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Effect of Coal Size on Coking Pressure and Coke Strength

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Abstract

Reducing the coking pressure and improving coke strength are important subjects in the coke-making process. Focusing on the fine crushing of coal to achieve them, we investigated the reduction of the coking pressure by a selective fine crushing of high-coking pressure coal and the effect of fine crushing of inertinite on coke strength. As a result, fine crushing of high-coking pressure coals increases the gas permeability of the plastic coal layer, which decreases coking pressure, and in a commercial coke-making plant, the internal pressure and maximum power current of coke pushing were decreased by the fine crushing of high-coking pressure coal. A method of measuring the representative inertinite size using X-ray CT was also established. In addition, our investigation of the relationship between inertinite size and coke strength revealed that the crushing of inertinite of 1.5 mm or more improves coke strength.

1. Introduction

Nippon Steel Corporation has developed dry coal-charging processes for coke-making, such as coal moisture control (CMC)[1] and a dry-cleaned and agglomerated precompaction system (DAPS).[2] With improved coal bulk density thanks to decreased coal moisture, the advantages of higher productivity, energy-saving, and higher coke strength were obtained. High bulk density operation increases the coking pressure (force when the swelling of the molten coal pushes the oven wall) during coal carbonization to a great extent, which increases the force needed for coke cake pushing and in some cases leads to operational problems. Therefore, it is important to control the coking pressure during the dry coal charging processes and thereby Nippon Steel has been studying coal blending techniques to control the coking pressure.[3]

However, as coke ovens have been deteriorating recently, an additional method to decrease coking pressure is required. In addition, the reduction material ratio needs to be decreased for CO_2 reduction in blast furnace operation and the usage ratio of inexpensive semi-soft coking coalneeds to be increased to reduce the coke production cost. Further enhancing the coke strength is also an important task.

One method that may contribute to decreasing the coking pressure and enhancing the coke strength at the same time is fine crushing of coal. Regarding the coking pressure, a previous study has reported that fine crushing of coal is effective[4] and another study has reported that the pressure is somewhat increased.[5] The mechanism of coking pressure decrease caused by fine crushing of coal is unclear. Meanwhile regarding the coke strength, it is considered that the size reduction of inertinite texture (hereinafter, inertinite) in coal by fine crushing of the coal contributes to enhancing the coke strength.[6] However, a method to measure the size of representative inertinite in coal had not been established and thereby the relationship between inertinite size and coke strength was not fully revealed.

This report describes a basic laboratory study on the decrease in coking pressure by fine crushing of high-coking pressure coal and its application to a commercial coke-making plant. In addition, we studied a method to measure the size of representative inertinite. Then, the method was used to measure inertinite size to study the relationship between inertinite size and coke strength in order to investigate target inertinite size required to enhance the coke strength.

2. Main Disclosure

2.1 Coking pressure decrease by fine crushing of high-coking pressure coal[7]

2.1.1 Laboratory-scale investigation of the influence of fine crushing of high-coking pressure coal

(1) Test conditions

(i) Measurement of gas pressure in plastic coal layers using a test coke oven

In a laboratory-scale investigation and the following commercial

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coke-making plant test, high-coking pressure coals A, B, and C were used. The gas pressure in the maximum plastic coal layer of each single coal was measured in a test coke oven[8] (where each single coal was crushed with a coal size of −3 mm 85% and charged at a bulk density of 850 kg/m^3). The pressure was 170 kPa for coal A, 370 kPa for coal B, and 50 kPa for coal C.

Six types of blended coals for which high-coking pressure coals B and C were blended from 25% to 50% were used (tests 1 to 6). In tests 1 to 4, each type of single coal was crushed to target particle size and then blended. In tests 5 and 6, the coals were blended in a predetermined ratio and then crushed into target particle size.

The prepared coal was then charged into a test pail at a bulk density of 850 dry kg/m^3 and carbonized for 18.5 hours in the test coke oven. The internal gas pressure was measured at the oven width center, oven length center, and 120 mm from the oven sole, using stainless steel tube probes with an inner diameter of 1 mm and outer diameter of 2 mm. Previous experiments in our laboratory showed that there was a good correlation between the internal gas pressure measured in this way and the coking pressure measured with a movable wall pilot oven.

(ii) Gas permeability of plastic coal layers

In order to investigate the effect of coal particle size on the gas permeability of plastic coal layers, coal was charged in a constant volume cell and heated with expansion of the coal being restricted. The gas permeability was then evaluated by measuring the pressure drop caused by forced inert gas flow through the plastic coal layer.

Figure 1 illustrates the reactor tube. The coal was placed between SUS wire meshes to hold it. Four reactor tubes containing coal were placed in a heating furnace and nitrogen was charged from the lower section of each reactor tube at 10 cm^3/min. The upper section of the reactor tube was open to the air and connected to a dust collector. The temperature was increased at 10°C/min from the room temperature to 300°C and at 5°C/min from 300°C to 600°C. The pressure was measured with a pressure gauge installed in the lower section of the reactor tube. The density of charged coals A and B was 0.80 g/cm^3.

(2) Results and discussion

Figure 2 shows the relationship between the mean coal particle size and gas pressure in the plastic coal layer. The mean particle size (horizontal axis) in tests 1 to 4 is that of only finely crushed high-coking pressure coals B and C. The mean particle size in tests 5 and 6 is that of the entire blended coal. Figure 2 shows that under all the conditions, as the mean coal particle size is smaller, the gas pressure in the plastic coal layer is significantly lower. These results show that fine crushing of high-coking pressure coal suppresses the gas pressure.

The cause was investigated from the perspective of the gas permeability in the plastic coal layer that was considered as a factor that would control the gas pressure in plastic coal layers. The relationship between the superficial velocity and flow resistance in a packed bed is expressed by Equation (1) according to Darcy's law:

$$u = (k/\eta)\,(\Delta P/L) \quad (1)$$

where u [m/s] is the superficial velocity, k [m^2] is the gas permeability coefficient, η [Pa·s] is the gas viscosity, ΔP [Pa] is the pressure drop, and L [m] is the length of the layer. The gas permeability of the plastic coal layer was described using the pressure drop ΔP.

Figure 3 shows example changes in the pressure drop ΔP with temperature. The figure shows that the pressure drop increases in the plastic temperature range of coal B and it decreases as the coal B particle size becomes smaller. **Figure 4** shows the relationship between the maximum pressure drop and mean particle size of coals A and B. The figure shows that as the high-coking pressure coal is more finely crushed, the pressure drop, ΔP_{max}, significantly decreases, which indicates that the gas permeability in the plastic coal layer is significantly improved. These results indicate that the decrease in the gas pressure in the plastic coal layer as a result of fine crushing of the high-coking pressure coal is caused by improved gas pressure permeability in the plastic coal layer due to the fine crushing.

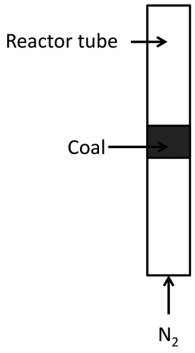


Fig. 1 Reactor tube of plastic coal permeability test

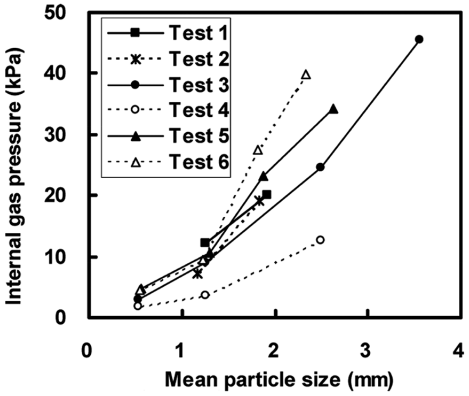


Fig. 2 Effect of mean particle size of coals B and C (in test 1–4) and blended coal (in test 5 and 6) on internal gas pressure[7]

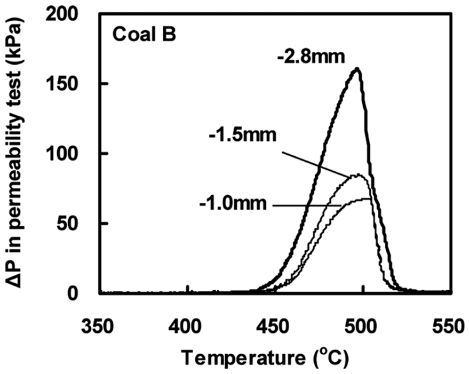


Fig. 3 Change in pressure drop in permeability test (ΔP) with temperature[7]

2.1.2 Fine crushing of high-coking pressure coal at commercial coke-making plant

Based on the findings in the laboratory test, we decreased pushing loads in testing the fine crushing of high-coking pressure coal at the Kimitsu coke-making plant using a few oven chambers. The ra-

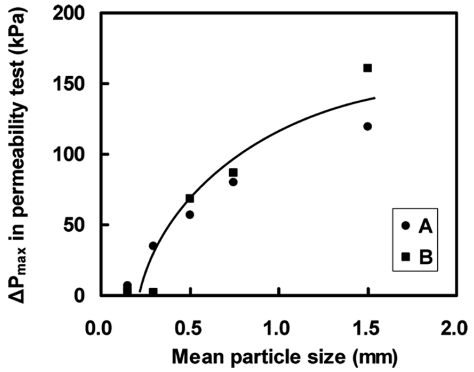


Fig. 4 Effect of coal particle size on maximum pressure drop (ΔP_{max}) measured in permeability test rig[7)]

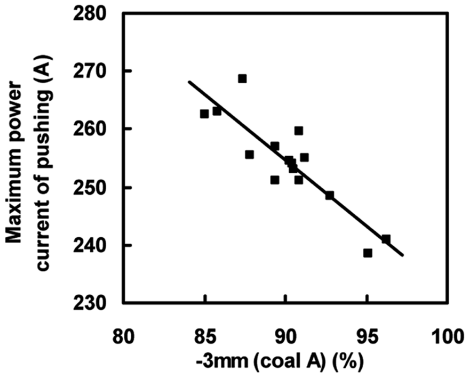


Fig. 6 Relationship between −3 mm% of high coking pressure coal A and maximum power current of pushing[7)]

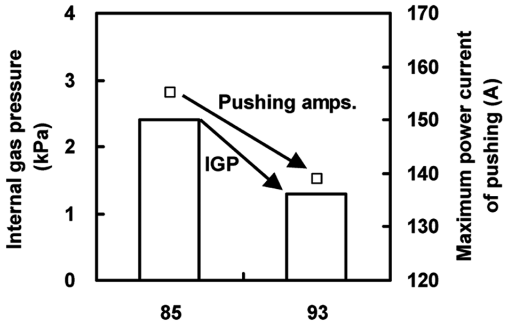


Fig. 5 Effect of particle size of high coking pressure coal B on internal gas pressure and maximum power current of pushing in an actual coke oven chamber[7)]

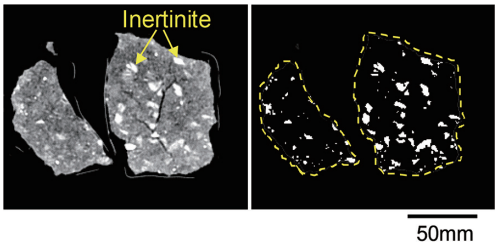


Fig. 7 Distinction of inertinite in coke[9)]

tio of high-coking pressure coal B in the blended coal was maintained constant at 6% and the ratio of −3 mm of coal B particles was increased from 85% to 93%. A stainless tube probe was inserted from the oven door at the oven width center below the charging hole to measure the gas pressure in the plastic coal layer.

Figure 5 shows the gas pressure in the plastic coal layer and maximum power current of pushing against the particle size of crushed coal B. The test results using the commercial coke-making plant confirm that fine crushing of high-coking pressure coal decreases both gas pressure in the plastic coal layer and maximum power current of pushing as shown in Fig. 5.

Furthermore, we conducted fine crushing of high-coking pressure coal at the Oita coke-making plant using all the oven chambers. The ratio of high-coking pressure coal A in the blended coal was maintained constant at 4%. In the 17-day test, the grain size of high-coking pressure coal A was changed from −3 mm 82% to −3 mm 96% step by step. The working rate of the coke oven was 121% during the test period, the flue temperature at the top was 1 145°C, and the moisture of the charged coal was 4.5%. **Figure 6** shows the relationship between the ratio of −3 mm coal A particles and maximum power current of pushing. The smaller the coal A particle size, the lower the maximum power current. These results confirm that fine crushing of high-coking pressure coal decreases the pushing load.

2.2 Method to measure representative inertinite size[9)]

2.2.1 Inertinite size measurement method

Inertinite in coal does not melt during carbonization and thereby its form in the coke is almost similar to that in the coal. On the other hand, vitrinite softens and swells during carbonization and becomes a foamy coke texture. To make it easy to identify inertinite, this study measured the size distribution of inertinite in carbonized coke.

In addition, to improve the representativeness of measurement, the X-ray computed tomography (CT) that could photograph a cross section in a wide range in a short time was used. Regarding a few pieces of lump coke that had agglomerated into one piece from the oven wall to the center of the oven, approximately 20 images of the cross section parallel to the oven wall were photographed. As the imaging conditions, the tube voltage was 120 kV, the tube current was 100 mA, the slice thickness was 1 mm, and the size of a single pixel was 0.5 mm. The total analysis area was approximately 1 500 cm^2.

Figure 7 shows some X-ray CT images of the coke. The CT value in the white sections in the images is high (the X-ray absorption degree is high (high density)) and that in the black sections is low (the X-ray absorption is low (low density)). The porosity of the inertinite in coke is lower than that of the other foaming texture, so it is recognized as a high-density section on CT images. Therefore, inertinite was distinguished from the other texture based on differences in the density and the inertinite size (absolute maximum length) was measured through image analysis. The threshold of the density for distinguishing inertinite was determined as 1.25 g/cm^3 such that, when inertinite for which the particle size had been adjusted to a designated size was added to coal and it was carbonized, the inertinite identified on X-ray CT images of the carbonized coke would be the designated particle size.

2.2.2 Inertinite size measurement results

This method was used to measure changes in the inertinite size in the coke as a result of fine crushing of coal. **Figure 8** shows part of the results. Single coal (total inertinite: 33%) was crushed such that the ratio of −3 mm of particles would be 71%, 89%, and 96%. The crushed coal was carbonized in a test coke oven to produce coke and that was used as samples for X-ray CT measurement.

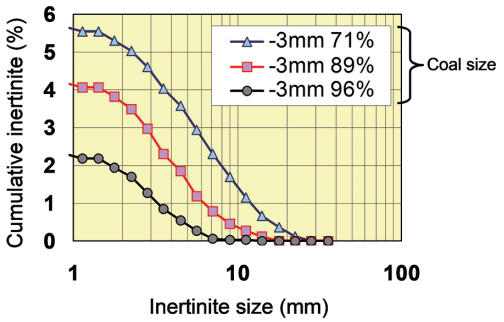


Fig. 8 Change in inertinite size distribution by coal crushing[9)]

Figure 8 quantitatively shows the changes in the inertinite size distribution as a result of finer crushing coal. It used to be difficult to quantitatively evaluate changes in the inertinite size as a result of finer crushing coal because in image analysis using microphotographs, the analysis region was too small. Using an X-ray CT apparatus to enlarge the analysis region has enabled the size distribution of representative inertinite to be measured.

3. Influence of Inertinite Size on Coke Strength

3.1 Test procedures

(1) Adjustment of coal samples

To examine the influence of inertinite size on the coke strength, pure inertinite in various sizes should desirably be used. However, obtaining pure inertinite in the order of several millimeters is difficult. Inertinite in coal is harder than other textures and thereby it is hardly crushed. This characteristic was used to prepare inertinite-concentrated coal as shown below.

First, raw coal of coal A with an entire inertinite ratio of 35.6% was screened with a 15-mm mesh. The lump coal particles on the mesh were primary crushed using a crusher and the crushed samples were screened with a 6-mm mesh. The coal 6 mm or larger is referred to as coal B (inertinite-concentrated coal) in this report.

Next, to produce several types of inertinite-concentrated coal for which only the size was different, coal B was adjusted to particle size fractions of 0.3 to 0.6 mm, 0.6 to 1.2 mm, 2.0 to 4.0 mm, 5.0 to 7.0 mm, and 10 to 15 mm. The samples in 10 to 15 mm were prepared by screening 6-mm or larger coal B particles with a 10-mm mesh and adjusting the particles remaining on the mesh to 10 to 15 mm. To make the texture component of each fraction the same, a mortar was used to lightly crush the coal B particles to adjust the particle size while preventing the generation of particles smaller than the fractions to the extent possible.

(2) Coke production conditions

Coal B (inertinite-concentrated coal) adjusted to each particle size range was added to coal A particles crushed to 1.5 mm by 15%. The blended coal was carbonized in a test coke oven with a width of 420 mm for 18.5 hours to produce coke. The density of the charged blended coal was 850 kg/m^3.

The red-hot carbonized coke was cooled to the normal temperature in nitrogen atmosphere. From the cooled coke cake, two coke lumps that had been agglomerated from the oven wall side to the center of the oven were taken as samples for X-ray CT. In addition, the cooled coke was subject to drop impact tests of 2 m three times using a shutter tester and the drum strength index (JIS K 2151) of the coke was measured.

3.2 Test results

Figure 9 shows some X-ray CT images of the coke lumps for which the size of coal B particles varied. These images show that the size of the remaining inertinite in the coke is almost the same as the particle size of coal B (inertinite-concentrated coal).

Figure 10 shows the inertinite size distribution that was obtained through image analysis of these X-ray CT images and coke drum strength DI^{150}_{15}. The inertinite size of No. 1 and No. 2 was measured by the analysis of microphotographs of the coke due to the resolution of the X-ray CT. As shown in the lower figure of Fig. 10, DI^{150}_{15} of cokes No. 1 and No. 2 is almost the same. Meanwhile, DI^{150}_{15} of cokes No. 3, No. 4, and No. 5 decreases as the inertinite size increases. These results show that the smaller the coarse inertinite in the order of several mm, the greater DI^{150}_{15}; however, DI^{150}_{15} does not increase even when the inertinite is finely crushed into sizes smaller than 1.5 mm. Thus, the inertinite size that starts affecting the coke strength DI^{150}_{15} adversely is approximately 1.5 mm.

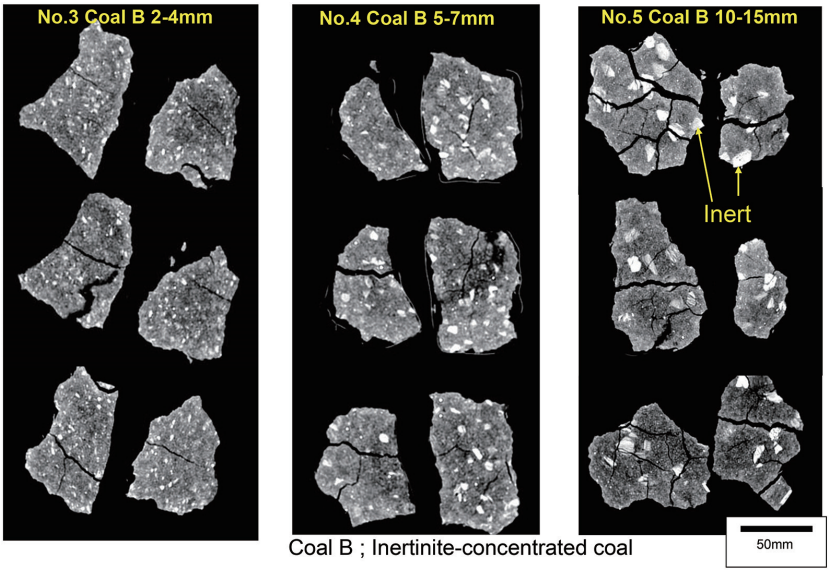


Fig. 9 Inertinite textures in coke with differente size of coal B

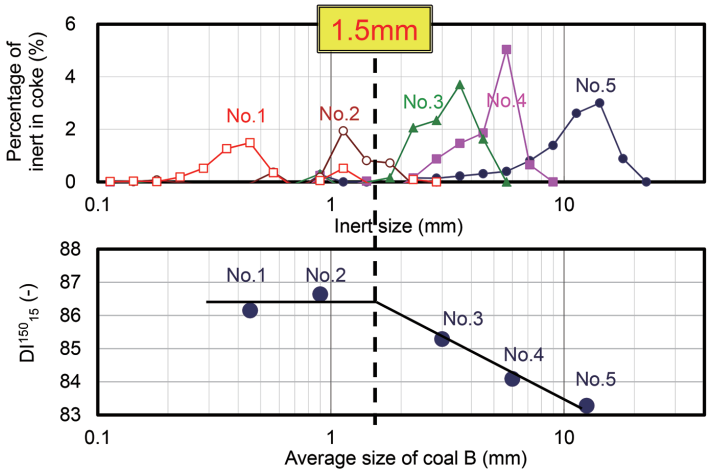


Fig. 10 Size distribution of inertinite texture and effect of inertinite size on coke strength[10)]

4. Conclusion

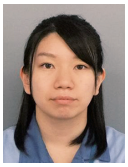
The laboratory tests to study the coking pressure decrease as a result of fine crushing of high-coking pressure coal clarified that fine crushing of such coal increases the gas permeability in the plastic coal layer and decreases the coking pressure. The test using the commercial coke-making plant also showed that fine crushing of high-coking pressure coal decreases the gas pressure and coke pushing load.

In addition, in this study, a method to measure representative inertinite size using an X-ray CT apparatus was established and the method was used to examine the relationship between the inertinite size and coke strength. As a result, as coarse inertinite in the order of several millimeters is more finely crushed, the coke strength DI^{150}_{15} increases; however, DI^{150}_{15} does not increase even when inertinite is finely crushed into sizes smaller than 1.5 mm. That is to say, the inertinite size that starts affecting the coke strength DI^{150}_{15} adversely is approximately 1.5 mm.

These findings confirm that fine crushing of coal is an effective means to decrease the coking pressure and enhance the coke strength. However, in general, fine crushing of coal may decrease the coke productivity and coke strength due to decrease in the bulk density of charged coal or may result in an increase in the pushing loads because more carbon may adhere to the oven walls due to increased powder. Therefore, in actual operation, attention should be paid to such influence in the fine crushing of coal.

References

1) Wakuri, S. et al.: AIME 45th Ironmaking Conference Proceedings. 303 (1986)
2) Nakashima, Y. et al.: 2nd Int. Cokemaking Congr. London, UK, 1992, p. 518
3) Nomura, S. et al.: Fuel. 83, 1771 (2004)
4) Loiso, R. et al.: Coke Quality and Production. London, Butterworth Publications, 1989, p. 353
5) Brysh, O. P. et al.: Research Bulletin 11. Chicago, Institute of Gas Technology, 1951
6) Miura, Y. et al.: J. Fuel Soc. Jpn. 60, 771 (1981)
7) Nomura, S. et al.: Tetsu-to-Hagané. 96, 265 (2010)
8) Nomura, S. et al.: Fuel. 75, 801 (1996)
9) Kubota, Y. et al.: CAMP-ISIJ. 30, 664 (2017)
10) Kubota, Y. et al.: Testu-to-Hagané. 92, 833 (2006)



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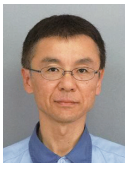

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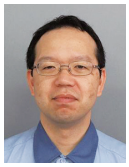

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