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CENTRIFUGAL CASTING OF ALUMINUM-URANIUM ALLOYS

by

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Centrifugal-casting techniques were investigated as a method of producing hollow cylindrical extrusion billets of aluminum-35 w/o uranium. Among the variables evaluated were melt temperature, mold and pouring-spout configurations, mold speed, and method of pouring. With the equipment employed it was found that the best castings were produced utilizing a pouring temperature of 2400 F, a heavy-walled steel cylinder rotating between 700 to 900 rpm for the mold and a bottom-pouring technique employing a retractable pouring spout.

Sound, nonporous billets 26 in. long and 5 in. in diameter were produced with a yield after machining of over 75 per cent of the original charge. The major losses occurred in the pouring spout-and-cup assembly. This loss is relatively unaffected by the casting length; and, therefore, castings of greater length than 26 in. should result in even greater recoveries.

INTRODUCTION

The most commonly used alloy fuel for low-temperature water-cooled water-moderated reactors are those of the aluminum-uranium alloy system. One method of fuel-element fabrication currently employed involves coextrusion of aluminum-uranium alloys and pure aluminum to form tubular elements clad inside and out with aluminum.[1,2] For this process a tubular casting is desirable. However, when alloys containing more than 20 w/o uranium are lip poured in static molds, porosity and segregation are encountered. The porosity is attributed to shrinkage and to gas evolved during freezing; the segregation is due primarily to differences in the densities of the various phases present and to the widely separated liquidus-solidus temperatures.[1,3-5]

The importance of segregation and porosity in the as-cast material can be evaluated by examining their effects on the fabrication procedures for the fuel element. After casting, it is necessary to machine the billet to the desired size with a relatively smooth nonporous surface to insure cladding-to-core bonding and uniform cladding thickness. To obtain this, surface irregularities caused by cold shuts and turbulence must be removed; shrinkage areas must be cropped; and porosity must be closed by pre-extrusion upsetting. Each of these imperfections causes an increased amount of handling with a corresponding increase in the quantity of material removed from the castings prior to fabrication. Since the castings are to be used to form tubular elements, it is necessary to obtain castings in which the end-to-end segregation is a minimum. However, the inside-to-outside segregation in an ingot will have little or no effect upon the uranium concentration along the length of the fuel element, and, therefore, inside-to-outside

(1) References at end.

uranium analyses may vary over a wide range and still be acceptable. Thus, the analyses obtained in evaluating an ingot are normally the average uranium concentrations across the tubular wall.

Efforts to obtain more homogeneous alloys in the form of hollow cylindrical castings have been concentrated upon increasing the freezing rate or imparting a directional solidification to the metal. In practice, the chill casting of alloys is complicated by the fact that gases rejected on solidification do not have sufficient time to escape and remain in place, causing porosity. Directional solidification, while helpful in improving the quality of the aluminum-uranium alloys containing concentrations up to and slightly in excess of the eutectic composition, does not produce much improvement in casting of higher uranium concentrations.

Since horizontal centrifugal casting has been established as a method of obtaining dense castings and has found acceptance in such diverse casting applications as the production of cast-iron pipe and high-integrity steel gun barrels[6], and since the castings desired are essentially pipes of unusually high integrity, this technique appeared particularly attractive as a method of casting aluminum-uranium extrusion billets. In addition to improving the ingot soundness, horizontal centrifugal casting should eliminate end-to-end gravity segregation. Permanent molds could be used and the casting surfaces obtained should require a minimum of machining prior to extrusion. No gating or riser scrap should be generated. Of equal importance to the above advantages is the fact that the centrifugal-casting process is adaptable to the production of long tubes; thus, it was considered possible that the process would be amenable to the production of multiple-length extrusion billets. The production of multiple-length billets and the reductions in scrap generation and in fabricating costs could offer a distinct economic advantage.

Because of the above-mentioned potential advantages of centrifugal casting, a study concerned with determining the feasibility of a centrifugal-casting process for the production of aluminum-25 and -35 w/o uranium-alloy extrusion billets was undertaken.

From previous studies at Battelle, it was possible to conclude that satisfactory aluminum-uranium billets containing up to 45 w/o uranium could be produced utilizing vacuum-melting techniques.[5] The porosity noted in the vacuum-cast extrusion billets was attributed to shrinkage and, therefore, should be alleviated through proper pouring and feeding techniques. Moreover, it was believed that the protection afforded the melt by a vacuum could be dispensed with, and that an air-molding technique could be successfully employed if the casting technique sufficiently encouraged and permitted the escape of the gases liberated during solidification. A review of the techniques employed for the production of cylindrical shapes indicated that centrifugal casting of aluminum-uranium alloys was feasible. Centrifugal force could be substituted for the head employed in static casting and the central opening offered a suitable avenue of escape for gases.

The ultimate objective of the program was the production of multiple-length extrusion billets. However, because of the numerous variables encountered in centrifugal casting it was desirable to conduct the investigation in two phases. The first phase was concerned with the application of the technique to the production of single-length billets (6 in.), and the second phase was concerned with the production of multiple-length billets (18 and 26 in.).

PREPARATION OF SINGLE-LENGTH CASTINGS

Experimental Procedures and Equipment

It was the purpose of the first series of casting experiments to obtain a more complete understanding of the problems that would be encountered in centrifugal casting these particular alloys and to establish the potentials of this casting technique. During these investigations, single-length extrusion billets of the aluminum-25 w/o uranium alloy were prepared. The alloys were melted in either graphite or zirconia crucibles utilizing air-melting techniques with the molten alloy being degassed by bubbling helium through it. The mold was made of tubular steel 4-3/4 in. in ID with a wall thickness of 1/4 in. The back or closed end of the mold was sealed with a 1/2-in. steel plate which was attached to a vertical turntable which was rotated at 550 rpm. The forward or charging end of the mold was closed with a 1-in.-thick graphite plate having a 2-in.-diameter hole for teeming. Through this hole a graphite pouring spout was inserted into the mold. The position of the pouring spout in relation to the forward end of the mold was changed with each succeeding melt. A diagram of the mold mounted onto the turntable is shown in Figure 1.

The evaluation of the casting consisted of visual examination of the whole and sections of the as-cast billets. The billets exhibited extremely good exterior surfaces and rough interior surfaces. The only evidence of excessive porosity was noted in a narrow band around the inside surface of the castings. This band, shown in Figure 2, was approximately 1 in. wide and was located about midway from the ends of the casting. As noted during casting, this area represented the last portion of the melt to solidify. Studies of the area indicated that the porosity was caused primarily by shrinkage. No appreciable advantage with respect to inductive stirring or cleanliness of the melt was gained by using zirconia crucibles in preference to the cheaper graphite crucibles. The results obtained from these tests clearly showed that before acceptable castings could be made it would be necessary to eliminate or displace the shrinkage area noted in the castings. Therefore, a study of the effects of mold configurations and pouring techniques was initiated. However, before these data could be obtained, it was deemed advisable to investigate further some of the variables which are encountered in centrifugally casting an alloy. The most important of these are pouring temperature, mold speed, and pouring rate. Initially, a series of melts containing 35 w/o uranium was made utilizing a steel mold lined with 1/4-in. thick graphite. The melts were poured at 2200, 2300, and 2400 F into the 5-in.-diameter mold rotating at 550 rpm. The mold was preheated to 500 F at the forward end where the metal entered.

Although no areas of gross porosity were noted, the entire interior surface of the castings was poor. The melts poured at 2300 and 2200 F contained folds and cold shuts, indicating that either the mold speed was too slow, causing the metal to slump, or the metal did not have sufficient fluidity when it entered the mold. The castings poured at 2400 F showed less evidence of cold shuts, but there was evidence of "raining" (fall of molten alloy across the mold cavity) which was attributed to the slow mold speed.

From this series of castings, it was apparent that the graphite-lined mold did not cool the metal sufficiently fast, and that the large volume of liquid metal present at any instant in the mold caused the poor interior surfaces that were noted.

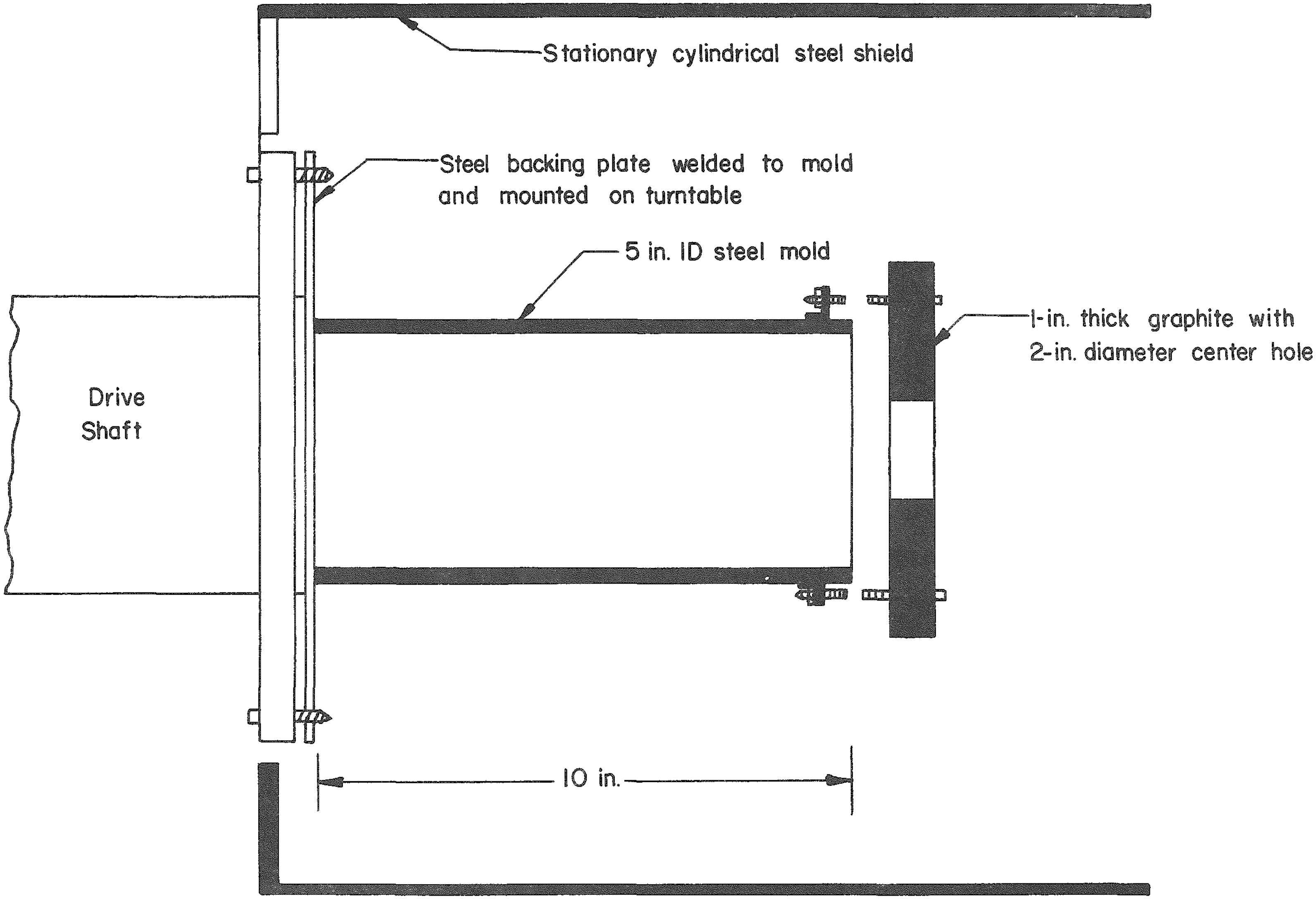

FIGURE 1. VERTICAL SECTION OF 10-IN. LONG CYLINDRICAL STEEL MOLD MOUNTED ON STEEL PLATE AND TURNTABLE

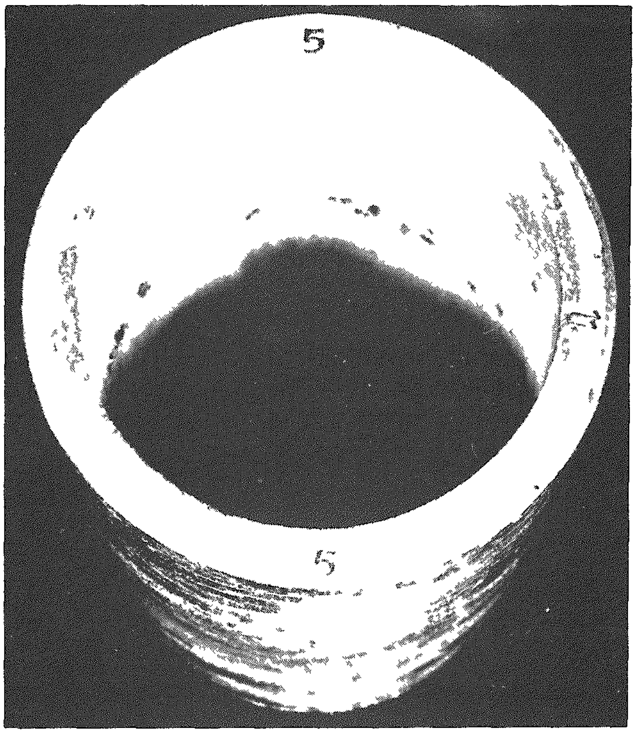

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FIGURE 2. MACHINED INTERIOR SURFACE OF AN ALUMINUM-35 w/o URANIUM 10-IN. EXTRUSION BILLET EXHIBITING CENTER SHRINKAGE BAND

In the next series of experiments, melts of both the 25 and 35 w/o uranium alloys were poured into a steel mold with a tapered wall. This mold, 10 in. in length with an ID of approximately 5 in., was mounted so that the rear of the mold, consisting of a heavy 1/2-in.-thick section, was in contact with the turntable. The front or charge end had a wall thickness of 1/8 in. and extended without support from the turntable. This mold was designed to impart directional cooling and displace the porous zone to the extreme front end of the casting. There it could be removed by cropping. Since the effect of mold speed had not been definitely established, castings were made using speeds of 350, 550, 700, 900, and 1200 rpm. The pouring temperatures investigated were 2100, 2200, and 2300 F for the 25 w/o uranium alloy and 2300, 2400, and 2500 F for the 35 w/o uranium alloy. As expected, the increased cooling rate obtained at the rear of the castings displaced the porous shrinkage area toward the front of the mold; however, the degree of displacement was not as great as expected. Visual examination of these castings revealed that mold speeds of 700 and 900 rpm yielded the best inside surfaces. The castings poured when the mold was rotating at 1200 rpm exhibited exterior surface imperfections. These appeared to be hot tears that had subsequently refilled with molten alloy. No improvement in the interior surface was noted in these castings made at 1200 rpm.

As noted above, visual observations indicated that the shrinkage area could be displaced by selective cooling and that mold speeds of 700 and 900 rpm would produce satisfactory inside surfaces. In an effort to further displace the shrinkage zone toward the front end of the cast billet, a number of melts were poured into the tapered mold which had been heated to 400 to 500 F at the front end. With these melts it was possible to obtain ingots containing sound material for 75 per cent of their length.

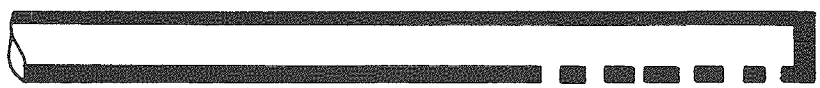
From the visual examination of these series of melts it was possible to evaluate the effects of the mold configuration and wall thickness. It was observed that the most critical factor in ingot quality was the method by which the metal was introduced into the mold. Therefore, a number of castings containing 35 w/o uranium were produced in a 10-in.-long steel mold with an ID of approximately 5 in. and a uniform wall thickness of 1/2 in. In this series of melts various placements and configurations of the graphite pouring spout were evaluated. In Figure 3 are shown four types of pouring spouts. The pouring spout, illustrated in Figure 3a, is shown inserted into the graphite pouring cup. When this type of fixed pouring spout was employed, the spout was placed so that the metal would impinge at either end or in the center of the mold. The section of the pouring spout shown in Figure 3b was used when it was desirable to introduce the metal at a number of places in the mold. These spouts were made with three to six holes with hole sizes up to 3/4 in. with various spacings. The spout shown in Figure 3c was investigated when it became apparent that it would be impossible to obtain uniform flow through a number of different holes in a single pouring spout. The last spout depicted (Figure 3d) is the type that proved most satisfactory.

An evaluation of the various types of pouring spouts was made on the bases of ingot quality and flow of the metal during pouring. While the spout shown in Figure 3a produced good results, it was impossible to control the exact position where the metal impinged upon the mold or upon the previously poured material. As stated previously, the use of a number of holes in the spout did not insure equal distribution of the metal in the mold. This was due primarily to the fact that holes of less than 5/8 in. in diameter would often freeze over during pouring. The tapered slot was also used in an effort to equalize the metal flow over the entire length of the mold. This slot also exhibited tendencies to freeze over at the small end. This would result in the metal flowing in a somewhat erratic manner through the large end of the slot opening. The pouring spout having only one large hole was designed to introduce the metal normal to the horizontal axis of the mold. This permitted the introduction of the metal at the exact location at which it was desired, and the hole was large enough so that it did not freeze shut.

Evaluation of Melts and Techniques

In most cases the as-cast shapes were evaluated by radiography and by macro- and microexamination. In certain cases these tests were supplemented by chemical analyses. Radiographic examination of the aluminum-35 w/o uranium billets cast in the graphite-lined mold disclosed extreme segregation. The aluminum-35 w/o uranium castings poured into steel molds were evaluated in detail. Visual examination revealed that acceptable inside surfaces were obtained at mold speeds of 700 and 900 rpm. All of the 35 w/o uranium castings poured at 2400 F and with mold speeds of 550 to 900 rpm exhibited extremely good exterior surfaces requiring little or no machining. Figure 4 shows an ingot cast in the tapered steel mold. It can be seen that the inside surface of the ingot nearest the camera (the back end of the mold) is very good. Approximately three-fifths the distance from this back end there is a beginning of the roughness and porosity noted in these ingots. The band of extreme porosity noted in the earlier ingots

a. Open-End $1\frac{1}{2}$-In.-OD by 1-In.-ID Graphite Spout inserted in Pouring Cup



b. Spout With Closed End and Six $\frac{5}{8}$ In. Holes Spaced to Cover 9 In.

c. Spout With Closed End and 7 In. Slot Tapering From $\frac{5}{8}$ In. to $\frac{1}{8}$ In.

d. Spout With Closed End and One 1 In. Diameter Hole 1 In. From Front

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FIGURE 3. SECTIONS OF THE VARIOUS TYPES OF POWER SPOUTS INVESTIGATED

All spouts were made of graphite and were cemented in the graphite pouring cup.

is located about three-fourths of the distance from the near end of the casting. Radiographic examination of sections cut from these ingots and from the ingots made with the various types of pouring spouts revealed areas of high uranium concentration present in those sections of the ingots where the molten metal was introduced. The variation in uranium content in a number of castings was plus or minus 5 to 8 w/o from the nominal 35 w/o with the lowest uranium concentrations occurring in the areas of the castings furthest removed from the pouring point.

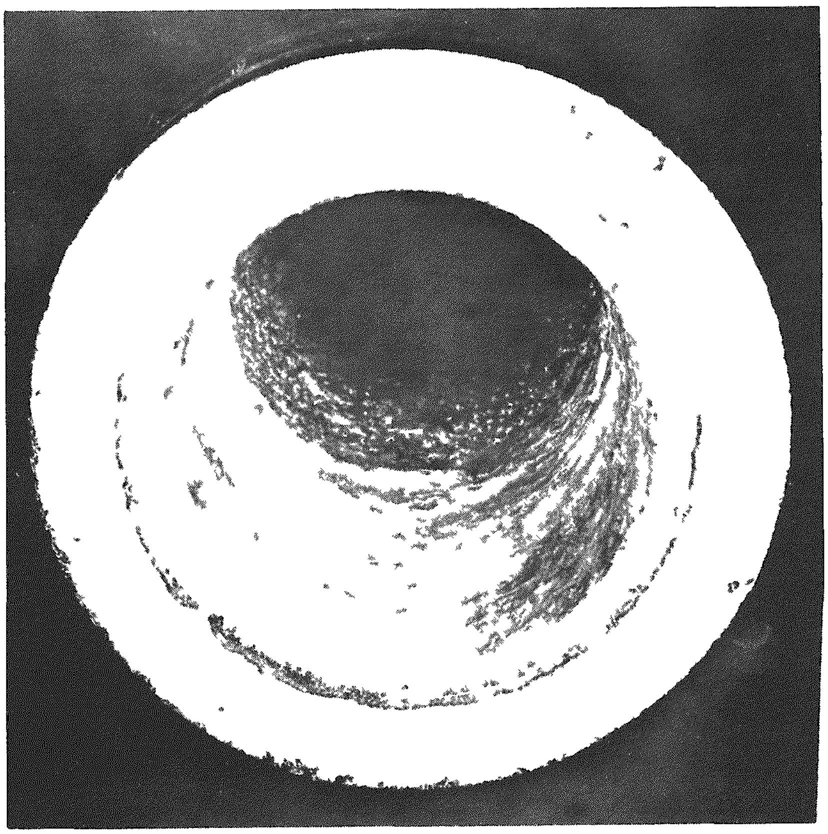

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FIGURE 4. PHOTOGRAPH OF 10-IN.-LONG ALUMINUM-35 w/o URANIUM INGOT CAST INTO TAPERED STEEL MOLD

Note surface imperfections and porosity in far end of casting.

Conclusions From the First Phase

From the foregoing experiments it was observed that the following conditions were necessary for the production of satisfactory castings:

(1) A mold speed at or near 700 rpm on a mold 5 in. in diameter. Since the effects of increasing the rotational speed of the mold is to increase the centrifugal force exerted on the molten metal and thus increase the tendency toward radial segregation, it is desirable to use the slowest mold speed compatible with good interior surface.

(2) A melt temperature of approximately 2400 F is optimum for the 35 w/o uranium alloys. This high temperature is necessary to insure that the melt remain at least partly fluid until the entire mold cavity is filled.

(3) A pouring spout with no openings less than 5/8 in. in diameter is required. Smaller openings freeze over and stop the flow of metal.

(4) A method of depositing the metal uniformly along the length of the mold is required. This eliminates or appreciably lessens the end-to-end segregation. Areas of high-uranium concentration are produced where the molten metal impinges upon the mold or upon previously solidified metal.

PREPARATION OF MULTIPLE-LENGTH CASTINGS

Experimental Procedures and Equipment

Upon the completion of the above-mentioned preliminary tests involving casting of single-length extrusion billets, emphasis was placed upon the production of aluminum-35 w/o uranium castings of sufficient length to yield two or more extrusion blanks up to 8.6 in. in length with an OD of 4.8 in. Mold speeds of 700 to 900 rpm, pouring temperatures of 2300 and 2400 F, and cooling rates as determined in the initial phase of the program served as the basis for the production of multiple-length castings. Further studies of spout configurations were required since the spout was to be moved along the axis of the mold as the metal was poured whereas previously it had remained stationary.

The mechanism designed to produce movement of the pouring spout is shown in Figure 5. As shown in the photograph, the crucible and induction-heating assembly are mounted on a movable platform which rests upon two 1-in.-diameter steel rods which serve as ways. The pouring cup and spout are also mounted on the movable platform. In the photograph, the cup and spout are in position for bottom pouring, a technique selected for use in the final stages of the program. Beneath the platform there is a reversible electric motor connected by a sprocket and chain to a speed reducer which in turn is connected by a chain and sprocket assembly to the sprocket cluster shown directly beneath the right end of the movable platform. A continuous chain drive connects the sprocket cluster to a single sprocket mounted at the left or forward end of the platform. Contact with the movable platform is obtained by an extended link which engages an extension welded onto the bottom of the platform. The chain drive permits essentially slip-free operation. By changing a sprocket located in the sprocket cluster, many spout-withdrawal speeds are obtainable.

The pouring-spout mechanism is mounted on an angle-iron frame with four casters to impart mobility to the platform, thus permitting the operator to locate the pouring mechanism wherever desired relative to the mold mechanism. Four leveling screws are welded onto the frame inside the wheels for more rigid placement when the

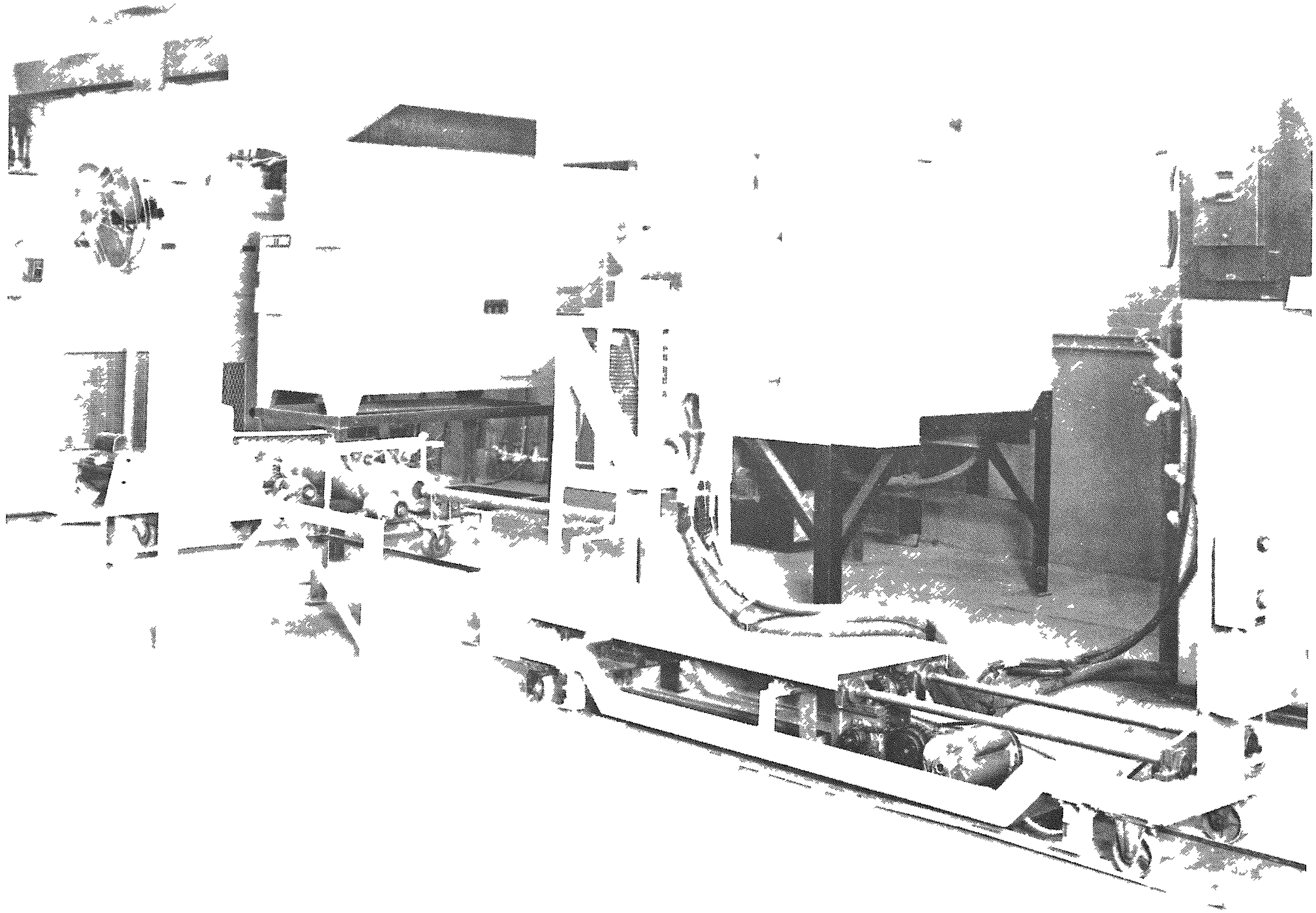

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FIGURE 5. CENTRIFUGAL APPARATUS WITH MECHANIZED POURING SPOUT RETRACTED

mechanism is operating. The electrical controls consist of a three-station push-button control box and two limit switches. These permit either automatic or manual control when it is desired to change the direction of travel of the pouring platform. The various speeds available, the ability to start, stop, and to change the direction of travel when and where desired, and the rigidity of the mechanism make this a sufficiently versatile piece of equipment for the investigation of pouring techniques for centrifugal casting.

Preparation of 18-In.-Long Castings

Prior to the preparation of 26-in.-long castings it was deemed advisable to evaluate the effects of the movable pouring spout on the quality of the cast billets. An 18-in.-long mold 5 in. in diameter with a uniform wall thickness of 1/4 in. was used for these experiments. The first three melts poured into this mold utilized a stationary pouring spout and served as a base for evaluation of the subsequent melts which were made utilizing a moving pouring spout. The melting and pouring procedure utilized is described briefly below:

(1) The aluminum was melted in a graphite crucible and superheated to 1800 F.

(2) The uranium was added intermittently and stirred into the melt after each addition.

(3) The melt was stirred until the uranium was in solution.

(4) The melt was degassed by bubbling helium through it for 10 min.

(5) A protective helium atmosphere was maintained over the melt and the melt temperature was increased to the approximate pour temperature of 2300 or 2400 F.

(6) The graphite pouring spout-and-cup assembly was heated _in situ_ by gas burners to temperatures of 400 to 800 F.

(7) Rotation of the steel mold (at room temperature) was started. Mold speeds of 700 to 900 rpm were used.

(8) The melt was skimmed, again degassed by bubbling helium through it for 3 to 5 min, and stirred vigorously.

(9) The heat was lip poured into the graphite-preheated pouring cup-and-spout assembly, which introduced the molten metal into the rotating steel mold.

The pouring temperatures investigated were 2300 and 2400 F as determined by a platinum-platinum 10 w/o rhodium thermocouple in a quartz tube protected from the melt by a graphite tube. The variables evaluated in conjunction with the movable pouring spout were the pouring rate, the location of the spout, and the rate of movement of the spout. These interdependent variables were believed to have the greatest effect upon the casting quality once the mold speed and pouring temperatures were determined.

The evaluation of these melts was confined to visual examination of as-cast and sectioned billets. Such an evaluation was sufficient to detect gross porosity and to evaluate the quality of the inside surface of the castings. It was found that all of the castings exhibited acceptable outside surfaces, and it was noted that there was some improvement in the quality of the inside surface of the castings when the mold speed was increased from 700 to 900 rpm. Freezing of the melt in the pour spout was encountered when the spout was heated to only 400 F prior to pouring. This is attributed to the longer spout necessary for the increased mold length. The rate of retraction of the pour spout was varied over a wide range as was the rate of pour. It was found that when the pouring rate was slow, the metal tended to freeze in the pour spout or failed to flow properly after entering the mold. It was also found that if the rate of refraction of the spout did not coincide with the pour rate there existed evidence of cold shuts in the castings. As a result of the length of these castings and because of the fact that it was impractical to support the forward end of the rotating mold, all of the 18-in.-long castings exhibited radial eccentricity to some extent.

The results of the evaluation of these castings led to the following conclusions:

(1) The rate of retraction of the pour spout should coincide with the rate of pour so that the metal is deposited evenly from end to end in the mold.

(2) The use of a retractable pouring spout eliminates the need for either a heated mold or a heat sink to promote directional solidification.

(3) The length of the pouring spout necessitates heating the pouring cup-and-spout assembly to temperatures of approximately 800 F to insure metal flow when pouring 18-in.-long castings.

(4) A method of supporting the mold to eliminate eccentricities in the cast products is required.

Preparation of 26-In.-Long Castings

Since the centrifugal casting apparatus used to produce the 18-in.-long billets introduced eccentricities in the ingots it was necessary to design an apparatus in which the mold could be supported upon a roller bed. This apparatus is shown in Figures 5 and 6, and has been used to produce castings of relatively uniform wall thickness. It consists of a steel mold supported by four 2-in.-wide by 4-in.-diameter wheels mounted on an angle-iron frame. The mold is driven by an electric motor through a Worthington speed selector connected by a belt drive to a shaft mounted in the back end of the mold. The mold is held firmly in contact with the roller bed by two rollers mounted in a bracket positioned over the mold. Pressure is maintained on the mold by spring loading the bracket. This serves to lessen the vibration without seriously hampering the rotation of the mold.

During the casting of 26-in.-long billets using this device the techniques were initially those described previously for the 18-in. billets. This technique involved lip pouring. Evaluation of ingots so produced was by visual examination of sections cut from the castings. It was observed that extensive porosity was prevalent beneath the interior

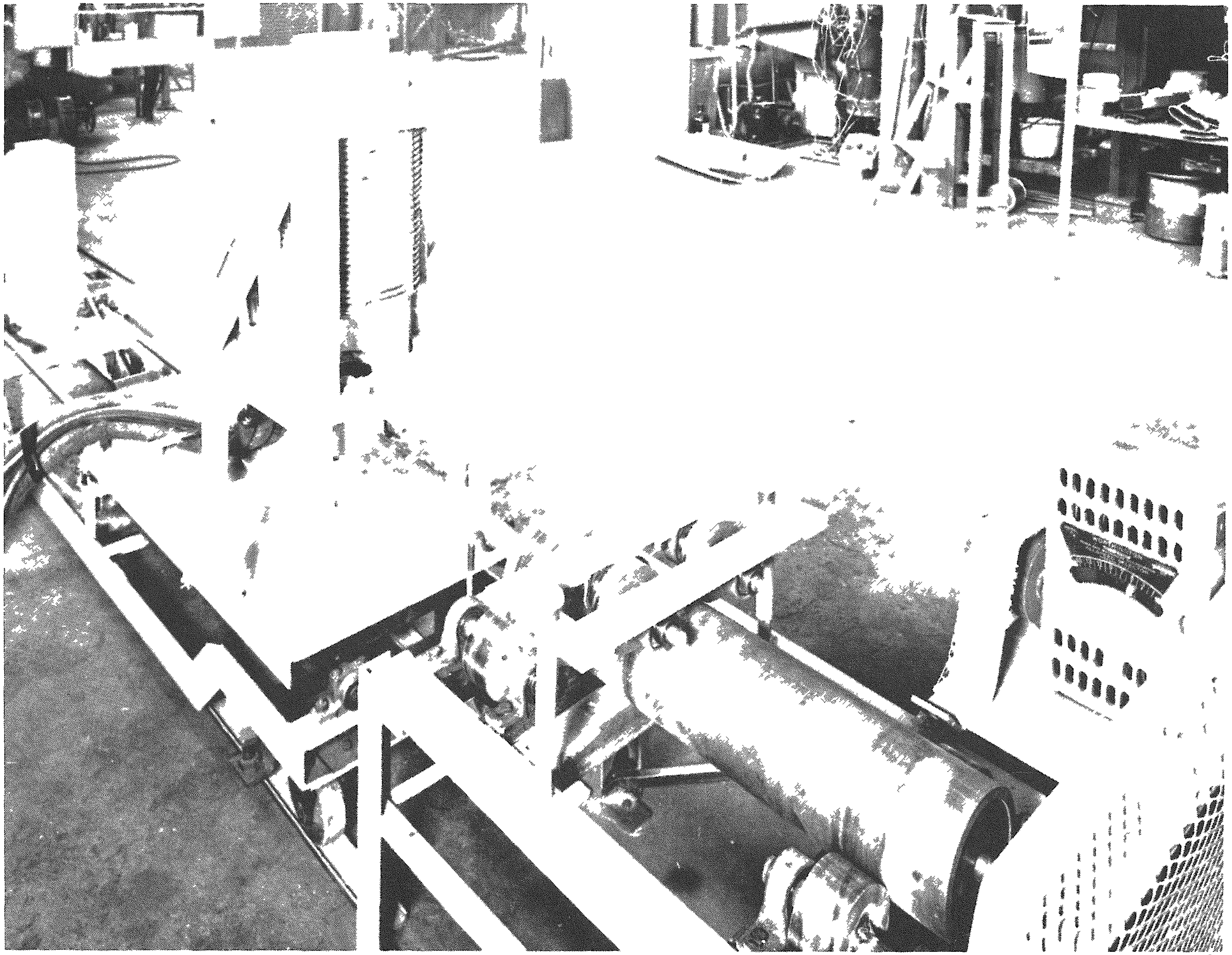

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FIGURE 6. CENTRIFUGAL APPARATUS WITH POURING SPOUT INSERTED IN MOLD

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surfaces of the castings and extended to a depth of approximately 50 per cent of the wall thickness. This porosity was attributed to the uneven feeding of the mold as a result of a variable pouring rate. Shrinkage was also noted, and manifested itself as linear depressions in the interior surface of the cast shapes.

These results indicated the need for a pouring rate that would deposit just the right amount of molten metal at or near the point in the mold where it was to solidify. It was thought that this could most easily be obtained by pouring through an orifice. It was also believed that either the helium was not degassing the melt sufficiently or that the melt was picking up gases during lip pouring.

Therefore, a bottom-pour induction coil-and-melting crucible assembly was mounted on the movable pouring-spout platform. The use of bottom pouring permitted the operator to attain the desired constant metal flow into the pouring cup by using a break-off plug with the required orifice. The bottom-pouring arrangement also decreased the exposure of the metal to the atmosphere. The photographs in Figures 5 and 6 show the bottom-pour coil-crucible assembly and mold assembly used in these studies. Figure 5 shows the pouring spout and crucible assembly withdrawn from the mold. In Figure 6 the pouring spout is in position for the beginning of a pour. As the pour proceeds the spout is mechanically retracted from the mold.

The melting and pouring techniques finally developed for 26-in.-long billets were as follows:

(1) The aluminum is melted to 1800 F.

(2) The uranium is added intermittently over a period of 10 to 20 min.

(3) The melt is stirred while adding uranium and after all the uranium is added to insure its solution.

(4) The temperature of the melt is raised to the pouring temperature of 2400 F.

(5) The graphite pouring cup-and-spout assembly preheated in an electric furnace to 1400 F is placed in position beneath the coil and extending into the mold.

(6) The coil-and-pouring mechanism is rolled forward to pouring position.

(7) The melt is stirred vigorously and bottom poured into the mold rotating at 850 rpm.

(8) Approximately at the same instant that the metal begins to fill the mold, the retraction mechanism of the pouring assembly is started.

It will be noted that this melting cycle differs from that used in the previous studies in two significant steps: (1) no outgassing techniques are employed, and (2) the melt is not skimmed prior to pouring. The improved protection from atmospheric contamination afforded the metal during pouring is thought to be partially responsible for eliminating the need for outgassing. Of course, in bottom pouring, the material normally skimmed from the melt before lip pouring is retained in the crucible.

A charge of 15 kg of metal is employed in casting 26-in.-long billets. It has been determined that approximately 19 sec is required to pour a melt; therefore, the rate of retraction of the pour spout is 26 in. in 19 sec. It is estimated from surface-temperature measurements that the pouring-cup and spout temperatures are normally 900 F at the time of pour. This represents a loss of 500 F from the temperature to which they were heated in the electric furnace (1400 F).

Evaluation of Multiple-Length Castings

Since one of the primary reasons for investigating centrifugal casting as a technique for the production of cylindrical extrusion billets was to determine if substantial savings could be effected in the amount of material that must be recycled or otherwise reclaimed, a material balance was maintained on all of the ingots produced by this technique. This material balance included the weights of all materials used in the charge and all losses during melting and cooling. Also included in the original material balances were the weights of all materials removed from the ingots during machining and for chemical and radiographic analyses. For brevity and to make the material balance more meaningful the average material balance for 5-in.-OD by 26-in.-long extrusion billets is given below.

Material Balance

Charge weight	15.00 kg
Material left in crucible and pouring cup and spout	1.60 kg
Casting weight	13.40 kg
Weight of material removed from ends and surfaces	1.20 kg
Total weight of machined casting	12.20 kg

The 26-in.-long ingots were evaluated by various techniques, including visual and radiographic examination and chemical analyses. The visual examination indicated extremely good exterior surfaces were obtained on all melts, including one aluminum-25 w/o uranium ingot. A photograph of the 25 w/o uranium ingot is shown in Figure 7. In Figure 8 are shown two aluminum-35 w/o uranium castings exhibiting the same fine surface as found on the 25 w/o uranium casting. The interior surface of an aluminum-35 w/o uranium casting is shown in Figure 9. Castings of this type required the removal of only approximately 1/16 in. of material from the radius of the inside surface to obtain completely sound material. Radiographic examination of sections cut from the ingots revealed areas of low uranium concentrations around the interior surface of all castings. This effect is shown in Figure 10 in typical radiographs of ring sections taken from each end of an ingot. Although the areas depleted in uranium vary in thickness from end to

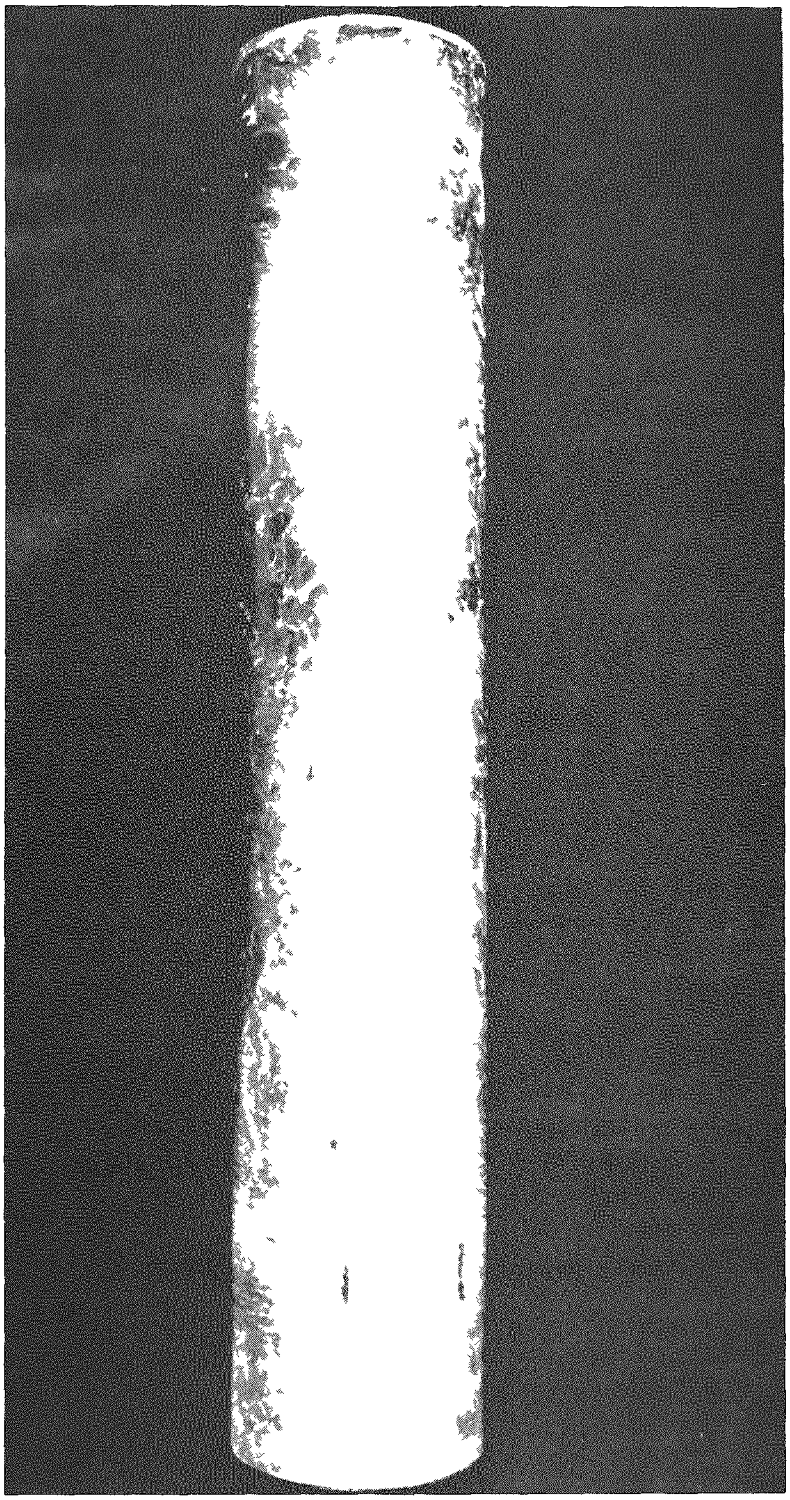

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FIGURE 7. EXTERIOR SURFACE OF 26-IN.-LONG ALUMINUM-25 w/o URANIUM EXTRUSION BILLET

The surface finish is superior to that generally obtained by static-casting methods.

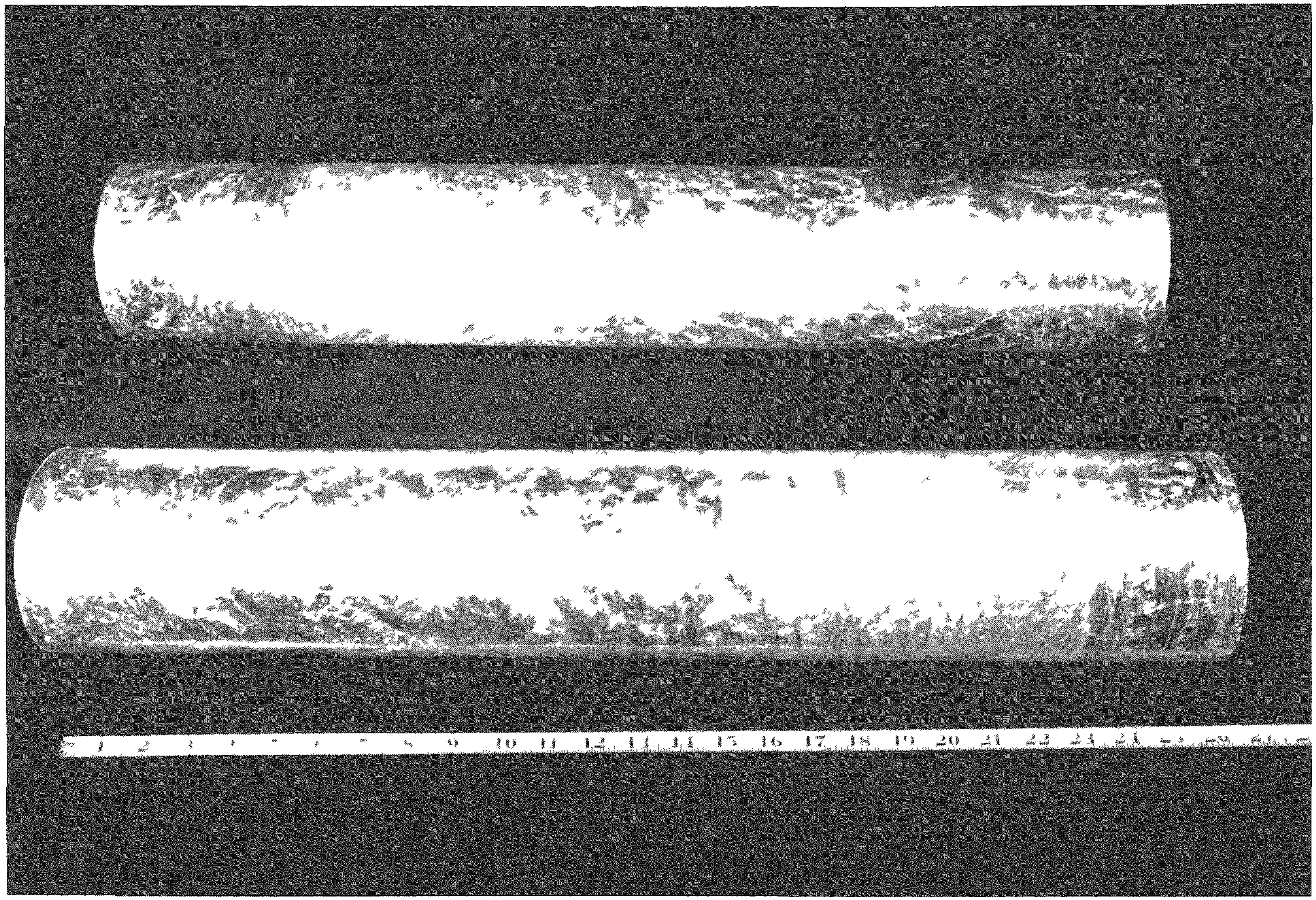

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FIGURE 8. EXTERIOR SURFACES OF TWO 26-IN.-LONG ALUMINUM-35 w/o URANIUM EXTRUSION BILLETS

The fine surface finish was typical of that obtained on multiple-length 35 w/o uranium castings toward the end of the program.

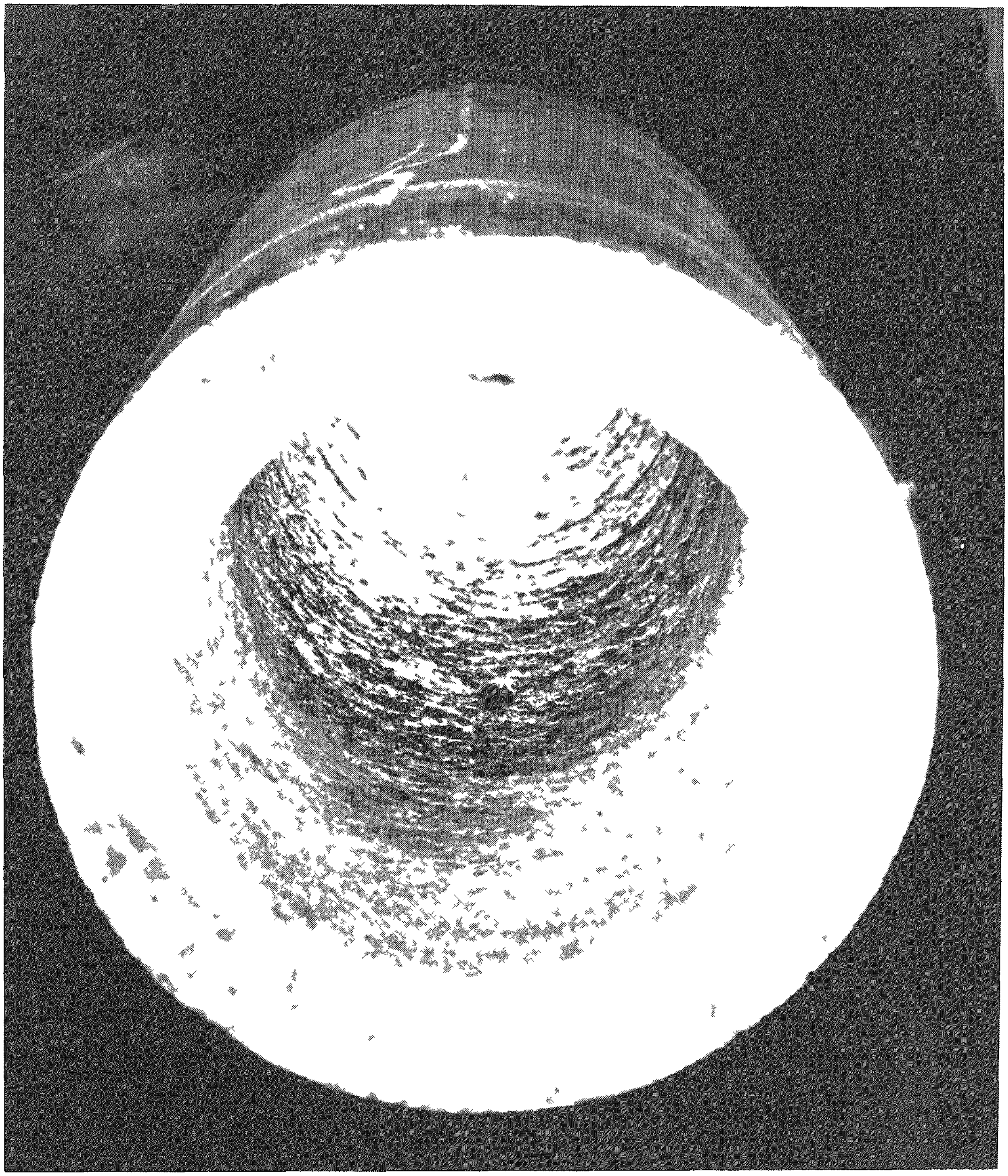

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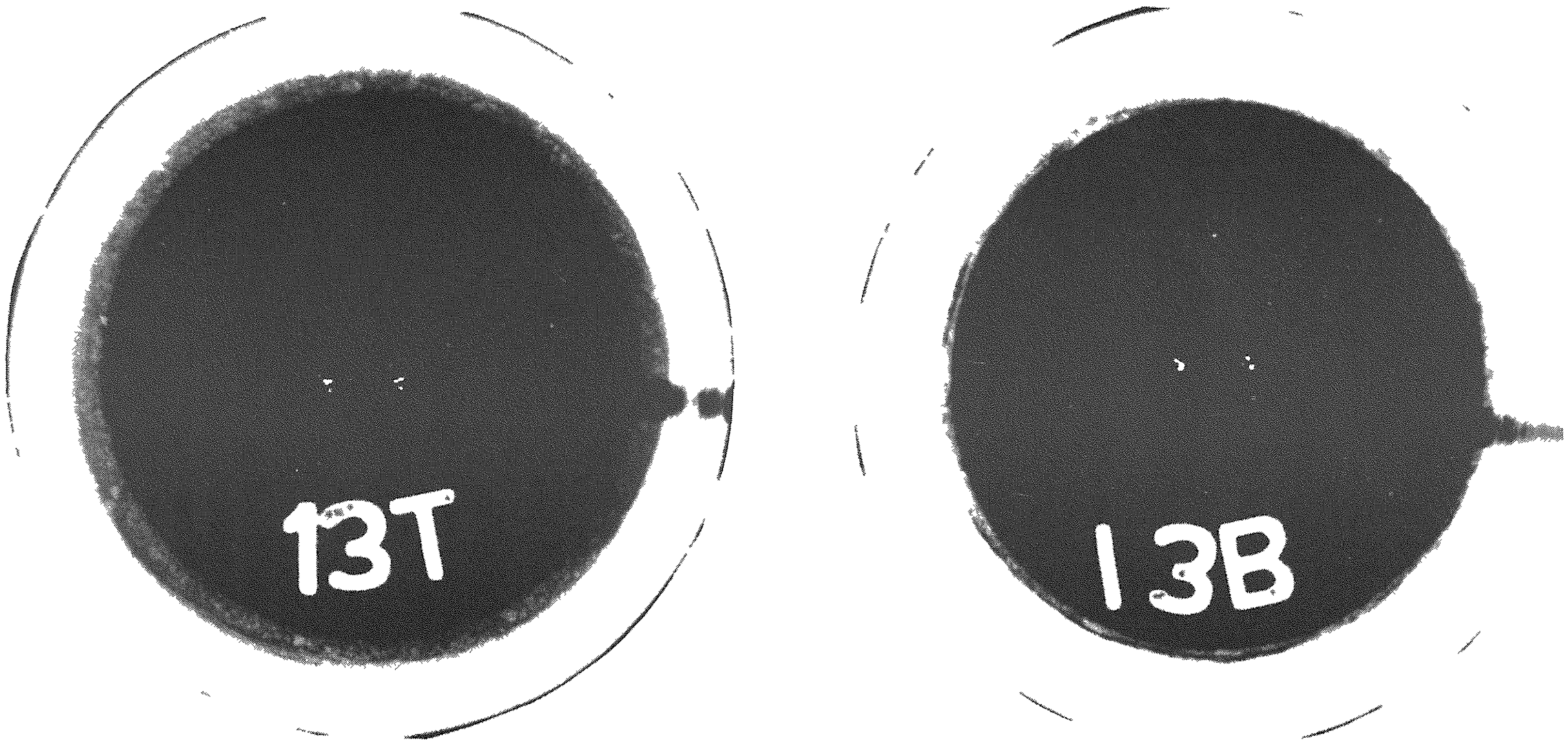
FIGURE 9. INTERIOR SURFACE OF 26-IN.-LONG ALUMINUM-35 w/o URANIUM EXTRUSION BILLET

Only minimum machining was necessary to produce a satisfactory interior surface.



Front　　　　　Rear

FIGURE 10. X-RAY OF FRONT AND REAR SECTIONS OF ALUMINUM-35 w/o URANIUM EXTRUSION BILLET

Some migration of the uranium toward the major diameter is apparent. The gaps in the edges were produced by sampling for chemical analysis.

end in the castings, chemical analyses of the best castings made varied only from 32.1 w/o uranium to 35.3 w/o uranium. The 1/4-in.-wide bands which transverse the radiographed sections represent gaps where material was removed for chemical analyses. Some of the chemical analyses obtained are shown in Table 1, and indicate the range of uranium concentrations that were detected. These analyses show that the material removed from the inside surface during machining to produce a sound and uniform surface was extemely low in uranium containing 14.5 to 16.8 w/o.

TABLE 1. CHEMICAL ANALYSES OF 26-IN.-LONG ALUMINUM-35 w/o URANIUM BILLETS

Ingot	Sample Location	Analyzed Composition, w/o
9	Front	34.7
	Middle	33.8
	Rear	27.8[a]
	Inside surface	16.8
12	Front	32.1
	Middle	35.3
	Rear	32.6
	Inside surface	15.5
13	Front	32.0
	Middle	33.0
	Rear	37.3
	Inside surface	14.5

(a) Analyses believed in error.

An examination of the material balance shows that the greatest loss of material was due to material left in the pouring train and in the crucible. The material left in the crucible was almost negligible and certainly no more than that which would have been removed from the melt if it had been skimmed. The balance of this 1.60 kg was left in the pouring cup and spout. This material was massive and was suitable for recharging. Of the material removed from the ends and surfaces of the casting, approximately 0.30 kg was massive metal cropped from the ends of the castings. The other losses were in the form of machine or saw chips which were not reused. Thus, it can be seen that with an initial charge of 15.00 kg it was possible to produce a machined casting weighing over 12.00 kg. This represents a casting containing over 75 w/o of the original charge after machining.

If present plant practices were followed in recycling scrap the over-all recoveries would be considerably higher. If the low uranium content of the machine chips is considered, still higher uranium recoveries would be indicated.

CONCLUSIONS AND RECOMMENDATIONS

The feasibility of producing sound extrusion billets up to 26 in. long by centrifugal casting is clearly indicated by the results of these melting and casting studies. The variation in uranium concentrations along the length of the billets compares favorably with variations obtained in static castings. Porosity within the centrifugally cast material is limited to the inside surfaces of the cast shape and can be removed with a minimum of machining. Similar soundness in static-cast billets is obtainable only by using elaborate outgassing and molding techniques. With the equipment used in these studies it was found that a pouring temperature of 2400 F, a pouring rate of 15 kg per 19 sec, and a pouring spout of the configuration shown in Figure 3d produced the most satisfactory castings. It was determined that the pouring spout should be at a temperature of at least 900 F and that it should be retracted at a rate just sufficient to deposit the metal uniformly to the required depth along the length of the mold. As expected, centrifugal force acting on the melt during solidification results in some transverse segregation in all castings, producing somewhat low uranium concentrations at the points closest to the axis of rotation. The use of the bottom-pouring technique in conjunction with a movable pouring spout eliminates the need for special degassing procedures to produce sound material. Shrinkage problems normally encountered when static casting these alloys are minimized and almost eliminated through the use of this centrifugal casting technique.

The results of these studies are particularly encouraging from the standpoints of material recovery and ingot soundness. The fact that sound ingots of sufficient length to yield up to four extrusion blanks can be cast in one operation indicates that production economies are sure to be realized by using this technique. However, there are certain areas in which developmental work remains to be done. To lower costs, materials other than graphite should be investigated for possible use in the pouring spout. Other, more convenient, methods of heating the spout such as resistance and muffle heating should be studied. Reductions in the severity of transverse segregation may be obtained by increasing the freezing rate and by ternary alterations(7) of the alloy system. Another technique that might be used to improve the quality of the product by refining the grain size of the cast structure as it solidifies would involve imposing ultrasonic energies to the solidifying interface.

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