To decrease carbon dioxide emission in iron ore sintering process through reduction of carbon consumption as sintering agent, reduction of fluctuation in iron ore sintering was studied. Transition phenomena of the sintering fluctuation through a sintering plant were observed and studied using a frequency analysis.

The sintering fluctuation was defined as the cyclic change in the exhaust gas temperatures at a certain wind-box. The observation of the wind box temperatures showed that the temperature changes of several minute cycles existed. To search for upstream causes, charging behavior of the sinter mix to pallet cars was observed using an index of “charging level”. Comparison of the charging level and the wind box temperature showed that the fluctuations of them were almost coincident in the occurring time and position. To search for further upstream causes, a near-infrared moisture meter was introduced to measure sinter mix moisture with high frequency. To investigate the relationship between the wind box temperature, the charging and the sinter mix moisture, a frequency analysis of the fluctuations of them was carried out. It showed that some frequency elements were almost coincident and that fluctuation transferred from the fluctuation in the sinter mix moisture to the sintering.

Then, a test operation of more precise control of the sinter mix moisture using the near-infrared moisture meters in a sintering plant was carried out. It successfully reduced sintering fluctuation.

KEY WORDS: sinter; fluctuation; moisture measurement; moisture control.

1. Introduction

Decrease in carbon dioxide emission is requested because of the prevention of the global warming.1) One of the sources of carbon dioxide in steel industry is an iron ore sintering process, which uses some amount of sintering agents such as coke including carbon and turns almost all of them into carbon dioxide. So, the reduction of the sintering agent consumption in the iron ore sintering process is an effective way to decrease carbon dioxide emission. The sintering agent supplies heat through oxidation reaction for the sintering process. The stability of sintering state is presumed to be important for the reduction of the sintering agent. The sintering agent is controlled mainly to fit the operational demands such as the cold strength target. When the sintering fluctuation is large, the sintering agent is likely controlled to the different value from the optimal to admit the fluctuation. Besides the excessive sintering agent, even the deficient sintering agent may increase the carbon unit consumption by some side effects such as the lower sinter yield.

It seems that the reduction of the sintering fluctuation is a requisite for the sinter agent reduction. In order to reduce the sintering fluctuation, the sintering fluctuation was observed on the basis of the temperature in exhaust gas of an actual sintering plant. The behavior that the fluctuation transits along the sintering process was considered by means of a frequency analysis method. The control of the fluctuation was attempted using the transition route of the fluctuation in a plant test.

2. Sintering Fluctuation in a Sintering Plant

2.1. Sintering Fluctuation

It is convenient for further consideration to represent the sintering fluctuation using an index, which was defined as the change in the exhaust gas temperature at the No. 11 wind-box of Kakogawa sintering machine. In the observation period, Kakogawa sintering machine was operated so that the burn through point which is a completion point of the sintering agent combustion should be put on the wind box of No. 14. Then, the temperature of the No. 11 wind box was the most changeable according to the sintering fluctuation among the wind boxes. Henceforth, the index is called as wind-box temperature.

An example of time transition data of the wind-box temperature is shown in Fig. 1. Two types of cyclic change in temperature are observed. One type that is comparatively small change of about 50°C or less arise with the cycle of 10 minutes or less, and the other type of comparatively large
change about 100°C to 200°C arise with the cycle of 20 minute or 30 minutes.

The gas flows from the top of the sintering bed into the wind box with the suction of blowers. After ignited on the top of the sintering bed, the sintering agents burn to supply heat. Some amount of the heat moves to the flowing gas in heat exchange. Under the zone where the sintering agent burns, the heat of the gas is exchanged to the sinter mix of relatively lower temperature than the gas. Consequently, the temperature of the exhaust gas depends on the heat amount moved from the gas. The amount of the exchanged heat depends on some factors such as gas flow rate and heat capacity in the sintering bed. The gas flow rate is controlled by the permeability of the sinter bed, and the heat capacity that is influenced with the density of the sinter bed. The change in the wind box temperature seems to occur due to the change in the sinter bed state.

2.2. Charging Level

The change in the wind-box temperature was traced back to the upper stream processes. When sinter mix is charged on palette cars, the state of sinter bed seems to be almost fixed, because the number of the actions on the sintering bed after the sinter mix charging in Kakogawa sintering machine is so few. To represent the state of the sinter bed, an index “charging level” was used. Hereafter, the charging level is defined as the data of ultrasonic range measurement equipments which indicate the distance to the slope surface of the sinter mix that was accumulating on the palette cars as shown in Fig. 2. Because sinter bed thickness is constantly adjusted to the predetermined value using scrapers, change in the charging level seems to be related to the density of the sinter mix charged on the pallet cars. The charging levels at nine points in lateral direction were measured in Kakogawa sintering machine. The relationship between the wind-box temperature and the charging level is considered. The measured values of the lateral direction of the wind-box temperature and the charging levels were arranged along with time transition to show in Fig. 3.

The areas which have deviated from the average value in each time greatly, which is seen as the position of fluctuation, are hatched in Fig. 3. The domains of low charging levels and the domains of high wind-box temperatures are almost coincident in positions. And it shows that the both fluctuations are closely related.

The domain of the low charging level is considered to have a good permeability because of the low charging density of sinter mix. In sintering bed, high temperature gas that produced by carbon combustion reaction is exchanging heat with sinter mix during flowing according to the suction pressure. If the permeability of sinter mix is low, hot gas flows too fast to effectively transfer its heat to solid materials, and the gas arrives at wind-boxes having relatively higher temperature. That seems to be the mechanism of the domain of high temperature wind-boxes.

In order to investigate the relationship between the wind-box temperature and the charging level, frequency analysis of the cyclic fluctuation of them was conducted. The frequency spectrum obtained by Fourier-transforming of the wind-box temperature of the edge of the lateral direction and the charging level at almost the same position is shown in Fig. 4. Since the peak whose frequency corresponds with the spectrum of a charging level and wind-box temperature is seen, it can be seen that a part of fluctuation of the charging level transits to that of the wind-box temperature. Moreover, the cycle of fluctuation to transit with cycles of tens of minutes.
2.3. Fluctuation in Charging Level

The upstream process next to the sinter mix charging is a discharging process from the sinter mix hopper using a drum feeder device. In this process, the feeding rate of sinter mix seems to be influenced by consistency of drum feeder device and fluctuation in flow of sinter mix in hopper. Depending on the results of the frequency analysis above, no suitable phenomena causing the charging level fluctuation were found in the mechanical examination about the drum feeder device. And no fluctuations which occur in the upper stream processes were found through the same consideration standard. Then, the fluctuation in discharging from the hopper was considered to be a dominating factor and was considered to be caused by the instability of the material flow in the hopper. The unstable states of the material flow are sometimes caused by the bridging of the materials, the breakage of the adherent layer inside the hopper, and others. It is known that the bridging and the adherent layer formation are influenced with the particle size distribution and the adhesion of materials.\(^3\) For permeability improvement of the sintering bed, the sinter mix and some water are mixed using a drum mixer. The moisture content influences on the size distributions and adhesion of the sinter mix.\(^4,5\) The moisture content depends on the amount of the water addition at the drum mixer and the contained moisture of the raw materials themselves.

At Kakogawa sintering plant, the drying moisture meters are used for measurement of the sinter mix moisture conventionally. A small portion of the sinter mix after drum mixers is sampled automatically by once in an hour. The sample is heated to dry at 120°C and changes in the sample weight are measured to determine the moisture content.

An actual measured data is shown in Fig. 5. The range of the fluctuation is smaller than 1 percent and seems to be sloping. However, it is difficult to evaluate the relationship between the wind-box temperature, the charging level and the moisture by this measurement frequency. The measurement frequency needed to be increased.

3. Continuous Measurement of Moisture - Near-infra Moisture Meter

In order to increase the measurement frequency of the sinter mix moisture than the conventional system, a set of near-infrared type moisture meter (JT engineering company J-7000) was tentatively installed at almost the same position of the conventional system. The moisture meter was put over a belt conveyor carrying the sinter mix, and probed the sinter mix surface on almost full width. The space between the probe device and the sinter mix was maintained almost constant. The measured moisture values were indicated every second. The standard curve between the sinter mix moisture and the infra-reflection intensities was beforehand created by the off-line test.

The data by the near-infra moisture meter is shown in Fig. 6. It contains the data plots of the conventional dry method. The data by the near-infra moisture meter have large range such as some percents. The data of the conventional method are included in the data range of the new one. Among the data plots of the conventional method, the data of the new one shows some changes in the moisture along time. It is clarified by introducing the near-infrared type moisture meter that the moisture variation of the short cycle which is not caught in the drying moisture meter has arisen by measurement of high frequency by a near-infrared type moisture meter.

The acquired moisture data were Fourier-transformed and the frequency analysis about the relationship between the charging levels and the wind-box temperatures was investigated. As shown in Fig. 7, the peak whose frequency corresponds with each spectrum was seen. It is thought that fluctuation of sinter mix moisture has spread from this to the fluctuation of the wind-box temperatures through the fluctuation of the charging levels.

Because the moisture variation with the shorter cycle rather than the conventional measurement is measured, the
charging level fluctuation seems to occur as follows. The moisture fluctuation of the short cycle possibly changes the size distribution of the pseudo particles in sinter mix at granulation processes. When the moisture content is less than the optimal one, the relatively smaller sized pseudo particles and the fine particles are carried into the sinter mix hopper. In other hands, when the moisture content is more than the optimal one, adhesion of the sinter mix becomes larger. Larger adhesion of the sinter mix seems to cause the bridging and the adherent layers in the sinter mix hopper.

When the fluctuation of the charging level is relatively small, the fluctuation in the density distribution of the sinter bed is presumably turns relatively small. If the density distribution is almost uniform, in order that the permeability of the sintering bed may be uniform, it leads to the reduction of the air turbulence and sintering advances uniformly in the lateral direction. Therefore, the fluctuation of the lateral direction of the wind-box temperature seems to decrease.

4. A Plant Test of Moisture Control

A plant test was carried out to control the sintering fluctuation is by means of reducing the fluctuation of the sinter mix moisture. The moisture content of the sinter mix was controlled in a certain small range.

Two routes supplying moisture to the sinter mix were watched during the test period. One route is the contained moisture in raw materials, and the other is the water supply at the mixing procedure. Various raw materials which consist of iron ores and flux materials are brought from stock yards to ore bins. The moisture contents of the raw materials are different from each others and are changeable along with the time, because of weather and yard actions such as water spraying for prevention of dust dispersion. The raw materials are discharged from the bins at the planned mass rate to be sent to the mixing equipment that consists of two parallel drum mixers which supply water with the controlled flow rate. The water supply had been regulated in order to maintain the optimal content of the sinter mix moisture depending on the measurement by a cycle of once in an hour.

During the plant test, the moisture content was controlled by means of regulating the water flow rate at the drum mixer shown in Fig. 8. As mentioned above, the moisture content of the raw materials before conveyed to the drum mixer are detected by a set of near-infrared moisture meter installed on the belt conveyor just after the discharge end of the raw material bin. Another set of near-infrared moisture meter was installed at the belt conveyor just after the discharge end of the drum mixer. Subject to the test instruction, operators watched the indicated values of the two near-infra moisture meters to find any fluctuation in the difference value between the two meters and manually adjusted the amount of watering at the drum mixer during the test period as shown in Fig. 9. The feedback control method based on the aft moisture meter was not applied because the delay time from the measurement to the action is not proper for the smooth moisture control. The delay time in the plant was some minutes and too long to depress the fluctuations of the cycle of about 10 minute.

The data of the plant test is shown in Fig. 10 and Table 1. The fluctuation in sinter mix moisture was expressed with the standard deviation of the sinter mix moisture by every 60 second data. The amount of the fluctuation of the moisture shows changeable before the control test. By introducing the moisture control procedure mentioned above, the standard deviation of the sinter mix moisture reduced to 0.34% from 0.45%. It shows the fluctuation of the moisture is well controlled by the control procedure.

Concerning the charging levels, the standard deviation in the longitudinal direction of sintering machine was reduced to 17.6 mm from 20.1 mm after the moisture control procedure. And, the standard deviation in the lateral direction was also reduced 33.0 mm from 42.1 mm at the same term.

Kakogawa sintering plant has the equipment that is spreading the sinter mix to the lateral direction of the sintering machine using reciprocal feeding motion of a shuttle-
motion conveyor. The fluctuation in the sinter mix moisture is expected to spread to the charging level in the lateral direction along with the longitudinal direction. The reciprocal feeding equipment seems to transform one dimensional fluctuation to two dimensional one. It shows that the reduced fluctuation in the moisture decreases the fluctuations in the charging level in both the lateral direction and the longitudinal. The timings of the fluctuation changes are different from each other. It seems to be caused by the different feeding motion of sinter mix on the pallet cars in the longitudinal direction and the lateral one. It seems to result in the different retardation times of each direction. The range of the lateral direction of the wind box temperature in every 60 seconds is shown in Fig. 7. The temperature range decreased to 80.7 degree Celsius from 106.9 degree Celsius after the moisture control procedure. The timings of the fluctuations in the moisture, the charging level and wind box temperature are not accord due to the different retardation times of each section. Fluctuation of both the charging level and the wind-box temperature were reduced by the control of sinter mix moisture.

5. Conclusion

A study to reduce sintering fluctuation was carried out. The sintering fluctuation was defined as the change of a wind box temperature, and the transition phenomena of the sintering fluctuation from upstream processes along a sintering plant were investigated.

(1) Some cyclic changes were observed in the sintering fluctuation. The changes arise at cycles of a few minutes or some tens minutes.

(2) A fluctuation transition route between the wind-box temperature, the charging level, and the sinter mix moisture was clarified through a frequency analysis of the fluctuations.

(3) Based on the sintering fluctuation transition route, a test operation precisely to control the sinter mix moisture was tested in an actual sintering plant. The sintering fluctuation was successfully reduced by the precise moisture control using a near-infrared type moisture meter.

REFERENCE


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<th>Table 1. Results of moisture control test.</th>
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<td>Parameter</td>
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<tr>
<td>σ of moisture (%)</td>
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<td>σ of charge level (longitudinal) (mm)</td>
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<td>σ of charge level (lateral) (mm)</td>
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<td>Range of windbox #11 temperature (°C)</td>
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※14-days summerized data.