METHOD AND APPARATUS FOR CONTINUOUSLY CASTING STEEL STRIP

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Abstract
A delivery nozzle for a twin roll caster for making has an elongated nozzle body having elongated extending side walls and end walls to form a nozzle trough, and side outlet openings in the side walls capable of discharging molten metal from the nozzle body laterally outwardly from the side walls of the nozzle body. The side walls below the side outlet openings extend downwardly to converge and meet at the lower extremity to form a bottom part of the nozzle body configured to inhibit entrapment of gas bubbles in a casting pool. The side walls forming the bottom part may have generally flat exterior surfaces throughout and meet at an acute angle to form a discrete edge along the nozzle body, or alternatively, convex curved external surfaces meeting at the bottom extremity in an arcuate shape along the nozzle body.
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TECHNICAL FIELD

[0001] This invention relates to the casting of metal strip. It has particular but not exclusive application to the casting of thin ferrous metal strip.

[0002] It is known to cast thin metal strip by continuous casting in a twin roll caster. Molten metal is introduced between a pair of counter-rotated horizontal casting rolls which are internally cooled so that metal shells solidify on the moving roll surfaces and are brought together at the nip between them to produce a solidified thin strip product delivered downwardly from the nip between the rolls. The term “nip” is used herein to refer to the general region at which the rolls are closest together. The molten metal may be poured from a ladle into a smaller vessel from which the molten metal flows through a metal delivery nozzle located between the casting rolls above the nip to form a casting pool of molten metal supported on the casting surfaces of the casting rolls immediately above the nip. This casting pool may be confined between side plates or dams held in sliding engagement with the ends of the rolls.

[0003] In using a twin roll caster to cast thin steel strip, much attention has been given to the design of metal delivery nozzles aimed at producing a smooth even flow of metal to and within the casting pool. There have been previous proposals to employ such a delivery nozzle formed with a trough to receive the molten metal that has a lower part submerged in the casting pool during a casting campaign, and having side openings through which the molten metal is capable of flowing into the casting pool outwardly toward the casting surfaces of the rolls. Examples of such metal delivery nozzles are disclosed in Japanese Patent No. 09-103855 and U.S. Pat. No. 6,012,508.

[0004] Such previous twin roll casters in our experience employed metal delivery nozzles with their bottom parts of a trapezoidal shape with a flat bottom immersed in the casting pool. Such a prior art metal delivery nozzle is shown in FIG. 1. The thin cast strip that was produced by the twin roll caster was found to have ripple shaped contractions and associated cracking, due to uneven solidification, to appear in the cast strip. The present invention provides a metal delivery nozzle that is capable of inhibiting, if not completely alleviating this problem.

DISCLOSURE OF THE INVENTION

[0005] A metal delivery nozzle is provided for delivering molten metal into a casting pool of a strip caster comprising:

[0006] (a) an elongate nozzle body having longitudinally extending side walls and end walls to form a nozzle trough;

[0007] (b) side outlet openings in the side walls capable of providing for flow of molten metal from the trough laterally outwardly from the sides of the nozzle; and

[0008] (c) the side walls of the nozzle below the side outlet openings extending downwardly to converge and meet at the lower extremity of the nozzle to form a bottom part of the nozzle body with an external surface configured to inhibit entrapment of gas bubbles under the nozzle trough in a casting pool.

[0009] The side outlet openings may be spaced longitudinally along the side walls of the nozzle. Also, the side outlet openings may be capable of providing for outward flow of molten metal adjacent the bottom part of the trough.

[0010] In the metal delivery nozzle, the bottom part may be an extension of the side walls, or a separate part. In any case, the bottom part may have a generally flat external surface angled downwardly and inwardly along the nozzle body. The bottom part may also have a generally flat external surface throughout and meet at an acute angle to form a distinct edge along the nozzle body. Alternatively, the bottom part may have convex curved external surfaces meeting at the bottom extremity of the nozzle body in an arcuate shape along the nozzle body.

[0011] Also, in certain embodiments, the upper parts of the side walls may extend downwardly to form the bottom part and have convex curved external surfaces along the nozzle body. In addition, the convex curved external surfaces of side walls forming the bottom part may meet at a bottom extremity in a rounded shape along the nozzle body. Alternatively, the convex curved external surfaces of the side walls forming the bottom part meet at an acute angle to a bottom extremity to form a distinct edge along the nozzle body.

[0012] With use of the delivery nozzles of the configuration as described in a twin roll caster, the thin cast strip that was produced by the twin roll caster was found to inhibit, if not completely eliminate ripple-shaped contractions and associated cracking, due to uneven solidification. Although the causal relationship is not certain, one theory is that gas bubbles that appear in the casting pool are not trapped under the bottom of the metal delivery nozzle where they can coalesce into large bubbles, which upon disturbance of equilibrium, can generate disturbances of the casting pool surface. It is known that gases are generated in the casting pool by reaction between oxides in the molten metal slag and carbon in the molten metal and in the nozzle refractories used to construct the metal delivery nozzle. It is believed that immediate release of the gases allows them to move smoothly up the external surfaces of the side walls forming the bottom part, and upwardly along the external surfaces of the upper side walls to reduce, if not totally alleviate, any disturbances in the casting pool surface, and to inhibit, if not completely eliminate ripple defects and cracking in the cast strip.

[0013] Further, the longitudinal side walls and end walls of the nozzle body of the metal delivery nozzle may be formed of a carbon free refractory material. It is believed that such refractory materials promote release of any generated gas. In addition, coating of the external surfaces of the side walls of the nozzle with carbon free material, for example an alkaline silicate material, alumina, zirconia or magnesia, is believed to further promote smooth release.

[0014] The invention also extends to apparatus for continuous casting of thin metal strip comprising a pair of laterally positioned casting rolls forming a nip between them, and an elongate metal delivery nozzle disposed above and extending along the nip between the casting rolls. The metal delivery nozzle is capable of delivery of molten metal
to form a casting pool of molten metal supported on the casting rolls above the nip. The delivery nozzle comprises an elongate nozzle body having longitudinally extending side walls and end walls disposed to form a nozzle trough, with side outlet openings in the side walls capable of providing flow of molten metal from the trough laterally outwardly from the side walls of the nozzle axially toward the circumferential surfaces of the casting rolls. The side walls of the nozzle below the side outlet openings extend downwardly to converge and meet at the lower extremity of the nozzle to form a bottom part of the nozzle body with an external surface configured to inhibit entrapment of gas bubbles under the nozzle trough in a casting pool.

In addition, or alternatively, a method of continuously casting thin metal strip is also provided comprising the steps of assembling a thin strip caster having a pair of casting rolls positioned to form a nip between them, assembling a metal delivery system capable of forming a casting pool between the casting rolls above the nip with side dams adjacent the ends of the nip to confine the casting pool, and assembling as part of the metal delivery system a delivery nozzle in one of the configurations described above.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention may be more fully explained some particular embodiments will be described with reference to the accompanying drawings in which:

FIG. 1 is a cross-sectional drawing showing a metal delivery nozzle of the prior art;
FIG. 2 is a cross-sectional drawing showing a first embodiment of a metal delivery nozzle of the present invention;
FIG. 3 is a cross-sectional drawing of a second embodiment of a metal delivery nozzle of the present invention;
FIG. 4 is a cross-sectional drawing of a third embodiment of a metal delivery nozzle of the present invention;
FIG. 5 is a cross-sectional drawing of a fourth embodiment of a metal delivery nozzle of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Referring to FIG. 2, a metal delivery nozzle of the present invention is shown. An elongated nozzle body 11 is provided for receiving the molten metal 1 that is formed with a pair of longitudinal side walls 15, whose lower portions extend downwardly to approach and intersect each other at the lower extremity to form a bottom part 30 of the nozzle body. A pair of end walls 19 also joins the longitudinal side walls 15 to form the bottom part 30.

The metal delivery nozzle is disposed above the roll gap G in the space enclosed by the side dams 7 and the casting rolls 6 of the twin roll caster. In the lower portion of the longitudinal side walls 15, a plurality of side outlet openings 23 are provided through which molten metal is capable of being discharged from the nozzle body 11, and are directed towards the outer circumferential surfaces of the casting rolls 6. When the molten metal 1 flows through the nozzle trough 11, the casting pool 10 of molten metal is formed above the roll gap G in contact with the outer circumferential surfaces of the casting rolls 6.

The downwardly extending side walls 15 of the nozzle body 11 form the bottom part 30 extending to the bottom extremity 32 of the delivery nozzle. In the delivery nozzle illustrated in FIG. 2, the side walls 31 of the nozzle bottom part 30 are generally flat external surfaces through-out and meet at an acute angle to form a distinct edge at the bottom extremity 32 along the nozzle body.

In the twin roll caster with a metal delivery nozzle as illustrated in FIG. 2, the casting rolls 6 counter-rotate and the casting pool 10 of molten metal is formed. With the passage of the cooling water through the casting rolls 6, heat is extracted through the casting rolls 6 from the molten metal 1 to solidify metal shells on the outer circumferential surfaces of the casting rolls 6, and cast thin strip 8 at the roll gap G between the casting rolls that is transported downwardly away from the roll gap G.

Thin cast strip thus made has been found to have ripple-shaped shrinkage inhibited, if not completely eliminated in the surface of the cast strip 8. Based on our experiments, it is believed that carbon monoxide and other entrained gases that are generated in the pool of molten metal 10 can rise in the form of small bubbles along the longitudinal side walls 15, and not be trapped in the casting pool 10 of molten metal under a flat base as shown in FIG. 1. It is believed that the gas generated in the casting pool passes up along the side walls 31 and escapes in a steady controlled manner at the surface of the casting pool 10. Consequently, it is believed, based on our experiments, that the disturbance of the surface of the pool of molten metal 10 by the floating upwards of bubbles of large diameter is reduced, if not completely alleviated, and ripple-shaped shrinkage is inhibited, if not completely eliminated in the surface of the cast strip 8.

FIG. 3 shows a second delivery nozzle of the present invention. The elongated nozzle body 12 for receiving the molten metal 1 is formed with a pair of longitudinal side walls 16 and a pair of end walls 20 that join the longitudinal side walls 16. The lower portions of the side walls 16 approach each other and intersect at the lower extremity of the nozzle body.

The metal delivery nozzle is so disposed as to be located above the roll gap G in the space enclosed by the side dams 7 and the casting rolls 6 of the twin roll caster. The lower portions of the longitudinal side walls 16 have a plurality of side outlet openings 24 capable of discharging molten metal from the nozzle body 12 towards the outer circumferential surfaces of the casting rolls 6. When the molten metal 1 flows through the nozzle body 12, the casting pool 10 of molten metal is formed above the roll gap G on the outer circumferential surfaces of the casting rolls 6.

In this case, the downwardly extending side walls 16 form a nozzle bottom part 33 extending to the bottom extremity 35 of the nozzle. The external surfaces of the upper parts of the side walls 34 are generally flat, and taper downwardly and inwardly in the same fashion as the side walls 31 in the nozzle body of FIG. 2. However, in this embodiment the external surfaces of the bottom parts of side walls 33 are convex curved to meet at the bottom extremity of the nozzle in an arcuate bottom edge along the nozzle body.
In the twin roll caster with a metal delivery nozzle as illustrated in FIG. 3, the casting rolls 6 counter-rotate and the casting pool 10 of molten metal is formed. With the passage of the cooling water through the casting rolls, heat is extracted from the molten metal 1 and solidifies metal shells on the outer circumferential surfaces of the casting rolls 6, and form thin cast strip 8 at the roll gap G that is transported downwards away from the roll gap G.

At this time, entrained gases and the carbon monoxide that is generated in the casting pool 10 of molten metal generally rise in the form of small bubbles along the longitudinal side walls 16, without becoming trapped in the casting pool 10, because of the shape of the longitudinal side walls 16 of the metal delivery nozzle. Consequently, the disturbance of the surface of the casting pool 10 of molten metal by the floating upwards of bubbles of large diameter is inhibited, if not completely eliminated, and ripple-shaped shrinkage in the surface of the strip 8 is inhibited, if not completely eliminated.

FIG. 4 shows a third metal delivery nozzle of the present invention, in which the nozzle body 13 for receiving the molten metal 1 is formed with a pair of longitudinal side walls 17, and a pair of end walls 21 that join the respective longitudinal side walls 17. Lower portions gradually approach each other and intersect at the lower extremity to form bottom part 36.

The molten metal delivery nozzle is disposed above the roll gap G in the space enclosed by the side dams 7 and the casting rolls 6 of the twin roll caster. The lower portions of the longitudinal side walls 17 have a plurality of side outlet openings 25 capable of discharging molten metal from the nozzle body 13 towards the outer circumferential surfaces of the cooling rolls 6. When the molten metal 1 flows through the nozzle body 13, the casting pool 10 of molten metal is formed above the roll gap G on the outer circumferential surfaces of the casting rolls 6.

The downwardly extending side walls 17 forming side walls 37 of a nozzle bottom part 36 extend to the bottom extremity 38 of the nozzle body. The external surfaces of the side walls 37 are convex curved, and meet at the bottom extremity of the nozzle body at a generally acute angle forming a distinct bottom edge along the nozzle body.

In the twin roll caster with a metal delivery nozzle as illustrated in FIG. 4, the casting rolls 6 counter-rotate and the casting pool 10 of molten metal is formed. With the passage of the cooling water through the casting rolls, heat is extracted from the molten metal 1 to solidify metal shells on the outer circumferential surfaces of the casting rolls 6 and form thin cast strip 8 at the roll gap G that is transported downwards away from roll gap G.

At this time, entrained gases and the carbon monoxide that are generated in the casting pool 10 of molten metal can rise generally in the form of small bubbles along the longitudinal side walls 17, without becoming trapped in the casting pool 10 of molten metal, because of shape of the external surfaces of lower parts of the longitudinal side walls 17 of the nozzle body forming the bottom part.

Consequently, the disturbance of the surface of the pool of molten metal 10 by the floating upwards of bubbles of large diameter is inhibited, if not completely eliminated, and ripple-shaped shrinkage in the surface of the strip 8 is inhibited, if not completely eliminated.

FIG. 5 shows a fourth delivery nozzle of the present invention. The nozzle body 14 for receiving the molten metal 1 is formed with a pair of longitudinal side walls 18 and a pair of end walls 22 that respectively join the longitudinal side walls 18. The lower portions of side walls 18 gradually approach each other and intersect at the lower extremity. The downwardly extended longitudinal walls 18 form side walls 47 of bottom part 46 of the nozzle body extending to the bottom extremity 48. The external surfaces of the side walls 47 are convex curved and meet at the bottom extremity of the nozzle in a rounded shape along the nozzle body.

The molten metal supply nozzle is disposed above the roll gap G in the space enclosed by the side dams 7 and the casting rolls 6 of the twin roll caster. In the lower portion of the longitudinal side walls 18 a plurality of side outlet openings 26 are capable of discharging molten metal from the nozzle body 14 towards the outer circumferential surfaces of the casting rolls 6. When the molten metal 1 flows through the nozzle body 14, the casting pool 10 of molten metal is formed above the roll gap G in contact with the outer circumferential surfaces of the cooling rolls 6.

In the twin roll caster with a metal delivery nozzle as illustrated in FIG. 5, the casting rolls 6 counter-rotate and the casting pool 10 of molten metal is formed. With the passage of the cooling water through the casting rolls 16, heat is extracted from the molten metal 1 to solidify metal shells on the outer circumferential surfaces of the casting rolls 6, and form thin cast strip 8 at the roll gap G, which strip is transported downwards away from the roll gap G.

At this time, entrained carbon monoxide and other gases that are generated in the casting pool 10 of molten metal rises in the form of small bubbles along the longitudinal side walls 18 of the nozzle body, without becoming trapped in the casting pool 10, because of the shape of the external surfaces of lower parts of the longitudinal side walls 18 of the nozzle body.

Consequently, the disturbance of the surface of the pool of molten metal 10 by the floating upwards of bubbles of large diameter is inhibited, if not eliminated, and ripple-shaped shrinkage in the surface of the strip 8 is inhibited if not eliminated.

Moreover, if the surfaces of the longitudinal side walls 15, 16, 17 and 18 shown in FIGS. 2 to 5 have been covered with a carbon free material, for example an alkaline silicate glaze (water glass), the small bubbles are prevented from adhering to the longitudinal side walls 15, 16, 17 and 18.

Furthermore, if refractories such as alumina, zirconia and magnesia that do not contain carbon are used to construct the longitudinal side walls 15, 16, 17 and 18 and the extremity walls 19, 20, 21 and 22, the generation of carbon monoxide and other gases within the casting pool 10 of molten metal is restricted and the amount of bubbles formed is reduced.

Although the invention has been described in detail with reference to certain embodiments, it should be understood that the invention is not limited to the disclosed
embodiments. Rather, the present invention covers variations, modifications and equivalent structures that exist within the scope and spirit of the invention and such are desired to be protected.

1. A delivery nozzle for delivering molten metal into a casting pool of a strip caster comprising:
   
an elongate nozzle body having longitudinally extending side walls and end walls to form a nozzle trough;
   
side outlet openings in the side walls capable of discharging molten metal from the nozzle body laterally outwardly from the side walls of the nozzle body; and
   
the side walls of the nozzle body below the side outlet openings extending downwardly to converge and meet at the lower extremity of the nozzle to form a bottom part of the nozzle body with an external surface configured to inhibit entrapment of gas bubbles in a casting pool.

2. The delivery nozzle as claimed in claim 1 where the side outlet openings are spaced longitudinally along the side walls.

3. The delivery nozzle as claimed in claim 1 wherein the side outlet openings are capable of providing outward flow of molten metal adjacent the bottom part of the trough.

4. The delivery nozzle as claimed in claim 1 where the bottom part is an integral part with the side walls.

5. The delivery nozzle as claimed in claim 1 where the bottom part is a separate part from the side walls.

6. The delivery nozzle as claimed in claim 1 where upper parts of the side walls forming the bottom part have a generally flat external surface angled downwardly and inwardly along the nozzle body.

7. The delivery nozzle as claimed in claim 6, where the side walls of the nozzle body extending downwardly to form the bottom part have a generally flat external surface throughout and meet at an acute angle to form a distinct edge along the nozzle body.

8. The delivery nozzle as claimed in claim 1 where the side walls of the nozzle body extending downwardly to form the bottom part have convex curved external surfaces meeting at the bottom extremity of the nozzle body in an arcuate shape along the nozzle body.

9. The delivery nozzle as claimed in claim 1, where the upper parts of the side walls extending downwardly to form the bottom part have convex curved external surfaces along the nozzle body.

10. The delivery nozzle as claimed in claim 9 where the convex curved external surfaces of the side walls forming the bottom part meet at a bottom extremity in a rounded shape along the nozzle body.

11. The delivery nozzle as claimed in claim 9 where the convex curved external surfaces of the side walls forming the bottom part meet at an acute angle at a bottom extremity to form a distinct edge along the nozzle body.

12. The delivery nozzle as claimed in claim 1 where external surfaces of the side walls are coated with a carbon free material.

13. The delivery nozzle as claimed in claim 12 where said carbon free material is an alkaline silicate material.

14. The delivery nozzle as claimed in claim 1 where the longitudinal side walls and end walls of the nozzle body are formed of a carbon free refractory material.

15. Apparatus for continuously casting thin metal strip comprising:
   
a pair of laterally positioned casting rolls forming a nip between them,
   
an elongate metal delivery nozzle disposed above and extending along the nip between the casting rolls capable of discharging molten metal to form a casting pool of molten metal supported on the casting rolls above the nip, the delivery nozzle comprising:
   
an elongate nozzle body having longitudinally extending side walls and end walls to form a nozzle trough;
   
side outlet openings in the side walls capable of discharging molten metal from the nozzle body laterally outwardly from the side walls of the nozzle body; and
   
the side walls of the nozzle body below the side outlet openings extending downwardly to converge and meet at the lower extremity of the nozzle to form a bottom part of the nozzle body with an external surface configured to inhibit entrapment of gas bubbles in a casting pool.

16. A method of continuously casting thin metal strip comprising the steps of:
   
assembling a thin strip caster having a pair of casting rolls positioned to form a nip between them;
   
assembling a metal delivery system capable of forming a casting pool between the casting rolls above the nip with side dams adjacent the ends of the nip to confine the casting pool; and
   
assembling as part of the metal delivery system a delivery nozzle comprising an elongate nozzle body having longitudinally extending side walls and end walls to form a nozzle trough, side outlet openings in the side walls capable of discharging molten metal from the nozzle body laterally outwardly from the side walls of the nozzle body, and the side walls of the nozzle body capable of discharging molten metal from the nozzle body extending downwardly to converge and meet at the lower extremity of the nozzle to form a bottom part of the nozzle body with an external surface configured to inhibit entrapment of gas bubbles in a casting pool.

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