

April 5, 1955

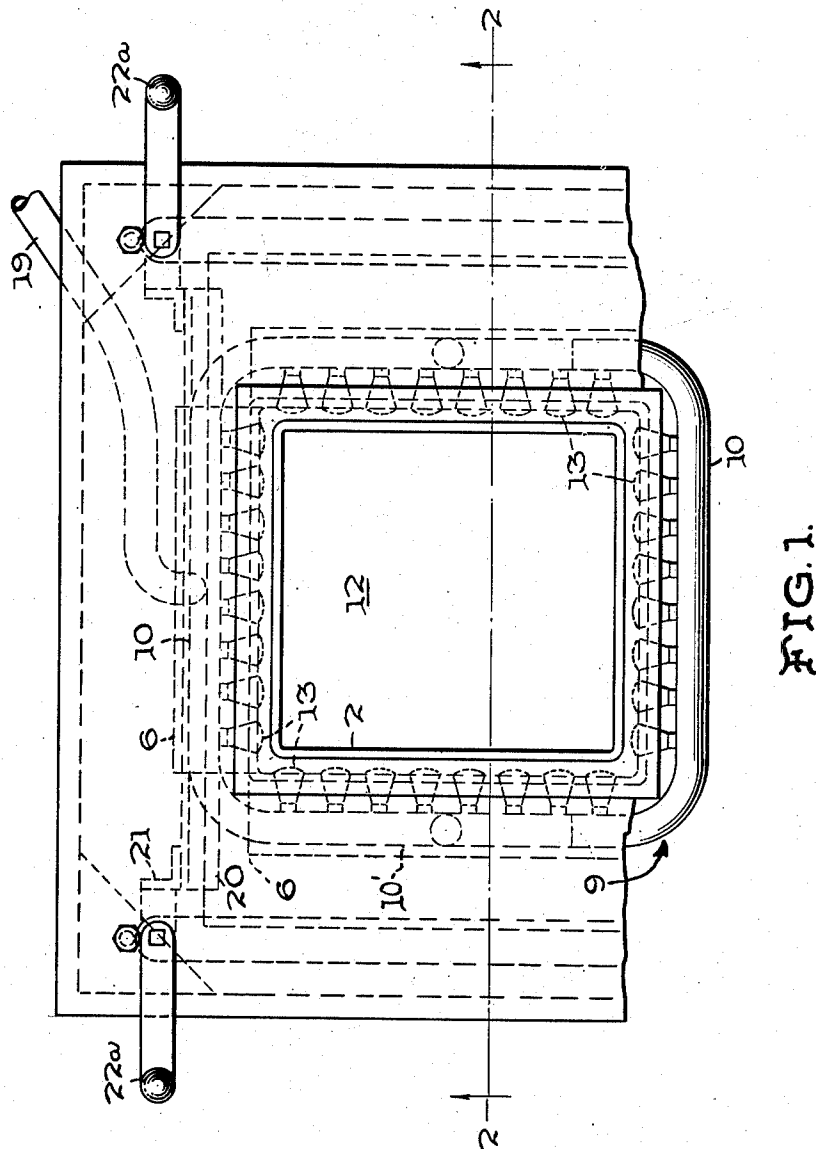
P. P. ZEIGLER

2,705,353

METHOD OF CONTINUOUS CASTING

Filed April 4, 1952

4 Sheets-Sheet 1



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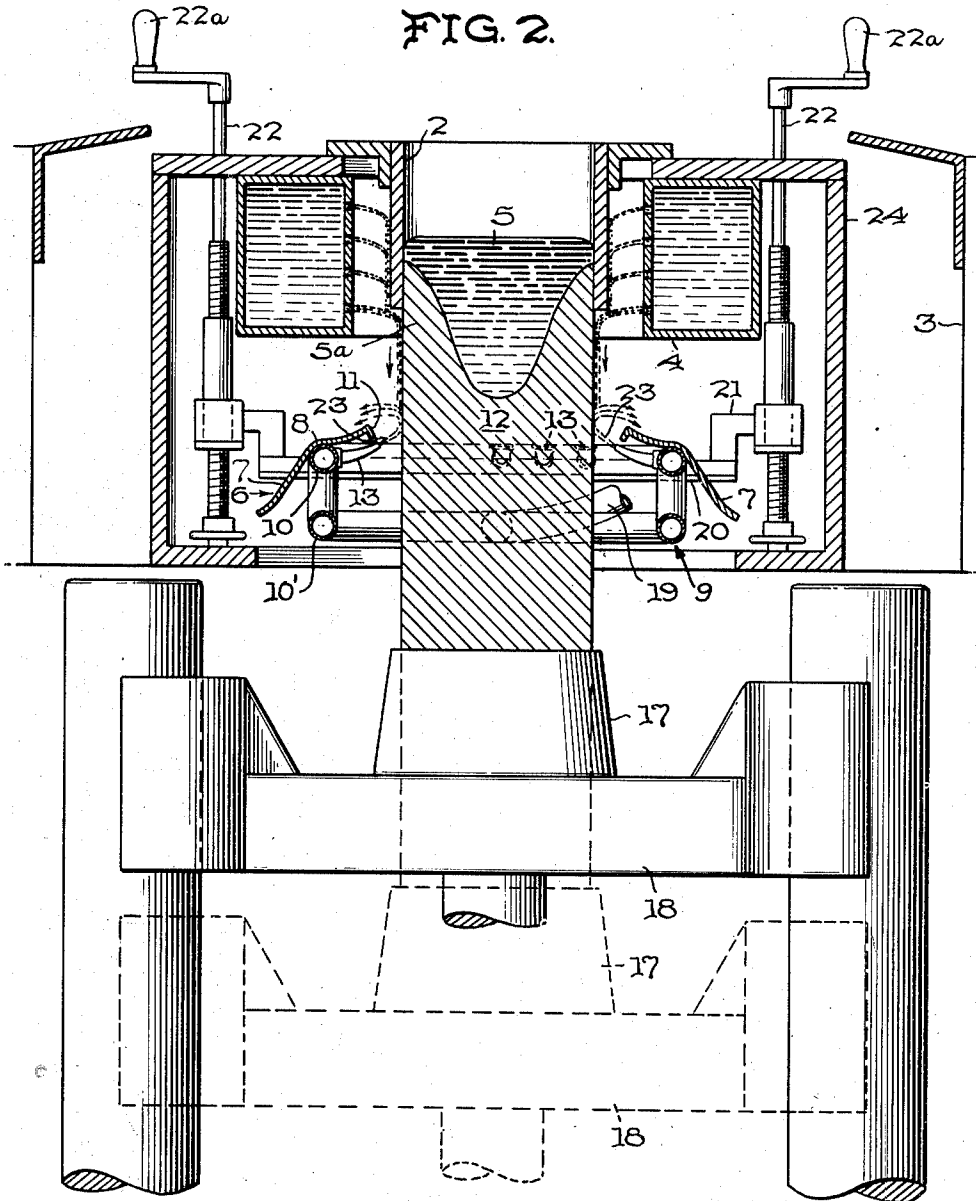
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METHOD OF CONTINUOUS CASTING

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4 Sheets-Sheet 2



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METHOD OF CONTINUOUS CASTING

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4 Sheets-Sheet 3

FIG. 3.

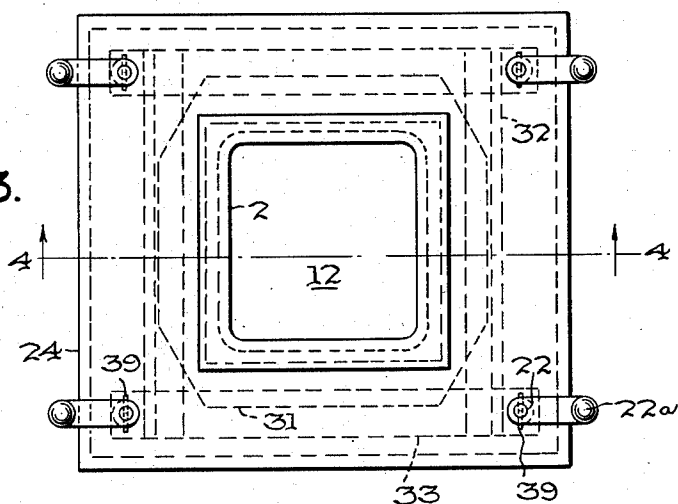
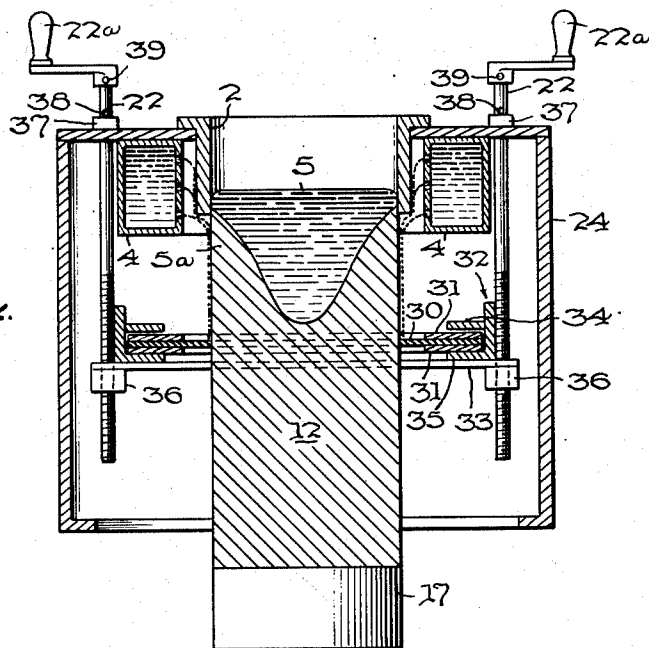


FIG. 4.



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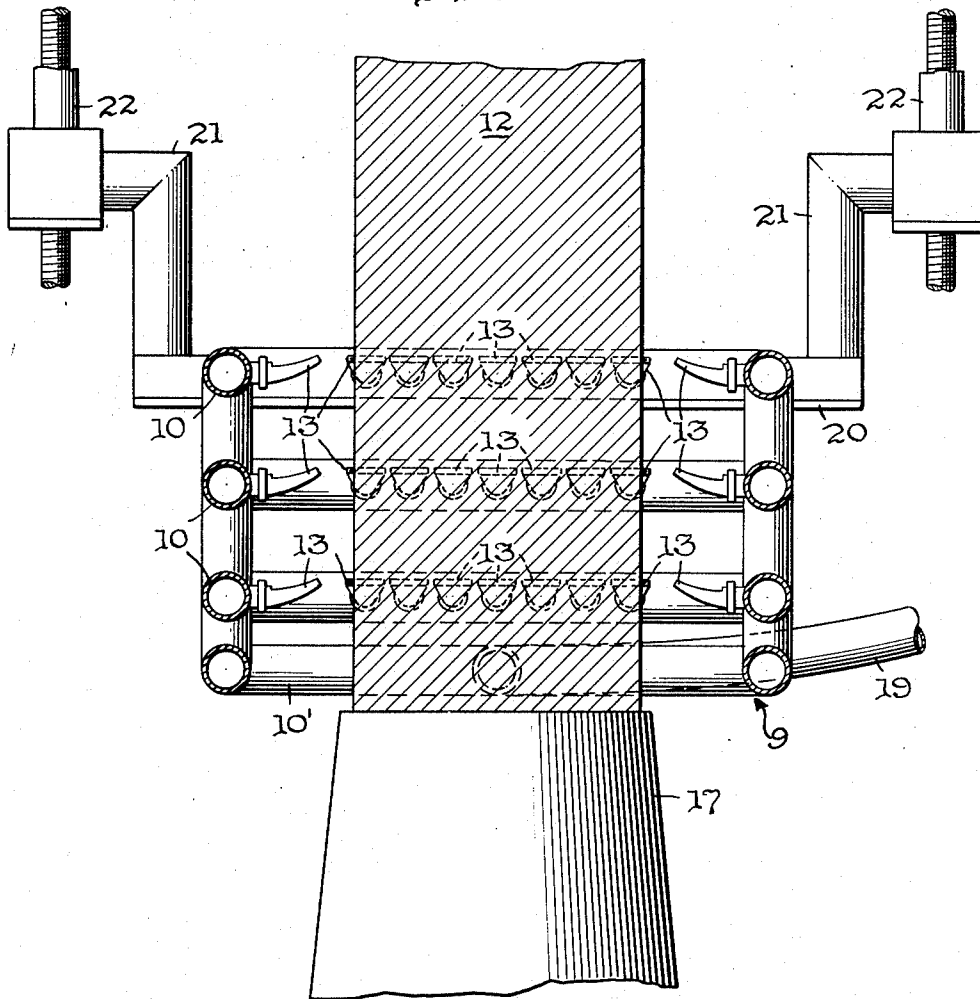
2,705,353

METHOD OF CONTINUOUS CASTING

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4 Sheets-Sheet 4

FIG. 5.



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2,705,353

METHOD OF CONTINUOUS CASTING

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Application April 4, 1952, Serial No. 280,469

13 Claims. (Cl. 22—200.1)

This invention relates to the continuous casting of light metals by the direct chill method. More particularly the invention relates to a method for continuously casting high strength aluminum alloy ingots of relatively massive cross-section.

This application is a continuation-in-part of application Serial No. 158,289, filed April 26, 1950.

In the continuous casting of various metals including aluminum and aluminum alloys, molten metal is fed into an open-ended mold which is continuously cooled. The casting is continuously withdrawn by any suitable means from the opposite end while at the same time a supply of cooling fluid, usually water, continuously contacts the embryo casting as it emerges from the mold. In the case of aluminum and aluminum alloys, one method commonly used is that disclosed in the Ennor Patent No. 2,301,027. The term "continuous" casting referred to herein is intended to include casting procedures which may be of a strictly continuous nature (in which the casting is cut to length without interruption of the casting procedure) or where the casting is of a semi-continuous nature; i. e. a casting of desired length may be cast, the flow of metal stopped, the casting removed and the procedure commenced anew.

In the Ennor patent the cooling is accomplished by means of a water spray directed around the periphery of the mold shell by means of spray pipes or a spray box. Water jets impinge upon the outer surface of the mold and the embryo ingot as it emerges below the mold. The amount of water applied or the amount of cooling accomplished is uniform about the periphery of the mold and casting.

The desirability in continuous casting processes of maintaining relatively rapid freezing of the molten metal and avoidance of a deep molten crater in order to obtain good metallurgical quality are recognized by the prior casting art as evidenced by Ennor. The rapid freezing of the molten metal and the maintenance of a relatively shallow molten metal crater is of particular importance in substantially reducing or eliminating a defect found in ingots of large cross-section commonly referred to as shrinkage porosity. Where the rate of solidification of the ingot is relatively slow, the molten crater becomes relatively deep and generally assumes a V-shaped configuration. The metal material within the lower portion or at the base of the molten metal crater is generally of a mushy consistency and comprises solid particles mixed with molten metal. During the freezing or solidification of this material, there appears to be a tendency for pre-freezing and bridging to occur over the lowermost portion of the crater material. As solidification of this portion goes on to completion, the remaining molten metal in this portion solidifies and contracts thus leaving a plurality of voids which are not subsequently filled by more molten metal from the molten crater above, due to the bridging or pre-freezing which has occurred.

While the application of coolant directly to the embryo ingot immediately upon emergence from below the bottom of a water-cooled mold sleeve of relatively short length has served to promote rapid freezing and to improve metallurgical quality considerably, the inherent characteristics of all prior processes and/or devices designed to accomplish such cooling are conducive to center splits and edge cracks in ingots or billets of large cross-section and particularly in the case of high strength aluminum alloys such as 14S (3.9–5.0% copper, 1.0% iron maximum, 0.5–1.2% silicon, 0.4–1.2% manganese, 0.2–0.8%

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magnesium, 0.25% zinc maximum, 0.10% chromium maximum, 0.15% titanium maximum, balance aluminum), 17S (3.5–4.5% copper, 1.0% iron maximum, 0.80% silicon maximum, 0.4–1.0% manganese, 0.2–0.8% magnesium, 0.10% zinc maximum, 0.10% chromium maximum, balance aluminum), 24S (3.8–4.9% copper, 0.50% iron maximum, 0.50% silicon maximum, 0.3–0.9% manganese, 1.2–1.8% magnesium, 0.10% zinc maximum, 0.10% chromium maximum, balance aluminum), 75S (1.2–2.0% copper, 0.70% iron maximum, 0.50% silicon maximum, 0.30% manganese maximum, 2.1–2.9% magnesium, 5.1–6.1% zinc, 0.18–0.40% chromium, 0.20% titanium maximum, balance aluminum), etc., wherein the ingot possesses a circular or square cross-sectional configuration or one which approaches the circular or square configuration, that is, shapes having transverse axes which are substantially equal.

It has been determined that where the cooling rates or, in other words, the rate and/or extent of heat abstraction both during and after solidification of large ingots is not closely controlled, there are set up in the ingots excessive internal stresses which generally will result in center splits, edge cracks and other serious defects. Such splits and cracks may occur during the actual casting operation. Other times these defects will become noticeable after the ingot has stood for a period of time after casting while in yet other instances the defects will occur during the subsequent machining of the ingot. These excessive stresses resulting in splits and cracks are in effect thermal stresses generated by overcooling the ingot after solidification is complete. These defects of splitting and cracking render the ingots unsuitable for working or machining and thus result in considerable economic loss to the industry. Also these defects constitute a hazard.

This tendency of high strength aluminum alloy ingots to develop center splits and edge cracks has imposed limits on the sizes or cross-sectional areas which may be cast by means of conventional practices. For example, it has been impossible to cast ingots on the order of 32 inches in diameter in alloys such as 14S, 17S, 24S and 75S. Moreover, this tendency toward center splits and edge cracks has made it impossible to obtain satisfactory results in casting ingots on the order of 18 by 18 inches square in alloys such as 24S and, in certain instances, such as 75S alloy, in casting ingots with cross-sectional dimensions as low as 12 by 12 inches square. As a consequence of this situation, the industry has labored under an extremely serious handicap in that it has not had available large ingots of a cross-section required for forging presses adapted to make large or massive forgings of the type required by the aircraft industry.

This invention embraces the discovery that arrestment or diminution of the rates of cooling, or, in other words, the rate and/or extent of heat abstraction of the ingots at levels properly spaced with respect to critical maximum distances below the mold shell will considerably reduce the incidence of center splits and edge cracks and yet will permit greatly extended control over other metallurgical characteristics such as grain size, shrinkage porosity, and size and dispersion of alloy constituents, for ingots of relatively massive size, such as circular, square, or other cross-sectional configurations approaching circular or square, such as hexagonal or elliptical wherein the transverse axes are substantially equal in length.

By means of the instant invention this excessive cooling is effectively prevented, that is, there is a controlling of the cooling fluid flowing down over the ingot and a restriction of its length of travel down the faces of the ingot. In this way the temperature differential between progressive portions of the ingot can be accurately controlled to eliminate the defects attendant in processes heretofore known. The distance downwardly along the ingot surface that the coolant flows with respect to the bottom of the mold is determined by factors such as composition of the alloy being cast, size of the ingot, necessary rate of heat abstraction, and the rate of ingot withdrawal from the mold.

It is contemplated, within the scope of the invention, that all of the coolant may be removed, or as much as is necessary, to facilitate proper control of the rate of heat abstraction and thus prevent center splitting, edge crack-

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ing, and other defects in the ingots under the other existing casting conditions.

Although the method of the instant invention has been found particularly adapted for use in the continuous casting of ingots of high strength aluminum alloys of relatively massive size, its use is not restricted thereto, and it can be advantageously employed in the continuous casting of any metal where the danger of center splitting and other serious defects caused by excessive cooling of the ingot or billet exist. Moreover, it has been found that the practice of the instant invention can be advantageously applied to the continuous direct chill casting of any aluminum alloy of an ingot size generally employed in industry today with the added result that increased rates of withdrawal and consequent increased production rates can be attained.

Accordingly, it is an object of this invention to provide a novel method for continuously casting sound metal ingots of large cross-sectional areas heretofore not possible with conventional methods.

Another object is to provide a novel method for continuously casting ingots including the control of the rate of heat abstraction from the ingot as it emerges from the mold to eliminate the formation of center splits and other defects.

Another object is to provide a method for eliminating center splitting and other defects in various types of metal ingots, and particularly high strength aluminum alloy ingots of relatively massive cross-section, by preventing development of excessive thermal stresses in the ingot as it is being cast.

A further object is to provide a novel method for continuously casting ingots of relatively massive cross-section and possessing a minimum of segregation of alloying constituents, relatively small grain size and low shrinkage porosity.

A more specific object is to provide a novel method for continuously casting ingots of high strength aluminum alloys having a relatively massive cross-sectional area and characterized by being free of center splits, edge cracks and possessing small grain structure, a relatively fine size and uniform distribution of constituents and a minimum of shrinkage porosity.

In the process of the invention, the cooling effect of the cooling liquid applied to the emerging embryo ingot, is controlled by permitting such cooling liquid to flow down the sides of the ingot for a predetermined distance below the mold shell employed in the casting operation, where it is removed by a wiper or the like. This predetermined or critical distance over which the cooling liquid is allowed to flow down over the ingot below the bottom of the mold shell for any given set of casting conditions, is that distance beyond which the lower portions of the ingot will be subjected to over-cooling, giving rise to the serious defects of center splitting, etc. This critical distance will vary with such factors as chemical composition of the ingot, size and shape of the ingot, rate of heat abstraction and rate of ingot withdrawal. The determination of this distance for any given set of casting conditions can be readily accomplished with a nominal amount of trial and error experimentation. The wiper removes the liquid on the outer surface of the ingot so as to prevent continued action by it on the cooling rate of the ingot.

Further objects and advantages of the invention will be apparent from the following detailed description taken in conjunction with the drawings which illustrate one form of specific apparatus for performing the method of the invention and wherein:

Figure 1 is a broken plan view showing the general arrangement of a continuous casting mold for square ingots and an air wiper used therewith;

Figure 2 is a vertical, sectional view taken along lines 2-2 of Figure 1 on reduced size, the position assumed by the ingot as it is lowered from the mold being shown in dotted lines.

Figure 3 is a plan view showing a modified general arrangement of a continuous casting mold for square ingots and a mechanical wiper used therewith.

Figure 4 is a vertical, sectional view taken along lines 4-4 of Figure 3 with parts removed for purposes of clarity, illustrating in more detail the mechanical wiper.

Figure 5 is an enlarged view, with parts removed for purpose of clarity, of a modified arrangement of the air wiper shown in Figure 2.

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With further reference to the drawings and particularly Figure 2, the apparatus is comprised of a mold shell 2, suitably mounted over a casting pit 3, by any of the conventional means. Within the mold shell 2 and extending therebelow, is an embryo ingot 12, comprising a pool of molten metal 5 and solidified casting 5a, the pool 5 extending downwardly and forming a liquid crater or core within the ingot. The molten metal is continuously poured into the mold by any of the means commonly used. The solidified portion of the ingot rests upon a block 17, which block in turn is mounted upon a vertically adjustable platen 18. It is to be noted that in the practice of the invention, it may be desirable in certain instances to apply a suitable lubricant, such as a high temperature grease, to the mold surfaces, in order to insure against sticking of molten metal to the mold and to insure smooth ingot surfaces.

Means are provided for cooling the mold shell 2, and also for directly cooling the embryo ingot 12 as it emerges from the shell. These means consist of the spray boxes 4, containing the cooling water. These boxes encircle the ingot, and may be of the same construction as that disclosed in Nicholls Patent No. 2,414,269. From these boxes water may be applied around the periphery of the outer surfaces of the mold shell 2, and the surfaces of the embryo ingot emerging therefrom.

Affixed to each of these spray boxes is a header tank (not shown) connected to the spray box by suitable means for regulating the amount of water head in the boxes.

Located at a predetermined distance below the bottom of the mold shell 2 is a plurality of air jet nozzles or wipers 13, which project from the air header pipe 9. These nozzles or wipers are mounted in battery formation in such a manner as to direct air against the sides of an ingot emerging from the mold shell, and to remove the water flowing down the ingot's sides. The air wipers are generally positioned with an elevation angle of from 20° to 50° with respect to a horizontal plane normal to the ingot face. The wipers are spaced back from the ingot surface to allow ample clearance between the nozzles and ingot surface. In most instances a spacing of from 3/8 to 1 1/2 inches has been found to give a satisfactory deflection clearance about the nozzles, thereby avoiding the dropping of water back into the nozzles which would interfere with the otherwise smooth action of the wiper. The air pressure is maintained at a figure suitable for producing a clean line of coolant removal. To avoid the effects of line pressure variations, a pressure regulator may be used on the inlet side of a control valve (not shown) so that the outlet pressure will remain constant for a given predetermined setting of the valve.

The term air jet, as employed herein is intended to apply to any gas, including nitrogen, the noble gases as well as any other gaseous media. Obviously, air is the most economic gas for such use and is not hazardous in the continuous casting of aluminum and the majority of other metals.

Although other means may be used for completing the removal of the water initially removed by the nozzles, it is contemplated that there be associated with each battery of nozzles a horizontally mounted deflector baffle 6. These baffles are successively bent along their lengths so as to form an inclined drain surface 7, a curved portion 8 fitting about the upper outer periphery of the aforementioned segment of the air header pipe 9, and finally end in a downwardly turned flange 11 located above the tips of the nozzles 13. The air header pipe 9 is comprised of a lower U-shaped portion 10, to which there is connected by suitable means a separate upper pipe member 10 which is substantially square in plan and which is mounted parallel with the lower U-shaped portion. The air jet nozzles 13 are suitably attached to upper member 10.

The water removed from the faces or sides of the ingot is deflected against the baffles 6, whence it finally flows down over the drain surfaces 7 thereof, and into a suitable drain (not shown).

The air header pipe 9 is connected to a suitable source of compressed air supply such as by means of the pipe 19. Associated with this pipe but not shown is an air pressure gauge and a control valve provided with a setting indicator for regulating the pressure of the air being emitted from the nozzles 13.

Each end of the air header pipe 9 may be mounted

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upon a bracket 20, and L-shaped arms 21 may be connected directly to this bracket. These arms are threadedly mounted upon shafts 22 suitably mounted on the frame 24, said frame also serving to mount the mold shell 2. When shafts 22 are turned by the cranks 22a, they will thereby cause brackets 20 and air header pipe 9 to move upwardly or downwardly, so that the air header pipe 9 and jet nozzles 13 may be drawn up or down with respect to the mold shell 2 and be placed at a greater or smaller distance from the shell, which distance will in turn be governed by the chemical composition of the ingot, the size and shape of the ingot or billet which is being cast, the rate of ingot withdrawal, the rate of flow of coolant, etc. Also, by this means this distance can be adjusted during casting if necessary.

Thus, it will be readily seen that as the ingot is lowered from the mold shell 2, the air streams 23 being emitted from the air nozzles 13, will deflect the water running down along the surfaces of the ingot over baffles 6 and into a suitable drain. These nozzles or wipers 13 are of a design which will deliver a uniform stream of air and can be of a standard type such as shown in Figure 2. They are preferably mounted closely together as shown in Figure 1 to give complete line coverage for each entire side of the ingot.

Although the air wiper described above, in conjunction with Figures 1 and 2, is preferred, it is contemplated, within the scope of the invention, to use other types of wipers. For example, it has been found that certain mechanical wipers, such as those made from neoprene or other suitable flexible material, may be satisfactory.

As one specific example of a suitable mechanical wiper, reference is made to Figures 3 and 4 of the drawings wherein like parts or members are designated by the same numbers. As shown in the drawings, and particularly in Figure 4, the wiper comprises a synthetic rubber or neoprene ring-like member 30 which is substantially square in plan and wherein the inner edge or surface thereof is in rubbing contact with the surfaces of downwardly moving ingot 12 to thereby remove the coolant flowing down the ingot surfaces. Wiper member 30 is positioned between two plate-like members 31, 31 such that these members in effect form a sandwich.

The wiper member 30 and plate-like members 31, 31 are supported in proper position below the bottom of open ended mold shell 2 by means of a pair of parallel brackets 32, 32 and cross members 33, 33. Each bracket 32 comprises an L-shaped member 35 and a flange member 34 which is suitably attached to the vertical leg of member 35, as by welding, and which is parallel to and spaced from the horizontal base or leg portion of L-shaped member 35. The groove defined by flange 34 and the horizontal base or leg portion of member 35 is such as to allow the outer portion of the sandwich comprising wiper 30 and plate-like members 31, 31 to slide in therebetween. Extending transversely with respect to brackets 32, 32 are members 33, 33 which are affixed to the underside of the brackets at the extremities thereof such that a rigid frame is provided having, in effect, grooves on two opposed sides.

On the underside of members 33, 33 and at the extremities thereof are attached suitable blocks 36. These blocks are each provided with a threaded vertical hole for mounting upon threaded shafts 22. It is to be understood that the ends of members 33, 33 are each provided with an aperture of such size as to be clear of the threads on shafts 22.

It will thus be seen that the arrangement of brackets 32, 32 and members 33, 33 results in a relatively rigid frame being substantially square in plan and providing opposed grooves into which the sandwich comprising wiper 30 and plate-like members 31, 31 may be slid into place and held against vertical movement. By means of cranks 22a which are suitably connected to shafts 22 which in turn are threadedly connected to the frame holding the wiper, the wiper can be moved upwardly or downwardly with respect to the open ended mold shell 2.

It is known that improper casting conditions may in certain instances cause rupturing of the relatively thin solidified shell on the embryo ingot just as it emerges from the mold 2 with the result that a protuberance or projection is formed on the surface of the ingot. When using a mechanical wiper wherein the wiper is in direct contact with the ingot surface, it is desirable to provide suitable safety means for allowing the wiper mechanism

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to move downwardly to the base of the ingot thereby preventing any protuberance or projection which might form on the ingot surface from contacting the wiper mechanism with possible damage thereto.

One such safety means is shown in Figure 4 wherein shafts 22 are suspended from frame 24 by means of washer and pin members 37 and 38. The upper ends of shafts 22 are detachably connected to cranks 22a by means of pins 39. These pins 38, 39 in each instance pass through transverse holes in shafts 22 with the opposite ends of the pins projecting outwardly therefrom. It will thus be seen that should a rupture of the embryo ingot shell occur with a resulting protuberance or projection of metal, the pins 38, 39 can be removed thereby allowing the entire wiper assembly to slide or move down the ingot surface to the base of the ingot. By this means, the protuberance or projection of metal does not contact the wiper and/or holder therefore.

It has been found that the most effective method for preventing excessive cooling of the lower portion of the ingot, thereby eliminating center splitting, edge cracks and other serious defects in high strength aluminum alloy ingots of relatively massive cross-sectional area, while at the same time maintaining close control over other factors such as shrinkage porosity, grain size, and segregation is to control the rate of heat abstraction from the ingots such that the stabilized temperature of the surface or outer portions of the ingots below the level of coolant removal is not substantially less than 300° F. and preferably is from about 400° to 650° F. The ingot surface temperatures can be measured by the use of any suitable means such as a surface pyrometer which will automatically record the surface temperature of the ingots during downward travel. The stabilized temperature of the surface of the ingot is the temperature which is reached below the level or zone of coolant removal wherein the surface temperature of the ingot remains substantially constant during the remainder of the casting operation. In the casting of massive ingots, it has been found that satisfactory stabilized temperatures can be attained with ingot withdrawal rates up to approximately 5 inches per minute and removing the coolant liquid from the surfaces of the ingot within a range of from about 3 to 10 inches below the bottom of the mold shell, depending on chemical composition, size and shape of the ingot being cast.

It has also been found that where the level or zone of coolant removal is such as to result in the desired ingot surface temperature of not appreciably below 300° F., that the level of the molten metal crater bottom, i. e., the level of substantially complete solidification, may be below or above the level of coolant removal. As discussed hereinbefore, the level of coolant removal which will be productive of satisfactory results in any given casting operation is influenced by such factors as chemical composition of the metal being cast, the size and shape of the ingot, the rate of heat abstraction, and the rate of ingot withdrawal. As a result of numerous casting operations wherein the ingot temperature below the level of coolant removal did not fall appreciably below 300° F., it was found that for the majority of alloys and massive cross-sections cast, that the level of coolant removal may, in certain instances, be within a region as much as 6 inches or over above or below the level of the bottom of the metal crater, i. e., the level of substantially complete solidification. It has been determined that for substantial reduction or elimination of such defects as center splits and edge cracks while allowing optimum control over other metallurgical characteristics, such as grain size, shrinkage porosity, and fineness and uniform distribution of alloying constituents, the level of coolant removal should be such that it is within a region adjacent the bottom of the molten metal crater, i. e., the level of substantially complete solidification, of the ingot which does not vary over about 4 inches above or below the bottom of the molten metal crater. It is to be noted that when the instant invention is practiced in the continuous casting of ingots of conventional sizes in order to increase the rates of ingot withdrawal, that the limits of the region of coolant removal with respect to the bottom of the molten metal crater as discussed above may be expanded.

It is to be understood that in any given casting operation, other factors remaining constant, the closer the level of coolant removal to the bottom of the mold shell

the deeper will be the molten metal crater and the higher will be the temperature of the solidified ingot during the balance of its downward travel. Conversely, the farther down the level of coolant removal is below the bottom of the mold shell the shallower will be the molten metal crater and the cooler will be the solidified ingot during the balance of its downward travel. The rate of ingot withdrawal bears a critical relation to the level of coolant removal, molten crater depth, and ingot temperature, in that other casting conditions remaining constant, the more rapid is the rate of ingot withdrawal the deeper will be the molten metal crater and the higher will be the temperature of the solidified ingot, and conversely, when the rate of ingot withdrawal is reduced the shallower will be the molten metal crater and the lower the temperature of the solidified ingot. It is thus seen that by control of the temperature of the solidified ingot that other factors such as level of coolant removal and withdrawal rate of the ingots must necessarily be taken into account. When the condition of ingot temperature is satisfied, the other conditions such as coolant removal and withdrawal rate will have been satisfied.

It has been further found that it is advantageous in realizing the principal objects of the invention that the level of coolant removal below the bottom of the mold shell be located within a range of from $\frac{1}{8}$ to $\frac{1}{2}$ times the minimum transverse dimension of the particular ingot being cast. Where the coolant is removed at a level below the mold shell less than $\frac{1}{8}$ times the minimum transverse dimension of the ingot, it is extremely difficult to prevent excessive shrinkage porosity and segregation of alloy constituents caused by too slow solidification of the ingot. Where the coolant is removed at a level below the mold shell greater than $\frac{1}{2}$ times the minimum transverse dimension of the ingot, there occurs excessive cooling of the solidified ingot with resultant center splits and edge cracks.

Accordingly, by controlling the extent of accelerated heat abstraction by means of the coolant directly contacting the ingot as it emerges from the bottom of the mold shell, such that the stabilized outer temperature of the ingot does not fall appreciably below approximately 300° F. below the level or zone of coolant removal, and preferably where the level of coolant removal below the mold shell is between $\frac{1}{8}$ and $\frac{1}{2}$ times the minimum transverse dimension of the ingot, massive ingots can now be successfully cast by the continuous method free of center splits and edge cracks. Moreover, the ingots have been found to possess a relatively fine grain structure and have low shrinkage porosity and a relatively fine size and uniform distribution of alloying constituents. In other words, solidification of the ingot will necessarily be sufficiently rapid to minimize the tendency for porosity and segregation, and the rate of heat abstraction from the solidified ingot will not be such that center splits and edge cracks occur.

After the coolant is removed from the surfaces of the ingot as it passes downward, the progressive portions of the ingot are allowed to air cool. Generally it is found as mentioned hereinbefore, that due to the highly heated condition of the core or central portion of the ingot, the outer portions are in effect reheated by conduction such that the temperature of the surface of the ingot is quickly brought to a substantially stable value during the remainder of the casting operation.

It has also been found in the casting of ingots having a square or a substantially square cross-section that in certain instances, depending on the chemical composition and size of the ingot, there may be a tendency for some edge or corner cracking to occur where the coolant has been removed on generally the same level around the periphery of the ingot due to the greater surface area for heat abstraction per unit amount of metal at the corners. In such instances it has been found preferable to remove the coolant on the corners of the ingot at a level closer to the mold shell than the level of removal of the coolant from the ingot surface between the corners. One apparatus for facilitating such coolant removal is shown in Figure 5 which is a modified arrangement of the air wiper illustrated in Figure 2. As shown in Figure 5 the air header pipe 9 is comprised of a lower U-shaped portion 10', to which there is connected by suitable means and in gas flow relation therewith a plurality of pipe members 10 which are each substantially square in plan and are mounted parallel with the lower U-shaped portion and

with each other. As in the case of Figures 1 and 2, the nozzles 13 are suitably attached to pipe members 10 and can be made active or inactive, as required.

In the operation of the modified apparatus shown in Figure 5, the nozzles of the first and/or second tier which are most closely adjacent the ingot corners are made active, thereby allowing the coolant to flow down the surface of the ingot between the corners until it is removed by the active nozzles of the second and/or third or last tier, as the case may be, which are adjacent the surface of the ingot between the corners. It will thus be seen that by proper selection of active nozzles the level of coolant removal for the corners of the ingot occurs at a distance closer to the mold shell than the level of coolant removal for the surface of the ingot located between the corners. By removing the coolant from the corners of the ingot at a level closer to the mold shell than the level of removal of coolant from the ingot surface between the corners, the tendency for corner cracking to occur in certain instances is eliminated. Although Figure 5 shows three tiers of nozzles, it is to be understood that two tiers can be used satisfactorily. The provision of more than two tiers of nozzles is desirable, however, in that it permits greater adjustability of the levels of coolant removal for the ingot surface. It is also to be understood that various other apparatus could be utilized to provide for removal of the coolant from the corners of the ingot at a level closer to the mold shell than the level of coolant removal for the ingot surface between the corners.

Satisfactory results were obtained in continuously casting 18 by 18 inch square ingots of well known 75S high strength aluminum alloy comprising about 1.6% copper, 0.1% silicon, 2.5% magnesium, 0.4% iron, 5.8% zinc, and 0.05% titanium. The ingot lengths varied from about 80 to 100 inches. The pouring temperature of the molten metal was in the range of from about 1225° to 1300° F., and the height of the molten metal head above the bottom of the mold shell was about 3 to 3½ inches. The crater depth varied from about 6 to 14 inches. Water was used as the coolant fluid in contact with the ingot with a flow rate of from 40 to 45 gallons per minute and at a temperature of from 35° to 40° F. The coolant was removed from the surfaces of the ingots by means of air wipers and in the range of from 4 to 7 inches below the bottom of the mold shell. The rate of ingot withdrawal varied from 1½ to 3 inches per minute. The stabilized temperatures of the surfaces of the solidified ingots below the level or zone of coolant removal varied from 440° to 650° F. The air wipers were positioned with an elevation angle of approximately 25° with respect to a horizontal plane normal to the ingot surfaces. They were spaced a distance back from the ingot surfaces of about ¾ inch to allow ample clearance between the nozzles and surfaces. An air pressure of approximately 12 p. s. i. was found to be suitable in maintaining a clean line of coolant removal. The rate of air flow varied from 250 to 300 cubic feet per minute.

Another example of the invention includes the casting of a 32 inch diameter ingot of 75S high strength aluminum alloy comprising about 1.75% copper, 0.15% silicon, 2.35% magnesium, 0.18% iron, 5.8% zinc, 0.21% chromium, and 0.06% titanium. The ingot length was on the order of about 90 inches. The pouring temperature of the molten metal was in the range of from 1270° to 1310° F. and the height of the molten metal head above the bottom of the mold shell was about 3¼ to 3¾ inches. Water was used as the coolant fluid in contact with the ingot with a flow rate on the order of 60 gallons per minute and at a temperature of from 35° to 40° F. The molten metal crater depth was about 14 inches. The coolant was removed from the ingot surfaces about 8½ inches below the bottom of the mold shell and the rate of ingot withdrawal varied from ¾ to 1½ inches per minute. The means used for removing the coolant were air wipers as discussed above. The air pressure was maintained at about 37 p. s. i. with an air flow of approximately 560 cubic feet per minute. The stabilized temperature of the surfaces of the solidified ingot below the level or zone of coolant removal was on the order of 575° F.

Other examples of the invention include the casting of 12 by 12 inch square ingots of 75S high strength aluminum alloy comprising about 1.6% copper, 0.10% silicon, 2.5% magnesium, 0.25% iron, 5.6% zinc, and 0.05% titanium. The ingot lengths varied from about

80 to 100 inches. The pouring temperature of the molten metal was in the range of from 1260° to 1280° F. and the height of the molten metal head above the bottom of the mold shell was about 3 to 3½ inches. The rate of ingot withdrawal from the mold shell was on the order of 2¼ inches per minute. Water was used as the coolant fluid in contact with the ingot with a flow rate of from 40 to 44 gallons per minute and at a temperature of about 40° to 45° F. the coolant was removed from the surfaces of the ingot at a level approximately 3½ inches below the bottom of the mold shell. The coolant was removed by means of the mechanical wiper. The wiper itself was a flat rubber (neoprene) sheet approximately ¾ inch thick having a substantially square central opening measuring 11½ by 11½ inches with ¾ inch radii on the corners. The stabilized temperatures of the surfaces of the solidified ingots below the level or zone of coolant removal varied from 450° to 550° F.

In all of the above examples the stabilized temperatures of the surfaces of the various ingots were controlled such that they were maintained above 300° F. below the level or zone of coolant removal, with the result that the ingots were free of center splits, edge cracks, and possess relatively small grain size, low shrinkage porosity and with fine size and uniform distribution of alloying constituents. It is also to be noted in the above examples that the level of coolant removal below the mold shell in each instance fell within the range of from ¼ to ½ times the minimum transverse dimension of the ingot, the level on the 18 by 18 inch square ingots being from about .2 to .4, on the 32 inch diameter ingot being about .26, and on the 12 x 12 inch square ingots being about .3 times the minimum transverse dimension thereof, respectively.

It will thus be seen that by proper selection of the rate of ingot withdrawal and the zone of coolant removal, such that the rate of heat abstraction by the coolant does not lower the temperature of the outer portions of the ingot to less than approximately 300° F., sound ingots of massive cross-section and of circular, square, or other polygonal or elliptical cross-section approaching circular or square can now be successfully continuously cast, particularly ingots of high strength aluminum alloys such as 75S. Other aluminum alloys eminently suited to be cast by such process are 14S, 17S, 24S, etc. Moreover, it has been found that the practice of the instant invention can be advantageously applied to the continuous direct chill casting of any aluminum alloy of an ingot size generally employed in industry today with the added result that increased rates of ingot withdrawal and consequently increased production rates can be attained.

It is contemplated, within the scope of the invention, that the massive ingots cast by this process may have to be annealed after casting thereof where they exhibit any tendency to form center splits or edge cracks on standing or on subsequent machining. The general process used is to slowly raise the temperature of the ingots from the take-off temperature, or from room temperature, whichever the case may be, to well known annealing temperatures in the range of from about 600° to 800° F. and hold at these temperatures for a time sufficient to obtain adequate stress relief and thereafter slowly cooling. The use of such an annealing operation is particularly advantageous on ingots on the order of 32 inches in diameter.

It is obvious that although this invention has been described in connection with the method of coolant application to the mold most commonly used in the aluminum industry (the method illustrated by Ennor Patent No. 2,301,027 and Nicholls Patent No. 2,414,269), it is equally applicable to the methods of coolant application to the mold disclosed by Williams Patent No. 2,079,644 and by Moudry in Figure 9 of Canadian Patent No. 485,043.

Although specific apparatus has been described for carrying out the invention, it will be apparent that various types and modifications of apparatus may be employed in performing this novel method of continuous casting. It will also be understood that various changes, omissions and additions may be made to this method without departing from the spirit and scope of the invention as set forth in the appended claims.

What is claimed is:

1. In the continuous casting of light metal ingots, wherein molten metal is continuously supplied to a relatively short open mold shell, is partially cooled therein to form an outer shell of solidified metal, and a fluid coolant is applied to the ingot emerging from said mold shell to rapidly cool the ingot, the improvement which comprises effectively removing said coolant from the ingot at a distance below the mold shell of not less than about one-eighth and not greater than about one-half times the minimum transverse dimension of said ingot, and applying no significant amount of coolant to the surface of the ingot below the level of coolant removal whereby the internal heat of the ingot will reheat the cooled surface of the ingot and after this reheating of the surface of the ingot maintain this surface at a temperature not substantially below about 300° F. during the remainder of the casting operation.

2. A method according to claim 1 wherein the surface temperature of the ingot during the remainder of the casting operation falls between about 400° F. and about 650° F.

3. A method according to claim 1 wherein the cast ingot has transverse axes of substantially equal length.

4. In the continuous casting of light metal ingots, wherein molten metal is continuously supplied to a relatively short open mold shell, is partially cooled therein to form an outer shell of solidified metal, and a coolant is applied to the ingot emerging from said mold shell to rapidly cool the ingot, the improvement which comprises directing gas streams against the ingot surface at a distance below the mold shell of not less than about one-eighth and not greater than about one-half times the minimum transverse dimension of said ingot to effectively wipe the coolant from the ingot surface, and applying no significant amount of coolant to the surface of the ingot below the level of coolant removal whereby the heat of the ingot will reheat the cooled surface of the ingot and after this reheating of the surface of the ingot maintain this surface at a temperature not substantially below about 300° F. during the remainder of the casting operation.

5. In the continuous casting of light metal ingots, wherein molten metal is continuously supplied to a relatively short open mold shell, is partially cooled therein to form an outer shell of solidified metal, and a coolant is applied to the ingot emerging from said mold shell to rapidly cool the ingot, the improvement which comprises contacting the ingot with a resilient wiper at a distance below the mold shell of not less than about one-eighth and not over about one-half times the minimum transverse dimension of said ingot to thereby effectively wipe the coolant from the ingot surface, and applying no significant amount of coolant to the surface of the ingot below the level of coolant removal whereby the heat of the ingot will reheat the cooled surface of the ingot and after this reheating of the surface of the ingot maintain this surface at a temperature not substantially below about 300° F. during the remainder of the casting operation.

6. In the continuous casting of light metal ingots of substantially square cross-section, wherein molten metal is continuously supplied to a relatively short open mold shell, is partially cooled therein to form an outer shell of solidified metal, and a fluid coolant is applied to the ingot emerging from said mold shell to rapidly cool the ingot, the improvement which comprises effectively removing said coolant from the ingot at a distance below the mold shell of not less than about one-eighth and not greater than about one-half times the minimum transverse dimension of said ingot, and applying no significant amount of coolant to the surface of the ingot below the level of coolant removal whereby the internal heat of the ingot will reheat the cooled surface of the ingot and after this reheating of the surface of the ingot maintain this surface at a temperature of not substantially below about 300° F. during the remainder of the casting operation, and wherein said coolant at the corners of said ingot is removed at a level closer to the mold shell than the level of removal of the coolant from the ingot surface between the corners of said ingot.

7. The method according to claim 6, wherein the surface temperature of the ingot during the remainder of the casting operation falls between about 400° F. and about 650° F.

8. In the continuous casting of light metal ingots, wherein molten metal is continuously supplied to a relatively short open mold shell, is partially cooled therein to form an outer shell of solidified metal containing a molten metal crater, and a fluid coolant is applied to the ingot emerging from said mold shell to rapidly cool the ingot, the improvement which comprises effectively removing the coolant from the ingot surface in a region adjacent the bottom of the molten metal crater of the ingot, said coolant being removed at a distance below the mold shell of not less than about one-eighth and not greater than about one-half times the minimum transverse dimension of said ingot, and applying no significant amount of coolant to the surface of the ingot below the level of coolant removal whereby the internal heat of the ingot will reheat the cooled surface of the ingot and after this reheating of the surface of the ingot maintain this surface at a temperature of not substantially less than about 300° F. during the remainder of the casting operation.

9. A method according to claim 8 wherein the surface temperature of the ingot during the remainder of the casting operation falls between about 400° F. and about 650° F.

10. A method of continuously casting massive high strength light metal ingots comprising the steps of supplying molten metal to a relatively short open mold shell, continuously applying a liquid coolant to the outer surface of said mold shell to form an outer shell of solidified metal containing a molten metal crater, continuously applying a liquid coolant to the surface of the ingot emerging from said mold shell to rapidly cool said ingot, withdrawing the ingot from said mold shell, and effectively removing substantially all of the liquid coolant from the surface of the ingot in a region adjacent the level of the bottom of the molten metal crater, said coolant being removed at a distance below the mold shell of not less than about one-eighth and not greater than about one-half times the minimum transverse dimension of said ingot, and applying no significant amount of coolant to the surface of the ingot below the level of coolant removal whereby the internal heat of the ingot will reheat the cooled surface of the ingot and

after this reheating of the surface of the ingot maintain this surface at a temperature not substantially less than about 300° F. during the remainder of the casting operation.

11. The method according to claim 10 in which the cast ingot has transverse axes of substantially equal length.

12. The method according to claim 10 in which the ingot surface temperature after coolant removal is within the range of from about 400° F. to about 650° F.

13. In the continuous casting of light metal ingots having transverse axes of substantially equal length, wherein molten metal is continuously supplied to a relatively short open mold shell, is partially cooled therein to form an outer shell of solidified metal, and a fluid coolant is applied to the ingot emerging from said mold shell to rapidly cool the ingot, the improvement which comprises effectively removing said coolant from the ingot at a distance below the mold shell of not less than about one-eighth and not greater than about one-half times the minimum transverse dimension of said ingot, and applying no significant amount of coolant to the surface of the ingot below the level of coolant removal whereby the internal heat of the ingot will reheat the cooled surface of the ingot and after this reheating of the surface of the ingot maintain this surface at a temperature in the range of from about 400° F. to about 650° F. during the remainder of the casting operation.

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