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PRELIMINARY REPORT ON VACUUM CASTING OF URANIUM INTO HEATED MOLDS

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ABSTRACT

Cast uranium with a carbon content/as low as 220 ppm, nitrogen content as low as 20 ppm, and density as high as 19.00 g/cc at both the bottom of the ingot and five inches from the top and with excellent surface and free of pipe below one inch from the top has been produced at Plant 6E by casting uranium into heated graphite molds. Melts have been poured at 2400°F (thermocouple temperature in the base of the crucible) and the surfaces obtained indicate that pouring temperature can be dropped even lower.

The experimental heating coil used required the lowering of the top of the charge in the mold to prevent pipe, which thus decreases production. Cooling time is also excessive with the present coil and insulation. Redesign of the coil and change of insulation are being planned. Further studies of hot topping procedure and of mold temperatures are continuing.

Due to differences in mold capacity, limited by space from floor to furnace, and to lengthened cooling cycle the Plant 6E production would be decreased by about 25% by the duplication of the present experimental assembly. The changes necessary to restore this production loss are discussed in this paper.

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INTRODUCTION

The production of vacuum cast uranium metal with surfaces suitable for rolling, i.e., free of cold-shuts, splashes, beads, and other imperfections and at the same time low in carbon and nitrogen and high in density, has offered considerable difficulty since the beginning of the uranium program. Since the beginning of the production of longer ingots at Plant 6-E about August 1, 1951 surfaces of the ingots were considerably improved but the carbon content of the metal was increased from control limits of 300 ppm $\pm$ 50 to 465 ppm $\pm$ 80. This increase in carbon content was brought about by raising the nominal temperature held during the final period of melt and at pouring from 2475°F $\pm$ 50° to 2650°F $\pm$ 50° which was done in order to improve the previously accepted surface, since the summer rollings at Lockport and the rollings of the longer ingots at Allegheny Ludlum had revealed the fact that pre-August surfaces had been unsatisfactory for several months.

At a meeting held in the New York A.E.C. office to settle upon steps necessary for increased production at Plant 6-E, the improvement of the surface of the ingots was one of the problems considered. It was pointed out by the writer that surfaces had been improved by making the above-mentioned change in temperature, but at the expense of an increase in carbon and nitrogen and a decrease in density. The writer then stated that a satisfactory surface could be obtained with low carbon and nitrogen and high density by pouring into heated molds at or near a temperature equal to the melting point of the metal. Authorization was then granted by the Atomic Energy Commission to Mallinckrodt Chemical Works to design and construct or to have designed and constructed a heating coil and vacuum jacket for testing such a process. The assembly was designed by Singmaster and Breyer and was very quickly fabricated by the active cooperation of Singmaster and Breyer, Atomic Energy Commission, and Mallinckrodt personnel. The first heat was made in this furnace on November 12, 1951.

EQUIPMENT AND PROCEDURE

The mold heating coil is designed in two sections, the upper section being 13½" long and having 14 turns of 5/8" o.d. copper tubing, and the lower section 27" long with 13 double turns in parallel. The coil is 10 7/8" i.d. by 12 1/8" o.d. by 40 1/2" long overall. The turns are supported on micalex legs which extend 5 1/2" below the bottom end of the coil, to support the coil at such a height as to prevent too much energy loss to the bottom of the vacuum jacket or tank. The coil is placed in a water cooled vacuum jacket

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TABLE I

CONDITIONS OF MELTING, POURING AND HOT-TOPPING WITH HOT MOLD

Date	Run No.	6-E Heat No.	Wt. of Charge lbs.	Wt. of Crude Ingot lbs.	Diam of Mold inches	Length of Ingot inches	Heating Cycle				Pour Temp. T.C. °F	Hot Top Temp. (Max) °F	Distance Top of Ingots to Heat Center inches	Length of Pipe in.	Qual. of Surface	Vac. during melt microns	Remarks		
							min	KW	min	KW								min	KW
11/13	1	5368	580.9	562.0	5	48	45 @	86;	24 @	60;	13 @	35	2400	2250.	5	13	good	300-400	
11/14	2	5457	560.1	537.0	5	46	40 @	86;	21 @	60;	14 @	35	2415	2250	5	13	good	800-1000	
11/16	3	5499	565.0	540.0	5	46	41 @	86;	22 @	60;	20 @	33	2420	2250	5	13	good	61-300	
11/20	4	5638	519.8	498.5	5 3/16	36	37 @	86;	30 @	60;	13 @	35	2415	2250	0		good	1000	
11/27	5	5867	549.7	514.5	5 3/16	37	37 @	86;	33 @	60;	14 @	30	2390	2250	0	3.5	good	400-800	
11/28	6	5911	554.2	534.0	5 3/16	38 5/8	37 @	86;	32 @	60;	17 @	30	2415	2250	0	5	good	100	Hot topping temp. was excessive
11/30	7	5990	554.0	274.0	5 3/16		37 @	86;	29 @	60;	20 @	30	2500	2250	0	--	cold shuts on bot- tom	200-300	Mold leaked due to cracked section. Mold T.C. destroyed.
12/7	8	6230	555.2	534.0	5 3/16	38 1/2	44 @	86;	29 @	60;	20 @	30	2365	2180 ?	0	--	Void on side up- per half	300-400	Mold T.C. burned out. Temp. excessive on hot topping
12/10	9	6328	551.7	530.0	5 3/16	38 1/2	39 @	86;	29 @	60;	18 @	30	2400	2150	0	1	good	15-200	

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TABLE II

CHEMICAL QUALITY AND DENSITY OF URANIUM CAST IN HOT MOLD.

Date	Run No.	6-E Heat No.	Density Bottom	Density Top	Carbon	Nitrogen	Magnesium	Silica
11/13	1	5368	18.97	18.98	360	30	< 1	
11/14	2	5457	18.98	18.99	310	25	3.2	
11/16	3	5499	18.99	19.01	250	34	< 1	
11/20	4	5638	18.98	18.99	220	20	< 1	
11/27	5	5867	18.98	18.97	380	22	< 1	
11/28	6	5911	19.00	18.95	340	30	< 1	
11/30	7	5990	18.98	19.00	500	67	< 1	
12/7	8	6230	18.98	18.96	380	30	< 1	
12/10	9	6328	19.00	19.00	250	30	< 1	

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The coil is insulated from the hot mold with cylindrical sections of Kaocast insulation 8" i.d. x 9 3/4" o.d., fired in the outgassing of the hot mold furnace. The molds now used are of standard length and diameter, but the sections are cemented together at the joints with "C-3" carbonaceous cement, except the upper joint which is cemented only with the MgO slurry used for mold dressing. The cementing is necessary to prevent leaking of the molten metal at the hot joints. The joints are self-sealing in a cold mold. The molds are dressed with two coats of MgO slurry.

RESULTS

The conditions of heating the molds, of melting and of pouring, and the physical results of the heats are presented in Table I. The chemical quality and density of the products are shown in Table II.

DISCUSSION OF RESULTS

It will be observed that in the first run an excellent surface was achieved and the carbon content had been reduced to the earlier carbon range of 300 ppm by pouring at a nominal temperature of 2400°F. However, the upper section of this ingot contained a pipe 13" long from the top of the ingot. Since it is desired to crop not more than five inches from the billets and less if possible, such a pipe would decrease the total plant throughput by 18%. Two more heats were run similarly with some variations in the hot topping procedure but still with 13" pipe. An examination of the heat distribution along the mold with both sections of the coil on during the preheating and up to pouring revealed the fact that the hottest point on the outside of the mold and presumably, on the inside, was at the junction of the two coils, which is 13" below the top of the ingot. With such a heating system the last metal to freeze may be as low as this point; hence the pipe will either be continuous for 13" or if discontinuous there will at least be a shrinkage cavity this far down. In order to determine how much pipe would be produced with a hot mold with hot topping and with the top of the ingot at the optimum position with respect to the heat center of the hot topping area, a charge was used in run No. 5 which placed the top of the ingot at the center of the upper coil, producing thereby an ingot 39 1/2" long instead of the usual 46" long. With this charge the mold was first heated with the entire coil; toward the close of the heat the mold was heated with the upper coil only. In this way the heat center was moved up from the junction of the two coils, which is thirteen inches below the top of the coil. Since the top of the poured melt occurred at this point, the pipe extended only three and one half inches down. With a similar charge in Heat No. 9 a pipe of only one inch was obtained by a still better control of the hot topping.

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It will be seen in Table II that carbon has been reduced to as low as 220 ppm, with a range of 220 to 380 ppm for all the conditions used thus far. (The 500 ppm in Heat No. 7 was obtained when the cracked mold leaked and destroyed the mold thermocouples after which the heating of the mold in hot-topping was excessive.)

Nitrogen has been reduced to as low as 20 ppm, with a range of 20 to 34 ppm (67 ppm in Heat No. 7 again due to over heating after loss of thermocouples), plant control limits of 36 to 60 ppm, with weekly averages of 45 to 50 ppm.

The density has been increased to a range of 18.95 to 19.00 at the equivalent of the present top of the shippable metal, as compared with a median of 18.93 with 4% below 18.82 in present plant production.

The effect of the lower temperatures of pouring on casting yield has been negligible, yields of metal poured ranging from 94 to 98.7 as compared with plant weekly averages ranging from 96 to 97%.

However, the production obtainable per heat with the present coil would be only 95% of the present production per heat, assuming a two-inch crop on a 550 pound charge could be maintained. Not sufficient cases are yet on hand to establish this possibility as a certainty. Only 89% of the present plant production could be maintained with the cooling cycle required ($2\frac{1}{2}$ hours) by the present hot mold assembly, thus reducing the total plant production to 75% of the present production. Hence the following investigations remain to be done before the installation of mold heating coils could be made without decreased production.

RECOMMENDATIONS

As shown above, the present coil and furnace body have the following difficulties:- The center of heat of the hot-topping coil is too low. This coil needs to be shorter, with the center of heat not more than 3 inches below the top of the coil to compensate for the great loss of heat by radiation at the top of the ingot. It would be desirable to cover the top of the mold with a movable insulating cover after pouring to gain maximum productivity with respect to freedom from pipe.

The lower coil should produce less heat in the central portion of the ingot, since the above-mentioned heat loss at the top and the loss to the vacuum-jacket at the bottom produce excessive temperature in the upper portion of the ingot, but still below the top, thus producing shrinkage cavities in the upper portion.

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The present system required too long a cooling period for the safety of the coil and the protection of the graphite and metal on removal from cooling water and vacuum. This can be overcome by thinner insulation and water-cooling the bottom of the mold jacket. It will be necessary to remove the assembly to another cooling line and possibly to bathe in inert gas.

The space now available in Plant 6E between the floor and the lower end of the conical section of the vacuum furnace does not permit a longer coil or mold. To maintain present production it will be necessary to decrease the pipe by four inches in a full charge, (1) by shortening the top section of the coil with a charge of 640 pounds of metal or (2) by the use of less cropping with shorter charge of metal, permissible due to the increased density at the top of the ingot. Thus if Heat No. 9 were cropped only two inches a shippable length of 38 inches would be obtained as against 40 inches at present. The upper coil can be shortened sufficiently to permit this gain.

PROPOSED FURTHER WORK

Hence the problems remaining for continued work at present are:-

1. Redesign coil to permit longer roll.
2. Decrease insulation and redistribute cooling to permit shorter time cycle; i.e., remove mold jacket from furnace two hours after pouring.
3. Determine minimum temperature at which pours can be made to control surface and pipe. Chemical quality will be benefited by pouring at lowest possible temperature compatible with surface requirement.

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