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URANIUM ALLOY DEVELOPMENT

PART VI

Uranium-Molybdenum Alloys

WORK DONE BY:

A. U. Seybolt

L. B. Stark

REPORT WRITTEN BY:

A. U. Seybolt

Metallurgy, All - Uranium

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ABSTRACT

Uranium alloys containing 0.71 to 3.12 per cent molybdenum have been examined in a number of different heat treatments, and a tentative phase diagram for this concentration region has been prepared.

The most promising heat treatable alloy contains about 2 per cent molybdenum, and the optimum strength properties are developed after quenching in water from 700° C followed by a one hour treatment at 300° C.

The modulus of elasticity in the 700° C quenched state is little over half that of the alloy in the fully hardened condition.

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URANIUM-MOLYBDENUM ALLOYS - Part VI

The four uranium-molybdenum alloys ranging from 0.71 per cent molybdenum to 3.12 per cent molybdenum described in the report of March 15, 1944, have been given a series of heat treatments after which the hardness and microstructure were examined. Six samples of each alloy were held at 900° C. for two hours to secure approximate homogenization, and the individual samples were then heated for 2 hours at 800° C., 700° C., 600° C., 500° C., and 400° C., quenching from each temperature level. The hardness values obtained are shown in Table I.

Hardness of Heat Treated Uranium-Molybdenum Alloys

As previously demonstrated, the highest hardness values were obtained on reheating the 900° C. quenched alloys at 400° C. The comparatively high hardness of the 1.09 and 2.26 per cent Mo alloys as quenched from 900° C. is probably due to partial transformation because of inadequate quenching. The 3.12 per cent alloy is more readily quenched and shows a lower hardness in the same condition.

Table I. Rockwell A Hardness of Uranium-Molybdenum Alloys Quenched from Different Temperatures

Alloy No.	Per Cent Molybdenum Analysis	As Cast	900° C	800° C	700° C	600° C	500° C	400° C
2264	0.71	65	60	63	66	53	65	65
2267	1.09	64	71	70	71	63	69	74
2266	2.26	69	70	70	71	66	70	78
2268	3.12	71	65	65	65	67	70	77

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Microstructures

The microstructure observed for each alloy in each heat treatment is shown in Fig. 1. The pictures are mounted on temperature-composition coordinates to better visualize the influence of heat treatment on structure. The Rockwell A hardness is entered under each micrograph.

The four pictures in the upper left hand corner show two phases, but this almost certainly caused by the ease with which decomposition can occur with relatively dilute alloys. It will be noted that at the same temperature level (800° C. and 900° C.) the 2 and 3 per cent alloys are essentially single phase ones. Also, the same structure is preserved in these alloys down to 700° C. On the other hand, it is clear that the 0.71 and 1.09 per cent alloys were quenched from a two phase region at 700° C.

At the 600° C. level, all four alloys are evidently in the same two phase field. The major difference is a strong tendency for the more dilute alloys to etch darker than more concentrated alloys.

At the 500° C. and 400° C. levels, the situation is by no means clear, and there is no reason to suppose that equilibrium was even approximated. However, there is a certain amount of evidence that in this region of the constitutional diagram all alloys lie in the same phase field. The 0.71 per cent alloy appears to show the same structure at both 500° C. and 400° C., and there is no question that the 1.09 per cent alloy is the same at 500° C. as at 400° C. The 2.26 and 3.12 per cent alloys show essentially the same structure at 500° C., but at 400° C. the difference between these two is striking. However, it is quite possible that the same phases are present, only their distribution is quite different.

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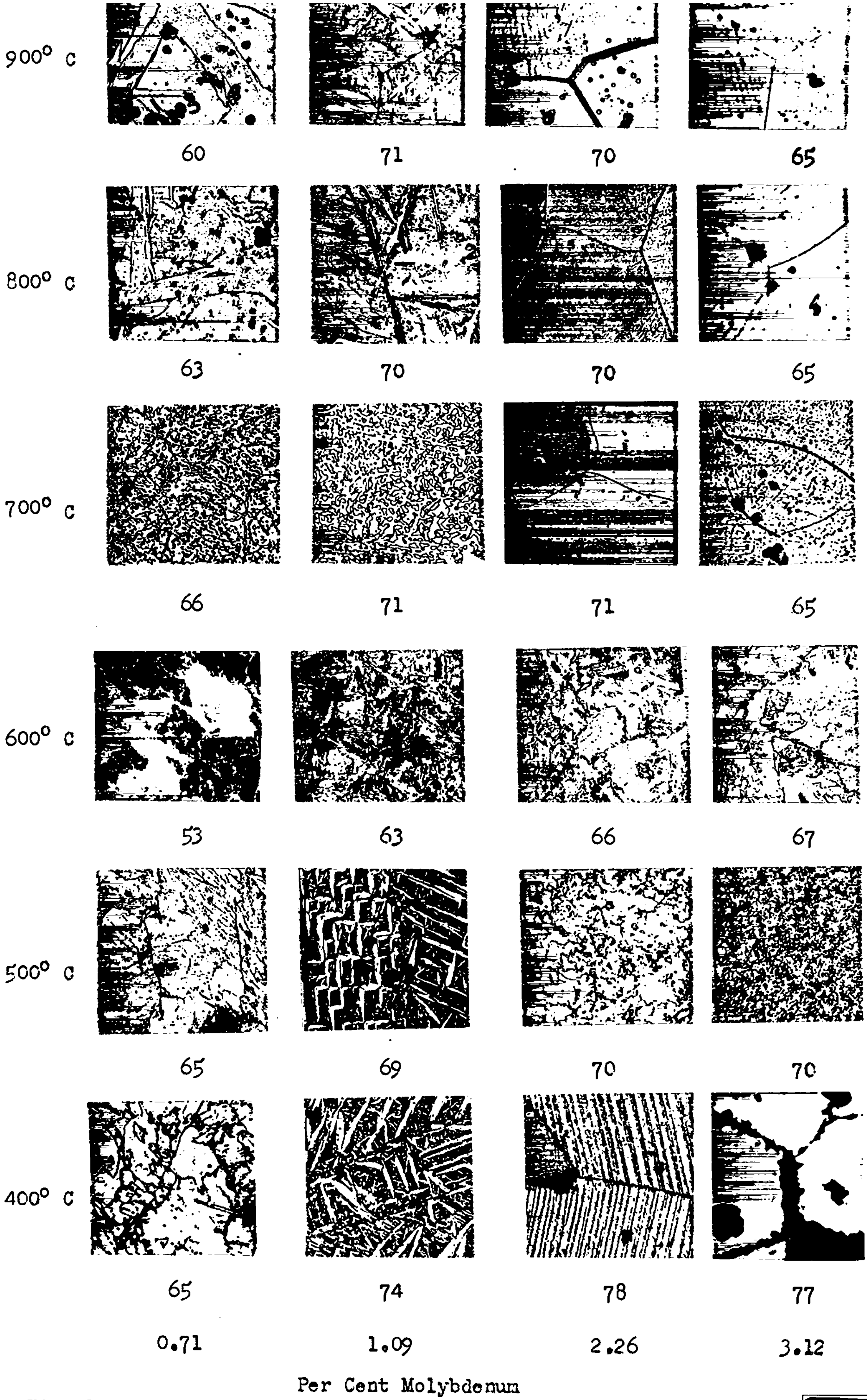

Fig. 1. Micros[illegible] [illegible]eated Alloys x 250

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From a practical heat treating view point, the main thing of interest is that a temperature of 900° C. is far higher than necessary to secure the single phase structure in 2 and 3 per cent alloys. It appears that quenching at 700° C. followed by the 400° C. treatment should be just as effective as a 900° C. quench and the same low temperature heat treatment. To test this, an extra disc cut from the 2.26 per cent alloy was quenched from 900° C. and then aged 1 hour at 400° C. The Rockwell A hardness was 77 (Rockwell C 52). This demonstrated the effectiveness of the 700° C. quench.

In order to clarify the microstructures of the four alloys in the 400°-600° C. level, two more samples of each alloy were treated as follows: one set of samples was heated 24 hours at 600° C. following the usual 900° C. homogenizing treatment. After the microstructures were examined, the same samples were held at 500° C. for 48 hours after the 900° C. homogenization treatment. The results are shown in Fig. 2. The appearance of the microstructures is in general different from that observed for very short heat treatments in Fig. 1. However, the 0.71 per cent molybdenum alloy shows essentially the same structures as before. The Widmanstatten character of the 1.09 per cent alloy still persists. Perhaps the most interesting feature is the similarity of the structure of the 2.26 Mo and 3.12 Mo alloys at 600° C. and 400° C. It still seems possible that all of the structures shown are in the same phase field, but this is, of course, not certain.

In order to find out how much lower than 700° C. a 2 per cent alloy could be quenched and still retain the "gamma" phase, a sample of this composition was quenched after 24 hours at 675° C. The resulting structure

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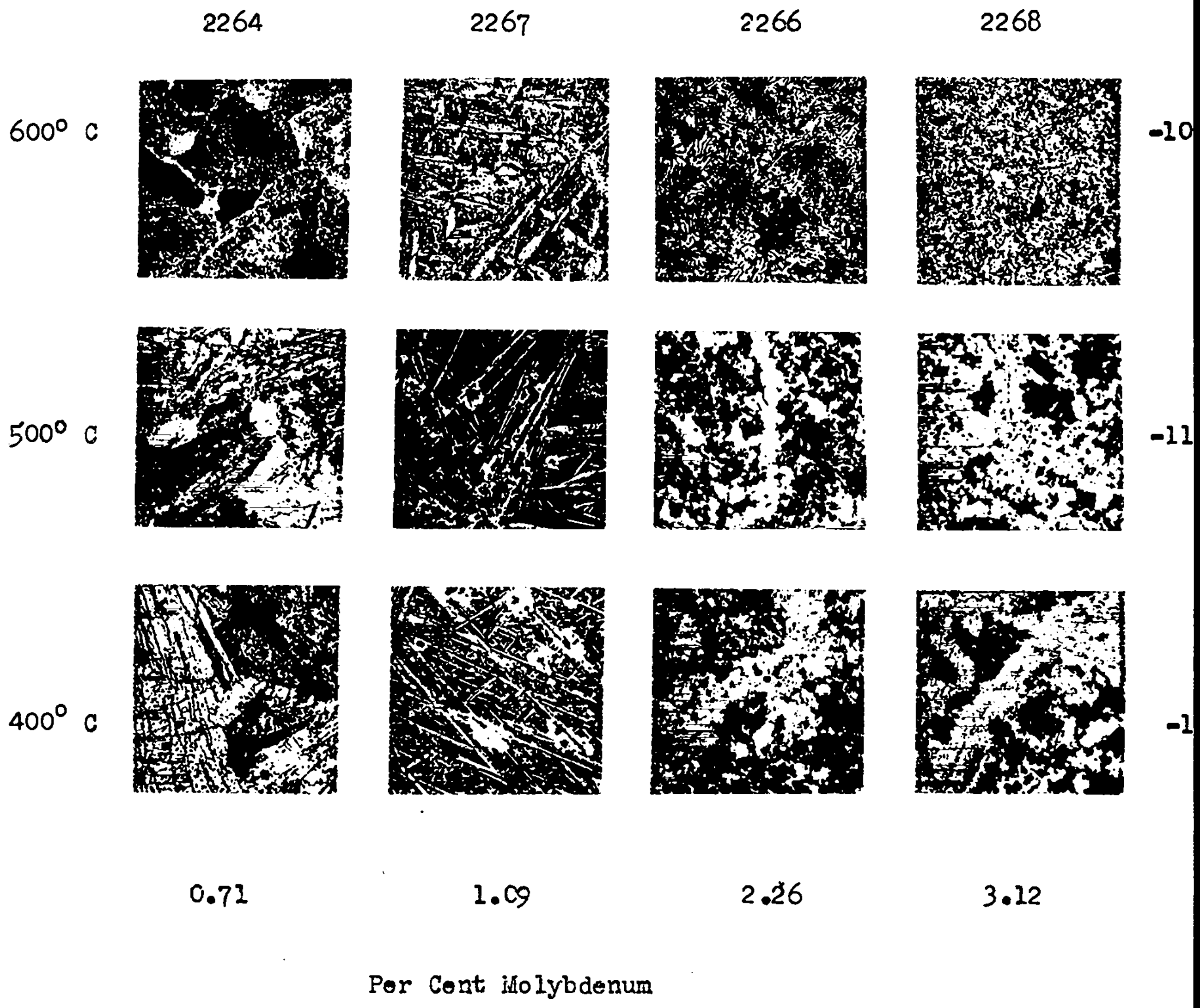

Fig. 2 Microstructure of the Long Time Heat Treated Alloys x 250

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is shown in Fig. 3. Apparently the transformation to beta occurs between 700° C. and 675° C.

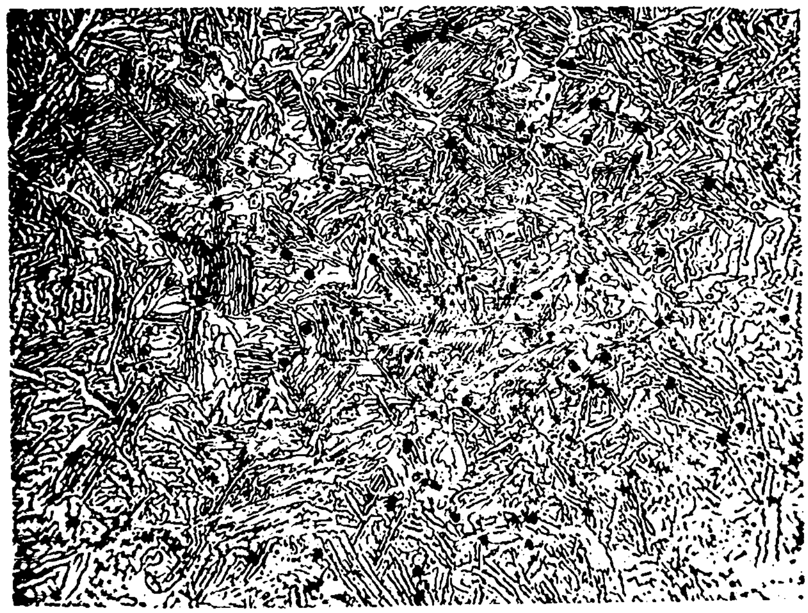

Figure 3: Structure of a 2.0 percent Mo-U alloy. Quenched after 24 hrs. at 675° C. Etched in 2 percent oxalic acid

2437-4-C x 250

Tentative Phase Diagram

A tentative phase diagram is shown in Fig. 4. This diagram appears to fit the observed structures with the possible exception of the lower temperature structures where there is considerable doubt as to what is happening. The alloys examined are indicated on the diagram by crosses; the results at 7 and 10 per cent molybdenum and 900° C. are based on structures observed and reported previously.

Additional Hardness Data on Low Temperature Heat Treatments

In order to find out the optimum low temperature heat treatment for aging 700° C. quenched samples, a series of heat treatments on a 2 percen

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1100
1000
900
800
700
600
500
400
300
γ
β
α
1 2 3 4 5 6 7 8 9 10 11 12 13
PERCENT MOLYBDENUM
FIG 4
TENTATIVE U-MO PHASE DIAGRAM

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alloy were conducted at 200° C., 300° C., and 400° C. A different sample was used for each temperature level, and was successively heat treated for 1 hr., 2 hr., 4 hr., and 8 hr. The results are shown in Table II.

Table II. Rockwell A Hardness After Successive Heat Treatments on a 2 percent 700° C. Quenched Molybdenum Alloy

Temperature		1 hr.	2 hr.	4 hr.	8 hr.
200° C.	Average of Results on #2436 and #2437 containing 2.02 and 2.00 percent Mo.	75	75	75	76
300° C.		77	77	77	78
400° C.		76	76	76	74

It will be observed that at any temperature level, time of heating is unimportant. Also, the actual temperature in this range does not matter much, although the results at 300° C. appear to be somewhat higher than at 200° C. or 400° C. This is fortunate, as uranium oxidizes much more rapidly at 400° C. than at 300° C., hence a one hour low temperature treatment at 300° C. appears to be most practical from the standpoint of securing nearly maximum strength. Shorter annealing times at 300° C. will be investigated later.

Compression Stress-Strain Results

Two 2 percent molybdenum alloys were cast in the vacuum melting furnace in the form of cylinders 9/16 in. dia. by 2 in. long. These were machined to 3/8 in. dia. by 2 in. long and were tested in the compression jig with Tuckerman strain gauges attached to opposite sides of the specimens. The results are shown in Table III.

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Table III. Summary of Compression Stress-Strain Results on Two 2 Percent Molybdenum Alloys

Alloy No.	% Mo Analysis	Heat Treatment	.2% offset yield strength psi	.02% offset yield strength psi	Modulus of elasticity psi
2436	2.02	Quenched 700° C.	103,500	74,500	13.2×10^6
2436	2.02	Quenched 700° C. aged 2 hr. 400° C.	248,000	190,000	24.2×10^6
2436	2.02	Quenched 700° C.	109,000	70,750	14.3×10^6
2437	2.00	Quenched 700° C. aged 2 hr. 400° C.	226,000	180,000	22.8×10^6
2437	2.00	Quenched 700° C.	109,500	65,000	13.8×10^6

It is interesting to note that the modulus of elasticity in the 700° C. quenched condition is about 14×10^6 psi while in the low temperature condition it is about $23\text{-}24 \times 10^6$ psi. This is probably because of the difference in crystal structure between the two conditions. The low temperature heat treatment approximately doubles the yield strength compared to the quenched condition.

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