

SHINAGAWA TECHNICAL REPORT

スライドバルブプレートの開発

Improvement of Slide Valve Plate

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要 旨

スライドバルブ (SV) プレートは取鍋やタンディッシュで溶鋼の流量を制御するために使用される重要な耐火物である。安定した流量制御を行うためにSVプレートには高い品質が求められる。今回は多様な鋼種に対する適応性や長寿命化の要求に対応して開発された各種SVプレート材質について報告する。これらの材質と最適化されたSVプレート形状の組み合わせにより、安定鑄造と耐火物の高耐用化が可能となる。

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. 緒言

取鍋やタンディッシュで溶鋼の流量制御方式として使用されるスライドバルブ (SV) 方式において、SVプレートは取鍋やタンディッシュの底部に設置されたSV装置内のカセットに組み込まれ、溶鋼の流量を制御するのに使用される。2枚または3枚一組で使用されるSVプレートには溶鋼の通過する孔が設けられており、一組のうち1枚のSVプレートを摺動して孔の有効面積を変化させることで、溶鋼の流量を制御する。そのためSVプレートには強度や耐食性、耐スポール性などがバランスよく必要とされる。また、近年は多様な鋼種に対する適応性や長寿命化の要求から、益々高

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,

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い耐用と安定性が求められている。今回は、これらの要求に対応するためのSVプレート材質、特にSVプレートの寿命に最も影響する面損傷の低減と溶損鋼種に対する耐用の向上、亀裂の制御に対する取り組みを中心に報告する。

2. SVプレートの材質

SVプレートには使用条件に応じてアルミナ・カーボン質、マグネシア・カーボン質、ジルコニア質等が適用される。中でも最も広く使用されているのがアルミナ・カーボン質である。Fig.1に当社SVプレート材質のラインナップを示す。アルミナ・カーボン質は耐熱スポール性と耐食性をバランスよく備えているため、加熱冷却の繰り返しによる熱衝撃に耐え、多数回使用することが可能である。Ca添加鋼や高酸素鋼などの、アルミナ・カーボン質の耐食性で対応できない溶損性の高い鋼種に対しては、塩基性材質やジルコニア質が適用される。

3. SVプレートの損傷形態

SVプレートの損傷を損傷部位や損傷形態で分類すると、主にエッジ損傷、亀裂、孔径拡大、面荒れ損傷の4種類に分けられる (Fig.2)。これらの損傷は

- ・耐火物特性…力学的特性、熱的特性、化学的特性
- ・構造因子…形状、装置への固定方法、プレート面間圧力
- ・操業条件…鋼種、 casting 温度、 casting 時間、 間欠使用

Material	Brand name	Steel grade
Alumina-C →	SVR-PK, FK	… General steel
Alumina-C →	SVR-PL, PF	… High [O] steel, Si killed steel
MgO-(Spinel)-C →	SVR-PB, FB	… High [Ca] steel, High [O] steel
MgO-Spinel →	SVR-PM	… High [Ca] steel, High [O] steel
Zirconia →	SVR-PZ	… High [Ca] steel, special steel

Fig. 1 Classification of Shinagawa SV plates.

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

$\text{Al}_2\text{O}_3\text{-C}$ materials, MgO-C materials, ZrO_2 materials and so on are used for SV plates according to usage conditions. Among them, $\text{Al}_2\text{O}_3\text{-C}$ materials are most widely used. Fig. 1 shows the lineup of our SV plate materials. Since $\text{Al}_2\text{O}_3\text{-C}$ 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 severely corrode $\text{Al}_2\text{O}_3\text{-C}$ materials.

3. Damage form of SV Plate

Damages to the SV plate are mainly classified into following four types : edge damage, cracks,

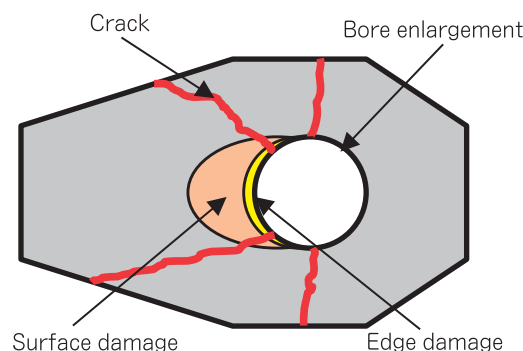


Fig. 2 Typical damages of SV plate.

・整備方法…酸素洗浄，開放点検
等，様々な要素に影響される。

3. 1 エッジ損傷

エッジ損傷の原因としては，スポーリングによる欠け，スポーリング亀裂からの吸気溶損，組織脆化，溶損などが考えられる。大きな溶損の場合，塩基性材質やジルコニア質などの高耐食性材質が適用される。

3. 2 亀裂

亀裂の原因は外部からの荷重と熱応力である。亀裂が開くと吸気による酸化や溶損が発生し，漏鋼の原因となる。また内孔から絞り方向に発生する「縦亀裂」はエッジ損傷の起点になり，耐用低下を引き起こす（Fig.3）。亀裂の発生パターンはSVプレートの形状，装置への固定方法などの構造的要素の影響を強く受ける。

3. 3 孔径拡大

孔径拡大は，溶損性の高い鋼種の場合を除いて， casting中の溶鋼流よりも整備時の酸素洗浄の影響が大きい。孔径が拡大すると流量調節のためにSVプレートは閉方向に動かされ，プレート摺動面と溶鋼の接触面積が増大する。接触面積の増大はエッジや摺動面の損傷拡大につながる。

3. 4 面損傷

一般に，プレートの寿命に最も影響するのが面損傷である。面損傷の拡大は摺動不良や湯止まり不良といった溶鋼流制御のトラブルや，面間漏鋼の原因になる。そのため摺動面の損傷深さは1 mm前後かそれ以下のスケールで議論される。面損傷の形態は摩耗，溶損，焼付き剥がれな

bore enlargement and sliding surface damage (Fig. 2). These damages are affected by various factors as follows:

- ・ 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.

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

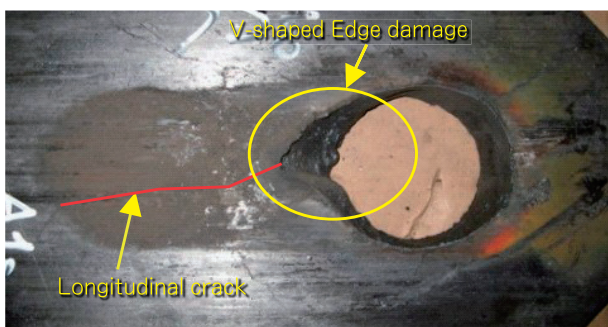


Fig. 3 Longitudinal crack and V-shaped edge damage.

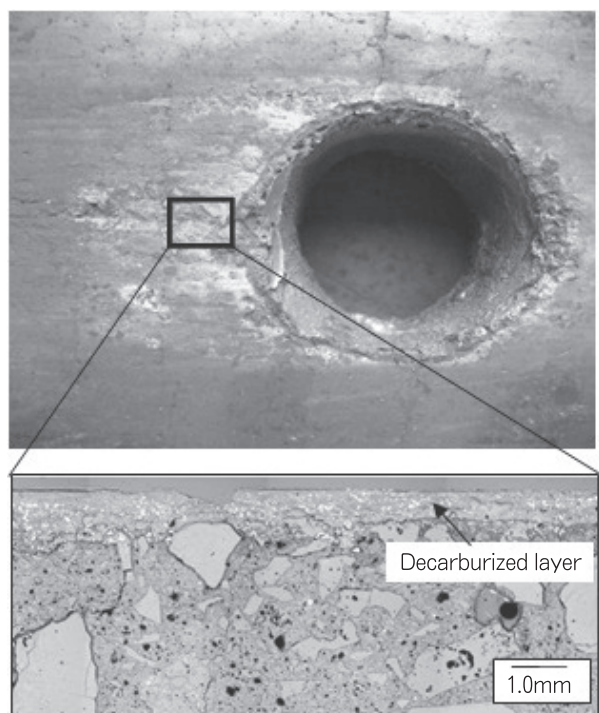


Fig. 4 Surface damage of $\text{Al}_2\text{O}_3\text{-C}$ plate after use.

どがある。それらの原因としては低融点物生成による溶損、熱衝撃による脆化、脱炭による脆化などがある。Fig.4に $\text{Al}_2\text{O}_3\text{-C}$ 材質の面損傷部を示す。稼働面に形成された脱炭層に地金の侵入、耐火物粒子の変質が見られる。炭素含有材質の場合、SVプレートの耐用向上には脱炭をとまなう組織脆化を抑制することが特に重要である。

4. 一般鋼製造時の損傷

一般鋼の casting では、SVプレートには長時間・多数回の使用が求められる。多数回使用にとまなう加熱冷却のサイクルに耐えるため、一般鋼用材質には比較的高い耐熱スポール性が要求される。弊社ブランドの中では $\text{Al}_2\text{O}_3\text{-C}$ 材質のSVR-PKシリーズが一般鋼向けに広く適用されている。一般鋼向け $\text{Al}_2\text{O}_3\text{-C}$ 材質の耐用に最も影響するのは、面損傷である。

4. 1 溶鋼との反応による $\text{Al}_2\text{O}_3\text{-C}$ 材質の組織脆化

$\text{Al}_2\text{O}_3\text{-C}$ 材質の面損傷は脱炭をとまなう組織脆化が引き金になる。林ら¹⁾は、単純化した $\text{Al}_2\text{O}_3\text{-C}$ 材質を用いて溶鋼への浸漬実験を行うことで $\text{Al}_2\text{O}_3\text{-C}$ 材質の組織変化に及ぼす鋼種の影響を調

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 corrosion due to eutectic reaction, texture deterioration due to thermal shock and/or decarburization. Fig.4 shows the surface damaged part of the $\text{Al}_2\text{O}_3\text{-C}$ 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 $\text{Al}_2\text{O}_3\text{-C}$ material SVR-PK series is widely applied for casting general steel. Surface damage is the main factor to determine the durable life of the $\text{Al}_2\text{O}_3\text{-C}$ material for casting general steel.

4. 1 Texture deterioration of $\text{Al}_2\text{O}_3\text{-C}$

material by reaction with molten steel

Texture deterioration accompanying decarburization triggers surface damage of $\text{Al}_2\text{O}_3\text{-C}$

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

Table 2 Composition of the specimens

Raw materials / mass%	M1	M2
Al ₂ O ₃	91	
C	9	
Si	12	12
Al	0	12

査し、稼働面における脱炭は耐火物中のアルミナとの反応によるもので、脆化層を形成する反応の駆動力は耐火物内部と耐火物-溶鋼界面におけるAl(g)、CO(g)の分圧や、溶鋼のカーボン活量に依存すると報告している。また赤峰ら²⁾は、 casting中に生じる溶鋼非充満部の負圧条件が、カーボンと酸化物粒子の反応を促進する可能性を指摘している。

これらの報告から、プレート稼働面の脆化を抑制するには耐火物内部から溶鋼中へのガス移動を防ぎ、炭素熱還元反応の進行を遅らせることが有効である。対策をTable 1に示す。炭素含有材質では(d)酸化防止剤として様々な物質が使用される。酸化防止剤の中でも特に有効なのが、焼成によって結合組織を形成する金属添加物である。

4. 2 Al₂O₃-C材質の耐面損傷性改善

Al₂O₃-C材質の耐面損傷性におよぼす金属添加物の効果を確認するため、Al₂O₃-C-Metalの単純系で金属添加物のみを変更した試料 (Table 2) を用いて溶鋼との反応実験を行った結果³⁾を以下に示す。試料は1000℃以上の還元雰囲気中で焼成し、Ar雰囲気中で1600℃の高酸素鋼([O]=120ppm)に1時間浸漬した。

実験後試料のEPMA観察結果をFig.5に示す。実験後試料には溶鋼と接していた稼働面 (画像右

material. Lin et al.¹⁾ investigated the effect of steel grade on the structural change of Al₂O₃-C material by performing an immersion experiment in molten steel by using a simplified Al₂O₃-C material. They reported that the reduction of Al₂O₃ 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 Al₂O₃-C material

In order to evaluate the effect of metal additives on the surface damage resistance of Al₂O₃-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

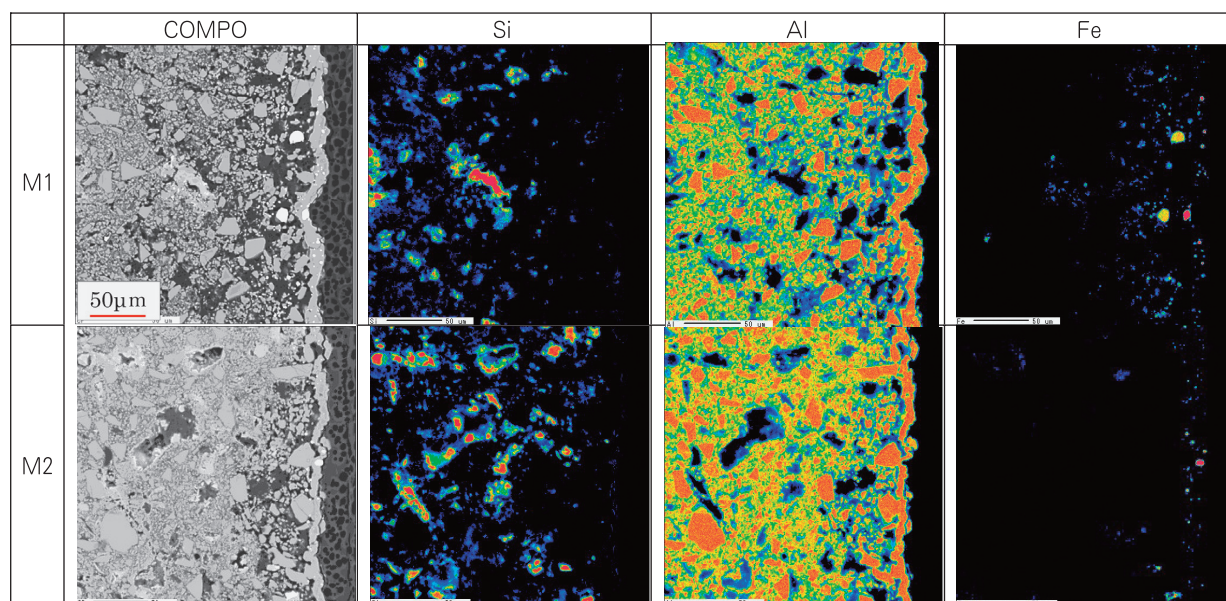


Fig. 5 Microstructure and EPMA analysis of immersed part of refractory specimens³⁾.

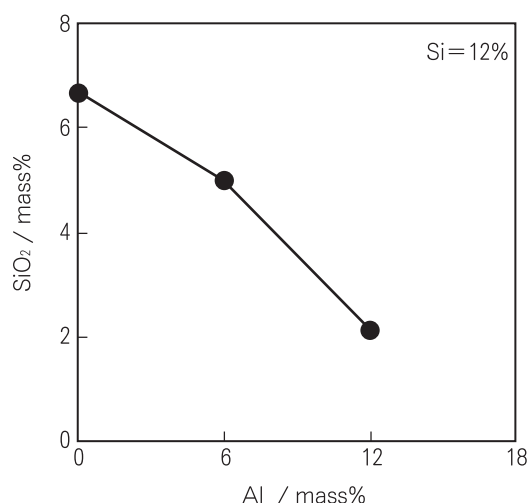


Fig. 6 Amount of SiO₂ formation during firing in reducing atmosphere above 1000 °C³⁾.

側) にアルミナ緻密層，その内側にC, Siの消失をともなう脆化層が形成されていた。脆化層厚みはM1で100～150 μ m，M2で20～50 μ m程度と，SiとAlの併用によって約3分の1に減少した。

これらの脆化層は，Al₂O₃とCの反応に加えてSiO₂とCの反応によって形成されたと考えられる。Al添加量と焼成中のSiO₂生成量の関係をFig.6に示す。焼成時に一部の金属添加物は酸化する

system of Al₂O₃-C-Metal (Table 2). The results are shown below³⁾. The specimens were fired in a reducing atmosphere at 1000 °C or more and immersed in high oxygen steel ([O] = 120 ppm) at 1600 °C 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 the deteriorated layers were approximately 100 to 150 μ m for M1 and approximately 20 to 50 μ m 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 SiO₂ and C in addition to the reaction between Al₂O₃ and C. The relationship between the amount of Al addition and the amount of SiO₂ 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

が、Al添加によって SiO_2 生成量は減少する。M2は安定なAl系結合の増加によって、脆化を抑制できたと考えられる。

弊社ではSiとAlの併用に加え、適切な焼成条件によって結合組織を改善した材質を開発した。Table 3にSi添加の従来材質A、SiとAl添加の従来材質B、焼成条件を改良したSiとAl添加の新材質Cの品質を示す。従来材質Aの結合組織はSi-O-C系が主体であったが、新材質CではAl-O-N系とSiCが結合の主体となっている。Fig.7は材質Aと材質Cの結合組織の一部で、焼成時に気相反応を介して生成したものである。材質Aの場合はSiC主体、材質Cの場合はAlN主体のウィスカで構成されている。

これら材質の製鉄所における使用後品の微構造をFig.8に示す。A→B→Cと脆化層の厚みが減少し、損傷は軽減された。これによって使用回数は最大7chから8chへと増加した。なお、材質C及び類似の設計で作られた製品は高炉製鉄所、電炉製鉄所などで広く使用され、好評を得ている。

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

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 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

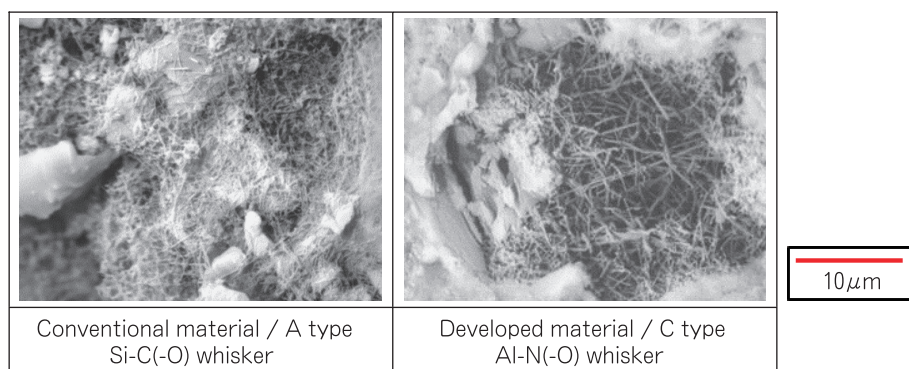


Fig. 7 Whiskers formed by the reactions of metal additives during firing.

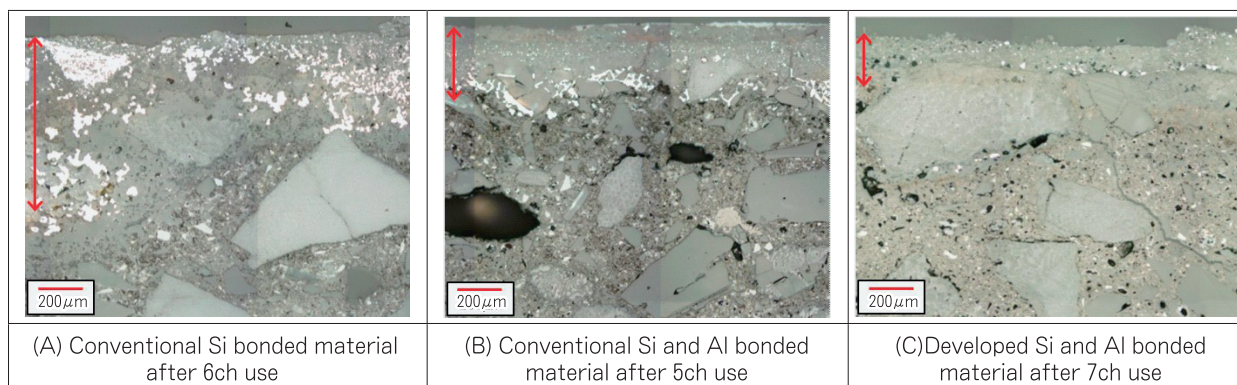


Fig. 8 Microstructures of surface damage zone of SV plate after use.

5. 溶損鋼種鑄造時の損傷

高酸素鋼やCa添加鋼などの溶損性が非常に高い鋼種には、高耐食性の塩基性材質が適用される。しかし塩基性材質は耐熱スポール性が低く多数回の使用に耐えないため、比較的溶損性が低い鋼種には未反応Al含有の Al_2O_3 -C材質が適用可能となる。未反応Al含有の Al_2O_3 -C材質は標準的な Al_2O_3 -C材質と塩基性材質の中間的な品質を持つ。しかしまだ未反応Al含有 Al_2O_3 -C材質と塩基性材質の間には大きなギャップがある。

両者のギャップを埋めるアプローチには未反応Al含有 Al_2O_3 -C材質の耐食性をさらに向上すること、塩基性材質の耐熱スポール性を改善することの2つの方法がある。この場合、 Al_2O_3 -C材質の耐用に最も影響するのは溶損由来のエッジおよび面損傷であり、塩基性材質の耐用に最も影響するのは熱衝撃亀裂となる。

5. 1 Al多量添加不焼成 Al_2O_3 -C材質

耐食性を向上させるためにAl添加量を増やすと、焼成後の弾性率が増加して耐熱スポール性が低下する。そこで、焼成をしないことでプレート全体の高弾性率化を回避した不焼成 Al_2O_3 -C材質を開発した⁴⁾。不焼成材質は鑄造中の受熱を利用してAlを反応させ、結合組織を形成する。Table 4に従来品D及び開発品Eの基本品質を示す。D、Eはいずれも不焼成材質であるが、材質Dに対して材質EはAl添加量を大幅に増量している。Fig.9

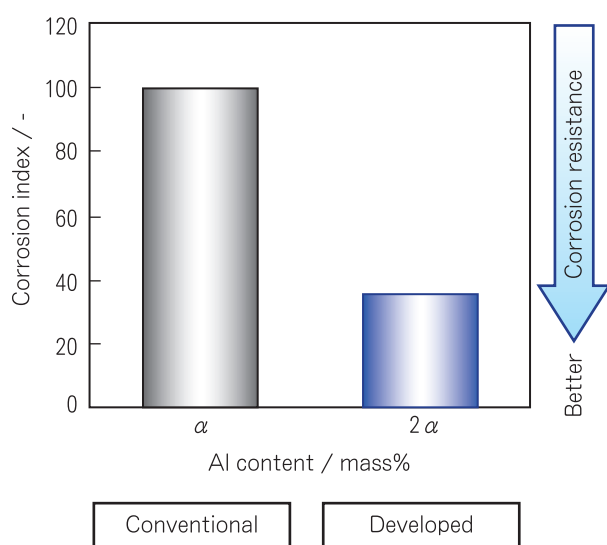
concept are being widely used and receiving favorable reviews in blast furnace steelworks as well as in electric arc furnace steelworks.

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

Table 4 Typical properties of unfired SV plate

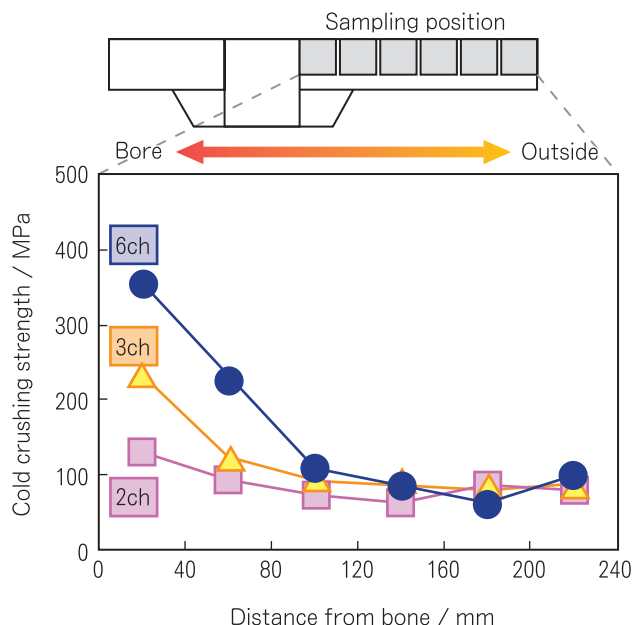
Material	D	E
	Conventional	Developed
Chemical composition / mass%		
SiO ₂	1	1
Al ₂ O ₃	82	80
ZrO ₂	4	4
C	6	6
Al	α	2 α
Apparent porosity / %	4.2	5.2
Bulk density / g·cm ⁻³	3.27	3.24
Cold crushing strength / MPa	136	145
Hot modulus of rupture / MPa	41	48

Fig. 10 Result of corrosion test by Fe+FeO, 1650 °C×4 h⁴⁾.

に、下プレート部位と圧縮強度の関係を使用回数毎の系列で示す。各系列とも内孔近傍の圧縮強度が高く、使用回数が増加するほどその傾向は顕著である。このように、溶鋼からの熱を受ける部分のみで強固な結合を形成する不焼成品Eはプレート全体を高弾性率化することなく、高い耐食性を示す (Fig.10)。その結果、従来品Dと比較して30%の耐用向上に成功している。

5. 2 塩基性材質(MgO-C)の耐熱スポール性改善

MgO-C材質はCaOやFeOに対して高い耐食性を持つが、熱膨張率が高く耐熱スポール性が非常に低い。そこで、MgOの一部をスピネルに置換して耐熱スポール性を向上させたMgO-Spinel-C材質を開発した^{5,6)}。スピネルはMgOと比較して低膨

Fig. 9 Relationship between distance from bore and cold crushing strength of developed SV plate E⁴⁾.

the main factor in determining the durability of basic material.

5. 1 Unfired Al₂O₃-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 Al₂O₃-C material which avoids increasing the elastic modulus of the whole plate⁴⁾. 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

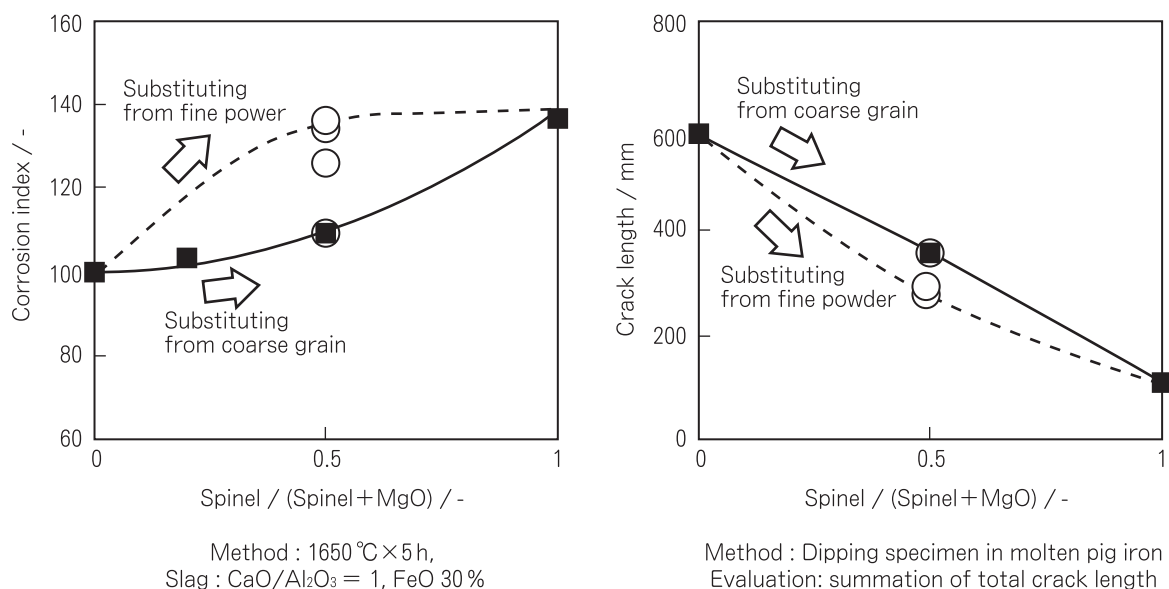


Fig. 11 Comprehensive diagram of influences of grain size and fraction of spinel on corrosion and spalling resistance evaluation results⁶⁾.

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

張で、 Al_2O_3 より高い耐食性を持つ。スピネルの耐食性は MgO に劣るが、スピネルを粗粒側で使用する事で耐食性の低下を最小限に抑えつつ、耐熱スポール性を向上させることが可能である (Fig.11)。弊社の標準的 MgO-C 材質Fと新開発の MgO-Spinel-C 材質Gの品質をTable 5に示す。Fig.12は、材質F, GのCa添加鋼における使用結果である。材質F, Gともに大きな溶損は見られないが、材質Gの亀裂は明らかに減少している。

6. SVプレート形状と亀裂抑制

次は、SVプレートの材質以外のアプローチを紹介する。SVプレートは摺動摩擦や溶鋼による侵食に耐えるために、緻密な組織と高い強度が要求

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.

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. Thus, it is possible to improve thermal spalling

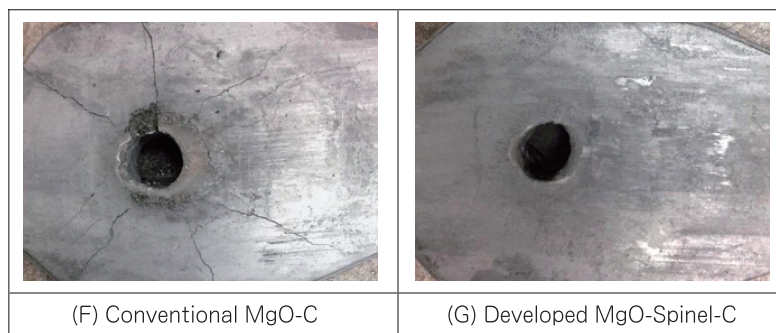


Fig. 12 External appearance of SV plates after use for Ca-treated steel, 2 heats.

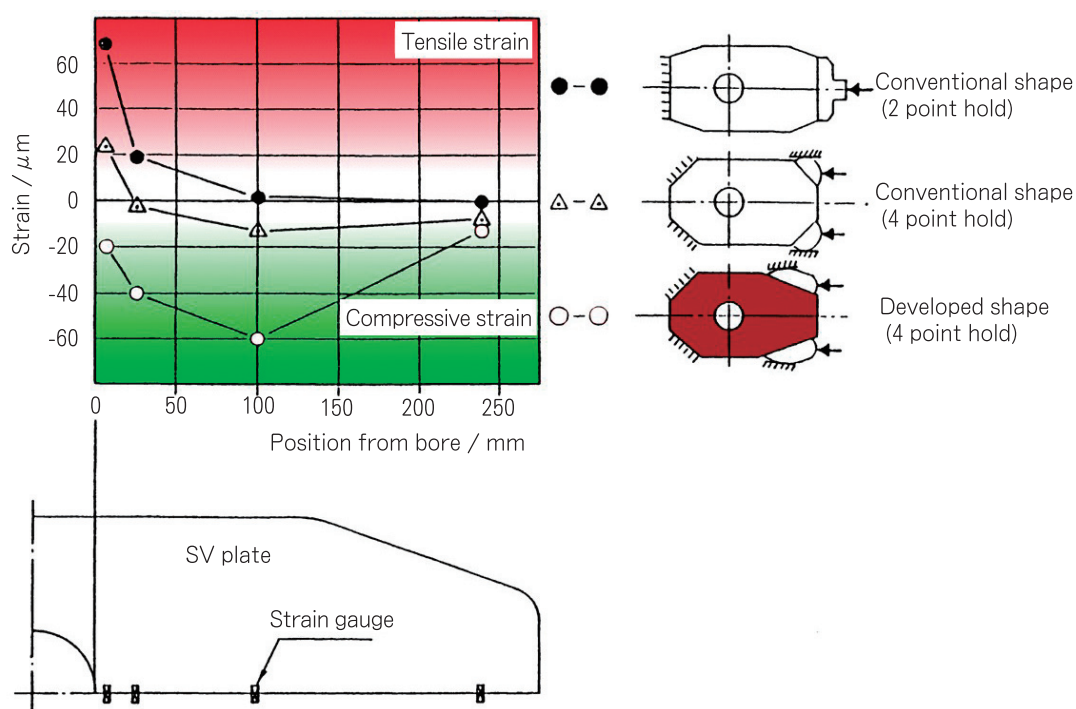


Fig. 13 Relationship between plate shape and strain⁷⁾.

される。そのため、亀裂の発生を完全に抑えることは難しい。したがって、亀裂の発生パターンの制御が重要となる。弊社では、内孔に近い位置でプレートを固定することで孔周りに圧縮応力を発生させて亀裂の伝播を抑制する形状を考案し、弊社SV装置「SAT」、「SST」などのシリーズに採用している⁷⁾。Fig.13は、SVプレートの固定構造とSVプレート内歪みの関係を調べた冷間での実験結果である⁸⁾。従来形状では絞り方向の一部または全体に引張歪みが発生するのに対し、SST形状では全体に圧縮歪みが発生させ、亀裂の伝播を防ぐことが可能となっている。従来形状では絞り方向に生じる引張応力により「縦亀裂」が発生してSVプレートの耐用低下に影響していたが、SST形

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.

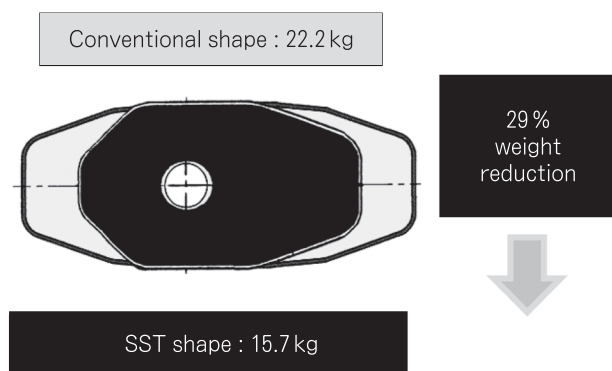


Fig. 14 Plate brick shape of SST at ArcelorMittal Tubarão¹⁰⁾.

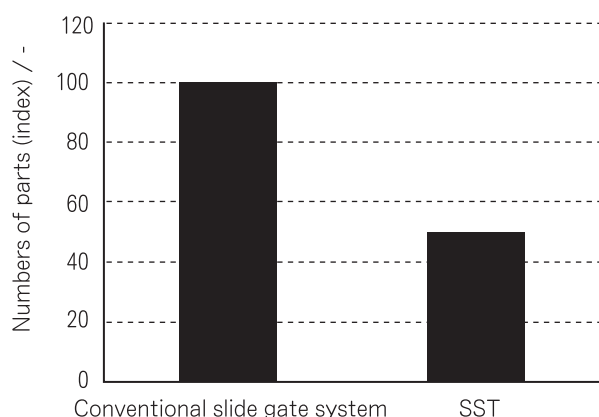


Fig. 15 Comparison of plate brick unit consumption¹⁰⁾.

状では縦亀裂の発生を防止して安定した耐用が期待できる。

このSST装置をArcelorMittal Tubarãoにて使用した結果、SVプレート寿命は5.0から6.9chに伸びた。さらにFig.14に示すような形状の最適化によってSVプレート重量が29%削減されたことと合わせ、プレート原単位を大幅に低減できた (Fig.15)^{9,10)}。

7. 結言

今回は鑄造条件に応じて適用される各種のSVプレートを中心に紹介した。耐食性と耐熱スポール性という両立の難しい特性を伸ばしつつ、耐用を最大化することがSVプレートには求められている。今後も材質改良だけに留まらず、SV装置や

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 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 strain⁸⁾. 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 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

プレート形状等の構造面の改良を含めた総合的な視野をもって、安定した鑄造と耐火物寿命の延長に取り組みたい。

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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