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SECOND PROGRESS REPORT

TO

MATERIALS LABORATORY

WRIGHT AIR DEVELOPMENT CENTER

ON

NOTCH SENSITIVITY OF STRUCTURAL ALLOYS

by

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NOTCH SENSITIVITY OF STRUCTURAL ALLOYS

SUMMARY

This investigation under Air Force Contract No. AF 33(616)-3380 is an extension of previous work relating notch sensitivity at elevated temperature to creep-rupture characteristics and other common properties.

During the period ending 15 June 1956 additional smooth-bar tests were started to complete establishment of creep properties for desired stress ranges at 600°, 800°, and 900°F.

A-286, alloy stock for this program has been received and survey tests are in progress to help select suitable heat treatments for extensive studies on the factors influencing notch sensitivity.

The investigation, started under the prior program, on reported variable notch response of Waspaloy with different heat treatments is being carried forward with small amounts of material from two additional heats.

INTRODUCTION

This report covers progress made under Air Force Contract No. AF 33(616)-3380 during the period from 1 April to 15 June 1956. This investigation seeks to extend concepts developed under Contract AF18(600)-62, relating notch sensitivity at elevated temperature to creep-rupture characteristics and other smooth-bar properties commonly available (See Ref. 1). In addition, efforts are being made to clarify questions left unanswered by the past research. Experiments started during the period reported here include tests on two such problems:

1. "Abnormal" and/or variable response of some lots of commercial alloys to the presence of a notch.

2. Effects of the appearance of a notch after an alloy has already been subjected to creep history.

As a part of the current program, notch rupture properties are to be determined for A-286 alloy at temperatures up to 1200°F and for a precipitation-hardened stainless sheet material (Armco 17-7PH) for a range of potential service conditions.

CURRENT STATUS OF THE INVESTIGATION

Tests now completed or else in progress should provide adequate basic data on creep and rupture properties of 17-7PH sheet in the TH 1050 condition at 600°, 800°, and 900°F. The first lot of notched specimens for this material are in preparation, for use in a survey of notch behavior at these same temperatures.

Sufficient A-286 bar stock for this present program has been received. A limited number of specimens have been heat treated using various solution temperatures between 1650° and 2100°F (1 hr., O. Q.), followed by a common aging treatment for 16 hours at 1325°F. Metallographic examination and preliminary creep-rupture tests are now under way to help choose final conditions of heat treatment to give a range of properties which might result in variable notch behavior.

Tests are in progress or scheduled for smooth and notched specimens from limited amounts of Waspaloy located by the Allegheny-Ludlum Steel Corporation from two different heats which appear to exhibit notch behavior similar to that of Heat 63,613 investigated under the prior program (Ref. 1). For the latter lot of material, notched specimens without an intermediate 1550°F age had shorter rupture life than did similar specimens given the complete conventional heat treatment. This difference in behavior seemed to be associated with plastic strains which occur near the notch root when a load is applied. This factor is among those being investigated for the two new lots of Waspaloy now in the program.

EXPERIMENTAL RESULTS

17-7PH

Some rupture data for 17-7PH (TH 1050) strip specimens were presented on page 4 of the First Progress Report, dated March 15, 1956. (See Ref. 2). The following additional data are now available:

ADDITIONAL RUPTURE TEST DATA FOR 17-7PH (TH 1050) STRIP SPECIMENS

Specimen No.	Temperature (Deg. F)	Stress (psi)	Rupture Life (hours)	Elongation (%)	Reduction of Area (%)
1C-T3	600	170,000	11.9	7.	15.
1L-T6	600	165,000	98.8	12	20.5
1C-T5	600	160,000	661.2	16.5	26
2E-T1	600	150,000	1676+	(In progress)	
2E-T5	600	125,000	1533+	(In progress)	
1G-T5	800	105,000	37.3	22	37
3A-T6	800	100,000	60.9	43.5	44
1C-T4	800	95,000	179.1	26	36.5
1U-T4	800	90,000	555.6	37.5	48.5
1Q-T25	800	70,000	1100+	(In progress)	
1G-T2	900	50,000	694.1	40	49.5

A-286

A total of 135 feet of 3/4-inch diameter A-286 stock was donated by Allegheny-Ludlum from their vacuum "Consutrode" Heat No. 21030. The chemical analysis was supplied by the producer:

C	Mn	Si	Cr	Ni	Mo	Ti	V	Al	S	P	Fe
0.06	1.35	0.47	14.58	25.30	1.38	2.00	0.21	0.17	0.014	0.018	Bal

The bars were processed by the supplier from a 20-inch round ingot in the following manner:

1. Pressed and cogged to 4-1/4 inch square from 2150°F,
2. Recogged to 2-7/8 inch square from 2100°F,
3. Rolled to 3/4 inch diameter round from 2100°F.

The stock was shipped as rolled and was neither straightened nor annealed prior to receipt by the University of Michigan. This procedure was followed in order to minimize the possibility of non-uniform response during heat treatment as a result of variable strains from point to point which can occur during cold straightening.

At this time the only results available are for five creep-rupture tests, all conducted at 1200°F with 65,000 psi stress:

Solution Temp., °F	Rupture Life (hours)	Elongation (%)	Reduction of Area, %	Grain Size ASTM No.
1650	23.8	13	18	Uniform, 8 and finer
1800	62.4	5.5	10.5	Non-uniform, mixed 8 and finer with 3 to 5
1900	112.2	5	6.5	Mixed, mostly 4 to 8 with some 1 to 3
2000	198.2	4	7.5	Rather uniform, mixed 3 to 7
2100	118.2	4	7	Rather uniform, mixed 1 to 4

The heat treatment in each case was a one-hour solution at the indicated temperature, oil quench, followed by 16 hours aging at 1325°F, air cool. Results are in the direction expected, with longer rupture life and lower ductilities as the solution temperature is increased.

Waspaloy

Small amounts of Waspaloy from two different heats have been supplied by Allegheny-Ludlum for use in the continuing study into reported variable notch response of this material according to the heat treatment employed. These two lots of material, not reported in previous studies, had the following compositions:

	Heat 63559	Heat 63561
C	0.06	0.03
Mn	0.74	0.64
Si	0.49	0.56
Cr	19.13	20.12
Ni	Bal	Bal
Co	13.29	14.10
Mo	2.89	3.06
Ti	2.30	2.21
Al	1.50	1.34
Fe	0.97	0.96
S	0.014	0.019
P	0.016	0.015
Cu	0.15	0.16

The Heat 63,559 material was hot rolled bar with 1-3/4 inch diameter. Specimens were prepared from wedges obtained by splitting the stock lengthwise into six equal segments. Specimens from Heat 63561 were machined directly from suitable lengths of the 7/8 inch diameter bar supplied. In each case test samples were given the appropriate heat treatment before machining took place.

For each heat of material, some specimens received the conventional heat treatment:

1975°F, 4 hours, air cool +

1550°F, 4 hours, air cool +

1400°F, 16 hours, air cool

Another group of specimens had the same treatment less the intermediate age at 1550°F.

Fifteen tests have been completed for Heat 63559, giving the results listed in Table 1 and shown graphically on Figure 1. In contrast to comparable results found for Heat 63613, smooth specimens of Heat 63559 with conventional heat treatment appear to have consistently higher rupture strength than when the intermediate 1550°F age is omitted. Other results for the two heat agree; namely, that initial plastic strains of about 1% introduced by momentary overloading at test temperature greatly lower smooth-bar rupture life and notched bars at the higher nominal stresses studied are severely notch weakened while at lower nominal stresses notch strengthening is indicated. As was noted in earlier reports, transition from notch weakening to notch strengthening occurs about at a nominal stress which corresponds to yielding near the notch root.

2024-T4 Aluminum Alloy

In the final report under the preceding contract (Ref. 1) experimental rupture lives at 400°F for notched specimens of 2024-T4 alloy consistently exceeded calculated lives predicted from smooth-bar data, assuming life fractions are strictly additive in a variable-stress test. A factor mentioned as a possible partial explanation of this discrepancy was the known change in volume accompanying the continuing overaging of the alloy at the test temperature. If the specimen contraction from the volume decrease was significant relative to the creep elongation, the predicted rate of stress redistribution by creep would be lower than actual.

A single specimen with uniform diameter of 0.400 inch was heated to 400°F in a thermal expansion test unit and held at that temperature. The total contraction over the four-inch length was only about 0.0012 inch, with most of this change occurring during the first fifteen hours. The indicated rate of dimensional change from this source is so small compared with the primary creep rates measured for stresses of interest that no further consideration of this factor seems necessary for this program.

DISCUSSION OF WASPALOY RESULTS

Data presented here for the latest lot of Waspaloy indicate that omission of the 1550°F age lowered the inherent strength of smooth specimens even in the absence of plastic prestrains. Results found in 1955 for Waspaloy Heat 63613 suggested that the rupture properties with zero plastic prestrain were the same for both heat treatments and that only the different response to initial strains caused the noted difference in notch strength.

As was true for Heat 63613, the material from Heat 63559 had a sufficiently lower yield strength when the 1550°F age was omitted that the extent of prestrain for the same overload stress differed for the two treatments under study. As a consequence data obtained so far on effects of prestrain are not completely comparable for the two heat treatments.

The relative importance of differences in inherent strength and of the varying response to initial plastic strains might be clarified by forthcoming tests with the third lot of Waspaloy (Heat 63561) and with the A-286 alloy. It appears best to hold the meager number of remaining specimens from Waspaloy Heats 63613 and 63559 until the most informative experiments can be decided upon.

The question arises whether the observed apparent lowering of notch strength from omission of the 1550°F age is general for all lots of Waspaloy, or whether for some compositions or prior histories omission of the intermediate age might give the higher inherent strength and/or the lesser susceptibility to damage from plastic strains for these two treatments under study.

FUTURE WORK

Initial emphasis for the coming quarter is to center on final selection of heat treatments to give the type of data desired with the A-286 stock on hand. As soon as notch behavior has been established for the conditions decided on, efforts will be made to explain these notch results in terms of smooth bar properties.

When the tests in progress on smooth bars of 17-7PH sheet specimens are completed, experimental work is to shift to notch tests, with notches introduced both prior to any testing and after prior creep exposure.

Research on Waspaloy is to continue along the lines now being pursued, to the extent that material is available.

BIBLIOGRAPHY

1. Voorhees, H. R. and Freeman, J. W., Notch Sensitivity of Heat-Resistant Alloys at Elevated Temperatures; Part 3: Final Data and Correlations. Preliminary Copy of WADC Technical Report 54-175 (Pt. 3). To be issued July 1956 as University of Michigan Engineering Research Institute Report No. 2024-10-F.

2. Voorhees, H. R., and Freeman, J. W., First Progress Report to Materials Laboratory, Wright Air Development Center on Notch Sensitivity of Structural Alloys, University of Michigan Engineering Research Institute, Report No. 2475-1-P, March 15, 1956.

TABLE 1

RUPTURE TESTS AT 1350°F FOR SMOOTH AND NOTCHED BARS OF WASPALOY HEAT 63559

Spec. No.	Stress psi	Rupture Life (hours)	Elongation %	Reduction of Area %	Remarks
			Smooth Specimens, Conventional H. T.		
S-W3	70,000	4.55	1	5	
S-W5	50,000	90.9	1.5	3.5	
S-W1	40,000	832.8	1.5	3.5	
OS-W9	50,360	14.4	1.5	4	0.725% Plastic Prestrain at Test Temp.
OS-W7	50,250	26.9	1.5	3.5	0.515% " " " "
			Notched Specimens, Conventional H. T.		
N-W13	45,000	16.9	--	--	$K_t = 2.4$
N-W17	40,000	792.1	--	--	$K_t = 2.4$
N-W15	35,000	115.5	--	--	$K_t = 2.4$
			Smooth Specimens, 1550°F Age Omitted		
S-W4	70,000	0.95	1	5.5	
S-W6	50,000	19.2	2	2.5	
S-W2	40,000	308.1+	(Discontinued due to controller failure)		
OS-W8	50,650	1.5	2	3.5	1.23% Plastic Prestrain at Test Temp.
			Notched Specimens, 1550°F Age Omitted		
N-W14	45,000	0.45	--	--	$K_t = 2.4$
N-W18	40,000	663.4	--	--	$K_t = 2.4$
N-W16	35,000	2283.2	--	--	$K_t = 2.4$

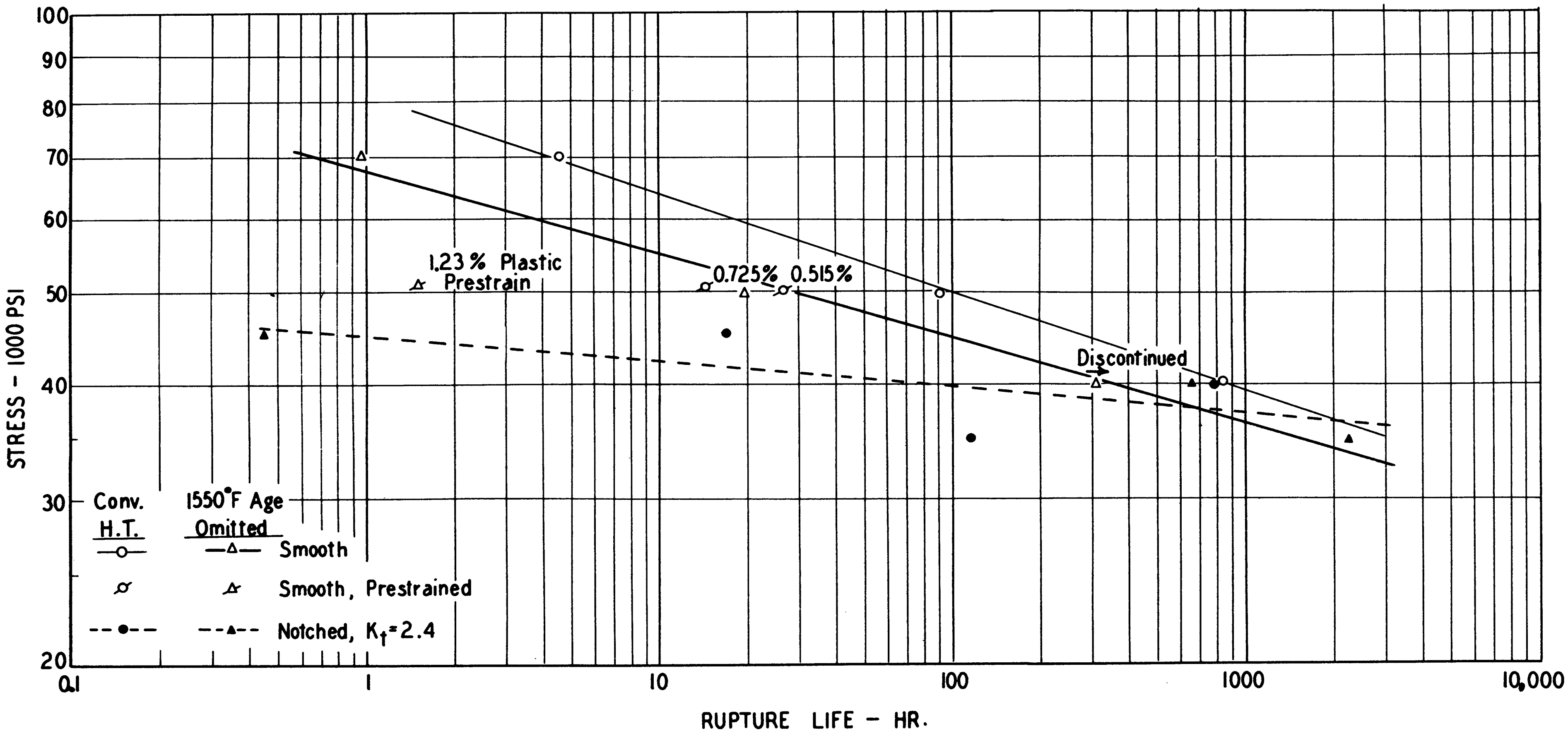

FIG. 1 — RUPTURE PROPERTIES AT 1350°F FOR WASPALOY HEAT 63,559.