

SHINAGAWA TECHNICAL REPORT

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Molten Steel

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品川技報

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Development of Anti-alumina-clogging Refractories Characterized by Reaction with Molten Steel

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Abstract

Alumina-silica and spinel refractories were submitted to molten-steel dipping tests in order to develop anti-alumina-clogging refractories for the inside liner of a submerged entry nozzle that are characterized by the formation of liquid-bearing microstructure. Alumina-silica refractories form a liquid-bearing reaction layer along the hot face via manganese invasion from the molten steel, but performance varies depending on the silica content of the refractory and manganese concentration of the molten steel. Spinel refractories containing MgO, CaO and SiO₂ as flux form a liquid-bearing microstructure by heating without reacting with the molten steel. Alumina adhesion on the inner wall of submerged entry nozzles was reduced by applying the newly developed refractories.

1. 序論

浸漬ノズル内管へのアルミナ付着防止は、浸漬ノズルの耐用延長につながるだけでなく、鑄片品質を向上させる上でも重要である¹⁾。アルミナ付着には、浸漬ノズルの耐火物から放出されるCOガスやSiOガスによって鋼中Alが酸化して生じる場合と、鋼中アルミナ介在物が直接付着する場合がある²⁾。前者によるアルミナ付着を防止する方策として、浸漬ノズルの内管にCOガスやSiOガスが発生しにくいカーボンフリー内管材が使用されることがある。他方、アルミナ介在物の耐火物稼動面への付着力は耐火物と溶鋼との濡れ性に深く関係していて³⁾、耐火物を溶鋼と濡れやすくすることでアルミナ付着を低減できると考えられる。耐火物は一般に固体の酸化物から構成されるので溶鋼とは濡れにくい。しかし、熱間で少量の液相を

1. Introduction

Preventing the alumina adhesion of submerged entry nozzles (SENs) is of great importance not only for prolonging SEN service life but for improving steel quality¹⁾. The mechanism of alumina adhesion can be classified into two types: oxidation of dissolved aluminum by CO and SiO gasses emitted from SEN refractories and direct adhesion of alumina inclusions suspended in the molten steel²⁾. Carbon-free refractories, which do not emit CO and SiO gasses, have commonly been used as the inside liner of a SEN to prevent alumina adhesion by the former mechanism. Meanwhile, alumina inclusion adhesion is closely related to the wettability of a SEN refractory to molten

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Table 1 Chemical compositions of refractory samples (in mass%)

Refractory	A	B	C	D	E
SiO ₂	56	40		16	2
Al ₂ O ₃	41	57	70	58	58
MgO			27	23	30
CaO					7
C	3	3	3	3	3
Total	100	100	100	100	100

伴う場合、溶鋼との濡れ性が向上すると考える。

今回検討する耐火物の材質として、アルミナ・シリカ質およびスピネル質を選定した。アルミナ・シリカ質の場合は耐火物中のSiO₂成分と鋼中Mnの反応により稼動面に溶鋼と濡れやすい液相を伴う反応層を形成させ、スピネル質耐火物の場合はフラックスを添加することで溶鋼と濡れやすい液相を伴う組織を形成させた。実機テストの結果、今回開発した溶鋼と濡れやすい耐火物は従来のカーボンフリー耐火物に比べ優れたアルミナ付着防止効果を示した。

2. 実験方法

耐火物試料と溶鋼の反応性を調査するため、Table 1に示す耐火物について溶鋼浸漬実験を行った。耐火物A、Bはムライトとシリカからなるアルミナ・シリカ質耐火物である。耐火物Aは耐火物Bよりシリカ含有量が高い。耐火物C、D、Eはスピネル質耐火物である。耐火物Cはスピネル単味からなり、耐火物Dはスピネルが81mass%、SiO₂が16mass%、耐火物Eはスピネルが81mass%、MgOが7mass%、CaOが7mass%、SiO₂が2mass%である。すべての耐火物試料はバインダーとして添加したフェノール樹脂の残炭として3mass%のカーボンを含む。ただし、残炭のカーボンは溶鋼と接すると直ちに消滅するので、これらの材料はカーボンフリー耐火物と呼ばれている。鋼試料は低炭素鋼と中炭素鋼の2種類を用意した。低炭素鋼はAlに富み、Mnに乏しいのに対し、中炭素鋼はAlに乏しく、Mnに富む (Table 2)。

実験条件は次の通りである。耐火物試料は、原料にフェノール樹脂を加えて混練し、100MPaの

steel³⁾、and the adhesion can be prevented by increasing the wettability. In general, carbon-free refractories are not wettable to molten steel because they consist of solid oxides. If they contain some amount of liquid-oxide phase in a hot environment, the wettability can improve greatly.

We chose alumina-silica and spinel refractories, both of which were carbon-free, as the test samples in this study. As for the alumina-silica refractories, wettable liquid-bearing reaction layer was formed along the hot face by utilizing the reaction between silica in the refractory and manganese in the molten steel, while as for spinel refractory, a wettable liquid-bearing microstructure was obtained by adding flux to the spinel. The actual caster tests showed that the newly developed wettable refractories had superior anti-alumina-clogging performances to the conventional carbon-free refractories.

2. Experimental Procedure

The refractory samples shown in Table 1 were submitted to molten-steel dipping experiments in order to investigate the reactivity to molten steel. Refractories A and B were alumina-silica refractories and were made up of mullite and silica. Refractory A had higher silica content than refractory B. Refractories C, D and E were spinel refractories. Refractory C was composed of spinel, refractory D contained 81mass% spinel and 16mass% SiO₂, and refractory E contained 81mass% spinel, 7mass% MgO, 7mass% CaO and 2mass% SiO₂. All the refractory samples contained 3mass% carbon which was the residue of phenol resin which had been added as the binder. The samples were regarded as carbon-free refractories because the residue carbon disappears immediately when contacting with molten steel. Two kinds of steel samples were prepared for the experiments: the low-carbon steel was relatively enriched with aluminum and low in manganese, while the medium-carbon

Table 2 Chemical compositions of steel samples (in mass%)

	Mn	Al	Si
Low-C steel	0.2	0.025	0.01
Medium-C steel	0.5	0.001	0.20

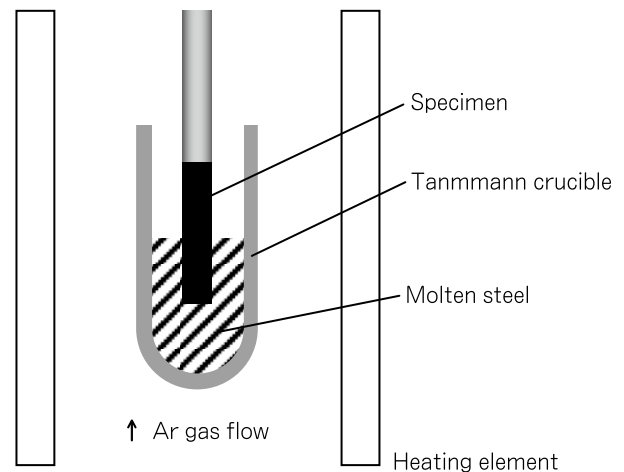
圧力で成形した後に1000℃で焼成し、6 mm角柱の寸法に切り出すことで得た。加熱装置は、温度と雰囲気を正確に制御できる小型の電気炉 (Fig. 1) を用いた。鋼試料300gをアルミナ製のタンマン管(φ40mm)に入れ、Ar雰囲気で1560℃まで加熱した。耐火物試料も予熱のため同時にタンマン管の直上へ配置した。1560℃で30分間保持した後、耐火物試料を溶鋼中へ深さ15mmまで浸漬させた。10分間の浸漬の後に耐火物試料は溶鋼から引き上げ、耐火物および鋼試料ともに炉内で自然冷却させた。耐火物試料は縦方向に切断し、EPMAを用いて組織観察を行った。耐火物試料と鋼試料の組み合わせをTable 3に示す。耐火物A, Bに対しては低炭素鋼と中炭素鋼を、耐火物C, D, Eに対しては中炭素鋼のみを使用した。

3. 結果, 考察

3. 1 実験1～4

Fig. 2に実験1～4での溶鋼浸漬後の耐火物A, Bの外観写真を示す。すべての試料で浸漬部に黒色の反応物が見られたが、実験2の耐火物Aでは溶損が生じていた。

実験1では、耐火物Aはムライトと $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ 系液相からなる厚さ約500 μm の反応層を形成した (Fig. 3)。実験2では、耐火物Aは実験1と同様にムライトと $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ 系液相からなる反応層が見られたが、その厚さは1 mmを超えていた (Fig. 4)。実験3では、耐火物Bはコランダムと少量の $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ 系液相からなる厚さ

**Fig. 1 Experimental apparatus for molten-steel dipping experiment.**

steel was depleted of aluminum and enriched with manganese (Table 2).

The experimental conditions were as follows. The raw materials were kneaded with phenol resin and pressed under 100MPa. The pressed samples were fired at 1000℃ and the fired samples were cut in a 6×6mm columnar shape. A small-sized electric furnace (Fig. 1) was used as a heating apparatus since the temperature and atmosphere can be regulated accurately. 300g of steel sample was put into a Tammann crucible (40mmφ) made of alumina and heated up to 1560℃ in an argon atmosphere. A refractory sample was also set over the crucible in order to be preheated. After holding the temperature for 30 minutes at 1560℃, the refractory sample was dipped into the molten steel at a depth of 15mm. After 10min immersion, the refractory sample was pulled out of the molten steel and both refractory and steel samples were cooled within the furnace naturally. The refractory

Table 3 Combinations of refractory and steel samples in molten-steel dipping experiments

Experiment	1	2	3	4	5	6	7
Refractory	A	A	B	B	C	D	E
Steel	Low-C	Medium-C	Low-C	Medium-C	Medium-C	Medium-C	Medium-C

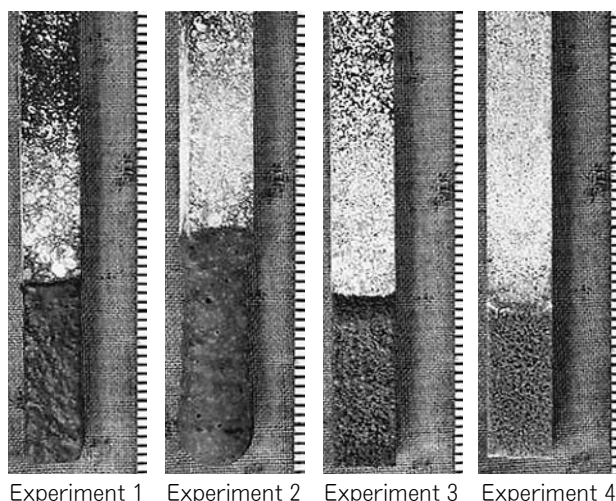


Fig. 2 Appearances of alumina-silica refractories after molten-steel dipping experiments.

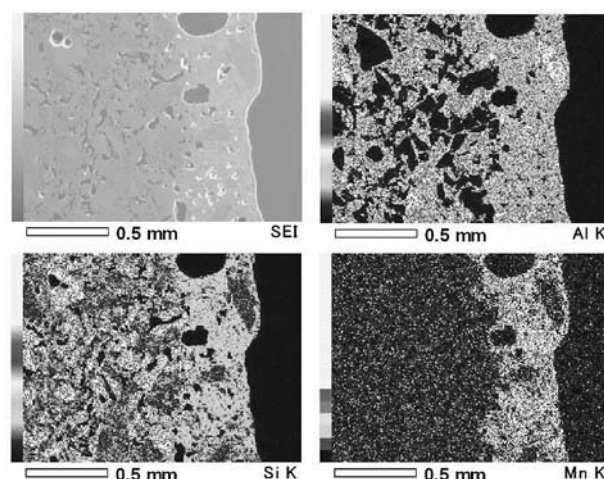


Fig. 3 Electron microprobe analysis of refractory A after experiment 1.

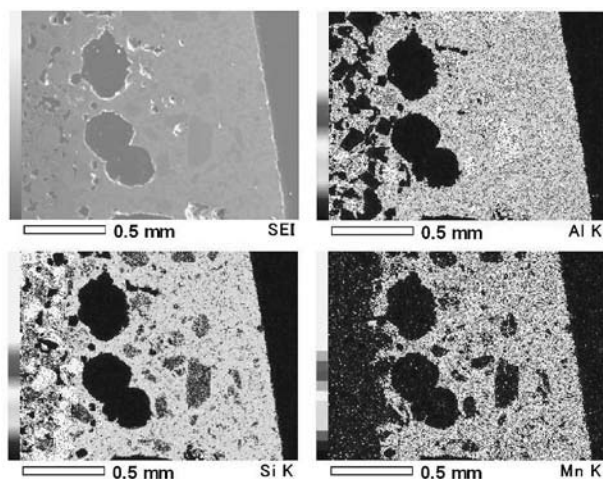


Fig. 4 Electron microprobe analysis of refractory A after experiment 2.

約 $300\mu\text{m}$ の反応層が見られた (Fig. 5)。実験4では、耐火物Bは実験3と同様にコランダムと少量の $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ 系液相からなる厚さ約 $300\mu\text{m}$ の反応層を形成していた (Fig. 6)。

$\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ 系液相の組成は耐火物Aと耐火物Bで異なったが、溶鋼の種類によらずほぼ同一の組成を示した (Fig. 7)。この液相と共存する結晶相も溶鋼の組成によらず耐火物Aではムライト、耐火物Bではコランダムと一定である。したがって、反応層のバルク組成は、Fig. 7において $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ 系液相とそれと共存する結晶相とを結ぶ線上のどこかにある。また、実験後の鋼試料では、SiとMnの組成が実験前とは異なってい

samples were cut longitudinally and observed with the aid of an electron microprobe.

The combinations of the refractory and steel samples are listed in Table 3. Both low- and medium-carbon steels were used for refractories A and B, whereas only medium-carbon steel was used for refractories C, D and E.

3. Results and Discussion

3.1 Experiment 1-4

Fig. 2 shows the appearances of alumina-silica refractories A and B after experiments 1-4. Though all the samples yielded a blackish reaction product in the dipped part, refractory A became corroded after experiment 2.

After experiment 1, refractory A contained a $500\mu\text{m}$ -thick reaction layer composed of $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ liquid phase and mullite (Fig. 3). After experiment 2, refractory A had a reaction layer of the same constituents as refractory A in experiment 1, but the thickness of the layer exceeded 1mm (Fig. 4). After experiment 3, refractory B contained a $300\mu\text{m}$ -thick reaction layer composed of corundum and a small amount of $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ glassy phase (Fig. 5). After experiment 4, refractory B contained a $300\mu\text{m}$ -thick reaction layer of the same constituents as

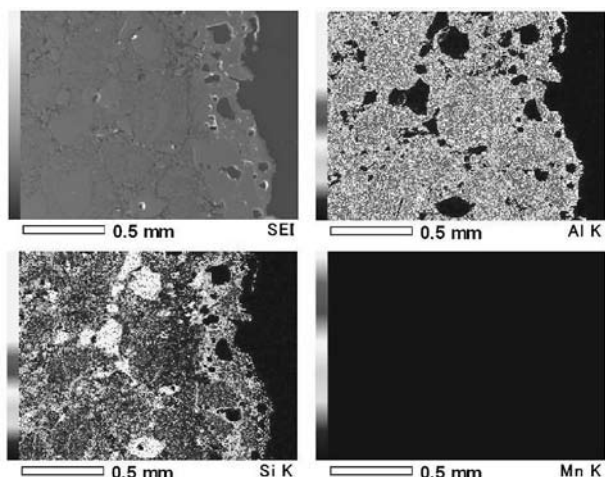


Fig. 5 Electron microprobe analysis of refractory B after experiment 3.

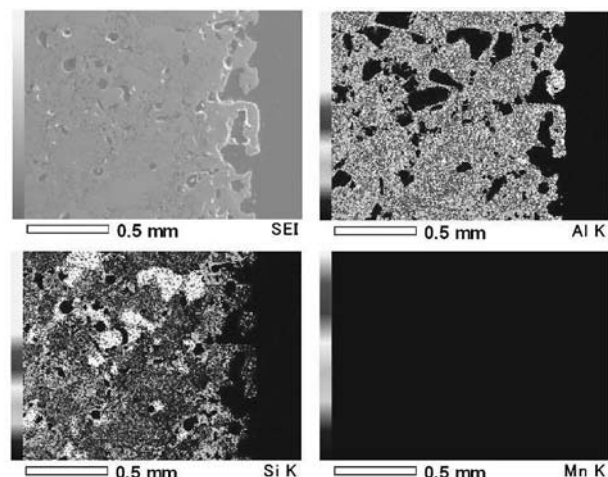


Fig. 6 Electron microprobe analysis of refractory B after experiment 4.

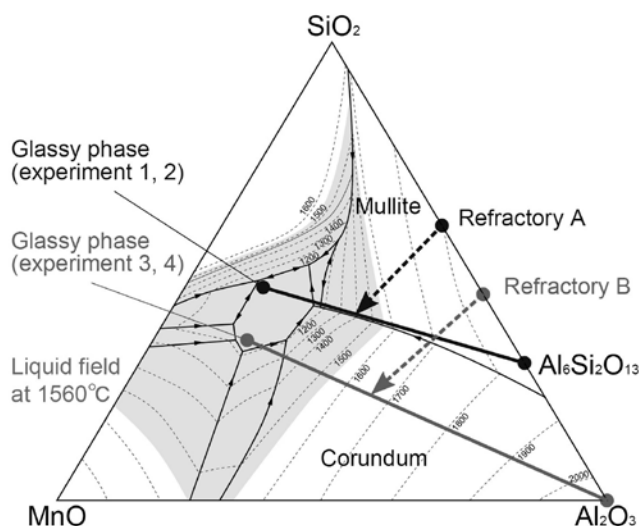
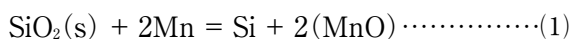


Fig. 7 Chemical compositions of refractories A and B, and of glassy phases formed in them after molten-steel dipping experiments in $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ phase diagram⁴⁾. Shaded area indicates a liquid field at 1560°C.

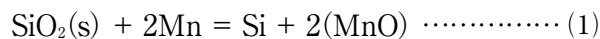
た。その変化量を実験 1 ～ 4 で比較すると、[Si] の増加が大きいほど [Mn] の低下が大きいという直線関係にあることがわかった (Fig. 8)。これは鋼中 Mn の耐火物中の SiO_2 への浸透が次の反応により生じていたことを示す。



耐火物 A, B の表層の組成がこの反応式にしたがって変化したと仮定すると、組成は Fig. 7 中の矢印に沿って変化したことになる。したがって、

refractory B in experiment 3 (Fig. 6).

The chemical composition of the $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ liquid phase found in the reaction layer differed between refractory A and refractory B, but was roughly the same, independent of the composition of the steel (Fig. 7). Likewise, the crystalline phases coexisting with the liquid phase were mullite and corundum in refractory A and refractory B, respectively, these assemblages being independent of the steel composition. Thus, the bulk chemical composition of the reaction layer should lie somewhere on the tie line that connects the compositions of the $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MnO}$ liquid phase and the coexisting crystalline phase. In addition, the chemical composition of the steel sample differed before and after the dipping test. Comparison of the composition changes in experiments 1-4 revealed a linear relationship where Mn loss increased with the increase in Si gain (Fig. 8). This suggests that invasion of manganese into the silica of the alumina-silica refractory can be caused by the following reaction:



Assuming that the superficial areas of the refractories changed their compositions according to this reaction, the compositions should

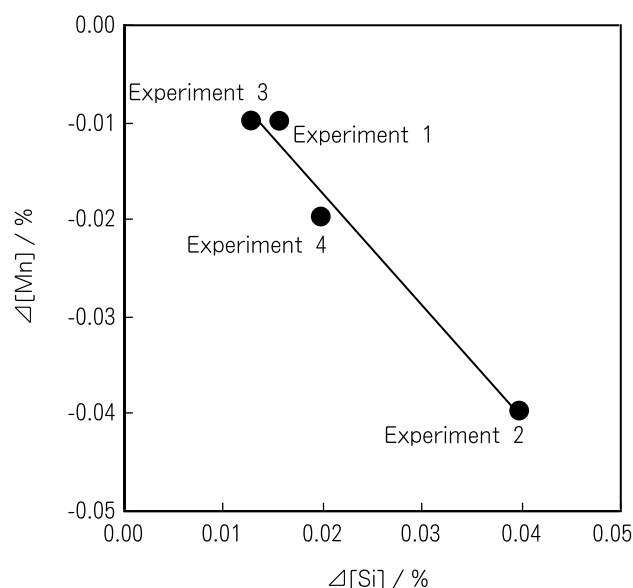


Fig. 8 Changes in [Si] and [Mn] of steel samples in molten-steel dipping experiments.

この矢印と上記の液相と結晶相を結ぶ線との交点が反応層のバルク組成に相当する。このことから、1560℃では、耐火物Aの稼動面は液相領域に位置していたと見られるが、一方の耐火物Bの場合はコランダム+液相の領域に位置していたと考えられる。これは、上で述べたように耐火物Aでは液相の生成量が比較的多く、耐火物Bでは液相生成量が少なくコランダムが析出するという観察事実と一致する。

3. 2 実験5～7

Fig. 9に実験5, 6, 7を経たスピネル質耐火物C, D, Eの外観写真を示す。耐火物Cは浸漬部分に白色の付着層が見られたのに対し、耐火物D, Eでは、灰色のガラス質反応層が見られた。

実験5では、耐火物Cは厚さ数 μm のスピネル質付着層が形成されていたが、液相を伴うような反応組織は認められなかった (Fig. 10)。実験6では、耐火物Dは組織全体がスピネルと $\text{SiO-Al}_2\text{O}_3\text{-MgO}$ 系液相から構成されていた。さらに、表層の部分では液相中にMnOが検出された (Fig. 11)。実験7では、耐火物Eは組織全体がスピネル、ペリクレス、 $\text{CaO-Al}_2\text{O}_3\text{-MgO-SiO}_2$ 系液相からなっていた。液相からMnOは検出されず、層状構造は示さなかった (Fig. 12)。

$\text{MgAl}_2\text{O}_4\text{-SiO}_2$ 系擬似2成分系状態図から、耐火

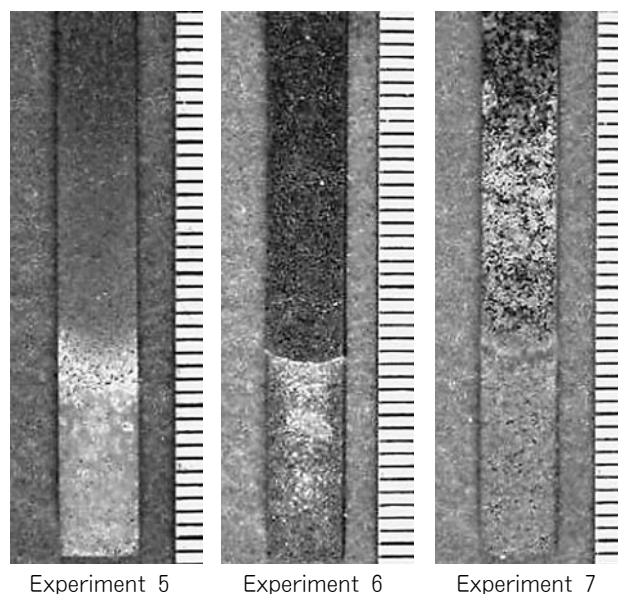


Fig. 9 Appearances of refractory samples after molten-steel dipping experiment.

have changed along the arrows in Fig. 7. Therefore, the bulk composition of the reaction layer can correspond to the intersection of the arrow with the tie line connecting the liquid and crystalline phases. This suggests that the surface of refractory A is estimated to have been in the liquid field, while that of refractory B is estimated to have been in the corundum plus liquid field. This estimation accords with the observed phenomena of refractory A generating a relatively high amount of liquid phase and refractory B generating corundum and a relatively minor amount of liquid phase.

3. 2 Experiments 5-7

Fig. 9 shows the appearances of spinel refractories C, D and E after experiments 5, 6 and 7, respectively. Refractory C had a thin whitish adhesion coat on the dipped part, whereas refractories D and E had a grayish glassy reaction product on the dipped part.

After experiment 5, refractory C had a spinel adhesion layer of a few μm in thickness while no reaction product involving liquid phase was formed (Fig. 10). After experiment 6, refractory D was composed of spinel and $\text{SiO}_2\text{-MgO-Al}_2\text{O}_3$

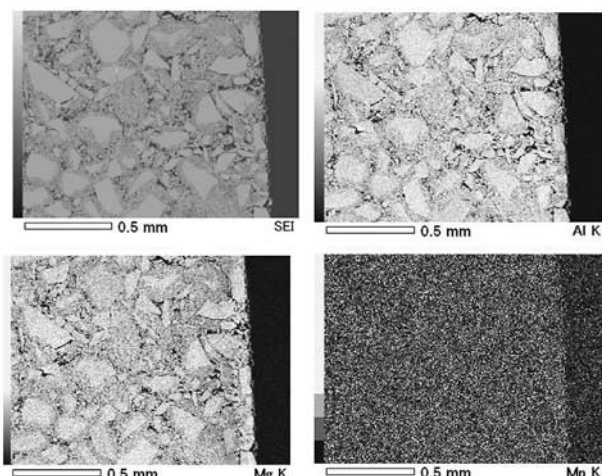


Fig. 10 Electron microprobe analysis of refractory C after experiment 5.

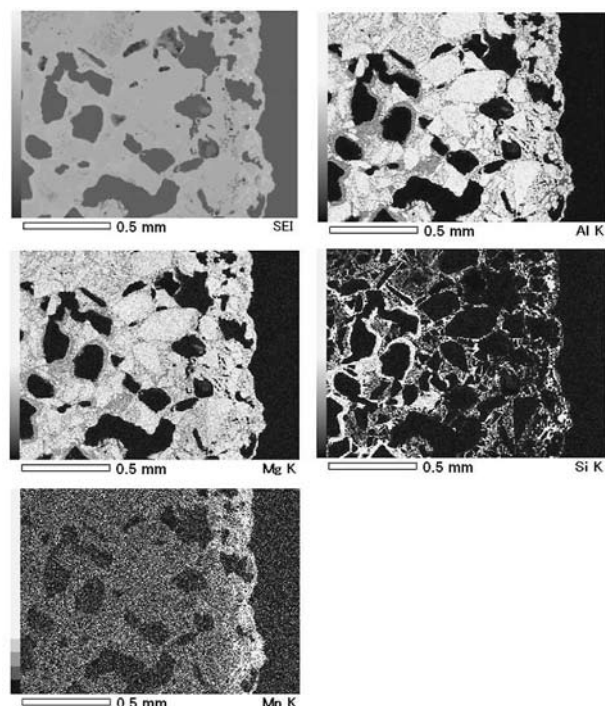


Fig. 11 Electron microprobe analysis of refractory D after experiment 6.

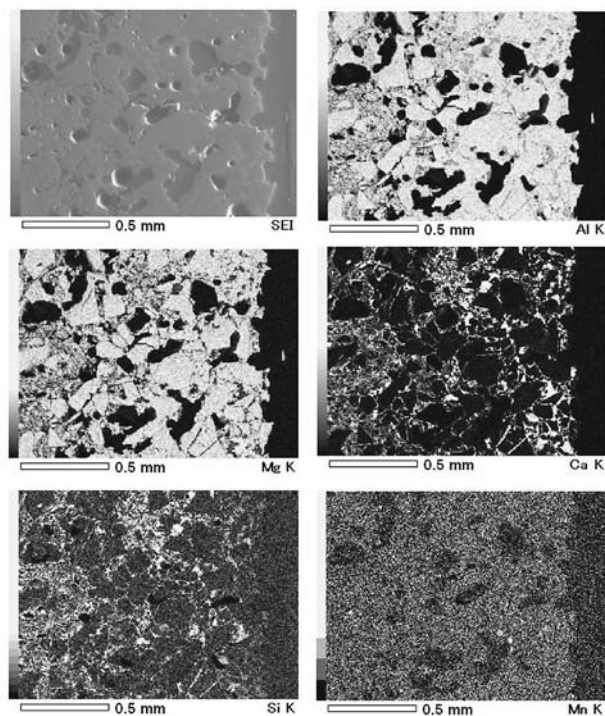


Fig. 12 Electron microprobe analysis of refractory E after experiment 7.

物Dの原料であるスピネルとシリカは炉内温度で反応し、スピネルと $\text{SiO}_2\text{-Al}_2\text{O}_3\text{-MgO}$ 系液相への組み合わせへと変化したと推定される (Fig. 13)。表層で検出されたMnOは実験1～4で見られたものと同様に液相中の SiO_2 成分に対して鋼中Mnの浸透が生じたものと考えられる。

liquid phase. MnO was detected in the liquid phase of the superficial area (Fig. 11). After experiment 7, refractory E consisted of spinel, periclase and $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ liquid phase but did not show a layered structure. Manganese was not detected in the liquid phase (Fig. 12).

It is presumed that the spinel and silica in refractory D reacted and transformed into the assemblage of spinel and $\text{SiO}_2\text{-MgO-Al}_2\text{O}_3$ liquid phase at 1560°C , based on the pseudo binary system $\text{MgAl}_2\text{O}_4\text{-SiO}_2$ (Fig. 13). The manganese detected in the superficial area of refractory D may result from the invasion into the SiO_2 component in the liquid phase by the same mechanism described above as reaction (1).

The pseudo binary system $\text{MgAl}_2\text{O}_4\text{-CaMgSiO}_4$ shows that a composite of spinel and monticellite, which is the approximation of refractory E, transforms into the assemblage of spinel, periclase and $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ liquid phase at 1560°C (Fig. 14). In fact, after

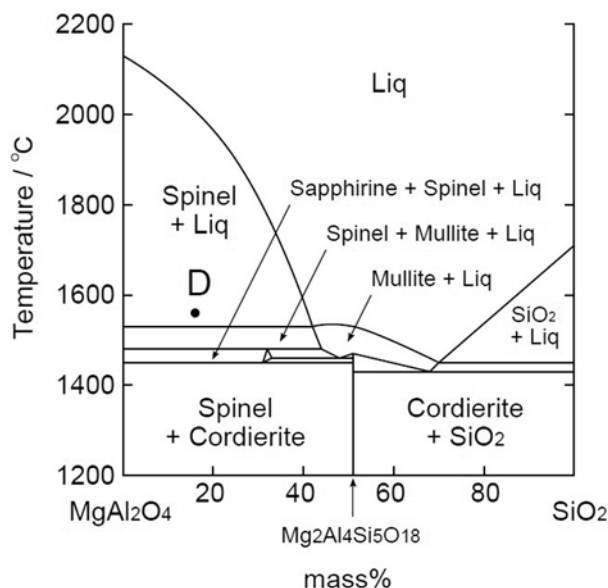


Fig. 13 Pseudo binary system $\text{MgAl}_2\text{O}_4\text{-SiO}_2^{(5)}$ showing composition of refractory D.

また、 $\text{MgAl}_2\text{O}_4\text{-CaMgSiO}_4$ 系擬似2成分系状態図からは、スピネルと耐火物Eのフラックス成分の近似組成物であるモンティセライト(CaMgSiO_4)の組み合わせは、炉内温度においてスピネル、ペリクレス、および $\text{CaO-Al}_2\text{O}_3\text{-MgO-SiO}_2$ 系液相の組み合わせへと変化することがわかる (Fig. 14)。実際、耐火物Eの溶鋼浸漬実験後の試料ではスピネル、ペリクレス、および $\text{CaO-Al}_2\text{O}_3\text{-MgO-SiO}_2$ 系液相が確認されており、耐火物Eにおける液相を伴う組織の形成は耐火物-溶鋼間の成分移動なしに受熱によってなされたことを意味する。

4. 溶鋼との濡れ性の評価

耐火物A～Eについて、溶鋼との濡れ性を簡便に評価する方法として次の実験を行った。まず、各耐火物試料を $30 \times 30 \times 50\text{mm}$ の寸法に切り出し、 $\phi 15 \times D40$ の穿孔を施すことでるつぼ形状とした試料を用意した。これに鋼試料30gを装入し、Ar雰囲気とした電気炉で $1560^\circ\text{C} \cdot 3$ 時間の条件で加熱し、鋼試料を溶融させた。加熱後の試料は自然冷却させた後に切断し、鋼試料のメニスカス形状から耐火物試料の溶鋼との濡れ性を評価した。耐火物A, Bに対しては前述の低炭素鋼を用い、耐

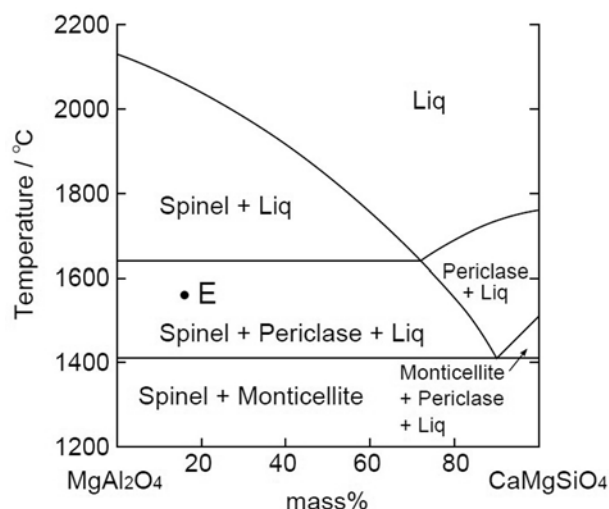


Fig. 14 Pseudo binary system $\text{MgAl}_2\text{O}_4\text{-CaMgSiO}_4^{(6)}$ showing approximate composition of refractory E.

the molten-steel dipping, refractory E contained spinel, periclase and $\text{CaO-MgO-Al}_2\text{O}_3\text{-SiO}_2$ liquid phase, suggesting that its liquid-bearing microstructure was basically created by heating without reacting with the molten steel.

4. Evaluation of Wettability to Molten Steel

We carried out the following crucible experiments to evaluate the wettability of refractories A to E to molten steel. Refractory samples with dimensions of $30 \times 30 \times 50\text{mm}$ with $\phi 15 \times D40\text{mm}$ bore for filling 30g of steel sample were heated at 1560°C for 3 hours in an argon atmosphere by means of an electric furnace. The samples were cooled naturally in the furnace and cut in half. The wettability was evaluated by observing the meniscus shape of the steel. Low-carbon steel was selected as the reactant for refractories A and B, and medium-carbon steel for refractories C, D and E.

Fig. 15 shows the cut surfaces of refractories A, B and conventional alumina carbon-free refractory after the experiment. The meniscus of the steel in the conventional alumina refractory had a convex shape while that in refractories A and

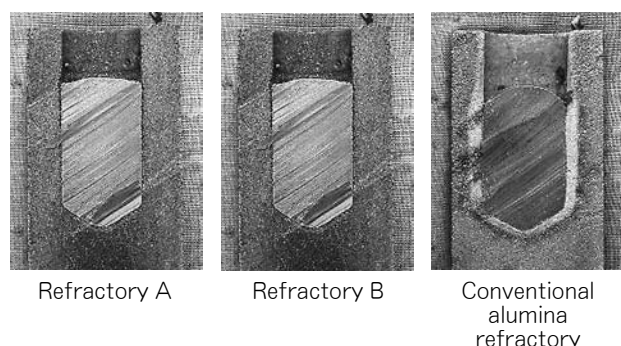


Fig. 15 Cut sections of refractories A, B and conventional alumina refractory after crucible experiment.

火物C, D, Eに対しては中炭素鋼を用いた。

Fig. 15に耐火物A, Bおよび従来のアルミナ質カーボンフリー耐火物について、実験後試料の切断面を示す。従来のアルミナ質耐火物はメニスカスが上に凸となっているのに対し、耐火物A, Bではほぼフラットなメニスカス形状であり、従来のアルミナ質耐火物より溶鋼と濡れやすかったことがわかる。また、Fig. 16には耐火物C, D, Eについて、実験後試料の切断面を示す。従来のスピネル単味のカーボンフリー耐火物である耐火物Cでは、メニスカス形状が上に凸となったのに対し、耐火物Dではほぼフラット、耐火物Eでは下に凸のメニスカス形状が得られ、スピネル質耐火物の中では耐火物Eがもっとも溶鋼と濡れやすかったことがわかる。

5. 実機テスト結果

耐火物Aおよび耐火物Eを内管材として用いた浸漬ノズルを低炭素鋼 castingの実機テストに供した。2種の開発品はともに従来品に比べ優れたアルミナ付着防止効果を示した (Figs. 17 and 18)。ただし、耐火物AをMn濃度の高い中炭素鋼の castingにおいて使用した場合、局部的に溶損することがあった。したがって、Mn濃度の高い鋼種の castingにはSiO₂含有量の低い耐火物Bもしくはスピネル質の耐火物Eを用いている。なお、スピネル質材料 (耐火物C, D, E)はアルミナ・シリカ質材料 (耐火物A, B)に比べ熱膨張率が高いため、予熱条件が良好な場合に適用している。

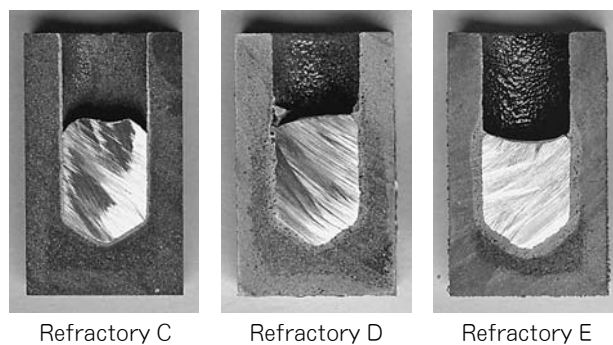


Fig. 16 Cut sections of refractories C, D and E after crucible experiment.

B had a flat surface, indicating that refractories A and B were more wettable to the molten steel than the conventional alumina refractory. Fig. 16 shows the cut surfaces of refractory C, D and E. The steel sample in refractory C, which was the conventional spinel carbon-free refractory, showed a convex meniscus. On the other hand, the steel sample in refractory D showed a flat surface and that in refractory E showed a concave meniscus. This indicates that refractory E was the most wettable to the molten steel among the spinel refractories.

5. Actual Caster Tests

SENs with inside liner of refractory A or refractory E were submitted to actual casting tests. Both of the newly developed products showed superior anti-alumina-clogging performance to the conventional products (Figs. 17 and 18). However, there were cases that the inner wall of refractory A was partially corroded by high-manganese medium-carbon steel casting. Therefore, refractory B or refractory E should be selected as the inside liner for high-manganese steel casting. Spinel refractories C, D and E can be applied on the condition that sufficient preheating is secured because thermal expansion rates of the spinel refractories were considerably higher than those of alumina-silica refractories A and B.

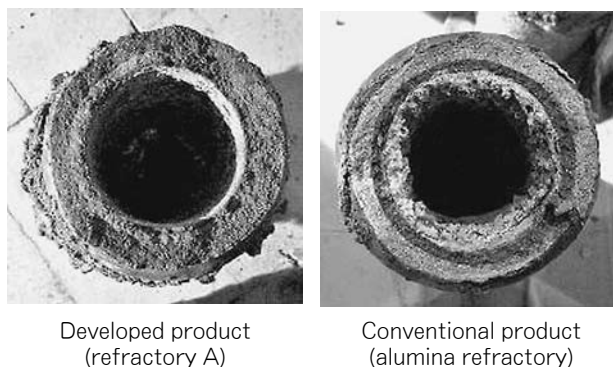


Fig. 17 Cut sections of SENs equipped with alumina inside liner after low-carbon steel casting.

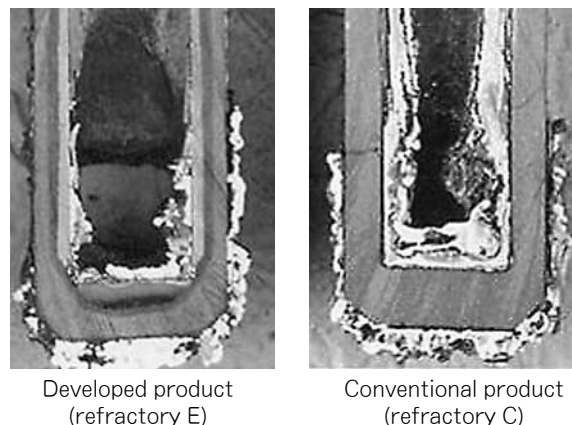


Fig. 18 Cut sections of SENs equipped with spinel inside liner after low-carbon steel casting.

6. 結論

鋼中Mnの浸透もしくは溶鋼からの受熱によって溶鋼と濡れやすい液相を伴う組織を形成させるカーボンフリーのアルミナ付着防止耐火物を開発した。適切な組成の耐火物を内管材として配材することで浸漬ノズル内管へのアルミナ付着を大幅に低減させることができる。

アルミナ・シリカ質耐火物の場合、鋼中Mnによる溶損を防止するため、適切な SiO_2 含有量の材料を選択することが必要となってくる。これに対し、フラックスとして MgO 、 CaO 、 SiO_2 を添加したスピネル質耐火物では耐火物－溶鋼間で成分移動がなく溶鋼からの受熱のみで液相を伴う組織を形成させることができる。後者の耐火物は熱膨張率が比較的高いため、十分に予熱される条件であれば溶鋼の組成によらず適用することができる。

6. Conclusions

We have developed new anti-alumina-clogging refractories that are carbon-free and form a wettable liquid surface by manganese invasion or heat absorption. Using an appropriate wettable refractory as an inside liner of a SEN can reduce alumina adhesion on the inner wall significantly.

But, as for alumina-silica refractories, selecting a refractory with an appropriate silica content is necessary to avoid corrosion by the manganese in molten steel. In contrast, spinel refractory containing MgO - CaO - SiO_2 flux develops liquid-bearing microstructure without component interaction between the refractory and the molten steel. This indicates that the latter refractory can be submitted regardless of the steel grade when preheating is sufficient.

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