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USE OF METAL MOLDS FOR CASTING
URANIUM

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Use of Metal Molds for Casting Uranium
by H. E. Cleaves

Work done by H. E. Cleaves, W. E. Lindlief, V. C. F. Holm, H. C. MacKerrow, J. T. Sterling, Marie C. Wallace and Ruth Kimble, under direction of Dr. J. G. Thompson.

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In the first attempts at casting uranium, molds of beryllia were used. The quality of the ingots was satisfactory but the short life of these molds, because of breakage, usually 1 or 2 castings, made their use impractical. Graphite molds were more durable but attack by the uranium and the scoring of the surface of the relatively soft graphite in removing the ingots caused progressive increase in dimensions and roughness of the molds.

Metal molds seemed more promising for the production of uranium castings, provided a metal could be found which was not attacked by uranium. Preliminary experiments involved testing small molds of various metals by filling with molten uranium at controlled casting temperatures in the course of a study of the solubility of oxygen in molten uranium.

A bottom-pour induction furnace, shown diagrammatically in Figure 1, was used in this preliminary work. The charge of uranium was melted in a beryllia crucible lined with uranium dioxide. The dioxide, after firing at about 1700°C, formed a hard dense lining which prolonged the life of the beryllia crucible and provided a more effective seal with the stopper rod than could be obtained by seating the rod against the thin-walled beryllia crucible.

The temperature of the molten metal was determined by sighting an optical pyrometer into a black-body sight tube immersed in the melt. The portion of the sight tube in the crucible was a closed-end beryllia tube filled with granular beryllia to the center of the melt. The upper portion of the sight tube was a porcelain tube cemented to the beryllia tube by means of a beryllia sleeve and cement consisting of finely ground beryllia moistened with beryllium chloride solution. The sight tube assembly was fired at about 1400°C to set the cement. The beryllia tube served both as a sight tube and as a stopper to close the hole in the crucible bottom.

When the uranium, heated inductively, reached the desired casting temperature the mold was pushed up into contact with the crucible support. Lifting the stopper rod permitted the molten uranium to flow into the mold below.

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Heating of the mold by induction and radiation was sufficient to raise its temperature about 30°C above room temperature at casting time. Preheating of the mold, when desired, was effected by raising the mold nearer the furnace coil. Mold temperatures were measured by a thermocouple brazed or peened to the outer surface of the mold, the leads passing through the helium outlet at the bottom of the furnace. A helium atmosphere protected the uranium from oxidation.

Metals with high melting points, tungsten (3410°C), molybdenum (2625°C), and platinum (1772.5°C) were tested first because they appeared less likely to react with uranium than metals whose melting points were in the vicinity of the casting temperature.

Tungsten and Molybdenum Molds

The tungsten molds tested had been prepared by compressing and sintering the metal powder. These molds were 2 cm inside diameter and 3 cm deep. The inside surface of each mold was ground to a slight taper, to eliminate roughness and permit removal of the ingots.

An ingot cast at 1400°C in one of the tungsten molds, used without any surface treatment, was loose in the mold and no evidence of attack on the mold was observed. The principal defect in this ingot was a large cold shut on one side. Raising the casting temperature to 1600°C, to avoid formation of cold shuts, resulted in welding of the ingot to the mold at one spot and cracking of the lower walls and bottom of the mold.

The tungsten molds used in subsequent castings were protected from contact with the uranium by smothering over a burning oil. Two castings at 1400°C in a tungsten mold so coated showed no evidence of attack on the mold but the ingot surface was badly creased. A casting at 1400°C into a tungsten mold preheated to 500°C cracked the bottom of the mold.

Although the tungsten molds were not attacked by uranium poured at 1400°C, their failure to withstand the thermal shock accompanying casting eliminated tungsten from consideration as mold material.

The molybdenum mold, also prepared by compacting and sintering, was somewhat larger than the tungsten mold, about 35 mm in diameter and 6 cm in depth. Two castings were made in this mold at 1400°F. There was no evidence of reaction with the mold.

Platinum-lined Copper Mold

The use of a ductile metal melting at a high temperature, such as ~~platinum~~, would minimize the danger of attack by uranium in the

failure by thermal shock such as occurred with tungsten.

A platinum crucible used for the test was backed by a close-fitting copper mold which served both to support the thin-walled crucible and to provide the necessary heat capacity. However, the copper mold contained a small casting cavity in the bottom so a small area of the platinum was not in contact with copper.

A melt of uranium poured at 1300°C was removed readily from the mold with no evidence of attack on the platinum. A second casting, poured at 1400°C, melted through the sides and bottom of the platinum crucible as shown in the photograph of the sectioned ingot and crucible (Figure 2). Attack on the crucible probably started at points where the crucible was not supported. The formation of the alloy precludes the use of platinum lined molds unless the metal backing is in contact with the platinum over its entire area to prevent any portion reaching the temperature at which the alloying occurs.

Copper Molds.

Although copper has a melting point below that of uranium, there existed the possibility that the high thermal conductivity of copper might result in sufficiently rapid chilling of the uranium to prevent reaction between the metals. Accordingly two copper molds were tested; one thick-walled and massive, the other light. Both were prepared by drilling a 1 inch hole in copper blocks to a depth of 1 3/4 inches. The holes were subsequently tapered to facilitate removal of the ingots. The heavy mold had a bottom thickness of 1 inch, a wall thickness of 1/2 inch and weighed 940 grams. The light mold had a bottom thickness of 1/2 inch, a wall thickness of 3/16 inch and weighed 190 grams. The molds were smoked before using.

Castings were poured at 1400°C, into the molds at about room temperature and preheated to temperatures up to 350°C. The maximum temperatures attained by the light copper mold were somewhat higher than with the heavy mold, as would be expected. With an initial mold temperature of about 50°C the maximum temperature of the outer surface of the light copper resulting from casting about 380 gm of uranium was 545°C whereas under the same condition the maximum attained by the heavy mold was 255°C. Similarly when preheated to 350°C, the maximum for the light mold was 695°C, for the heavy mold 525°C.

None of the castings of uranium in the smoked copper molds showed any evidence of reaction with the mold metal. Ingots cast in the light mold were superior, as regards surface defects, to those cast in the heavy mold, presumably because of the drastic chilling effect of the heavy mold.

During tests of the copper molds the same uranium was used in a series of 5 castings. Copper determinations on samples the original charge and the final ingot showed that no pickup of copper resulted from casting the metal 5 times in copper.

Steel Molds.

Iron or steel are the materials generally used for permanent molds but there was doubt as to their suitability for casting uranium. The melting point of iron, 1535°C , is considerably above the melting point of uranium but formation of a low-melting eutectic was indicated by results of an attempt to determine hydrogen in uranium by the vacuum extraction method. A specimen of uranium contained in an iron thimble, when heated in vacuum to a temperature not exceeding 800°C , reacted with iron at the point of contact to form drops of a fluid eutectic. Subsequent work in other laboratories established the existence of a eutectic at 725°C in the iron-uranium system. Use of a mold wash or coating to prevent contact of uranium and iron appeared essential for successful use of iron or steel molds.

A split steel mold, designed for the drastic chilling necessary in the study of oxygen solubility in uranium, was used to test the suitability of steel for molds. The cavity in the mold was a rectangular wedge 1 inch wide and 4 inches long, tapering from about $5/8$ inch at the top to $1/4$ inch at the bottom. The volume of metal in the mold was about 8 times the volume of the casting.

The steel surface was protected by coating with oily soot from burning light oil, heating the coating with a gas flame to decompose any condensed oil, then brushing lightly with cotton to remove loose soot.

Twenty castings were poured in the smoked steel mold at temperatures from 1400 to 1800°C . Metals cast at 1635°C and below into the normally smoked mold did not attack the metal. However, when the smoked mold was swabbed heavily with cotton wet with ether to remove all non-adherent soot and produce a smooth surface, a casting at 1635°C attacked the mold at one small area. Metals cast at 1730°C and 1800°C attacked the mold appreciably, combining the uranium with iron. Analyses of charged metal and ingots showed that where no visible attack on the mold occurred no pickup of iron resulted from casting in a steel mold.

The results showed that under the conditions obtaining, viz the wedge mold a soot coating protected the steel from attack at casting temperature up to about 1600°C but could not be relied upon for protection at higher temperatures. Surface defects on the ingots appeared to result from excessive chill, which might be avoided by reducing the ratio between the weight of mold and casting.

Although the protection afforded by smoking the mold was sufficient, This Document contains a mold dressing smoother than the soot coating and not requiring re-

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neral for each casting would be an improvement. A ceramic enamel developed at the National Bureau of Standards for protection of metals at temperatures up to about 700°C offered the possibility of meeting these requirements.

A coating of this enamel, about 0.001 inch in thickness, was applied to the small split mold and uranium at 1400°C was cast in the mold. The glossy enamel was roughened to a matte surface but appeared unharmed otherwise.

One pound castings were made at 1400°C in the mold preheated to 150°, 250°, 350°, and 450°C without evidence of further change in the enamel. At the highest preheat temperature 450°C, the temperature of the outside of the mold reached a maximum of 380°C. The inner surface of the mold must have reached a temperature approaching the softening point of the enamel but no indication of damage to the enamel was observed.

Except for a brighter surface the ingots from the enameled mold were similar to those from the smoked mold. Ripples or creases, the principal defect, became less noticeable with increase in the preheat temperature. The appearance of two ingots cast in the enameled mold is shown in Figure 3.

The permanence of the enamel coating was tested by continuing the casting of uranium at 1400°C into the mold at room temperature, to provide the maximum thermal shock. A total of 30 castings were made in the mold without apparent damage to the enamel.

As boron is an important constituent in temperature-resistant enamel, boron content in uranium cast in the enameled mold was possible. However, the boron content in the charged metal and the resulting ingots are found to be within the precision of the analytical method, showing that no appreciable boron content resulted.

The results showed that under the conditions obtaining with the small, split mold the ceramic coating protected the steel from attack by uranium cast at 1400°C, even with the mold reheated to 450°C, and had a life of at least 30 castings.

Metal Molds for Bar Casting

Success with the small wedge mold encouraged use of steel molds for casting 20 pound bars of uranium.

A split mold 3 inches square, 1.4 inches inside diameter and 16 inches in length was used initially in testing the casting of bars in steel. The mold was coated by sacking over kerosene flake then wiping

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with cotton. This coating apparently offered adequate protection from attack by the molten uranium, no alteration in the mold surface being evident after 14 castings at 1400°C (Figure 4).

These tests demonstrated that 20 pound bars could be cast in steel but the large ~~(split)~~ molds were found to have disadvantages not encountered with the small wedge mold. Because of the much greater ratio of length to thickness, the ~~(split)~~ mold warped with formation of fins and variation in ingot diameter resulting. Increasing the wall thickness to minimize warpage caused excessive chilling, causing defects in the ingot surface. Split molds were abandoned, therefore, in favor of solid steel molds.

The solid molds used were heavy walled steel tubes 1 1/2 inches inside diameter, 2 3/4 inches outside diameter and 20 inches in length.

Although the coating applied by smoking protected the large mold satisfactorily it left room for improvement of the ingot surface.

Attempts to apply the enamel, which was so satisfactory on the wedge mold, failed when the big molds were used. The enamel and inner surface of the mold came up to temperature slowly during firing, oxidation of the mold surface resulted and the iron oxide deteriorated the enamel. Thin walled steel tubes could be enameled satisfactorily. Molds prepared by casting aluminum silicon alloy around enameled steel cores were tested and found to produce satisfactory ingots but the life of such molds was so short, usually 2 or 3 castings, that their use was not practical.

All mold washes tested gave ingot surfaces inferior to those cast in smoked molds. The coating procedure which proved the most satisfactory was a modification of that used in coating the wedge mold. The mold was given an initial coating by smoking over burning mixture of kerosene and lubricating oil. A preliminary casting in the mold eliminated volatile matter and left a firm coating. The mold was prepared for subsequent melts by smoking over a benzoin flame, then a pad of cotton was drawn through the mold to remove loose soot.

more than *each approximately*
1 ~~(over)~~ 200 bars, 20 pounds in weight, for fabrication of uranium slugs, were cast at the Bureau in steel molds using this method of coating.

Summary

Steel molds were successfully used for uranium castings up to 20 or 25 pounds, at casting temperatures from 1400° to 1475°C, a mold coating to prevent contact between the steel and the molten uranium being essential. A carbonaceous coating applied by smoking the mold

over burning benzol, after an initial coating over a kerosene flame, met the requirements of ease of application, adequate protection and good ingot surface.

A temperature resistant ceramic coating was used successfully on small molds but could not be applied successfully to large molds.

Other metals, copper and molybdenum for example, could be used but offered no advantages over steel, which was cheap and ~~easy~~ readily available.

Fig. 1. Furnace used for casting one pound uranium ingots in metal molds. Scale 3" = 1'.

Fig. 2. Section of platinum crucible and contents. x 2.

Fig. 3. Rippled surface of uranium ingot cast in wedge mold resulted from excessive chill (left side and face views). Higher casting and mold temperatures eliminated this defect (right). x 1.

Fig. 4. Split steel mold after 14 castings. Horizontal scratches are tool marks.

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