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K. H. STEIGERWALD
METHOD AND MEANS FOR CONTINUOUS CASTING
EMPLOYING COMPARTMENTED MOLDS

3,085,303

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4 Sheets-Sheet 2

Fig. 2e

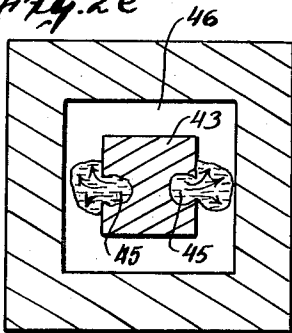


Fig. 3a

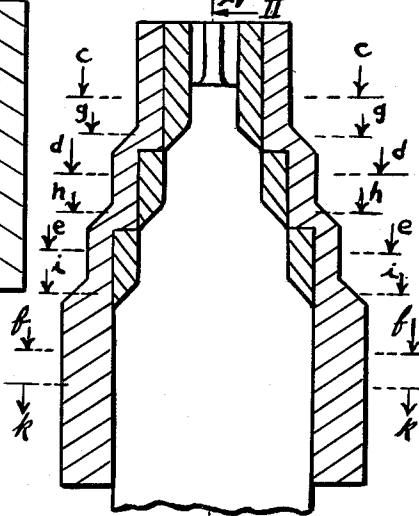


Fig. 3b

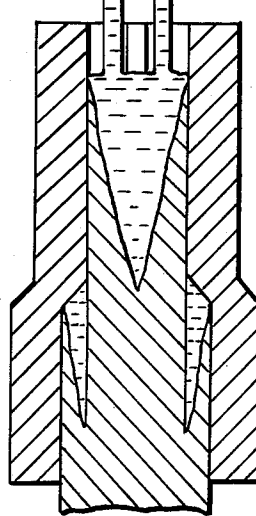


Fig. 3c

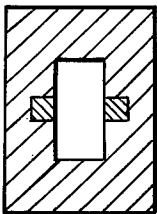


Fig. 3d

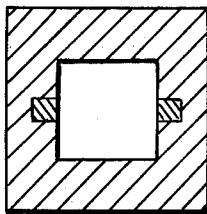


Fig. 3e

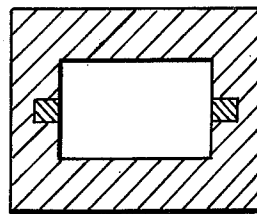


Fig. 3f

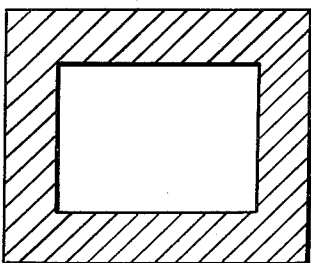


Fig. 3g



Fig. 3h



Fig. 3i



Fig. 3k

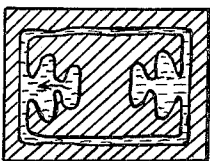


Fig. 3m

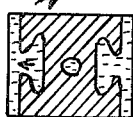


Fig. 3n

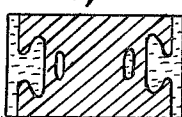
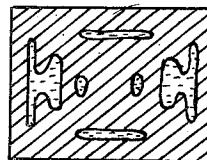


Fig. 3o



Fig. 3l

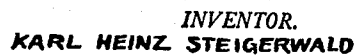
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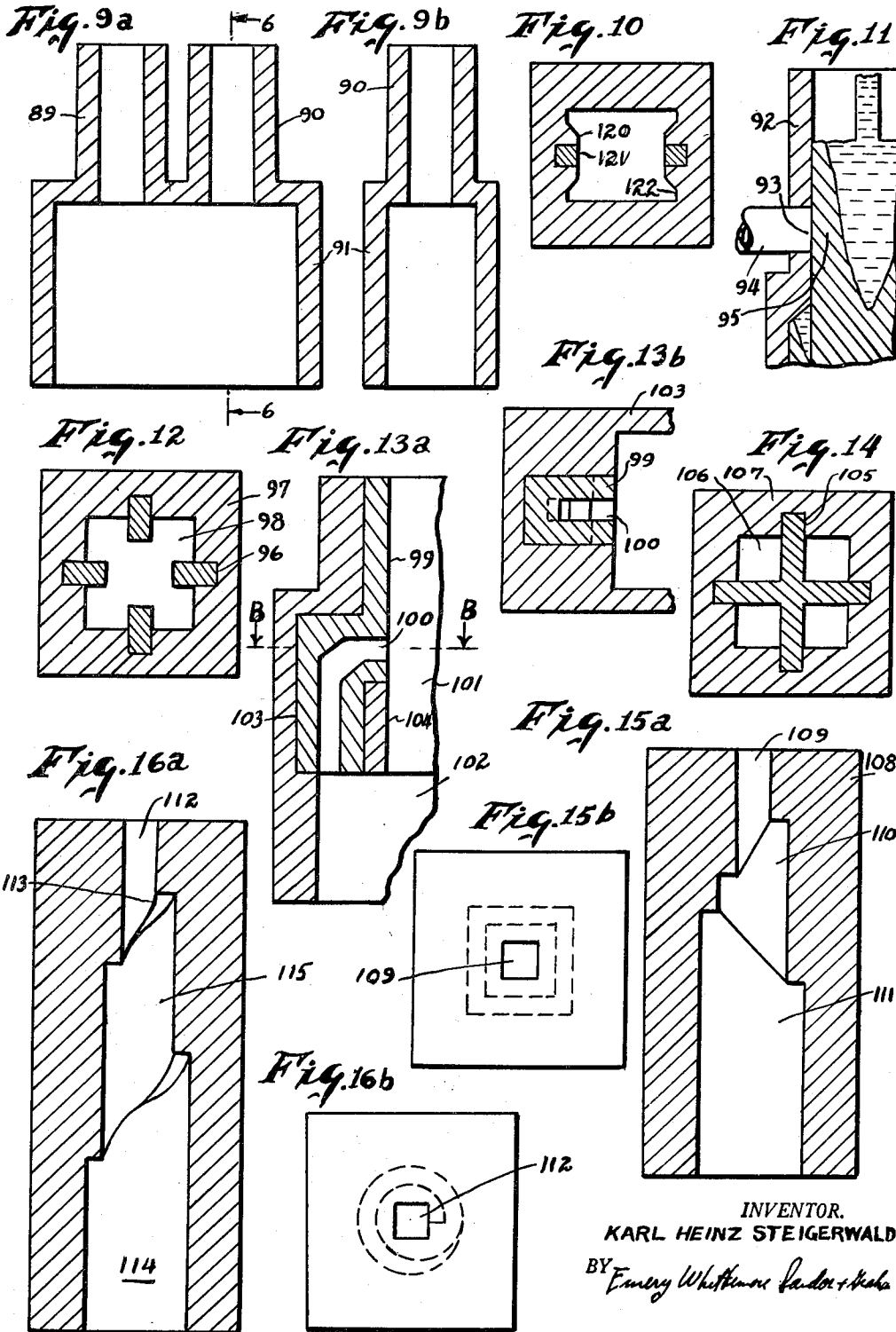
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4 Sheets-Sheet 4



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METHOD AND MEANS FOR CONTINUOUS CASTING EMPLOYING COMPARTMENTED MOLDS

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8 Claims. (Cl. 22-139)

This invention relates to the continuous casting of liquid metal, and more particularly, to continuous casting in which heat flow between the mold and the casting is improved by the mold configuration.

The continuous casting process is known to the art. In a typical process, liquid metal is cast into a continuous strand by a vertical bottomless mold. The walls of the mold are cooled so that the heat is removed from the liquid metal by the wall and the metal solidifies from the exterior to the interior in a strand. The resulting strand or casting is drawn from the mold.

The shrinkage of the metal during solidification of the casting causes separation of the casting skin from the mold walls in comparatively short time. After separation of the skin from the mold walls, the heat flow between the surface of the casting and the mold is substantially reduced. Reduction of the rate of heat transfer limits the casting speed. Lengthening of the mold beyond the minimum safe length (the length necessary to ensure solidification of the shell of the casting to a thickness sufficient to withstand the hydrostatic pressure of the enclosed molten liquid) does not substantially increase the cooling effect and, thus, the production rate. This can be easily understood by recognition of the fact that the separation between the casting skin and the mold walls is the basic cause of any decrease of heat transfer.

Although the decrease in rate of casting due to such separation is observable in all casting processes, it is particularly disturbing when large castings are made. In the casting of large strands or slabs the change of heat flow has even greater influence because the maximum possible casting rate is essentially an inverse function of the cross-sectional area of the casting.

Also, since the solidification of the liquid mass proceeds from the exterior to the interior of the casting, the crystal growth is similarly oriented. The formation of dendritic crystals oriented to point to the strand's center adversely affects the properties of the cast strand, particularly the resistance of the strand to transverse bending.

Moreover, the shrinkage of the core material as the strand solidifies from the skin to the interior often forms pipes and develops stresses and cracks in the casting. Such faults are particularly prejudicial to the utilization of such castings for engineering construction.

The art has attempted to obtain more uniform cooling across the entire cross section of the casting by emersion of cold materials of the same composition as the molten metal in the melt as it is poured into the continuous casting mold. These attempts have not, however, given satisfactory results.

It is, therefore, one object of this invention to provide a continuous casting method and apparatus in which the casting rate is increased over that possible with apparatus of prior art.

It is a further object of this invention to provide a continuous casting method and apparatus in which the cast strand is cooled at the interior and the exterior.

It is a further object of this invention to provide an improved method and apparatus for the continuous casting of metal in which the strand exhibits a more favorable crystallization.

It is a further object of this invention to provide a continuous casting mold in which the cast strand skin is solidified in axially extending sections separated by molten

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metal to maintain physical contact of the skin with the mold over the entire mold length.

It is a further object of this invention to provide an improved method and means for the casting of the metal using a multiple chamber mold of increasing cross-sectional area in which the chambers are filled with molten metal to progressively increase the cross section of the strand.

In accordance with these objects there is provided in a preferred embodiment of this invention a mold having a plurality of contiguous mold chambers of increasing cross sectional area. The strand is thus built up in stages and at each stage the central strand formed by the preceding stage serves as a path for heat transfer to cool the molten metal in addition to the cooling of the metal by the mold walls. The decreased length of path for heat transfer over the heated sections favorably influences the crystal growth of the cast strand. Further, the crystallization is controllable by control of the dimensions of the contiguous chambers.

The control afforded at each stage allows casting of strands of cross sectional shape which have been difficult to obtain by previously known methods such as round strands. Further, the control makes feasible casting of a round strand out of two or more chambers, the cross sectional areas of which need not be circular in shape.

In the use of such multiple molds it is possible to decrease the length of the crater formed in the top of the cast strand. The shortening of the crater and increase of apex angle thereof greatly reduces the danger of piping even at high rates of casting.

To form the casting it is necessary to supply molten metal to each of the chambers to ensure filling of the chambers to develop the strand of the desired cross sectional dimensions. The necessary supply of molten metal may advantageously be supplied to each chamber of increased cross sectional area by providing axially extending strips of poor thermal conductivity and good heat resistance in the preceded section. The strand will not solidify along the strip, providing a passage for the flow of molten material into the next mold chamber. If necessary, the strip may be artificially heated to maintain the passage-way in molten form.

By positioning the strips on diametrically opposed wall portions, the metal in the mold solidifies in axially extending skin sections which are separated by molten metal.

Thus, the solidified skin portions remain in contact with the mold walls for efficient heat transfer thereto. No connecting skin exists between the solidified skin portions to pull the solidified skin from the mold walls. For example, if the strips are positioned along the midpoint of the end walls of a rectangular mold, the skin solidified along the side walls will remain in contact with the side walls since the side wall portions are not connected by an end wall skin which would pull the side walls from the mold during shrinkage of the end walls. Thus, it is possible to maintain contact of the skin with the mold walls until the strand leaves the mold.

In another embodiment of this invention the liquid metal in the chambers of increased cross sectional area may be piped directly to the individual chambers. To prevent solidification of material within such piping, the piping should be made of material having a poor thermal conductivity and high heat resistance.

In a still further embodiment of this invention at least one mold wall is maintained sufficiently short to preclude solidification of the material in contact therewith. By this means, the liquid metal is supplied to subsequent chambers directly and the inserts of heat resistant material of poor thermal conductivity is not necessary.

In all embodiments, it is advisable to make the dif-

ference of cross sectional area between the separate chambers as small as possible. In such manner filling of the space resulting from the shrinkage of the strand is ensured by the additional molten material flowing therein and at the same time a continuous casting is produced with no discontinuities at the junction between the original strand and the added material.

It should be noted that in each embodiment the separate mold chambers may be symmetrical or unsymmetrical one to the other. Additionally, the various steps in a mold chamber can have similar or different shapes.

The invention will be more clearly understood by reference to the following description taken in conjunction with the accompanying drawings of which:

FIGURE 1 is a schematic view in cross section of a continuous casting process in accordance with the prior art.

FIGURE 2 is a diagrammatic view of a two-stage continuous casting mold in accordance with the present invention of which FIGURE 2a is a partially sectioned perspective view and FIGURE 2b is a sectional view taken along lines B—B of FIGURE 2; FIGURE 2c is a sectional view taken along lines C—C of FIGURE 2a; 2d is a sectional view taken along lines D—D of FIGURE 2b; and FIGURE 2e is a sectional view taken along lines E—E of FIG. 2b.

FIGURE 3 is a diagrammatic view of a multiple stage mold according to the present invention in which FIGURE 3a is a vertical sectional view; FIGURE 3b is a sectional view taken along lines II—II of FIGURE 3a; FIGS. 3c—3f are sectional views of the mold taken along lines c—c, d—d, e—e and f—f respectively; and FIGS. 3g—3k are sectioned views of the casting taken along lines g—g, h—h, i—i and k—k respectively; and FIGS. 3l—3o are sectional views of the casting taken along lines g—g, h—h, i—i and k—k respectively in a different state of solidification.

FIGURE 4 is a diagrammatic view of a two-stage mold with the contiguous chambers arranged unsymmetrically in which FIGURE 4a is a vertical section through a two-stage mold and FIGURE 4b is a section through lines B—B of FIGURE 4a.

FIGURE 5 is a diagrammatic view of a two-stage mold with a square and circular contiguous chamber in which FIGURE 5a is a vertical section, 5b is a section taken along lines b—b of FIGURE 5a and FIGURE 5c is a section taken along lines c—c of FIGURE 5a.

FIGURE 6 is a sectional view of a two-stage mold in accordance with the present invention in which the mold chambers are movable relative one to the other.

FIGURE 7 is a sectioned view of a two-stage mold having an opening in a mold wall between two mold chambers.

FIGURE 8 is a sectional view of a two-stage mold with the steps partially fitted one into the other, in which FIG. 8a is a plan view of the top of the mold and FIG. 8b is a sectional view taken along line b—b of FIG. 8a.

FIGURE 9 is a sectional view of a two-stage mold for a continuous casting of a slab in which two mold chambers jointly feed a parallel second mold chamber of larger cross sectional area in which FIGURE 9a is a vertical section and FIGURE 9b is a section taken along lines G—G of FIGURE 9a.

FIGURE 10 is a cross sectional view of a mold step.

FIGURE 11 is a diagrammatic sectioned view of a mold in accordance with the present invention including means for evacuating the mold chambers.

FIGURE 12 is a cross sectional view of a mold having axially extending inserts dimensioned to protrude into the casting cavity.

FIGURE 13 is a partially sectioned view of a mold chamber having an insert for channeling the molten metal from one mold chamber to the next mold chamber in

which FIGURE 13a is a cross sectional view along the axis of the mold and FIGURE 13b is a cross sectional view taken along line B—B of 13a.

FIGURE 14 is a cross sectional view of a mold chamber separated into areas of smaller cross sectional area by intersecting inserts of high heat resistance and poor thermal conductivity;

FIGURE 15 is a schematic diagram of a three-step cascade mold with obliquely cut steps between the mold chambers in which FIGURE 15a is a cross sectional view taken axially along the mold and FIGURE 15b is a plan view of the top of the mold.

FIGURE 16 shows a cascade mold with a spirally expanding shaft in which FIGURE 16a is a cross sectional view taken along the axis of the mold and FIGURE 16b is a plan view of the top of the mold.

In FIGURE 1 there is shown a conventional continuous casting mold in which the liquid metal 11 is poured into the mold 12. In the mold, heat is removed from the molten metal by the water cooled walls of the mold. As the heat is removed from the metal, the metal solidifies into a completely or partially solidified cylindrical strand 13 and leaves the mold. The strand or casting is pulled from the mold by conventional means such as withdrawal rollers. Such equipment and the process of casting therein is well known and only the few characteristics of interest are illustrated in FIGURE 1.

When the liquid metal comes into contact with the cooled wall of the mold, a self-containing shell of partially solidified metal is quickly formed about the periphery of the cylindrical casting. The cylindrical shell must be sufficiently thick when it leaves the mold so as to contain the hydrostatic head of the molten material contained thereby.

Of course, initially the shell is in close contact with the wall, since the liquid material flows until it is restrained by the mold walls. However, subsequently, the strengthened shell of the solidified material shrinks and parts from the mold as at line 19.

Thus, a casting is in contact with the mold only over a small portion (between lines 18 and 19) of the total mold axial length. In this area, of course, effective cooling takes place to form the skin of the mold. However, as the casting passes below line 19 shrinkage of the skin of the strand causes a gap to exist between the strand skin and the mold wall. This gap causes a noticeable decrease in heat transfer between the casting and the mold wall. For this reason, elongation of the mold in an axial direction does not produce any noticeable gain in the rate of heat transfer. Thus the casting speed with such molds is limited.

Further, it is typical of such processes of continuous casting that a crater 20 of generally sharply conical shape filled with molten metal forms in the center of the cast strand. The shape and length of the crater depends essentially upon the following factors; (a) the thermal properties of the cast metal, (b) the cooling properties of the mold, (c) the size of the cross sectional area and the shape of the mold cross section, and (d) the rate of the casting.

In addition to the influence of the crater upon the rate of casting in such continuous casting process, the shape and length influences the quality of the casting. Since the conical crater contains molten metal, the conical section has the material of the highest temperature on the inside of the casting dropping to a minimum temperature at the outside. Cooling of the casting in this fashion produces a crystallization which in many cases inhibits the use of continuous cast columns for structural purposes. Further, the crater formation leads to other faults such as pipe, porosity and cracking.

Unfortunately, the failure rate and the limits of rates of casting by the continuous casting process become in-

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creasingly aggravated as the cross section of the casting increases and as the rate of casting increases.

The faults associated with casting according to the prior art is obviated by cooling the casting from the interior thereof as well as cooling the casting by the heat transfer to the mold walls. An apparatus in accordance with this invention for so effecting the cooling of the casting is shown in FIGURE 2.

In FIGS. 2a—2e there is shown a continuous casting composite mold for the vertical casting of strands of molten metal poured therein. The composite mold comprises two contiguous concentric molds or mold chambers 30 and 31.

As in the formation of molds common to the art of continuous casting, the mold shown in FIGURE 2 may be fabricated from copper and water cooled in conventional fashion as by water cooling ports 16.

The mold shaft of chamber 30 and shaft of the mold 31 are both formed with a square cross sectional shape by walls 32, 33 respectively. The area of shaft 32 is approximately $\frac{1}{2}$ of the area of the cross section of shaft 33.

On diametrically opposed wall portions of walls 32 of the shaft in mold 30, axially extending inserts 34, 35 are provided. The inserts are fabricated of material having good heat resistance but poor thermal conductivity.

In operation, molten metal 36 is poured into the mold and it is cast into a strand by mold walls 32 of mold chamber 30. Continuous movement of the cast strand will cause the strand to be moved into the mold chamber 31. In the mold chamber 31 additional metal is cast on the periphery of the strand formed by chamber 30 to increase the cross sectional area of the resultant strand. During such addition the strand formed by chamber 30 will serve as a heat conducting path to cool the interior of the strand cast by mold chamber 31 eliminating the faults encountered by exterior cooling alone.

To supply the chamber 31 with the molten metal in order to fill the chamber to the periphery thereof, there must be provided means for conducting molten material from the entrance port of the mold chamber 30 to the mold chamber 31.

The inserts 34, 35 extending axially along the walls of the mold chamber 31 serve this purpose by preventing solidification of the material into a skin along the axially extending strips. As best seen by reference to FIGURES 2b and 2d simultaneously the axially extending strips of material having poor thermal conductivity prevents solidification of the skin. Thus, there is provided a path for the flow of molten metal from chamber 30 to the chamber 31.

As the casting moves through the mold, the skin is first formed in axially extending sections 39 by the cooled walls of the mold. The skin sections 39 are separated by molten metal extending between the axially extending strips 34 and 35 since the poor thermal conductivity of the axially extending strips prevents solidification of the molten metal. As the strand progresses through the mold chamber 30 it is solidified into a strand 43 with axially extending passages 45 for the flow of molten metal to the chamber 31.

In the second mold chamber 31, the strand is immersed in the molten metal 57 flowing therein through the passages in the strand formed in the first chamber. The metal 57 will solidify into the strand of final dimensions by heat transfer to both the mold walls and the strand cast by the mold chamber 30.

The molten metal 57 will solidify, joining strands 39 at 52, 53, 54 and 55, to form the final strand 47. The molten metal 57 forms the same crater configuration as the crater 56 in the top of mold chamber 30.

It will be noted that the strand in both mold sections is connected by solidified metal. Thus the usual withdrawal rollers may be employed to pull the completed strand from the composite mold. In many cases, the molten metal surrounding the strands 39 will cause some

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melting thereof as indicated at 58. The melting augments proper joinder at the interface and causes no difficulty since the composite strand is always coupled through solidified metal.

As will be noted from the drawings, the strand advances at the same speed through both chambers. Thus the chambers may be oscillated in the usual fashion and other casting aids such as a vacuum at the exit end of the mold may be employed if desired for the application intended.

In addition to providing an unsolidified path for the flow of molten metal the axially extending inserts vastly improve the rate of cooling of the cast strand. Along the axially extending strips, the strand is maintained in the molten condition. Thus, the strand skin sections 39 formed by contact with the cooled surfaces of the mold are not connected by solidified metal which would exert a force to pull the skin from the mold walls during shrinkage thereof. Instead, the diametrically opposed skin sections 39 are separated by molten metal and the skin sections will maintain their contact with the cooling mold walls throughout the entire axial length of the mold.

It will be recognized that the process of casting by additive casting of a plurality of increased sections upon a central strand of smaller dimension can be variously modified to suit the application intended. For example, the length of the mold step may be varied to conform to a systematic distribution of cooling and non-cooling elements inside the individual mold steps.

Similarly, each mold step can be variously modified to suit the application intended by variation of the arrangement of cooling and non-cooling elements in each step.

Further, it is possible, of course, to cascade more than two steps when it is desirable to cast a strand of large finished dimensions. Control of the cooling at each step is provided by maintaining the increase in cross sections of contiguous chambers to thereby keep the path of heat transfer across the added strand portion small. An arrangement which may be advantageously used in such applications is shown in FIGURE 3.

In FIGS. 3a—3o there is a multiple mold having four transverse steps and two longitudinal steps, as is best illustrated by FIGURES 3c—2f which are sections of the mold taken along lines c—c, d—d, e—e and f—f respectively on FIG. 3a.

Thus, it can be seen that the strand is slowly built up from a small rectangle in gradually increasing steps to a large square strand.

During movement of the molten material through the mold chambers as explained in connection with FIGURE 2 and is illustrated by FIGURES 3g through 3k, the molten metal will solidify on the mold walls in two strand skin sections separated from each other by molten material.

By properly dimensioning the step length with respect to the increase in cross sectional area at each chamber step, the solidification of the center of the strand will proceed without isolating a subsequent chamber from the source of molten metal. In order to provide for the flow of molten metal, axially extending strips of heat resistant material of poor thermal conductivity are inserted in each of the mold chambers except the last mold chamber.

By varying the length of each mold chamber, the solidification of the strand can be controlled. For example, in FIGURES 3l to 3o there is shown a plurality of sections of a strand along the same section lines as FIGURES 3g to 3k in which, however, the cooling effect in each chamber has been increased as for example by increase in the chamber axial length. As illustrated, the strand solidifies faster without, however, interfering with the passage provided for flow of molten metal to each chamber. It is, of course, necessary to maintain the passageway to prevent gas entrapment and to prevent piping.

In the embodiments illustrated thus far, concentric

mold chambers have been shown. However, with this process concentricity of the mold chambers is not required. Where it is desirable to provide eccentric mold chambers, as for example, for simplicity of mold construction the embodiments shown in FIGURE 4 may advantageously be employed.

In FIGS. 4a and 4b there is shown a composite mold comprising a chamber 71 and a chamber 72 in which the chambers are contiguous one to the other but in which the axis thereof are displaced one from the other.

By displacing the axial position of the two chambers as shown, the mold walls 73 and 74 extend as straight walls across both chambers and may be formed in a continuous length. The chamber may then be formed and supported on the continuous wall portion. An axially extending 75 of heat resistant material having poor thermal conductivity is provided in the wall portion of the upper mold 71 so that a passageway to mold 72 is provided.

The insert of heat resistant material of poor thermal conductivity is preferably placed as close to the axis of the second chamber 72 as is possible to ensure the shortest flow distance to the periphery thereof.

In many applications it is desirable that the final stage of the composite mold be of one cross sectional shape but that the intermediate chambers be of different cross sectional shapes as, for example, for the heat transfer characteristics of the shapes involved. In such applications the embodiment shown in FIGURE 5 may advantageously be employed.

In FIGURE 5a there is shown a composite mold in which the first mold chamber, illustrated in cross section in FIGURE 5b, is square in cross sectional shape. The second mold chamber arranged contiguous thereto is circular in cross sectional shape, illustrated in cross section in FIGURE 5c. In such matter the cast strand can take a cylindrical form. However, the increased cooling effect of the square mold is utilized in the initial strand formation for increased heat flow to the walls of the mold and thus a higher casting rate.

In many applications it is advantageous to have the various mold chambers integrally formed in a single mold. In other applications it is desirable to fabricate the separate chambers so that, for example, they may be oscillated with different phase relationships during the casting process. In such applications the embodiment shown in FIGURE 6 may advantageously be employed.

In FIGURE 6 there is shown a mold comprising a mold chamber 76 which is movably mounted on axially extending guide rails 78 upon which the mold is mounted by means of struts 77. A second mold chamber 79 the bore of which matches the external periphery of the chamber 76 is movably positioned in telescopic relationship to the mold chamber 76. The mold 79 is similarly movably mounted on guide rails 78 by means of struts 80.

In such application the molds may be reciprocated in accordance with the speed of casting in conventional fashion and the phase relationship may be adjusted to suit the casting contained therein. For example, chamber 76 may be moved in the direction of arrow 81 at the same time that mold chamber 79 is moved in the direction of arrow 82. Of course, different phase relationships than a 180° phase relationship may be maintained between the oscillations of the respective mold chambers.

Between the mold steps a circular orifice can remain open or it is possible to provide window shaped openings at the gate between the two steps as is shown schematically by the opening 83 in FIGURE 7. The opening 83 can port the lower mold into a shaft-like chamber formed by an extension of the lower mold illustrated in dotted outline as extension 84 in the FIGURE 7.

In FIGS. 8a and 8b there is shown a mold comprising two cascade steps in which the chamber is defined by wall 85 and the chamber of a larger dimension defined by wall 86. To provide a passageway for flow of molten

metal into the chamber of larger dimensions, the mold chamber defined by wall 85 is provided with a plurality of axially extending inserts 88 of high heat resistance but poor thermal conductivity.

The molds are joined at the tops thereof by outwardly extending ribs 87. At the base of the small chamber there is provided a peripherally extending rectangle 89 of the insert material to join the inserts together and to completely separate the inner chamber from the outer chamber. It will be noted that the inserts are the same thickness as the mold chamber walls 85.

With the arrangement shown in FIGURE 8, it is possible to let the liquid metal in the chamber defined by walls 86 extend over the lower end 89 of the chamber 85. It has been found advantageous so to do in order to utilize the cooling effect of the mold wall of the chamber 85 to provide an additional heat path for cooling of the material in the interior of the chamber 86. In such embodiment, the water cooling of chamber 85 will be provided through the ribs 87.

In those applications where it is desirable to cast a large slab of material, it is often difficult to provide the necessary quantity of the flow of molten metal of the mold and to provide a passageway for the molten metal to the lowest mold chamber. In such applications the embodiment shown in FIGURE 9 may advantageously be employed.

In FIGS. 9a and 9b there is shown a composite mold having paralleled mold chambers 89 and 90 to which is connected a contiguous slab chamber 91. The two mold chambers 89 and 90 chill the strand and are joined together in a single continuous slab defined by the periphery of the chamber 91. Flow of material into the chamber 91 may be provided by maintaining the material molten through the use of axially extending insert of poor thermal conductivity in the two chambers 89 and 90 as has been explained in connection with the explanation of FIGURES 2-8.

It will be noted that the transition between the mold chambers may be gradual as it is illustrated in connection with the embodiment shown in FIGURE 3. It is often simpler to construct the beveled connection between mold chambers in the different cascade steps and it is often found that the beveled transition secures maximum contact between the skin and the mold walls.

It has been found further that to secure the maximum heat transfer contact between the skin and the mold walls that the mold chambers are desirably maintained relatively short in axial length. A short axial length and the relatively small difference in cross sectional area between such stages ensures that the molten metal fills the peripheral gap between the mold walls and the strand skin and at the same time ensures that there is a continuous casting of the metal with proper joining of the added peripheral castings.

In many applications it has been found that variations in the mold wall design will improve the heat transfer relationship and the guidance of the strand skins through the mold. An example of such mold is shown in FIGURE 10.

In FIGURE 10 there is shown a mold having a projecting wall portion 120 within which is inserted an axially extending strip 121 of material having high heat resistance and poor thermal conductivity. The extending wall forms a flange-shaped guide 122 for the solidified wall portions of the strand, as the portions are formed by contact with the walls of the mold separated by the inserts.

In many applications it is desirable to augment the contact between the strand skin and the wall of the mold by a vacuum therebetween. In such applications, the embodiment shown in FIGURE 11 may advantageously be employed.

In FIGURE 11 there is shown the mold wall 92 having an aperture 93 extending therethrough. Coupled to

the aperture is a conduit 94 to which is connected a vacuum pump in conventional manner. The vacuum developed by the pump continuously maintains a vacuum between the skin of the casting 95 and the mold wall to force the skin into contact with the mold wall.

In many applications it is desirable that the skin be formed in a plurality of axially extending sections. In such applications the embodiment shown in FIGURE 12 may advantageously be employed.

In FIGURE 12 there is shown a mold comprising walls 97 having axially extending inserts 96 of material having poor thermal conductivity. The insert extends into the center of the mold 98. The insert prevents solidification of the molten metal in contact therewith and provides shoulders to support the casting skin sections developed by contact with the mold walls at the portions separated by the inserts.

Although in the examples given passage of molten metal has been provided for by the maintenance of axially extending passageways, it is equally feasible to provide means for piping the molten metal to mold chambers of increased cross sectional area. In such applications the embodiments shown in FIGURE 13 may advantageously be employed.

In FIGS. 13a and 13b there is shown a mold having two contiguous chambers 101 and 102. In the upper chamber an axially extending insert of poor thermal conductivity 99 is provided to maintain a passageway for the flow of material therethrough. At the termination of the insert there is provided a pipe 100 between the upper chamber 101 and the lower chamber 102 defined by walls 103 and 104. The walls 103 and 104 are preferably coated or plated with a material having good heat resistance and poor thermal conductivity to prevent solidification of the molten metal within the pipe 100.

With such a mold the material cast in molten form is maintained molten in the passageway defined by the insert 99. The passage is extended by the pipe 100 to supply metal to the strand in chamber 102. By such arrangement a completely solidified strand can be cast into a larger strand by the addition of material to the periphery thereof which will solidify into contact therewith in a strand of increased cross sectional area.

In some applications it has been found desirable for the improved heat transfer of material to cast the strand in a plurality of thin strands joined together in subsequent chambers. In such applications the embodiment shown in FIGURE 14 may advantageously be employed.

In FIGURE 14 there is shown a mold 107 having axially extending inserts 105 which extend across the mold to divide the mold into four parts defined by the area 106. In such applications the strand will comprise a plurality of small strands which will be joined during passage through subsequent mold chambers.

It will be noted by those skilled in the art that the supply of metal to the two contiguous mold chambers may be made independently from separate or similar sources of the molten metal by pipes leading directly to the mold chambers. In principle, of course, it is possible to cast the strands independently of one another. That is, the inner strand can be completely solidified and increases in the strand cross sectional area made by metal introduced in the subsequent mold chambers and cast to the periphery of the central strand. The fact that the central strand is in a soft and heated state allows sufficient melting thereof to ensure proper fusion between the strand periphery by the molten metal applied in the subsequent chamber.

In many applications it is desirable to provide for flow of molten metal from the contiguous chambers by means of the design of the length of the walls of the mold chambers. In this manner inserts of heat resistant material of poor thermal conductivity and the provision of piping may be eliminated by mold design. In such applications

the embodiment shown in FIGURE 15 may be advantageously employed.

In FIGS. 15a and 15b there is shown a composite mold 108 formed of three contiguous chambers 109, 110 and 111 respectively. The common edge between each mold chamber is cut obliquely.

By providing for an obliquely cut common edge between mold chambers, it is apparent that the diametrically opposed walls of the mold chambers are of varying lengths. It is, therefore, possible by correct dimensioning of the wall length to ensure that the shorter wall is insufficient to solidify the molten material into a skin before reaching the second chamber 110. Thus, the molten metal poured into the composite mold will flow into the subsequent chambers by virtue of the fact that the mold wall is of insufficient length to solidify the molten material into a skin. As will be noted particularly from FIGURE 15b the mold chambers are concentric.

In those applications where it is desired to form a cylindrical strand the embodiment shown in FIGURE 16 may advantageously be employed.

In FIGURE 16 there is shown a composite mold comprising a chamber 112 of square cross sectional shape and a chamber 115 contiguous thereto. The mold chamber 115 is of varying cross sectional area developed by the spirally developed wall thereof. The wall expansion starts at point 113 and continues outwardly along a spiral until the desired circular cross sectional shape is reached. By correct dimensioning of the pitch of the spiral, filling of the enlarged mold chambers is ensured and molten metal flow to all such chambers is ensured.

It will be noted that the dimensions of the mold chambers will be governed by the thermal characteristics of the molten metal cast as well as by the desired rate of casting of the metal.

This invention may be variously modified and embodied within the scope of the subjoined claims.

What is claimed is:

1. The method of continuously casting a metal strand from molten metal which comprises pouring the molten metal into a first constraining mold having a shaft to define the periphery of the molten metal as it travels through the shaft along the central axis thereof, selectively cooling the mold to form a skin on opposed discontinuous wall portions of the shaft, each of said wall portions being less than one-half of the wall periphery of said shaft, said formed skins being completely separated by a central core of molten metal, moving the chilled skins into a second constraining mold having a mold shaft of greater cross section area than the shaft of said first mold, filling the shaft of said second mold by molten metal flow through said central core, cooling said second mold to form a peripheral skin defining said strand, and continuously removing said strand as formed from said second mold.

2. The method according to claim 1 which includes the step of piping the molten metal from said first constraining mold into said second constraining mold to fill the shaft thereof.

3. The method of continuously casting a metal strand from molten metal in accordance with claim 1 which includes the step of laterally supporting said chilled skins during continuous movement through said first mold section to maintain continuous contact of said skins with the respective wall portions.

4. A composite mold for the continuous casting of a metal strand from molten metal comprising a first constraining mold having walls defining a mold shaft, said shaft constraining molten metal poured therein to define the periphery thereof as the metal passes through the shaft along the central axis thereof, inserts mounted in the walls of said shaft and extending along said central axis of said shaft, said inserts having sufficiently poor

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thermal conductivity as to prevent solidification of said molten metal as it passes through said mold shaft, means to cool the walls of said first constraining mold to form a skin of solidified metal on opposed wall portions separated by a central core of molten metal extending into contact with said inserts, a second constraining mold having walls defining a second mold shaft having a larger cross sectional area than the mold shaft of said first mold, said second mold shaft positioned contiguous with said first mold shaft, and means to cool the walls of the shaft of the second mold to form a strand from the solidified skins formed by the first mold and the molten metal flowing through the molten central core in said first mold and into the second mold.

5. A mold in accordance with claim 4 which includes pipe means for transferring molten metal from said central core in said first mold to the mold shaft of said second mold.

6. A composite mold in accordance with claim 4 in which said first mold is movably mounted for movement along said central axis thereof, in which said second mold is movably mounted for movement along the central axis thereof, and in which said first and second molds are positioned in telescopic relationship.

7. A composite mold for the continuous casting of a metal strand from molten metal comprising a first constraining mold having a wall defining a mold shaft, said shaft constraining the metal to define the periphery thereof as it passes through the mold along the central axis of said shaft, one portion of said wall having a shorter length in the direction of said central axis than the remaining portion of the wall, means to cool the walls of said shaft sufficiently rapidly with respect to the rate of movement through said shaft to form a skin of said metal on the surface of said wall encircling a molten core except at that portion of the wall having a shorter length, a second constraining mold said constraining mold positioned contiguous with said first constraining mold, said second constraining mold having walls defining a

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mold shaft having a larger cross sectional area than the mold shaft of said first mold, and means to cool the walls of the shaft of the second mold to form a strand from the solidified skin formed in said first mold and the molten metal fed into the second mold through the molten central core.

8. A composite mold for the continuous casting of a strand of metal from molten metal poured into said composite mold which comprises a first mold chamber having walls defining a first shaft, a second mold chamber having walls defining a second shaft of larger cross sectional dimension than said first shaft, said chambers being coupled together with said first shaft and second shafts in contiguous relationship, means for cooling the walls of said chambers to solidify molten metal contained by said walls, and axially extending strips of material of poor thermal conductivity mounted in the walls of said first shaft to prevent solidification of said molten metal along said strips thereby to provide channels of molten metal for flow of said metal into said second shaft.

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