

TUNDISH STOPPER ROD FOR CONTINUOUS MOLTEN METAL CASTING**FIELD OF THE INVENTION**

The present invention relates generally to the casting of molten metal, such as steel, copper, aluminium and alloys thereof. More specifically, the present invention relates to stopper rods for regulating the flow rate of molten metal discharged from a tundish during a continuous casting operation.

BACKGROUND AND SUMMARY OF THE INVENTION

The continuous casting of molten metal involves providing an available source of molten metal in a suitable vessel, for example, a tundish or ladle, which is located physically above a mould in the continuous casting apparatus. When using a tundish as the vessel for holding the molten metal, a flow of molten metal is discharged therefrom into the mould via a tundish discharge nozzle at a flow rate which is suitable for the casting conditions. The flow rate of molten metal being discharged from the tundish nozzle is controllably regulated by a stopper rod. More specifically, the stopper rod is moveable relative to the tundish nozzle between seated and unseated conditions. Thus, movement of the stopper rod relative to the tundish nozzle will selective adjust the annular orifice area defined between the stopper rod tip and the tundish nozzle through which molten metal is allowed to flow. Adjustably varying the effective annular orifice area will thereby in turn adjustably control over the flow rate of the molten metal being discharged from the tundish.

One problem associated with controlling molten metal flow is that so-called inclusions (e.g., contaminants in the molten metal such as oxidized particles of the metal being cast) are typically present in the molten metal as it is discharged from the tundish through the nozzle. The particular geometry of the stopper rod tip which is capable of seating with the tundish nozzle may create flow profiles which encourage the inclusions to deposit on the surface of the stopper rod and/or tundish nozzle. Over time, therefore, the geometry of the orifice defined between the tundish nozzle and the stopper rod tip may change due to continual deposit of inclusions thereby eventually detrimentally affecting the stopper rod's flow control characteristics.

A boundary layer is developed when a fluid flows over solid surfaces which may be flat, curved or three-dimensional (3-D) curves along 3-D surfaces. It is characterized mainly because there is a velocity gradient at the surface and far away from it, out of the so called boundary layer; the flow behaves as an inviscid flow. Then, inside the boundary layer viscous forces have preponderance over inertial or convective forces.

Velocity profiles inside boundary layers are very dependent on the radius of curvature of the surfaces. This radius can be so determinant that flow separation phenomena may arise depending on the specific flow conditions. Separation phenomena mean that the fluid instead of continuing flowing downstream along a surface driven by a negative pressure gradient, finds itself in front of a positive pressure gradient. A flow condition like this brings about downstream flow instability causing an incomplete useage of a port area in a SEN. In other words, separation phenomena may bring about instability in the internal walls of a SEN and its ports promoting flow fluctuations, meniscus

oscillations of bath in the mould and out of control turbulent spikes of velocity. All those phenomena induce severe slab defects.

The main source of flow control in a tundish using stopper rods is the shape of the stopper tip. Most of the stoppers in the continuous casting industry have rounded tips with different radiuses. When a rounded tip is used steel forms a very thick boundary layer where fluid velocities are very small. Then just at the tip a stagnant zone is formed and any inclusion that touches that area loses momentum and can be easily trapped on the ceramic surface of the tip becoming, with time, into a clogging problem. Moreover, rounded tips enhance boundary layer thickness in zones upstream the tip and these are prone for inclusions trapping increasing danger of nozzle clogging.

It would therefore be desirable if a stopper rod for continuous molten metal casting could be provided which minimizes (if not eliminates entirely) deposition of inclusions onto the stopper rod tip thereby allowing the stopper rod to be maintained in service for prolonged time periods and/or improving steel cleanliness. It is towards fulfilling such a need that the present invention is directed.

Broadly the present invention is embodied in a stopper rod for continuous molten metal casting which creates flow profiles of the molten metal as it is being discharged from a vessel holding the molten metal through a nozzle so as to enhance metal cleanliness. That is, the stopper rods according to the present invention discourage the deposition of inclusions (e.g., undesirable particulates, such as metal oxides) onto the stopper rod tip. According to one especially preferred aspect of the present invention, a stopper rod for continuous molten metal casting is provided which has a geometric profile so as to increase the

velocity of the flowing molten metal sufficient to reduce the boundary layer thickness of such flowing molten metal adjacent the nozzle and stopper rod tip surfaces so as to minimize the deposition of inclusions thereon.

Advantageously, the geometric profile of the stopper rod tip according to the present invention also does not detrimentally affect the lifting force sensitivities of the stopper rod. That is, the geometric profile of the stopper rod tip does not create molten metal flow profiles which would make it difficult to exercise physical displacement of the stopper rod tip relative to the tundish nozzle. As a result, the stopper rods of the present invention exhibit a relatively wide range of flow rate control of the molten metal flow discharged from the tundish.

According to one aspect of the present invention, a tundish stopper rod for continuous casting of molten metal comprises a stopper rod body, and a stopper rod tip at a lower end of the stopper rod body, said stopper rod tip having a frustoconically shaped exterior surface which terminates in a recessed nose.

Advantageously the recessed nose is a recessed curvilinear surface (e.g., a spherical segment, but non-curvilinear surfaces (e.g. prismatic, pyramidal, triangular, and quadrangular surfaces) may also be provided.

In especially preferred embodiments, the frustoconically shaped surface forms an angle θ with a horizontal surface which is between about 55° to about 85° , and more preferably, greater than 70° . A central gas flow channel and tip gas flow channel are advantageously formed in the stopper rod body and stopper rod tip, respectively, to allow inert gas to be supplied to the recessed nose. The

junction between the frustoconical exterior surface and the exterior surface of the body is desirably smooth, i.e. without a sharp change of direction.

According to another aspect of the invention, there is provided a system for continuous casting of molten metal comprising a vessel for holding a supply of molten metal to be cast, a discharge nozzle for discharging molten metal from the vessel, and a stopper rod mounted for reciprocal rectilinear movements towards and away from the discharge nozzle to allow flow rate regulation of the molten metal discharged from the vessel through the discharge nozzle, wherein the stopper rod includes a stopper rod body, and a stopper rod tip at a lower end of the stopper rod body, the stopper rod tip having a frustoconically shaped exterior surface which terminates in a recessed nose. Advantageously, the vessel is a tundish or a ladle.

According to a third aspect of the invention, there is provided a method of regulating the flow rate of molten metal being discharged from a vessel through a discharge nozzle during a continuous casting operation, the method comprising providing a stopper rod comprising a stopper rod body, and a stopper rod tip at a lower end of the stopper rod body, the stopper rod tip having a frustoconically shaped exterior surface which terminates in a recessed nose; and positioning the stopper rod within the vessel so that the stopper rod tip operatively cooperates with the discharge nozzle; and controllably displacing the stopper rod tip relative to the discharge nozzle so as to regulate the flow rate of molten metal being discharged from the vessel through the vessel discharge nozzle.

These and other aspects and advantages will become more apparent after careful consideration is given to the following detailed description of the preferred exemplary embodiments thereof.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

Reference will hereinafter be made to the accompanying drawings, wherein like reference numerals throughout the various FIGURES denote like structural elements, and wherein;

FIGURE 1 is a schematic cross-sectional elevational view of a tundish having a stopper rod for continuous molten metal casting according to an especially preferred embodiment of the present invention;

FIGURE 2 is a cross-sectional elevational view of the stopper rod depicted in FIGURE 1;

FIGURE 3 is an enlarged detailed cross-sectional view of the stopper rod tip; and

FIGURE 4 is a bar graph of the percent of trapped inclusions in the molten metal that can expected to be trapped on the refractory surfaces of a stopper rod in accordance with the present invention in comparison to stopper rods outside the scope of the present invention,

FIGURE 5 is a view like FIGURE 2 of a further example of a stopper rod of the invention, and

FIGURE 6 is a view like FIGURES 2 and 5 of a still further example of a stopper rod of the invention.

DETAILED DESCRIPTION OF THE INVENTION

Accompanying FIGURE 1 depicts a continuous casting tundish system 10 which includes a tundish 12 for containing a supply of molten metal 14 therein. The molten metal 14 is introduced into the tundish 10 by a tundish inlet nozzle 16, and is discharged from the tundish through the tundish discharge nozzle 18. Typically, the tundish discharge nozzle is connected to an immersion nozzle 20 associated with the continuous casting mould (not shown) so as to transfer the molten metal to the mould. Although a tundish 12 is shown and will be referenced specifically hereinafter, a ladle may also be employed as the vessel for holding the molten metal 14. However, for ease of discussion, a tundish 12 will be described specifically below as it represents an especially preferred vessel for use in the present invention.

A stopper rod 22 in accordance with the present invention is mounted for reciprocal rectilinear movements relative to the tundish discharge nozzle 18 so that the stopper rod tip 22-1 is capable of substantial vertically displacements towards and away from the nozzle 18 (arrow A1 in FIGURE 1). Displacement of the stopper rod tip 22-1 thereby varies the orifice area defined with the nozzle 18 which in turn controls the flow rate of the molten metal being discharged therethrough. In this regard, the stopper rod 22 includes a cross-pin 22-2 which is coupled to an arm 24 associated with a lifting mechanism, for example, a hydraulic actuator (not shown).

The stopper rod 22 according to the present invention is perhaps more clearly depicted in accompanying FIGURES 2 and 3. As shown therein, the stopper rod 22 is an elongate generally cylindrical stopper rod body member 22-3 which is tapered somewhat between its upper end 22-4 and its lower end 22-5. The stopper rod body 22-3 is most preferably formed of a high temperature ceramic material adapted to being immersed in molten metal.

The stopper rod tip 22-1 is joined to the lower end of the stopper rod body 22-3 at the lower end 22-5 thereof and is also most preferably formed of a high temperature ceramic material adapted to being immersed into molten metal. The stopper rod tip 22-1 may be formed of the same or different ceramic material as compared to the stopper rod body 22-3. In addition, although the stopper rod body 22-3 and tip 22-1 are depicted as separate structural component, they could for example be formed as a unitary structure is desired.

A tip vent channel 22-6 is centrally formed in the stopper rod tip 22-1 and communicates with the central vent channel 22-7 formed in the

stopper rod body 22-3. The tip vent channel 22-6 is most preferably a smaller diameter as compared to the central vent channel 22-7. Collectively, the vent channels 22-6 and 22-7 allow off-gas that may be generated by the ceramic materials forming the stopper rod body 22-3 and/or tip 22-1 to be vented out of the tundish 12 so it does not contaminate the molten metal 14 therein. Although vent channels 22-6 and 22-7 are shown in the accompanying FIGURES 1-3, the stopper rod 22 in accordance with the present invention could be provided without any such vent channels. In addition, as shown in FIGURE 5, a channel 22-9 through the tip 22-1 may be provided and is especially useful if an inert purge gas is desired to be introduced therethrough. Argon is typically supplied through channels 22-7 and 22-9 to the tip.

An aperture 22-8 is formed through the stopper rod body 22-3 so as to receive the cross-pin 22-2. Alternative means of lifting the stopper rod 22 may also be provided. For example, a threaded nut may be physically embedded or affixed to the upper end of the stopper rod body 22-3 so that the stopper rod 22 may be threadably attached to a lifting rod. Alternatively or additionally, an external pressure collar may be attached to the upper end of the stopper rod body 22-3 for such purpose.

Important to the present invention, the stopper rod tip 22-1 has a frustoconically shaped exterior surface 22-1a which includes a recessed nose 22-1b. Most preferably, the recessed nose 22-1b is a smoothly arcuate concavity such as a spherical segment. However, virtually any concavity may be employed in the practice of the present invention. Thus, the recessed nose 22-1b may be embodied in regular and irregular curvilinear surfaces. Alternatively, non-curvilinear surfaces (e.g., prismatic, pyramidal, triangular, quadrangular and the like) may be employed to form the recessed nose 22-1b.

The frustoconically shaped exterior surface 22-1a of the stopper rod tip 22-1 most preferably forms an angle θ with respect to a horizontal plane which is sufficiently great so as to increase the velocity of the flowing molten metal to reduce the boundary layer thickness thereof adjacent the nozzle and stopper rod tip surfaces so as to minimize the deposition of inclusions thereon. In addition, the angle θ formed by the frustoconically shaped exterior surface 22-1a is not so great as to detrimentally affect the lifting force sensitivities of the stopper rod 22. Advantageously, the frustoconically shaped exterior surface 22-1a of the stopper rod tip 22-1 forms an angle θ with a horizontal surface which is between about 55° to about 85° . According to a particularly preferred embodiment of the invention, the angle θ formed by the frustoconically shaped exterior surface 22-1a is greater than about 70° , for example between 70° and 76° .

The use of a recessed or dimpled nose 22-1b causes, in use, a sudden change of pressure increasing cast metal (steel) velocities and then decreasing the size of the stagnant metal. The dimple depth should be approximately 5mm.

When argon gas is injected through the stopper rod, it reaches higher velocities at the recess or dimple, the gas bubbles stripping away clogging material at the nose. Fluid flow patterns through the stopper-nozzle are improved by the supply of argon, because the thickness of the boundary layers along surfaces of the stopper-tip cone, the tundish bottom and the region above the junction between the stopper nose and the cylindrical body are streamlined and thinner than those observed with single-phase flow. The floating rate of inclusions in the tundish is increased. In addition to reducing the boundary layer on the surface of the recess or dimple, the injection of inert gas reduces the local

density of the steel-gas mixture and the result is that buoyancy forces in the nozzle-dimple throat are higher. This facilitates the floating out of inclusions in the proximity. Inert gas (i.e. argon) injection stabilises the flow pattern in the tundish. The flow pattern in the entire liquid will be consistent, independent of the inert gas flow rate. Large bore sizes for injecting the inert gas enhance the above advantages, although some chilling effect is expected. This is the only reason why small bore sizes, like 2mm, may be preferred over, say, a 5mm bore.

To reduce further the boundary layer at the (sharp) junction between the frustoconical surface of the nose and the cylindrical body of the stopper rod body, this junction can be rounded, as shown at 22-1c in FIGURE 5.

A rounding of this annular junction produces several benefits, namely:

- i) It decreases the velocity of steel flowing along the cylindrical stopper rod body and the frustoconical tip.
- ii) It reduces the size of the high velocity field concentrating high velocities very close to the stopper rod nozzle throat.
- iii) Inclusions 'swimming' close to the stopper rod throat will find themselves in a field of smaller velocities, with the result that buoyancy forces may drive the inclusion upwards instead of being dragged toward the nozzle throat by inertial forces.
- iv) It will enhance adherence of inclusions on the body of the stopper rod instead of at regions located at the tip or in the nozzle throat.

The present invention will be further understood by reference to the following non-limiting Examples.

EXAMPLES

Computer simulations were conducted based on a mathematical fluid turbulence model coupled with a Lagrange model for trajectory of particles. The selected model for momentum transfer was the turbulent regime known as $k-\epsilon$. A constant casting rate of 4.0 tons/minute was simulated for each of the stopper rods being examined.

Comparative Stopper Rod No. 1 (CSR1) was formed with a stopper rod tip configured to have an upper cylindrical surface portion, an intermediate frustoconical surface portion, and a terminal smoothly convex nose. The Comparative Stopper Rod No. 2 (CSR2) was formed with a stopper rod tip having a hemi-ellipsoidal surface configuration. The stopper rod according to the present invention was configured as shown in FIGURES 1-3 above. A bar graph plot of percentage of trapped inclusions to form a clog for each of the stopper rods is shown in FIGURE 4. It is evident that the stopper rod according to the present invention results in substantially less percentage of trapped inclusions as compared to the stopper rods CSR1 and CSR 2 outside the scope of this invention.

While the invention has been described in connection with what is presently considered to be the most practical and preferred embodiment, it is to be understood that the invention is not to be limited to the disclosed embodiment, but on the contrary, is intended to cover various modifications and

equivalent arrangements included within the spirit and scope of the appended claims.

CLAIMS:

1. A stopper rod for continuous casting of molten metal comprising a stopper rod body, and a stopper rod tip at a lower end of the stopper rod body, said stopper rod tip having a frustoconically shaped exterior surface which terminates in a recessed nose.
2. A stopper rod as claimed in Claim 1, wherein the recessed nose is a recessed curvilinear surface.
3. A stopper rod as claimed in Claim 2, wherein the recessed curvilinear surface is a spherical segment.
4. A stopper rod as claimed in Claim 1, wherein the recessed nose is a recessed non-curvilinear surface.
5. A stopper rod as claimed in Claim 4, wherein the recessed non-curvilinear surface is selected from prismatic, pyramidal, triangular, and quadrangular surfaces.
6. A stopper rod as claimed in any one of Claims 1 to 5, wherein the frustoconically shaped surface forms an angle θ with a horizontal surface which is between about 55° to about 85° .
7. A stopper rod as claimed in Claim 6, wherein the angle θ is greater than about 70° .

8. A stopper rod as claimed in any one of Claims 1 to 7, comprising a gas supply channel formed in the stopper rod body.

9. A stopper rod as claimed in Claim 8, wherein the stopper rod tip includes a tip gas supply channel joined to the stopper rod body gas supply channel so as to enable a gas to be supplied from through the stopper rod body channel and the tip gas supply channel, to said recess of the nose.

10. A stopper rod as claimed in any of the preceding claims, wherein the junction between the stopper rod body and the frustoconically shaped exterior is curved/rounded.

11. A system for continuous casting of molten metal comprising:
a vessel for holding a supply of molten metal to be cast;
a discharge nozzle for discharging molten metal from the vessel; and
a stopper rod mounted for reciprocal rectilinear movements towards and away from the discharge nozzle to allow flow rate regulation of the molten metal discharged from the vessel through the discharge nozzle, wherein said stopper rod includes,

- (i) a stopper rod body, and
- (ii) a stopper rod tip at a lower end of the stopper rod body,
- (iii) said stopper rod tip having a frustoconically shaped exterior surface which terminates in a recessed nose.

12. A system as claimed in Claim 11, wherein the recessed nose of the stopper rod tip is a recessed curvilinear surface.

13. A system as claimed in Claim 12 wherein the recessed curvilinear surface is a spherical segment.

14. A system as claimed in Claim 11, wherein the recessed nose of the stopper rod tip is a recessed non-curvilinear surface.

15. A system as claimed in Claim 14, wherein the recessed non-curvilinear surface is selected from prismatic, pyramidal, triangular, and quadrangular surfaces.

16. A system as claimed in any one of Claims 11 to 15, wherein the frustoconically shaped surface forms an angle θ with a horizontal surface which is between about 55° to about 85°

17. A system as claimed in Claim 16, wherein the angle θ is greater than about 70° .

18. A system as claimed in any one of Claims 11 to 17, wherein the stopper rod further includes a gas supply channel formed in the stopper rod body.

19. A system as claimed in Claim 18, wherein the stopper rod tip includes a tip gas supply channel joined to the stopper rod body gas supply channel, so as to enable a gas to be supplied from through the stopper rod body channel and the tip gas supply channel, to said recess of the nose.

20. A system as claimed in any one of Claims 11 to 19, wherein the junction between the stopper rod body and the frustoconically shaped exterior is curved/rounded.

21. A system as claimed in any one of the Claims 11 to 20, wherein the stopper rod further includes a cross-pin adapted to being attached to a lifting mechanism.

22. A system as claimed in any one of Claims 11 to 21, wherein the vessel is a tundish.

23. A method of regulating the flow rate of molten metal being discharged from a vessel through a discharge nozzle during a continuous casting operation, the method comprising:

- (a) providing a stopper rod comprising a stopper rod body, and a stopper rod tip at a lower end of the stopper rod body, said stopper rod tip having a frustoconically shaped exterior surface which terminates in a recessed nose; and
- (b) positioning the stopper rod within the vessel so that the stopper rod tip operatively cooperates with the discharge nozzle; and
- (c) controllably displacing the stopper rod tip relative to the discharge nozzle so as to regulate the flow rate of molten metal being discharged from the vessel through the vessel discharge nozzle.

24. The method of Claim 21, wherein step (b) comprises positioning the stopper rod within a tundish.