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ON

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN MICROSTRUCTURE AND CREEP-RUPTURE PROPERTIES OF HEAT-RESISTANT ALLOYS

by

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SUMMARY

This report covers progress made from December 15, 1956 to March 15, 1957 in an investigation concerning the relationship between microstructure and high-temperature properties of heat-resistant alloys.

The current phase of the investigation involves primarily a study of the effect of hot-working conditions on the creep-rupture properties of three types of alloys, including three ferritic steels (SAE 4340, "17-22-A"S, "17-22-A"V), one precipitation-strengthened, austenitic alloy (A-286), and one commercially pure metal ("A" Nickel).

The basis for selecting the specific hot-working and heat-treating conditions is discussed for each type of alloy. The plan for evaluating creep and rupture properties is also outlined.

Preliminary experiments designed to establish appropriate hot-working temperatures are described, and the results for the A-286 experiment are presented.

INTRODUCTION

This report, the fourth progress report issued under Air Force Contract No. AF 33(616)-3239, covers work done from December 15, 1956 to March 15, 1957. The general procedures planned for this year's work are outlined, and some preliminary experiments are described.

The present investigation is a continuation of work initiated at the University of Michigan for the Wright Air Development Center concerning the relationship between microstructure and high-temperature properties of heat-resistant alloys. In the previous work, the properties of several ferritic alloys were surveyed over a wide range of microstructure, with heat treatment being the sole means of controlling the structure. The present work is designed to widen the scope of study (1) by using hot working as a source of structure variation; and (2) by studying the structural effects involved in the basic mechanisms causing prior history conditions to influence properties. The type of alloy to be studied has also been extended to include a precipitation-strengthened, austenitic alloy (A-286) and a commercially pure metal ("A" Nickel).

TEST MATERIALS

The materials were supplied gratis by the following organizations: SAE 4340 from the Universal-Cyclops Steel Corporation, "17-22-A"S and "17-22-A"V from the Timken Roller Bearing Company, A-286 from the Allegheny-Ludlum Steel Corporation, and "A" Nickel from the International Nickel Company. The chemical compositions were reported by the manufacturers as follows:

Alloy	C	Mn	Si	Cr	Ni	Mo	V	Fe	Other
SAE 4340 (Ht. D-14064)	0.40	0.80	0.27	0.82	1.67	0.32	----	Base	----
"17-22-A"S (Ht. 10420)	0.29	0.61	0.67	1.30	0.18	0.47	0.26	Base	----
"17-22-A"V (Ht. 11833)	0.29	0.70	0.71	1.43	0.31	0.51	0.81	Base	----
A-286 (Ht. 21030)	0.06	1.35	0.47	14.58	2.53	1.38	0.21	Base	2.00 Ti; 0.17 Al
"A" Nickel (Ht. N9500A)	0.06	0.27	0.06	----99.46(Ni + Co)			----	0.09	0.03 Cu 0.008 S

GENERAL PROCEDURE

The general procedure for the study of hot-working conditions will consist primarily of the following sequence of operations: (1) hot working each material over a range of temperatures and reductions, (2) heat treating each alloy with a standard treatment, (3) evaluating the creep-rupture properties of each alloy at selected temperatures, and (4) correlating the properties with the structure as observed with x-ray studies and electron and ordinary-light microscopy.

The specific mode of hot working will be limited to hot rolling because of the close control of temperatures and reductions possible with this method. The specific conditions of hot rolling, heat treating, and creep-rupture testing for each alloy will be selected to establish general principles.

The influence of hot-working conditions will generally be evaluated by creep and rupture tests at two temperatures. There is reason to expect that the influence of working conditions varies as the test temperature is raised and as the creep rate is reduced. At low temperatures and high strain rates, resistance to slip within the grains seems to control the creep strength; whereas, resistance to metal movement in the vicinity of the grain boundaries seems to control creep resistance at high temperatures and low strain rates. Therefore, evaluation of effects should include both rapid and slow creep at both relatively low and relatively high temperatures. Survey-type tests involving a comparison of rupture times and creep rates will be used, at least initially.

For the short-time tests stresses will be selected to cause rupture in 20-200 hours; whereas, stresses for the long-time tests will be chosen to produce minimum creep rates of the order of 1 percent per thousand hours. Single tests will be run unless circumstances indicate that duplicate tests are necessary.

The choice of the hot-rolling and heat-treating conditions will be made on the basis of alloy type as outlined below.

Ferritic Alloys

The basic assumption concerning the ferritic alloys is that the hot-working conditions affect the high-temperature properties primarily by determining the condition of the austenite just prior to the transformation to the final microstructure during cooling. Specifically it is assumed that the time and temperature of heating and the severity of working will determine largely the austenitic grain size and the degree of solution of excess phases, which would, in turn, affect the final structure and properties.

In accordance with the above assumptions, the hot-rolling temperatures and reductions for the ferritic alloys will be selected so that the prior austenite grain size and the degree of solution of excess phases will be varied over appreciable ranges.

The heat treating of the ferritic alloys will be limited to tempering the bainitic (or bainitic-martensitic) structures formed during cooling from the rolling operation. The tempering will be such as to bring all structures to a hardness of 300 BHN (±20 BHN).

Precipitation-Strengthened, Austenitic Alloy (A-286)

Presumably A-286 alloy derives its strength mainly from solid solution and precipitation effects. It is always solution treated and aged prior to use. The usual solution treatment of 1650°F, however, is probably too low to remove all prior cold work and to result in complete solution of excess phases. Commercial "hot-working" conditions appear to extend to temperatures below those at which recrystallization occurs during working. The procedure will, therefore, be to vary temperature and amount of reduction to obtain reduction both above and below temperatures of simultaneous recrystallization. Attention will be focused on the relative effects of solution and precipitation of excess phases as influenced by varying degrees of residual cold work after working and after heat treatment.

Initially the hot-rolled material will be given the heat treatment considered standard for the alloy:

Solution Treat 1 Hour at 1650°F, Oil Quench +
Age 16 Hours at 1325°F.

Later experiments will probably require higher temperature solution treatments.

Commercially Pure Metal ("A" Nickel)

It is assumed that solution and precipitation effects in commercially pure nickel will be non-existent or vanishingly small, and that "within-heat" variations in creep-rupture properties due to differences in hot-working conditions will be caused only by internal strain, grain size, and sub-structure effects. Accordingly, the hot-working temperatures will be selected to bracket the simultaneous recrystallization temperature so that substantial differences in structure and lattice strain will exist in the as-rolled condition.

Most of the nickel specimens will be tested in the as-rolled condition. As information accumulates, however, it may become evident that a recovery type of heat treatment after certain rolling operations would be helpful in the study of the influence of sub-structures.

The research on nickel is considered the most essential part of the whole investigation. The comments on the program for commercial alloys did not consider the influence of sub-structures although there is considerable reason to expect that it may be the single most important structural variable involved in hot-working effects. There is reason to expect that sub-structures can be studied in nickel so that the ground work established may be extended to more complicated alloys where it is more difficult to study sub-structures.

PRELIMINARY EXPERIMENTS

Preliminary experiments either have been completed or are in progress to determine for each alloy the appropriate range of hot-working temperatures to use. For A-286 and "A" Nickel the experiments are designed to show the minimum temperature for simultaneous recrystallization so as to define useful hot-working conditions for the experiments. The experiments on the ferritic alloys are to determine the variation in prior austenite grain size with rolling temperature.

A secondary purpose in the A-286 experiment was to make sure that this particular heat of A-286 exhibits sufficiently variable response to hot-working conditions for this investigation. The procedure included (1) hot-rolling ten bars over wide ranges of temperature and reductions, (2) solution treating and aging the rolled bars, and (3) rupture testing all bars under identical conditions. The rolling conditions and the rupture-test results for 1200°F and 65,000 psi were as follows:

Rolling Conditions		Rupture-Test Results		
Temperature of Rolling (°F)	Reduction of Area (%)	Rupture Time (hours)	Elongation (%)	Reduction of Area (%)
1650	0	16.5	13.8	19.6
	18.1	17.4	7.3	9.8
	42.3	19.3	10.8	14.0
1900	0	91.6	7.6	10.6
	18.8	56.6	12.5	13.0
	43.7	32.8	11.7	13.5
2150	0	200.2	2.5	4.7
	9.3	94.4	5.8	7.1
	20.1	146.2	5.8	8.0
	44.1	210.1	4.2	6.4

It was concluded from these data that the given heat of A-286 was suitable for this investigation. Also, metallographic examination of samples prior to rupture testing showed no recrystallization except in the bar rolled 44.1 percent at 2150°F where less than 5 percent recrystallization was evident.

The results of the preliminary experiments on "A" Nickel and the ferritic alloys are not yet complete.

FUTURE WORK

Full-scale rolling, heat treating, and machining of A-286 specimens will be started immediately. Completion of the preliminary experiments on the other materials is expected within two weeks at which time the processing and testing of these alloys will be started.

Procedures for the electron microscopy and x-ray studies will also be established in the very near future.