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URANIUM ALLOY DEVELOPMENT FOR NON-NUCLEAR APPLICATION

PROGRESS REPORT NO. 5

BY

C. F. DIXON, N. S. SPENCE AND H. M. SKELLY

Physical Metallurgy Division

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SUMMARY OF RESULTS

Twelve ternary uranium-base alloys, containing molybdenum and one of the elements niobium, vanadium, zirconium or titanium, were prepared, and their heat treatment response and mechanical properties were investigated.

The heat treatment for producing maximum hardness consisted of holding at 800°C (1470°F) for 1/2 hour and water quenching, followed by ageing at 400°C (750°F) or 500°C (930°F) for periods ranging from 1 minute to 2 hours. The maximum hardness after heat treatment varied from 516 VHN for the U-1%Mo-0.5%Zr alloy to 639 VHN for the U-1%Mo-2%Ti alloy.

The highest as-cast tensile strength was 176 kpsi for the U-1%Mo-2%Nb alloy and the highest heat-treated tensile strength was 219 kpsi for U-1%Mo-0.5%Ti. The heat-treated alloys all exhibited low ductility.

The compressive strengths of the as-cast alloys were all in the range 330 to 362.5 kpsi. The highest heat-treated compressive strength was 385.5 kpsi for U-1%Mo-0.5%Zr.

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1. INTRODUCTION

The high density of uranium makes it a potentially useful material for applications where inertia and kinetic energy properties are important, as in ballistics. The work described in this report is part of a larger program on the development of high-strength uranium-base alloys for ballistic applications that is being carried out for the Department of National Defence.

Four previous progress reports(1-4) dealt with heat treatment procedures, and preparation and properties of experimental uranium alloys. Progress Report No. 3(3) gave details of the preparation and properties of a series of binary alloys of uranium with molybdenum, niobium, vanadium, zirconium and titanium. The present report which is a continuation of the latter work, investigates the properties of ternary alloys of uranium and molybdenum plus one of the elements niobium, vanadium, zirconium and titanium. The nominal compositions of the alloys studied were as follows:

U-1%Mo-1%Nb	U-1%Mo-0.5%Zr
U-1%Mo-2%Nb	U-1%Mo-2%Zr
U-2%Mo-1%Nb	U-2%Mo-0.5%Zr
U-1%Mo-1%V	U-1%Mo-0.5%Ti
U-1%Mo-2%V	U-1%Mo-2%Ti
U-2%Mo-1%V	U-2%Mo-0.5%Ti

2. EXPERIMENTAL PROCEDURE

2.1 Preparation of Alloys

The uranium was supplied by Eldorado Mining and Refining Limited and contained 35 ppm (0.0035%) carbon. The suppliers and purity of the alloying elements were as follows:

Element	Supplier	Purity (min.)
Molybdenum	Sylvania Electric Products Inc.	99.5%
Niobium	Fansteel Metallurgical Corporation	99.7%
Vanadium	Vanadium Corporation of America	99.5%
Zirconium	Wah Chang Corporation	99.5%
Titanium	Osaka Titanium Corporation	99.5%

To facilitate alloying, hardeners were first made in a tungsten arc furnace. The alloys themselves were prepared and cast under vacuum in an electric resistance furnace. The charge weighed 1700 grams and the melt was poured into a heated graphite mould. Full details of equipment and procedure are given in the earlier report[3].

2.2 Examination and Testing of Alloys

The alloys were chemically analyzed for the alloying element and carbon.

Tensile and compressive tests were carried out on the as-cast and heat-treated alloys. Details of the test specimens are given elsewhere[3].

No extensive metallographic study was carried out on the alloys, but the castings were examined in the as-cast condition to assess their quality. The metallographic procedure is described in a previous report[3].

Castings were inspected for flaws by gamma radiography using a Cobalt-60 source.

The density of the alloys was determined by the water-displacement method (ASTM Designation B311-58).

2.3 Heat Treatment and Hardness

For heat-treating purposes and hardness determinations, 1/2-inch-long specimens were cut from the cast bars. The specimens were coated with graphite to minimize surface attack during heat treatment. The solution heat-treatment consisted of heating in a fused salt bath (Houghton "980" salt) at 800°C (1740°F) for 1/2 hour, followed by water quenching. Ageing was carried out in a Pb-11% Sb alloy at 400°C (750°F) and 500°C (930°F) for 1, 3 and 5 minutes. After determining the Vickers hardness, the specimens aged for 1 and 3 minutes were further aged in argon for 1 and 2 hours, respectively, then hardness tested. Hardness determinations were also carried out on as-cast specimens and specimens water-quenched from 800°C (1470°F).

The heat treatment chosen for determination of mechanical properties in the hardened condition was the one giving the highest hardness for each alloy.

3. RESULTS

3.1 Composition and Quality of Castings

The results of the chemical analyses are given in Table 1. The compositions were all close to the aimed-at values except for the niobium contents of melts R-BZ and R-BS, which were low. The carbon contents were all below the maximum content of 150 ppm except for one melt (R-CA) that analyzed 190 ppm.

Metallographic and gamma-ray inspection showed the castings to be clean and sound.

3.2 Response to Heat Treatment

Table 2 lists the Vicker's hardnesses of the alloys in the as-cast, solution-heat-treated, and solution-heat-treated and aged conditions. The hardnesses range from Vicker's hardness number (VHN) 289 for the U-1%Mo-2%V alloy in the as-cast condition to VHN 639 for the U-1%Mo-2%Ti alloy after ageing for 5 minutes at 500°C (930°F). Table 2 also shows that 8 of the 12 alloys attained maximum hardnesses after water quenching from 800°C (1470°F) and ageing at 400°C (75°F) for 2 hours.

The highest hardness obtained for each alloy is underlined in Table 2.

3.3 Mechanical Properties

The tensile, compression and hardness properties of the alloys in the as-cast and heat-treated conditions are listed in Tables 3 and 4, respectively. The heat treatments were those giving the highest hardnesses as show in Table 2.

3.4 Density

The densities of the alloys are given in Table 5. Except for the U-1%Mo-2%Ti composition, which had a density of 17.71 g/cc, they are all greater than 18 g/cc.

4. DISCUSSION

The procedure followed in heat-treating the ternary alloys examined in this report was selected to cover the temperatures and times found to give the optimum hardnesses for the uranium binary alloys examined in previous reports[1,3] and uranium ternary alloys examined by H. P. Tardiff, Department of National Defence[5].

Each of the ternary alloys were heat-treated to hardnesses above VHN 500 and were, except for alloy U-2%Ti, harder than any of the uranium binary alloys previously examined[3].

The as-cast mechanical properties (Table 3) show that one alloy (U-1%Mo-2%Ti) broke before the 0.2% tensile yield strength was reached. Five of the as-cast alloys showed no ultimate compressive strength as they flattened without breaking at a definite load. Highest tensile properties (161-176 kpsi) were shown by the uranium-molybdenum-niobium alloys. The alloys with the lower alloy contents had the highest elongations. All the ultimate compressive strengths were in a narrow range from about 330 to 362 kpsi. The highest compressive yield strength was shown by the U-1%Mo-2%Nb and U-1%Mo-2%Ti alloys (both about 148 kpsi).

The heat-treated alloys exhibited a brittleness that made it difficult to obtain accurate tensile properties (See Table 4). No tensile values were obtained for the U-1%Mo-2%Ti and U-2%Mo-0.5%Ti alloys. Highest tensile strength was shown by U-1%Mo-0.5%Ti (219.1 kpsi) and by U-1%Mo-0.5Zr (199.2 kpsi). The only alloy to show a 0.2% tensile offset was U-1%Mo-0.5Zr (197.5 kpsi). The U-1%Mo-0.5%Ti composition had a 0.1% offset of 214.2 kpsi. Elongations were low in all cases. The highest ultimate compressive strengths were obtained from the two alloys showing the highest tensile strength, viz, U-1%Mo-0.5%Zr (385.5 kpsi) and U-1%Mo-0.5%Ti (369.8 kpsi). However, the highest 0.2% compressive yield strength was 306.5 kpsi for U-2%Mo-1%V.

4. CONCLUSIONS

1. All the alloys examined could be heat-treated to hardnesses over 500 VHN.
2. All the alloys could be heat-treated to give hardnesses greater than those of the previously examined uranium binary alloys[3], with the exception of alloy U-2%Ti.

3. Highest mechanical properties in the as-cast condition were shown by the U-Mo-Nb alloys.
4. Highest mechanical strength in the heat-treated condition was shown by U-1%Mo-0.5%Ti and U-1%Mo-0.5%Zr alloys. However, the poor ductility of the hardened alloys made it difficult to obtain accurate tensile properties.

ACKNOWLEDGEMENTS

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TABLE 1

Composition of Uranium Alloy Melts

Melt Identification	Nominal Composition (wt %)	Actual Composition (wt %)	Carbon (ppm)
R-CC	1%Mo-1%Nb	1.03%Mo-1.08%Nb	80
R-BZ	1%Mo-2%Nb	1.0%Mo-1.51%Nb	100
R-BS	2%Mo-1%Nb	1.92%Mo-0.64%Nb	98
R-BY	1%Mo-1%V	0.99%Mo-1.01%V	64
R-CA	1%Mo-2%V	1.02%Mo-1.96%V	190
R-BR	2%Mo-1%V	1.97%Mo-0.99%V	120
R-CD	2%Mo-1%V	2.03%Mo-0.96%V	110
R-BT	1%Mo-0.5%Zr	1.0%Mo-0.48%Zr	64
R-CB	1%Mo-2%Zr	1.04%Mo-1.82%Zr	56
R-BW	2%Mo-0.5%Zr	2.0%Mo-0.48%Zr	76
R-CG	2%Mo-0.5%Zr	2.04%Mo-0.46%Zr	80
R-BU	1%Mo-0.5%Ti	1.0%Mo-0.43%Ti	68
R-BV	1%Mo-2.0%Ti	1.04%Mo-2.25%Ti	70
R-CF	1%Mo-2.0%Ti	1.04%Mo-2.02%Ti	60
R-BX	2%Mo-0.5%Ti	1.96%Mo-0.48%Ti	68
R-CE	2%Mo-0.5%Ti	2.0%Mo-0.56%Ti	120

TABLE 2

VHN of Uranium Alloys (20 kg Load)

Alloy (Nominal Composition)	As-Cast	Heat Treated 800°C (1470°F), 1/2 hr W.Q.										
		Aged at 400°C (750°F)						Aged at 500°C (930°F)				
		0	1 min	3 min	5 min	1 hr	2 hr	1 min	3 min	5 min	1 hr	2 hr
U-1%Mo-1%Nb	335	441	463	480	483	460	463	520	509	483	388	394
U-2%Mo-1%V	362	407	463	483	562	579	593	498	502	490	498	536
U-2%Mo-1%Nb	379	319	450	483	505	524	540	502	490	487	457	435
U-1%Mo-0.5%Zr	303	460	470	470	466	509	516	476	494	502	509	516
U-1%Mo-0.5%Ti	312	450	447	494	483	520	562	524	549	540	415	391
U-1%Mo-2%Ti	435	460	544	532	571	588	608	608	628	639	608	628
U-2%Mo-0.5%Zr	331	360	466	494	494	540	562	487	480	483	432	418
U-2%Mo-0.5%Ti	362	331	513	494	524	571	584	509	505	509	483	470
U-1%Mo-1%V	315	401	528	562	579	584	553	562	540	520	498	480
U-1%Mo-2%Nb	429	308	438	483	480	536	557	505	502	505	463	429
U-1%Mo-2%V	289	444	536	544	549	536	487	490	483	473	453	441
U-1%Mo-2%Zr	321	544	532	571	557	566	603	584	584	588	566	571

TABLE 3

Mechanical Properties of As-Cast Uranium Alloys*

Alloy (Nominal Composition)	Tensile Properties			Compressive Properties	
	UTS (kpsi)	0.2% YS (kpsi)	% El $4\sqrt{A}$	UCS (kpsi)	0.2% CYS (kpsi)
1%Mo-1%Nb	161.0 (1)	105.8 (2)	23.0 (1)	Nil	96.0 (2)
1%Mo-2%Nb	176.0 (2)	150.0 (2)	2.5 (2)	330.2 (4)	147.8 (2)
2%Mo-1%Nb	174.2 (2)	148.9 (2)	3.5 (2)	362.5 (4)	123.3 (2)
1%Mo-1%V	109.2 (2)	99.4 (2)	1.8 (2)	Nil	88.6 (2)
1%Mo-2%V	110.0 (2)	93.8 (2)	2.5 (2)	348.0 (2)	77.8 (2)
2%Mo-1%V	147.9 (3)	129.6 (3)	2.2 (3)	355.2 (4)	120.4 (4)
1%Mo-0.5%Zr	148.0 (1)	84.4 (2)	15.0 (1)	Nil	71.2 (2)
1%Mo-2%Zr	140.4 (1)	104.7 (2)	4.0 (1)	340.5 (2)	92.8 (1)
2%Mo-0.5%Zr	157.8 (2)	113.3 (2)	10.5 (2)	Nil	105.8 (4)
1%Mo-0.5%Ti	157.6 (2)	106.3 (2)	17.5 (2)	Nil	87.4 (2)
1%Mo-2%Ti	118.7 (2)	Nil	1.0 (2)	336.0 (8)	148.2 (3)
2%Mo-0.5%Ti	157.2 (2)	135.2 (2)	3.0 (2)	350.0 (6)	128.0 (4)

*The figures in brackets are the number of tests.

TABLE 4

Mechanical Properties of Heat-Treated Uranium Alloys*

Alloy (Nominal Composition)	Tensile Properties			Compressive Properties	
	UTS (kpsi)	0.2% YS (kpsi)	% El $4\sqrt{A}$	UCS (kpsi)	0.2% CYS (kpsi)
1%Mo-1%Nb	157.8 (1)	* *	0.5 (1)	352.4 (4)	224.5 (2)
1%Mo-2%Nb	149.8 (1)	* *	0.5 (1)	328.6 (4)	262.0 (2)
2%Mo-1%Nb	145.4 (2)	* *	0.5 (2)	292.6 (2)	NA
1%Mo-1%V	126.3 (1)	* *	2.5 (1)	320.3 (4)	289.6 (2)
1%Mo-2%V	154.5 (1)	* *	0 (1)	332.3 (3)	282.0 (1)
2%Mo-1%V	141.0 (1)	* *	1.0 (1)	334.0 (2)	306.5 (2)
1%Mo-0.5%Zr	199.2 (1)	197.5 (1)	1.5 (1)	385.5 (1)	192.0 (1)
1%Mo-2%Zr	147.8 (2)	* *	0.25 (2)	362.7 (4)	258.0 (2)
2%Mo-0.5%Zr	182.0 (1)	* *	1.0 (1)	327.2 (4)	251.8 (2)
1%Mo-0.5%Ti	219.1 (2)	.1% YS 214.2 (2)	1.5 (2)	369.8 (4)	233.9 (2)
1%Mo-2%Ti	NA	NA	NA	300.2 (1)	NA
2%Mo-0.5%Ti	NA	NA	NA	328.8 (4)	283.2 (2)

*The figures in brackets are the number of tests.
NA = not available
**Specimen broke before 0.2% offset reached.

TABLE 5

Densities of Uranium Alloys

Alloy (Nominal Composition)	Density (g/cc)
1%Mo-1%Nb	18.64
1%Mo-2%Nb	18.31
2%Mo-1%Nb	18.37
1%Mo-1%V	18.45
1%Mo-2%V	18.07
2%Mo-1%V	18.24
1%Mo-0.5%Zr	18.64
1%Mo-2%Zr	18.32
2%Mo-0.5%Zr	18.45
1%Mo-0.5%Ti	18.54
1%Mo-2%Ti	17.71
2%Mo-0.5%Ti	18.35