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METHOD OF CASTING METAL INGOTS AND APPARATUS THEREFOR

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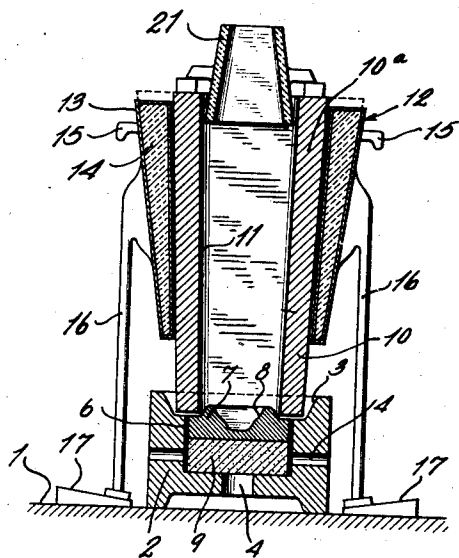


Fig. 1.

Fig. 2.

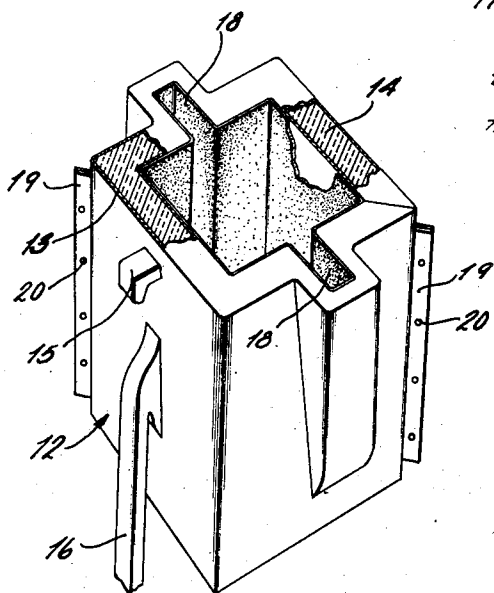
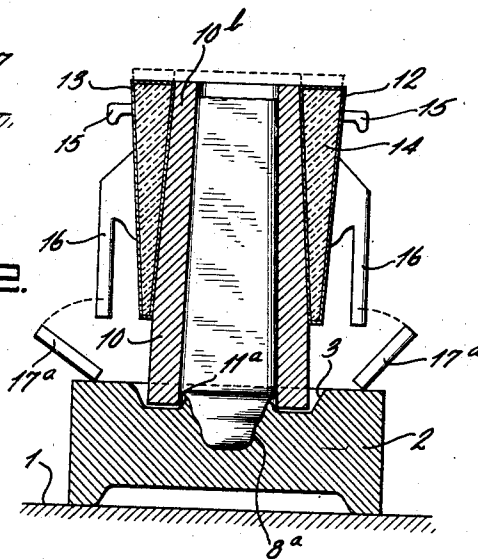


Fig. 3.

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METHOD OF CASTING METAL INGOTS AND APPARATUS THEREFOR

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25 Claims. (Cl. 22—139)

This invention relates to the art of casting metal ingots and has especial reference to a method and apparatus for casting ingots of steel and steel alloys for later rolling or mechanical working.

A principal object of this invention is to so cast molten metal as to provide an ingot with a smooth surface and substantially free of surface defects.

A further and important object of this invention is to provide a forming ingot with a "skin" uniformly strong enough to minimize the tendency of ingots to "hang" in molds with tapered chamber walls.

A still further and important object of this invention is the provision of a method and apparatus whereby a forming ingot is cooled initially in the solidification process predominantly radially by the side walls of the mold and subsequently is cooled predominantly progressively upwardly by the side walls of the mold.

Other objects will hereinafter appear.

Whatever the composition of molten steel or whatever the ultimate use for which it may be intended, the purpose in casting it into ingot form is to solidify it into a body of suitable shapes and dimensions for handling and working, but under various conditions casting steel ingots in the prior art has resulted in various defects in the ingot, such as interior and surface blow holes, cavities, segregation, large crystal growth, cracks, "bleed-outs," etc., chiefly due to the manner in which steel solidifies in a mold and the physical laws which it obeys when contracting in cooling. It is well known that if molten steel could be poured into a mold with such extreme slowness as to permit it to solidify layer by layer from the bottom to the top, a sound body of steel free of important defects would result. However, as is well known also, there are important reasons why this process of pouring cannot be undertaken in great commercial production. To approximate horizontal layer solidification, many methods have been used in the prior art with the general object of keeping the steel liquid in the upper portion by applying heat to this portion while cooling the lower portion by water-cooling the mold, and by various combinations of heating and cooling elements. However, the art developed commercially to the use, generally, of metallic molds, such as cast-iron molds of various shapes, ingot forming chambers of various shapes and contours, relationship of metallic mass to mold chamber area, degrees of taper of chamber walls, supplemented

by the use of accessories such as hot-tops, covers, chill tops, etc. The present practice includes top-pouring, bottom-pouring and combinations of both, continual pouring and intermittent pouring. So, present practice has by various combinations controlled to some appreciable degree many of the defects present in the earlier periods of the art. However, it frequently happens that ingots stick or "hang" in molds and emerge when stripped with surface cracks which cannot be subsequently welded and which appear in the final fabricated article.

Among the objects of our present invention is to minimize the tendency of forming ingots to rupture the "skin" when solidifying in a metallic mold, such as a cast-iron mold, and thereby permitting molten metal to run out and freeze against the matrix wall and wedge the ingot. This "bleed out" occurs substantially because uneven cooling of the molten metal along the side walls of the matrix of the mold produces a "skin" of uneven thickness and strength along the longitudinal axis of the "skin," so, that as a natural result of time elapsed in pouring the metal a cooling differential is present and the forces of contraction operate to place a stress on the "skin." This has been particularly true in cases of metallic molds having walls of progressively tapering thickness from one end to the other, a common practice to effect side wall cooling progressively from one end to the other, for example from bottom upwards in molds of big-end down and big-end up types provided with ingot forming chambers having tapered walls. Because of decreasing thickness of the metallic walls towards the horizontal planes of the last portions of metal to rise in the mold body proper, the heat absorbing power of the mold walls is less in this area than the heat absorbing power of the mold walls opposite lower horizontal planes of the forming ingot. This condition causes uneven cooling of the metallic mold contacting surfaces of the forming ingot and consequently the "skin" is sufficiently unevenly strong along its axis to be unable to withstand the forces of shrinkage, due to vertical and horizontal contraction, in many cases, and tends to pull itself apart. This tendency is increased somewhat by the heat absorbing power of metallic stools or plugs at the bottom of the forming ingot, in vertical molds, and by a slow rate of rise of the molten metal during teeming. As molten steel is poured into a metallic mold chamber of molds of above types, the metal as it comes into contact with the chamber surfaces is chilled along

these surfaces by the relative coldness of the mold walls and heat is extracted from the molten metal along these surfaces by the heat absorptive or heat conductive power of the mold walls, and, along these mold surfaces a "skin" begins to form on the cooling forming ingot, and the process of solidification is under way whereby heat is further absorbed by the mold walls and radiated therefrom by differential sidewall cooling at a progressively decreasing rate from the bottom to the upper levels, and as the process of solidification continues in this manner, the cooling power of the bottom closure for the mold walls, such as a stool or a plug gradually decreases because of the growing insulating effect of the increasing thickness of the metal solidifying above. This manner of solidifying has advantages well known to the art, but chiefly due to this manner of freezing, since the manner and rate are fixed by the mold, it produces the early stresses on the "skin" which have been referred to above, and results in frequent ruptures of the "skin" causing "bleed outs." The "skin" as it forms at the bottom levels to the upper levels around molten metal is, in the above, progressively increasingly stronger and thicker from the upper levels to the bottom levels due to the differential cooling rate of the mold and the time of rise in the mold body proper, and as the forces of shrinkage come into action these forces affects the cooling "skin" in a differential manner: Roughly, the bottom levels are cooled sooner than the upper levels and in between levels the pressure behind the "skin" of hot metal due to the weight thereof tends to prevent the skin in this area from shrinking away from the mold walls and frequently results in cracking the "skin." In this connection it should be observed, other things being equal, that the greater the vertical height of the molten mass, the greater the pressure in the vicinity of the central axes acting radially against the "skin" and tending to hold the "skin" against the mold walls in this area. In addition to wedging the forming ingot in the mold, "bleed outs" from "skin" ruptures quite frequently bind the forming ingot to the matrix wall of the mold pulling the ingot as it solidifies in the direction of the area where the "bleed out" has occurred, causing a distortion along the long axis of the solidifying mass, and, by maintaining contact with the walls of the matrix of the mold which continues to absorb heat by direct conductivity in this area, while opposite area, in cooling, shrink away from the matrix of the mold and lose contact therewith, result in uneven cooling and crystallization in opposite areas of the forming ingot.

Our present invention provides a "skin" of substantially uniform thickness and strength along the axis of the "skin" for substantially the entire length of its mold contacting surface in the mold body proper by cooling the matrix contacting surface of the molten mass preferably at a substantially uniform rate, and more preferably at a faster rate opposite the portion of the mass, in the mold body proper, where the levels have been last to rise. It will be understood that in a mold having chamber walls tapering substantially uniformly from approximately one end to the other that the degree of taper and the length of the tapered walls effect a horizontal area differential between horizontal planes of the molten mass resulting in increasing the area towards one end relative to the other. And, in this respect, among others, our invention is dif-

ferent from the above referred to prior art of casting. However, the casting of molten metal, steel, for example, in molds having ingot-forming chamber walls of uniform thickness has long been practiced and is well-known throughout the art. In this practice, solidification progresses substantially directly radially of the central axis of the forming ingot by side wall cooling circumferentially inward toward the central axis and, since the rate of radial cooling is fixed by the mold walls and except in cases where there is a very heavy taper to the matrix walls resulting in a very important difference in the area of forming ingot in horizontal planes between its upper and lower portions, the ingot is formed with a relatively large core of porous metal or centrally disposed cavities. To minimize such tendencies when using molds of this type and to force the porous core or cavities to be formed nearer to the top of the metal, we differentially arrest or differentially impede the substantially direct radial side wall cooling at a period after the formation of the substantially uniform "skin." This period may be immediately after the "skin" has sufficient strength to withstand the stresses imposed upon it by the shrinkage forces, or it may be after an interval of time sufficient to permit this "skin" to grow to form a shell of greater strength and greater thickness. It will be apparent, other things being equal, that the relative proportions of the ingot forming chamber predetermine the shortening or lengthening of the interval which may elapse in good practice. For example, other things being equal, a short, wide ingot forming chamber permits a longer interval of time to elapse before impeding substantially uniform direct radial side wall cooling than a long, narrow ingot forming chamber.

Our present invention, then, includes, among others, the provision of a method in casting whereby the initial solidification of a molten mass may be caused by substantially uniform direct radial side wall cooling and the later stages of solidification caused by substantially differential cooling progressively decreasing in rate in the direction of the solidifying levels last to rise. This, we accomplish by teeming the molten mass into a mold having side walls of substantially uniform heat absorbing power or having side walls of greater heat absorbing power opposite the wall contacting levels of molten mass last to rise than the walls opposite the lower levels, and allowing solidification to progress for an interval of time at the rate of cooling predetermined by the fixed mass of the walls of the mold body proper and the relationship of the mass of the walls to the ingot-forming chamber, and then altering the predetermined cooling rate of the side walls of the mold by retarding the radiation of heat from the exterior surface of the chamber walls over a large area of the exterior surface, preferably circumferentially of an exterior area, and preferably progressively increasingly retarding the heat radiation in the direction of the mass levels last to rise, i. e., we alter the predetermined heat absorbing power of the side walls of the mold proper by retarding the radiation of heat from the exterior surface of the side walls so that as the mold becomes heated throughout we slow up the heat conductive rate of the walls by retarding radiation of absorbed heat from an area of the exterior surface of the side walls opposite the forming ingot contacting surface and storing the absorbed heat in the walls to delay dissipation of

heat from the solidifying ingot. In our present invention, then, we apply externally to the mold walls a conservator of heat extending circumferentially of the mold walls and surrounding the exterior surface to a predetermined depth. This conservator of heat includes a circumferential cape of material having low heat conducting power and is adapted to circumferentially contact the exterior surface of the mold walls around the predetermined area to heat-insulate the walls in that area, and preferably to differentially heat-insulate said area in a manner progressively increasing in insulating power in the direction of the areas of the walls opposite the levels of the mass last to rise. In the prior art, more particularly in earlier phases, there have been attempts to promote the solidification of molten mass from bottom levels gradually to top levels in substantially progressive horizontal layers and, generally speaking, these methods have emphasized mold walls of poor heat conductive power, such as refractory or refractory lined walls, and/or, the application of heat at the upper levels, and, in some cases, the withdrawal of heat from the bottom by water cooling; in other instances circulating fluid systems have been employed; and circulating air systems having their courses directed through framework of various constructions to effect a differential in time of solidification between the upper and lower portions of the solidifying mass. As far as we are aware, these attempts have all been directed, essentially, to the origination of a particular directional solidifying process and to the continual maintenance during solidification of that particular system as originally commenced and, further, have been directed to the principle of minimizing as much as possible from the very inception of the solidifying process, or as soon thereafter as the elements or forces employed could, from a practical standpoint, be caused to function, the heat absorptive power of the walls of the mold surrounding the mass in the mold chamber proper in the area of the levels last to rise. Our present invention, on the other hand, does not tend to minimize the absorption of heat from the molten mass in the upper levels of the solidifying mass in the mold chamber proper until at least a "skin" or thin shell of substantially uniform thickness and strength has been formed along the side walls of the matrix of the mold body proper, and after this "skin" or shell has been formed of suitably substantial uniform thickness, or at a subsequent interval of time, our invention retards radiation of absorbed heat from an area of the exterior surface of the mold side walls, thereby decreasing in said area the heat conductive power of the side walls and thereby decreasing in said area the heat absorptive rate of said side walls.

Referring now to the drawing in which like characters of reference denote corresponding parts and in which for purposes of these illustrations the chamber walls taper moderately to provide no marked increase in cross-section of the mass of molten metal at one end of the chamber relative to the other end.

Fig. 1 is a vertical section through our mold assembly showing a conservator of heat adjustably positioned relative to the walls of the mold.

Fig. 2 is a vertical section of another form of our invention showing a forming ingot in the mold and the conservator of heat positioned against the mold walls.

Fig. 3 is a perspective view of the conservator

of heat partly broken away to show heat insulating material and a compressible facing of heat insulating material.

In Fig. 1 is illustrated a mold having an ingot forming chamber of substantially square cross-section and rounded corners, whose side walls 11 taper moderately upwardly and outwardly substantially uniformly, at least to within a short distance from the top. The mold walls 10 are supported by a stool 2 having guide walls or lugs 3 and the stool is supported by a primary support such as a platform, floor or transfer car 1, and is preferably supported in spaced relation therefrom on legs or feet as shown. The ingot forming chamber is substantially closed at the bottom by the plug 7, which is provided with a circumferential ledge extending beneath the mold walls 10, to be held in position thereby. Below the plug and seated in the annular recess 6 of the stool is a preferably mutable support 9 and below said mutable support is an opening 4 extending vertically through the bottom of the stool. The plug 7 is provided with a recess 8 having a contour suitable to form a protruding end on an ingot 11a. Additional openings 4 extending laterally from the surface of the stool inwardly to the recess 6 may be provided for a purpose more fully described hereinafter, and as shown and described in our co-pending application, Serial Number 223,158, filed simultaneously herewith. The joints in the assembly may be sealed in any suitable and well known manner but preferably including applying argillaceous material such as a mixture of fire clay in a condition having the consistency of heavy tar circumferentially of and angularly on the ledge of the plug so that the mold, when positioned, will squeeze the material upwards to seal the joint between plug and mold walls, and then the seal is allowed to "set." The mold walls 10 are thicker at the upper portions 10a than at the lower portions and are externally circumferentially surrounded by a conservator of heat 12 having the general plane of its inner wall paralleling or suitably shaped to conform to the exterior contour of the mold, preferably being curved or rounded at its inner corners, and extending from substantially the top of the mold walls downwardly for a suitable distance, in this instance, below the horizontal axis of the mold and comprising a body or composition of material 14 of low heat-conductive power progressively decreasing in heat-insulating power from the upper to the lower portions and preferably encased in a frame 13 or chamber suitably shaped which, in this instance, is of substantially triangular shape in section. For purposes of protecting the heat-insulating material 14 during handling and commercial usage, this frame 13 is preferably constructed durably of metal and in sections which may be bolted 20 together through joints 19 and is preferably faced upon its mold wall confronting surfaces by compressible and elastic heat-insulating material such as asbestos pads. The facing material serves to insulate the metallic portions of the frame against the direct conductivity of heat from the mold, and also to provide a renewable or replaceable part which is easily replaced and at small cost at intervals during the commercial life of the more durable and more expensive major portion of the conservator; and the facing, preferably in the form of pads, being of heat-insulating material which is elastic, serves to provide a close fit of the conservator on the external side surface of the mold to efficiently impede the dissipation of heat and to

insure the close fit during expansion of, or contraction of, the mold, or, if desired, before expansion of the mold, and, further, the elastic facing compensates for relative variation in the rates and or extent of expansion or contraction of the metallic mold walls and the conservator of heat; and, still further, the elastic facing co-operates to provide the close fit irrespective of the extent of expansion or contraction, and is preferably supported to provide a forced close fit to the mold walls whereby the facing is pressed; preferably compressed, against the external side surface of the mold walls with its inherent resilience serving to insure the closeness or tightness of fit, and, also, in effect, providing a conservator of heat in resilient engagement with the mold walls. The conservator 12 may be supported in its relative position externally of the mold walls in any suitable and convenient manner such as by the uprights 16 on the movable wedges 17. While we recognize that there may be instances in which the thickness of the mold walls relative to the area of the chamber may be massive, and advantageously so, for example to exert pressure on a forming ingot as described in our co-pending application Serial Number 223,158, filed simultaneously herewith, and, therefore, possess heat-absorbing power of such quantity as to make it immaterial whether the conservator 12 be positioned in heat-insulating contact with the walls of the mold prior to teeming the mold in so far as the formation of a suitably substantially uniform "skin" or shell is concerned, we prefer, generally, to space the conservator from the mold walls prior to teeming the mold so that after the mold has expanded somewhat the conservator can then be positioned hard in contact with the mold and will remain in close contact therewith by the compressed facing during the cooling and radial contraction of the mold, and, preferably the compressible facing is forcibly maintained in hard contact with the outer surface of the mold during the radial contraction of the mold. It will be clear that manipulation of the wedges inwardly forces the conservator upwardly as indicated by the dotted lines into close engagement or hard contact with the side walls of the mold. The feature shown here of supporting the conservator by a primary support such as a platform or transfer car has the advantage of providing a means of bracing or steadying the mold and is useful, generally in serving as a brace or cradle for molds and castings in transfer cars in transit, starting or stopping, and especially for relatively long narrow molds and castings, and castings and or molds in which the upper parts are relatively more massive or wider than the base. Further, it will be observed, that any tendency of the forming ingot to become axially distorted, or undesirably axially distorted, or lean from the perpendicular because the mold is not held level by the stool, or the stool not held level by the platform or car, causing the ingot to lean and provide uneven radial cooling in horizontal areas and stripping difficulties, may be corrected or compensated for by relative adjustment of the supporting uprights by manipulation of the wedges which are, as shown, preferably radially arranged and independent of each other. Recesses 18 are provided in the conservator to house the projecting lugs of the mold, and any suitable heat-insulating material may be used, such as zircon whose co-efficient of expansion is very low and whose thermal conductivity is likewise very low. By supporting the plug 7 in its relative position to the stool 75

and mold chamber by the mutable element or elements 9, means are provided to permit the plug to drop relative to the side walls of the mold and allow the force of gravity to lower the forming ingot relative to the mold side walls, as set forth more completely and generically claimed in our co-pending application Serial Number 223,158, filed simultaneously herewith. As described therein, the element or elements 9, constituting the support for the plug 7 may comprise any suitable material or combinations of materials susceptible to mutability in the presence of heat or pressure, or a combination of heat and pressure, and the rate of mutability may be fixed or variable or a combination of both. For example, we may use a support susceptible to combustion such as wood of any degree of hardness or softness or combinations of both, in laminated assembly or otherwise; or a composition of resin and wax alone or in combination with other material, or a mixture of sand and combustible binder. The relative body movement between the ingot and the side walls of the mold prolongs the usual period of heat-conducting contact between the skin of the ingot and the side walls of the mold and provides in the shell of the ingot a formation of small crystals to a greater radial depth, or thickness, and preferably, this relative body movement is under way while the shell of the ingot is relatively compressible or is sufficiently compressible to be laterally compressed by the mold side walls so that the cross-section of the forming ingot, preferably for the major portion of its length or height, is reduced, so that the width of the container, so to speak, of the fluid or pasty portion of the mass within is narrowed. This action forces the fluid or pasty portion in an upward direction as it settles down in the mold, and, further, the movement of the forming ingot while its shell is relatively compressible against the mold walls maintains co-axial alignment of the ingot, particularly its upper portion or half, with the vertical axis of the mold chamber and counteracts any tendency of the ingot to lean toward one side of the chamber resulting in uneven cooling in a horizontal area or areas. The relative body movement, during this stage, may be produced by withdrawing the mutable support or portions of it or by burning it. The vertical passage 4 in the stool, which may also serve as an opening for a stripper rod is advantageously located centrally below the recess with which it connects and which receives the mutable support and is positioned relative to the mutable support centrally, or substantially centrally, below it so that the support or residue may drop out of the recess, and in the preferred form of mutable support, that is a support at least partially combustible, the vertical passage connecting with the recess also directs air flowing under the raised stool to the support to support combustion. The laterally extending passages 4 in the stool also connect with the recess and the atmosphere. The plug, or chamber bottom-closure, is preferably of sufficiently smaller cross-sectional width than the recess, and is positioned on the mutable support in such a manner as to provide a continuous or circumferential space between the side walls of the recess and the plug in order that the plug may be lowered without risk of jamming in the recess, and, also, so that as the plug becomes lowered and the mutable support withdrawn or burned out cool air, or at least relatively cool air, may flow in through the lateral passages in the stool and circulate around the plug, recess,

lower portion of the ingot and apparatus generally. The bottom of the plug will also be cooled by air in the vertical passage, and the underside of the stool will be cooled by air flowing between the legs or feet. An advantage in providing a mutable support which is combustible is that support for the plug may be withdrawn at a rate controlled by the nature of the support and the supply of air thereto and the origination of combustion may be controlled by the heat conducting quality and or mass of metal through which heat is transmitted to the combustible support and by the supply of air to the support. It will be obvious from the apparatus that these factors can be manually controlled if desired; for example, air can be substantially shut off from the mutable support, or its supply regulated or controlled, for any suitable period by simply placing sheets of suitable material on the primary support and against the plane outer surface of the stool covering up, or partially so, the spaces between the legs or feet of the stool and the outer ends of the laterally extending passages. Further, the combustible support during burning supplies heat in the stool and retards dissipation of heat generally from the lower portion of the ingot and mold, altering the cooling rate of the mold in the lower regions by slowing up the cooling rate. The heat absorbing power of the lower portion of the side walls of a mold is to some degree reduced, and may be by a sufficient supply of heat considerably reduced, while the combustible support is burning and this is of value in altering the relative heat extracting power between the upper and lower portions of a mold, for example in preventing, or tending to prevent the lower portion of the ingot from contracting too fast relative to the lower portion of the mold walls and shrinking away therefrom while the upper portion of the ingot is in contact with the walls of the mold during the relative body movement; and, in addition to altering the relative heat absorbing power of the side walls of a mold, the heat supplied by the combustion of the support slows up the rate of base cooling by retarding the dissipation of heat absorbed from the ingot by the bottom closure, or plug, during the burning of the mutable support and, thereby, prolong the contact of the major part of or substantially the entire lower portion of the ingot skin with the mold walls; also, the supply of heat assists in maintaining the lower portion of the side walls of the ingot shell relatively compressible in this region for at least a part of the time in which the side of the shell is forced inwards or towards the axis of the mass by the side walls of the mold by the relative body movement. In some instances the mutable support may be burned out at such a rate as to cause the plug to drop away from the base of the ingot. Usually, however, while the side walls of the shell are relatively compressible by the mold walls we prefer to burn out the mutable support at a rate to give support to the ingot base during its downward movement. A hot-top 21 is positioned above the ingot forming chamber of the mold body proper which under some conditions is preferred, but the chamber may be otherwise extended, or covered, or left open depending upon conditions of best practice to meet particular circumstances. As shown here the hot top is supported on top of the mold by removable blocks during pouring, and upon removal of the blocks settles on the mass with which it is lowered by the action of the mutable support. The free ends of the mold walls may be heat-insulated by extend-

ing inwardly and circumferentially a projection from the conservator, or otherwise heat-insulated wholly or partially. From the foregoing and the drawing it is clear that the lowering of the plug and the forming ingot by the reduction of the mutable support causes the forming ingot to be held in sliding contact with the tapered chamber walls 11 of the mold.

In Fig. 2 the matrix walls 11 taper moderately inwardly and upwardly uniformly and the thickness of the mold walls is substantially uniform, being slightly thinner in the area opposite the levels last to rise than at the bottom levels and the heat-insulating material 14 in the conservator 12 is wider in cross-section relative to height than in Fig. 1 to indicate the desirability of increasing the heat-insulating effectiveness of the conservator 12 in molds where the cross sectional area of the chamber in the mold body proper is smaller above the bottom. The conservator 12 is positioned relative to the exterior surface of the mold by removable supports 17a to allow the conservator to settle, upon removal of the said supports as shown, in heat-insulating contact with the mold. A recess 8 is provided on the ingot contacting face of the stool to form a protruding end on the ingot 11a. The free ends of the mold walls may be wholly or partially heat-insulated by the conservator, or otherwise and the open end of the chamber of the mold may be provided or not at any time prior to or during the casting with any accessory useful under particular circumstances.

It will be observed from Figures 1 and 2 that the conservator of heat and the side walls of the molds are preferably in telescopic relationship and that the conservator is longitudinally adjustable relative to the sidewalls of the mold and is movable, especially during radial contraction of the mold, in the direction of the increasing tapering with of the mold, so that as the walls of the mold cool and shrink inwardly the conservator is maintained in hard contact, or the facing held compressed, by forcing the conservator upwardly in the apparatus of Fig. 1 by moving the wedges inwardly, or by the force of gravity in the example of Figure 2 and in which the weight of the conservator causes it to maintain a snug or tight fit on the mold side walls during radial or inward contraction of the latter. This feature of telescopic or longitudinal adjustment of the conservator providing a continuous tight fit is believed to have advantages in castings of any cross-sectional width, and to have particular advantage with castings of medium and large cross-sectional dimensions. It will be apparent from the foregoing that the conservator of heat is usually positioned in surrounding relation to the mold prior to pouring, and that the inner periphery of the conservator of heat may, if desired, be spaced slightly enough from the outer periphery of the mold so that the engagement with the mold can be effected by radial expansion of the mold.

The invention is susceptible to variations of forms, proportions and details within the broad principle without departing from the spirit of the invention, and while we have illustrated and described it in its preferred forms, it will be readily seen that the invention can be employed with varying degrees of success in molds having various relative dimensions of the sidewall thickness from top to bottom, such as sidewalls half as thick at the top as at the bottom, but of sufficient mass to have suitable heat-absorbing power in the walls relative to the mass to be cooled.

Therefore, what we claim is:

1. A method of casting ingots including pouring molten metal into a metallic body provided with an ingot-forming chamber of differential horizontal cross-sectional areas and chamber side walls of longitudinally differential thickness, and having the relatively larger cross-sectional portion of the chamber disposed in longitudinally opposite relation to the relatively thinner portion of the side walls, whereby the portion of the poured mass of relatively larger cross-section is in horizontally opposed relation to the relatively thicker portion of the side walls of the mold, absorbing heat at a faster rate radially from the larger horizontal cross-sectional areas and at a slower rate radially from the smaller horizontal cross-sectional areas of the poured mass, and later reducing the rate of heat absorption from the levels of the mass last to rise by retarding the radiation of absorbed heat from a circumferentially extending lateral area of the upper portion of the metallic walls of the mold radially opposite the upper portion of the poured mass.
2. A method of casting ingots including pouring molten metal into a metallic mold body provided with an ingot-forming chamber of progressively tapering cross-sectional areas and chamber side walls of tapering thickness, said mold body having the cross-section of the chamber and the thickness of the side walls progressively increasing in relatively the same longitudinal direction, absorbing heat at a faster rate radially from the larger cross-sectional areas and at a slower rate radially from the smaller horizontal cross-sectional areas of the poured mass, and later progressively reducing the rate of heat absorption from the upper levels of the mass by progressively upwardly retarding the radiation of absorbed heat from a circumferentially extending lateral area of the upper portion of the metallic walls of the mold radially opposite the upper portion of the poured mass.
3. The hereindescribed method of casting metallic ingots including pouring molten metal into a mold, partially freezing the molten mass at least along the side walls of the mold by absorbing heat from the mass by the said side walls at a faster rate towards the levels of poured mass last to rise than at lower levels and continuing the freezing later by reversing the differential rate whereby the lower levels are cooled at a faster rate than the upper levels.
4. The hereindescribed method of casting metallic ingots including pouring molten metal into a mold, partially freezing the molten mass at least along the side walls of the mold by absorbing heat from the mass by the said side walls at a progressively increasing rate in the upper levels at least of the poured mass and then continuing the solidification of the mass by freezing said upper levels of the poured mass at a progressively decreasing rate by progressively increasingly retarding the radiation of absorbed heat by the mold walls opposite said upper levels.
5. A method of casting ingots including pouring molten metal into a metallic body provided with an ingot-forming chamber of differential horizontal cross-sectional areas and chamber side walls of longitudinally differential thickness, and having the relatively larger cross-sectional portion of the chamber disposed in longitudinally opposite relation to the relatively thinner portion of the side walls, whereby the portion of the poured mass of relatively larger cross-section is in horizontally opposed relation to the relatively thicker portion of the side walls of the mold, absorbing heat at a faster rate radially from the larger horizontal cross-sectional areas and at a slower rate radially from the smaller horizontal area of the poured mass, providing sliding contact of the ingot skin with the mold walls by producing a relative longitudinal whole body movement between the poured mass and the chamber side walls, and reducing the rate of heat absorption from the levels of the mass last to rise by retarding the radiation of absorbed heat from a circumferentially extending lateral area of the upper portion of the metallic walls of the mold radially opposite the upper portion of the poured mass.
6. A method of casting ingots including pouring molten metal into a metallic mold provided with an ingot-forming chamber of differential horizontal cross-sectional areas and chamber side walls longitudinally of differential thickness, the relatively larger cross-sectional portion of the chamber being disposed in longitudinally opposite relation to the relatively thinner portion of the side walls, whereby the portion of the poured mass of relatively larger cross-section is in horizontally opposed relation to the relatively thicker portion of the side walls of the mold, absorbing heat at a faster rate radially from the larger horizontal cross-sectional areas and at a slower rate radially from the smaller horizontal areas of the poured mass and forming a shell, laterally compressing the poured mass by the side walls of the mold by producing a relative longitudinal body movement of sliding contact between said mass and walls, retarding during at least part of said relative body movement the cooling of the lower portion of the ingot by supplying heat generated outside the ingot-forming chamber to the lower portion of the metallic mold, and retarding the radiation of absorbed heat from the upper portion of the metallic side walls of the mold radially opposite the ingot-forming chamber and the upper portion of the poured mass.
7. A method of casting ingots including pouring molten metal into a metallic mold provided with an ingot-forming chamber of tapering cross-section, absorbing heat basally and radially from the poured mass, providing sliding contact between the skin of the forming ingot and the mold walls by producing a relative longitudinal body movement between the poured mass and the chamber bottom-closure on the one hand and the chamber side walls on the other hand, and retarding the solidification of the upper portion of the poured mass radially opposite the upper portion of the metallic side walls of the mold by circumferentially retarding the dissipation of heat from the outer peripheral metallic surface of the side walls of the mold in an upper area of the metallic mold by circumferentially engaging, or engaging substantially circumferentially, said outer peripheral surface radially opposite the ingot-forming chamber with heat-insulating material circumferentially extending and separable of the mold and having its inner peripheral plane paralleling the longitudinal plane of the outer periphery of the mold.
8. A method of casting ingots including pouring molten metal into a vertical metallic mold provided with an ingot-forming chamber of tapering cross-section at a rate sufficient to produce a relatively rapid rise of molten metal in the chamber whereby initial peripheral side wall cooling by the mold of the upper portion of the poured mass radially opposite the metallic side

walls of the chamber occurs relatively quickly after commencement of side wall cooling of the lower portion of the poured mass and whereby inward radial cooling of the poured mass for its height in contact with the metallic side walls of the mold progresses at a substantially uniform radial rate for a period of time, continuing to absorb heat radially and also basally from the poured mass to form a skin of solidified metal to confine the molten interior, providing sliding contact between the skin of the forming-ingot and the side walls of the mold by producing a relative longitudinal body movement between the poured mass and the chamber bottom-closure on the one hand and the chamber side walls on the other hand, and retarding the solidification of the upper portion of the poured mass radially opposite the upper portion of the metallic side walls of the chamber by circumferentially retarding the dissipation of heat from the outer peripheral metallic surface of the side walls of the mold in the upper portion radially opposite the ingot-forming chamber by closely surrounding said upper outer peripheral metallic surface with a body of heat-insulating material separable of said mold.

9. A method of casting an ingot in a vertical metallic mold provided with an ingot-forming chamber of tapering cross-section which includes pouring molten metal into the chamber at a temperature sufficiently high above the freezing point of the molten metal relative to the relationship of the cross-sectional thickness of the side walls of the mold to the cross-section of the ingot-forming chamber so that heat absorbed by the mold walls from the poured mass heats the outer metallic periphery of the upper portion of the mold while at least the interior of the upper portion of the poured mass is still molten radially opposite the upper portion of the inner metallic periphery of the ingot-forming chamber, providing sliding contact between the skin of the partially solidified mass and the side walls of the mold by producing a relative longitudinal body movement between the poured mass and the chamber bottom-closure on the one hand and the chamber side walls on the other hand, and allowing absorbed heat to radiate normally from the outer periphery of the lower portion of the side walls of the mold while retarding the solidification of the upper portion of the poured mass radially opposite the upper portion of the metallic side walls of the chamber by circumferentially retarding the dissipation of heat from the outer peripheral metallic surface of the side walls of the mold in the upper portion radially opposite the ingot-forming chamber by closely surrounding said upper outer peripheral metallic surface with a body of heat-insulating material separable of said mold.

10. A method of casting an ingot in a vertical metallic mold provided with an ingot-forming chamber of tapering cross-section which includes pouring molten metal into the chamber at a rate to produce a relatively rapid rise of molten metal in the chamber whereby initial peripheral side wall cooling by the mold of the upper portion of poured mass radially opposite the metallic side walls of the chamber occurs relatively quickly after commencement of side wall cooling of the lower portion of the poured mass and inward radial cooling of the poured mass for its height in contact with the metallic side walls of the mold progresses at a substantially uniform radial rate for a period of time, and pouring said molten

metal at a temperature sufficiently high above its freezing point relative to the relationship of the cross-sectional thickness of the side walls of the mold to the cross-section of the ingot-forming chamber so that heat absorbed by the mold walls from the poured mass heats the outer metallic periphery of the upper portion of the mold while at least the interior of the upper portion of the poured mass is still molten radially opposite the upper portion of the inner metallic periphery of the ingot-forming chamber, providing sliding contact between the skin of the partially solidified mass and the side walls of the mold by producing a relative longitudinal body movement between the poured mass and the chamber bottom-closure on the one hand and the chamber side walls on the other hand, and retarding the solidification of the upper portion of the poured mass radially opposite the upper portion of the metallic side walls of the chamber by circumferentially retarding the dissipation of heat from the outer peripheral metallic surface of the side walls of the mold in the upper portion radially opposite the ingot-forming chamber by closely surrounding said upper outer peripheral metallic surface with a body of heat-insulating material separable of said mold.

11. In a method of producing an ingot from molten metal poured into a metallic mold provided with an ingot-forming chamber of tapering cross-section, the process of solidifying a part of the poured mass which includes absorbing heat basally and radially from the poured mass, providing sliding contact of the skin of the forming ingot and the mold walls by producing a relative longitudinal body movement between the poured mass and chamber bottom-closure on the one hand and the chamber side walls on the other hand, and retarding during at least part of the relative body movement the cooling of the lower portion of the ingot by supplying heat generated outside the ingot-forming chamber to the lower portion of the metallic mold.

12. A method of casting ingots including pouring molten metal into a metallic mold provided with an ingot-forming chamber of tapering cross-section, absorbing heat basally and radially from the poured mass, providing sliding contact of the skin of the forming ingot and the mold walls by producing a relative longitudinal body movement between the poured mass and chamber bottom-closure on the one hand and the chamber side walls on the other hand, retarding during at least part of the relative body movement the cooling of the lower portion of the ingot by supplying heat generated outside the ingot-forming chamber to the lower portion of the mold, then increasing the cooling of the lower portion of the ingot relative to its upper portion radially opposite the metallic side walls of the mold.

13. In a method of producing an ingot from molten metal poured into a metallic mold provided with an ingot-forming chamber of tapering cross-section, the process of solidifying a part of the poured mass which includes absorbing heat basally and radially from the poured mass and forming a shell, laterally compressing the poured mass by the side walls of the mold by producing a relative longitudinal body movement of sliding contact between said mass and walls, retarding during at least part of said relative body movement the cooling of the lower portion of the ingot by supplying heat generated outside the ingot-forming chamber to the lower portion of the metallic mold, then increasing the cooling

of the lower portion of the ingot relative to its upper portion radially opposite the metallic side walls of the mold.

14. A method of casting ingots including pouring molten metal into a metallic mold provided with an ingot-forming chamber of tapering cross-section, absorbing heat basally and radially from the poured mass and forming a shell, laterally compressing the poured mass by the side walls of the mold by producing a relative longitudinal body movement of sliding contact between said mass and walls, retarding during at least part of said relative body movement the cooling of the lower portion of the ingot by supplying heat generated outside the ingot-forming chamber to the lower portion of the metallic mold, and retarding the radiation of absorbed heat from the upper portion of the metallic side walls of the mold radially opposite the ingot-forming chamber.

15. A method of casting ingots including supporting a sleeve-like conservator of heat, open at top and bottom and provided with a circumferentially extending body of heat-insulating material, telescopically movable to and surrounding the upper portion of the side walls of a metallic ingot mold provided with an ingot-forming chamber of tapering cross-section, then pouring molten metal into the chamber of the mold, partially solidifying the poured mass to form a skin confining the molten interior, providing sliding contact of the skin of the poured mass and the side walls of the mold by producing a relative longitudinal body movement between the poured mass and the metallic side walls of the mold, and retarding the solidification of the upper portion of the poured mass radially opposite the upper portion of the metallic side walls of the mold and the dissipation of heat from said upper portion of the mold by telescopically moving the conservator of heat into peripheral engagement with the outer periphery of the upper metallic portion of the side walls of the mold.

16. A method of casting metal ingots including pouring molten metal into a vertical metallic mold provided with an ingot-forming chamber of tapering cross-sectional width, freezing the poured mass for an interval of time circumferentially along the side walls of the chamber by absorbing heat at a faster rate radially in the upper levels of poured mass opposite the side walls of the mold than at lower levels, thickening the skin of the forming ingot by producing a relative sliding longitudinal whole body movement between the ingot and the side walls of the mold and prolonging thereby the normal time of direct contact between said skin and chamber side walls, and retarding the radiation of heat from the external surface of the metallic side walls of the mold in an upper circumferentially extending area radially opposite the ingot-forming chamber.

17. In a method of casting metal ingots including pouring molten metal into a metallic mold provided with an ingot-forming chamber of upwardly and outwardly tapering cross-sectional width, the process of solidifying the molten metal which includes conducting heat from the base of the poured mass and partially freezing the mass circumferentially along the side walls of the chamber by absorbing heat at a faster rate radially at upper levels than at lower levels of said mass, permitting heat to radiate normally from the external surface of the side walls of the mold while causing a relative longitudinal whole body

movement between the forming ingot and the side walls of the mold to continue direct radial conductivity of heat from the poured mass for a further interval, and continuing the cooling of the poured metal by circumferentially retarding the radiation of heat from the external surface of the side walls of the mold in an upper area of the metallic mold.

18. The method of casting ingots which includes positioning in the region of the upper end of a vertical metallic mold provided with an ingot-forming chamber of upwardly and outwardly tapering cross-section a hot top, removably supporting with the temporary co-operation of the mold the hot top in a manner whereby the hot top may be lowered relatively to, and downwardly in, the ingot-forming chamber, pouring molten metal into the chamber of the metallic mold, floating the hot top on the poured mass, at least partially filling the hot top with molten metal, lowering the poured mass when partially solidified together with the hot top in the chamber to thereby prolong the normal time of contact between the poured mass and the metallic side walls of the mold, and retarding the solidification of the upper portion of the poured mass below the hot top and the dissipation of heat from the upper portion of the metallic side walls of the mold radially opposite said upper portion of the poured mass by closely surrounding the upper outer peripheral metallic surface of the side walls of the mold with a body of heat-insulating material.

19. For an ingot mold assembly, a separable conservator of heat including a circumferentially extending body of heat-insulating material and a resiliently yieldable inner peripheral wall surrounding a hollow portion and defining variably the cross-section of the hollow portion, the inner peripheral plane of said wall being radially expandable by, and shaped for close circumferentially extending lateral contact with, the outer peripheral surface of the side walls of an ingot mold surrounding the upper portion of the ingot-forming chamber.

20. For an ingot mold assembly, a separable conservator of heat including a circumferentially extending body of heat-insulating material supported by a frame of relatively hard material, means laterally retaining said material, and a relatively soft, elastic compressible heat-insulating facing provided on the conservator radially inwardly of said body of heat-insulating material, said facing surrounding and confronting a hollow portion of the conservator and adapted to telescopically receive and peripherally engage in a forced fit the upper portion of the outer periphery of the side walls of a mold.

21. In an ingot mold assembly, the combination of a metallic mold body having tapered cross-sectional width providing a tapering external peripheral side wall surface, and a separable conservator of heat including a circumferentially extending body of heat-insulating material of progressively increasing thickness in cross-section supported by a frame, said conservator of heat provided with an inner peripheral wall shaped for close surrounding engagement with the external side surface of the chamber of the mold and surrounding a hollow portion of tapering cross-sectional dimension telescopically receiving the upper portion of the mold, and said conservator supported longitudinally adjustable relative to the external lateral surface of the side walls of the mold, with the tapered outer peripheral side surface of the mold body adapted to

co-operate with the tapered inner peripheral wall of the conservator to provide a close fit and to solely limit by a relative wedging action therewith longitudinal movement of the conservator in the direction of the increasing width of the mold body.

22. Apparatus for casting ingots including a metallic mold body of upwardly increasing width having its outer peripheral surface longitudinally tapering upwardly and outwardly, a separable conservator of heat including a sleeve-like body of heat-insulating material surrounding a hollow portion of upwardly and outwardly increasing cross-section telescopically receiving the mold body, and means supporting the conservator of heat with the peripheral plane of its inner peripheral surface parallel to the tapering plane of the outer peripheral surface of the mold body.

23. Apparatus for casting metal ingots including an ingot mold and a separable conservator of heat provided with a circumferentially extending sleeve-like body of heat-insulating material carried by a frame, said conservator of heat having its inner wall shaped in a plane adapted to circumferentially confront an area of the external surface of the mold, a facing of compressible insulating material provided on the mold-confronting wall of the conservator of heat, means to support the conservator of heat independently of and surrounding the mold walls radially opposite the ingot-forming chamber, and means to force the conservator of heat to the mold with the compressible facing pressed against a circumferential area of the external surface of the side walls of the mold and means to maintain the facing compressed laterally against the mold radially opposite the ingot chamber during contraction of the mold.

24. In apparatus for casting metal ingots, a

mold provided with a vertically extending ingot-forming chamber having upwardly and outwardly tapering inner walls, a stool to support the mold and having a recess formed in its mold-confronting side, a mutable support positioned in the recess, a separable chamber-closure member for the mold, said closure-member supported by the mutable support and adapted to radially extend below the plane of the bottom ends of the side walls of the mold and be held down thereby, a circumferentially extending wall provided in the stool and adapted to externally surround the side walls of the chamber and terminating outwardly in a higher plane than, and inwardly in a lower plane than the bottom ends of said walls to define said recess and confront the side of the chamber-closure, and at least one passage of suitable dimension provided in the stool and leading from said recess through the stool wall, a conservator of heat surrounding the mold, a compressible heat-insulating facing providing the mold-confronting wall, and means to support said conservator of heat telescopically adjustable to the external surface of the side walls of the mold.

25. In apparatus for casting ingots, an ingot mold assembly including the combination of a vertically extending metallic mold body provided with an ingot-forming chamber of tapered cross-section and a separable metallic bottom closure, a combustible support supporting the one longitudinally movable relatively to the other and adapted to supply heat to the lower portion of the mold during diminution of said combustible support, rigid means in the bottom of the assembly to support the combustible support, and means to supply air to the combustible support.

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