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TO

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WRIGHT AIR DEVELOPMENT CENTER

ON

NOTCH SENSITIVITY OF AIRCRAFT STRUCTURAL ALLOYS

by

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NOTCH SENSITIVITY OF AIRCRAFT STRUCTURAL ALLOYS

SUMMARY

The current investigation under Contract AF 33(616)-3380 is an extension of prior research into notch sensitivity of aircraft materials, performed for the Materials Laboratory, WADC under another contract. The prior studies yielded an analysis of stress changes in representative fibers of a notched specimen held at elevated temperature under fixed axial load, permitting correlation of notched-bar rupture life with properties obtained in smooth-bar creep and rupture tests. The present work seeks to generalize this specific analysis to form an engineering method of design of aircraft structures subjected to creep under the action of variable multiaxial stresses.

Tests have started on one material (Armco 17-7PH sheet in the TH 1050 condition). A stock of another alloy (wrought A-286) should be received during April. Preliminary tests on both materials are expected to be completed during the coming quarter.

A major effort is planned to devise ways to study the factors influencing creep-rupture life of ductile materials after exposure to variable stresses of complex pattern.

INTRODUCTION

This report covers progress made between 1 January and 31 March 1956 on Task No. 73605 under Air Force Contract No. AF 33(616)-3380.

The current investigation is designed to extend concepts developed previously under Contract AF 18(600)-62. In that research (Ref. 1) stress-rupture life characteristics were determined for notched and unnotched specimens of six alloys ranging in type from heat-resistant turbine-blade alloys to an age-hardenable aluminum alloy. Creep, relaxation and tensile stress-strain properties were also obtained for the several alloys, using smooth specimens.

A method was proposed to analyze the stress changes which occur in representative fibers of a notched specimen held at elevated temperature under fixed axial load. Based on rupture results for smooth specimens with discrete changes in the applied stress during the test, calculation methods were devised to correlate rupture life of notched specimens with properties obtained in conventional smooth-bar creep and rupture tests. It is now sought to generalize this specific analysis and to find a method of predicting effects of two- and three-dimensional stress conditions upon service life of aircraft structures subjected to creep conditions.

The past research program demonstrated need for a clearer understanding of the fracture of ductile materials after exposure to creep under variable and/or complex stresses. Before general design methods can be established, it appears necessary to determine:

(1) the combination of principal stresses controlling stress rupture under a steady pattern of complex stress. Of initial interest is the relative significance of the largest principal stress and the shear stress invariant to rupture characteristics under multiaxial stressing.

(2) the basic factors which determine when a ductile metal will fracture under variable creep stress of simple nature. Considerations will include the accu-

mulated strain and accumulated deformation energy before rupture.

Should satisfactory answers be found for these separate questions, an attempt will be made to combine the results to allow for simultaneous complex pattern and variable level of the applied stresses.

Additional work has been specified to clarify past investigations into causes for "abnormal" notch weakening for some heats of commercial alloys and to ascertain the influence of prior processing history on such behavior. The analysis developed previously will be checked against experimental observations for these abnormal heats of alloy, as well as against test results for materials notched after subjection to prior creep or for notched bars tested under cyclic loading.

Test materials for the current research are to include A-286 alloy at temperatures up to 1200°F and Armco 17-7PH alloy up to 900°F. The former alloy was selected with a view to testing a material in which a range of mechanical properties can be obtained by varying the heat treatment employed. The 17-7PH was chosen as an iron-base sheet material with wide potential use in aircraft-type structures. Initial research on the latter alloy will be on material in the TH 1050 condition, but a second heat treatment may be found desirable for use in later work.

CURRENT STATUS OF THE INVESTIGATION

The same lot of 17-7PH sheet material is to be used for the present program and for another investigation under Contract AF 33(616)-3368. The latter research calls for determining changes in short-time mechanical properties after prior exposure to creep conditions.

The 17-7PH stock was received at the University of Michigan on March 6, 1956. Strip specimens were cut from three of the sixteen sheets supplied for preliminary tests on scatter in properties for material taken from different portions of the sheet. All initial studies will use samples oriented transverse to the direc-

tion of rolling of the sheets. Twelve creep rupture tests have been completed and four more are in progress. These tests were all for material given the TH 1050 heat treatment.

Allegheny-Ludlum Steel Corporation has agreed to donate sufficient A-286 stock for the research on that alloy. This material is expected to be delivered some time in April.

A short length of 1-3/4 inch diameter bar has also been supplied by Allegheny-Ludlum from a second heat of Waspaloy which appears to exhibit different notch behavior according to whether an intermediate 1550°F age was included or omitted, similar to the material from Heat 63613 investigated in 1955. Tests are in progress to learn whether the different notch behaviors for the two treatments are associated with differences in creep and rupture strengths or are caused by unequal response of the two conditions to initial plastic strains which occur near the notch root when the load is applied. These tests should be completed in the next quarter, so that the results can be used to guide more extensive research planned for the similar-type alloy, A-286.

EXPERIMENTAL RESULTS

Some data are available for the Armco 17-7PH (TH 1050) sheet. This material was supplied from Heat 55651 as annealed sheets 36 x 120 x 0.063 inches, with a 2D finish. Chemical analysis was certified by the supplier to be as follows:

C	Mn	P	S	Si	Cr	Ni	Al
0.072	0.55	0.018	0.011	0.33	17.03	7.25	1.28

Specimens were heat treated in air for 1-1/2 hours at 1400°F, air cooled for 10 minutes (to about 500°F), then quenched in water at 60°F. After an 8 to 12 hour period at 60°F, the specimens were aged 1-1/2 hour at 1050°F and air cooled.

Preliminary machining was with a milling cutter. The gauge section was then ground to final dimensions of 2 inches long by 0.500 inch wide. Specimens

were placed into preheated furnaces and brought to temperature and loaded within approximately four hours.

Rupture data obtained are summarized below.

STRESS-RUPTURE TIME FOR 17-7PH (TH 1050) STRIP SPECIMENS

Spec. No.	Temp. (°F)	Stress (psi)	Rupture Life (hours)	Elongation (%)	Reduction of Area (%)
1K-T5	600	180,000	0.1	4	13
1K-T2	600	180,000	Broke during loading		
1U-T1	600	175,000	15.1	10	17.5
1G-T1	600	170,000	42.6	9.	20.5
1U-T3	800	100,000	107 (± 5)	32.	44.
1U-T5	900	75,000	19.8	31.	46.5
1L-T5	900	70,000	24.6	30.	48.5
1K-T6	900	70,000	56.7	38.5	53.
1K-T4	900	70,000	29.1	28.	49.
1C-T2	900	70,000	28.4	32.	47.
1K-T3	900	60,000	152.2	33.	48.5
1G-T4	900	55,000	323.6	43.	51.

In general, these rupture strengths seem to fall somewhat below the following values reported by the producer as typical for the alloy (See Ref. 2):

Temp. (°F)	100-hour Rupture Strength (psi)	Elongation at Rupture (%)	1000-hour Rupture Strength (psi)	Elongation at Rupture (%)
600	170,000	19	158,000	17
800	110,000	21	90,000	23
900	78,000	30	52,000	40

FUTURE WORK

During the next quarter year, efforts will be made to complete the survey of smooth-bar creep-rupture properties of 17-7PH in the TH 1050 condition and to determine notch behavior of this material.

When the A-286 stock arrives, preliminary tests will be started to choose the heat treatments to be used for more detailed studies on this alloy.

Experimentation will continue with any obtainable lots of Waspaloy or similar alloys which show variable or anomalous notch sensitivity for some conditions.

Major analytical efforts during the coming period will be devoted to selecting suitable critical tests to study factors influencing stress rupture of materials after exposure to variable stresses of complex pattern.

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, (Part 3), (Submitted to WADC for review February 17, 1956.) University of Michigan Engineering Research Institute, Report No. 2024-10-F, December 1955.

2. Product Data Bulletin "Armco Precipitation Hardening Stainless Steels: Armco 17-7PH Sheet, Strip and Plate", Armco Steel Corp., Middletown, Ohio, March 1, 1954.