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RESEARCH PAPER

Morphological and interfacial characterization of molten slags on the refractory surface

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Abstract: The interfacial properties between three types of coal slags (A, J1 and J2 with various base/acid ratios) and two refractory materials (mullite and corundum) were studied. The results indicate that the slag A has good wettability on both of refractory materials, while the slags J1/J2 have experienced the process from incomplete wetting to whole wetting. The contact angles decrease with increasing interface width of slag and refractory materials (S-R). The contact angles of J1 on mullite decrease with increasing inclination angles from deformation temperature to 1520°C, but significantly increase when the inclination angle is 20°. The SEM-EDS analysis show that the quantity of slag A penetrating into the refractory material is more than that of J1 slags because of interfacial reaction. The infusion and acid-base reactions are the key factors for the refractory corrosion.

Key words: refractory material; slag; erosion; interface

The corrosiveness of slag to furnace wall is a key factor affecting the stability and cost of coal gasification[1–4]. In the process of gasification and combustion, minerals and inorganic matters from coal are melting and part of the molten slags adhere to and react with the refractory of wall liner, causing the erosion and spalling of the refractory.

There are several physical and chemical processes during the corrosion of slags to refractory: the interfacial wettability of slags on refractory surface; the permeation of slags in refractory; and the chemical reaction of slags with refractory[5]. The corrosions have a great correlation with slag compositions and refractory types[6–8].

The ash fusion temperature (AFT), compositions and ratio of Acid/Base are the key factors for corrosion[5]; in addition, the compositions and compactness of refractory have an important effect on the reactions among minerals and the penetration of slags[9]. After melting, some of the slags penetrate into the refractory through the edges or micro pores of particles on the refractory surface. Meanwhile, the dissociative alumina particulates enter into slag, resulting in the dissolution of some small particles in the slag to prompt the spalling of the refractory[10]. Slags, which do not penetrate into refractory, distribute at the top of the interface of slags with refractory through aggregation and solidification. In this process, the iron-containing minerals in the slags are agglomerated or react with the minerals on the refractory surface to deposit on the surface layer of the interface, influencing the surface tension and viscosity[11,12].

The wettability of molten slag particles on refractory surface directly influences the fouling and corrosion of refractory. With good wettability, the molten ash particles adhere strongly to the refectory surface which are not easy to spalling, and thus are easy to penetrate into the interior of the refractory. In this condition, the dissociate alumina in refractory would be transformed into liquid phase and destroy the material structure, causing the flaking of refractory, which has adverse effect on the stability and security of the gasification process[2,10].

The critical factors affecting wettability are contact angle and S-R interface width (Figure 1). According to Yang's equation, the angle of 90° is the boundary point for evaluating a substance wetting or not. Wettability plays a key role in corrosion of slags on refractory. The change of S-R interface width reflects the variation of surface wettability.

The morphological change of slags is an indicator that synthetically reflects the effect of penetration, wettability and chemical reaction on refractory surface. The corrosion mechanism of different slags on refractory surface has great theoretical and practical significances. It was investigated by contact angle, S-R interface width and morphological change of slag in this study. At higher temperature, slags on inclined refractory surface are affected by both gravity and interface

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adhesive forces, which has an important influence on the morphological change of slag and interface properties. However, few related researches were reported.

To analyze the corrosion mechanism of slags on the refractory of gasifiers, the interfacial properties of three types of coal slags on two kind of refractory materials (mullite and corundum) were investigated, and the adhesion and corrosion mechanism of slags on two kind of refractory were studied.

1 Experimental

The refractories used in this study were corundum and mullite. The corresponding fusion temperatures of them were 2050°C and 1850°C with porosity of 15% and 23%, respectively. The alumina fraction was more than 99% in corundum and 71%–78% (by weight) in mullite.

Based on the Chinese standard GB/T212—2008, the ash samples employed in this study were prepared. The size of as-prepared samples particles was less than 0.074 mm and these ash samples were analyzed by X-ray fluorescence diffraction (XRF), as shown in Table 1. The as-prepared ashes were made into cylindrical ash columns with 5 mm in diameter, 10 mm in height and 0.20 g in mass. The ash model cylinder on the smooth refractory (25 mm long, 25 mm wide and 5 mm thick) was put into the tube furnace. The inclination angles of refractory in this experiment were 0°, 5°, 10°, 15°, and 20°, respectively. The tube furnace was heated to the ash fusion temperature at air atmosphere. The heating rate was 15°C/min before 900°C, and 5°C/min after 900°C. The morphological change of the ash columns at varying temperatures was recorded by a CCD camera.

2 Results and discussion

2.1 Wettability of molten slag on the refractory surface

Table 2 shows the morphological change of slags on the mullite surface. Sample A has a good wettability on mullite surface in the whole range of molten and the contact angles decrease from 90° with increasing temperature, while the slags J1/J2 have experienced the process from incomplete wetting to whole wetting. The contact angle increases firstly and then decreases with increasing temperature. Likewise, such molten slags demonstrate similar wettability on the corundum surface.

The acid-base reaction in mineral is the principle chemical reaction in corrosion of molten slag to refractory. In terms of classification, corundum and mullite are neutral refractory. According to coal ash compositions, SiO_2 and Al_2O_3 belong to acid components, which react easily with basic matters in coal ash at high temperatures. The higher content of basic components in coal ash, the more easy reaction will be occurring with acidic fraction. From Table 1, the value of Base/Acid of A J1 and J2 are 0.79, 0.14, and 0.19, respectively.

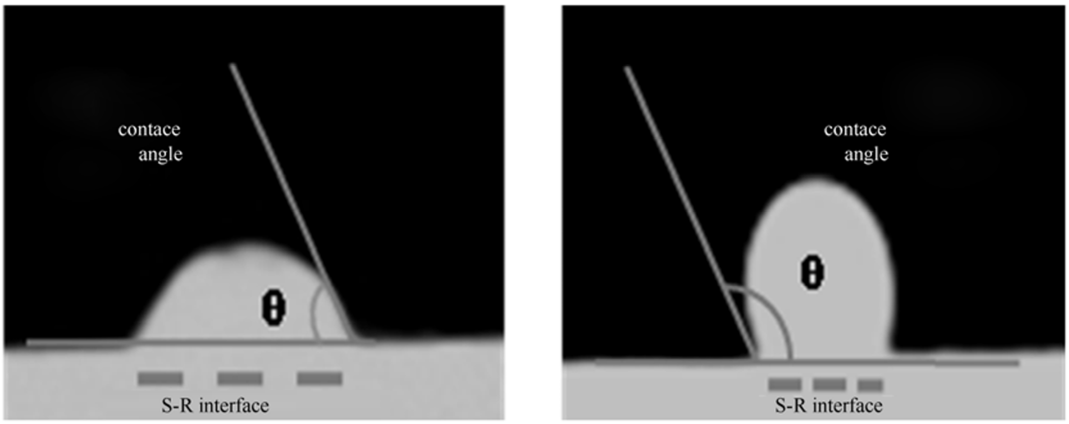

Fig. 1 Diagram of contact angle and S-R interface width

Table 1 Analysis of XRF about coal ashes

Sample	Composition *w* /%										B/A*	Si/ Al
	SiO_2	Al_2O_3	CaO	Fe_2O_3	SO_3	TiO_2	K_2O	Na_2O	P_2O_5	MgO		
A	33.30	17.60	16.56	16.80	6.27	1.26	1.10	ND	ND	6.64	0.79	1.89
J1	52.11	32.13	5.94	3.02	2.03	1.31	1.16	1.09	0.45	0.42	0.14	1.63
J2	46.83	32.84	6.21	7.71	3.32	1.46	0.85	0.24	0.04	0.29	0.19	1.45

*: B/A is the ratio of base to acid, B/A=($CaO+Fe_2O_3+MgO+Na_2O+K_2O$)/($SiO_2+Al_2O_3+TiO_2$)