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DEVELOPMENTS IN THE CASTING
DEPARTMENT OF THE METAL PRODUCTION
PLANT AT IOWA STATE COLLEGE

The Casting of Uranium Rods at Iowa State College

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DEVELOPMENTS IN THE CASTING DEPARTMENT OF THE
METAL PRODUCTION PLANT AT IOWA STATE COLLEGE

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The Casting of Uranium Rods at Iowa State College

In regular production casting of uranium, billets $4\frac{1}{4}$ in. in diameter by 22 in. in length are cast from a charge of crude or scrap metal. The billets are produced merely as an intermediate form that is convenient for extrusion into rods having a diameter of about 1.450 in. The rods are later machined to 1.360 in. in diameter and cut into sections 8 in. in length; these sections are referred to as "dogs". The final dogs have to meet rigid requirements regarding surface condition and soundness. Considerable work has been done on casting the metal directly into rods of the proper size as a process for eliminating the extrusion operation. For efficiency, rods long enough to make at least two dogs (17 in.) should be cast and longer rods for making three or more dogs each are very desirable. However, casting a long rod in a 1.5 in. I.D. mold introduces some additional difficulties in obtaining high quality surfaces on the rods and in preventing the formation of long central pipes. The 1.5 in. I.D. mold gives a cast rod which, when cooled to room temperature, has a diameter of about 1.460 in.

Ordinary graphite molds give small pits and irregularities in the surfaces that do not completely machine out on finishing a cast rod to the final dimension. With proper control of casting conditions, steel molds are very satisfactory for the production of rods with good surfaces. A number of mold dressings have been tried with a steel mold made from 1.5 in. I.D. seamless steel tubing. Smoking the mold with benzene smoke, as suggested by Dr. J. G. Thompson of the Bureau of Standards, is a convenient and very satisfactory method for treating the mold. Controlled pouring temperature and controlled pouring rate with the proper amount and distribution of the dressing make it possible to control the pipes to a fair degree in a rod

29 in. in length. Practically all of the pipe is located in the upper 3 in. which is cropped off. The remaining 26 in. can be machined to give three dogs. The degree of success of casting uranium rods for the present use is still undertermined since the first batch, enough for one thousand dogs, has been produced and shipped only recently and it will be some time before a final test can be made on the quality of this metal.

The casting setup for rods at Iowa State College is much the same as for billets except that in place of the one billet mold there are nine rod molds arranged vertically under a graphite feedway plate that has a pouring hole for each mold. The metal is poured from the crucible into a reservoir of which the feedway forms the bottom. The metal flows through the pouring holes in the feedway and into the molds, the nine rods each 29 in. in length being poured simultaneously.

The casting assembly that is used in making rods of the type recently shipped is shown in Figure 1. The charge, not shown in the figure, consists of about 330 lbs. of crude metal which is sufficient to fill all of the molds and leave an excess of metal to serve as a head that remains in the reservoir space above the feedway.

In assembling the unit for casting, the steel molds (18) are smoked individually with a benzene flame as described in detail later. The feathers of soot that hang loosely in the mold following the smoking operation are removed by an air blast from a small blower. A graphite plug (28) is pressed into the lower end of the mold and the mold is then set in a steel template (21) in the bottom of the casting cart. After all nine molds are prepared and are in the cart, the steel ring (17) and the graphite feedway plate (15) which is supported by this steel ring are set in position. The graphite

Figure 1. Casting Assembly for Rods. (1) 15 in. O.D. quartz tube. (2) Sillimanite insulation shields. (3) Graphite crucible. (4) Graphite valve disk. (5) Graphite spillway. (6) Graphite push rod. (7) Graphite chimney. (8) Insulation base. (9) Graphite cover plate. (10) Steel ring insulation support. (11) Steel water jacket. (12) Graphite reservoir (upper section). (13) Graphite reservoir (lower section). (14) Offset Steel push rod (upper section). (15) Graphite feedway plate. (16) Graphite plug with orifice. (17) Steel ring feedway support. (18) Steel mold. (19) Offset steel push rod (lower section). (20) Steel vacuum jacket. (21) Steel template. (22) Graphite plug. (23) Water-cooled base. (Thermocouples, vacuum connection and charge not shown in this figure.)

feedway plate fits in the ring and onto the top end of each of the nine molds. Specially shaped graphite plugs (15) each with a $7/16$ in. diameter pouring orifice are set into the feedway holes and pushed down to contact the tops of the molds. Next the two sections of the graphite reservoir (13) and (12) are placed on the feedway plate. On top of the reservoir is placed the graphite cover plate (9) with its chimney (7). Then the upper steel section (14) of the valve push rod is inserted. The removable welded-steel water jacket (11) is set on the cart in position around the reservoir. A steel ring (10) that serves to support the insulation (2) is seated at the top of this water jacket. An insulation base (8) for the spillway (5) and crucible (3) is then set on the cover plate; this base consists of two parts made from K-30 insulation brick. Two thermocouples, not shown in the figure, are used as a precaution against losing control of the temperature since the probability is small that both will fail during a run. It is very important that the temperature be known for proper control of the casting in this process. After placing the thermocouples through the spillway and adjusting their height so that they will extend about two inches into the bottom of the crucible, the graphite push rod (6) is cut to the proper length and inserted through the spillway and into the arm of the upper section of the steel push rod. The crucible is placed on the spillway, care being taken to assure that good contact is made between the bottom surface of the crucible and the top surface of the spillway. The valve disk (4) is sealed to the valve seat by coating the face and seat with a thin aqueous suspension of ZrO_2 and setting the disk in position before the coatings dry completely. About one half pound of granular magnesium is placed in the bottom of the crucible and the charge of crude metal is added

by the method used in ordinary billet casting. The large biscuits are lowered into the crucible one at a time by a steel packaging band which passes around a biscuit and through the hook of an electric hoist on a monorail. The steel band is cut and pulled out after a biscuit is loaded. For the 125 lb. biscuits the small space between the inside surface of the crucible and the biscuit is not sufficient for any special gripping device. In case the charge of metal extends above the crucible, a graphite extension is set on the crucible and the graphite lid is set on this extension. The melting crucible is insulated by enclosing it with two layers of shields (2) and a lid that are made of sillimanite. A large quartz vacuum tube (1), closed at one end, is lowered into position around the insulation and sealed to the steel water jacket (11) by means of a rubber gasket coated with Cello-Seal. Not shown in the figure is a two inch valve on the side of the steel vacuum jacket (20). Through this valve, connection is made to a fixed vacuum line when the assembly is in position at the heating station. The bottom end of a heating coil, 15 in. I.D. by 17 in. long, is adjusted at a level 5 in. above the top of the steel water jacket (11). The power of the high frequency generator is turned on and adjusted to about 38 to 40 KW where it is held during the entire heating cycle. When the temperature at the thermocouples reaches 1350°C the heating coil is raised 6 in. and the heating of the upper region of the crucible is continued as the lower region cools to 1300°C. The power is then turned off and when the thermocouples indicate that the charge has cooled to 1275°C the metal is poured and the rods cast. In Figure 2 is shown an operator using a wooden lever to raise the lower section of the push rod. This movement results in the graphite disk being forced from its seat in the crucible allowing the metal to pour into the reservoir from which it flows into the molds.

Figure 2
Pouring the Metal

Figure 3
Removing Quartz Vacuum Tube

The hoist type furnace coil is then lifted above the unit and the unit is moved from the casting station to a cooling line. Here a vacuum is maintained on the system until the metal has cooled for 3 or 4 hrs. The assembly is then ready to dismantle and the unit is moved under a basket grip hoist which is used to remove the quartz tube as shown in Figure 3. (This same grip and hoist combination is used for lowering the quartz tube into position as the unit is being assembled.) After the quartz tube has been removed, the insulation layers are dismantled as shown in Figure 4 and the pieces set in racks for use again.

Figure 5 is an elevated view showing the head of metal that remains on the feedway. All of the super structure of the setup including the reservoir has been removed and the thin shell of metal that forms around the inside surface of the reservoir during the pouring is left standing. In Figure 6 the operator has lifted the feedway and the head of metal from the molds. The special shape of the graphite plugs containing the pouring orifices permits the rods to break their connection to the metal head during the cooling period; therefore, separation of the parts at this point offers no problem. The orifice plug is shown sketched in detail in Figure 7.

The individual molds with their cast rods are removed from the cart by means of a hoist as shown in Figure 8. A removable bail that fits onto the molds is used in this operation. The operator in Figure 9 is removing a rod from a mold. This is accomplished by merely slipping the short steel extension (see Figure 10) onto the bottom end of the mold and jolting that end of the combination on the floor. The mass of the rod is sufficient to free the rod from the mold in this operation and the rod can then be readily pulled out of the bottom end of the mold.

Figure 4
Removing the Insulation

Figure 5
Elevated View of Metal Head

Figure 6.
Removing Metal Head and Feedway
From Molds.

Figure 7.
Arrangement of Pouring Orifice
and Mold.
(1) Orifice plug. (2) Feedway
plate (3) Steel mold (4) Bottom
plug.

Figure 8
Removing Molds and Rods From Cart

Figure 9
Removing Rod from Mold

Figure 10
Adapter for Removing Rod From Mold.
(1) Steel spring. (2) Mold.
(3) Cast Uranium Rod. (4) Graphite
plug. (5) Steel Extension.

Figure 11
Cast Rods and Head

The nine rods and the metal head from one run are shown in Figure 11. The graphite feedway plate and orifice plugs have been broken off of the head. The rods are later brushed free of the carbon from the smoked molds that adheres to the rod surfaces. The toe cast on the bottom end of each rod is ground off and the rods cropped to 25-3/4 in. in length. The croppings with the metal head are returned to be recast. Figure 7 also shows the construction of the bottom ends of the molds where the toe is cast on the rod. This toe assures contact between the bottom of the rod and the mold during cooling.

Close inspection of the rods shown in Figure 11 reveals bends in some of them. A straightening operation should be given these rods before they are machined. In order to remove possible internal stresses set up during the relatively rapid cooling in the steel mold they should also be given some annealing. The ordinary reheating and straightening operations used for extruded rods should suffice for the cast rods. In a few cases, some of the cropped rods may be down to about 1.440 in. in diameter at their upper ends. This is due to the fact that the metal in the upper end of a rod is relatively hot while the rod is shrinking in the mold and if the upper end of the rod is not free to move at that time there will be some drawing down of the diameter in that region. Practically all of the small diameter portion of a rod is removed in cropping.

A detailed sketch of the device used to smoke the molds is shown in Figure 12. In preparing a mold for casting, twenty cubic centimeters of benzene are used to moisten two double sheets of "Kleenex" that are rolled into a small wad and placed in the graphite cup. After igniting the benzene this cup keeps the source of the flame directly under the steel mold which

Figure 12. Device for Smoking the Molds. (1) Steel mold. (2) Support rod. (3) Sheet metal skirt. (4) Kleenex moistened with benzene. (5) Graphite cup. (6) Steel base plate.

serves as a stack during the smoking. The mold is in an up-and-down position during the first seventy-five seconds of the smoking operation; it is then reversed and remains in that position until the flame has subsided. A small blower is used to remove the loose pieces of soot (or feathers) that hang on the inside wall of the mold. The bottom plug is driven into the mold and the mold is then set in position in the casting cart.

Certain imperfections in cast rods have been detected during the course of the casting work at Iowa State College. What degrees of these imperfections would be classed as sufficient defects to cause rejection by the user is not known here. In addition to bent rods, internal strain, and small diameters pointed out above, the main classes of imperfections as well as their possible causes will be pointed out briefly. These classes are pipes, large inclusions, fine inclusions, bubbles, porosity, surface folds and surface cracks. The pipes are caused by the usual combination of conditions met in metal casting. The rate of pour, the pouring temperature and the heat dissipation in the mold during solidification of the metal as they affect pipe formation have been considered in arriving at the procedure given above. The fine carbon deposited on the wall of the mold during smoking seems to result in relatively low heat conduction from the casting.

The large inclusions are probably oxide and have as their origin the oxide film on the metal or oxide inclusions in the metal that is used in the charge. An oxide film on the metal can also form during the heating and pouring operations. In order to reduce such inclusions to a minimum in the final cast rods, good quality metal should be used in making up the charge and a good vacuum should be maintained during heating and pouring.

It is also desirable to form a head of metal such as that formed during the pouring in the above process if a number of rods are to be poured simultaneously. To build up this head the metal is allowed to flow from the crucible at a faster rate than it flows into the molds from the reservoir. There is less splashing of the metal on pouring into the head of liquid metal and light weight inclusions tend to float to the top while the rods are being poured from the bottom of the head of metal. As a further precaution, the feedway plate and orifice plugs should be preheated in a vacuum before using in the setup. Magnesium is added to the charge in order to cause stirring of the liquid which would tend to break up any oxide films around pieces that make up the charge in the crucible. The fragments of film could then float freely to the top of the molten charge.

The fine inclusions are probably due to particles of carbon that are washed off the mold wall and dispersed in the metal during pouring. Efforts are made to keep the molds in a vertical position during the pouring so that the metal will fall as far as possible in the mold without hitting the mold wall. An orifice length of one inch is used to direct the stream of metal down the center of each mold. The removal of the feathers or loose pieces of soot from the mold by the blower following the smoking operation is carried out for the purpose of reducing such inclusions. These fine inclusions give the appearance of porosity to the metal.

Spherical cavities of all sizes up to $1/8$ in. in diameter have been detected in some castings. These cavities are no doubt due to bubbles of gas that have been trapped in the metal as it solidified. The sources of gas that cause these bubbles are not known. Gas, volatile liquids or reactive substances in the mold or in parts contacted by the metal during

pouring are possible sources of the gas. Moisture or volatile hydrocarbons in the mold could react with the liquid metal to give bubbles of hydrogen gas. The decrease in solubility of some gases in the metal as it solidifies might cause bubbles to form but it is doubtful that the effect could be as great as that observed in some cases in this work. Preheating the steel molds and smoking them while hot reduces the possibility of moisture collecting in the molds.

There is another type of cavity that has been detected in some castings. This type is usually quite small and has a tendency to be irregular with little if any spherical surface. The cause of this porosity might possibly be a combination of irregular solid inclusion with some gas. Shrinkage of the metal within the spaces between dendrites might also offer a possible explanation for such imperfections.

Surface folds have been observed at the lower end of a rod in a few cases. These folds have the appearance of cold shuts and are assumed to be due to factors usually associated with such surface structure. Machining tests have shown that of the few cases in which the folds have been found, their depth is not usually sufficient to affect the quality of the rod.

Surface cracks are found at the top ends of some of the rods and only occasionally will such a crack be below the cropping line. These cracks tend to be perpendicular to the length of the rod and are no doubt produced during the cooling when the metal is shrinking in the mold. Freedom of movement of the metal in the top end of the mold eliminates this imperfection. As explained earlier, the diameter of the rod at the top is sometimes less than at the bottom because of this same tension set up in some cases by the contraction of the cooling rods.

The above observations and suggested explanations regarding possible defects are the results of inspections made at the plant during the preliminary trials and production work for the casting of 1,001 dogs for testing at Hanford. These observations are presented here in order to point out some of the possible factors that should be considered in case it is deemed necessary to expand the program for rod casting. In the preliminary trials the casting conditions were varied in order to determine the conditions necessary for reducing or eliminating the possible defects. It is felt, therefore, that complete information regarding the quality of the rods in the recent shipment to Hanford will point definitely to the possibilities of casting satisfactory rods.

The equipment described above was built up after the general plans of the present billet casting units as used at Iowa State College. The main purpose was to produce only a few hundred dogs; therefore, some revisions in the design of equipment would be in order if a large scale rod production program were undertaken.