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Behr et al.

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[54] **DIRECT CHILL CASTING METHOD**

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[51] **Int. Cl.** **B22d 11/00**

[58] **Field of Search** 164/89, 283, 273, 164/122, 126, 82, 338

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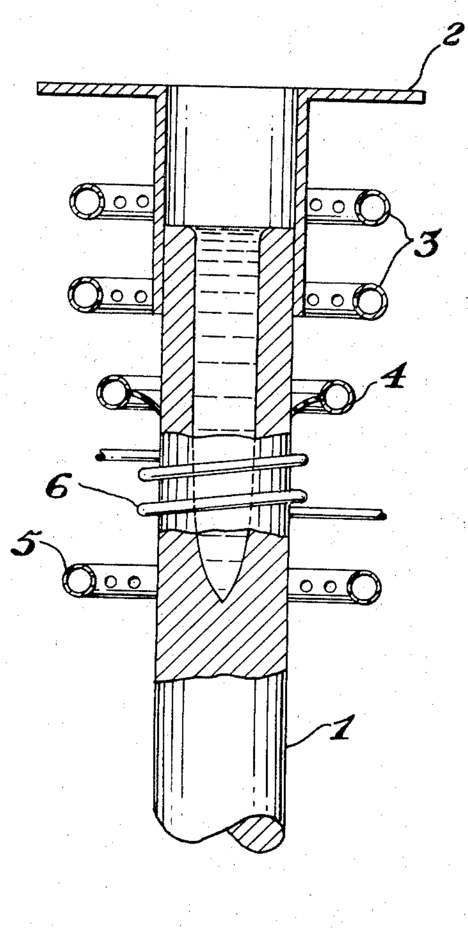
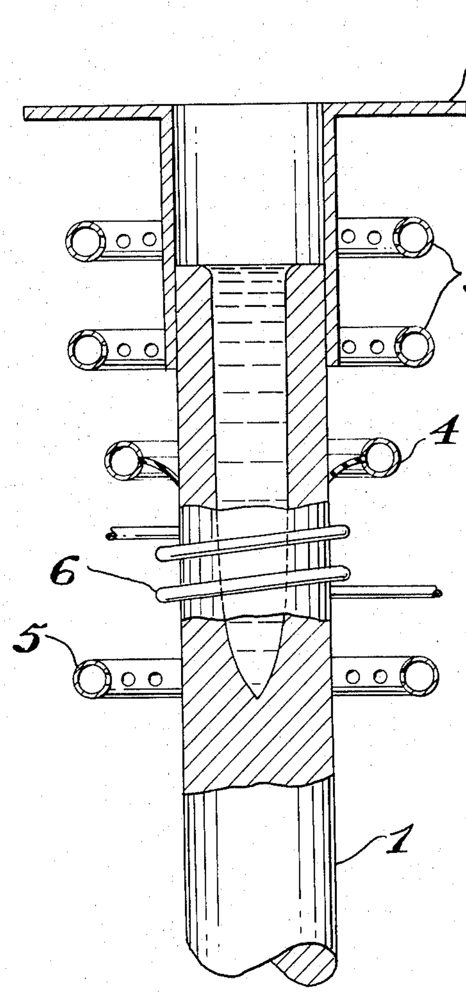
[57] **ABSTRACT**

In the direct chill casting of metal ingots wherein the coolant is removed from the ingot surface shortly below the mold to permit a reheating of the ingot surface, the improvement which comprises reapplying the coolant to the ingot surface at a somewhat lower level corresponding approximately to the level of the bottom of the molten metal pool. The improved method reduces ingot cracking and permits higher ingot casting speeds by preventing the generation of excessive internal stresses during solidification and further cooling of the ingot.

6 Claims, 1 Drawing Figure

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DIRECT CHILL CASTING METHOD

BACKGROUND OF THE INVENTION

Many metals, e.g., aluminum alloys, magnesium alloys and steel, are conventionally direct chill (DC) cast by feeding molten metal into an open-ended, cooled mold. The molten metal touching the mold walls solidifies into an outer shell containing an internal molten metal pool. This embryo ingot is continuously or semicontinously withdrawn from the mold and cooled further by means of, for example, a water spray ring.

When this casting method is followed, one troublesome problem which may be encountered is the occurrence of internal cracks. These often manifest themselves as radial cracks, often with several branches which are referred to as "star cracks." In other cases they may occur across a single radial plane. In extreme cases they will extend to the ingot surface and even result in splitting the ingot into halves.

In some alloys, this tendency toward internal cracks, when the above-described casting method is followed, will limit the maximum permissible casting speed, and will thus impose a limitation on the productivity of the process. In some high-strength alloys, there will be a limiting maximum cross-section that can feasibly be cast by this method; for even at the lowest practical casting rates, internal cracking will occur in these alloys when cast by this method.

U.S. Pat. No. 2,705,353 discloses and claims an improvement in this direct chill casting method which comprises removing the coolant from the ingot surface at a distance below the mold of between 1/8 and 1/2 times the minimum transverse dimension of the ingot. In this manner, the ingot surface is permitted to reheat. This decreases the temperature differential between the surface of the ingot and its interior, and thereby presumably decreases the magnitude of internal stresses generated by the solidification and further cooling of the ingot.

This improvement has importantly extended the range of alloys and ingot sizes that can be economically cast.

The present invention further extends the range of alloys, casting sizes and casting speeds that are permissible without the occurrence of center cracking or splitting of the ingot during the processes of solidification and further cooling.

An object of the present invention is to provide a method of casting metal ingots.

A further object of the present invention is to provide a method of producing essentially sound, crack-free metal ingots.

Another object of the present invention is to provide a method of direct chill casting metal ingots whereby such can be produced at casting speeds significantly higher than are presently used in commercial practice.

A still further object of the present invention is to provide a method of direct chill casting large diameter ingots which heretofore could not be cast because the casting speed to avoid cracking was lower than the practical casting speed.

THE INVENTION

The present invention comprises an improvement in the method of direct chill casting of metal ingots wherein molten metal is supplied to an open-ended, cooled mold, the metal being partially cooled in the mold to form a solidified outer ingot surface containing a molten metal pool; further cooling the ingot as it is continuously withdrawn from the mold, by direct application of coolant to said surface; and removing the coolant to allow a reheating of said ingot surface. The improvement comprises reapplying coolant at a distance within the range of from about PD/4 above to about PD/4 below the level corresponding to the bottom of the molten metal pool, where PD is the depth of the molten metal pool measured from the top of the molten metal to the central point of the ingot where the metal temperature is the nonequilibrium solidus temperature of the alloy being cast. Preferably, the coolant is reapplied at a distance within the range of from about $t/4$ above to about $t/4$ below the level corresponding to the pool bottom, where t is the minimum transverse dimension of the ingot being cast.

We have observed that employing the aforesaid sequence, i.e., removing the coolant to permit a reheating of the ingot surface, then reapplying coolant at the prescribed level permits very substantial increases in casting speed without incurring center cracking of the ingot.

A possible further improvement of the method is to apply external heat to the ingot surface in the interval between where the water is removed by wiping and where water is reapplied. Induction heating would be the preferred method of ingot heating in this interval but such heating could also be accomplished by gas jet.

The FIGURE represents one embodiment of the present invention. An ingot **1** of metal such as a magnesium or aluminum alloy is continuously cast out of a short, open-ended water cooled mold **2.** Spray rings **3** spray coolant on the mold surface. The water coolant runs down the sides of the mold and onto the ingot. The water is removed from the ingot surface by a rubber wiper **4.** Coolant is then reapplied to the ingot surface by means of spray ring **5.** Optionally the ingot surface is reheated prior to the application of coolant, for example by heating element **6.**

The present method is applicable to direct chill casting of magnesium alloy cylindrical billets, rectangular slabs and similar configuration, at a wide range of casting speeds, e.g., for aluminum and magnesium alloys from about 0.5 in. to about 50 ins. per minute. Such method could also be employed to cast other metals which, when rapidly direct chill cast, have a tendency to have internal radial cracks, such as aluminum alloys, e.g., 2024, 7075 and 7178, steel, copper and brass.

The following theory is suggested although it is understood that the validity of the present method is not dependent thereon.

Center cracks occur in direct chill cast ingots when internal tensile stresses are generated of a magnitude exceeding the strength of the alloy at the temperature at which such stresses are present. As a rule, high stresses are generated when cooling conditions produce a wide differential between the temperature of the casting surface and that of the casting interior. For example, if coolant is applied to the solidified shell of the embryo ingot at a time when the center is still molten, the outer solidified shell will shrink, and will develop high strength as it cools to a low temperature. Subsequently, as the center of the ingot solidifies and then further cools, its shirnkage will cause it to shrink away from this solidified shell, producing tensile stresses exceeding the limited hot strength of the interior metal at some stage in the cooling process. In support of this mechanism, it is observed that higher casting speeds lead to center cracking; higher speeds are also observed to deepen the pool of molten metal.

The success of the method of U.S. Pat. No. 2,705,353, whereby the coolant is removed from the surface of the ingot shortly below the mold is believed to be the result of a reduction in thermal gradient from the ingot surface to the ingot interior, resulting in turn in a decrease in the magnitude of internal tensile stresses that develop.

The improvement of the present invention, comprising the reapplication of water at a still lower level, further affects these stresses. If the external surface of the ingot is hot at the time when the ingot center begins to solidify, vigorous chilling of the outer surface by application of coolant will cause the outer surface of the ingot to contract; this contraction of the outer surface will cause the center metal to be compressed. As cooling of the ingot continues, the metal of the center will shrink and the initial compressive stresses, to be sure, will be dissipated. In fact the continued shrinkage of the interior metal will result in the reversal of these stresses, so that the cold ingot will eventually contain tensile stresses in its central regions. However, these tensile stresses will develop only after the center metal has dropped to a low enough temperature so that its strength will be sufficient to bear these stresses without cracking.

External heating applied to the ingot surface in the reheat interval will cause the metal near the surface to thermally expand and if the heating is rapid enough this surface metal will undergo compressive plastic flow. The requench will thereupon cause the initial tensile forces in the outer metal to be of even greater magnitude than if such plastic flow had not occurred, with the result that the center metal is initially compressed even more.

This hypothesis suggests the importance of careful timing of the reapplication of coolant. If the coolant is reapplied while the ingot interior is still molten, obviously the ingot interior cannot be thrown into a condition of compressive stress. If, however, the reapplication of coolant is delayed too long, internal tensile forces sufficient to crack the very weak, just solidified structure may develop before the compression is applied.

In practice, it is observed that this timing is indeed important for the avoidance of internal cracking. Freedom from center cracking is promoted by (1) a high surface-reheat temperature following the removal of coolant from the ingot surface, and (2) accurate timing of the requench, such that the level of reapplication of coolant occurs as prescribed herein. The higher the surface reheat temperature, the less sensitive the casting will be to slight deviations from optimum timing of the requench.

The following examples are illustrative of the method.

A direct chill casting operation was set up including a casting pot; a short, open-ended, water spray cooled, copper mold with movable dummy block for starting the ingot; a wiper system for removing coolant from the ingot surface; and a water spray ring positioned below the wiper for reapplication of coolant to the ingot.

The general procedure involved pouring an alloy melt from the casting pot into the mold, withdrawing

the ingot from the mold at a selected speed, applying coolant to (by allowing the coolant applied to the mold surface to run onto the emerging ingot) and then removing the coolant from the ingot surface below the mold, and reapplying coolant. The resulting casting was sectioned, visually inspected for large cracks and then treated with dye penetrant to determine whether very small cracks might be present. Also 1/2 inch transverse sections were fracture examined. For comparison, castings were prepared without reapplication of coolant with and without coolant removal.

In these tests, surface reheat temperature was measured by inserting thermocouples into the freezing metal near the outer billet edge. The temperature was continuously recorded as the imbedded thermocouple traveled with the casting; the maximum reheat temperature was read from the recorder graph. The approximate molten pool depth was determined by sticking a rod into the pool center and measuring the distance reached before substantial resistance was met (dip stick method), or by dumping 1–2 pounds zinc into the cast at shut down, sectioning the casting, and etching in dilute acid thus revealing the higher Zn-containing material, indicating pool depth for Mg-base alloys (Zn-section-etch method).

Example A — Conventional Practice — AZ31B

Melts of AZ31B (nominal composition 3% Al, 1% Zn, 0.5% Mn, balance Mg) were direct chill cast into 12 inch diameter billets. The mold used was a copper sleeve, inside diameter 12 inches, and the effective mold length was 8 inches. A series of billets was cast using conventional practice (water from spray rings covered the outside of the mold and all of the emerging casting). The casting speed was varied so that in some cases the safe "no-cracking" speed was exceeded. With a casting speed of 3.0 inches per minute the billets were substantially sound; at 3.8 inches per minute, dye penetrant examination revealed scattered minute cracks; at 4.0 inches per minute, more small cracks were present; at 5.2 inches per minute a billet had an 8 inch long internal radial crack.

Example B — Use of a Wipe With No Requench — AZ31B

Melts of AZ31B were cast into the same 12 inch diameter billet shape using the same copper mold. The casting speed was 5.4 inches per minute and a rubber wipe was positioned below the mold to remove the water from the emerging cast, thus allowing the surface to reheat. In the first experiment, the wipe was 5 inches below the bottom of the mold and the surface temperature reheated to a maximum of 690° F.; in the second experiment, the wipe was 4.5 inches below the mold and a maximum surface reheat temperature of 740° F. was recorded. The first billet was cut up and found to have a 6 to 8 inch long radial crack; the second billet had a radial crack which extended almost to the surface of the billet.

Examples 1–3 (present invention) — Use of a Wipe With Requench - AZ31B

Additional melts of AZ31B were cast into the same 12 inch diameter billet shape using the same 8 inch effective mold length. The casting speed was 5.4 inches per minute. A rubber wipe was positioned below the mold to remove the water from the emerging cast, thus allowing the billet surface to reheat; a water quench ring was placed below the wipe, positioned slightly below the bottom of the molten pool (as determined by dip-stick). The following results were obtained.

TABLE I

Example	Casting speed, in./min.	Distance from top of molten metal to wipe, in.	Distance from top of molten metal to requench position, in.	Distance from top of molten metal to bottom of molten pool-PD (As determined with dip-stick), in.	Maximum recorded surface reheat temperature, ° F.	Results of examination of cast billets for cracks
1	5.4	10.4	17.8	16.5	800	No cracks found by dye penetrant examination.
2	5.4	11.0	17.5	16.3	750	Do.
3	5.4	11.1	16.4	15.0	660	Do.

Example C — Conventional Practice — ZS21

Melts of ZS21 (nominal composition Mg + 1.8% Zn, 0.8% Si) were direct chill cast into 12 inch diameter billets using conventional practice where cooling water covered all of the outside of the mold and the emerging billet. The effective mold length used for a series of casts was 5½ to 6 inches. At speeds of 3.5, 3.6 and 4.0 inches per minute, the billets cast were sound and had no cracks; at speeds of 4.2, 4.4 and 5.8 inches per minute, the billets were star-cracked at the center.

Examples 4–8 (present invention) — Use of Wipe with Requench — ZS21

Additional melts of ZS21 were cast into the same 12 inch diameter billet shape using a 6 inch effective mold length. Casting speed was varied between 6.1 and 7.5 inches per minute. A rubber wipe below the mold removed the water from the cast, thus allowing the billet surface to reheat; the water was reapplied to the cast at a position corresponding very approximately with the bottom of the liquid pool. The following results were obtained:

TABLE II

Example	Casting speed, in./min.	Distance from top of molten metal to wipe, in.	Distance from top of molten metal to requench position, in.	Distance from top of molten metal to bottom of liquid pool—PD (Using the "Add Zn-Section-Etch" method), in.	Maximum recorded surface temperature in reheat region, ° F.	Results of examination for cracks
4	6.1	7.0	16	(1)	750	No cracks.
5	6.5	7.0	16	15.2	750	Do.
6	7.5	9.0	16	18.0	640	Do.
7	7.5	8.5	16	16.2	655	Do.
8	7.5	8.5	16	17.6	650	Do.

[1] Not measured.

Other examples, which were similarly prepared, did exhibit some minor, small cracks. However, without requench these castings would have had very severe cracking and undoubtedly some would have split.

Thus, it has been shown that by the method of the present invention metals can be direct chill cast at increased speeds without cracking.

What is claimed is:

1. A method which comprises:

a. continuously casting a metal ingot through an open-ended, cooled mold;

b. applying coolant to the ingot surface as it emerges from the mold whereby the ingot surface is cooled substantially below 650° F.;

c. removing the coolant by mechanical means to cause reheating of the ingot surface;

d. further applying coolant to the ingot surface at a sufficient distance from said coolant removal whereby the surface of the ingot is allowed to reheat to a maximum temperature in the range of about 650° to 800° F., said distance being within the range of from about PD/4 below to about PD/4 above the level corresponding to the bottom of the molten pool, where PD is the depth of the molten pool.

2. The method of claim 1 wherein the light metal is a magnesium alloy.

3. The method of claim 1 wherein the light metal is an aluminum alloy.

4. The method of claim 1 wherein the coolant is reapplied at a distance within the range of from about *t*/4 above to about *t*/4 below the level corresponding to the bottom of the pool, where t is the minimum transverse dimension of the ingot being cast.

5. The method of claim 2 wherein the casting speed is from about 0.5 to about 50 inches per minute.

6. The method of claim 1 including the additional step of externally heating the ingot surface after step (*c*) and before step (*d*).

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