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CONTINUOUS CASTING METHOD AND APPARATUS FOR CONTROLLING
FREEZE LINE LOCATION
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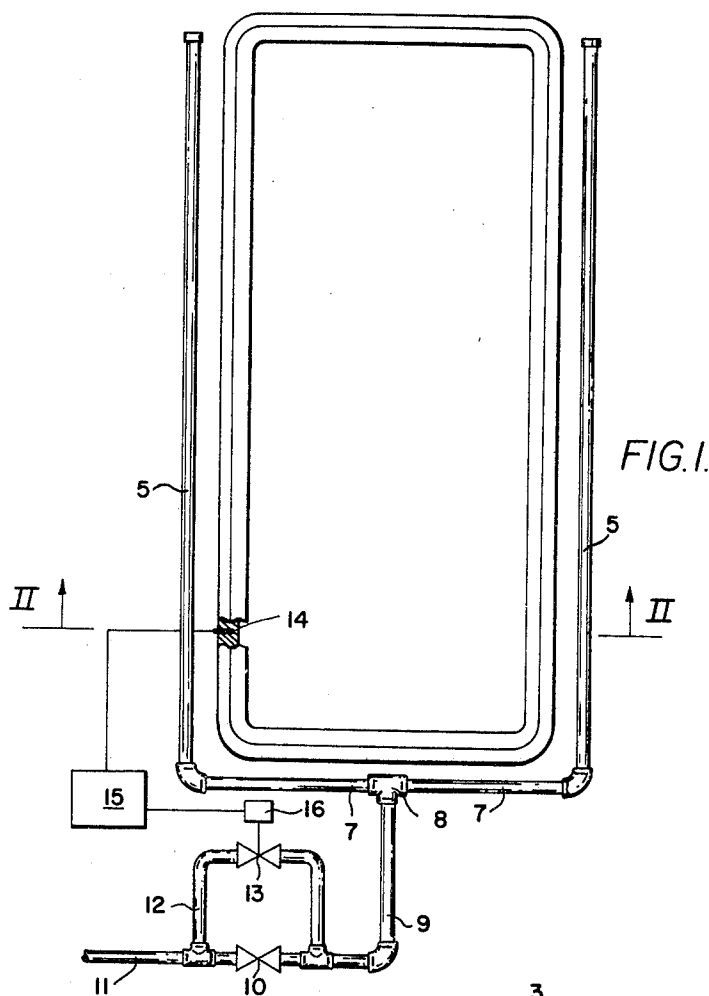


FIG. 1.

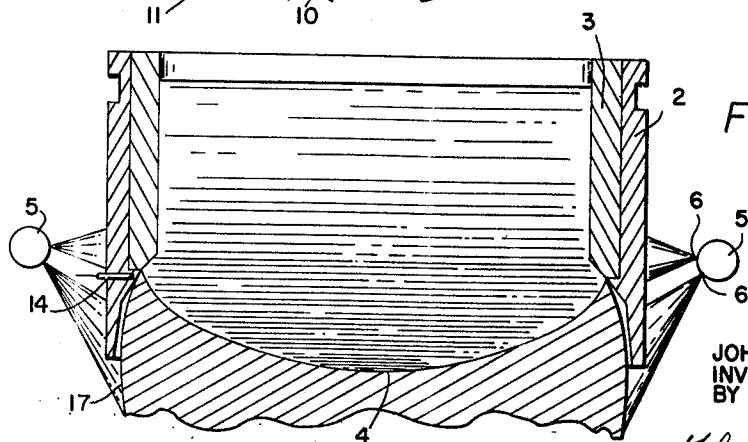


FIG. 2.

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CONTINUOUS CASTING METHOD AND APPARATUS FOR CONTROLLING FREEZE LINE LOCATION

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ABSTRACT OF THE DISCLOSURE

A continuous casting method and apparatus involving sensing temperature variations in the mold adjacent the surface of the incipient ingot being continuously cast in the region of the freeze line, especially in the casting of an ingot, such as of aluminum, at least about 6 inches thick and having a width to thickness ratio of at least about 3 to 1, and responsively to the sensed temperature variations controlling the application, as by spraying, of coolant, normally water, to minimize inward and outward movement of the freeze line. The sensing means, which may include a thermocouple, are preferably located opposite a wide face of the incipient ingot and at a location closer to the corner than to the center of the wide face and close enough to the corner to sense the temperature variations in the region of the corner. The coolant is preferably applied to the mold or/and ingot only at the wide faces of the ingot.

This invention relates to a continuous casting method and apparatus. It relates particularly to continuous casting involving regulation of the cooling of the metal being cast to minimize inward and outward movement of the freeze line and by so doing promote uniformity and superior quality of the casting produced.

Continuous casting of metal, both ferrous and non-ferrous, is known in the art but difficulty has been experienced in obtaining optimum quality and uniformity of product. A coolant, normally water, is employed to cool the metal as it solidifies. The relatively narrow zone between the liquidus and solidus isotherms, in which the metal changes state from liquid or molten to solid is known as the liquid-solid interface or "freeze-line." If the freeze line can be maintained at a substantially constant location optimum results are obtained. Prior efforts to so maintain the freeze line have not been entirely successful.

Variations in the temperature of the feed metal, especially due to fluctuations of furnace temperature within the limits of practical control, are sometimes so great as to move the freeze line inwardly (in the direction opposite the direction of advance of the metal during casting) with resultant sticking and tearing of the ingot, or outwardly (in the direction of advance of the metal during casting) with resultant colds shutting and lapping.

Other factors can cause or contribute to inward and outward movement of the freeze line, such as variations in the casting rate or in the temperature of the coolant. Operators try to offset these variables when they can be detected, as by adjusting the rate of application of coolant, but such adjustments involve the human factor and cannot be relied upon to stabilize the location of the freeze line.

Particularly troublesome is the start-up portion of the casting operation in which the outer or lower end of the mold (depending on whether it is arranged vertically or horizontally) is closed off by a so-called starter block and the mold is filled with molten metal after which intensive cooling of the mold is required before casting

of an ingot can be initiated by withdrawing the starter block. The rate of application of coolant during this phase of the casting operation should be much greater than is necessary during subsequent steady-state operation. The problem is to know how much to increase the cooling rate and for how long before reducing the cooling rate to the point that the freeze line does not move upwardly or inwardly too far while still being reasonably assured that the frozen shell of metal adjacent the mold wall at the outlet end of the mold will not rupture and release the molten metal. In the past this has been accomplished only by reliance on the operator's skill.

The effect of each of the factors above mentioned may vary from one casting operation to another, particularly where different ingot sizes and different alloys are involved.

I have devised an improved system of control whereby a more uniform and superior quality ingot can be produced than has heretofore been possible on a regular basis. I have discovered that detectable changes in the temperature of a portion of the mold close to the surface of the incipient ingot in the region of the freeze line can be used to effect control of inward and outward movement of the freeze line. I provide for locating a temperature sensing element in the mold wall and employing variations in the sensed temperature to control the casting operation.

My invention is especially well adapted for improving continuous casting operation in the production of large rectangular ingots such, for example, as ingots of aluminum or aluminum alloy having a transverse section several feet in width and at least about six inches in thickness, especially such ingots having a width to thickness ratio on the order of 3 to 1 or more. The casting of generally rectangular ingots having a width and thickness suitable for continuous rolling without the necessity of employing the usual ingot slabbing or breakdown operations offers considerable advantage over conventional procedures. A major difficulty in the casting of such ingots has been the grossly uneven cooling rate which results when the coolant is applied peripherally of the mold in a uniform manner. This is due to the relatively great cooling effect at the corners of the ingot and the consequent difficulty of balancing heat extraction around the periphery of the ingot. Thus the cooling rate for an increment of metal along the longitudinal axis of the mold (at the center of the ingot) is considerably less than that for increments of metal near the surface of the ingot.

I have discovered that in such cases coolant should be applied to the wide faces of the ingot or/and the mold walls at the wide faces of the ingot and not at all (or at least at a reduced rate) to the relatively narrow end faces of the ingot or/and the mold walls at the relatively narrow end faces of the ingot. I control the solidification rate of the metal by varying the rate of applying coolant to the wide faces of the ingot or the adjacent walls of the mold or both.

I provide a continuous casting method comprising feeding molten metal into the entrance end of a mold, effecting solidification of the metal during its passage through the mold, withdrawing solidified metal from the exit end of the mold, applying coolant to at least one of the mold and metal to promote solidification of the metal, the juncture of molten and solidified portions of the metal being cast defining a so-called freeze line therebetween, sensing temperature variations in the region of the freeze line, an increase in temperature being associated with outward movement of the freeze line away from the entrance end of the mold and a decrease in temperature being associated with inward movement of the freeze line away from the exit end of the mold, and responsively to the

sensed temperature variations controlling the application of the coolant to minimize inward and outward movement of the freeze line. The coolant is normally water; it may be applied to the mold in the region of the freeze line or directly against the solidified metal emerging from the mold exit or both.

I further provide a method of continuously casting an ingot at least about six inches thick and having a width to thickness ratio of at least about 3 to 1 comprising feeding molten metal into the entrance end of a mold, effecting solidification of the metal during its passage through the mold, withdrawing solidified metal from the exit end of the mold, applying coolant to at least one of the mold and metal at least at the wide faces of the ingot to promote solidification of the metal, the juncture of molten and solidified portions of the metal being cast defining a so-called freeze line therebetween, sensing temperature variations in the region of the freeze line, an increase in temperature being associated with outward movement of the freeze line away from the entrance end of the mold and a decrease in temperature being associated with inward movement of the freeze line away from the exit end of the mold, and responsively to the sensed temperature variations controlling application of the coolant to minimize inward and outward movement of the freeze line. The coolant may, as above indicated, be applied only to the wide faces of the ingot or/and the mold walls at the wide faces of the ingot. Desirably the temperature variations are sensed at a wide face of the ingot at a location closer to a corner than to the center of the wide face and close enough to the corner to sense the temperature variations in the region of the corner.

I still further provide continuous casting apparatus comprising a mold having a passageway therethrough, means for feeding molten metal into the entrance end of said passageway, means for withdrawing solidified metal from the exit end of said passageway, means for applying coolant to at least one of the mold and metal to promote solidification of the metal, the juncture of molten and solidified portions of the metal being cast defining a so-called freeze line therebetween, means sensing temperature variations in the region of the freeze line, an increase in temperature being associated with outward movement of the freeze line away from the entrance end of said passageway and a decrease in temperature being associated with inward movement of the freeze line away from the exit end of said passageway, and means responsive to the sensing means controlling the application of the coolant to minimize inward and outward movement of the freeze line. The coolant applying means are desirably constructed and arranged to apply the coolant to the mold in the region of the freeze line or directly against the solidified metal emerging from the exit end of the passageway or both.

I also provide continuous casting apparatus comprising a mold having a passageway therethrough shaped to cast an ingot at least about six inches thick and having a width to thickness ratio of at least about 3 to 1, means for feeding molten metal into the entrance end of said passageway, means for withdrawing solidified metal from the exit end of said passageway, means for applying coolant to at least one of the mold and metal at least at the wide faces of the ingot to promote solidification of the metal, the juncture of molten and solidified portions of the metal being cast defining a so-called freeze line therebetween, means sensing temperature variations in the region of the freeze line, an increase in temperature being associated with outward movement of the freeze line away from the entrance end of said passageway and a decrease in temperature being associated with inward movement of the freeze line away from the exit end of said passageway, and means responsive to the sensing means controlling the application of the coolant to minimize inward and outward movement of the freeze line. The coolant applying means may be constructed and ar-

ranged to apply the coolant only to the wide faces of the ingot or/and the mold walls at the wide faces of the ingot. The sensing means are desirably located opposite a wide face of the ingot at a location closer to a corner than to the center of the wide face and close enough to the corner to sense the temperature variations in the region of the corner.

Other details, objects and advantages of the invention will become apparent as the following description of a present preferred embodiment thereof and a present preferred method of practicing the same proceeds.

In the accompanying drawings I have shown a present preferred embodiment of the invention and have illustrated a present preferred method of practicing the same in which

FIGURE 1 is a diagrammatic plan view of a continuous casting mold to which my invention is applied; and

FIGURE 2 is an enlarged vertical cross-sectional view taken on the line II—II of FIGURE 1.

Referring now more particularly to the drawings, there is shown a mold 2 for continuous casting, the mold being of generally rectangular shape with rounded corners and being of such size that the cast ingot is about 6 inches thick (the horizontal dimension in FIGURE 1) while its width (the vertical dimension in FIGURE 1) is of the order of at least three times the thickness. The mold is lined with a wall 3 of insulating material (as, for example, as shown in United States Patent No. 2,983,972) just above the freeze line. The freeze line is indicated at 4 in FIGURE 2.

A coolant spray system is provided including pipes 5 disposed horizontally alongside the mold with orifices 6 for spraying coolant, normally water, onto the outside of the mold and also onto the casting emerging from the mold as shown in FIGURE 2. The coolant is sprayed only onto the long sides of the mold and the wide faces of the ingot and not on the short sides of the mold or the narrow faces of the ingot. The pipes 5 are connected by pipes 7 which contain no orifices leading to a T 8 from which a pipe 9 leads to a valve 10 and thence to a coolant supply pipe 11. A by-pass 12 extends around the valve 10 with a valve 13 in the by-pass.

I provide a temperature sensing element 14 in the wall of the mold just below the bottom of the wall 3 of insulating material and reaching almost but not quite to the inner surface of the mold wall 2 as shown in FIGURE 2. The sensing element 14 is, as shown in FIGURE 1, located opposite a wide face of the ingot at a location closer to a corner than to the center of the wide face and close enough to the corner to sense the temperature variations in the region of the corner. The sensing element 14 may be a thermocouple transmitting a signal to a proportioning control 15 controlling a motor operator 16 for the by-pass valve 13. The valve 10 is manually set and the valve 13 is automatically controlled by the thermocouple 14. Increase in temperature sensed by the thermocouple results in opening somewhat the valve 13 with consequent increased flow of coolant through the system and onto the wide faces of the mold and ingot. Decrease in temperature sensed by the thermocouple results in closing somewhat the valve 13 with consequent decreased flow of coolant through the system and onto the wide faces of the mold and ingot.

As mentioned above and as shown in FIGURE 2, the coolant is sprayed onto both the mold and the ingot at the wide faces of the ingot. It impinges upon the ingot emerging from the mold at 17 (see FIGURE 2). Impingement of the coolant at point 17 establishes an ingot surface temperature that creates the driving force for heat flow, particularly the latent heat of fusion of the solidifying metal. This driving force tends to act in an arc near the ingot surface, especially when there is minor heat flow to the upper region of the mold. If true equilibrium exists the temperature of the mold in the region

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where the freeze line reaches the wide face of the ingot should be constant.

When the temperature at 17 decreases an increased driving force for heat flow is created from the large heat of fusion reservoir at the yet unchanged liquid-solid interface or freeze line. Heat flow is accelerated along the shorter parts and liquid solidifies at a higher point, possibly within the wall 3. The mold temperature opposite the freeze line tends to approach the coolant temperature.

When the temperature at 17 increases the driving force for heat flow from the large heat of fusion reservoir is reduced. Since more of the mold is in contact with the plastic ingot mass the mold temperature opposite the freeze line increases. The mold temperature measurement at the location of the thermocouple 13 is an indirect method of gauging the thermal equilibrium of the ingot, particularly in the vicinity of the ingot surface. A refinement in heat transfer balancing is achieved by utilizing that measurement in conjunction with the automatic flow control system for coolant application as above described.

While I have shown and described a present preferred embodiment of the invention and have illustrated a present preferred method of practicing the same, it is to be distinctly understood that the invention is not limited thereto but may be otherwise variously embodied and practiced within the scope of the following claims.

I claim:

1. A continuous casting method comprising feeding molten metal into the entrance end of a mold, effecting solidification of the metal during its passage through the mold, withdrawing solidified metal from the exit end of the mold, applying coolant to at least one of the mold and metal to promote solidification of the metal, the juncture of molten and solidified portions of the metal being cast defining a so-called freeze line therebetween, sensing temperature variations of the mold in the region of the freeze line, an increase in temperature being associated with outward movement of the freeze line away from the entrance end of the mold and a decrease in temperature being associated with inward movement of the freeze line away from the exit end of the mold, and responsively to the sensed temperature variations controlling the application of the coolant to minimize inward and outward movement of the freeze line.

2. A continuous casting method as claimed in claim 1 in which the coolant is applied to the mold in the region of the freeze line.

3. A continuous casting method as claimed in claim 1 in which the coolant is applied directly against the solidified metal emerging from the mold exit.

4. A continuous casting method as claimed in claim 1 in which the coolant is applied both to the mold in the region of the freeze line and directly against the solidified metal emerging from the mold exit.

5. A method of continuously casting an ingot at least about six inches thick and having a width to thickness ratio of at least about 3 to 1 comprising feeding molten metal into the entrance end of a mold, effecting solidification of the metal during its passage through the mold, withdrawing solidified metal from the exit end of the mold, applying coolant to at least one of the mold and metal at least at the wide faces of the ingot to promote solidification of the metal, the juncture of molten and solidified portions of the metal being cast defining a so-called freeze line therebetween, sensing temperature variations of the mold in the region of the freeze line, an increase in temperature being associated with outward movement of the freeze line away from the entrance end of the mold and a decrease in temperature being associated with inward movement of the freeze line away from the exit end of the mold, and responsively to the sensed temperature variations controlling application of the coolant to minimize inward and outward movement of the freeze line.

6. A method of continuously casting an ingot as claimed

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in claim 5 in which coolant is applied only at the wide faces of the ingot.

7. A method of continuously casting an ingot as claimed in claim 5 in which the temperature variations are sensed at a wide face of the ingot at a location closer to a corner than to the center of the wide face and close enough to the corner to sense the temperature variations in the region of the corner.

8. A method of continuously casting an ingot as claimed in claim 6 in which the temperature variations are sensed at a wide face of the ingot at a location closer to a corner than to the center of the wide face and close enough to the corner to sense the temperature variations in the region of the corner.

9. Continuous casting apparatus comprising a mold having a passageway therethrough, said mold being adapted to receive molten metal fed into the entrance end of said passageway, the solidified metal being withdrawn from the exit end of said passageway, means for applying coolant to at least one of the mold and metal to promote solidification of the metal, the juncture of molten and solidified portions of the metal being cast defining a so-called freeze line therebetween, means for sensing temperature variations of the mold in the region of the freeze line, the mold having a heat insulating interior lining spaced inwardly from the exit end of said passageway and extending along the passageway toward the entrance end thereof, said sensing means being located in the mold wall adjacent the outer end of said interior lining at a zone where the metal being cast is in contact with the mold wall, and control means responsive to said temperature sensing means for counteracting such temperature variations of the mold.

10. Continuous casting apparatus as claimed in claim 9 in which the coolant applying means are constructed and arranged to apply the coolant to the mold in the region of the freeze line.

11. Continuous casting apparatus as claimed in claim 9 in which the coolant applying means are constructed and arranged to apply the coolant directly against the solidified metal emerging from the exit end of the passageway.

12. Continuous casting apparatus as claimed in claim 9 in which the coolant applying means are constructed and arranged to apply the coolant both to the mold in the region of the freeze line and directly against the solidified metal emerging from the exit end of the passageway.

13. Continuous casting apparatus comprising a mold having a passageway therethrough shaped to cast an ingot at least about six inches thick and having a width to thickness ratio of at least about 3 to 1, said mold being adapted to receive molten metal fed into the entrance end of said passageway, the solidified metal being withdrawn from the exit end of said passageway, means for applying coolant to at least one of the mold and metal at least at the wide faces of the ingot to promote solidification of the metal, the juncture of molten and solidified portions of the metal being cast defining a so-called freeze line therebetween, means for sensing temperature variations of the mold in the region of the freeze line, the mold having a heat insulating interior lining spaced inwardly from the exit end of said passageway and extending along the passageway toward the entrance end thereof, said sensing means being located in the mold wall adjacent the outer end of said interior lining at a zone where the metal being cast is in contact with the mold wall, and control means responsive to said temperature sensing means for counteracting such temperature variations of the mold.

14. Continuous casting apparatus as claimed in claim 13 in which the coolant applying means are constructed and arranged to apply the coolant only at the wide faces of the ingot.

15. Continuous casting apparatus as claimed in claim 13 in which the sensing means are located opposite a wide

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face of the ingot at a location closer to a corner than to the center of the wide face and close enough to the corner to sense the temperature variations in the region of the corner.

16. Continuous casting apparatus as claimed in claim 14 in which the sensing means are located opposite a wide face of the ingot at a location closer to a corner than to the center of the wide face and close enough to the corner to sense the temperature variations in the region of the corner.

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