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Johnson

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[54] **MOLDS FOR CONTINUOUS CASTING**

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[52] **U.S. Cl.** .... **164/273 R;** 164/82

[51] **Int. Cl.**^{2} **B22D 11/02**

[58] **Field of Search** ...... 164/82, 273 R, 282, 283 M

[56] **References Cited**

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3,580,328	5/1971	Eppich	164/283 M
3,628,596	12/1971	Easton	164/82 X
3,765,472	10/1973	Rossi	164/282
3,766,962	10/1973	Rossi	164/282 X
3,774,671	11/1973	Rossi	164/282

Primary Examiner—R. Spencer Annear
Attorney, Agent, or Firm—Nichol M. Sandoe

[57] **ABSTRACT**

A casting mold for continuous casting machines having a rectangular mold passage extending therethrough for casting strands of rectangular cross section such as slabs, billets and the like in which the surfaces of at least two of the opposed walls of the mold passage are convex in cross section, and in which the radius of curvature of said convex surfaces is progressively greater at successively lower levels of the mold passage in order to prolong contact between the strand and the mold walls.

5 Claims, 5 Drawing Figures

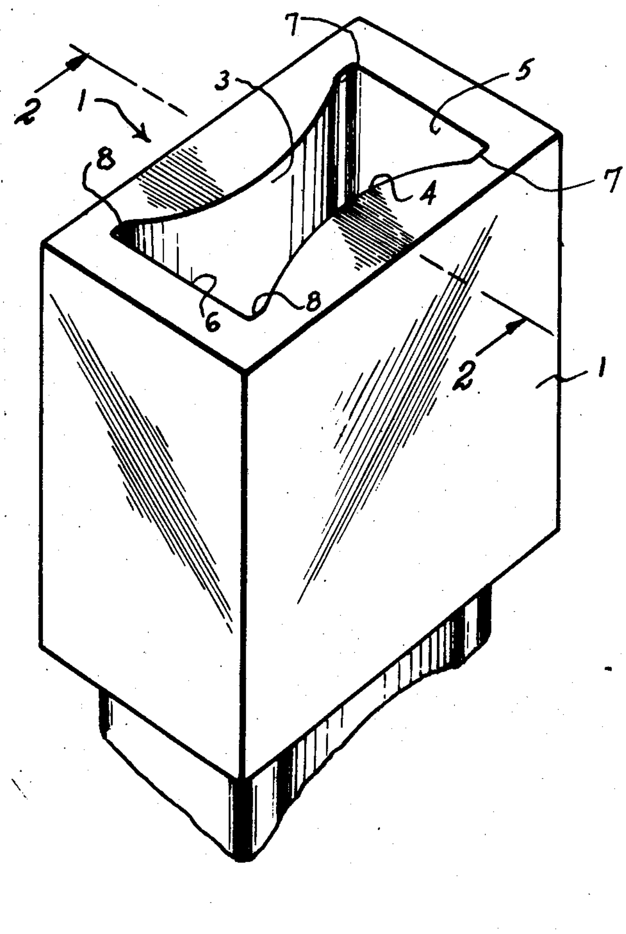


FIG.1

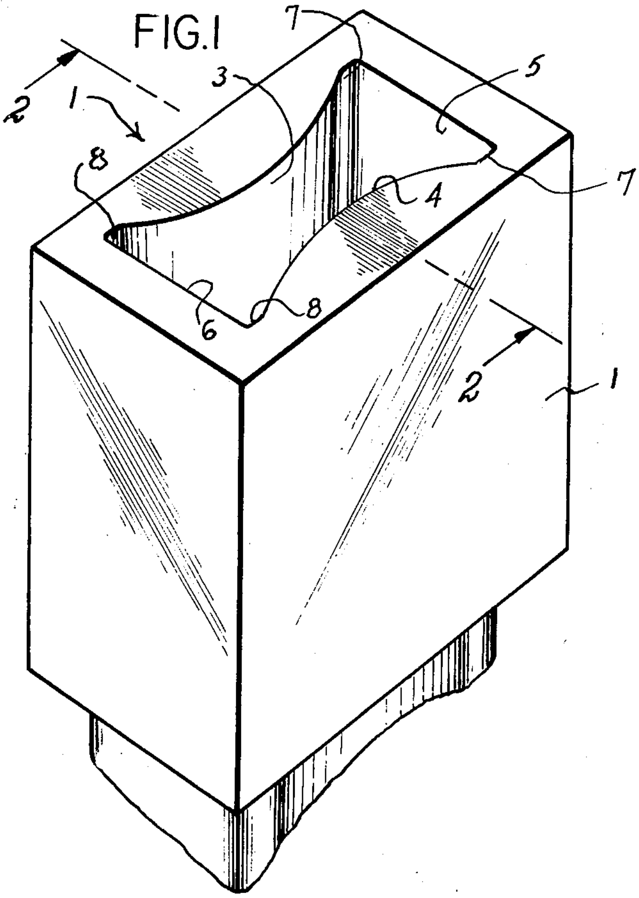


FIG.2

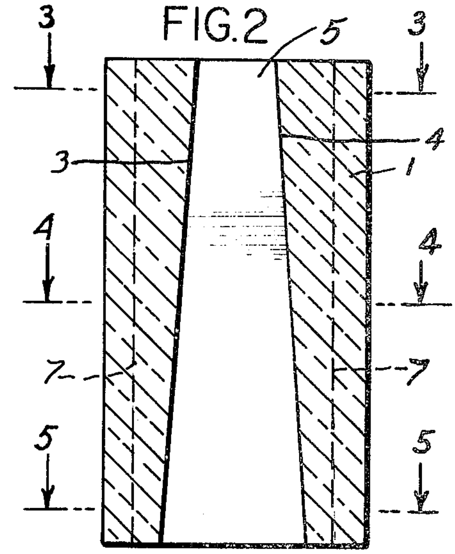


FIG.3

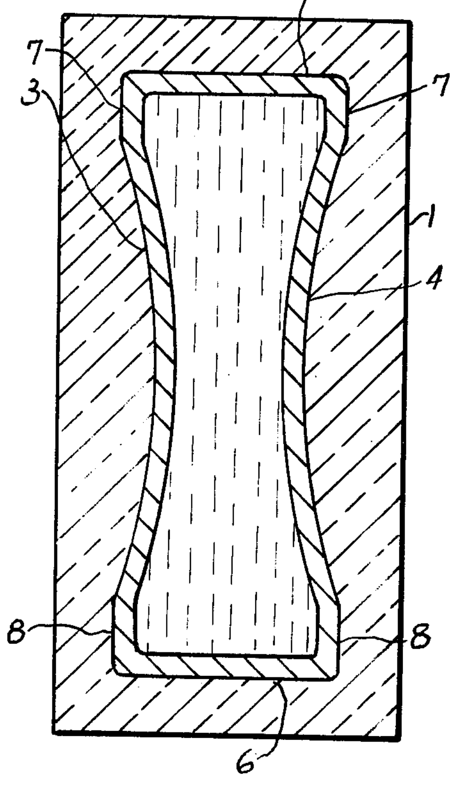


FIG.4

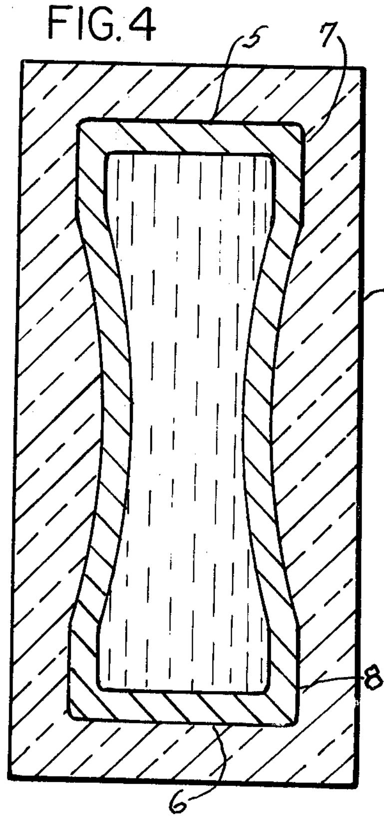
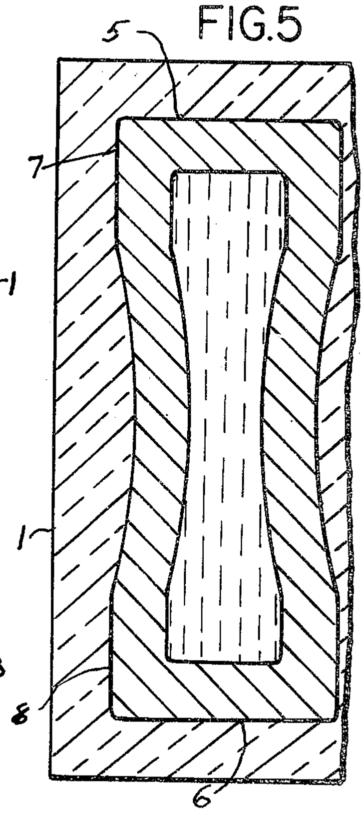


FIG.5



MOLDS FOR CONTINUOUS CASTING

This invention relates to continuous casting, and pertains more particularly to the continuous casting of steel strands of substantially rectangular cross section such as slabs or billets. The techniques used in the casting of steel are different from those used in the casting of non-ferrous metals, because of the high temperature of molten steel and the large quantity of heat which must be removed to produce complete solidification of the cast strand.

In typical continuous steel casting machines, molten metal is poured continuously into the open upper end of a water cooled mold having a mold passage extending therethrough, and a partially solidified strand is withdrawn continuously from the lower end of the mold. The said strand consists of an outer solidified shell enclosing a still molten interior, sometimes referred to as a core or crater. As the strand emerges from the mold, it is guided into what is commonly referred to as a secondary cooling zone where cooling water is applied directly to the outer shell, usually in the form of high velocity jets. As the strand progresses through the secondary cooling zone and heat is withdrawn and dissipated by the cooling water the outer shell thickens gradually until the molten interior is completely solidified, after which the strand is cut into desired lengths.

As the strand emerges from the mold, the outer shell is relatively thin and weak and heretofore, in order to resist bulging and possible fracture of the flat faces of strands of rectangular cross section due to the ferrostatic pressure applied by the still molten interior core, provision has been made to support the strand walls, usually in the form of a series of opposed sets of transverse rollers which engage opposite faces of the strand. The rollers are usually journalled in a frame commonly referred to as a roller apron.

In typical continuous stell casting machines the path of the strand through the secondary cooling zone is curved in order to reduce the overall height of the machine. Thus the strand, which emerges from the mold in a substantially vertical direction, follows a curved path such that it eventually moves in a substantially horizontal direction by the time it reaches the straightening and withdrawal rolls. The desired curvature may be introduced into the strand either by the use of a mold having a curved mold passage as in U.S. Pat. No. 2,947,075, or by bending the strand after it emerges from a mold having a straight mold passage as in U.S. Pat. No. 2,920,359.

In such machines, in order to resist bulging and possible fracture of the flat faces of strands of rectangular cross section, the rollers of the roller apron must be spaced together relatively closely, and in casting strands of large dimensions, the rollers must be of relatively large diameter. Because of these considerations, the space available for the application of cooling water to the strand is restricted and therefore the rate of cooling and solidification is lower than is desirable. Moreover, the repeated flexing of the shell as the strand moves through successive pairs of rollers produces undesirable effects on the structure of the metal.

In order to overcome these and other disadvantages, it has been proposed in U.S. Pat. Nos. 3,766,962 and 3,773,099, to use a mold in which some or all of the surfaces of the rectangular mold passage are convex in cross section, rather than flat as in the usual molds for casting strands of rectangular cross section. Some or all of the surfaces of strands cast in such molds, therefore, are concave in cross section, thus resulting in arched surfaces which resist bulging. As described in the said patents, the inherent resistance to bulging provided by the arched surfaces is aided by application of compressive stresses acting transversely of the strand as described in U.S. Pat. No. 3,766,962, or by thermal stresses as in U.S. Pat. No. 3,773,099. As a result, the usual transverse rollers may be dispensed with so that cooling water may be applied to substantially the entire area of the concave arched surfaces.

It is an object of the present invention to provide an improved mold of the type above referred to in which some or all of the surfaces of the mold passage are convex in cross section, but in which the nature of the convexity is such as to retain contact between the chilled mold walls and the surfaces of the strand for a longer time in order to permit more heat to be withdrawn from the strand while it is still within the mold. Such an improved mold may be used to advantage in various types of continuous casting machines including those using a conventional roller apron as well as in machines as above described in which a roller apron having transverse rollers may be dispensed with.

In the art of continuous casting a problem of long standing has been the restriction of heat transfer from the strand to the mold due to the formation of so-called "air gaps" between the surfaces of the mold and the opposed surfaces of the strand. It is well known that as the solidified shell of the casting forms and thickens as heat is withdrawn by the mold, the shell begins to shrink i.e. its perimeter is shortened so that the surface of the shell tends to pull away from the wall of the mold, leaving a gap therebetween which fills with air. Wherever an air gap exists the heat exchange capacity of the mold is drastically reduced.

One of the problems resulting from the formation of air gaps is that they are not uniform. That is, as shrinkage occurs, the surface of the strand does not move away from the wall of the mold by a uniform distance around the entire perimeter of the strand. On the contrary, due to the fact that the shell is thin and pliable, the surface of the strand tends to pull away from the wall of the mold at one or more places while remaining in contact with the mold wall at other places, thus causing distortions due to uneven heat transfer.

In addition to reducing heat exchange, the presence of an air gap also causes difficulty in keeping the strand centered in the mold. The portions of the shell of the strand which are in contact with the mold wall are not very thick and not very strong so that the strand itself can have only limited self-centering ability.

Whenever, due to shrinkage, the strand tends to move laterally in the mold, the usual result is that the shell pulls completely free from one corner of the mold. This results in a drastic reduction in heat exchange at this corner and thus a thinner shell which will not be termperature symmetrical. Frequently, under these conditions, the shell will crack at this point and may cause a breakout. In some cases, two adjacent or opposite corners may pull away from the mold wall causing an even more hazardous condition. In casting billets or blooms, even if a breakout is avoided, the product may become rhomboidal in cross section and not usable for further processing.

Various mechanical devices such as rolls, shoes and rails located at the exit end of the mold have been proposed to keep the strand centered in the mold. These devices have not been successful for billets and blooms, and achieve only limited degrees of success with larger rectangular shapes.

Attempts have also been made to design the mold passage to reduce the air gap and to keep the strand centered in the mold, as by the use of inwardly tapered mold walls. That is, it has been attempted to compensate for shrinkage by tapering the mold walls inwardly to maintain contact with the shrinking wall of the casting.

According to the present invention, it is proposed to provide a mold in which some or all of the surfaces of the walls of the mold passage are convex in cross section, but in which the radius of curvature of the convex surfaces increases progressively from the top of the mold, or from the normal level of the molten metal in the mold, to the bottom of the mold. For purposes of this description the normal level of the molten metal in the mold may be deemed to be the top of the mold for the configuration of the mold passage above that level does not affect the casting. In the upper portions of the mold, the radius of curvature will be such that the convexity of the mold surfaces will be greater than that required to produce the desired degree of concavity in the arched surfaces of the strand as it leaves the mold. At the bottom of the mold the radius of curvature will be increased to an extent such as to produce the desired lesser degree of concavity in the arched surfaces of the strand as it leaves the mold. If desired, the radius of curvature at the bottom of the mold may be increased to infinity so that the surface of the casting as it leaves the mold will be flat.

The effect of increasing progressively the radius of curvature of the mold surfaces and thereby decreasing progressively the degree of convexity thereof is to shorten progressively the perimeter of the mold passage at successively lower levels of the mold passage. Thereby the configuration of the mold passage is made to be consistent with and to conform to the shrinkage which is known to occur as the metal cools in the mold with the resulting shortening of the perimeter of the strand at successively lower levels of the mold passage. Therefore, since the wall of the strand within the mold is thin and pliable, it gradually adjusts itself to the gradually reduced convexity of the mold wall as the strand moves downwardly. As a result, the strand remains in contact with the mold wall over all or substantially all of its area within the mold, thereby greatly increasing the heat transfer which occurs within the mold.

A preferred embodiment of the invention selected for purposes of illustration is shown in the accompanying drawings in which:

FIG. **1** is a semi-diagrammatic perspective view of a continuous casting mold for casting rectangular slabs.

FIG. **2** is a vertical section on the line **2—2** of FIG. **1**.

FIGS. **3**, **4** and **5** are horizontal sections on the lines **3—3**, **4—4**, and **5—5**, respectively, of FIG. **1**.

Referring to FIG. **1** of the drawings, the mold **1** is shown in perspective with the mold passage **2** extending therethrough. As shown, the usual details of a continuous casting mold such as cooling water passages and connections, mold supports, etc. have been omitted as unnecessary because they form no part of the present invention.

As shown in FIG. **1**, at the top of the mold, the two long side walls **3** and **4** of the mold passage are convex, while the two short end walls **5** and **6** are straight. This is because in casting slabs in which the width of the slab greatly exceeds their thickness, there is little or no tendency for the short end walls to bulge. In casting such slabs, therefore, it is not necessary to provide convexity of the end walls in order to produce concave or arched surfaces in the end walls of the casting. It will be understood, however, that in casting billets which are square in cross section, or in any case where the thickness of a slab is such that bulging of the end walls is possible or likely, all four of the walls of the mold passage may be convex as above described.

It will be understood, further, that it is not necessary that the convex walls of the mold passage be convex across their entire width. On the contrary, the convex surfaces may be flattened at the ends as at **7** and **8** in order to provide short flattened surfaces on the casting for engagemnt by short supporting rollers as shown and described in the patents above referred to. However, the convex walls of the mold passage are convex across a major portion of their entire width. If desired, the corners of the casting may be rounded or bevelled as in said patents.

Referring now to FIGS. **3**, **4** and **5**, it will be noted that the radius of curvature of the opposed convex surfaces **3** and **4** increase progressively from the top of the mold to the bottom so that at cross sections taken at successively lower levels the degree of convexity becomes less, i.e. the convexity becomes shallower. Thus, the radius of curvature of the convex surfaces **3** and **4** of the mold passage at a cross section taken on the line **3—3** near the top of the mold is relatively short. On the other hand, the radius of curvature at a cross section taken on the line **4—4** near the mid-section of the mold is longer so that the convexity of the surfaces **3** and **4** at that level is shallower than at the section on the line **3—3**. Then again, the radius of curvature at a cross section taken on the line **5—5** near the bottom of the mold is still longer so that the convexity of the surfaces **3** and **4** at that level is shallower than at the section on the line **4—4**.

Moreover, it will be noted that corresponding points of the opposed convex arcs become progressively more widely separated at successively lower cross sections through the mold. Thus, the distance between the mid points of the convex arcs at the cross section on the line **5—5** is greater than the distance between the mid points of the convex arcs at the cross section on the line **4—4**, and the distance between the latter points, in turn, is greater than the distance between the mid points of the convex arcs at the cross section on the line **3—3**.

Thereby, due to the pliability of the shell of the casting while still in the mold, the shell of the casting is permitted to bulge outwardly to maintain contact with the convex mold walls as the casting moves downwardly within the mold, while always maintaining concavity so that the wide walls of the slab will have the desired concave arched surfaces as they exit from the mold.

It will be noted, too, that the length of the perimeter of the mold passage decreases progressively at successively lower cross sections through the mold due to the progressively lessening convexity of the convex arcs.

This is consistent with the fact that the length of the perimeter of the casting decreases progressively at successively lower cross sections through the mold due to shrinkage of the casting.

In the manufacture of molds according to the invention, therefore, the radii of curvature of the convex surfaces of the mold passage at successively lower cross sections through the mold are adjusted to conform as nearly as possible to the known or estimated shrinkage of the casting. The required radii for any given set of conditions can readily be determined by those skilled in the art by trial and error or by computer calculations.

Because of the reduced heat transfer and other difficulties resulting from the formation of air gaps it is prevailing practice in the continuous casting of steel to use relatively short molds so that the cast strand may reach the secondary cooling zone as soon as possible. Since molds according to the present invention result in maintaining contact between mold surfaces and casting surfaces, and minimize or eliminate the formation of air gaps, and does improve heat transfer, it becomes possible to use longer molds and thus produce a thicker and stronger shell within the mold.

Although the invention has been illustrated and described herein with reference to a mold having an elongated rectangular passage for casting slabs, it will be understood that the principles of the invention may be applied to a mold having a square mold passage for casting billets, in which case all four of the surfaces of the mold passage may be convex.

It will also be understood that the principles of the

invention are applicable, not only to a mold having a straight axis as shown herein, but also to a mold having a curved axis as in U.S. Pat. No. 2,947,075 previously referred to.

What is claimed is:

1. A continuous casting mold for casting steel strands of substantially rectangular cross section, said mold having a substantially rectangular mold passage extending therethrough, a major portion of the surfaces of at least two of the opposed walls of said mold passage being convex in transverse cross section, the radius of curvature of said convex surfaces being progressively greater at successively lower cross sections through the mold wall.

2. A mold according to claim **1** in which the said mold passage has two opposed long sides and two opposed short sides and in which the surfaces of the opposed long sides are convex in cross section.

3. A mold according to claim **1** in which the length of the perimeter of the mold passage decreases progressively at successively lower cross sections through the mold wall.

4. A mold according to claim **1** in which the radius of curvature of said surfaces is infinite at the bottom of the mold.

5. A mold according to claim **3** in which the decreases in the length of the perimeter of the mold passage at successively lower cross sections through the mold wall conform to the decreases in the length of the perimeter of the casting at successively lower cross sections through the mold wall.

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