HORIZONTAL DIRECT CHILL CASTING APPARATUS AND METHOD

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ABSTRACT

A casting apparatus (10) for direct chill casting metal includes a tundish (12) containing a supply of molten metal, a casting mold (14), and a starter block (44) associated with the casting mold (14). The casting mold (14) is in fluid communication with the tundish (12) through a passage (22) defined in the tundish wall. The casting mold (14) includes a header plate (24), a casting ring (26), and a feed ring (28). The header plate (24) defines an arcuate shaped opening (36) connected to the passage (22). The header plate (24) has an upstream side (38) and a downstream side (40). The casting ring (26) is connected to the downstream side (40) of the header plate (24) and defines a groove (52) proximate to the sidewall (48) of the header plate (24). The feed ring (28) is disposed in the groove.
HORIZONTAL DIRECT CHILL CASTING APPARATUS AND METHOD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to direct chill casting machines. More particularly, the present invention relates generally to horizontally oriented direct chill casting machines adapted to produce metal articles of indefinite length. Further, the present invention is directed to methods of direct chill casting metals, such as aluminum, into elongated metal articles, such as billets, rods, slabs, etc.

2. Description of Related Art

Direct chill casting is a well-known technique in the art for casting metal, such as aluminum, into elongated metal articles such as billets. When casting molten metal in such a fashion, the molten metal is generally introduced into a vertically oriented and open-ended mold cavity having a support located at the discharge end. The support, or bottom block, is lowered slowly while the molten metal flows downward in the cavity. The wall of the direct chill casting mold is continuously cooled so that a solid skin of metal forms in contact with the wall. The metal is fully solidified further downstream in the mold cavity to form the elongated metal article.

A recent improvement in direct chill casting techniques is the use of a graphite or graphite-like ring in the wall of the direct chill casting mold. The graphite ring generally forms a solid but fluid permeable wall section in the mold cavity. One example of a direct chill casting apparatus or casting mold incorporating a graphite or graphite-like ring is disclosed in U.S. Pat. No. 4,598,763 to Wagstaff et al.

In the Wagstaff ‘763 patent, the graphite ring is located below a peripheral wall in a vertically oriented mold cavity of the casting mold. The peripheral wall is formed by a ring of insulative refractory material. The peripheral wall defines a sharp corner or overhang immediately upstream of the graphite ring. The graphite ring is fluid permeable. During operation of the casting mold, the graphite ring is supplied with lubricating oil and gas, which at least partially solidifies the molten metal flowing downward in the mold cavity (i.e., forms a solid skin of metal). The fluid permeable graphite ring allows the lubricating oil and gas to diffuse therethrough. Several other Wagstaff et al. patents are known in the field and which each generally disclose the use of a graphite ring in a direct chill casting mold and, particularly, a vertically-oriented direct chill casting mold. Additional pertinent Wagstaff et al. patents in the field include U.S. Pat. Nos. 5,582,230; 5,323,841; 5,318,008; and 4,947,925. Each of the Wagstaff et al. patents identified hereinabove is incorporated herein by reference.

The Wagstaff ‘098 patent discloses a conventional, vertically oriented direct chill casting mold incorporating a graphite ring. This reference further discloses a liquid coolant discharge device for solidifying the molten metal downstream of the graphite ring. The coolant device is in the form of a liquid coolant box that defines a plurality of holes for supplying liquid coolant onto the surface of the metal passing downward from the graphite ring. The holes are downward directed (i.e., angled) to discharge the coolant onto the metal body generally formed at the graphite ring.

U.S. Pat. No. 4,947,925 to Wagstaff et al. discloses a direct chill casting mold that is generally configured to form rectangular cross section ingots and the like. The casting ring used in the casting mold disclosed by this reference is divided into four (4) generally rectilinear wall segments that are secured together with mechanical fasteners.

U.S. Pat. No. 5,582,230 to Wagstaff et al. discloses a direct chill casting mold that incorporates a similar downstream coolant device to that disclosed in the Wagstaff ‘098 patent. The coolant device is adapted to apply liquid coolant directly on the outer surface of the semi-solidified metal passing downward from the graphite ring when the casting mold is in use. The mold cavity is provided with a plurality of fluid discharge openings through which pressurized jets of fluid are discharged onto the surface of the semi-solidified metal. The liquid cooling streams or jets are discharged through two sets of openings.

While direct chill casting molds incorporating a graphite or graphite-like ring are known in the art, there still remains room for improvement in the field, particularly at the interface between the graphite ring and the molten metal in the mold cavity of the direct chill casting mold during operation of the casting mold.

SUMMARY OF THE INVENTION

The present invention relates generally to a casting apparatus for direct chill casting metal along a horizontal axis. The casting apparatus comprises a tundish for containing a supply of molten metal, a casting mold, and a starter block associated with the casting mold. The casting mold is in fluid communication with the tundish through a passage defined in the tundish wall. The casting mold is generally comprised of a header plate, a casting ring, and a feed ring. The header plate defines an arcuate shaped opening connecting to the passage. The header plate has an upstream side and a downstream side. The downstream side defines a recess having a tapered sidewall. The casting ring is connected to the downstream side of the header plate and defines a groove proximate to the sidewall of the header plate. The feed ring is disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold. The starter block is generally positioned within the casting ring.

The sidewall of the header plate preferably tapers outward from a central axis of the casting mold. The sidewall may taper directly to the feed ring. The feed ring is preferably made of graphite. The feed ring may be fluid permeable and the casting ring may be configured to supply cooling and lubricating fluid to the feed ring. A cooling ring may be connected to the casting ring. The cooling ring may define a plurality of raised teeth. The cooling ring may cooperate with the casting ring such that the teeth form a plurality of spray nozzles for delivering cooling fluid sprays at least to the casting ring during operation of the casting mold. The cooling ring may define an annular chamber in fluid communication with the spray nozzles. The annular chamber may be adapted to supply cooling fluid to the spray nozzles for application at least to the casting ring during operation of the casting mold.
The feed ring may be connected to the casting ring by a threaded connection. The arcuate shaped opening may comprise a diverging opening. The passage defined in the tundish wall may be at least partially convergent.

The present invention also relates generally to casting molds for direct chill casting metal. The casting mold of the present invention generally comprises a header plate, a casting ring, and a feed ring. The header plate defines an arcuate shaped opening. The header plate has an upstream side and a downstream side. The downstream side defines a recess having a tapered sidewall. The casting ring is connected to the downstream side of the header plate and defines a groove proximate to the sidewall of the header plate. The feed ring is disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold.

Further, the present invention relates to methods of direct chill casting metal. In the method of the present invention, the direct chill casting apparatus generally comprises a tundish, a casting mold, and a starting block associated with the casting mold. The tundish contains a supply of molten metal. The casting mold is in fluid communication with the tundish through a passage defined in the tundish wall. The casting mold is generally comprised of a header plate, a casting ring, and a feed ring. The header plate defines an arcuate shaped opening connected to the passage. The header plate has an upstream side and a downstream side. The downstream side defines a recess having a tapered sidewall. A casting ring is connected to the downstream side of the header plate and defines a groove proximate to the sidewall of the header plate. The feed ring is disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold.

The method generally comprises withdrawing the starter block in the casting ring, delivering molten metal to the casting mold through the tundish passage in the tundish wall and the arcuate shaped opening in the header plate, and cooling at least partially solidifying the molten metal at the feed ring to form a metal article. The step of delivering molten metal may comprise the molten metal diverging outward in the casting mold along the sidewall of the header plate before contacting the feed ring. The feed ring may be fluid permeable and the casting ring may be configured to supply cooling and lubricating fluid to the feed ring. The method may comprise supplying the cooling and lubricating fluid to the feed ring to cool and at least partially solidify the molten metal at the feed ring.

A cooling ring may be connected to the casting ring. The cooling ring may define a plurality of raised teeth and cooperate with the casting ring such that the teeth form a plurality of spray nozzles. The method may further comprise delivering cooling fluid sprays at least to the casting ring through the spray nozzles to cool the casting ring during operation of the casting mold. The cooling ring may define an annular chamber in fluid communication with the spray nozzles. The method may further comprise the supplying of cooling fluid from the annular chamber to the spray nozzles.

Further details and advantages of the casting apparatus and method of direct chill casting metal of the present invention will become apparent when reading the following detailed description in conjunction with the drawing figures.

**Brief Description of the Drawings**

**FIG. 1** is a cross sectional view of a horizontal direct chill casting apparatus comprising a tundish and casting mold in accordance with the present invention;

**FIG. 2** is a cross sectional view of the casting mold used in the casting apparatus of **FIG. 1**;

**FIG. 3** is a front view of the casting mold of **FIG. 2**;

**FIG. 4** is a cross sectional view of a header plate used in the casting mold shown in **FIGS. 1 and 2**;

**FIG. 5** is a front view of the header plate of **FIG. 4**;

**FIG. 6** is a cross sectional view of a casting ring used in the casting mold shown in **FIGS. 1 and 2**;

**FIG. 7** is a front view of the casting ring of **FIG. 6**;

**FIG. 8** is a cross sectional view taken along line 8-8 in **FIG. 7**;

**FIG. 9** is a plan view of a feed ring used in the casting mold shown in **FIGS. 1 and 2**;

**FIG. 10** is a cross sectional view taken along line 10-10 in **FIG. 9**;

**FIG. 11** is a discharge end view of the casting mold of **FIG. 2** showing a cooling ring used in the casting mold of **FIGS. 1 and 2**;

**FIG. 12** is a cross sectional view taken along line 12-12 in **FIG. 11**;

**FIG. 13** is a tundish side view of a tundish opening connecting the tundish and casting mold in the casting apparatus of **FIG. 1**;

**FIG. 14** is a cross sectional view taken along a vertical axis of the tundish opening of **FIG. 13**;

**FIG. 15** is a cross sectional view taken along a horizontal axis of the tundish opening of **FIG. 13**;

**FIG. 16** is a casting mold side view of the tundish opening of **FIGS. 13-15**.

**Description of the Preferred Embodiments**

For purposes of the description hereinafter, the terms “upper”, “lower”, “right”, “left”, “vertical”, “horizontal”, “top”, “bottom”, and derivatives thereof shall relate to the invention, as it is oriented in the drawing figures. However, it is to be understood that the invention may assume various alternative variations and step sequences except where expressly specified to the contrary. It is also to be understood that the specific devices and processes illustrated in the attached drawings and described in the following text are simply exemplary embodiments of the invention. Hence, specific dimensions and other physical characteristics related to the embodiments disclosed hereinafter are not to be considered limiting.

Referring to the **FIG. 1**, the present invention is a casting apparatus 10 adapted to direct chill cast solid cross section metal articles (not shown). The casting apparatus 10
is generally comprised of a tundish 12 and a casting mold 14 in fluid communication with the tundish 12. The tundish 12 is adapted to maintain a supply of molten metal, for example, molten aluminum or magnesium, which is supplied to the casting mold 14. Other typical metals that may be used in the casting apparatus 10 include zinc, bronze, copper, or other non-ferrous metals.

[0037] The tundish 12 generally includes an outer shell 16, which is preferably made of metal such as steel, and an insulating layer 18 lining the outer shell 16. The insulating layer 18 is preferably a refractory material that is suitable for use with aluminum or magnesium alloys and the like. The insulating layer 18 defines a molten metal holding chamber 20, which maintains a ready supply of molten metal for delivery to the casting mold 14 during operation of the casting apparatus 10. As shown in FIG. 1, a passage 22 (hereinafter “tundish passage 22”) is formed in the insulating layer 18 and outer shell 16 for supplying the casting mold 14 with molten metal. The tundish passage 22 is at least partially convergent, as illustrated, to facilitate the delivery of molten metal to the casting mold 14. Further details of the tundish passage are described hereinafter in connection with FIGS. 13-16. The tundish passage 22 generally has two functions. First, the tundish passage 22 allows non-turbulent passage of molten metal to the casting mold 14 and, second, prevents surface defects by directing the hot molten metal to the bottom of the casting mold 14.

[0038] Referring to FIGS. 1-3, the casting mold 14 is preferably fixedly connected to the outer shell 16. The casting mold 14 is generally comprised of a header plate 24, a casting ring 26 connected to the header plate 24, a feed ring 28 connected to the casting ring 26 and, preferably, a cooling ring 30 connected to the casting ring 26. The header plate 24 is connected, preferably fixedly, to the outer shell 16 by a header clamp 32 and mechanical fasteners 34. The header plate 24 defines an arcuate shaped opening 36, which is in fluid communication with the tundish passage 22 in the tundish 12. The opening 36 admits molten metal into the casting mold 14 during operation of the casting apparatus 10. As shown in FIGS. 1 and 2, the opening 36 is preferably formed as a divergent opening.

[0039] Referring to FIGS. 1-5, the header plate 24 has a first or upstream side 38 and a second or downstream side 40. The downstream side 40 faces inward toward a mold cavity 42 of the casting mold 14. The mold cavity 42 is generally defined by the downstream side 40 of the header plate 24, the casting ring 26, and a bottom or starter block 44. During operation of the casting apparatus 10 and casting mold 14, the starter block 44 is initially positioned or seated within the casting ring 26 and is slowly withdrawn from the casting ring 26 while molten metal simultaneously flows into the mold cavity 42 through the opening 36 in header plate 24 and the tundish passage 22, as is conventionally known in the art.

[0040] The downstream side 40 of the header plate 24 defines a depression or recess 46. The recess 46 has tapered sidewall 48 as shown in FIGS. 1 and 2. The tapered sidewall 48 generally tapers outward from a central axis L of the casting mold 14. Preferably, the sidewall 48 tapers from the arcuate opening 36 in the header plate 24 substantially to the feed ring 28 so that the molten metal received into the mold cavity 42 during operation of the casting mold 14 smoothly transitions from the header plate 24 to the feed ring 28, where the molten metal is at least partially solidified to form an elongated metal article. The tapered sidewall 48 provides uniform molten metal flow and delivers the molten metal smoothly to the solidification interface, which occurs substantially at the feed ring 28.

[0041] Referring to FIGS. 1-10, the casting ring 26 is located next to the header plate 24 and is preferably connected fixedly to the header plate 24 with mechanical fasteners, for example. The casting ring 26 may be made of metal, such as aluminum, copper, or steel. The casting ring 26 has an elongated inner wall 50, which defines an annular recess 52, which generally faces mold cavity 44. As shown, the recess 52 is preferably located immediately adjacent and downstream of the header plate 24. The feed ring 28 is disposed in the recess 52 and is preferably mounted fixedly to the casting ring 26, for example by a threaded connection. The feed ring 28 is preferably a fluid permeable graphite ring and is used to at least partially solidify the molten metal passing flowing through the mold cavity 42 during operation of the casting apparatus 10 and casting mold 14, as described further hereinafter. The use of graphite rings in direct chill casting apparatus is well known in the art as discussed previously in connection with the Waystaff patents, which were previously incorporated herein by reference.

[0042] Referring to FIGS. 1-12, the cooling ring 30 is located next to the casting ring 26. The cooling ring 30 is configured to cool the casting ring 26 and fully solidify the at least partially solidified metal passing the feed ring 28 when the casting mold 14 is in operation. The cooling ring is configured to deliver cooling fluid sprays onto an outer surface 54 of the elongated wall 50 of the casting ring 26 and, preferably, the surface of the at least partially solidified metal passing the casting ring 26. The cooling ring 30 is preferably mounted fixedly to the casting ring 26, for example by mechanical fasteners. The cooling ring 30 may be made of metal such as aluminum, copper, steel or stainless steel, or a non-metallic material material, such as a polymer of suitable properties.

[0043] The cooling ring 30 defines an annular chamber 58 therein. The annular chamber 58 is adapted to hold a supply of cooling fluid, such as water, which is to be applied to the outer surface 54 of the elongated wall 50 of the casting ring 26 and the at least partially solidified metal passing the feed ring 28 and casting ring 26 during operation of the casting mold 14. Preferably, the cooling fluid (i.e., water) is applied to the outer surface 54 and semi-solidified metal as cooling sprays. For this purpose, the cooling ring 30 defines a plurality of raised teeth 60. The cooling ring 30 is connected to or cooperates with the casting ring 26 such that the raised teeth 60 define a plurality of spray nozzles 62 for supplying the cooling sprays onto the outer wall 54 of the casting ring 26. The spray nozzles 62 are in fluid communication with the annular chamber 58, which supplies the cooling fluid to the spray nozzles 62. The spray nozzles 62 are generally directed toward the central axis L of the casting mold 14. The raised teeth 60 and, hence, spray nozzles 62 are preferably spaced regularly around the casting ring 26 to provide substantially uniform cooling fluid sprays onto the outer wall 54 of the casting ring 26 and onto the semi-solidified metal passing from the casting ring 26.

[0044] The feed ring 28 is fed with a cooling and lubricating fluid or combination of fluids, such as caster oil,
canola oil, peanut oil or appropriate synthetic lubricant, for solidifying the molten metal admitted to the casting mold 14 from the tundish 12 and flowing through the mold cavity 44 during operation of the casting mold 14. The cooling and lubricating fluid is delivered to the feed ring 28 by a system of conduits defined in the casting ring 26. The system of conduits includes a circumferentially extending supply conduit 64 that circulates the cooling and lubricating fluid circumferentially through the casting ring 26, and a plurality of transversely extending branch conduits 66, which supply the cooling and lubricating fluid directly to the fluid permeable feed ring 28. The fluid permeable feed ring 28 allows the cooling and lubricating fluid to reach the surface of the feed ring 28 to cool and at least partially solidify the molten metal flowing through the mold cavity 42 from the tundish 12. The feed ring 28 operates in a substantially analogous manner to graphite rings known in the art, such as those disclosed in the Wagstaff patents discussed previously.

[0045] Referring to FIGS. 13-16, the tundish passage 22 defined in the sidewall of the tundish 12 is shown. The tundish passage 22 facilitates the movement of molten metal from the tundish 12 to the casting mold 14. The molten metal flows by gravity from the molten metal holding chamber 20 through the tundish passage 22 (i.e., head level differences between the chamber 20 and tundish passage 22). The tundish passage 22 is a generally convergent passage that is divided in two portions or regions. In particular, the tundish passage 22 includes a first portion 70, which forms the convergent area in the tundish passage 22, and a second portion 72, which is generally cylindrically shaped. The first portion 70 forms the entry region or opening to the tundish passage 22 and allows molten metal to smoothly transition into the tundish passage 22 from the holding chamber 20. The second portion 72 forms the outlet of the tundish passage 22 and delivers molten metal to the arcuate opening 36 in the header plate 24. The arcuate opening 36 is generally divergent over its length and allows the molten metal flowing into the mold cavity 42 to smoothly transition into contact with the downstream side 40 of the header plate 24.

[0046] Referring to FIGS. 1-16, the casting apparatus 10 generally described hereinabove operates substantially as follows. Initially, the starter block 44 is seated in the casting ring 26 proximate to the header plate 24. As the starter block 44 is withdrawn from the casting ring 26, molten metal flows from the holding chamber 20 into the tundish passage 22. The first portion 70 of the tundish passage 22 funnels the molten metal into the second portion 72. The molten metal then flows into the mold cavity 42 of the casting mold 14 through the divergent arcuate opening 36. As the molten metal flows into the mold cavity 42, the molten metal diverges outward along the sidewall 48 formed in the downstream side 40 of the header plate 24. The molten metal diverges outward until it contacts the feed ring 28. The feed ring 28 freezes the molten metal to form a solid outer skin of solidified metal in contact with the feed ring 28. The now at least partially solidified metal passes to the casting ring 26 where it is fully solidified into the desired metal article, such as a billet. The at least partially solidified metal flows along the elongated wall 50 of the casting ring 26 where it is cooled and solidified. The casting ring 26 and at least partially solidified metal are cooled by the application of cooling fluid sprays as indicated previously, which are emitted by the spray nozzles 62 defined by the raised teeth 60 formed on the cooling ring 30. The cooling fluid for the cooling sprays is supplied from the annular chamber 58 defined by the cooling ring 30. The annular chamber 58 is preferably in fluid communication with an external source of cooling fluid, such as water.

[0047] While the present invention was described with reference to preferred embodiments of the casting apparatus and casting mold, those skilled in the art may make modifications and alterations to the present invention without departing from the spirit and scope of the invention. Accordingly, the foregoing detailed description is intended to be illustrative rather than restrictive. The invention is defined by the appended claims and all changes to the invention that fall within the meaning and range of equivalency of the appended claims are to be embraced within their scope.

What is claimed is:

1. A casting mold for direct chill casting metal, comprising:
   a header plate defining an arcuate shaped opening, the header plate having an upstream side and a downstream side, the downstream side defining a recess having a tapered sidewalk;
   a casting ring connected to the downstream side of the header plate and defining a groove proximate to the sidewall of the header plate; and
   a feed ring disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold.

2. The casting mold of claim 1, wherein the sidewall tapers outward from a central axis of the casting mold.

3. The casting mold of claim 2, wherein the sidewall tapers to the feed ring.

4. The casting mold of claim 1, wherein the feed ring is made of graphite.

5. The casting mold of claim 1, wherein the feed ring is fluid permeable and the casting ring is configured to supply cooling and lubricating fluid to the feed ring.

6. The casting mold of claim 1, further comprising a cooling ring connected to the casting ring.

7. The casting mold of claim 6, the cooling ring defining a plurality of raised teeth and cooperating with the casting ring such that the teeth form a plurality of spray nozzles for delivering cooling fluid sprays at least to the casting ring during operation of the casting mold.

8. The casting mold of claim 7, the cooling ring defining an annular chamber in fluid communication with the spray nozzles, the annular chamber adapted to supply cooling fluid to the spray nozzles for application at least to the casting ring during operation of the casting mold.

9. The casting mold of claim 1, wherein the feed ring is connected to the casting ring by a threaded connection.

10. The casting mold of claim 1, wherein the arcuate opening comprises a diverging opening.

11. A casting apparatus for direct chill casting metal, comprising:
   a tundish for containing a supply of molten metal;
   a casting mold in fluid communication with the tundish through a passage defined in the tundish wall, the casting mold further comprising:
a header plate defining an arcuate shaped opening connected to the passage, the header plate having an upstream side and a downstream side, the downstream side defining a recess having a tapered sidewall;

a casting ring connected to the downstream side of the header plate and defining a groove proximate to the sidewall of the header plate; and

a feed ring disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold; and

a starter block associated with the casting ring.

12. The casting apparatus of claim 11, wherein the sidewall tapers outward from a central axis of the casting mold.

13. The casting apparatus of claim 12, wherein the sidewall tapers to the feed ring.

14. The casting apparatus of claim 11, wherein the feed ring is made of graphite.

15. The casting apparatus of claim 11, wherein the feed ring is fluid permeable and the casting ring is configured to supply cooling and lubricating fluid to the feed ring.

16. The casting apparatus of claim 11, further comprising a cooling ring connected to the casting ring.

17. The casting apparatus of claim 16, the cooling ring defining a plurality of raised teeth and cooperating with the casting ring such that the teeth form a plurality of spray nozzles for delivering cooling fluid sprays at least to the casting ring during operation of the casting mold.

18. The casting apparatus of claim 17, the cooling ring defining an annular chamber in fluid communication with the spray nozzles, the annular chamber adapted to supply cooling fluid to the spray nozzles for application at least to the casting ring during operation of the casting mold.

19. The casting apparatus of claim 11, wherein the feed ring is connected to the casting ring by a threaded connection.

20. The casting apparatus of claim 11, wherein the arcuate shaped opening comprises a diverging opening.

21. The casting apparatus of claim 11, wherein the passage defined in the tundish wall is at least partially convergent.

22. A method of casting metal in a direct chill casting apparatus, comprising:

a tundish containing a supply of molten metal;

a casting mold in fluid communication with the tundish through a passage defined in the tundish wall, the casting mold further comprising:

a header plate defining an arcuate shaped opening connected to the passage, the header plate having an upstream side and a downstream side, the downstream side defining a recess having a tapered sidewall;

a casting ring connected to the downstream side of the header plate and defining a groove proximate to the sidewall of the header plate; and

a feed ring disposed in the groove for cooling and at least partially solidifying molten metal flowing through the casting mold; and

a starter block associated with the casting ring;

the method comprising the steps of:

withdrawing the starter block in the casting ring;

delivering molten metal to the casting mold through the passage in the tundish wall and the arcuate shaped opening in the header plate; and

cooling and at least partially solidifying the molten metal at the feed ring to form a metal article.

23. The method of claim 22, the step of delivering molten metal comprising the molten metal diverging outward in the casting mold along the sidewall of the header plate before contacting the feed ring.

24. The method of claim 22, wherein the feed ring is fluid permeable and the casting ring is configured to supply cooling and lubricating fluid to the feed ring, the method further comprising supplying the cooling and lubricating fluid to the feed ring to cool and at least partially solidify the molten metal at the feed ring.

25. The method of claim 22, further comprising a cooling ring connected to the casting ring, the cooling ring defining a plurality of raised teeth and cooperating with the casting ring such that the teeth form a plurality of spray nozzles, the method further comprising delivering cooling fluid sprays at least to the casting ring through the spray nozzles to cool the casting ring during operation of the casting mold.

26. The method of claim 25, the cooling ring defining an annular chamber in fluid communication with the spray nozzles, the method further comprising supplying cooling fluid to the spray nozzles from the annular chamber.

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