United States Patent [19]

Goodrich et al.

[11] **3,726,333**

[45] **Apr. 10, 1973**

[54] CONTROL OF CONTINUOUS CASTING OPERATION

[75] Inventors: **George M. Goodrich,** Almont; **Robert G. Williams,** Birmingham; **Fred J. Webbere,** Orchard Lake, all of Mich.

[73] Assignee: **General Motors Corporation,** Detroit, Mich.

[22] Filed: **July 7, 1971**

[21] Appl. No.: **160,487**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 879,832, Nov. 25, 1969, abandoned.

[52] **U.S. Cl.** **164/82,** 164/154, 164/283

[51] **Int. Cl.** **B22d 11/12**

[58] **Field of Search**.....164/4, 82, 83, 154, 164/158, 273 R, 282, 283, 260

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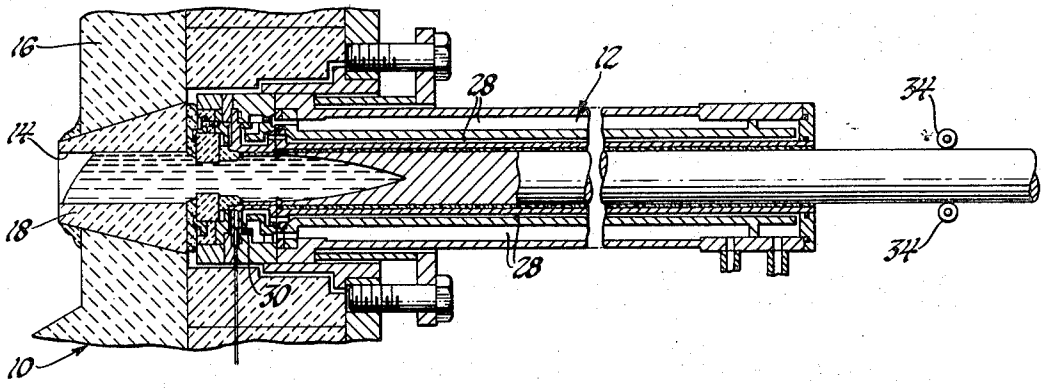
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Primary Examiner—R. Spencer Annear
Attorney—Sidney Carter et al.

[57] **ABSTRACT**

A method and apparatus for continuously monitoring and controlling a continuous casting operation to detect and heal breakouts occurring periodically during the casting operation is disclosed. In a continuous casting operation wherein molten metal is progressively passed through three consecutive zones: a first zone wherein molten metal is passed from a holding vessel without significant solidification due to its low heat transfer capacity, a second zone wherein a thin skin of metal forms progressively due to its relatively high heat transfer capacity, and a third zone in which the molten metal solidifies to form a self-sustaining rod; a thermocouple is placed in the vicinity of the juncture of the first and second zones to measure the temperature fluctuation at the juncture. The advance of the solidified rod is automatically stopped on a continued decrease in temperature at the juncture as measured by the thermocouple which results from a breakout occurring in zone two. Stopping of the rod advance allows for the breakout to heat after which advance is automatically resumed.

7 Claims, 9 Drawing Figures



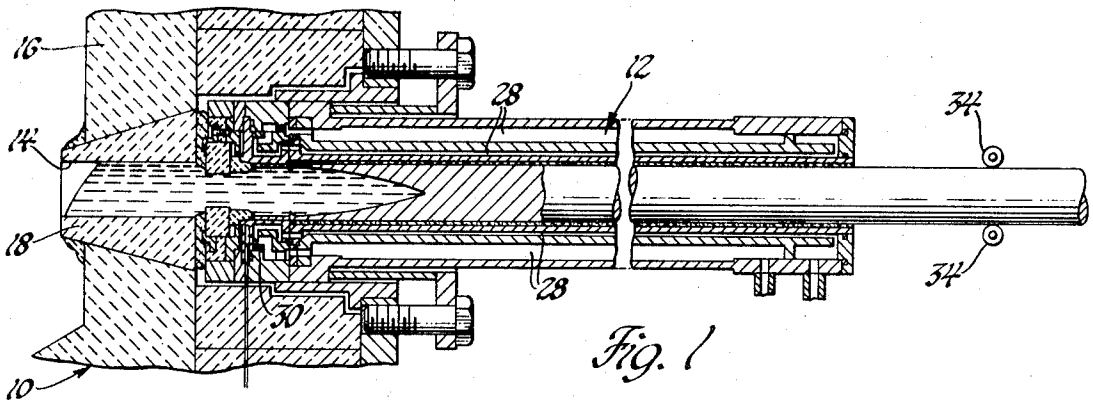


Fig. 1

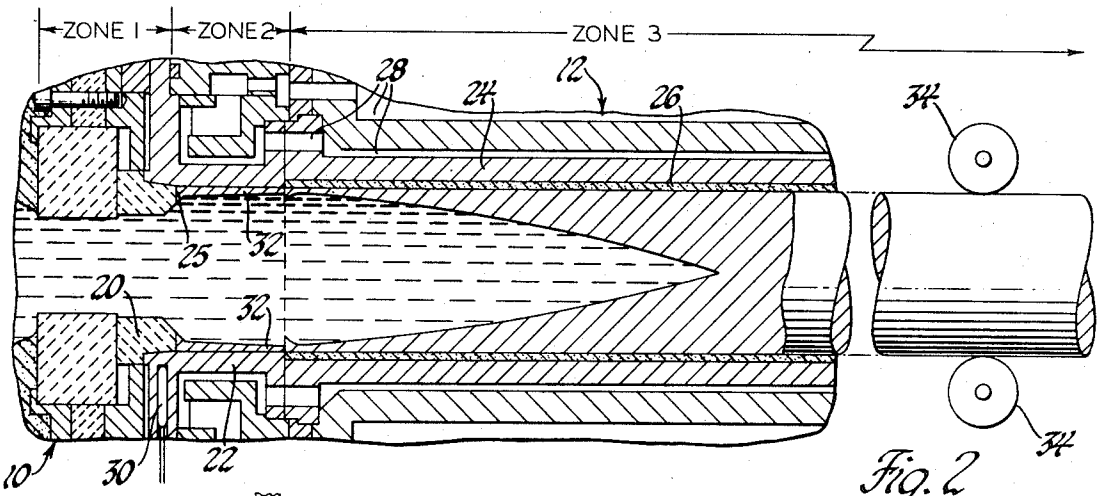


Fig. 2

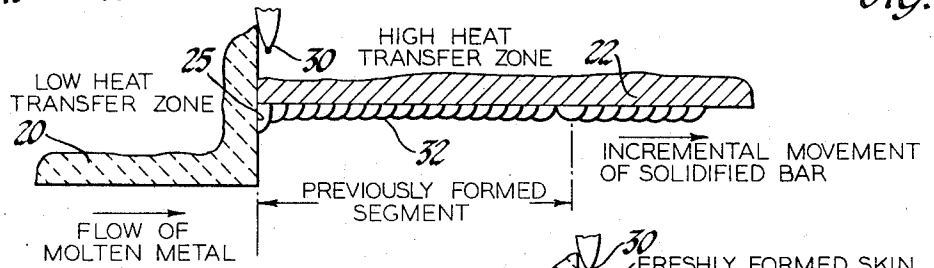


Fig. 3

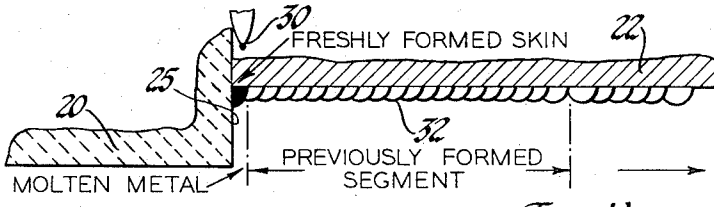


Fig. 4

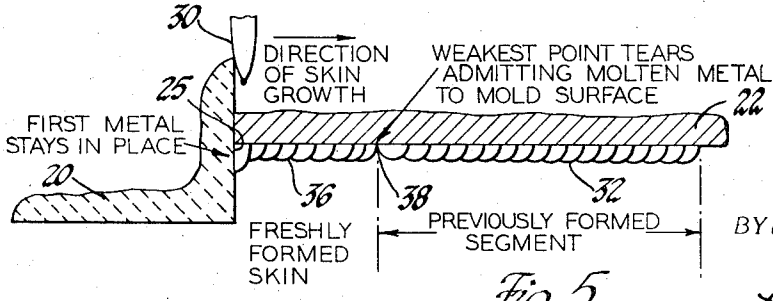


Fig. 5

INVENTORS
George M. Goodrich,
BY Robert G. Williams &
Fred J. Webbere
Peter P. Kozak
ATTORNEY

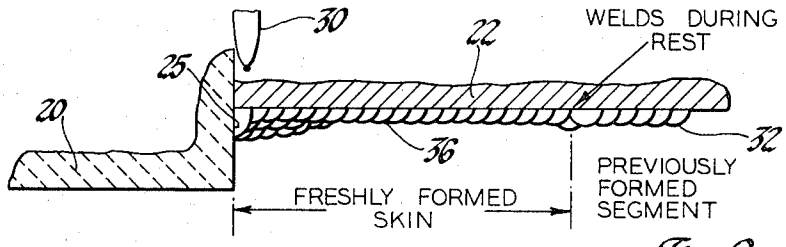


Fig. 6

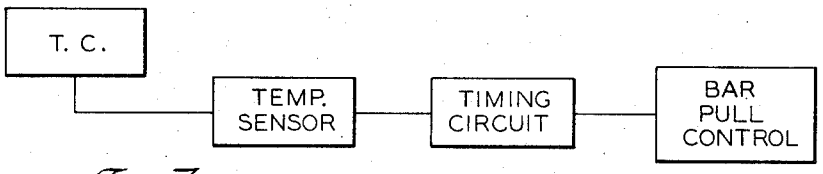


Fig. 7

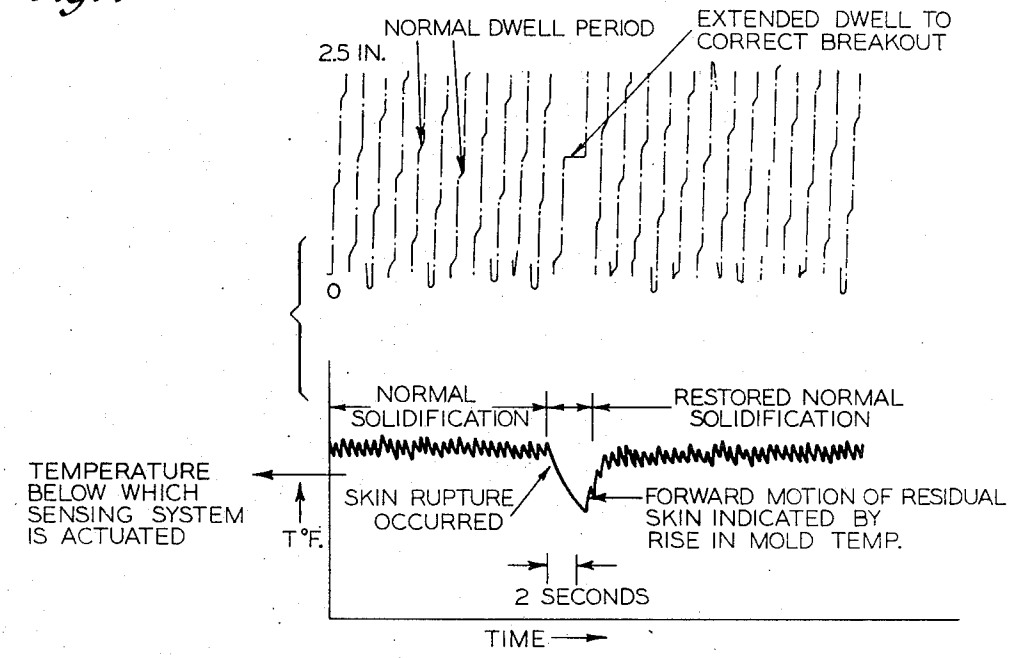


Fig. 8

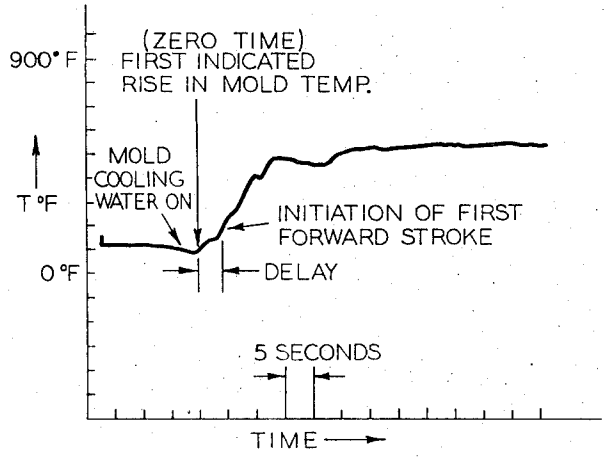


Fig. 9

INVENTORS
George M. Goodrich,
BY Robert G. Williams &
Fred J. Webbere
Peter P. Kozak
ATTORNEY

CONTROL OF CONTINUOUS CASTING OPERATION

This application is a continuation-in-part of our application Ser. No. 879,832 entitled "Control of Continuous Casting Operation", filed Nov. 25, 1969 now abandoned and assigned to the assignee of the present invention.

This invention relates to continuous casting of round bars or ingots, and more particularly to a method and apparatus for continuously monitoring and controlling the continuous casting operation.

This invention comprises an improvement over the method and apparatus for continuous casting round bars and ingots, particularly rods having a diameter of about 1 to 3 inches, described in copending applications, Ser. No. 827,673 and Ser. No. 827,747, respectively, filed May 26, 1969, and assigned to the assignee of the present invention. That invention described, in general, a horizontally disposed open-ended mold associated with a molten metal holding vessel or furnace including a low heat transfer first zone immediately adjacent the holding vessel which is effective to contain and convey molten metal therethrough without appreciable solidification and which is substantially chemically inert to the molten metal, a relatively high heat transfer second zone adjacent the first zone which effects the initial solidification in the form of a thin skin of solidified metal progressively and coextensively, first at the interface of the first and second zones and progressively to the end of the second zone, and a third zone adjacent the second zone wherein the molten metal is further solidified to form a self-sustaining rod. The apparatus also includes means to mechanically pull the solidified rod from the opposite end of the mold continuously but intermittently in predetermined increments and with predetermined time intervals between the increments of length or segments of movement of the rod wherein each increment corresponds in length to the aforesaid second or initial solidification zone so that with each incremental pull of the rod the thin solidified skin layer or segment formed in the second zone is advanced into the third zone thereby exposing the second zone to the advance of molten metal from the first zone and the progressive solidification of a new skin layer or segment is formed in the second zone. The time interval or dwell time between the pulling intervals is sufficient to permit the forward end of the newly formed skin layer in the second zone to weld to the rod in the third zone, so that when the rod is pulled again, it will carry with it the newly formed segment into the third zone in a continuous rod solidification process.

It has been observed, however, that periodically during the casting operation breakouts can occur when the new skin layer or segment formed in the second zone fails to weld to the previously cast increment in the third zone with sufficient strength to be pulled or stripped from the mold wall during forward movement of the bar. Molten metal then issues from the rupture in the solid skin and solidifies in an improper section of the mold resulting in disruptions in the normal cast bar surface. If breakouts continue to occur during the casting operation, a series of humps or enlarged diameter increments on the bar surface are produced which make it difficult to pull the bar through the third zone and which cause considerable scoring of the third zone mold wall. It has also been found that breakouts can be cured by a prolonged dwell in the casting cycle which allows for healing of the rupture. However, previous to the invention hereinafter described it has been impossible to quickly detect when a breakout occurs and to stop the casting operation to allow for healing of the rupture to take place.

Accordingly, it is among the principal objects of this invention to provide apparatus for continuously monitoring the casting operation which will sense in a very short time when a breakout occurs and which will upon sensing a breakout automatically stop the casting operation for an extending dwell period to allow for healing of the rupture.

It is another object of this invention to provide a method for continuously casting metal rods in which the solidified bar is advanced intermittently in predetermined increments with predetermined time intervals between the increments and in which extended dwell periods are inserted in the intermittent advance of the rod when a breakout occurs to allow for healing of the ruptured skin after which the intermittent advance of the rod is again resumed.

It is a further object of this invention to provide apparatus for continuously monitoring the casting operation in order to detect breakouts and in order to obtain a reliable time reference for starting the casting operation and to obtain a reliable indication of wear and erosion of the first zone of the mold during the casting operation.

These and other objects are accomplished by providing a thermocouple having its temperature sensing element in close proximity to the juncture of the low heat transfer first zone and the relatively high heat transfer second zone and whose terminal leads are attached through a high speed temperature sensor and timing circuit apparatus to the apparatus for advancing the solidified bar. This invention is based on a finding that when a breakout occurs during the casting operation it is accompanied by an improper formation of the skin layer at the juncture of the low heat transfer first zone and the relatively high heat transfer second zone which results in a change in the heat transfer characteristics of the casting process which is indicated by a decrease in temperature at this juncture. By continuously monitoring the temperature in the vicinity of this juncture by means of the sensing apparatus, the rod advancing means can be automatically topped to allow for an extended dwell period in which the rupture heals after which dwell period the rod advancing means automatically resumes intermittent advance of the solidified rod and continuation of the casting operation.

Other objects and advantages of the invention will be apparent from the following description, reference being had to the accompaning drawings of which:

FIG. 1 is a cross-sectional view of a horizontal continuous casting apparatus;

FIG. 2 is an enlarged view of a portion of the mold shown in FIG. 1;

FIG. 3 to 6 are schematic illustrations of the mold at various stages of the casting process showing the solidification sequence in the mold;

FIG. 7 is a block diagram showing the arrangement of the temperature monitoring system;

FIG. 8 is a graph showing a mold temperature variation with casting cycles, skin rupture and corrective extended dwell, and

FIG. 9 is a graph showing the variation in mold temperature with start up.

Referring now to FIG. 1 in the drawings, the molding apparatus of this invention consists generally of a molten metal reservoir 10, shown as a fragment thereof, and a horizontally disposed open-ended mold 12 mounted adjacent an opening 14 near the base of the reservoir. The reservoir is of conventional construction including an outer metal shell (not shown) having a lining 16 of suitable refractory material for containing molten metal, such as steel. The opening or channel 14 in the reservoir is formed in a frusto-conical refractory body 18 cemented to the lining 16. The refractory reservoir may include heating means such as an induction heating coil or a resistance heating element for maintaining the metal at a desired temperature.

Referring to FIG. 2, the mold 12 consists of three distinctly different portions with different heat transfer characteristics. The first portion immediately adjacent the reservoir includes a nozzle portion 20 preferably formed of boron nitride having relatively low heat transfer characteristics such as will contain the molten metal therein without any appreciable solidification. The second portion 22 is positioned immediately adjacent the nozzle 20 and is formed of a material having a relatively high heat transfer characteristic as, for example, a beryllium-copper alloy. The third portion 24 is disposed immediately adjacent the second portion 22 and preferably provided with a graphite liner 26. The third portion preferably has somewhat lower heat transfer characteristics than the second portion 22. The use of the graphite liner is advantageous because it is relatively soft and self-lubricating and it permits the solidified bar to be readily drawn through even though minor imperfections may have occurred on the surface of the rod during solidification thereof. The design of the mold elements is such that there is a shoulder at the juncture 25 of the low heat transfer zone and the relatively high heat transfer zone. The second mold portion 22, as well as the third mold portion 24, are both provided with coolant passages 28. The mold 12 is also provided with a thermocouple 30 having its temperature sensing element in close proximity to the juncture 25 of the low heat transfer zone and the relatively high heat transfer zone and having its terminal ends extending outside of the mold.

After the process of this invention has been started and is in continuous operation as hereinafter described, it is characterized basically by the molten metal passing from the reservoir 10 through three successive zones in the mold 12. The molten metal is conveyed from the reservoir 10 to the first zone without exposure to air whereby the buildup of oxide deposits in the region of zone one is substantially prevented. No significant solidification occurs due to sufficiently low heat transfer capacity of the first zone. As the metal flows into the second zone, a thin skin layer of solidified metal 32 is progressively formed along its length due to the high heat transfer capacity of the second zone portion of the mold. This skin layer is then advanced as a segment or increment into the third zone of the mold wherein the molten metal is further solidified to form a self-sustaining rod which is mechanically pulled out of the mold by suitable means such as the rollers 34. The rollers are clamped on the bar and ride on a sliding carriage such that when the carriage is moved away from the mold, the bar is advanced; and when moved towards the mold in a direction opposite that of the rollers, the bar remains stationary thereby providing intermittent advance of the rod. As the aforesaid skin layer 32 is advanced from the second zone to the third zone, a second skin layer is formed in the second zone which subsequently welds itself to the rod being solidified in the third zone. This skin layer is advanced into the third zone as the rod is pulled incremently whereby a continuous rod is formed in a continuous but incremental process.

Periodically during the casting operation as previously described, it is possible for breakouts to occur. The term "breakout" refers to ruptures in the skin of the solidifying bar during its earliest stages of formation. If breakouts persist or will not heal, they may terminate the casting operation. However, by monitoring the process previously described, the breakout problem can be cured.

The following detailed explanation will make the nature of the improved process more clear, reference being had to FIGS. 2 to 6. The reservoir 10 is provided with a suitable quantity of molten metal such as steel so that its level extends substantially above the mold 12. The molten metal advances due to gravity in the mold through the nozzle 20 which constitutes the aforementioned first zone. Since the first zone is made of a material of relatively low heat conductivity and is not provided with any cooling means, the molten metal does not significantly solidify therein. As soon as the molten metal enters the second zone an initial circumferential annulus solidifies against the mold surface portion 22, as shown in FIGS. 2 and 3. This occurs because the mold portion 22 is formed of a material of relatively high heat conductivity and is cooled by means of suitable coolants such as water circulating in the coolant passages 28 to provide a high heat transfer capacity whereby a film or skin of metal 32 solidifies on the surface of the mold the instant contact is made. As the molten metal advances into the second zone, solidified skin layer 32 forms progressively on the surface of the mold portion 22 in a downstream direction. This formation of skin layer 32 occurs entirely within the mold portion 22 beginning at the juncture 25 of zone one and zone two.

Referring to FIG. 4, the skin layer segment 32 is then advanced as a segment into a third zone of the mold wherein further solidification takes place to form the self-sustaining rod. As the skin layer 32 begins to advance into the third zone, it must release from the nozzle 20 at the interface 25 to form a slight space between the skin 32 and the nozzle. This space is immediately filled with molten metal flowing from the first zone to initiate the formation of a new skin layer at the interface 25 with the nozzle and the mold portion 22 and to closely follow the advancing skin layer 32 and to progressively form a new skin layer 36, as shown in FIG. 5. After the layer 32 has reached its full increment of movement, it is permitted to remain stationary for a time sufficient to permit the new layer 36 to weld to the layer 32. It is essential to the successful operation of the process that the skin layer 36 part cleanly from the nozzle 20 and the skin layer 32 remain stationary for a time sufficient to permit the new skin layer 36 to weld thereto. If either of these process steps are not per-

formed properly, a breakout will occur in the successively formed skin layers causing molten metal to breakout and to prevent proper rod solidification. The use of boron nitride for forming at least said portion of nozzle adjacent the mold portion 22 is highly advantageous because the skin layer does not readily adhere to boron nitride and thereby results in a clean release. However, occasionally during the operation of the process, the freshly formed skin layer 36 does not part from the boron nitride nozzle at the juncture 25 on incremental movement of the previously formed segment 32 and a tear occurs at 38 admitting molten metal to the mold surface.

It is characteristic of this process that solidification occurs in a downstream direction beginning at the juncture of zone one and zone two and that therefore, the weakest point is the juncture 38 of the freshly formed skin 36 and the previously formed segment 32 which is the point of last metal solidification and the point where the freshly formed skin is supposed to weld to the previously formed segment before incremental advance is resumed. Therefore, when a tear or breakout occurs at this weak point, molten metal issues against this point of the mold resulting in an improper solidification sequence as compared to the normal casting process. Such a change in the solidification sequence alters the heat transfer characteristics in this region of the mold, i.e., zone two, and also the heat transfer characteristic in zone one. It may be seen then, that the method for sensing breakouts depends essentially on sensing a change in the normal heat transfer characteristics of the casting process.

As the previously formed segment 32 is moved forward incrementally, molten metal continues to be admitted against the mold wall 22 in a downstream direction. As this molten metal is solidifying, solidification also continues at the juncture 25 of zone one and zone two thus increasing the thickness of the skin layer at the junction, as shown in FIG. 6. As this skin layer increases, it presents an increasingly thick thermal barrier and as a consequence the temperature at this junction as measured by the thermocouple 30 begins to decrease below the temperature of the normally molten metal entering and beginning solidification at the junction during the normal operation of the process. This temperature decrease at this junction as measured by the thermocouple is a practical method of determining a change in heat transfer resulting from a breakout in the casting process.

In the casting process the solidified bar is being advanced in increments of a fraction of a second, and therefore, it is mandatory that a breakout be sensed very quickly. Rapid breakout detection has been achieved through an automatic breakout sensing system, as shown in block form in FIG. 7. The sensing unit utilizes a Chromel-Alumel thermocouple to detect the temperature in the vicinity of the juncture of zone one and zone two. The EMF from the thermocouple is amplified and displayed on a DC microammeter which has an adjustable low limit switching capability. An emergency stoppage or extended dwell in the casting operation is actuated when the juncture temperature decreases below a preset lower limit on the microammeter by disengaging the rod pulling means from the rod.

Referring again to FIG. 6, it may be seen that during the extended dwell period the freshly formed skin 36 welds to the previously formed segment 32. At the end of the preset extended dwell period, the rod advancing means is automatically actuated by the timing circuit to begin advance of the rod again. If the breakout has been healed, the thermocouple will begin to register an increase in temperature as molten metal begins to form a fresh skin at the junction 25 of zone one and zone two. However, if the dwell period has not been sufficient for the freshly formed segment to weld to the previously formed segment the temperature will continue to decrease and the breakout sensing system will again be actuated through the temperature sensor, the timing circuit and the bar pull control, as shown in FIG. 7, to disengage the rod advancing means and the thereby provide for another extended dwell period for welding to take place between the freshly formed skin and the previously formed segment. It has been found that two extended dwell periods are normally sufficient for complete healing of a breakout during the casting operation.

The axial length of the skin layer or segment 32 has a practical limitation and we have found that it should preferably be from 0.1 to 1.5 times the diameter of the rod being cast. If the incremental pull or stroke is shorter, the casting rate is sacrificed and nozzle erosion is excessive. If the stroke is longer, shrinkage porosity in the casting will be excessive. By way of a specific example, a bar of about 1½ inches in diameter is successfully cast with the segment 32 being about 1 inch in length. In casting stock of about 1½ inches in diameter, we have successfully used a segment of 1 inch in a cycle time of 0.25 seconds, the cycle being the sum of the time consumed in drawing the bar one segment as above described and the dwell time, i.e., the time the rod is permitted to remain at rest. A typical dwell time is 0.12 seconds. Satisfactory casting results are obtained with a variation of dwell time from about 0.1 to 0.36 seconds with the proportion of the dwell to the cycle time being about 33 percent to 65 percent and with the cycle time, accordingly, being about 0.15 to 1.1 seconds. We have further successfully used extended dwell periods of from 2 to 10 seconds for complete healing of breakouts.

Referring to FIG. 8, the normal solidification process, breakout, and restored normal solidification may be seen by comparing the incremental movement of the rod with the mold temperature at the juncture of zone one and zone two. Reading from left to right, it may be seen that in normal operation the rod advances incrementally with a stroke of about 1 inch with periodic dwell periods between strokes. During normal operation the temperature fluctuates 10°– 30° F cyclicly with each stroke from a maximum temperature shortly after the time when molten metal first enters the juncture of zone one and zone two on the advance of the rod to a minimum temperature at the end of the dwell period when solidification is completed in zone two and just prior to the advance of the rod. As seen at the center of the graph, a skin rupture or breakout is sensed as the temperature continues to decrease below the normal minimum fluctuation temperature after a normal dwell period. When the temperature decreases below this normal minimum temperature, the sensing

system is actuated and the rod advancing means stopped to allow for an extended dwell period to correct the breakout. In practical applications we have found that excellent results can be obtained when the sensing system is actuated when the temperature falls below a fixed predetermined temperature, for example 15° to 45° F below the minimum temperature, as shown in FIG. 8. During the extended dwell, the temperature continues to decrease as solidification proceeds in zone two and the thickness of the skin layer at the juncture between zone one and zone two increases. At the end of the predetermined fixed extended dwell period forward motion of the solidified rod is again resumed and forward motion of the residual or previously unwelded skin is indicated by a rise in mold temperature as fresh molten metal enters zone two. Observing the right side of the graph, it may be seen that after the extended dwell, the normal solidification mode is restored and the temperature fluctuations again follow the normal rise and fall with incremental motion.

As the skin layer moves into zone three, a progressively greater radial thickness of the molten metal solidifies therein as the bar advances to eventually form a self-sustaining bar which is pulled mechanically from the zone three, as shown in FIG. 2.

It will be apparent to one skilled in the art that numerous variations of the monitoring system herein described can be made. As previously described, the thermocouple, located preferably in the vicinity of the juncture of zone one and zone two, registers a decrease in mold temperature at the juncture when a breakout occurs. This decrease in mold temperature is a result of a change in the normal heat transfer characteristics of the molding process due to an improper mode of solidification in zone two and is reflected progressively in a downstream direction at all points along zone two, beginning at the juncture of zone one and zone two, by a decreasing temperature. It may be seen then, that the thermocouple may be placed at any point along zone two and will measure a temperature decrease corresponding to that at the juncture with equal sensitivity but at a slightly later time because the skin is solidifying into an increasingly thick thermal barrier in a downstream direction away from the juncture. In addition, zone one will also reflect a temperature decrease but with less sensitivity at points remote from the juncture because of the relatively low heat transfer capacity of the zone one material. Thus, since the effect actually being monitored is a change in heat transfer characteristics in zone two which is also reflected in zone one, the thermocouple or any suitable temperature sensitive device will be operative in the molding and monitoring process hereinabove described if it is positioned so as to sense changes in mold temperature in a region between the beginning of zone one and the beginning of zone three.

It will be further apparent to one skilled in the art that more than one thermocouple may be used in the monitoring process. That is, when one thermocouple is used in the monitoring process the change in mold temperature is referenced with respect to room temperature. Since the mold temperature changes progressively in a downstream direction, two thermocouples may be positioned along the mold in the region between the beginning of the first zone and the beginning of the third zone with the change in mold temperature being referenced to the differential temperature between the thermocouples. The practical effect of this method is the decrease in the amount of fluctuation in temperature, as previously seen in FIG. 8, and thereby lend increased sensitivity to the temperature monitoring process. The sensing system is actuated for an extended dwell period on the occurrence of a breakout when the differential temperature between the thermocouples falls below the minimum differential in temperature normally occurring in operation or, alternatively, below a predetermined differential in temperature.

The method of this invention has particular utility in casting metals which have a relatively high melting temperature of about 2200° of or more, and are unsaturated in carbon so that they cannot be cast or solidified in a graphite mold because of their tendency to absorb carbon by diffusion. Of particular importance in this class of metals are ferrous metals such as steel, and other ferrous metals typically containing up to about 2 percent carbon. Illustrative of metal which may be cast in accordance with this invention are SAE **4118** steel containing, by weight, 0.18 percent to 0.23 percent carbon, 0.7 percent to 0.9 percent manganese, 0.4 percent to 0.6 percent chromium, 0.08 percent to 0.15 percent molybdenum, 0.04 percent maximum, phosphorus, 0.04 percent maximum, sulphur, and the balance essentially iron; SAE 5160 steel containing, by weight, 0.55 percent to 0.65 percent carbon, 0.75 percent to 1.0 percent manganese, 0.2 percent to 0.9 percent chromium, 0.04 percent maximum, phosphorus, 0.04 percent maximum, sulphur, and the balance essentially iron; SAE 52100 steel containing, by weight, 0.95 percent to 1.1 percent carbon, 0.25 percent to 0.45 percent manganese, 1.3 percent to 1.6 percent chromium, 0.25 percent maximum, phosphorus, 0.25 percent maximum, sulphur, and the balance essentially iron. Nickel based alloys and cobalt based alloys containing predominant amounts of nickel or cobalt may also be successfully cast in accordance with the process of this invention.

Illustrative of a nickel base alloy of this type is Inconel 610 consisting of 0.2 percent carbon, 1.0 percent manganese, 9 percent iron, 1.6 percent silicon, 0.5 percent copper, 15.5 percent chromium, columbium plus tantalum about 2 percent, and the balance essentially nickel; and Rene 41 consisting of about 18 percent to 20 percent chromium, 10 percent to 12 percent cobalt, 9 percent to 10.5 percent molybdenum, 5 percent iron, 0.09 percent to 0.12 percent carbon, 0.5 percent silicon, 0.1 percent manganese, 3 percent to 3.3 percent titanium, 1.4 percent to 1.6 percent aluminum, and the balance nickel. Illustrative of a cobalt based alloy which may be cast in accordance with the invention is Haynes 25, consisting of 0.05 percent to 0.15 percent carbon, 1.9 percent to 2 percent manganese, 19 percent to 21 percent chromium, 9 percent to 11 percent nickel. 14 percent to 16 percent tungsten, 3 percent iron, 1 percent silicon, and the balance essentially cobalt.

As described above, the metal solidification occurs in a metal mold portion of the zone two so that there is no carbon source for carbon diffusion. The skin layer **32** is well formed when it is transferred to the graphite lined zone three so that no appreciable carbon diffusion occurs during the casting process.

The above description of the process and apparatus is applicable to normal operational conditions after the molding process has commenced. The process is commenced by inserting a suitable rod (not shown) into the exit end of the mold until it reaches approximately to the juncture of the first and second zones. The initial molten metal flowing into the mold is permitted to flow against the rod end and to bond thereto. This rod is then pulled incrementally as described above to establish the casting process. This same temperature sensing arrangement as previously described can also be used to advantage in obtaining a reliable time reference for starting the casting operation. Start-up is a particularly critical operation in any continuous casting operation because of its sensitivity to metal temperature, preheat of the casting vessel, mold condition, presence of entrapped slag, and gas and other variables. It has been found that an initial extended delay is required after the first metal enters the mold to ensure complete solidification of the cast material around the anchoring projection at the end of the starter bar. The length of this delay will vary with the size of the bar and the metal composition. Referring to FIG. 9, it may be seen that the rise in the mold temperature indicated by the mold thermocouple located near the juncture of zone one and two gives an accurate readout of entry of the first metal and can be used as a time reference for either manual or automatic initiation of the casting process in which initiation of the casting process is delayed for an extended dwell period after which initiation of the first forward stroke is begun. A continued rise in mold temperature indicates that the solidification process is proceeding normally with each forward stroke. At a given time after casting has begun, the temperature fluctuations within the mold will establish a stable pattern as previously seen in FIG. 8.

It has also been observed that the temperature sensing apparatus is operative to determine the amount of nozzle wear and erosion at the juncture of zone one and zone two. Since the length of time that casting can be continued is depended on the integrity of the juncture between zone one and zone two, the control apparatus adds another control dimension to the casting operation. As the process proceeds, the thermocouple located at the juncture of zone one and zone two registers a gradual increase in temperature during extended casting periods. This gradual increase in temperature is indicative to wear and erosion of the material which forms the low heat transfer zone that overlaps the high heat transfer material. The magnitude of the gradual increase can, therefore, be utilized to determine when the casting process should be terminated because of extreme nozzle erosion conditions and thereby prevent permanent mold damage.

This invention has been described with reference to horizontal continuous casting only, however, those skilled in the art will recognize that it may be easily adapted to vertical continuous casting through such obvious modifications as placing the opening **14** in the bottom of the reservoir **10** and aligning the mold vertically with said revervoir. In the vertical position the method embodying this invention may be used to control the vertical casting operation.

Although this invention has been described in terms of specific examples, it is to be understood that other forms of the invention may be readily adapted within the scope of the invention.

We claim:

1. A method of continuously casting a continuous rod comprising the steps of:

a. continuously introducing molten metal into the inlet end of the cavity of an open-ended continuous casting mold;

b. said mold including a first zone adjacent said inlet end having a relatively low heat transfer capacity, a second zone immediately adjacent said first zone having a relatively high heat transfer capacity, and a third zone adjacent said second zone terminating in an open outlet end;

c. advancing said molten metal into said first zone, the heat transfer characteristics of said first zone being operative to substantially prevent any metal solidification therein;

d. advancing said molten metal into said second zone, the high heat transfer characteristics of said second zone being operative to cause solidification of a thin layer of said metal at first immediately at the juncture of said first and second zone and then progressively in the direction of said third zone whereby a thin layer of said molten metal is formed coextensively of said second zone;

e. advancing said rod intermittently in fixed predetermined increments at fixed predetermined time intervals, said increments being equal to the length of said second zone whereby said thin layer of said solidified metal formed in said second zone is advanced progressively into said third zone and the molten metal advancing from said first zone follows the advance of said thin layer to progressively fill said second zone immediately behind said advancing thin layer and to thereby progressively form a new thin solidified layer coextensively of said second zone cavity surface, said intervals being of sufficient duration to permit the forward axial end of said newly formed thin layer to weld to the solidified metal in said third zone;

f. continuously monitoring the change in mold temperature in a region between the beginning of said first zone and the beginning of said third zone, said mold temperature normally fluctuating between a maximum temperature and a minimum temperature during said time interval;

g. stopping the advance of said rod for a fixed predetermined dwell period when said mold temperature falls below said minimum temperature which indicates that said newly formed thin layer has failed to weld to the solidified metal in said third zone, said dwell period being longer than said fixed time intervals, to permit said layer, which previously failed to weld, to weld to the solidified metal in said third zone, and

h. resuming the advance of said rod at the completion of said dwell period in said fixed predetermined increments at said fixed predetermined time intervals.

2. A method of continuously casting a continuous rod comprising the steps of:

a. continuously introducing molten metal into the inlet end of the cavity of an open-ended continuous casting mold;

b. said mold including a first zone adjacent said inlet end having a relatively low heat transfer capacity, a second zone immediately adjacent said first zone

having a relatively high heat transfer capacity, and a third zone adjacent said second zone terminating in an open outlet end;

c. advancing said molten metal into said first zone, the heat transfer characteristics of said first zone being operative to substantially prevent any metal solidification therein;

d. advancing said molten metal into said second zone, the high heat transfer characteristics of said second zone being operative to cause solidification of a thin layer of said metal at first immediately at the juncture of said first and second zones and then progressively in the direction of said third zone whereby a thin layer of said molten metal is formed coextensively of said second zone;

e. advancing said rod intermittently in fixed predetermined increments at fixed predetermined time intervals, said increments being equal to the length of said second zone whereby said thin layer of said solidified metal formed in said second zone is advanced progressively into said third zone and the molten metal advancing from said first zone follows the advance of said thin layer to progressively fill said second zone immediately behind said advancing thin layer and to thereby progressively form a new thin solidified layer coextensively of said second zone cavity surface, said intervals being of sufficient duration to permit the forward axial end of said newly formed thin layer to weld to the solidified metal in said third zone;

f. continuously monitoring the mold temperature in the vicinity of said juncture, said mold temperature normally fluctuating between a maximum temperature and a minimum temperature during said time interval;

g. stopping the advance of said rod for a fixed predetermined dwell period when said mold temperature falls below a predetermined temperature, said predetermined temperature being below said minimum temperature, which indicates that said newly formed thin layer has failed to weld to the solidified metal in said third zone, said dwell period being longer than said fixed time intervals, to permit said layer, which previously failed to weld, to weld to the solidified metal in said third zone, and

h. resuming the advance of said rod at the completion of said dwell period in said fixed predetermined increments at said fixed predetermined time intervals.

3. The method of claim 2 wherein said predetermined temperature is about 15° to 45° F below said minimum temperature.

4. A method of continuously casting a continuous rod comprising the steps of:

a. continuously introducing molten metal into the inlet end of the cavity of an open-ended continuous casting mold;

b. said mold including a first zone adjacent said inlet end having a relatively low heat transfer capacity, a second zone immediately adjacent said first zone having a relatively high heat transfer capacity, and a third zone adjacent said second zone terminating in an open outlet end;

c. advancing said molten metal into said first zone, the heat transfer characteristics of said first zone being operative to substantially prevent any metal solidification therein;

d. advancing said molten metal into said second zone, the high heat transfer characteristics of said second zone being operative to cause solidification of a thin layer of said metal at first immediately at the juncture of said first and second zone and then progressively in the direction of said third zone whereby a thin layer of said molten metal is formed coextensively of said second zone; and

e. advancing said rod continuously but in fixed increments of 0.1 to 1.5 times the diameter of the rod being cast at fixed cycle time intervals of about 0.15 to 1.1 seconds, said increments being equal to the length of said second zone whereby said thin layer of said solidified metal formed in said second zone is advanced progressively into said third zone and the molten metal advancing from said first zone follows the advance of said thin layer to progressively fill said second zone immediately behind said advancing thin layer and to thereby progressively form a new thin solidified layer coextensively of said second zone cavity surface, said rod being at rest for a time of 33 percent to 65 percent of said cycle time interval to permit the forward axial end of said newly formed thin layer to weld to the solidified metal in said third zone;

f. continuously monitoring the change in mold temperature in a region between the beginning of said first zone and the beginning of said third zone, said mold temperature normally fluctuating between a maximum temperature and a minimum temperature during said time interval;

g. stopping the advance of said rod for a fixed predetermined dwell period of about 2 to 10 seconds when said mold temperature falls below said minimum temperature which indicates that said newly formed thin layer has failed to weld to the solidified metal in said third zone to permit said layer, which previously failed to weld, to weld to the solidified metal in said third zone, and

h. resuming the advance of said rod at the completion of said dwell period in said fixed predetermined increments at said fixed predetermined time intervals.

5. The method of claim 4 wherein said metal is a ferrous metal containing less than 2percent by weight carbon.

6. Apparatus for continuous casting of a metal ingot comprising, in combination, an open-ended mold having an inlet end and an outlet end and a molten metal reservoir associated with said inlet end in sealed fluid flow relationship,

said mold including a first portion, including said inlet end having a relatively low heat transfer capacity disposed adjacent said reservoir, a second portion adjacent said first portion having a relatively high heat transfer capacity, and a third portion adjacent said second portion,

the heat transfer capacities of said first portion and said second portion being related so that molten metal flowing through said mold is maintained in a substantially completely molten state within said

first mold portion and the high heat transfer capacity of said second portion is operative to form at least a skin layer of solidified metal on the surface thereof beginning immediately at the juncture of said first portion and said second portion,

temperature sensing means located between the beginning of said first portion and the beginning of said third portion to sense normal mold temperature fluctuations occurring during casting,

means for advancing said ingot formed in said mold intermittently in predetermined increments and at predetermined time intervals, and

means responsive to said temperature fluctuations to stop said advancing means for a fixed predetermined dwell period when said mold temperature falls below the minimum temperature of said fluctuations and to restart said advancing means at the completion of said dwell period.

7. Apparatus for continuous casting of metal ingot comprising, in combination, an open-ended mold having an inlet end and an outlet end and a molten metal reservoir associated with said inlet end in sealed fluid flow relationship,

said mold including a first portion, including said inlet end having a relatively low heat transfer capacity disposed adjacent said reservoir, a second portion adjacent said first portion having a relatively high heat transfer capacity, and a third portion adjacent said second portion,

the heat transfer capacities of said first portion and said second portion being related so that molten metal flowing through said mold is maintained in a substantially completely molten state within said first mold portion and the high heat transfer capacity of said second portion is operative to form at least a skin layer of solidified metal on the surface thereof beginning immediately at the juncture of said first portion and said second portion,

a thermocouple having its sensing element in close proximity to said juncture to sense normal mold temperature fluctuations occurring during casting,

means for advancing said ingot formed in said mold intermittently in predetermined increments and at predetermined time intervals, and

means responsive to said temperature fluctuations to stop said advancing means for a fixed predetermined dwell period when the mold temperature at said juncture falls below a predetermined temperature, said predetermined temperature being below the minimum temperature of said fluctuations, and to restart said advancing means at the completion of said dwell period.

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