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**CHARACTERIZATION OF URANIUM-1
AND 2 WEIGHT PERCENT
ZIRCONIUM ALLOYS**

V. C. Hemperly

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ABSTRACT

A preparation method for wrought uranium-1 and 2 wt % zirconium alloys has been developed. Tensile tests of the 2 wt % zirconium alloy demonstrate that it can be solution treated, water quenched, and age hardened to obtain high strength with good ductility; hardening response of the 1 wt % zirconium is much smaller. A metallographic study shows that the alloys on lower-level aging respond in a manner somewhat similar to the uranium-titanium alloys at comparable atomic percentage compositions.

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SUMMARY

Wrought uranium-1 and 2 wt % zirconium alloys were prepared by vacuum-induction melting, casting, homogenizing, and rolling in the high-alpha region. The alloys did respond to solution treatment, water quenching, and age hardening like other alloys of low-level, gamma-miscible elements in uranium. The 1 wt % zirconium alloy attained a 1150-MPa tensile strength, a 450-MPa yield strength (0.2%), a 30% elongation, and a 32% reduction in area; the 2 wt % zirconium alloy attained a 1580-MPa tensile strength, a 1000-MPa yield strength, an 18% elongation, and a 36% reduction in area. In both alloys, most of the hardening occurred in the quench, and both overaged with a 400° C, 24-hour treatment. A metallographic study showed that both alloys responded to aging in a manner somewhat similar to the uranium-titanium alloys at comparable atomic-percentage compositions.

INTRODUCTION

The mechanical properties of uranium can be markedly improved by alloying the metal, followed by a proper heat treatment. In general, low-level alloys of the gamma-miscible elements in uranium can be solution treated, water quenched, and then age hardened to obtain relatively high strengths with good ductility. This particular study was made at the Oak Ridge Y-12 Plant^(a) to examine this generality with respect to the uranium-zirconium alloy system.

The literature is concerned mostly with the uranium-zirconium system at high levels of zirconium in uranium or with ternary alloys containing zirconium, both for nuclear reactor service. Chiswik, et al⁽¹⁾, did evaluate uranium-2 and 3 wt % zirconium alloys, but no attempt was made to obtain a high strength. Johnson⁽²⁾ in unpublished work concerning cast-metal alloys demonstrated that uranium-0.5 wt % zirconium alloys did not respond to age hardening after solution treatment, water quenching, and aging at 400° C, while the alloys at 1.0 and 1.4 wt % zirconium could be age hardened. The study levels of 1 and 2 wt % zirconium in this report were selected on the basis of that work. However, wrought, rather than cast, metal is characterized here. Uranium-0.75 to 1.1 wt % zirconium alloys have been examined for weld strength, but without any attempts to obtain high strength levels by heat treating.⁽³⁾

Caution: Alloys of uranium and zirconium may produce explosions on pickling in nitric acid. Although the problem is mostly with the higher zirconium alloys, explosions have been reported at the one percent zirconium level. Hydrofluoric acid addition to the pickling bath eliminates the problem.

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

CHARACTERIZATION OF TWO URANIUM-ZIRCONIUM ALLOYS

ALLOY PREPARATION

Both alloys were prepared by comelting a uranium-10 wt % zirconium master alloy and Derby-grade uranium in a vacuum-induction furnace using a graphite crucible that was plasma-arc sprayed with zirconia to minimize the metal/crucible reaction. The 1 wt % alloy was charged to 1.1 wt % zirconium and the 2 wt % alloy was charged to 2.2 wt % zirconium. Small ingots of each (40 x 125 x 180 mm) were poured at 1450° C in graphite molds washed with Zirconite A. After vacuum homogenization at 1000° C for four hours, both ingots were rolled to 13-mm plates from an argon-atmosphere furnace set at 575° C.

Chemical analyses of the two ingots are reported in Table 1. Hydrogen, which is detrimental to the mechanical properties of uranium and uranium alloys, is readily removed by vacuum treating at elevated temperatures. For this reason, the hydrogen determinations were made after the solution treatment at 800° C in vacuum. Zirconium in the 1 wt % alloy was just slightly lower than anticipated. Some of the carbon was removed by the flotation of zirconium carbide particles in the melt, so the carbon levels were also lower in the ingots than in the charge metal.

Table 1
CHEMICAL ANALYSIS OF URANIUM-1
AND 2 WT % ZIRCONIUM ALLOYS

Zirconium (wt %)	Carbon (ppm)	Hydrogen (ppm)
0.86	23	0.15
1.98	24	0.17

HEAT TREATMENT

Test blanks, 13 x 13 x 125 mm, were cut from the plates, solution treated in vacuum at 800° C for one hour, and then water quenched. The various aging treatments were also performed in a vacuum-atmosphere furnace.

MECHANICAL PROPERTIES

Plots of the tensile-test results after selected heat treatments are given in Figure 1 for the 1 wt % zirconium alloy and in Figure 2 for the 2 wt % zirconium alloy. The 1 wt % zirconium alloy hardened some small amount and was overaged when treated at 400° C for 24 hours. On the other hand, the 2 wt % zirconium alloy did age harden significantly, and it also overaged after 24 hours at 400° C. In both alloys, the major portion of the age-hardening response occurred during the quench from the solution-treating temperature rather than on reheating. As with other age-hardening alloys, the response to aging would be different at other quenching-blank thicknesses.

METALLOGRAPHY

Figures 3 and 4 are polarized light photomicrographs of the two alloys in the gamma-quenched condition. The matrix of the 1 wt % zirconium alloy is alpha uranium; the matrix of the 2 wt % zirconium alloy is lamellar martensite. X-ray diffraction analyses demonstrated that the 2 wt % alloy, as gamma quenched, was alpha-prime uranium. The alpha prime is an orthorhombic transition phase with a contraction of the b parameter as

compared with the a and c parameters. Comparable gamma-quenched structures are obtained with uranium-titanium alloys at comparable atomic-percent compositions (0.48 and 1.0 wt % Ti).⁽⁴⁾

Figure 1. TENSILE TESTS OF THE URANIUM-1 WT % ZIRCONIUM ALLOY AFTER SELECTED HEAT TREATMENTS. (Average of 2 Tests)

here. Metallography of the 1 wt % titanium alloy would show nucleation and growth of alpha uranium at the grain boundaries on overaging.

Density determinations and elastic moduli (sonic) of age-hardened materials are reported in Table 2. The moduli are comparable to those obtained by Johnson for 1 and 1.4 wt % zirconium alloys of cast metal.

Conclusions

The uranium-1 and 2 weight percent zirconium alloys do respond to solution treatment, quenching, and aging, as with other low-level, gamma-miscible elements in

As indicated in Figures 5 and 6, aging the uranium-zirconium alloys at 300°C for 24 hours did not change the metallographic structures. Such behavior is also normal for the comparable age-hardened uranium-titanium alloys.

Figures 7 and 8 are polarized light photomicrographs of the alloys aged at 400°C for 24 hours. Overaging, indicated by precipitation of the delta phase, is evident; but this phenomenon is more readily discerned under bright-field illumination in Figures 9 and 10. The uranium-titanium analogy is not applicable

Figure 2. TENSILE TESTS OF THE URANIUM-2 WT % ZIRCONIUM ALLOY AFTER SELECTED HEAT TREATMENTS. (Average of 2 Tests)

L48-A

Figure 3. PHOTOMICROGRAPH OF URANIUM-1 WT % ZIRCONIUM ALLOY, AS QUENCHED (Polarized Light; 100X)

L60-A

Figure 4. PHOTOMICROGRAPH OF URANIUM-2 WT % ZIRCONIUM ALLOY, AS QUENCHED. (Polarized Light; 100X)

L78-1

Figure 5. PHOTOMICROGRAPH OF URANIUM-1 WT % ZIRCONIUM ALLOY THAT WAS GAMMA QUENCHED AND AGE HARDENED AT 300° C FOR 24 HOURS. (Polarized Light; 100X)

L78-2

Figure 6. PHOTOMICROGRAPH OF URANIUM-2 WT % ZIRCONIUM ALLOY THAT WAS GAMMA QUENCHED AND AGE HARDENED AT 300° C FOR 24 HOURS. (Polarized Light; 100X)

L125-1

Figure 7. PHOTOMICROGRAPH OF URANIUM-1 WT % ZIRCONIUM ALLOY THAT WAS GAMMA QUENCHED AND OVERAGED AT 400° C FOR 24 HOURS. (Polarized Light; 100X)

L125-2

Figure 8. PHOTOMICROGRAPH OF URANIUM-2 WT % ZIRCONIUM ALLOY THAT WAS GAMMA QUENCHED AND OVERAGED AT 400° C FOR 24 HOURS. (Polarized Light; 100X)

L125-1A

Figure 9. PHOTOMICROGRAPH OF URANIUM-1 WT % ZIRCONIUM ALLOY THAT WAS GAMMA QUENCHED AND OVERAGED AT 400° C FOR 24 HOURS. (Bright Field Illumination; 100X)

L125-2A

Figure 10. PHOTOMICROGRAPH OF URANIUM-2 WT % ZIRCONIUM ALLOY THAT WAS GAMMA QUENCHED AND OVERAGED AT 400° C FOR 24 HOURS. (Bright Field Illumination; 100X)

Table 2
MODULI (SONIC) OF URANIUM-1 AND 2 WT % ZIRCONIUM
ALLOYS IN THE AGED CONDITION
(Average of 2 Tests)

	Uranium-1 wt % Zirconium	Uranium-2 wt % Zirconium
Density (g/cm ³)	18.72	18.35
Youngs Modulus (MPa x 10 ⁴)	19.2	18.9
Shear Modulus (MPa x 10 ⁴)	7.5	7.6
Poisson's Ratio	0.28	0.24

uranium. Hardening response of the 1 wt % alloy is small, but it is much higher with the 2 wt % alloy. With both alloy levels, most of the hardening occurs on quenching, and both overage in the 400^o C treatment. The alloys respond to aging in a manner somewhat similar to the uranium-titanium alloys at comparable atomic-percent compositions.

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