Moisture effect on coking course of coal

Zhang Xuehong¹, Xue Gaifeng¹, Fang Hongming² and Zhao Luhan²

¹Hubei Province Key Laboratory of Coking Coal Utilization (Research and Development Center of Wuhan Iron and Steel Limited Company), Wuhan 430080, China
²Hubei Province Key Laboratory of Coal Conversion and New Carbon Material (Wuhan University of Science and Technology), Wuhan 430081, China

The corresponding author’s e-mail address: xhzhang0108@163.com

Abstract. In order to successfully transform coking technology of moisture-free coal, which has energy conservation and environmental protection properties into production, moisture effects on coking course of coal was researched and the caking indices; plastometric indices, Gieseler fluidity, and coke optical texture of coking coal under different moisture proportions were studied. The result showed that when the moisture proportion of charging coal was decreased, the voids among coal particle minished. The size and proportion of pores produced by moisture’s volatilization declined, the expansion pressure produced in coking course increased and inborn plastometric layer’s spreading property was improved. All these made caking indices of coking coal take on increasing trend. They also made the shrinking value x decrease, the solid-soft interval increase, the fluidity and the spreading property of layer among anthracite be improved and coke tight property be improved. These provided many useful conditions for coke with good quality and the decrease of coking wastewater.

1. Introduction

The moisture from the coking coal in the coking production is the main source of coking wastewater. At the same time, the moisture of charging coal increases coking energy consumption. In the general, the time used for the wet coal center to reach 100°C requires more than one third or even half of the total coking time. It is mainly the dehydration stage of coal in coking oven. Therefore, reducing the moisture in the coal is one of the solutions to solve the environmental pollution and high energy consumption problems in the coking industry. With the advancement of coking technology, the moisture in coking oven is gradually reduced to less than 2%. Related technologies include coal moisture control (CMC) process, dry-cleaned and agglomerated pre-compaction system (DAPS), SCOPE21 [1]. The moisture pretreatment process of coking coal is well developed in Japan [2-3]. China still stays in the stage of conventional coal moisture control process, and the moisture controlled is 6% to 8%. The dry-cleaned and agglomerated pre-compaction system is still in the research stage, and there is currently no dry coal coking technology under the moisture of 2% in domestic production.

Due to many advantages of moisture pretreatment process of coking coal, domestic scholars have also carried out related research. Xue et al. [4-6] studied coal moisture’s influence on coking process and coke products, including bulk density, coking speed and coke quality. Lei et al. [7] studied the production of gas and tar and the content of each component on the basis of researching coke quality.

There are many reports on the moisture pretreatment technology of coking coal [8-9]. But it is mainly limited to the distribution characteristics of charging coal, heat transfer, coke quality, chemical
product composition, and the moisture pretreatment solution and its effect. There are Less reports on the effect of coking process and mechanism. In this paper, the effect of moisture pretreatment on the coal caking, fluidity and other properties and the combination with inert material was studied in order to provide a theoretical basis for the development of coking technology in the direction of optimization of coking coal resources, environmental protection and low energy consumption.

2. Experiment

2.1. Raw materials
The blended coal was from coal blending tray; 1/3 coking coal was from Fucun Mine in Shandong province.

2.2. Experiment Methods

2.2.1. Coking experiment. Single coal coking experiment was carried out in a muffle furnace to obtain coke optical tissue; The standard anthracite as an inert substance was choosed to analyzed coking behavior of coal and anthracite.

2.2.2. Analysis method. Proximate analysis of coal was carried out according to GB/T 212-2008; The determination of coal caking index was carried out according to GB/T5447-1997; The determination of coal plastometric indices was carried out according to GB/T 479-2000; Gieseler fluidity of coal was determined according to ASTM D 2639-04; Coke optical texture was observed by a Leica MSP-200 microscope.

3. Results and discussion
The blended coal and 1/3 coking coal were used for analysis and research. The specific proximate analysis indices are shown in Table 1.

Table 1. Proximate analysis of samples

| Mine sites     | V_{daf} (%) | A_d (%) | S_{lad} / % |
|----------------|-------------|---------|-------------|
| Blended coal   | 27.95       | 9.15    | 0.66        |
| 1/3 Coking coal| 34.86       | 7.84    | 0.52        |

3.1. Effect of moisture on coal caking index
The caking index is widely used in coking coal blending production and research. The caking indices of coal under different moisture are shown in Table 2.

Table 2. Caking indices of sample under different moisture

| Total moisture (%) | Caking indices |
|--------------------|---------------|
| 10                 | 74.1          |
| 8                  | 72.9          |
| 6                  | 76.7          |
| 2                  | 79.2          |

It can be seen from Table 2 that when the moisture decreases from 10% to 8%, the caking indices decrease slightly from 74.1 to 72.9, with a difference of 1.2. But according to the national standard GB/T 5447-1997, when the caking index is greater than or equal to 18, the repeatability is less than or equal to 3. So the difference is not obvious. As the moisture continues to decrease, the caking indices of coal generally increase because the dehydration time of coking coal in the muffle furnace reduced. The formation time of plastometric layer advanced and it was well caked with anthracite. The shrinking value increased and tight property of coke was improved. Therefore, the caking indices take on increasing trend [10].
3.2. Effect of moisture on coal plastometric index

Plastometric index is one of the important evaluation indices of coking coal. It is widely used in laboratory research and production tracking. As an important classification index in national standard, it plays an important guiding role in procurement of coking coal.

The thickness value $Y$ reflects the number of plastometric layer and the shrinking $x$ value reflects the shrinking amount of coal after coking. In this paper, Plastometric index was applied for researching the effect of moisture on coal properties. On the basis of same dry coal quality, the moisture of coal samples was adjusted to be 10%, 8%, 6%, and 2% respectively.

| Total moisture (%) | X (mm) | Y (mm) |
|--------------------|--------|--------|
| 10                 | 42.7   | 24.2   |
| 8                  | 37.8   | 22.8   |
| 6                  | 35.0   | 24.5   |
| 2                  | 19.0   | 23.9   |

It can be seen from Table 3 there are no obvious difference about $Y$ value, the highest value is 24.5mm, the lowest one is 22.8mm. According to the national standard GB/T 479-2000, When the $Y$ value is larger than 20 mm, the repeatability is 2 mm. Therefore, it can be considered that there is no obvious difference in $Y$ value. The highest $X$ value is up to 42.7 mm, the lowest one is 19.0 mm. Their difference is very obvious, and the $X$ value decreases as the moisture decreases. This is mainly due to the decrease of the voids among coal particles as the moisture of the coking coal decreases. The size and proportion of the pores formed by water evaporation decreases, the pore walls thickens. The expansion pressure generated during the formation of plastometric layer increases, but the shrinking force and amount are limited. So the shrinking value $X$ appears to decrease. The plastometric volume curves of coal under different moisture are shown in Figure 1.

![Figure 1](image1.png)

It can also be seen from Figure 1 that as the moisture decreases, the expansion degree increases. It is mainly manifested that the volume curve of the plastometric layer gradually changes from the inconspicuous mountain shape to the obvious "Z" mixed with mountain shape. Softening temperature of coal under the moisture 10% and 2% is lower. When the moisture amount is too high, its lost
amount in the initial stage of coking and the voids among coal particles increase, so the pressure plate in the upper part of the coal cup drops earlier and coal shrinks earlier. When the moisture is too low, the heat transfer rate accelerates, the pyrolysis temperature of coking coal advances, the gas volatilizes earlier, so the pressure plate drops and coal shrinks earlier too.

3.3. Effect of moisture on coal fluidity

Gieseler fluidity is an effective way to study the rheologic property and thermal decomposition kinetics of coal [11]. Gieseler fluidity not only measures plastoic amount, but also reflects the quality of plastometric layer. Gieseler fluidity index is very sensitive to coking coal quality. The specific indices are shown in Table 4.

| Total moisture (%) | Softening temperature (°C) | Solid soft interval (°C) | MF (ddpm) |
|-------------------|-----------------------------|--------------------------|-----------|
| 10                | 393                         | 93                       | 1707      |
| 8                 | 394                         | 93                       | 1664      |
| 6                 | 395                         | 93                       | 1534      |
| 2                 | 392                         | 96                       | 1880      |

It can be seen from Table 4 that the softening temperature change of coking coal is consistent with the softening law of the plastometric layer curve. They are all with the lowest softening temperature of coal under the moisture 10% and 2%. When the moisture content is 2%, the solid soft interval of coking coal is broadest, it reaches 96°C; and the fluidity is highest, it reaches 1880 ddp. This is mainly due to the decrease of moisture content and voids among coal particles, and the gas can’t volatilize. So the residence time of three phases of gas, liquid and solid extends. This promotes the formation of more plastometric layer. It’s beneficial to improve the fluidity of the plastometric layer.

3.4. Optical texture of coking coal and anthracite under different moisture content

While the optical texture of coke through a microscope is measured, the distribution of coke pores and the combined state of different coking coal can also be observed. Coke morphology figures of coking coal under the moisture of 10% and 2% are shown in Figure 2. Coke morphology figures of coking coal and anthracite under the moisture of 10% and 2% are shown in Figure 3.

![Coke microstructure of coal under different moisture content](image)

(a) 10% moisture  (b) 2% moisture

Figure 2. Coke microstructure of coal under different moisture content

![Coke microstructure of gas-fat and anthracite under different moisture content](image)

(a) 10% moisture  (b) 2% moisture

Figure 3. Coke microstructure of gas-fat and anthracite under different moisture content
From the pore distribution of coke, the coke obtained under 10% moisture is with the bigger pores, while the pores of coke obtained under 2% moisture are obviously smaller, the number of pores is reduced, and the coke is obviously tight. This is because the coking coal moisture increases, the pores left by moisture volatilization during heating process increase, and the expansion pressure drops, so the plastometric layer formed during the coking process can’t fill more pores. And at the same time it causes the decrease of spreading property of coking coal around anthracite. This can be seen from the microstructure of coking coal and anthracite. When the moisture content is under 2%, the bonding surface of coking coal and anthracite is more, and the bonding state is tighter.

4. Conclusions
Based on the comparison and analysis, it is found that the decrease of coking coal moisture is beneficial to improve caking property and fluidity of the plastometric layer, prolong the residence time of the plastometric layer, and increase the expansion property during coking process. So it promotes the mutual integration of different coking coal, enhances the close combination of coal particles, lays a foundation for the improvement of coke quality, and provides a advantageous basis for the coking coal pretreatment process of moisture. At the same time, it also provides a chance of increasing the amount of inferior and low-cost coking coal.

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