MOLD APPARATUS FOR CONTINUOUS CASTING

Inventors: Fred J. Webbere, Orchard Lake; Robert G. Williams, Birmingham, both of Mich.

Assignee: General Motors Corporation, Detroit, Mich.

Filed: Sept. 27, 1971

Appl. No.: 184,297

Related U.S. Application Data


References Cited

UNITED STATES PATENTS
3,212,142 10/1965 Moritz......................164/89
3,329,200 7/1967 Craig..................................164/89 X
3,344,846 10/1967 Rossing.....................164/281
3,388,737 6/1968 Buckwalter et al..................164/283
3,450,188 6/1969 Vallak et al....................164/82
3,455,369 7/1969 Craig..........................164/281 X
3,460,609 8/1969 Olsson.......................164/281
3,598,173 8/1971 Dore et al....................164/281 X

Primary Examiner—J. Spencer Overholser
Assistant Examiner—John E. Roethel
Attorney—Sidney Carter et al.

ABSTRACT

Apparatus for continuous casting including an open-ended mold with a first portion adjacent the inlet end having a low heat transfer capacity where no significant solidification of metal takes place, a second portion adjacent the first portion adapted to effect initial skin layer solidification and a third portion adjacent the second portion where progressive solidification is accomplished to form solid bar stock.

6 Claims, 8 Drawing Figures
MOLD APPARATUS FOR CONTINUOUS CASTING

This application is a continuation-in-part of the United States patent application Ser. No. 827,747 filed May 26, 1969, now abandoned, and assigned to the assignee of the present invention.

This invention relates to the continuous casting of solid bar stock or billets, and more particularly to the continuous casting of solid bar stock formed of relatively high melting point metals which are unsaturated in carbon, such as steel.

In the common practice of the continuous casting of steel, the mold apparatus is usually of the vertical type including a vertically positioned open-ended mold, a tundish positioned above the mold and spaced therefrom and a teeming ladle positioned above the tundish. The molten metal is teemed by gravity into the tundish and thence directly into the mold. This arrangement offers the advantage that no molten metal is held in continuous contact with the mold wall inasmuch as the skin of solidified metal forms progressively at the metal mold interface and the rate of propagation of this skin is at least equal to the withdrawal rate of the casting from the bottom of the mold. This requires, of course, a mold material having good thermal conductivity and adequate cooling. In most current practice, the mold wall is made of a water cooled copper or high density graphite.

A further characteristic of this vertical arrangement is that the surface of the metal being poured into the mold is exposed so that a lubricating medium can be continuously added during the casting operation. Various lubricants such as rape-seed oil, mineral oil, and powdered graphite have been successfully used. Because a convex meniscus is developed at the point of contact of the molten metal with the mold wall, a lubricant may readily be distributed between the solidifying skin and the mold wall as the metal passes through the mold.

The vertical casting arrangement described above has achieved wide industrial application in casting steel billets and slabs of approximately eight square inches in cross-section and larger. However, for casting billets having a diameter of three inches or less, the teeming operation becomes a greater problem in control and the linear rate of extraction becomes high. In consequence, the surface quality and internal soundness of the casting is seriously impaired. As a result, under the present state of technology, the vertical casting method has not been successfully used to cast steel bars two inches or less in diameter.

Vertical casting is well adapted to casting relatively large slabs and billets on a high volume continuous basis but requires a substantial vertical plant space which well suits the operation of metal producers such as steel mills. However, in view of persistent efforts by steel users to achieve greater efficiency and economy by the utilization of scrap metals resulting from their operation, there is a great need for small compact casting units for converting scrap steel into relatively small diameter useable rods of about two inches or less in diameter, which may be conveniently installed in existing plant facilities.

It is an object of this invention to provide apparatus for continuously casting steel bars. It is another object of this invention to provide apparatus for continuously casting bars formed of relatively high temperature metals, such as steel, nickel based alloys and cobalt based alloys, having a melting temperature in excess of about 2,200°F and which are not saturated in carbon.

These and other objects are accomplished by the provision of a horizontally disposed open-ended mold associated with a molten metal holding vessel or furnace. The mold includes means providing a low heat transfer first zone immediately adjacent the holding vessel which is effective to contain and convey the molten metal therethrough without appreciable solidification and which is substantially chemically inert to the molten metal, means providing 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 means providing a third zone adjacent the second zone wherein the molten metal is further solidified to form a self-sustaining rod which may be progressively withdrawn from the mold by mechanical means. Means is provided 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. 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 the 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 again pulled, it will carry with it the newly formed segment into the third zone in a continuous rod solidification process.

A process which may be practiced by means of the apparatus of this invention is disclosed and claimed in the copending patent application Ser. No. 155,263 filed June 21, 1971 which is a continuation-in-part of the patent application Ser. No. 827,673 now abandoned.

Other objects and advantages of the invention will be apparent from the following description, reference being had to the drawings in 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;

FIGS. 3-5 are fragmentary cross-sectional views of the mold at various stages of the casting process;

FIG. 6 is a diagram showing internal dimensions of one embodiment of the mold;

FIG. 7 is a fragmentary cross-sectional view of the nozzle portion of the mold; and

FIG. 8 is another embodiment of the nozzle shown in FIG. 6.

Referring now to FIG. 1 of 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 supported
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 a suitable refractory material for containing molten metal, such as steel. The opening or channel 14 in the reservoir is formed in a frustoconical refractory body 18 cemented to the lining 16. The refractory reservoir may include heating means (not shown), such as an induction heating coil or a resistance heating element for maintaining the metal at a desired casting temperature.

The mold 12 is supported horizontally at its inlet end by means of a brick wall 20 constructed in abutment with the reservoir 16, a steel plate 22 attached to the brick wall and the flanged collar 26. The inlet end of the mold is held in fluid tight engagement with the channel member 18 and the reservoir by means of a refractory cement layer 28 and the collar 26 which abuts the shoulder 30 of the mold 12 and is bolted to the metal wall 22 whereby the collar 26 exerts axial pressure against the mold 12 in the direction of the reservoir 10 to thereby maintain the inlet end of the mold into sealing engagement with the cement layer 28 and the channel 18.

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 consists of a nozzle portion 32 preferably formed of boron nitride having relatively low heat transfer characteristics such that it will contain the molten metal therein without any appreciable solidification and a refractory ring 34, preferably formed of zirconia. The second portion 36 is positioned immediately adjacent the nozzle 20 and is formed of a material having relatively high heat transfer characteristics as, for example, a beryllium-copper alloy. The third portion 38 is disposed immediately adjacent the second portion 36 and is preferably provided with a graphite liner 40. A third portion preferably has somewhat lower heat transfer characteristics than the second portion 36 for reasons which will appear hereinafter.

An important feature of the mold structure resides in the shape of the nozzle 32 including the annular radially disposed shoulder 42 and the frustoconical axial surface 44 which mates with a corresponding frustoconical surface 46 on the second mold portion 36. Preferably, the angle of the frustoconical surfaces with the longitudinal axis of the mold is about five degrees for reasons to be hereinafter explained. The mold portion 36 receives a portion of the nozzle 32 with the frustoconical surface providing a snug fit and with the shoulder 42 engaging a radial surface of the mold portion 36 to accurately locate the nozzle 32 with respect to the mold portion 36. The annular ring 34 is in engagement with the nozzle 32 and is securely locked in place by a flanged ring 48 bolted to the mold housing portion 50. The ring 34 is preferably made of zirconia because of the expensive nature of boron nitride. However, if desired, the nozzle 32 and the ring 34 may be both formed of boron nitride.

The second mold portion 36 as well as a third mold portion 38 are both provided with coolant passages 52. The second mold portion is preferably formed of a beryllium-copper alloy because of its high heat transmission characteristics. As will be explained hereinafter, the molten metal contacts the surfaces of the second mold portion 36 only in a transient manner.

In the continuous casting of rods in the apparatus after the casting process has started and is in continuous operation, it is characterized basically by the molten metal passing from the reservoir 10 through three successive zones in the mold 12 corresponding more or less to the ring 34 and nozzle 32 as the first zone and the mold portions 36 and 38 as the second and third zones respectively. The molten metal is conveyed from the reservoir 10 through the first zone without significant solidification due to a sufficiently low heat transfer capacity of the ring 34 and nozzle 32 and without exposure to air. As the metal flows into the second zone, a thin skin layer of solidified metal is progressively formed along the length of the mold portion 36 due to the high heat transfer capacity thereof. This skin layer is then advanced as a segment or increment into the third zone or mold portion 38, wherein the molten metal is further solidified to form a self-sustaining rod 54 which is mechanically pulled out of the mold by suitable means such as the rollers 56. As the aforementioned skin layer 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 second skin layer is advanced into the third zone as the rod is pulled incrementally whereby a continuous rod is formed in a continuous but incremental process.

The following detailed explanation will make the nature of the apparatus and the casting process involved more clear. 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 into the mold through the ring 34 and the boron nitride nozzle 32 which constitutes the aforementioned first zone. Since boron nitride is a material of relatively low heat conductivity, and is not provided with any cooling means, the molten metal does not significantly solidify therein. The use of boron nitride for this purpose is also advantageous because the material has a high heat shock resistance; it is not wetted by the molten metal and it is relatively inert to the molten metal. Other materials with similar properties may be used in place of boron nitride.

As soon as the molten metal enters the second zone or the mold portion 36, an initial circumferential annulus solidifies against the mold surface portion 36 at the interface 33 of the nozzle element 32 and the mold portion 36 as is shown in FIG. 2. This occurs because the mold portion 36 is formed of a material of relatively high heat conductivity and is cooled by means of suitable coolant, such as water, circulating in the coolant passages 52 to provide a high heat transfer capacity whereby a film or skin of metal solidifies on the mold 36 the instant contact is made. It is essential in the casting process of this invention that solidification begin immediately at the interface 33 of the nozzle 32 and the mold portion 36. This is accomplished by the difference in heat transfer capacity of the nozzle 32 and the mold portion 36. As the molten metal advances into the second zone, a solidified skin layer 35 as shown in FIG. 3 forms progressively on the surfaces of the mold portion 36 in the downstream direction.
The skin layer 35 is then advanced as a segment into the third zone of the mold portion 38 of the mold wherein further solidification takes place to form the self-sustaining rod.

As the skin layer 35 begins to advance into the third zone, it must first break away or release from the nozzle 32 as shown at 37 of FIG. 4 to form a slight space between the skin 35 and the nozzle, shown in greatly exaggerated dimensions for purpose of illustration. This space is immediately filled with fresh molten metal flowing from the nozzle to initiate the formation of a new skin layer 39 (FIG. 5) at the interface 33 of the nozzle and the mold portion 36 and to closely follow the advancing skin layer 35 and to progressively form the new skin layer 39. After the layer 35 has reached its full increment of movement, it is permitted to remain stationary for a time sufficient to permit the new layer 39 to weld to the layer 35 as shown at 29 of FIG. 5. It is essential to the successful operation of the process that the skin layer 35 part cleanly from the nozzle 32 and that it remain stationary in its advanced position for a time sufficient to permit the new skin layer 39 to weld thereto. If either of these process steps is not performed properly, a break will occur in the successively formed skin layers causing molten metal to break out and to prevent proper rod solidification. The use of boron nitride for forming at least that portion of the nozzle adjacent the mold portion 36 is highly advantageous because the skin layer does not adhere to the boron nitride to thereby result in a clean release.

The above description of the process and apparatus is applicable to normal operational conditions and after the molding process has commenced. The process is commences by inserting a rod (not shown) into the exit end of the mold until it reaches approximately to the junction of the second and third zones. The initial molten metal flowing into the mold is permitted to flow against the rod end and to bond thereto. This bar is then pulled out incrementally as described above to establish the casting process.

The axial length of the skin layer 35 has practical limitation and we have found that in one particular apparatus it should preferably be from 0.1 to 1.5 times the diameter of the inside diameter of the mold portion 36. If the incremental pull or stroke is shorter, casting rate is sacrificed and nozzle erosion is excessive. If the stroke is longer, porosity of the casting will result. By way of specific example, a bar about 1 and 1/2 inches in diameter is successfully cast with the segment 35 about 1 inch in length.

As the skin layer 35 moves into zone three or mold portion 38, a progressively greater radial thickness of the molten metal solidifies therein as the bar is advanced to eventually form a self-sustaining bar which is pulled mechanically from the zone three as is shown in FIG. 3.

It will be observed from the above description that the molten metal contacts only the first zone portion of the mold to any substantial extent wherein it is not contaminated because of the inert character of the boron nitride. The molten metal contacts the primary solidification zone two portion of the mold for only an extremely transitory period of time since solidification occurs at virtually the instant the molten metal contacts the mold 36 portion. When the metal has advanced into the third zone, the solidified layer is of substantial thickness and is relatively cool so that no significant graphite diffusion occurs in consequence of the graphite liner provided in the third zone of the mold. 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 in the surface of the rod during solidification thereof. There is no need for fluid lubricants such as rapeseed oil which is commonly used in vertical continuous casting.

In accordance with this invention, round bar stock may be cast in sizes of from about 1 to 3 inches in diameter with a roundness variation of 2½ percent or less, expressed in terms of the difference in mean and minor diameters of the rod. Both the roundness and the mean diameter variations are markedly less than the commercial limits for hot rolled bar.

In casting stock one and one-half inches in diameter, we have successfully used segment lengths of 1 inch and 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 in the dwell time of from about 0.1 to about 0.36 seconds with the proportion of the dwell time to the cycle time being between about 33 percent to 65 percent and with the cycle time accordingly being about 0.15 to 1.1 seconds.

It will be observed from FIG. 2 that the zone one consists of more or less the refractory ring 34 and the nozzle 32. Zone two is generally defined by the mold portion 36 and zone three includes the balance of the mold. However, it should be recognized that the three defined zones are process concepts and are not necessarily coextensive with these mold portions. In particular, it should be noted that the zone two of the process is located entirely within the confines of the mold portion 36 extending from the interface 33 for the length of the segment 35 or the pull stroke. It is important that this segment solidifies initially entirely within the mold portion 36. Depending upon the length of the segment employed, it is to be expected that in a given mold design, the zone three will actually commence within the mold portion 36. In practicing the process of this invention, it is preferable that the inside diameter of the mold vary in accordance with the progressive solidification of the rod so that the mold surfaces are in close contact with the solidifying and shrinking rod to enhance roundness of the rod and to effect optimum heat transfer between the mold and the solidifying rod.

FIG. 6 is a diagrammatic representation showing a preferred design. The zone one, which includes the refractory ring 34 and the nozzle 32, is shown to be of constant diameter although this is not necessary since the metal exists in this zone only in molten form. It has been found advantageous that the mold portion 36 have a gradually increasing diameter over its length in the direction of the outlet end of the mold. As shown in FIG. 6, a 5-minute taper with the longitudinal axis of the mold wall produces desired results in the case where the length of the segment 35 is about 1 inch. The reason for the zone two portion of the mold being...
tapered outwardly is that it appears to prevent molten metal breakouts through the solidified skin. The mold in the third portion 38 is provided with the graphite liner 40 and is gradually decreased in diameter in an amount of 4 and ½ minutes to the longitudinal axis over the first 3-inch portion. For casting a 1-7/16 inch diameter bar this mold portion continues to decrease in diameter in increments of 2 to 4 inches by about two-thousandths of an inch, as shown in FIG. 6. The purpose of this taper is to compensate for the fact that the rod is undergoing substantial solidification as may be seen from inspection of FIG. 3. Then, for a final 26 inch interval, the diameter of the mold remains constant. The zone three portion of the mold tapers in accordance with the increased solidification and decreasing temperature to compensate for shrinkage. The effect is to maintain roundness and good heat transmission from the bar to the mold. In the last 26 inch portion of zone three, referred to above, the diameter is preferably maintained constant to slow down heat transfer from the bar to the mold. This is desirable to minimize the reheating of the bar surface and, hence, cracking thereof after the bar has emerged from the mold and to reduce frictional resistance to the movement of the bar.

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 35 is well formed when it is transferred to the graphite lined zone three so that appreciable carbon diffusion occurs during the casting process.

An important feature of this invention resides in the shape of the nozzle 32 and in particular its conical outer configuration. Referring to FIG. 7, there is shown a detailed view of the nozzle 32, the backup ring 34, and the mold portion 36. We have demonstrated conclusively that by forming the nozzle with an outer surface portion 44 being a conical section which fits into a similar conical seat 46 in the mold portion 36, a great advantage is gained by retaining the desired heat balance and preventing the forward movement of the nozzle 32 in the event that damage occurs due to thermal or mechanical stress during the casting operation whereby the length of the segment 35 remains constant. We have found that the angle θ between the conical surfaces and the longitudinal axis of the nozzle should be between about 3° and 30°. An angle θ of less than 3° does not provide sufficient restraint to the forward movement of the nozzle under all operating conditions and an angle greater than 30° may expose excessive back draft on the inside surface of the mold should the leading edge of the nozzle become worn away as the casting proceeds.

The nozzle configuration may be that of a simple truncated cone 58 as shown in FIG. 8 in which case the nozzle is held in intimate contact with the mold surface 60 by a shrink fit or by applying a longitudinal clamping force in the form of the ring 62. As shown in FIG. 7, a flange 43 may be provided on the rearward portion of the nozzle to take up excessive forces resulting from thermal expansion of the mold during service.

We have also found it desirable to place certain limitations on dimensions of the nozzle relating to the inside diameter A of the mold portion 36 as shown in FIG. 7. For castings bars in the range of 1 to 3 inches in diameter, the inside diameter B of the nozzle is preferably greater than 50 percent but not more than 80 percent of the inside diameter A of the mold 36 portion at the junction with the nozzle. The longitudinal length C of the conical section of the nozzle extending into the mold portion 36 is preferably not less than 10 percent and not more than 30 percent of the inside diameter A of the mold.

As above indicated, the method of this invention has particular utility in casting metals which have a relatively high melting temperature of about 2,200° F. 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 metals which may be cast in accordance with this invention are SAE 4118 steel containing, by weight, 0.18 to 0.23 percent carbon, 0.7 to 0.9 percent manganese, 0.4 to 0.6 percent chromium, 0.08 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 to 0.65 percent carbon, 0.75 to 1.0 percent manganese, 0.2 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 to 1.1 percent carbon 0.25 to 0.45 percent manganese, 1.3 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 based alloy of this type is Inconel 610 consisting of 68.5 percent nickel, 0.2 carbon, 1.0 percent manganese, 9.0 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 to 20 percent chromium, 10 to 12 percent cobalt, 9 to 10.5 percent molybdenum, 5 percent iron, 0.09 to 0.12 percent carbon, 0.5 percent silicon, 0.1 percent manganese, 3 to 3.3 percent titanium, 1.4 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 to 0.15 percent carbon, 1.0 to 2.0 percent manganese, 19 to 21 percent chromium, 9 to 11 percent nickel, 14 to 16 percent tungsten, 3 percent iron, 1 percent silicon, and the balance essentially cobalt.

As previously stated, the mold portion 36 may suitably be formed of a beryllium-copper alloy and in particular an alloy consisting of 97 percent copper, 0.5 percent beryllium, and 2.5 percent cobalt, available commercially under the name Berilco 10A, a product of the Beryllium Company of America. This alloy has a suitably high thermal conductivity and high yield strength.

Although the apparatus has been described specifically in terms of a horizontal casting process for round bar stock, it will be apparent to those skilled in the art that the mold apparatus may readily be adapted for ver-
tical casting and for casting bar stock of various shapes including ovals, hexagonals, rectangles and the like.

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.

It is claimed:

1. Apparatus for the continuous casting of a metal bar comprising, in combination, a stationary 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 and including the exit of said mold, said first portion having a peripheral internal dimension which is less than the peripheral internal dimension of said second portion whereby the juncture of said first portion and said second portion within the mold cavity is defined by a radially extending wall of said first portion and an axial wall of 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 a thin layer of solidified metal on the entire surface thereof beginning immediately at said juncture, the section of said first portion immediately adjacent said second portion being formed of a material which is substantially inert to said molten metal and is non-adherent to said skin layer, and means for advancing said bar formed in said stationary mold intermittently in predetermined segments and at predetermined time intervals.

2. The apparatus of claim 1 wherein the internal peripheral dimension of said third portion progressively decreases in a downstream direction for at least a portion thereof substantially in proportion to the progressive decrease in the peripheral dimension of the bar due to shrinkage of said bar solidified in said mold whereby the mold is in snug contact with said bar whereby the transmission of heat from said solidified rod to said mold is promoted.

3. The apparatus of claim 1 wherein said inlet end of said first portion is formed of boron nitride.

4. Apparatus for the continuous casting of a cylindrical metal bar 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 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, said first portion including a refractory nozzle adjacent said second portion substantially inert to said metal in molten form having a lesser internal diameter than said second portion and having a frustoconical outer surface on at least a portion thereof adjacent said second mold portion in snug engagement with a corresponding frustoconical surface of said second mold portion with the juncture of said nozzle and said second mold portion within the casting cavity being defined by radial nozzle surfaces and axial second mold portion surfaces, the angle of said frustoconical surfaces to the longitudinal axis of said mold being about 3° to 30°, the heat transfer capacity of said first portion and said second portion being such that molten metal flowing through said mold is maintained in a substantially molten condition within said first mold portion and the high heat transfer capacity of said second portion being operative to form a thin layer of solidified metal in the surface thereof beginning immediately at said juncture, and means for advancing said bar formed in said third portion intermittently in predetermined segments and at predetermined time intervals.

5. Apparatus for the continuous casting of a cylindrical metal bar comprising, in combination, a horizontally disposed, open-ended mold having a cavity therethrough and 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 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, said first portion including a boron nitride nozzle adjacent said second portion having a lesser internal diameter than said second portion and having a frustoconical outer surface on at least a portion thereof adjacent said second mold portion in snug engagement with a corresponding frustoconical surface of said second mold portion with the juncture of said nozzle and said second mold portion within the cavity being defined by radially extending nozzle surfaces and axial second mold portion surfaces, the angle of said frustoconical surfaces to the longitudinal axis of said mold being about 3° to 30°, the heat transfer capacity of said first portion and said second portion being such that molten metal flowing through the mold is maintained in a substantially molten condition within said first mold portion and the high heat transfer capacity of said second portion being operative to form at least the skin of solidified metal in the surface thereof beginning immediately at said juncture, the internal diameter of said third portion having a progressively decreasing diameter in a downstream direction for at least a portion thereof substantially in proportion to the progressively decreasing diameter due to shrinkage of the bar solidified in said mold whereby the mold is in snug contact with said ingot to promote roundness thereof and whereby the transmission of heat from said solidified bar to said mold is promoted, and
means for advancing said bar formed in said third portion intermittently in predetermined segments and at predetermined time intervals.

6. The apparatus of claim 4 wherein the internal diameter of said second portion is from about one to about three inches, the internal diameter of said nozzle is from about 50 percent to 80 percent of the internal diameter of said second portion and the axial length of said frustoconical surface is about 10 percent to 30 percent of the internal diameter of said second portion.

* * * * *