United States Patent

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[54] **HIGH-SPEED CONTINUOUS CASTING METHOD**
4 Claims, 7 Drawing Figs.

[52] U.S. Cl. **164/87,** 164/89, 164/278
[51] **Int. Cl.** **B22d 11/06**
[50] **Field of Search** 164/82, 87, 89, 278, 283

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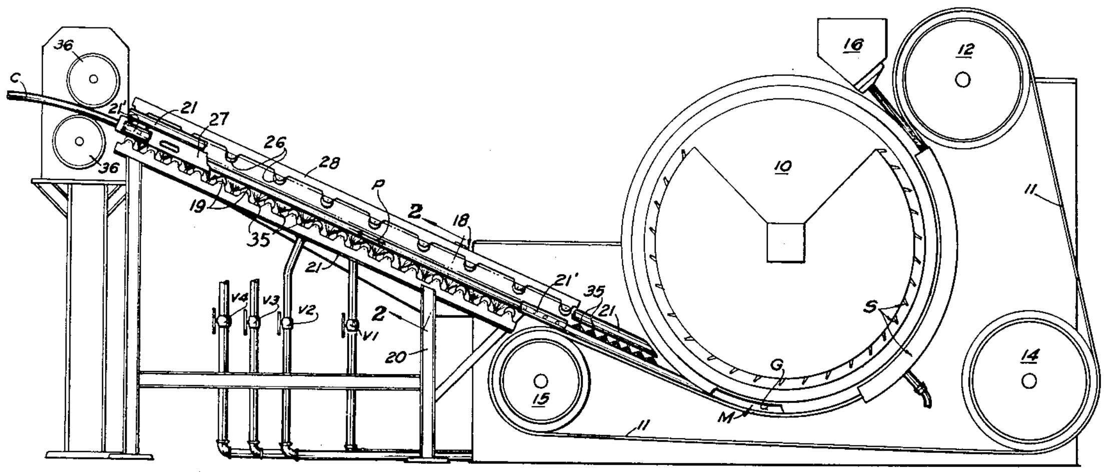
ABSTRACT: A high-speed continuous casting apparatus and method wherein the method includes partially solidifying a molten metal in a mold defined between the peripheral groove of a rotating casting wheel and a flexible band until the metal shrinks and draws away from the casting wheel, thereupon removing the band from the casting wheel and subsequently cooling the metal to complete its solidification. The apparatus includes the combination of a casting wheel having a peripheral groove with a portion of its length closed by an endless band to form a casting mold and an auxiliary cooling means for cooling the metal to complete its solidification. This allows the casting wheel to be rotated at that rotational speed which causes the metal to pass from the casting wheel as, or shortly before or after, the metal shrinks away from the casting wheel.



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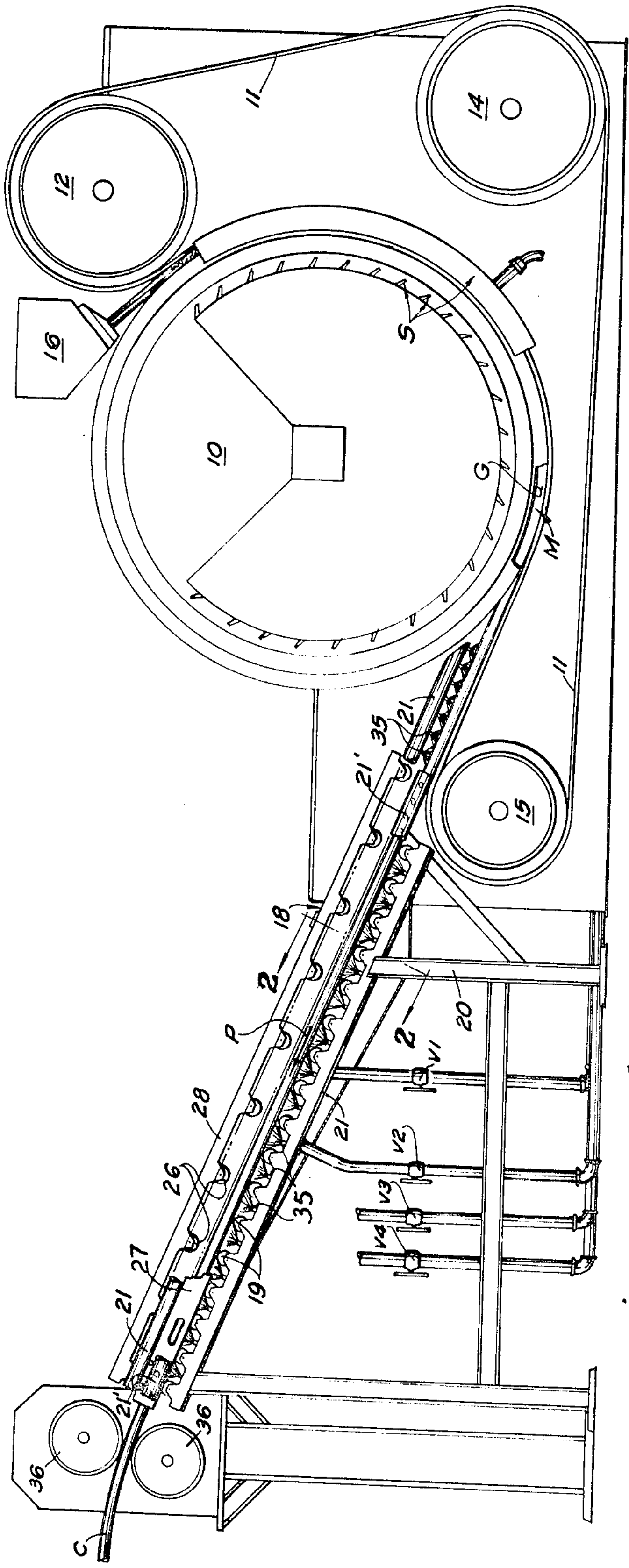

Fig. 1

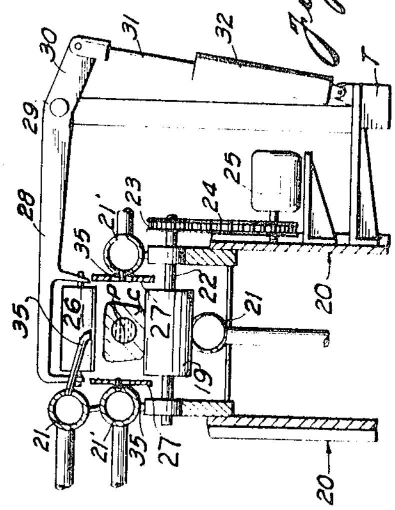

Fig. 2

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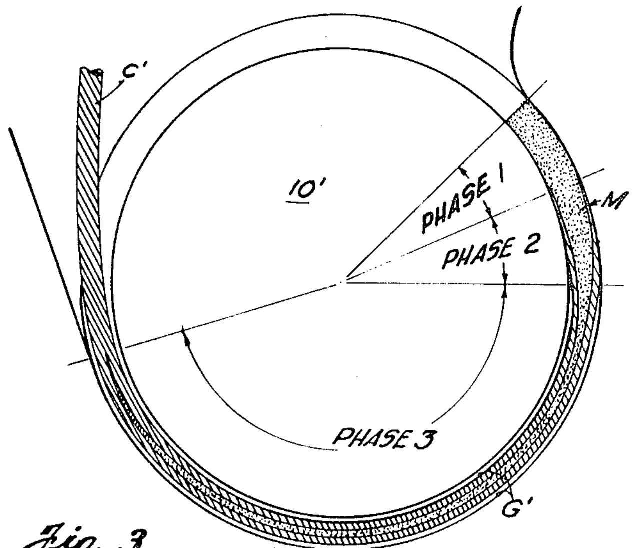

Fig. 3
Prior Art

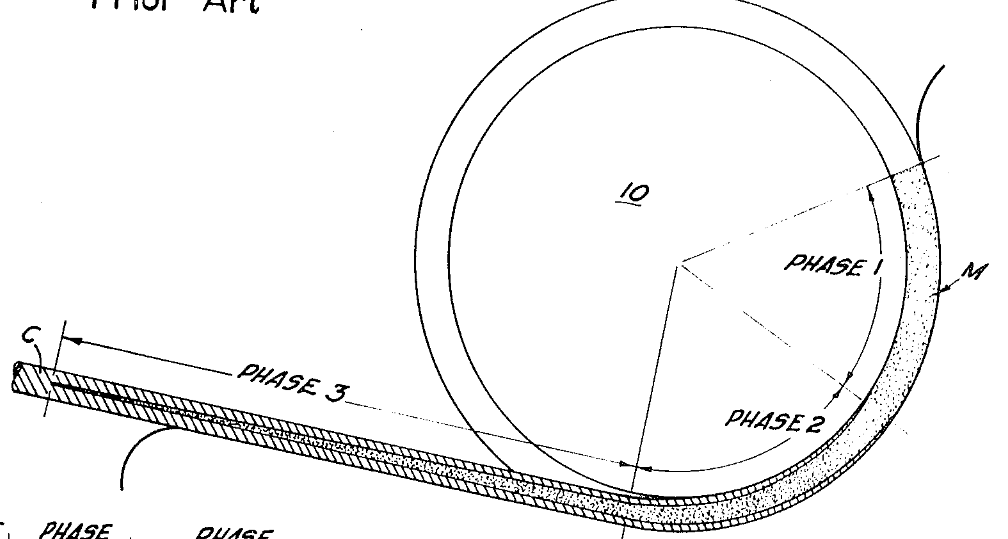

Fig. 4

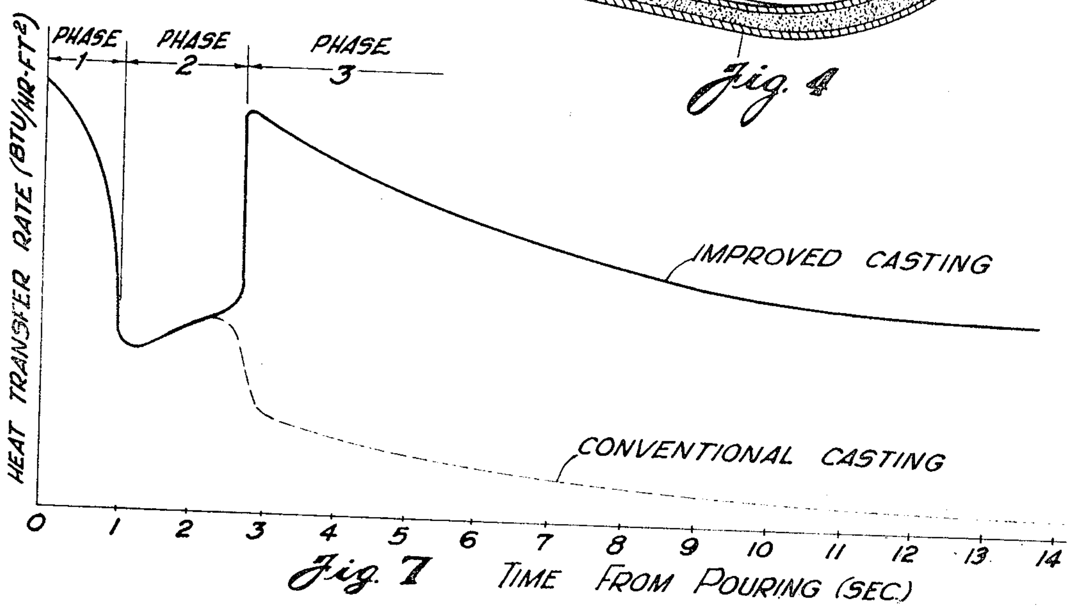

Fig. 7

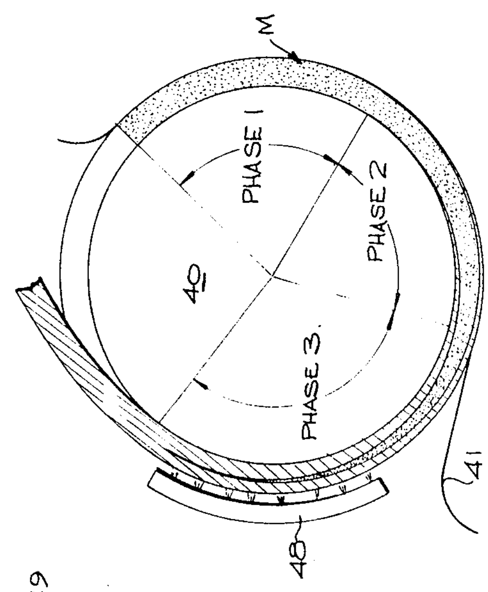

Fig. 6

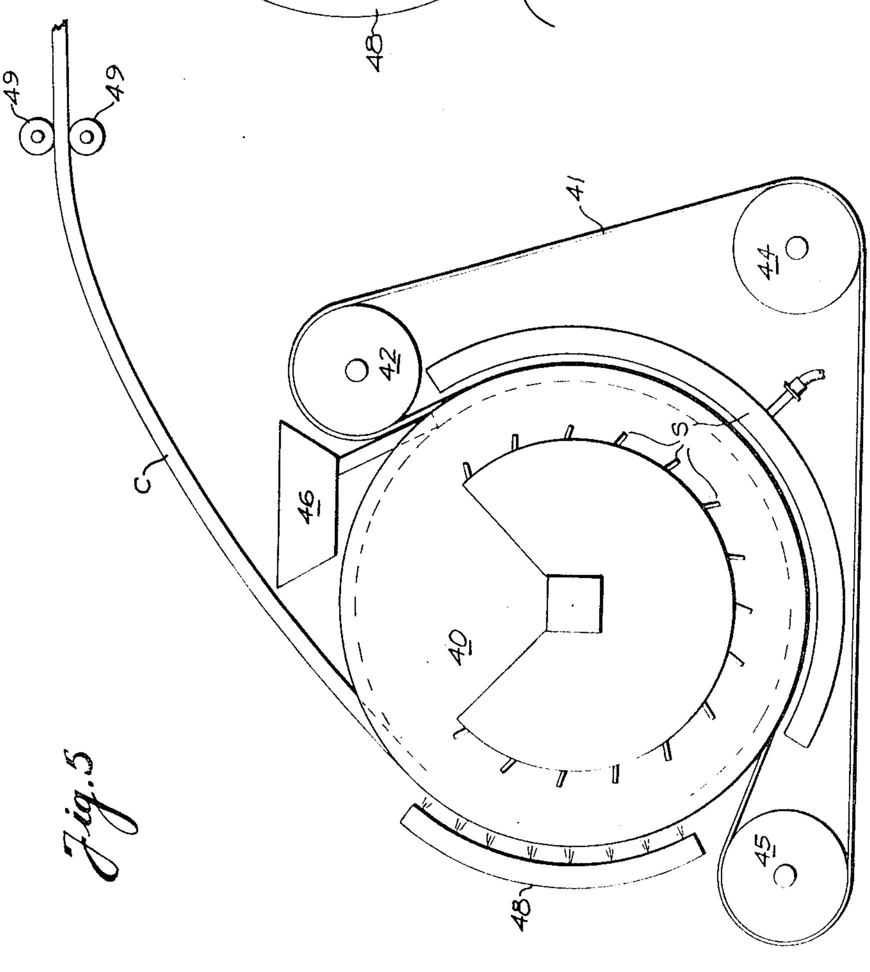

Fig. 5

HIGH-SPEED CONTINUOUS CASTING METHOD

BACKGROUND OF THE INVENTION

The continuous casting of molten metal in a peripheral groove around a rotating casting wheel is well known in the metal foundry art. In the casting of molten metal in a rotating casting wheel, it has been found that as the metal is cooled, it solidified in three distinct phases. The first phase begins when the metal is fed into the peripheral groove of the casting wheel and includes that portion of the casting process during which the metal is being cooled but is completely liquid within the casting wheel so as to be in complete contact with the casting wheel. The second phase is that portion of the casting process during which the continued cooling of the metal causes an outer crust of solidified metal to form adjacent the casting wheel but during which the metal is still in substantially complete contact with the casting wheel. The third phase is that portion of the casting process beginning generally at or near that point in the solidification of the molten metal at which the continued cooling of the metal and thickening of the outer crust of solidified metal cause the metal to shrink away from the casting wheel and is that portion during which an air gap forms between the metal and the casting wheel.

The third solidification phase is the most troublesome in the casting of molten metal in a prior art rotating casting wheel since the air gap between the metal and the casting wheel greatly reduces the rate of heat transfer to the casting wheel from the metal during the final solidification of the metal. This is because the heat must be transferred from the cast metal to the casting wheel in the third solidification phase principally by radiation through the air in the gap as well as by some direct metal-to-metal conduction, rather than only by direct metal-to-metal conduction as was the case in the first and second solidification phases. Of course, less heat can be transferred in a unit of time by radiation than by conduction at the same relative temperatures.

In turn, the low rate of heat transfer during the third solidification phase in a casting wheel of the prior art limits the rotational speed of the casting wheel and the casting rate which can be achieved. The rotational speed of a prior casting wheel must be sufficiently slow to provide a sufficient dwell time of the metal in the third solidification phase for the metal to completely solidify in the casting wheel.

SUMMARY OF THE INVENTION

The invention disclosed herein overcomes these and other problems and disadvantages of prior art casting wheels by providing a casting method and a casting apparatus wherein the metal is kept between the peripheral groove of a casting wheel and the flexible band covering the groove only during the first and second solidification phases, and wherein the flexible band is removed from the casting wheel to expose the metal for direct cooling during some or all of the third solidification phase. This allows the rotational speed and therefore the casting rate of the casting wheel to be greatly increased since the effect of the air gap between the metal and casting wheel is eliminated and the metal is exposed for direct cooling. The method of the invention allows the rotational speed of the casting wheel to be such that the metal passes from the casting wheel at the beginning of or early in the third solidification phase and that an efficient rate of heat transfer be achieved during some or all of the third solidification phase.

The apparatus of the invention includes a casting wheel having a peripheral groove with a portion of its length closed by a flexible band. In addition, the apparatus includes a cooling device which receives the partially solidified metal from the casting wheel for cooling during some or all of the third solidification phase and which serves to finish solidifying the metal either internally or externally of the casting wheel at a relatively high rate of heat transfer while at the same time supporting the metal in a manner that prevents breaks during the cooling process. This casting apparatus provides a casting rate which has not been achieved with prior art casting wheels.

These and other features and advantages of the invention will be more clearly understood upon consideration of the following specification and accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a side elevational view of one embodiment of the invention;

FIG. 2 is a cross-sectional view taken along line 2—2 in FIG. 1;

FIG. 3 is a schematic representation of a prior art casting wheel illustrating the three solidification phases during the continuous casting of a molten metal;

FIG. 4 is a schematic representation of that embodiment of the invention shown in FIG. 1 showing the three solidification phases therein;

FIG. 5 is a side elevational view, similar to FIG. 1, but showing an alternate form of the invention;

FIG. 6 is a schematic representation of that embodiment of the invention shown in FIG. 5; and

FIG. 7 is a graph illustrating the relationship between the heat-transfer characteristics of a prior art casting wheel and of that embodiment of the invention shown in FIGS. 1 and 5.

These figures and the following detailed description disclose specific embodiments of the invention; however, it is to be understood that the invention may be embodied in other forms.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now in more detail to the drawing, in which like numerals of reference illustrate like parts throughout the several views, FIG. 1, shows casting wheel **10** having an endless flexible band or belt **11** positioned against a portion of its periphery by three band support wheels **12, 14,** and **15**. The band support wheel **12** is positioned at that point on the casting wheel **10** wherein molten metal is discharged by a pouring pot **16** into a mold M formed by the band **11** and a peripheral groove G around the casting wheel **10**. The band support wheel **15** is positioned tangentially outwardly from that point on the casting wheel **10** at which partially solidified metal is discharged from the casting wheel **10**.

Positioned outwardly of the band support wheel **15** is an extended cooling section **18** which serves as a cooling means for receiving partially solidified metal from the casting wheel **10** and controls the cooling of the metal for the complete solidification thereof. The cooling section **18** includes a plurality of support rolls **19** supported by frame **20** of the cooling section **18** and a plurality of manifolds **21** and **21'**; the manifolds **21** being positioned above and below the path P of the metal through the cooling section **18** and the manifolds **21'** being positioned at the sides of the path P of the metal through the cooling section **18**.

Support rolls **19** may either be driven or nondriven since the incline of rolls **19** from the bottom of the casting wheel is gradual and in most situations, the longitudinal compressive strength of the metal emerging from the casting wheel is sufficient to drive the metal up the incline without substantial hazard of the metal collapsing. However, when it is desired to assist the movement of the metal up the incline of path P, rolls **19** can be positively driven. Axles **22** carrying the support rolls **19** can each have a sprocket **23** mounted thereon for driving engagement with a chain and sprocket arrangement **24** driven by a motor **25** as seen in FIG. **2**. As seen in FIG. **1**, the rolls **19** are rotated counterclockwise so that metal C resting thereon will be carried away from the casting wheel **10**. A plurality of upper rolls **26** are mounted above the path of metal C through the cooling section **18** and are positionable to retain the metal in path P. Side guide walls **27** are positioned on opposite sides of path P and also serve to retain the metal in its path.

Upper rolls **26** are rotatably mounted in a frame **28** pivoted as at **29** so that they can be selectively raised from above the path of the metal or lowered into a position above the path through an extension **30** connected to the extending end of a piston rod **31** slidably positioned by a fluid cylinder **32** carried by the frame 20. The cylinder 32 has a suitable control circuit T to selectively extend and retract the rolls 26 as seen in FIG. 2. If it is desired to more positively drive the metal up the incline of path P with support rolls 19, cylinder 32 can be adjusted to move upper rolls 26 into engagement with the upper surface of the metal to urge the metal into more positive contact with support rolls 19.

The manifolds 21 and 21' are so positioned that all sides of metal C are cooled and each manifold 21 21' can be independently controlled through valves V1, V2, V3 and V4 to selectively control the cooling rate of each side of metal C. The cooling fluid is discharged on metal C through a plurality of conventional nozzles 35.

As metal C exits the cooling section 18, it passes to a rolling mill (not shown) or other subsequent processing equipment. If desired, the metal can be received between a pair of pinch rolls 36 of conventional design to assist its movement.

As is best shown in FIGS. 5 and 6, an alternate embodiment of the invention is provided which includes casting wheel 40, flexible band 41, and band support wheels 42, 44, and 45. Pouring pot 46 is arranged to pour molten metal into the peripheral groove of casting wheel 40. The arrangement of casting wheel 40, band supports wheels 42–45 and pouring pot 46 is similar to the arrangement of FIG. 1; however, the extended cooling section 18 of FIG. 1 is replaced by water spray manifold 48, and the cast bar C is allowed to remain in the casting wheel until it is extracted therefrom at the conventional position. Water spray manifold 48 is arcuate and extends around the casting wheel from the position where band 41 is removed from the peripheral groove of the casting wheel by support wheel 45, to the point of extraction of the cast bar C. Water spray manifold 48 functions to spray water or some other coolant directly onto the surface of cast bar C as the cast bar approaches the point of extraction from casting wheel 40. The cast bar is guided between pinch rolls 49 after it has been extracted from casting wheel 40, and is subsequently guided to a rolling mill, or the like for further processing. Thus, the band arrangement shown in FIG. 5 is similar to the arrangement of FIG. 1, but the partially solidified cast bar emerging from band 41 is allowed to remain in the casting wheel as it is further directly cooled by the water spray.

OPERATION

In operation it will be seen that casting is started in both embodiments of the invention by starting the rotation of the casting wheel, the band support wheels and the flexible band in the known manner. The molten metal is then introduced into the casting mold M from the pouring pot whereupon the metal is cooled in the mold M by spraying the outside of the mold M from conventional spray assemblies S as seen in FIGS. 1 and 5. As the molten metal moves with the mold M, it is cooled sufficiently during its first solidification phase to start partial solidification of the metal. This forms a crust of the metal adjacent the sides of the mold M while the metal in the center of the mold M is still unsolidified. This is best seen by reference to FIGS. 4 and 6 wherein the mold M and the solidifying metal are shown schematically.

This crust continues to thicken during the second solidification phase and the rotational speed of the casting wheel is such that by the time the metal has reached the end of phase 2, the crust enclosing the molten center is sufficiently thick to support the molten center without collapsing.

As illustrated in the embodiment of FIGS. 1, 2, and 4, the metal is discharged from the casting wheel 10 at or near the beginning of its third solidification phase, and is supported by the band 11 until it reaches support rolls 19 in cooling section 18. Upon entering the cooling section 18, metal C is transported over support rolls 19 to the pinch rolls 36. The manifolds 21 and 21' spray a conventional coolant between the support rolls and upper rolls and through the opening in guide walls 27 onto the outside of metal C to finish the solidification thereof while metal C is within the cooling section 18.

When the first portion of metal C is discharged from the casting wheel 10 during startup of the casting operation, upper rolls 26 are lowered to a position above the upper surface of metal C by the cylinder 32 to insure that support rolls 19 guide metal C upwardly along the cooling section 18 until it passes through the pinch rolls 36. The casting process continues until the flow of molten metal into the casting mold M from the pouring pot 16 is stopped.

Referring to FIG. 3 of the drawings, it will be seen that in a conventional casting wheel 10', the molten metal is poured into the mold M' in the casting wheel 10'. Immediately after entering the mold M', the metal is cooled during its first phase of solidification by the transfer of heat from the metal to the mold M'. Subsequently, the metal cools in its second phase of solidification with a thin crust but with the metal still in substantially complete direct contact with the mold M'.

When the crust of solidified metal becomes sufficiently thick, metal draws away from the mold M' and the solidification of the metal enters its third phase. However, in the mold M' during the third phase, the gap G' formed between the mold M' and the metal C' greatly reduces the rate at which heat is transferred from the metal C' to the mold M'. This is shown by the graph of FIG. 7 wherein the rate of heat transfer to the mold M' during the solidification of the metal in the mold M' of a prior art casting wheel 10' is indicated by a dashed line. The greatly reduced cooling rate during the third phase of solidification characteristic of the mold M' limits the maximum speed of the casting wheel 10' to that speed which insures that complete solidification of metal C' takes place while metal C' is positioned within the mold M' of the casting wheel 10'.

Referring to FIG. 4, the solidification phases of a metal being cast by the invention are illustrated schematically, showing that the metal is removed from the casting wheel 10 when the forming of the outer crust has reached that point at which the metal has shrunk and drawn away from the mold M. This point is or near the start of the third solidification phase and metal C still has a liquid core as indicated in FIG. 4 when it is discharged from the casting wheel 10. However, it will be seen that any conventional coolant may be passed over metal C to complete the solidification thereof at a much faster rate of heat transfer than any rate possible in the third phase in the conventional casting wheel 10' illustrated in FIG. 3.

The rate of heat transfer or cooling in the third phase of solidification by the invention relative cooling in the mold M' can be best seen by referring to FIG. 7 wherein the solid line indicates that the rate of heat transfer by the invention in the third phase is much higher than that of a conventional casting wheel 10' as shown by the dashed line. Thus, it will now be understood that the invention requires the operation of the casting machine C at a rotational speed which will result in the metal passing to the cooling section 18 at the beginning of or early in the third solidification phase. It will also be understood that this requirement provides greater casting rates than were possible with prior art casting wheels. It will be further understood that although the cooling section 18 sprays a coolant onto metal C, other types of cooling may be utilized such as passing metal C through a tank filled with a coolant to cool the metal C.

As illustrated in the embodiment of FIGS. 5 and 6, the partially solidified bar can remain in the casting wheel during the third phase of solidification. When flexible band 41 is removed from the periphery of the casting wheel, the partially solidified cast bar is exposed, and coolant is sprayed from manifold 48 directly onto the outer surface of the cast bar. This direct cooling is generally similar to the direct cooling which results in the embodiment of the invention shown in FIGS. 1, 2, and 4, except that the cast bar is completely solidified before it is extracted from the casting wheel.

While the general concept of the invention includes directly cooling a partially solidified cast bar, the first embodiment of the invention shown in FIGS. 1, 2, and 4 provides extracting the partially solidified bar from the casting wheel and completing the solidification of the bar as the bar moves away from the casting wheel, while the second embodiment of the invention shown in FIGS. 5 and 6 allows the partially solidified cast bar to remain in the casting wheel until it has been completely solidified.

The first embodiment of the invention allows phase three of the cooling phases to be stretched out over an extended length, so that a coolant sprayed onto the surface of the partially solidified cast bar can be sprayed onto all surfaces of the bar and adequate bar length is available for positive solidification. Furthermore, phases one and two of the cooling phases are not limited in their lengths by requiring that phase three be present in the casting wheel. The disadvantage of the first embodiment of the invention might be that the partially solidified bar, which has a tubular shell, must be straightened as it passes from phase two into phase three. However, the bar cast in this manner so far has not been damaged. It is believed that the tubular shell remains relatively hot because of the presence of the inner core of molten metal as the bar is straightened, and the hot tubular shell remains relatively plastic and is able to straighten without fracture. This belief is supported by the fact that the bar virtually extracts itself from the casting wheel under its own weight and tends to "lay" onto the support rollers of cooling section 18. Thus, the weight of the bar is all the force required to extract the bar from the casting wheel.

The second embodiment of the invention shown in FIGS. 5 and 6 does not bend the partially solidified cast bar, but waits until the bar is completely solid before it is straightened and extracted from the casting wheel. With this arrangement, the bar is not bent away or straightened from the casting wheel during a portion of its formation when its strength characteristics may be considered critical, or when only the tubular crust in phase 3 cooling has been formed. The full cross section of the bar will have been formed and the bar will have attained higher strength characteristics, even though it remains relatively hot as its point of extraction from the casting wheel and is flexible enough to straighten. A disadvantage of the arrangement of the second embodiment of the invention which is not present in the first embodiment of the invention might be that phase three of the cooling phases is located entirely within the peripheral groove of the casting wheel, which might limit the speed of rotation of the casting wheel. Of course, even with this possible limitation the speed of rotation of the casting wheel of the second embodiment of the invention is much faster than that of the conventional casting wheel, as illustrated in FIG. 3.

In order that the disadvantage of holding the bar in the casting wheel of the second embodiment of the invention be overcome, manifold 48 can be extended in an upward direction along the path of the bar as it is extracted from the casting wheel to apply water coolant to the bar after the bar has been extracted from the casting wheel, and the speed of the casting machine can be increased. The bar will be extracted from the casting wheel before it is completely solid, but the elongated manifold 48 will continue to apply coolant to the bar so that the bar will become completely solid as it leaves the vicinity of the casting machine.

In the first embodiment of the invention, the molten metal is poured into the arcuate mold at a high level and the metal is completely solidified before the molten core reaches a high level along the inclined path of support rollers 19. Thus, the molten core is always maintained under a high hydrostatic pressure, which is effective to reduce the frequency of voids or cavities appearing in the cast bar.

Although specific embodiments of the invention have been disclosed herein in illustrating the invention, it is understood that the inventive concept is not limited thereto since it may be embodied in other forms without departing from the scope thereof as set forth by the appended claims.

I claim:

1. In a metal casting process the steps of:

engaging the peripheral groove of a rotating casting wheel with a continuous flexible band to form an arcuate mold,

feeding metal in a molten condition into the mold,

cooling the metal in the mold until the metal has partially solidified,

guiding the flexible band away from the peripheral groove in an upwardly inclined tangent from the lower portion of the casting wheel,

removing the metal from the mold as an only partially solidified metal and moving the metal with the flexible band away from the peripheral groove along the upwardly inclined tangent so that the metal is supported by the flexible band,

guiding the flexible band downwardly away from the metal while continuing to move the metal along the upwardly inclined tangent, and

applying cooling fluid directly to the metal as the metal moves along the upwardly inclined tangent in sufficient quantity to complete the solidification of the metal before it reaches the level at which it was fed in a molten state into the mold.

2. In a metal casting process, the steps of:

engaging the peripheral groove of a rotating casting wheel with a continuous flexible band to form a mold,

feeding metal in a molten condition into the mold,

cooling the metal in the mold as the metal passes around the casting wheel until the metal has at least partially solidified,

guiding the flexible band generally tangentially away from the casting wheel to open the mold and to expose the partially solidified metal in the peripheral groove of the casting wheel,

continuing to pass the exposed partially solidified metal around the casting wheel in the peripheral groove so that the metal is continuously supported by the groove of the casting wheel,

applying coolant directly to the exposed surfaces of the partially solidified metal to complete the solidification thereof as the metal remains in the peripheral groove of the casting wheel, and

removing the metal from the peripheral groove of the rotating casting wheel after the metal has become substantially solidified.

3. In a continuous casting process for casting metal wherein the metal in a molten condition is poured into an arcuate channel defined by a peripheral groove of a rotatable casting wheel and an endless band extending about a portion of the peripheral groove, the improvement therein of guiding the band tangentially away from the vicinity of the peripheral groove of the casting wheel at a position about the casting wheel when the outer portion of the metal has solidified but before the inner portion of the metal has solidified to open the peripheral groove of the casting wheel, and continuously supporting the partially solidified metal and applying a fluid coolant directly to the metal so that the inner portion of the metal has completely solidified before it reaches the level at which it was poured in a molten state into the mold.

4. In a casting process, the steps of:

engaging the peripheral groove of a rotating casting wheel with a continuous flexible band to form an arcuate mold,

feeding metal in a molten condition into the mold,

cooling the molten metal in the mold until the metal has partially solidified,

guiding the flexible band along an upwardly inclined tangent away from the peripheral groove at the lower portion of the casting wheel,

removing the metal from the lower portion of the mold as an only partially solidified metal and moving the metal with the flexible band along the upwardly inclined tangent so that the metal is supported by the flexible band,

gripping the metal along the upwardly inclined tangent with rotating rollers and moving the partially solidified metal with the rollers along the upwardly inclined tangent, and

cooling the partially solidified metal to complete the solidification thereof as the metal moves through the upwardly inclined tangent and before the metal reaches the level at which it was poured in a molten condition into the mold.