74,250	-------	38,000	41,000	20,000	30.5	30.8	---	21.5
	1200	75,000	-------	36,500	39,000	22,500	33.5	33.7	---	20
Heat B10429 - Bar 2 hot-rolled, finished at 1650° F, and stress-relieved at 1200° F	Room	131,500	75,000	86,500	91,500	50,000	31.5	44.7	252	29
	Room	130,500	66,000	82,500	88,500	42,500	22.0	45.4	242	29
	1200	76,500	-------	53,500	57,700	22,500	26.0	42.3	---	19.5
Heat B10429 - Hot-rolled, finished at 1900° F, heated 1 hr at 2100° F, and air-cooled; stress-relieved at 1200° F for 1 hr	Room	101,750	23,000	35,500	41,500	15,000	52.5	58.2	186	30.5
	Room	102,950	30,000	38,500	43,000	20,000	54.0	57.6	189	----
	1200	67,400	-------	23,000	24,500	7,500	35.5	37.9	---	21
	1200	66,400	-------	23,000	25,000	7,500	35.0	35.0	---	21
Heat B10429 - Bar 2 hot-rolled, finished at 1650° F and stress-relieved at 1200° F; reduced 20 percent at 1200° F and stress-relieved at 1200° F for 1 hr	Room	152,500	97,500	118,500	121,000	72,500	24.5	44.0	321	29
	Room	155,900	103,000	123,000	129,000	75,000	24.0	43.5	335	28
	1200	98,625	-------	83,500	88,000	32,500	13.5	30.8	---	21
	1200	98,400	-------	84,000	88,000	30,000	12.0	23.7	---	20.5

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TABLE II

RUPTURE TEST CHARACTERISTICS OF 19-9DL ALLOY BAR STOCK

AT 1200° F

Processing and heat treatment	Stress (psi)	Rupture time (hr)	Elongation (percent)	Reduction of area (percent)
Hot-rolled and stress-relieved	48,000	68	17	18.8
	45,000	199	15	28.0
	40,000	498	11.5	19.0
	37,000	1111	14	29.5
Heated 1 hr at 2100° F, air-cooled, and stress-relieved	45,000	60	10	14.0
	40,000	180	19	25.6
	36,000	693	30	33.5
	32,500	2069	10	17.8
Hot-rolled, stress-relieved, hot-cold-rolled 20 percent at 1200° F, and stress-relieved	60,000	36	2	1.2
	55,000	123	2	2.0
	50,000	157	2	4.0
	46,000	420	2	2.7
	45,000	605	2.5	3.2
	40,000	843	2.5	4.2
	40,000	971	4	1.6
	36,000	978	3	6.1
	35,000	1406	4	6.2
	35,000	1754	3.5	1.0

Rupture strength

Processing and heat treatment	Stress (psi) for rupture in -			
	100 hr	1000 hr	2000 hr	10,000 hr (1)
Hot-rolled and stress-relieved	48,000	37,000	34,500	29,000
Heated 1 hr at 2100° F, air-cooled, and stress-relieved	42,500	34,500	32,500	29,000
Hot-rolled, stress-relieved, hot-cold-rolled 20 percent at 1200° F, and stress-relieved	54,500	39,000	33,000	23,000

[1]Estimated.

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TABLE III

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION FOR HOT-ROLLED

19-9DL ALLOY BAR STOCK

Heat number	Temperature (°F)	Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of -				Transition to third-stage creep		Rupture data	
				0.1 percent	0.2 percent	0.5 percent	1.0 percent	Time (hr)	Deformation (percent)	Rupture time (hr)	Elongation (percent)
N163	1200	10,000	0.0507	------							
	1200	11,000	.0570	[a]3000							
	1200	12,000	.062	235							
	1200	15,000	.076	27	[a]2000						
	1200	17,500	.089	2.5	290						
	1200	20,000	.102	------	180						
	1200	37,000	.29	------	----	13	70	620	3.1	1111	14.0
	1200	40,000	.50	------	----	----	12	310	4.1	498	11.5
	1200	45,000	4.0	------	----	----	----	150	8	199	15.0
	1200	48,000	------	------	----	----	----	---	----	68	17.0
B10429	1350	8,000	.047	28	355	[a]1290	----	650	.26	----	----
	1350	10,000	.055	17	165	875	----	525	.33	----	----
	1350	12,000	.067	5	105	700	[a]1100	500	.38	----	----

[a]Estimated by creep-data extrapolation.

TABLE IV

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1200° F FOR SOLUTION-TREATED 19-9DL ALLOY BAR STOCK

Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of -				Transition to third-stage creep		Rupture data	
		0.1 percent	0.2 percent	0.5 percent	1.0 percent	Time (hr)	Deformation (percent)	Rupture time (hr)	Elongation (percent)
10,500	0.0480	1800							
12,000	.0583	425	[a]>3000						
15,000	.0716	115	660						
17,500	.0912	1	255	[a]3600					
20,000	.129	----	20	350	[a]>7000				
25,000	.258	----	----	70	455				
32,500	(b)	----	----	----	----	1300	----	2069	10.0
36,000	(b)	----	----	----	----	525	----	693	30.0
40,000	(b)	----	----	----	----	100	----	180	19.0
45,000	(b)	----	----	----	----	----	----	60	10.0

[a]Minimum time to reach indicated deformation estimated by extrapolation of time-elongation curve.

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[b]The yield point was exceeded during application of the stress and the initial deformation could not be measured because of excessive yielding. The stress-strain curves from the tensile tests showed that the deformation due to a stress of 32,500 psi would be in excess of 2 percent.

TABLE V

DATA ON STRESS AND TIME FOR TOTAL DEFORMATION AT 1200° F FOR HOT-COLD-WORKED 19-9DL ALLOY BAR STOCK

Stress (psi)	Initial deformation (percent)	Time (hr) for total deformations of -				Transition to third-stage creep		Rupture data	
		0.1 percent	0.2 percent	0.5 percent	1.0 percent	Time (hr)	Deformation (percent)	Rupture time (hr)	Elongation (percent)
11,000	0.0611	520							
15,000	.0700	85							
17,500	.0833	11	1750						
20,000	.0995	---	525						
25,000	.1200	---	130						
30,000	.1580	---	4	675					
30,000	.1615	---	3	1120					
32,500	.1680	---	2	575					
35,000	.22	---	----	295	1360	1000	0.80	1754	3.5
40,000	.27	---	----	48	495	625	1.12	971	4.0
45,000	.37	---	----	10	350	550	1.25	605	2.5

TABLE VI

TIME-DEFORMATION STRENGTHS AT 1200° F FOR 19-9DL BAR STOCK

Treatment	Total deformation (percent)	Stress (psi) to cause total deformation in -				
		10 hr	100 hr	1000 hr	2000 hr	10,000 hr
Hot-rolled	0.1	16,000	13,000	11,250	11,000	[a]10,000
Solution-treated	.1	16,000	15,000	11,000	10,000	[a]8,000
Hot-cold-worked	.1	17,500	14,500	9,500	8,000	[a]4,500
Hot-rolled	.2	------	19,000	16,000	15,000	[a]13,000
Solution-treated	.2	21,000	18,500	14,500	13,000	[a]11,000
Hot-cold-worked	.2	29,000	25,000	19,000	17,000	[a]12,000
Hot-rolled	.5	37,500	32,500	------	------	------
Solution-treated	.5	27,500	24,000	19,000	18,000	[a]16,000
Hot-cold-worked	.5	45,000	38,000	30,000	27,000	[a]20,000
Hot-rolled	1.0	41,000	36,000	------	------	------
Solution-treated	1.0	29,500	28,000	23,500	22,500	[a]20,000
Hot-cold-worked	1.0	------	------	36,500	31,500	[a]21,000
Hot-rolled	Transition	------	46,000	34,000	30,500	[a]22,500
Solution-treated	Transition	------	41,000	33,500	31,000	[a]25,000
Hot-cold-worked	Transition	------	------	35,000	27,000	[a]11,000

[a]Estimated.

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TABLE VII

CREEP TEST DATA FOR 19-9DL ALLOY BAR STOCK

Treatment	Temper-ature (°F)	Stress (psi)	Duration (hr)	Initial deformation (percent)	Creep rate (percent/hr) at -			
					500 hr	1000 hr	1500 hr	2000 hr
Hot-rolled (Heat N163)	1200	10,000	1040	0.0507	0.000024	0.000009	--------	--------
		11,000	2000	.0570	.000024	.000016	0.000013	0.000010
		12,000	1150	.062	.000038	.000019	--------	--------
		15,000	1060	.076	.000044	.000040	--------	--------
		20,000	1150	.102	.000083	.000072	--------	--------
		37,000	[a]620	.29	--------	[b].0031	--------	--------
		40,000	[a]310	.50	--------	[b].0087	--------	--------
		45,000	[a]147	4.0	--------	[b].023	--------	--------
Solution-treated (Heat B10429)	1200	10,500	1650	.0480	.00006	.000012	.000008	--------
		12,000	2300	.0583	.00010	.000055	.000025	.000012
		15,000	1008	.0716	.00018	.00010	--------	--------
		17,500	2608	.0912	.00029	.00012	.000050	.000030
		20,000	1005	.129	.00038	.00014	--------	--------
		25,000	1150	.258	.00060	.00019	--------	--------
		32,500	[a]1300	(c)	.0016	[b].00045	--------	--------
		36,000	[a]525	(c)	--------	[b].0026	--------	--------
		40,000	[a]100	(c)	--------	[b].034	--------	--------
Hot-cold-worked (Heat B10429)	1200	11,000	1160	.0611	.000032	.000009	--------	--------
		15,000	1060	.0700	.000033	.000026	--------	--------
		17,500	1561	.0833	.000050	.000036	.000020	--------
		20,000	1004	.0995	.000078	.000054	--------	--------
		25,000	1050	.1200	.00011	.00010	--------	--------
		30,000	1167	.1580	.00021	.00018	--------	--------
		30,000	1006	.1615	.00031	.00027	--------	--------
		32,500	1150	.1680	.00034	.00030	--------	--------
		35,000	[a]1000	.22	.00044	[b].00040	--------	--------
		40,000	[a]625	.27	--------	.00096	--------	--------
		45,000	[a]550	.37	--------	.0013	--------	--------
Hot-rolled (Heat B10429)	1350	8,000	[a]650	.047	--------	[b].00019	--------	--------
		10,000	[a]525	.055	--------	[b].00030	--------	--------
		12,000	[a]500	.067	--------	[b].00042	--------	--------

[a]Time of transition to third-stage creep.

[b]Minimum rate.

[c]Tests far above yield strength.

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TABLE VIII

CREEP STRENGTHS FOR 19-9DL ALLOY BAR STOCK

Treatment	Temperature (°F)	Creep strengths (psi) from tests at -			
		0.00001 percent/hr		0.0001 percent/hr	
		1000 hr	2000 hr	1000 hr	2000 hr
Hot-rolled (Heat N163)	1200	9,500	11,000	22,000	22,000
Solution-treated (Heat B10429)	1200	10,000	11,000	15,000	[a]25,000
Hot-cold-worked (Heat B10429)	1200	11,000	[a]14,500	25,000	[a]25,000
Hot-rolled (Heat B10429)	1350	------	------	5,700	------

[a]Estimated.

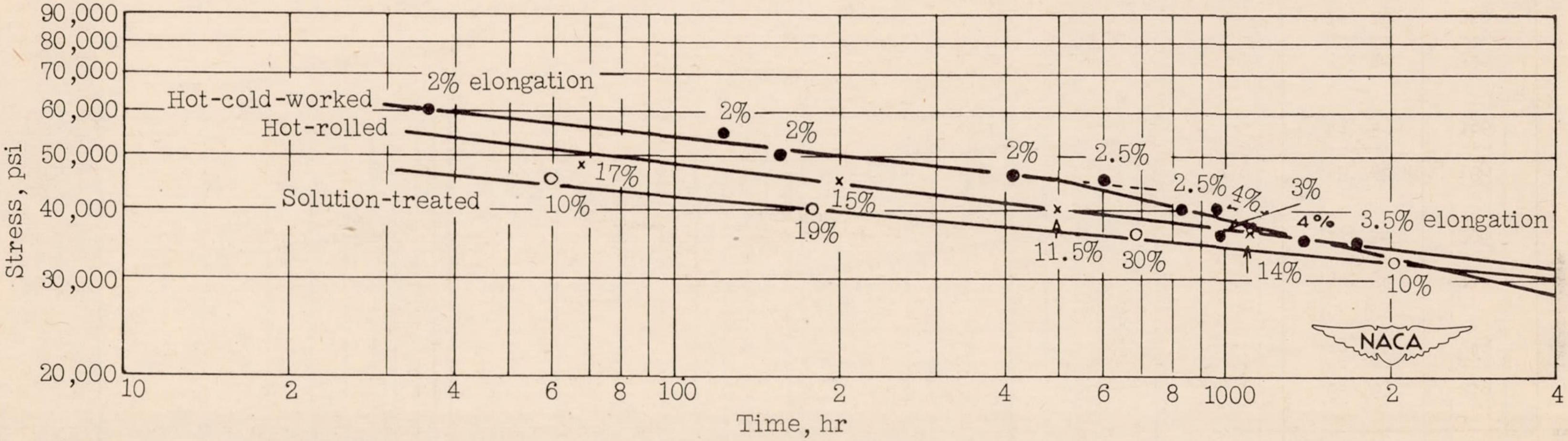
TABLE IX

EFFECT OF CREEP TESTING AT 1200° AND 1350° F ON THE PHYSICAL PROPERTIES

AT ROOM TEMPERATURE OF 19-9DL ALLOY BAR STOCK

Treatment	Testing conditions			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
	Temperature (°F)	Stress (psi)	Time (hr)		0.02 percent	0.1 percent	0.2 percent					
Hot-rolled (N163)	(1)	(1)	(1)	117,500	54,500	64,750	67,750	40,750	56.2	55.7	62, 63	219
	1200	15,000	1060	111,625	49,000	59,000	64,000	35,000	36.5	43.1	------	---
	1200	20,000	1150	-------	-------	-------	-------	------	----	----	39, 44	243
Hot-rolled (B10429, bar 2)	(1)	(1)	(1)	131,000	70,500	84,500	90,000	46,000	32.0	45.0	34, 34	214
	1350	10,000	1075	127,875	45,000	67,000	75,000	30,000	19.5	25.8	------	---
	1350	12,000	1073	-------	-------	-------	-------	------	----	----	17, 16	296
Solution-treated	(1)	(1)	(1)	102,350	26,500	37,000	42,250	17,500	53.2	57.9	58, 69	185
	1200	17,500	2608	104,000	38,000	42,500	45,500	32,500	35.5	31.2	------	---
	1200	20,000	1005	-------	-------	-------	-------	------	----	----	43, 47	196
Hot-cold-worked	(1)	(1)	(1)	154,200	100,250	120,750	125,000	73,750	24.2	43.7	30, 30	325
	1200	25,000	1050	159,875	95,000	110,000	119,000	77,500	22.0	41.9	------	---
	1200	30,000	1167	-------	-------	-------	-------	------	----	----	15, 18	359

[1]Original material.



Treatment

× Hot-rolled
○ 1 hr at 2100° F; air-cooled
● Hot-rolled; 20-percent hot-cold-worked at 1200° F
(All three stress-relieved at 1200° F)

Figure 1.- Curves of stress against rupture time at 1200° F for 19-9DL alloy bar stock.

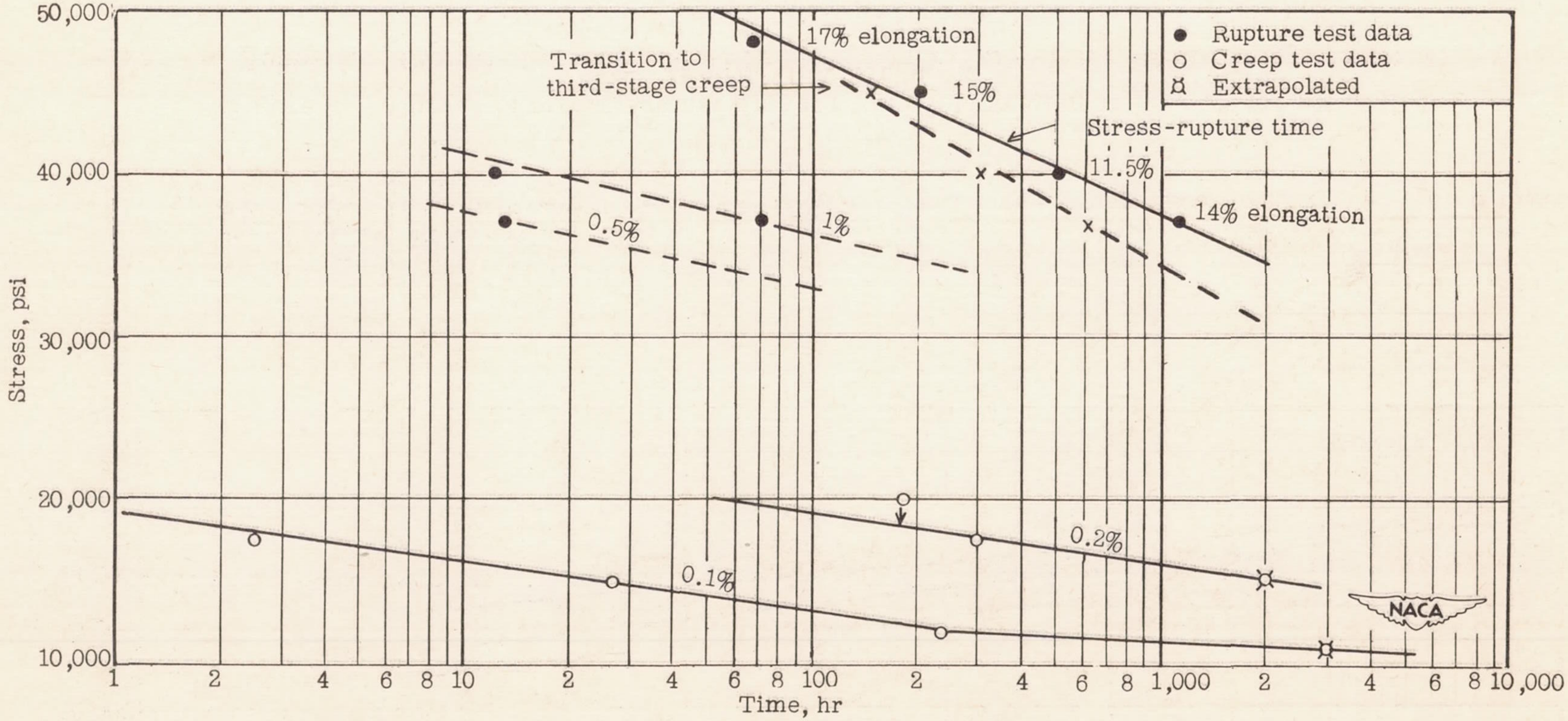


Figure 2.- Curves of stress against time for total deformation at 1200° F for hot-rolled bar stock of 19-9DL alloy.

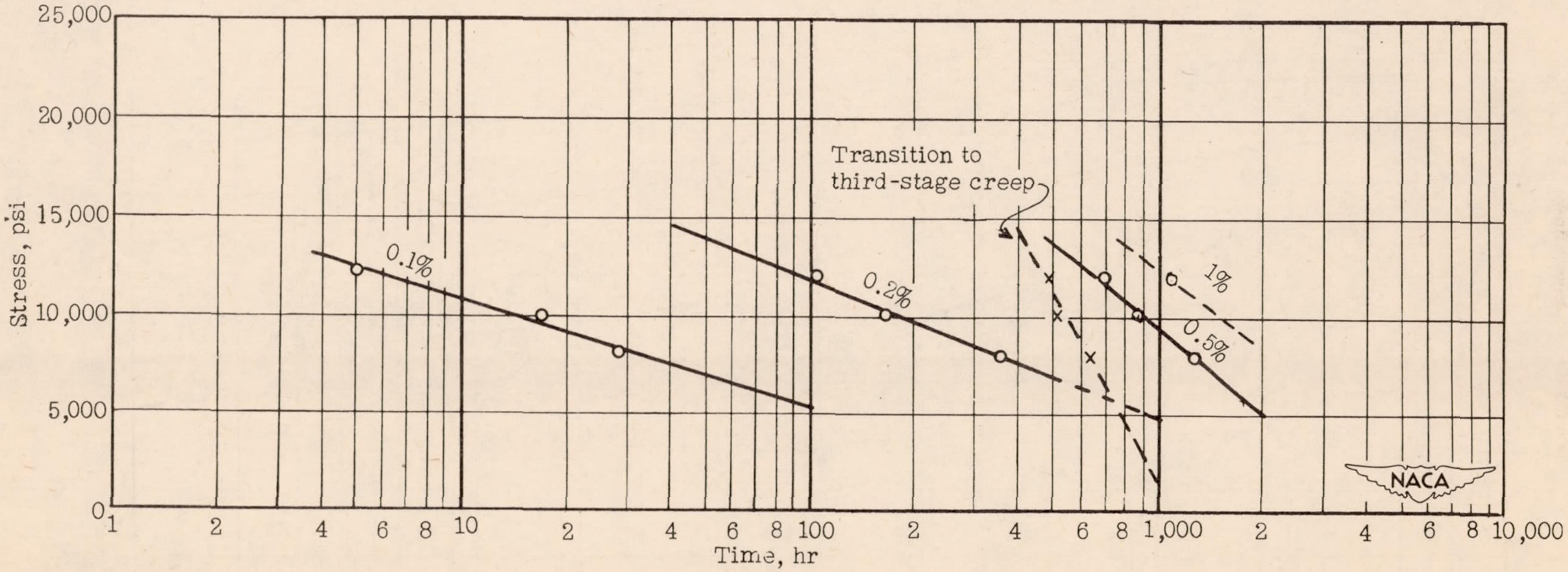


Figure 3.- Curves of stress against time for total deformation at 1350° F for hot-rolled 19-9DL alloy bar stock.

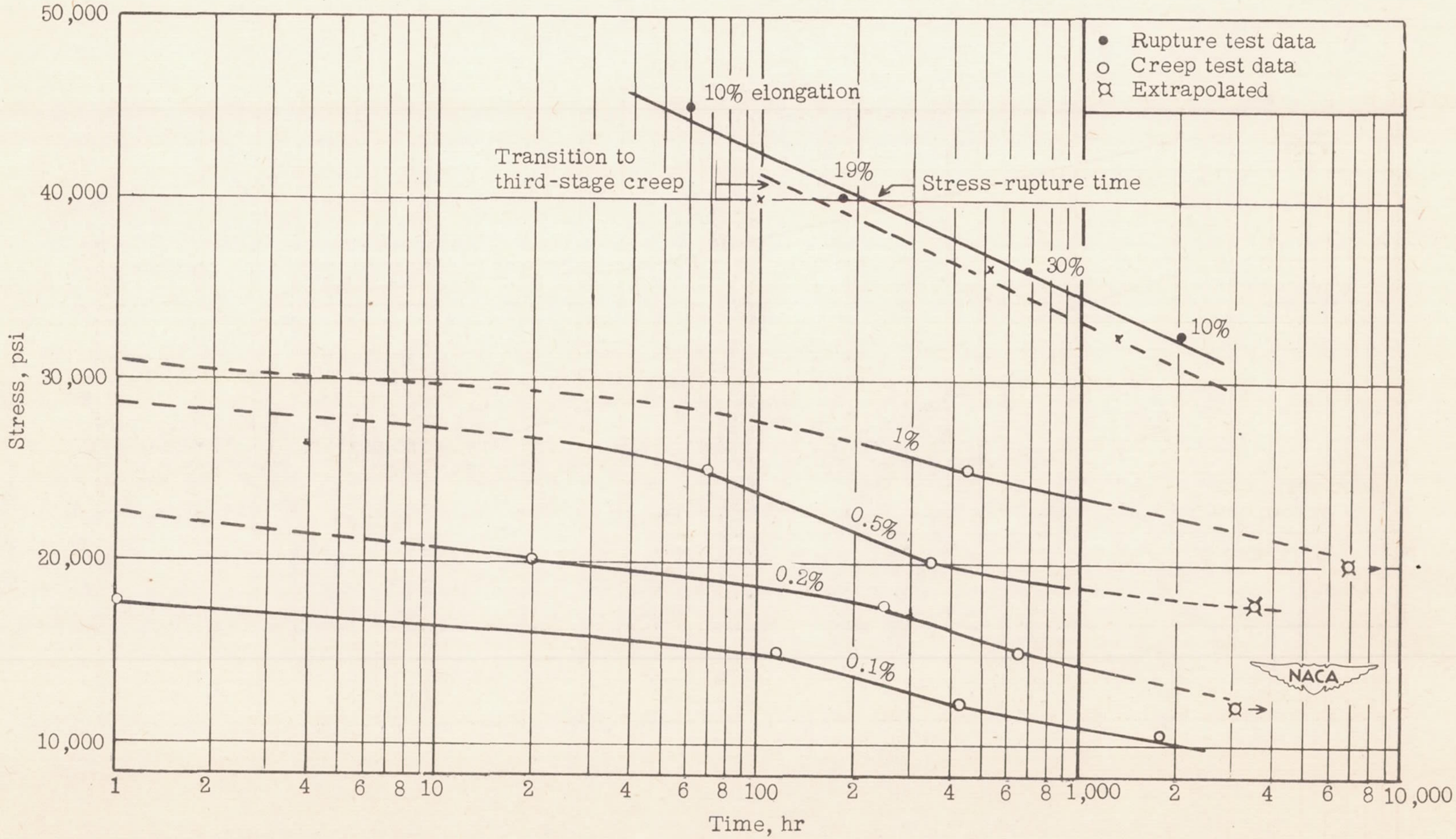


Figure 4.- Curves of stress against time for total deformation at 1200° F for solution-treated 19-9DL alloy bar stock.

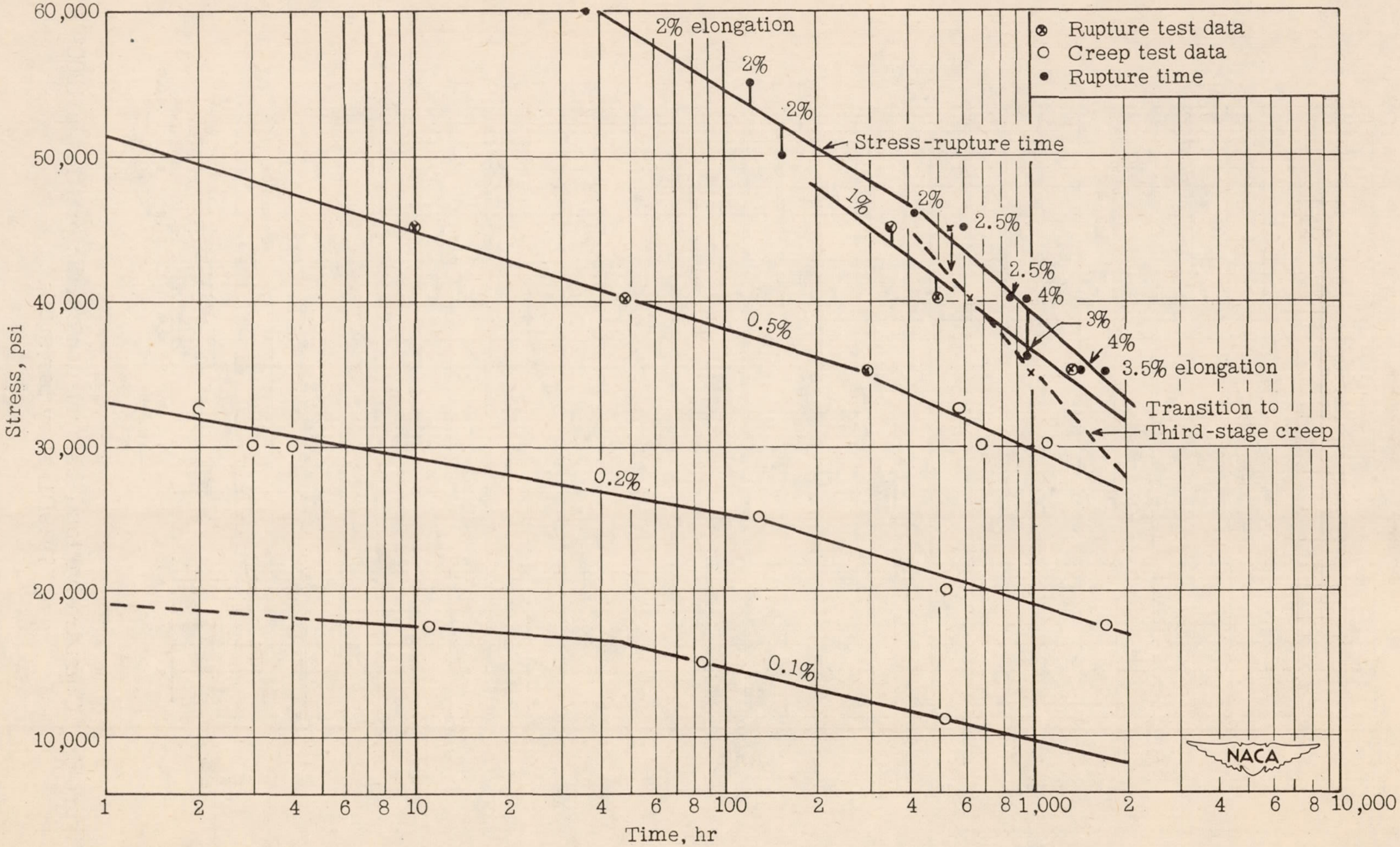


Figure 5.- Curves of stress against time for total deformation at 1200° F for hot-cold-worked 19-9DL alloy bar stock.

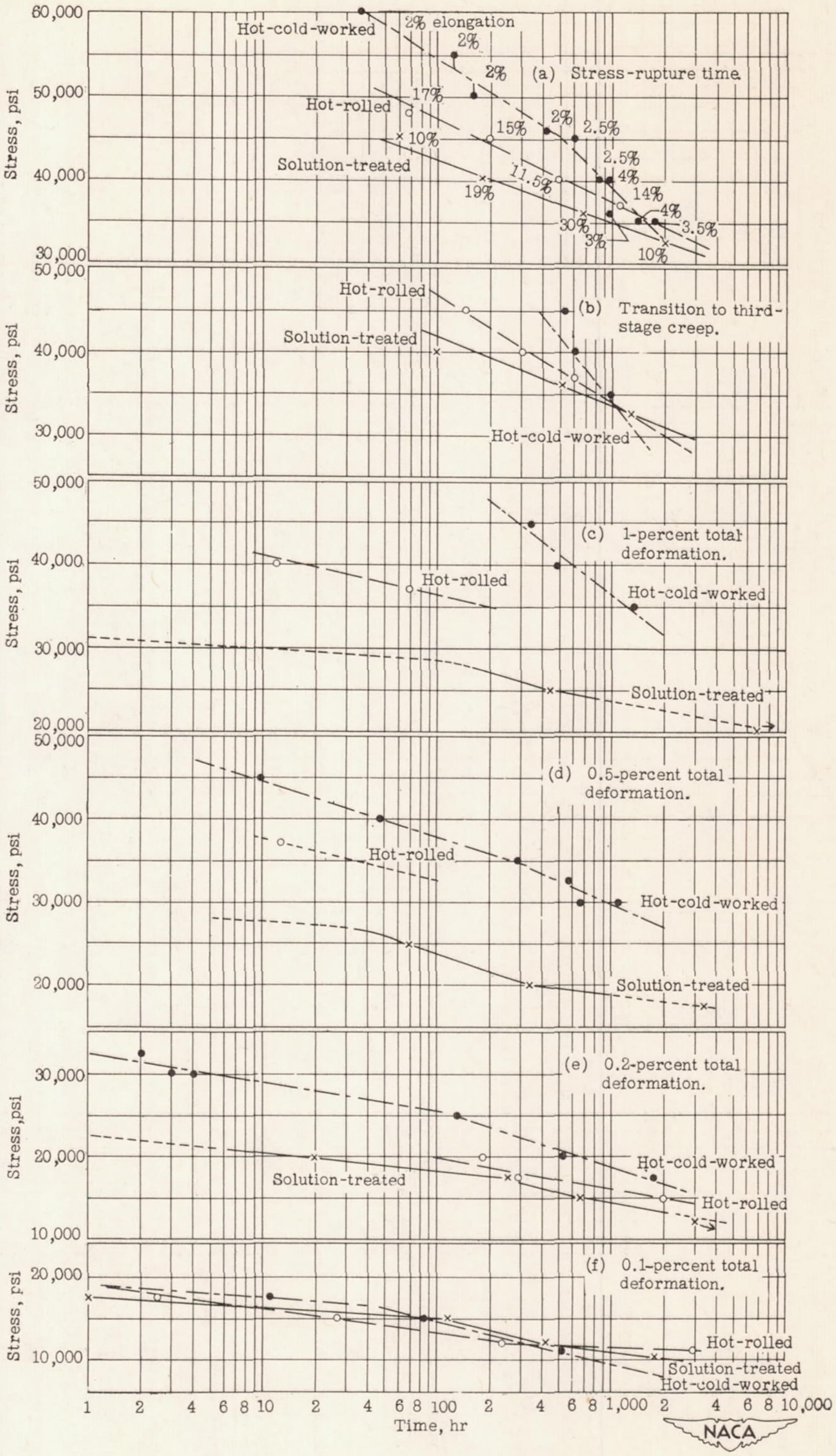


Figure 6.- Comparative total-deformation characteristics at 1200° F of 19-9DL alloy bar stock.

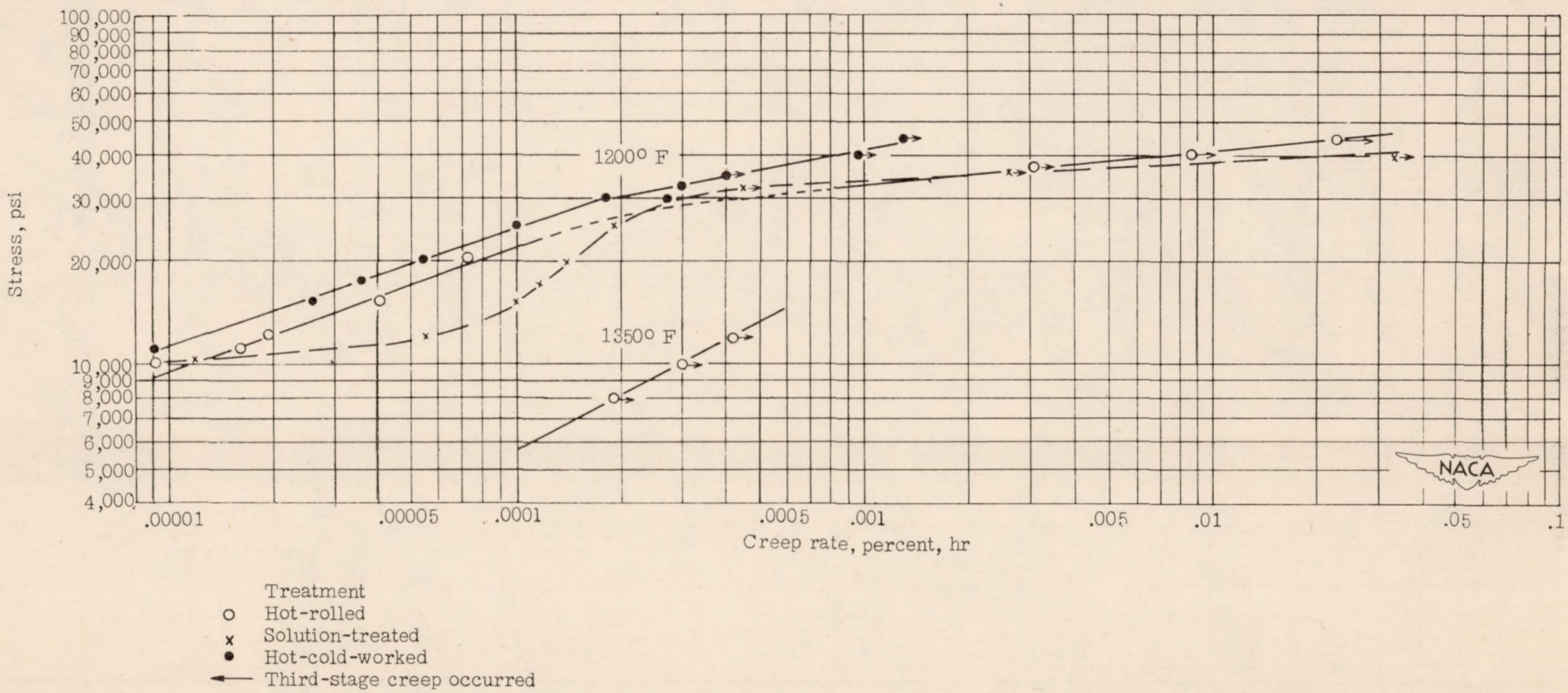
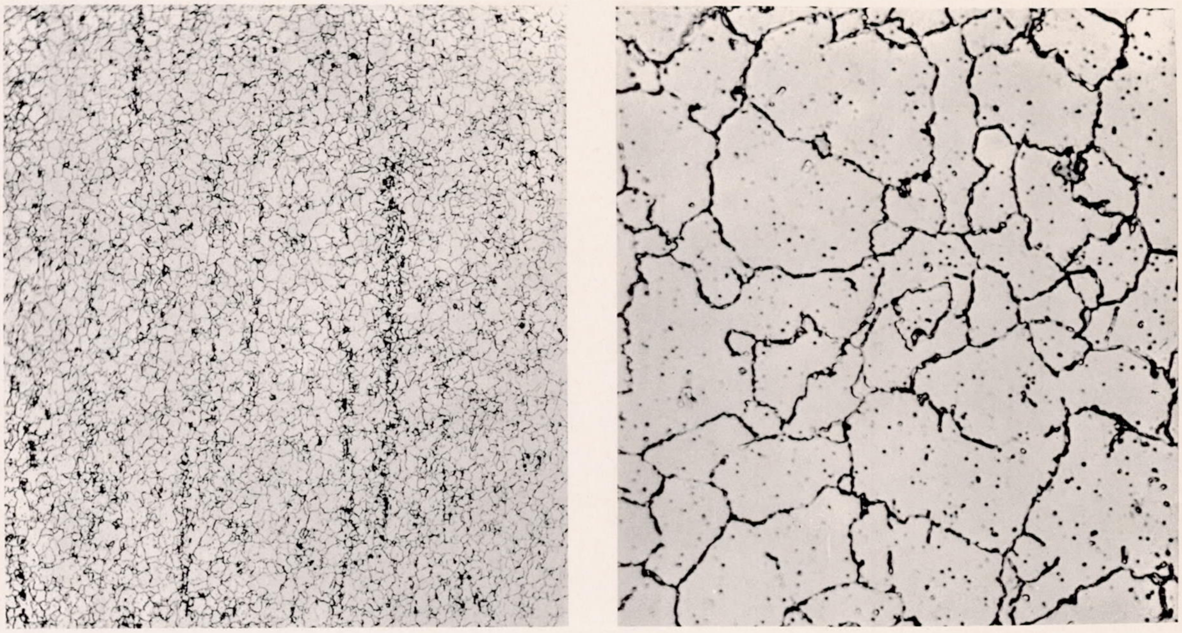
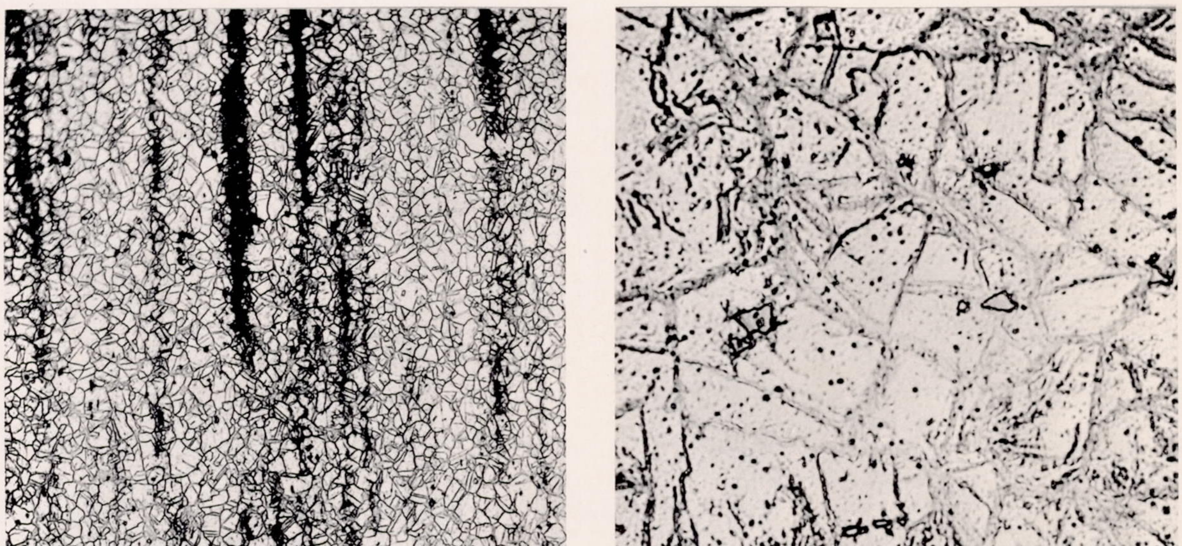


Figure 7.- Stress-creep-rate curves for 19-9DL alloy bar stock. Rates shown are those at 1000 hours or minimum rates if third-stage creep occurred.



100X 1000X

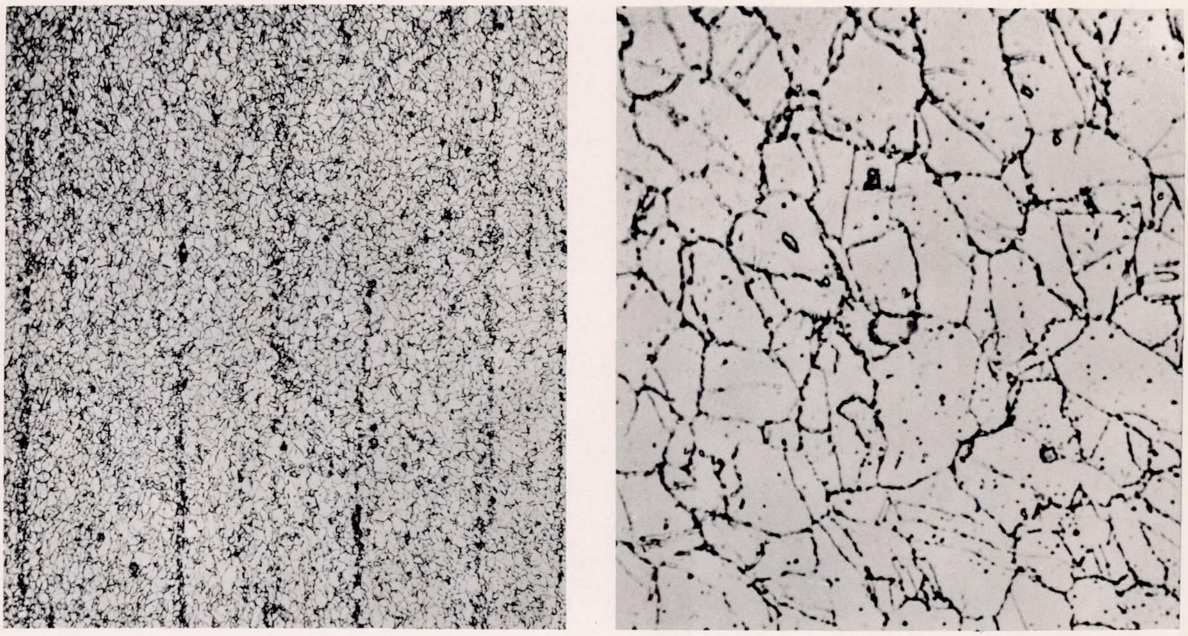
(a) Original microstructure.



100X 1000X

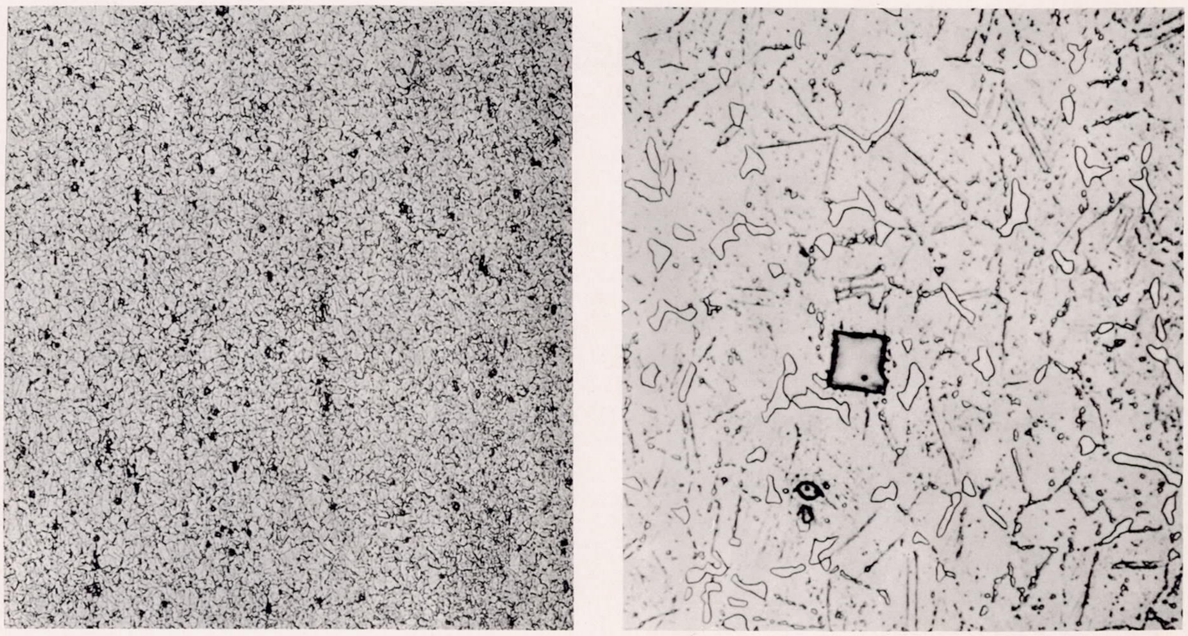
(b) Microstructure after creep testing at 1200° F for 1150 hours under 20,000 psi.

Figure 8.- Microstructure of hot-rolled 19-9DL alloy bar stock (heat N163). Aqua regia in glycerine etch.



100X 1000X

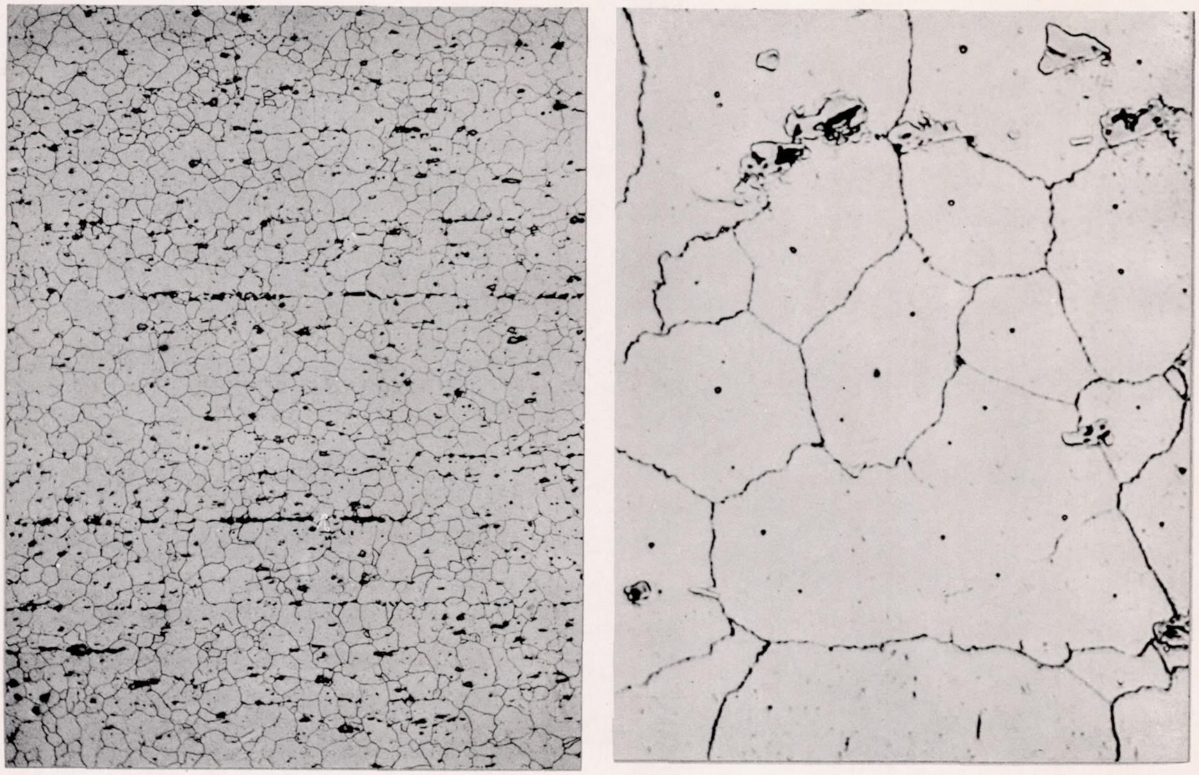
(a) Original microstructure



100X 1000X

(b) Microstructure after creep testing at 1350° F for 987 hours under 12,000 psi.

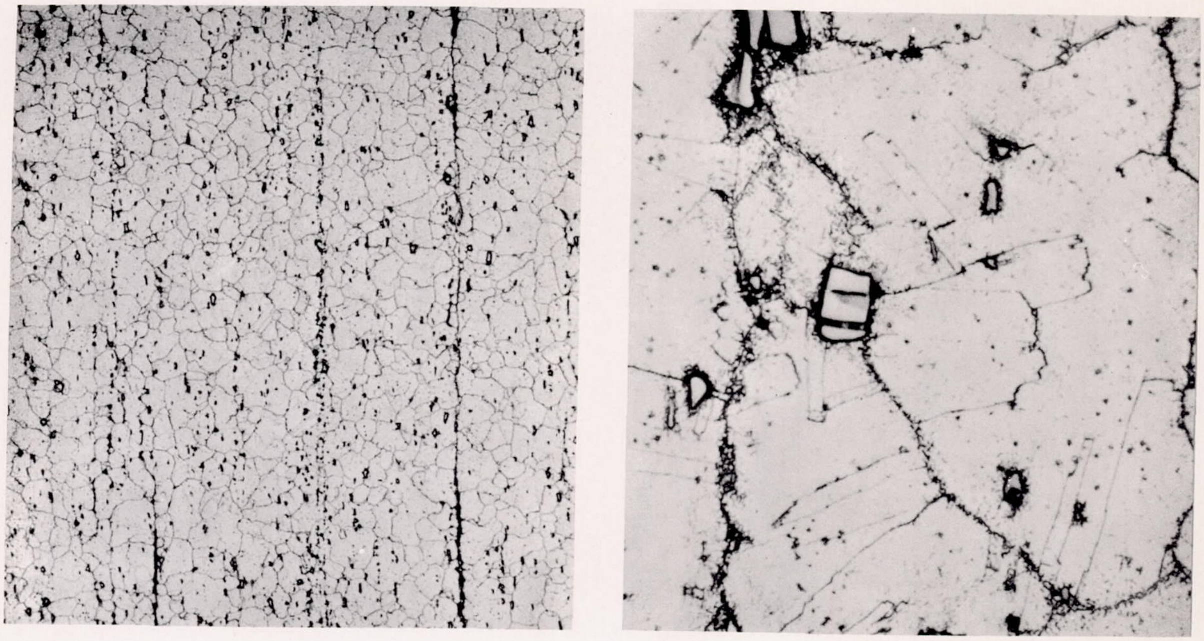
Figure 9.- Microstructure of hot-rolled 19-9DL alloy bar stock (heat B10429; bar 2). Aqua regia in glycerine etch.



100X 1000X

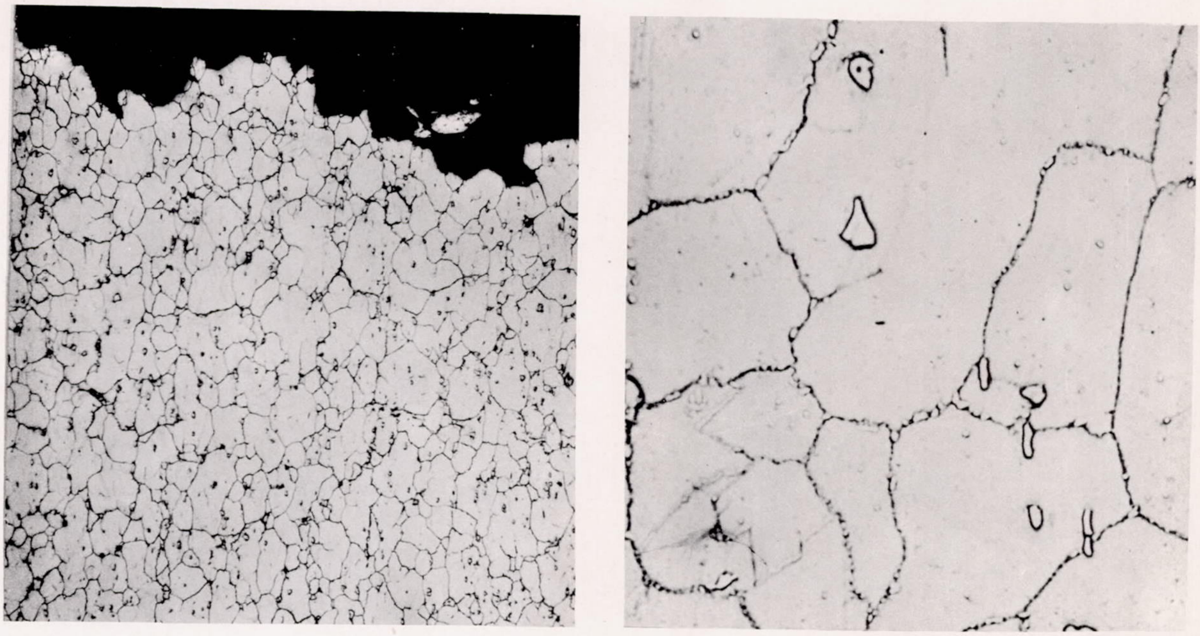
(a) Original microstructure.

Figure 10.- Microstructure of solution-treated 19-9DL alloy bar stock. Aqua regia in glycerine etch.



100X 1000X

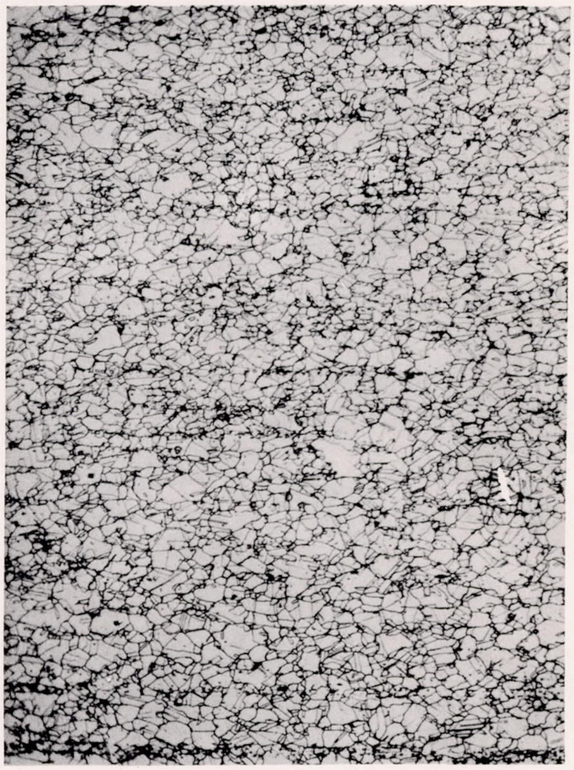
(b) Microstructure after creep testing at 1200° F for 1005 hours under 20,000 psi.



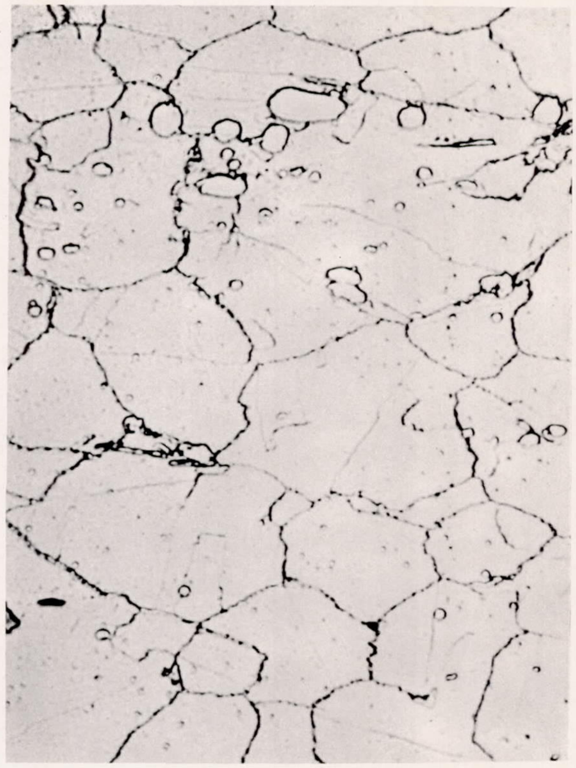
Fracture - 100X Interior - 1000X

(c) Microstructure of fractured rupture specimen; 2069 hours for rupture at 1200° F under 32,500 psi.

Figure 10.- Concluded.



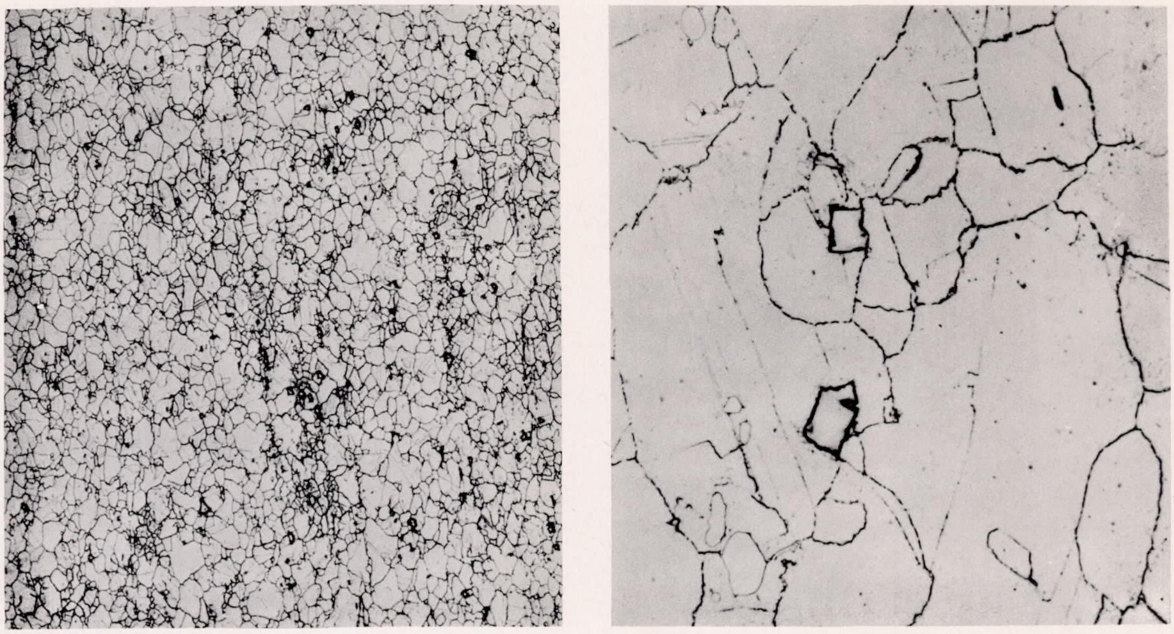
100X



1000X

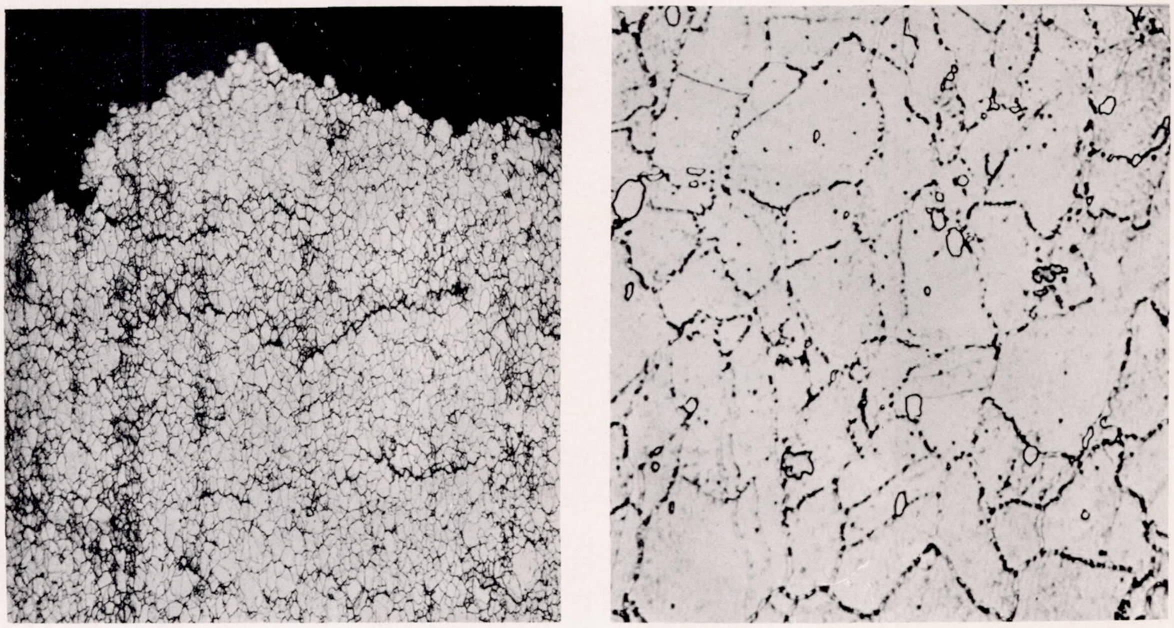
(a) Original microstructure.

Figure 11.- Microstructure of hot-cold-worked 19-9DL alloy bar stock. Aqua regia in glycerine etch.



100X 1000X

(b) Microstructure after creep testing at 1200° F for 1005 hours under 30,000 psi.



Fracture - 100X Interior - 1000X

(c) Microstructure of fractured rupture specimen; 1406 hours for rupture at 1200° F under 35,000 psi.

Figure 11.- Concluded.