Optimization of Coke Breeze Segregation in Sintering Bed under High Pisolite Ore Ratio

Satoshi MACHIDA,1) Takahide HIGUCHI,1) Nobuyuki OYAMA,1) Hideaki SATO,1) Kanji TAKEDA,1) Katsuhiro YAMASHITA2) and Koichi TAMURA2)

1) Steel Research Laboratory, JFE Steel Corporation, 1 Kokan-cho, Fukuyama, Hiroshima 721-8510 Japan.
2) East Japan Works, JFE Steel Corporation, 1-1 Ogishima, Kawasaki-ku, Kawasaki, Kanagawa 210-8510 Japan.

(Received on September 30, 2008; accepted on February 23, 2009)

Increased demand and the diminishing high grade resources have resulted in a shift to using low grade iron ore in Japanese steel mills. Especially, pisolite ore ratio is quite high. Therefore, decrease in sinter productivity became serious problem with increasing the amount of pisolite ore.

To improve the sinter productivity, effective method at the charging device in sintering machine was investigated by laboratory experiments.

The following results were obtained.

1) It was expected that the holding time over 1200°C at the middle and bottom layer of the sintering bed decreased with high pisolite ore ratio. On the other hand, in order to preserve the sinter strength, it was suggested that the holding time over 1200°C in sintering must be extended under high pisolite ore ratio.

2) There is the optimum coke segregation degree according to the pisolite ore ratio. It was decreased with increase of the pisolite ore ratio.

3) To control the coke segregation in the sintering bed, Magnetic Braking Feeder (MBF) was introduced, and the operating conditions were investigated with the laboratory charging tests and sintering pot test.

4) Based on the fundamental research, MBF has been applied to Keihin No. 1 sinter plant, and the productivity was improved by 4.2% under constant sinter strength.

KEY WORDS: sinter; pisolite ore; coke breeze; segregation; charging device.

1. Introduction

The sharp rise of the raw material prices, caused by the remarkable increase of the steelmaking amount in Asia especially China, and the deterioration of the high grade hematite ore in Australia are the serious issue for the steelmaking mills in Japan. Therefore, an increase of pisolite ore in the sinter plant of Japan caused serious subject to keep the strength and productivity of sinter.

It is known that porous pisolite ore affects on the reducing melt fluidity as the reason of the deterioration of strength and productivity.1) And, some of pisolite ore, which is used with large amount in Japan, includes high Al2O3. To avoid the influence of it, the selective granulation2) was introduced to Nippon Steel Co. Oita works to involve Al2O3 element that disturb the sintering reaction of iron ore to granulated particle, and to control dispersion of Al2O3 into the sintering bed. On the other hand, Sumitomo Metals Co. introduced CaO separated granulation method3,4) to decrease the reduction degradation index (RDI) by controlling the secondary hematite to granulate separately the ore component of high CaO and low CaO. But, the improvement of the granulating process has the problem that capital investment is large, and the flexible correspondence to the change in the resource trend is difficult.

Corresponding to the change in the resource trend, granulated ore charging to the sintering machine is given as one of effective measure. Segregating Slit Wire (SSW) feeder5) and Intensified Sifting Feeder (ISF)6) was developed and introduced as charging device of sintering machine from the idea that the operational result improves by increasing permeability in sintering bed.

As the charging device, Magnetic Braking Feeder (MBF)8) and deflector plate type feeder7) was developed with the aim of controlling the ore segregation and improving the permeability of charged bed by decreasing the bulk density of charged ore bed by reducing the impact pressure while charging the sintering mixture.

Therefore, the authors began fundamental experiments in order to examine the technologies for improvement of charging device from a new viewpoint. To investigate the influence by using large amount of pisolite ore on sintering, the heat pattern in the sintering bed was estimated by a simulation model analysis, and the effect for sinter strength was evaluated in an electric furnace test. Moreover, a optimum coke segregation according to the pisolite ore ratio and the charging device to form the proper coke segregation was examined by the pot test. The aim of this paper is to present the results of these laboratory tests and the improvement of the operation under high pisolite ore ratio at
JFE Steel Keihin No. 1 sinter plant based on the results of the laboratory test.

2. Characteristics of Pisolite Ore and Effect of Blending

2.1. Characteristics of Pisolite Ore

The properties of hematite ore and pisolite ore are shown in Table 1. Cross sectional photographs of the structures of the two ores are shown in Fig. 1. On physical properties, pisolite ore is coarse-grained and porous in comparison with hematite ore. On chemical properties, it contains a lot of SiO₂, Al₂O₃, and combined water. Some kind of pisolite ore contains smaller amount of Al₂O₃. From the sectional photograph, pisolite ore includes goethite structure and contains large amount of pores.

2.2. Segregation of Coke Breeze and Combined Water with Large Amount of Pisolite Ore

Measuring the segregation of coke breeze and combined water in the bed, chemical analysis of the charged ore was carried out at Keihin No. 1 sinter plant. Figure 2 shows the measured results. Carbon content was calculated by dividing free carbon content in the sample by free carbon in the coke. Combined water was measured by Karl Fischer titration method (JIS M 8211). Then the blending ratio of pisolite ore was 30 mass% in the iron ore and 17 mass% in the all materials. The sintering mixture was gathered from three points, which are the center of each three layers having equal thickness in the height direction. The difference in the coke content and combined water content in the upper and bottom layers were 0.81 mass% and 0.70 mass%, respectively.

It is thought that the optimum coke segregation in the sintering bed has close correlation with segregation of combined water and CaO in the sintering bed. Under the increase of pisolite ore ratio, the influence of optimum coke segregation in the sintering bed was investigated in the laboratory test.

3. Experimental Method

3.1. Electric Furnace Test for Evaluating Sinter Strength

In order to evaluate the effect of pisolite ore blending on sinter strength, cylindrical-shaped samples (tablets) simulating sinter were prepared by heating in an electric furnace, and their strength was measured. Table 2 shows the blending conditions of raw material of the tablet. Two kinds of ore blending which is only hematite ore and pisolite ore were compared, using Ore N of hematite ore and Ore R of pisolite ore. The chemical composition after heating was adjusted to 5.6 mass% of SiO₂ and 1.80 of CaO/SiO₂ (mass%/mass%) by adding reagents of CaCO₃ and SiO₂. Tablet preparation and strength evaluations were performed by the following procedure.

Figure 3 shows the appearance of the samples at each step in the procedure. In preparation of the tablets, raw materials that had been completely crushed to under 125 μm was mixed well and molded into a cylindrical shape with a diameter of 16 mm and a length of 16 mm under a load of 5.0 kg/mm². They were held for 1, 2 or 3 min in an electric furnace, which had been heated in advance to 1200°C.

Table 1. Properties of pisolite ore compared with hematite ore.

|                         | Ore N (Hematite) | Ore R (Pisolite) |
|-------------------------|------------------|------------------|
| Mean diameter (mm)      | 2.2              | 3.9              |
| Pore volume (cm³/g)     | 0.045            | 0.137            |
| Chemical composition (mass%) | SiO₂     | 0.63            | 5.58            |
|                         | Al₂O₃            | 0.89            | 2.61            |
| Combined water          | 1.31             | 7.51             |

Table 2. Blending condition of raw materials in the tablet (mass%). Composition after heating: SiO₂ = 5.6 mass%, CaO/SiO₂ = 1.80 (mass%/mass%).

|                  | Hematite ore | Pisolite ore |
|------------------|--------------|--------------|
| Ore N(Hematite)  | 82.5         | 85.3         |
| Ore R(Pisolite)  |              |              |
| CaCO₃ reagent    | 15.8         | 14.7         |
| SiO₂ reagent     | 1.7          |              |

Fig. 1. Sectional photograph of hematite ore and pisolite ore.

Fig. 2. Coke and combined water segregation in sintering bed at Keihin No. 1 sinter plant.

Fig. 3. Appearance of the samples at each step for measuring tablet strength.
After heating, the samples were cooled in the air. After cooling, the crushing strength of the tablets was measured, and the results were converted to tensile strength by Eq. (1).  

\[ \sigma_t = \frac{2P}{\pi DL} \]  

\( \sigma_t \) : tensile strength of tablet (MPa)  
\( P \) : crushing strength tablet (kgf)  
\( D \) : diameter of tablet (mm)  
\( L \) : length of tablet (mm)

### 3.2. Evaluation of Sintering Heat Pattern by Simulation Model Analysis

Simulation model analysis was performed in order to evaluate the effect of using pisolite ore on the sintering heat pattern.

Figure 4 shows the blending ratios of coke breeze and ores in the upper layer, middle layer, and bottom layer of the bed. Two kinds of conditions were adopted in the model analysis, which are 0 mass% and 50 mass% of pisolite ore ratio. Ore N was used as the hematite ore and Ore R as the pisolite ore. In both condition, total coke breeze ratio was 4.7 mass%, and the coke segregation was decided from the measurement of the charged ore to sintering machine shown in Fig. 2. For 50 mass% of pisolite ore ratio, the difference of combined water in upper layer and bottom layer was considered as 1.17 mass% based on the measurement of sintering machine shown Fig. 2 under 30 mass% of pisolite ore ratio. The blending ratio of coke breeze, Ore N and Ore R in middle layer was assumed to be the average of the upper and bottom layers.

In simulating the heat patterns, calculations were made based on the heat and mass balance in the sintering bed as previously reported. In addition, decomposition of the combined water in the ore were considered in this analysis. In the endothermic value and the reaction temperature of combined water decomposition, 2.0 kJ/g-H\(_2\)O and 300°C were adopted based on the previous study.

Table 3 shows the main conditions used in the simulation model analysis. Though return fine was included in the sintering ore, it was assumed to have no participation to the sintering reaction.

### 3.3. Sintering Pot Tests

Sintering tests were performed using a pot with an inner diameter of 300 mm and height of 400 mm. As raw materials, Ore N and Ore R were used as the hematite and pisolite ores, respectively. Limestone and coke breeze gathered from the sintering plant were used. Granulating moisture was decided to an appropriate amount corresponding to the blending ratio, and granulated for 3 min in a drum mixer with a diameter of 1 m.

First, in evaluating the effect of pisolite ore blending on shatter strength, conditions were decided for three levels, divided into the upper, middle and bottom layers in the same forms as in the simulation model analysis based on the result of the measurement at Keihin No. 1 sinter plant. Two experimental blending conditions were decided to 0 mass% and 50 mass% of pisolite ore ratio. Table 4 shows the blending ratios of the coke breeze, Ore N, and Ore R for each layer with the two blending patterns. The limestone, coke breeze and return fine used in the tests were gathered from the sintering plant. For 50 mass% of pisolite ore ratio, the difference of combined water in upper layer and bottom layer was considered as 1.17 mass% based on the measured result of charged ore shown Fig. 2 under 30 mass% of pisolite ore ratio. Average coke blending ratio was decided to become the maximum temperature in middle layer in the sintering bed to 1 350°C. The ignition time was 90 s, and the suction pressure during igniting was 3.0 kPa. The suction pressure during sintering was fixed to 6.9 kPa. The temperature in the bed during sintering was measured in the center of each layer inserting R type ther-
mocouple. After the experiment, the shatter strength of the sinter cake was measured based on JIS M 8711 for the upper, middle, and bottom layer respectively. To get the sample for shatter strength measurement, sintering test was conducted three times for each condition.

As the second test, the optimum coke segregation corresponding to the pisolite ore ratio was evaluated by pot test with same condition as above described. Table 5 shows the blending conditions of raw materials in the sintering pot test. The pisolite ore blending ratio was decided to three levels of 0 mass%, 25 mass%, and 50 mass%. For 25 and 50 mass% of pisolite ore ratio, the difference of combined water in the upper layer and the bottom layer was considered as 0.59 mass% and 1.17 mass%.

For evaluation of coke segregation, the sintering bed was divided into three equal parts in the height direction, and each layer was decided to the specified blending ratio. A coke segregation index $\alpha$ (mass%/m) was defined as Eq. (2) and Fig. 5 for evaluating optimum coke segregation for sintering operation by pot test based on the following reason. Comparing the ore bed between sintering machine of 660 mm in height and test pot of 400 mm in height, test pot is correspond to the upper and middle layer of sintering machine. The heat for sintering is provided by not only the coke combustion but also the hot gas from above layer. Therefore, in order to apply the coke segregation of pot test to sintering machine, the ratio of coke breeze segregation to the bed height should be assumed to be constant, and the difference of the coke breeze blending between the upper and lower layer should be decided corresponding to the thickness of the layer. The index $\alpha$ is the value obtained by dividing the difference in the coke content in the upper and bottom layers by the height of the sintering bed. In the sintering pot tests, $\alpha$ was varied in the range from −0.7 to 1.4.

$$\alpha = \frac{C_{\text{upper}} - C_{\text{bottom}}}{H} \quad \text{..................(2)}$$

$C_{\text{upper}}$: coke content in upper layer of sintering bed (mass%)

$C_{\text{bottom}}$: coke content in bottom layer of sintering bed (mass%)

$H$: height of sintering bed (m)

3.4. Charging Test

To optimize and control the coke segregation, charging test of sinter ore was conducted. Figure 6 shows a schematic diagram of the charging device used in the test. Figure 6(a) shows the Rod Feeder (RF), which is the conventional type used at Keihin No. 1 sinter plant. Figure 6(b) shows the MBF, which was adopted because of flexibility of charging condition.

The sintering mixture is discharged from a hopper, and fed onto the pallet via the charging device. In the feeding section, either the RF or MBF devices can be used. In the RF, the diameter and arrangement of the installed rods are the same as in the commercial machine. In the MBF, the magnetic flux density at the chute surface can be changed in the range of 0–0.12 T by adjusting the position of the permanent magnets installed on the backside of the chute.

Table 6 shows the charging conditions in the experiments. With this device, feed rate of sintering ore was simulated to the Keihin No. 1 sintering plant. The chute angle can also be adjusted in the range of 50–60° at MBF. The pallet width and length are 400 mm and 3.5 m, respectively, and the bed height is 480 mm.

After the charging test, part of the bed was extracted and a sintering test was performed using the charged sintering mixture. During extracting and carrying the bed, great care was taken to avoid the shrink using a tool with shock absorber. The dimensions of the sintering bed were 400 mm in length and width, and 480 mm in height. The suction pressure was 14.0 kPa. Table 7 shows the blending ratio of raw materials used in the charging test. Pisolite ore was blended by 30 mass% in iron ore based on the sintering operation.
4. Test Results

4.1. Evaluation of Strength of Tablets Simulating Sinter

Figure 7 shows the results of the measurements of the strength of hematite ore was larger than that of pisolite ore for all heating condition. With both the hematite ore and the pisolite ore blends, tensile strength increased with increasing holding time at 1 200°C. However, the slope of the pisolite ore blend was larger than that of hematite ore, therefore tablet strength of the pisolite ore blend highly depends on the heating time at 1 200°C.

4.2. Evaluation of Sintering Heat Pattern by Simulation Model Analysis

As the results of the simulation model analysis, Fig. 8 shows contour maps of the temperature in the sintering bed, in which the horizontal axis shows the elapsed time after ignition and the vertical axis shows the bed height. In contrast to the 0 mass% blend of pisolite ore in Fig. 8(a), with the 50 mass% blend in Fig. 8(b), the holding time over 1 200°C in the middle and bottom layers was remarkably reduced, and the holding time at over 1 200°C in the bottom layer was greatly shortened.

Figure 9 shows the heat patterns in the upper, middle, and bottom layers. The holding time over 1 200°C was shortened from 1.6 to 1.4 min in the upper layer, from 2.2 to 1.3 min in the middle layer and from 3.3 to 1.0 min in the bottom layer as the result of increasing pisolite ore ratio from 0 to 50 mass%. In 50 mass% of pisolite ore ratio, the maximum temperatures were 1 295°C in upper layer, 1 260°C in middle layer and 1 215°C in bottom layer, respectively.

4.3. Effect of Pisolite Ore Blending on Sinter Strength by Sintering Pot Test

Figure 10 shows the comparison of shatter strength and holding time over 1 200°C between 0 mass% and 50 mass% of pisolite ore ratio in the sintering pot test. In Fig. 10(a), the shatter strength is lower in all layers with 50 mass% of pisolite ore ratio than with 0 mass%. Although the difference was only 1.4 mass% in the upper layer, shatter strength decreased greatly in the middle and bottom layer by 7.3 mass% and 9.6 mass% respectively. It is thought that the remarkable reduction of shatter strength is caused by the properties of pisolite ore, such as combined water content, Al₂O₃ content, particle size, pore volume in the particle and so on. Figure 10(b) shows the holding time over 1 200°C in each layer. With 50 mass% blending of pisolite ore, the holding time is reduced in all layers. The reduction in the upper layer was 0.3 min, but the reduction was particularly remarkable in the middle layer by 0.7 min and bottom layer by 1.5 min.

From Fig. 10, the correlation between holding time over 1 200°C and shatter strength is low in 50 mass% of pisolite ore ratio. The densification of ore particle by heat and load is considered as one of the causes.

Table 6. Blending condition of raw materials in charging test (mass%).

| Feed rate                  | 38.8 kg/m³s       |
|----------------------------|-------------------|
| Chute angle of MF          | 50° – 60°         |
| Travelling distance on the chute of MF | 1.12 m (50°) |
| Distance from conveyor to pallet | 2.1 m          |
| Bed height                 | 480 mm            |
| Width of pallet            | 400 mm            |
| Length of pallet           | 3.5 mm            |

Table 7. Measured results of the calcium–ferrite component measured by EPMA (mass%).

| Ore N (Hematite ore) | 40.8 |
|----------------------|------|
| Ore R (Pisolite ore) | 17.5 |
| Silica stone         | 1.5  |
| Limestone            | 13.5 |
| Return fine          | 22.0 |
| Coke breeze          | 4.7  |

Fig. 7. Relationship between heating time and tensile strength.

Fig. 6. Schematic diagram of charging device used in the charging test.
4.4. Evaluation of Optimum Coke Segregation Corresponding to Pisolite Ore Blending Ratio by Sinter Pot Test

Figure 11 shows the influence of coke segregation on shatter strength for each pisolite ore ratio in a sintering pot test. The coke segregation index $\alpha$, for maximizing shatter strength, decreased as the pisolite ore ratio increased, was 1.1 with 0 mass% of the pisolite ore ratio, 0.8 with 25 mass%, and 0.3 with 50 mass%. Figure 12 shows the relationship between the pisolite ore ratio and the optimum coke segregation. It was found that optimum coke segregation is decrease with the increase of the pisolite ore ratio. The pisolite ore ratio at Keihin No. 1 sinter plant is 30 mass%. The optimum value of $\alpha$ estimated for this condition was 0.70 mass%/m. Because the thickness of the sintering bed in Keihin No. 1 sinter plant is 660 mm, the optimum difference in the coke contents of the upper and bottom layers was estimated to be 0.46 mass%.

5. Discussion

5.1. Optimum Condition of Coke Segregation

In 1980s, when the small amount of pisolite ore than recent was used, it was considered that the segregation of coke breeze in the upper layer of sintering bed is effective for improving sinter yield. When the pisolite ore ratio was increased in recent years, deterioration of the strength and productivity of sinter with the increasing amount of pisolite ore was reported and discussed. From the pot test result of Fig. 10, the change of combined water segregation between upper layer and bottom layer with increase of pisolite ore has large influence for sinter production. So, the control of sintering temperature is significant countermeasure for the reduction of sinter strength under high pisolite ore ratio. Then, the optimization of coke breeze segregation in sintering bed is focused as one of effective method.

The causes based on the characteristics of pisolite ore like combined water content and required water for granulation. Beside this, from the result of the pot test shown in Fig. 12, unsuitability of coke segregation for the distribu-
tion of pisolite ore in sintering bed was considered. That is the shortage of sintering heat in the bottom layer. And, the charging condition became insufficient with increasing the amount of pisolite ore.

The result of electric furnace test, which is agree with previous report, indicated that it is effective to increase coke breeze content in bottom layer of the sintering bed as the pisolite ore ratio increases. In the sintering reaction of pisolite ore, the decomposition energy to Fe2O3 and H2O is necessary and in the charging to the sintering machine, pisolite ore is charged into the bottom layer of the sintering bed. Then, sintering energy in the bottom layer is insufficient from the heat pattern of sintering simulation model analysis.

Figure 13 shows the estimated influence of pisolite ore blending on the tensile strength of the sinter structure. Tensile strength in 50 mass% of pisolite ore ratio was assumed to be an intermediate value between 0 mass% of pisolite ore (100 mass% hematite ore) and 100 mass% pisolite ore. By increasing pisolite ore ratio from 0 to 50 mass%, the strength will decrease by 17% from 9.5 to 7.9 MPa in the upper layer, 26% from 10.1 to 7.7 MPa in the middle layer and 35%, from 11.3 to 7.3 MPa in the bottom layer. The reduction of strength was large in bottom layer and small in upper layer based on the holding time over 1 200°C. Thus, it is considered that the reduction in the yield and strength of sinter become the problem in the sinter production. In addition, from the result of pot test it is found that under the pisolite ore blending the increase of the coke breeze ratio in the middle and bottom layer in the sintering bed, namely the reduction of coke segregation is effective. Though, sinter strength in entire sinter cake will be improved up to a point by optimizing coke segregation. The effect is depends on the balance between the improvement in the middle–bottom layer and the deterioration in the upper layer.

The optimum value of α estimated from 30% of pisolite ore ratio at Keihin No. 1 sinter plant was 0.70 mass%/m from Fig. 12. With the thickness of the sintering bed in the commercial sintering machine is 660 mm, the optimum difference in the coke contents of the upper and bottom layers was estimated to be 0.46 mass% (= 0.7 · 0.66).

The laboratory test was performed in the representative operating condition of sintering machine for the purpose of investigating the optimum coke breeze segregation in the sintering bed. However, it is thought that the combined water and granulating water, chemical components like FeO and CaO are also large influence factor for the optimum coke breeze segregation. In addition, it is expected that as the operating factor, the size distribution of sintering material and the degree of granulation, namely the optimum addition of water have large influence for the optimum coke segregation.

Based on the laboratory test and the influence factor for coke breeze segregation, changing test of a lot of operating factor above mentioned was conducted, but the results of controlling the coke segregation and sintering operation were not good enough. So, the effect of optimizing coke breeze segregation must be verified by improving the charging device of sintering machine.

5.2. Optimization of Charging Condition

The sintering bed thickness in the charging test was 480 mm. Therefore, based on the evaluation of the optimum coke segregation, the target of coke content difference was decided to 0.34 mass%.

First, as an evaluation of methods used in the feeder, RF and MBF were compared. Figure 14 shows the measured results of coke segregation with the each charging device and the optimum condition of coke segregation. With the RF, α is 1.41 mass%/m, which is considerably larger than the optimum value of 0.70 mass%/m. With the MBF, α is 0.73 mass%/m, which is almost equal to the optimum value.

Figure 15 shows the results of an evaluation of the sintering ore in a sintering test. The results confirmed that yield improves with the MBF, and productivity increases 0.08 t/h·m².

Based on the conventional study, the dropping impact pressure and bulk density in the sintering bed can be evaluated by Eq. (3) and Eq. (4), respectively.

\[ P = \frac{m}{\Delta t} \] ..........................(3)

\[ BD = a \cdot P + b \] ..........................(4)

where, 
- \( P \): dropping impact pressure (Pa)
- \( m/\Delta t \): feed rate of sinter ore (kg/s)

![Fig. 13. Relationship between holding time over 1200°C and calculated tensile strength.](image)

![Fig. 14. Comparison between RF and MBF on coke segregation in sintering bed.](image)

![Fig. 15. Comparison between RF and MBF on sinter yield and productivity.](image)
\( V_y \): dropping velocity in vertical direction (m/s)

\( S \): dropping area (m\(^2\))

\( S_0 \): dropping area using MBF with 50° of chute gradient and 0 T of magnetic flux density (m\(^2\))

\( BD \): bulk density (t/m\(^3\))

\( a, b \): constants

To estimate the influence of charge from RF to MBF on permeability, the bulk density of ore bed was analyzed using the results of charging tests. Figure 16 shows the charging state indicated with \( V_y \) of the vertical velocity of charging ore and \( S/S_0 \) of the dispersion degree of the charging ore, defining the dispersion area on the condition of 50° and 0 T for the MBF as \( S_0 \). The contour line of the bulk density in Fig. 16 was drawn based on the Eqs. (3) and (4). The bulk density changed greatly with the charging condition. The optimization of charging condition was pursued in the order of (A), (B), (C) and (D). The change of ore charging was as follows.

At the condition of MBF with 60° of chute angle and 0 T of the magnetic flux density (point (B)) which is close condition to RF in the falling angle of ore, the bulk density was increased so much compared with RF (point (A)), because of the increase in the vertical velocity of charging ore and the decrease in the dispersion degree of charging ore. Therefore, the chute angle was decreased to 50° (point (C)). The bulk density was decreased because of the large decrease in the vertical velocity. Finally, in order to reduce the bulk density further, the magnetic plate was set to MBF in the back side of the chute. At the condition of MBF with 50° and 0.08 T, the vertical velocity was decreased and the dispersion degree was increased compared with no magnet (point (C)). As the result, the bulk density was decreased and reached to 1.74 t/m\(^3\), which was almost same level of RF.

6. Application to Commercial Plant and Operational Results

Based on the results of laboratory test, the optimization of the coke segregation was applied to Keihin No. 1 sinter plant. MBF was introduced as the charging device from the viewpoint of flexibility for charging condition corresponding to the optimum coke segregation. The magnetic flux density at the chute surface was set to 0.08 T.

When the MBF charging device was introduced, the chute angle and the magnetic flux density at the chute surface were decided to 50° and 0.08 T, respectively, based on the charging tests results. The pisolite ore ratio before and after improvement was held constant at 30 mass% in the iron ore. After startup of the MBF, the chute angle was varied in the range of 47°–55°, and the effect on operation was investigated. However, the operational results showed serious deterioration when the angle was reduced to 47°, confirming that the optimum condition is 50°.

Figure 17 shows the measured results of the segregation of the coke and combined water contents before and after improvement. The results confirmed that the difference in the coke content decreased from 0.81 mass% (\( \alpha = 1.29 \text{ mass%/m} \)) before improvement to 0.48 mass% (\( \alpha = 0.76 \text{ mass%/m} \)) after improvement. At the same time, the difference in the combined water content also decreased. However, the influence of it is small enough, because the endothermic amount of decomposing reaction from \( \text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O} \) to \( \text{Fe}_2\text{O}_3 \) and \( \text{H}_2\text{O} \), 2.0 kJ/g-\( \text{H}_2\text{O} \)\(^{1)} \) is extremely smaller than exothermic amount of coke combustion (27.2 kJ/g-coke). Thus, it is considered that the optimum value of coke segregation substantially agree with the value estimated in the laboratory experiments.

In the sintering operation, FeO segregation to the upper layer by magnetic field of charging device affects reducing the optimum coke segregation in sintering bed, because of the increase of sintering energy in the upper layer. On the other hand, the reduction of the combined water segregation caused by the change of charging device affects increasing the optimum coke segregation, because of the increase of combined water in the upper layer. Consequently, these facts caused the agreement of the suitable charging condition between the laboratory test and the sinter machine operation.

Figure 18 shows the monthly transition in operation at Keihin No. 1 sinter plant before and after improvement of
the charging equipment. During this period, the tumble index (TI) was controlled to a constant level. After November 2006, when the charging device was changed to MBF, productivity increased from 1.65 to 1.72 t/h·m², then improved by 0.07 t/h·m² (4.2%). The bulk densities in the sintering ore bed before and after improvement were 1.60 t/m³ and 1.61 t/m³ respectively. Thus, the bulk density was maintained at same level.

**Figure 19** shows the results of sintering operation during the six months periods before and after improvement of the charging device. The points in the figure show the average values of the daily data for 3-d periods when operation was stable. It was confirmed that TI after changing to MBF was improved by 2.6% in comparison with TI with RF. Thus, the expected effects from laboratory test were obtained.

### 7. Conclusion

Optimum coke breeze segregation and the charging condition for sintering operation were investigated under high ratio of pisolite ore as sintering material from the laboratory tests. The following conclusions were obtained.

1. From the simulation model analysis and electric furnace test, it was found that increasing the sintering temperature in the middle and bottom layers of the sintering bed is effective as a measure against the reduction of sinter strength, using large amount of pisolite ore.

2. From the sintering pot test, it was found that there is an optimum coke segregation corresponding to the blending ratio of pisolite ore, and the optimum segregating degree decreases with pisolite ore increases.

3. From laboratory charging test simulating the charging device in sintering machine, the charging condition for achieving optimum coke segregation in MBF was obtained.

4. The charging device at JFE Steel Keihin No. 1 sinter plant was applied to the MBF in order to optimize carbon segregation in the sintering bed. As the result, the improvement of productivity by 0.07 t/h·m² (+4.2%) was confirmed, and the improvement of tumble index by 2.6% was expected.

### REFERENCES

1. N. Oyama, K. Nushiro, K. Igawa and K. Sorimachi: *Tetsu-to-Hagané*, 83 (1997), 287.
2. T. Haga, A. Oshio, K. Nakamura, T. Kozono and K. Uekawa: *Tetsu-to-Hagané*, 83 (1997), 103.
3. T. Kawaguchi, K. Kuriyama, S. Sato and K. Takada: *Tetsu-to-Hagané*, 73 (1987), 1924.
4. T. Kawaguchi, K. Kuriyama, S. Sato and K. Takada: *Tetsu-to-Hagané*, 76 (1990), 1642.
5. T. Takai, S. Kishimoto, A. Sakai, H. Sato, O. Komatsu and H. Noda: *CAMP-ISIJ*, 6 (1993), 916.
6. T. Inazumi, M. Fujimoto, S. Kasama, K. Sato, E. Shimozawa and A. Gushima: *CAMP-ISIJ*, 1 (1988), 970.
7. M. Matsumura, T. Kawaguchi, K. Oone and K. Imagawa: *CAMP-ISIJ*, 15 (2002), 702.
8. N. Oyama, K. Nushiro, K. Igawa, N. Fujii and K. Nakashima: 60th Ironmaking Conference Proceedings, Baltimore, ISS, Warrendale, PA, 60, (2001), 817.
9. T. Horibe: *J. Min. Metall. Inst. Jpn.*, 66 (1950), 355.
10. H. Noda, N. Sakamoto, K. Ichikawa, S. Machida and S. Rokugawa: *Tetsu-to-Hagané*, 87 (2001), 305.
11. T. Inazumi: *Tetsu-to-Hagané*, 81 (1995), 266.
12. T. Kawaguchi, M. Hoshi, Y. Hatano, M. Yariyama, H. Hashikawa and K. Kitamura: *CAMP-ISIJ*, 8 (1995), 864.
13. T. Noda, T. Yabada, K. Hoshino, T. Matsuo, T. Muramatsu and N. Tamura: *CAMP-ISIJ*, 6 (1993), 65.
14. Y. Hida, J. Okazaki, K. Nakamura, K. Uekawa and N. Kasai: *Tetsu-to-Hagané*, 78 (1992), 1021.
15. T. Uno, K. Miyagawa and Y. Okikawa: *Tetsu-to-Hagané*, 48 (1962), 1251.