April 30, 1946. A. E. SCHUH ET AL 2,399,606

CENTRIFUGAL CASTING

Filed Dec. 4, 1943 2 Sheets-Sheet 1

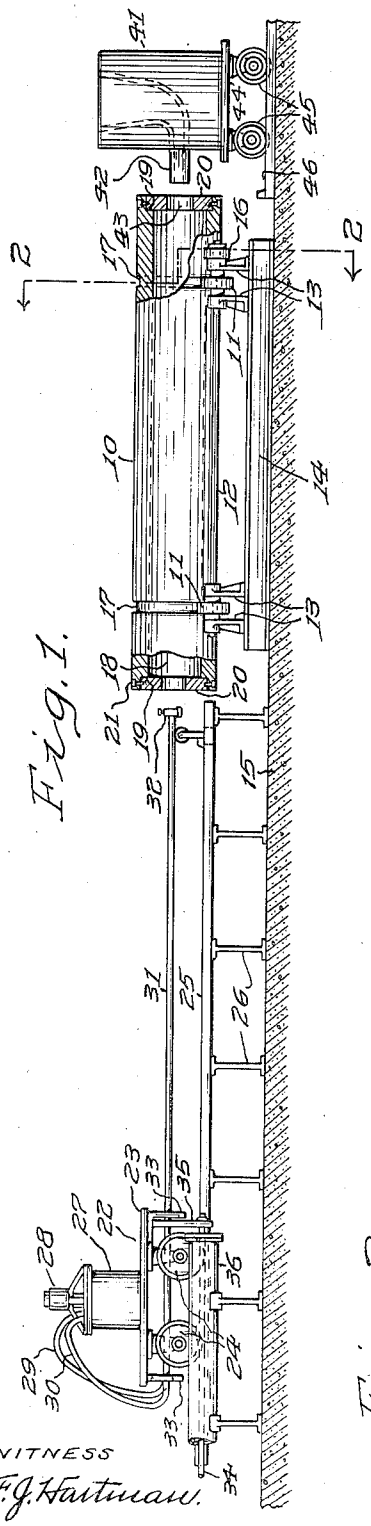


Fig. 1.

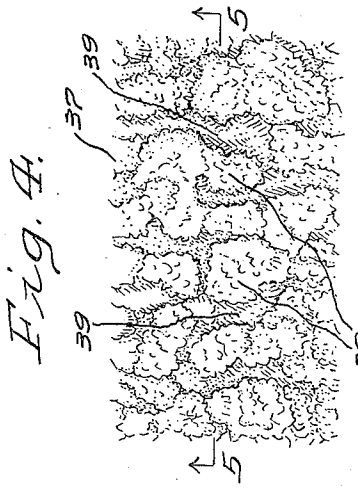


Fig. 4.



Fig. 5.

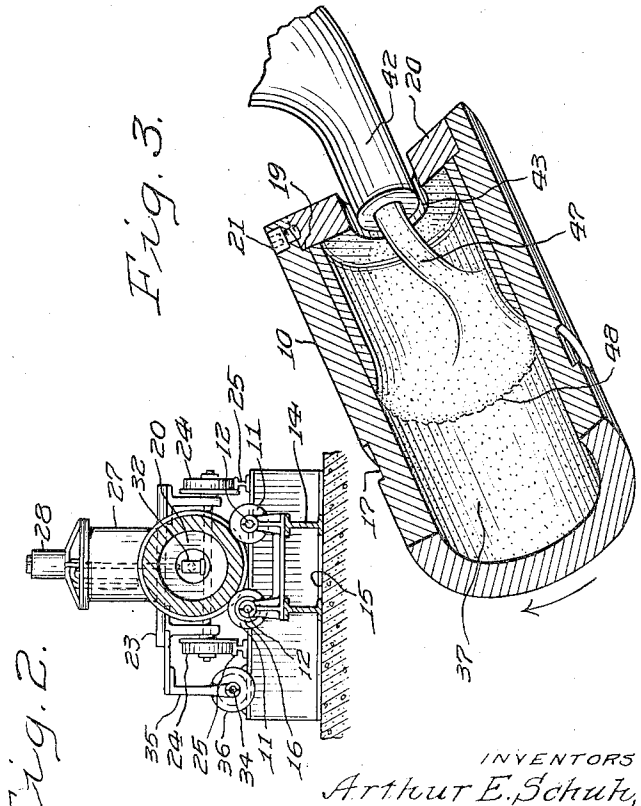


Fig. 3.

Fig. 2.

WITNESS
F. J. Hartman.

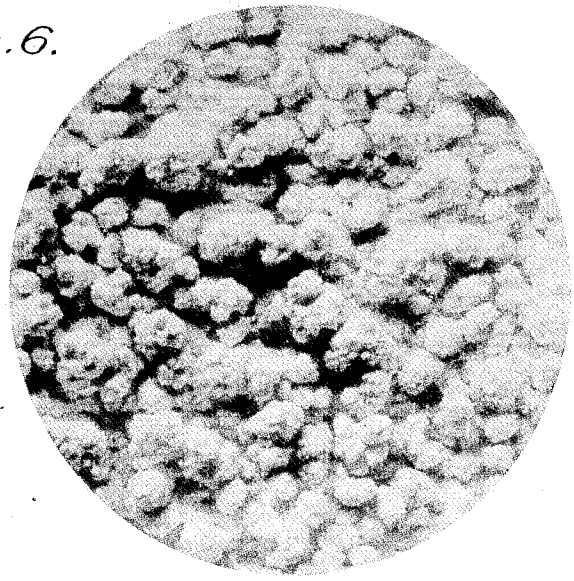
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Fig. 6.



PHOTOGRAPH OF SURFACE OF COATING, MAGNIFIED 10 TIMES.

Fig. 7.



PHOTOGRAPH OF CROSS SECTION OF COATING, MAGNIFIED 20 TIMES.

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2,399,606

UNITED STATES PATENT OFFICE

2,399,606

CENTRIFUGAL CASTING

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Application December 4, 1943, Serial No. 512,958

17 Claims. (Cl. 22—113.5)

This invention relates to the manufacture of tubular metal castings, and is directed particularly to certain improvements in the manufacture of such castings centrifugally in permanent metal molds rotated horizontally or substantially so.

In centrifugally casting in this manner and particularly when casting a relatively long tubular body, that is, whose length exceeds three or four times its outside diameter, the art has long been confronted with the problem of producing a casting in which the metal is completely fused throughout the wall and which has a substantially defect-free outer surface.

While this problem is more or less acute according to the particular method of centrifugal casting employed, it has not heretofore been solved.

For instance, one particular method of centrifugal casting heretofore employed in the production of long tubular bodies in permanent metal molds involves the pouring of the charge of molten metal into the metal mold in such a manner that the distribution of the metal longitudinally of the mold is effected primarily by the action of centrifugal force. A common way of doing this is to pour the metal from a spout occupying a relatively fixed position lengthwise of the mold and located say at one end of the mold. However, attempts to produce long tubular castings centrifugally by such a method have heretofore resulted in the formation of castings having so-called "pinholes" and "laps" or "cold shuts," which render the castings commercially unacceptable.

In another method which is widely employed commercially the molten metal is delivered to the mold by means of a pouring trough relatively retractable over the length of the mold so that the molten metal is deposited progressively to form a helix, the convolutions of which fuse together to form an integral structure. In this method the metal is distributed longitudinally over the mold surface primarily by means of the retractive pour, and the centrifugal force holds the molten metal against the mold, as in all centrifugal casting. However, in actual practice the metal upon being so deposited does spread to some extent because of the lateral pressure resulting from the centrifugal force, and is thus caused to flow longitudinally of the mold to advance beyond the helical zone of deposition. This spreading is sometimes excessive, and is frequently irregular, or, as it is sometimes called, discontinuous, on the leading edge, and then results in the formation of excessively thin offshoots which solidify almost instantaneously and produce small laps or cold shuts in the outer surface or portion of the casting. While this method reduces the troublesome defects, it does not solve the problem above referred to.

As a result of extensive efforts to make long tubular casting free of such defects, centrifugally from steel or other metals or alloys poured into horizontal or substantially horizontal permanent metal molds by either of these methods, it has been found that the incomplete fusion of the metal and the defects on the outer surface of the casting are due to an uncontrolled advance of the charge of molten metal lengthwise of the mold without sufficiently partaking of the rotational motion of the mold. When the advancing molten metal slips over the mold, moving lengthwise thereof intermittently and/or too rapidly, it tends to result in the formation of pinholes originating at the outer surface of the casting. The laps or cold shuts are produced when the leading edge of the molten metal moves longitudinally of the mold more or less intermittently and/or discontinuously, at a speed whereby it becomes so thin that it rapidly cools, prematurely solidifies and also oxidizes, to such an extent that it does not properly weld to or unite with the mass of metal which subsequently flows over it as the distribution of the charge progresses. These pinholes and laps or cold shuts sometimes extend throughout the thickness of the wall of the casting, but usually occur only in the outer portion of the wall or in what is often termed the outer surface.

The present invention has for its principal object to provide a procedure whereby long tubular castings made of steel or other metals or alloys may be centrifugally cast in horizontal or approximately horizontal permanent metal molds in such a manner that the castings have the metal completely fused throughout their walls and have their outer portions substantially free from pinholes and laps or cold shuts, as would detract from the quality of the castings or render them commercially unacceptable.

More particularly, an important object of the invention is to solve the problem above referred to by employing, in a centrifugal casting method wherein the molten metal is poured into the mold while the mold is rotated to distribute the metal both circumferentially and longitudinally therein, a procedure in which the pick-up of the molten metal for rotation with the mold is accelerated, the flow of the metal longitudinally

of the mold is retarded, and, while maintaining the over-all rate of solidification of the casting substantially the same as in the bare metal mold, the heat flow to the mold from the leading edge of the longitudinally advancing molten metal is momentarily arrested to maintain the leading edge at a temperature to fuse with the molten metal which subsequently flows thereover.

Another object of the invention is to effect the procedure above referred to, by providing a relatively thin refractory mold coating of such a character and texture that it both serves as a thermal barrier to arrest and control the rate of solidification of the leading edge of the molten metal, and provides a surface of controlled roughness to give the degree of traction required between the molten metal and the mold. The thermal barrier action is necessary in order to assure complete fusion of the metal forming the outer portion of the casting as the molten metal is propagated in the mold, but requires no more than a momentary arrest of the heat flow to the mold without substantially slowing down the over-all heat flow and the quick freezing of the metal characteristic of casting in metal molds or retarding the rate of casting production. Hence the superior grain structure of the cast metal and other well-known advantages attained by and inherent in casting centrifugally in a metal mold are retained. The traction is required to accelerate the speed with which the poured charge of the molten metal partakes of the rotary movement of the mold and give a quick pick-up, and also to control the longitudinal propagation of the metal in the mold, that is, to keep the molten metal from slipping over the mold in a longitudinal direction intermittently and too rapidly and with a discontinuous and excessively thin leading edge. These properties and functions of the coating act conjointly to produce the desired result.

A further object is to provide such a coating which is applied by spraying a liquid suspension of the coating material on the mold, and in which the above mentioned required properties thereof may be varied and controlled by the regulation of the spraying operation.

A composition which has been found suitable for providing a coating having the desired characteristics above referred to is composed of a suspension of silica flour and bentonite in water, and is applied to the mold by a spraying operation in which the composition is atomized and discharged on the inner surface of the heated metal mold by a relative reciprocation of a spray nozzle thereover. While the coating composition may be varied, a uniform aqueous suspension made up in the proportions of 1 litre of water, from 500 to 1000 grams of silica flour and from 10 to 40 grams of bentonite has proved to be satisfactory. The particles of silica flour should be of such a fineness that the composition is sprayable in an atomizer type of spray, and are preferably of about #325 sieve size or finer. Although bentonite aids materially in keeping the silica flour in suspension in the water, it is desirable to agitate the liquid composition more or less continuously in order that a uniform suspension may be maintained during the application of the composition.

In applying such a composition to the inner surface of the mold it is essential that the mold be heated to a temperature within the range of 250° to 800° F., with a preferred range of 350° to 500° F. The composition should be atomized and sprayed on the mold at such a rate that the carrier liquid will evaporate very quickly after the sprayed globules come into contact with the heated surface. The mold should not be so hot, however, as to vaporize the liquid before the globules are deposited. When the composition is applied in the manner indicated, the solid refractory and binder materials of each globule remain essentially in the position where they are deposited on the mold surface with the result that an incremental coating is formed by the spraying operation. As the coating is thus formed by an accretionary growth of the solid material of these globules and the spray conditions are such that the globules do not spread or run together on the mold surface, the coating which is thus built up is provided with a surface of controlled roughness, which is formed of a multiplicity of projections or protuberances.

The particular shape and contour of the protuberances do not appear to be important, although a surface which, upon being enlarged photographically, resembles somewhat the surface of a cauliflower has been found to produce very satisfactory results. The protuberances on such a surface are, of course, irregular in shape and size and are usually so arranged as to be noticeably spaced from each other. It is not to be understood, however, that such irregularity is essential. It is desirable that the coating be so formed that the protuberances merge into a basal portion or that they be basi-connected in order that the surface of the mold may be substantially covered by the coating, and in order that the charge of molten metal may be subjected substantially uniformly to the thermal barrier action of the coating.

The character of the coating surface may be readily varied to avoid one which is too smooth to effect the desired control over the distribution of the molten metal in the mold or one which is rougher than need be for the purpose. Desired variations in the roughness of the surface of the coating may be made by suitably controlling various features of the procedure which is followed in applying the coating composition, such as by altering the shape and direction of the spray jet issuing from the spray nozzle, altering the distance of the nozzle from the surface of the mold, changing the degree of atomization of the coating composition or varying the air pressure employed, varying the amount of coating composition applied to a given area of the mold surface in a given time interval, and varying the extent of the incremental formation of the coating.

While different forms of nozzles or spray heads may be used in applying the coating composition, a fan spray has been found suitable as it can be readily controlled to vary the dimensions and directions of the fan or sheet emitted by the nozzle. In coating a rotating cylindrical mold by relative reciprocation of a spray device longitudinally within the bore of the mold, the spray device is preferably so arranged that the fan or sheet of spray extends parallel to the longitudinal axis of the mold. Such an arrangement is desirable in order to produce a coating having a rough surface of the character required in the practice of the invention. A less rough coating may be obtained by varying the direction of the fan from the axial position toward a position in which it is at right angles thereto, that is, in a position transverse to the longitudinal mold axis.

Variations in the angle of the spray nozzle with

respect to the mold surface may also be used to effect changes in the character of the surface of the coating. Owing to the greater concentration of the spray upon a given area of the mold surface, a smooth surfaced coating may be made when the nozzle is directed at an angle of 90° with respect to the mold surface, while a rough surface may be provided on the coating with the nozzle directed at an angle of 45°. It has also been found that an increase in the air pressure utilized with an air spray device tends to produce a rougher coating, but this tendency may be neutralized if the spray nozzle is operated too close to the mold surface. Increasing the distance of the nozzle from the mold surface tends to increase the roughness of the surface of the coating.

The roughness of the coating surface may also be varied by altering the quantity of the coating composition sprayed upon a given area of the mold surface in a given time interval. When applied at a suitable rate, the solid materials of the separate globules remain in place so that the accretionary growth produces a rough surfaced coating. Upon increasing the amount of the composition applied to the mold, or the rate of application of the composition, the composition tends to spread over the mold surface by reason of the slower evaporation of the carrier liquid, with the result that a coating with a smoother surface is formed.

When other conditions are such as to produce a coating with a rough surface of suitable character, the roughness of the surface tends to increase as the coating is incrementally built up by the spraying operation. This is believed to be due to the fact that the separate masses of solid material in the first globules which strike the mold surface project from the surface and are thus in position to intercept more of the sprayed material than the surrounding mold surface. These small masses of solid material thus grow more rapidly than the surrounding areas of the mold surface, and this rapid growth continues until the thickness of the protuberances thus formed becomes sufficient to insulate their exposed surfaces from the heat effect of the mold and thus prevent the liquid from evaporating quickly from the additional globules or parts of globules which are directed upon them. When this occurs there is ultimately attained a condition whereby the sprayed globules flow together into a relatively smooth surface which is no longer suitable for the production of defect-free long centrifugal castings in accordance with this invention.

It has been found that the average thickness of a coating of this composition may vary within a range of from 0.002 inch to 0.08 inch; that the average number of protuberances may vary from 10 to 120 per lineal inch measured in any direction across the surface of the coating, and that the average height of the protuberances above the surrounding area of the coating may vary within a range of from 0.001 inch to 0.050 inch. As to the roughness of the surface of the coating, to put it another way, it is comparable to and may vary within the range of No. 24 to No. 240 abrasive paper or cloth.

The thickness of the coating and the order of roughness may be varied to some extent with the casting conditions, such as with the particular centrifugal casting method employed, the metal being cast, the length and diameter of the tubular casting to be made, the wall thickness of the casting, and the particular coating composition used. For instance, when using this coating in the particular method of centrifugal casting wherein action of centrifugal force is primarily relied upon to distribute the molten metal longitudinally of the mold, the following ranges may be used: an average thickness within approximately from 0.01 inch to 0.08 inch; 10 to 50 protuberances per inch when measured in any direction across the surface of the coating, 20 to 25 protuberances per inch being preferred; and an average protuberance height ranging from approximating 0.005 inch to 0.050 inch, the roughness being of the order and within the range of No. 24 to No. 100 according to the abrasive cloth or paper scale and preferably within the range of No. 40 to No. 60. On the other hand, in the particular form of centrifugal casting in which the molten metal is delivered by means of a pouring trough relatively retractable over the length of the mold, it has been found that this coating may be thinner and of a lesser order of roughness and still give satisfactory results.

The above composition, with the proportions given, produces a coating which adheres together and to the mold and yet which is sufficiently friable upon the completion of the casting operation that the particles do not adhere to each other and to the mold to such an extent as to interfere with the ready withdrawal of the casting from the mold. This coating appears to be somewhat more friable after the casting operation than before it. In this connection we have discovered that notwithstanding such friability, the coating will resist the washing away effect of the molten metal stream as it is poured into the mold, and furthermore the protuberances forming the rough surface of the coating will effectively engage with, and control the movement of, the molten metal without being crushed thereby. So far as we are aware, it is novel to employ a coating of this character for permanent metal molds used in centrifugal casting. It would not ordinarily be expected that such a coating would act in the manner above indicated, and that it does so may be due to the fact that the forces exerted on the coating by the molten metal are actually of a lower order than the art has understood them to be. It is also to be noted that the friability may be varied and controlled by varying the proportion of the bentonite in the coating composition.

A coating of this composition is of temporary character, and is applied to the mold before each casting operation. After the application of the coating, the coated mold may be subjected to handling, inspection, recoating, and/or storage, as required, without interfering with its subsequent use. Upon the withdrawal of the casting, the coating may, because of its friability, be readily removed from the mold by means of a wire brush and/or a jet of compressed air, to facilitate the preparation of the mold for the next casting.

Irrespective of the other advantages attained through the use of a thin coating of this particular composition, its chief advantage and importance lies in providing both a controlled, momentary thermal barrier and an exposed surface of controlled roughness, the rough surface producing the required traction to cause a quick pick-up of the molten metal to partake of the rotary movement of the mold and to keep the metal from slipping over the mold in a longitudinal direction intermittently and too rapidly and with a discontinuous and excessively thin leading edge, and the action of the thermal barrier pro-

viding a momentary arrest of the heat flow to the metal mold to assure the complete fusion of the metal forming such leading edge and the outer surface of the casting with the oncoming metal subsequently flowing thereover as the metal is propagated in the mold, while maintaining the over-all rate of solidification of the casting substantially the same as in the bare metal mold. By the expression substantially the same as in the bare metal mold we mean that the over-all rate of solidification of the casting is of that order of quick freezing which is well-known in the art as characteristic of centrifugal casting in a metal mold with its attendant advantages, as distinguished from the slow freezing characteristic of centrifugal casting in a refractory mold with its attendant disadvantages. The thickness and the order of roughness are both affected by the accretionary growth of the coating as the composition is sprayed.

Various other compositions may be used in the practice of the invention to provide, when sprayed upon the mold, a thin refractory coating having both the required thermal barrier action and the surface roughness required for traction. For instance, while silica flour is a satisfactory refractory since it is not difficult to obtain and, when applied as above described, produces the necessary resistance to heat to provide the requisite thermal barrier action, any other suitable refractory materials, such as, for example, the oxides of aluminum, magnesium, beryllium, zirconium, chromium, etc., may be used. As indicated above, bentonite has been found to be a satisfactory binder as it serves not only as a binding agent for the particles of refractory material in the coating, but as a suspending agent for the particles in the liquid carrier used in spraying the coating composition on the mold. Nevertheless other suitable binding agents may be used, provided they have the necessary adhesive qualities to enable the coating to withstand the forces exerted thereon by the charge of molten metal, as well as to adhere properly to the metal mold, and are sufficiently refractory and free of components tending to emit gases during the casting operation. Furthermore while water is a convenient carrier vehicle for the solid ingredients of the composition it is to be understood that any other suitable liquid may be employed for this purpose.

Regardless of the particular composition used in the practice of the invention it is to be noted that the magnitude and distribution of the protuberances on the inner surface of the coating are such that the traction of said protuberances on the molten metal serves both to accelerate the pickup of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of the mold, and that the thickness of the coating is such that the thermal barrier action thereof serves to momentarily arrest the heat flow to the mold from the longitudinally advancing edge of the molten metal to maintain such leading edge at a temperature to fuse with the molten metal subsequently flowing thereover. These are essential physical characteristics of the coating to enable it to perform its required function in carrying out the present invention.

In order that the present improvement may be better understood, reference is made to the accompanying drawings illustrating apparatus for the practice of one form of the invention, and a coating suitable for use in producing tubular castings in accordance with the invention. In the drawings,

Fig. 1 is a diagrammatic side elevational view of such apparatus, certain parts thereof being shown in section;

Fig. 2 is a transverse sectional view taken on the line 2—2 of Fig. 1;

Fig. 3 is a sectional, perspective view of the right end of the mold illustrated in Fig. 1, showing the pouring device discharging molten metal into the mold, also showing the manner in which the mold coating operates to control the forward flow of the molten metal in the mold;

Fig. 4 is a diagrammatic plan view, on an enlarged scale, showing the surface of the improved coating;

Fig. 5 is a diagrammatic sectional view of the coating taken on the line 5—5 of Fig. 4;

Fig. 6 is an enlarged photographic view of the surface of a coating made in accordance with the invention; and

Fig. 7 is an enlarged photographic view of a cross section of the coating shown in Fig. 6.

By way of specific illustration, the invention will now be described and shown in connection with the particular method of centrifugal casting in which centrifugal force is primarily depended upon to distribute the metal longitudinally of the mold, or, in other words, in which a non-retractive type of pour is employed. According to this form of the invention, it may be conveniently carried out with a cylindrical mold 10 which is supported in a horizontal position upon two sets of rollers 11 in a manner well understood in the art. The two aligned rollers 11 on each side of the mold 10 are secured on a shaft 12 supported in bearing blocks 13 on beams 14. These beams may be laid on a floor 15 serving as a base for the entire apparatus. The projecting end of one shaft 11 may be provided with a pulley 16 or other suitable means connected to a power device for driving the shaft and thereby rotating the mold. Annular grooves 17 may be provided in the outer surface of the mold to serve as tracks for the rollers 11 in order that the mold may be held against endwise shifting. The ends of the mold bore 18 are provided with enlargements 19 to receive end plates 20 which may be retained in position by set screws 21 threaded through the mold wall.

The coating composition described above may be applied to the inner surface of the mold 10 by spraying apparatus 22, such as illustrated at the left of Fig. 1. The spraying apparatus 22 is mounted upon a carriage 23 having wheels 24 running on rails 25 so that the carriage may be moved toward and away from the adjacent end of the mold 10. The rails 25 are in alignment with the mold and may be supported on ties 26 on the floor 15. Supported on the carriage 23 is a suitable container 27 for the coating composition. An electric motor 28 mounted over the container 27 may be used for driving an agitator in the container and for operating a pump therein to circulate the coating composition through suitable piping 29, 30, in the lance 31 to the spray device 32 on the outer end thereof. The lance 31 is secured to the carriage 23 in such a manner that movement of the carriage back and forth on the rails 25 will reciprocate the spray device 32 from end to end within the bore 18 and parallel to the mold axis. It is preferably mounted in hangers 33 in such a manner that it may be adjusted in a vertical direction in order to vary

the distance of the spray head from the inner surface of a given mold, or to adjust the spray head for coating molds of different diameters. The carriage 23 may be moved toward and away from the mold by means of a piston rod 34 having one end connected to the carriage by an arm 35 and having its opposite end connected to a piston operating in a cylinder 36 supported alongside one of the rails 25.

With a spraying apparatus of this character the coating composition may be applied to the inner surface of the mold by reciprocating the spray device 32 throughout the length of the bore of the heated, rotating mold as many times as may be necessary to build up a coating having the necessary thickness and a surface roughness of the character desired under the given casting conditions. A coating which has been found satisfactory for casting long tubular bodies by the method of centrifugal casting employing the non-retractive type of pour, is illustrated at 37 in Figs. 4 and 5 of the drawings on a scale which represents a magnification of approximately ten times. As indicated therein, the separate protuberances 38 are spaced from each other by depressions 39, are more or less irregular in shape and size, and they merge into a continuous base portion 40 which covers the inner surface of the mold so that the latter is insulated from the metal which is poured into it during the casting operation. Another such coating which is also satisfactory for this purpose is illustrated photographically in Figs. 6 and 7, Fig. 6 being magnified ten times and Fig. 7 being magnified twenty times.

After the coating is applied to the inner surface of the mold, the end plates 20 are positioned in the enlargements 19 and secured therein by the set screws 21. Before they are inserted the end plates are provided on their inner faces with a suitable coating which may conveniently be similar to the coating heretofore described. The charge of molten metal is delivered to one end of the rotating mold from a pouring device 41 which can be an ordinary casting ladle, an induction furnace, or simply a receptacle for molten metal as illustrated in the drawings. The pouring device 41 is provided with a spout 42 which is so constructed and arranged as to project into the end of the mold, through a central opening 43 in the adjacent end plate 20, when the charge is poured. The pouring device 41 may be supported on a carriage 44 provided with a set of wheels 45 running on rails 46 so that it may be readily moved into and out of pouring position.

When the charge is poured at a suitable rate into the mold the thin refractory coating previously sprayed on the mold and having both a controlled thermal barrier action and a controlled surface roughness, performs the functions described above in detail and modifies the casting operation accordingly, whereby to make possible the centrifugal casting in a permanent metal mold of a long tubular body in which the metal is completely fused throughout its wall and which is substantially free from pinholes, and laps and like defects in its outer portion or surface. While the outer surface of a casting produced in accordance with this invention substantially conforms to the roughness of the mold coating so employed in its production, this roughness is not objectionable in castings employed for many purposes. However, where a smoother outer surface is required it may be readily obtained by machining the casting to the degree required to remove the roughness found in its outer surface in the as cast condition.

The manner in which the invention is employed in the particular method of centrifugal casting involving a retractive type of pour, will be obvious to those skilled in the art, in view of what has been set forth above, and hence is not specifically illustrated.

An apparatus which has been found satisfactory in the application of a thin refractory coating to a metal mold for centrifugal casting in accordance with the present invention, forms the subject matter of a pending application for patent by Alfred Boyles, Serial No. 469,751, filed December 19, 1942, for Process and apparatus for coating molds.

What we desire to claim is:

1. In the method of making a tubular metal casting centrifugally in a cylindrical metal mold, the improvement which comprises forming on the inner surface of said mold a refractory, insulating coating adherent to said mold and having a multiplicity of spaced protuberances on its inner face, supporting said mold substantially horizontally and rotating it about its longitudinal axis, and pouring molten metal into said mold, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pick-up of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of said mold, and the thickness of the coating being such that the thermal barrier action thereof serves to momentarily arrest the heat flow to the mold from the longitudinally advancing leading edge of the molten metal to maintain such leading edge at a temperature to fuse with the molten metal subsequently flowing thereover, while maintaining the over-all rate of solidification of the casting substantially the same as in the bare metal mold.

2. In the method of making tubular metal castings centrifugally in a permanent metal mold, the improvement which comprises heating said mold, spraying the inner surface of said mold with a liquid suspension of a powdered refractory material and a binder to form incrementally an insulating coating adherent to said mold and having a multiplicity of spaced protuberances on its inner face, supporting said mold substantially horizontally and rotating it about its longitudinal axis, and pouring molten metal into said mold, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pick-up of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of said mold, and the thickness of the coating being such that the thermal barrier action thereof maintains the leading edge of the molten metal at a temperature to fuse with the molten metal subsequently flowing over it, while maintaining the over-all rate of solidification of the casting substantially the same as in the bare metal mold.

3. In the method of making tubular metal castings centrifugally in a permanent metal mold, the improvement which comprises heating said mold to a temperature of 250° to 800° F., spraying the inner surface of the heated mold with an aqueous suspension of a powdered refractory material and a binder to form incrementally thereon an adherent, insulating coating having a multiplicity of spaced protuberances on its inner face, sup-

porting said mold substantially horizontally and rotating it about its longitudinal axis, and pouring molten metal into said mold, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pick-up of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of said mold, and the thickness of the crating being such that the thermal barrier action thereof maintains the leading edge of the molten metal at a temperature to fuse with the molten metal subsequently flowing over it.

4. In the method of centrifugally casting tubular metal bodies in a permanent metal mold, the improvement which comprises heating the mold to a temperature within the range of 250° to 800° F., supporting said mold substantially horizontally and rotating it about its longitudinal axis, relatively reciprocating a spray device throughout the length of the bore of said mold while discharging from said device an aqueous suspension of a powdered refractory material and a binder to provide the mold with an adherent, insulating coating comprising a multiplicity of incrementally formed, basi-connected protuberances, and pouring molten metal into said mold, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pick-up of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of said mold, and the thickness of the coating being such that the thermal barrier action thereof maintains the leading edge of the molten metal at a temperature to fuse with the molten metal subsequently flowing over it.

5. In the method of producing tubular metal castings centrifugally in a permanent metal mold, the improvement which comprises applying to said mold a refractory, insulating coating adherent to said mold and having an average thickness of from 0.002 inch to 0.080 inch and having a rough exposed surface within the range of No. 24 to No. 240 abrasive cloth or paper, supporting said mold substantially horizontally and rotating it about its longitudinal axis, and pouring molten metal into said mold, the magnitude and distribution of said protuberances being such that the traction of said rough surface on the molten metal serves both to accelerate the pick-up of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of said mold, and the thickness of the coating being such that the thermal barrier action of the coating maintains the leading edge of the molten metal at a temperature to fuse with the molten metal subsequently flowing over it.

6. In the method of producing tubular metal castings centrifugally in a permanent metal mold, the improvement which comprises providing the mold with a refractory, insulating coating adherent to said mold and having an average thickness of from 0.002 inch to 0.080 inch and having on its exposed surface a multiplicity of protuberances the average number of which measured in any direction across the surface of the coating is from 10 to 120 per lineal inch, and which protuberances have an average height above the surrounding coating within a range of 0.001 inch to 0.050 inch, supporting said mold substantially horizontally and rotating it about its longitudinal axis, and pouring a charge of molten metal into said mold.

7. In the method of producing tubular metal castings centrifugally in a permanent metal mold into which the molten metal is poured from a spout relatively fixed lengthwise of the mold, the improvement which comprises providing the mold with a refractory, insulating coating adherent to said mold and having an average thickness of from 0.01 inch to 0.08 inch and having on its exposed surface a multiplicity of protuberances the average number of which measured in any direction across the surface of the coating is from 10 to 50 per lineal inch, and which protuberances have an average height above the surrounding coating within the range of from 0.005 inch to 0.050 inch, supporting said mold substantially horizontally and rotating it about its longitudinal axis, and pouring molten metal into said mold.

8. In the method of making tubular metal castings centrifugally in a permanent metal mold, the improvement which comprises heating said mold, spraying the inner surface of said mold with an aqueous suspension of silica flour and bentonite to form incrementally an adherent, insulating coating having a multiplicity of spaced protuberances on its inner face, supporting said mold substantially horizontally and rotating it about its longitudinal axis, and pouring molten metal into said mold, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pick-up of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of said mold, and the thickness of the coating being such that the thermal barrier action thereof maintains the leading edge of the molten metal at a temperature to fuse with the molten metal subsequently flowing over it.

9. In the method of making tubular metal castings centrifugally in a permanent metal mold, the improvement which comprises heating said mold, spraying the inner surface of said mold with an aqueous suspension of silica flour and bentonite in the proportions of from 500 to 1000 grams of silica flour and from 10 to 40 grams of bentonite, per litre of water, to form incrementally an adherent, insulating coating having a multiplicity of spaced protuberances on its inner face, supporting said mold substantially horizontally and rotating it about its longitudinal axis, and pouring molten metal into said mold, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pick-up of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of said mold, and the thickness of the coating being such that the thermal barrier action thereof maintains the leading edge of the molten metal at a temperature to fuse with the molten metal subsequently flowing over it.

10. The method of preparing a permanent metal mold for casting tubular metal bodies centrifugally therein, which comprises heating said mold, and spraying on the inner surface of said mold a liquid suspension of powdered refractory material and a binder in atomized condition so that the heat of the mold evaporates the liquid upon contact of the sprayed globules with the mold to thereby form incrementally on said mold an adherent, refractory, insulating coating having on its exposed surface a multiplicity of irregular, rough protuberances, the magnitude and distribution of said protuberances being such that the

traction of said protuberances on the molten metal serves both to accelerate the pickup of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of the mold, and the thickness of the coating being such that the thermal barrier action thereof maintains the leading edge of the molten metal at a temperature to fuse with the molten metal subsequently flowing over it.

11. The method of preparing a permanent metal mold for casting tubular metal bodies centrifugally therein, which comprises heating said mold to a temperature within the range of 250° to 800° F., and spraying on the inner surface of said mold an aqueous suspension of powdered refractory material and a binder in atomized condition so that the heat of the mold evaporates the liquid upon contact of the sprayed globules with the mold to thereby form incrementally on said mold a refractory, insulating coating having an average thickness within the range of 0.002 inch to 0.080 inch and having on its exposed surface a multiplicity of irregular, rough protuberances, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pickup of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of the mold.

12. The method of coating the inner surface of a cylindrical metal mold used for making tubular metal castings centrifugally, which comprises heating said mold, and reciprocating a spray device throughout the length of the bore of the heated mold in a direction parallel to the axis thereof while discharging from said device a liquid suspension of a powdered refractory material and a binder in atomized condition so that the heat of the mold evaporates the liquid upon contact of the sprayed globules with the mold to thereby form incrementally on said mold a refractory, insulating coating having an average thickness within the range of 0.002 inch to 0.080 inch and having on its exposed surface a multiplicity of irregular, rough protuberances, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pickup of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of the mold.

13. A permanent metal mold for centrifugal casting, having adherent on its inner surface an insulating coating of powdered refractory material and a binder, said coating having an average thickness of from 0.002 inch to 0.080 inch and having on its exposed surface a multiplicity of protuberances, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pickup of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of the mold.

14. A permanent metal mold for centrifugal casting, having adherent on its inner surface an insulating coating of powdered refractory material and a binder, said coating having an average thickness of from 0.002 inch to 0.080 inch and having a rough exposed surface within the range of No. 24 to No. 240 abrasive cloth or paper, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pickup of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of the mold.

15. A permanent metal mold for centrifugal casting, having an incremental, insulating coating sprayed thereon and adherent thereto, which coating has an average thickness of from 0.002 inch to 0.080 inch and has on its exposed surface a multiplicity of protuberances the average number of which measured in any direction across the surface of the coating is from 10 to 120 per lineal inch, and which protuberances have an average height above the surrounding coating within a range of 0.001 inch to 0.050 inch.

16. A permanent metal mold for centrifugal casting, having an incremental, insulating coating sprayed thereon and consisting of powdered refractory material and a binder, said coating having an average thickness of from 0.002 inch to 0.080 inch, having on its exposed surface a multiplicity of protuberances for providing traction on the molten metal, the magnitude and distribution of said protuberances being such that the traction of said protuberances on the molten metal serves both to accelerate the pickup of the molten metal for rotation with the mold and to retard the flow of the molten metal longitudinally of the mold, and the coating being sufficiently adherent to withstand the washing away action of the molten metal and sufficiently friable upon solidification of the casting to permit the casting to be readily withdrawn from the mold.

17. A permanent metal mold for centrifugal casting, having an incremental, insulating coating sprayed thereon and consisting of powdered refractory material and a binder, said coating having an average thickness within the range of 0.002 inch to 0.080 inch and having on its exposed surface a multiplicity of protuberances the average number of which measured in any direction across the surface of the coating is from 10 to 120 per lineal inch, and which protuberances have an average height above the surrounding coating within a range of 0.001 inch to 0.050 inch, said coating also being sufficiently adherent to withstand the washing away action of the molten metal and sufficiently friable upon the solidification of the casting to permit the casting to be readily withdrawn from the mold.

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