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CHARACTERIZATION OF THE URANIUM-2.25
WEIGHT PERCENT NIOBIUM ALLOY

V. C. Hemperly

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ABSTRACT

A study has been made of the methods for preparing, processing, and heat treating the uranium-2.25 wt % niobium alloy. The rolling technique is critical, but the alloy responds to conventional solution treatment, water quenching, and aging to provide high strength with good ductility. Data on tensile tests and Charpy tests as functions of the temperature have been obtained. Elastic moduli, density, coefficient of thermal expansion, and differential thermal analysis data have also been determined.

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SUMMARY

Uranium-2.25 wt % niobium alloy (U-2.25 Nb) ingots were prepared by vacuum-induction melting, homogenization, and rolling to plates. The rolling technique was critical. After age hardening, plate material rolled from a salt bath at 800° C had a much lower ductility than plate that had been rolled from an argon-atmosphere furnace at 575 or 630° C. The alloy responded to conventional age hardening (solution treatment at 800° C, water quenching, and aging) to provide high strength (1460 MPa tensile and 1050 MPa yield) with high ductility, 17.5% elongation, and 40% reduction in area. The alloy could also be age hardened using a 655° C solution-treatment temperature. Tensile tests made between - 50 and 100° C showed a ductile/brittle transition below - 25° C, but such was not the case with Charpy impact tests in the same temperature range. To further characterize the alloy, linear coefficient of thermal expansion, density, elastic moduli, and differential thermal analyses data were also determined.

INTRODUCTION

The mechanical properties of uranium can be improved markedly by alloying the metal, followed by 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 an alloy with relatively high strength and good ductility for engineering applications. This particular study was made at the Oak Ridge Y-12 Plant^(a) to examine this general alloy treatment and the resulting properties, specifically with respect to U-2.25 Nb alloy.

Most of the recent literature concerning U-2.25 Nb has been contributed by personnel at Dow-Rocky Flats. Avery developed a procedure for preparing the alloy by induction melting and casting,⁽¹⁾ and Jackson and Boland determined the mechanical properties that could be obtained by age hardening the alloy.⁽²⁾ Their work demonstrated that the alloy could be age hardened to high strength levels, but only with relatively low ductility values. The particular purpose of the present study is to vary the material processing and /or heat treatment in order to obtain an increased ductility and still retain the desirable high strength. Avery also determined the effect of alloy content and carbon, oxygen, and nitrogen levels on the properties of the alloy.⁽³⁾ Wilkinson gives tensile-test properties of the uranium-niobium system at niobium levels up to 6%.⁽⁴⁾ For the as-quenched condition, the 2.25 wt % Nb alloy showed the highest ultimate strength (1447 MPa) with about a 10% elongation. There are no test results given for age-hardened specimens. Weld strengths of the alloy at 1.5 wt % Nb have also been determined,⁽⁵⁾ but there was no attempt to obtain a high strength by heat treatment. Zehr at Sandia-Albuquerque has also examined the alloy that was heat treated to its two-phase structures.

CAUTION: Alloys of niobium with uranium may produce explosions on pickling in nitric acid, but hydrofluoric acid added 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.

CHARACTERIZING THE URANIUM-2.25 NIOBIUM ALLOY

ALLOY PREPARATION

The alloys for this study were prepared by comelting uranium-6 wt % niobium plate scrap and derby-grade uranium in a vacuum-induction furnace, using a graphite crucible that had been plasma-arc sprayed with zirconia to minimize the metal/crucible reaction. Small ingots (40 x 125 x 180 mm) were poured at 1450° C into graphite molds that had been washed with Zirconite A.

Chemical analyses of the ingots showed carbon levels between 60 and 90 ppm and niobium levels between 2.18 and 2.27 wt %. Because of the small analysis ranges, and because there were no properties differences in the study that could be related to alloy composition, ingot identification is not maintained in this report.

ALLOY PROCESSING

All of the ingots were vacuum homogenized at 1000° C for four hours and then rolled in the alpha-plus-gamma range (with the one exception noted in the next topic) to 13-mm plates out of an argon-atmosphere furnace. Hydrogen, which is detrimental to the mechanical properties of uranium and uranium alloys, is readily removed by vacuum treating at an elevated temperature. For this reason, all solution treatment was performed in a vacuum environment. As with other age-hardening alloys, the mechanical properties developed are related to specimen thickness on quenching, so the properties reported herein are for 13-mm-square test blanks only.

HARDENING RESPONSE

One ingot was rolled in the gamma region out of an 800° C salt bath to a 13-mm plate. Blanks were cut from this plate, solution treated at 800° C, water quenched, and aged at 250 and 300° C for six hours. Tensile test results from these specimens are reported in Table 1. The mechanical properties obtained compare favorably with those in the literature.

Table 1
TENSILE TESTS OF AGE-HARDENED URANIUM-2.25 WEIGHT PERCENT
NIOBIUM ALLOY THAT WAS GAMMA ROLLED FROM A
SALT BATH AT 800° C
(Heat Treatment—800° C in Vacuum, Water Quenched, and Aged as Shown)

Aging Temperature (° C)	Tensile Strength (MPa)	Yield Strength (1) (MPa)	Elongation (2) (%)	Reduction In Area (%)
300	1460	980	12.0	10.8
	1445	1018	9.0	9.7
250	1431	876	13.0	12.3
	1426	909	14.0	12.0

(1) At 0.2% offset.

(2) In 25.4-mm gage length.

In an effort to improve the mechanical properties by processing changes, ingots were rolled out of an argon-atmosphere furnace—one at 630° C and one at 575° C. Blanks were cut,

given selected heat treatments, and tested. Those tensile-test results which were deemed useful for this investigation are reported in Table 2. Rolling in the alpha-plus-gamma-three region (575 or 600° C) provided the desired high strength with good ductility after a solution treatment in vacuo at 800° C, water quenching, and age hardening. These test results demonstrate the usefulness of a single-material processing change (rolling the U-2.25 Nb alloy at 575° C rather than in the 800° C gamma region, as was done for the tests in Table 1). With respect to varying the heat treatment to improve its mechanical properties, the tests quenched from 655° C instead of 800° C also provided high strength with good ductility.

Table 2
TENSILE TEST OF URANIUM-2.25 WEIGHT PERCENT NIOBIUM ALLOY
AFTER SELECTED HEAT TREATMENTS AND STOCK ROLLED
TO 13-mm PLATE FROM AN ARGON-ATMOSPHERE
FURNACE
(Average of 2 Tests)

Rolling Temperature (° C)	Heat Treatment	Tensile Strength (MPa)	Yield Strength ⁽¹⁾ (MPa)	Elongation ⁽²⁾ (%)	Reduction in Area (%)
575	Vacuum-Water Quenched at 800° C + Aged at 200° C for 6 Hours	1428	833	18.7	40.2
630	Vacuum-Water Quenched at 800° C + Aged at 200° C for 6 Hours	1441	833	18.5	44.0
575	Vacuum-Water Quenched at 800° C + Aged at 300° C for 6 Hours	1458	1052	17.2	38.2
630	Vacuum-Water Quenched at 800° C + Aged at 300° C for 6 Hours	1483	1048	17.5	42.2
630	Vacuum-Water Quenched at 655° C	1194	915	19.7	45.6
630	Vacuum-Water Quenched at 655° C + Aged at 400° C for 6 Hours	1553	1082	10.0	17.7

(1) At 0.2% offset.

(2) In 25.4-mm gage length.

Figures 1 and 2 reveal the metallographic structures obtained with the 800 and 655° C quenches. The mixed grain size of the 800° C sample was not found on subsequent metallographic examination of pieces that were water quenched from the gamma-phase region. Samples showed only the smaller grains. The 655° C quenching temperature is in the alpha-plus-gamma-one region of the equilibrium diagram rather than in the gamma region, and is the reason for the metallographic differences in Figure 2. Polarized-light illumination was used here because no grain boundaries or structures could be developed by etching for bright-field examination. Just why the alloy can be age hardened after a 655° C quench is not understood, but this question would make an interesting subject for a separate metallurgical investigation. This information is not considered pertinent to this particular report because the necessary tight temperature control limits the practicality of such a processing technique.

The mixed grain size in Figure 2 indicated the need to establish the possible effects of a temperature variability in the solutioning temperature upon the hardening response. Blanks were vacuum-water quenched from 750, 800, and 850° C for one hour at temperature, and age hardened at 300° C for six hours. The tensile test results after such heat treatments are listed in Table 3. There was no difference between the 750 and 800° C tests, but there was a

K430

Figure 1. PHOTOMICROGRAPH OF A SPECIMEN OF URANIUM-2.25 WEIGHT PERCENT NIOBIUM ALLOY THAT WAS WATER QUENCHED FROM 800° C AND AGE HARDENED. (Bright Field Illumination; 100X)

K436

Figure 2. PHOTOMICROGRAPH OF A SPECIMEN OF URANIUM-2.25 WEIGHT PERCENT NIOBIUM ALLOY THAT WAS WATER QUENCHED FROM 655° C AND AGE HARDENED. (Polarized Light; 250 X)

Table 3
TENSILE TESTS OF URANIUM-2.25 WEIGHT PERCENT
NIOBIUM ALLOY THAT WAS VACUUM-WATER
QUENCHED AND AGED AT 300° C FOR
SIX HOURS

Quenching Temperature (° C)	Tensile Strength (MPa)	Yield Strength ⁽¹⁾ (MPa)	Elongation ⁽²⁾ (%)	Reduction in Area (%)
750	1523	1039	17.0	43.4
	1490	-	19.0	39.6
800	1457	1070	18.0	42.0
	1449	1040	19.0	44.2
850	1460	1076	17.5	36.3
	1469	1089	17.5	37.6

(1) At 0.2% offset.

(2) In 25.4-mm gage length.

small increase in strength with a corresponding small decrease in ductility with the 850° C tests. However, the difference would not be sufficient to be a processing problem. Metallographically, there was no significant difference among the three.

Another technique to vary the best treating response is the addition of another alloy element. A 0.25 wt % addition of rhenium was made in a 2.25 wt % niobium alloy and similarly processed through casting, homogenization, rolling (630° C), solution treatment (800° C), water quenching, and aging at selected temperatures. This ingot actually contained 60 ppm C, 2.22 wt % Nb, and 0.25 wt % Re. The literature reports that rhenium is also soluble in gamma uranium and, at levels of about 1.5%, also produces the alpha-prime structure on quenching. The tensile test results after hardening were quite comparable to those of the alloy without the rhenium addition. Because there was no readily apparent advantage gained with the rhenium addition, there was no further characterization study of this alloy.

MECHANICAL PROPERTIES IN TERMS OF THE TEST TEMPERATURE

Tensile-test results versus the test temperature are reported by the graph in Figure 3. The test blanks were solution treated in vacuo at 800° C, water quenched, and then age hardened at 300° C for six hours. There was a decrease in both the tensile and yield strengths for test temperatures from - 50 to 100° C. The ductility measurements (elongation and reduction in area) were relatively uniform at test temperatures between - 25 and 100° C, but lower, due to a ductile/brittle transition, when tested at - 50° C.

A similar test series was made with blanks solution treated at 655° C, rather than at 800° C. Plots from these specimens (Figure 4) show similar mechanical property changes to those shown in Figure 3 for the 800° C-quenched samples. However, because of the lower aging temperature used (250° C), the yield and tensile strengths are lower, while the elongation and reduction-in-area values are higher.

Charpy impact tests were made on test blanks solution treated at 800° C in vacuo, water quenched, and age hardened for six hours at 300° C. When tested at temperatures from - 50 to 100° C, the average values (two tests at each temperature) ranged from 13.6 joules at

Figure 3. TENSILE TESTS AS FUNCTIONS OF THE TEST TEMPERATURE FOR THE URANIUM-2.25 WEIGHT PERCENT NIOBIUM ALLOY THAT WAS VACUUM-WATER QUENCHED FROM 800° C AND AGED AT 300° C FOR SIX HOURS. (Average of Two Tests)

expansion of the alloy was $15.3 \times 10^{-6}/^{\circ}\text{C}$ between room temperature and 300° C.

Three samples were submitted for differential thermal analysis. The determinations are reported in Table 4. The data indicate that the 655° C quenching temperature is just inside the alpha-plus-gamma-one region, and further demonstrates the fine control required to use 655° C as the solution-treating temperature as a processing technique.

- 50° C to 15.7 joules at 100° C. There was no evidence of a ductile/brittle transition temperature such as was obtained below - 25° C in the comparable series of data on tensile tests versus the test temperature.

PHYSICAL PROPERTIES

Density of the U-2.25 Nb alloy was 17.83 g/cm³. Elastic moduli of an age-hardened specimen were determined with a sonic technique. Young's modulus was 14.2×10^4 MPa, the shear modulus was 4.8×10^4 MPa, and Poisson's ratio was 0.47. The linear coefficient of thermal

Figure 4. TENSILE TESTS AS FUNCTIONS OF THE TEST TEMPERATURE FOR THE URANIUM-2.25 WEIGHT PERCENT NIOBIUM ALLOY THAT WAS VACUUM-WATER QUENCHED FROM 655° C AND AGED AT 250° C FOR SIX HOURS.

Conclusions

As with other low-level, gamma-miscible alloys of uranium, the U-2.25 Nb alloy can be solution treated, water quenched, and age hardened to obtain high strength with good ductility. Rolling is a critical processing step, because plate rolled from a salt bath at 800° C, rather than from an argon-atmosphere furnace at 575 to 600° C, will not provide the desired mechanical properties.

Table 4
DIFFERENTIAL THERMAL ANALYSIS
RESULTS OF THE URANIUM-2.25
WEIGHT PERCENT NIOBIUM
ALLOY

Analysis Number	+ r ₃ to + r ₁ (° C)	Solidus Temperature (° C)	Liquidus Temperature (° C)
1	648	1175 1170	1223 1224
2	651	1178 1170	1230 1228
3	643	1178 1174	1228 1219
Average	647	1174	1225

Although solution treating at either 800 or 655° C can be used, the 655° C quench requires a very close temperature control and is, therefore, not recommended.

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