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TENSILE PROPERTIES OF
YTTRIUM-TITANIUM AND
YTTRIUM-ZIRCONIUM ALLOYS

by

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TENSILE PROPERTIES OF YTTRIUM-TITANIUM AND YTTRIUM-ZIRCONIUM ALLOYS

D. W. Bare, E. D. Gibson and O. N. Carlson

ABSTRACT

Complete series of yttrium-titanium and yttrium-zirconium alloys were tested in tension at room temperature, and ultimate tensile strength, yield strength and reduction in area data are reported for these alloys. Yield point phenomena were encountered in both of these alloy systems.

INTRODUCTION

Yttrium metal has potential value as a structural material in nuclear reactor design due to its relatively low neutron cross-section, high melting point, compatibility with molten uranium alloy fuels,¹ and other desirable properties. Yttrium itself, however, has little strength even at room temperature, so a study of the possible improvement of its tensile and mechanical properties by alloying was undertaken. Because of its affinity for oxygen and hydrogen, yttrium offers promise as an additive in developing alloys with improved fabricability, chemical stability and resistance to hydrogen embrittlement.

¹ R. W. Fisher and C. B. Fullhart, Feasibility Studies on Molten Metal Reactor Components, USAEC Report, ISC-1020, June, 1958.

A survey of the mechanical properties of various yttrium alloys was initiated and results of this study² have been published recently. This survey revealed that additions of up to 5 w/o of various elements had little effect on strengthening yttrium or improving its mechanical properties effectively. Of the various binary alloys tested in this survey, the yttrium-titanium and yttrium-zirconium systems were chosen for more detailed study. These binary systems are of the simple eutectic-type with no intermediate phases,^{3, 4} and for this reason were considered to be more likely to yield usable and fabricable high-strength alloys. Zirconium is well known for its use as a structural material in nuclear reactors and titanium for its desirable corrosion resistance and favorable weight-to-strength ratio. This paper is a report of the tensile data obtained from a detailed study of these systems.

² O. N. Carlson, D. W. Bare, E. D. Gibson and F. A. Schmidt, Survey of the Mechanical Properties of Yttrium and Yttrium Alloys, Symposium on Newer Metals, Special ASTM Technical Publication No. 272, pp. 144-159, 1959.

³ D. W. Bare and O. N. Carlson, Phase Equilibria and Properties of Yttrium-Titanium Alloys, ASM Trans. Preprint No. 178, 1960.

⁴ Charles E. Lundin and Donald T. Klodt, Quarterly Progress Report No. 5, APEX 300, Denver Research Institute, February, 1957.

EXPERIMENTAL PROCEDURE

Materials:

The yttrium used in these alloy studies was prepared by a process involving the reduction of YF_3 with calcium metal in the presence of magnesium to form a low melting yttrium-magnesium alloy.⁵ Yttrium sponge was obtained as a final product of this process by vacuum sublimation of the magnesium from the alloy. Sponge metal designated as 40-69Y was used for the yttrium-titanium alloys while that designated as 40-199Y was used for the yttrium-zirconium alloys. Titanium sponge obtained from the Crane Corporation and crystal-bar titanium prepared in the Ames Laboratory were used in the yttrium-titanium alloys. All yttrium-zirconium alloys were prepared from reactor grade crystal-bar zirconium. Chemical compositions for the yttrium and titanium sponges and for crystal-bar titanium and zirconium are given in Table I.

Preparation of Alloys:

The alloys were prepared from an accurately weighed 40-50 gram quantity of the component metals. The metals were melted in button form in a non-consumable arc-melter under an inert atmosphere of helium. The loss in weight during melting was negligible so nominal composition was assumed to be the actual composition of the alloy. The buttons were sectioned and remelted into finger-shaped ingots. They were sheathed in

⁵ O. N. Carlson, J. A. Haefling, F. A. Schmidt and F. H. Spedding, Preparation and Refining of Yttrium Metal by the Y-Mg Alloy Process, J. Electrochem. Soc., 107, No. 6, June, 1960.

Table I.

Chemical Composition of Yttrium, Titanium and Zirconium

Metal	Impurity - ppm											
	C	N	O	F	Cl	Ca	Cu	Fe	Mg	Ni	Si	Ti
40-69Y	56	18	200	49	---	38	20	238	10	500	160	4923
40-199Y	63	6	435	72	---	10	--	200	14	150	---	N. D. *
Titanium Sponge	400	200	1500	--	300	--	--	300	200	---	---	---
Ti Crystal-bar	570	150	410	--	---	--	--	670	---	---	---	---
Zr Crystal-bar	100	10	200	--	---	50	1	200	10	30	30	10

* Not detected

S. A. E. 1010 steel tubing jackets, hot swaged at 650°C with a reduction in diameter of approximately 30% to break down the arc-cast structure, de-jacketed and annealed in vacuo at 800°C for one hour and then cold swaged to a final diameter of 0.2 inch. Some variation in the alloy rod fabrication procedure was necessary with a few of the yttrium-zirconium alloys due to an inability to cold-swage these alloys.

Tensile Specimen Preparation:

From the 0.2-inch diameter cold-swaged alloy rod, tensile specimens were machined to dimensions as shown in Fig. 1. A final heat treatment, consisting of a one-hour anneal at 800°C in vacuo was given each specimen prior to testing. This recrystallization step was carried out to assure a uniformly fine-grained structure. The average grain size of the specimens was ASTM No. 5.

Fig. 1. Tensile Test Specimen

Testing Procedure:

A 12,000 pound capacity Tinius-Olsen Electromatic testing machine was used for testing all alloys in this investigation. The diameter of each specimen was measured at top and bottom of the reduced section prior to testing. The extension of the specimen was measured with a differential transformer extensometer placed on the specimen or between the cross-heads of the machine. The extension and load were plotted simultaneously on an X-Y recorder. From the load-extension curve the ultimate tensile strength was calculated at the maximum load. The yield strength was calculated on the basis of load at 0.5% extension of a one-inch gage length or from the load at the yield point if such occurred. The ductility is reported in terms of percentage reduction in area as calculated from the original and fractured areas.

PRESENTATION AND INTERPRETATION OF THE DATA

Yttrium-Titanium Alloys:

A total of twenty-three yttrium-titanium alloys in two different series was prepared for study of the tensile properties. One series comprising the entire composition range was prepared from titanium and yttrium sponges to determine the basic alloying effects. The second series employing crystal-bar titanium was included to study the significance of the yield point phenomenon and also the maxima in the tensile strength-composition curves which were observed in this investigation.

Curves showing the relationship between ultimate tensile strength and composition for both series of yttrium-titanium alloys are presented

in Fig. 2. A maximum in this property occurs near 70 w/o Ti for those alloys prepared from titanium sponge and near 60 w/o Ti for those prepared from crystal-bar titanium. The highest ultimate strength achieved in any of the alloys was 53,500 psi, an increase of only 2,000 psi over unalloyed sponge titanium. The maxima which occur in these curves do not correspond to any significant feature of the binary phase diagram such as solid solubility limits or eutectic composition and have been attributed to an optimum geometrical arrangement of the phases comprising the eutectic to form the highest strength alloy.

Another phenomenon to be noted in these curves is the seemingly opposite effects on the ultimate tensile strength of equivalent 5 w/o yttrium additions to sponge and crystal-bar titanium. Upon addition of 5 w/o yttrium the ultimate tensile strength of the titanium sponge drops from 51,000 psi to 44,000 psi, while the crystal-bar titanium increases from 33,500 psi to 41,000 psi. The decrease in strength of the sponge alloys is considered to be caused by a depletion of oxygen from solid solution by the formation of Y_2O_3 in the matrix, while the corresponding increase in strength of the higher purity crystal-bar metal is attributed to solid solution hardening.

In Fig. 2, bottom, the curves relating yield strength and composition for the yttrium-titanium alloys are shown. The forms of the curves are similar to the ultimate tensile strength curves with a more gradual slope in the yttrium-rich and titanium-rich regions. There is a sharp maximum in yield strength occurring near 70 w/o Ti. The initial in-

Fig. 2 - Top - Ultimate Tensile Strength versus Composition for Y-Ti Alloys.
Bottom - Yield Strength versus Composition for Y-Ti Alloys.

crease in strength for the crystal-bar titanium alloys is evident in these curves also, but the initial decrease for the sponge titanium alloys is absent.

Figure 3 is a plot of percentage reduction in area for the yttrium-titanium alloys versus composition. The unalloyed titanium exhibits a rather high percentage reduction in area, but in both the sponge and crystal-bar alloys a decline in this property is noted with the addition of yttrium. There appears to be some relationship between the features of the Y-Ti binary phase diagram and the reduction in area curves for these alloys. The rapid decline in ductility in both the titanium-rich and yttrium-rich regions are probably associated with solid solubility limits in the system, while the flattening of the curve near 15 w/o appears to coincide with the eutectic composition (13 w/o Ti). Assuming reduction in area to be a criterion for the degree of ductility important in fabrication procedures, these curves bear out the fact that yttrium can be cold worked by swaging or rolling less readily than titanium.

Alloys containing between 30 and 100 w/o titanium were found to exhibit yield points. The single exception to this was the unalloyed crystal-bar titanium which showed no such behavior. The maximum yield point drop in load was found in the Y-70 w/o Ti alloy. The nominal stress versus nominal strain curve for this alloy is reproduced in Fig. 4. Maxima in the ultimate tensile strength and the yield strength curves were found to occur at this same composition. A yield point was first observed in the crystal-bar titanium alloy containing 1 w/o Y. This

Fig. 3 - Percentage Reduction in area versus Composition for Yttrium-Titanium Alloys.

Fig. 4 - Nominal Stress versus Nominal Strain Curve for the Y-70 Wt. % Ti Alloy.

corresponds approximately to the limit of solid solubility. The exact nature of this yield point is not understood, however.

Yttrium-Zirconium Alloys:

Sixteen yttrium-zirconium alloys were prepared for investigation of the tensile properties of these binary alloys. Curves of ultimate tensile and yield strength versus composition are shown in Fig. 5. Unlike the data for the yttrium-titanium alloys, there are no distinct maxima exhibited in these properties but rather broad plateaus comprising approximately two-thirds of the composition range.

These curves point up the relative insensitivity of yttrium to alloy strengthening by the addition of zirconium compared to that produced in zirconium by the addition of yttrium. The ultimate tensile strength of zirconium is doubled and the yield strength tripled by the addition of 5 w/o yttrium whereas the addition of this amount of zirconium to yttrium produces noticeably less strengthening. The slight drop in yield strength with the first few percent addition of yttrium to zirconium is similar to that effect observed in the titanium-rich alloys.

A plot of percentage reduction in area versus composition (see Fig. 6) resembles that obtained for the yttrium-titanium alloys in its general features. After an initial decrease in the yttrium-rich alloys the ductility rises sharply to a maximum and falls off to a minimum at the eutectic composition. This is particularly noticeable in the zirconium-yttrium alloys which exhibit an anomalous behaviour in reduction

Fig. 5 - Ultimate Tensile Strength versus Composition and Yield Strength versus Composition for Y-Zr Alloys.

Fig. 6 - Percentage Reduction in Area versus Composition for Yttrium-Zirconium Alloys.

in area in the composition range of 5 to 30 w/o Zr. Alloys in the middle of this composition range were difficult to fabricate and by necessity were hot swaged (650°C) only, whereas the other alloys were given a cold swaging treatment. The effect of this change in fabrication procedure was checked on the 5 and 30 w/o Zr alloys which were swaged both in the hot and cold condition. Little difference was noted in the ductility of the specimens. The initial decrease in reduction in area on the yttrium side of the curves appears to be associated with the region of solid solubility in yttrium. The maximum in the curve at about 20 w/o zirconium is difficult to explain on the basis of the phase diagram. The second minimum occurring at about 30 w/o zirconium corresponds closely to the eutectic composition.

Yield point phenomena were encountered in all yttrium-zirconium alloys in the composition range 50 to 97 w/o Zr. These alloys exhibited a pronounced discontinuity in the stress-strain curve; however, yielding in the yttrium-zirconium alloys was not accompanied by the sharp drop in load as was characteristic of the yttrium-titanium alloys. Instead, they leveled off approaching zero slope at the yield point.

SUMMARY AND DISCUSSION

A study of yttrium-titanium and yttrium-zirconium alloys has been made with regard to their room temperature tensile properties. In several respects alloys of these two systems exhibited similar characteristics. They exhibit maxima in tensile and yield strengths in the

intermediate composition ranges and the percentage increases in these properties were similar for the two systems.

Yield points were encountered in both the titanium-rich and zirconium-rich alloys and in both cases the yield points were first detected at compositions just beyond the limit of solid solubility. Likewise a similarity in the slope of the reduction in area versus composition curves was noted with a maximum occurring in both systems at the yttrium-rich end of the diagram.

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