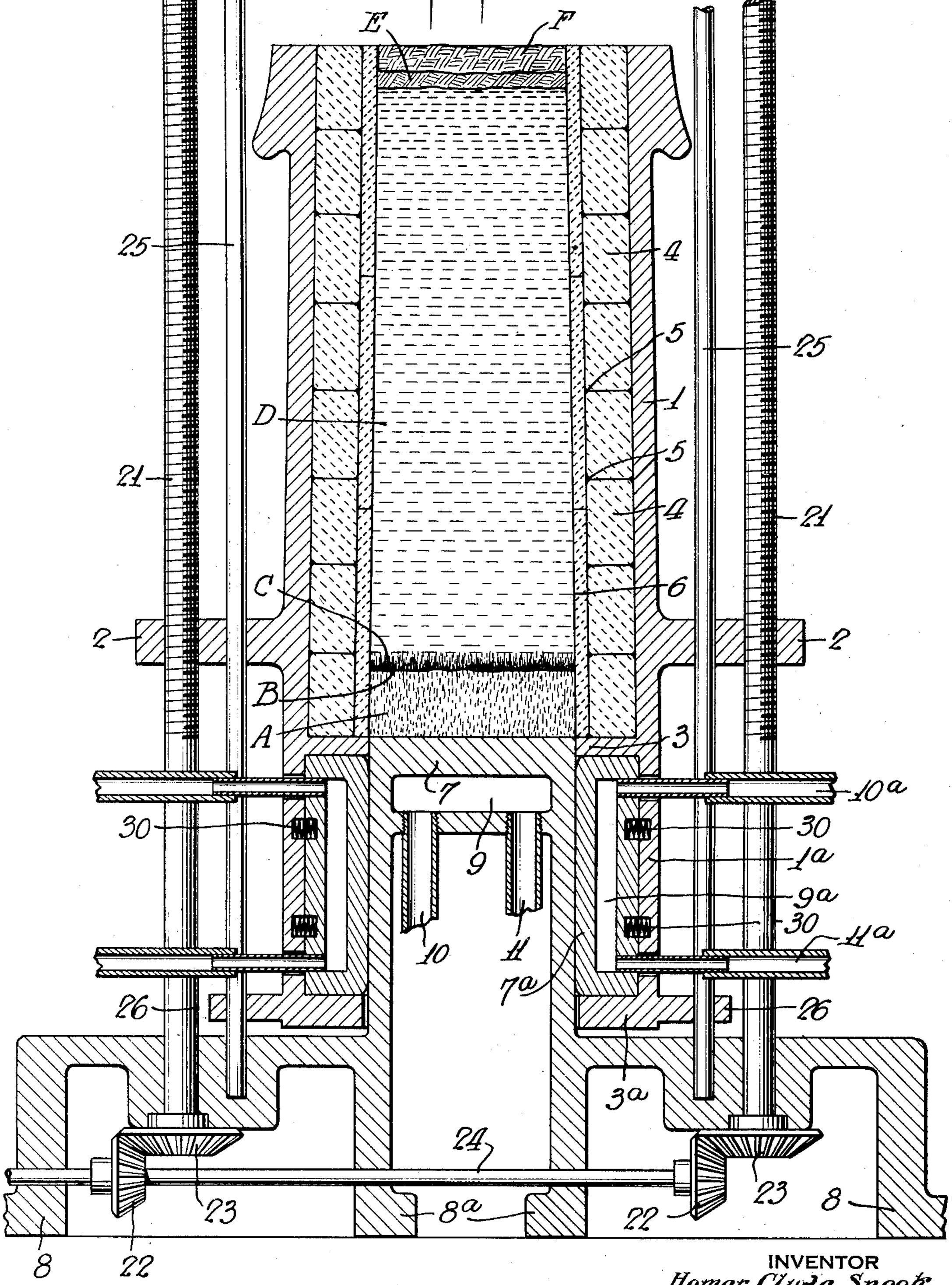
June 5, 1934. H. C. SNÖOK 1,961,399

INGOT CASTING METHOD

Filed Sept. 23, 1931 2 Sheets-Sheet 1

FIG. 1.



INVENTOR
Homer Clyde Snook
BY

ATTORNEY

June 5, 1934. H. C. SNOOK **1,961,399**

INGOT CASTING METHOD

Filed Sept. 23, 1931 2 Sheets-Sheet 2

FIG.2.

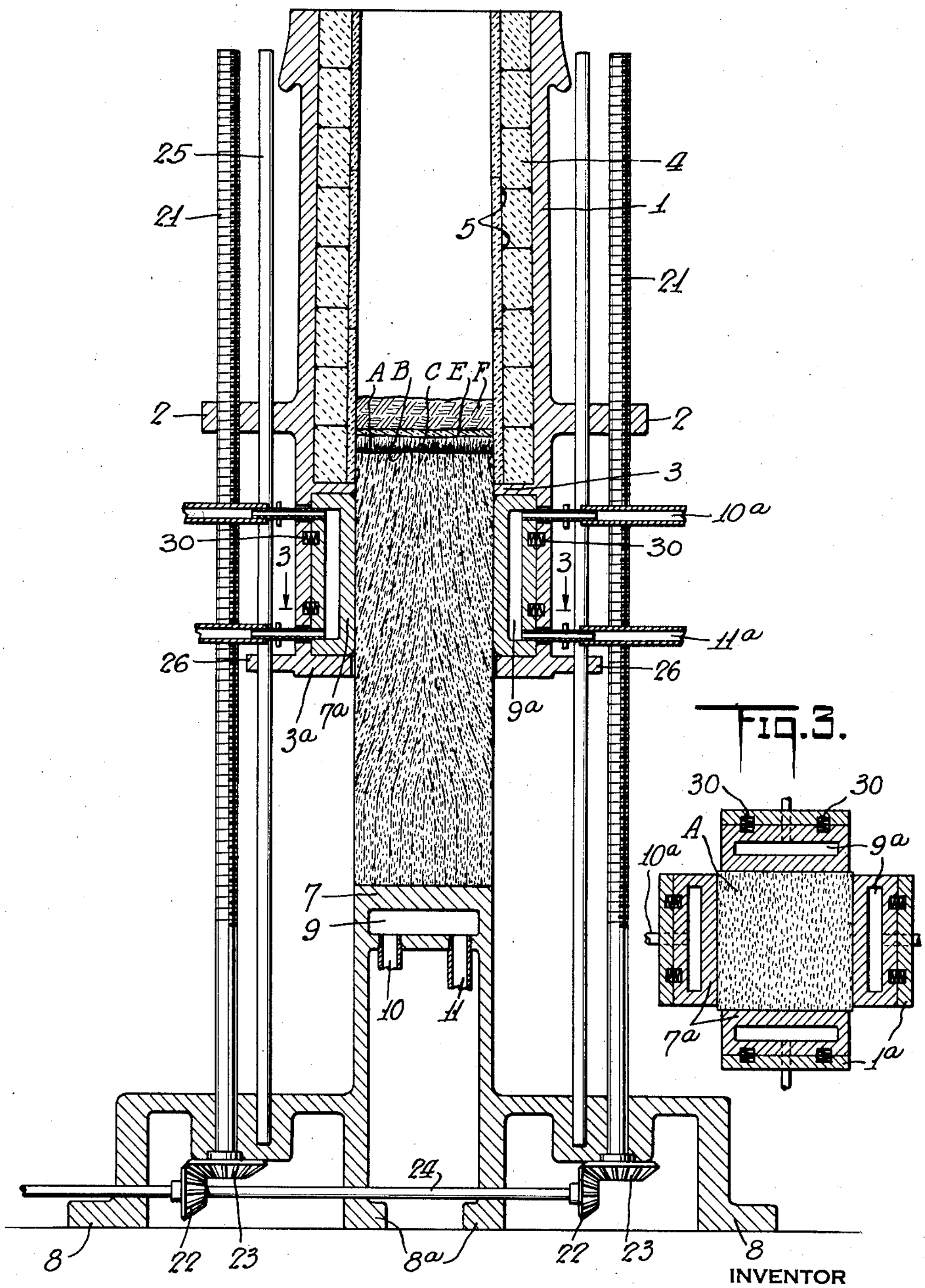


FIG.3.

INVENTOR
Homer Clyde Snook
BY
ATTORNEY

UNITED STATES PATENT OFFICE

1,961,399

INGOT CASTING METHOD

Homer Clyde Snook, Summit, N. J.

Application September 23, 1931, Serial No. 564,526

4 Claims. (Cl. 22—200)

My present invention relates more particularly to the casting of sound ingots suitable for rolling and mechanical working and includes novel features of apparatus, processes and product. While primarily directed to the problems involved in casting such ingots from steel and steel alloys, various of the novel features may be found applicable to the production of ingots of other metals or alloys suitable for rolling and mechanical working.

As concerns steel, some of the problems involved, and some features of the solutions thereof, are like those set forth in prior application Ser. No. 528,762 filed by me jointly with Byron E. Eldred, April 9, 1931 which issued Dec. 27, 1932, as Patent No. 1,892,044. In this, as in said patent, it is recognized that there are many kinds of steel and steel alloys having widely varying percentage of carbon as well as varying percentages of other ingredients, some beneficial and others detrimental, but the present invention does not particularly concern the composition or the methods of making the various kinds of steel. It is assumed that the steel will be made in accordance with the best known practices of the art and will be available and ready for pouring; also that in the practice of my method, the pouring ladles and methods, as well as the molds and technique of assembling, lining, luting, etc., will be in accordance with approved practices in these branches of the art.

While my present invention will be of advantage in connection with any variety of steel, it is assumed for purposes of this disclosure that the steel is one of the conventional types containing less than ½% of carbon and of good quality as concerns detrimental impurities.

In the production of an ingot of any metal or alloy suitable for rolling and mechanical working, the upper half is the part of the ingot that usually contains the greatest amount of imperfections, such as blow-holes, pipes, segregations, areas of weakness, slag inclusions, etc. In order to minimize these defects, many devices have been employed, such as "sink heads" to provide large masses of hot, molten metal at the tops of the ingots; such as flames of burning gas to heat the upper surfaces of the ingots; such as highly heated refractory material placed on the tops of the ingots; and such as the molds having highly insulated, highly heated refractory lined walls, in combination with a water cooled bottom, and poured with super-molten steel, as is described in said patent.

While sound castings substantially free from blow-holes, pipes and deleterious segregations may be produced by the process and apparatus set forth in said application, the degree of success depends upon the degree of success in causing solidification of the metal to proceed from the bottom upwards and, if the temperature of the super molten metal is insufficiently preheated, or if the heat insulation of the refractory is insufficient, freezing of the metal downwards from the top of the ingot, and inwards from the upper parts of the refractory linings of the mold, may take place in a moderate amount before the freezing upwards from the bottom of the ingot can arrive at the top of the ingot. In such case, the crystals growing downwards from the top of the ingot will meet the more rapidly upwardly growing crystals in a location above the center of the ingot. In any such localized meeting place, is found a segregation of material liquated from the metal in the lower part of the ingot. It is also a boundary area for meeting of two groups of crystals, one growing upwardly and the other growing downwardly. The metal in such a boundary area is mechanically weak compared with the metal elsewhere in the ingot.

Accordingly, an object of my present invention is to reduce the time required for completing the freezing upwards from the bottom of the ingot so that even with lower temperatures for the super-molten metal or with lowered temperatures for the preheated refractory mold lining, or with reduced heat insulation for said lining, the metal crystals freezing upwards may arrive at the top of the ingot before downwards crystallization of the metal becomes serious or even appreciable. By thus maintaining a liquid state of the metal in the upper parts of the ingot, until the freezing from the bottom upwards reaches the tops of the ingot, I insure upward liquation during the entire period of freezing, thereby locating the ensuing segregation right at the top of the ingot; and I eliminate localized areas or planes of mechanical weakness that are formed at the boundaries between groups of crystals growing towards each other in opposite or substantially opposite directions. As a result, the ingots are entirely free from pipes and blow-holes; the segregations are reduced to negligible dimensions, are less intense and are located in the extreme tops of the ingots; and they have no areas of mechanical weakness due to the varying orientation of groups of crystallites.

In producing the above results, the initial steps of my method may be similar to or even approximately the same as in said patent, that is to say, it is desirable to have the steel heated to a temperature as high or higher than that characteristic of what is known as "rising" steel and I utilize the thus stored heat in the molten metal to maintain complete liquidity as against heat losses through the top and side walls of the mold. The side wall loss is prevented by heavily insulating the interior of the mold throughout its entire length. A layer of powdered glass, or other suitable slag forming material may be poured on top of the ingot immediately after teeming, or pouring, in order to protect the molten metal from undesirable reaction with, or absorption of, atmospheric gases which would otherwise take place.

Complete liquidity of the contents of the mold being assured for a reasonable time, heat is withdrawn through the water cooled base of the mold and during the initial period all of it is so withdrawn, as in said application. This causes the heat to flow downward parallel with the axis of the ingot, so that solidification begins at the bottom and progresses upward substantially at a horizontal plane. The super-molten metal source of heat affords high temperatures, maintaining complete fluidity almost down to the horizontal solidification surface, thereby minimizing the depth of the "mushy" or "viscous" layer, thereby practically eliminating all difficulty of escape of the gas or slag which is ejected from the solidifying surface.

For a certain length of time, while the steel is freezing upward, the results are ideal, that is to say, the great rapidity of withdrawal of the heat makes the crystalline structure of extremely fine grain and the direction of the withdrawal makes the grain parallel with the axis. The freezing becomes progressively slower, however, as the freezing surface recedes upward away from the water cooled base, and I have discovered that the base water cooling may be supplemented by side wall water cooling provided the side wall water cooling is kept substantially below the freezing level. That is to say, after the metal has been solidified sufficiently so that it partakes of a ductile solid condition rather than the "mushy" condition, it becomes a far better conductor of heat and its crystalline structure has been predetermined sufficiently so that the heat may be withdrawn through the side walls, provided the withdrawal zone is kept substantially below the freezing surface.

An important feature of the method concerns withdrawing the mold to expose the solidified side walls of the ingot for contact with a water cooled jacket. Preferably the ingot remains on its water cooled base so that the latter continues its cooling effect on the base, in cooperation with the side wall cooler which is caused to progress upward at a rate sufficient to keep it near but substantially below the freezing surface in the ingot.

The above and other features of my invention will be more evident from the following description in connection with the accompanying drawings, in which

Fig. 1 is a somewhat diagrammatic vertical sectional view representing a mold in which the lower part of super-molten steel is being solidified by base cooling only.

Fig. 2 is a similar view showing the side wall cooling operation; and

Fig. 3 is a detail section on line 3—3, Fig. 2.

In these drawings the mold is shown as being similar to that of said application. The exterior shell 1 may be of cast iron formed with lifting lugs after the manner of the usual mold, but it is provided with inturned flanges 3 to support a refractory lining the interior surface of which constitutes the mold. The refractory lining preferably comprises a layer of fire brick 4 laid with refractory cement 5. The inner surface of the fire brick lining may constitute the mold, but fire brick material though of most excellent non-conducting quality, is likely to contaminate the steel under certain conditions, and I prefer to employ a thin inner lining 6, which may consist of refractory chromite material which, though slightly more heat conducting, is less likely to contaminate or react with the molten steel. It may be in the form of slabs secured by chromite cement, as shown; or the cement alone may be used. In either case, the entire lining is permitted to dry thoroughly before use. Also it may be initially heated to very high temperature after the manner of refractory lined ladles into which molten steel is drawn for pouring. Moreover, if the steel happens to be of a quality or made under conditions where it is likely to be deficient in super heat, such pre-heating of the lining may immediately precede the pouring of the steel into the mold.

The bottom of the mold is formed by the massive plate 7 supported by and preferably integral with the base 8. This base is preferably formed with a water chamber 9, directly below the plate 7, which chamber is kept cold by circulation of water or other cooling medium through pipes 10 and 11, supplied from any suitable source.

The mold may be provided with a "hot top" but a sufficiently thick layer of glass or slag, indicated at E may be sufficient and is sometimes preferable.

The walls of the mold cavity preferably diverge slightly toward the bottom. This facilitates stripping of the ingot but is not essential because by my method the stripping is progressive and is effected while the metal is yet slightly plastic.

The means whereby the ingot may be cooled through the sides, in addition to the cooling through the bottom, is shown as including a supplemental downward extension 1*a*, from the cast iron walls 1 of the mold, terminating in a second horizontal flange like member 3*a* corresponding to 3. This forms in 1*a*, 3*a*, a cavity corresponding to the space filled by the insulation in the body of the mold 1. In this space is provided a lining which instead of being insulating, is highly conducting and takes the form of cast steel or iron or copper sections having inwardly exposed walls 7*a* corresponding to 7 of the base, behind which is the water jacket space 9*a* corresponding to 9. These latter mold lining sections are water cooled through pipes 10*a*, 11*a*, like those of the water cooled base.

In this way, the water cooled side sections move integrally with the mold 1 and, while this is highly desirable, it is of course not essential to the practice of my present method of side wall cooling of the ingot. As shown, the mold is provided with integral lateral projections 2, which are in screw-threaded engagement with vertical elevating screws 21, which are preferably geared for simultaneous operation through bevel gears 22, 23, and shaft 24. Preferably also, there are guides 25, 25, rigidly secured in the base 8, with which the mold extensions 2 have sliding engagement. Preferably spaced apart, two-point engagement with each of said guides is afforded by additional lateral extensions 26, 26 which in this case are shown at the base of the water cooled section of the mold.

The screws 21 may be rotated by any suitable means not shown, for the purpose of performing the important step of my method, which is the lateral cooling of the solidified part of the ingot.

In Fig. 1, I have shown the solidifying operation by the same diagrammatic conventions employed in said joint application. The solidified steel A is indicated as having a vertical grain parallel with the lines of vertical heat flow and perpendicular to the horizontal surface B where the solidification is taking place. C is intended to indicate the thin transition zone where the steel is in the mushy or viscous transition state, and D is intended to represent the great body of super-molten metal which contains heat enough to insure complete liquidity almost down to the surface of solidification at B, thereby making the transition layer C very thin. E is intended to represent the slag on top of the molten steel, while F represents the refractory heat insulating powder.

In practice of the invention, the super-molten steel is prepared and poured into the mold according to approved practice in the art, the mold being preheated or not, as seems necessary or desirable in any particular case. A sheet of iron or steel may be placed on mold bottom 7 to prevent erosion, if desired.

The water which is kept flowing through the water chamber 9, in cast iron base 8, extracts heat from the bottom 7 which in turn extracts heat rapidly from the bottom of the liquid steel. By extracting the heat from the liquid steel rapidly and from the lower end of the ingot only, a number of beneficial results are obtained in the resulting solidified metal, A. The solidification progresses in an upwardly shifting horizontal surface approximating a plane, and the crystal formation grows from the bottom upward with the major axes of the crystals vertical to said surface and tending toward approximate parallelism with the major axis of the ingot, so that the ingot is of unusually uniform composition and freedom from strains. Moreover, as indicated in Fig. 2, the axes of the crystals are parallel with each other and even in the upper portions, they lie approximately parallel with the direction of extension of the metal when subsequently rolled. They are thus in the most favorable position to afford maximum ductility, density and strength for the rolled product.

It is to be noted that in the prior art, cooling of the steel through the side walls of the mold from the lower portions upward, has not been properly controlled so as to lag a proper distance behind a substantially horizontal freezing surface of the metal and the result has been that side wall freezing has progressed in advance of interior freezing, thus causing the crystals to grow and the viscous zones to develop radially, instead of vertically, thereby causing entrapment of gas, piping, liquation, segregation and coarse crystallization. It is obvious that under such conditions a large part of the metal is being cooled all the time, and even though this may result in a shorter total time for the final cooling, the actual cooling time at any one point is relatively long. The point is that the longer the cooling time of any given zone or layer independently of the total cooling time, the more voluminous will be the viscous zone, the coarser the crystallization on freezing, the greater the segregation, the greater the liquation, and the greater the tendency to pipe formation.

As before noted, the first part of the freezing of the steel, from the bottom upward, progresses as rapidly as one could wish, but as the column of solidified steel through which the heat is withdrawn becomes longer, the rate of heat flow therethrough necessarily becomes slower. Accordingly, by my method, as soon as freezing has progressed a desired distance above the bottom, easily determined by experience, the mold is slowly lifted as by operating the elevating screws 21, 21 to bring the water cooled side walls 7*a* into contact with a hardened lower portion of the steel. Perfect contact may be facilitated by having the water cooled units urged inwardly by any desired means, such means being indicated by the springs 30, Figs. 2 and 3.

The rate of upward lifting is carefully regulated, with reference to the thickness of the ingot so that the lines of heat flow will always be substantially downward through the freezing surface C and through a sufficient depth of ingot. The thing to be avoided of course is causing the water cooled side walls to progress upward at too rapid a rate, because if they get too near the freezing surface, they tend to short circuit the heat flow, thereby making the flow tend toward radial, thus causing the freezing to progress at the sides more rapidly than in the middle. That is to say, by as much as the side wall cooling takes effect too near the freezing surface C, it tends to make that surface downwardly concave and by as much as there is any such concavity, the crystals will tend to incline toward the axis of the billet. While a certain amount of such departure from parallel vertical formation will not prevent proper liquation of impurities from the freezing surface and will not impair the quality of the metal as concerns lengthwise rolling, it is obvious that all such effects should be avoided as far as possible, and even allowing for a permissible amount of such variation, it will still be found necessary to keep the water cooled surfaces 7*a*, a substantial distance below the freezing surface. The rapid freezing tends to promote fineness of grain and the uniformity of direction of withdrawal of the heat, at all distances from bottom to top of the ingot, promotes uniformity of direction of the grain. Both these features tend to compensate for departures from exact parallelism of the grain with the axis of the ingot. Nevertheless, it will be found that a safe rule is to keep the water cooled walls below the freezing surface, a distance which is very substantial as compared with the radius of the ingot. For instance, as shown in Fig. 2, even the extreme upper edges of the water cooled surfaces 7*a* are a substantial distance below the freezing surface of the ingot and for the really effective part of the cooling area, the distance is approximately equal to the radius of the billet.

As shown in Fig. 3, it is not desirable to have the water-cooled surfaces contact with the metal at the extreme corner edges of the ingot, because edges are necessarily cooled from two directions and may tend to cool too fast. In fact, it may be desirable in some cases to protect the corner edges against cooling faster than the intermediate surfaces on the same level. However, it seems preferable to leave these edges exposed, somewhat as indicated in Fig. 3, because an experienced operator can accurately judge the temperature and condition by inspection and will thus be able to regulate the rate of upward progress of the cooling surfaces to keep them near but a safe distance below, the freezing surface of the metal. The latter is highly desirable for practice of my present novel method of rapid, uniformly progressing freezing by vertical downflow of heat through an approximately horizontal freezing surface.

Naturally, the hotter the mass of liquid steel when poured into the mold and the more rapidly the heat is thus extracted, the thinner will the viscous layer be squeezed, so to speak, between the hot molten metal and the advancing surface of the freezing, solid steel.

As will be evident from the above, and as is well known, powdered heat insulating, refractory material, such as sand, lime, charcoal, magnesite, chromite, etc., at the option of the operator, may be placed on top of the slag to conserve the heat that otherwise would be radiated from the molten slag. Also, heat may be applied to the metal in the upper part of the ingot by any of the well known methods, such as high frequency electric induction, burning gas, coal, coke, etc., electric arcs, etc.

The mold may be raised by manual operation of the drive mechanism, or by electric motor. It may be automatic, controlled by thermocouple or other temperature detecting devices; or it may be predetermined as to time and rate by previous experimental determination of the most desirable values of these quantities.

A valuable feature of the preferred apparatus is the ease with which the temperature of the solidified metal of the ingot may be estimated or measured by optical methods because of the visibility which may be had of one or more corners of the solidified metal, or substantially all of it if radiation cooling is employed and of a substantial part of the surface of the lower end of the ingot. This feature is of value in the routine control of the rate of raising of the mold.

I am well aware that preformed metal has been inserted in the bottom of a furnace, crucible or mold, and that by water, air or other cooling of this preformed metal, freezing from the bottom upwards has been accomplished of molten metal poured into or melted in the furnace, crucible or mold, and that this preformed material, fused and frozen to the metal poured into or melted in the mold, has been employed to withdraw from the bottom of the mold additional amounts of such molten metal that have been frozen from the bottom upwards.

It is to be understood that other mechanical arrangements of the elevating and guiding means may be employed to raise the mold with respect to its chill base, the screw elevator and the guide rods being only illustrative of such means as may be employed.

I claim:

1. In the art of casting an elongated steel ingot to be further elongated by rolling or the like, a process which includes forming a vertically elongated mold having side walls of insulating material constituting the lining of an exterior ferrous metal mold; charging said mold with liquid steel to a height substantially greater than the diameter of the mold and hot enough to insure supermolten temperature for all of said liquid steel and for the walls of said insulating liner mold; solidifying the liquid steel by abstracting heat through a liquid cooled metal bottom of the mold, rapidly enough so that side wall cooling is negligible as compared with bottom cooling, thereby forming a solid bottom portion, having a substantially horizontal upper freezing surface; then continuing such heat abstraction through the bottom until solidification has progressed to a substantial height within the mold; and thereafter vertically separating said mold bottom from said mold walls while further extracting heat through said bottom and also the thus exposed lateral surfaces of said solid portion, the rate of separation of the mold walls and bottom being approximately at the rate of upward progress of the freezing surface, so that the lines of heat flow from said freezing surface are downward approximately lengthwise of the solidified portion of the ingot that is continuously maintained within and protected by the insulating lining of the mold, and the upwardly progressing freezing surface is thereby maintained approximately horizontal.

2. In the art of casting an elongated steel ingot to be further elongated by rolling or the like, a process which includes forming a vertically elongated mold having side walls of insulating material constituting the lining of an exterior ferrous metal mold; charging said mold with liquid steel to a height substantially greater than the diameter of the mold and hot enough to insure supermolten temperature for all of said liquid steel and for the walls of said insulating liner mold; cooling the liquid through a metal bottom of the mold, while rise of temperature of the bottom is limited by supplying a liquid cooling medium and while the sides of the liquid steel are protected by the heat insulating lining, so as to form a solid bottom portion, of substantial height, constituting the base of the ingot and having an upper freezing surface which is substantially horizontal; and thereafter causing the said freezing surface to progress upward at a rapid, uniform rate, by vertically separating said mold bottom from said mold walls and abstracting heat through the thus exposed lateral surfaces of said solid portion, the rate of separation of mold and bottom to expose said lateral surfaces being approximately at the rate of upward progress of said horizontal freezing, so the length of progressively solidified upper portion of the ingot within and protected by the insulating lining remains substantially constant.

3. In the art of casting an elongated steel ingot to be further elongated by rolling or the like, a process which includes forming a vertically elongated mold having side walls of insulating material constituting the lining of an exterior ferrous metal mold; charging said mold with liquid steel to a height substantially greater than the diameter of the mold and hot enough to insure supermolten temperature for all of said liquid steel and for the walls of said insulating liner mold; cooling the liquid steel through a metal bottom of the mold while rise of temperature of the bottom is limited by supplying a liquid cooling medium and while the sides of the liquid steel are protected by the heat insulating lining, so as to form a solid bottom portion, of substantial height, constituting the base of the ingot and having an upper freezing surface which is substantially horizontal; and thereafter causing the said freezing surface to progress upward at a rapid, approximately uniform rate, by vertically separating the said mold bottom from said mold walls and abstracting heat through the thus exposed lateral surfaces of said solid portion by laterally applied liquid cooled metal walls; the rate of separation of mold walls and bottom to expose said lateral surfaces of

the ingot to said laterally applied metal walls being approximately at the rate of upward progress of said horizontal freezing, so that a substantial length of the progressively solidifying upper end of the solid portion remains within and has its lateral surfaces protected by the insulating lining.

4. In the art of casting elongated steel ingots to be further elongated by rolling or the like, in connection with a mold having a heat insulated lining and a water cooled bottom designed and arranged so that the rate of heat abstraction through said lining is negligible as compared with rate of heat abstraction through said water cooled bottom; the method which includes charging said mold with liquid steel to a height substantially greater than the diameter of the mold, said liquid steel being superheated sufficiently to insure supermolten temperature for all of said liquid steel and also for the walls of said insulating lining of the mold; then allowing the charged mold to stand until a substantial height of the lower portion of the liquid steel has been solidified by flow of heat vertically downward through said cooled bottom of the mold; and thereafter vertically separating said mold bottom from said mold wall at approximately the rate of upward progress of said freezing surface and abstracting heat through the thus exposed lateral surfaces of the lower part of the solidified portion of the ingot while the freezing surface and a substantial height of upper portion of the solidified ingot remains within and protected by the insulating lining, so that the lines of heat flow from said freezing surface are downward approximately lengthwise of the solidified portion of the ingot which remains within and is protected by the insulating lining of the mold.

HOMER CLYDE SNOOK.