Improvement of Slide Valve Plate

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Abstract

Slide valve (SV) plates are important refractories used to control the molten steel flow discharged from the ladle and tundish. SV plates are required to have high quality in order to control the flow rate accurately. In this article, we report on various SV plate materials, which were developed in accordance with demands of adaptability to various steel grades and longer life. By combining the structural evolution such as the SV plate shape with these new materials, it is possible to improve casting stability as well as SV plate durability.

1. Introduction

In a slide valve (SV) system, SV plates are set in a cassette in SV equipment installed at the bottom of the ladle and tundish, and used to control the flow rate of molten steel. SV plates are used in a set of two or three pieces and each plate has at least one bore through which molten steel flows. The flow rate of the molten steel can be controlled by sliding one of SV plates in the set to change the effective area of the bore. In order to control molten steel flow safely, SV plates are required to have well-balanced properties in terms of strength, corrosion resistance and spalling resistance. In addition, in recent years, higher durability and stability are required from the demand for longer life of refractories and adaptability to various steel grades. In this article, we report on some SV plate materials developed to satisfy these requirements. Especially, this article focuses on the following three topics, i.e., a countermeasure to reduce surface damage that affects the service life of SV plates, improvement in durability against corrosive steel grades, and the control of crack formation.

2. SV Plate Material

Al_2O_3–C materials, MgO–C materials, ZrO_2 materials and so on are used for SV plates according to usage conditions. Among them, Al_2O_3–C materials are most widely used. Fig. 1 shows the lineup of our SV plate materials. Since Al_2O_3–C materials have well-balanced properties in terms of thermal spalling resistance and corrosion resistance, they can be used through several casting times undergoing repetition of heating/cooling cycles. Basic materials and zirconia materials are used for highly corrosive steels such as Ca-treated steel and high oxygen steel, which severly corrode Al_2O_3–C materials.

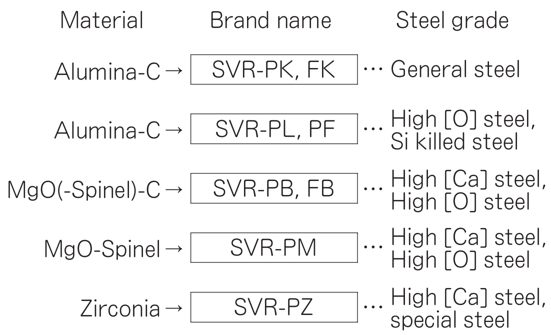

Fig. 1 Classification of Shinagawa SV plates.

3. Damage form of SV Plate

Damages to the SV plate are mainly classified into following four types : edge damage, cracks, bore enlargement and sliding surface damage (Fig. 2). These damages are affected by various factors as follows:

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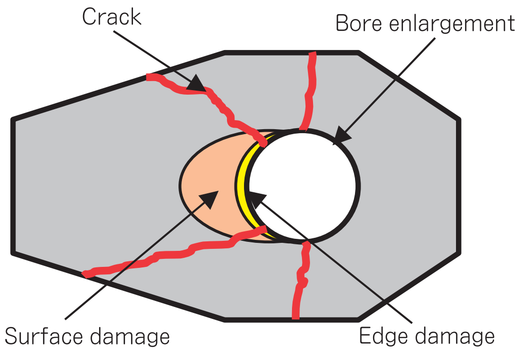

Fig. 2 Typical damages of SV plate.

- Refractory properties…Mechanical properties, thermal properties, chemical properties
- Structural factors…shape, fixing method to the SV equipment, pressure between sliding surfaces
- Operating conditions…steel grade, casting temperature, casting time, intermittent use
- Maintenance…oxygen cleaning, opening check

3. 1 Edge damage

Causes of edge damage are attributable to chipping due to spalling cracks, corrosion by air suction via large cracks, texture deterioration and corrosion by molten steel attack. In case of large corrosion by molten steel attack, high corrosion resistant materials such as basic materials and zirconia materials are applied.

3. 2 Crack

The causes of cracking include external load and thermal stress. If a crack opens, oxidation and corrosion due to an air suction will occur, causing leakage of molten steel. Moreover, a "longitudinal crack" formed in the throttling direction from the bore becomes the origin of edge damage, causing deterioration in durability (Fig. 3). The pattern of crack formation is strongly influenced by the structural factors such as the shape of the SV plate and the fixing method to the SV equipment.

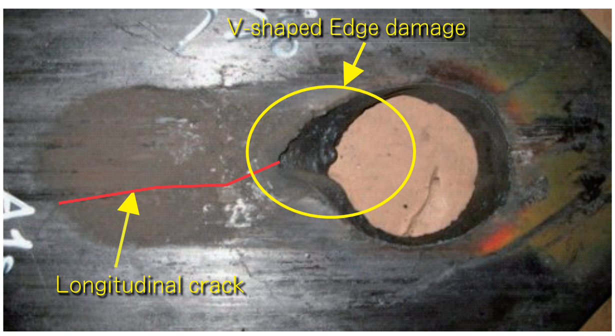

Fig. 3 Longitudinal crack and V-shaped edge damage.

3. 3 Bore diameter enlargement

Bore diameter enlargement is influenced by oxygen cleaning during maintenance rather than molten steel flow during casting except for casting of corrosive steel grades. As the bore diameter enlarges, the SV plate moves in the closing direction in order to maintain the equivalent flow rate, and the contact area between the sliding surface of the SV plate and the molten steel increases. An increase in the contact area leads to an increase in damage to the edge and the sliding surface.

3. 4 Sliding surface damage

Generally, surface damage limits SV plate life. Expansion of surface damage area may cause troubles from the view point of molten steel flow control such as sliding difficulty and stoppage failure, and causes inter-plate leakage of molten steel. Therefore, the damage depth of the sliding surface is discussed on a scale of around 1 mm or less. Morphologically, surface damage is classified into three categories such as abrasion, corrosion and peeling which are a result of sticking. The causes of these include

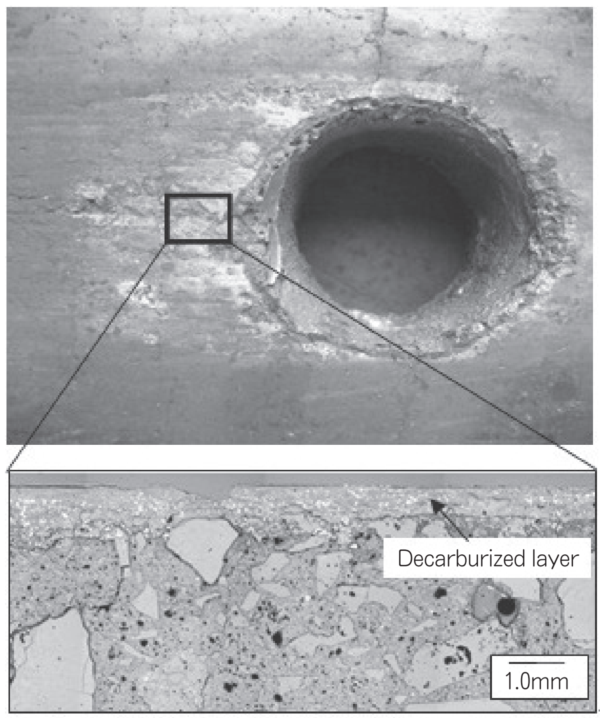

Fig. 4 Surface damage of Al_2O_3-C plate after use.

Table 1 Method for preventing reactions between oxides and carbon

	Method	Effect
(a)	Reduction of carbon content	Suppression of total decarburization amount
(b)	Decrease in pore diameter	Suppression of gas diffusion
(c)	Reduction of SiO_2 content	Suppression of reaction with unstable oxide
(d)	Addition of Antioxidant	Carbon deposition by reaction with CO gas, pore sealing

corrosion due to eutectic reaction, texture deterioration due to thermal shock and/or decarburization. Fig. 4 shows the surface damaged part of the Al_2O_3-C material. The penetration of metal and the alteration of refractory particles can be observed in the decarburized layer formed in the vicinity of the hot face. In the case of carbon-containing materials, it is particularly important to suppress the texture deterioration accompanying decarburization in order to improve the durability of the SV plate.

4. Damages During General Steel Casting

In general steel casting, SV plates are used for several long time casting operations. In order to withstand multiple cycles of heating and cooling, relatively high thermal spalling resistance is required for SV plate materials. Among our brands, the Al_2O_3-C material SVR-PK series is widely applied for casting general steel. Surface damage is the main factor to determine the durable life of the Al_2O_3-C material for casting general steel.

4. 1 Texture deterioration of Al_2O_3-C material by reaction with molten steel

Texture deterioration accompanying decar burization triggers surface damage of Al_2O_3-C material. Lin et al.[1] investigated the effect of steel grade on the structural change of Al_2O_3-C material by performing an immersion experiment in molten steel by using a simplified Al_2O_3-C material. They reported that the reduction of Al_2O_3 by C occurring in the refractory structure causes the deteriorated layer. They found that the reaction occurs depending on the partial pressures of the Al(g) and CO(g) at the refractory interior and the refractory-molten steel interface, and the activity of carbon in the molten steel. In addition, Akamine et al.[2] pointed out the possibility of a negative pressure condition at the unfilled part of molten steel generated during casting promoting the reaction between carbon and oxide particles.

Those reports explain that delaying the progress of the carbothermal reduction reaction by preventing gas migration from the inside of the refractory into molten steel is effective for suppressing the deterioration of the plate hot face. Countermeasures are shown in Table 1. For carbon-containing materials, various substances are used as antioxidants (d). Particularly effective antioxidants are metal additives which form bonding texture during firing.

4. 2 Improvement of surface damage resistance of Al_2O_3-C material

In order to evaluate the effect of metal additives on the surface damage resistance of Al_2O_3-C material, a reaction experiment with the molten steel was carried out using specimens in which only a metal additive was changed in a simple system of Al_2O_3-C-Metal (Table 2). The results are shown below[3]. The specimens were fired in a reducing atmosphere at 1000℃ or more and immersed in high oxygen steel ([O] = 120 ppm) at 1600℃ for 1 hour in an Ar atmosphere.

The results of EPMA observation of the specimens after the experiment are shown in Fig. 5. On the hot face of the specimens after the experiment that was in contact with the molten steel, that is, the right side of each image, a dense alumina layer and deteriorated layer with the disappearance of C and Si were formed. The thickness of

Table 2 Composition of the specimens

Raw materials / mass%	M1	M2
Al_2O_3	91	
C	9	
Si	12	12
Al	0	12

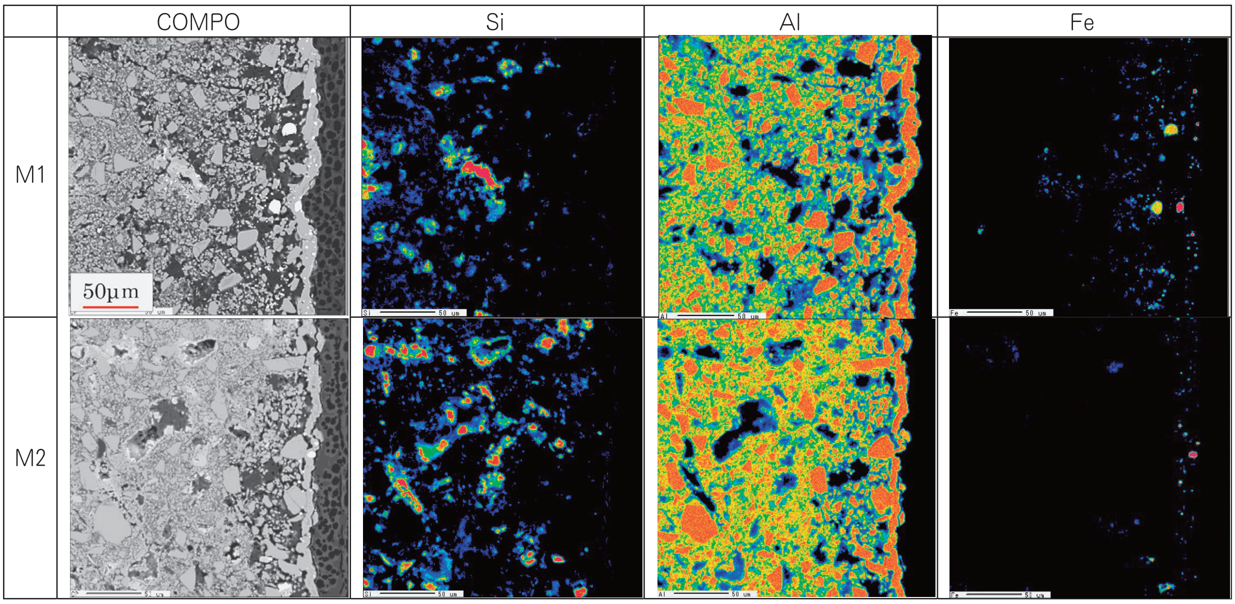

Fig. 5 Microstructure and EPMA analysis of immersed part of refractory specimens[3].

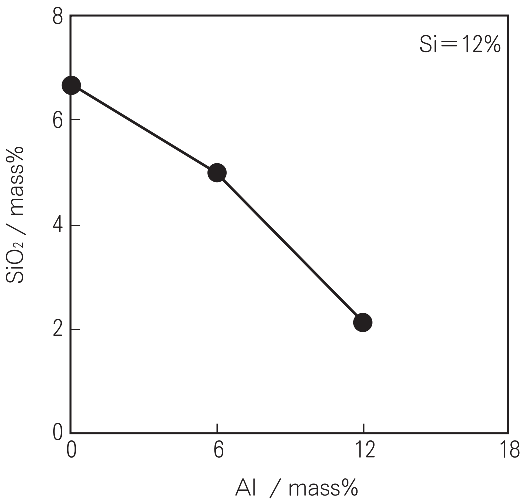

Fig. 6 Amount of SiO_2 formation during firing in reducing atmosphere above 1000℃[3].

Table 3 Chemical composition of SV plate

Material	A	B	C
	Conventional	Conventional	Developed
Metal additives	Si	Si, Al	Si, Al
/ mass%			
SiO_2	1	1	1
Al_2O_3	84	84	80
ZrO_2	5	5	9
C	6	6	6

the deteriorated layers were approximately 100 to 150 μm for M1 and approximately 20 to 50 μm for M2, which was reduced to about 1/3 by the combined use of Si and Al.

These deteriorated layers are considered to have been formed by the reaction between SiO_2 and C in addition to the reaction between Al_2O_3 and C. The relationship between the amount of Al addition and the amount of SiO_2 produced during the firing is shown in Fig. 6. While some metal additives are oxidized during firing, the addition of Al reduces the amount of SiO_2 produced. Hence, microstructure deterioration of M2 is considered to be suppressed by increasing the stable Al-based bond formed during firing.

In addition to combined application of Si and Al, we have developed a material that possesses a novel bonding texture by improving appropriate firing conditions. Table 3 shows the chemical compositions of conventional material A, to which only Si was added, conventional material B, to which both Si and Al were added, and new material C which also contains Si and Al fired under improved conditions. While the main bonding texture of conventional material A is Si-O-C type, Al-O-N and SiC types are the main part of the bonding structure developed in new material C. Fig. 7 shows a part of the bonding texture of material A and material C, which were formed

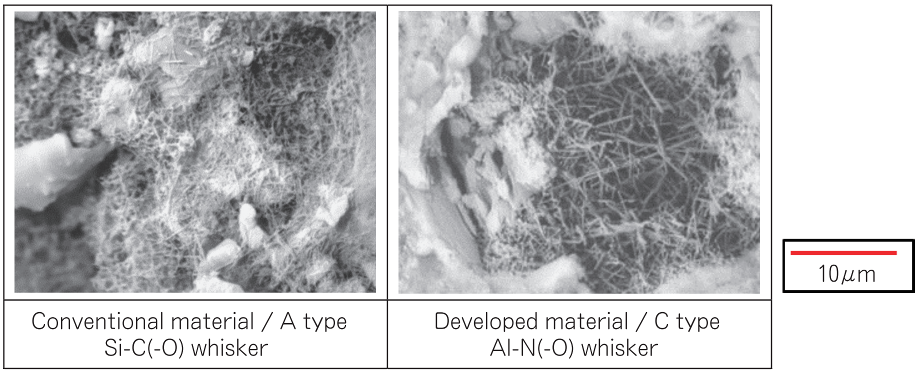

Fig. 7 Whiskers formed by the reactions of metal additives during firing.

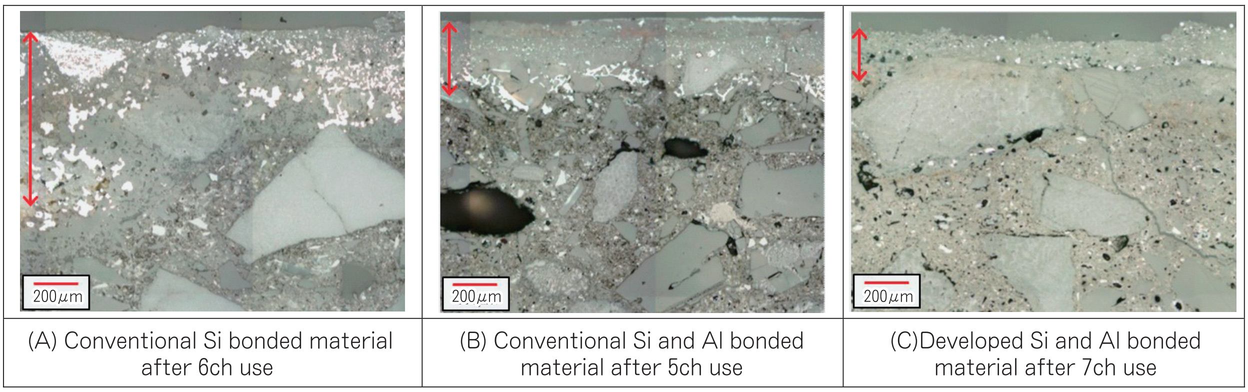

Fig. 8 Microstructures of surface damage zone of SV plate after use.

through a gas phase reaction during firing. In the case of material A, it is composed mainly of SiC whiskers, and in the case of the material C, it is composed mainly of AlN whiskers.

Fig. 8 shows the microstructure of the SV plate of these materials after use in a steel mill. The thickness of the deteriorated layer and the damage degree were reduced in the order of A, B and C. As a result, the maximum life increased from 7 heats to 8 heats. In addition, material C and other products designed by an identical concept are being widely used and receiving favorable reviews in blast furnace steelworks as well as in electric arc furnace steelworks.

5. Damages During Corrosive Steel Casting

Highly corrosion resistant basic materials are used to cast steel grades with very high corrosivity such as high oxygen steel and Ca treated steel. However, since thermal spalling resistance of basic materials is too poor to be used for many heat cycles, Al_2O_3-C materials containing unreacted Al can be a candidate of plate material for casting steels having relatively low corrosivity. Al_2O_3-C material containing unreacted Al shows an intermediate property between standard Al_2O_3-C material and the basic material in terms of corrosion resistance and spalling resistance. However, there is still a large gap between unreacted Al-containing Al_2O_3-C material and basic material. The approach for filling the gap between them includes two methods; further improving the corrosion resistance of the unreacted Al-containing Al_2O_3-C material and improving the thermal spalling resistance of the basic material. In this case, edge and surface damages caused by corrosion are the main factors in determining the durability of Al_2O_3-C material, whereas thermal crack formation is the main factor in determining the durability of basic material.

5. 1 Unfired Al_2O_3-C material, which contains a large amount of Al

Increasing the amount of Al addition, which is effective measure to improve corrosion resistance, increases the modulus of elasticity after firing, resulting in thermal spalling resistance deterioration. Therefore, we developed an unfired Al_2O_3–C material which avoids increasing the elastic modulus of the whole plate[4]. In the unfired material, the reaction of Al occurs by utilizing heat received from molten steel during casting to form a bonding texture. Table 4 shows the basic properties of conventional material D and developed material E. Although both D and E are unfired materials, material E has a much larger amount of Al than material D. Fig. 9 shows the variation in compressive strength of lower plate as functions of distance from bore and numbers of heat. The compressive strength increases as in distance from the bore decreases and the tendency is emphasized by an increase in the numbers of heat. In this way, unfired material E, that forms a strong bond only at the part near the bore where heat is received from the molten steel, shows high corrosion resistance without an excessive increase in the elastic modulus of the whole plate (Fig. 10). As a result, we succeeded in improving the durability by 30 % compared to conventional material D.

Table 4 Typical properties of unfired SV plate

Material	D Conventional	E Developed
Chemical composition / mass%		
SiO_2	1	1
Al_2O_3	82	80
ZrO_2	4	4
C	6	6
Al	α	2α
Apparent porosity / %	4.2	5.2
Bulk density / g・cm^{-3}	3.27	3.24
Cold crushing strength / MPa	136	145
Hot modulus of rupture / MPa	41	48

5. 2 Improvement of thermal spalling resistance of basic material (MgO-C)

Although MgO–C materials have high corrosion resistance to CaO and FeO, their large thermal expansion coefficient reduces their spalling resistance considerably. Therefore, we developed a MgO–Spinel–C material of which the thermal spalling resistance was improved by replacing a part of MgO with spinel[5,6]. Spinel exhibits lower expansion than MgO and shows higher corrosion resistance than Al_2O_3. While it is obvious that the corrosion resistance of spinel is inferior to that of MgO, the problem can be minimized by using coarse grain spinel.

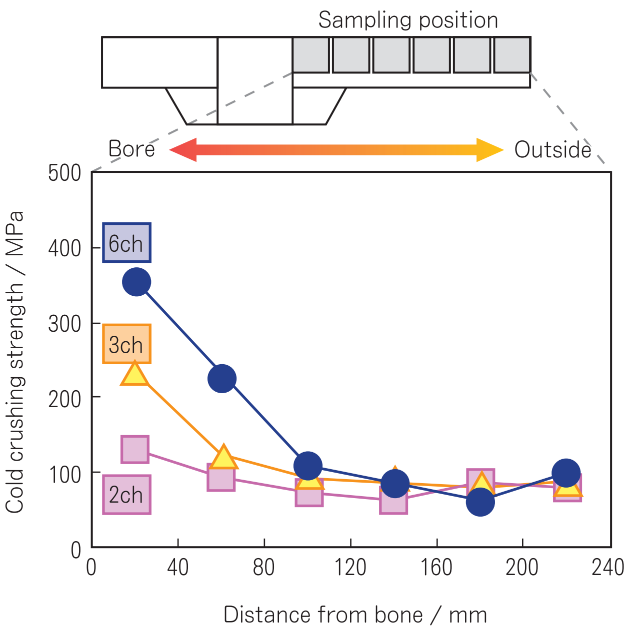

Fig. 9 Relationship between distance from bore and cold crushing strength of developed SV plate E[4].

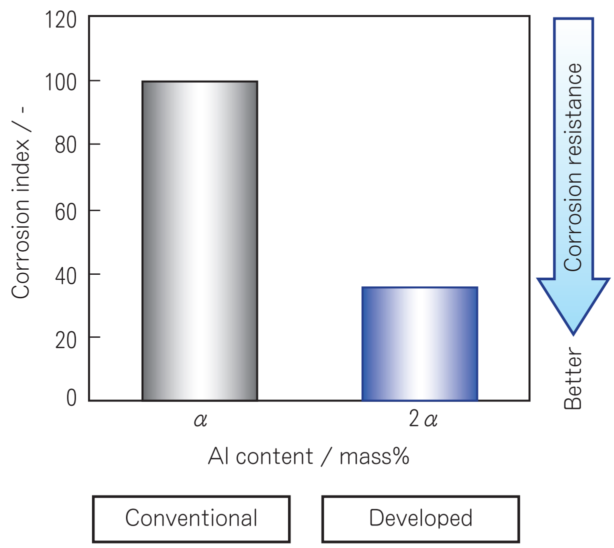

Fig. 10 Result of corrosion test by Fe+FeO, 1650 ℃×4 h[4].

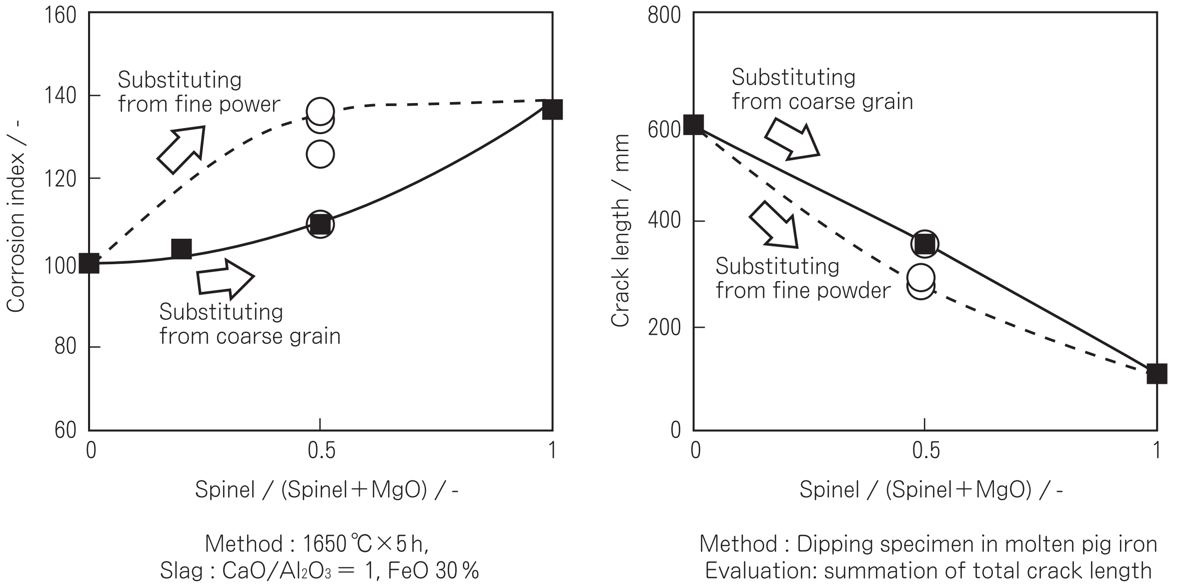

Fig. 11 Comprehensive diagram of influences of grain size and fraction of spinel on corrosion and spalling resistance evaluation results[6].

Table 5 Typical properties of basic SV plate

Material	F	G
	Conventional	Developed
Mass fraction of spinel Spinel / (Spinel+MgO)	0	0.5
Apparent porosity / %	10	10
Bulk density / g•cm^{-3}	3.00	2.98
Cold crushing strength / MPa	80	75

Thus, it is possible to improve thermal spalling resistance while minimizing the reduction in corrosion resistance (Fig. 11). Table 5 shows the quality of our standard MgO-C material F and the newly developed MgO-Spinel-C material G. Fig. 12 shows the results of using materials F and G for casting Ca-treated steel in steel mills. Although materials F and G showed no significant corrosion damage, the number of cracks in material G clearly decreased.

6. SV Plate Shape and Suppression of Crack Formation

In this section, the mechanical approach to improve SV plate durability will be discussed. SV plates are required to have dense structure and high strength in order to withstand sliding friction and corrosion by molten steel. Therefore, it is difficult to completely eliminate crack formation. Under such conditions, control of the cracking status is important. We have devised a shape that suppresses crack propagation by generating compressive stress around the bore by fixing the plate at a position

(F) Conventional MgO-C	(G) Developed MgO-Spinel-C

Fig. 12 External appearance of SV plates after use for Ca-treated steel, 2 heats.

close to the bore. Its shape is applied for our SV equipment "SAT", "SST", etc.[7]. Fig. 13 is the cold experimental result examining the relationship between the fixing structure of the SV plate and the in-plate strain[8]. In the conventional shape, tensile strain occurs at a certain part or the whole of plate in the throttling direction. Whereas in the SST shape, compressive strain is generated over the entire part in the throttling direction and it is possible to prevent cracks from propagating. With the conventional shape, "longitudinal cracks" often occur due to tensile stress occurring in the throttling direction, which has affected the durability of the SV plate. In the case of the SST shape, however, the occurrence of longitudinal cracks is prevented thus stable durability can be expected.

As a result of using this SST equipment at ArcelorMittal Tubarão, the average SV plate life has increased from

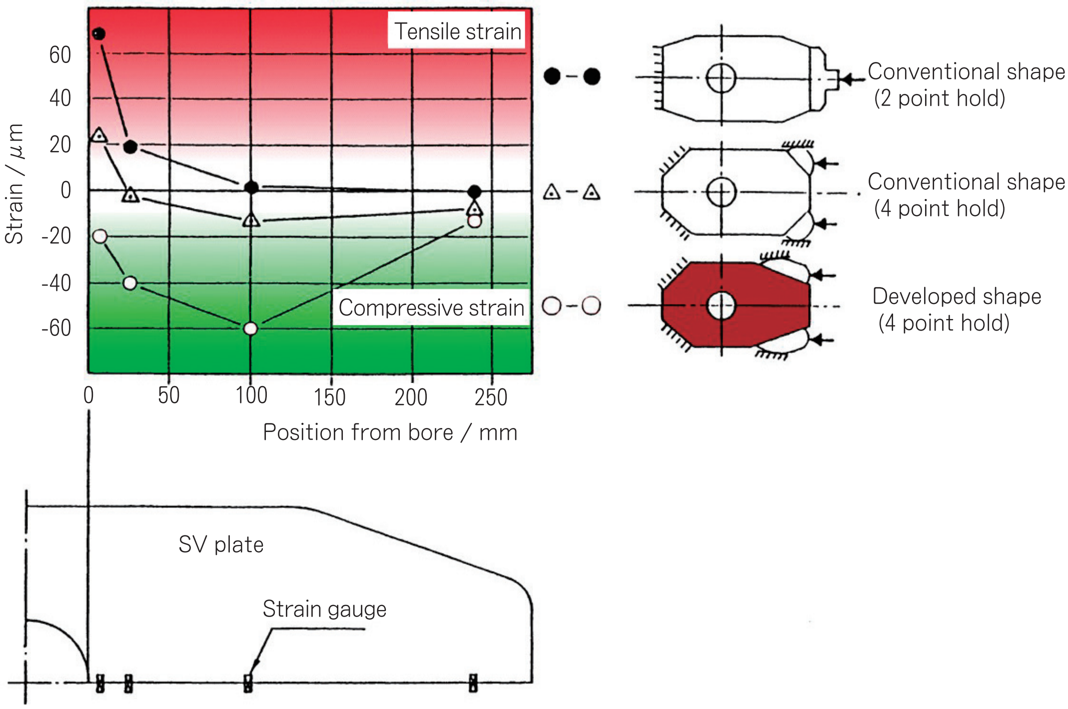

Fig. 13 Relationship between plate shape and strain[7].

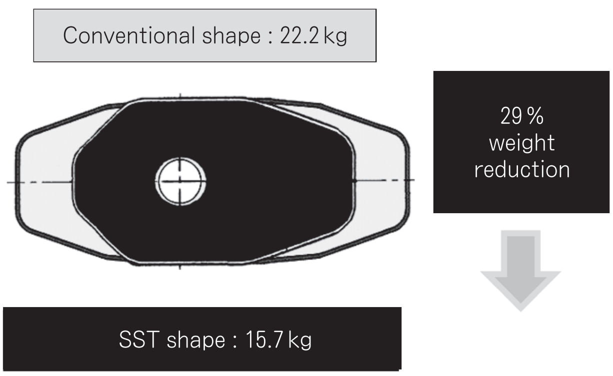

Fig. 14 Plate brick shape of SST at ArcelorMittal Tubarão[10].

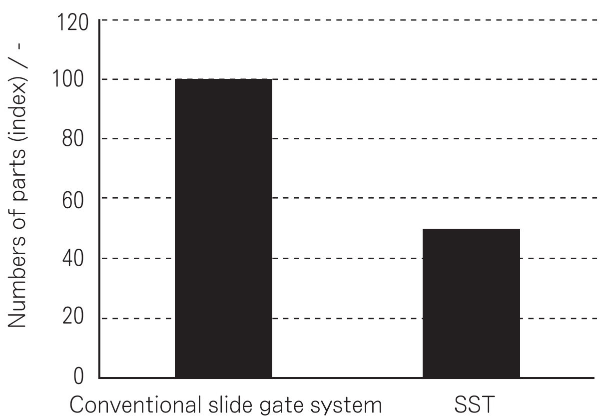

Fig. 15 Comparison of plate brick unit consumption[10].

5.0 to 6.9 heats. Furthermore, by optimizing the shape as shown in Fig. 14, the weight of the SV plate was reduced by 29%, resulting in a marked reduction in plate unit consumption. (Fig. 15)[9,10].

7. Conclusion

In this report, we mainly focused on variations in SV plate application according to casting conditions. SV plates are required to maximize durability by improving characteristics such as corrosion resistance and thermal spalling resistance, which are difficult to achieve simultaneously. We will continue to address stable casting and extension of refractory life by improving SV systems from comprehensive perspectives, i.e., material improvement as well as structural improvements such as SV plate shape and SV equipment.

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