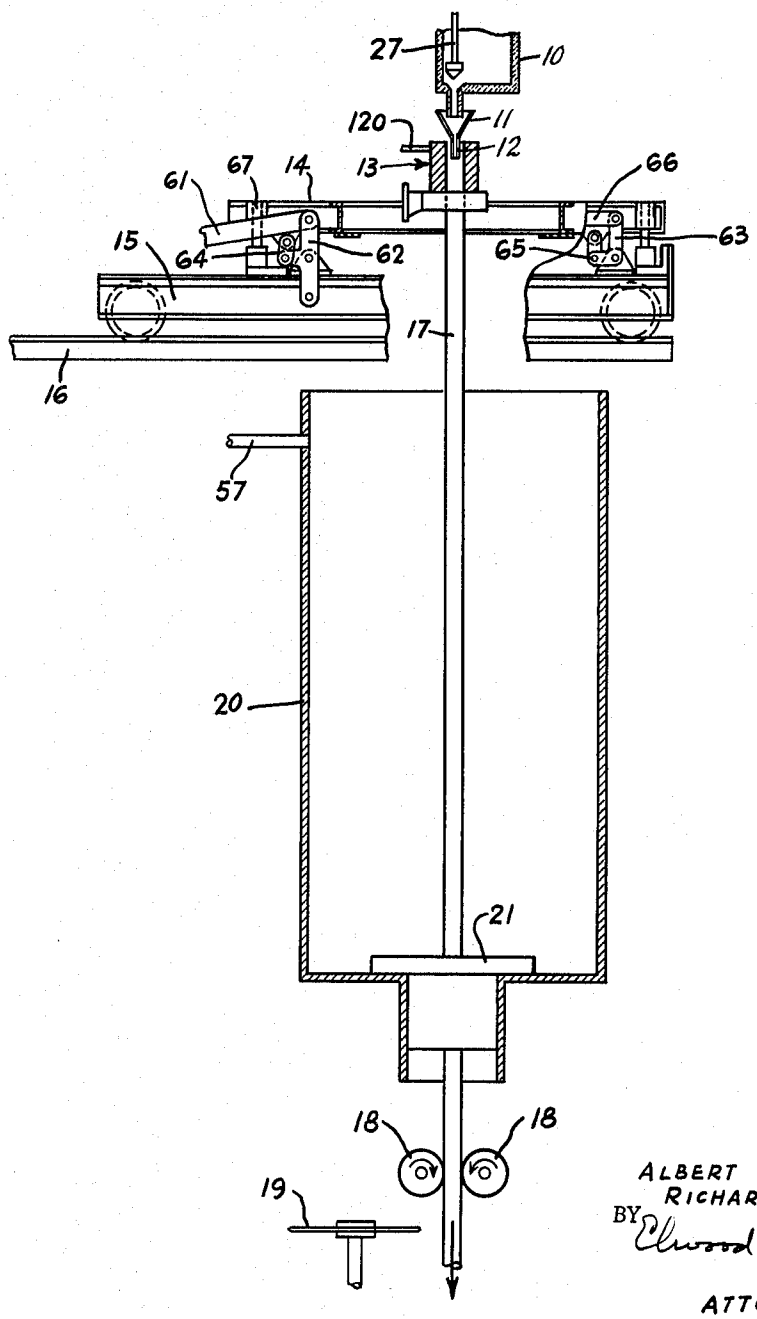
April 12, 1966 A. J. PHILLIPS ETAL 3,245,126

INTRODUCING HYDROGEN GAS TO THE MENISCUS FOR CONTINUOUSLY CASTING STEEL

Filed May 13, 1963 3 Sheets-Sheet 1

FIG. 1.



INVENTORS
ALBERT J. PHILLIPS
RICHARD BAIER
BY Elwood J. Schaffer
ATTORNEY

April 12, 1966 A. J. PHILLIPS ETAL 3,245,126

INTRODUCING HYDROGEN GAS TO THE MENISCUS FOR CONTINUOUSLY CASTING STEEL

Filed May 13, 1963 3 Sheets-Sheet 2

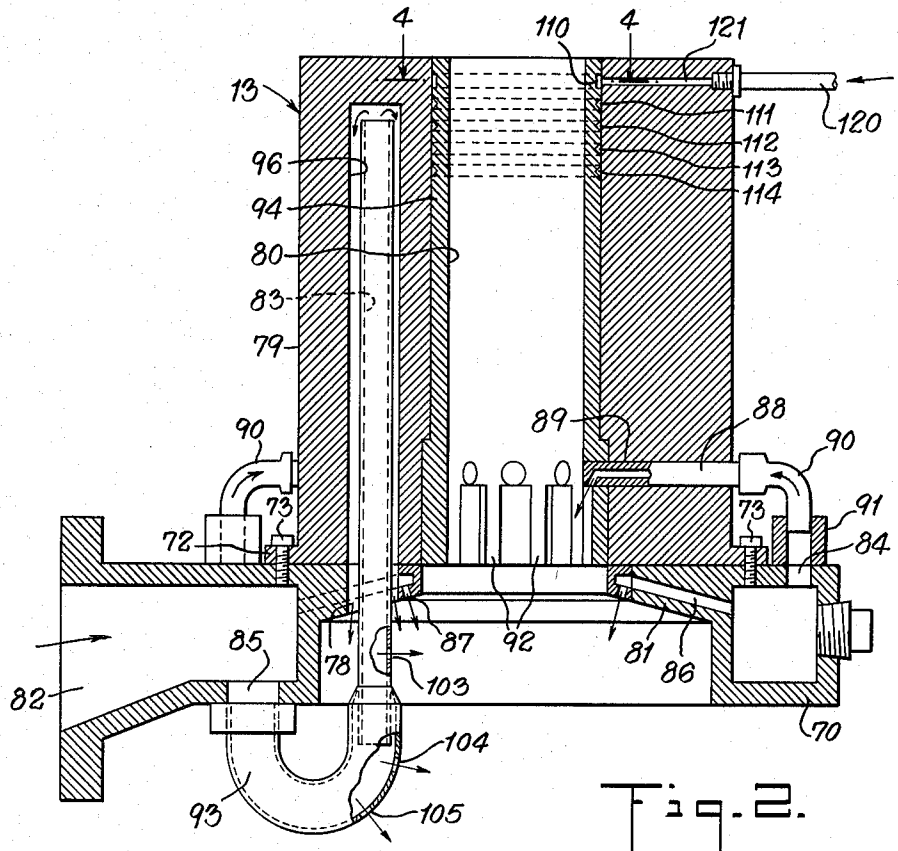


Fig. 2.

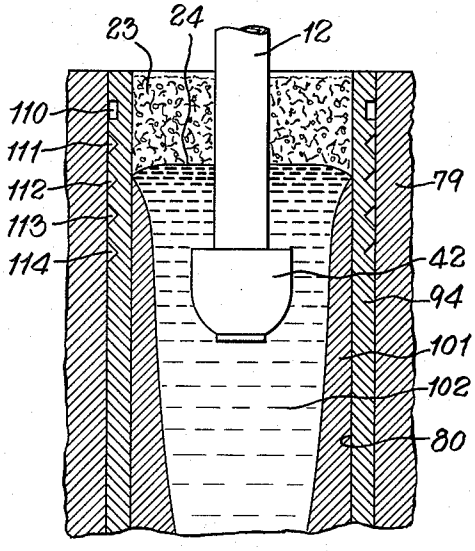


Fig. 3.

INVENTORS
ALBERT J. PHILLIPS
RICHARD BAIER
BY Edmund J. Schaffer
ATTORNEY

April 12, 1966 A. J. PHILLIPS ETAL 3,245,126

INTRODUCING HYDROGEN GAS TO THE MENISCUS FOR CONTINUOUSLY CASTING STEEL

Filed May 13, 1963 3 Sheets-Sheet 3

FIG. 6

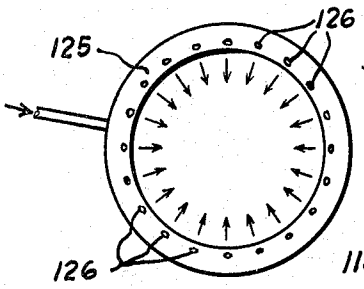


FIG. 4.

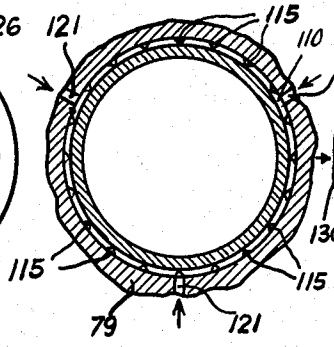
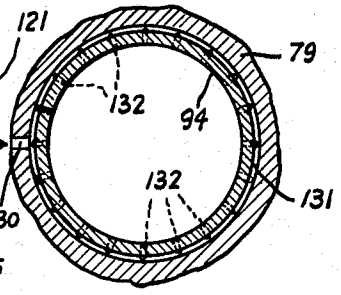


FIG. 8.



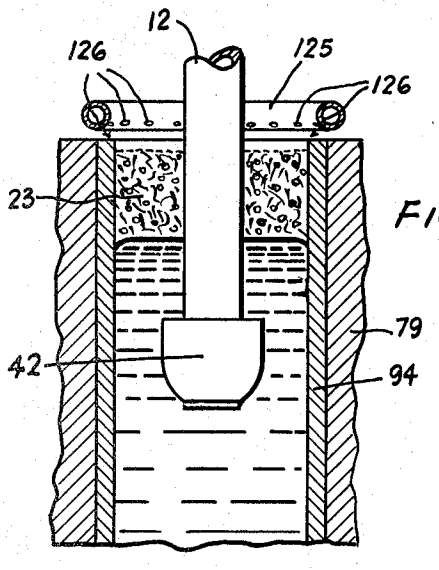


FIG. 5.

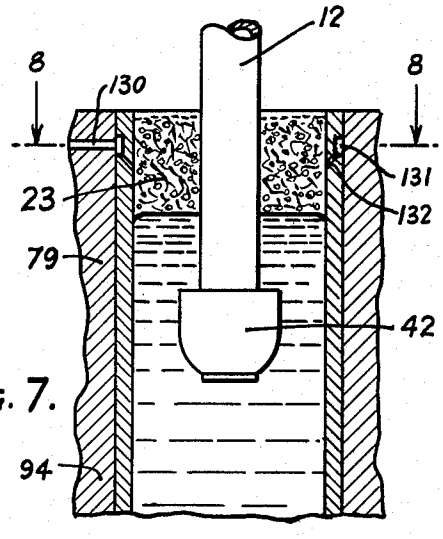


FIG. 7.

INVENTORS
ALBERT J. PHILLIPS
RICHARD BAIER
BY Elwood J. Schaffer
ATTORNEY

United States Patent Office 3,245,126 Patented Apr. 12, 1966

3,245,126

INTRODUCING HYDROGEN GAS TO THE MENISCUS FOR CONTINUOUSLY CASTING STEEL

Albert J. Phillips, Plainfield, and Richard Baier, New Brunswick, N.J., assignors to American Smelting and Refining Company, New York, N.Y., a corporation of New Jersey

Filed May 13, 1963, Ser. No. 279,871
The portion of the term of the patent subsequent to May 14, 1980, has been disclaimed
8 Claims. (Cl. 22—200.1)

This application is a continuation-in-part of our copending application Serial Number 894, filed January 6, 1960, now Patent No. 3,089,209, entitled "Method for Continuous Casting of Metal" which copending application is made a part hereof and is incorporated herein by reference.

This invention relates to a process for the continuously casting of steel. More particularly, it relates to a process for continuously casting steel in a graphite mold.

Broadly in one aspect, the invention comprehends, in a method for continuously casting steel in which molten steel is introduced into one end of an open ended mold and cast metal is withdrawn from the other end of the mold, the improvement which comprises introducing a gas containing more than about 30% by volume of hydrogen to that area of the mold wall at which freezing of the introduced molten metal commences during the casting procedure. Preferably in practicing the invention, the hydrogen gas contains more than about 40% by volume of hydrogen. More preferably, the gas contains at least 75% by volume of hydrogen and most preferably is a substantially pure hydrogen gas such as is available commercially. Preferably also, the instant hydrogen gas is continuously introduced to said area of the mold.

The invention is especially useful in continuous casting steel procedures in which the molten steel is introduced into the chilled zone of an open ended, vertically disposed mold and the rate of introduction of the molten metal with respect to the rate of withdrawal of the cast metal is such as to maintain a free mold wall surface in the chill zone of the mold, i.e., a portion of the chill zone mold wall extends above the level of the metal in the mold. In such casting procedures, the molten metal commences to freeze at the meniscus of the metal in the mold; and in accordance with the invention, the hydrogen gas is introduced to that area of the mold wall in which the meniscus of the molten metal is located.

An important advantage of the invention is that it affords a method by which steel can be successfully continuously cast either or both for longer periods and at higher speeds than are possible in the absence of the invention. Moreover, the castings produced by the process possess uniformly excellent surface characteristics and this is a further advantage of the process. These and other advantages of the invention will become apparent from the following description thereof.

In practicing the invention, such introduction of such hydrogen gas may be accomplished in any appropriate manner. For example, the gas may be introduced to said area by delivering it as such thereto from an outside source or by releasing such gas at said area in any other suitable manner from any suitable source, for example, by decomposing in situ a suitable hydrogen producing gas. For best results in casting procedures in which the meniscus of the metal is located in the chill zone of the mold, introduction of the hydrogen gas is accomplished by conducting the hydrogen gas as such from an outside source to the mold adjacent the mold wall area where the incoming molten metal contacts the chilled wall of

the mold. For example, the hydrogen gas may be introduced into the mold cavity above the level of the metal in the mold from a perforated ring disposed over the mold cavity above the metal in the mold or from ports in the mold wall above and adjacent to the metal level intended to be maintained in the mold during the casting procedure; or by diffusion through the mold wall where the latter is fabricated of a sufficiently porous material such as, for example, graphite. Most efficient use of the hydrogen is made when it is introduced by diffusion through the mold wall.

In accordance with another important feature of the invention, the instant hydrogen gas is introduced to said mold wall area in controlled amounts. Such control is effected most readily and advantageously by regulating the amount of introduced gas to obtain a surface of a desired character on the casting as is indicated on the latter as it emerges from the mold. In general, with the introduction of increased amounts of the hydrogen gas, the appearance of an irregular pattern of irregularities on the surface of the emerging casting is indicative that introduction of the hydrogen gas is approaching undesirably excessive amounts and an irregular pattern of irregularities on a major portion of the surface of the emerging casting indicates an undesirable excess of the introduced gas. An irregular pattern of irregularities having the appearance of cold shuts, folds or bleed-through which are perceptible to the touch are typical of such an irregular pattern on the surface of the casting. On the other hand, with the introduction of decreased amounts of the hydrogen gas, the occurrence of small visible surface scuffs on the emerging casting is indicative that the introduction of the hydrogen gas is approaching undesirably small amounts and severe sticking which causes deep tears in the casting indicates the use of an undesirably small amount of gas.

By way of further illustration of the invention, for example in the continuous casting of steel against a graphite surface in a vertical mold by a procedure in which during the casting the meniscus of the metal was located in the chill section of the mold, reciprocation of the meniscus with respect to the mold wall is employed and a protective layer of solid particulate cover material is maintained on top of the metal in the mold, it will be found that when the introduction of the instant hydrogen gas is adjusted to provide a regular uniformly rippled surface on the emerging casting and thereafter increased amounts of the gas are introduced, the ripple becomes more and more coarse until a point is reached when a further increase in the amount of the introduced gas causes the regular rippled surface pattern to begin to deteriorate into an irregular pattern in that the ripple begins to become scattered or a crazy quilt pattern of surface imperfections having the appearance of cold shuts or folds at disorganized angles or bleed-through begins to appear on the casting. Thereafter such deterioration of the surface increases until a major portion of the surface of the emerging casting is involved; and, if when this occurs, the rate of introduction of the gas is quickly reduced, the possibility of rupture of the casting in the mold is avoided. On the other hand, with introduction of decreasing amount of the gas, it will be found that the ripples gradually become more and more faint until a point is reached at which the surface of the casting becomes relatively smooth after which small visible surface scuffs begin gradually to appear on the emerging casting followed by the gradual appearance of small visible surface tears thereon due to slight sticking of the casting in the mold. Thereafter, sticking may become so severe that rupture of the casting in the mold may occur. However, if the rate of introduced of the gas is increased after the smooth surface or the small visible surface scuffs or the

small visible surface tears appear on the casting surface, the possibility of rupture of the casting may be avoided.

In accordance with the foregoing, a further feature of the invention comprises controlling the introduction of the instant hydrogen gas to said mold wall area to a rate below that at which an irregular pattern of irregularities occurs on a major portion of the steel casting and above that at which rupture of the casting occurs due to deep tearing. Preferably, the introduction of the gas is controlled to a rate below that at which said irregular pattern begins to occur and above that at which deep tears, more preferably above that rate at which small visible surface tears, occur on the surface of the emerging casting, and still more preferably above that rate at which small visible surface scuffs occur thereon and most preferably above that rate at which the surface of the casting is relatively smooth. In the best mode of operating, the introduction of the gas is regulated to obtain regular uniformly spaced ripples on the emerging surface of the casting. For best results the gas is introduced at a rate sufficient to maintain the regular uniformly spaced ripples on the emerging casting surface during the entire casting procedure.

The invention is most advantageously used in casting procedures employing a vertical mold in which the level of the molten metal in the mold is maintained below the top of the chilled zone of the mold and the level of the meniscus of the molten metal in the chill zone is moved in vertical reciprocal relative movement with respect to the mold wall during the casting procedure. Such reciprocal movement of the meniscus may be obtained by any appropriate relative movement between the mold wall and the metal therein; for example, by horizontal reciprocation of the sides of a segmented mold, or, more preferably, by vertical reciprocation of the mold. In the best mode of operating with such casting procedures, the introduction of the instant gas to the mold wall area upon which the meniscus moves is regulated to obtain regular, uniformly spaced ripples on the surface of the emerging casting.

Dilution of the hydrogen gas at the mold wall area where the introduced molten metal begins to freeze can readily occur in casting procedures employing a vertical mold in which the level of the molten metal in the mold is maintained below the top of the chill zone of the mold. With such procedures, it is highly desirable to introduce the instant gas to the metal meniscus beneath a protective cover which prevents or reduces the dilution which would otherwise occur. The cover may be disposed on or above the metal in the mold. Preferably the cover is a layer of solid particulate material floating on the molten metal in the mold. Where a cover of the latter type is employed, sufficient of such cover material is added from time to time during the casting procedure to provide and maintain on the molten metal a protective cover of substantial thickness which generally is not less than about one-eighth inches thick. Preferably such particulate cover material is employed in amounts sufficient to maintain a protective blanket about one-half to two inches thick floating on top of the molten metal. Any appropriate material may be used for the cover. Thus the cover material may be a material which is substantially inert to the steel or it may be a carbonaceous material such as, for example, flake graphite, lamp black, etc. Where a carbonaceous cover material is employed, it preferably is composed of fine bead-like carbon particles obtained by flash distillation of a liquid petroleum material such as still bottoms and known as Micronex beads. Where a solid particulate cover material is employed, it is possible to employ the cover as a means for the introduction of the instant hydrogen gas to the metal meniscus in the mold. For example, where the absorption characteristics of the cover material are sufficient, such material may be suitably treated outside the mold, as for example, with an appropriate gas, to releasably provide therein the instant hydrogen gas, and then adding the cover material to the mold and removing it therefrom at a sufficient rate to release therein, under the temperature conditions therein obtaining, the instant hydrogen gas in sufficient quantities to provide the instant results. However, such a procedure is cumbersome and is not preferred.

In practicing the invention, the casting speed employed is affected by the cross-sectional shape and size of the casting to be produced, the presence or absence of tapers in the chill zone of the mold, and the rate of reciprocation of the metal meniscus or freezing metal in the chill zones as well as by the heat conductivity of the steel being cast and the overall heat extractive capacity of the mold. In general, the reciprocation rate is increased as the casting speed (i.e., the net rate of withdrawal of the casting from the mold) is increased and vice versa. The presence of a converging taper on the mold wall defining the mold cavity increases the heat extractive capacity of the mold and permits the use of higher casting speeds than would otherwise be possible. On the other hand, the casting speed is decreased as the least cross-sectional linear dimension of the casting is increased.

The invention may be practiced in continuously casting steel of any composition in any conventional continuous casting mold fabricated of any conventional material. Practice of the invention enables the casting procedure to be conducted continuously for a longer period than is possible in the absence of the invention, even when exceptionally high casting speeds are employed. The invention is most useful in casting steel in a mold in which the metal is cast against a graphite surface, especially a tapered graphite surface, by a procedure in which a free mold wall surface is maintained in the chill zone of the mold, especially when employing a cover of a particulate solid material on the surface of the metal in the mold during the casting procedure, and particularly when the meniscus of the metal in the mold during such procedure is moved in a reciprocal movement with respect to the mold wall during the casting of the metal in the mold.

In practicing the invention, it is advantageous to maintain the temperature of the molten metal introduced into the mold as close as practicable to the freezing point of the metal inasmuch as excess superheat, to the extent that it exits in the molten metal, increases the heat extractive load on the mold and results in lower casting speeds than would otherwise be possible in a given mold. For this purpose, in general, the temperature of the molten metal introduced into the mold is preferably less than about 200° F. above the freezing point of the metal.

So far as we are aware no other gas affords the benefits provided by the present gas and the instant use of a hydrogen gas containing more than about 30% by volume of hydrogen is unique and critically important in obtaining our results.

The reason or reasons for the success of the present process are not understood. Normally, in continuously casting metals such as steel, the presence or use of hydrogen is avoided at all costs because of its known detrimental effect on the physical properties of the metal. In the instant process, however, the hydrogen has the beneficial effects described herein. Moreover, so far as we are aware, the hydrogen has no detectable affect on the composition of the metal being cast. While we do not wish to be bound by any particular theory, it is possible that the hydrogen may affect surface tension at the involved mold wall area so as to result in the benefits obtained in practicing the invention.

The invention is further illustrated in the accompanying drawings. It should be understood, however, that the drawings and examples are given for purposes of illustration and the invention in its broader aspects is not limited thereto.

In the drawings:

FIG. 1 is a diagrammatic view in side elevation and partly in section of a casting system employing the preferred mode of introducing the instant hydrogen gas to the mold;

FIG. 2 is a diagrammatic elevation in section of the mold illustrated in FIG. 1;

FIG. 3 is a diagrammatic view of a portion of the mold shown in FIG. 1;

FIG. 4 is a view taken on line 4—4 of FIG. 2;

FIG. 5 is a diagrammatic elevation in section illustrating an alternative mode of introducing the instant hydrogen gas to the mold;

FIG. 6 is a view from the bottom of the ring shown in FIG. 5;

FIG. 7 is a diagrammatic elevation in section illustrating another alternative mode of introducing the instant gas to the mold;

FIG. 8 is a view taken on line 8—8 of FIG. 7.

Referring now to the drawings, FIG. 1 illustrates a casting system which is at present preferred for the continuous casting of steel. A melting furnace (not shown) supplies ladle 10 with the molten metal to be cast. The molten metal is poured from the ladle into funnel 11 from which it flows through pipe 12 into mold 13. The latter is mounted on platform 14 which in turn is mounted for vertical reciprocation on carriage 15. The casting 17 is withdrawn from the mold by a conventional roll drive mechanism 18 and is cut into desired lengths by a conventional cut-off mechanism, such as is illustrated by cut-off saw 19.

Before passing to roll drive mechanism 18, the casting 17 may be passed through chamber 20 which may be provided with a suitable sealing gasket 21. The carriage 15 may be movable horizontally on tracks 16 from over tank 20 to permit installation of molds of different size or shape or otherwise provide access to the mold. A stationary working platform (not shown) may be located on opposite sides of track 16 and at the same level on which workmen may walk during the casting procedure.

As shown in FIG. 1, mold 13 its supported by a frame 14 which is vertically oscillated by a reciprocating mechanism. A suitable prime mover (omitted for simplicity) is mounted on carriage 15, which reciprocates connecting rod 61. Rod 61 is pivoted to a series of bell crank levers 62 on one side of the frame 14. A series of bell crank levers 63 are pivoted to the carriage on the other side of frame 14. Line 64 and 65 pivotally connect ball crank levers 62 and 63 to oscillatory frame 14. A connecting rod 66 connects bell crank levers 62 and 63. A series of guide posts 67 are supported on carriage 15, and slidably engage guides on frame 14 to insure vertical reciprocation of the mold in a substantially vertical straight line. Any suitable means may be provided to vary stroke and frequency of vertical reciprocation of the mold. For example, to vary stroke, the drive motor may have a crank arm whose length is adjustable. To vary frequency, motor speed may be changed.

Mold 13, as shown in FIG. 2 may be a composite mold. Metal block 79 provided with removable graphite sleeve 94 is mounted on bottom annular manifold 70 by means of bottom ring 72 which is bolted to the manifold at 73. The manifold 70 rests on suitable cross pieces forming part of platform 14 reciprocatably mounted on carriage 15.

Sleeve 94 may be made of any suitable commercial graphite and is machined to the desired shape. The interior mold surface 80 may be machined to provide a taper which converges toward the bottom of the sleeve although the surface 80 may, if desired, be a true cylinder. Preferably, in order to obtain optimum heat transfer, the sleeve 94 is carefully fitted into block 79; the contacting surfaces being cylindrical and carefully machined so that solid-to-solid contact is obtained between sleeve and block without any fluid layer at the interface which will interfere with excellent heat transfer.

Preferably, in molds for casting round shapes—for example, billets which are circular in transverse cross section, sleeve 94 is made oversize with respect to the block 79 and is assembled into the latter by forcing it axially into the block. Preferably, also, the compression fit between the assembled sleeve and block is sufficiently severe to provide the solid-to-solid, fluid-free contact at operating temperatures. If desired, the sleeve 94 may be omitted and the block 79 made unitary with the molding surface 80 machined directly into the block; such a unitary structure being preferred in molds for casting shapes such as cakes which in transverse cross section are square or rectangular or for other multi-sided shapes.

The shape of manifold 70 is in general conformity with that of block 79. At its upper and inner corner manifold 70 is provided with an extension ledge 81 facing the interior of the mold and has an inlet passage 82 having a flange for connection with a pipe (not shown) which supplies the manifold with cold water. Additional inlet passages located at equidistant points along the outside of the periphery of the manifold may be provided, if desired, for supplying larger quantities of water to the mold.

The manifold 70 delivers water to the main cooling tubes 83 disposed in passages 96 which are bored into block 79 and preferably also to deliver water to water sprays disposed at different levels. For this purpose the manifold has a series of top holes 84; a series of bottom holes 85; its ledge 81 has a series of drilled passages 86; the ledge contains holes 78 to clear the main cooling tubes 83.

For water delivery to the top level sprays, block 79 is provided with a series of horizontal radial passages containing cross tubes 88, each of the latter having a nozzle tip 89 having a downwardly directed discharge passage disposed at an angle which preferably is less than 30° to the vertical and more preferably is about 20° thereto. The passages 88 connect with elbows 90 which are connected to fittings 91 connected to the top holes 84 in the manifold 70. The inner face of the lower portion of sleeve 94 has clearance bays below the discharge nozzles 89 providing, in effect, vertical ribs or projections 92 which are available to support the casting while the water sprays are directed between the ribs onto the surface of the casting before it leaves the mold. Water sprays, preferably of such construction, are preferred when high casting speeds are employed.

Another level of sprays may be provided by nozzle holes 87 drilled into the ledge 81 and connecting with the passages 86 in the manifold. The axes of the nozzle holes 87 also may have an angle which is less than about 30° with the vertical, said angle preferably being about 20°. Additional sprays may be provided by openings 103, 104 and 105 located in cooling tubes 83 and in the return bends 93. All of these spray openings direct water against the emerging casting in the directions indicated by the arrows. The return bends 93 connect lower openings 85 with inner tubes 83.

In accordance with the most preferred mode of practicing the present invention, mold 13 is also provided with means for diffusing the instant hydrogen gas through graphite sleeves 94 to introduce the gas to that area of the mold wall 80 at which freezing of the introduced metal commences during the casting procedure. As shown in FIGS. 2, 3 and 4, the outside surface of liner 94 is provided with a plurality of machined horizontal grooves 110 through 114 extending around the outside surface of the liner. Such grooves may be V-shaped and are suitably spaced from each other, preferably by a distance of about one-half inch. The horizontal grooves are connected by a plurality of machined vertical grooves 115 disposed around the outside surface of sleeve 94 and produce a waffle-like pattern in the sleeve. Such vertical grooves may also be V-shaped and are suitably spaced from each other preferably also by a distance of about one-half inch. The instant hydrogen gas from an outside

source (not shown) is conducted through pipe **120** preferably to the uppermost horizontal ring **110** through at least one passage **121** machined in block **79**, and preferably through at least three such passages distributed equidistantly around the periphery of block **79**. The gas thus supplied to the uppermost groove flows around this groove to the remaining grooves from whence it is distributed by diffusing through the pores of the graphite to the inner surface area of the liner which is embraced by the grooves; such diffusion taking place even under slight pressure—for example, as little as one-half pound per square inch, gauge, or less. For best results in this mode of introduction of the gas, a sufficient number of the horizontal grooves are employed to insure the bracketing with such grooves of that area of the mold wall at which the introduced metal commences to freeze during the process. In mold **13** the entire length of sleeve **94** is chilled and, as illustrated in FIG. 3, the introduced molten metal commences to freeze at the meniscus. Preferably, as shown in FIG. 3, a sufficient number of horizontal grooves, preferably at least five, are employed to accommodate reciprocation of the meniscus and also to permit change of the mean operating level of the metal in the mold.

Alternative modes of introducing the instant hydrogen gas are illustrated in FIGS. 5 through 8. As shown in FIGS. 5 and 6, the gas may be introduced to the mold wall area at which freezing of the introduced metal commences by conducting it from a source (not shown) to ring **125** from which it is discharged into the mold cavity above the metal therein through a series of downwardly directed perforations **126** of suitable size, for example, about .01 inch in diameter, spaced at regular intervals around the ring, preferably about one-half inch apart. Alternatively, the gas may be introduced as illustrated in FIGS. 7 and 8, by conducting it from an outside source through passage **130** drilled in block **79** to annular channel **131** machined in the outer face of sleeve **94** from which it is discharged into the mold cavity above the metal therein through downwardly directed ports **132** of suitable size, for example, about .01 inch diameter, which are drilled in the sleeve and spaced at regular intervals around the periphery thereof, preferably at one-half inch intervals.

In starting the casting system illustrated in FIG. 1, a conventional starting bar of appropriate length and having a cross section of a size and shape conforming to that of the mold cavity defined by mold surface **80** and preferably also having a conventional threaded tip of reduced size on the top thereof is employed. The top of the starting bar is inserted into the bottom of the mold a sufficient distance to cover the ribs **92** on sleeve **94** with the lower end of the bar extending below withdrawal rolls **18** so that, as the initial molten metal is fed into the mold, it freezes around the threaded tip and the frozen product is pulled downwardly and out of the mold by rolls **18**.

After the starting bar is inserted, cooling water is circulated through mold **13** flowing therethrough in the direction indicated by the arrows in FIG. 2 and discharging therefrom through orifices **89**, **87**, **103**, **104** and **105** into tank **20**. Plug **27** (see FIG. 1) is raised sufficiently to allow molten metal to flow into the mold at a reduced rate, usually about one-half of that required for the intended operating casting speed. If reciprocation of the mold is to be employed, reciprocation is commenced when the mold is partly filled. When the metal covers distributor cup **42** and reaches its normal operating level, the operator starts withdrawal rolls **18** to withdraw the starting bar at a pre-selected reduced starting speed. When the operator is ready, he increases the lowering rate of the starting bar to the intended running speed and at the same time adjusts the position of plug **27** to deliver molten metal to the mold at a sufficient rate to raise the level of the molten metal in the mold to the normal operating level.

When the level of the metal in the mold has reached its normal operating level therein, introduction of the instant hydrogen gas is preferably begun and continued during the casting procedure, the gas being introduced at a sufficient rate during the procedure to provide the surface described earlier herein on the emerging casting. Also, where employed, a cover of solid material is placed in the mold on top of the metal therein when the latter has reached its normal operating level. Where the cover is comprised of discrete particles as is illustrated in FIG. 3, sufficient additional material of this type is added from time to time during the casting procedure to provide and maintain a protective cover on the metal.

With the high heat extractive capacity provided by a mold of the type illustrated in FIG. 2 and with the sustained high casting speeds obtainable by practice of the present invention, the casting **17** emerging from the mold is red hot and may thereafter be further cooled by the series of pressurized water sprays **89**, **87** and **103–105**, and the large volume of water which is collected in tank **20**. The water in tank **20** may be removed therefrom at any desired level as by a suitable drain line **57** and may be circulated by a circulation and pumping system through a cooling device, and back to the water manifold **70** on the mold **13**. The intensity of cooling of mold **13** is such that, even at the sustained high casting speeds obtainable with the present invention, the molten metal congeals practically as soon as it touches the mold wall, causing the edge of the crater shell **101** (see FIG. 3) to extend substantially to the free surface **24**.

The critical importance of the concentration of the hydrogen in the instant gas in continuously casting steel is shown by the following example. Molten steel having a carbon content of approximately 0.35% carbon by weight is cast in the system shown in FIG. 1 employing the mold illustrated in FIGS. 2, 3 and 4. The continuous casting procedure is initiated as described above in the discussion of the drawings, employing substantially pure hydrogen gas which is introduced into the mold through pipe **120**. After the system has been started, the rate of introduction of the gas is controlled to produce and maintain the uniformly rippled surface on the casting emerging from the mold. Thereafter the substantially pure hydrogen gas introduced into the mold is progressively diluted with helium, or other inert gas. As the concentration of the hydrogen in the gas mixture is decreased, the character of the rippled surface changes in that the ripple becomes progressively more faint. When the hydrogen concentration in the gas reaches about 30% by volume, the surface of the casting emerging from the mold possesses the small surface tears which precede the deep tearing and rupture of the casting.

While certain novel features of the invention have been disclosed herein, and are pointed out in the annexed claims, it will be understood that various omissions, substitutions and changes may be made by those skilled in the art without departing from the spirit of the invention.

What is claimed is:

1. In a method for continuously casting steel in which molten steel is fed into the top of a vertically disposed open-ended mold having a chill section for casting the molten metal and cast metal is withdrawn from the other end of the mold while maintaining the level of the metal in the mold below the top of the chill section, and the meniscus of the metal in said chill section is vertically reciprocated with respect to the wall of the chill section, the improvement in combination therewith which comprises introducing a gas containing more than about 30% by volume of hydrogen to the meniscus of the metal in the chill section during the casting procedure, and controlling the amount of hydrogen which is delivered to said meniscus by controlling the amount of said hydrogen delivered to the meniscus during the casting procedure to a rate of introduction which is between that rate which produces an irregular pattern of irregularities on a major

portion of the surface of the casting emerging from the mold and that rate which produces deep tears on the surface of the emerging casting.

2. A method according to claim 1 in which a cover is maintained above the molten metal being cast in the mold and the chill section of the mold presents a graphite face to the metal being cast in the mold.

3. A method according to claim 2 in which said hydrogen gas is introduced to said meniscus beneath a cover of solid particulate material which is added to and maintained on top of the metal in the mold during the casting procedure in amounts sufficient to provide a cover of said material which is not less than about one-eighth inches thick and the casting emerging from the mold possesses a rippled surface, and said hydrogen gas contains at least 40% hydrogen by volume.

4. A method according to claim 3 in which the gas providing said hydrogen gas at said meniscus is led into the mold cavity above the metal level therein.

5. A method according to claim 4 in which said cover material is a carbonaceous cover material and the gas providing said hydrogen gas is lead into the mold cavity above said cover material.

6. A method according to claim 3 in which said hydrogen gas is introduced to said metal meniscus by diffusion through said graphite face of said mold.

7. A method according to claim 6 in which said hydrogen gas introduced to said meniscus contains at least 75% hydrogen by volume.

8. A method according to claim 7 in which said hydrogen gas is substantially pure hydrogen gas.

References Cited by the Examiner

UNITED STATES PATENTS

3,089,209 5/1963 Phillips et al. ------ 22—200.1

OTHER REFERENCES

Boichenko: Continuous Casting of Steel, Butterworths (London, 1961, Moscow, 1957). (Found in Group 320.)

J. SPENCER OVERHOLSER, *Primary Examiner.*

MICHAEL V. BRINDISI, MARCUS U. LYONS, R. A. SANDLER, R. D. BALDWIN, *Examiners.*