Engineering Research Institute
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INFORMAL PROGRESS REPORT

ON

METALLURGICAL RESEARCH FOR THE DEVELOPMENT OF METALS FOR USE IN HIGH-TEMPERATURE COMPONENTS OF AIRCRAFT PROPULSION SYSTEMS

TO

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Project M478-8

Freeman

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EFFECT OF OVERHEATING ON PROPERTIES OF BLADE ALLOYS

Three alloys, S816, M252 and Cast HS31 alloy, are being studied. Overheating is being carried out with and without stress, according to the procedures outlined in Table I. Most overheating has involved cyclic overheating with the effect being measured by the change in time for rupture at 1500°F under the stress causing rupture in 1000 hours. The results to date will be summarized according to the type of variable under investigation. The detailed test results are shown in Tables II, III, and IV.

1. Cyclic Overheating with Stress Removed during Overheat.

The rupture time at 1500°F under the stress normally causing rupture in 1000 hours was reduced for S816 and particularly for HS31 alloy by heating to 1800° or 1900°F for 2 minutes twice daily. M252 alloy did not lose rupture life and may have been slightly improved by similar treatments. The comparative rupture times were as follows, and are compared graphically in Figure 1:

Alloy	Stress at 1500°F (psi)	Overheat Temp(°F)	Rupture Time		
			Standard Rupture Test(hours)	Cyclically Overheated	
				(hours)	(cycles)
S816	16,200	1800	1000	525	44
S816	16,200	1900	1000	369	31
HS31	23,000	1800	1000	240	20
HS31	23,000	1900	1000	187	16
M252	14,000	1800	1000	>1133	93
M252	14,000	1900	1000	1172	98

Cyclic loading and unloading at 1500°F without overheating (Procedure 4) did not significantly change the rupture time. The cyclic heating was, therefore, mainly responsible for changes in rupture time.

2. Cyclic Overheating under Stress.

The rupture life at 1500°F of all three alloys was drastically reduced by overheating to 1800° or 1900°F every 5 hours for 2 minutes with the stress causing rupture in 1000 hours at 1500°F left on the specimens. The pertinent data were as follows, and the details are given in Tables II, III, and IV:

Alloy	Stress (psi)	Overheat Temp (°F)	Rupture Time (hours)	Number of Cycles	Time at Overheat Temp(min)	Normal Rupture Time at Overheat Temp (min)
S816	16,200	1800	39.5	8	14	35, 42
S816	16,200	1900	10	2	2.6	4
HS31	23,000	1800	50	10	19.1	10, 18, 19
M252	14,000	1800	25	5	9.3	15
M252	14,000	1900	10	2	2.3	2.2

The life of the specimens was entirely used up by the relatively high stress at the overheat temperatures. The shorter total times at the overheat temperatures than were obtained by normal rupture tests, particularly at 1800°F, were unexpected. Check tests are being made using the same procedure as for the overheat tests. Specimens are being brought to 1500°F, loaded at 1500°F, and then heated to and held at the overheat temperature by the same technique as used for the cyclic overheats. For HS31, this procedure has given 8.4 minutes at 1800°F. It appears as if the difference in total time at 1800° or 1900°F between cyclic and normal rupture tests may be due to effects resulting from prolonged heating at those temperatures prior to loading in the normal rupture test.

3. Single overheats to 1600° or 1800°F in the absence of stress did not change the rupture time more than the normal scatter in data. In the presence of stress, there was no effect at 1600°F. The total time at 1600°F of 2 hours, however, was small in comparison to the total available

rupture time at 1600°F under the stress for rupture in 1000 hours at 1500°F. The percentage of time at 1600°F was less than the normal scatter which might be expected, so that no significant reduction in life was noticed.

4. At the December meeting of the Subcommittee, it was requested that work on the M252 stock be discontinued in favor of a new lot of stock with higher strength. To date, it has not been possible to acquire such stock.

5. A number of specimens of S816 have been subjected to partial overheat damage for investigation of the changes in structure by internal friction. This is very preliminary work of a small magnitude and results are not yet available. Dr. Frederick offered to make the measurements as a matter of interest in the problem and it was thought worthwhile to provide him with the necessary specimens.

6. The proposal being considered outlines the additional work thought desirable. Overheats are in progress at 1650°F. Data for standard rupture tests for the limited damage program have been obtained. The stresses proposed for the various parts of the program will be as follows or close to the following values:

Test	S816 (psi)	HS31 (psi)
100-hr at 1500°F	22,000	27,500
500-hr at 1500°F	18,500	24,000
193-minute at 1800°F	12,500	~15,000
193-minute at 2000°F	~6,000	~7,500

INFLUENCE OF HOT-WORKING CONDITIONS ON THE HIGH-TEMPERATURE STRENGTH OF WASPALOY

The relationships between rupture properties after the standard treatment and conditions of hot working are being studied for Waspaloy. The objective is to establish the fundamental reasons for variable properties after the standard treatment.

Stock from a commercial heat 44036 made by the Allegheny Ludlum Steel Corporation is being used. Analysis of the heat was reported as follows:

C	Mn	Si	Cr	Co	Mo	Ti	Al	Fe	Ni
.09	.88	.62	19.5	13.4	2.8	2.20	1.09	2.9	Bal.

Bars were rolled from 1-5/8 to 1-1/2 inch rounds from 2050°F, heated 1 hour at 1950°F and oil quenched, and centerless ground to 1-3/16 inch rounds.

The solution treatment being used is an air cool after 4 hours at 1975°F. The aging treatment is 4 hours at 1550°F, followed by 16 hours at 1400°F.

Results

1. The rupture strength tends to decrease with increasing percentage reduction, as is shown by Figure 2.

2. Reduction at 2200°F was considerably more detrimental to rupture strength than reduction at 2000°F (Figure 2).

3. The available data showing the influence of rolling temperature is summarized by Figure 3. Reduction at 1800°F apparently may not

give quite as high rupture strength as rolling at 2000°F.

4. The maximum range to date in rupture times at 1500°F for stock solution treated 4 hours at 1975°F and tested at 25,000 psi is:

> 310 hours for stock rolled 8% at 2000°F (100-hr rupture strength = 32,000 psi)
>
> 125 hours for stock rolled 40% at 2200°F (100-hr rupture strength = 25,000 psi)

5. Two reductions of 20 percent at 2000°F gave nearly the same rupture times as one reduction of 20 percent at 2000°F. (See Figure 2.) An intermediate solution treatment had no effect.

6. In all cases, the as-rolled condition had rather low rupture strength. (See Figure 2.)

7. After rolling at 2000°F, the as-rolled condition responded to aging about as well as solution treated stock. After rolling at 2200°F, there was very little response. (See Figure 2.)

8. In all cases check to date, there was very little difference in rupture strength between solution treated and solution treated plus aged samples.

9. Although relatively little work has been done to date on the influence of stress during rupture testing, Figure 4 shows a trend that seems to be emerging. There may be a considerable range in stress over which there will be very little change in rupture time, followed by a tendency for the normal slope for the stress - rupture time curve. This probably is far more pronounced in the as-rolled condition than after solution treatment, although there is some evidence that it persists even then.

10. The data in Figure 4 (except for as-received stock) all involve variations from the previously reported data. Reheating between passes was used during rolling to maintain temperature. The solution treatment was 1950°F for 4 hours and an oil quench. Aging was 16 hours at 1375°F. It

is therefore difficult to be certain of the significance of the magnitude of the rupture strengths in comparison to the previous discussed data. It will be noted that:

(a) Rupture strength for stock rolled 20 percent at 2000°F appears to be considerably lower than for the same stock rolled 20 percent without reheats, as shown by Figure 2.

(b) Stock rolled 75 percent at either 1950° or 2200°F had rupture times at 25,000 psi at the low end of the range, shown by Figure 2. Apparently this reduction in strength in comparison to the original stock was increased at longer rupture times.

(c) These data suggest that maintenance of temperature during rolling by frequent reheats tends to reduce response to heat treatment. As previously noted, however, this should be checked with the higher solution treatment.

11. The figures show the elongations for the rupture specimens. No substantial influence of hot-working conditions has been observed. Aging increases elongation somewhat in most cases.

Experiments in Progress

Further rolling is in progress to establish the influence on rupture properties of reheats on the response to heat treatment. Further testing is also being done to establish the influence of stress for key conditions.

The original bar stock gave a fairly coarse grain size (No. 1) on solution treating at 1975°F. None of the rerolled bars have had grain sizes coarser than No. 3. Experiments are in progress to attempt to produce larger grains and determine any effects on rupture strength.

Future work will largely concentrate on determination of the mechanism involved in the variation in strength.

Discussion

From the data to date, the following trends are emerging:

1. Increasing reduction without reheats reduces rupture strength at 1500°F after normal heat treatment.

2. Working at 2200°F is considerably more detrimental to rupture strength than working at 2000°F.

3. The influence of reheats remains obscure. Reheating between 20 percent reductions starting at 2000°F apparently arrested the decrease in rupture strength with percent reduction. Frequent reheats to 75 percent reduction were no worse than 40 percent reduction without reheats at 2200°F. A reduction of 75 percent at 1950°F with frequent reheats resulted in lower strength than 20 percent at 2000°F without reheats. Further work will be necessary to clarify effects of reheats and the mechanism of maintenance of strength which must exist in working ingots to bar stock. This work probably should include larger reductions than have been considered to date.

4. It is evident from Figure 2 that rolling at 2200°F upsets the response to aging, whereas rolling at 2000°F did not. Aging the stock rolled at 2200°F increased strength only slightly, whereas after rolling at 2000°F it responded nearly as well as it did to solution treatment. Reheating at 1975°F after rolling apparently restored response to aging only partially.

5. The possibility, therefore, exists that high temperatures for working are detrimental through alteration of the aging mechanism.

6. The establishment of the mechanism is proving very difficult. The aging reaction through which the alloy is presumed to derive its strength is most effective where there is little or no evidence of its presence in the microstructure. Various structure studies and attempts to identify the pre-

cipitates are in progress. It is hoped that the general mechanism can be established without the extensive testing involved in working out temperature - reduction - reheat raminfications.

TABLE I

Testing Procedures

(1) Standard constant load - constant stress rupture tests at indicated temperatures.

(1a) Rupture - rapid heating - test brought to 1500°F with furnace, load applied and temperature raised to overheat temperature with welder; test continued to rupture at overheat temperature, maintaining temperature with welder.

(2) Single cycle no load tests: specimens were overheated once to indicated temperatures for indicated times from 1500°F, cooled to 1500°F, reloaded, and continued to rupture at 1500°F. Overheating was carried out before loading at 1500°F, and after the creep curves had reached the indicated stages of creep.

(3) Single cycle - loaded tests: tests were carried out as in (2), except that the load was left on during overheating.

(4) Cyclic stressing at 1500°F: load was removed and reapplied at 1500°F twice a day to establish possible influence of periodic unloading and loading in procedure (5).

(5) Cyclic overheat - no load: specimens were brought to 1500°F, loaded, held 12 hours, unloaded, overheated to indicated temperatures for 2 minutes, cooled to 1500°F, reloaded, held for 12 hours, and the cycle again repeated twice a day until it failed.

(6) Cyclic overheat - loaded: specimens were brought to 1500°F, loaded, held 5 hours, overheated to indicated temperatures for 2 minutes, cooled to 1500°F, and the cycle repeated every 5 hours until rupture.

TABLE II

Effect of Overheating on the Life of S816 Alloy under the Stress for Rupture in 1000 Hours at 1500°F (16,200 psi)

Type Test*	Cycles	Time at Indicated Temperatures 1500°F (hr)	1600°F (hr)	1800°F (min)	1900°F (min)
(1) Rupture	--	1110 (43%)	85 (27%)	35 (17%)	4 (25%)
(1)		1242 (46%)		42 (26%)	
(1)		1215 (50%)			
(2) Single Overheat - No Load	1 (before testing)	1432 (40%)	4		
(2)		1070 (57%)	4		
(2)	1 (second stage)	1104 (40%)	2		
(2)	1 (before testing)	990 (47%)		5	
(2)	1 (second stage)	798 (54%)		5	
(3) Single Overheat - Loaded	1 (start second stage)	1120 (34%)	2		
(3)	1 (second stage)	1076 (37%)	2		
(4) Cyclic Stressing at 1500°F	69	829 (34%)			
(5) Cyclic Overheat - No Load	44	525 (47%)		88	
(5)	31	369 (36%)			62
(6) Cyclic Overheat - Loaded	8	39.5		14 (15%)	
(6)	2	10			2.6 (19%)

NOTE: Values in parentheses are elongation values after rupture -- where given indicates temperatures at which rupture occurred.

* See Table I for detailed testing procedures.

TABLE III

Effect of Overheating on the Life of HS31 Alloy under the Stress for Rupture in 1000 Hours at 1500°F (23,000 psi)

Type Test*	Cycles	Time at Indicated Temperature			
		1500°F (hr)	1600°F (hr)	1800°F (min)	1900°F (min)
(1) Rupture	--	682 (9%)	--	19 (37%)	2.6 (41%)
(1)		624 (7%)		10 (27%)	1.8 (37%)
(1)		1075 (6%)		18 (16%)	
(1a) Rupture - Rapid Heating	--	--	--	8.4	--
(2) Single Overheat - No Load	1 (before testing)	749 (4%)	4		
(2)		822 (4%)	4		
(2)	1 (second stage)	1562.9 (4%)	2		
(2)	1 (before testing)	480 (10%)		5	
(2)	1 (second stage)	578.5 (6%)		5	
(3) Single Overheat - Loaded	1 (start second stage)	944 (8%)	2		
(3)	1 (second stage)	1037 (6%)	2		
(4) Cyclic Stressing at 1500°F	74	896.5 (14%)			
(5) Cyclic Overheat - No Load	20	240 (16%)		40	
(5)	16	187 (16%)			32
(6) Cyclic Overheat - Loaded	10	50		19.1 (21%)	

NOTE: Values in parentheses are elongation values after rupture -- where given indicates temperatures at which rupture occurred.

* See Table I for detailed testing procedures.

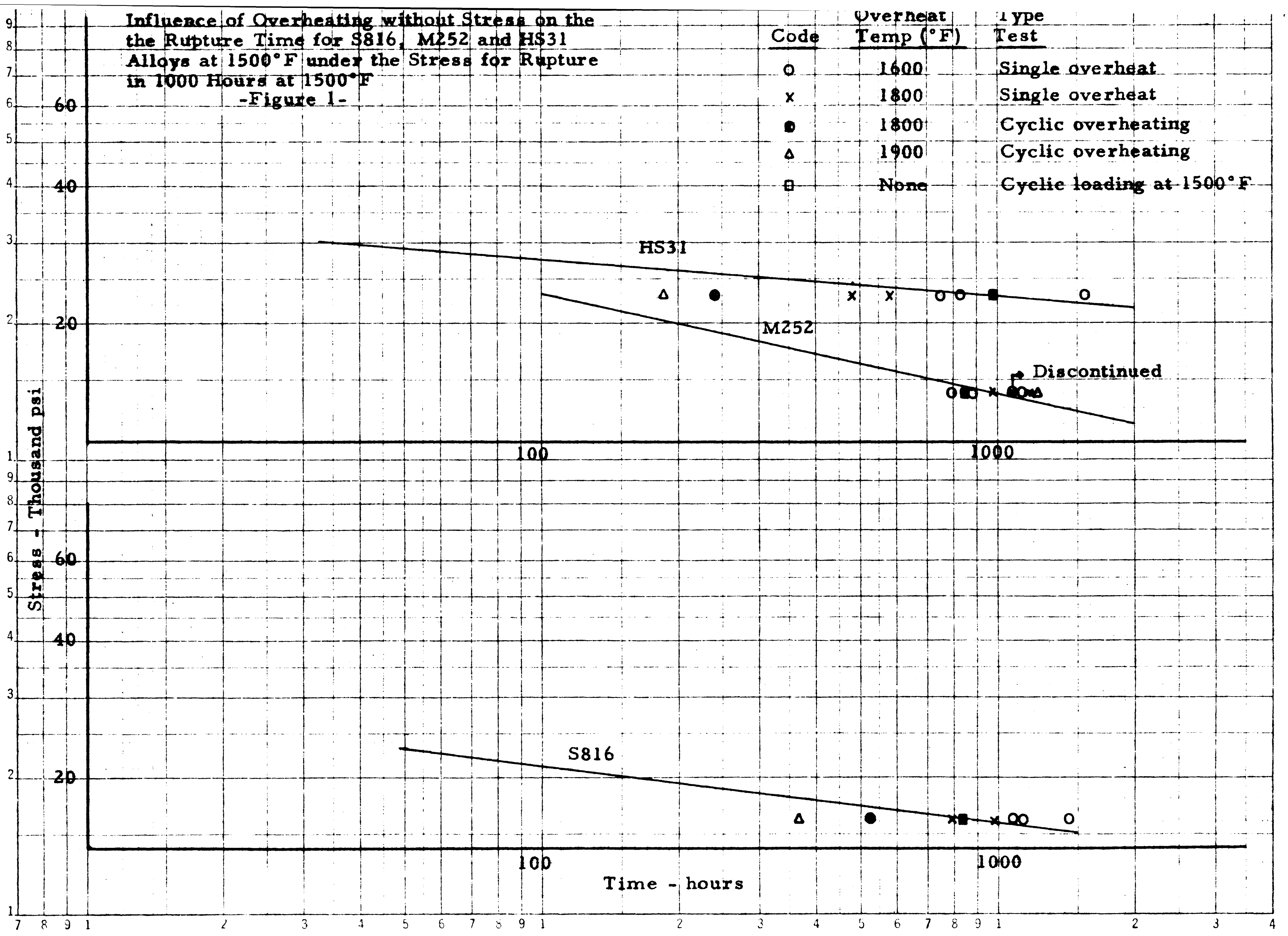
TABLE IV

Effect of Overheating on the Life of M252 Alloy under the Stress for Rupture in 1000 Hours at 1500°F (14,000 psi)

Type Test*	Cycles	Time at Indicated Temperatures			
		1500°F (hr)	1600°F (hr)	1800°F (min)	1900°F (min)
(1) Rupture	--	1385 (37%)	90 (52%)	15 (92%)	2.2 (108%)
(1)		1034 (26%)			
(1)		1121 (28%)			
(2) Single Overheat - No Load	1 (before testing)	869 (40%)	4		
(2)		1232 (32%)	4		
(2)	1 (second stage)	792 (33%)	2		
(2)	1 (before testing)	1232 (37%)		5	
(2)	1 (second stage)	983 (39%)		5	
(3) Single Overheat - Loaded	1 (start second stage)	1043 (38%)	2		
(3)	1 (second stage)	1286 (49%)	2		
(4) Cyclic Stressing at 1500°F	72	863 (30%)			
(5) Cyclic Overheat - No Load	93	disc at 1133		186	
(5)	98	1172 (25%)			196
(6) Cyclic Overheat - Loaded	5	25		9.3 (31%)	
(6)	2	10			2.3 (37%)

NOTE: Values in parentheses are elongation values after rupture -- where given indicates temperatures at which rupture occurred.

* See Table I for detailed testing procedures.



Influence of Overheating without Stress on the the Rupture Time for S816, M252 and HS31 Alloys at 1500°F under the Stress for Rupture in 1000 Hours at 1500°F

-Figure 1-

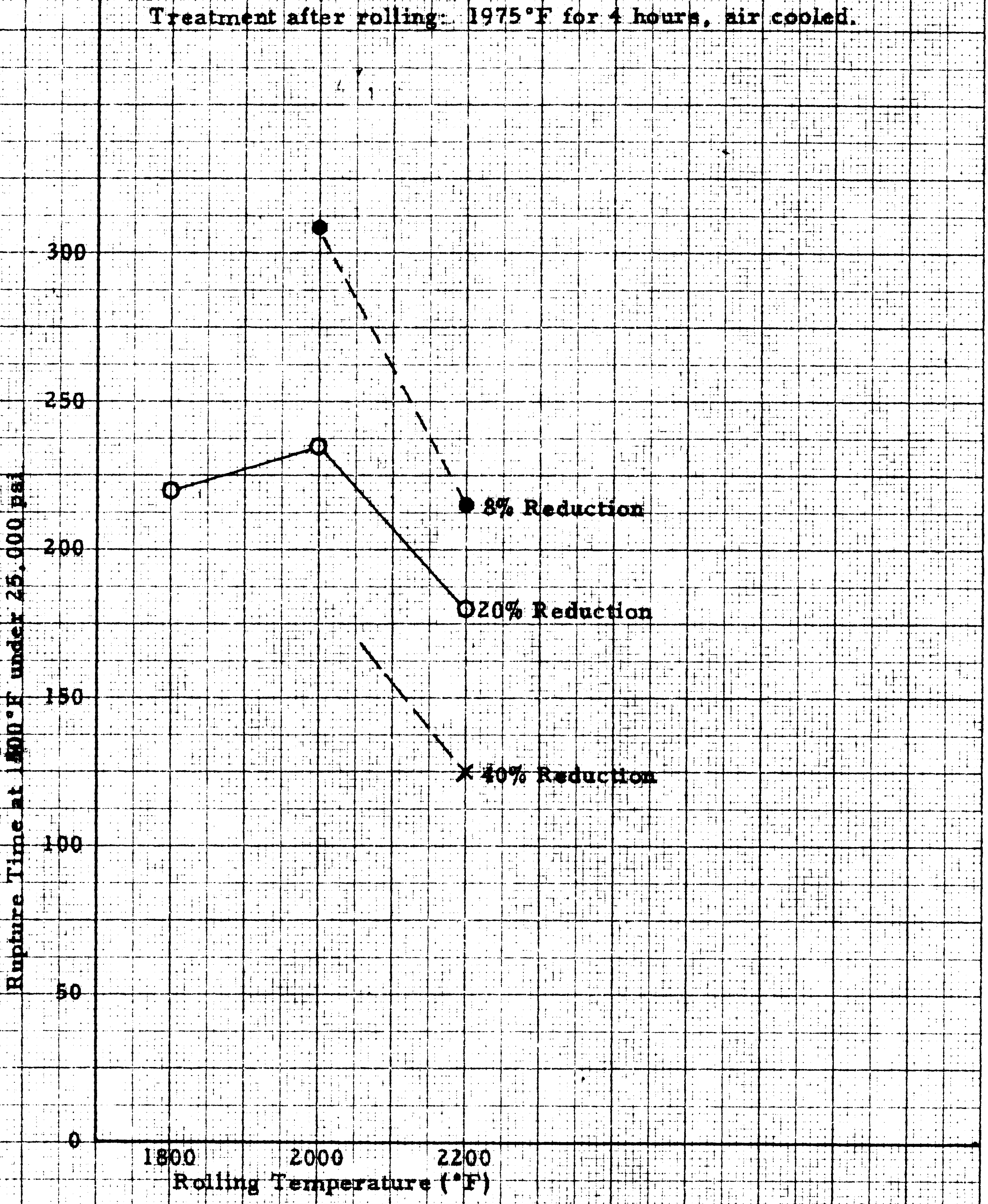


Figure 3. - Effect of Rolling Temperature on Rupture Time of Waspaloy at 1500°F under 25,000 psi.

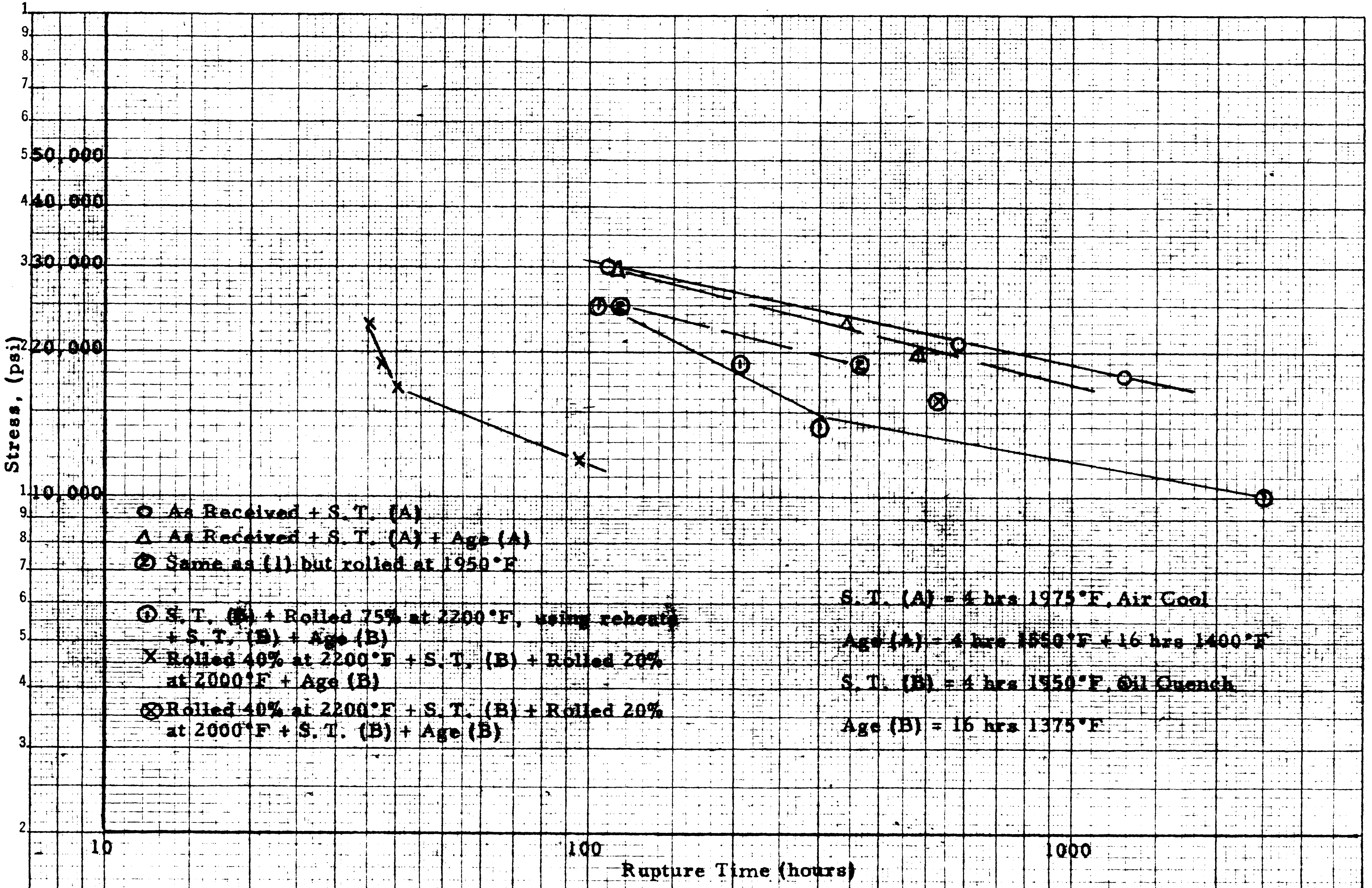


Figure 4. - Stress-Rupture Data at 1500°F for Waspaloy Rolled and Heat Treated as Indicated.