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**EFFECT OF MELT TEMPERATURE AND TIME
MOLTEN UPON THE HARDENING RESPONSE
OF URANIUM-0.75 WEIGHT PERCENT
TITANIUM ALLOY PLATE**

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OAK RIDGE Y-12 PLANT
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ABSTRACT

Uranium-0.75 weight percent titanium alloy ingots were prepared with different melt temperatures and times in the molten condition. The ingots were rolled, homogenized, solution treated, water quenched, and each aged at two different temperatures. Hardening response was measured by the yield strength-elongation relationship obtained in tensile tests. Increasing the melt temperature and melt time produced an increasing hardening response.

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SUMMARY

Six uranium-0.75 weight percent titanium (U-0.75 Ti) alloy ingots were prepared by comelting the elements in vacuum-induction furnaces. The experiment was designed to include two melt temperatures, two ingot sizes, and two double-melted ingots. All of the ingots were gamma rolled to 1/2 inch (13 mm) and homogenized. Blanks from each plate were solution treated, water quenched, age hardened at two different temperatures, and tested. Hardening response was measured by the resulting yield strength-elongation relationship of the tensile tests. Increasing the melt temperature and melt time increased the hardening response. There was no undissolved titanium in the plates, so the difference in hardening response was not a matter of slow solutioning of the alloying elements. Scanning electron microscope (SEM) examination of two fractured tensile test specimens (high and low hardening response) showed that the porosity associated with titanium carbide inclusions was more prevalent in the low-response specimen than in the high-response specimen.

INTRODUCTION

Low-level alloying of uranium can provide the metal with enhanced mechanical properties. In addition, the metallurgical processing of such alloys influences their mechanical properties. This particular study was instituted for the purpose of evaluating the effects of the melt temperature and times in the molten condition (time molten) in preparing the U-0.75 Ti alloy upon the hardening response of the alloy plate. Some variability in the hardening response had been experienced earlier among different melts of the alloy, but the reason for such variability was not known.

This study, conducted at the Oak Ridge Y-12 Plant,^(a) was designed specifically to produce information directly applicable to the usual melting and processing practices. Consequently, it was not possible to eliminate all of the variables except melt temperature and time molten, but the metallurgical processing to hardened plate specimens was held reasonably uniform. Tensile tests from age-hardened plate were used as the measure of the hardening response, with particular consideration to the yield strength-elongation relationship.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Energy Research and Development Administration.

HARDENING RESPONSE OF A BINARY ALLOY TO TWO EFFECTS

MATERIALS AND METHODS

This experiment was designed to obtain data that could be applied directly to the usual melting and processing procedures, and could also be related directly to earlier melting experience. To accomplish this objective, six ingots of the U-0.75 Ti alloy were prepared as follows: (1) single melt, small, 1310° C; (2) single melt, large, 1310° C; (3) single melt, small, 1450° C; (4) double melt, small, 1450° C; (5) single melt, large, 1450° C (15-min hold); (6) double melt, large, 1450° C (15-min hold).

For the double-melt ingots, the alloy was remelted and cast under the same conditions as in the first melt. Double melting thus provided ingots with the same solidification conditions as their comparable single-melt ingots, but provided a longer time molten with the equivalent melt temperature. Variation in the hardening response of the pairs could then be attributed solely to the time-molten factor.

All of the small ingots were 40 by 125 by 175 millimetres, while the large ingots were 50 by 455 by 610 millimetres. Of necessity, the large ingots required a longer time molten than did the small ingots with equivalent melt temperatures. In addition, the large ingots at 1450° C were held 15 minutes at temperature prior to pouring, while the small ingots were poured without a hold time. The hold time also increased the time-molten difference at equivalent temperatures.

The 1310° C temperature was selected for the low-temperature melts because it was high enough to have sufficient superheat to produce sound ingots. The 1450° C melt temperature was selected because that would be a practical high temperature for the usual melting facility. An intermediate melt temperature was not explored in this study because there were some data already available for 1350° C melts. Melt temperatures were measured with an optical pyrometer. In one case (single melt, large, 1310° C) the temperature, inadvertently, was not read directly on the melt, so the melt was at some slightly higher temperature than that indicated in this report.

All of the tensile-test specimens were tested at a strain rate of 0.005/min up to the yield strength (0.2%); and, thereafter, at a crosshead speed of 4 mm/min. The tests were performed at room temperature with the relative humidity of the air below 50%. With the U-0.75 Ti alloy, the tensile-test ductility, elongation, and reduction in area are decreased by testing in high-humidity air. The yield strength is unaffected by humidity in the laboratory air.

The results (average) of tests from blanks age hardened at two different temperatures were plotted in terms of yield strength as a function of the percent elongation for each of the six melts. A line drawn between each pair from one melt then represented the values that would result from intermediate aging temperatures. This technique was used to reduce the number of tests required as well as to remove the effects of some of the variability from metallurgical processing and level of alloy element.

All of the U-0.75 Ti alloy ingots were prepared in vacuum-induction furnaces by comelting Derby uranium and titanium sponge, and pouring at the required melt temperature. Total time molten is not reported because of the practical difficulty in determining the start time. The alloy was melted in graphite crucibles that were plasma sprayed with zirconia to minimize carbon pickup, and poured into graphite ingot molds washed with Zirconite A mold coating. On comelting the elements, there was considerable outgassing when the titanium started to dissolve in molten uranium at 1150 to 1200° C. This activity decreased with increasing melt temperature above 1250° C. By 1350° C, all of the outgassing had ceased. Both of the 1310° C ingots were, therefore, poured while the melt was still outgassing. All of the six ingots were gamma rolled out of a carbonate salt bath to 1/2-inch (13-mm)-thick plates.

These plates were homogenized at 1000° C (24 hours) in vacuo. The homogenization treatment also removed any hydrogen introduced by salt-bath heating for rolling. Tensile-test blanks were cut from the plates, solution treated at 800° C (1 hour), in vacuo, and water quenched. Four blanks from each plate were age hardened at each of two different temperatures and tested.

TEST RESULTS

Table 1 reports the average mechanical properties values from the tensile tests. However, the relation of melt temperature and time molten can be more readily evaluated with respect to hardening response from Figure 1, which plots elongation as a function of yield strength. The hardening response from all of the experimental results can be related visually in the chart. These individual points between the bottom two lines are values taken from plates from earlier melts at 1350° C, and were not prepared for this study. The line for the single melt, large, 1310° C ingot is probably higher than it should be because of an error in the melt-temperature measurement.

The lowest hardening response was obtained with the small single-melted ingot at 1310° C; the highest response was from the large double-melted ingot at 1450° C. Large ingots provided better hardening response than did small ingots with the same melt temperature, but large ingots required the longer time molten before pouring. Double melting raised the hardening response with both small and large ingots. Both first and second melts solidified under approximately the same conditions, so the hardening response measured was related to melt time rather than to ingot solidification patterns.

These data suggested that the titanium sponge, on comelting with uranium, does not dissolve as readily as had been visualized. However, chemical analyses, microprobe analysis, and metallographic examination did not show a segregation of metallic titanium in specimens from this series or from other melts of the U-0.75 Ti alloy.

SEM was used to examine the tensile test fracture of a low-response specimen—single melt, small, 1310° C. The fracture was a mixture of ductile dimple and intergranular modes. However, there were many holes distributed across the section, and the sides of the holes were covered with a fine "gravel". A series of photographs showing this condition are presented in Figure 2.

A similar scan of a high-response tensile-test fracture provided the photographs in Figure 3. Fractography does not lend itself to quantitative measurement of the size and number of inclusions across the section. However, in a qualitative way, the segregant hole size was smaller in this high-response specimen than that of the low-response specimen. As could be expected, the amount of ductile-dimple fracture was larger in the high-response sample.

CONCLUSIONS

In the preparation of U-0.75 Ti ingots by comelting, both increasing the melt temperature and increasing the time molten, provided increasing age-hardening response in hardened plate made from the ingots. Although the data may be interpreted that the titanium is slow in dissolving, no undissolved titanium could be found in the alloy plates, so that the explanation is inadequate.

Table 1
TENSILE TESTS OF AGE HARDENED URANIUM-0.75 TITANIUM ALLOY
PREPARED BY VACUUM-INDUCTION MELTING
(Average of 4 Specimens)

Aging Temperature (° C)	Tensile Strength		Yield Strength ⁽¹⁾		Elongation ⁽²⁾ (%)	Reduction in Area (%)
	(ksi)	(MPa)	(ksi)	(MPa)		
<u>Small, 1310⁰ C Ingot, Single Melt</u>						
360	177.0	1220	107.0	760	13.0	13.7
400	138.2	955	127.4	880	1.3	1.1
<u>Large, 1310⁰ C Ingot, Single Melt</u>						
360	192.9	1330	114.9	790	19.8	21.4
400	199.2	1375	138.8	955	4.6	5.4
<u>Small, 1450⁰ C Ingot, Single Melt</u>						
340	200.5	1380	123.7	850	16.0	16.6
400	218.9	1510	135.3	930	12.6	12.5
<u>Small, 1450⁰ C Ingot, Double Melt</u>						
340	194.0	1340	109.5	755	24.1	37.9
400	221.0	1520	134.6	925	14.3	14.5
<u>Large, 1450⁰ C Ingot, Single Melt</u>						
360	215.8	1485	129.8	895	21.1	28.5
400	226.8	1565	151.8	105	11.2	10.9
<u>Large, 1450⁰ C Ingot, Double Melt</u>						
360	194.5	1340	114.8	790	27.8	43.7
400	218.1	1505	140.0	965	20.5	27.7

(1) At 0.2% offset.

(2) In one-inch gage.

Fractography did indicate that the lowered hardening response was related to titanium carbide segregant and an associated porosity. The segregant and porosity were sufficient in themselves to lower ductility without affecting the yield strength. Increased melt temperature and melt time increased the hardening response by creating a distribution of smaller segregant-pore areas which are not so apt to decrease tensile test ductility.

Obviously, the voids are vacancy accumulations during the cold working in tensile testing. Such voids have also been observed with SEM examinations of other uranium alloy fractures, such as uranium-2 niobium-1 titanium and uranium-8 molybdenum, but they could not always be associated with inclusions. Grain boundaries are also vacancy sinks during tensile testing. Other unpublished work with uranium-0.75 titanium and uranium-0.75 titanium-0.25 vanadium processed to obtain alpha uranium nucleating and growing from the grain boundaries has shown higher ductility with reduction-in-area values numerically higher than elongation values at comparable yield strengths. Such behavior

Figure 1. YIELD STRENGTH AND ELONGATION (AVERAGE) OF AN AGE-HARDENED PLATE FROM URANIUM-0.75 TITANIUM ALLOY. (SM - Single Melt; DM Double Melt)

(a) At 10,000X.

SM-37681

(b) At 3000X.

SM-37682

(c) At 300X.

SM-37684

(d) At 100X.

SM-37685

Figure 2. SCANNING ELECTRON MICROSCOPE PHOTOGRAPHS OF SEGREGANT-PORE AREA FROM LOW-RESPONSE TENSILE-TEST-FRACTURE URANIUM-0.75 TITANIUM ALLOY.

(a) At 10,000X.

SM-39712

(b) At 3000X.

SM-39713

(c) At 1000X.

SM-39714

(d) At 300X.

SM-39715

Figure 3. SCANNING ELECTRON MICROSCOPE PHOTOGRAPHS OF SEGREGANT-PORE AREA FROM HIGH-RESPONSE TENSILE-TEST-FRACTURE URANIUM-0.75 TITANIUM ALLOY.

demonstrates that vacancy embrittlement at the fine grain boundaries of the alloy in this study, as well as the vacancy accumulations at inclusion sites, are both factors limiting the tensile-test ductility.

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