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FIFTH QUARTERLY PROGRESS REPORT

TO

MATERIALS LABORATORY, WRIGHT AIR DEVELOPMENT CENTER

DEPARTMENT OF THE AIR FORCE

ON

INTERMEDIATE TEMPERATURE CREEP AND RUPTURE BEHAVIOR OF TITANIUM AND TITANIUM ALLOYS

By

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Project 2076

covering the period

October 1, 1953 to January 14, 1954

SUMMARY

This report, the fifth progress report under Contract AF 33(616)-244, covers the period from October 1, 1953 to January 14, 1954.

The major effort during this period was devoted to preparation of a Summary report covering the period from July 1, 1952 to September 30, 1953.

The present progress report discusses the proposed work under a recently negotiated one year's extension of the contract. In addition, limited data are presented covering a study under this extension of hot-working conditions of Ti 150A and a second heat of the 6% Al-Ti alpha alloy.

INTRODUCTION

The present report is the fifth progress report to be issued under Contract AF 33(616)-244, and is the first to be issued under Supplemental Agreement S4 (54-288). The period covered by this report is from October 1, 1953, the end of the first 15 months' work, to January 14, 1954. Although some experimental work was accomplished during this time period, the major effort was devoted to preparation of the Summary report covering the period from July 1, 1952 to September 30, 1953. The Summary report included the period from July 15, 1953, the date of the fourth progress report, to September 30, 1953.

Negotiations with representatives of Materials Laboratory, Wright Air Development Center, resulted in the renewal of the contract in order to extend the investigation along lines developed during the first 15 months. This study consisted of surveying the tensile, rupture and creep properties over the range from 600° to 1000°F of four titanium alloys, representing typical and different transformation systems. The present investigation will extend and corroborate this work in the following ways:

1. Creep and rupture data for selected treatments will be extended out to 1000 hours for the materials previously studied.

2. The general validity of the results obtained for each type of alloy will be studied by surveying another material of the same alloy type; however, containing a different alloying element or elements.

In addition, prior processing variables are known to have significant effects on high temperature properties. The investigation will be extended in the following manner:

3. The effect of hot rolling temperatures and reductions will be studied for two typical alloys.

Thus, the investigation has been extended to one of a three-fold nature. First, the general principles of failure and total deformation will be extended to temperatures and time periods of interest in the field of jet engine technology. Information of this nature is of importance in governing the proper choice of alloy and metallurgical treatment in order to obtain best performance over extended time periods. Such variables tend to have different effects, depending both on the time period and the amount of total deformation by creep under consideration.

The same alloys previously surveyed will be used for this study. These are:

(a) Commercially pure titanium (Ti 75A)

(b) Eutectoid decomposition alloy (Ti 150A)

(c) Stable alpha alloy (6% Al - bal. Ti)

(d) Meta-stable beta alloy (10% Mo - bal. Ti)

(e) Stable beta alloy (30% Mo - bal. Ti)

Of the above materials, the fourth, the meta-stable beta alloy, did not arrive in time to be tested during the first portion of the contract. Consequently, survey tests will be carried out on this material before consideration of any 1000 hour testing is made. The other four materials have been completely surveyed and long-time testing will be initiated on them immediately.

Each of these alloys will be examined in those conditions of treatment that appeared to be of greatest interest in the survey work. Probably three conditions per material involving variations in temperatures and cooling rates of heat treatment, cold work, grain size, or processing conditions will be involved. Each alloy will be evaluated only at temperatures where properties are of useful interest. Thus, commercially pure titanium will be studied only at 600°F. Above this temperature, the material has low strength. Actual details of testing will be discussed in a succeeding section.

The second portion of the program is in recognition of the possibility that the type of alloy may not be the controlling factor in determining high temperature properties, rather the particular alloying elements added to produce these structural changes may be more important. Thus, the first year's work will be generalized by procuring additional alloys of the same structural types. The testing of these materials would be under the same survey method as employed in the first year's work.

Discussion with representatives of the Wright Air Development Center resulted in the selection of the following materials for this part of the program:

(a) Alpha-beta alloy (Ti 155AX)

(b) Alpha alloy (6% Al - 0.5% Si - bal. Ti)

(c) Meta-stable beta alloy (8-10% Cr - bal. Ti)

(d) Beta alloy (50% V - bal. Ti)

Finally, the effect of hot working conditions are to be studied, since it is known that in other alloy systems such variables can have a profound effect on deformation properties. To a first approximation, hot working influences properties through its control of grain size and other microstructural characteristics. These effects will be studied through survey creep-rupture tests. Two alloy types will be used:

(a) An alloy undergoing transformation and which requires working in the alpha plus beta range (Ti 150A).

(b) An alpha alloy (6% Al - bal. Ti).

In order to limit this work to a program of reasonable proportions, the following steps will be used:

1. Efforts will be confined to approximations of the effects of final passes by reworking 3/4-inch bar stock.

2. All working will be done as nearly isothermally as possible. Short lengths will be used and given only one pass through the rolling mill. Reductions will be varied, insofar as it is possible, from 5 percent to as large a reduction as can be obtained in one pass, probably 25-40 percent.

3. Rolling temperatures will be in 100° - 200°F increments over the range of temperatures in which these alloys might be worked.

4. Creep-rupture testing will be confined to one temperature for each material. These temperatures will be 800°F for Ti 150A and 1000°F for the 6% Al alloy.

The purpose of this study is to define qualitative trends and relative magnitude of possible variation in properties, rather than making a detailed investigation of systematic variations in these conditions.

The experimental results of the three phases of this investigation will be correlated with such things as microstructure, hardness changes, x-ray diffraction studies, insofar as possible, so that a series of broad, well-founded generalizations can be formulated to explain the behavior of all types of titanium alloys in the temperature range from 600° to 1000°F.

TEST MATERIALS

The materials chosen for study under this contract are briefly named on pages 2 and 3. They are presently under order and several have been received. Titanium Metals Corporation of America is furnishing Ti 75A, Ti 150A, and Ti 155AX, and the Armour Research Foundation of Illinois Institute of Technology has consented to prepare the experimental heats needed for the other alloys.

Materials already received, (unless otherwise noted, as 1/2-inch rounds), are the following:

1. 6% Al - bal. Ti -- 20 pound heat from Armour -- for total deformation and heat treatment studies.

2. 10% Mo - bal. Ti -- 8-1/4 pound heat from Armour -- for survey testing of tensile and creep-rupture properties.

3. Ti 75A -- 10 pounds from Titanium Metals -- for total deformation studies.

4. Ti 150A -- 17-1/2 pounds, 3/4-inch squares, from Titanium Metals -- for hot rolling studies.

5. Ti 150A -- 10-1/4 pounds from Titanium Metals -- for total deformation work.

The following materials have been ordered:

6. Ti 155AX -- 10 pounds from Titanium Metals -- for survey work.

7. 6% Al - bal. Ti -- 20 pounds, 3/4-inch squares, from Armour -- for hot rolling.

8. 50% V - bal. Ti -- 10 pounds from Armour -- for check survey tests.

9. 6% Al - 0.5% Si - bal. Ti -- 10 pounds from Armour -- check survey tests.

10. 8-10% Cr - bal. Ti -- 10 pounds from Armour -- check survey tests.

Chemical analyses available for the materials (numbered as above) received to date are presented in Table I.

TABLE I

Alloy No.	Nominal Composition	Actual Composition - % Alloying Element(s) "Impurities" C	N2	O2	H2	Al	Cr	
1	6% Al - Ti	0.075	0.055	0.097	0.023	5.89		(Armour)
						Mo		
2	10% Mo - Ti	0.056	0.022	*	*	10.50		(Armour)
						Fe		
3	Ti 75A	0.0423	0.0263	*	*	0.142		(Ti Met. Heat M626)
4	Ti 150A	0.076	0.12	*	*	1.35	2.63	(Ti Met. Heat L897)
5	Ti 150A	0.080	0.026	*	*	1.47	2.76	(Ti Met. Heat M739)

In addition, oxygen and hydrogen analyses are available for two experimental heats studied under the first 15 months' survey work **.

	O_2	H_2
6% Al - Ti	0.21	0.018
30% Mo - Ti	0.17	0.030

PROCEDURE

In general, the procedure adopted follows that developed during the first portion of the contract. Thus, for survey work the test procedure is as follows:

(a) Tensile testing at room temperature and each temperature of creep-rupture testing.

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* Not available.

** Reported in WADC Technical Report 54-112 (forthcoming). (See also Progress Reports.)

(b) Two rupture tests aimed to fracture in 35 and 100 hours respectively. As the theoretical test times are rarely attained, every effort is made to cover the time period so that the 100-hour rupture strength may be estimated as accurately as possible.

(c) One creep test at a stress so as to cause a minimum creep rate of between 10^{-5} and 10^{-6} inches/inch/hour. This stress is estimated using time-deformation data obtained during short time rupture testing.

This general procedure has been successful in estimating short time properties.

For long time testing involving total deformation studies, the following procedure has been adopted:

(a) Four rupture tests of about 100, 300, 600, and 1000 hours duration will be used. The 100-hour test is to be used as a check from one heat to another, since new test stock is being procured for these studies.

(b) In order to establish the curve for one-percent total creep deformation to 1000 hours, it is estimated that four test stresses will be needed. These are necessary since it has been found that rupture tests have exceeded one-percent deformation in 100 hours or less. Therefore, at least three lower stresses than that causing rupture in 1000 hours will be required. Creep tests of 300, 600, and 1000 hours duration will be required.

Other studies will be directed to the establishment of the effect of stress, temperature, and time on the metallographic properties of the test materials, in addition to such metallurgical studies as may prove warranted.

Actual testing will be conducted, as before, in University of Michigan individual creep-rupture units. ASTM Recommended Practices are followed in all tests.

RESULTS

The period covered by this report was confined mainly to materials procurement and preparation of the First Summary Report. Experimental work has been performed on two aspects of the investigation and is briefly discussed here.

Alpha Alloy (6% Al - bal. Ti)

Limited rupture tests have been run on this material at 1000°F in order to establish if any variation in properties exists between this heat and the previously tested heat.

Data are as follows:

Condition	Test Temp (°F)	Stress (psi)	Time to Rupture (hrs)	Elongation (%)	Reduction of Area (%)
As Forged (2nd Heat)	1000	37,000	48.0	18.1	11.0
		33,000	192.2	26.8	47.0

Estimated 100-hour rupture strength: 34,500 psi

Condition	Test Temp (°F)	Stress (psi)	Time to Rupture (hrs)	Elongation (%)	Reduction of Area (%)
As Forged (1st Heat)	1000	37,500	102.3	28.6	66.6

Estimated 100-hour rupture strength: 37,500 psi

These limited data indicate that the second heat has slightly lower 1000°F rupture properties than the first heat. The difference is probably attributable to differences of oxygen, nitrogen, and hydrogen content. Thus,

Heat No.	% "Impurities" O_2	N_2	H_2	100-Hour Rupture Strength (psi)
1st Heat	0.20	--	0.018	37,500
2nd Heat	0.09	0.055	0.023	34,500

The first heat contains over twice the amount of oxygen as the second heat. Because oxygen increases strength, this probably accounts for the difference in properties.

One heat treatment of the 6% Al alloy has been tested at 1000°F. This consisted of a one hour anneal at 1200°F, followed by air cooling. The results indicate that no change in the 100-hour rupture strength was obtained by this treatment.

Eutectoid Decomposition Alloy (Ti 150A)

During the period covered by this report, the 3/4-inch square bar stock of Ti 150A was rolled to size for the investigation of hot working conditions. Four temperatures were employed in the work, 1200°, 1350°, 1500°, and 1650°F. Two degrees of reduction were accomplished at 1200°F and three at other temperatures. Holding time at temperature before rolling was one-half hour. The atmosphere used was natural gas combustion. The maximum reduction obtained at 1200°F was 21.3 percent, and at 1650°F was 37.8 percent. Intermediate reductions of about 5-10 percent and 15-20 percent were accomplished easily at 1350°F and above. This work, as mentioned before, was one-pass, closed-pass rolling, in order to roll as nearly isothermally as possible. The bars are now being machined into test specimens.