URANIUM-12 w/o MOLYBDENUM HOMOGENEITY AND DENSITY

E. S. Foster
January 21, 1955

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WESTINGHOUSE ELECTRIC CORPORATION
ATOMIC POWER DIVISION

PITTSBURGH

P. O. BOX 1468

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INTRODUCTION

Several thousand pounds of uranium-12 w/o molybdenum alloy were melted for the fuel materials development program for possible application in the Pressurized Water Reactor, PWR Project. Extensive development work was done on this alloy during the period May, 1954 to May, 1955 because at the time it was one of the better metallic fuels in the experimental program from the standpoints of corrosion resistance and resistance to irradiation effects. Melting and casting properties of the uranium-12 w/o molybdenum fuel alloy were investigated to determine the most satisfactory procedures for preparing the alloy.

Uranium-12 w/o molybdenum casting properties discussed herein are limited to the homogeneity and density of material vacuum induction melted and cast in graphite molds, and consumable electrode arc remelted ingots. Graphite was first considered as a mold material for uranium-12 w/o molybdenum alloy when it was planned to cast ingots weighing more than 30 lb. Water cooled copper molds were satisfactory for smaller chill castings even though secondary piping extended for practically the full length of the casting. This was not particularly harmful since the induction castings were remelted by the consumable electrode arc process in order to improve the soundness. For larger castings, on the order of 65 lb, 2-in. diam by 26 in. long, mold cost and the possibility of alloying with copper because of insufficient water cooling, became important. Consequently, if graphite molds were to be utilized for possibly eliminating the consumable arc remelting operation casting soundness and homogeneity required investigation. Some advantages to be obtained by using graphite molds were: low cost, good machinability, strength

at high temperatures, low thermal co-efficient of expansion, and excellent resistance to thermal shock.

EXPERIMENTAL PROCEDURE

The ingots were melted in vacuum induction melting furnaces in ZrO_2 coated graphite crucibles with similarly coated graphite stopper rods, and were cast in split-type graphite molds which were also coated with ZrO_2 . The coated parts were dried for 24 hr at $100^\circ C$ before they were used. Induction castings which were consumably remelted were made in an arc furnace as illustrated in WAPD-T-260, Fig. 4.

Initial melts cast in graphite molds were small, 17 lb, 2 1/8-in. diam x 8 in. long. One such casting, No. Y-393, was sampled to check molybdenum homogeneity. A piece about 1 1/2 in. long was cut from the bottom and chips were obtained from three annular rings of the cross section to check molybdenum distribution from the surface to the center of the casting. The remaining 6 1/2-in. long piece was halved longitudinally and drillings were obtained at six locations on the length from one half of the cut piece. The other half was machined and ground on the cut surface and examined visually for porosity.

Two 50 lb induction-melted graphite castings, 2-in. diam x 26 in. long, Nos. 127 and 135, were sampled to check molybdenum homogeneity from the bottom to top of the castings. Samples were obtained at 8 places, or every 3 1/4 in., on the length of each casting. These castings were representative of alloys made for development experiments.

Consumable electrode arc remelting of induction castings was considered to be advantageous from the standpoints of improving soundness and homogeneity. Improved soundness was found to be the case, since from the nature of the operation only a thin layer of metal is molten at one particular time and freezing occurs in a directional manner, that is, from bottom to top. It was known from previous experimental work that

an electrode containing gross alloy segregation would not be improved appreciably in homogeneity by the consumable electrode arc melting process. Micro homogeneity might be improved since the liquid metal solidifies rapidly permitting minimum segregation. One example to show molybdenum distribution in an induction casting and subsequent consumably remelted ingot was included. From the induction casting, No. 083, 2-in. diam x 27 in. long, about 7 in. of material was cut off the bottom. The remaining 20 in. was consumably remelted to a 3-in. diam ingot, No. 086. Samples were obtained from both the induction casting and consumably remelted ingot to check molybdenum distribution.

Density measurements were made on samples obtained from a 65-lb, 2 3/8-in. diam x 24-in. long induction-melted graphite casting, No. M-50, and an induction casting which was consumably remelted into a 60-lb ingot, 4-in. diam x 8 in. long, No. J-906. Since both ingots were halved longitudinally to obtain the samples, the halves which were not sampled were machined and ground and visually examined for porosity.

DISCUSSION

The analytical data from Ingot No. Y-393, listed in Table I, showed molybdenum concentration to increase slightly from bottom to top. Since sintered molybdenum pellets were used for the alloy addition, probably insufficient alloying was allowed before the melt was poured. In general, sintered molybdenum pellets produced poor melting results and were abandoned in favor of hot-drawn rod, 1/4-in. diam. With regard to porosity, the ground piece looked sound, but when etched, a few pin-point etching stains remained near the top and along the axis of the piece indicating some lower density areas.

Alloy homogeneity data, listed in Table II, were obtained from two 50 lb, 2-in. diam x 26-in. long induction-melted graphite castings, Nos. 127 and 135. The

determinations showed excellent molybdenum distribution for both castings. The values are believed to be accurate to within $\pm 2.7\%$ of the amount reported.

The analytical data from induction casting No. 083 and the subsequent consumable remelt of the top 20 in., Ingot No. 086, is listed in Table III. Since the molybdenum determinations obtained from the induction casting indicated that good homogeneity was obtained, there was no reason to believe that the molybdenum analyses from the consumable remelt would be any different. It was not learned how much consumable electrode arc melting improved alloy homogeneity since an electrode having areas of gross segregation was not remelted.

The density measurements, listed in Table IV, obtained from Ingot No. M-50, an induction-melted graphite casting, and Ingot No. J-906, a consumably-remelted graphite casting, showed the latter to be slightly denser. Figs. 1 and 2 also bear this out, even though all of the values are within the acceptable density range for uranium-12 w/o molybdenum alloy, which is $16.95 \pm 2\%$ gms/cc.

CONCLUSIONS

It was shown that graphite molds could be used successfully to cast uranium-12 w/o molybdenum in shapes approximately 2-in. diam x 26 in. long, and maintain alloy homogeneity to within the accuracy of the chemical determination, which is 12.0 ± 0.3 w/o molybdenum.

Consumable remelting improved the density by about 0.05 gms/cc but it was not learned how much it improved homogeneity.

/amc
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TABLE I

Analytical Data from Induction Casting No. Y-393
2 1/8-in. Diam x 8 in. Long

<u>Ingot Number</u>	<u>Casting Weight</u>	<u>Mold</u>	<u>Sample Location</u>	<u>Mo Analysis (%)</u>	<u>Nominal Composition</u>
Y-393	17 lb	Graphite	1 1/2 in. from bottom		U-12 w/o Mo
			Outside Surface	11.3	
			Middle Ring	11.3	
			Center	11.3	
			2 in. from bottom	11.5	
			3 in. from bottom	11.7	
			4 in. from bottom	11.9	
			5 in. from bottom	12.0	
			6 in. from bottom	12.0	
			7 in. from bottom	12.0	

TABLE II

Analytical Data from Two 50-lb, 2-in. diam x 26-in. long Induction Castings;
Nos. 127 and 135

<u>Ingot Number</u>	<u>Ingot Weight</u>	<u>Mold</u>	<u>Sample Location</u>	<u>Mo Analysis (%)</u>	<u>Nominal Composition</u>
127	50 lb	Graphite	1 (Bottom)	11.8	U-12 w/o Mo
			2	12.1	
			3	11.9	
			4	12.0	
			5	11.9	
			6	12.0	
			7	12.0	
			8 (Top)	12.0	
135	50 lb	Graphite	1 (Bottom)	12.0	U-12 w/o Mo
			2	11.9	
			3	12.0	
			4	11.9	
			5	12.0	
			6	12.1	
			7	12.1	
			8 (Top)	11.9	

TABLE III

Analytical Data from Induction Casting No. 083 and
Subsequent Consumable Remelted Ingot No. 086

<u>Ingot Number</u>	<u>Ingot Weight</u>	<u>Mold</u>	<u>Sample Location</u>	<u>Mo Analyses (%)</u>	<u>Nominal Composition</u>
083	50 lb	Graphite	Bottom	11.9	U-12 w/o Mo
			3 1/2 in. from bottom	12.0	
			7 in. from bottom	12.0	
			26 in. from bottom or top	11.9	

The top 20 in. of Ingot No. 083 was consumably remelted to 3-in. diam Ingot No. 086.

<u>Ingot Number</u>	<u>Crucible</u>	<u>Sample Location</u>	<u>Mo Analyses (%)</u>	<u>Nominal Composition</u>
086	Water Cooled Copper	Bottom	12.0	U-12 w/o Mo
		Middle	12.1	
		Top	11.9	

TABLE IV

Density Measurements from Induction Casting No. M-50
and Consumable Remelted Ingot J-906

<u>Ingot Number</u>	<u>Type of Ingot</u>	<u>Sample Location</u>	<u>Density Measurement</u>	<u>Mo Analyses (%)</u>	<u>Nominal Composition</u>
M-50	Induction Casting	Bottom	16.94 gms/cc	12.0	U-12 w/o Mo
		6 in. from bottom	16.90 gms/cc		
		12 in. from bottom	16.80 gms/cc		
		18 in. from bottom	16.85 gms/cc		
		Top	16.93 gms/cc	12.1	
J-906	Consumable Remelt	Bottom	16.94 gms/cc	11.9	U-12 w/o Mo
		Middle	16.96 gms/cc		
		Top	16.90 gms/cc	11.8	

Fig. 1

Top

18 in. from Bottom

12 in. from Bottom

6 in. from Bottom

Neg. No. 14706, Ingot M-50, U-12 w/o Mo; Photograph shows the casting cut in four length segments then halved longitudinally. Notice porosity along axis of casting extending to the bottom 6-in. piece.

Fig. 2

Top Half

Bottom Half

Neg. No. 14707, Ingot J-906, U-12 w/o Mo; Consumable remelt. Photograph shows ingot cut in half transversally then halved longitudinally. The material was very sound.