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INVESTIGATION OF PROPERTIES OF AISI TYPE 310B ALLOY SHEET AT HIGH TEMPERATURES

By E. E. Reynolds, J. W. Freeman, and A. E. White
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SUMMARY

The alloy having a composition of 25 percent chromium, 20 percent nickel, and 2 percent silicon (AISI Type 310B alloy) is known to be subject to low ductility in the temperature range from 1200° to 1400° F. The present investigation was undertaken to determine by means of tensile tests whether service at 1700° to 1800° F, such as that in combustion chambers of jet engines, would cause further loss of ductility resulting in brittleness at 1200° to 1400° F. In addition, tensile tests were made on samples after heating at 1900° to 2100° F for short time periods. Rupture tests were also made at 1700° F and, to a limited extent, at 1800° F. Three heats of stock were used in order to evaluate heat-to-heat reproducibility and the relative effects of annealing, cold-working, and hot-rolling as initial treatments.

Elongation in the tensile test, the criterion of brittleness used, was found to be a minimum at about 1300° F. Elongation at 1300° F was markedly increased by short periods of prior heating at temperatures from 1700° to 2000° F. Prolonged exposure at 1700° or 1800° F also increased elongation at 1300° F. The cold-rolled and hot-rolled sheet had considerably higher tensile strength than the annealed sheet from 900° to 1800° F. The cold-rolled stock had the lowest ductility.

Both carbon content and prior treatment influenced the rupture properties, but not so greatly as had been expected. Sheet containing 0.16 percent carbon had considerably higher rupture strength than 0.05-percent-carbon sheet. Annealed sheet had higher rupture strength than hot-rolled or cold-rolled sheet, except at short time periods.

INTRODUCTION

The alloy having a composition of 25 percent chromium, 20 percent nickel, and 2 percent silicon (AISI Type 310B alloy) has oxidation resistance and strength properties suitable for sheet applications at high temperatures in gas turbines. Its rupture strength at 1700°

and 1800° F compares favorably with that of several more highly alloyed sheet materials. (See reference 1.) It is, however, subject to low ductility in the temperature range from 1200° to 1400° F as the result of precipitation reactions and probably the formation of sigma phase.

This investigation was undertaken to determine whether service at 1700° to 1800° F, particularly in combustion chambers of jet engines, would cause increased brittleness at 1200° to 1400° F with resultant troubles during heating and cooling. Experiments were also conducted to determine if short periods of exposure to even higher temperatures would cause reduced ductility at 1200° to 1400° F. Tests were also made to establish the influence of heat-to-heat variations and of various types of prior treatment on the tensile properties from 900° to 2000° F and on the rupture properties at 1700° and 1800° F.

The experimental work was somewhat more extensive than originally planned because the heat on which most of the tests were made was found to be contaminated with titanium. Further tests were made to determine whether titanium was influencing the results.

The investigation was conducted under the sponsorship and with the financial assistance of the National Advisory Committee for Aeronautics as part of their program of sponsored research on heat-resisting alloys for aircraft propulsion systems at the Engineering Research Institute of the University of Michigan.

TEST MATERIAL

Three heats of AISI 310B alloy were used in this investigation. Two of these heats had been used in a previous investigation which studied the properties of 14 sheet materials at 1700° and 1800° F. (See reference 1.) The other heat (14998) was included only in the present study and was supplied in three different original conditions.

The materials were supplied as strips 22 inches long, $1\frac{1}{4}$ inches wide, and approximately 0.040 inch thick. The width was reduced to 1 inch over a 2-inch gage length in preparing test specimens.

The following information was supplied by the Allegheny Ludlum Steel Corporation, the manufacturer of the test stocks:

Heat	Chemical composition (percent)						
	C	Mn	Si	P	S	Cr	Ni
[a]AF18	[b]0.13	----	2	-----	-----	25	20
[c]14626	.044 .051	1.92 ----	2.14 2.39	0.023 -----	0.008 -----	25.40 24.26	20.43 20.54
[c]14998	.05 .06	1.79 ----	1.86 1.91	.015 -----	.010 -----	24.58 24.98	21.55 21.87

[a]Type designation rather than heat number; however, for convenience the specific heat of AF18 tested will be referred to as "heat AF18."

[b]Univ. of Mich. check analysis showed 0.16 percent carbon.

[c]Second values are from check analysis.

The processing of the various heats as described by the Allegheny Ludlum Steel Corporation was as follows:

Heat AF18 (310B): The sheets were hot-rolled to 0.045-inch-thick sheet at 2100° F, annealed for 6 to 8 minutes at 2100° to 2150° F, and air-cooled; sand-blasted, spot-ground, and cold-rolled to 0.033-inch thickness; annealed at 2100° to 2150° F; and cold-rolled one pass and buckled. This alloy was made by the Allegheny Ludlum Steel Corporation and supplied by the General Electric Company.

Heat 14626 (310B-1): The sheets were hot-rolled to 0.050-inch-thick sheet; pickled, annealed at 2180° F for 6 minutes, and water-quenched; and sand-blasted, scrubbed, cold-rolled one pass to flatten, roller-leveled, and sheared.

Heat 14998 (310B-2-3-4):

310B-2 (hot-rolled): The sheets were hot-rolled from 3/4-inch plate, stock size $\frac{3}{4}$ by $8\frac{3}{4}$ by $26\frac{1}{2}$ inches. The material was reduced at 2000° F to 0.300-inch thickness in three passes on a roughing mill, reheated to 2000° F, and given four passes on a chill mill to reduce it to 0.180-inch thickness. The sheets were cut in half, pickled, and ground; then reheated to 2000° F, given three single passes, reheated to 2000° F, matched in pairs, and rolled to final 0.040-inch thickness in three passes; and pickled.

310B-3 (cold-rolled): This sheet was hot-rolled in the same manner as 310B-2 with a 10 percent cold-rolling in two passes on a four-high mill in addition.

310B-4 (annealed): This sheet was hot-rolled in the same manner as 310B-2 and in addition was heated 7 minutes at 2160° F, steam-quenched, and pickled.

Microstructural examination of material from heat 14998 showed a constituent resembling a titanium compound. This constituent was not present in the other two heats. Heat 14998, when checked spectrographically, developed spectral lines of titanium. A subsequent chemical analysis yielded the following composition:

Analysis by	Chemical composition (percent)						
	C	Mn	Si	Cr	Ni	Ti	V, Mo, W, Cb
Univ. of Mich.[1]	0.054 .066	1.89 1.88	1.94 1.86	24.87 24.78	21.54 21.61	0.12 .13	None
Allegheny Ludlum[1]	.05 .06	1.79 ----	1.86 1.91	24.58 24.98	21.55 21.87	(2)	(2)

[1]Second values are from check analysis.

[2]Not analyzed for titanium, vanadium, molybdenum, tungsten, or columbium.

After this discovery Allegheny Ludlum reported that heat 14998 was melted in a furnace in which an alloy containing titanium had been previously melted and that this probably accounted for the titanium content.

EXPERIMENTAL PROCEDURE

The experimental program was designed to establish the effect of heating 310B alloy at 1700° to 1800° F on the ductility characteristics at 1300° F, the effect of short heating periods between 1800° and 2100° F, and the effects of heat-to-heat variations and standard prior treatments on the tensile properties from 900° to 2000° F and on the rupture properties at 1700° and 1800° F. Two heats of the alloy were available in only the annealed condition while one heat was submitted in the hot-rolled, cold-rolled, and annealed conditions. Various heat treatments consisting of aging at 1700° and 1800° F and short exposures from 1850° to 2100° F were used and their effect on tensile properties determined. The complete treatment and testing schedule is given in table I.

Heat-treating at temperatures of 1700° and 1800° F was done in an electric resistance furnace. Above 1800° F a gas-fired furnace was used. A few of the tensile specimens were heat-treated in the tensile furnace prior to testing, then cooled in the furnace to the test temperature, and tested. With the exception of these few specimens the treatments were made on the complete 22 inches of the strip.

Tensile tests were conducted in a 60,000-pound hydraulic testing machine. The 22-inch specimens were gripped outside the furnace and the temperature controlled over the 2-inch reduced section. The specimens were held 1 hour at test temperature before starting the test. A constant rate of loading of 0.1 inch per minute was used and the ultimate strength obtained. No stress-strain measurements were taken. The total elongation of the fractured specimen was recorded.

Rupture tests were run in individual stationary units. The load was applied to the more highly stressed specimens through a simple beam and knife-edge system. However, the stress on most of the rupture tests was applied by direct loading of the specimen. Approximately 24 hours was allowed for temperature adjustments prior to application of the load. Only the minimum number of tests necessary to establish the rupture strengths at 10, 100, and 1000 hours were run.

Metallographic samples were prepared of the original materials and of specimens from the longest completed rupture tests. Photomicrographs were taken of representative samples.

RESULTS

Tensile Properties

The data obtained from the tensile tests are summarized in tables II to VI. The graphical summaries of figures 1 and 2 show that normal treatment prior to service can have the following influence on tensile properties:

(1) The hot-rolled and the cold-rolled test stocks had considerably higher tensile strength over the temperature range from 900° to 1800° F

than the annealed. On the basis of tests at 1700° and 1800° F only, the high-carbon annealed sheet, AF18, had higher strength than the other two annealed materials.

(2) Cold work apparently caused erratic changes in tensile strength in the range from 1300° to 1500° F.

(3) 310B alloys had a distinct minimum of 4- to 13-percent elongation at 1200° to 1300° F followed by an increase to a maximum in the temperature range from 1500° to 1700° F and then a sharp decrease from 1700° to 1900° F to elongations of approximately 10 to 30 percent.

(4) The effect of prior treatment on ductility was not so definite as it was for tensile strength. Cold-rolling apparently resulted in lower minimum ductility at 1200° to 1300° F than an annealing or a hot-rolling treatment. The cold-rolled and the hot-rolled sheet had lower ductility above 1400° F than the annealed or the annealed plus cold-passed sheet.

Holding the annealed test stock at 1800° F for 50 hours prior to testing also influenced the tensile properties (see figs. 3 and 4) by increasing the ductility and the tensile strength up to a temperature of 1500° F. There was a slight decrease at 1100° to 1300° F in tensile strength of the stock cold-rolled 10 percent, and the minimum ductility at 1300° F was increased considerably by prolonged exposure at 1800° F.

Holding at 1700° or 1800° F for time periods as short as 15 minutes increased the minimum ductility at 1300° F of the annealed 310B-1 and the cold-rolled stocks. (See fig. 5.) The tensile strength of the annealed stock was increased and that of the cold-rolled was reduced by the short-time treatments. Tensile strength and elongation of both the annealed and the cold-rolled materials tended to level off after 1/4- to 1/2-hour heating at 1700° or 1800° F. One exception which might be important was a large decrease in the ductility of the cold-rolled stock when the holding time at 1800° F was increased from 4 to 50 hours.

Apparently furnace-cooling to 1300° from 1800° F and testing did not result in properties significantly different from those obtained by air-cooling and reheating to 1300° F for testing. (See fig. 5.) The tensile strength and ductility at 1300° F were essentially the same after heating for short periods at temperatures between 1800° and 2100° F, except for a reduction in both after heating 10 minutes at 2100° F.

Data are included in table II showing that the size of the test section had very little effect on the results of tensile tests at room temperature. It will be noted that the 310B-1 material had about 60-percent elongation at room temperature.

Rupture Properties

The rupture data are summarized in table VII and figure 6. The rupture strengths and elongations for time periods of 10, 100, and 1000 hours obtained from these data are shown in table VIII and figure 7.

There was considerable variation in rupture strength and ductility at 1700° F between the three heats of annealed 310B alloy. The results at least suggest that the cold pass given heats AF18 and 14626 after annealing was detrimental to elongation in the rupture test. Hot-rolled and cold-rolled sheet from heat 14998 had higher rupture strengths at 10 hours but lower strengths at 100 and 1000 hours than the annealed sheet from the same heat. All three conditions had good ductility, although the cold-rolled material was somewhat lower at 10 and 100 hours.

Heating the annealed sheet for 50 hours at 1800° F prior to rupture testing at 1700° F reduced the rupture strength at 10 hours but had no significant effect on 100- and 1000-hour strengths. This treatment also had little effect on the strength of the cold-rolled sheet. Its effect on ductility was erratic. Heating hot-rolled stock from heat 14998 at temperatures from 1900° to 2100° F increased both rupture strength and ductility at 1700° F.

Only a small amount of rupture testing was done at 1800° F. Heat 14626 had lower rupture strength and higher ductility than heat AF18, particularly at the shorter time periods. Holding heat 14626 at 1800° F for 50 hours prior to rupture testing at 1800° F reduced the rupture strength.

Microstructural Examination

Microstructures of the five original materials show the difference in grain size between the various materials. (See figs. 8, 9, and 10.) The annealed sheet from heat 14626 had much the largest grain size. The hot-rolled sheet from heat 14998 had finer grain size than the other three materials. There was also considerable precipitation present originally in the annealed AF18 sheet.

Heating the cold-rolled and the annealed stocks from heat 14998 for 50 hours at 1800° F resulted in both general and grain-boundary precipitation. There was also some formation of large particles which are probably a form of sigma phase.

The fractured specimens after rupture testing at 1700° F showed a considerable increase in the new phase as well as agglomeration of the precipitated constituents. There was no great difference in structure between the samples tested with or without the 50-hour treatment at 1800° F.

Photomicrographs have not been included for all the materials after the 1800° F treatment or after rupture. Those shown in figure 10 for the annealed sheet from heat 14998 are typical for all the others except the cold-rolled sheet. The tendency toward precipitation on the slip planes of the cold-rolled stock is shown by figure 9. As was shown in reference 1, the AF18 stock did not develop so much of the new phase during rupture testing as did the other 310B materials.

DISCUSSION OF RESULTS

The results of this investigation demonstrate that ductility at 1200° to 1400° F, as measured by tensile test elongation, is markedly improved by heating at 1700° and 1800° F. This improvement results from exposures as long as 50 hours as well as from a very short time exposure at these temperatures. Apparently the reheating temperature must be above 2000° F in order to develop brittleness. This finding indicates that service at temperatures of 1700° to 1800° F should not result in excessive embrittlement upon cooling to about 1300° F. Exposure at 1700° and 1800° F also increased strength of the annealed material. The loss in strength of the cold-rolled material was probably the result of removal of strain-hardening by the heating.

The microstructures indicate that the reason for the increase in ductility at 1300° F as a result of heating at 1700° to 1800° F was that excess constituents precipitate and agglomerate at the higher temperatures. In the agglomerated form the constituents improve ductility, while if precipitation occurs in the temperature range of 1200° to 1400° F they form a fine dispersion in the grain boundaries which results in embrittlement. The prior precipitation also probably strengthened the annealed materials, resulting in higher tensile strengths.

There are certain limitations to these findings. There was no stress on the specimens during heating. Stress would be expected to increase the rate of precipitation and agglomeration and, therefore, contribute to increasing ductility. There might be a further limitation in that there was a sharp drop in ductility of the cold-rolled stock at 1300° F between 4 and 50 hours heating time at 1800° F. This might be evidence that the extensive development during prolonged service under stress of the new phase (probably some form of sigma phase) might contribute to the reembrittlement of the alloy because the cold-working probably increased the rate of formation of the new phase over that of the annealed materials.

It is to be presumed that prolonged exposures in the temperature range from 1200° to 1500° F, without a prior treatment at 1700° to 2000° F, would have resulted in considerably more embrittlement than was observed in the experiments at this investigation. On the basis of one test, heating 50 hours at 1800° F did decrease tensile elongation at room temperature, but the ductility still remained adequate.

It is important to note that normal treatment prior to testing had a very pronounced effect on the tensile strength and ductility over the entire temperature range covered. Annealed stocks had much lower strength than the hot-rolled or the cold-rolled materials. The cold work was detrimental to ductility at temperatures above 1200° F. Therefore, insofar as short-time strength and ductility are concerned, very pronounced effects can be obtained by variable conditions of cold-rolling or hot-rolling.

On a percentage basis there were wide variations in rupture strength between the five lots of material considered. Apparently the higher carbon content of the AF18 material resulted in much higher rupture strength. There was less difference between the lower-carbon heats, although the annealed condition was stronger than the hot-rolled and cold-rolled stock, except for short time periods.

In general there was less difference in rupture strength between the three conditions of heat 14998 than might have been expected. Cold work would ordinarily be expected to be quite detrimental to rupture strength at 1700° F, except for short time periods. The difference between the cold-rolled and the annealed or the hot-rolled stock was not too great. The cold reduction of 10 percent may not have been sufficient to reduce strength drastically. Cold work, even one pass after annealing, may be responsible for decreased elongation in the rupture tests.

Prior precipitation and agglomeration of excess constituents by heating at 1800° F for 50 hours did not have much effect on rupture properties at 1700° F except to reduce short-time strength and ductility. It did, however, appreciably reduce the rupture strength of the annealed stock at 1800° F.

The presence of titanium in heat 14998 did not appear to have a significant effect. The reduction in effective carbon may have contributed to slightly greater instability of austenite. The possibility exists that the very low effective carbon content in heat 14998 may have reduced the effects of variation in the initial treatment on the tensile and rupture properties. Likewise, a clear-cut effect from the grain-size variations was not apparent.

There may have been some effect from nitrogen absorption during rupture testing, a phenomenon known to occur in this type of steel. The microstructures were somewhat suggestive of this effect. No attempt was made to analyze for nitrogen, largely because a similar attempt reported in reference 1 was not successful.

The new phase appearing in the samples heated at 1800° F and in the rupture specimens was not positively identified. Its etching characteristics were not typical of those reported for sigma phase. Most discussions of the alloy in the literature, however, indicate that sigma phase should form. Similar constituents in AISI 310 alloy were identified as sigma phase in reference 2. It is therefore presumed that the constituent was some form of sigma phase.

CONCLUSIONS

The results of an investigation of the properties of AISI 310B alloy sheet at high temperatures indicate that:

1. The minimum ductility in tensile tests at about 1300° F will be substantially increased by heating at 1700° to 2000° F for short time periods.

2. Prolonged exposure (50 hr) at 1700° and 1800° F would not be expected to cause low ductility at 1300° F in annealed sheet.

3. The low ductility at about 1300° F is probably the result of the type of precipitation occurring in that temperature range. Heating at 1700° to 1800° F results in prior precipitation and agglomeration of excess constituents which apparently reduce the embrittling precipitation process at 1300° F.

4. Hot-rolled and cold-rolled sheet had substantially higher tensile strength up to 1800° F than annealed sheet. The ductility of the cold-rolled sheet was, in general, the lowest.

5. A 0.16-percent-carbon heat had substantially higher rupture strength at 1700° and 1800° F than two 0.05-percent-carbon heats. Annealed sheet had higher rupture strength than hot-rolled or cold-rolled sheet, except at short time periods.

6. The influence of prior treatment on rupture properties was not so great as was expected. A very low effective carbon content may have been responsible, however, because the 0.05-percent-carbon test stock was contaminated with 0.12 percent titanium.

7. Wide variation in grain size between heats was not found to influence properties definitely.

University of Michigan
Ann Arbor, Mich., November 12, 1948

REFERENCES

1. Freeman, J. W., Reynolds, E. E., and White, A. E.: The Rupture-Test Characteristics of Heat-Resistant Sheet Alloys at 1700° and 1800° F. NACA TN 1465, 1948.

2. Barnett, W. J., and Troiano, A. R.: X-Ray Identification of Sigma Phase in 25-20 Cr-Ni Stainless. Metal Progress, vol. 53, no. 3, March 1948, pp. 366-367.

TABLE I

TREATMENT AND TESTING SCHEDULE FOR 310B ALLOY SHEET

Alloy	Original condition	Heat Treatment			Test	
		Temperature (°F)	Time (hr)	Cooling (1)	Type test	Temperature (°F)
310B (AF18)	Annealed, one cold pass	----	-----------------	----	Tensile Rupture	1700 and 1800 1700 and 1800
310B-1 (14626)	Annealed, one cold pass	----	-----------------	----	Rupture Tensile	1700 and 1800 Room, 900 to 2000
		1800	50	A.C.	Tensile Rupture	Room, 900 to 1800 1700 and 1800
		1800	1/4, 1/2, 3/4, 1, 2, 4, 8, 24, 50	A.C.	Tensile	1300
		1700	1/4, 1/2, 1, 2, 4	A.C.	Tensile	1300
		1800	1/4, 1	F.C.	Tensile	1300
		1700	1	F.C.	Tensile	1300
		1850	1/2	A.C.	Tensile	1300
		1900	1/2	A.C.	Tensile	1300
		1950	1/2	A.C.	Tensile	1300
		2000	1/4	A.C.	Tensile	1300
		2100	1/6	A.C.	Tensile	1300
310B-2 (14998)	Hot-rolled	----	-----------------	----	Tensile Rupture	1100 to 2000 1700
		1900	1/2	A.C.	Rupture	1700
		2000	1/4	A.C.	Rupture	1700
		2100	1/6	A.C.	Rupture	1700
310B-3 (14998)	Cold-rolled 10 percent	----	-----------------	----	Tensile Rupture	1100 to 1800 1700
		1800	50	A.C.	Tensile Rupture	1100 to 1300 1700
		1800	1/4, 1/2, 1, 4	A.C.	Tensile	1300
		1700	1/2, 1, 4	A.C.	Tensile	1300
310B-4 (14998)	Annealed	----	-----------------	----	Tensile Rupture	1100 to 1800 1700
		1800	50	A.C.	Tensile Rupture	1100 to 1300 1700

[1]A.C. air-cooled to room temperature and reheated for testing.
F.C. furnace-cooled to test temperature and tested.

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TABLE II

TENSILE PROPERTIES FROM ROOM TEMPERATURE TO 2000° F OF 310B-1 ALLOY SHEET

[Heat 14626; annealed, one cold pass]

Test temperature (°F)	Original condition		1800° F, 50 hr, air-cooled	
	Tensile strength (psi)	Elongation (percent in 2 in.)	Tensile strength (psi)	Elongation (percent in 2 in.)
Room	83,200 86,000	64 64	83,200 ------	33.5 ----
900	64,900	48.5	65,500	38
1000	57,100	34	62,000	44
1100	40,600	20	55,400	35
1200	36,700	12.5	48,000	22.5
1300	30,400 31,300	5.5 10	42,000 ------	24.5 ----
1350	31,200	9	------	----
1400	32,600 32,100	15 12	35,800 ------	21 ----
1500	18,300	39	28,000	31.5
1600	14,100	43.5	15,900	48
1700	10,200	42.5	11,450	51
1800	7,550	32.5	8,900	34
1900	6,100	17.5	------	----
2000	3,900	21.5	------	----

Approximate specimen dimensions (in.)	Specimen area (sq in.)	Tensile properties at room temperature	
		Tensile strength (psi)	Elongation (percent in 2 in.)
1.0 by 0.04	0.0415 .0415	83,200 86,000	64 64
0.8 by 0.04	.03275 .03330	81,700 84,700	54 61
0.5 by 0.04	.0208 .0209	85,600 85,200	50.5 60.5

Heat treatment			Tensile properties at 1300° F	
Temperature (°F)	Time (hr)	Cooling (1)	Tensile strength (psi)	Elongation (percent in 2 in.)
----	---	----	30,400 31,300	5.5 10
1700	1/4	A.C.	39,500	20
1700	1/2	A.C.	37,800	21
1700	1	A.C.	40,800	21.5
1700	2	A.C.	37,500	18
1700	4	A.C.	40,000	29
1700	1	F.C.	38,950	18
1800	1/4	A.C.	40,000	24
1800	1/2	A.C.	38,000	22
1800	3/4	A.C.	40,100	21.5
1800	1	A.C.	38,800	21
1800	2	A.C.	38,400	26.5
1800	4	A.C.	38,400	25
1800	8	A.C.	39,300	20
1800	24	A.C.	39,600	26.5
1800	50	A.C.	42,000	24.5
1800	1/4	F.C.	39,590 38,900	26 23
1800	1	F.C.	40,400	27.5
1850	1/2	A.C.	38,500	16
1900	1/2	A.C.	39,600	24.5
1950	1/2	A.C.	39,600	17.5
2000	1/4	A.C.	39,150	22.5
2100	1/6	A.C.	37,200	11

[1] A.C. air-cooled to room temperature and reheated to 1300° F for testing.
F.C. furnace-cooled to 1300° F and tested.

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TABLE III

TENSILE PROPERTIES FROM 1100° TO 2000° F OF 310B-2 ALLOY SHEET

[Heat 14998; hot-rolled]

Test temperature (°F)	Tensile strength (psi)	Elongation (percent in 2 in.)
1100	62,600	31
1200	57,000	11
1300	45,400	11.5
1400	36,900	21
1500	28,500	29
1700	16,700	13
1800	13,000	9
1900	5,825	39.5
2000	4,730	58

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TABLE IV

TENSILE PROPERTIES FROM 1100° TO 1800° F OF 310B-3 ALLOY SHEET

[Heat 14998; cold-rolled 10 percent]

Test Temperature (°F)	Original condition		1800° F, 50 hr, air-cooled	
	Tensile strength (psi)	Elongation (percent)	Tensile strength (psi)	Elongation (percent in 2 in.)
1100	65,500	8.5	64,900	31.5
1200	57,500	4.5	53,900	24
1300	46,500	4	42,600	17
1300	51,100	10	------	----
1400	27,200	17	------	----
1500	27,600	24.5	------	----
1700	17,700	22.5	------	----
1800	13,600	10.5	------	----

Heat treatment			Tensile properties at 1300° F	
Temperature (°F)	Time (hr)	Cooling (1)	Tensile strength (psi)	Elongation (percent in 2 in.)
----	---	----	46,500	4
			51,100	10
1700	1/2	A.C.	40,700	36.5
1700	1	A.C.	40,300	27.5
1700	4	A.C.	38,400	27.5
1800	1/4	A.C.	40,800	36.5
1800	1/2	A.C.	38,000	32.5
1800	1	A.C.	37,600	32
1800	4	A.C.	39,000	41
1800	50	A.C.	42,600	17

[1]A.C. air-cooled to room temperature and reheated to 1300° F for testing.

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TABLE V

TENSILE PROPERTIES FROM 1100° TO 1800° F OF 310B-4 ALLOY SHEET

[Heat 14998; annealed]

Test temperature (°F)	Original condition		1800° F, 50 hr, air-cooled	
	Tensile strength (psi)	Elongation (percent)	Tensile strength (psi)	Elongation (percent in 2 in.)
1100	47,600	18.5	57,100	27
1200	40,000	13	49,700	24
1300	34,700	17	41,800	27
1400	28,200	40	------	--
1500	19,100	53	------	--
1700	11,100	62.5	------	--
1800	8,420	38	------	--

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TABLE VI

TENSILE PROPERTIES AT 1700° AND 1800° F OF FIVE LOTS OF 310B ALLOYS

Alloy	Original condition	Test temperature (°F)	Tensile strength (psi)	Elongation (percent in 2 in.)
310B (AF18)	Annealed, one cold pass	1700	15,600	42
310B-1 (14626)	Annealed, one cold pass	1700	10,200	42.5
310B-2 (14998)	Hot-rolled	1700	16,700	13
310B-3 (14998)	Cold-rolled 10 percent	1700	17,700	22.5
310B-4 (14998)	Annealed	1700	11,100	62.5
310B (AF18)	Annealed, one cold pass	1800	12,900	26
310B-1 (14626)	Annealed, one cold pass	1800	7,550	32.5
310B-2 (14998)	Hot-rolled	1800	13,000	9
310B-3 (14998)	Cold-rolled 10 percent	1800	13,600	10.5
310B-4 (14998)	Annealed	1800	8,420	38

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TABLE VII

RUPTURE TEST DATA AT 1700° AND 1800° F FOR 310B ALLOYS

Alloy	Original condition	Heat treatment		Test temperature (°F)	Stress (psi)	Rupture time (hr)	Elongation (percent)
		Temperature (°F)	Time (hr)				
310B (AF18)	Annealed, one cold pass	----	---	[a]1700	11,000	1.05	12
					9,000	5.0	5
					5,000	87	7
					4,000	276	6
					3,000	1124	3.5
				[a]1800	8,000	2.0	14
					6,500	11.2	16
					4,000	75	7
					3,500	112	5
					3,000	231	5
					2,500	289	6
					2,200	384	4
310B-1 (14626)	Annealed, one cold pass	----	---	[a]1700	5,000	25	6
					4,000	64	10
					3,000	233	9
					2,400	397	7
					2,100	478	4
				[a]1800	4,000	23	54
					3,000	85	8
					2,000	345	4
					1,700	569	5
		1800	50	1700	5,000	14	11
					4,000	40	11
					3,000	192	7
					2,500	165	4
					2,300	687	6
				1800	3,000	40	20
					2,000	147	7.5
					1,750	280	6
310B-2 (14998)	Hot-rolled	----	---	1700	5,000	36	17
					4,000	66	16.5
					3,000	163	13
					2,500	276	15
					2,000	483	15
		1900	1/2	1700	4,000	123	19
					3,000	(b)	----
					2,500	677	13
		2000	1/4	1700	4,000	106	29
					3,500	185	21
					3,000	316	18
		2100	1/6	1700	4,000	108	24
					3,000	447	23
					2,500	858	22
310B-3 (14998)	Cold-rolled 10 percent	----	---	1700	5,000	35	6.5
					4,000	78	7
					3,000	157	14.5
					2,500	266	5
					2,000	610	16
		1800	50	1700	4,000	78	10
					3,000	171	11
					2,500	195	6
					2,000	852	7.5
310B-4 (14998)	Annealed	----	---	1700	5,000	36	20.5
					4,000	98	14
					3,000	277	11
					2,500	630	12
		1800	50	1700	4,000	38	14
					3,500	107	18
					3,000	252	10.5
					2,500	489	8

[a]Data from reference 1.

[b]Overheated at 291 hr; test discontinued.

TABLE VIII

RUPTURE STRENGTHS AND ELONGATIONS AT 1700° AND 1800° F FOR 310B ALLOYS

Alloy	Original condition	Heat treatment		Test temperature (°F)	Stress (psi) for rupture in -			Estimated elongations (percent in 2 in.) to fracture in -		
		Temperature (°F)	Time (hr)		10 hr	100 hr	1000 hr	10 hr	100 hr	1000 hr
310B (AF18)	Annealed, one cold pass	----	---	1700	8000	5000	3100	5	7	4
310B-1 (14626	Annealed, one cold pass	----	---	1700	6600	3500	1850	6	10	4
		1800	50	1700	5400	3300	2100	11	8	6
310B-2 (14998)	Hot-rolled	----	---	1700	7700	3500	1600	20	15	15
		1900	1/2	1700	----	4200	2250	--	20	13
		2000	1/4	1700	----	4200	2250	--	30	15
		2100	1/6	1700	----	4100	2400	--	25	22
310B-3 (14998)	Cold-rolled 10 percent	----	---	1700	7000	3400	1700	7	7	16
		1800	50	1700	7000	3400	1700	--	10	7
310B-4 (14998)	Annealed	----	---	1700	6800	3900	2200	20	14	12
		1800	50	1700	[a]4700	3550	2050	14	18	8
310B (AF18)	Annealed	----	---	1800	6600	3600	[a]1600	15	6	4
310B-1 (14626)	Annealed, one cold pass	----	---	1800	5300	2800	1500	55	8	5
		1800	50	1800	4400	2300	1250	20	8	--

[a]Estimated.

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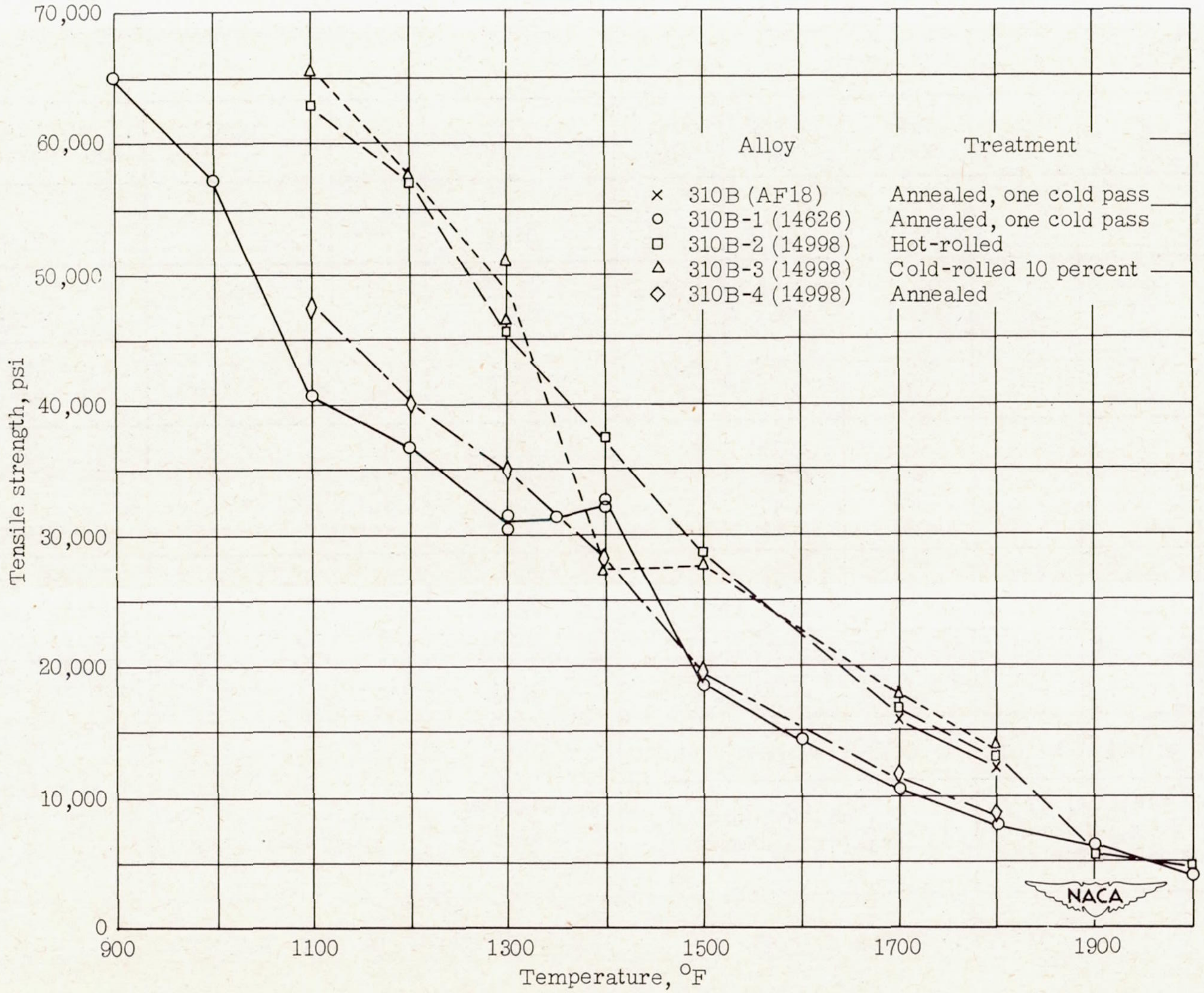


Figure 1.- Effect of treatment and temperature on tensile strength of 310B alloys.

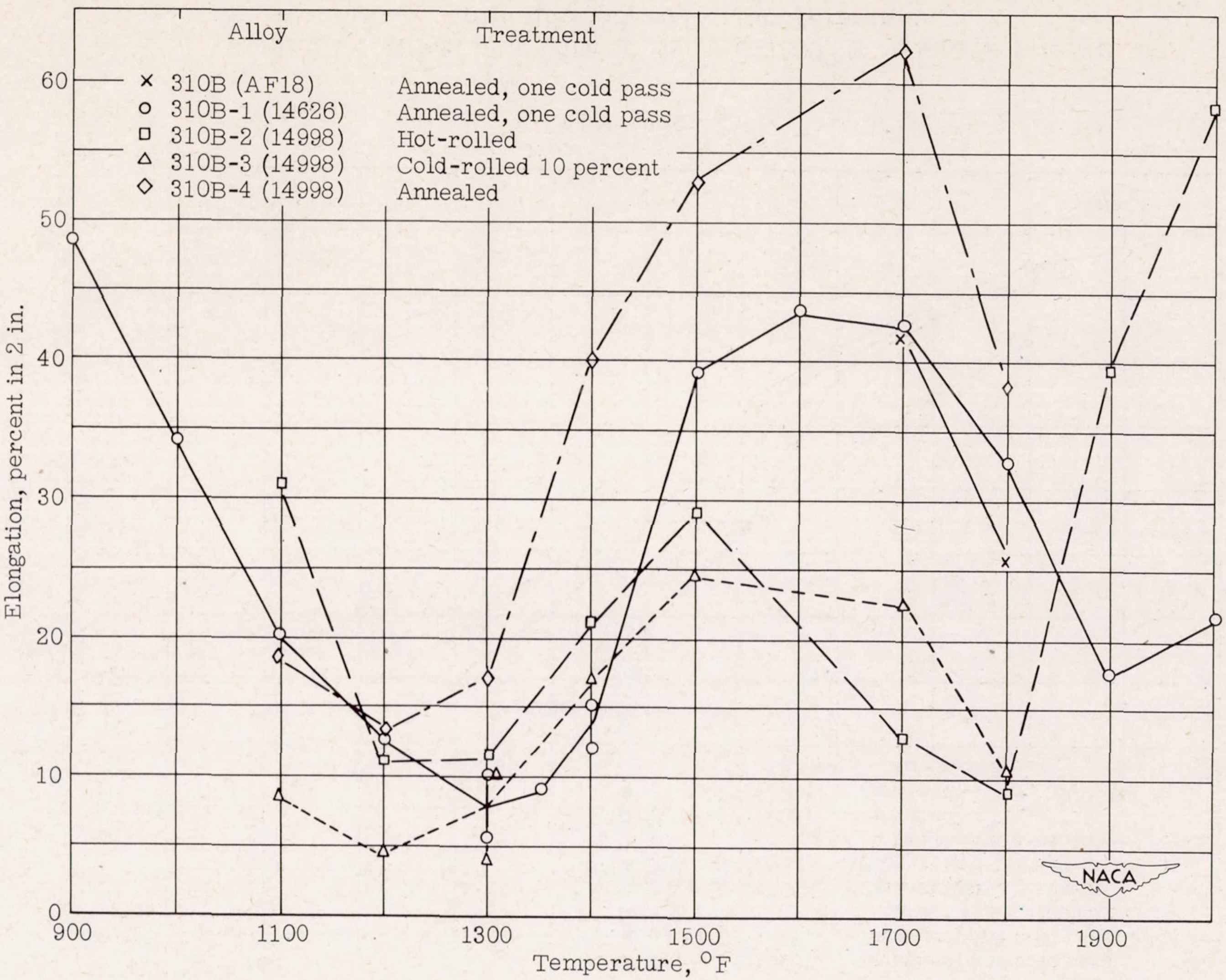


Figure 2.- Effect of treatment and temperature on tensile test elongation of 310B alloys.

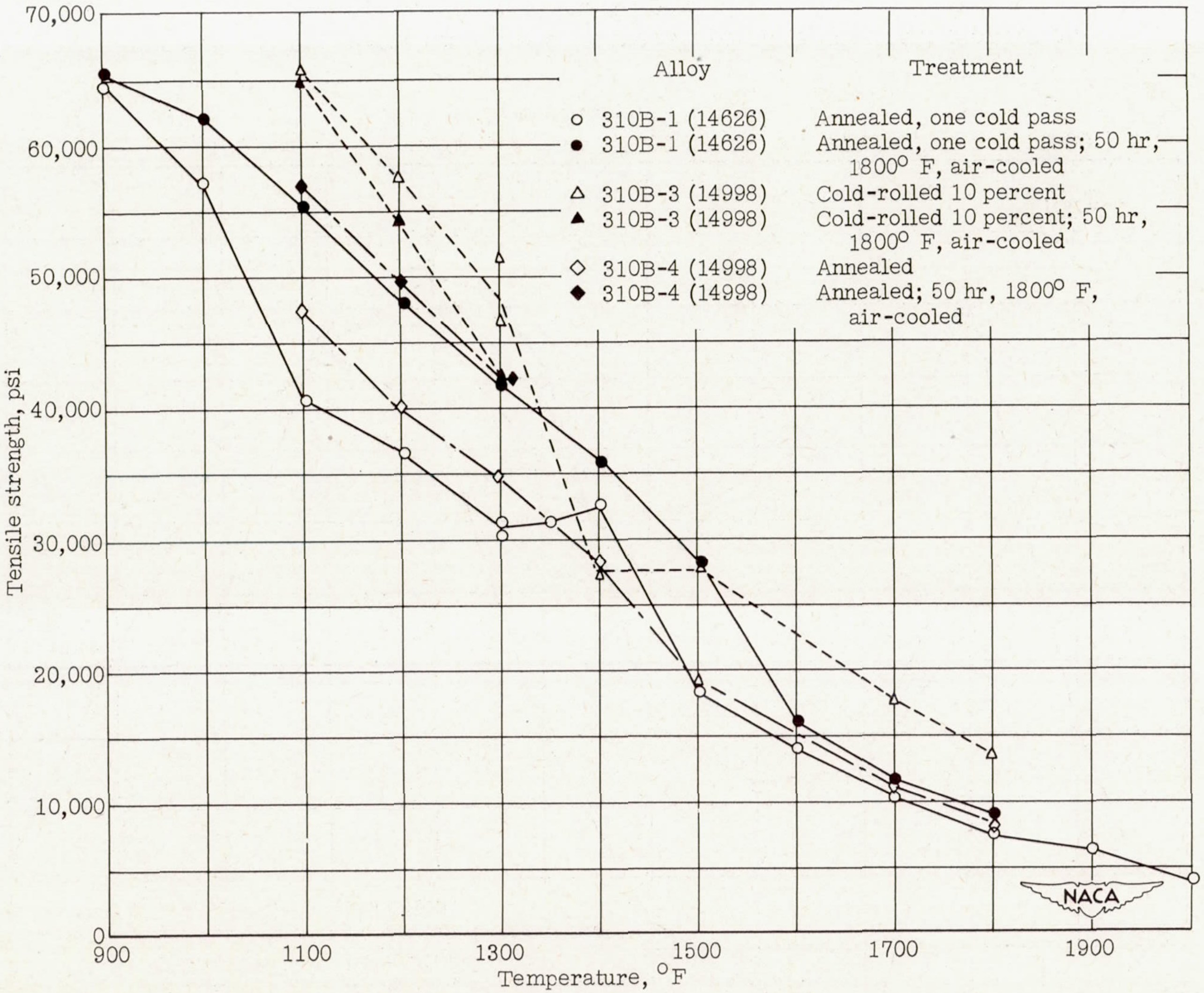


Figure 3.- Effect of holding 50 hours at 1800° F on tensile strength of 310B alloys at various temperatures.

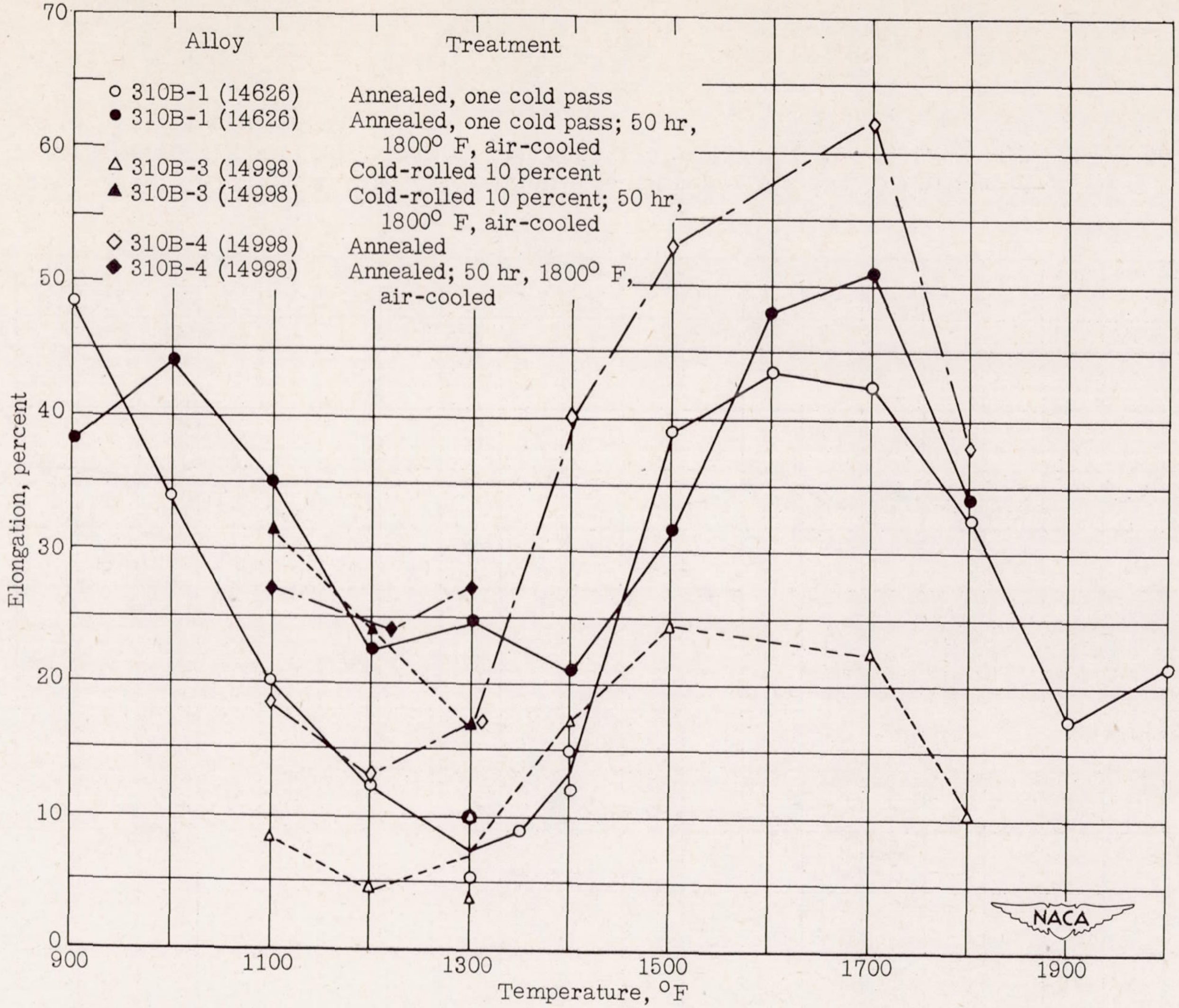


Figure 4.- Effect of holding 50 hours at 1800° F on the tensile test elongation of 310B alloys at various temperatures.

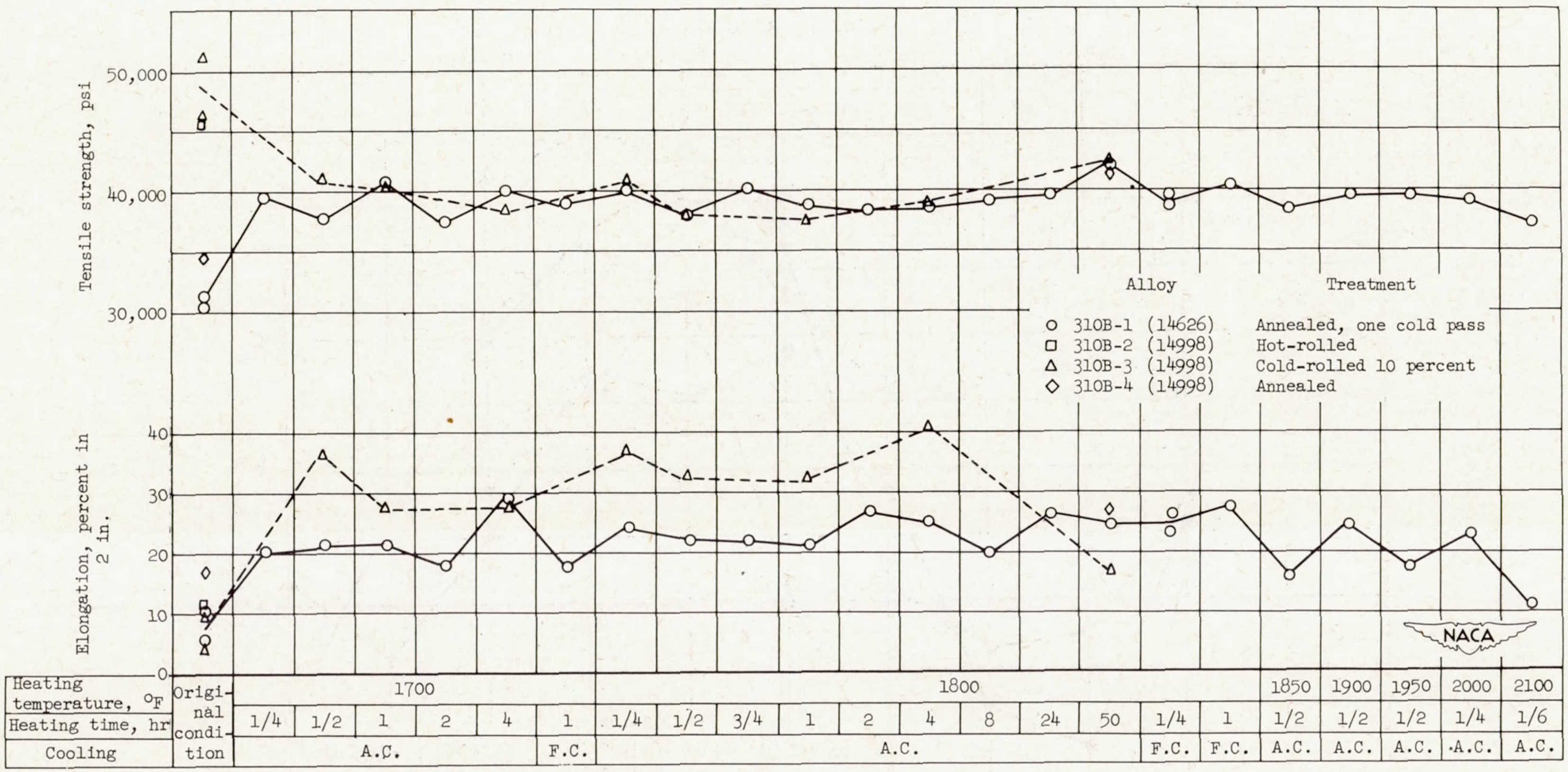
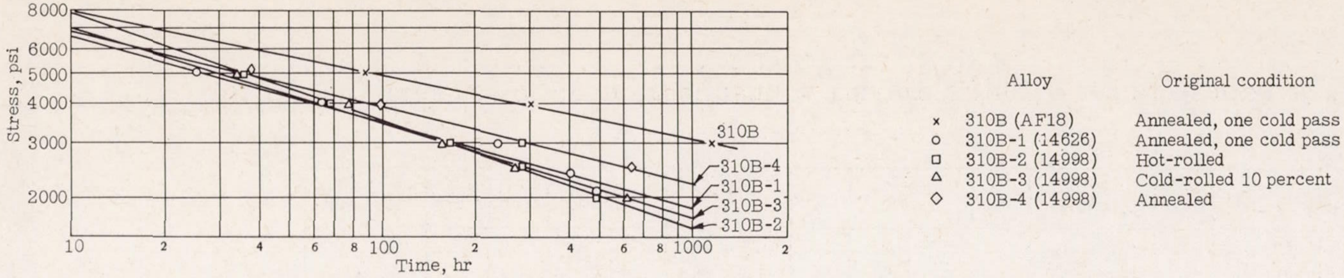
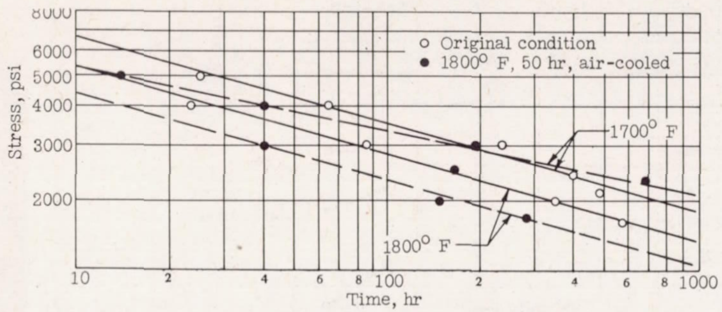


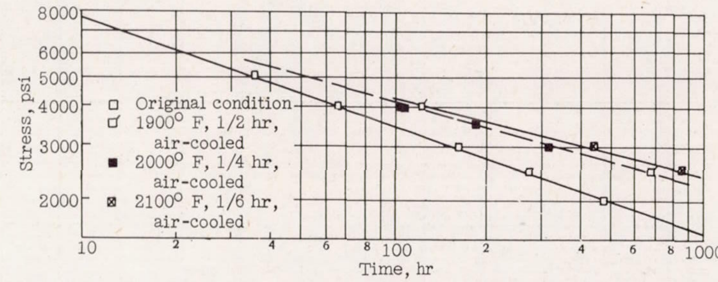
Figure 5.- Effect of prior heating on the tensile test properties of 310B alloys at 1300° F. A.C., air-cooled to room temperature and reheated to 1300° F for testing; F.C., furnace-cooled to 1300° F and tested.



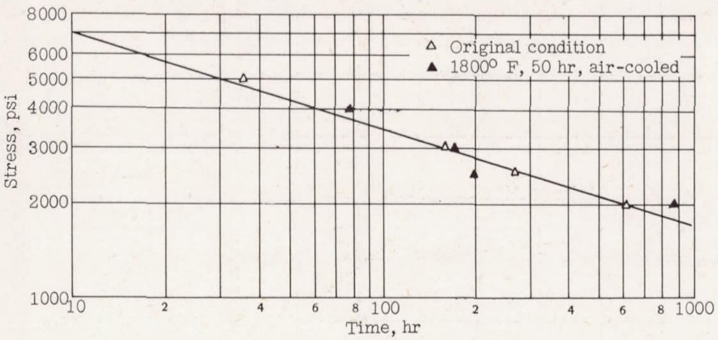
(a) 310B alloys tested at 1700° F.



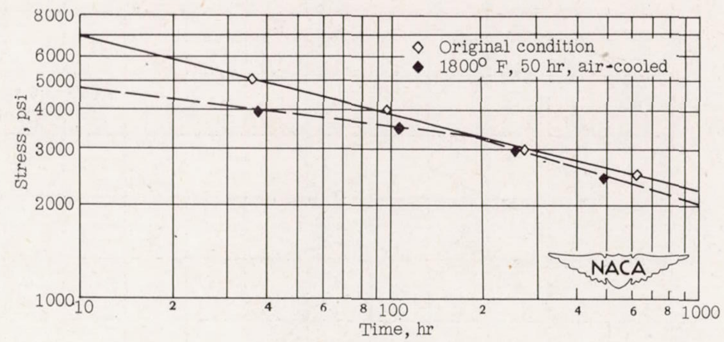
(b) 310B-1 alloy tested at 1700° and 1800° F.



(c) 310B-2 alloy tested at 1700° F.



(d) 310B-3 alloy tested at 1700° F.



(e) 310B-4 alloy tested at 1700° F.

Figure 6.- Curves of stress against rupture time at 1700° and 1800° F for 310B alloys.

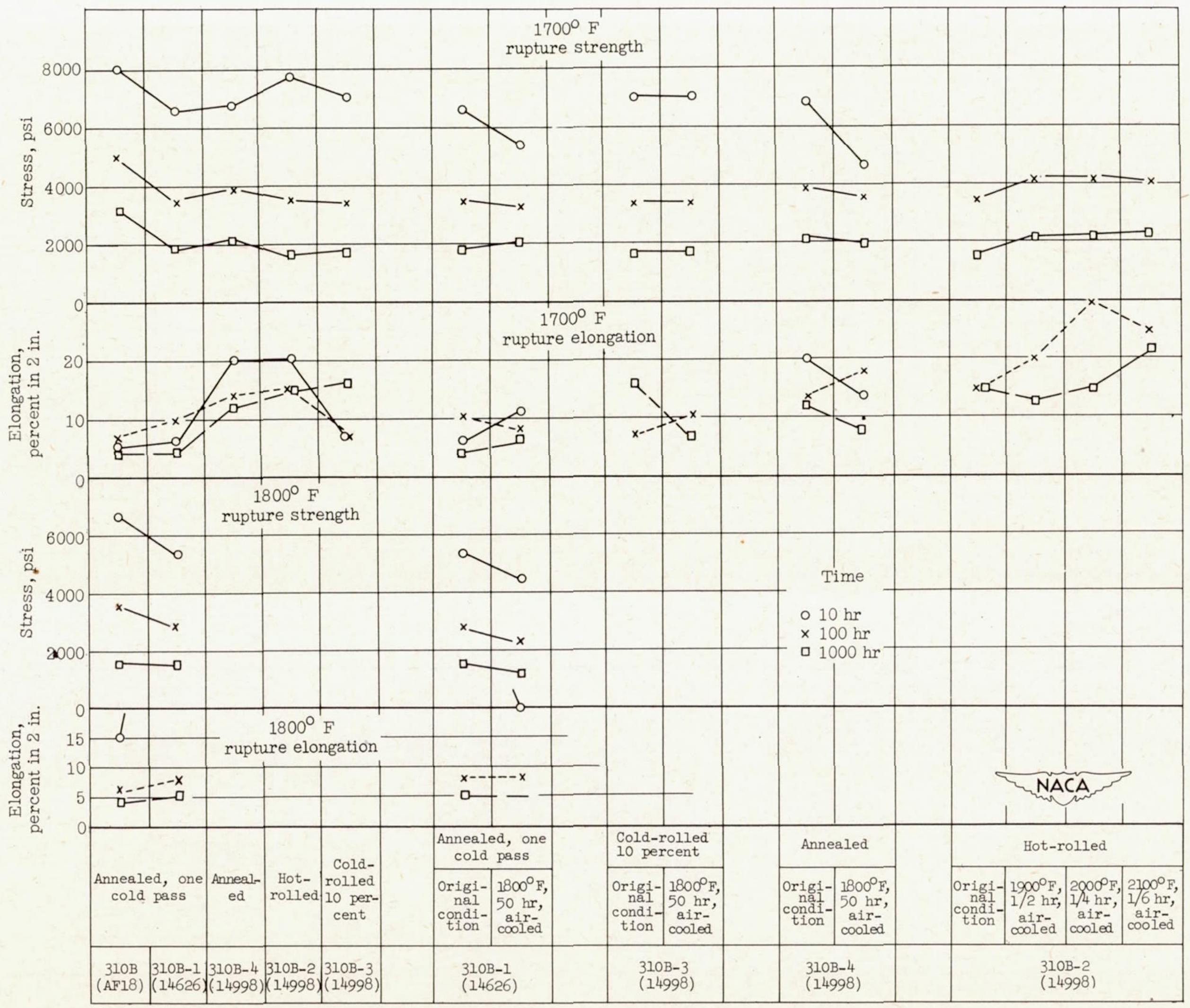
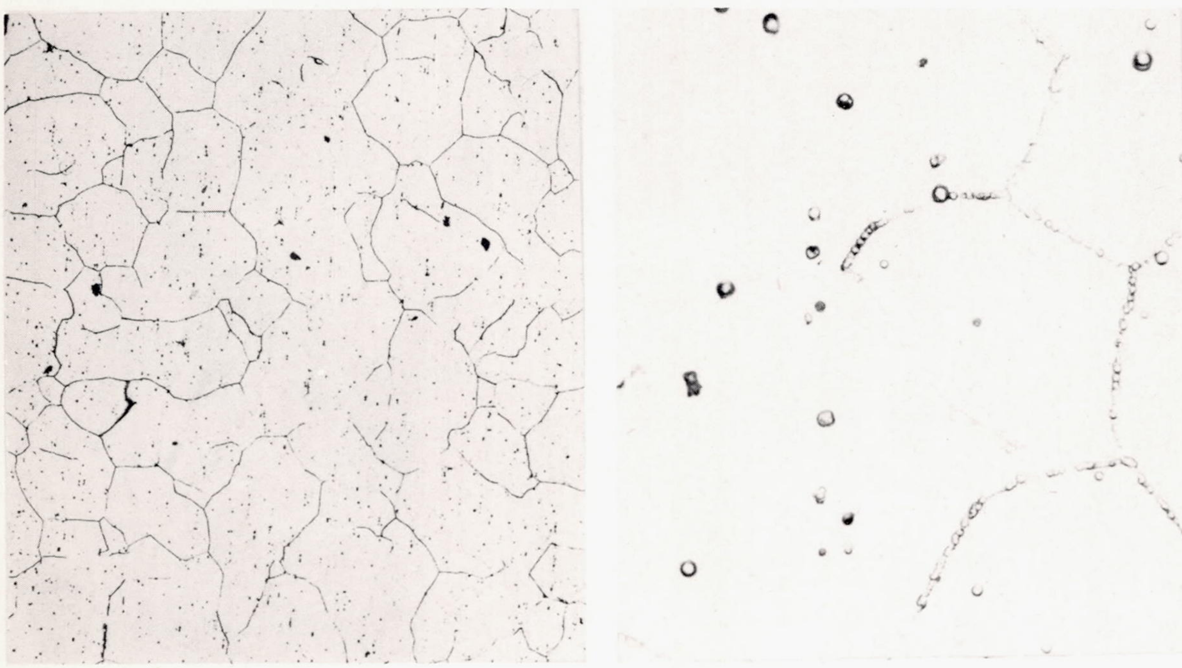


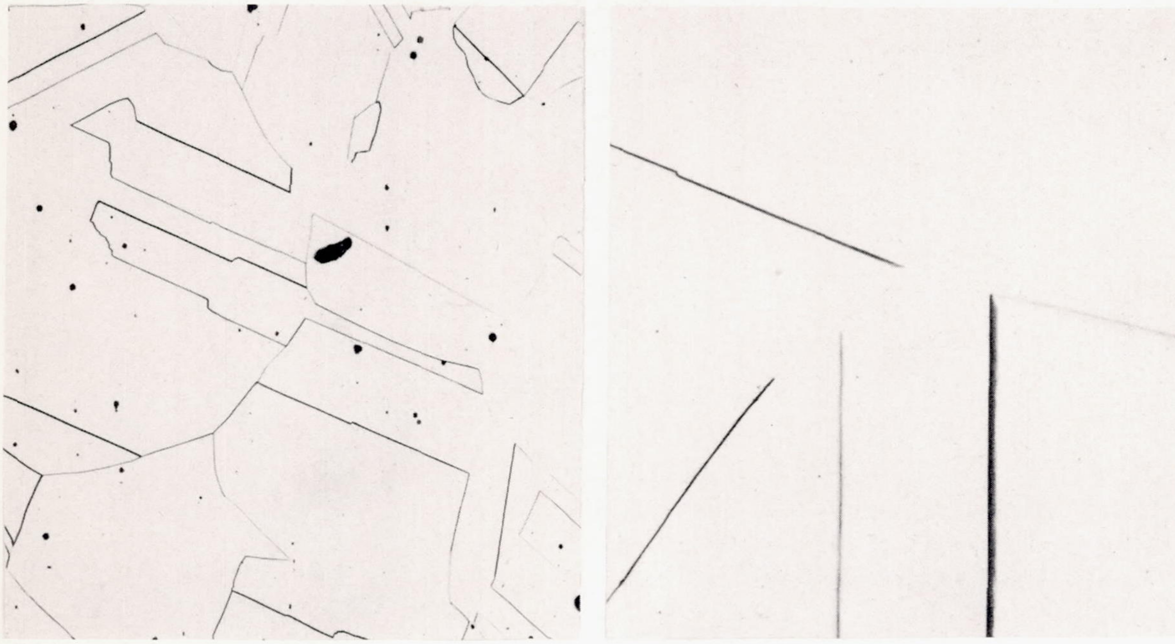
Figure 7.- Influence of prior treatment on rupture strength and elongation of 310B alloy sheet at 1700° and 1800° F.



100X 1000X

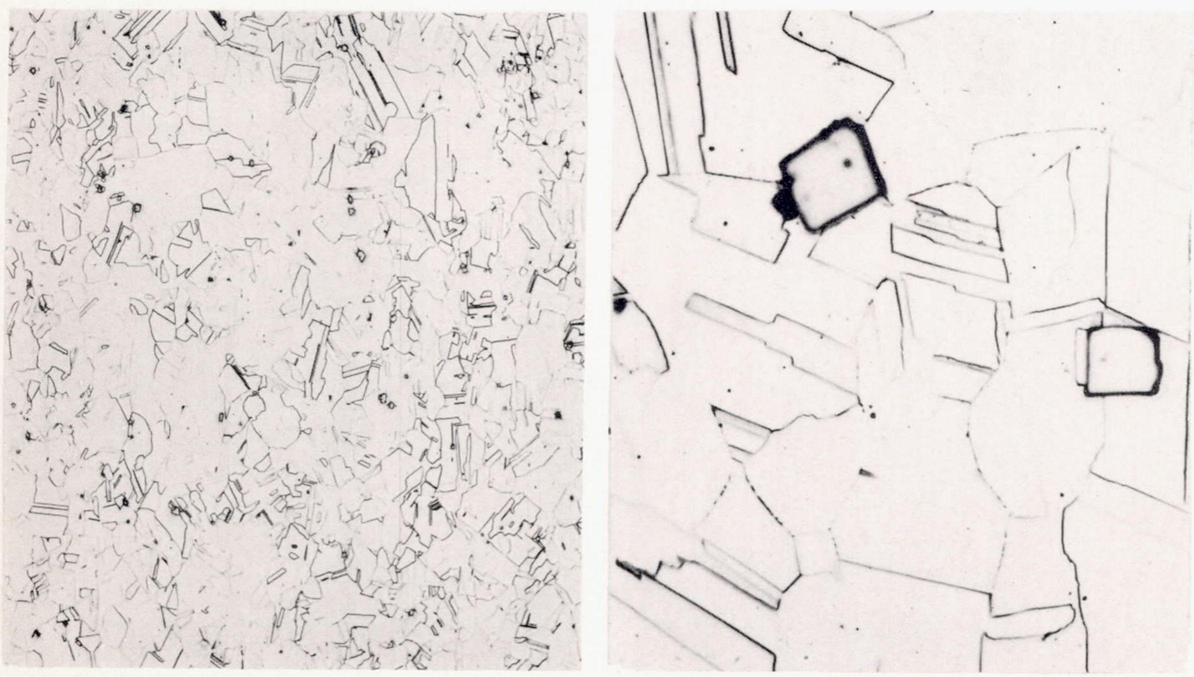
(a) Heat AF18, 310B alloy sheet; annealed, one cold pass. No titanium.

Figure 8.- Original microstructures of three heats of 310B alloy sheet. Etchant, aqua regia in glycerin.



100X 1000X

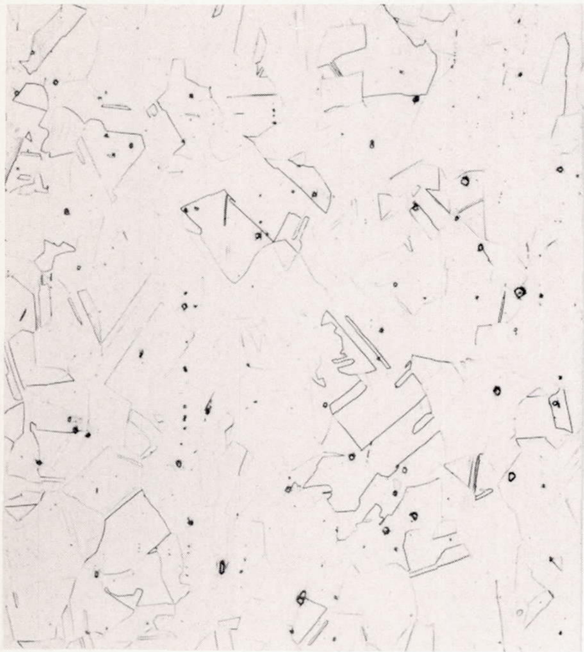
(b) Heat 14626, 310B-1 alloy sheet; annealed, one cold pass. No titanium.



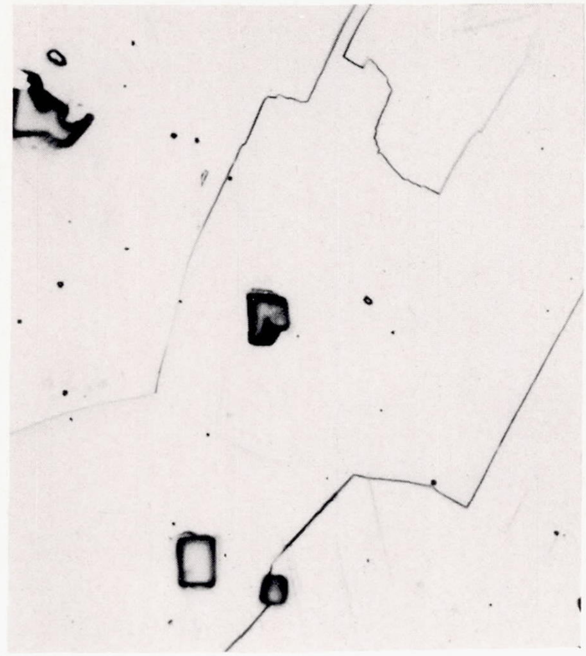
100X 1000X

(c) Heat 14998, 310B-2 alloy sheet; hot-rolled. 0.12 percent titanium.

Figure 8.- Concluded.

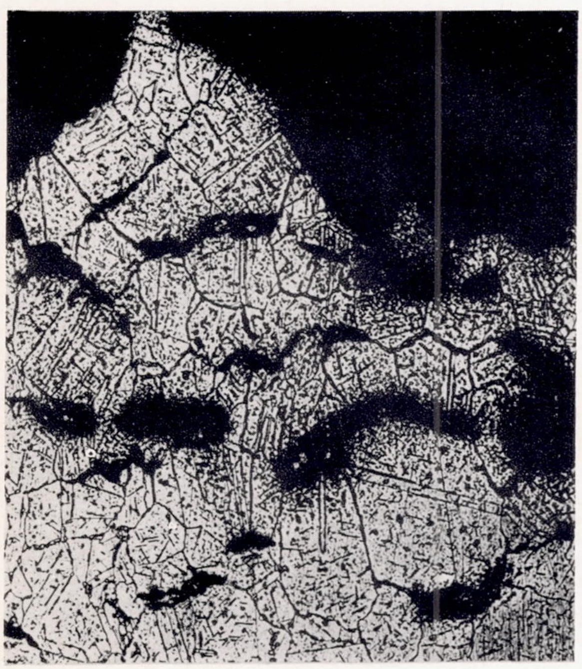


100X



1000X

(a) Original condition.

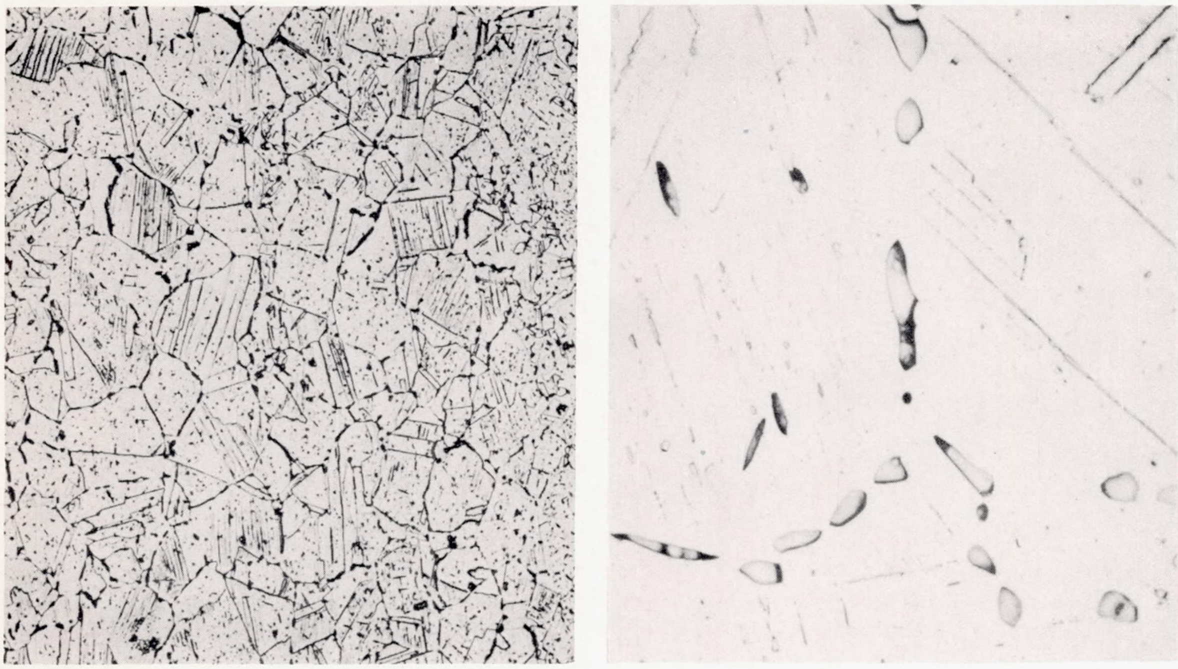


Fracture - 100X

Interior - 1000X

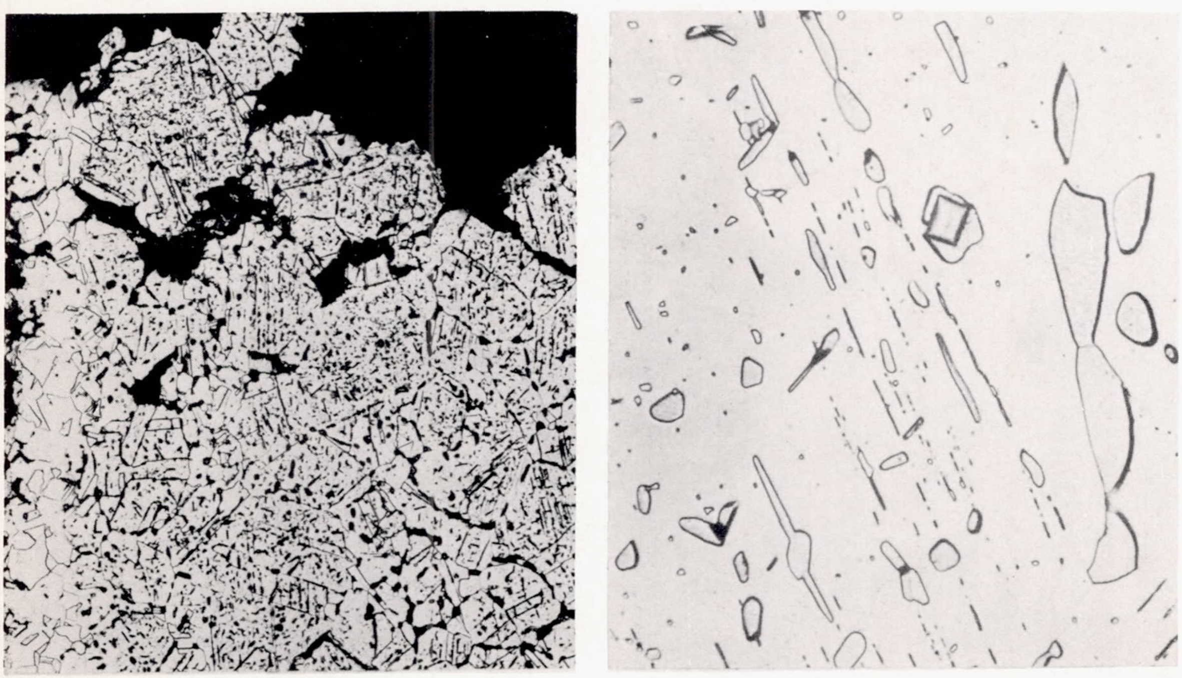
(b) Rupture specimen, original condition; 610 hours for rupture at 1700° F under 2000 psi.

Figure 9.- Microstructures of 310B-3 alloy sheet. Original condition, cold-rolled 10 percent. Etchant, aqua regia in glycerin.



100X 1000X

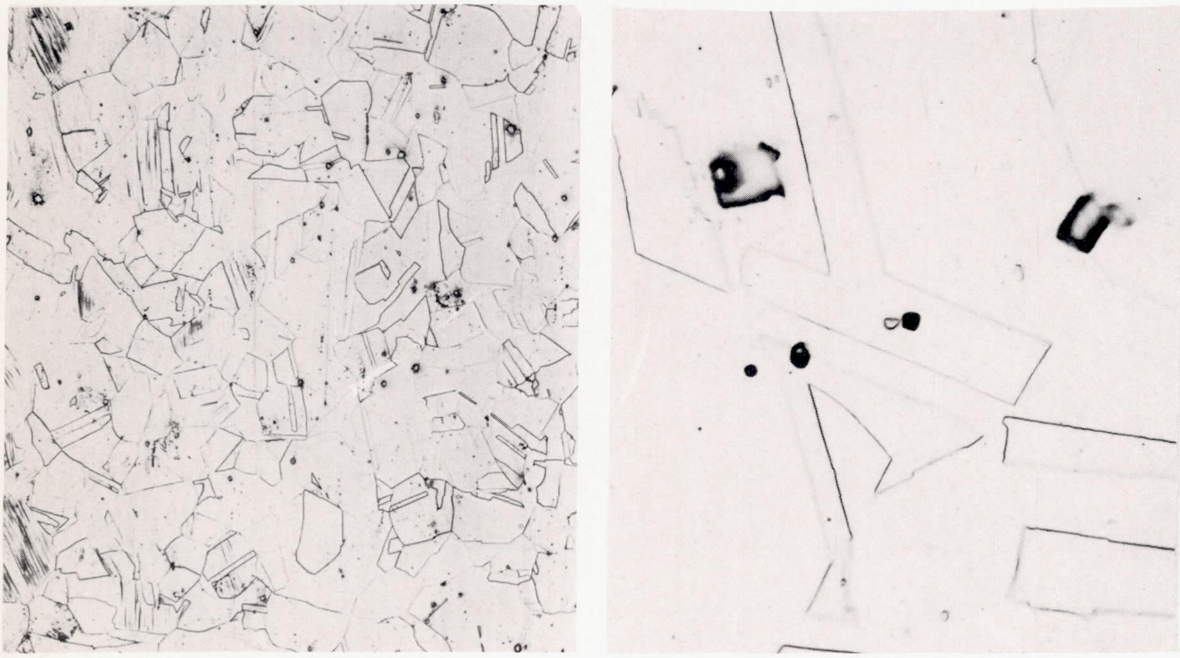
(c) Heated 50 hours at 1800° F, air-cooled.



Fracture - 100X Interior - 1000X

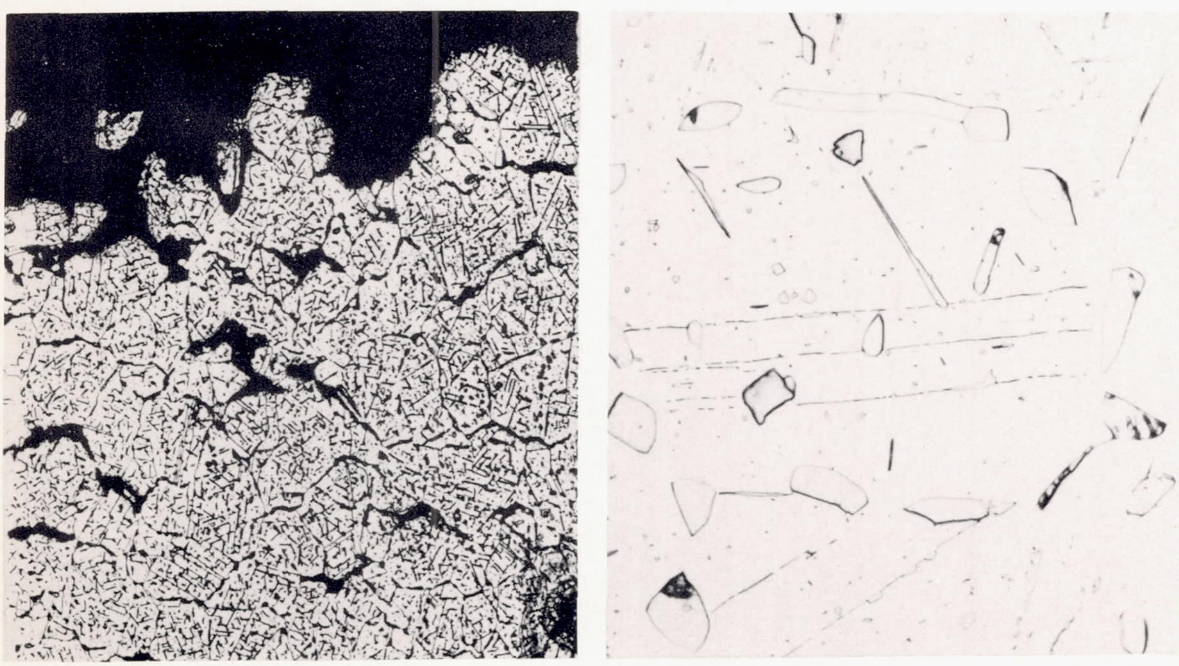
(d) Rupture specimen, heated 50 hours at 1800° F, air-cooled; 852 hours for rupture at 1700° F under 2000 psi.

Figure 9.- Concluded.



100X 1000X

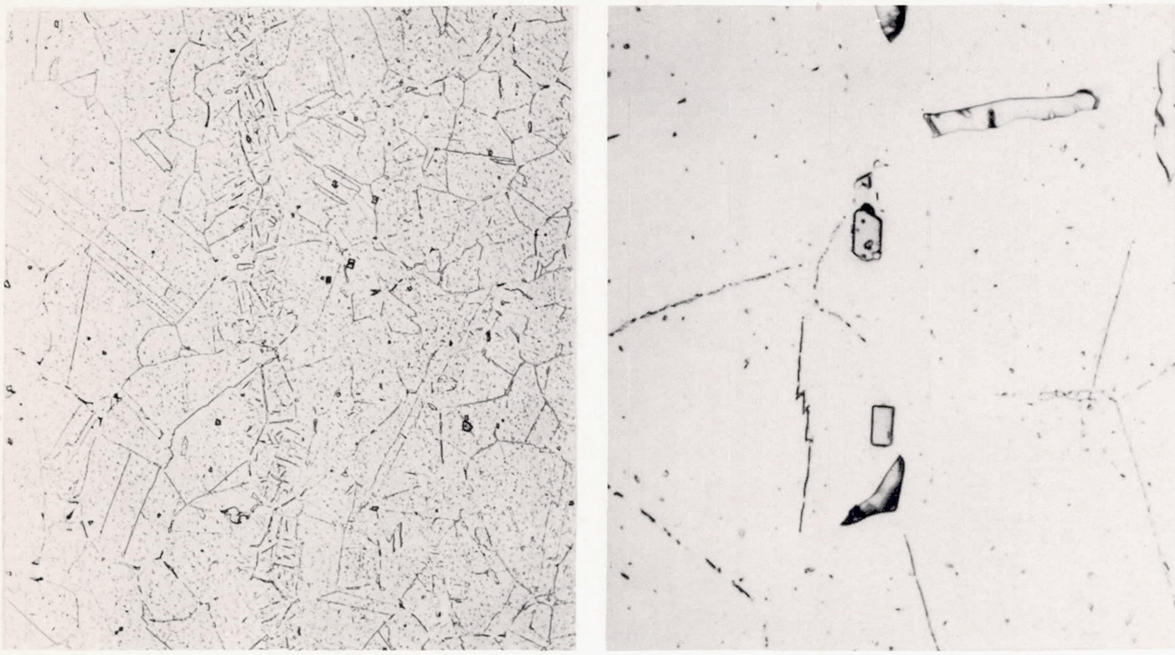
(a) Original condition.



Fracture - 100X Interior - 1000X

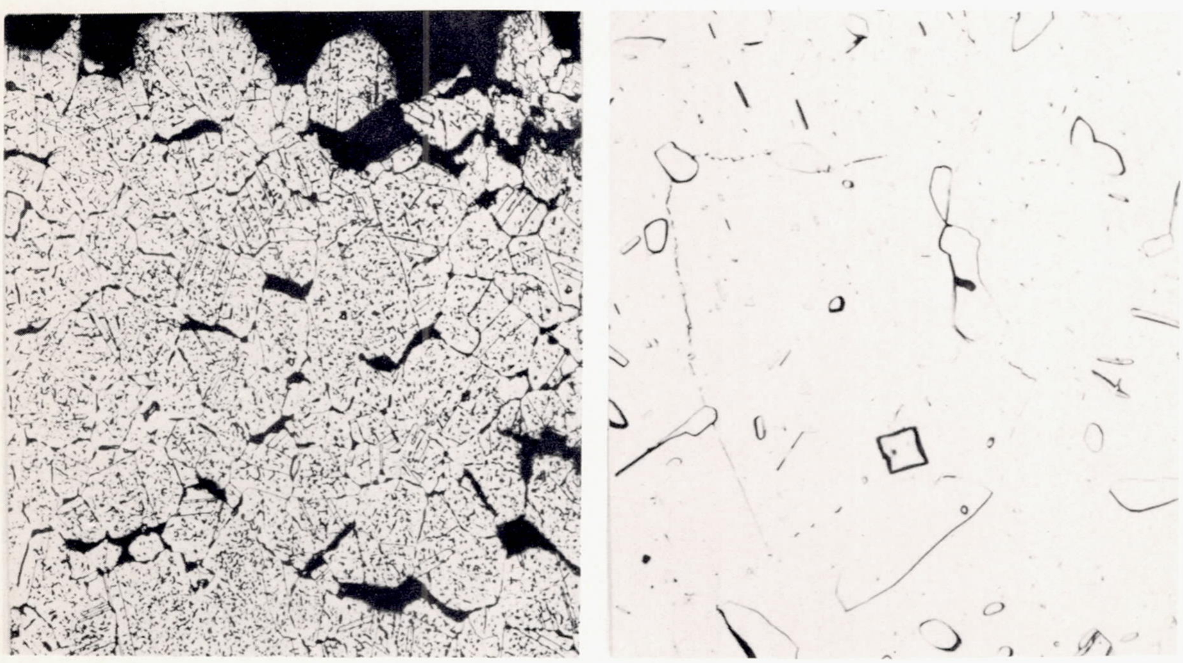
(b) Rupture specimen, original condition; 630 hours for rupture at 1700° F under 2500 psi.

Figure 10.- Microstructures of 310B-4 alloy sheet. Original condition, annealed. Etchant, aqua regia in glycerin.



100X 1000X

(c) Heated 50 hours at 1800° F, air-cooled.



Fracture - 100X Interior - 1000X

(d) Rupture specimen, heated 50 hours at 1800° F, air-cooled; 489 hours for rupture at 1700° F under 2500 psi.

Figure 10.- Concluded.