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DISCUSSION ON COKE PROPORTIONING IN BLAST FURNACE LUMPY ZONE CONSIDERING BOTH CSR AND ORE/COKE COUPLING REACTION[1]

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Abstract
Adding nut coke or high reactivity coke (HRC) can promote ore/coke coupling reaction in the lumpy zone of blast furnace (BF), thus improving iron ore reduction degree (RD) efficiency. Although lots of works aiming to increase coke strength after reaction (CSR) of HRC are studied, few of them take the reasonable coke proportioning for BF into consideration. Present work firstly compares the RD of iron ore as well as CSR when HRC is mixed in sinter, pellet and lump ore column respectively. Then, the above behaviors are further investigated under different proportions of HRC in sinter column. Finally, two methods, named 'More HRC of Lower Reactivity' and 'Less HRC of Higher Reactivity', are proposed and the relative results are compared to discuss the reasonable coke proportioning for BF. The results show that sinter performs better considering both CSR and ore/coke coupling reaction when mixed with HRC. The increasing proportion of HRC reduces CSR, but the increase in RD by such drop in unit CSR of coke almost keeps constant. The gasification degree of coke in 'Less HRC of Higher Reactivity' method is less to obtain high CSR while the RD of iron ore is almost the same in comparison with 'More HRC of Lower Reactivity', so the increase in RD by the drop in unit CSR of coke doubles correspondingly. Therefore, the 'Less HRC of Higher Reactivity method' is preferred reasonable coke proportioning in BF.
Key words: Blast furnace; Ore/coke coupling reaction; CSR; Coke proportioning.

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1 INTRODUCTION

Coke takes up a major portion of hot metal costs and it is the irreplaceable raw material for the blast furnace. Its properties affect the coke's gasification degree and the furnace productivity.(1) It was reported that the use of highly reactive 'nut coke' in a commercial scale blast furnace can not only increase the coke's utilization but also improve the reaction efficiency.(2,3) Due to the high reactivity, the nut coke can promote the ore/coke coupling reaction in the lumpy zone and protect metallurgical coke from the solution loss reaction. Based on the above reasons, the nut coke has the possibility of coke saving, increase of furnace productivity and cut down the CO_2 emission.(4)
Then the usage of 'nut coke' infers us an important phenomenon that the highly reactive coke (HRC), the traditional sense of inferior coke, can be partial used in the BF. The resource of high quality metallurgical coke is becoming limited,(5) it is urgent to expand the range of coke that can be used for BF. Furthermore, the highly reactivity coke can also promote ore/coke coupling reaction(6) in the lumpy zone, playing the same role as 'nut coke'.
Although lots of works aiming at the method of how to increase the coke strength after reaction (CSR) of HRC(7-9) have been done, the reasonable coke proportioning for BF has not yet been considered. In this paper, the best kind of ore mixing with HRC, influence on RD of different proportion of HRC and suitable method of coke proportioning are discussed.

2 MATERIALS AND METHODS

2.1 Materials Preparation

In the experiment, four types of coke are used, which are respectively Baosteel-coke named as A and different degree of catalytic coke named as B, C, D. The coke B, C, D is produce by spraying different amount of catalyst on the surface of coke A and then dehumidifying at 378K for 12 hours.
With the static-load-reductive apparatus shown in Figure 1, the reactivity of these four types of coke is obtained. The percentage of weight loss after reaction under the mixed gas '32.5%CO+12.5%CO_2+55%N_2' at 1173K for 2 hours is listed in Table 1. A's reactivity is very low under present experiment conditions, while the reactivity of other three types of coke is higher in comparison with A. Thus, it can be concluded that the reactivity order of these coke is: D> C>B>A.

Table 1. The coke weight loss ratio of different types (weight %)

Types of coke	A	B	C	D
Coke weight lose ratio /%	0.56	11.68	17.00	21.76

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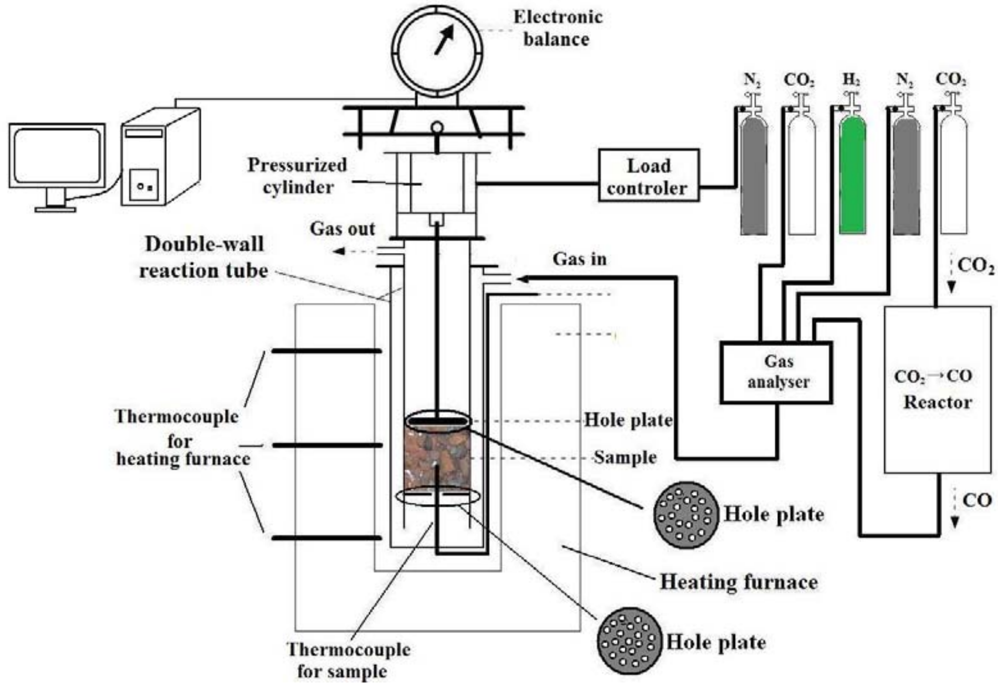

Figure 1. Schematic diagram of static-load-reductive apparatus.

Sinter, pellet and lump ore are used in the experiment with their chemical composition listed in Table 2. The basicity (CaO/SiO_2) of sinter, pellet and lump ore is 1.94, 1.10 and 0.01 respectively which indicates the basic properties of sinter and the acidic properties of lump ore and pellet.

Table 2. Chemical composition analysis of different types of ore（wt%）

Types of ore	TFe	Fe_2O_3	FeO	CaO	MgO	SiO_2	Al_2O_3	S	P	LOI
Sinter	58.13	74.19	7.97	9.47	1.57	4.88	1.66	0.02	0.05	0.01
Pellet	65.65	92.15	0.29	2.73	0.03	2.48	0.76	0.01	0.03	0.15
Lump ore	63.82	90.84	0.30	0.03	0.06	3.55	1.32	0.02	0.06	3.15

2.2 Test Methods

In the experiment, the weight of ore and coke are 1000g and 364g respectively while the size of ore and coke are 10-12.5mm and 8-10mm respectively. The layer packing mode is shown in Figure 2. The other experiment conditions such as heating rate and gas composition are given in Table 3.The reactor is shown in Figure 1.

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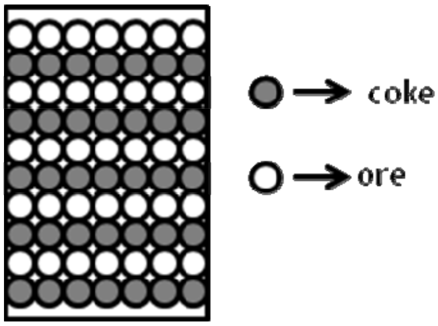

Figure 2. The packing mode of ore and coke.

Table 3. The experiment conditions

Temperature	Room Temperature-1173K	Constant Temperature of 1173K for 2h	1173K-Room Temperature
Heating rate	10K/min	-	-
Gas composition	100%N_2	32.5%CO+12.5%CO_2+55%N_2	100%N_2
Gas flow	5L/min	15L/min	5L/min

And put the coke after reaction into a drum with the size of Φ 130 mm × 800 mm and roll it for 30 min with the rotating speed of 30 r·min^{-1}. The weight percent of the particle size larger than 6.3 mm is measured as the CSR.

Figure 3. The drum to test the strength of coke after reaction.

3 RESULTS AND DISCUSSION

3.1 Different Types of Ore Mixing with HRC

In order to determine which types of iron ore is most suitable to mix with HRC, the RD of sinter, pellet and lump ore mixed with coke B are examined. First the samples are moved out from the reactor when the temperature reduces to the room temperature and then separated into coke and ore. Coke and iron are weight to obtain the coke weight

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loss ratio (CWLR) and reduction degree of iron ore through calculation. Take the samples out of the reactor after they have been cooled to the room temperature. Separate the coke from the iron ore, and then weight them separately. Calculate the coke weight loss ratio (CWLR) and the reduction degree of iron ore.
Results of the RD of iron ore, the CWLR, and the CSR are given in Table 4.

Table 4. Reduction degree, coke weight loss and CSR for different types of ore

Ore Type	RD /%	CWLR /%	CSR /%
sinter	48.29	16.13	84.27
pellet	47.87	16.70	81.92
Lump ore	29.97	13.65	85.47

As for the RD, the sinter performs best when mixed with HRC, which attributes to the sinter's rough, loose and porous characteristics. In addition, these characteristics promote the ore/coke coupling reaction that makes the RD of sinter higher. The pellet has more micro-pore and its surface is denser and smoother than the sinter, which can also promote the ore/coke coupling reaction. Therefore the RD of pellet is a little lower than the sinter. Since the lump ore has the most compact and smooth surface which restrains the ore/coke coupling reaction, the lump ore's RD is lowest among these three types of ore. As the trend of CWLR is the same with RD, higher RD leads more CWLR.
As for the CSR, although the RD of sinter and pellet are nearly the same, the coke's strength after reaction mixed with sinter is better than that of pellet. The reason is that the oxygen content of pellet is more than that of the sinter and the HRC mixed with the pellet has to lose more weight to reach the same RD, which results in a decreased CSR. When considering both CSR and ore/coke coupling reaction, the sinter performs best. As the proportion of sinter is about 70% in BF burden composition in China, mixing HRC with sinter is relatively easy to realize in actual situations.

3.2 The Influence of Different Proportion of HRC

Due to different reactivity, different HRCs are obtained by adding coke C into coke A with the proportion of 0%, 40%, 50%, 60%, 70%, and 100% respectively. Then the HRCs are mixed with sinter to study the influence of different proportion of HRC on the RD of iron ore and the CSR itself.
The processing method is the same as mentioned above. Results of the RD of iron ore, CWLR, and CSR are given in Table 5.

Table 5. Reduction degree, coke weight loss and CSR for different proportion of HRC

coke proportioning	RD /%	CWLR /%	CSR /%
100%A	33.67	1.29	89.09
60%A+40%C	42.35	10.41	80.80
50%A+50%C	43.69	11.59	79.06
40%A+60%C	45.12	12.75	78.02
30%A+70%C	47.69	14.73	75.64
100%C	54.64	19.95	69.39

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As shown in Table 5, the RD of iron ore and CWLR increases and the CSR reduces with increasing proportion of coke C. Considering only RD, more proportion is better. However, the CSR drops by a large margin when the proportion of coke C increases from 60% to 70%. Therefore the best proportion of HRC is 60% when taking both the CSR and RD into consideration.
As the variation trends of the RD and the CSR shown above are opposite with the increasing proportion of HRC, it is hard to estimate whether it is beneficial or not to use HRC. Therefore two indexes are put up. One is ‘the increase in RD by the increase in unit coke weight lose rate’ (ΔRD/ΔCWLR), and the other is ‘the increase in RD by the drop in unit CSR of coke’ (ΔRD/ΔCSR).
The ΔRD/ΔCWLR means that the increase in RD divide the increase in CWLR compared with the coke proportion of 100%A. Results of ΔRD, ΔCWLR and ΔRD/ΔCWLR are shown in Figure 4.

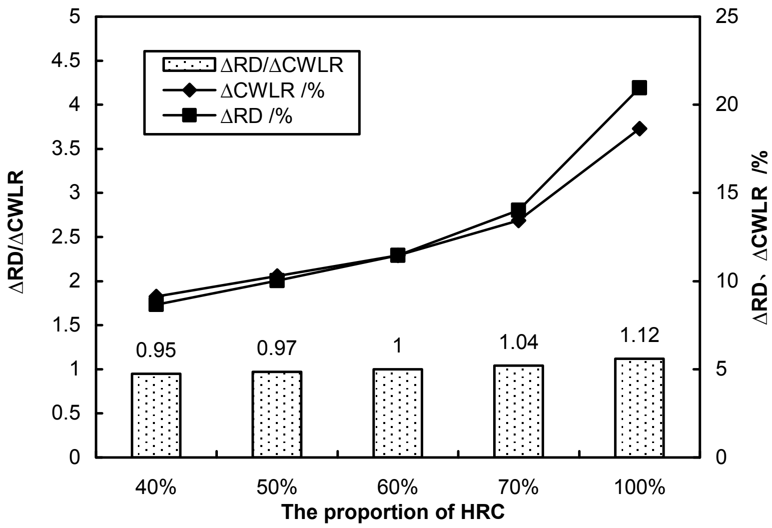

Figure 4. The results of ΔRD/ΔCWLR with different proportion of HRC.

As is shown in Figure 4, the ΔRD and ΔCWLR both increase along with increasing proportion of HRC. But the increasing rate of ΔRD is faster than that of ΔCWLR, which makes the ΔRD/ΔCWLR rise gradually with the increasing proportion of HRC. Therefore, putting HRC into normal coke is beneficial to the iron ore reduction and the coke utilization efficiency becomes better with the increasing proportion.
The ΔRD/ΔCSR means that the increase in RD divide the drop CSR of coke compared with the coke proportion of 100%A. Results of ΔRD, ΔCSR and ΔRD/ΔCSR are shown in Figure 5.

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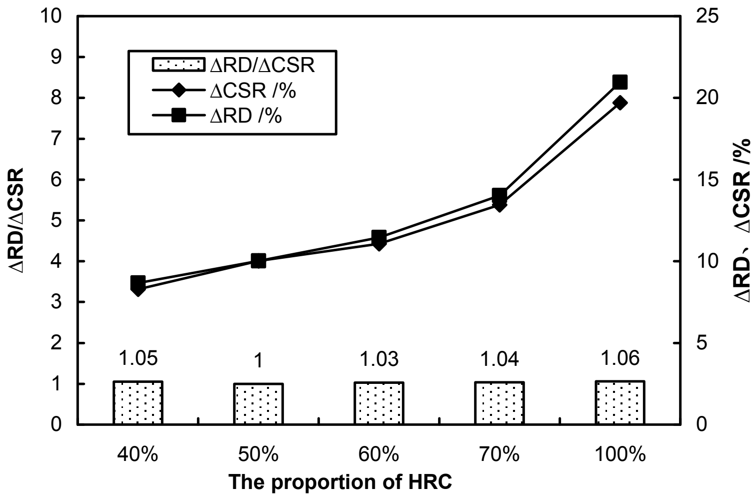

Figure 5. The results of ΔRD/ΔCSR with different proportion of HRC.

As is shown in Figure 5, the ΔRD and the ΔCSR are increasing along with the increasing proportion of HRC. And the increasing rate of ΔRD is almost the same as that of ΔCSR, which makes the ΔRD/ΔCSR nearly remains unchanged with increasing proportion of HRC.
The above analysis shows that with the increasing proportion of HRC, the RD of iron ore and the CWLR are increasing, while the CSR is opposite. Though the CWLR is increasing, the ΔRD/ΔCWLR rising gradually, and this indicates that the RD increases more under the same coke loss when increasing proportion of HRC. While the CSR is decreasing, the ΔRD/ΔCSR almost unchanged. Whether to the aspect of saving coke or the aspect of the improvement of ore reduction degree, it is worthy to use some HRC in the actual BF.

3.3 The Discussion of Coke Proportioning Methods

As mentioned above, the rising reactivity of whole coke can be achieved by more proportion of high reactivity coke, which results in good reduction effect. This coke proportioning method belongs to the category of ‘More HRC of Lower Reactivity’ (method-1).
Another coke proportioning method of ‘Less HRC of Higher Reactivity’ (method-2) is proposed in this paper. Due to different high reactivity, the coke proportioning of ‘100%A’, ‘40%A+60%C’ and ‘67%A+33%D’ can be used to stand for the ‘traditional’, ‘method-1’ and ‘method-2’ respectively to study the differences of these methods. Results of the RD of iron ore, the CWLR, and the CSR are given in Table 6.

Table 6. Reduction degree, coke weight loss and CSR for different coke proportioning methods

Methods of coke proportioning	RD /%	CWLR /%	CSR /%
traditonal	33.67	1.29	89.09
method-1	45.12	12.75	78.02
method-2	46.30	12.01	83.30

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As is shown in Table 6, the two methods of coke proportioning can both increase the RD of iron ore compared with the traditional method. The RD is almost the same of these two methods, but the CSR of method-2 is obviously much higher than that of method-1. The reason is that the HRC can protect the normal metallurgical coke from solution loss reaction in the BF due to its higher reactivity and keep the whole coke's CSR in a higher level, and the 'protection' is more obvious with the higher reactivity of coke.
Then the two indexes 'ΔRD/ΔCWLR' and 'ΔRD/ΔCSR' mentioned above are used to investigate the two coke proportioning methods with the basis of the traditional method.

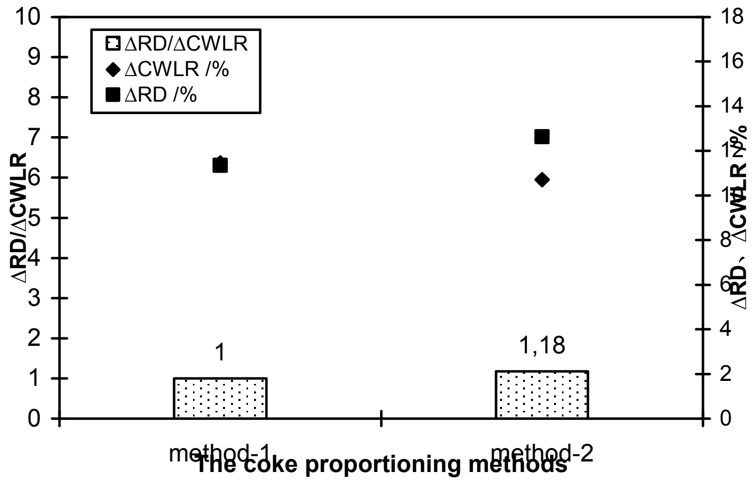

Figure 6. The results of ΔRD/ΔCWLR with different coke proportioning methods.

The result of 'ΔRD/ΔCWLR' is shown in Figure 6. Compared with the method-1, the ΔCWLR is lower and the ΔRD is higher when under the method-2, and the (ΔRD/ΔCWLR) is larger. Therefore the method-2 is conductive to the coke utilization.

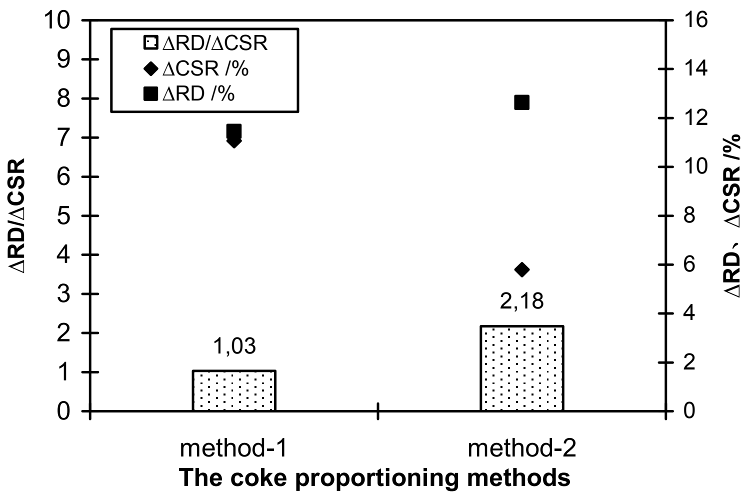

Figure 7. The results of ΔRD/ΔCSR with different coke proportioning methods.

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The result of '∆RD/∆CSR' is shown in Figure 7. Compared with the method-1, the ∆RD changes a little under the method-2, while the ∆CSR dramatically reduced. In other word, with the same RD, better CSR can be achieved by using method-2. And under the method-2, the '∆RD/∆CSR' value is doubled compared with the method-1.
The above analysis shows that the 'Less HRC of Higher Reactivity method' is preferred for reasonable coke proportioning in BF. In another word, coke proportioning method of less amount of higher reactivity coke collocated with normal coke can be adopted in BF to improve reaction efficiency, which could not only guarantee the CSR effectively but also improve the production efficiency.

4 CONCLUSIONS

This paper firstly compares the RD of iron ore as well as CSR when HRC is mixed in sinter, pellet and lump ore column respectively. Then, the above behaviors are further investigated under different proportions of HRC in sinter column. Finally, two methods, named 'More HRC of Lower Reactivity' and 'Less HRC of Higher Reactivity', are proposed and the relative results are compared to discuss the reasonable coke proportioning for BF. The main finding can be summarized as follows:

- Compared with pellet and lump ore, sinter performs best considering both CSR and ore/coke coupling reaction when mixed with HRC. As the proportion of sinter is about 70% in BF burden composition in China, mixing HRC with sinter is relatively easy to realize in actual situations.
- With the increasing proportion of HRC adding into the normal coke, the reduction degree of iron ore, the metallization ratio of iron ore and the whole coke weight loss ratio are increasing, while CSR is opposite. Under current experiment condition, the best proportion of coke C is 60% when taking the CSR into consideration under.
- Two indexes '∆RD/∆CWLR' and '∆RD/∆CSR' are proposed to measure the benefit of using HRC. With the increasing proportion of HRC, the '∆RD/∆CWLR' gradually increased, and the '∆RD/∆CSR' almost remains unchanged. Therefore it is worthy to use some HRC in the actual BF.
- Two methods of coke proportioning are proposed called 'More HRC of Lower Reactivity' and 'Less HRC of Higher Reactivity'. The gasification degree of coke in 'Less HRC of Higher Reactivity' method is less to obtain high CSR while the RD of iron ore is almost the same in comparison with 'More HRC of Lower Reactivity'. Therefore, the 'Less HRC of Higher Reactivity method' is preferred for reasonable coke proportioning in BF.

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