Effects of Low-grade Coke on the Operation of an Experimental Blast Furnace*

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Synopsis

In August 1975, the experimental blast furnace in the Institute of Industrial Science, The University of Tokyo, was operated first with ordinary coke (of 90.8 in DI_{15}^{30}) and then with low-grade coke (of 88.7 in DI_{15}^{30}) specially made for comparison. The latter caused a marked increase of pressure drop (especially in the lower part of the furnace) and irregular stock-descent which was often followed by obstinate hanging. In situ observations by a fibre-scope within the furnace and later examinations of samples taken therefrom showed a severe disintegration of the coke, the accumulation and fluidization of resultant coke fines.

The coke fines were extremely porous and their micro strength was much lower than that of large particles found in the vicinity. Laboratory experiments on the degradation of the two grades of coke by gasification with CO_2 in the presence of alkali vapour showed that:

- (1) the gasification reaction is not only accelerated but also localized to the surface zone of coke particles by some catalytic action of alkali;
- (2) the acceleration and localization are more remarkable in the ordinary coke whose initial porosity is smaller;
- (3) the localization seems to reduce the degradation of each coke particle, but it magnifies the difference in the degradation between the two grades of coke.

These results suggest that gasification with CO_2 in a high-temperature region near the raceway could be at least one of the main causes that led to the severe disintegration of the low-grade coke.

I. Introduction

As was reported previously,¹⁾ furnace irregularities due to high-temperature degradation of coke happened to appear in the 25th operation of the experimental blast furnace. However, the analysis of the results was insufficient because of the accidental character of the conditions.

In the 26th operation carried out in August 1975, it was tried to reproduce them and to investigate the mechanism of degradation as well as disintegration, by using low-grade coke specially made for the purpose. According to expectation the furnace behavior was very irregular when ordinary coke was replaced with the low-grade coke. Direct observations with a

fibre-scope and surface appearance of samples taken out of the furnace showed clearly that the abnormal behaviors resulted from formation and accumulation of a large quantity of coke fines in the lower part of the furnace.

The difficulties in understanding the "intrinsic nature of hot strength of coke" have prevented the authors from coming to a definite conclusion on the mechanism of degradation and disintegration, and researches on the mechanism of degradation is still continued. The following is a summary of the investigations and researches so far.

II. Equipments

1. Blast Furnace and Accessory Equipments

The inner volume and the profile of the experimental blast furnace are the same as those described before.²⁾ Accessory equipments and facilities are also virtually unchanged.

2. Positions of Observation

Six slightly inclined holes for direct observation were made through the furnace wall in the lower part, as shown in Fig. 1. Five of them faced to the tuyere No. 1 or its upper part and made possible the radial movement of an observing probe. The rest one had a direction lateral to the raceway of the tuyere No. 2. The arabic numerals in Fig. 1 represent the positions of observation.

3. Positions of Sampling

Two horizontal and one slightly inclined sampling holes were made through the shaft wall. Two more inclined ones were made in the lower part. The arabic numerals in Fig. 2 represent the positions of sampling in each direction.

Fig. 1.
Positions of direct observation

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Fig. 2.
Directions and positions
of sampling

III. Properties of Coke

Table 1 shows some important properties of the two grades of coke used in the operation. The ordinary and low-grade coke are designated “ A ” and “ B ”, respectively.

It can be seen that coke B is inferior in all properties except chemical composition, but its DI_{15}^{30} , the index of cold strength, does not very much differ from that of coke A.

IV. Outline of Operation

Average conditions and results of base (by coke A) and test (by coke B) operation are shown in Table 2.

Coke was crushed and sized from 10 mm to 20 mm. The harmonic mean sizes were 11.65 mm(A) and 12.17 mm(B), respectively.

Only self-fluxing sinter of 55.58%T.Fe and 1.56 basicity (CaO / SiO₂) was used as burden. Some quantities of quartzite were added to adjust basicity. Both of the materials were sized from 3 mm to 10 mm.

Hot metal was tapped every three hours, during which slag was flushed two times.

V. Features of Furnace Irregularities

1. Irregular Running

About 30 hr after the complete change of coke from A to B, blast pressure began to rise, and the descent of stock column became more and more irregular (as shown in Fig. 3) and eventually the stock hung (in the upper part near stock-line) so obstinately that it had to be thrust down artificially.

After that, the furnace running was comparatively smooth for a time, and then the stock column tended to stagnate or slip down and at last came to hang again. Thus the sequence was repeated more and more frequently and finally the operation could hardly be continued.

Gas pressure distributions along the furnace height shown in Figs. 4 to 6 indicate that:

(1) their general patterns in the test period resemble that observed when stock column becomes less permeable owing to an increased liquid hold-up just

Table 1. Properties of the coke

Coke	A	B
Proximate analysis (%)		
Fixed carbon	86.58	86.38
Volatile matter	0.98	1.03
Ash	12.44	12.55
Reactivity Index (%) ^{*1}	24.8	34.6
Porosity (%)	45.1	47.4
Strength Index (%)		
DI_{15}^{30}	90.8	88.7
TI_{25}^{1400}	54.7	45.1
MSI +28 mesh ^{*2}	54.5	43.9
MSI +48 mesh ^{*2}	70.8	63.1
MDI ^{*3}	82.3	75.3
IDI (initial) ^{*4}	88.8	83.6
IDI (after reaction) ^{*5}	63.9	45.2

Note :

^{*1} Reactivity index represents the weight loss (percentage) of a coke sample subjected to the treatment described in ^{*4}.

^{*2} MSI+28 (or +48) mesh is determined as the weight percentage of coke with sizes over 28 (or 48) mesh after treatment for 32 min in a cross-shaped capsule of 25.4 mm in diameter and 304.8 mm in length and breadth, rotated with a rate of 25 rpm around a horizontal normal to the capsule at its center. Initial coke size is adjusted to be 1 to 2 mm, and the total weight of coke is 2 g.

^{*3} MDI is determined as the weight percentage of coke with sizes over 2.38 mm after treatment for 30 min in a horizontal steel-drum 150 mm I.D. and 150 mm long rotated by the rate of 50 rpm, with 25 steel-balls of 20 mm diameter in it. Initial coke size is adjusted to be 11.0±1.5 mm, and the total coke weight is 100 to 150 g.

^{*4} IDI is determined as the weight percentage of coke with sizes over 10 mm after treatment for 30 min in a steel-drum 130 mm I.D. and 700 mm high. The drum is rotated by the rate of 20 rpm around a horizontal axis crossing normally to the drum axis at its middle point. Coke size is controlled to be 20±1 mm, and the total coke weight is 200 g.

^{*5} 200 g of dry coke of the same size as above, contained in a capsule 81 mm I.D. and 235 mm high, is subjected to reaction at 1 100°C with 100%CO₂ flowing at the rate of 5 l/min for 2 hr. Heating of the capsule from 800°C to 1 100°C and its cooling to room temperature are carried out in N₂ atmosphere for 1 hr. IDI after reaction is determined in the same manner as above at room temperature.

Table 2. Conditions and results of operation

			Base	Test
Blast :	Volume (dry) (Nm ³ /min)		4.55	4.33
	Temperature (°C)		844	826
	Pressure (kg/cm ²)		0.149	0.182
	Moisture (%)		2.53	2.33
Charge :	Coke Base (kg)		10	10
	Burden Ratio (O/C)		2.49	2.33
Hot Metal :	C (%)		4.15	3.93
	Si (%)		0.97	1.00
	S (%)		0.042	0.075
	Production (t/d)		3.540	3.280
Slag :	Basicity (CaO/SiO ₂)		1.29	1.25
	Al ₂ O ₃		12.4	12.6
	FeO		0.48	0.62
	Ratio (kg/t H.M.)		427	527
Top Gas :	CO (%)		24.3	24.9
	CO ₂ (%)		15.4	14.5
	H ₂ (%)		1.36	1.36
	Temperature (°C)		269	278
Ore Ratio (kg/t H.M.)			1 688	1 690
Coke Rate (kg/t H.M.)			678	709

Fig. 3. Frequency-charging interval relationship

before tapping in the basic period (compare a dotted line in Fig. 4 with those in Fig. 5);

(2) the use of coke B caused a marked increase of pressure drop in the lower part near the tuyere, and the increase became extremely large in case of abnormal running (Figs. 5 and 6);

(3) the increase of total pressure drop tends to bring about a closer packing in the top part of the furnace, where the obstinate hanging occurred.

Fig. 4. Vertical distribution of gas pressure in the base operation

Fig. 5. Vertical distribution of gas pressure when the furnace was in relatively normal and smooth operation in the test period

2. Informations Obtained by Direct Observations

Direct observations by a fibre scope described in the previous paper²⁾ provided the following information.

(1) Exceedingly more coke fines or small-size coke particles fluidizing above the raceway (at positions D-4.0 and E-4.0) are found in the test period than in the basic one (Photo. 1).

(2) In the test period, a large quantity of coke fines is blown up to high level G and it is caught by softened ore-layers, which, naturally, become less permeable and slip down intermittently.

(3) The depth of the raceway in the test period is

Fig. 6. Gas pressure distribution in case of abnormal running

Fig. 7. Mean sizes of coke particles taken out of furnace in operation

(a) base operation (at D-4.0)
(b) test operation (at E-4.0)
Photo. 1.

Coke fines observed above the raceway

definitely smaller than that in the basic period because of the accumulation of coke fines in the center of the furnace, resulting in an increased peripheral gas flow.

3. Informations Provided by Sampling

Coke samples were taken out of the operating furnace by the same apparatus as described previously.²⁾ The results of investigation on the samples are summarized as follows.

(1) Mean sizes of coke B are much smaller than those of coke A in all positions except level IV, where sampling of coke A failed. (See Fig. 7)

(2) Coke particles smaller than 5 mm are distinguished from larger ones by distinctly smaller MSI. (See Fig. 10) They have an extremely porous structure as shown in Photo. 2.

4. Results of Investigations on Cooled Stock Column

The investigations were carried out after the furnace cooled down to room temperature. The results shown in Figs. 8 to 10 indicate that:

Photo. 2. Porous structure of coke fines

(1) degradation of coke B occurs below the 8th to 10th layer and is more distinct in the periphery than in the center (Figs. 8 and 9);

(2) coke fines under 5 mm in size are found not only in the periphery of the 14th layer but also in the center of lower layers; the fines are characterized by

Fig. 8. Distributions of the mean coke size and the fine fraction in the cooled stock column (C-1 . . . 19 are the levels of coke layer)

Fig. 9. Distribution of MDI and the alkali content in the cooled stock column

Fig. 10. Distribution of MSI in the cooled stock column

low MSI as shown in Fig. 10;

(3) typical distribution patterns of water-soluble alkali species are seen (Fig. 9); many degraded coke particles had some macroscopic and microscopic cracks

and were extremely brittle.

The facts and information described in 5.1~5.4 are clear enough for us to consider the furnace irregularities as that a large quantity of coke fines formed from disintegration of coke B (probably below the lower part of shaft), accumulated gradually in the furnace (especially in the lower region), and made the stock column less permeable.

VI. Laboratory Researches on the Mechanism of Degradation of Coke B

Some laboratory experiments were carried out to verify the two hypothetical degradation mechanisms of coke B, attack by alkali and by CO_2 .

1. Experiments on Alkali Attack

1. Methods

25 g of coke sized from 9.52 mm to 12.7 mm was put into a reactor made of stainless tube of 55 mm I.D. heated in an electric-resistance furnace, and exposed to alkali vapor (generated by heating KOH in the same reactor and carried by N_2 with 4 l/min flow rate) at 800° to 1 000°C for 1 hr.

2. Results

The more alkali was absorbed, the more coke particles cracked and the more sharply their MSI decreased. The degradation of coke A by this mechanism was more severe than that of coke B (Fig. 11).

2. Experiments on CO_2 Attack

1. Methods

40 or 150 g of coke of the same size as above was

Fig. 11. Degradation of coke due to alkali-adsorption

Fig. 12. Effect of alkali on the reactivity of coke

Fig. 13. Decrease of MSI due to reaction

Fig. 14. Decrease of MDI due to reaction

subjected to reaction with an N_2 - CO_2 mixture of 4 l/min flow rate at 1050°C for 1 to 2 hr. Similar experiments were also performed in the presence of alkali vapor. The same apparatus as above was used.

2. Results

(1) As shown in Fig. 12, a difference in reactivity between the two grades of coke tends to disappear in the presence of alkali.

(2) Generally, MSI decreases as the reaction proceeds, but the decrease seems to be retarded by the presence of alkali (Fig. 13).

(3) The difference in MSI between the two grades, which tends to disappear at some degree of reaction, seems to be widened by the presence of alkali (Fig. 13).

(4) As for the decrease and the difference in MDI, the tendencies are similar to those in MSI. Moreover, the decrease in MDI of coke B is accelerated at a reaction degree of about 10%, resulting in a larger difference between the two grades of coke. The effect of alkali on MDI is similar to that on MSI (Fig. 14).

3. Discussion

The apparent retardation of the coke degradation

in the presence of alkali can be explained as a result of its catalytic action that leads to the localization of reaction to a surface zone of each coke particle. The localization should bring about a high degree of reaction in the zone even when overall degree is not so high. Very low carbon contents of fines under 1 mm size generated during the reaction in the presence of alkali seems to support this view (Fig. 15). Thus, the acceleration of the difference in MSI between the two grades of coke with the progress of reaction suggests that the inferiority of coke B manifests itself clearly at a high degree of reaction.

Explanation for the change of MDI shown in Fig. 14 is not straightforward because a change of reaction degree with the bed height superposes on the localization mentioned above. But the abrupt decrease in MDI of coke B at about 10% of degree of reaction may be regarded as another evidence of intensified degradation of the coke at a high degree of reaction. In fact, spontaneous disintegration of coke B at a high degree of reaction with CO_2 and of coke A at a higher degree was observed in recent experiments.³⁾

Fig. 15. Carbon contents of fines generated spontaneously during reaction

In order to determine the degradation mechanism of coke B, it will be necessary to investigate its reaction with CO_2 at temperatures as high as in the reducing zone outside the raceway and to compare the results with those for coke A.

VII. Summary

- (1) When coke B was used in place of coke A, the stock descended irregularly, and eventually it hung obstinately.
- (2) Informations from the direct observation,

sampling from the operating furnace and investigations of cooled-furnace stock gave the foundation to consider that the furnace irregularities resulted from the disintegration of coke B in the lower part of the furnace.

- (3) Model experiments showed that the degradation of coke B due probably to CO_2 attack was much more severe than that of coke A.

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REFERENCES

- 1) M. Tate, Y. Kuwano, K. Suzuki, T. S. Chang, H. Go and M. Matsuzaki: *Tetsu-to-Hagané*, **62** (1976), 495.
- 2) M. Tate, Y. Kuwano, K. Suzuki, M. Matsuzaki, E. Tsuji, T. S. Chang, H. Go and K. Honda: *Trans. ISIJ*, **16** (1976) 447.
- 3) T. S. Chang and M. Tate: *Tetsu-to-Hagané*, **64** (1978), S515.