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FIFTH PROGRESS REPORT

TO

MATERIALS LABORATORY

WRIGHT AIR DEVELOPMENT CENTER

ON

NOTCH SENSITIVITY OF HEAT-RESISTANT ALLOYS

AT ELEVATED TEMPERATURES

by

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SUMMARY

This Fifth Progress Report under Contract No. AF 18(600)-62 covers work performed between June 16 and September 15, 1953 on a program to investigate conditions under which heat-resistant alloys are subject to notch embrittlement at elevated temperatures.

Previous reports have presented relaxation data for S-816 at 1350°F and for Waspaloy at 1500°F. Similar results are given herein for Inconel X-550 at 1350°F in the range of initial stresses between 50,000 and 80,000 psi.

When data for the three alloys studied are compared, it is found that Inconel X-550 at 1350°F has a much higher relaxation strength than do the other two alloys. For example, the estimated time required for the three materials to relax from the 0.2% offset yield stress to the 500-hour rupture strength are:

S-816 at 1350°F	0.1 hr
Waspaloy at 1500°F	2 hr
Inconel X-550 at 1350°F	25 hr

Specimens of S-816 and of Waspaloy have been prepared with an A.S.T.M. grain size larger than zero by critical cold reduction prior to a conventional solution treatment and aging. Smooth-bar tests on specimens in the coarsened condition are in progress.

Other tests on S-816 and Waspaloy are being carried out at 1500°F to study the following metallurgical variables:

a. Deviation from usual temperatures employed for heat treatment of these alloys

b. Extraneous cold working introduced after various

stages of conventional heat treatment.

Data obtained so far are included in this report.

Wherever results of smooth-bar tests indicate marked change from properties found for conventional treatments, notch bars will be prepared and tested.

INTRODUCTION

This report covers work performed between June 16 and September 15, 1953 under Contract No. AF 18(600)-62, Expenditure Order No. R-605-227 SR-3a. The overall program seeks to investigate conditions under which heat-resistant alloys are subject to notch embrittlement at elevated temperatures. Special attention is to be devoted to the role of stress relaxation and to certain metallurgical variables as they affect life of notched bars subjected to axial loading in stress-rupture tests.

Previous progress reports have outlined a possible manner in which reduction, by creep relaxation, of high initial stresses near the root of a notch may be able to account for notch strengthening under favorable conditions, whereas materials with a high relaxation strength may exhibit a short notched-bar rupture life due to the consequent retention of stress concentrations.

Data of other investigators were compiled and discussed in earlier reports. While no general conclusions were drawn from these test results on many alloys under widely-different conditions, notch sensitivity was found frequently to be associated with low ductility in the smooth-bar rupture test. A few isolated test findings indicated that perhps treatments which gave coarse grains promoted notch brittleness. Using these general guides, a program has been initiated to study effects of a limited number of metallurgical treatments. Constant-stress smooth-bar rupture tests are being used for preliminary sorting. At least until some apparently general trend is discovered, notched specimens will be prepared and tested only for those treatments which result in markedly lower ductility or much larger grain size than with conventional prior history and final heat treatment.

Types of Metallurgical Variables to Be Studied in This Program

The chief reson for studying metallurgical variables is to determine whether such variations as are usually encountered in practice are apt to induce notch brittleness. It is assumed that standard alloys, properly processed and heat-treated, and then tested at recommended service temperatures will not be notch brittle. It is presumed that the three alloys under consideration in the present program should not be evaluated for this purpose below 1500°F. Most of the tests will therefore be conducted at 1500°F.

Initial studies on metallurgical variables may be segregated into three categories for convenience:

1. Abnormal response to a standard heat treatment, reflecting effects of past history.
2. Deviations from recommended heat treatments such as might occur by acident or errors in pyrometric control.
3. Cold working and other extraneous treatments not usually included as part of the deliberate conditioning for the alloys under study.

Abnormal Response to Standard Treatment

The most obvious abnormal response to standard treatment is development of unusually large grains during the treatment. Other work at the University of Michigan has indicated that such abnormal grain growth only results from critical deformation. The critical deformation is of the order of 0.5 to 2 per cent and is largely independent of temperature of deformation. In practice such grain growth is frequently encountered in forged blades for jet engines, due to the difficulty of avoiding critical deformation in blades forged to size.

It is also possible that some alloys may have varying notch characteristics depending on hot-working conditions and response to heat treatment, even when the grain size is normal.

Deviations from Standard Heat Treating Conditions

In actual practice, for different reasons, conditions of treatment occasionally deviate from those generally prescribed. Effects of such occurrences on notch properties should be useful information. The experimental program will cover minor variations from prescribed heat treatment conditions, such as heat treatment at temperatures above and below the standard conditions. In addition, it is planned to treat specimens above the grain coarsening temperature to show the maximum effects to be expected.

Extraneous Treatments During or after Standard Heat Treatment

Finished parts may be subjected to additional operations which could influence properties. One such operation would be cold straightening. Cold work normally has a detrimental effect on notch toughness. In some cases, straightening is performed before aging or after partial aging.

Surface-finish effects are reported to have a profound effect on tests with sharp notches. This would seem to be a difficult problem to attack and has not been considered to date.

CURRENT STATUS OF THE INVESTIGATION

Creep and Relaxation Properties

S-815 at 1350°F

All experimental work originally planned has been completed and reported.

Results for two notched-bar tests on S-816 at 1350°F have also been supplied by the other contractor in this program (1). However, data on the change of shape of the notch root on loading notched specimens for a rupture test appear to be desirable before a final correlation with notched-bar data is attempted. Without this latter information, the initial state of stress over the notched section at the start of the test is difficult to estimate.

Waspaloy at 1500°F

Tests now in progress or scheduled for October should complete work needed for present purposes to define smooth-bar rupture properties under both constant and variable stresses. When these data are on hand, all planned tests on smooth bars of Waspaloy with standard heat treatments should be accomplished.

Inconel X-550 at 1350°F

Relaxation properties have been obtained for four stresses. Another scheduled relaxation test with prior overloading should complete the relaxation data needed.

Further smooth-bar rupture tests under constant stress and with variable stress are either running or planned; a short-time tensile test at 1350°F has also been planned for the coming quarter.

Metallurgical Variables Affecting Notch Properties

Abnormal Response to Standard Heat Treatments

It has been found possible to obtain an A.S.T.M. grain size as large as (-1) for both S-816 and Waspaloy by suitable deformations prior to the final solution treatment. To date, only smooth bars of Waspaloy have actually been tested.

Deviations from Standard Heat-Treating Conditions

Specimens of S-816 were prepared using the highest possible solution temperature (2325°F). Smooth bars have been machined for samples with and without aging, and with and without a 13.5 per cent reduction at 1200°F after the solution treatment.

Tests on these bars are in progress at both 1350° and 1500°F. Notched bars will be tested for conditions giving low ductility (5 per cent or less) in these smooth-bar tests.

Waspaloy specimens with solution temperatures ranging from 1925° to 2150°F, followed by standard aging for 4 hours at 1500°F + 16 hours at 1400°F, have been prepared for testing in the coming quarter.

Effects of Extraneous Treatment

After solution treatment of S-816 for 1 hour at 2150°F, water quench, the effect of 10 per cent cold reduction has been studied at 1350°F and scheduled for study at 1500°F.

Waspaloy specimens are in preparation for a program involving combinations of normal or elevated solution temperature, and 5 or 15 per cent cold work, to be performed either after the solution treatment, after the 1550°F stabilizing treatment, or after the completion of aging at 1400°F.

PROPERTIES OF INCONEL X-550 AT 1350°F

Stress Relaxation Properties

Four step-down relaxation tests at 1350°F covered the range of initial stresses between 50,000 and 80,000 psi. In all cases the residual stress had fallen to about 40,000 psi at the end of 100 hours. The specimen started at 80,000 psi had a measurable plastic deformation of about 0.00012 in./in. on loading. For this specimen the initial relaxation rate was quite rapid (approximately 13,000 psi drop in the first 0.1 hour). Test data are shown graphically in Figure 1.

Stress - Rupture Time Data

Smooth-bar rupture tests under constant load gave the following results:

Stress (psi)	Rupture Life (hours)	Elongation (%)[a]	Reduction of Area (%)
80,000	0.84	4.5	7.5
70,000	7.2	4.5	6.5
70,000	4.6	5.	6.
50,000	161.4	1.	3.
35,000	In progress		

[a] Based on a gauge length of 2.1 inches.

TESTS TO DATE ON METALLURGICAL VARIABLES

S-816

Abnormal Response to Standard Heat Treatment

Attempts were first made to obtain as A.S.T.M. grain size larger than zero by cold rolling of the as-received stock before a standard solution + aging schedule. The results assembled in Table I (A) show that little, if any, coarsening took place for the reductions of 1, 2 and 5 per cent investigated. In all three bars the grains were quite near the A.S.T.M. 4-7 range obtained with conventional treatment. Apparently the as-received stock had been deformed past the critical amount before being furnished to us.

The very coarse grain sought was produced, however, by solution treating a number of bars given various amounts of cold reduction after an initial 11.5 per cent reduction from 1200°F + 1 hour at 2150°F, water quench. Data for these specimens are included in Table I (A). In most instances, the grains obtained were of mixed sizes. Grain sizes listed in parentheses appeared in lesser numbers than other values reported.

As yet, no rupture tests have been started for the above treatment.

Deviations from Standard Heat Treatment

Various treatments given a number of specimens and rupture properties measured for these specimens are assembled in Table I (B), together with data for conventional treatments obtained by this laboratory and by Simmons (1). Graphical presentation of these results is included in Figure 2.

When S-816 was solution treated at 2325°F, instead of 2150°F, and then given the usual 12-hour age at 1400°F, there was little change in strength. Ductility was considerably reduced, but still adequate at 1350°F. Omission of the aging treatment for the material with 2325°F solution temperature showed little effect other than reduced ductility in rupture tests at 1350°F. Results at 1500°F are still incomplete.

Specimens solutioned at 2325°F and then reduced 13.5 per cent at 1200°F exhibited strengthening of the order of 10,000 psi in the stress - rupture time test, but at the expense of much-decreased ductility. Aging at 1400°F for 12 hours before testing appeared to enhance strength even more, with some further lowering of ductility. These last effects appear common to test temperatures of both 1350° and 1500°F.

In no specimen examined was the grain size made coarse by the 2325°F treatment alone.

Effects of Extraneous Treatments

Extraneous treatments have been confined to 10 per cent reduction by rolling at room temperature after a standard 1 hour at 2150°F, water quench.

Test findings for 1350°F are listed in Table I (C) and plotted on Figure 2. Cold working between standard solution and aging treatments increased strength, with approximately the same ductility as found with conventional treatments. Failure to age after the cold rolling also raised the strength, but caused the reduction in area at rupture to drop one-fourth its usual high value (14 per cent reduction of area compared with 52 per cent).

Waspaloy

Abnormal Response to Standard Heat Treatment

Results have been reported previously (2) for five bars of Waspaloy which were rolled either 1.5 or 10 per cent at room temperature before a final solution treatment. (Cold rolling followed a preliminary reduction of 45 per cent at 1950°F + solution treatment at 1975°F. This was an effort to eliminate possible residual effects resulting from past treatments of the stock and to provide material of known initial condition.)

These preliminary tests showed somewhat increased strength, lowered ductility and coarser grain for the 1.5 reduction than for the 10 per cent. Still, a grain size coarser than A.S.T.M. 0 had not been achieved.

During the past quarter A.S.T.M. grain size (-1) or larger has been produced in a number of specimens by using critical reducion of 1-1/4 per cent or by multiple reductions of smaller amounts with an intermediate 1-hour solution treatment between cold reductions. Results of all tests made to date are rathered in Table II and are plotted on Figure 3.

All deformations which resulted in grain size of A.S.T.M. +1 or larger upon subsequent treatment of 1975°F showed a rupture strength at 1500°F about 4,000 psi higher than for bars without critical deformation. Reduction in area at rupture was also reduced for the materials in the coarse-grained condition.

DISCUSSION

Comparison of Relaxation and Stress-Rupture Properties for the Alloys with Standard Heat Treatments

The outstanding observation to date about the relaxation data obtained is the much slower rate of Inconel X-550 at 1350°F, than for the other two alloys and temperatures studied.

Comparisons between alloys of relaxation strengths and rupture strengths should be instructive, though it is difficult to formulate a common standard by which to judge the different materials. In any sharp notch loaded to stresses of practical interest, localized yielding may be supposed to occur near the notch root. Of possible significance is the relative magnitude of the estimated time required for a specimen to relax from the 0.2 per cent offset yield strength to, say, the stress at which rupture would occur in 500 hours under steady load. Order-of-magnitude results can be listed as follows:

Alloy and Temp (°F):	S-816 at 1350°F	Waspaloy at 1500°F	Inconel X-550 at 1350°F
Proportional limit, psi	35,000	40-45,000	about 65,000
0.2% offset yield strength	47,500 psi	75,000 psi	more than 90,000 psi
Rupture life at yield point stress, hours	20	0.05	(0.15)
500-hr rupture strength	31,000 psi	21,000 psi	115,000 psi
Time to relax to the latter residual stress starting at the 0.2% yield strength	0.1 hr	2 hr	25 hr

These crude calculations involve questionable extrapolations of data, but they make immediately evident an apparent ability of S-816 to relieve localized stresses through relaxation, probable ability of Waspaloy at 1500°F to do and same thing, and a more questionable status for Inconel X-550 at 1350°F. These qualitative expectations of freedom from notch effects in the first two instances, but with probable notch susceptibility in the last case, are supported by as yet incomplete work of Simmons (1) with smooth and notched bars of these same alloys.

The relaxation data reported herein for Inconel X-550 at 1350°F do have at least one feature in common with results for S-816 at 1350°F (3) and for Waspaloy at 1500°F (4) presented earlier. In all three instances, loading to stresses above the proportional limit appears to accelerate the relaxation process so that, after like time periods, specimens loaded to high initial stresses quickly attain residual stresses below those for specimens started at lower stresses. For the highest stresses, a step-down type of relaxation test involves experimental difficulties which may introduce considerable error at very short times. Despite this, the observed effects of increased relaxation rate by prior plastic strains do appear to be real. The very least one can infer from the total data collected is that small plastic strains do not seem to retard the relaxation of high stresses for the alloys and conditions under test.

If this observation is assumed to remain valid for the higher localized strains expected to be present in a notched tensile bar, the actual relaxation pattern for a fiber in a notched bar should be capable of sufficiently close approximation using data of the type now on hand.

Metallurgical Variables

Abnormal Response to Standard Heat Treatment

Failure to obtain grain coarsening in S-816 after small cold reductions prior to the 2150°F solution treatment indicates residual strains in the stock as recieved were probably already uniformly above the critical value. The 11.5 per cent reduction at 1200°F + 2150°F, 1 hour, water quench conditioning used at this laboratory for all later speci mens was considered desirable to insure uniform properties before critical rolling was attempted. Probably the one hour at 2150°F alone would have been sufficient to remove any residual strains from production steps.

The reason for occurrence of very fine (A. S. T. M. 6-9) grain over the entire center of specimen S-52 with 1/2 per cent cold reduction before final solution treatment is not understood.

When the prior history of Waspaloy was such as the cause +1 to -1 A. S. T. M. grain size on final solution treatment at 1975°F, the rupture strength was raised about 8,000 to 10,000 psi above that for bars with normal (4-5) grain size. Of more probable significance is the observed lowering of the ductility (3 to 7.5 per cent reduction of area compared with 10 to 16 per cent obtained for the usual grain size). The data of Simmons (1) for 1350°F suggest that Waspaloy with reduction of area at rupture of 5 to 7 per cent might be expected to show at least borderline tendencies to be notch brittle. This point should be checked with notched bars to ascertain whether the same heat of this alloy may actually be either notch brittle or notch ductile for identical final treatments and notches.

The small reductions involved in obtaining critical deformations are difficult to obtain with accuracy. Before notched bars were made it appeared advisable to determine how critical the exact amount of rolling is if the same final grain size is obtained. This is the reason for an otherwise apparent duplication of tests at 35,000 psi (test specimens W-140, 142, 143 and 146). For all four bars the grain sizes, rupture lives and ductility properties demonstrate very satisfactory agreement, despite considerable relative deviations in the extent of the last cold rolling before the final solution treatment. From this it is tentatively assume that any amount of cold reduction in the range 1.0 to 1.5 per cent which gives A.S.T.M. grain size of zero or larger should be satisfactory for use in notched bars to compare with smooth-bar behavior in the coarsened condition.

Two tests for Waspaloy with 10 per cent reduction prior to solution indicate rather small, but definite, increase in strength and probable slight drop in ductility. Large amounts of cold work in the material before conventional treatment, such as might be induced by low forging temperatures, may have adverse effects on notch properties if the ductility was further reduced. This possibly warrants further study.

Effects of Deviation from Standard Heat-Treating Conditions and of Extraneous Cold Rolling

A solution temperature 175°F above the normal value of 2150°F. and very near the melting range of S-816, did not appear to have any real effect on the resultant grain size. Effects on rupture strength and ductility were also small. Failure to age the alloy after solution treating at 2325°F did reduce ductility, but not to a very low value (the reduction of area for a 35,000 psi tests was still 20.5 per cent).

However, the temperature of solution does have quite a marked effect on the resulting ductility when a specimen is cold worked following the solution step. The high-temperature solution plus 10-15 per cent cold working results in significantly higher strength and lowered ductility, both with or without subsequent aging at 1400°F. In contrast, S-816 with conventional 2150°F solution treatment plus 10 per cent cold work and then 12 hours of aging at 1400°F still retains its high ductility for strengths somewhat above those for the material not cold worked.

Aging conditions appear to be of considerable importance in determining ductility of S-816 cold worked after solution treatment at 2150°F. Unaged, the alloy had only 13.5 per cent reduction of area for the same stress at which the reduction of area was 50 per cent after aging 12 hours at 1400°F. Perhaps shorter aging times ought to be investigated because commercial practice now uses shorter time periods.

The planned program with Waspaloy for studying effects of deviations in heat treating conditions has been limited initially to variation of solution temperature. (Data of Thielemann on results of varying aging time and temperature after 4 hours solution at 1975°F have already been reported on by Simmons and Cross (5). Initial tests will seek to determine a solution temperature at which excess grain growth begins. If the resultant material has low enough ductility with standard aging conditions to indicate possible notch embrittlement, the tests can be extended to include variable aging conditions.

Changes in rupture properties brought about by cold working after solution treatment have been adoped for rather complete investigation because the effects of cold work on notch properties are expected to be large. It appears that a minimum program must include at least the following test variables:

1. Two degrees of cold working. Tentatively values of 5 per cent and 15 per cent reductions at room temperature are under consideration.

2. Place in the heat-treating schedule where the cold work occurs:

a. After solution and before any aging operations.

b. Between the 1550°F and 1400°F agings.

c. After all aging operations have been completed.

This program is subject to modification as results are obtained. Notched bars are planned for testing only when a given treatment results in a marked change in grain size, rupture strength, or ductility at rupture from values for conventional treatments.

Inconel X-550

At present no work on effects of metallurgical variables or notched-bar tests with Inconel X-550 are contemplated. Since Waspaloy and Inconel X-550 are metallurgically similar, a rather complete program on one of these alloys should be of greater value than a more spotty coverage of both materials.

FUTURE EXPERIMENTAL WORK

Properties of Inconel X-550 at 1350°F

Past work has shown the possibility that for S-816 at 1350°F and Waspaloy at 1500°F. one can express the total life of a bar under variable-stress conditions as the sum of fractions:

$$\frac{\text{actual time at any given stress}}{\text{rupture life at that stress}}$$

Any dependence on ductility at rupture was masked for the above alloys by a nearly constant reduction of area for all stresses in the range tested. Data gathered so far for Inconel X-550 at 1350°F indicate a probable variation of at least two-fold in reduction of area between high-stress and low-stress tests. Multi-stress rupture tests with this alloy are planned for the coming quarter to determine whether the simple rule formulated previously must be modified for the changes in ductility with time for Inconel X-550.

Other tests to be completed for this alloy at 1350°F include a short-time tensile test, a long-time constant-stress creep test to rupture, and relaxation after prior plastic straining.

Metallurgical Variables

In the coming quarter it is hoped to obtain smooth-bar results at 1500°F for both S-816 and Waspaloy covering effects of abnormal grain growth, various solution temperatures and extraneous cold working. Notched bars are to be tested where notch sensitivity may reasonably be expected.

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TABLE I

Results of Tests on Metallurgical Variables for S-816 Alloy

A. Abnormal Response of S-816 to Standard Treatment (2150°F, 1 hr, water quench + 1400°F, 12 hrs, air cool)

Spec. No.	History Prior to Final Heat Treatment: Conditioning Treatment	History Prior to Final Heat Treatment: Cold Reductions and Intermediate Solution Treatments	A.S.T.M. Grain Size		Test Results Obtained
S-44	None (as received)	2 per cent cold reduction	3 to 6		Not to be tested--preliminary grain size studies
S-45	None (as received)	1 per cent cold reduction	4 to 6, (7)		
S-46	None (as received)	5 per cent cold reduction	5 to 7 (some as large as 3)		
			Center of Bar	Outer Rim	
S-48	Red. 11.5% at 1200°F + 2150°F, 1 hr, water	2% C.R. + 2150°F, 1 hr, water + 1% C.R.	0 to 2, 3 to 4		This series not yet tested.
S-49	Same as S-48	2 per cent cold roll	-1 to 2	3 to 5	
S-47	Same as S-48	1 per cent cold roll	-1 to 1 (stringer 6 to 9)	2 to 4	
S-50	Same as S-48	1% C.R. + 2150°F, 1 hr, water + 1/2% C.R.	-1 to 1	(2 to 3)	
S-52	Same as S-48	1/2 per cent cold roll	6 to 9	-1 to 3	

TABLE I, Continued

B. Effects of Deviations from Standard Heat Treatment

Spec. No.	Heat Treatment Used: Solution Treatment	Heat Treatment Used: Rolling	Heat Treatment Used: Aging	A. S. T. M. Grain Size	Test Results Obtained: Temp (°F)	Test Results Obtained: Stress (psi)	Test Results Obtained: Life (hrs)	Test Results Obtained: Reduction of Area(%)	Ref. No.
S-10	2150°F, 1 hr, water	---	1400°F, 12hrs, air		1350	65,000	1.2	39.5	
S-17	"		"		1350	55,000	4.25	49.5	
S-13	"		"	5-7, (4)	1350	45,000	25.2(±.8)	58.	
S-20	"		"		1350	40,000	73.3(±2)	54.	
S-9	"		"		1350	35,000	180.6	51.5	
B-S-37	"		"		1350	35,000	177.5	55.5	
S-1	2150°F, 1 hr, water	---	1400°F, 12 hrs, air		1350	45,000	44.0	53.8	1
S-6	"		"		1350	40,000	96.0	51.2	1
S-9	"		"		1350	34,000	260.1	57.1	1
S-12	"		"		1350	28,000	958.7	53.0	1
S-2	2150°F, 1 hr, water	---	1400°F, 12 hrs, air		1500	30,000	20.4	51.8	1
S-4	"		"		1500	25,000	63.8	58.5	1
S-9	"		"		1500	20,000	342.8	55.7	1
S-11	"		"		1500	17,000	1014.4	45.4	1
S-30	2325°F, 1 hr, water	---	1400°F, 12 hrs, air	4-7, (3)	1350	35,000	317.5	38.5	
S-31	"		"		1500	25,000	scheduled		
S-33	2325°F, 1 hr, water	---	---	4-6, (3)	1350	35,000	308.0	20.5	
S-34	"				1500	25,000	scheduled		
S-29	2325°F, 1 hr, water +	13.5%, 1200°F	---	4-6	1350	35,000	1188.9	17.	
S-27	"	"			1500	20,000	In progress		
S-25	2325°F, 1 hr, water +	13.5% Red., 1200°F	+ 1400°F, 12 hrs, air	4-7	1350	45,000	476	13.5	
S-24	"	"	"		1350	35,000	[a]2477.7+	--	
S-26	"	"	"		1500	30,000	204.1	5.	
S-28	"	"	"		1500	40,000	scheduled		

[a] Test discontinued.

TABLE I, Continued

C. Effect on S-816 of 10 Per Cent Cold Reduction after a 2150°F Solution Treatment

Spec. No.	Heat Treatment Used: Solution Treatment	Heat Treatment Used: Rolling	Heat Treatment Used: Aging	A. S. T. M. Grain Size	Test Results Obtained: Temp (°F)	Test Results Obtained: Stress (psi)	Test Results Obtained: Life (hrs)	Test Results Obtained: Reduction of Area(%)
S-38	2150°F, 1 hr, water	+ 10% Red., 75°F	+ 1400°F, 12 hrs, air	5-8, (4)	1350	45,000	105.2	50.
S-39	"	"	"		1500	25,000	scheduled	
S-41	2150°F, 1 hr, water	+ 10% Red., 75°F	---	5-7, (4)	1350	45,000	75.4	13.5
S-42	"	"			1500	25,000	scheduled	

TABLE II

Abnormal Response of Waspaloy to Standard Treatment after Cold Reduction

Spec. No.	History Prior to Final Heat Treatment: Conditioning Treatment	History Prior to Final Heat Treatment: Cold Reductions and Intermediate Solutions	A. S. T. M. Grain Size	Test Results Obtained: Temp (°F)	Test Results Obtained: Stress (psi)	Test Results Obtained: Life (hrs)	Test Results Obtained: Reduction of Area(%)	Ref. No.
W102	Red. 45%, 1950°F, air, + 1975°F, 4 hrs, air	10%	(3), 4-5, (6)	1500	25,000	260.5	9.	
W117	"	10%	"	1500	30,000	88.9	8.	
W112	"	1.5%	1-3, (4)	1500	20,000	1203.3	7.	
W113	"	1.5%	(1), 2-3, (4)	1500	30,000	132.6	7.	
W114	"	1.5%	(0), 1-2, (3-5)	1500	25,000	479.1	7.5	
W127	Red. 45%, in 4 rolls from 1950°F, air + 1975°F, 1 hr, air	1-1/4%	-1 to 1, (2-4)	1500	25,000	509.1	6.5	
W128	"	1-1/4%	-1 to 1, (2-4)	1500	35,000	61.7	5.	
W129	"	1-1/4%	-1 to 1, (2-4)	1500	45,000	6.7	3.	
W140	"	1% Red. + 1975°F, 1hr + 1.2% Red.		1500	35,000	47.8	7.5	
W141	"	1% Red. + 1975°F, 1hr + 1% Red.	-1 to 2, (3-4)	1500	25,000	528.5	6.5	
W142	"	1% Red. + 1975°F, 1hr + 1% Red.	-1 to 1, (2-4)	1500	35,000	54.4	7.5	
W143	"	1.5% Red. + 1975°F, 1hr + 1.2% Red.	-1 to 1, (3-6)	1500	35,000	52.8	5.5	
W146	"	1.3% Red. + 1975°F, 1hr + 1% Red.	-1 to 1, (2-4)	1500	35,000	48.2	4.	
W171	None (as received	---		1500	70,000	0.13	9.5	
W157	"			1500	60,000	0.5	10.5	
W175	"			1500	50,000	2.4	11.5	
W163	"			1500	40,000	10.15	9.5	
W162	"			1500	30,000	65.5	--	
W174	"			1500	23,000	292.1	12.	
W161	"			1500	20,000	498.9	13.	
W170	"			1500	17,000	In progress		
W-6	"			1500	35,000	17.2	15.7	1
W-8	"			1500	25,000	184.3	12.2	1
W-13	"			1500	20,000	307.6	9.8	1

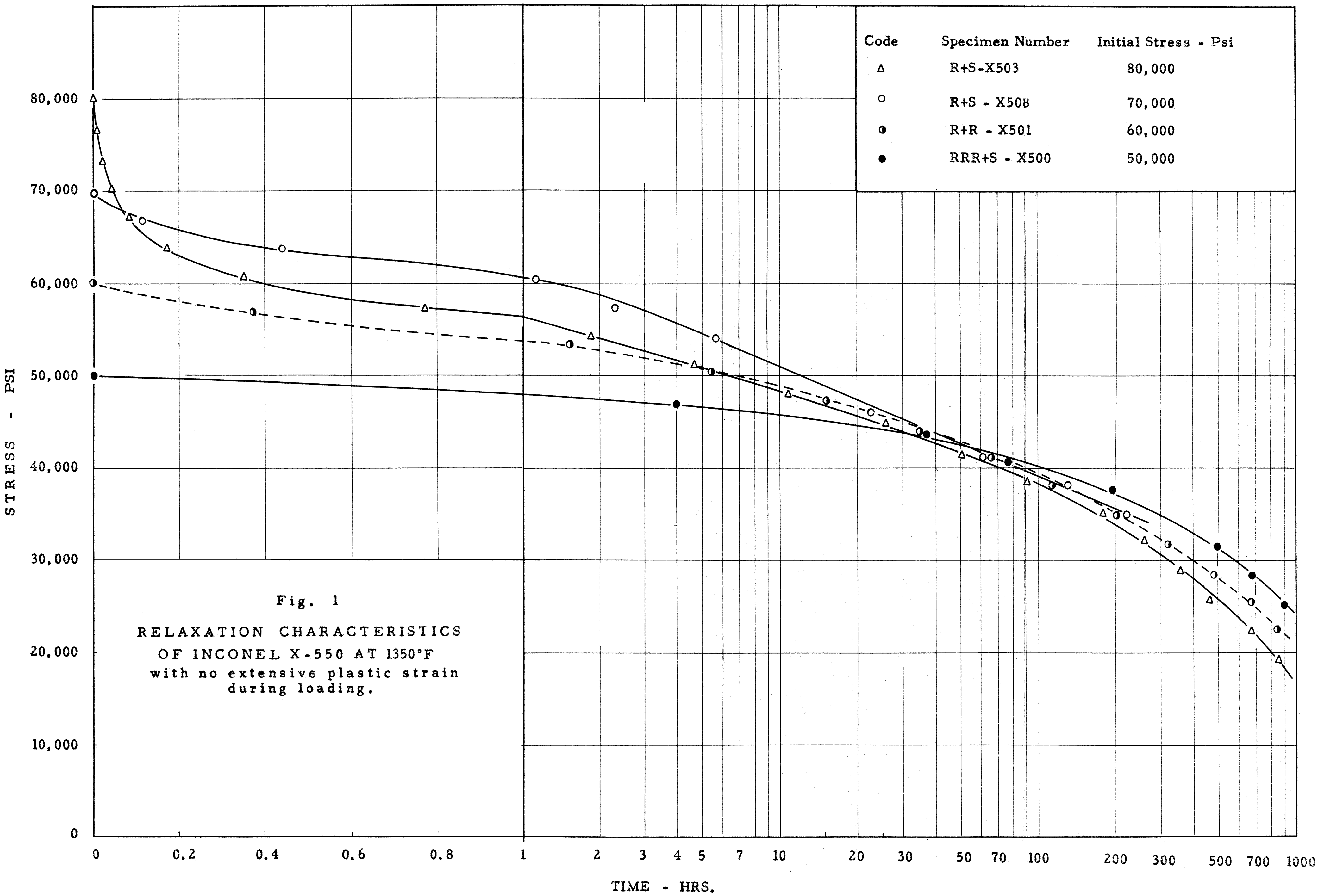

Fig. 1

RELAXATION CHARACTERISTICS OF INCONEL X-550 AT 1350°F with no extensive plastic strain during loading.

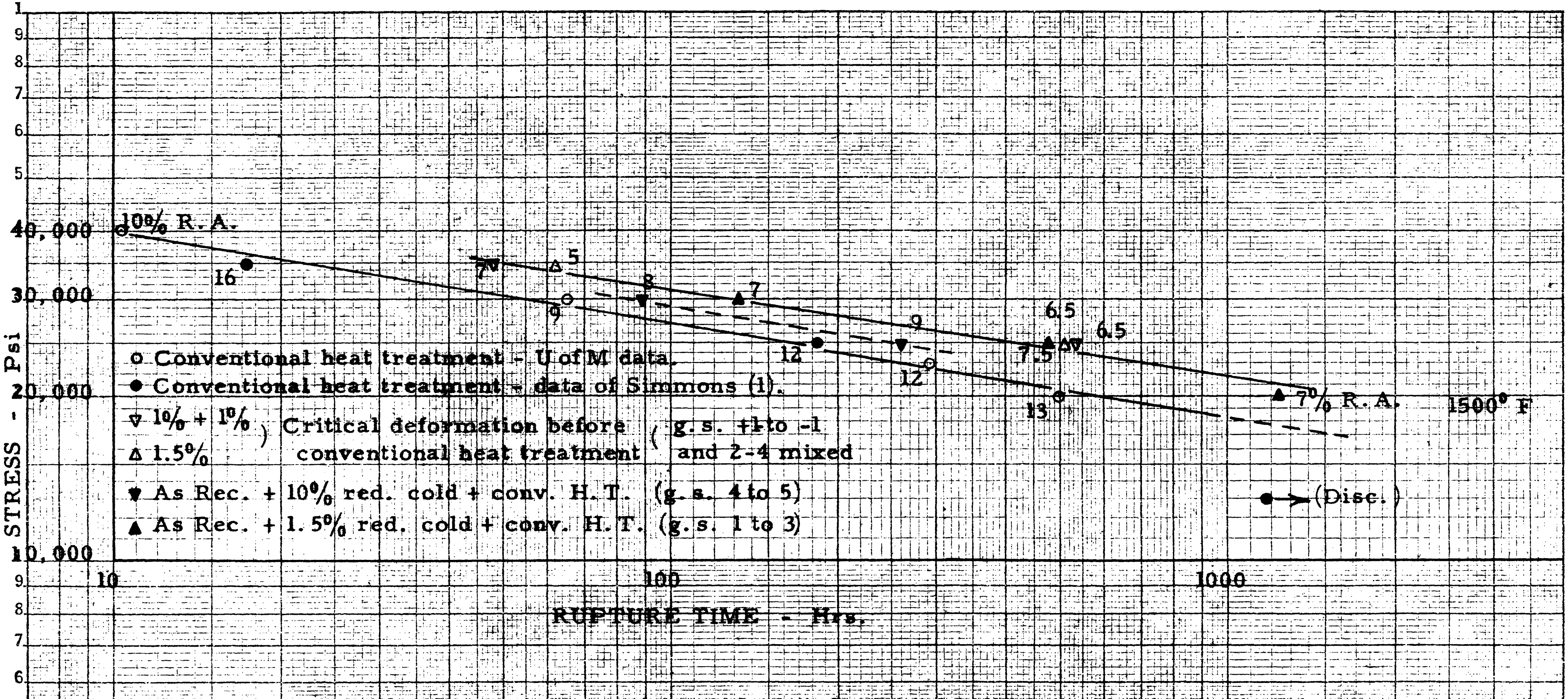

Fig. 3 - TESTS OF SOME METALLURGICAL VARIABLES OF WASPALOY AT 1500° F.
(Numbers adjacent to test points give reduction of area at rupture in per cent).

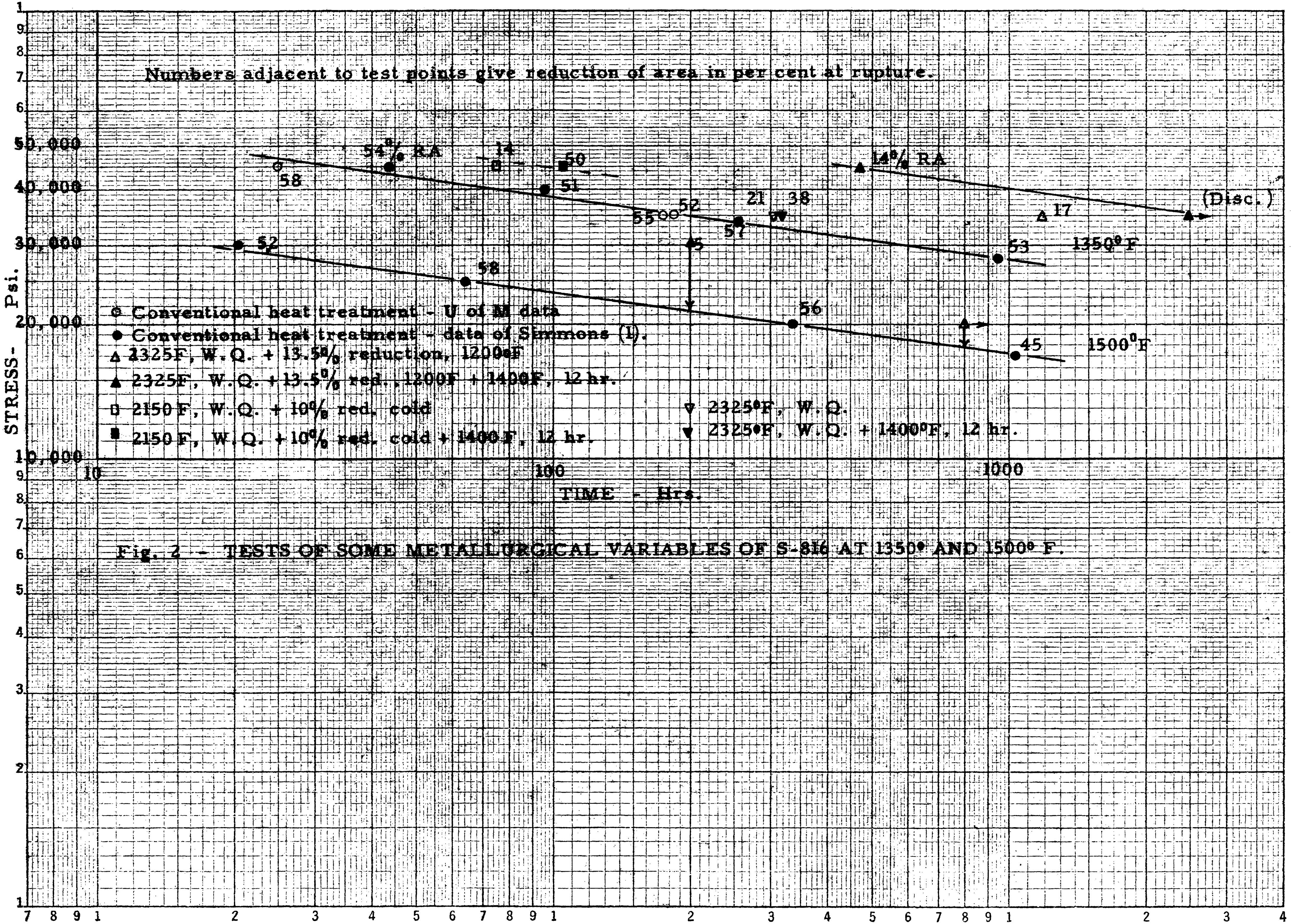

Fig. 2 - TESTS OF SOME METALLURGICAL VARIABLES OF S-816 AT 1350° AND 1500° F.