METHOD OF CONTINUOUSLY CASTING A SLAB

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ABSTRACT
A method of continuous casting steel into a wide-faced continuous slab is disclosed wherein the oppositely disposed wide faces of the outer shell of the cast slab are concavely arched to resist outward bulging due to the ferrostatic head of the molten core. The cast strip is passed between spaced pairs of guide rollers which bear against only the opposite edges of the strip and also buttress the strip against the internal ferrostatic head of the molten core. Therefore, the necessity of guide rollers that bear against the wide surfaces of the strip is eliminated, allowing uniform application of coolant liquid to the wide surfaces, thus greatly enhancing the rate of solidification of the strip.

13 Claims, 22 Drawing Figures
METHOD OF CONTINUOUSLY CASTING A SLAB

This invention pertains to methods and apparatus for the continuous casting of metal, and provides improvements therein for continuously casting molten metal into relatively wide and thick slabs.

The present tendency in the design and construction of continuous casting machines, for slabs, especially for steel slabs, is to build the same for increasing widths and thicknesses of the continuously cast metal. Such machines have been built for producing slabs $80'' \times 12'''$ in cross-section, and even larger sizes are presently under consideration. But such machines as have heretofore been contemplated for producing such larger slabs, present problems which, when considered in accordance with heretofore known design and construction techniques, have failed to take into consideration the full advantages of the characteristics of the solidifying metal.

As discussed more fully below with reference to the accompanying drawings, a conventional type of apparatus for continuously cast metal, especially steel, into wide and thick slabs, comprises a vertically mounted, water cooled, tubular-shaped copper mold, generally of elongated, rectangular cross-section, into the top of which molten metal is cast to produce a relatively wide and thick, continuous strip or slab of cast metal issuing from the lower or exit end, and consisting of a thin walled, outer shell of solidified metal enclosing a core of molten metal. Cooling water spray jets are mounted commencing immediately beneath the mold for increasing the thickness of the solidified shell as it progresses downward. Also mounted commencing at the bottom of the mold, is a series of spaced roll pairs referred to as a “roller apron,” with interposed additional spray jets, which roll pairs bear against the oppositely disposed wide faces of the slab for guiding the slab along a preselected path.

This path may be vertical, slanted or arcuate. In the present disclosure, the principles of the invention will be described for simplicity with reference to an arcuate path as applied to the casting of steel, but it will be understood that these same principles apply to any path in which the molten metal input to the mold is higher than the casting exit from the mold. If the axis of the mold is rectilinear, the roller apron will bend the casting along a curved path which may be an arc of a circle, that of an ellipse or of a parabola or otherwise, until it becomes tangent to the horizontal or to a direction mounting a straightening unit, at which point it is straightened by passage thru a straightening unit. If, on the other hand, the axis of the mold is curved, the roller apron extends or continues the curvature of the casting as established by the curvature of the mold axis until the aforesaid point of tangency is again reached at which point the casting is straightened by passage thru a straightening unit.

Since the mold conventionally employed in the continuous casting of slabs is of rectangular cross-section, the slab as cast is of corresponding cross-section. However, both prior to and upon issuance of the cast slab from the mold, the ferrostatic pressure of its molten core becomes effective to place the outer shell under tension, in which direction of stress the shell is relatively weak owing to its hot and plastic state, in consequence of which the shell bulges. This bulging is most pronounced across the slab faces because the edges of the slab owing to their greater surface area per unit volume, cool more rapidly than do the slab faces, whereby the slab faces bulge outwardly from their initially flat or rectilinear surfaces. This bulging tendency becomes increasingly accentuated as the strip passes downwardly from the mold due to the progressively increasing ferrostatic pressure exerted by the molten core against the solidified outer shell, until the shell is thick enough to support the ferrostatic pressure.

The apron rolls restrain the bulging as the slab strip passes under the rolls of each pair, but the bulging, nevertheless, occurs between roll pairs and this is deleterious in a number of respects as follows, especially as regards the casting of steel. The slab turns black under the coolant spray jets due to the spray cooling and as the rolls interrupt the spray cooling, the slab emerges from the rolls at a red heat again due to the heat emanating from the molten metal core. The bulging deformation of the strip between the rolls of each pair tends to produce cracking of the solidified metal shell since the shell, especially if the metal is steel, is in a “hot short” condition and hence is weak in tension at this stage. This also applies to the metal beneath the solidified shell which tends to stress the shell in tension. The alternate bulging and contraction of the shell requires a greater withdrawal force by the rolls of the straightening unit, by reason of the drawing action produced in the low strength steel shell under tension. Also, the relatively slow rotating movement of the rolls as compared to those of a hot rolling mill and the impossibility of adequately cooling the rolls even if water cooled, produces a temperature differential peripherally about each roll surface as it passes into and out of contact with the hot metal strip, the resultant alternate expansions and contractions of which produces checking and early breakdown of the rolls.

Another serious defect of having the apron rolls bear against the wide faces of the strip, is that it precludes the uniform application of coolant sprays throughout said surfaces, and thereby greatly reduces the efficiency of overall cooling. Consequently, the total length of cooling must be greatly increased or the casting rate reduced and a much larger and more expensive apparatus required for a given capacity than is really necessary.

There are also many metallurgical disadvantages with continuous slab casting machines of the above-described and related conventional designs. Because of the relatively slow permissible casting rate, due to the low cooling rate per unit of length of the strip, it is necessary to reduce the extent of cooling in the mold, otherwise the steel in the miniscus of the molten metal will freeze too quickly and produce folds, laps or other surface defects. There is also danger of breaks in the hot steel shell due to the repetitive in-and-out movement of the wide faces of the strip in passing between successive roll pairs. This is particularly the case just below the mold.

In accordance with the present invention, the above and other objectionable aspects of conventional practices as above-described, are eliminated by continuously casting molten metal, such as steel, into a wide-faced continuous slab, the oppositely disposed wide faces of the outer shell of which are concavely arched to resist outward bulging by the ferrostatic head of the molten core, and by passing the strip as thus cast between spaced pairs of guide or apron rolls which bear...
against the opposite edges only of the strip, and which are so shaped as to buttress the concavely arched portions of the solidified shell against the uniform internal pressure exerted thereagainst by the ferrostatic head of the molten metal core, on the same principle as that of buttressing a structural arch subjected to uniform loading, against collapse. With my invention, the use of guide rolls which bear against the wide surface portions of the strip shelf are completely eliminated, whereby a coolant liquid may be sprayed uniformly throughout the opposite surfaces thereof, thereby greatly expediting the rate of solidification of the molten core and hence of the strip throughout, as compared to practices heretofore known.

Steel in the "hot short" condition is stronger per unit of cross-section in compression than it is in tension, and one object of my invention is to take advantage of this condition. Also, it is a well-known law in the design of mechanical structures that an arch is the strongest design for a given cross-section to carry a given load. This principle is employed in my invention wherein the wide-faced, concavely-arched surface portions of the solidified outer shell of the slab as cast, are buttressed by the contiguous edge portions of the shell and by the pressure exerted by the edge rolls bearing thereagainst, thus to prevent outward bulging or rupture of the shell due to the uniform outward ferrostatic pressure of the molten core exerted against the hot metal of the solidified outer shell.

Thus, with my invention wherein the wide faces of the slab are fully exposed, they can be uniformly cooled throughout, which cannot be done with present practice. As compared thereto, my invention provides a more uniform end product and one which is achieved at an overall higher casting rate.

It is also one of the principal purposes of my invention to keep the metal as hot as possible throughout the casting operation, because the hotter it is the softer it is and it lends itself more readily to the straightening operation. This also effects an economy in the use of cooling water for other mediums. My method stresses that the casting operation is a metallurgical operation under constant control which the present method is not.

The edge rolls employed in accordance with my invention will be relatively short and commensurate with the thickness of the slab strip at its edges and will be adequate with respect to the pressure there applied to the strip to carry the thrust action of the arched portions. These short edge rolls which also are of small diameter are thus far less expensive than the long rolls of large diameter required in conventional practice, and are more easily and efficiently cooled than are the rolls of present practice.

The slab strip is preferably cast with edge portions which are normal to the contiguous termini of the arched portions respectively, and the edge rolls are roughly of spool-like configuration, provided with flanged ends which are so chamered as to bear against the aforesaid edge portions of the slab and thereby directly oppose the thrusts of said arched termini.

The oscillating mold which is in general use in continuous casting, has a slow forward or downward movement in the direction of the casting, and an upward or return movement which is several times as fast. This is for the purpose of tearing the casting and mold apart. Generally, when casting a slab in a mold of rectangular cross-section in accordance with present practice, the slab bulges outwardly in the mold across its wider faces, thereby increasing the withdrawal friction of the casting with respect to the mold.

In contrast with my invention wherein the mold is shaped to cast a slab with concavely-arched faces, it is evident that if the pressure exerted by the edge rolls against the cast slab is greater than the thrust exerted against them by the arched portions of the slab shell due to the ferrostatic head, the result is that the curvature of the arched portions will be increased. It is an object of my invention to employ this method of increasing the arch curvature of the slab within the mold in order to eliminate or reduce the withdrawal friction between the cast slab and the mold. This is accomplished by controlling the horizontal spacing between the edge rolls, as a supplement to the natural shrinkage which the cast metal undergoes in passing from the liquid to the solid state in casting. In this way the conventional oscillatory movement imparted to the mold for breaking the cast slab from the mold is minimized and or completely eliminated. At this stage of the casting operation adequate concavity to support the ferrostatic head is all that is required, because later in the casting operation provision is made for a reduction of the concavity after the shell is thicker so that any possible disadvantages in the subsequent rolling operation due to the concavity, are eliminated.

Another improvement in continuous slab casting technique achieved with my invention as compared to conventional results from the following. In accordance with conventional practice wherein as above explained, the rolls of the roller apron bear against the wide faces of the slab strip, the available surface area of the strip that can be subjected to spray cooling is often less than the area covered by the rolls. It is, therefore, difficult to control the temperature of the strip at the point of tangency of the arched strip at which it enters the straightening unit. With the present invention, on the other hand, wherein the wide faces of the slab strip are exposed to cooling spray throughout, the cooling rate may be so controlled that the strip is brought to the point of tangency at a temperature such that it almost straightens out of its own weight as it enters the straightening unit. Consequently, only a relatively light weight construction is required for this unit.

Straightening units for continuous slab casting as conventionally constructed must be strong and powerful enough to withdraw the strip from the roller apron in a relatively cold and solidified state, and to cold straighten the same for cutting into sections and removal in the event of sudden power failure or interruption of casting for other reasons. This is due to the fact that the closely spaced apron rolls do not permit convenient sectioning of and removal of the cold strip from between these rolls. Hence, the strip must be completely withdrawn from the roller apron and straightened in the straightening unit prior to sectioning and removal. With the present invention, however, wherein the wide faces of the slab strip are fully exposed throughout the length of the roller apron, the cold and solidified strip can be sectioned and removed from the roller apron in the event of such power failure or other casting interruptions.

Still another complicating factor in straightening units for slab casting as conventionally constructed, is that flattening rolls like those of the roller apron must
be provided therein to minimize bulging of the slab strip across its wide faces during straightening. This is due to the fact that the slab strip is often not completely solidified as it enters or issues from the straightening unit. Such flattening rolls are, of course, not required with the present invention owing to the concave arching of the slab faces which prevent bulging thereof.

For the above reasons, the straightening unit of the present invention is of much simpler and less powerful construction than is required in conventional practice and employs only edge rolls for straightening which, however, are of a different design from those employed for the apron rolls, as explained below.

Having thus described the invention in general terms in relation to the most pertinent prior art known to me, reference will now be had for a detailed description of these and other features of the invention, to the accompanying drawings wherein:

FIGS. 1 to 6 inc., are drawings illustrative of the prior art continuous slab casting practice above-described in which:

FIG. 1 is a view in side elevation and partly in longitudinal section of a complete continuous casting machine; and while

FIGS. 2 and 3 are enlarged fragmentary sectional views of FIG. 1 as taken at 2—2', and 3—3.

FIG. 4 is an enlarged, fragmentary portion of FIG. 1.

FIG. 5 is a section of 5—5 of FIG. 1.

FIG. 6 is a diagrammatic showing in side elevation illustrative of the method and apparatus for start-up operations of the FIGS. 1—5 inc., apparatus.

FIG. 7 is a view in side elevation and partly in longitudinal section of a continuous casting machine or apparatus in accordance with this invention; while

FIGS. 8, 9 and 10 are enlarged sectional views of FIG. 5 as taken at 8—8, 9—9 and 10—10 of FIG. 1, respectively.

FIG. 11 is a view similar to FIG. 9 illustrating an apparatus for automatically adjusting the rate of coolant sprayed against the concavely arched surfaces of the slab strip in accordance with expansions or contractions thereof.

FIG. 12 is a view in side elevation of an edge roll construction adjustable for edge rolling slab strips of different thicknesses.

FIG. 13 is a transverse sectional view of a modified cast slab strip configuration in accordance with my invention wherein the wide faces of the strips are doubly arched, this view also showing the apron roller arrangement for feeding the strip.

FIG. 14 is a diagrammatic showing to illustrate the arch buttressing provided by the edge rolls of this invention.

FIGS. 15 and 16 are views of a dummy starting slab for starting up casting operations in accordance with this invention, FIG. 15 being a transverse sectional elevation thereof as taken at 15—15 of FIG. 16; while FIG. 16 is a view in side elevation thereof as taken at 16—16 of FIG. 15.

FIGS. 17 and 18 are views in axial sectional elevation of metal casting molds according to this invention having arcuate and rectilinear casting ducts, respectively.

FIG. 19 is an enlarged axial sectional elevation through the mold and uppermost pair of the apron rolls of the FIG. 7 showing as taken at right angles thereto; while

FIG. 20 is a transverse section of FIG. 19 as taken at 20—20 thereof.

FIG. 21 is a view taken at right angle to FIG. 7, of a fragmentary portion of the cast slab strip and associated apron rolls illustrative of a modified arrangement of said rolls wherein each pair of edge rolls are spaced apart by increasing amounts from roll-pair-to-roll-pair to permit progressive widening of the slab strip and corresponding decrease in arching of the concave slab surfaces; while

FIG. 22 graphically depicts such decrease in arching at various points along the slab strip.

Reference will first be had to FIGS. 1—5 inc., illustrative of the construction and operation of a continuous casting machine of conventional construction designed more particularly for the casting of steel into wide slabs. The overall construction comprises, referring for the moment more particularly to FIG. 1, a vertically-mounted, water-cooled, tubular copper mold 10, of elongated rectangular aperture, into the top of which is charged molten steel, as at 11 from a tundish 12. From the base of the mold there is continuously discharged, a partially solidified slab as at 14, comprising an outer shell 15, of solidified metal, and an inner core 16, of molten steel. The slab has typically the relative transverse dimensions shown at 14 in FIG. 3, the width of which is generally considerably in excess of its thickness as shown.

From the mold, the slab passes downwardly and in an arched path as shown in FIG. 1, through a roller apron comprising a succession of spaced roll pairs of progressively increasing diameters, as at 17—20, etc., which engage the oppositely disposed wide faces of the outer shell of the strip. Interposed at intervals between the roll pairs are nozzles, as at 22, 23, etc., for spraying a coolant, such as cold water, onto the oppositely disposed wide faces of the slab. The roller apron delivers the slab to a straightening unit 24 at the tangent point 25 of the strip with the horizontal, from whence it passes to a cutter 26, which cuts the casting into slabs as at 27, 28, discharged via rolls 29. The straightening unit mounts rolls as at 24a and 24b, which bear against the oppositely disposed wide faces of the slab and straightens the slab by fulcrum action of these rolls.

To start the casting operation, a starting device must be employed, a commonly used type being that illustrated diagrammatically in FIG. 6. Referring to FIG. 6, the starting device is a dummy slab which is usually a chain 30 of the general cross-section of the slab 14 of FIG. 1. This chain is wound up the roller apron 17—20 by driven rolls thereof, until its upper end enters the mold 10, as at 31, where it is sealed into position with asbestos rope or other sealing material. The incoming molten steel from the tundish 12, solidifies around a ring or hook 32 of the dummy slab and this is withdrawn by lowering the chain 30, during which additional molten steel is poured into the mold and thus the continuous casting process has begun. The chain is withdrawn followed by the slab, as at 33, by the action of the roller apron 17—20 and the rolls of the straightening unit 24, and in order to remove it from the casting or production line, a bridge 34 is used, up which the dummy slab 30 is pulled by means of a cable 35 and power driven drum 36. As the end of the chain attached to the casting passes the shear 26, the shear is actuated to cut the chain loose from the casting (now
shown at 33), which is thereafter sheared into slabs as it is now fed past the shear.

Continuous casting machines of the conventional design shown in FIG. 1 have been built in which the height of the ingot mold 10, is as much as 40 feet or more above the level at which the molten core of the slab strip is almost solidified throughout as it passes into or beyond the straightening unit, at which level the ferrostatic pressure is about 135 pounds per linear inch of the width of the rolls. The cooling distance is, however, much greater than the height of the mold above the straightening unit in that it comprises the length of the arcuate path of the strip 14 between the mold 10 and the straightening unit 24, which for a mold height of 40 feet would be about 63 feet.

Since the ferrostatic pressure of the molten core increases progressively as the slab strip is fed downwardly through the roller apron, the rolls thereof are made of progressively larger diameters as shown, in order to withstand the ferrostatic pressure of the molten core at any given height and also in some cases to bend the slab along the arcuate path shown, or alternatively may be provided with back-up rolls, as at 37. The construction therefore becomes quite complicated and expensive. This is especially the case where the slabs are about 80 inches or more in width, which require very long rolls and heavy bearings, especially if the mold is disposed as much as 40 feet above the straightening unit.

In the case of wide slabs and with high ferrostatic pressure, the rolls become so large in diameter that insufficient area of the slab strip is exposed to the coolant spray for rapid cooling, so that the required initial cooling distance along the cooling path becomes greater in order to assure that the slab will be solidified completely prior to cutting into slabs. In some instances warm water is used to retard the cooling at the meniscus because of the low casting rate that must be employed.

What actually happens is that the slab bulges between the apron rolls in the manner shown in FIGS. 3 and 4, and as it is drawn downward, the rolls compress the slab as shown in FIG. 2, the action being like that of drawing a strip through a die. What happens in that the cooling is that the spray cools the slab from a to b, FIG. 4, but as the next pair of rolls 38, 39 cover the slab, it emerges from the rolls hot again due to the internal heat from its molten core 16.

Reference will now be had to FIGS. 7-21, inc., for a detailed description of the continuous casting machine of the present invention. The mold employed is basically of the tubular construction shown in axial and transverse sections at 50 in FIGS. 7 and 8, respectively. The axis of the tube may be straight or rectilinear, as at 51, FIG. 18, or may be curved, as at 52, FIG. 17. The mold is made of copper or equivalent metal of high thermal conductivity and heat resistance, and is housed except for the mold cavity, in a water jacket 53 for circulation of a coolant, such as cold water, about the mold via inlet and outlet connections 54, 55. As shown in FIG. 8, the mold cavity 56 is formed of oppositely disposed, relatively wide sidewalls, inwardly arched toward one another, as at 57, 58, and flattened at the ends, as at 59, 60, and of oppositely disposed, relatively narrow and parallel end walls, as at 61, 62, which are bevelled at the corners, as at 63, 64. As shown in FIG. 8, the water jacket 53, preferably follows the contour in plan view of the mold, and is coaxial therewith but of greater transverse section than the mold.

Referring to FIG. 7, in the continuous casting machine according to the embodiment of the invention therein shown, the mold 50 is vertically mounted and is charged with molten metal as at 76, from a tundish 71, thus to cast from the base of the mold, a continuous slab strip, as at 73, comprising an outer solidified shell 74, and a molten core 75. As the slab strip leaves the mold, it passes into a roller apron comprising a series of roll pairs which engage the opposite edges only of the slab, as at 76, 77, FIG. 9, these roll pairs being successively mounted along an arcuate path, as at 79, 80, 81, etc., FIG. 7, to deliver the slab to a straightening unit 82 and thence to a slab cutting unit 83, for cutting the slab into lengths as at 84, discharged via rolls 85. Certain of the apron rolls are driven and for reasons as discussed below.

Referring to FIG. 9, the edge rolls, 76, 77, are of the spool-like configuration corresponding to the narrow edges 78, 79, of the slab, having flanged ends, as at 90, 91, bevelled on their inner faces, as at 92, 93, and spaced by a cylindrical shaft, as at 94, to provide a profile in accordance with an end including the bevelled corners of the slab, as at 95. The bevelled faces, as at 92, 93, of the rolls engage the outer shell of the slab shell thus directly oppose and buttress the ends of concave walls 96, 97, of the slab against bulging tendencies produced by the uniform pressure exerted thereagainst by the ferrostatic head of the molten core 75 of the slab, in the manner illustrated by the opposed arrows 98, illustrative of the thus-opposed forces exerted.

Referring to FIG. 14, the action is similar to that of a structural arch 100, subjected to a uniform load per unit length, as at 101, and buttressed by abutments, as at 102, 103, having faces bevelled, as at 104, 105, to directly oppose the terminal thrusts of the arch, as indicated by the arrows 106, 107.

Reverting to FIG. 9, the lower flanges, as at 110, of rolls 76, 77, also extend under the flattened edges, as at 111, of the underside of the slab strip 73, thereby to support the same as it passes arcutely downward between the mold and the straightening unit in the manner shown in FIG. 7.

It will be seen from FIGS. 7 and 9, that since no rolls engage the wide surfaces 96, 97, of the slab strip 73, spray nozzles may be mounted at closely spaced intervals lengthwise of the strip, and on both sides thereof, as at 112, 113, and across the width thereof, as at 114, 115, FIG. 11, to apply a coolant spray, such as cold water, throughout the entire length and width of the strip. The rapid cooling and solidification of the slab strip thus-obtained permits, referring to FIG. 7, of mounting the mold 50 at a much lower level and thus providing a much shorter traverse of the slab between the mold and straightening unit 82, than in conventional continuous casting machines, or for a higher casting speed or capacity for the same cooling length. A much more efficient and economical construction is thus obtained with the apparatus of my invention as compared to those heretofore known.

Reverting to FIG. 11, bulging tendencies of the slab strip 73 due to the ferrostatic pressure of the molten core, are advantageously controlled by the degree of concavity initially imparted by the mold to the wide surfaces thereof in casting, and by the amount of trans-
verse pressure exerted on the slab by the edge rolls 76, 77. Additionally, in accordance with a further feature of my invention, the rate of coolant flow from a supply line, as at 116, to associated spray nozzles, as at 117, 118, may be automatically regulated in accordance with expansions or contractions of the wide surfaces 96, 97, of the slab, by interposing between the supply line and the spray nozzles, valve means as at 119, at various points in the cooling length, each having a spring loaded actuating arm, as at 120, 121, carrying a wheel, as at 122, which bears against a concave arched surface of the strip as at 96. Regulation is such that bulging tendencies of the slab strip will increase the coolant flow, to increase the thickness and rigidity of the slab shell.

Referring to FIG. 12, in order to provide for axial adjustments of the flanged ends of the edge rolls, to adjust for thicker or thinner slab strips, the flanged ends, as at 123, are slidably mounted on a separate shaft 124, to which the flanged ends are adjustably secured by screws, as at 125, projecting into a keyway, as at 126.

The description of my invention thus far has been directed to the casting of slabs in which the wide faces are cast with a single concavely arched surface on each side, as at 96, 97. FIG. 9 further shows, for extremely wide slabs, the single arch may prove too great to give a good end product. In such case, the arched surfaces of the slab may be cast in the form of two or more contiguous arches transversely of the wide faces in the manner illustrated in FIG. 13, wherein a double arched construction is imparted to the oppositely disposed wide faces of the slab strip in the manner shown at 140, 141, and 142, 143. With this modification, the thrust at the junction between connected arches, as at 144, 145, is taken up by grooved idler rolls, as at 146, 147, journaling to bearing supports 148, 149. With this double arch modification, the depth of the arch is not so great for a given slab width as the single arch modification. Also, it breaks up the long width of the single arch and creates three crystallization zones in the slab, i.e., at the ends and at the center of the slab width. A similar action is employed in steel casting practice for large ingots, wherein the surface is frequently broken up into various crystallization points to distribute movement of the surface, thus to provide for various shrinkage points of the steel in changing from liquid to solid. Also, the arrangement shown in FIG. 13 gives support to the center of the slab without the use of wide faced, large diameter water cooled rolls, and heavy water cooled bearings therefor with resultant high maintenance. The multiple concave arch embodiment of the FIG. 13 embodiment has all the advantages of the FIG. 9 embodiment as regards the concave surface arch action and surface freedom of arched surfaces for cooling.

The present invention provides a straightening unit for the slab which is of novel construction and mode of operation and which takes advantage of the fact that the wide faces are free of transverse rolls, as in the present practice, and consequently it is possible to pass the slab to the straightener at a controlled high temperature so that it requires very little, if any, force to straighten the slab as compared to the conventional practice.

If in the conventional method the casting reaches the straightener with a liquid core, it will also straighten itself because the surfaces will have high temperature and be weak. In such case, however, there will be bulging of the faces. As above explained, the conventional machine, due to restricted cooling (due to the rolls), cannot control the temperature at the straightener and also cannot easily remove a cold slab. Therefore, the straightener is designed for both of the following conditions.

1. The possibility of having to straighten the slab cold, which requires the placement of rolls far from the fulcrum roll, and on both sides thereof; and
2. The possibility that the slab may come down to the straightener with a liquid core, as a result of which it will bulge, and therefore require that small anti-bulging rolls be placed between the heavy straightening rolls.

With the present invention, the temperature of the slab can be so-controlled as to deliver the slab to the straightener sufficiently hot that it will almost straighten itself, and due to the concave faces, it will not bulge. If, however, the machine for any reason stops and the slab freezes in the machine, it can be easily cut into pieces and the pieces removed, because there are no cross rolls on the faces as in the conventional design.

Also in the conventional machines, the straightening rolls in addition to straightening the slab, must serve as withdrawal rolls for withdrawing the slab from the roller apron extending between the mold and the straightening unit, the rolls of which are usually idler rolls, which, owing to the bulging of the slab between adjacent roll pairs thereof, requires that the slab must be compressed, as illustrated in FIGS. 2-4, inc., which, in turn, requires that the straightening rolls exert considerable tension on the slab to withdraw it from the roller apron.

Were it not for this alternate bulging and compression of the slab due to the action of the roller apron in the aforesaid conventional construction, the slab would tend to slid downward of its own weight. With the present invention wherein the slab is concavely cast on its wide faces to prevent bulging, and only edge rolls employed for guiding the slab, as illustrated in FIGS. 7 and 9, the straightening unit is greatly simplified in that no appreciable withdrawal force is required of it. The result is that in accordance with the present invention, only edge rollers are required in the straightening unit for this reason and because the strip is flattened in the hot state and prior to complete solidification of the molten core, or in any event while the slab is still in a high temperature, plastic state.

Referring to FIGS. 7 and 10, the straightening unit 82 of this invention comprises a series of upper and lower pairs of edge rollers, as at 155, 156, FIG. 7, and 157, 158 and 159, 160, FIG. 10, which as shown engage the now solidified, oppositely disposed upper and lower edges only of the slab strip 73. As shown in FIG. 10, the rolls on each side of the strip are driven by motors, as at 161, thru intermeshing gears, as at 162, 163, mounted on and keyed to the roller shafts, as at 164, 165. Referring to FIG. 7, the upper series of rolls 155, may be mounted in staggered relation to the lower series of rolls 156, for straightening the strip by fulcrum action therebetween.

Since as shown in FIG. 10, the core 75 of the slab strip is not completely solidified, the slab is still in a sufficiently hot and plastic state that very little bending force is required to straighten the same to a completely flat slab prior to shearing into discrete lengths. Also,
the straightening rolls are required to exert only a light tension on the strip for withdrawing the same for the roller apron, since the edges of the strip are completely solidified while the concavely arched wide faces of the strip undergo no bulging requiring flattening rolls on the wide faces.

The start-up devices employed for start-up operations in known types of continuous casting machines are quite complicated, as above-described with reference to FIG. 1. One reason for this is that since the apron rolls engage the wide faces of the cast slab, the dummy slab employed for starting must travel thru the entire roller apron before it can be removed. In contrast for the casting process of the present invention, a start-up device comprising a dummy slab of extremely simple construction and operation is employed, as shown in FIGS. 15 and 16. Referring thereto and to FIG. 7, the uppermost rolls of the FIG. 7 roller apron are shown at 170, 171, and the dummy slab at 172. It is made of two hollow castings 173 and 174, each about five feet long and of the configurations shown in the drawing. The castings are joined by a hinge 175 which extends along the length thereof on the underside, as shown. The sections are so constructed that the widths of the upper faces 176, 177 are longer than those of the corresponding lower faces, 178, 179, and the difference is such as will cause the device to press against the lower flanges 180, 181 of the rolls 170, 171, when inserted therebetween in the manner shown in the drawings. As shown in FIG. 16, the castings 173, 174, are of arcuate shape as viewed in side elevation to conform to the arcuate path formed by the apron rolls 79, 80, 81, FIG. 7, such that the dummy slab will pass between the roll pairs thereof in the manner shown in FIG. 15.

Referring to FIG. 16, the ends of the castings 173, 174, terminate in projecting portions, as at 182, which conjointly are shaped to slide into the lower end of the mold 50, FIG. 7, and are concavely arched across the upper and lower faces, as at 183, 184, in conformity with the arched sidewalks 57, 58, FIG. 8 of the mold. In order to insert the dummy between the upper rolls 170, 171, of the roller apron, FIG. 7, the castings 173, 174, are provided with ring bolts 184, 185, which normally rest in cavities 186, 187, of the castings 173, 174. To insert the dummy the ring bolts 184, 185 are gripped by hooks of a crane, which swings the castings 173, 174, into the side-by-side abutting positions shown in FIG. 15. and the dummy thus dropped into position on rolls 170, 171, as shown. To remove the dummy additional ring bolts are provided, as at 188, 189, which when gripped by the crane hooks will swing the castings 173, 174, into back-to-back relation and thus collapse the assembly for removal from between the apron rolls 170, 171.

For start-up of continuous casting the dummy is placed in the position shown in FIG. 15, and the apron rolls 170, 171 are driven to advance the end 182 of the dummy into the lower end of the mold, which is then sealed in place by conventional techniques. Thereupon the casting of the molten metal is initiated, following which the dummy is gradually withdrawn with reverse driving of the apron rolls 170, 171. A number of the edge rolls along the roller apron are motor driven in order to control the speed of casting. In this case, they act as brakes because the casting would probably slide down as the restraining force if the bulging is missing.

FIGS. 19 and 20 illustrate the feature of my invention above referred to wherein friction between the mold and the cast slab is reduced by applying rolling pressure to the opposite edges of the slab as it issues from the mold. Referring to FIGS. 19 and 20, the slab as cast by the mold 50 would normally have the configuration shown by the full line 200 of FIG. 20. By applying sufficient rolling pressure to the opposite slab edges as the casting issues from the mold, as by means of rolls 170, 171, the slab has imparted thereto within the mold the configuration shown by the dashed line 201, wherein the width of the slab is reduced, as at 202, 203, and the concavity of the arched surfaces is increased, as at 204, 205, thereby to break the casting away from the mold walls to reduce the frictional force required to withdraw the casting from the mold.

FIGS. 21 and 22 illustrate the further feature of my invention whereby the width of the cast slab may be progressively increased and the concavity of the arched surfaces of the slab correspondingly reduced, by increasing the distance between the roll pairs of the apron rolls. FIG. 21 shows a section 215 of the cast slab. As it passes along the pairs of table rolls, the distance between the rolls of each pair is increased as shown at 216-225 inc. By thus increasing the distance between these rolls the ferrostatic pressure of the molten core of the slab progressively widens the slab as shown and correspondingly decreases the degree of concavity of the arched slab surfaces as shown comparatively at 226-230 inc. of FIG. 22 by the pitch distances X-1 to X-5 inc. In this way slabs of different widths may be produced from a single mold such as the mold 50, of FIG. 19.

Reverting to FIG. 7, the molten steel is cast into the mold 50 at temperature of about 2,800° to 2,900°F. The cast slab 73 issuing from the mold is subjected to controlled colling by the spray jets to the extent that the slab at the point of tangency with the straightening unit 82, is at temperature of about 2,000° to 2,200°F, and thus in a sufficiently plastic state as to require relatively little force for straightening.

I claim:

1. The method of continuous metal casting which comprises: casting said metal from a molten state into a continuous slab comprising a thin walled shell of solidified metal and a core of molten metal, said shell having a width which is substantially greater than its thickness and having formed across its width, oppositely disposed concavely arched and relatively wide sidewalks, and having formed across its thickness oppositely disposed and relatively narrow end walls, subjecting said shell as cast to inwardly directed restraining pressure applied to its opposite end walls to prevent medial outward bulging of the sidewalks of said shell due to ferrostatic pressure of said molten core while leaving the corresponding arched surfaces of said sidewalks substantially free of mechanical engagement thereby permitting continuous surface cooling of said slab throughout the length and width of said concavely arched surfaces, until said slab is solidified, and while concurrently directionally feeding said slab.

2. The method according to claim 1 wherein said slab is cast with edge portions of said slab contiguous to said concave surfaces which are bevelled substantially normal thereto, and wherein at least a portion of said restraining pressure is applied substantially normal to said bevelled edge portions for buttressing said arched
sidewalls against bulging due to ferrostatic pressure and for controlling the degree of concavity of said arched sidewalls.

3. The method according to claim 2 wherein said shell is cast with the termination portions of the arched sidewalls of the shell homogeneous with said end walls which are so shaped to take the thrust of the arched sidewalls and wherein said end walls are normal to a transverse axis through the slab and are supported by rolling restraining pressure.

4. The method according to claim 1 wherein rolling pressure is additionally applied to bend and direct said continuous slab into tangency at a given location, with a predetermined direction of traverse, continually so controlling the cooling of said slab that at said given location, said slab is in a hot and relatively plastic state thereby facilitating straightening said slab while moving the same from the point of liquid metal supply in the mold to a point of discharge of said slab.

5. The method according to claim 4 wherein said slab is straightened by rolling pressure applied between the upper and lower edges thereof at it is continuously moving to said discharge position.

6. The method according to claim 1 wherein said molten metal is so cast into said continuous slab as to impart to said solidified shell first formed thereof, a plurality of concavely arched sidewalls from a mold correspondingly formed transversely of said shell on each of its said oppositely disposed sidewalls, and wherein said shell is subjected to restraining pressure applied vertically at the junctions between said arched sidewalls on each face of said shell in addition to said pressure applied between the opposite edges of said shell in order to maintain said previously formed arched sidewalls.

7. The method according to 1 wherein the distance transversely of the slab between which edge rolling pressure is applied is increased, to permit the ferrostatic pressure of said molten core to widen said slab and reduce the degree of concavity of the arched side-walls thereof.

8. The method according to 7 wherein slabs of different widths can be so produced from a cast slab of constant initial width.

9. The method according to 7 in which the distance between the concave surfaces of said arched sidewalls at their median points is thus increased thereby permitting liquid metal to flow into the gap created by such increased distance, and thus avoiding pipes or bridging and other defects in the center of the slab caused by intensely concentrated cooling.

10. The method according to claim 4, wherein said metal is cast at temperature of about 2,800°F to 2,900°F, and the cast slab cooled at a rate such that at said point given location of tangency the slab temperature is about 2,000°F to 2,200°F.

11. A method of continuously casting a slab comprising the steps of pouring molten metal into a cooled tubular mold and continuously withdrawing an elongated slab from beneath said mold, said slab comprising an outer shell surrounding an internal molten core, shaping said outer shell to provide a pair of oppositely disposed relatively wide sidewalls inwardly arched toward each other and interconnected at their edges by a pair of oppositely disposed relatively narrow end walls, guiding said slab away from said mold by contacting said slab solely at said end walls and subjecting said slab to buttressing forces directed along the width of said sidewalls to maintain their arched configuration while leaving the arched surfaces of said sidewalls substantially free of mechanical engagement.

12. The method according to claim 1 wherein said arched sidewalls are formed during casting of the molten metal with chilling.

13. The method according to claim 1 wherein the arched sidewalls of said slab as continuously cast are subjected to coolant sprays for progressively solidifying said slab throughout.

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