NIPPON STEEL TECHNICAL REPORT No. 94 JULY 2006

UDC 662 . 741 : 622 . 33

Coal Blending Theory for Dry Coal Charging Processes

Seiji NOMURA*[1] Takashi ARIMA*[1]
Kenji KATO*[1] Kouichi YAMAGUCHI*[2]

Abstract

Nippon Steel has successfully developed dry coal charging processes such as CMC and DAPS for cokemaking. In this report the fundamental aspects of the coal blending theory for dry coal charging processes are investigated. The investigation has made it clear that even in cases of high coal bulk density due to dry coal charging processes, it is possible to control coking pressure by adjusting the blending ratio of a low rank and slightly caking coal; and it is also possible to produce high quality coke by adjusting the total dilatation of the blended coal at a suitable level. This blending theory has been applied to cokemaking plants and helps to increase the blending ratio of cheap slightly caking coals.

1. Introduction

Nippon Steel Corporation developed dry coal charging processes for coke production: the coal moisture control (CMC) process was commercially applied at Oita Works in 1983[1)], and the dry-cleaned and agglomerated pre-compaction system (DAPS) at the same Works in 1992[2, 3)]. The CMC process decreases the moisture content of coal to 5 to 7% and the DAPS process to 2 to 4%, approximately. A decrease in the moisture content in charging coal not only improves coke quality but also enhances the productivity of the plant and decreases energy consumption. These coal drying technologies have spread to the other steel works of Nippon Steel, and practically all the coke ovens of the company now use dry coal as the feedstock.

While these processes improve coke quality because the drying increases the charging bulk density of coal (see **Fig. 1**), the increase in the bulk density increases the swelling pressure of coal on the coking chamber walls, leading to the possibility of troubles in the coke pushing (discharging) operation. For this reason, control of the swelling pressure is of great importance in the coke oven operation with dry coal.

There have been many reports on the coal blending for metallurgical coke production[4)] and the swelling pressure in the coke production process[5)], but all of them are based on the widely practiced wet coal charging, and little has been known about the coal blending and swelling pressure control under the condition of dry coal charging at a high bulk density.

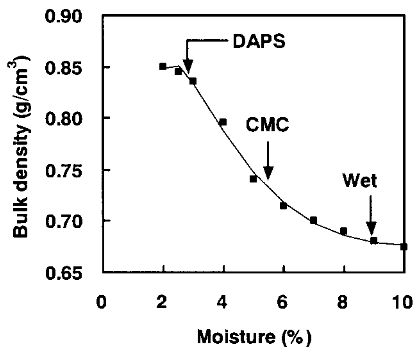

Fig. 1 Relationship between moisture and bulk density

In view of the above, this paper presents the coal blending technology for producing high-strength coke while controlling the swelling pressure under dry coal charging.

2. Test Method

2.1 Swelling pressure (internal gas pressure in softening and melting zone)

Five coal brands A to E shown in **Table 1** were used for the test;

*[1] Environment & Process Technology Center

*[2] Oita Works

Table 1 Characterization data for the coals used

Coal	Proximate analysis (mass% db)		Dilatometry Total dilatation	Gieseler plastometry Maximum fluidity	Reflectance
	VM	Ash	(vol %)	(log MF/ddpm)	(ave.) (%)
A	18.6	10.0	50	1.65	1.48
B	28.7	8.5	298	4.14	1.02
C	27.2	7.9	88	3.03	0.97
D	36.2	8.1	32	2.34	0.68
E	36.3	8.8	27	1.60	0.72
F	20.7	9.8	102	2.56	1.41
G	23.8	8.9	104	2.93	1.28
H	35.7	9.1	29	2.08	0.79
I	18.5	9.7	65	1.71	1.57
J	20.9	9.6	28	1.45	1.42
K	25.8	9.0	260	3.84	1.14
L	25.7	8.0	108	2.53	1.15
M	34.4	6.9	189	4.31	0.89
N	36.4	9.7	65	2.57	0.76
O	36.1	10.2	19	1.96	0.74
P	36.6	10.4	30	2.39	0.72

coals B to E were mixed, individually, by prescribed ratios with coal A, which has a high swelling pressure. Coals D and E are of a low coal rank (average reflectance of vitrinite of 0.8 or less) and a poor caking property (maximum fluidity of 2.5 or less); a coal brand that demonstrates the figures between the parentheses above is hereinafter referred to as a low-rank and slightly caking coal (SCC). After controlling the moisture content to 3%, each of the coal blends was charged into an electrically heated test coke oven (chamber width 420 mm, length 600 mm, height 400 mm, see **Fig. 2**) at a bulk density of 0.85 g/cm^3, and carbonized into coke for 18.5 h. Here the temperature of the electric heater was controlled so as to simulate the heating pattern of coal in a real coking chamber under a flue temperature of 1250℃. In addition to the above, three coal blends B1 to B3 were prepared using coals F, G and H shown in Table 1; here, the mixing ratio of coal H, a SCC, was set at 10, 22 and 35%, respectively (see **Table 2**). Changing the moisture content from 3 to 10%, each of B1 to B3 was charged into the test coke oven at a bulk density of 0.68 to 0.88 g/cm^3 and carbonized.

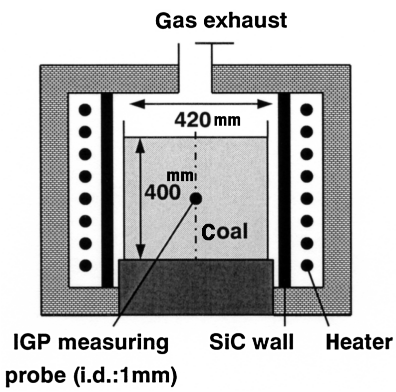

Fig. 2 NSC pilot coke oven

Table 2 Blending composition of coal blends B1, B2 and B3

Coal	Blend		
	B1	B2	B3
F	20%	20%	20%
G	70%	58%	45%
H	10%	22%	35%

The internal gas pressure of the softening and melting zone (hereinafter referred to as the IGP) was measured at the center of the chamber width (210 mm from either wall) and 120 mm above the chamber floor using a stainless steel pipe 1 mm in inner diameter and 2 mm in outer diameter [6]. Note that, using a test coking chamber with movable walls, previous confirmations were made that there was a correlation between the IGP and the swelling pressure of coal, and thus, they are hereinafter considered as synonymous with each other.

2.2 Coke strength

Controlling the charging bulk density to 0.70, 0.80 and 0.90 g/cm^3 and the moisture content to 9, 5 and 3%, respectively, each of the eight coal brands I to P of Table 1 were carbonized into coke using the test coke oven, and measured the drum indices DI^{150}_{15} (the percentage mass fraction of the grains larger than 15 mm in size after 150 revolutions in a drum tester) and DI^{150}_{6} (the same of the grains larger than 6 mm) of the product coke. Besides the above, a variety of coal blends were also carbonized into coke using the same test coke oven at charging bulk densities of 0.70 and 0.83 g/cm^3, and the drum index of the product coke was measured. Furthermore, the drum index was measured of the coke produced using blends B1, B2 and B3 at charging bulk densities of 0.68, 0.75 and 0.82 g/cm^3, respectively.

2.3 Caking property

The total dilatation and maximum fluidity of each coal brand used for the tests were measured according to JIS M 8801. At the measurement of the total dilatation, the weight of the coal sample piece was also measured in addition to the volume.

3. Test Results and Discussion

3.1 Internal gas pressure of softening and melting zone under dry coal charging

Fig. 3 shows the relationship between the blending ratio and IGP of two-brand blends of coals A + B and A + C, and **Fig. 4** the same of coals A + D and A + E. Fig. 3 shows that, when caking coals B and C containing 27 to 29% volatile matter were mixed with coal A of a high swelling pressure, the IGP of the blend was near the weighted

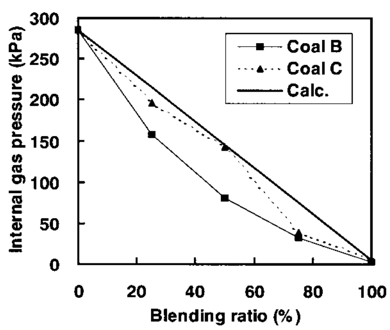

Fig. 3 Effect of blending ratio of a caking coal, B and C, with coal A, on internal gas pressure

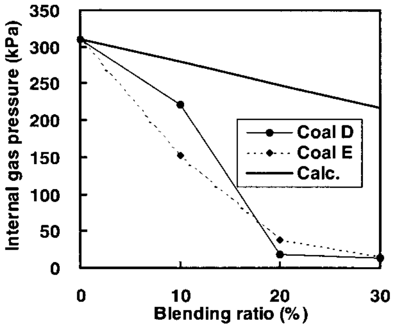

Fig. 4 Effect of blending ratio of a low rank and slightly caking coal, D and E, with coal A, on internal gas pressure

average of the individually measured swelling pressures of the material coal brands. On the other hand, Fig. 4 shows that, when coal D or E, either of which is a SCC, was mixed with coal A, the IGP of the blend was significantly below the weighted average.

Because of the low coal rank, coal D or E begins to soften and melt at a temperature lower than coal A does, and when coal A softens and melts, coal D or E has already resolidified. For this reason, coal D or E presumably serves as the paths of the gas coming from the softening and melting zone of the high-swelling-pressure coal A, lowering the IGP of the zone (see **Fig. 5**).

Fig. 6 shows the relationship between the charging bulk density and IGP. The graph indicates that, as has been reported, the increase in the IGP was accelerated as the bulk density increased. On the other hand, the IGP fell as the blending ratio of SCC increased; the graph shows that the IGP was substantially the same when the charging bulk densities of B1, B2 and B3 were 0.68, 0.75 and 0.82 g/cm^3, respectively. The above indicates that, at a high charging bulk density under dry coal charging, it is possible to maintain the swelling pressure at the level of wet coal charging (a bulk density of 0.68 g/cm^3) by increasing the mixing ratio of a SCC. However, the question here is if or not it is possible to maintain the same coke strength with the increased blending of a SCC.

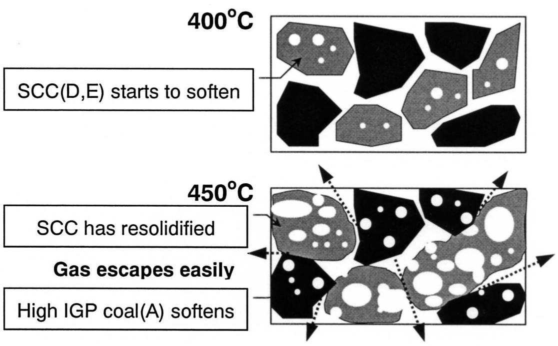

Fig. 5 Suppression of internal gas pressure by blending low rank and slightly caking coal

3.2 Coke strength under dry coal charging

3.2.1 Relationship of coke strength with bulk density and total dilatation of charging coal

Fig. 7 shows the relationship between the coke strength and charging bulk density of different coal brands used singly, without blending with other brands. Here, coke strength was evaluated using the DI^{150}_{6}, which is considered to represent the surface breakage strength of coke[7]. While the DI^{150}_{6} increased as the bulk density increased, the relationship between the two was significantly different from brand to brand. **Figs 8 and 9** show the relationships of the DI^{150}_{6} with the total dilatation and maximum fluidity, respectively. As has been conventionally considered, the DI^{150}_{6} tended to increase as the maximum fluidity increased[4], but the graphs show that the correlation of the DI^{150}_{6} with the total dilatation was stronger than that with the maximum fluidity, and that the DI^{150}_{6} fell drastically when the total dilatation became smaller than a certain threshold value. What is more, the threshold total dilatation value shifted to the lower side as the bulk density increased. It was presumed that the mechanism by which the total dilatation exercises influence over the DI^{150}_{6} as described above is as follows.

Fig. 10 schematically shows the formation process of the pore structure of coke[8]. Note that the size of coal grains is widely varied in reality, and smaller grains fill the voids between larger grains, but the smaller grains are omitted in Fig. 10 for simplicity's sake. At the time of charging coal into a coking chamber, coal grains contact with each other only partially. When the temperature rises to roughly 400 ℃, the grains soften and expand to fill the voids between themselves. When the expansion of the coal grains is larger than the volume of the voids between them, they fuse with each other in large contact areas to form strong bonding, but when the expansion is smaller than the void volume, on the other hand, coal grains cannot form strong bonding between them, and as a result, the strength of the product coke is low. Thinking as above, the initial bulk density and the dilatation property of coal are important for the fusion of coal grains.

3.2.2 Relationship between void filling ability of coal and coke

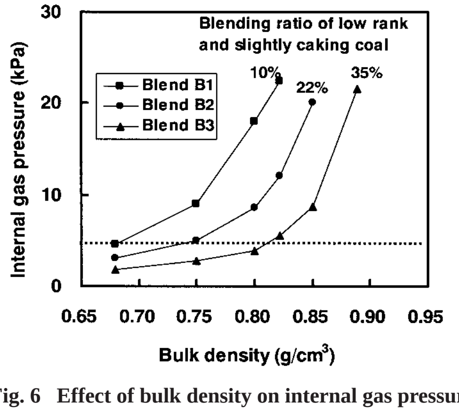

Fig. 6 Effect of bulk density on internal gas pressure

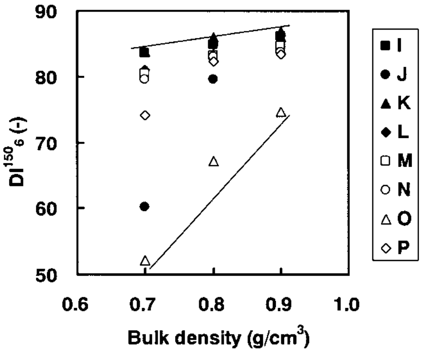

Fig. 7 Effect of bulk density on DI^{150}_{6}

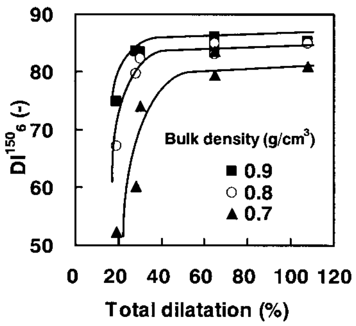

Fig. 8 Effect of total dilatation on DI^{150}_{6}

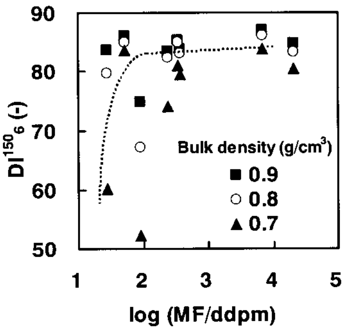

Fig. 9 Effect of maximum fluidity on DI^{150}_{6}

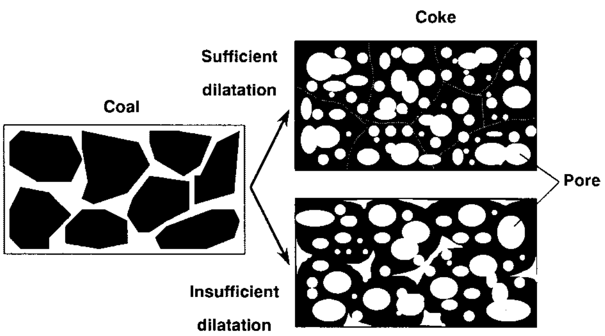

Fig.10 Coal expansion and pore formation

strength

In consideration of the above, it was thought that the dilatation property of coal and the bulk density at the charging should be considered equivalent to each other from the viewpoint of filling the voids, and introduced a concept of "specific dilatation volume" as a quantitative index for evaluating the influence of the dilatation property and bulk density of coal over the coke strength. The specific dilatation volume was defined using the volume of a unit mass of coal after expansion, as schematically illustrated in **Fig. 11**, and calculated it as the ratio of the volume of a formed coal specimen after expansion at a dilatometer test (the height of the expanded coal specimen × sectional area of retort) to the mass of the specimen. The product of the charging bulk density (g/cm^3) and the specific dilatation volume (cm^3/g) is a dimensionless number, and it serves as a parameter, so to speak, of the degree to which the expansion of coal grains fills the voids (void filling ability).

Fig. 12 shows the relationship of the DI^{150}_{6} with the product of the charging bulk density and specific dilatation volume. The graph demonstrates that the introduction of the concept of the specific dilatation volume makes it possible to express the influence of the dilatation property and charging bulk density of coal over the coke strength with a single curve. To maintain the DI^{150}_{6} at a sufficiently high level, it is necessary only to make the product of the charging bulk density and specific dilatation volume larger than a certain value. In other words, it is possible to produce high-strength coke while controlling the swelling pressure of coal by blending a SCC, which suppresses the swelling pressure, by such an amount that the product of the charging bulk density and specific dilatation volume falls within a range where a target coke strength (DI^{150}_{6}) is achieved.

Fig. 13 shows the relationship between the total dilatation of a variety of coal blends and the DI^{150}_{6} under charging bulk densities of

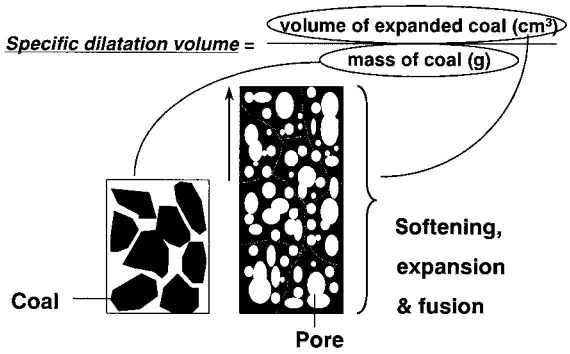

Fig.11 Definition of specific dilatation volume

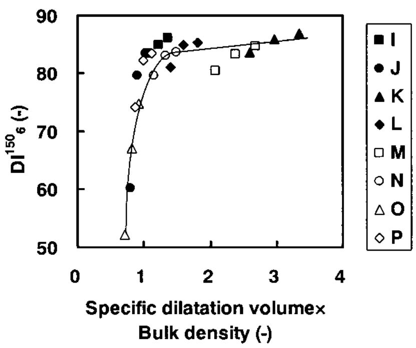

Fig.12 Relationship between the product of specific dilatation volume by bulk density and DI^{150}_{6}

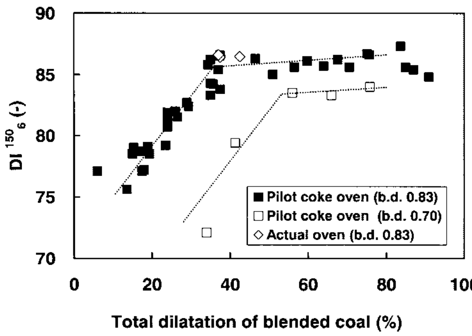

Fig.13 Relationship between total dilatation of blended coals and DI^{150}_{6}

0.70 and 0.83 g/cm^3. The graph shows that, as seen with Fig. 8, the DI^{150}_6 decreases as the total dilatation of the coal blends decreases, and the DI^{150}_6 can be maintained at a high level by keeping the total dilatation larger than a certain value. The graph also shows that an increase in the charging bulk density causes the turning point of the curve (the point at which the DI begins to fall drastically) to shift to the low-total-dilation side.

3.2.3 Application of coal blending theory to commercial coke production

The plotting of Fig. 13 marked with ◇ shows examples of the application of a coal blending theory based on the void filling ability described above to the coke production at Nippon Steel's Oita Works (at a charging bulk density of 0.83 g/cm^3). To minimize the coke production costs while maintaining the DI higher than a certain value, commercial coke ovens are requested to maximize the blending ratio of economical SCCs of low total dilatation. The plotting shows that, as a result of coke quality design applying the coal blending theory based on the product of the charging bulk density and specific dilatation volume (void filling ability), both a high DI^{150}_6 and a low total dilatation are realized by maximizing the blending ratios of the economical SCCs within the limit of not adversely affecting the DI.

3.2.4 Swelling pressure control and production of high-strength coke under dry coal charging

Fig. 14 indicates that, in spite of the different mixing ratios of the SCC, coal blends B1, B2 and B3 showed substantially the same DI^{150}_{15} and IGP when they were charged at bulk densities of 0.68, 0.75 and 0.82 g/cm^3, respectively. This means that, by increasing the mixing ratio of a SCC, it is possible to maintain the coke strength at a high level and at the same time suppress the increase in the swelling pressure due to a higher charging bulk density. What Fig. 14 shows is examples of only a limited number of coal blends, but it is possible to design coal blending employing a wider variety coal brands to maintain or improve the coke strength and keep the swelling pressure at a low level under a high charging bulk density.

In the operation of Nippon Steel's coke ovens, adequate blending of SCCs has controlled the swelling pressure to a low level and the coke strength to a high level, in spite of a high bulk density due to dry coal charging.

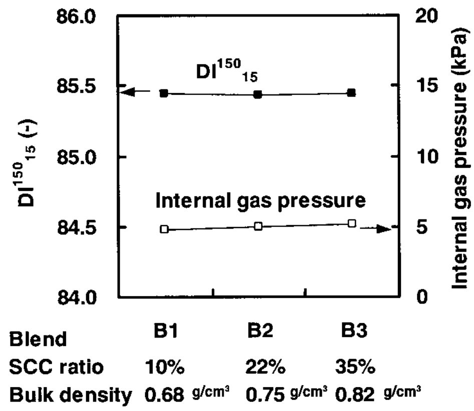

Fig.14 Effect of bulk density and the blending ratio of low rank and slightly coking coal on DI^{150}_{15} and internal gas pressure

4. Summary

A series of studies into coal blending technology for producing high-strength coke, while adequately controlling the swelling pressure of coal under dry coal charging, yielded the following conclusions:

(1) Even under the condition of a high charging bulk density under dry coal charging, it is possible to control the swelling pressure of coal to a low level and produce high-strength coke by blending low rank, poorly caking coals by an adequate amount.

(2) When blending the low rank, poorly caking coals, controlling the dilation property of the blended coal is important: maintaining the dilation property of the blended coal within an adequate range in relation to the charging bulk density makes it possible to produce high-strength coke.

The coal blending technology presented herein has been successfully applied to the operation of commercial coke ovens of Nippon Steel to increase the use of economical, poorly caking coals. Further improvement of the technology for increased use of poorly caking coals will enhance our capability to appropriately cope with the expected deterioration of world coal resources.

References

1) Wakuri, S. et al.: AIME 45th Ironmaking Conference Proceedings. 1986, p.303
2) Nakashima, Y. et al.: 2nd Int. Cokemaking Congr. London, UK, 1992, p.518
3) Tanaka, S. et al.: AIME 56th Ironmaking Conference Proceedings. 1997, p.139
4) Miura, Y. et al.: Trans. ISIJ. 21, 518(1981)
5) Tucker, J. et al.: 2nd Int. Cokemaking Congr. London, UK, 1992, p.40
6) Nomura, S. et al.: Fuel. 75, 801(1996)
7) Arima, T. et al.: Tetsu-to-Hagané. 78, 1101(1992)
8) Arima, T.: Tetsu-to-Hagané. 87, 274(2001)