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Isolation or corrosion of microporous alumina in contact with various $CaO\text{-}Al_2O_3\text{-}SiO_2$ slags

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ABSTRACT

Is the microporous structure able to protect lightweight alumina aggregates against corrosion of various molten slags? The effects of the slag compositions and structural parameters of alumina aggregates on their slag resistance behavior were investigated, and a dissolution rate model was proposed to describe the dissolution of alumina in the various molten slags inside the pores. Compared to the apparent porosity, the pore size has a crucial impact on dissolution of the lightweight alumina aggregates in the molten slags. A balance between the alumina dissolution rate and the solid phase precipitation rate should be achieved to form an isolation layer.

1. Introduction

A lightweight wear lining in industrial furnaces has attracted increased attention in the field of refractory materials as the lightweight wear lining could enhance the energy-saving efficiency. Further, the introduction of pores would lead to an improvement in the thermal spalling resistance of the wear lining refractories. Hence, several studies on lightweight aggregates and corresponding lightweight wear lining refractories have recently been carried out. Usually, lightweight aggregates are fabricated by direct foaming [1–3], decomposition of organic/inorganic matter [4–7], in situ pore forming [8–11], and superplastic foaming [12]. However, lightweight aggregates fabricated using the abovementioned methods typically exhibit high apparent porosities or large pore sizes, resulting in a poor slag resistance of the corresponding lightweight refractories. Hence, the key challenge in developing lightweight wear lining refractories lies in achieving guaranteed resistance against slag corrosion.

Huang et al. [13] investigated slag corrosion of lightweight aggregates using simulation methods and reported that the slag resistance of lightweight aggregates could be improved by reducing the pore size. Consequently, the lightweight microporous alumina aggregates with small pore sizes and low apparent porosities were fabricated by wet milling with our own effort and applied in alumina-magnesia castables [14]. The introduction of microporous alumina with small pores and low apparent porosities led to an improvement in the performances of the alumina-magnesia castables. Further, the slag resistance of these lightweight alumina-magnesia castables was also significantly higher than that of the conventional alumina-magnesia castables. Therefore, the trade-off between the low thermal conductivity and the guaranteed slag resistance could be solved using microporous lightweight refractory aggregates with a low apparent porosity and a small pore size.

Furthermore, a converter slag was selected to examine the slag resistance of the lightweight microporous and the tabular alumina and an intrinsic slag resistance mechanism of the microporous alumina was proposed [15]. A continuous isolation layer consisting of $CaAl_{12}O_{19}$ (CA_6) and $CaAl_4O_7$ (CA_2) was observed around the microporous alumina, which exhibited significantly higher slag resistance than that of the tabular alumina. The small pore size of the microporous alumina aggregate was assumed to lead to the formation of columnar crystals of CA_6 and CA_2, resulting in the slag resistance changes. However, it is still unclear that if the formation of the continuous isolation layer would always occur in-situ when reacting microporous alumina with different molten slags. In addition, the structural parameters such as the apparent porosity and the pore size of alumina are assumed to affect the slag resistance behavior. However, the intrinsic relationship between the structural parameters of the refractory material and the slag resistance

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Table 1
Physical properties of the various alumina aggregates.

Sample No.	Bulk density (g cm^{-3})	True density (g cm^{-3})	Apparent porosity (%)	Closed porosity (%)	Median pore diameter (μm)
A1	3.36	3.92	4.1	10.1	~0.5
A2	3.39	3.94	7.2	7.8	~0.5
A3	3.16	3.92	10.2	9.2	~1
A4	3.63	3.94	2.8	5.0	~1

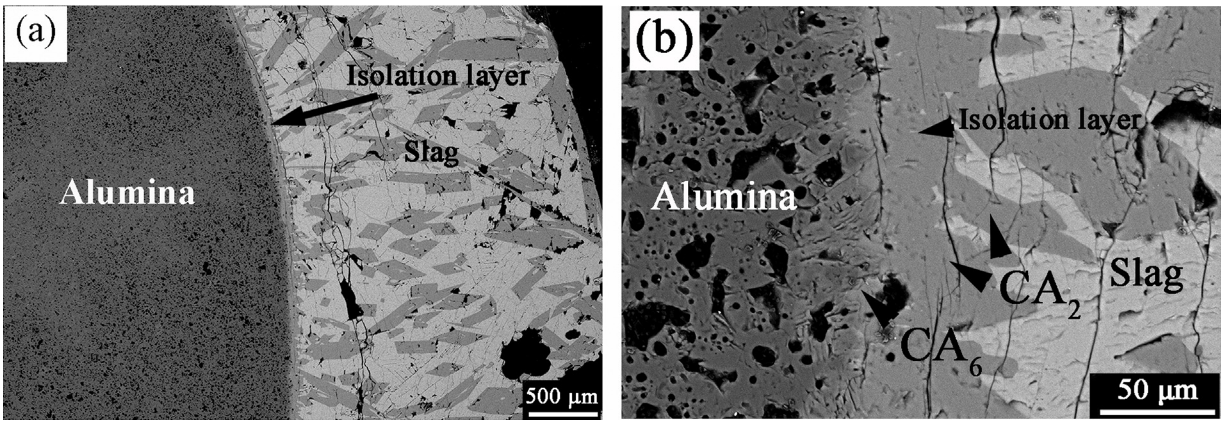

Fig. 1. SEM images of the reaction interface between slag S1 and alumina A1.

is still not understood, which would have important implications in the development of new lightweight wear lining refractories.

In the present study, the slag corrosion tests of various alumina aggregates having different structural parameters in various molten slags were performed to investigate the effects of the slag compositions and structural parameters of alumina aggregates on their slag resistance:

(i) Firstly, a dissolution rate model was proposed to describe the dissolution of alumina in the various molten slags inside the pores with different structural parameters.
(ii) Then, the slag resistance behavior of microporous alumina aggregates in contact with various slags were discussed.

2. Experimental

Alumina aggregates with diameters of approximately 12 mm were used as raw materials for performing the slag corrosion tests.

Various lime-alumina-silica slags were synthesized from powders (analytical purity) of CaO (Tianjin Bodi Chemical Co., Ltd., China), Al_2O_3 (Sinopharm Chemical Reagent Co., Ltd., China), and SiO_2 (Tianjin Bodi Chemical Co., Ltd., China). The powders were mixed with a planetary ball mill (QM-BP, Nanjing Nanda Instrument Plant, China) for 30 min followed by melting at 1550 °C for 3 h and quenching to room temperature. The solidified slag was milled to powders with particle size smaller than 0.088 mm.

Alumina aggregates were added to an alumina crucible with the powdered slag. The slag to alumina weight ratio was approximately 3:1. The alumina crucibles were heated to 1600 °C in an electric furnace at 5 °C/min and were held at that temperature for 3 h. The microporous alumina aggregates are mainly applied in the wear lining of metallurgical furnaces. During the process of steelmaking, the furnaces are operated intermittently, that means they are cooled naturally to room temperature after each heat. Therefore, the electric furnace was then switched off and the samples were allowed to cool naturally to room temperature. After corrosion testing, the samples were separated perpendicular to the alumina/slag interface and were embedded and fixed in a cold-setting resin. Then,

Table 2
Compositions of various synthetic slags.

Slag No.	CaO (wt%)	Al_2O_3 (wt%)	SiO_2 (wt%)
S1	60	20	20
S2	48	36	16
S3	55	42	3
S4	72	4	24

standard grinding and polishing techniques were employed and the samples were coated with gold. The microstructure and the composition of the samples were examined using scanning electron microscopy (SEM, JSM-6610, Jeol, Tokyo, Japan) and X-ray energy dispersive spectroscopy (EDX, Quantax, Bruker, Berlin, Germany).

Four types of alumina aggregates and synthetic slags were used for this study. The bulk density and apparent porosity of corundum aggregates were determined by the Archimedes' Principle with water as the medium. True density was measured using automatic true density analyzer (ACCUPYC 1330, Micromeritrics Instrument Corporation, Norcross, USA). The pore-size distribution and average pore diameter of different alumina aggregates were measured by mercury intrusion porosimetry measurements (AutoPore IV 9500, Micromeritrics Instrument Corporation, Norcross, USA). Physical properties of the alumina aggregates used in this study are listed in Table 1, and the slag compositions are shown in Table 2. Alumina A4 is a tabular alumina supplied by Jiangsu Jingxin High-temperature Materials Co., Ltd., Jiangsu, China. Alumina A1–A3 are microporous alumina aggregates produced in the laboratory using previously reported procedures [15–17]. The alumina aggregates were ground by a jaw crusher (PEX–60 × 100, Zhejiang Fute Machinery Co., Ltd., Zhejiang, China.) to obtain aggregates with diameters of approximately 12 mm. In order to guarantee the accuracy of the experimental results, two samples of each type were tested. Since a continuous isolation layer was observed when alumina A1 was dissolved in a converter slag as we have previously reported [15], the slag corrosion tests of alumina A1 in various synthetic slags were performed to investigate the slag resistance behavior of microporous alumina in contact with various molten slags. Further, slag corrosion tests of various alumina aggregates in slag S1 were per-