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High-productivity Operation of Commercial Sintering Machine by Stand-support Sintering

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Abstract

The sinter cake load on the combustion-melting zone causes gas channel plugging during the formation of pore structure of sinter cake, resulting in low productivity and inferior quality of the sinter product in the sintering process. The influence of gravity was focused on to develop a new sintering technique, called 'stand-support sintering', for obtaining high permeability at the lower layer as a result of reducing shrinkage due to gravity and suction by supporting the sinter cake load with plates attached to pallets. This technique has been applied to four sintering machines at Kimitsu and Oita Works, Nippon steel Corp. since 1996 and contributed to their high productivity operation without lowering quality of the sinter product. This paper provides the principle of stand-support sintering and the influence of productivity and quality of the sinter product in commercial sintering machines.

1. Introduction

Iron ore resources are degrading as their mining proceeds; the degradation shows itself in such as the decrease in the ratio of lump ore and increase in that of particulates in fine ore. An important task of sintering, a principal method of ore pretreatment, to cope with these problems is to increase productivity. For the first time in the world, Nippon Steel Corporation developed a technique to analyze the structure of sinter cake using X-ray CT[1], clarified by the technique that the forming process of a permeation network in the ore bed had a significant influence over the productivity of a sintering machine[2], and pointed out that to control the process it was effective to reduce the loads of the sinter cake on the combustion-melting zone[3]. Based on the finding, the company developed the stand-support sintering method[4], applied it to the commercial operation of its sintering machines, and achieved significant improvement in productivity. The method makes it possible to remarkably enhance the productivity of a downward-suction type sintering machine by decreasing the adverse effect of gravity, which constitutes a constraint on the operation of this type of machine. This paper outlines the principle of the method and its effects of improving the commercial operation of sintering machines.

2. Principle of Stand-support Sintering Method

In a typical sintering machine, blended fine iron ore mixed with coke breeze, which serves as the fuel, is loaded onto grate pallets to form a thick bed, ignited at the upper surface of the bed, and the combustion of the fuel proceeds downwards under the downward suction of the air to melt and sinter the fine ore and preheat the ore bed portion below the combustion-melting zone. Since the permeation resistance of the ore bed determines the propagation speed of the combustion, a decrease in the permeation resistance increases the productivity of the machine. Because the combustion proceeds downwards and the combustion-melting zone is just below the layer of sintered ore (sinter cake), the sintering process (melting and so-

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lidification of the ore) in the zone takes place under the loads of the sinter cake layer above. As a result, the permeation paths inevitably clog under the loads, and this, together with the gas expansion due to the temperature rise, leads to an increase in the permeation resistance of the combustion-melting zone[2,5].

The stand-support sintering method is a technology to support the weight of the sinter cake with stands provided to the pallets and thereby improve the rate of the sinter cake formation in the combustion-melting zone after the stands begin to support the sinter cake (see **Fig. 1**). This method is characterized by the ability to improve the permeation of the lower part of the ore bed selectively without adversely affecting the sintering speed of the upper part of the bed, where heat supply is comparatively small. As a result, the airflow distribution of a sintering strand is automatically optimized in commercial operation. Different from those production increasing methods[6] wherein ventilation holes are provided in the ore bed to improve its permeation, the developed method is possible to enhance productivity maintaining the sinter strength and production yield at high levels.

Fig. 2 shows the result of a pot test to analyze the sinter cake supporting behavior of a support stand. A slight increase in the load due to the suction pressure showed immediately after the ignition of the ore-bed surface layer, and thereafter, the load on the stand increased further from the time when the temperature around the stand top rose quickly and then fell to 1,200℃ to the time of the completion of the sintering process. This indicates that the stand supported the load of the sinter cake layer above from the time when the ore bed around the stand top began to solidify through a semi-molten state after the combustion and melting to the time of the completion of sintering.

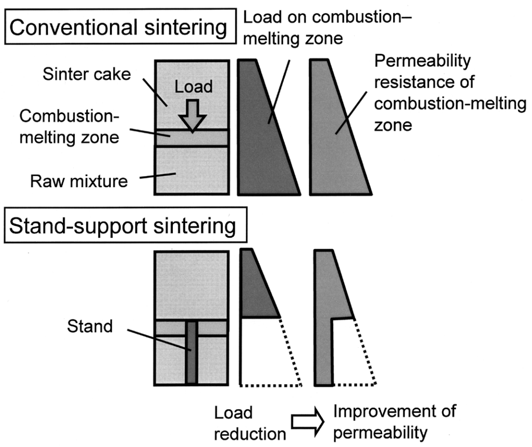

Fig. 1 Schematic diagram showing the principle of stand-support sintering

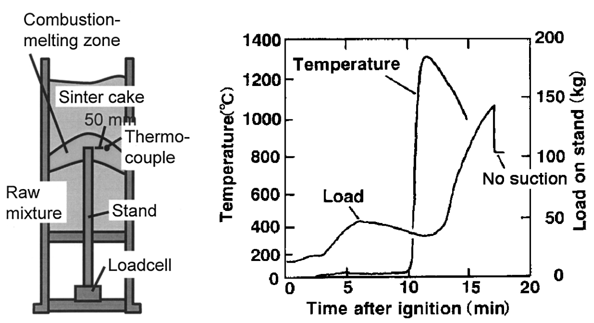

Fig. 2 Supporting behavior of load on combustion-melting zone by stand during sintering

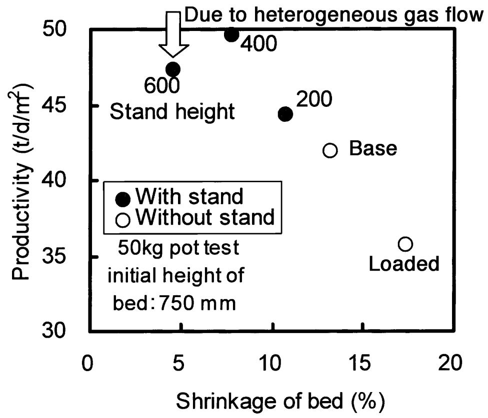

Fig. 3 Improvement of productivity by stand-support

Fig. 3 shows the results of pot tests to examine the supporting effect of the stand; the pot inner diameter was 300 mm, suction pressure was 19.6 kPa, and the ore bed height was 750 mm. Here, a square bar was set vertically to the plane of the grate as shown in Fig. 2 to simulate a support stand. To examine the effects of the load, measurement was done also under a pressure of 0.15 MPa on the upper surface of the ore bed. The tests showed that the support stand suppressed the shrinkage of the ore bed, and as a result, the production rate (t/d/m^2) increased by 20%. Conventionally, the liquid phase amount and fluidity of the combustion-melting zone were considered to influence the shrinkage behavior of the ore bed[7,8]. However, in our tests, the shrinkage increased and the productivity decreased when the load was imposed on the upper surface of the ore bed. Thus, the tests made it clear that the load from above made the ore bed shrink and significantly and adversely affected the productivity of the sintering process.

3. Application of Stand-support Sintering Method to Commercial Sintering Machines

3.1 Definition of material, shape and arrangement of support stands

A support stand, which is set on the grate pallet to sink in the ore bed, undergoes a tough thermal condition where heating to around 1,300℃ and cooling are repeated roughly in every hour, and the temperature of its top becomes 700℃ or higher[4]. What is more, after the discharging of the sinter cake from the pallet, the stand undergoes impacts of the sinter cake falling from the succeeding pallet. Therefore, it was necessary to design the material and shape of the support stands to withstand the condition. Based on the results of endurance tests, a steel of ferrite-pearlite system was selected because of its resistance to crack propagation under repetitive heat cycles and good high-temperature strength. To increase the supporting effect and minimize stress, a trapezoidal plate shape with the top side having a certain length was selected based on the result of an FEM analysis. In consideration of the support effect and durability, the height of the stands was set at 300 mm, approximately a half of the ore bed depth. It has to be noted in this respect that, if the stand height is too large, the durability is deteriorated, and in addition, the tops of the stands break through the fragile surface of the sinter cake, and the support effect is lost[9]. As a result of these studies, support stands having a service life of two years or more under the normal commercial operation conditions were developed.

With respect to the arrangement of the stands, while it was desirable cost-wise to minimize the number of the support stands, when the distance between two stands was too large, the sinter cake tended to sag because of its porous structure. Eventually, based on the results of measurement of the ore bed shrinkage and the distribution of gas flow rate through the bed surface layer, the longitudinal and transversal distances between the stands were determined to realize homogeneous distribution of the support effect, and the difference in the shrinkage of the ore bed was controlled to less than 10 mm[4]. **Fig. 4** shows the support stands installed on a pallet of No. 3 Sintering Machine of Nippon Steel's Kimitsu Works.

Fig. 4 An appearance of stands attached to a pallet in Kimitsu No. 3 sintering machine

3.2 Production increasing effect of stand-support sintering

The stand-support sintering method was introduced to the following sintering machines of Nippon Steel: Kimitsu No. 1 (grate area 183 m^2) in June 1996, Kimitsu No. 3 (500 m^2) in March 1997, Kimitsu No. 2 (280 m^2) in December 1997, and Oita No. 2 (660 m^2) in November 2004.

Fig. 5 and **Table 1** show the change in the operation data of Kimitsu No. 3 Sintering Machine before and after the application of the method[10]. The support stands were installed on three occasions of scheduled shutdown for maintenance. After the completion of the installation work, the permeation of the ore bed was improved in spite of a high bulk density of the bed and a low mixing ratio of quicklime at that time, and the flame front speed (FFS) increased. What is more, in spite of the increased FFS, the product yield increased, maintaining a high strength of the product. This is presum-

Table 1 Operation results at Kimitsu No. 3 sintering machine

Period		Base 1997/12/30 -1998/1/27	With stand 1998/3/22 -1998/7/31
Productivity	t/d/m^2	37.3	40.8
Bulk density of bed	t/m^3	1.61	1.66
FFS	mm/min	24.2	25.9
Product yield	%	78.4	79.4
Shatter index	%	89.3	89.5
Burnt-lime	kg/t-sinter	18.3	15.8
JPU	–	24.3	26.3
Bed height	mm	562	608

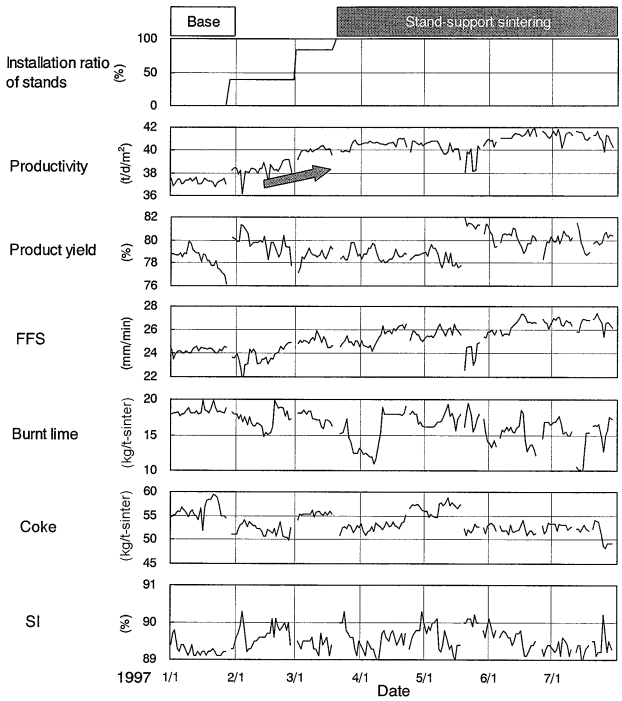

Fig. 5 Changes in operation by installing stand-support sintering at Kimitsu No. 3 sintering machine

ably because (1) the advantage of the permeability improvement by the support stands was made the most of by increasing the height and bulk density of the ore bed instead of increasing the pallet travelling speed, and (2) the sintering process of the lower portion of the ore bed was homogenized. As a result of these improvements, the production rate (t/d/m^2) increased by 9%.

Fig. 6 shows the change in the shrinkage behavior of the ore bed and that of the gas flow rate through the surface layer of the ore bed. The graphs confirm that the support stands effectively suppress the shrinkage of the ore bed at the later stages of the sintering process and improve the permeation of the ore bed.

The factors of the production increase (+9.4%) were analyzed using equation (1), and it was found that the most significant factor was the increase in the FFS (+6.9%) due to the improvement in permeability. In addition, while the pallet inner volume decreased by 0.9%, the bulk density of the bed increased by 3.2%. In spite of the higher FFS, the product yield increased by 1.3% thanks to the homogeneous sintering process in the lower bed portion. As a result, the production rate increased by 9% in total.

$$\text{Prod.} = 60 \cdot 24 / 1000 \cdot \text{FFS} \cdot \rho \cdot \eta_1 \cdot \eta_2 \qquad (1)$$

where, Prod. is the production rate (t/d/m^2),
FFS is the flame front speed (mm/min),
ρ is the bulk density of the ore bed (t/m^3),
η_1 is sintering yield (sinter cake / feedstock ore, %), and
η_2 is product yield (%).

Since the introduction of the stand-support sintering method, the sintering machines of Kimitsu Works have been producing high-quality sinter at a high productivity with high blending ratios of pisolite ores[11,12]. **Fig. 7** shows the relationship between the bed height and suction pressure before and after the introduction of the new method. Thanks to the improvement in permeability, it became possible to increase the bed height to 700 mm or more, and as a result, production efficiency increased, keeping the shatter strength (SI) at 92.5% or higher[12].

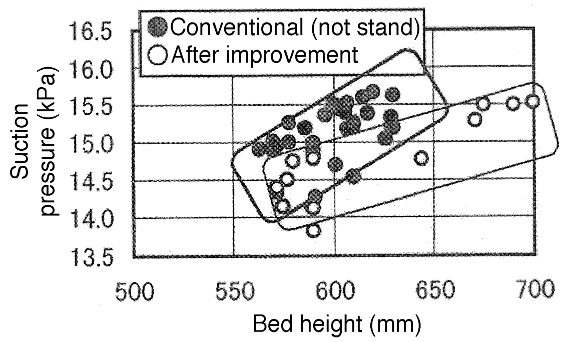

Fig. 7 Changes in relationship between bed height and suction pressure in Kimitsu No. 3 sintering machine

Table 2 shows the operation data of Oita No. 2 Sintering Machine (with a VVVF blower motor) before and after the introduction of the stand-support sintering method[13]. The support stands were installed at the time of the width expansion of the machine, and as a result, the production increased by as much as 18%; of this, the stand-support sintering method was responsible for 7%. In addition, as a result of the improvement in permeability, the unit power consumption of the main blower (MB) decreased. **Fig. 8** shows the relationship between the tumbler strength (TI) of product sinter and FFS of the sintering machine before and after the introduction of the new method. The bed height was increased after the installation of the support stands, and the TI improved in spite of an increase in the FFS.

3.3 Change in sinter cake structure

Fig. 9 compares the X-ray CT images of the sinter cakes of

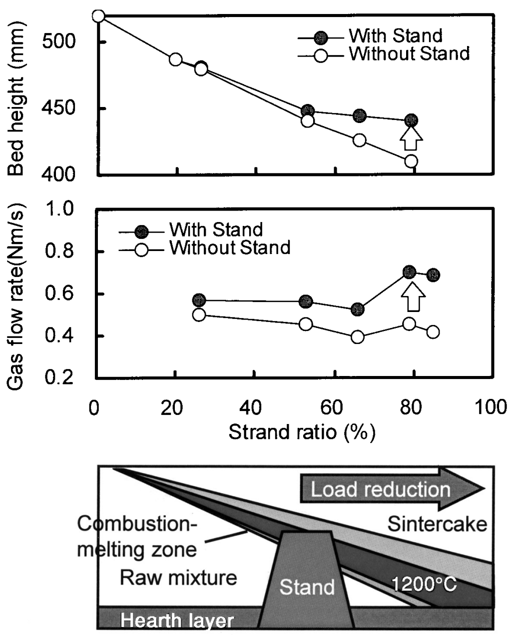

Fig. 6 Changes in shrinkage behavior of bed and gas flow distribution at Kimitsu No. 1 sintering machine

Table 2 Operation results at Oita No. 2 sintering machine

Period		Base 2004/10/1 -2004/12/31	With stand 2005/11/17 -2005/11/30
Sintering area	m^2	600	660
Productivity	t/h	713	840*
	t/d/m^2	28.5	30.5
FFS	mm/min	21.4	22.0
Product yield	%	77.4	78.6
Burnt-lime	kg/t-sinter	7.1	8.4
Bed height	mm	578	670
MB	kWh/t-sinter	18.4	16.7
O_2 in exhaust gas	%	14.9	13.5
Air consumption	Nm^3/t-sinter	1721	1323
η CO	%	86.0	86.3
Tumbler index	%	77.1	78.9
− 5mm	%	5.0	4.2
RDI	%	37.7	35.1
JIS-RI	%	66.5	65.9

* Inclusive of effect of width extension

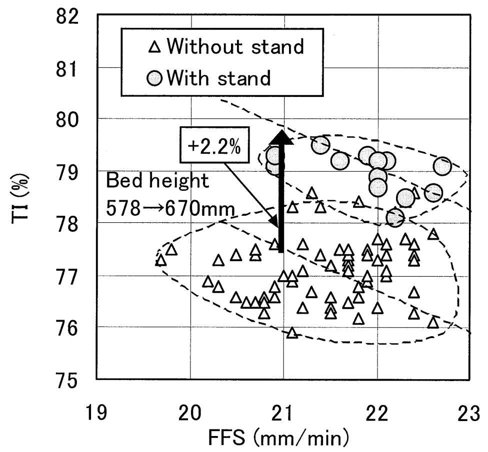

Fig. 8 Improvement of TI by installing stand-support and width extension at Oita No. 2 sintering machine

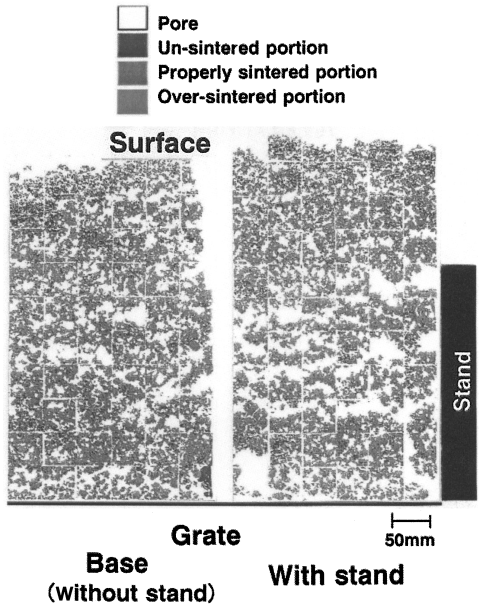

Fig. 9 Changes in sinter cake structure with stand-support measured by X-ray CT in the width direction

Kimitsu No. 1 Sintering Machine produced before and after the introduction of the method. As a result of the suppression of the ore bed shrinkage by the stands, permeation pores well developed in the lower portion of the sinter cake produced with the support stands. Non-sintered portions were not observed near the support stands; we confirmed that, under the operating condition of a commercial sintering machine where the heat capacity is large, the adverse effect of the heat removal from the ore bed by the support stands was insignificant.

4. Summary

To cope with the degradation of iron ore resources, Nippon Steel developed the stand-support sintering method, whereby the load of sinter cake in the upper portion of the ore bed is supported by steel stands during the sintering process, and applied the method to the sintering machines of Kimitsu and Oita Works. The following findings were obtained through the tests and commercial application of the method:

(1) The load of the sinter cake on the combustion-melting zone below it makes the ore bed shrink (ore bed compaction), and thus significantly deteriorates the permeability of the bed.

(2) The support stands installed inside the sintering pallets begin to support the load of the sinter cake above at the time when the ore bed portion around the tops of the stands begins to solidify after heating and melting. The sintering process of the lower portion of the bed proceeds thereafter under a reduced load, and a permeation network develops well in the portion to improve permeability.

(3) As a result of the commercial application of the method to the sintering machines of Kimitsu and Oita Works, productivity increased significantly.

The machines continue to operate stably after the application of the method, contributing to the high productivity of the sintering operation of the company.

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