Technology

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Refractories for Continuous Casting

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Abstract

Continuous casting is a process in which molten steel whose components and temperature have been adjusted through a refining process is poured into a mold and then cast. Since the refractory for continuous casting is used in the final stage of the steelmaking process, its stability greatly affects the quality of steel. This chapter describes the progress of refractory technology for continuous casting in Nippon Steel Corporation, focusing on tundishes, immersion nozzles and SN plates with examples of technical development.

1. Introduction

Continuous casting is a process in which molten steel is teemed to molds and cast after its chemical compositions and temperature are adjusted through a previous refining process. The average sharing ratio of continuous casting in 2017 was 96.2% in the world iron and steel industry and 98.5% in Japan.[1)] Another method of casting is the ingot casting method wherein molten steel is cast to ingot molds.

Figure 1 shows a schematic image of the refractories for continuous casting. The refractories for continuous casting are mainly classified into the following types: tundish refractories, flow control system refractories and teeming system refractories. This article describes the outline of the function of the respective refractory for continuous casting, materials and usages thereof, and reports the current state of technology development in Nippon Steel Corporation.

2. Tundish

2.1 Function of tundish

A tundish (TD) is an intermediate vessel installed between a ladle and continuous casting molds and has four major functions.

1) Molten steel distributing function

By installing a plurality of submerged entry nozzles onto a tundish, multistrand continuous casting from a ladle is made possible via a tundish.

2) Flow control function

In continuous casting, in order for the molten steel to be solidified uniformly in a stable manner, the control of the flow of the molten steel teemed to each mold is required. For such molten steel flow control for a mold, flow control system refractories are used for a sliding nozzle (SN) plate and a stopper.

3) Cast steel material quality improving function

Nonmetallic inclusions such as oxides and sulfides (hereinafter referred to as inclusions) are formed in the steel making process and when coarse inclusions are existent in the molten steel and cast into steel materials, they develop surface defects in the subsequent process of rolling and exert adverse effects on steel product quality. In order to suppress the penetration of the inclusions into cast steel materials, floating of the inclusions is promoted by holding the molten steel in a tundish. To this end, the amount of the floating inclusions can be increased by installing dams in a tundish and extending thereby the passage of the flow from the ladle to submerged entry nozzles. Furthermore, the floating of the inclusions is promoted

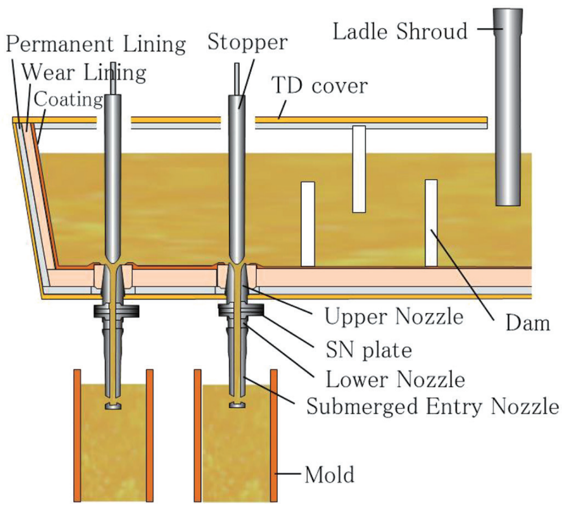

Fig. 1 Schematic image of the refractories for continuous casting

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more efficiently by improving the condition of the molten steel flow in the tundish by improving the arrangement of the dams.

4) Compensation of molten steel temperature

By applying plasma-heating using a graphite torch or induction heating (IH) and raising the molten steel temperature thereby, solidification of the molten steel in the tundish and/or in the submerged entry nozzle is prevented.

2.2 Structure of tundish and refractory lining

The horizontal shape of a tundish is generally either of the I-type or T-type with occasional ⊐-type or H-type. The capacity of a tundish is about 80 tons at the maximum.

The inner lining of a tundish is generally comprised of three layers: a permanent refractory lining, a wear refractory lining and a coating refractory, all lined in the said order from a steel shell. To suppress the temperature drop of the molten steel in the tundish, an insulation material may be used between the steel shell and the permanent refractory lining.

As the coating material, a material of the magnesia (MgO) system excellent in detachability with respect to the wear lining refractory is used. The coating material is required for the functions of simplifying the removal work of the residues of scull and slag in the tundish after casting and the protection of the wear lining refractory. Furthermore, as the coating is dismantled after each cast and the tundish is recoated, cleanliness in the area contacting the molten steel is maintained and therefore, the coating serves to prevent the contamination of the molten steel. Coating work is conducted by trowel work or by spraying.

For the wear lining refractory, a material of the alumina-silica (Al_2O_3-SiO_2) system is generally used. As the molten steel temperature in the tundish is about 1 500 to 1 570°C, and lower by about 100°C as compared with that in the ladle, the alumina content is lower than that of the ladle lining refractory.

A tundish cover is used for the purpose of retaining heat and suppressing oxidization through contact with air within the tundish. For the tundish cover, a casting material of the Al_2O_3-SiO_2 system is used.

2.3 Usage of tundish refractory and form of damage

The tundish usage cycle after the constructions and drying of the permanent lining refractory and the wear lining refractory generally consists of: spraying of a coating material, preheating, on-line steel casting, cooling, removal of skull (dismantling of coating) and repair. After dismantling the coating, the wear lining refractory is repaired and a new coating is constructed. At the same time, the refractories of the teeming system and the flow control system are exchanged.

As described above, the general practice is to cool the tundish once after the completion of casting and then to exchange the refractories. However, recycling of a hot tundish is also conducted, wherein the residues of steel and slag in the tundish are removed in a hot state on-line, and the exchanges of the refractories of the teeming system and the flow control system are conducted quickly.[2] A maximum of about 500 charges of continuous casting was achieved by applying recycling of a hot tundish and the merits of saving the work load in the maintenance between casts and the reduction of refractory cost have been achieved.

The tundish wear lining refractory is damaged due to mainly three factors.

The first is the occurrence of cracks caused by the heating and cooling of the tundish. In the case that a monolithic refractory is used as the wear lining refractory, a refractory body extending as long as 10 m is constructed integrally into one single body, and as the displacement caused by thermal expansion and/or thermal contraction is large, cracks tend to readily occur. In the early stage of operation, cracks perpendicular to the lengthwise direction dominantly occur. Furthermore, as the frequency of the casting operation further increases and the repetitions of the cycle of heating and cooling are further increased, cracks in the horizontal direction also occur and progress in addition to the cracks perpendicular to the ground level, resulting in the spalling of the surface layer.

The second is the direct adhesion of coating material to the wear lining phenomenon on the interface between the wear lining refractory and the coating material. For example, Kyoda et al. report that in a state of the wear lining refractory simply being in contact with the coating material, direct adhesion does not take place. On the other hand, strong direct adhesion occurs under the condition where slag penetrates the coating material.[3] Furthermore, Oogami et al. studied the characteristics of direct adhesion between a castable refractory material of the Al_2O_3-SiO_2 system and a SiO_2-bearing coating material of the MgO system[4] and state that, due to the increase of SiO_2 in the coating material, a low melting point phase is readily formed on the interface between the coating material and the wear lining refractory, and therefore, direct adhesion progresses. In either case, direct adhesion occurs when the elements such as slag and/or SiO_2 that increase the liquid phase ratio on the interface between the coating material and the wear lining refractory richly exist. In the case of the occurrence of the direct adhesion, the wear lining refractory is also damaged when the coating material is dismantled and the damage further progresses simultaneously.

The third is the erosion caused by the tundish slag. The tundish slag mainly consists of ladle slag and the joint sands that flow into the tundish and the heat insulating material charged from above the tundish for retaining the molten steel temperature. Because a coating material of the magnesia system having high corrosion resistance with respect to tundish slag is coated on the surface of the wear lining refractory, the corrosion of the wear lining refractory is not a serious matter. However, the erosion due to the tundish slag becomes problematic when the number of castings increases as in the recycling of a hot tundish operation.

2.4 Development of technology for tundish refractories

Sato et al. evaluated, with respect to the wear lining refractories for a tundish, the effects of the amount of the metal fiber addition and its distributive situation on the resistance to fracture value after the occurrence of cracks, and pursued the optimum addition amount of metal fiber[5] (**Fig. 2**). They found that the resistance to fracture value increases proportionally along with the increase of the amount of the metal fiber addition in the range of 0 to 4 mass% of the amount of addition, and that the value does not increase greatly above the said range. The distributive situation of the meal fiber does not vary greatly in the range of 2 to 6 mass%. Based on these findings, in the Kyushu Works (Oita Area), the amount of the metal fiber addition for tundishes was increased from 2 mass% to 3 mass%. The life was improved by 15% and the consumption of the repairing material could be reduced by 10%.

A major cause of damage to tundish wear lining refractory is spalling that is caused by the mechanical shock at the time of dismantling the coating and the extension of cracks due to heating and cooling. Matsui et al. prevented the direct adhesion of coating material and wear lining refractory to conduct dismantling of the coating, reducing the mechanical shock to the wear lining refractory.[6] They considered that the direct adhesion is caused by a reaction between a coating material and a wear lining refractory, and reduced the impurities to suppress the growth of a liquid phase in the coating material (**Table 1**). With this, the rate of wear of the wear lining refractory could be improved by 7%.

Furthermore, Matsui et al., to suppress the extension of cracks of the wear lining refractory due to heating and cooling, optimized the expansion characteristic of the tundish wear lining refractory. The permanent linear change ratio at 1 500°C was reduced to 0.41% from 1.45% and the expansion in the vicinity of the working face was reduced. Furthermore, by increasing the permanent linear change ratio at 1 000°C from −0.21% to −0.06%, the expansion difference between the working surface and the inside of the wear lining refractory was reduced and the cracks were suppressed. As a result, the damage progress rate of wear lining refractory was reduced by 28%.

Takashima et al. tackled the application of dry coating for the purpose of reducing the direct adhesion of coating material.[7)] Conventionally, for tundishes, the construction of coating was conducted by spraying and to reduce the direct adhesion to the base material caused by the trace compositions contained in a binder, dry coating technology was employed (**Fig. 3**). However, since the maintenance time extended to 15.5 hours due to the employment of the dry coating method from that of 12 hours by the conventional spraying method and the application to practical maintenance was difficult, improvement of the dry coating method was promoted. For instance, the coating material was conventionally fed to a tundish from a fixed tank by a screw conveyor. Instead, by employing a mobile type tank, the coating material feeding rate was enhanced from 40 kg/min to 100 kg/min and the construction time was shortened by 110 minutes.

Furthermore, through off-line evaluation, it was found that the hardening of the dry coating material is completed at over about 100°C. Based on this knowledge, an optimum preheating condition was established so that the hardening temperature is reached at any point between the heated side and its opposite side within a shorter period of time of heating and the construction time was shortened by 15 minutes (**Fig. 4**). Owing to such and other improvements, the maintenance time was shortened to 9 hours from 15.5 hours. Due to these improvements, reduction of the direct adhesion and the im-

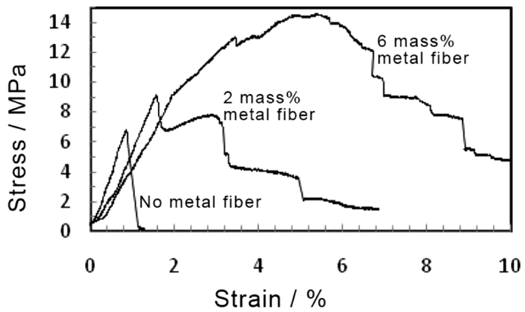


Fig. 2 Stress-strain curve by difference among the amounts of metal fiber addition

Table 1 Chemical compositions of coating

		Conventional	Improved
Chemical composition (mass%)	Al_2O_3	2	1
	SiO_2	12	5
	MgO	74	86
	CaO	5	2
	Fe_2O_3	4	1

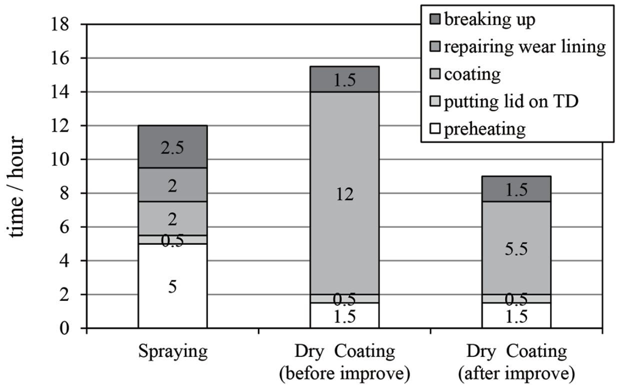


Fig. 4 Improvement of maintenance time

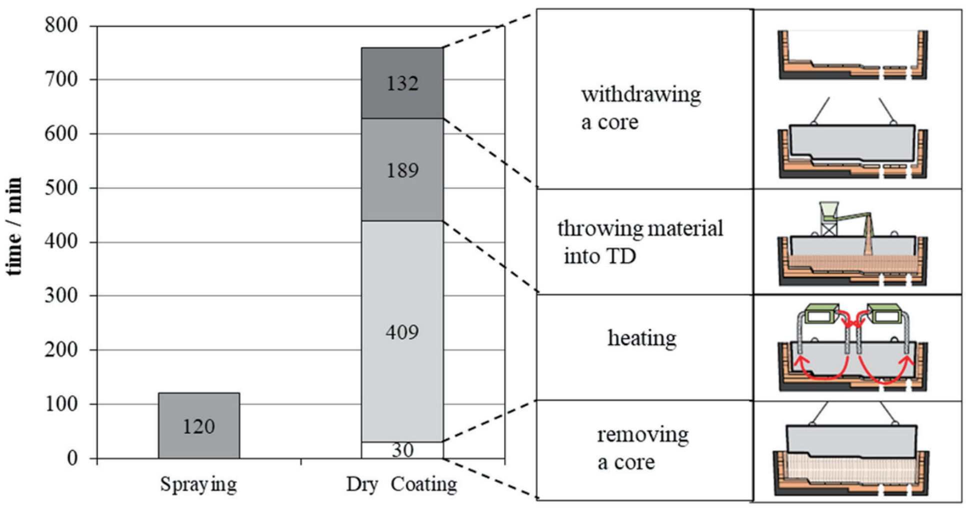


Fig. 3 Change in maintenance time by applying dry coating technique

provement of the construction efficiency were compatibly attained. Furthermore, in dry coating, as water is not used as in the case of spray coating, the hydrogen pick-up reaching as high as 1.5 ppm was reduced to and remained below 0.3 ppm. Thus, the effect of lowering the hydrogen level was confirmed.

3. Flow Control System Refractories

3.1 Stopper

A stopper is a bar-shaped refractory having a point and has the function of controlling the flow of molten steel by adjusting the vertical gap between its point and the upper nozzle installed on the tundish. Stoppers are classified into two types: sleeve type and long stopper type.

A sleeve type stopper consists of a bar laid over with a cylindrical sleeve and its front edge tip termed as the stopper head. Since the stopper head needs to maintain a high sealing performance with respect to a tuyer refractory, in addition to hot strength, corrosion resistance and abrasion resistance to molten steel flow, thermal shock resistance to avoid fracture even under a rapid temperature change is required. Therefore, a refractory of the Al_2O_3-graphite system is used for the stopper head. Thermal shock resistance is required of the sleeve similarly. However, high corrosion resistance is required at the slag line level part in particular to prevent the refractory erosion due to tundish slag that results in melting and fracture of the core bar. To prevent this, a high Al_2O_3 refractory is used for the sleeve in many cases.

As for the long stopper type, the stopper head and the sleeve part integrally consist of one body. This type of long stopper is manufactured by integrally molding a refractory of the Al_2O_3-graphite system excellent in thermal shock resistance to a single body generally by a cold isostatic press (CIP). In addition to the stopper, the ladle shroud, seal pipe and the submerged entry nozzle all referred to hereafter are manufactured by the CIP-molding and by sintering under a non-oxidizing atmosphere. When filling in the material in CIP, as the blending ratio of the refractory materials can be changed in each region, the integrated molding of a nozzle having a plurality of different materials arranged for a piece is possible.

3.2 SN plate

An SN plate is a component consisting of two or three smooth refractory plates, each of which has a bore and overlaps with each other. The flow of molten steel is controlled by sliding one of the plates and by adjusting the extent of overlapping of the bores. The SN plate is also termed as a slide gate (SG).

An SN plate is installed on the outside of the bottom of a ladle and on that of a tundish, and used. The SN plate for a tundish is generally smaller than that of a ladle. The SN plate with two plates is simple in structure. On the other hand however, the lower nozzle that contacts the lower plate is also subject to sliding simultaneously on the lower plate of the SN plate. In the case of an SN plate with three plates, only the middle plate slides and therefore, the lower nozzle that contacts the lower plate does not move simultaneously. Since the molten steel flow in the mold exerts a direct influence on the quality of cast steel materials, the movement of the submerged entry nozzle due to the sliding with the SN sliding plate is inferior. Therefore, the SN plate for a tundish consists of three plates in many cases.

The bores of the tundish SN plate are eroded and the bore diameters increase as used, resulting in damages. A refractory of the high Al_2O_3 system bearing very small amounts of such metals as Al and Si and excellent in corrosion resistance and resistance to surface roughening has become mainstream. An SN plate of the Al_2O_3-ZrO_2-C system intended for higher resistance to thermal shock in particular is also generally used.

In recent years, to deal with the continuous casting of Ca-added steel and/or high manganese steel as a part of the production of high quality steel and special steel, SN plate of the MgO-C system[8] and ZrO_2-C system[9] that does not tend to form low-melting point compounds in combination with molten steel compositions has been developed and is applied to actual machines.

Figure 5 shows the bore diameter increase of the SN plate of the Al_2O_3-ZrO_2-C system used for casting Ca-added steel in East Nippon Works (Kimitsu Area).[10] When used for the casting of Ca-added steel, increments of the bore diameter are significantly large. Kato et al. conducted a study on the microstructure of a used SN plate of the Al_2O_3-ZrO_2-C system and found that the mullite of the ZrO_2-mullite used as an aggregate is decomposed and voids are formed, and Ca penetrates the voids and promotes wear. Under a condition where an SN plate and molten steel coexist and according to thermodynamic studies conducted for the conditions with Ca and without Ca in the molten steel, under the condition with Ca, the equilibrium partial pressure of the gas of SiO is highest, and therefore, decomposition of mullite progresses more readily (**Fig. 6**).

Then, a material applied with calcium hexaaluminate (CA6) that is stable as an oxide, and neither digested nor decomposed by heat during casting, was considered as effective for obtaining high corrosion resistance of refractories and an off-line test was conducted using an exclusively developed test sample applied with CA6 to simu-

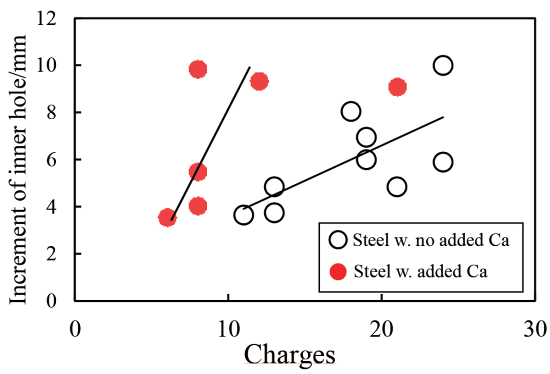


Fig. 5 Diameter change of AZC slide gate plates used for casting steel with and without added-Ca at East Nippon Works (Kimitsu)

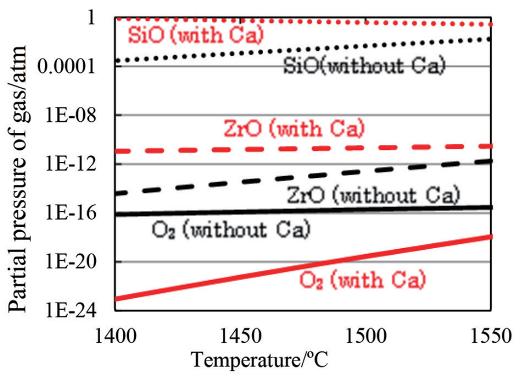


Fig. 6 Equilibrium partial pressure of the main components in the slide gate plate material

late the wear caused by Ca-treated steel. As a result thereof, improvement of corrosion resistance by about 30% as compared with that of the base material was achieved.

4. Teeming System Refractories

4.1 Ladle shroud

A ladle shroud is a cylindrical refractory used for feeding molten steel from a ladle to a tundish. This is used to prevent the molten steel from contacting the open air to suppress the oxidization of the molten steel and picking up nitrogen when feeding molten steel to a tundish. Furthermore, it serves to maintain laminar flow of the molten steel in a tundish and thereby to prevent the trapping of slag therein.

Since the refractory requires thermal shock resistance, as the material for the main body, a material of the Al_2O_3-SiO_2-graphite system consisting of Al_2O_3 as the main material, graphite and fused SiO_2 is generally applied. A material of the ZrO_2-graphite system is sometimes used for the immersion part in the molten steel in a tundish to suppress the corrosion due to tundish slag and heat insulating material. The pure ZrO_2 has a crystal structure of the orthorhombic system and rapidly expands when heated up to about 900°C, with such expansion causing cracks in refractories. To suppress such cracks, CaO and/or Y_2O_3 are added for stabilization. For the inner lining of the shroud, to focus on corrosion resistance, the materials of systems such as the Al_2O_3-graphite system without fused SiO_2 and/or Al_2O_3-MgO system are used.

Ladle shrouds, seal pipes and submerged entry nozzles contain graphite and to suppress the deterioration of the refractory quality due to the oxidization of the graphite, an oxidant inhibitor is coated.[11] The oxidant inhibitor mainly consists of SiO_2, which fuses during preheating and coats the refractory, and prevents thereby the contact of the refractory with air.

At the termination of a continuous-continuous casting and when the tundish is exchanged, the ladle shroud is disposed in many cases. However, there are cases in which the ladle shroud is preheated and reused even after the termination of a continuous-continuous casting. Therefore, the demand for the enhanced thermal shock resistance continues to increase significantly.

4.2 Seal pipe

In addition to the ladle shroud, a clay-pipe-like refractory termed as a seal pipe or tundish pipe is used for teeming molten steel from a ladle to a tundish. The seal pipe is fixed on the tundish cover. Accordingly, the pipe is stationary during teeming and free of problems such as breakage like that of the ladle shroud that takes place in the vicinity of a metal case. When using a ladle shroud, a working space and a tolerance in height are required to exchange the shroud and to remedy the connection portion. However, in the case of employing a seal pipe, such restrictions are not required and there are fewer design restrictions.

Similarly to ladle shrouds, a material of the Al_2O_3-graphite system containing fused SiO_2 is generally used as the material of the tube. As the internal diameter is larger than that of a ladle shroud, the flow of the molten steel teemed from a ladle does not contact directly with the inner side of the tube. However, the splash of the molten steel teemed to the tundish adheres to and deposits on the inner side of the seal pipe, occasionally causing clogging.[12] To solve this problem, for the purpose of preventing the clogging due to the scull adhesion, the development of a refractory that can suppress the deposition of the scull is being promoted.

4.3 Submerged entry nozzle

A submerged entry nozzle is a cylindrical refractory used to feed the molten steel from a tundish to a mold. It is used to prevent the molten steel from contacting the air in feeding to the mold so as to suppress the oxidization and nitrogen pick-up of the molten steel. As opposed to a ladle shroud with a simple cylindrical design in general, the submerged entry nozzle is generally designed to be provided on its side with two holes, each of which is termed as a discharge hole. In the cases of casting bloom and billet, a submerged entry nozzle having four discharge holes on its side is used and furthermore, a submerged entry nozzle with five discharge holes with one of them being provided at its bottom is used occasionally. The diameter of the discharge hole and the number thereof are determined based on the required molten steel throughput. In the case that the discharging flow rate from the submerged entry nozzle is high, floating of the inclusions is insufficiently conducted and inclusions are trapped within the cast steel materials, deteriorating the product quality. Therefore, lowering the maximum discharge flow rate and maintaining a uniform discharge flow rate are required for enhancing the steel quality.[13]

The molten steel flow in the mold is also controlled by an electromagnetic stirrer and an electromagnetic brake, both of which exploit an electromagnetic force. The electromagnetic stirrer is used for the purpose of reducing the non-uniformity of the compositions and the temperature of the molten steel in the vicinity of the surface by stirring the molten steel. The electromagnetic brake is used to reduce the discharging flow rate from a submerged entry nozzle by an electromagnetic force. Therefore, the flow of the molten steel in the mold is not determined by the submerged entry nozzle configuration alone, and also the influences of such electromagnetic stirrer and electromagnetic brake have to be taken into consideration. Conventionally, the shape and the angle of the discharging holes have been improved based on the result of water model tests.[14] However, in recent years, thanks to the development of computing technology, flow analysis with the influence of electromagnetic force taken into consideration is conducted to promote the improvement of the submerged entry nozzle configuration.[15]

The submerged entry nozzle refractory is required for thermal shock resistance, suppression capability of clogging caused by inclusions and the corrosion resistance against mold powder. In the early stage of the introduction of continuous casting, refractories of the fused SiO_2 system were mainstream. Later on, along with the progress of the continuous casting method, employment of continuous-continuous casting to enhance productivity and diversification of steel type to meet the demand for high grade steel were promoted and the properties required of submerged entry nozzles have become further stringent. When used for high manganese steel in particular, a low-melting point compound of fused SiO_2 and Mn in steel is formed, and as erosion is promoted further thereby, a material having a higher corrosion resistance is now being demanded.[16]

Then, to address these points, a refractory of the Al_2O_3-graphite system has started to be used. Since submerged entry nozzles are manufactured with CIP similarly to ladle shrouds, an appropriate material is applied to the respective part of the submerged entry nozzle according to its required characteristic, and such materials can be integrally molded into one single body. **Table 2** shows an example of the properties of refractory materials used for a submerged entry nozzle.[17]

For instance, as the mold powder contacts the nozzle in the immersion region in the mold and erosion occurs, a refractory of the

Table 2 Properties of refractory materials used for submerged entry nozzle

Application site		Base material		Powder line		Inner lining					
Chemical composition (%)	F.C+SiC	25	23	22	9	17	20	2	–	27	30
	Al_2O_3	50	65	–	–	63	63	72	96	–	–
	SiO_2	26	3	–	–	19	12	–	–	–	–
	ZrO_2	–	5	74	86	–	–	–	–	50	–
	CaO	–	–	–	–	–	–	–	3	21	40
	MgO	–	–	–	–	–	–	25	–	–	28
Bulk density		2.33	2.66	3.39	3.98	2.43	2.46	2.70	2.94	2.90	2.36
Apparent porosity (%)		13.6	11.8	15.1	15.6	17	18.4	20.7	20.9	16.1	15.5
Modulus of rupture (MPa)		8.0	12.1	7.1	9.0	4.1	4.8	3.0	4.7	9.9	3.8
Thermal expansion (1 000°C, %)		0.23	0.34	0.37	0.31	0.32	0.36	0.67	0.80	0.32	0.42

ZrO_2-graphite system is used with emphasis on corrosion resistance. Generally, mold powder consists mainly of CaO, SiO_2, CaF, Na_2O and so forth and has high corrosiveness, so the life of a submerged entry nozzle is sometimes limited by the duration of the refractory used for this region. When the mold powder contacts the refractory, the ZrO_2 particles in the refractory lose stability and are grain-fined. It was considered that the ZrO_2 particles so grain-fined separate themselves from the nozzle refractory and penetrate the mold powder, thus promoting wear on the part of the nozzle.[18] Then, by controlling the particle size[19] and the purity[20] of the ZrO_2 aggregate, grain-fining has started to be suppressed. Furthermore, there is a report that corrosion resistance is improved by applying a material of the ZrO_2-graphite system with its ZrO_2 acting as the aggregate designed to be grain-fined to small sizes below 75 μm in advance, and to keep the grain-fined ZrO_2 particles below the working face to act as a protective layer.[21]

On the other hand, in the case of the inner lining, clogging of the flow passage due the adhesion of the inclusions mainly consisting of Al_2O_3 is a problem. Various studies have been conducted to clarify the mechanism. For instance, there are reports that the compositions of a gas produced at a high temperature from a refractory deoxidize Al in the steel and develop the formation of Al_2O_3 in the neighborhood of the interface surface of the refractory.[22, 23] Also, there's another report that since the flow velocity of the molten steel is considered to be almost nil near the interface with the refractory, the inclusions reaching near the interface do not flow downward and contact the refractory.[24] Additionally, there is a report that the temperature gradient and/or the subsurface tension gradient of the molten steel caused by the dissolution of the compositions of a gas that occurred from the refractory work as a driving force for the adhesion of the inclusions.[25] For this reason, an anti-adhesion material that suppresses the adhesion of inclusions is provided. By using a porous material of the Al_2O_3-graphite system and by blowing a gas through the inner lining of the submerged entry nozzle, and by preventing the physical contact of the inclusions with the submerged entry nozzle, clogging can be suppressed.

Furthermore, along with the progress of the oxidizing reaction or reducing reaction of the graphite and/or SiO_2 contained in the refractory, a subsurface tension gradient in molten steel is caused by the dissolution of carbon and/or silicon into the steel. Since the tension gradient becomes a driving force that expels the inclusions onto the inner lining, adhesion of inclusions can be suppressed by providing the inner lining with a material free of graphite and SiO_2 that cause the adhesion. Furthermore, by providing the inner lining with a refractory that contains CaO that produces a low-melting point compound through a reaction with Al_2O_3, the main composition of inclusions, the adhesion of inclusions can be suppressed. As for the refractories that contain CaO, refractories of the ZrO_2-CaO-graphite system[26] and of the dolomite-graphite system[27] are considered.

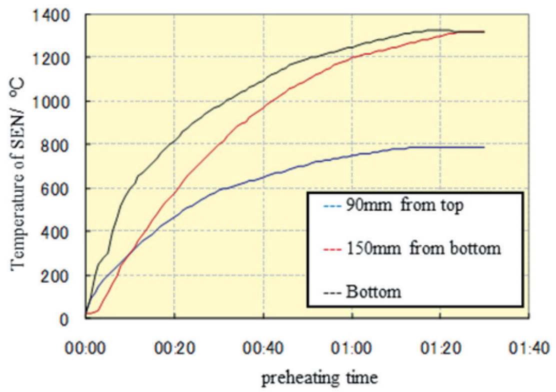


Fig. 7 Temperature change of submerged entry nozzle during burner preheating

Moreover, there's another effective technology that suppresses the adhesion of inclusions electro-magnetically by using the submerged entry nozzle of the Al_2O_3-graphite system as a negative electrode, and applying a current of several amperes across the molten steel and the nozzle.[28]

To prevent the breakage of the submerged entry nozzle due to thermal shock, the nozzle is preheated up to 1 000 to 1 200°C by a burner and then used (**Fig. 7**). However, in inserting a burner from the top of the submerged entry nozzle, as compared with the temperature near the burner, the temperature rise at the nozzle bottom is insufficient and uneven preheating temperature distribution occurs. Due to this uneven temperature distribution, preheating becomes insufficient, sometime causing a problem of submerged entry nozzle breakage. Furthermore, when preheating is applied for a long time to improve this uneven temperature distribution, a problem of oxidization of the graphite in the material of the submerged entry nozzle occurs. Nakamura, by taking advantage of the property whereby an induced current flows through a graphite-bearing submerged entry nozzle, applied IH to preheat a submerged entry nozzle[29] (**Fig. 8**). As opposed to a maximum of 600°C uneven temperature distribution in the case of preheating with a burner, with the application of IH to preheating, the uneven temperature distribution was deceased to about 200°C in addition to the realization of a shorter preheating time.

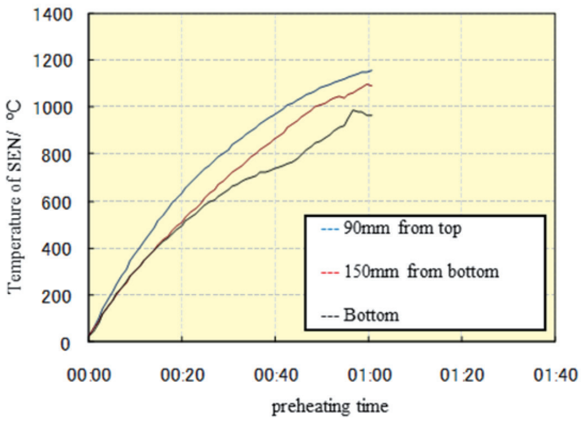


Fig. 8 Temperature change of submerged entry nozzle during preheating by induction heating

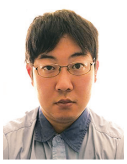
In the burner preheating, an oxidization depth of about 5 mm was formed on the submerged entry nozzle surface. However, as a result of preheating by IH, the oxidization depth formation was suppressed to less than 1 mm below the surface. Thanks to these results, the problem of the breakage of the submerged entry nozzle was eliminated.

5. Conclusion

This article outlines the function of the respective refractory for continuous casting, materials and usages thereof, and reports the current state of technology development in Nippon Steel. Since the refractories for continuous casting are used at the final stage of the steel making process, their stability closely affects the steel quality. We are determined to contribute further to the stabilized production of high quality steel through further development of technologies to enhance the durability of the refractories for continuous casting.

References

1) Worldsteel: Steel Statistical Yearbooks 2018. 2018
2) Kimura, M., Nakajima, S., Ueda, H., Nakao, M.: Kobe Steel Engineering Reports. 50, 12 (2000)
3) Kyoda, H., Ichikawa, K., Sugimoto, H., Nakamura, R.: Taikabutsu. 37, 596 (1985)
4) Oogami, S., Fukami, N., Nakano, T.: Taikabutsu. 66, 317 (2014)
5) Sato, M., Sukenari, S., Shimpo, A.: Submitted to the 86th Refractory Subcommittee. The Iron and Steel Institute of Japan, 2008
6) Matsui, S.: Submitted to the 96th Refractory Subcommittee. The Iron and Steel Institute of Japan, 2018
7) Takashima, S., Kubo, Y, Hosoi, T., Yamazoe, H.: Taikabutsu. 65, 84 (2013)
8) Akamine, K.: Taikabutsu Overseas. 18, 22 (1998)
9) Fukuoka, H., Kaneko, T., Furusato, I., Nitawaki, S.: Taikabutsu. 45, 586 (1993)
10) Kato, Y., Ikemoto, T., Goto, K.: Proceedings of the UNITECR 2017 Conference, 2017, p.13
11) Fujii, K., Koyago, K., Sakakidani, K., Harada, M., Asoo, Y., Yamaguchi, F.: Taikabutsu. 44, 582 (1992)
12) Kasai, N., Yamazoe, H., Iguchi, M.: Tetsu-to-Hagané. 91, 763 (2005)
13) Mizobe, A., Tachikawa, K., Kurisu, J., Ueki, M.: Taikabutsu. 69, 58 (2017)
14) For example, Mochizuki, Y., Hayami, K., Hasebe, E., Takigawa, T., Ando, M.: Taikabutsu. 51, 503 (1999)
15) Toh, T.: Proc EPM, Sendai, 2006, ISIJ, p.21
16) Onimaru, Y.: Taikabutsu. 65, 383 (2013)
17) Refractories Handbook. Revised 12th Edition. The Technical Association of Refractories, Japan
18) Mukai, K.: Taikabutsu. 42, 710 (1990)
19) Hayashi, Y.: Taikabutsu. 42, 668 (1990)
20) Uchida, K.: Taikabutsu. 53, 274 (2001)
21) Ikemoto, T. et al.: Taikabutsu. 51, 588 (1999)
22) Fukuda, Y., Ueshima, Y., Mizoguchi, S.: ISIJ Int. 32, 164 (1992)
23) Sasai, K., Minakami, Y., Yamamura, H.: Tetsu-to-Hagané. 79, 1067 (1993)
24) Singh: Metallurgical Transactions. 5, 2165 (1974)
25) Mukai, K.: Tetsu-to-Hagané. 80, 527 (1994)
26) Tsujino, Y.: Tetsu-to-Hagané. 80, 765 (1994)
27) Ogata, K., Amano, J., Morikawa, K.: Krosaki Harima Technical Report. 152, 24 (2004)
28) Tsukaguchi, Y., Kato, T., Watanabe, N., Ooga, S., Tanaka, T.: Materia Japan. 50, 27 (2011)
29) Nakamura, H.: Submitted to the 90th Refractory Subcommittee. The Iron and Steel Institute of Japan, 2012



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