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UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

Printed in the United States of America. Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.95

LA-4781
UC-25
ISSUED: December 1971

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SOME MECHANICAL AND PHYSICAL PROPERTIES OF HEAT-TREATED ALLOYS OF URANIUM WITH SMALL ADDITIONS OF TITANIUM OR MOLYBENUM

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ABSTRACT

Alloys of uranium with small ≤ 1.5 wt% additions of titanium have been investigated at LASL. These alloys have been prepared from castings worked, either by hot rolling or hot extrusion, to yield a wrought structure. The alloys have been heat treated by quenching in water from the gamma region of the phase diagram to yield "solution heat-treated" alloys. The "as quenched" material is significantly ductile and strong. After quenching, samples have been subjected to artificial aging treatments, and they seem to undergo an age-hardening reaction. A 30 to 50% increase in yield strength and increased ductility can be measured in samples that have been aged at 400°C for 2 h.

These materials do not appear susceptible to stress-corrosion cracking in environments of 100% relative humidity. Their general corrosion resistance is superior to that of unalloyed uranium.

I. INTRODUCTION

Alloys of uranium with small additions of either titanium or molybdenum have been under investigation at the Los Alamos Scientific Laboratory (LASL). These alloys are of special interest because of their high mechanical strength, apparent freedom from stress-corrosion cracking, > 18.2 g/cm^3 density, and fabricability. These alloys are not "stainless" but their general corrosion resistance is somewhat superior to that of unalloyed material in ambient atmospheres. Their most interesting properties, from a design standpoint, are their mechanical strengths and densities.

Most of the work has been performed on wrought material but the mechanical properties of cast alloys containing small percentages of titanium or molybdenum are being evaluated because there will undoubtedly be some necessity for using these alloys in the cast condition.

II. PREVIOUS WORK

The uranium-titanium and uranium-molybdenum alloy systems have been the subject of previous studies. Murphy[1] reported that the low-titanium alloys of uranium exhibited precipitation hardening when quenched from the gamma phase at different cooling rates. Data presented in Ref. 2 showed the effect of increasing titanium content on the mechanical strength of alpha-annealed uranium-titanium alloys.

III. OBJECTIVE

Taking into account the background of previous work and our intent to develop a high-strength, readily fabricable uranium alloy of > 18.2 g/cm^3 density, the specific objectives of the present Los Alamos program can be outlined as follows:

1. To optimize the chemistry of the alloys to achieve the best combination of mechanical properties and fabricability.
2. To develop heat treatments that will be compatible with the particular alloy and the system in which it may be used.
3. To determine the effect of section thickness and alloy chemistry on the required quenching rates for low titanium and low molybdenum alloys.

4. To evaluate the effect of welding and other fabrication procedures on the resultant mechanical properties in the various alloys of uranium-titanium and uranium-molybdenum.
5. To determine the effect of alloy condition, i.e., heat treatment, structure (cast or wrought) and alloy chemistry on the materials modulus of elasticity and density.
6. To determine the effect of heat treatment on crystallographic structure and composition.

The last two objectives require a longer range study. The modulus measurements are being made using dynamic ultrasonic techniques. The crystallographic studies involve both x-ray diffraction and microprobe analyses of the samples in various conditions.

IV. MATERIAL PREPARATION

All materials used in this program were prepared by vacuum-induction melting the alloys of interest and casting them into 8 in. by 8 in. by 0.500-in.-thick plates. The plates were all rolled from salt from the starting thickness to a nominal thickness of 0.080 in. This is an ~ 85% reduction and is adequate to produce a material having a uniform equiaxed grain. After the salt rolling, the 0.080-in.-thick material was further warm rolled from a hot-oil bath down to ~ 0.050-in.-thick. The high-titanium alloy (> 1.5 wt% titanium) and the high-molybdenum alloy (> 1.5 wt% molybdenum) developed some edge cracking when warm rolled from the oil. It would, therefore, appear desirable to roll alloys having greater than 1% alloy addition from salt down to the desired thickness.

A. Uranium-Molybdenum Alloys

Several samples of the uranium-1.5 wt% molybdenum alloy have been prepared by salt rolling in the gamma temperature range. Material rolled in the gamma range has different mechanical properties from that rolled in the alpha range. This difference can be associated with a variation in the material's cooling rate which actually results in precipitation hardening in the molybdenum alloy. Table 1 presents mechanical properties of a uranium-1.5 wt% molybdenum alloy sample which was rolled either in the alpha range at 600°C or the gamma range at 800°C.

TABLE I

MECHANICAL PROPERTIES OF U-1.5 Mo ALLOY ROLLED IN THE GAMMA RANGE (800°C) AND ALPHA RANGE (600°C) OF THE PHASE DIAGRAM

SPECIMEN NUMBER	CONDITION	TENSILE STRENGTH, psi	YIELD STRENGTH, psi[1]	% ELONGATION 1/4"	1/2"	1"
1-1	ROLLED AT 600°C	134,700	60,400[2]	12	11	8
1-2		130,600	47,500	12	12	9
1-3		136,700	54,300	18	15	10
2-1	ROLLED AT 800°C	152,700	60,200[2]	8	4	2
2-2		155,800	97,000[2]	6	4	2
2-3		157,600	89,700[2]	8	5	4

[1] BASED ON 0.2% OFFSET FROM THE "APPROXIMATE MODULUS"

[2] FAILED IN THE SHOULDER AREA RATHER THAN AT THE DESIRED MID ZONE OF THE REDUCED SECTION.

All samples were tested in the "as-rolled" condition which corresponds to a recrystallized wrought structure. The microstructure of the alpha-rolled uranium-1.5 wt% molybdenum alloy is the typical martensite-like structure associated with other low-uranium alloys. The material rolled in the gamma range and slowly cooled had a complex structure that appeared to consist of a precipitated third phase in the grain boundaries of the alloy. This material has significantly higher ultimate tensile and yield strength than the alpha-range rolled material. Also, its ductility is significantly less than that of the alpha-range rolled material. Most of the reduction in ductility is assumed to be due to gases absorbed during rolling. No chemical analysis has been made, but previous experience with unalloyed uranium supports this argument. Samples of the same material discussed in Table I were subsequently quenched from the gamma range in water in an evacuated copper can to determine the resultant mechanical properties. The results are shown in Table II.

TABLE II

THE MECHANICAL STRENGTH OF WROUGHT U-1.5 Mo ALLOY IN THE GAMMA QUENCHED CONDITION

SPECIMEN NUMBER	CONDITION	TENSILE STRENGTH, psi	YIELD STRENGTH, psi	% ELONGATION 1/4"	1/2"	1"
1-1	ROLLED AT 625°C	171,400	101,200	16	11	9
1-2	γ QUENCHED AT 850°C	170,100	103,600	20	14	10
2-1	ROLLED AT 800°C	176,800	90,300	12	10	7
2-2	γ QUENCHED AT 850°C	178,400	96,600	16	13	10

As expected, there is no significant difference between the physical properties of the samples independent of their prior rolling history. The ductility of the vacuum-quenched material is significantly better than that of the slowly cooled material rolled in the gamma range. Metallography of the gamma-quenched material shows a clearly defined grain structure with an intragranular structure that looks like tempered martensite.

Additional studies are now underway to determine how artificial aging affects the properties of gamma-quenched uranium-molybdenum alloys. Sample preparation in the new test series has involved extrusion of cast ingots into round rods as the technique for primary ingot breakdown. Samples of cast material are also included in this program, and they have been subjected to gamma-range quenching and artificial aging. Tensile tests will be performed on all of this material as soon as it becomes available from the Shops Department.

Samples have been prepared, and measurements are being made to determine Young's modulus and the shear modulus. The density of the 1.5 wt% molybdenum alloy is 18.68 g/cm^3.

B. Uranium-Titanium Alloys

The uranium-titanium alloy system has been the subject of several investigations and is currently receiving a great deal of attention at several AEC Laboratories.

The effect of increasing titanium content on mechanical properties has been clearly demonstrated. Figure 1 is a plot of tensile and yield strengths of uranium-titanium alloys as a function of increasing titanium content. This study was performed over two years ago at Los Alamos and demonstrated the effect of salt annealing and vacuum annealing on the properties of U-Ti alloys heat treated below the alpha-beta transformation temperature. The results are exactly as would be expected; the vacuum annealed material has higher ultimate strength and ductility. These properties are related to the lower interstitial content of the vacuum-annealed stock.

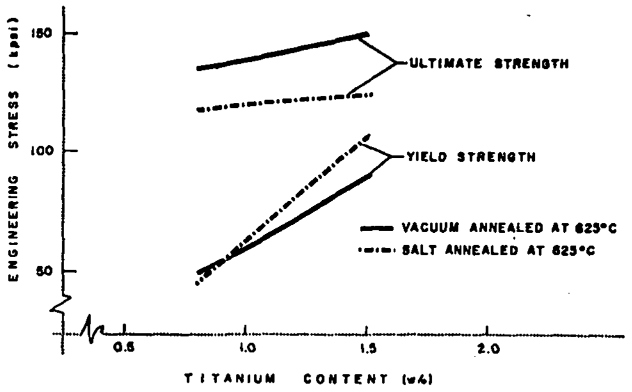

Fig. 1 Mechanical Strength vs Titanium Content For Uranium-Titanium Alloys

Recent experiments show that the uranium-titanium alloy can be greatly enhanced by various thermal treatments. Treatments performed to date involved heating the alloys into the single-phase gamma range and quenching them in water. The quenched alloys were then examined using metallography and hardness as a criterion. Figure 2 is a plot of the hardness developed in a uranium-0.5 wt% titanium alloy gamma-quenched and aged at three different temperatures for three different times. The hardness is greatly increased by aging at 400°C and appears to be greatest after a 4-h heat treatment. Aging at 200 or 600°C semms not to affect the hardness of the gamma-quenched sample.

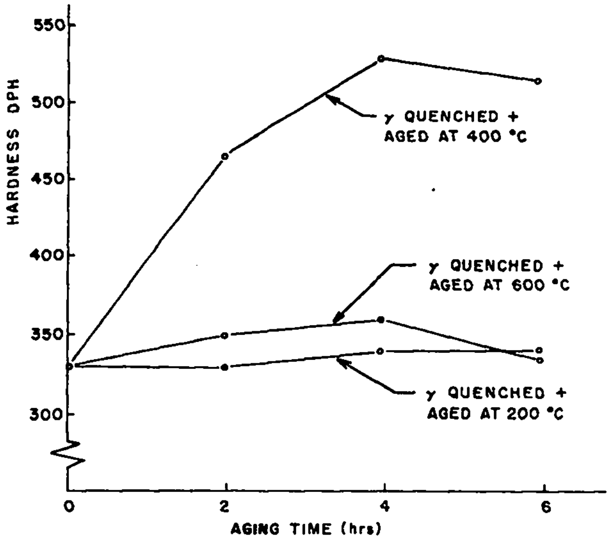

Fig. 2 The Effects of Various Aging Treatments On The Hardness Of A Uranium + 0.5 wt% Titanium Alloy

Figures 3 and 4 are plots of hardness vs aging time and temperature for the 0.8 and 1.5 wt% titanium alloys, respectively. The results are all consistent in that the hardness increases with increasing titanium content, and maximum hardening is produced in samples aged at 400°C.

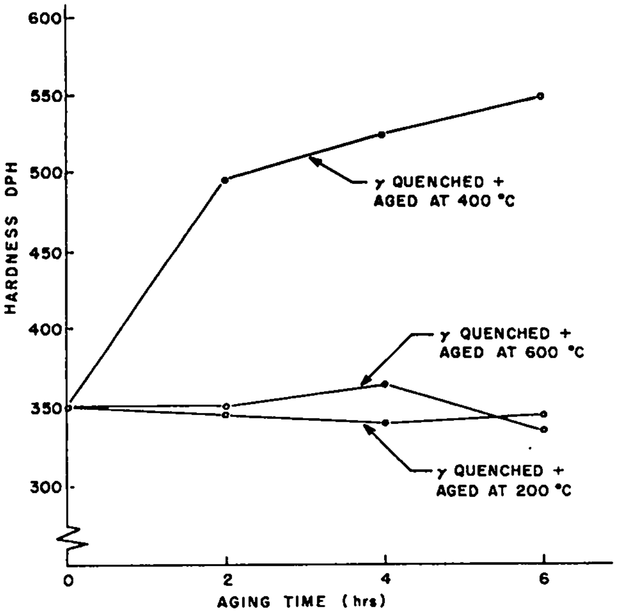

Fig. 3 The Effects of Various Aging Treatments On The Hardness of A Uranium + 0.8 wt% Ti Alloy

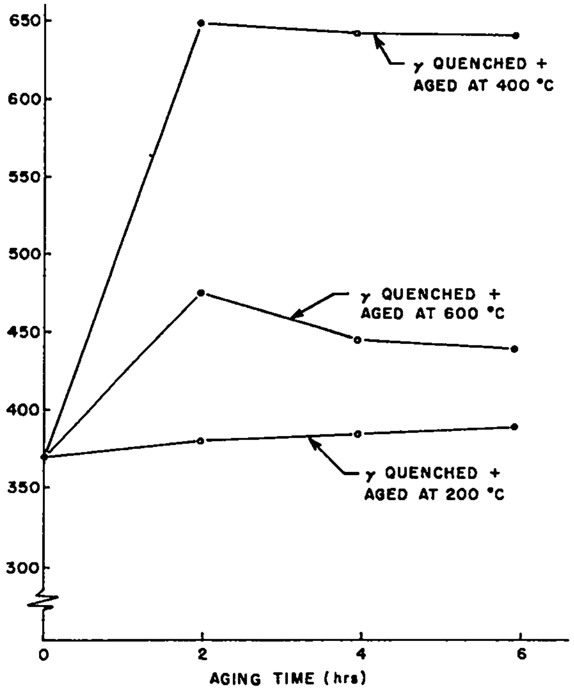

Fig. 4 The Effects of Various Aging Treatments On The Hardness of a Uranium + 1.5 wt% Ti Alloy

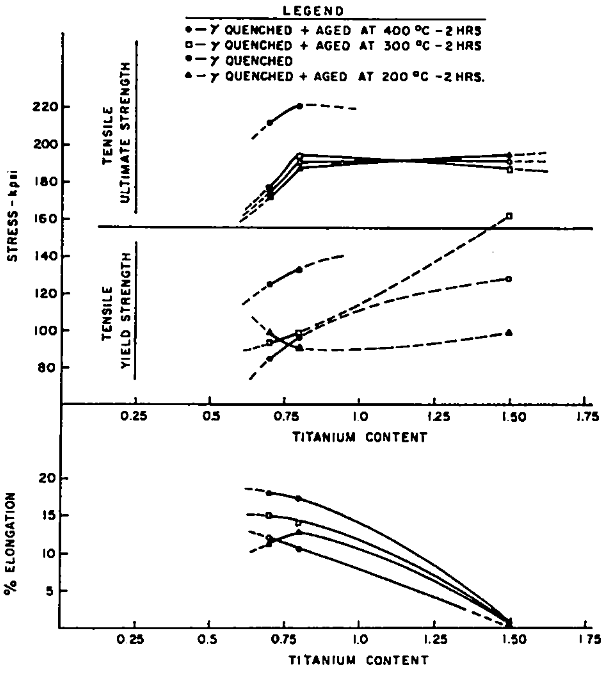

Fig. 5 Mechanical Properties of γ Quenched And Aged U-Ti Alloys Vs Titanium Content

A mechanical testing program has been conducted on the various U-Ti alloys heat treated in several ways. Figure 5 is a plot of the mechanical properties of three alloys which were gamma quenched and aged at different temperatures. The alloys contained 0.68, 0.78, and 1.56 wt% titanium, respectively. The highest strengths and the highest ductility were obtained in material aged at 400°C for 2 h. The 1.56 wt% titanium alloy had a very-low ultimate strength when aged at 400°C and displayed brittle failure in all cases. We believe that the low ultimate strength is a strong indicator of low fracture toughness in this alloy. One very interesting feature of these properties is shown in the alloy's ductility. The most ductile material was also the strongest. We believe that these properties can be attributed to the lower interstitial content in the material aged at 400°C for 2 h. Gamma quenching was performed by cladding the specimens in this copper foil, but this technique does not seem adequate for producing "as-quenched" material with very low interstitial impurities.

Figure 6 is two photomicrographs of the structure developed in gamma-quenched and aged, gamma-quenched U-0.68 wt% titanium alloy. The structure appears to be Widmanstatten in nature. The grain boundaries of the aged material appear to have some precipitate on them.

250X

γ Quenched

U.T.S. = 176.5 kpsi
Y.S. = 85.1 kpsi
% EL = 18.7
DPH = 340
ρ = 18.65 gm/cc

250X

γ Quenched + Aged at 400°C - 2 h

U.T.S. = 212.3 kpsi
Y.S. = 125.4 kpsi
% EL = 12.0
DPH = 410

Fig. 6 Structure Developed in γ quenched and Aged, γ quenched U-0.68 wt% Ti

Figure 7 is two photomicrographis of the U-0.78 wt% titanium alloy. Again, the Widmanstatten structure is evident in the quenched and aged sample. The general darkening of the structure of the aged sample could be evidence of precipitation.

250X

γ Quenched

U.T.S. = 191.8 kpsi
Y.S. = 97.0 kpsi
% EL = 18.5
DPH = 365
ρ = 18.602 gm/cc

250X

γ Quenched + Aged at 400°C - 2 h

U.T.S. = 221.6 kpsi
Y.S. = ? (1.)
% EL = ? (1.)
DPH = 440

(1.) Failures occurred in a brittle manner

Fig. 7 Structure Developed in γ quenched and Aged, γ quenched U-0.78 wt% Ti

Figure 8 is the photomicrographs of the microstructures developed in the gamma-quenched and aged, gamma-quenched U-1.58 wt% Titanium alloy. This structure is multiphase with a second phase appearing as the needle-like structure. The exact nature of this phase is not know. There is considerable

γ Quenched

U.T.S. = 180.0 kpsi
Y.S. = (1.)
% EL = 1%
DPH = 505
ρ = 18.18 g/cc
(1.) Failure occurred in a brittle fashion

γ Quenched + Aged at 300°C - 2 h

U.T.S. = > 200 kpsi
Y.S. = (1.)
% EL = (1.)
DPH = 560
(1.) Failure occurred in a brittle fashion

Fig. 8 Structure Developed in γ quenched and Aged, γ quenched U-1.58 wt% Ti

precipitate in the grain boundaries of these samples. The matrix structure appears to contain a martensite -like structure. This material is extremely brittle.

X-ray diffraction and microprobe analysis of uranium alloys is being performed by LASL Group CMB-13, and has not been completed.

The uranium-molybdenum system has also been investigated from the standpoint of precipitation hardening. Jones et al[3] reported that alloys of uranium with up to 2.2 wt% molybdenum showed precipitation hardening when quenched from the gamma phase and reheated to 400 to 500°C for several hours. Other investigators[4,5] have shown that the mechanical properties of the uranium alloys are greatly effected by various heat treatments.

ACKNOWLEDGMENTS

I wish to acknowledge the valuable technical guidance on this program given by James Taub, Materials Technology Group Leader, and Gale S. Hanks, Fabrication Section Leader of Group CMB-6.

Other people who were instrumental in this evaluation are George Jaynes, Foundry Section Leader, CMB-6, who was responsible for alloy casting; and Dale S. Fisher, Fred Flick, Victor Vigil, John LaMotte, and Quay Nims, who processed the material into forms usable for the evaluation program.

I also thank T. I. Jones, Section Leader of the Physical Metallurgy Section, CMB-6, for the metallographic specimen preparation and mechanical testing.

Finally I thank the Shops Department and other support facilities of the laboratory for their contributions to the program.

REFERENCES

3. T. I. Jones, C. G. Hoffman, J. M. Taub, and D. T. Doll, "The Influence of a Precipitation Hardening Heat Treatment on the Hardness of Several Uranium-Molybdenum Alloys", Los Alamos Scientific Laboratory Report LA-1715 (Aug. 1954)
4. E. B. Blasch, H. M. Drucker, D. M. Page, "The Development of Depleted Uranium-2 wt% Molybdenum for Specific Applications", Private Communication.
5. E. G. Zukas, "Properties of As-Cast and Heat Treated 2 wt% Molybdenum Uranium", Trans. American Society Metals,(1959), Vol. 51, pp 752-757.