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Report A-1073
(Special)

**THE DIRECT POURING OF LIQUID METAL FROM THE
REDUCTION BOMB**

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MADISON SQUARE AREA
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9 March 1945

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THE DIRECT POURING OF LIQUID METAL FROM THE REDUCTION
BOMB AT THE PRODUCTION PLANT AT IOWA STATE COLLEGE

By the time regular crude biscuit production was interrupted at Ames on November 9, 1944, we had made well over 100 special experimental castings by pouring the liquid metal directly from the bomb. The workmen on the regular crude production line were alternating these special castings with the regular runs without the assistance of the research group. The process had reached a state of development wherein the castings were made by pouring batches of about 135 pounds of liquid metal directly from the bomb into a water-cooled steel mold in the presence of air at atmospheric pressure. The pouring operation was effected through a mechanically operated valve in the bottom of the bomb.

The workability of such a process has been well established, and the quality of the metal has been proved through candling and chemical tests. The first sixty billets produced by this method have been extruded successfully. A number of changes, designed to improve the quality and yield of the product and to simplify the process, have been made since producing the metal for these tests.

The first set-up to test the possibility of pouring the metal directly from the bomb was made on a small scale here last spring. The fortunate success of that first trial, although made with a valve mechanism that failed repeatedly to pour in the next few runs, pointed definitely to the feasibility of such a process. The development of a practicable set-up and procedure was then undertaken, and the plan of experimentation was to make a run, closely observe the operation, and inspect the complete set-up afterwards. Observations in each case led to changes that were made for the following trials. This method of development was slow at first, but, after an acquaintance was gained with the main factors involved, the developments came relatively fast.

The process has grown through numerous minor changes from the initial set-up to the present stage of development. It is felt that the process is already a long way toward perfection, but more work is needed before plans for a production plant based on this process can be drawn. It is necessary that further experimental work be carried out in order to establish the possibilities and limitations of the process as well as to gain a better understanding of each of the variables involved.

In this report a rather detailed presentation of the process as it now stands (A) will be given first. A discussion of the initial set-up in connection with a presentation of the more important changes (B) that have been made to date will follow. Lastly, the variables (C) that possibly need further study will be discussed along with proposed future developments in view of experience to date.

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(A) The status of the process when last operated on November 9, 1944, is presented in the following discussion. Figure 1 shows a sketch of the latest crucible which is made from standard 10-inch steel pipe. A standard 10-inch companion Flange is screwed on the upper end, and a special bottom with a valve hole is welded in at about three inches from the lower end of the 42-inch section of pipe. The lower rim of the crucible is faced with a hard surfacing alloy which reduced distortion at that point during the jolting operation.

The valve mechanism (shown in Figure 2) is made entirely of graphite with the exception of the steel nut. The sketch shows the valve assembled and in the closed position. In order to place the valve in position through the hole in the crucible, the valve is disassembled and the housing placed on the special adapter on the bottom end of the steel mandrel as shown in Figure 3. The powdered refractory for forming the insulation layer on the bottom of the crucible is introduced and the mandrel lowered into a position that allows the valve housing to fit into the hole provided in the bottom of the crucible. The crucible walls are then lined in the same manner as in regular crude production. The threaded end of the housing extends at least one-half inch through the bottom of the crucible. The upper portion of the housing which is inside the crucible is packed firmly in powdered refractory during the jolting. Following the lining operation, the valve housing is freed from the mandrel by removing the cone and lock nuts shown in Figure 3. The graphite washer and steel nut (shown in Figure 2) are next placed on the housing to hold it securely in the bottom of the crucible. The mandrel is then pulled from the lined crucible by means of a hoist. The remainder of the valve is then assembled through the housing. A small amount of dioxide is sprinkled around the valve for sealing purposes, and the charge of green salt and magnesium is introduced. The charge is then topped with the graphite cake which, in turn, is covered with powdered refractory, and the blind flange is bolted on leaving two opposite bolt holes clear for later use.

The completely charged bomb ready for the soaking pit is shown in Figure 4. The two rings shown in the bail to the bomb are for the purpose of transferring from one hoist to another. This transfer is necessary with the equipment at hand in order to remove these special direct-pour bombs to a pouring location to one side of the regular overhead trolley line. The bomb is next placed in the soaking pit, and a firing detector rod (Report A-1063, Section D) is set into one of the clear bolt holes in the flanges. The soaking pit is held at the same temperature, and the firing time is the same, as for regular crude production. When the charge fires, the detector rod is removed and the bomb is conveyed to a position over the mold. Two special upright 7/8" steel rods (shown in Figure 5) go through the clear bolt holes in the flanges and align the bomb with the mold as the bomb is lowered. The bomb is suspended at a position such that the spherical surface on the lower end of the valve is about one-half inch from contact with the cone-shaped surface in the mold head.

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One and one-half minutes after the charge has fired, a special link in the hoisting chain is cut, and the bomb drops, thus opening the valve as in Figure 5 which shows the metal on its way down the spout. The metal then flows through the valve and into the water-cooled steel mold. Figure 6 shows details of the mold as well as the solidified metal in ingot form. The bomb is ordinarily removed from the mold fifteen minutes after the metal has been poured. The bomb is then allowed to cool and opened as in regular crude production. The graphite cone plate is removed from the ingot, and the ingot is then hoisted out of the mold by means of a cable around its upper end. After the egg is cut off, the ingot is cropped to give a finished billet weighing around 110 pounds.

The groove around the outside and at two inches from the top of the 9 $\frac{1}{2}$ -inch diameter cone plate, (see Figure 6) marks the holding position for the bottom end of the bomb at the time the special link in the chain is cut. The small graphite ring at the upper end of the egg cup eliminates reaction that often takes place between the liquid metal and steel at such points. A quite satisfactory mold dressing for steel in this case is a paint made of pure zinc oxide and water, which is allowed to dry before returning the mold to service.

(B) The more important changes that have been introduced since the first trial run are in:

1. Valve Design:

The original valve had a large, flat plate that screwed onto the lower end of the hollow valve spout. In pouring the metal, the bomb was lowered and the flat plate was supposed to directly engage and cover the top end of a simple mold, at the same time opening the valve and allowing the metal to pour. Often the valve spout would break off just above the plate because of strain set up when the plate would contact the mold unevenly. This defect therefore, repeatedly caused failure of the valve to open.

To overcome this fault, a number of valve spouts were made with metal reinforcement, but these were far from satisfactory. The truly significant improvement in valve design came with the introduction of a valve in which a hemisphere, instead of the flat plate, was screwed onto the valve spout and together with this, the introduction of a mold cover with sunken cone surface to engage the hemisphere of the valve. Two main advantages were gained with this combination. First, the strain on the valve spout was eliminated, since the pressure was always distributed evenly when the hemisphere came into contact with the cone. Second, the ball and cone formed the good seal necessary at the valve-mold junction. Over 100 runs, using the ball and cone combination, have been made without a single failure to pour. The latest design of the valve is shown in Figure 2. The hemisphere and valve spout are now made in one piece as

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shown in the figure. This one-piece design gives increased strength to the part at the point where some earlier models in which the hemisphere was screwed onto the lower end of the valve spout often shattered during the opening operation.

2. Mold Design:

The pressure of gases in the bomb causes a rapid flow of metal into the mold. The first mold had a capacity much greater than was necessary to hold all of the metal produced in the bomb. During the pouring operation, the rapid-flowing stream of slag following the metal would mix with the metal and give many slag inclusions in the upper region of the ingot. The mold was redesigned to have about the capacity necessary to hold only the liquid metal. The high-velocity stream of molten slag was then reduced or eliminated, giving a much better top on the ingot. Figure 6 shows the distribution of slag and metal in the latest mold. The main slag inclusion is formed slowly in the top as the metal solidifies in the ingot. It is necessary to have sufficient capacity in the mold and cone plate to allow all the metal to flow out of the valve, otherwise a cast, solid, metal rod connecting the ingot to the inside of the bomb might result. Variations in volume of metal due to variation in yield are taken care of by the extra volume in the cone plate.

The first molds were made entirely of graphite. After gradual substitution of water-cooled steel parts for graphite parts, a mold practically entirely of steel became the standard. The small graphite section which serves as an extension on the top of the steel mold and the small graphite ring (both shown in Figure 6) are the only graphite parts now used in the mold proper.

3. Size of Charge:

The first bomb used was only six inches in diameter by 36 in. in length, and it held a charge sufficient to furnish about 35 lbs. of metal. The castings were all made with a diameter of $2\frac{1}{4}$ inches which furnished eggs and samples for testing the quality of the metal. Castings XC-1 to XC-11 inclusive were made with this small size charge.

Beginning with XC-12 the bomb used was ten in. in diameter by 36 in. in length over-all made from standard ten-inch pipe. The charge used in this bomb gave about 112 lbs. of metal. All of the XC billets that have been tested for extrudability were cut from ingots made with this bomb.

Shortly before the interruption of the work on November 9, the bomb made from a 42-inch length of ten-inch pipe, fully described above and shown in Figures 1 and 4, was put into service. This size was introduced in order to give a billet length closer to the desired size for extrusion at that time.

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4. The Atmosphere in the Mold:

The first atmosphere tried was butane, which was introduced into the mold through a small jet in the bottom of the egg cup. The butane jet was ignited, and the flame that enveloped the bottom of the bomb just before pouring assured the absence of air. Next, hydrogen was used in place of the butane, then argon, and finally air without special treatment or condition served as the atmosphere in the mold when the liquid metal was poured. About one-fourth of the billets that have been tested through the extrusion step were cast in argon and the other three-fourths were cast in air. Air was used exclusively in the mold for all castings after October 4th.

5. Firing Indicator:

Since it is absolutely essential with this process to know when the bomb fires, it was necessary at the beginning for the furnace operator to watch the bomb closely for several minutes as it approached firing time. To eliminate this inconvenience, the detector mentioned above was introduced and has proved very useful for both the regular crude production as well as the direct-pour runs for which it was originally designed.

6. Method of Opening the Valve:

In the early stages of development, the valve was opened by merely lowering the bomb to the mold by means of the chain hoist. The valve contacted the mold rather slowly, and quite often did not open because of sticking of the valve. A more drastic method for opening the valve, i.e., dropping the bomb to the mold, was then adopted. The sudden impact of the valve and cone plate caused by actually dropping the bomb through a distance of about two inches was very effective. This change in procedure was made when only the six-inch bomb was being used in the experimental work. For the ten-inch bomb which was later introduced, the valve was opened by dropping the bomb about one-half inch before the hemisphere contacted the cone plate. Although with the heavier bomb, lowering the bomb by means of the hoist might serve satisfactorily, the dropping method has been used exclusively.

- (C) Future developments in connection with this one-step process have as their starting point the set-up and procedure described above. Now that a workable process has been established, numerous variations or arrangements are possible to use the direct-pour idea in a regular production plant. The over-all plans for the future investigations here are to make studies of a number of variables in more detail and to work out features and designs that can be adopted by the present production plants with the least interruption of production and the greatest economy of operation consistent with proper safety to the workmen.

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The planned order of the work at present is, first, to study a number of the variables using the present bomb described in detail above, then change to a larger bomb in an attempt to cast longer 4 $\frac{1}{2}$ -inch diameter ingots directly from the bomb, and, lastly, to try to work out a system by which hot dogs can be cast directly. It is likely that the machinery for the set-up to cast the longer 4 $\frac{1}{2}$ -inch ingots will not be ready as early as that for the hot dogs. Possibly some attempts will be made to cast hot dogs before the longer ingots are tried.

It is obvious at this stage of development that all the variables connected with pouring the metal directly from the bomb cannot be thoroughly investigated under the limitations of time and materials now specified. It is hoped, however, that beginning with the present status of the process we can gain sufficient additional information to fulfill our purpose to the satisfaction of all concerned. Numerous small variations from the final status of the work here will, no doubt, be made by other producers in adopting the process. This is to be expected on the basis of experience with the present crude process which we put on a working basis at Ames and which was later adopted with minor changes by the plants elsewhere.

Investigations now being considered in connection with further developments are as follows:

1. Pouring Time:

All castings to date have been made by pouring the metal at about one and one-half minutes after the charge ignites. It is planned to determine what factors are affected by varying the time of pouring. With our present set-up, a pouring time of one minute seems to be about the shortest practicable; we plan to increase the time up to where the metal does not pour or gives strong evidence of cold shuts.

2. Method of Opening the Valve:

Dropping the present bomb by cutting a special link in the chain is effective as far as opening the valve is concerned. At times, however, some fracture of the lower portion of the valve spout resulted. The dropping method seems impracticable for the large-size bomb now in process of construction. It is possible that lowering the bomb onto the mold by means of the hoist, which was very inefficient with the small experimental size, might be satisfactory in the case of larger bombs. The latter method of opening will be tried first in an attempt to find the best method for opening the valve.

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3. Sealing the Valve:

In our regular recasting operation, a small amount of powdered dioxide is sprinkled around the valve after it is properly positioned on the valve seat. The powder serves to seal the valve and prevent dribbling of the liquid metal in recasting. In all work in which $4\frac{1}{2}$ -inch billets have been made by the direct-pour method, dioxide has been employed without proof that it is essential. There are indications, however, that we might be able to eliminate its use without ill effects to the process. The possibility of reducing, eliminating, or finding a suitable substitute for the dioxide is to be investigated.

4. Temperature of the Metal:

The temperature variation of the reaction mixture or products from the time the reaction is initiated until a number of minutes have passed would be very desirable information. The direct-pour process has given good results without this information, but a knowledge of the temperature variations could offer valuable assistance in developing the process further. Some attempts will be made to determine temperatures within the bomb, especially temperatures of the molten metal.

5. Pressure in Bomb:

The total pressure within the bomb at any one time probably cannot be measured directly by means of a single gauge. There is a possibility that a value approximating the total may be obtained by roughly measuring the non-condensable gas pressure, which is probably mainly due to hydrogen, and then adding to that gas pressure the estimated pressure of magnesium vapor at the temperature of the bomb. Thus, the estimation of total pressure by this method depends on a knowledge of the internal temperature. This might prove difficult to measure. In such a case the pressure of the non-condensable gases alone would no doubt offer useful information in the interpretation of results, as that pressure probably varies from run to run more than does the pressure of the magnesium. The hydrogen pressure in the bomb is largely produced by water which may be introduced through the refractory. We have experienced one failure with the direct pour which we attribute to the use of refractory that was too high in water.

6. Strength of Valve Head:

To date, no failures have been experienced in the head of the valve. A certain type of failure in this part before the pouring time could cause loss of the metal and make it necessary to shut down a part of the plant for cleaning. The fact that we have used much weaker valve heads under more drastic conditions in the past without failure gives a degree of assurance that the safety factor is sufficient. However, we hope to be able to get some measured or calculated value of the strength of this part under operating conditions. Regardless of safety factor, protection to workmen from injury by such a failure can be effected and must be taken into account in the construction of production units for this process.

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7. Large-Size Bomb:

The parts are now under construction for making double-length billets which, at the time the materials were ordered, were to be about 27 inches in length. The crucible is to be 15 inches outside diameter and 42 inches in length. If a crucible this size gives a billet of the estimated length, then a crucible 14 inches in outside diameter by 40 inches in length should make a finished billet that is at least 20 inches in length. It might be necessary at some locations to use the smaller size crucible. There should be no new problems with the 14 in. x 40 in. crucible if our 15 in. x 42 in. crucible functions in accordance with predictions based on experience with the 10 in. by 36 in. crucible. The latter followed predictions based on work with the 6 in. x 36 in. crucible.

8. Casting Hot Dogs:

The fact that the liquid metal is driven out of the bomb under pressure and is not just flowing under gravity offers possibilities of getting a rapid pour which might prove very desirable in casting the long rods from which the final slugs are machined. A water-cooled steel mold is being constructed for the purpose of casting six 18 in. x 1.5 in. rods simultaneously from one bomb load. This mold is designed to fit the standard 10 in. x 42 in. bomb, therefore very little extra work outside of actually constructing the mold is necessary before trial runs can be made. We expect to find that the quality of the hot dogs produced by this method is closely related to the temperature of the metal and the pressure within the bomb (numbers 4 and 5 above) at the time of pouring.

9. Mold Design:

Much work has been done here on molds in the past, and each new set up for direct pour has so far presented new problems in mold design. The main features of the finished billet that may be affected by the mold are surface condition, slag distribution, pipe formation, and other internal voids. The water-cooled steel mold is serving satisfactorily for the 4 $\frac{1}{2}$ -inch billets in connection with the direct pour. The first few attempts to cast the double-length billets will probably be made with a mold the lower half of which is water-cooled steel and the upper half graphite. The mold to be tried in casting hot dogs is discussed briefly above under number 8.

Some other factors that have been studied in connection with mold problems, and will probably be investigated further, are mold dressing, mold atmosphere, mold capacity, and materials of construction.

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Dr. Thompson, of the Bureau of Standards, has been making small castings of metal in solid metal molds. It is understood that the Madison Square Area is anxious to have some castings made in such a mold by the direct-pour method. In case a satisfactory large-size solid metal mold can be designed for 4 inch billets, tests will be made to determine its possibilities. It seems that casting hot dogs in solid metal molds offers good chances for success.

10. Miscellaneous:

There were a number of other investigations in progress here on November 9th that will probably be worked in along with investigation here during further development work. There are also other factors connected with the operation of the process that may be refined by each plant where production is to be maintained. There are in addition some ideas worth investigating that possibly will be studied here, but are not presented earlier in the report. These three classifications of problems for investigation are as follows:

- a) All factors connected with regular crude production, such as excess magnesium, temperature of furnace, jolting time, lime wall thickness, quality of green, fineness of green grind, etc. are still with us and a few of these will probably need reinvestigating.
- b) Size of Valve:---The valve sketched in Figure 2 has the largest capacity (one-inch diameter) spout that we have tried. This size should be satisfactory for pouring double-length billets, but it may be necessary to change the valve spout diameter for casting the hot dogs.
- c) Slope of Bottom of Bomb:---A slope of 30 degrees is the only slope used to date in the bottom of the bomb to cause the metal to flow from the sides of the bomb to the valve. When the larger bomb for the extra-length billets is used, it might be necessary to increase this slope in order to allow all of the metal to flow out ahead of the slag. The large bomb is designed to have a liquid metal depth about the same as in the 10-inch bomb, but the diameter of the metal pool is 13 inches instead of 9 inches in the smaller bomb.
- d) Crucible Dressing:---The inside walls of the crucible can be coated with a material that facilitates removal of the liner material from the crucible during the cleaning operation. These coating experiments will be continued along with other studies.

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- e) Graphite Cake:---The graphite cake used in the top section of the bomb will probably undergo some changes in design as the work progresses.
- f) Graphite Liner:---Some time ago Electromet did some work with a graphite liner in their regular crude production bomb. Recently Mallinckrodt used graphite liners in connection with experimental casting within the bomb. (See Report A-1071). A graphite liner or combination graphite-lime liner will be designed and tried in an attempt to combine the graphite liner with the direct pour. The Madison Square Area has suggested that this work be carried out here.
- g) Firing Indicator:---A firing indicator will be used on all bombs for direct pour. Besides using the indicator to detect the time of ignition, some attempts will be made to test its usefulness as a tool to follow bomb reactions.
- h) No doubt other ideas will develop and factors affecting the operation of the process will present themselves during the progress of further work.

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Fig 3

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Fig 4

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Fig. 5

- Steel
- Cast Iron
- EFD Liner
- Graphite
- Slag
- Metal
- Welded Metal

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