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INFLUENCE OF BURDEN DISTRIBUTION ON COUPING EFFECT OF IRON ORE REDUCTION AND COKE GASIFICATION IN BLAST FURNACE LUMP ZONE [1]

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Abstract

Recently, the improvement of coupling effect of iron ore reduction and coke gasification reactions have been concerned much in order to decrease reducing agent rate in blast furnace. High reactive coke could improve the reduction efficiency of iron ores in lump zone significantly, which has also been proved in our former study. Therefore, in this paper the influence of burden distribution (includes layered and mixed distributions) on coke gasification and iron ore reduction was laboratory investigated by using high reactive coke. The results showed that with the increase of layered number under the condition of layered distribution, the contact surface of iron ores and cokes are increased, which improves the reactions of coke gasification and iron ore reduction. Compared with layered distribution, mixed distribution had relatively low coke gasification and iron ore reduction at low temperature of 1173 K. When the reaction temperature increased to 1373 K, the direct reduction between iron ore and coke developed, which increased the coupling effect of iron ore reduction and coke gasification. Considering the coke reactivity and the strength after reaction for blast furnace ironmaking process, the mixed distribution had better effect on coupling effect on coke gasification and iron ore reduction for practical application.

Key words: Blast furnace; High reactivity coke; Burden distribution; Iron ore reduction.

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1 INTRODUCTION

With the increasing problems of resources exhaustion and environment pollution, the methods of how to further improve the reduction efficiency and decrease the reducing agent rate (RAR) of blast furnace ironmaking process have been one of the improtant research theme for the researchers all over the world.[1-3] Many research works have been conducted in this field. T. Ariyama and Sato[2] showed the concept and measures for low RAR operation of the blast furnace as an independent unit. Basically, measures for low RAR operation consist of improvement of shaft efficiency, charge of metallic iron, reduction of the heat loss in the lower part of blast furnace, and furthermore control of the reduction equilibrium on FeO/Fe. The improvement of shaft efficiency, heat balance and charge of metallic iron are realistic, whereas control of the reduction equilibrium relatively depends on the temperature of the reaction.

The thermodynamics of the indirect reduction reaction of FeO by CO shows that with temperature decreasing, the equilibrium concentration of $CO/(CO+CO_2)$ is decreased, which could improve the reaction efficiency thermodynamically. Therefore, decreasing the thermal reserve zone temperature is considered to be one of the methods to improve the shaft efficiency and control the reduction equilibrium on FeO/Fe. Many researches have been reported to realize low temperature operation of blast furnace, such as carbon composite pellets charging, carbon iron composite or ferrocoke charging.

Recently, the use of high reactivity coke to lower the temperature of thermal reserve zone and decrease the RAR was conducted by Naito et al.[4] In this regard, it has been reported that the use of highly reactive nut coke improved the efficiency of reaction in an actual furnace and lowered the temperature of the thermal reserve zone. In our former study[5], the reduction of iron ores in thermal reserve zone under the condition of using high reactivity coke was simulated, which showed that coupling effect of iron ore reduction and coke gasification could be improved, resulted in the increase of reduction efficiency.

In these reported studies, many researches focused on reduction phenomena of iron ores by adding highly reactive coke and the preparation of the coke with high reactive and high strength after reaction[6-8]. However, the influence of burden distribution on coupling effect of iron ore reduction and coke gasification is rare reported under the condition of using highly reactive coke[9]. Therefore, in this work the influence of burden distribution on coupling effect of iron ore reduction and coke gasification at 1173 K and 1373 K in blast furnace lump zone is researched respectively. The phenomena of iron ore reduction and coke gasification at different temperature were then analyzed.

2 MATERIALS AND METHODS

In order to investigate the effect of burden distribution on coupling effect of iron ore reduction and coke gasification, the experiment was conducted at two temperatures of 1173 K and 1373 K. The experiments at two temperatures has following differents. For the experiment at 1173 K, the coke was pretreated to improve the reactivity, while in the experiment at 1373 K, the metallurgical coke with relativtly high reactivity was from

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steelwork. Therefore, the two kinds of coke were evaluated for the reactivity under the different parameters.

2.1 Experiment at 1173 K

2.1.1 Materials

Raw materials of sinter and coke were from Baosteel Group (China) products. The sinter and coke was pulverized and the size in the range of 10.0—12.5 mm was selected for the reduction experiments. The composition of sinter was shown in Table 1. As the coke has low reactivity, it is very difficult for gasification reaction at 1173 K. Therefore, in order to obtain the coke that could react with CO_2 at relatively low temperature, the coke from Baosteel was catalyzed (write as “catalyzed coke” in this paper), and the reactivity and strength after reaction was analyzed in following conditions.

The coke of 250 g was dried for 12 h at 383 K, and then put into a reaction tube. The reactor was heated to 1173 K with gas flow N_2 of 5 $L \cdot min^{-1}$, and then the coke was kept at 1173 K for 2 h with the reaction gas of CO, CO_2 and N_2 mixture (volume ratio: CO-32.5%, CO_2-12.5%, N_2-55%). After that, the coke was cooled to room temperature with the atmosphere of N_2 (5 $L \cdot min^{-1}$). The weight loss of the coke during the experiment shows the reactivity of the coke. And the coke after reaction was put into a tumbler with the size of Φ 130 mm × 800 mm and rolled for 30 min with the rotating speed of 30 $r \cdot min^{-1}$. The weight percent of the particle size larger than 6.3 mm and smaller than 0.5 mm were measured as $DI_{+6.3}$ and $AI_{-0.5}$ respectively. The reactivity and the strength after reaction of the catalyzed coke are shown in Table 2.

Table 1 Compositon of sinter (wt%)

TFe	Fe_2O_3	FeO	CaO	MgO	SiO_2	Al_2O_3	S	P	LOI
58.13	74.19	7.97	9.47	1.57	4.88	1.66	0.02	0.05	0.01

Table 2 Reactivity and strength after reaction of the catalyzed coke

Weight before reaction (g)	Weight after reaction (g)	Weight loss (%)	$DI_{+6.3}$ (%)	$AI_{-0.5}$ (%)
250.0	220.8	11.68	74.05	4.57

2.1.2 Reduction experiment of sinter with different burden distribution at 1173 K

The reduction experiment at 1173 K was conducted on the equipment of static reduction furnace, the schematic diagram of which was shown in Figure 1. The samples of 1000 g sinter and 364 g coke was charged in the tubular reactor with the size of Φ 125 mm × 950 mm. The distribution of sinter and coke has three kinds: one-layer-distribution, five-layer-distribution, and mixed distribution. Figure 2 shows the schematic of burden distribution methods of the experiment at 1173 K and 1373 K. After being charged, the sinter and coke was heated to 1173 K and kept for 2 h, and then cooled down to room temperature. The atmosphere during the experiment was the same as that of coke reactivity experiment. After the reduction experiment, sinter and coke was separated and weighted respectively. The reduction degree of sinter was calculated by Eq. (1).

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$$R_0 = \frac{(W_0 - W_t) \times 100}{W_0 \times (0.43\text{TFe} - 0.11\text{FeO})} \times 100\% \qquad (1)$$

where
R_0: reduction degree, %;
W_t: weight of iron ores after reduction, g;
W_0: weight of post-drying iron ores before experiment, g;
TFe: weight percent of Fe in the iron ores before reduction, %;
FeO: weight percent of FeO in the iron ores before reduction, %.

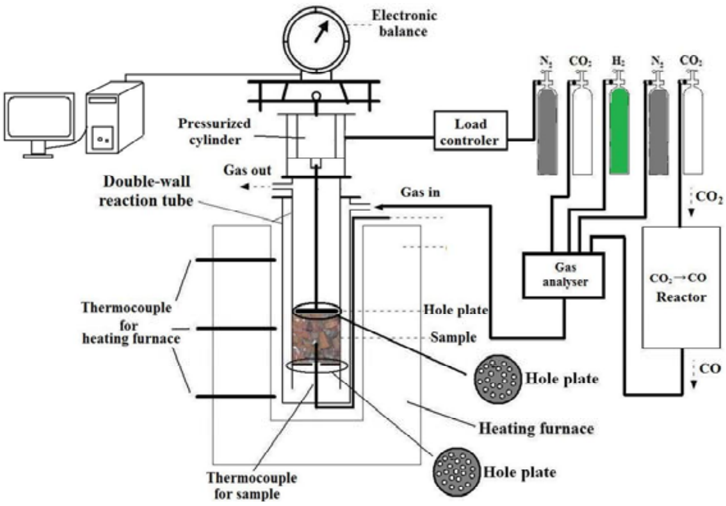

Figure 1. Schematic diagram of reduction equipment.

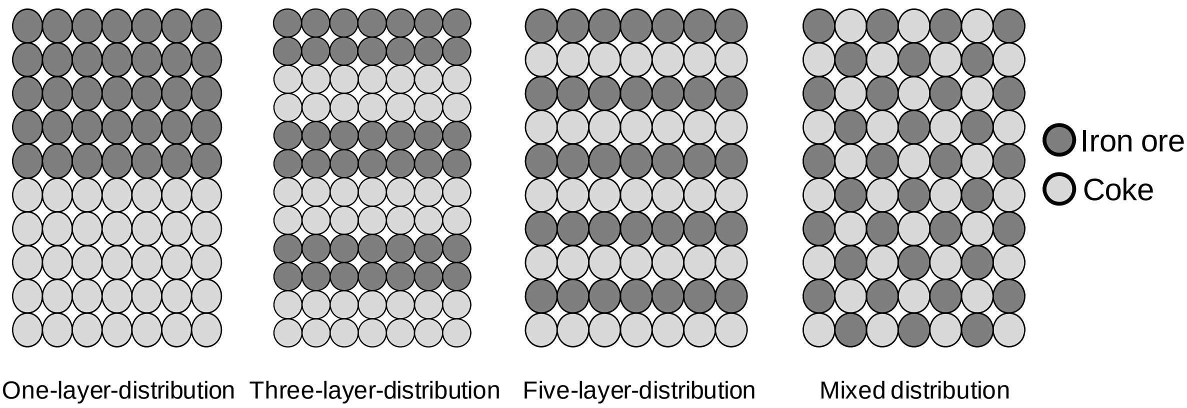

Figure 2. Schematic of burden distribution methods.

The strength of the separated coke after reaction was measured by drum test. The parameter of the drum test was the same as the coke strength experiment. The particles in different sizes were also screen separated.

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2.2 Experiment at 1373 K

2.2.1 Materials

Sinter used at 1373 K is the same as that used in 1173 K experiment. The coke was from Baosteel Bayi (write as "Bayi coke" in this paper), and the coke reactivity index (CRI) and coke strength after reaction (CSR) of it was evaluated as following. Coke of 200 g with the size larger than 25 mm was selected for test. The coke was heated to 1373 K at N_2 atmosphere and then the input gas was changed to CO_2 of 5L·min^{-1} for 2 h. After that, the coke was cooled down to room temperature in N_2. The reacted coke was then weighted, and the rate of weight loss is evaluated as CRI. CSR was evaluated by drum test. The size of tumbler is Φ 130 mm × 700 mm and the coke was rolled for 30 min with the rotating speed of 20 r·min^{-1}. The weight percent of the particle size larger than 10 mm were measured as CSR. As a result, the CRI of Bayi coke was 42.62%, and CSR was 37.92%.

2.2.2 Reduction experiment of sinter with different burden distribution at 1373 K

The samples of 450 g sinter and 150 g coke in the range of 8~10 mm was charged in the tubular reactor. The distribution of sinter and coke has four kinds: one-layer-distribution, three-layer-distribution, five-layer-distribution, and mixed distribution, which is also shown in Figure 2. After charging, the sinter and coke was heated to 1373 K and kept for 2 h, and then cooled down to room temperature. The atmosphere during the experiment was the same as the reduction experiment at 1173 K but the gas flow is 8 L·min^{-1}. After the experiment, the reduction degree of sinter was calculated by Eq. (1), and the size of the coke was also evaluated by the methods conducted in 1173 K.

3 RESULTS AND DISCUSSION

3.1. Results of the Experiment at 1173 K

After the reduction experiment, the weight loss of coke and iron ore was evaluated respectively. Figure 3 shows the weight loss of coke and iron ore under the experiment at 1173 K.

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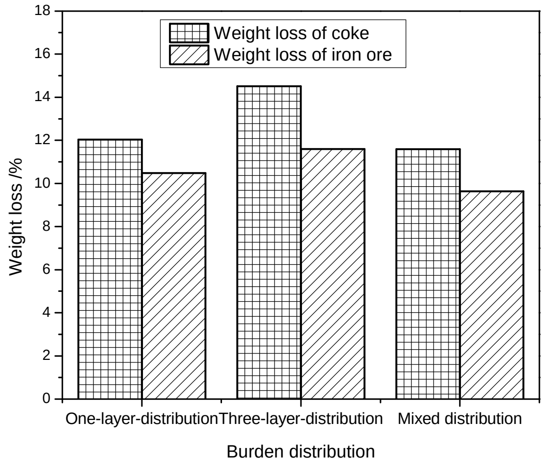

Figure 3. Weight loss of coke and iron ore after the reaction at 1173 K.

At 1173 K, the weight loss of coke with layered distribution is higher than that with mixed distribution, and the coke loss increased with the layer number increasing. As for the weight loss of iron ore, it had the same trends as that of coke loss with different burden distributions. With coke loss increasing, the iron ore reduction degree increases, which was caused by increasing CO concentration.

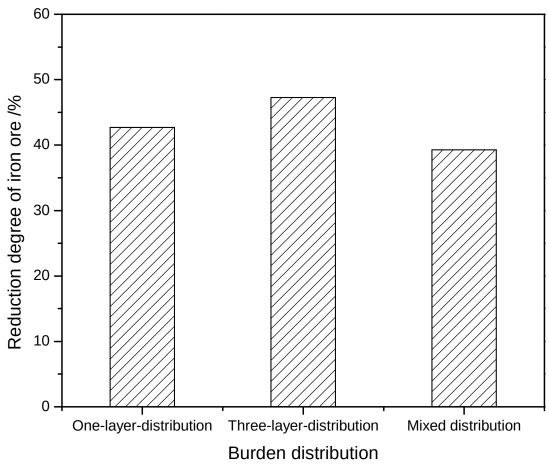

Figure 4. Reduction degree of iron ore after the reaction at 1173 K.

The reduction degree of the iron ore was calculated, which was shown in Figure 4. After reduction at 1173 K for 2 h, the reduction degrees of all the samples were higher than 39%, which indicated that the metal iron was generated after experiment.

The above results showed that at relative low temperature of 1173 K, comparing with mixed burden distribution, the layered burden distribution could improve the coupling effect of coke gasification reaction and iron ore reduction reaction. When the gas flowed through the bed of coke and sinter, it was firstly contact with coke in the

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condition of layered distribution, then the coke reacted with CO_2 because of its good reactivity by catalyzing. The reaction of coke gasification resulted in the increasing of CO concentration in the burden layer, which improves the indirect reduction of FeO to Fe thermodynamically. Therefore, the layered distribution could improve the coupling effect of coke gasification and iron ore reduction compared with the mixed distribution. On the other hand, comparing one-layer-distribution with fire-layer-distribution, with the layer number increasing, the coupling effect increased because the reduction product of CO_2 could improve coke gasification.

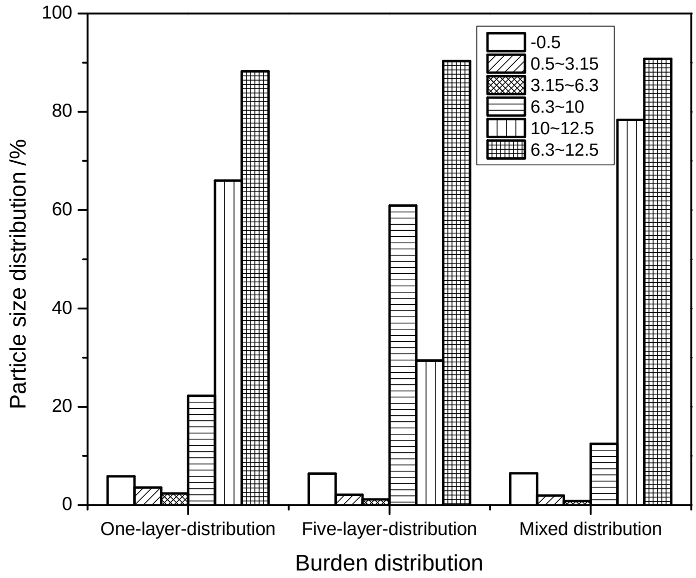

Figure 5. Particle size distribution of the coke reacted at 1173 K after drum test.

After reduction experiment, the coke was evaluated by drum test and the particle size distribution of it is shown in Figure 5. For the different burden distribution reduction, the reacted cokes after drum have similar particle size distribution. The percentage of the particle size less than 0.5 mm is in the range of 5.8—6.5%, and the percentage of the particle size large than 6.3 mm is in the range of 88.2—90.8%. The degradation of the cokes after the reaction by different burden distribution is affected by coke gasification. Therefore, for one-layer-distribution and the mixed distribution, the percentage of the particle size in the range of 10—12.5 mm are relatively larger than that of the five-layer-distribution, which was caused by the high gasification rate of the coke for five-layer-distribution.

3.2 Results of the Experiment at 1373 K

As for the experiment results at 1373 K, the weight loss of coke and iron ore after experiment is shown in Figure 6. With layer number increasing, the weight loss of both coke and iron ore are increased, which was similar to that of the experiment at 1173 K. However, under the condition of the mixed distribution, the weight loss of both coke and

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iron ore are between that of three- and five-layer distributions. This was considered to be caused by the direct reduction of FeO by coke. Compare with the experiment at 1173 K, the relatively high temperature could improve the direction reduction $FeO + C = Fe + CO$, which is easier to be happened at 1373 K under the condition of using high reactivity coke compared with that at 1173 K. Therefore, the mixed distribution of burden, which made the interface of coke and iron ore increased, could improve the coupling effect of coke gasification and iron ore reduction compared with the layered distribution. When the layer number is five in the layered distribution, the coke layer and iron ore layer was very thin, almost one particle layer, which greatly improved the contact of coke and iron ore, and the interface of coke and iron ore was larger than at the condition of irregular array of coke and iron for the mixed distribution.

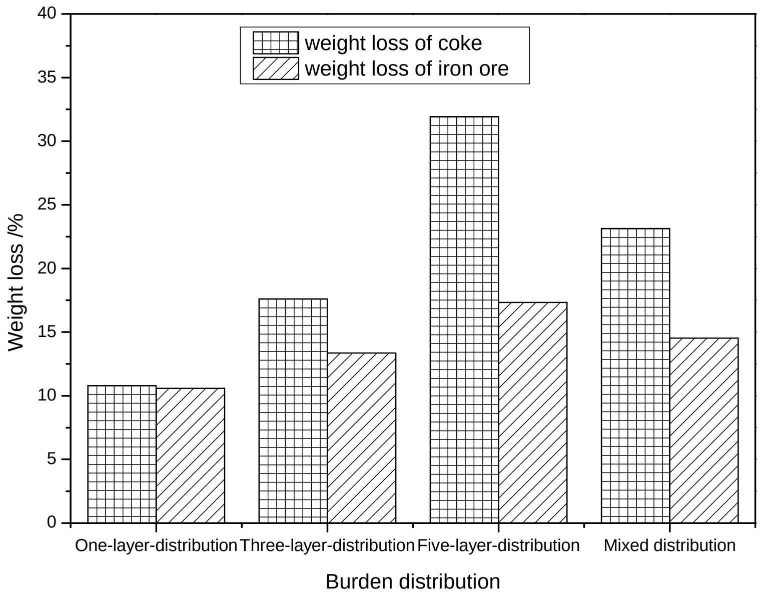

Figure 6. Weight loss of coke and iron ore after the reaction at 1373 K.

Comparing the experiment results at 1173 K and 1373 K, the indirect reduction was mainly developed at relatively lower temperature, therefore to increase the CO concentration could improve the ore reduction, at the same time the generated CO_2 by reduction reaction could improve the coke gasification. For this reasons, layered distribution could improve the coupling effect of coke gasification and iron ore reduction. At relatively higher temperature, both indirect reduction and direct reduction are developed. In order to further improve the indirect reduction, the coke gasification should be improved; and the interface between iron ore and coke should be increased to further improve the direction reduction. Therefore, coupling effect could be generally improved by mixed distribution at relatively high temperature.

Figure 7 shows the reduction degree of iron ores after experiment. The reduction degree had the same trend with that of weight loss. The reduction degrees were larger than 40% and the iron ore under the experiment condition of five-layer-distribution has the maximum reduction degree, which was 70.7%. Comparing the reduction degree of the iron ores under the different experiment temperatures, the iron ores after 1373 K had

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relatively higher reduction degree, which was mainly caused by the improvement of direct reduction of iron ore at high reaction temperature of 1373 K.

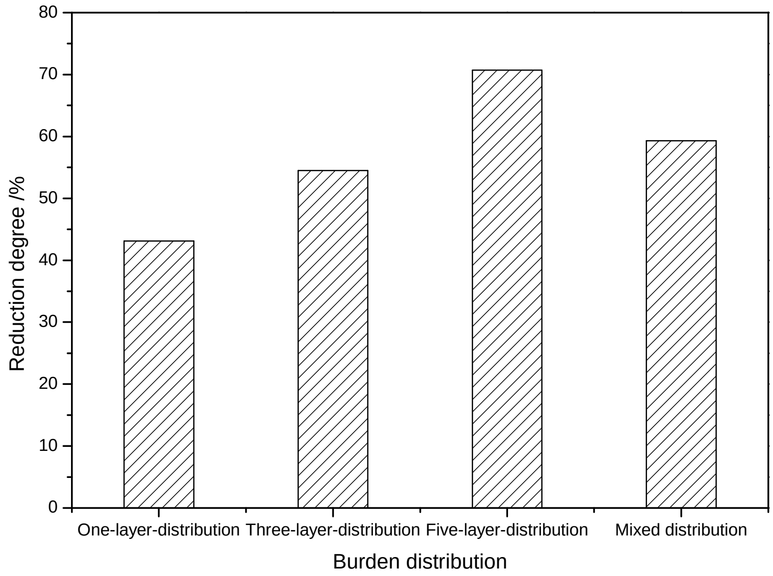

Figure 7. Reduction degree of iron ore after the reaction at 1373 K.

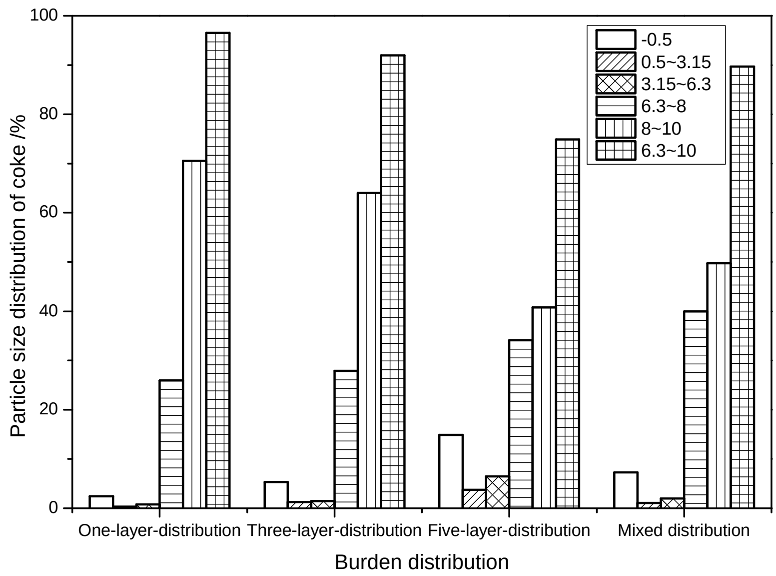

Figure 8. Particle size distribution of the coke reacted at 1373 K after drum test.

Figure 8 shows the particle size distribution of the coke reacted at 1373 K after drum test. The particle size of the reacted coke under different burden distribution experiments had similar distribution. With coke gasification reaction increasing, the particle size less than 0.5 mm and larger than 8 mm decreased. The weight percentage of the particle in the range of 6.3~10 indicated the strength after reaction, with was larger than 75% for all the samples, and with the coke gasification increasing, the strength

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decreased.

For a practical blast furnace, the pre-catalyzed coke would increase the cost, therefore the relatively high reactivity coke could be obtained by decreasing the particle size, such as using nut coke, which had relatively high reactivity at 1373 K. Considering the practical application of high reactivity coke, the coke could be mixed in one batch of iron ore and distributed in the blast furnace.

4 CONCLUSIONS

This paper studied the influence of burden distribution on coke gasification and iron ore reduction coupling effect under the condition of using high reactivity coke. The reduction experiment was conducted at 1173 K and 1373 K, and the following conclusions could be obtained.

(1) When the experiment temperature was 1173 K, comparing with the mixed distribution the layered burden distribution could improve the coupling effect of coke gasification reaction and iron ore reduction reaction.

(2) When the experiment temperature was 1373 K, mixed distribution could improve the coupling effect of coke gasification and iron ore reduction more efficiently. When layer number was five, the interface between iron ore and coke was larger than that of irregularly mixed distribution, and the coupling effect then increased.

(3) For the layered distribution, the coupling effect of coke gasification and iron ore reduction increased with the increase of layer number at both 1173 K and 1373 K.

(4) The coke strength decreased slightly in the experiments at two temperatures after reduction, and mixed distribution of relatively high reactivity coke could be selected for practical application.

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REFERENCES

1 ARIYAMA T., MURAI R., ISHII J., SATO M. Reduction of CO_2 emission from integrated steel works and its subjects for a future study. *ISIJ Int.*, v. 45, p. 1371-1378, 2005.
2 ARIYAMA T., SATO M. Optimization of ironmaking process for reducing CO_2 emissions in the integrated steel works. *ISIJ Int.*, v. 46, p. 1736-1744, 2006.
3 NOMURA S., AYUKAWA H., KITAGUCHI H., TAHARA T., MATSUZAKI S., NAITO M., KOIZUMI S., OGATA Y., NAKAYAMA T., ABE T. Improvement in blast furnace reaction efficiency through the use of highly reactive calcium rich coke. *ISIJ Int.*, v. 45, p. 316-324, 2005.
4 NAITO M., OKAMOTO A., YAMAGUCHI K., YAMAGUCHI T., INOUE Y. Advanced approach to intelligent ironmaking processes. Improvement of blast furnace reaction efficiency by use of high reactivity coke. *Tetsu-To-Hagane*, v. 87, p. 357-364, 2001.
5 WU S., TUO B., ZHANG L., GUO L., WU J., ZHOU Y. Study of influence law of coke reactivity on reduction of ferric burden of the lump zone in blast furnace. *J. Univ. Sci. Technol. Beijing*, in press.

ISSN 2176-3135

6 NOMURA S., MATCUZAKI S., NAITO M., AYUKAWA H., KOIZUMI S., ABE T., KITAGUCHI H., TAHARA T. Improvement in blast furnace reaction efficiency through the use of catalyst-doped highly reactive coke. *Nipp. Steel Tech. Rep.*, v. 91, p. 109-114, 2006.
7 NOMURA S., NAITO M., YAMAGUCHI K. Post-reaction strength of catalyst-added highly reactive coke. *ISIJ Int.*, v. 47, p. 831-839, 2007.
8 NOMURA S., KITAGUCHI H., YAMAGUCHI K., NAITO M. The characteristics of catalyst-coated highly reactive coke. *ISIJ Int.*, v. 47, p. 245-253, 2007.
9 WATAKABE S., TAKEDA K., NISHIMURA H., GOTO S., NISHIMURA N., UCHIDA T., KIGUCHI M. Development of high ratio coke mixed charging technique to the blast furnace. *ISIJ Int.*, v. 46, p. 513-522, 2006.