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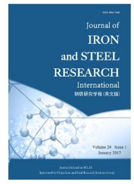

Interaction mechanism between coal combustion products and coke in raceway of blast furnaces

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ABSTRACT

The interaction mechanism between the combustion products of pulverized coal injected and coke in the raceway of blast furnace was studied through thermodynamic calculation and experiments. The results indicated that additives significantly affected the melting property of coal ash in high temperature zone. Although the unburnt char, raw coal ash, and catalyzed coal ash failed to wet the coke surface, the wettability of the catalyzed coal ash on the coke was greater than that of the raw coal ash. Since the unburnt char had weak reaction with the coke surface, it showed little influence on the surface morphology of the coke. The interaction between the raw coal ash and the coke gave rise to the increase in the pore size on the coke surface. However, the raw coal ash only affected the coke surface and the entrances of the pores owing to its poor fluidity. After being melted, the catalyzed coal ash was expected to immerge into the inside part of the coke and then react with the coke, resulting in an expansion and increase of coke cavities. The raw coal ash and the unburnt char reduced the coke reactivity, while the catalyzed coal ash improved the coke reactivity. Thereinto, the coal ash containing Fe_2O_3 exhibited a larger influence on the reactivity than that containing CaO.

1. Introduction

Pulverized coal injection (PCI) is a primary technology for optimizing fuels constitution and reducing fuels consumption in blast furnace (BF). This technology not only saves cost for ironmaking process, but reduces environmental pollution from coke making process[1,2].

Pulverized coal is combusted and gasified immediately at high temperature in the tuyere raceway of BFs, but its combustion rate keeps decreasing with the increase in coal injection rate of BFs[3,4]. By sampling coke and simulating the working conditions at the tuyere, it is found that with the increase in coal injection ratio, the degradation of the coke particles within BFs exhibits an increasing tendency[5]. There have been controversies regarding the deterioration mechanism of the coke in BFs, especially in the raceway. Most of researches on the reaction and deterioration mechanism of coke in raceway indicated that the coke deterioration in raceway is caused by mechanical wear, temperature stress, and chemical reaction[6-13]. Yamaguchi et al.[6] argued that coke deterioration is induced by mechanical wear rather than thermal stress or temperature vibration. Peters et al.[9] considered that with the increase in PCI ratio, the total amount of unburnt pulverized coal in raceway is increased. Accordingly, the total momentum of particles is increased, leading to coke deterioration in the raceway. Gudenau et al.[10] demonstrated that when unburnt pulverized coal is mixed with coke, the solid products can protect coke from being deteriorated. Meanwhile, the coke strength after reaction is improved because the reaction rate of char is greater than that of coke when they react with CO_2. Similar conclusion is obtained by Yu et al.[11] and Zhang et al.[12]. However, the research carried out by Naruse et al.[13] indicated that after the pulverized coal injected is burnt out, the produced coal ash particles are expected to react with coke, leading to coke deterioration. The experimental results of Khairil et al.[8] suggested that the gasification products of the pulverized coal with high ash fusion point are usually deposited on coke surface, which prevents coke from reacting with gas phases and thereby reduces the reaction

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rate of solution loss. On the contrary, the pulverized coal with low ash fusion point is likely to adhere to coke surface, resulting in an improved reaction rate of coke, which is possibly induced by the catalysis of several minerals contained in coal ash. Therefore, it can be seen that due to different burning degrees of pulverized coal injected, the combustion products have complex influences on the coke properties when they were mixed with coke. The influence of the solid or molten products generated in the combustion and gasification of pulverized coal on the physical and chemical properities of high temperature coke is required to be further studied.

Besides, in order to improve the combustion reactivity of pulverized coal in raceway or optimize the energy consumption in BFs, a number of catalysts[14-17] and auxiliary fuels[18-22] mainly composed of inorgainc minerals are added intentionally into pulverized coal; however, few studies have been performed on the influence of the physical and chemical properties of the products of combustion and gasification on the coke properties when the properties of traditional fuels (bituminous coal and anthracite) have changed.

Starting with thermodynamic calculation, high temperature melting characteristics of the products generated in the combustion process was analyzed. Furthermore, by comparing the wettability of the combustion products on coke and their influence on coke properties before and after the catalytic combustion, the interaction mechanism between the combustion products of pulverized coal injected and coke was acquired. The results are expected to provide reference for the application of the pulverized coal injection technology and the catalytic combustion technology in BF.

2. Experimental Proceduce

2.1. Sample preparation

The extremely short residence time of pulverized coal in the tuyere and raceway of BFs gives rise to the incomplete combustion and gasification, and the products of the incomplete reaction are called the unburnt char. Over time, the combusiton and gasification ratio is improved gradually in raceway. As a result, the carbon content in the unburnt char is reduced gradually, which finally gives rise to the burnt-out coal ash. In addition, applying the technology of catalytic combusition, the catalysts blended with coal finally enter into the coal ash. Therefore, three different combustion products were investigated in the experiment including the unburnt char, raw coal ash, and the coal ash produced by the addition of catalyst into raw coal, namely, the catalyzed coal ash. The pulverized coal adopted in this experiment was the anthracite used for BF injection, 70% of which was less than 74 μm in diameter. The results of proximate and ultimate analysis of the anthracite are shown in Table 1.

Table 1
Properties of coke and coal (%)

Analysis	Component	Coke	Anthracite
Proximate analysis	Moisture	0.91	0.46
	Ash	14.12	12.54
	Volatile matter	3.61	10.80
	Fixed carbon	81.36	76.71
Ultimate analysis	Carbon	82.51	78.22
	Hydrogen	0.26	2.49
	Nitrogen	1.13	0.91
	Sulfur	4.48	0.52
	Oxygen (by difference)	2.17	4.86
Analysis of ash	SiO_2	52.71	58.22
	CaO	7.70	6.10
	Al_2O_3	31.11	27.65
	MgO	1.41	0.55
	Fe_2O_3	5.17	4.12
	TiO_2	2.17	2.84

Note: The analyses are made in air dry basis.

The unburnt char, the raw coal ash, and the catalyzed coal ash were prepared in a muffle furnace. Specifically, the preparation process of unburnt char was described as follows: the pulverized coal (200 g) was spread uniformly on the bottom of a crucible, and then it was heated from ambient temperature to 700 ℃ during 30 min. Afterwards, the furnace was kept at 700 ℃ for 30 min. The burnout rate of coal S can be determined by the ash tracer method[14], which can be expressed as

$$S=\frac{1-A_r/A_u}{1-A_r}\times 100\% \tag{1}$$

where, A_r and A_u are ash contents in the raw coal and unburnt char, respectively. The unburnt char has 76.54% of burnout rate according to this method, which approximated to the actual burnout rate of pulverized coal in the raceway of BF. In addition, the raw coal ash was prepared based on the Chinese standard GB/T 1574-2007. After 1.0% of two typical catalysts (Fe_2O_3 and CaO) commonly used in the catalytic combustion of coal was blended into the raw coal, the combustion product was prepared also based on the Chinese standard GB/T 1574-2007.

The coke utilized in the research was taken from an iron and steel enterprise and its proximate analysis is given in Table 1. The coke with length, width and height all greater than 8 cm was selected, which was then carefully cut into several cuboids with the dimension of 3 cm×3 cm×1 cm by using a cutting machine. In order to remove the possible powders left by the cutting in the coke surface and the pores, these cuboids were cleaned in an ultrasonic cleaning