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Possible improvements of alumina–magnesia castable by lightweight microporous aggregates

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Abstract

This paper focuses on the properties of lightweight alumina–magnesia castable prepared with homemade microporous corundum aggregate, as well as on the investigation of the effects due to the introduction of microporous corundum aggregate on alumina–magnesia castable. The results showed that, in comparison to common alumina–magnesia castable, due to the small pore size and low apparent porosity of microporous corundum aggregate, its introduction leads to an improvement in volume stability, strength, heat insulation and thermal shock resistance of alumina–magnesia castable. The slag resistance of lightweight alumina–magnesia castable is significantly better than that of common alumina–magnesia castable. Microstructure and energy dispersive analyses show that the formation of conically crystallizing CA_2 and CA_6 is the main reason for the difference in slag resistance. The conical crystals, interlaced and distributed around the aggregate, prevent the sample from further corrosion and penetration of the slag. In addition, since the CaO content of the slag is largely absorbed by the refractory, the viscosity of slag increases, and a solidified layer is formed and adhered on the hot face of sample, thus further deterring the penetration of the slag.

Keywords: Lightweight alumina–magnesia castable; Microporous corundum; Properties; Slag resistance

1. Introduction

In order to reduce the energy consumption, heat insulation material has been rapidly developed. Heat insulation material closest to the working lining has the better heat insulation function. Therefore, the exploitation of lightweight wear lining refractories has gradually become an important research hotspot of the refractory industry [1].

Several studies on lightweight aggregate and corresponding lightweight wear lining refractories have been carried out in recent years. Among which, there have been quite a few reported methods for the preparation of lightweight aggregate, such as decomposition of organic matter [2–6], pore-forming in situ technique [7–10] and decomposition of hydrated/carbonated inorganic compounds [11–13]. Lyckfeldt and Ferreira [2] prepared porous alumina with starch as both binder and pore former; Li et al. [7] used kaolinite as pore-forming agents to prepare porous corundum–mullite ceramics; Salomãoa et al. [11] fabricated porous alumina-spinel ceramics by decomposing an aluminum–magnesium hydro-carbonate. The use of this kind of lightweight aggregate has positive effect on the heat-shielding performance and thermal shock resistance of wear lining refractories. However, due to the high apparent porosity and large pore size of the prepared lightweight aggregates, the refractories were seriously corroded. The key challenge in the development of lightweight wear lining refractories lies in achieving guaranteed resistance against slag corrosion.

Based on the above background, the influence of pore size on slag penetration into the aggregate was investigated with mathematical simulation methods by Huang et al. [14], who pointed out

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that miniaturization of pore size is expected to improve the slag resistance of lightweight wear lining refractories. In addition, other studies [15,16] showed that the slag resistance of refractories can be improved by decreasing apparent porosity of lightweight aggregate. However, due to the difficulties in preparation of lightweight aggregate with low apparent porosity and small pore size, the properties of lightweight alumina–magnesia castable prepared with such aggregate, especially the slag resistance performance, have not yet been investigated.

Hence, this paper focuses on the properties of lightweight alumina–magnesia castable prepared with a homemade microporous corundum aggregate, with apparent porosity and median pore diameter of 4.1% and 0.49 μm, respectively. In particular, the comparison with common alumina–magnesia castable is presented and the effects due to the introduction of microporous corundum aggregate on alumina–magnesia castable are investigated.

2. Experimental

In this study, a kind of microporous corundum had been prepared by decomposition of organic matter with α-Al_2O_3 micro-powder as main raw material. The homemade microporous corundum and tabular corundum were chosen as the aggregates. Corundum aggregate, fused magnesia (<0.088 mm), white corundum powder (<0.074 mm), α-Al_2O_3 micro-powder and Al_2O_3–SiO_2 gel powder were weighed and mixed. Subsequently, alumina–magnesia castables with different kinds of corundum aggregates were prepared by casting as 40 × 40 × 160 mm, 70 × 70 × 70 mm (aperture is ∅(20–30) × 40 mm) and D180 mm × H20 mm samples. After curing at room temperature for 24 h, the samples were dried at 110 °C for 24 h.

Samples with a size of 40 × 40 × 160 mm^3were heated at 1000 and 1500 °C, respectively, for 3 h. The linear change rate, apparent porosity, bulk density, modulus of rupture and crushing strength of the samples were measured according to ISO 2477:2005, 5017:1998, 5014:1997 and 8895:2004, respectively. Water quenching tests at 1100 °C under air atmosphere were conducted to evaluate the thermal shock resistance of the samples. Samples with a size of D180 × H20 mm^2 were heated at 1500 °C for 3 h, and the thermal conductivity of samples at 350, 600 and 800 °C were tested according to ISO 8301:1991.

The slag resistance experiment on samples was carried out adopting the static crucible method. A certain amount of converter slag (20 g) was weighed and put in crucible. The main chemical composition of the slag is listed in Table 1. After heated at 1600 °C for 3 h, samples were cut open along the center line to observe the status of the erosion.

Table 1
Main chemical constituents of the slag composition (wt%).

SiO_2	Al_2O_3	CaO	MgO	MnO	TiO_2	Fe_2O_3	CaF_2
10.52	2.28	43.86	8.65	2.23	0.54	26.1	3.87

The pore-size distribution and average pore-diameter of different corundum aggregates were measured by mercury intrusion porosimetry measurement (AutoPore IV 9500, Micromeritrics Instrument Corporation). The microstructures of samples were observed by scanning electron microscopy (Philips XL30).

3. Characterizations of different corundum aggregates

3.1. Material properties

The material properties of different corundum aggregates are shown in Table 2. It can be seen that, in comparison to tabular corundum, the bulk density of microporous corundum significantly reduces. Furthermore, despite a slight increase in apparent porosity, the closed porosity of microporous corundum is twice as much as that of tabular corundum.

3.2. Pore size distribution and microstructure

As shown in Fig. 1, the pore size distribution of microporous corundum exhibits a single and relatively centered peak; the vast majority of pore sizes are below 1 μm. On the other hand, the range in pore size distribution for tabular corundum is larger, which indicates the existence of many pores with different sizes, mainly of 1–10 μm. In addition, the median pore diameters of microporous corundum and tabular corundum are 0.49 and 0.95 μm, respectively.

As shown in Fig. 2, the amount of pores in microporous corundum is obviously larger than that in tabular corundum. Moreover, in the former, the majority of the pores are circular, while, in the latter, the shape of pores is irregular.

Thus, in brief, compared to tabular corundum, microporous corundum contains more pores of significantly smaller size.

4. Results and discussion

4.1. Properties of sintered materials

The properties of common alumina–magnesia castable (prepared with tabular corundum) and of lightweight alumina–magnesia castable (prepared with microporous corundum) are shown in Table 3. It can be seen that the introduction of lightweight microporous corundum aggregate causes an improvement of volume

Table 2
Material properties of different corundum aggregates.

Corundum aggregate	Bulk density (g cm^{-3})	True density (g cm^{-3})	Apparent porosity (%)	Closed porosity (%)
Tabular corundum	3.63	3.94	2.8	5.0
Microporous corundum	3.36	3.92	4.1	10.1