

SHINAGAWA TECHNICAL REPORT

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Spinel-C Brick for Sidewall of Lower Vessel of
RH Degassers

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品川技報

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要 旨

RHやVODなどの減圧機能を有する二次精錬設備ではMgO-Cやマグクロなどの塩基性耐火物が広く使用されているが、RH下部槽においてMgO-Cは減圧、高温下でMgO-C反応を起こす。MgO-CはMgO-C反応にともなう組織脆化によって損傷が増大していると考えられる。種々検討した結果、耐MgO-C反応性に優れるSpinel-CはRH下部槽側壁用として優れた耐用を示す可能性が示唆された。

Abstract

Basic refractories such as MgO-C and magnesia-chrome are widely used in secondary refining facilities with a vacuum function such as RH and VOD. However, use of MgO-C results in MgO-C reaction under reduced pressure and high temperature in the lower vessel of RH degasser. Damage of MgO-C seems to be increased by the structural embrittlement associated with the MgO-C reaction. As a result of various investigations, it was indicated that Spinel-C, which provides superior resistance to MgO-C reaction, may have excellent durability for the lower vessel sidewall of RH degasser.

1. 緒言

今日、製鋼プロセスの中でもとりわけ二次精錬においては、溶鋼の脱ガスや脱炭を効率的に進めるためにRH-OTBやVODのような減圧機能と酸素吹き込み機能を備えた窯炉が導入されている。これらの内張りれんがとしては塩基性材質、特にマグクロれんがやMgO-Cれんがが用いられることがほとんどである。これらのうちMgO-Cれんがは高温、減圧下において、骨材のマグネシアと黒鉛の反応による

$$\text{MgO(s)} + \text{C(s)} \Rightarrow \text{Mg(g)} + \text{CO(g)} \cdots \cdots (1)$$
というMgO-C反応と呼ばれる反応を起こすこと

1. Introduction

At present, in secondary refining especially in the steelmaking process, many steelmakers have introduced refining facilities with vacuum and oxygen blowing functions such as RH-OTB and VOD in order to degas and decarburize molten steel efficiently. Basic material, especially MgO-C and magnesia-chrome bricks, are mostly used for the work lining of these facilities. Among these, it has been indicated that MgO-C bricks cause the reaction between their constituents, magnesia and graphite,

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が示唆されている¹⁻⁵⁾。本報告ではRH下部槽内部でのこのMgO-C反応に着目し、減圧下で精錬処理を行うRH下部槽側壁用としてMgOとCの反応を抑制しうるSpinel-C質れんがを検討した結果について報告する。

2. 稼働中のRH下部槽内部状態の推定

検討に先立ち、稼働中の下部槽内部の状態の推定を試みた。RH下部槽はその構造上、内部の状況を知る手段に乏しく、とりわけ処理中の状態についてはなかなか情報が得られない。須藤ら⁶⁾はRH下部槽内部で生成するスラグの組成を推定するために各所のRH下部槽で使用されたマグクロレンがの浸潤層の化学組成を調査した。Fig.1は須藤らのデータから下部槽側壁で使用されたマグクロレンがのデータをピックアップし、さらに他所RH下部槽での調査結果を加筆した結果である。浸潤したスラグの組成はRHで行われる処理内容で大きく異なり、ランスからの酸素吹き込みだけを行う場合はC/S=1.0前後のスラグが、脱硫を目的としてフラックス吹き込みを行う場合は高塩基度スラグが浸潤していることがわかる。

また、今日のRHの重要な役割の一つに合金投

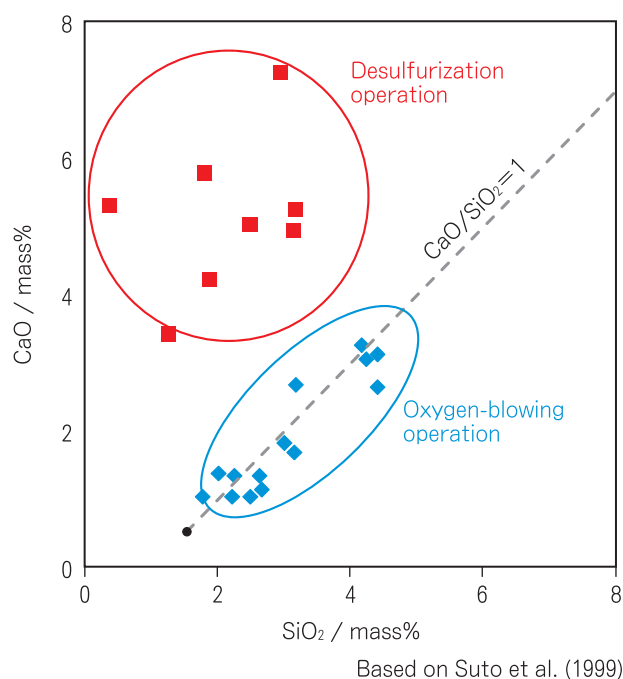
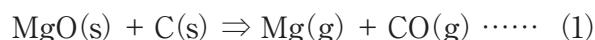


Fig.1 Chemical composition of penetration layer of MgO-Cr₂O₃ bricks after use in RH degasser.

called MgO-C reaction as expressed in equation (1), under high temperature and reduced pressure¹⁻⁵⁾.



In the investigations carried out for this report, we focused on the MgO-C reaction in the lower vessel of RH degasser. The investigation results of the Spinel-C brick strongly suggest that it has the possibility of suppressing the MgO-C reaction in the lower vessel sidewall of RH degassers which refine under reduced pressure.

2. Estimation of Internal Condition of RH Lower Vessel During Operation

Prior to this study, we tried to estimate the conditions inside the lower vessel during operation. It is difficult to obtain internal conditions of the RH lower vessel because of its structure, especially during treatment. Suto et al.⁶⁾ investigated the chemical composition of the penetration layer in magnesia-chrome bricks that had been used in various RH lower vessels in order to estimate the slag composition generated inside the lower vessel. Fig. 1 shows the data that Suto et al. gathered on magnesia-chrome bricks from the sidewall of the lower vessel, and the results from surveying other RH lower vessels has been added. Infiltrated slag compositions vary widely depending on the treatment carried out in the RH. It has been shown that when only oxygen blowing from the lance is carried out, the basicity of infiltrated slag is around 1. On the other hand, when flux injection is carried out for the purpose of desulfurization, the basicity of infiltrated slag is high.

The adjustment of steel composition by alloy addition and temperature compensation by burning metallic aluminum are important roles of the RH today. In most cases, the temperature of molten steel is around 1600℃ after RH

入による鋼の成分調整や投入したAlを燃焼させることによる温度補償があげられる。RH処理後の溶鋼温度は1600℃前後となるケースがほとんどであるが、OTB操業中の湯面付近は鋼や鋼中成分の酸化反応熱によりかなりの高温になることが示唆されている^{7,8)}。Fig.2は温度および P_{CO} 、 P_{Mg} と $MgO(s)$ 、 $C(s)$ の安定性の関係を示した図である²⁾。RH-OTBの処理条件を考慮すると、少なくとも1600℃以上と見積もられる湯面付近では $MgO-C$ 反応は不可避と考えられる。

3. 実機で確認された $MgO-C$ 反応とその影響について

前述したように $MgO-C$ 反応はれんがを構成するマグネシアとカーボンが相互に反応し散逸してしまう反応であり、必ず組織脆化をともなう

treatment. However, it is indicated that the temperature of the molten steel surface during OTB operation becomes considerably high due to the oxidation reaction heat of steel and components in steel^{7,8)}. Fig. 2 shows the relationship between temperature and stability of P_{CO} , P_{Mg} , $MgO(s)$ and $C(s)$ ²⁾. Considering the treatment conditions of RH-OTB, $MgO-C$ reaction is inevitable near the surface of the molten steel where temperatures are estimated to be at least 1600℃ or higher.

3. $MgO-C$ Reaction Observed in Actual Operation and Its Influence

As mentioned above, $MgO-C$ reaction is an interaction between the magnesia and carbon

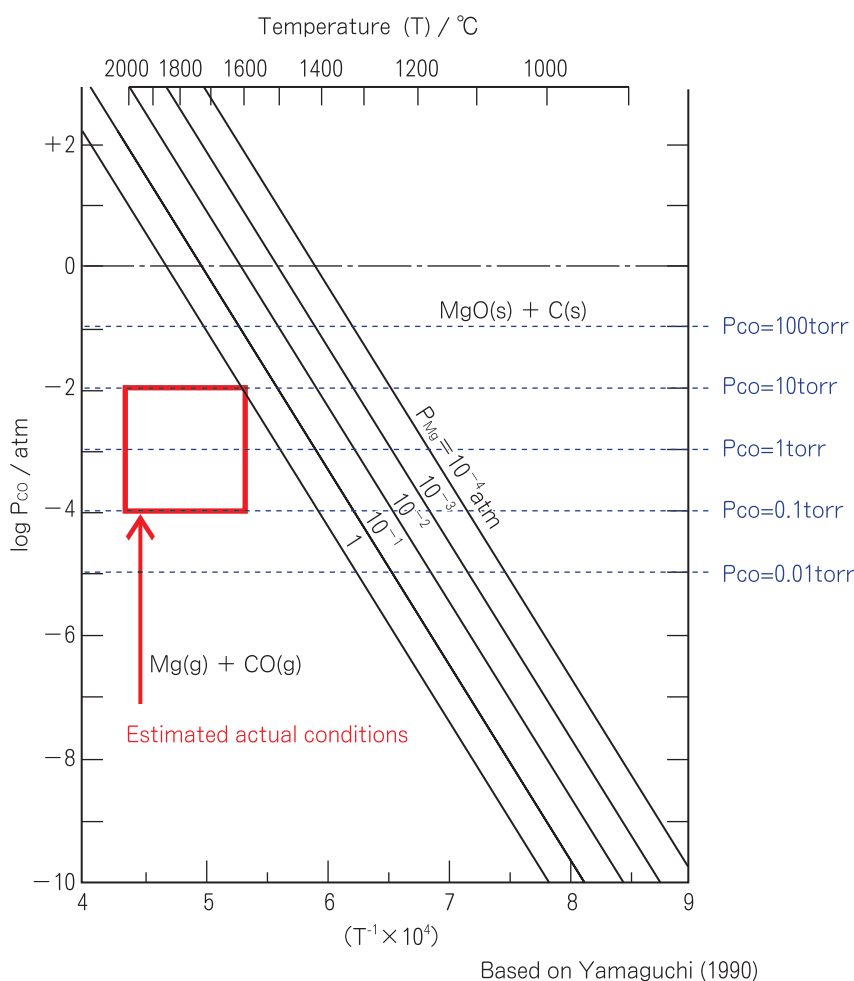


Fig. 2 Stability of $MgO(s)$ and $C(s)$ in relation to P_{Mg} , P_{CO} and temperature²⁾.

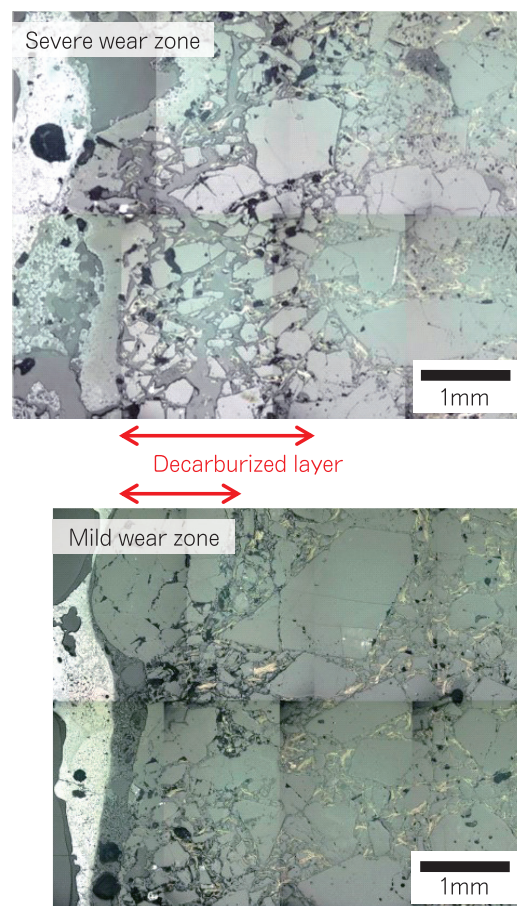
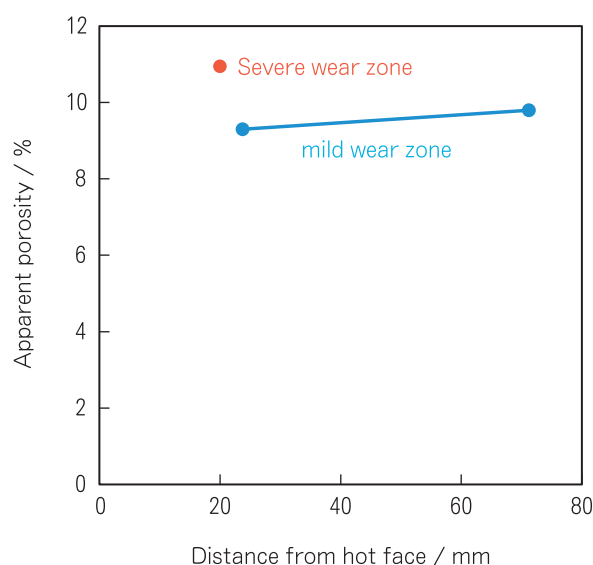


Fig. 3 Microstructures and physical properties of MgO-C bricks used in RH degasser.

はずである。そこで筆者らはRH下部槽におけるMgO-C反応の有無を確認するためにOTB操作を行うRH下部槽側壁で使用されたMgO-Cレンガを調査した。Fig.3に使用後MgO-Cレンガの物性と稼働面近傍の微組織写真を示す。損傷の小さい軽負荷部と激食部の使用後レンガの物性を比べると激食部のレンガがより高気孔率となっている。微組織観察では激食部から採取したレンガの稼働面により厚い脱炭層が形成されていることがわかった。この脱炭による組織脆化が損傷を大きくしている一因である可能性が高い。また、このような稼働面近傍の脱炭層ではMgOにも変化が見られ、MgO微粉が消失し、MgO粗粒の縁辺部も鋸刃状に損傷している。脱炭層における典型的なマグネシアの損傷例をFig.4に示す。

Fig.5に稼働面の脱炭層から採取したマグネシア粒子表面のEPMAによる観察結果を示す。背面側から採取したMgO粒子の表面が比較的平滑

constituting brick, and the gases which generated by MgO-C reaction are dispersed. Hence, MgO-C reaction always accompanies structure embrittlement. Therefore, the authors investigated MgO-C bricks used in the sidewalls of the RH-OTB lower vessel in order to confirm the presence or absence of MgO-C reaction. Fig.3 shows the physical properties of the MgO-C bricks after use and photographs of the microstructure near the hot face. In comparison with the physical properties between the mild and severe wear zone, the brick in the severe wear zone had a higher porosity. In microscopic observation, it was found that a thicker decarburized layer was formed near the hot face sampled from severe wear zone. There is a high possibility that structural embrittlement due to decarburization is one of factors contributing

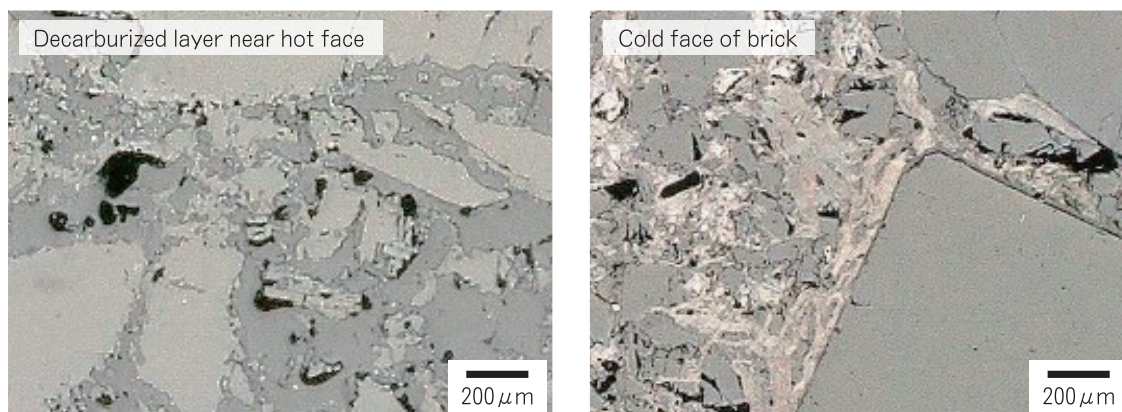


Fig. 4 Microstructures of MgO-C brick used in RH degasser.

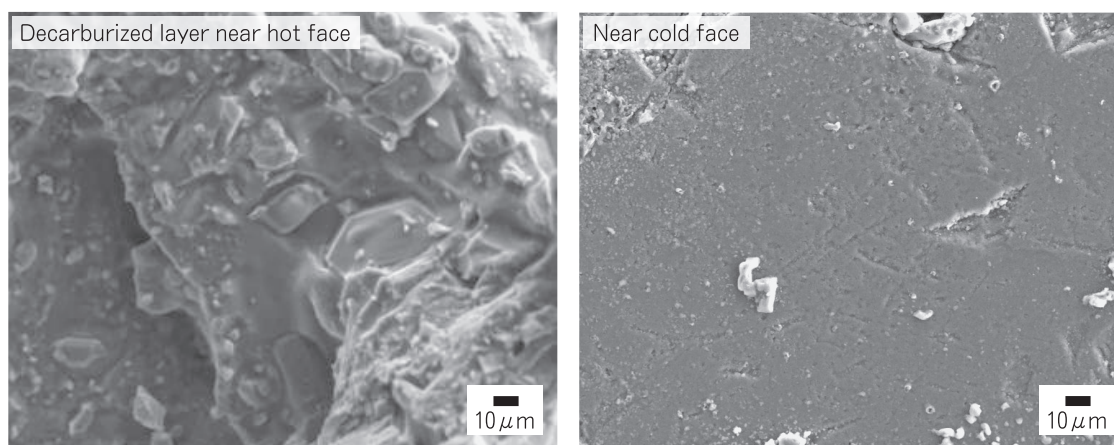


Fig. 5 Surface condition of MgO grains collected from MgO-C brick after use.

だったのに対し、脱炭層から採取した粒子は粒界に沿ってえぐられたような状態であった。実験室でMgO-C反応を起こしたMgO粒子の表面観察結果としては長舟らの報告⁹⁾があり、MgO-C反応を起こしたMgO粒子表面はこの使用後同様に粒界が凹状に損傷していることが確認されている。これらの結果から稼働面に形成された脱炭層はMgO-C反応の結果として生じたと理解される。

減圧、高温下でのMgO-C反応がMgO-Cレンガの損傷に与える寄与率はよくわかっていない。ただ、前述のようにRHのような減圧容器で使用される場合にはMgO-C反応を抑制することは難しく、MgOに変わる酸化物骨材を適用し、MgO-C反応を抑制しうる材料を開発・選定することで耐用を伸ばせる可能性があると考えた。

to the increase in damage. In the decarburized layer near the hot face, MgO grains also altered; MgO fine grains disappeared and the edges of MgO coarse grains were jagged. Typical MgO damage in decarburized layer is shown in Fig. 4.

Fig.5 shows electron probe microanalyzer images of the surface of the MgO particles taken from the decarburized layer near the hot face. While the surface of the MgO particles collected from the cold face was relatively flat and smooth, the particles collected from the decarburized layer were dented along the grain boundary. Nagafune et al.⁹⁾ observed the surface of the MgO particles where the MgO-C

Table 1 Composition of samples

	/ mass%		
	Sample A	Sample B	Sample C
Material	MgO-C (C=5 %)	Spinel-C (C=5 %)	Spinel-C (C=10 %)
Fused MgO	95	—	—
Fused Spinel	—	95	90
Flake graphite	5	5	10
Aluminum	α	α	α
Silicon	β	β	β

Table 2 Chemical composition of fused spinel

	/ mass%	
	Theoretical composition	
SiO ₂	0.37	
Al ₂ O ₃	73.38	
Fe ₂ O ₃	0.17	
MgO	25.10	
CaO	0.33	

4. 評価試験

4.1 供試試料

本検討においてはMgOに代わる酸化物骨材としてSpinelを選定した。供試試料はTable 1に示す配合を適量のバインダーで混練後、プレス機で一軸成形して作製した。Spinel骨材にはTable 2に示す理論組成の電融品を使用した。供試試料のカーボン量は一般的にRH下部槽で使用されるMgO-Cれんがと同水準の5%とし、MgO-C配合をサンプルA、Spinel-C配合をサンプルBとした。またSpinel-Cについては黒鉛を10%添加したサンプルCもあわせて評価した。

4.2 試験方法

4.1項で準備した試料に対し、侵食試験、および低P_{CO}雰囲気下での高温加熱試験を行った。また、耐熱スポーリング性を評価するために熱膨張率の測定、熱処理後の弾性率測定および溶銑浸漬スポーリング試験を行った。

侵食試験は高周波誘導炉法で行い、侵食材としてOTB操業下においてRH下部槽内で生ずるスラグを想定したC/S=1.0、Al₂O₃=30%、FeO=20%の

reaction occurred in the laboratory and it was confirmed that the surface of the MgO particles with the MgO-C reaction had dented grain boundaries as with bricks after use. From these results, it is considered that the decarburized layer formed near the hot face was generated as a result of the MgO-C reaction.

While the contribution ratio of MgO-C reaction to the damage of MgO-C brick under reduced pressure and high temperature is unclear, it is natural to assume that inhibition of the reaction improves the brick durability. As mentioned above, it is difficult to suppress the MgO-C reaction when MgO-C brick is used in the facilities with reduced pressure such as RH. However, we thought that the MgO-C reaction could be suppressed by developing and applying a different oxide aggregate as a substitute for MgO and durability might be improved.

4. Evaluation Test

4.1 Test samples

Spinel was selected as the oxide aggregate substitute for MgO in this study. Test samples were prepared by kneading the formulation shown in Table 1 with an appropriate amount of binder and pressed by uniaxial pressing machine. As for the spinel aggregate, fused material with the theoretical composition shown in Table 2 was used. We decided that the carbon content of the test samples should be 5%, the same level as general MgO-C brick used in the RH lower vessel. MgO-C and Spinel-C sample were denoted as A and B. For Spinel-C brick, a sample with a carbon content of 10%, called sample C, was also evaluated.

4.2 Test method

The samples prepared in section 4.1 were evaluated by corrosion test and high temperature heating test under a low P_{CO} atmosphere. And, in order to evaluate the thermal spalling

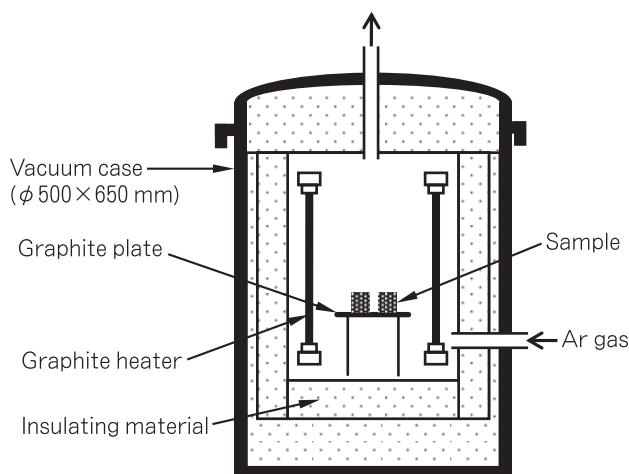


Fig. 6 Experimental apparatus of MgO-C reaction test.

合成スラグを用い、MgO-C反応を促進するために1800℃で1時間試験した。低 P_{CO} 雰囲気下での高温加熱試験は耐MgO-C反応性を評価するもので、Fig.6に示す雰囲気焼成炉を用いて実施した。試料は事前にブリーズ中で1000℃-3h熱処理した。試験はカーボン質のプレートの上に試料を置き10℃・min⁻¹で所定温度まで加熱し30分保持後に自然冷却した。試験温度は1600℃と1700℃の2水準である。また、試験中は2ℓ・min⁻¹のArガスで炉内を置換した。評価は加熱前後の重量変化率をMgO-C反応にともなう影響と見なした。熱膨張率はN₂雰囲気において7℃・min⁻¹で昇温する条件で測定した。溶銑浸漬スポーリング試験は1650℃の溶銑に1分浸漬後に15秒水冷する条件で行った。また試料はL230×H40×W40mmに加工したれんがを事前にブリーズ中で1000℃-3h、1500℃-10h熱処理し、試験に供した。また、L150×H35×W35mmに加工した試料を同条件で熱処理した後に動弾性率を測定した。

5. 試験結果

Fig.7に侵食試験結果を示す。比較品となるMgO-Cれんがに比べSpinel-Cれんがはいずれも耐食性に優れる結果であった。侵食試験後のサンプルAとサンプルBの稼働面付近の微組織写真をFig.8に示す。MgO-Cは組織に空隙が多く見ら

れ、resistance, the measurement of thermal expansion, the measurement of modulus of elasticity after heat treatment and spalling test by hot metal dipping were carried out.

A corrosion test was performed with a high-frequency induction furnace by using a synthetic corrosive agent with C/S = 1.0, Al₂O₃ = 30 %, FeO = 20 %. The chemical composition of the agent was assumed from the slag generated in a lower vessel under OTB operation. And in order to accelerate the MgO-C reaction, the temperature was held at 1800℃ for an hour. In order to evaluate MgO-C reaction resistance, high temperature heating test under low P_{CO} atmosphere was conducted by using an atmosphere baking furnace as shown in Fig. 6. The samples were pre-heated at 1000℃ for 3 hours in a coke breeze-filled sagger. And the samples were placed on a graphite board and heated at 10℃ per minute up to the predefined temperature, then maintained for 30 minutes followed by natural cooling. The test was conducted at 1700℃ and 1800℃. The atmosphere in the furnace was displaced with argon gas supplied at a rate of 2ℓ per minute during heating. The mass change rate during heating was evaluated and it was regarded as the effect of the MgO-C reaction. The thermal expansion rate was measured in an N₂ atmosphere under the condition of heating at 7℃ per minute. A spalling test by hot metal dipping was conducted in which the samples were immersed in molten 1650℃ pig iron for a minute followed by water cooling for 15 seconds. Specimens for the spalling test were prepared as follows, the samples were cut into L230×H40×W40 mm, then were pre-heated at 1000℃ for 3 hours or 1500℃ for 10 hours in coke breeze-filled sagger. In addition, the modulus of elasticity after heating under the same conditions were measured for the samples in the shape of L150×H35×W35 mm.

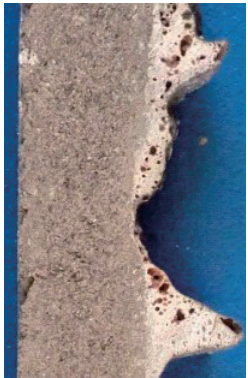
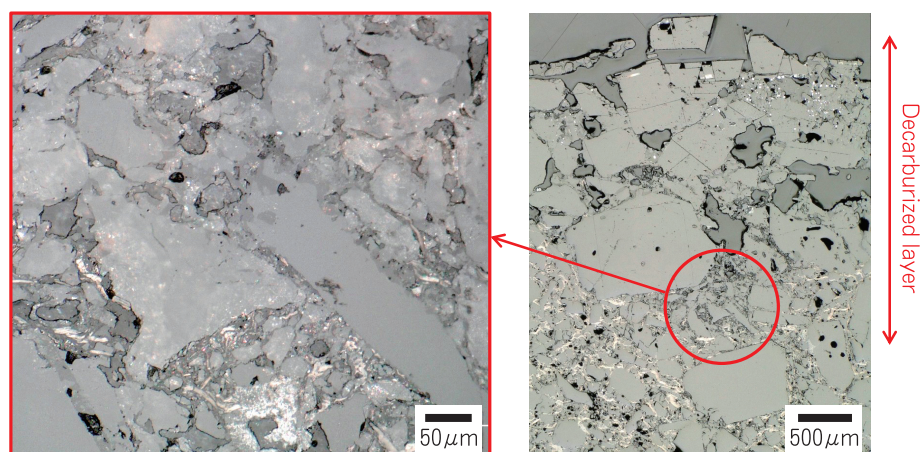
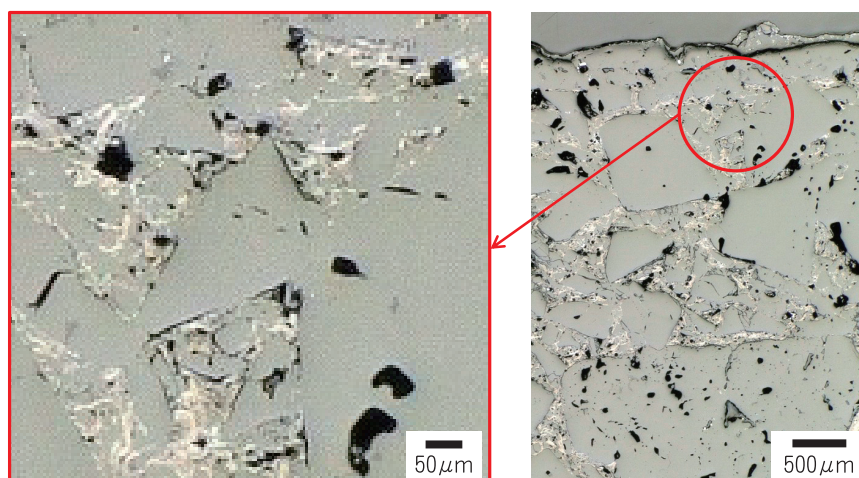
	Sample A	Sample B	Sample C
Material	MgO-C	Spinel-C	Spinel-C
Carbon content / mass%	5	5	10
Cut section			
Corrosion depth / mm	14.3	6.9	7.5

Fig. 7 Results of corrosion test.



(a) MgO-C brick - Sample A



(b) Spinel-C brick - Sample B

Fig. 8 Microstructures of bricks after corrosion test.

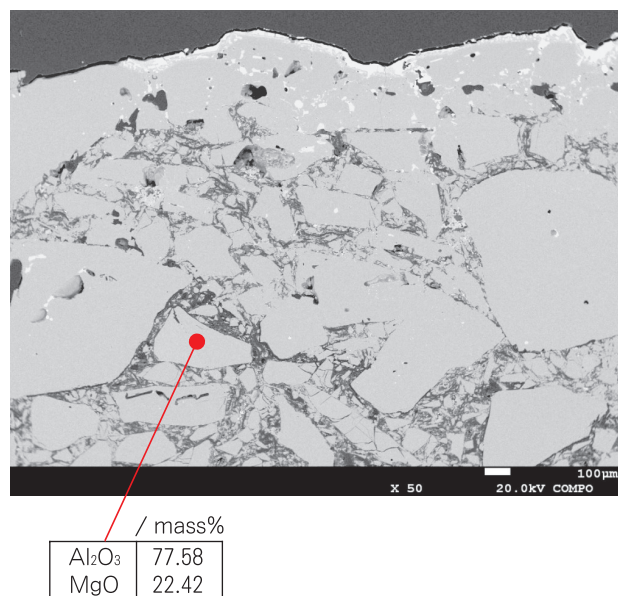


Fig. 9 Chemical analysis of spinel grain near the hot face by EDS.

れ、一部に脱炭層が形成されている。脱炭層を観察するとMgO粒子の縁辺が鋸刃状になっていることが確認された。サンプルBは組織に目立った緩みは見られないが、骨材間で焼結が進み、ネックが形成されている様子が見られた。Fig.9にサンプルBのEDSによる骨材組成の定量結果を示す。稼働面表層のSpinel粒は理論組成からアルミナリッチな組成に変化していることがわかる。Fig.10に熱膨張率の測定結果を示す。MgO-Cに比べSpinel-Cは1500℃で約40%膨張が小さい結果であった。Fig.11に熱スポーリング試験の結果を示す。事前熱処理温度が1000℃の場合、MgO-Cに比べSpinel-Cは亀裂軽微で良好な結果であった。しかし事前熱処理温度が1500℃の場合、サンプルAとサンプルBの比較ではサンプルBの方が亀裂多数で耐熱スポーリング性が劣る結果であったが、サンプルCは亀裂が軽微であり良好な結果であった。Fig.12に各材質をブリーズ中で1000℃-3hおよび1500℃-10h熱処理した後の弾性率を示す。1500℃熱処理後にサンプルBは明瞭に高弾性率化していることがわかる。一方、サンプルCは高弾性率化が軽微でサンプルAと同等の結果であった。Fig.13に耐MgO-C反応性試験の結果を示す。Spinel-CはMgO-Cより明らかに重量減少率が小

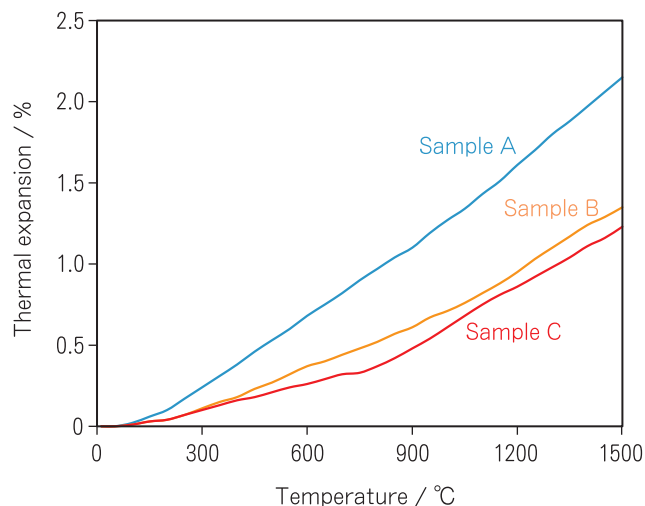


Fig. 10 Thermal expansion rate of each sample.

5. Test Result

Fig. 7 shows the results of the corrosion test. Compared to the MgO-C brick, all the Spinel-C samples were excellent in corrosion resistance. The photographs of the microstructure near the hot face of sample A and B after the corrosion test are shown in Fig. 8. Many voids can be observed in the structure of the MgO-C and a decarburized layer is formed in part of it. By observing of the decarburized layer, it was confirmed that the edges of MgO grains were changed to jagged shape. Although sample B had no significant voids or decarburized layer, sintering and neck growing were observed among the aggregates. Fig. 9 shows the chemical composition of an aggregate included in sample B analyzed by EDS quantitatively. The Spinel grains near the hot face turned out to be changing from the theoretical composition to an alumina-rich composition. The measurement results for the thermal expansion rate are shown in Fig. 10. The expansion of Spinel-C was about 40 % smaller than MgO-C at 1500 °C. Fig. 11 shows the results of the thermal spalling

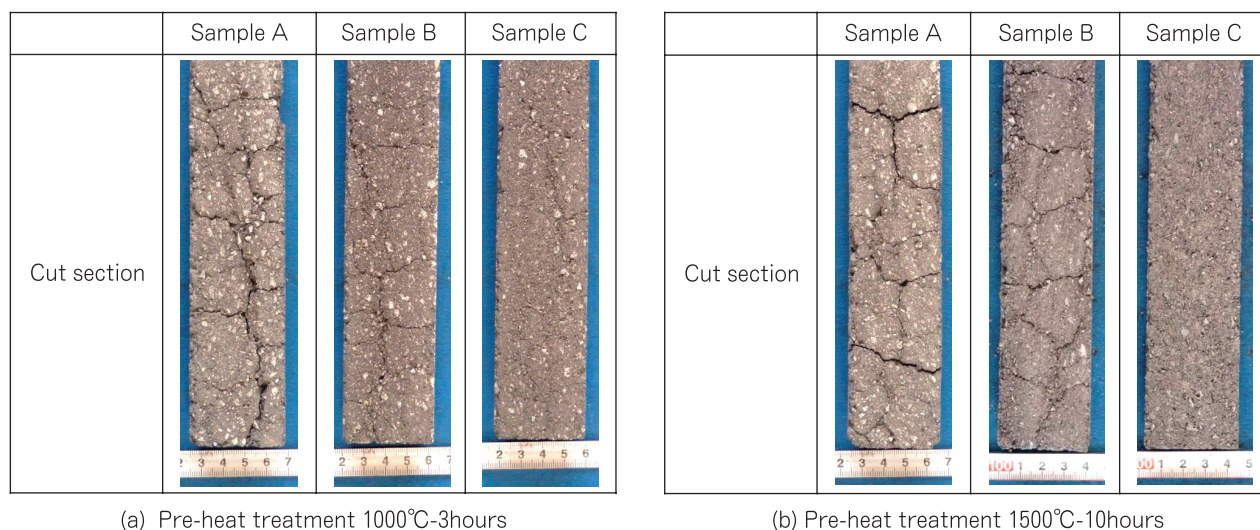


Fig. 11 Results of spalling test.

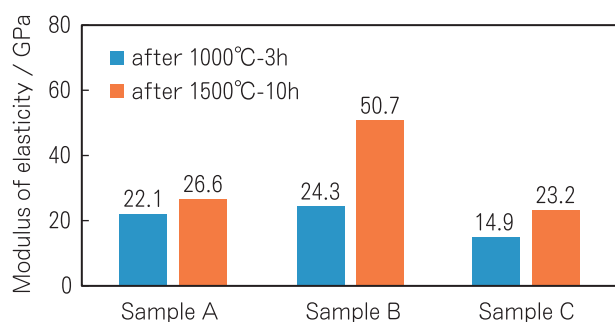


Fig. 12 Modulus of elasticity of each sample after heating.

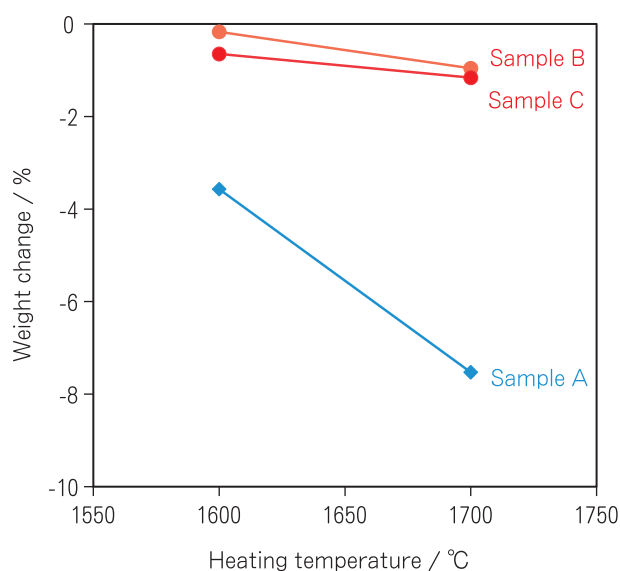


Fig. 13 Results of MgO-C reaction test.

さい結果であった。またSpinel-Cの重量減少率にC量の違いによる明瞭な差は見られなかった。

test. When the preheat treatment temperature was 1000 °C, all the Spinel-C samples had minor cracks and were better than MgO-C. However, when the preheat treatment temperature was 1500 °C, in comparison between sample A and B, sample B had many cracks and was poorer in thermal spalling resistance than sample A. On the other hand, the cracks of sample C were minor and sample C was evaluated as a good result. Fig.12 shows the modulus of elasticity of each material after 1000 °C for 3 hours and 1500 °C for 10 hours heating. The modulus of elasticity of sample B significantly increased after 1500 °C heating. While the modulus of elasticity of sample C after heating was low and the same level as that of sample A. Fig. 13 shows the results of the MgO-C reaction test. Spinel-C was obviously lower in mass reduction rate than MgO-C. There is no clear relationship between carbon content and mass reduction rate of Spinel-C.

6. Discussion

From the microstructural observation of the MgO-C brick after the corrosion test, it was confirmed that a decarburized layer was

6. 考察

侵食試験後のMgO-Cレンガの微組織を見ると、脱炭層が形成されておりかつMgOの縁辺に鋸刃状の損傷が見られる。これはRH下部槽側壁で使用されたMgO-Cの微組織と類似した特徴であり、今回の試験条件下ではMgO-C反応が起こっていたと考えられる。Spinel-Cでは明瞭な脱炭層の形成は見られないものの稼働面近傍のSpinel粒子がアルミナリッチな組成に変化している。これはSpinel-CでもMgO-C反応が起こっておりMgO成分が選択的に散逸したものと解釈される。耐MgO-C反応性試験の結果もこれと調和的な結果であり、Spinel-Cも加熱後にわずかながら重量を減ずる結果であった。ただしMgO-Cに比べて重量減少率はかなり小さい。重量変化が全てMgO-C反応によるMgOとCの揮発の結果と仮定し、試験前重量を W_0/g 、試験後重量を W/g 、MgOとCの密度を ρ_{MgO} 、 ρ_C とすると、この揮発によるMgOとCの体積変化量 $\Delta V_{MgO}/cm^3$ 、 $\Delta V_C/cm^3$ は次式で表される。

$$\Delta V_{MgO} = \frac{0.771(W - W_0)}{\rho_{MgO}} \dots\dots\dots (2)$$

$$\Delta V_C = \frac{0.229(W - W_0)}{\rho_C} \dots\dots\dots (3)$$

ここで、0.771および0.229はMgO-C反応におけるMgOとCの重量比である。式(2)、(3)を用いてMgO-C反応試験結果を整理するとFig.14のようになる。Spinel-Cに比べMgO-Cは体積減少が大きく、MgO-C反応によって著しく気孔率が増大していると思われる。このMgO-C反応に起因する気孔率変化の差は侵食試験においてSpinel-CがMgO-Cより優れる結果を示した一因であると思われる。

他方、Spinel-CはMgO-Cに比べてかなり低膨張率であるにもかかわらず、1500℃で事前熱処理した場合は耐熱スポーリング性に劣る傾向を示す。これは侵食試験後の微組織観察で見られたようにSpinel-Cは受熱時に骨材どうしの焼結が進みやすいためと考えられる。各材質の1500℃-10h熱処理

formed and the edges of MgO grains had jagged damage. This is a feature similar to the microstructure of MgO-C used at the sidewall of the RH lower vessel, hence it is considered that the MgO-C reaction occurred under this test condition. On the other hand, Spinel-C showed no clear decarburized layer formation, Spinel grains near the hot face changed to an alumina-rich composition. From these points, we have concluded that MgO-C reaction also occurs in Spinel-C and the MgO component is selectively reacted with and dispersed. The results of the MgO-C reaction resistance test were also consistent with this result, and Spinel-C also showed a slight mass loss after heating. However, the mass reduction rate of Spinel-C is considerably smaller than that of MgO-C. Assuming that all mass changes are the result of evaporation of MgO and C by MgO-C reaction, the volume change amounts of MgO and C by this evaporation, $\Delta V_{MgO}/cm^3$ and $\Delta V_C/cm^3$, are expressed by the following equations (2) and (3). Where W_0/g , W/g , ρ_{MgO} and ρ_C are the initial mass, mass after test, density of MgO and C, respectively.

$$\Delta V_{MgO} = \frac{0.771(W - W_0)}{\rho_{MgO}} \dots\dots\dots (2)$$

$$\Delta V_C = \frac{0.229(W - W_0)}{\rho_C} \dots\dots\dots (3)$$

0.771 and 0.229 are the mass ratios of MgO and C in the MgO-C reaction. The MgO-C reaction test results organized by using equations (2) and (3) are shown in Fig.14. Compared to Spinel-C, it is estimated that the volume reduction of MgO-C is larger and the porosity is markedly increased by the MgO-C reaction. The difference in porosity change caused by this MgO-C reaction seems to be one of the reasons that Spinel-C shows better results than MgO-C in the corrosion test.

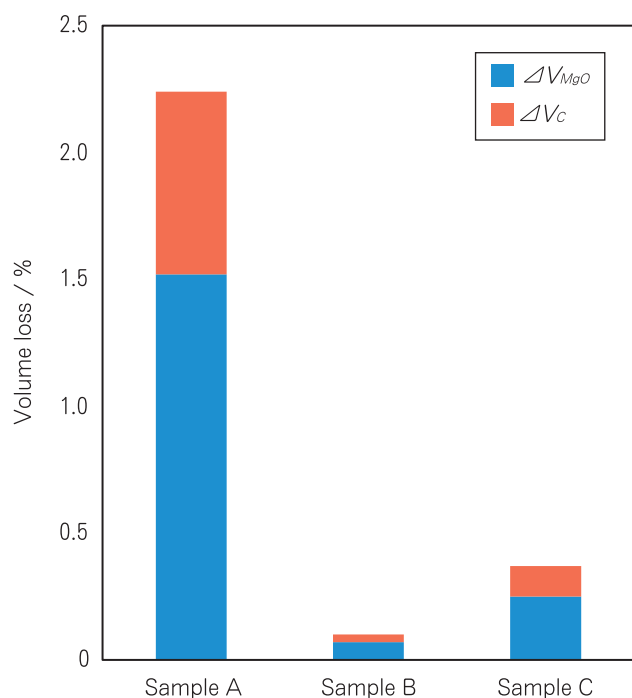


Fig. 14 Estimation of volume loss after MgO-C reaction test.

後の弾性率変化もそれを支持する傾向を示しており、サンプルBは明瞭に高弾性率化していることがわかる。一方、サンプルCの熱処理後弾性率はサンプルAと同等であった。サンプルBに比べ熱スポーリング試験においてサンプルCは耐熱スポーリング性に大きな改善が見られたが、これはC量増による高熱伝導率化効果に加え、マトリックスに分布した黒鉛がSpinel骨材どうしの接触を妨げることで焼結による高弾性率化が抑制されたためと考えられる。

RH下部槽側壁は減圧下で高温に曝される上、OTB操業下においては槽内で生成した低塩基度スラグの影響を受けるものと推定される。このような状況下においてはSpinel-CはMgO-Cより優れた耐食性を示すと思われる。また、耐熱スポーリング性についても骨材の焼結抑制を志向することでMgO-Cと同等以上の耐熱スポーリング性を付与することが可能である。これらの点からSpinel-Cはスラグに対する耐食性や耐MgO-C反応性の点でMgO-Cれんがを超える耐用が期待される。

Spinel-C tends to be inferior in thermal spalling resistance when preheated at 1500 °C despite its much lower thermal expansion than MgO-C. This is because the aggregates in the Spinel-C are easy to sinter during heating as this phenomenon was observed in the microstructure after the corrosion test. The change in the modulus of elasticity of each sample after heat treatment at 1500 °C for 10 hours is also a result of this phenomenon and sample B showed a markedly high modulus of elasticity. On the other hand, the modulus of elasticity of sample C was on the same level as that of sample A. In the thermal spalling test, sample C had significant improvement in thermal spalling resistance compared to sample B. We concluded that the thermal spalling resistance was improved not only due to the effect of increasing the thermal conductivity by the increase in the amount of C, but also due to suppressing the modulus of elasticity increase by sintering because the graphite distributed in the matrix prevents spinel aggregates contact.

It is estimated that the sidewall of the RH lower vessel is exposed to high temperature under reduced pressure and the sidewall bricks are affected by low basicity slag generated in the lower vessel under OTB operation. Under such circumstances, Spinel-C shows better corrosion resistance than MgO-C. As for the thermal spalling resistance of Spinel-C, it is also possible to increase thermal spalling resistance equal to or higher than that of MgO-C by suppressing sintering. In terms of MgO-C reactivity and corrosion resistance against low basicity slag, Spinel-C is expected to have higher durability than MgO-C.

7. Conclusion

We estimate that the sidewall of the RH lower vessel is exposed to high temperature

7. まとめ

RH下部槽側壁は減圧下で高温に曝される上、操業内容によっては槽内で生成した低塩基度スラグの影響を受けるものと推定される。これらの条件下ではMgO-CレンがMgO-C反応の影響から逃れることは難しい。代替材質について検討した結果、Spinel-CはRH下部槽側壁用として優れた耐用を示す可能性が示唆された。RH下部槽のさらなる高耐用化が期待できるため、今後さらなる検討・評価を進めていく所存である。

under reduced pressure and low basicity slag generated in the lower vessel during operation. Under these conditions, it is difficult to reduce the influence of the MgO-C reaction in MgO-C bricks. As a result of investigating substitute materials, it was indicated that Spinel-C may exhibit excellent durability as a sidewall of the RH lower vessel. We will continue to study and evaluate furthermore in order to improve the durability of the RH lower vessel.

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