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Effect of bulk density of coking coal on swelling pressure

Jinfeng Bai[1,*], Chunwang Yang[1], Zhenning Zhao[1], Xiangyun Zhong[1], Yaru Zhang[1], Jun Xu[1], Bai Xi[1], Hongchun Liu[2]

1. Key Laboratory of Advanced Coal & Coking Technology, University of Science and Technology Liaoning, Anshan 114051, China.
2. ACRE Coking & Refractory Engineering Consulting Corporation, MCC, Anshan 104002, China

Abstract

Coking coals are the important raw materials for the iron and steel industries and play an important role on its sustainable development, especially on the stamp-charging coke making with the characteristics of increasing the bulk density. There is a significance on the reasonable usage of the coking coal resource with the reduced production cost, improved efficiency of the economy to develop the stamp-charging coke making technology. Important effects of the density of coking coal on the coking and caking properties were investigated. In the article, the maximum values of swelling pressure and variation of Laowan gas coal and Xinjian 1/3 coking coal, Longhu fat coal and Didao coking coal, which were mined at Shenyang and Qitaihe respectively, were investigated under different bulk densities during the coking. The results showed that when the values of density increased from 0.85 ton/m^3 to 1.05 ton/m^3, for the Laowan gas coal, swelling pressure variation and even the maximum value changed slightly. The swelling pressure was 3.63 KPa when the density was improved to 1.05 ton/m^3; for the Xinjian 1/3 coking coal, the values of swelling pressure changed significantly and the maximum values was 82.88 KPa with the density improved to 1.05 when the coal was heated to 600°C. The coke porosity, which was investigated by automatic microphotometer, decreased from 47.4% to 33.1% with the increasing of the density from 0.85 ton/m^3 to 1.05 ton/m^3, and the decreased value was 14.3%. Meanwhile, the pore structures of four cokes were characterized by an optical microscope.

Key words: coking coal; bulk density; swelling pressure

Introduction

Iron and steel industry is the pillar industry of China's economic development, which has become a significant signal of the national industrial growth. For the current level of development, there are many problems in the industry including high resource consumption, high energy sources and high pollution, etc. So far coke is still the main raw material in the blast furnace operation, and according to the economic factors this phenomenon will be continued for a long time. In order to reasonable use the coal resource, reduce the cost of production and realize the sustainable development of the coal resources, it is of practical significance to actively carry out the stamp-charging coke making technology with the characteristics of increasing the bulk density. Now, the production of coking coal from stamp-charging coke is more than eighty million tons (Zhong, 2011). Coke production in China accounts for 60% in the world's total output, and China now is becoming the biggest factory and trading center of coking coal for the world. The study of the effects of bulk density on the swelling properties in the coking process is significant to effectively improve the coke quality, protect coke oven wall and extend coke oven life. Recently, scientist investigated the swelling properties of different coking coal by small coking reactor; they found that swelling pressure of the feed coal related to the plastic layer in pyrolysis process and the resistance to the exhalation gas, and the permeability of the material, which was located away from the wall of the coke oven and near the feeding coal, was poor (Barriocanal et al., 1998a, 1998b). Others studied the pressure characteristics of coking coals in both box charging and top charging methods and they found that when high volatile coking coal, semianthracite and coke powder was added to low volatile coal respectively, the permeability of the exhalation gas in the plastic body became higher, and the swelling pressure of the feeding coal became lower, and the decrease of swelling pressure causing by adding semianthracite was bigger than that of high volatile coking coal (Mahoney et al., 2010; Nomura et al., 2010). Fu et al. (2007) investigated the morphological structure change of feeding coal in pyrolysis process by using Shanxi coal. The scientists mentioned above have devoted a lot of efforts to study the expansion character of the coking coal in the coking process, and obtained many meaningful experimental results. However, the study of the effects of stamp charged coking, which can improve

* Corresponding author. E-mail: Jinfengbai@tom.com

bulk density of coking coal, on the swelling pressure of the feeding coal is rarely reported. In this work, the swelling pressure of Laowan gas coal and Xinjian 1/3 coking coal, Longhu fat coal and Didao coking coal, which were mined at Shenyang and Qitaihe respectively, were investigated, this work has very important practical significance for understanding of the swelling pressure of coking coal mined in Northeast of China, expanding coking coal resources for stamp charged coking and optimizing suitable coking coal resources. Meanwhile, the pore structures of four cokes were characterized by an optical microscope.

1 Experimental

1.1 Coal samples

Four feed coals used in the experiment were gas coal of Laowan of Fushun of Liaoning, 1/3 coking coal of Xinjian and Fat coal of Longhu of Qitaihe of Heilongjiang and coking coal of Didao coal of Jixi of Heilongjiang. As determining the swelling pressure during the coking, the feed coal needs to break less than 1.5 mm. The results of Proximate analysis, caking index, Plastic layer indices, Dilatometry Audibert-arnu, mean maximum vitrininte reflectance for the coals used in this study are shown in **Table 1**.

1.2 Experimental apparatus

Figure 1 shows the schematic of the one-way heating test coke oven used in the experiment. The loading vessel is a metallic-cup of 60 mm inner diameter and 110 mm high and the sample mass was approximately 100 g. Moisture content of coal is controlled within 10%. The pressure sensor is set up on the top of the coal sample to study the change of the swelling pressure of coking coal during the coking. The temperature of oven and the swelling pressure of coking coal during the coking process are controlled by computer. In the experiment, the heating rate was 8°C/min up to 250°C, therefore the heating rate is 3°C/min and heating was stopped at 730°C. The caking index and the Arnu dilatation indices are determined by caking index drum and Arnu dilatation meter respectively. The mean max reflectance of vitrinite and the coke pore structure parameters are all determined by the Leitz polarizing microscope with the type of ORTHOLUX-II-POL-BK produced in Germany and the HD automatic micro photometer.

1.3 Characteristics of the coal and coke samples

The coal and coke simples test methods for proximate analysis, Caking Index, plastometric Indices, Arnu Dilatation, the vitrinite reflectance of the coal and the coke pore structure parameters were in accordance with the current Chinese Standard Methods.

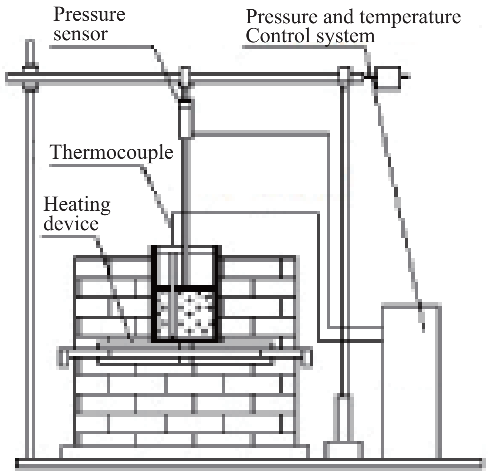

Fig. 1 Coking pressure test apparatus.

2 Results and discussion

2.1 Effect of bulk density of coking coal on swelling pressure

The swelling pressure was investigated using three bulk density values for: gas coal of Laowan 0.8 ton/m^3, 1/3 coking coal of Xinjian 0.95 ton/m^3, Fat coal of Longhu and coking coal of Didao 1.05 ton/m^3. As can be seen from **Fig. 2**, there were large difference of influence of density on density of coking coal among the different rank coal. The swelling pressure of Laowan gas coal could not be determined during coking with bulk density of 0.70 ton/m^3, and the swelling pressure was with bulk density of 1.05 ton/m^3 at the range of 450°C–500°C. As seen from **Table 1**, the Laowan gas coal had a low caking index value, which made the swelling pressure change slightly.

In the heating range of 500°C–600°C, the swelling pressure of 1/3 coking coal of Xinjian reached the maximum value. The swelling pressure values rose from 6.4 to 82.9 KPa with the bulk density values of 0.70 to 1.05 ton/m^3. Moreover, the swelling pressure of Xinjian coal with bulk density of 1.05 ton/m^3 increased by a factor of 13 comparing with that of coal with bulk density of 0.70 ton/m^3. For the fat coal of Longhu, the swelling pressure increased by 214.3 kpa from the 384.6 to 598.9 KPa with the bulk density variety of 0.70 to 1.05 ton/m^3.

By analyzing the influence of bulk density on the swelling pressure, the values exhibit that, for Laowan gas coal with the characteristic of weakly caking index, the swelling pressure has been influenced slightly by increasing the bulk density; for the Xinjian 1/3 coking coal with the characteristics of strongly caking index, the swelling pressure has the largest volatility, especially at the bulk density of 0.95 ton/m^3, the swelling pressure increased up to the 11.8 kPa, but the volatility of swelling pressure decreased to a certain degree when the bulk density increased up to 1.05 ton/m^3 and the temperature of the oven is over 450°C, the values exhibit that the gas,

Table 1 Properties of the coal samples

Coal samples	Proximate analysis			G value	Plastic layer indices		Dilatometry audibert-arnu		Mean maximum vitrinitereflectance
	M_{ad}(%)	A_d (%)	V_{daf} (%)		Y (mm)	X (mm)	b (%)	a (%)	$\bar{R}_{max}$ (%)
Laowan gas coal	3.54	–	40.42	75	7.1	29.3	–	43.8	0.564
Xinjian 1/3 coking coal	1.13	9.35	30.87	90	15.1	23.8	92.8	29.5	0.963
Longhu fat coal	1.16	9.06	28.18	97	20.6	4.3	163.75	32.3	1.165
Didao coking coal	0.83	10.39	25.68	82	16.5	12.3	45.9	26.4	1.327

Experimental coke is derived from geometric center of the coke block.

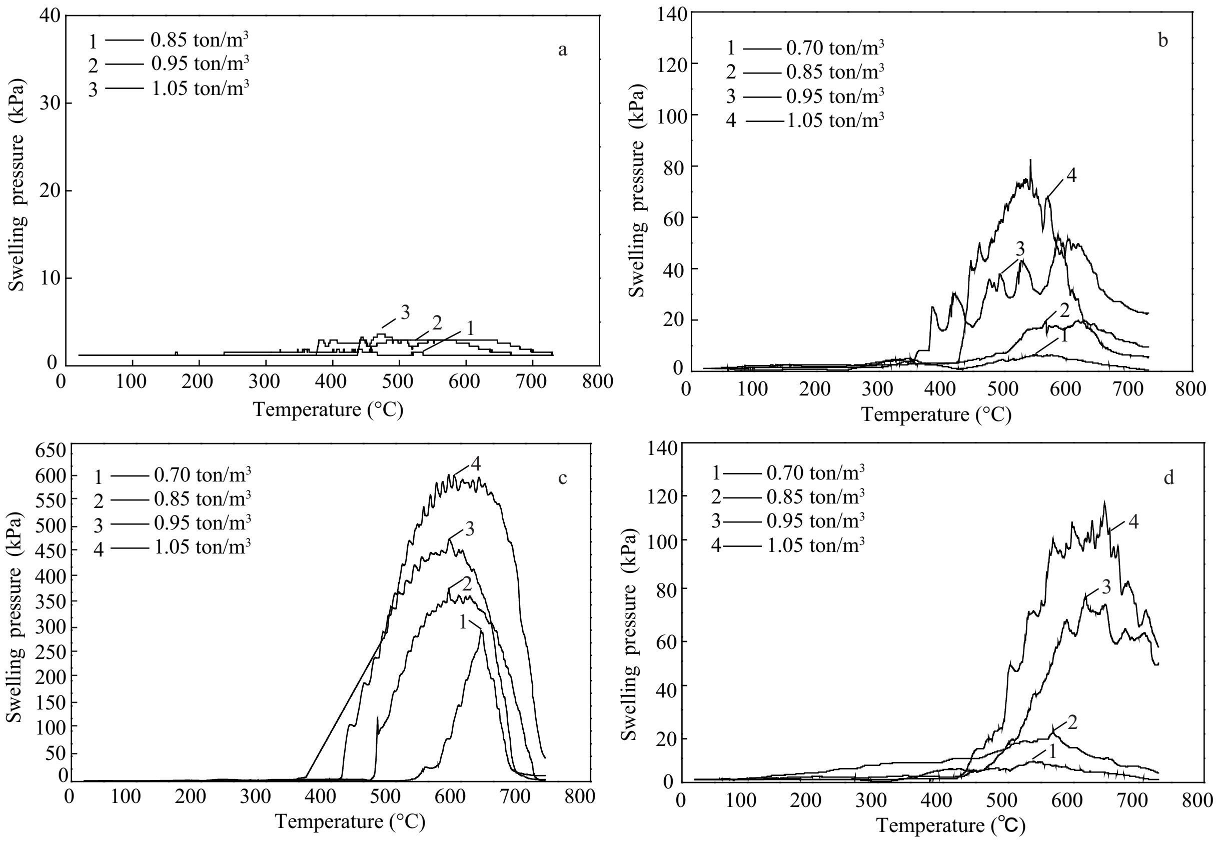

Fig. 2 Swelling curve of different bulk density on Laowan gas coal (a), Xinjian 1/3 coking coal (b), Longhu fat coal (c), Didao coking coal (d).

liquid and solid three-phases of 1/3 coking coal effect more fully at high bulk density, which benefit to increase the pore wall thickness of coke and decreased the porosity of coke. The volatility of the swelling pressure of Didao coking coal is lager than that of Longhu fat coal with the increasing of the oven temperature, but the volatilities of the two coals are lower than that of Xinjian 1/3 coking coal. The volatility of Longhu fat coal is the smallest among the four coals, but it change more frequently than that all the others, which benefits to form the compact coke structure.

The fat coal of Longhu had the stronger caking property due to a large G value and b value, 97 and 163.8% respectively. Much plastic mass could be produced from the coal during pyrolysing and coal the coal particles had good meltbility.

For the Didao coking coal, the maximum value of

Table 2 Porosity of coke at different coal buck density

Coal sample	0.85 (ton/m^3)	0.95 (ton/m^3)	1.05 (ton/m^3)
Xinjian 1/3coking coal	63.4%	53.1%	41.5%
Longhu fat coal	46.0%	35.1%	20.4%
Didao coking coal	58.3%	50.6%	32.5%

Experimental coke is derived from geometric center of the coke block.

pressure appeared in the range of 550°C–650°C and the swelling pressure increased from the 8.8 KPa to 107.6 KPa with the bulk density variety of 0.70 ton/m^3 to 1.05 ton/m^3, 98.7 KPa increased.

These studies determined the swelling process were determined to be: Longhu > Didao > Xinjian > Laowan.

It is thus clear that the Longhu fat coal had the biggest influence on the oven wall of all the coal studied, which can be explained by the G value and b value (shown

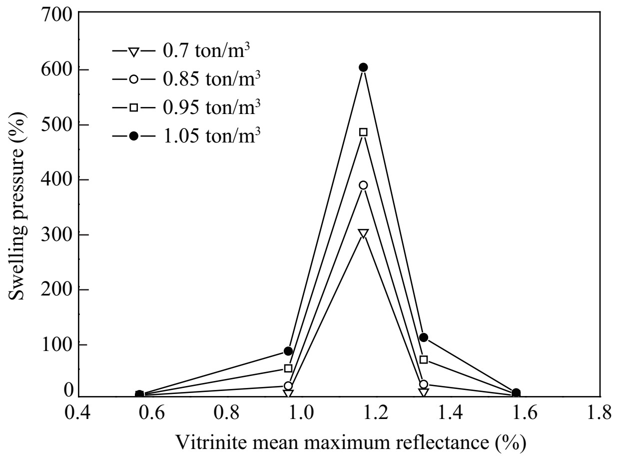

Fig. 3 Swelling pressure curve of different bulk density on vitrinite mean maximum reflectance

in **Table 1**). **Figure 3** shows the results of combining the maximum swelling pressure and the mean maximum vitrininte reflectance ($\bar{R}_{max}$) value. When the $\bar{R}_{max}$ value obtains 1.2%, the highest coking pressure is obtained. Fat coal provides a $\bar{R}_{max}$ value of less than 1.2%, whereas coking coal provides a $\bar{R}_{max}$ value of greater than 1.2%. From the results of this study, we can see that high swelling pressure can be obtained from fat coal. Additionally, fat coal can also increase the caking index and also improve the interaction between gas, liquid and solid phases in the parolysis system.

2.2 Effect of bulk density of coking coal on the porosity of coke

The quality of pore structure and wall thickness significantly influences the physical and chemical properties of coke. There are significant differences in coke pore structure due to the differences in melting properties of the active components during pyrolysis, gas release and the char contraction. But the increase of bulk density and swelling pressure were beneficial to improve the pore structure of coke. The porosities and the pore wall thickness of cokes of gas coal of Laowan, 1/3 coking coal of Xinjian, Fat coal of Longhu, coking coal of Didao coal were investigated under different bulk density. Results can be seen from **Table 2**.

As the caking index of Laowan gas coal was bad. It could not be the whole coke as coking alone and only being the coke fines, in this experiment Xinjian 1/3 coking coal, Longhu fat coal and Didao coking coal were used to investigate the porosity change of coke. As can be seen from **Table 2**, the densities of the cokes were 0.85, 0.95 and 1.05 ton/m^3 respectively in this experiment. From **Table 2**, the porosity of coke of Xinjian 1/3 coking coal, Longhu fat coal and Didao coking coal decreased with the increasing bulk density. When the bulk densities of coals were increased from 0.85 to 1.05 ton/m^3, the porosity of Xingjian coke decreased from 63.4% to 41.5%, reduced by 21.9%; the porosity of Longhu coke decreased from 46.0% to 20.4%, reduced by 25.6%; and the porosity of Didao coke decreased from 58.37% to 32.5%, reduced by 25.8%. The study established that the increasing bulk density had significant effect on the pore structure of coke.

The study established that the changes of pore wall thickness of coke were greater than those of pore diameter distribution. The proportions of different pore wall thickness were studied using four bulk density values for: 0.7 ton/m^3, 0.85 ton/m^3, 0.95 ton/m^3, and 1.05 ton/m^3. The pore wall thicknesses were divided to two stages: ≤ 120 μm and > 120–480 μm. As can be seen from **Table 3**, when the bulk density was increased from 0.7 to 1.05 ton/m^3, the amount of Xinjian coke with the pore wall thickness of less than 120 μm was reduced by 23.4% and those of between 120 μm and 480 μm was increased 18.8% and added about two times. The amount of Longhul coke with the pore wall thickness of less than 120 μm was reduced 49.9% and those of between 120 μm and 480 μm was increased 18.4%, the amount of Didao coke with the pore wall thickness of less than 120 μm was reduced 12.1% and those of between 120 μm and 480 μm was increased 10.2%. The study established that the increasing bulk density of coal could decrease the amount of coke of thickness less than 120 μm, especially for the fat coal and the 1/3 coking coal; and the amount of coke of thickness of 120–480 μm increased sharply, except for coking coal.

3 Conclusions

The result of these studies indicated that there are greater different effects of bulk density of coal on the swelling pressure of different rank coals. The influence on the bulk density of 1/3 coking coal is the largest among the four kinds of coal tested followed by the coking coal and the

Table 3 Pore wall thickness of coke block at different coal buck desity

Buck density (ton/m^3)	Xinjian 1/3 coking coal		Longhu fet coal		Didao coking coal	
	≤ 120 μm (%)	>120–480 μm (%)	≤ 120 μm (%)	> 120–480 μm (%)	≤ 120 μm (%)	> 120–480 μm (%)
0.7	89.9	10.3	88.3	12.0	77.6	21.8
0.85	88.5	12.0	69.5	28.1	74.1	22.8
0.95	84.1	15.5	50.3	38.4	76.3	21.2
1.05	66.5	19.1	38.4	30.4	65.5	32.0

fat coal. Moreover, the effect on the swelling pressure increased with the reducing caking properties of coking coal. With the increase of the bulk density, the swelling press was improved significantly of Xinjian coal with weakly coking coal and high-volatile. And the swelling pressure obtained the maximum value of 82.9 KPa at the bulk density of 1.05 ton/m^3, which is 13 times value of 0.7 ton/m^3 and the swelling pressure changed a lot during pyrolysis. Similarly, the biggest swelling pressure value of Longhu fat coal was increased 1.56 times and that of Didao coking coal was increase 11.2 times. The amount of coke with thin pore wall thickness was reduced and that of coke he thick pore wall thickness was increased due to the increasing bulk density. The highest swelling pressure of the coking coal was obtained when the $\bar{R}_{max}$ value was about 1.2%.

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