Design of nozzle for steel continuous casting system based on flow analysis I -Tundish(TD) upper nozzle-

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Abstract
In steel continuous casting system, tundish upper nozzle has an important role on the flow rate control of the molten steel and the elimination of the inclusions and etc. Based on the basic principle of hydrodynamics, the optimal nozzle bore profile was determined with aiming to suppress the turbulence with high kinetic energy generated in the flow of the molten steel. A simulation by flow analysis and a water model experiment were performed and clarified that the turbulence with high kinetic energy could be minimized in the nozzle with newly devised inner bore profile. The actual nozzle devised was manufactured and tested in the steel works with satisfying results. It can contribute to not only improve the durability of the refractories as materials of the nozzle but also stabilize the casting operation by preventing from clogging of the nozzle.

Keywords : Continuous casting system, Molten steel flow, Tundish upper nozzle, Inner bore shape, Turbulent flow, Flow analysis, Computer fluid dynamics

1. Introduction

Adhesion of Al₂O₃ system inclusion in molten steel occurs in the inner bore of pouring upper nozzle installed in the continuous casting tundish. The cross-sectional area of the inner bore will be reduced when adhesion occurred, and also if the adhesion increased further, the nozzle clogs, and resulting in the interruption of the operation. Al₂O₃ system or Al₂O₃-C system refractories are mainly used as the upper nozzle material. Although there is a possibility that adhesion-proof will be slightly improved by difference in the materials selected, it has not yet resulted in fundamental solution. Moreover, although there is also technology which gives adhesion-proof by blowing inert gas by penetration hole installation or application of the gas permeable porous material for the nozzle, and making small contact probability on the surface of refractories of the inclusion in the molten steel, however, as a result, sufficient improvement of adhesion-proof just by such way is not obtained because of difficulty to cover the whole refractories surface by blowing-in gas. As for the shape of the nozzle, there have been no report other than so called non-swirl nozzle by Halliday of the 1950s (Halliday 1959).

In the present investigation, the concept which serves as the foundation about the design of the inner bore profile of the nozzle for suppressing the energy loss due to turbulence in the molten steel flow to the minimum in terms of a different method from the "non-swirl nozzle", and examined the effect through flow analysis and a water model experiment. Furthermore, the upper nozzle which has the optimum bore shape determined in the experiment based on the results examined through analysis and the experiment was used in the actual continuous casting machine, and not only the bore surface of the upper nozzle but the adhesion-proof improvement effect in the inner surface of the submerged entry nozzle installed in the lower stream side was also investigated.

2. Underlying concept on flow in tundish upper nozzle
In the molten steel flow of the bore in a nozzle, Fig. 1 explains the underlying concept of the bore shape determination in the nozzle as conditions for minimizing the energy loss by turbulence. The flow velocity of the molten steel which flows through the bore in the nozzle, \( V \), is obtained by transforming the potential energy determined by the height (depth) from the meniscus \( H_r \) of tundish, into the kinetic energy. From an energy-conservation-law (Tomita 1971), if static pressure of the system is set to \( P \), molten steel density is set to \( \rho \), and acceleration due to gravity is set to \( g \), the following Eq. (1) (Bernoulli equation) is hold.

\[
\rho V^2/2 + \rho g H_r + P = \text{Const.}
\]

If it is applied to at the molten steel surface (meniscus) (subscript "0") and the outlet of the nozzle (subscript "1"),

\[
\rho V_0^2/2 + \rho g H_r + P_0 = \rho V_1^2/2 + P_1
\]

It can be regarded as \( V_0 = 0 \), because the area of the meniscus is so large compared to that of the nozzle bore. The pressure at meniscus and the pressure of the outlet are also considered as the atmospheric pressure, it is set to \( P_0 = P_1 = 0 \) (gauge pressure).

\[
V = (2gH_r)^{1/2}
\]

Fig. 1 Schematic illustration of the vertical section of tundish and its upper nozzle to explain a fundamental concept for suppression of intensified kinetic energy for the turbulent flow in the nozzle based on the pressure distribution in the tundish shown in the right hand figure.

Here, the 1st term of the left side of the Eq. (1) is the kinetic energy, and the 2nd term of the left side is the potential energy. Then, in Fig. 1, in whole structure including a nozzle, the domain on the right side of Line 1 in the right hand figure can show potential energy in the depth direction of the tundish, i.e., the bore height direction in the nozzle. If the kinetic energy can be expressed in linear function (straight line) like Line 1, \( P \) becomes a constant, as for it, all the energy distribution is stabilized, and it is thought that it is ideal. However, since the tundish is installed for stabilization of the molten steel flow and for the purpose of inclusion surfacing in molten steel in the continuous casting operation, it has big enough capacity. Therefore, as mentioned above, in the tundish the flow velocity of the molten steel is considered to be zero except for the very vicinity of the nozzle inlet. Thus, the conversion to kinetic energy from potential energy is generated only inside the nozzle. The kinetic energy change inside the nozzle is large as shown in Line 2 in the right hand figure, but within the tundish until the molten steel flow reaches there, namely the inlet of nozzle, as shown in Line 3 in the right hand figure, the kinetic energy change is comparatively small. In addition, the domain of the left side of the Line 1 and the right side of the Line 2 or Line 3 in the figure is equivalent to the above mentioned static pressure, \( P \). That is, when the molten steel reaches the nozzle inlet part, it means that rapid energy conversion takes place. Therefore, if this energy (pressure) change by the bore in the nozzle including the nozzle inlet can be made small as much as possible, on the whole, energy loss becomes small and becomes possible suppressing the energy loss by the turbulence in the molten steel flow in the nozzle bore to the minimum. Thus, generation and growth of the inclusion in the molten steel are confined, and probability that the inclusions contact to the nozzle bore surface can be made small, and it is thought that it becomes possible as the result to decrease the adhesion of the inclusion to the refractories.

It is possible to consider that the molten steel flow through the upper nozzle of the tundish is similar problem of general hydrodynamics (Yamane 2003) on the "energy loss in the fluid flow through the pipe in which section reduces suddenly". It was known on experience that the energy loss is small in the pipe inlet in this case for the diameter

reducing pipe (nozzle) which gave a certain curvature like the shape of trumpet. However, in the Fig. 1, the trial which determines the shape of the curve shown by Line4 strictly is not yet made so far.

According to the following methods, the shape of this curve (correctly curved surface) can be determined here. If the amount of flow is set to $Q$ and the flow velocity $V$ and the bore cross-sectional area in the nozzle are set to $A$ in the nozzle bore, the following relation is hold from the continuity of fluid (Tomita 1971) in every height position of the nozzle.

$$Q = VA = \text{Const.} \quad (4)$$

Here, in practice, since the molten steel flow $Q$ is controlled (restricted) by the sliding gate (it is described as notation SG, which does not appear in Fig. 1) installed in the connection to the nozzle bottom, considering the molten steel head $H$ of imagination, the Eq. (3) is expressed as follows.

$$V = (2gH)^{1/2} \quad (5)$$

And from the radius of the nozzle, $R$, since $A = \pi R^2$, the Eq. (4) becomes to the following relation.

$$(2gH)^{1/2}\pi R^2 = \text{Const.} \quad (6)$$

Finally, the relation of the following formula is hold in between the nozzle radius $R$ and the virtual molten steel head (height) $H$.

$$R \propto H^{-1/4} \quad (7)$$

That is, as for the formula (7), it is a solution obtained for the first time for the determination of the curve shown as Line 4 in the Fig. 1 which is a curve expressing the bore profile in the nozzle which makes energy loss the minimum, and it is the 4th curve (Biquadratic). Furthermore, since the relation of $V^2 \propto H$ holds from the Eq. (5), that is, kinetic energy ($V^2$) and height (depth) $H$ have a straight line relation. Since the static pressure $P$ which is the difference from all the energies has straight line relation with the height (depth) $H$, the Line2 of the right hand figure in the Fig. 1 can be expressed in a straight line (see also right hand figure in the Fig. 6(b)).

3. Flow analysis

3.1 Conditions for the calculation

Calculation was conducted with about 100,000 elements using the Fluent6.3.26 (finite volume method) system software. Analysis modeling of the molten steel flow from the tundish to the upper nozzle and the sliding gate (SG) was carried out. The coordinates set the height direction to Z, and the lower part is the plus side, and it made the nozzle upper surface center the starting point ($X=Y=Z=0$). Moreover, the slide direction of the SG was set to X, and the perpendicular direction was set to Y to Z and X. The molten steel surface (meniscus) in the tundish was made 1m from the bottom. The grid structure is shown in Fig.2 (a) and (b). Calculation fluid considered it as water for a reason which is mentioned later, and the mass flow rate considered it as two conditions of the low-velocity 1.76 and high-velocity 4.485kg/s, and was calculated by using the $k-\omega$ viscosity model with Fluent default condition. Also analysis is conducted in isothermal conditions with consideration supposing actual use of nozzle as refractory materials used in a constant high temperature. As mentioned above, by making it slide, the SG is equipment which changes valve travel and performs control of the flow, and fixed valve travel with 50% was used in calculation here.

![Fig. 2 Computational grid for the analysis for total system including tundish(TD), TD upper nozzle, sliding gate(SG) and outlet part(a) and magnified view of the TD upper nozzle(b).](image-url)
The bore shape in the nozzle taken up here can be expressed as shown in Fig. 3 as the function of the radius $R$ and the height $H$. That is, if the height position which nozzle height is 230mm and the distance from the upper end (inlet) of the nozzle to the lower part is set to $Z$, Shape① has the basic profile used for the pouring nozzle (tundish upper nozzle) until now, in which the nozzle outlet radius is 35mm (70mm in diameter), and the radius from the outlet to 50mm above the height direction is 35mm. And in the section, the linear taper was formed from the height position ($Z= 180$mm) to the nozzle top end ($Z= 0$mm), and the radius in the nozzle upper most plane is 70mm, and the curvature (radius of curvature of 295mm) was given in the corner part to avoid the rapid change at $Z= 180$mm position. Shape② is the 4th curvilinear shape previously shown by the formula (7) and Line4 in Fig. 1, and the outlet 35mm in radius, and inlet 70mm in radius presupposed that it is the same as that of Shape①.

![Fig. 3 Representations of two nozzle bore shapes tested in the present work as the function of the nozzle height and radius.](image)

### 3.2 Characteristics of the molten steel flow

The molten steel flow in the nozzle (circular pipe) in this simulation model are considered with comparison of the flow of water from a viewpoint of the Reynolds number, $R_e$. That is, $R_e$ is expressed with the following Eq. (8), when the average flow velocity is set to $U$ and the diameter of the nozzle, $d (=2R)$ and coefficient of kinematic viscosity of a fluid is set to $\nu$.

$$R_e = \frac{Ud}{\nu} \quad (8)$$

From experimental value of the coefficient-of-viscosity(Morita and Adachi 1970) of 5.35-5.76cP(5.35-5.76x10⁻³Pa·s) in 1500-1650°C for Fe-0.18%C steel, the approximate value of the $\nu$ as 0.84-0.76x10⁻⁶m²/s was acquired using density value(Morita and Adachi 1970) of 7.0-6.8g/cm³ in this temperature region for the similar composition of the steel (0.35%C). Based on this, the approximate values of the Reynolds number calculated using the Eq. (8) are shown in Table 1 for each of low- and high-flow velocity conditions. It turns out that the Reynolds number of molten steel is almost the same as value of the water for each condition.

<table>
<thead>
<tr>
<th>Material / Temp. / Flow velocity</th>
<th>Molten steel at 1500 °C</th>
<th>Molten steel at 1650 °C</th>
<th>Water at 25 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.76kg(ℓ)/s (0.46 m/s)</td>
<td>38</td>
<td>42</td>
<td>32</td>
</tr>
<tr>
<td>4.485kg(ℓ)/s (1.17 m/s)</td>
<td>97</td>
<td>107</td>
<td>82</td>
</tr>
</tbody>
</table>

Generally, in the flow in circular pipe, the behavior of the flow changes by $R_e=2320$, and at the $R_e$ larger than this value, pressure loss increases in proportion to the approximately 2nd power of the average flow velocity. And the flow of this domain is called “turbulence”, a three-dimensional swirl exists in the flow in turbulence, and it is divided and/or unified repeatedly, and it exhibits time to time change locally (Watanabe 2002), and it is possible to consider that such disorder in the flow brings about the increase in loss. That is, the flow in the nozzle dealt with this research is the turbulence region whose Reynolds number is all in range of 3.2-10.7x10⁴, for both in molten steel and water as shown in Table 1.
On the other hand, in the "laminar-flow" region whose Reynolds number is 2320 or less, the velocity distribution in the circular pipe shows the shape of the parabola (the 1/2 power rule), as shown in Fig. 4 (a), but if it becomes turbulence region, as similarly shown in the figure, the flow velocity in the pipe center part falls, and, generally becoming flat velocity distribution (the 1/7 power rule) is known (Watanabe 2002).

Fig. 4 Schematic illustration of difference in flow velocity distribution of the laminar and the turbulent flow(a), concept of energy loss due to flow transition from laminar to turbulent(b) and the energy loss due to nozzle geometry in the turbulent flow(c).

3.3 Calculation results and discussion

The flow velocity distribution in the nozzle and the vector diagram which were obtained by the calculation are shown in Fig. 5(a) and (b), respectively. For both figures, distribution in the nozzle center section (Y= 0mm section at the time of setting the direction of SG slide to X, and setting the perpendicular direction to Y) is shown. At Shape ①, although the flow velocity change in a corner part (Z= 180mm) is remarkable, it turns out that the flow velocity is changing from the inlet gradually to outlet including the neighborhood of the SG for Shape ②.

Fig. 5 Comparison of calculated velocity of the molten steel flow in the tundish upper nozzle of Shape① and Shape② (a), and the flow velocity vectors colored by the velocity magnitude for both shapes (b) at throughput (flow velocity) condition of 1.76kg/s.

In Fig. 6, by calculation as similarly as the previous figure, Shape① and Shape② are compared in both the pressure-distribution diagram in (a) and the variation of the static pressure with the nozzle (height) position (b) in the nozzle. Here, the former is the pressure distribution on the inner surface of the nozzle, and the latter is the pressure distribution in the nozzle center section (Y= 0mm section). Although the pressure is declining rapidly in the corner part (Z = 180mm) for the Shape① like the velocity distribution shown in Fig. 5, it turns out that pressure is declining gradually (linearly)
from the inlet to the outlet for the Shape②. Moreover, since the flow control mechanism by the SG exists in the nozzle outlet side, the shape is largely change for both shapes at the SG open and close side, the pressure distribution is changing in the SG stroke direction (the direction of X).

Fig. 6 Comparison of calculated static pressure of the molten steel flow for the tundish upper nozzle of Shape① and Shape② (a), and the graphic presentation of the static pressure change with position from top to bottom of the nozzle for both shapes (b) at throughput(flow velocity) condition of 1.76kg/s.

Fig. 7 Comparison of calculated velocity of the molten steel flow for the tundish upper nozzle of Shape① and Shape② at the higher throughput (flow velocity) condition of 4.485kg/s.

Next, in order to investigate the influence of the molten steel flow velocity, calculation on the conditions raised to 4.485kg/s of average flow corresponding to the actual operation was performed. The velocity-distribution diagrams for both shapes are shown in Fig. 7. Shape② exhibits uniform velocity distribution, but the Shape① showed the unique radial-velocity distribution to which a high-speed region is seen in the corner part (Z = 180mm) by the portion near the nozzle wall, and a low-speed region exists in the center part, and the stability of the flow disappeared. Next, as shown previously in Fig. 4(a), the velocity distribution of the corner part for both cases was compared as shown in the Fig. 8(a).

In Shape②, velocity distribution is rather “flat” form peculiar to turbulence, showing the velocity distribution almost uniform from the portion near the nozzle outer wall to the center part, but in Shape①, the velocity became low in the nozzle center part and the velocity became high near the nozzle surface (position at where a radius position ± is large except for the real surface), and namely there was a considerable velocity change in the radial direction. It is, thus, thought
that the area under the curve which shows velocity distribution expresses energy notionally, the energy loss by changing from laminar to turbulent flow can be shown as the area difference in Fig. 4(b). Then, the energy loss in Shape① shown here can be expressed with the slash part (a centerline is separated and only a half is illustrated) shown in Fig. 8(b). That is, it is typically shown in Fig. 4(c), and the area of these slash parts can be considered as energy loss by the shape of the nozzle also in turbulence from the energy loss by the changes to turbulence from the laminar flow. Furthermore, although Fig. 9 shows the calculation result of kinetic energy distribution for turbulence, in Shape①, the turbulence with high energy occurs in the nozzle central part in the height position of the corner part, and the high turbulence energy also is seen in the SG entrance part. However, in the Shape②, the high turbulence energy is not seen within the nozzle, and even in the SG entrance part, the energy is not so high, either. That is, it is thought that the existence of turbulence generating with the high kinetic energy in the upper stream affects to the downstream SG section.

**Fig. 8** Comparison of the flow velocity distribution in the horizontal section of the nozzle at the height of 180mm from the top which corresponds to the corner point for nozzle of Shape① (a) and the concept of the energy loss expressed by the shaded part (1/2 of total divided by the center line) due to intensified kinetic energy of the turbulent flow (b).

**Fig. 9** Comparison of calculated turbulent kinetic energy for the tundish upper nozzle of Shape① and Shape② at the higher throughput (flow velocity) condition of 4.485kg/s.

The influence of the turbulence energy in the nozzle on the inclusion adhesion is reviewed here. Nakaoka (2006) has reported that the collision frequency of inclusion particles is proportional to the 1/2 power of turbulence energy dissipation rate based on the results (Higashitani et al., 1983, Taniguchi and Kikuchi 1992) that the inclusion in the molten steel condenses by turbulence. According to these results, it is considered that growth rate of the inclusion in the bore part of the nozzle is high for Shape① with high kinetic energy of turbulence due to increased collision frequency of the inclusions inside the nozzle. Moreover, it has also described simultaneously (Nakaoka 2006) that collision frequency is proportional to the 3rd power of a particle radius, if inclusion grows, collision frequency with the nozzle surface of wall will also increase, and it will be thought that it becomes further easy to adhere. It is also suggested that when the grown-up inclusion flows for the SG plate and the submerged entry nozzle by the side of the lower stream, a possibility that adhesion by the part will also increase. Next, Shimasaki et al. (2003, 2004) carried out the detailed examination about flow behavior of the molten steel, such as surfacing and sedimentation of the particles in flow with
turbulence. The relative velocity of $\text{Al}_2\text{O}_3$ inclusion particles in the molten steel is greatly dependent on intensity of turbulence, and it is shown clearly in the portion with strong turbulence that relative velocity decreases sharply etc. And about the adhesion behavior on the surface of a nozzle Mukai et al. (1999) have reported that since the traveling velocity (terminal velocity) of the particles based on interfacial tension migration is proportional to the diameter of particles, and is proportional inversely to the viscosity, when the interfacial tension gradient is constant, and particles are more far away from refractories wall, if the inclusion grows and its diameter becomes large, it has been said that the traveling velocity becomes high and tends to adhere the nozzle surface easily. From the above argument, it is expected that adhesion of the inclusion decreases by Shape ② in which turbulence energy suppressed significantly.

The turbulence dissipation rate as the parameter correlated with the collision frequency of inclusion particles, is compared in Fig. 10. A significant difference between Shape ① and Shape ② is apparent that almost zero-level for the latter and the higher level for the former especially at the position of the nozzle center.

![Fig. 10 Calculated turbulent dissipation rate for the tundish upper nozzle of Shape ① and Shape ② is plotted against radial position from nozzle center at the higher throughput (flow velocity) condition of 4.485 kg/s.](image)

4. Water model experiment

Supposing the actual system, upper nozzle, SG, and submerged entry nozzle were set to the experimental tank, and the mold was set to the lower part. Same as the high-speed conditions in previous flow analysis, the amount of flow per unit time (the flow velocity) set to 4.485 kg (ℓ)/s. The upper nozzle used was usual porous type, and it had the structure from which gas flows out of the whole bore surface in the nozzle, and the air of 15 ℓ/ min was blown in the water model experiment. With the actual system, since the gas is blown at high temperature at around 1550ºC, it counts upon cubical expansion and it is thought that it becomes one several times the amount of capacity of this. Therefore, in the system, it is thought in a water model experiment that the conditions of 15 ℓ/ min are comparable to the amount of gas blowing in about 3 - 5 ℓ/ min for the actual operation. Although the diameter of blow out gas changes by the gas pressure and kind of fluid blowing out etc., it was about 1 mm on the conditions which blow out the air of 10 ℓ/ min to water. Although the gas blow technology which described previously in the introduction part, has not all round effect for the prevention from adhesion, even if a certain effect is accepted in reduction of adhesion by covering the nozzle surface by gas, it was utilized together with the present improvement in the nozzle bore profile. In the simulation in flow analysis, however it was not taken into consideration.

![Fig. 11 Comparison of the test results of water model simulation for the nozzle of Shape ① (left) and Shape ② (right) as the photograph taken from nozzle top with blowing gas, showing much higher transparency in the Shape ② because of the minimized turbulence of the flow.](image)
When the flow situation of the air blown into the stream is observed from the nozzle upper part for the Shape① and ②, respectively, as shown in Fig. 11. In the Shape①, the blown air flows violently through the bore in the nozzle, spiral flow was also seen. The probability which air attains to the nozzle center is also very high, and it is thought by Shape① that the intense high turbulence with high kinetic energy has occurred in the nozzle bore. A flow of gas was very quiet and the air which blew off from the surface in the nozzle flew toward straight under by Shape② along the surface in the nozzle toward the nozzle outlet (bottom) mostly to it.

From this, by Shape②, the turbulence with high kinetic energy is not generated but it is thought that the comparatively steady flow was obtained.

5. Field test results in the actual continuous casting system in the steel works

The examination for the system to compare Shape① and ② was done to the same timing using the continuous casting facility of two strands as shown in Fig. 12, and the upper nozzle of Shape① was set to one strand of the two and by another strand in the upper nozzle of Shape②. The test was performed at the same conditions in both strands, such as SG and submerged entry nozzle other than the upper nozzle. In addition, as described previously, for the upper nozzle of Shape① and ②, an inert gas blowing was carried out for both using all porous type nozzle, as the case of the water model experiment. The gas blowing was controlled by the back-pressure of about 100kPa. The capacity of the ladle was 180ton and 6-cast was performed in the throughput (flow velocity) of 4.485kg (ℓ)/s which is the high-speed conditions in the previous flow analysis and water model experiment, corresponding to about 2ton/min for each strand.

![Fig. 12 Set-up of test nozzles of Shape① and Shape② for two strands tundish in the continuous caster.](image)

![Fig. 13 Comparison of the appearance of spigots obtained in the test.](image)

The solidified metal (spigot) which remained in the inner bore was investigated after casting. Although the metal which remained in the bore in the upper nozzle was shown in Fig. 13. In the case of the Shape①, adhesion was seen at the corner part from which inner bore profile changes, and the nozzle lower part near the SG. On the other hand in the Shape②, adhesion was not observed at all to it. Moreover, the quality of the cut surface of the spigot was also very...
smooth, and the contamination of the inclusion etc. was not seen. In the detailed observation after casting, and adhesion or erosion were not observed at all in the case of Shape②.

Although adhesion of 15-20mm thickness was observed in the inner bore of the submerged entry nozzle connected to Shape① as shown in Fig. 14(a), adhesion was not observed at all in the inner bore of the submerged entry nozzle connected to Shape② as shown in Fig. 14(b).

The improved prevention effect from adhesion due to suppression of condensation growth in the inclusions also might be brought by the increased flow velocity of the inner bore part, facilitating the air bubbles to downstream.

Fig. 14 Comparison of the cross section of the submerged entry nozzles connected from the upper nozzles of Shape① (a) and Shape② (b), respectively, 15 to 20mm thick adhesion is observed in (a) but no adhesion is observed in (b).

6. Concluding remarks

The bore shape of the tundish upper nozzles in continuous casting facility of the steel, was investigated based on the basic principle of hydrodynamics, aiming to suppress the turbulence with high kinetic energy generated in the molten steel flow. The optimal nozzle bore profile (4th curve) was determined as the function of the molten steel head (height) and nozzle radius which derived from the principle of the energy minimum in the molten steel flow. The simulations by flow analysis and water model experiment were first performed for both shapes of this 4th curvilinear nozzle and conventional one. It was clarified that generating of the turbulence with high kinetic energy can be controlled in the upper nozzle which made the inner bore profile the 4th curve(curved surface) of alignment. Furthermore, when the actual nozzle was made as an experiment for the trial in the actual steel works was presented with the conventional shape nozzle for comparison, with the 4th curvilinear shape upper nozzle, it became clear that it not only can control the adhesion of the inclusion to itself, but it demonstrated the adhesion control effect also in the submerged entry nozzle installed in the lower stream side. By application of the nozzle newly devised from this, not only the durability improvement of the refractories in the molten steel continuous casting process but both the slanted flow within the mold generated by alumina adhesion and the contamination due to mixing of the exfoliated inclusions decreased, and it was thought that it could contribute to the improved quality of steel or operation stabilization.

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