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Technical Report

Improving Granulation of Sinter Materials by Using a Wet Vertical Ball Mill

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Abstract

In order to increase productivity and decrease the Reducing Agent Rate (RAR) of blast furnaces, it is important to decrease the slag volume of burdens. Therefore, using a high amount of iron ore concentrate as sinter materials is desired because of its lower slag contents. However, when using concentrates, it causes a decrease of the permeability of the sintering bed and sinter productivity. In this report, a new technique, adding micro-particles to concentrates as a binder, was investigated. A vertical wet ball mill was installed on a separate granulation line of the Wakayama No. 5 Sinter Machine, and 0.5 mass% of Australian goethite ore was ground to −10 microns. Then ground ore slurry was added into an intensive mixer of concentrates and other sinter materials. After mixing, they were granulated by a pan-pelletizer and charged into the sinter machine with other materials granulated at the main granulation line. It was confirmed that granulation was improved by adding micro-particles. By the technique, sinter productivity increased by 2.4% when using 13.3 mass% of concentrates.

1. Introduction

The quality of the burden exerts significant influence on the performance of a blast furnace. In the blast furnaces of Nippon Steel Corporation, about 75% of the burdens is the sinter with the rest of the pellets and lump ore accounting for about 10–15% each. To further pursue blast furnace operation of higher productivity and lower reducing agent rate, enhancement of the sinter quality, decreasing slag contents for instance, is a crucial factor.

However, since the fine ore is a natural resource, the deterioration in quality, namely, the decrease of the total Fe and the increase of the slag content, is unavoidable. To reduce the slag content of the sinter in the progress of the deterioration in resource quality, using a higher amount of the iron ore concentrate containing high total Fe is required.

Beneficiation is a process wherein the ROM (Run-of Mine) containing ferruginous mineral particles (target of concentration) and the gangue particles (target of elimination for tailing) are crushed to sizes small enough to be separated into the respective single substances by taking advantage of their properties such as specific gravity and magnetism (**Fig. 1**). So the iron ore concentrate is finely grounded. Because of its adverse effect on granulation as discussed in a later section, its application to sinter is restrictive, and used to be treated mainly as a material for pellets (pellet feed).

In the sinter process, before being embedded in the sinter ma-

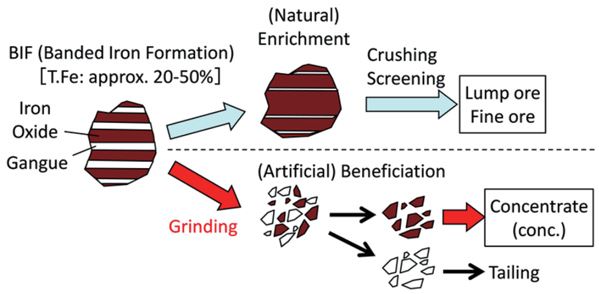

Fig. 1 Schematic diagram of beneficiation process

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chine and sintering, a pretreatment termed as granulation is applied and pseudo-particles are formed. The use of the concentrate simultaneously decreases the amount of particles to be the core of the pseudo-particles (mainly +1 mm), and increases the amount of the particles to be the adhesive powder (mainly −0.25 mm). Accordingly, when the granulating capacity is limited, the granulation is deteriorated (increase of the inadhesive powder ratio, decrease of the mean pseudo-particle size), the permeability of the material layer formed in the sinter machine is reduced and the productivity is diminished.

To cope with the abovementioned problem, various technologies have been proposed targeting the utilization of the concentrate in the sintering process, among which the HPS (Hybrid Pelletized Sinter),[1] MEBIOS method (Mosaic Embedding Iron Ore Sintering)[2] and SPExII[3, 4] have been put into production operation.

In the MEBIOS method, by arranging green balls, the iron ore that is thickly granulation-treated to large sizes of about 5–15 mm (hereinafter referred to as GB), in the conventional material layer consisting of the pseudo-particles 2–3 mm in size on average, highly porous regions are formed around the GB, and the permeability is improved thereby.[2] Nippon Steel introduced the E-P line of the P-type separate granulation line consisting of a high-speed agitating mixer and a pan pelletizer at the Wakayama No. 5 Sinter Machine (details to be described in a later section).[5] The line is capable of handling about 20% of the entire materials for sintering and, by adding the concentrate to more than half of it or more than 10% of the entire sintering materials, produces a large size thick GB proposed by the MEBIOS method.

SPExII is a technology developed based on the basic study focusing on the behavior of the micro-particles contained to a certain degree in the fine ore. In the granulation process, water is added to the fine ore and other sinter materials, and by the rolling motion for granulation of a drum mixer or the like, and by the inter-ore-particle interactive capillary force working as the driving force, the particles are approximated, condensed and thickened to form pseudo-particles. In that case, during the granulation process, the iron ore micro-particles of a size completely immersible in water and water-suspendable for slurrying, or specifically below about 10 μm, move with water, penetrate the inter-particle voids and are positioned therein effectively. At sintering in the sinter machine after the granulation, water is vaporized and the micro-particles are dried and solidified, function as a solid cross-bridge and exert a significant effect as a binder as reported (**Fig. 2**[7])).[6, 7]

In the Tobata No. 3 Sinter Machine in Yawata Works, an SPExII line was introduced and has exhibited a high productivity-enhancing effect (**Fig. 3**[4])).[3, 4] In the line, a portion of iron ore is ground in the dry state by a roller press mill to produce a micro-particle binder, which is granulated with other ore, and a sturdy granulated substance is produced after the drying treatment by using the waste heat in the steel works.

This article reports the result of the study on the enhancement of the production capacity of large size thick GB at the P-type separate granulation line of the Wakayama No. 5 Sinter Machine by adding the micro-particle binder. This means micro-particle binder technology is applied to the MEBIOS method. In a laboratory base study, the effect on granulation of the change of the particle structure of the concentrate layer adhering to the pseudo-particles by the addition of a micro-particle binder was analyzed, and the tensile cohesive strength in the mixture field of fine concentrate and the micro-particle binder was investigated.[8] Then, simulating the Wakayama No. 5 Sinter Machine, a sintered ore production pot test of about 50 kg in scale was conducted, and the required amount of the micro-particle binder addition was studied.[9] Based on the test result, as a pilot plant for producing and supplying iron ore micro-particle binder continuously, a vertical type wet-type ball mill was introduced to the Wakayama No. 5 Sinter Machine, and the long-term evaluation of the effect of the mill on the granulation properties and the sintering productivity of the sinter machine was implemented.[10]

2. Basic Study (Evaluation of Cohesive Strength)

In Nippon Steel, as one of the indices for the evaluation of the granulation properties of iron ore, cohesive strength is measured by a vertical directional tensile rupture test (hereinafter referred to as cohesive strength). Okazaki et al.[11] evaluated the cohesive strength and the like of the concentrate from the plurality of different places of production and of different properties, and report that the granulation properties could be evaluated from the surface configuration and the cohesive strength.

To evaluate the effect of the micro-particle binder on the improvement of granulation properties when a micro-particle binder is added to concentrate, we investigated the change of the cohesive strength when two types of particles each having different particle size are mixed.

2.1 Experimental procedure

The test samples of the concentrate from the North American ore (Ore A) and that from the Australian ore of the pisolite (Ore B) were prepared (**Table 1**). Ore B was ground in the dry state by a laborato-

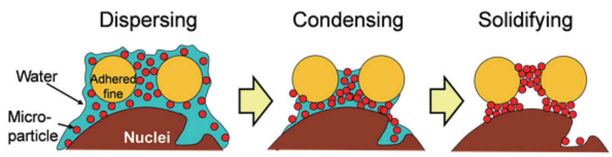

Fig. 2 Behavior of micro-particle on granulation[7])

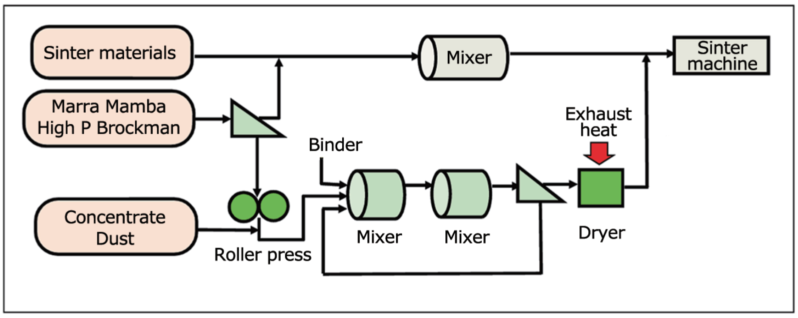

Fig. 3 Process flow of SPExII[4])

ry use horizontal counter type jet mill, and the iron ore micro-particle binder Ore B' was prepared. The mean sizes of Ore A and Ore B' measured by the laser diffraction and scattering method were about 500 μm and 4 μm, respectively (**Fig. 4**). Both of the particles appear thick and smooth on the surface although the adhesion of very fine particles to the surface of Ore B' was observed (**Fig. 5**).

The cohesive strength tester is outlined hereunder.[12] The sample cell is cylindrical with a diameter of about 35.7 mm (cross sectional area 10.0 cm^2) for the layer height of about 30 mm, and is of the split type consisting of the lower cell 10 mm high from the bottom and the upper cell 20 mm from the top surface. The boundary surface of the top cell and the bottom cell is the rupture surface. As a pull mechanism, a spring and a wire are equipped to the upper part of the tester, a tensional load is applied by winding the wire and the load at the time of rupture is indicated (**Fig. 6**[12]). The cohesive strength was measured in the following procedure.

(1) Several samples reduced to a common weight were prepared.
(2) A predetermined amount of water was added to one of the samples and mixed.
(3) After the adjustment of the moisture, the sample was charged to the cell and was compressed and densified to the layer height of 30 mm to form a packed layer.
(4) The cell filled in by the sample was installed in the tester and the lower cell was fixed by a stopper.
(5) A load was applied and increased slowly in the vertical direction. The tensile force at the time of the rupture when the upper cell and the lower cell were separated was divided by the sectional area, and was defined as cohesive strength.
(6) By changing the moisture, the abovementioned measurement was repeated, and the relationship between the moisture and the cohesive strength was arranged. Then, the initial stage moisture was set at 3 mass% and the measurement was started, and conducted stepwise by 2 mass% upward increment. When the maximum value of the cohesive strength (referred to later on) appeared in the step region, the measurement was conducted by 1 mass% increment and the maximum value of the cohesive strength was fixed.

The above measurement was conducted for Ore A and the sole Ore B', and under the conditions of the addition of Ore B' by 5, 10, 20, 30% to Ore A and then mixing, the effect of the addition of the micro-particle binder on the cohesive strength was examined.

2.2 Result and examination

From the relationship between the moisture and the cohesive strength in the respective sample, the cohesive strength rises along with the increase of the moisture, reaches its maximum value at a certain moisture value and then declines (**Fig. 7**). Among the interactively working inter-powder particle forces, the liquid cross-bridge force is considered to rise along with the increase of the moisture. In this test, along with the increase of the moisture, the number of the liquid cross-bridge rises (Pendular region), and its peak (ideally liquid cross-bridges are formed in all inter-particle combinations) is shown at a certain moisture point (Funicular region). Thereafter, the liquid cross-bridges are incorporated and the cross-bridge force ceases to exist (Capillary region), wherein the excess moisture is considered to exert a lubricating effect and then reduce the cohesive strength.

As compared with Ore A, the maximum cohesive strength of Ore B' increased. From the Rumpf's expression[13] that is a relational expression to denote the force of a single spherical particle acting on a packed layer, this is considered to be attributed to the increase of the total of the inter-powder particle liquid cross-bridge force due to

Table 1 Chemical compositions of sample (mass%)

	T. Fe	CaO	SiO_2	Al_2O_3	MgO	P	CW
Ore A	66.14	0.34	4.78	0.09	0.07	0.017	0.09
Ore B	58.22	0.08	4.22	1.54	0.10	0.056	9.53

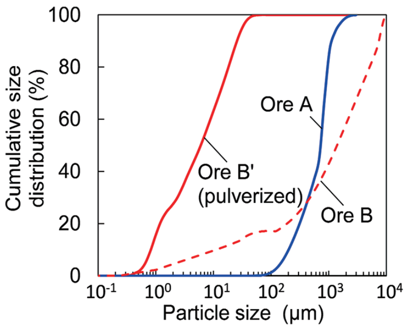

Fig. 4 Size distribution of sample ores

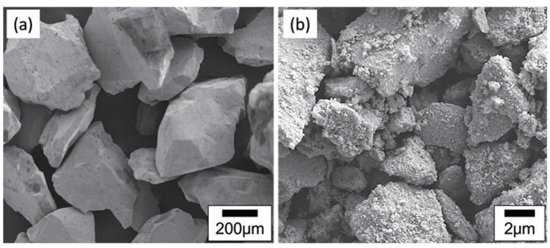

Fig. 5 SEM image of samples (a) Ore A, (b) Ore B'

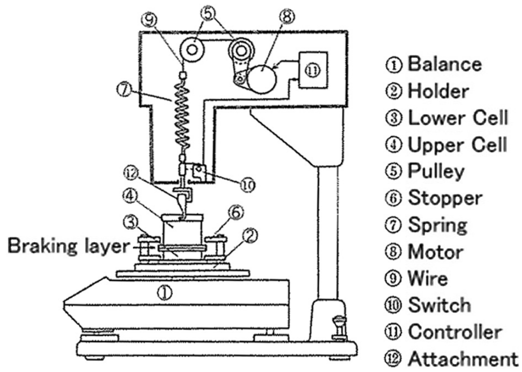

Fig. 6 Schematic diagram of cohesive strength tester[12]

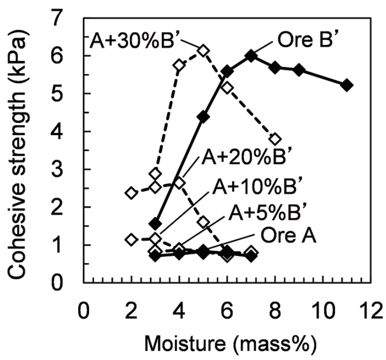

Fig. 7 Cohesive strength of sample ores

the increase of the number of particle contact points and the increase of the specific surface area both developed by grain-refining (although the cross-bridge force per one contact point becomes smaller, the effect of the increase of the total number of contacts increases).

In the mixed field wherein Ore B' is added to Ore A, two changes were recognized. The first is that the maximum cohesive strength rose along with the addition of Ore B'. The second is that the moisture value that corresponds to the maximum cohesive strength tends to move to values lower than those of the sole Ore A and the sole Ore B'. In this test, in the case that Ore B' is mixed by 10%, the moisture dropped most remarkably, and the maximum cohesive strength was shown at 3% moisture.

As described above, the moisture value that shows the maximum cohesive strength differed depending on the type of sample. As the moisture value is a factor controllable to some extent in the granulation, only the respective maximum cohesive strength was targeted and extracted, and as a result of the examination of the maximum cohesive strength and the porosity with respect to the mixing ratio of Ore A and Ore B', along with the increase of the addition of Ore B', the porosity lowered and the maximum cohesive strength rose in a quadric-function-like manner (**Fig. 8**).

The descent of the porosity is considered to be attributed to the progress of the penetration of the Ore B' particles into the inter-particle voids of Ore A, and continued to lower until the addition of Ore B' by 30%. The porosity of the sole Ore B' was high, which, as shown by the experiment of Roller,[14] is considered to be due to the effect of the surface force (cohesive strength) being larger as compared with gravity along with the drop in particle size, thereby lowering the packing density.

The reason for the increase of the maximum cohesive strength not being linear but quadric-function-like is considered to be as follows. In the region where the addition of Ore B' is small, the inter-particle contact points of Ore A, the initiation points of rupture, still remain, and when the Ore A contact points are replaced by the contact of Ore B', and the inter-particle contact points of Ore A are reduced, the cohesive strength greatly increases.

From the above result, it is predicted that, by the addition of the micro-particle binder, the constitutive particle of the powder layer adhered to the pseudo-particles becomes highly cohesive and promotes granulation more readily, and that the pseudo-particle strength after granulation rises thereby. However, the cohesive strength rise verified by this experiment applies only under the condition of the existence of the liquid cross-bridge, or under a wet condition. Therefore, it cannot be judged immediately whether the above increase of the cohesive strength contributes to the rise of the cohesive strength of the pseudo-particles after drying. Regarding the manifestation mechanisms of the wet state strength and the strength after drying, Maeda. et al.[15] report that; although the liquid cross-bridge strength is dominant in the wet state strength, the strength after drying was increased by the direct addition of a clay mineral, or by the use of the iron ore bearing kaolinite, a clay mineral, in its gangue mineral. Therefore, the use of the ground ore bearing a rich clay mineral component as a micro-particle binder is expected to effectively contribute to the enhancement of the dry-state strength.

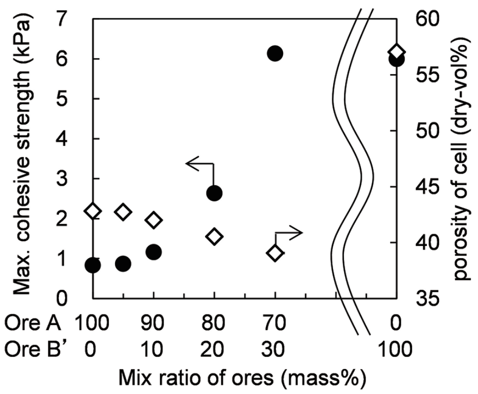

Fig. 8 Changing of maximum cohesive strength by adding micro-particles

2.3 Brief summary of basic study

As a result of the basic study conducted to verify the effect of the addition of the micro-particle binder to the concentrate, the change of the cohesive strength measured by the vertical directional tensile rupture test was investigated, and the following results were obtained.

(1) The cohesive strength changes along with the change of the moisture, and each sample showed its maximum value at its own respective specific moisture value.
(2) The smaller the particle size of the powder sample, the higher the maximum sample cohesive strength becomes.
(3) In company with the addition of the micro-particle binder to the concentrate, the cohesive strength of the mixed powder layer increased.

3. Simulation Test for Sinter Process (Pot Test)

In the preceding chapter, the increase of the cohesive strength of the powder layer by the addition of the micro-particle binder was confirmed. In this chapter, the following test is reported. As a preliminary study for the introduction of micro-particle production equipment to the Wakayama No. 5 Sinter Machine, a 50 kg scale pot test simulating the sintering process was conducted to examine the appropriate amount of micro-particle binder to be added for the case of the combined use with quicklime used as a binder.

3.1 Experimental procedure

A P-type separate granulation line is installed in the Wakayama No. 5 Sinter Machine, and there are two granulation lines. The pot test was conducted simulating the lines. The 23.5 mass% of the new material (iron ores, quicklime and fluxes) was granulation-processed in the E-P line consisting of a high-speed agitating mixer and a pan pelletizer, and the remaining new material of 76.5 mass%, return fine and carbonaceous materials were granulation-processed in the D-D line of a drum mixer. In the laboratory test, samples of the granulated substances of the E-P line and the D-D line were prepared according to the actual material mix and through the simulated methods of the E-P and D-D line processes being mixed and charged to the pot and sintered.

The materials of the E-P line were: North American hematite concentrate Ore A, Australian pisolite Ore B, blast furnace dust and quicklime. As described in the preceding chapter, a portion of the Ore B was ground and was added as the micro-particle binder Ore B'. The amount of quicklime added was set at three levels with respect to the entire E-P line material mass (Case-1: 3.5 mass% of the entire E-P line material (100%), Case-2: 2.7 mass% and Case-3: 1.8 mass%), simulating the amount of consumption in the Wakayama Works. The amount of Ore B' added was changed according to four levels set likewise with respect to the entire E-P line material mass (Case X-0: 0.0 mass%, Case-1: 3.0 mass%, Case-2: 5.0 mass% and Case-3: 7.0 mass%). The test results of the total twelve cases were compared. For the mixing simulating the D-D line, a plurality of fine ores of Australian product and Brazilian product, auxiliary materials, return fine and carbonaceous materials were used. In the case of the addition of Ore B’, a portion of the Ore B to be mixed in the D-D line was ground (**Table 2**[9]).

To simulate the granulation process of the E-P line, water was added to the materials and they were mixed and humidity-adjusted by a high-speed agitating mixer, charged at the rate of 1 kg/min to a pan pelletizer 580 mm in diameter, then granulated, and the discharged GB was recovered. To simulate the granulation process of the D-D line, all the materials were charged into a drum mixer, were mixed for 2 min, added with water and granulated for 4 min. Then, the granulated substance from the simulated E-P line granulation was added to the drum mixer so as to achieve a predetermined mixing ratio, and the granulated substances from both simulated line granulation were mixed for 15 s and then discharged from the mixer. Then, the material substance was drop-charged to a pot 300 mm in diameter and 500 mm in height. Air was suctioned continuously at less than 9.8 kPa, and the material was ignited for 1 min by LPG gas at the top and sintered.

In addition, for the evaluation of the granulated substance, a sample of about 500 g was taken from each of the following three granulated substances: the E-P line granulated substance, the D-D line granulated substance and the mixture of the two granulated substances of the two lines The samples were heated for 2 hours or longer at 105°C and dried to bring the moisture to 0%, and sieved for 15 seconds by a rotation-tap type shaker without the tapping motion. From the result of the size-wise classification, the mean size of the weight average was calculated.

3.2 Result and examination

As for the effects of the additions of quicklime (QL) and the micro-particle binder Ore B’, along with the increase of the addition of Ore B’, the average size of the GB grows, and when the amount of quicklime added is increased with a fixed Ore B’ mass%, the trend of the growth of GB mean size is observed (**Fig. 9**[9]).

In the E-P line of the Wakayama No.5 Sinter Machine, in addition to the newly added Ore B’ as studied herein, the following are existent as binders: the quicklime that used to be added as a conventional binder and the micro-particles originally adhered to the fine ore mixed for the purpose of forming cores (Ore B in this test). Therefore, different from the basic study case described in the preceding chapter, the binder particles are considered to be originated in the pluralities of materials. In this test, on the assumption that the abovementioned three types of micro-particles are equipped with the equal granulation-improvement function, the total amount of the binder particles was defined as the total sum of the amounts of the added Ore B’ and quicklime, and the amount of −10 μm particles contained in Ore B, each amount being corrected for density difference.

Rearranging the result in Fig. 9 with respect to the abovementioned total amount of the binder particles, a correlation curve exists between the total binder addition amount and the mean size of GB, and along with the increase of the total amount of the binder particles, the mean size of GB grows in a quadric-function-like manner (**Fig. 10**). This trend agrees with the trend in the region where the cohesive strength starts to sharply rise by the addition of micro-particle binder as discussed in the preceding chapter. Accordingly, at least in the moistened state in the granulating step, it is suggested that the micro-particle binder fills in the inter-particle voids of concentrate regardless of its type, and contributes to the growth of the mean size of GB in conjunction with the increase of the volume-based addition amount.

The sintering productivity rose until the addition of Ore B’ by 5 mass% as the sintering speed increased while maintaining a constant yield value. However, with the addition of 7 mass%, although the sintering speed increased, the sinter yield deteriorated and the sinter

Table 2 Blending conditions of pot test[9] (mass%)

		Case 1- 0, 1, 2, 3	Case 2- 0, 1, 2, 3	Case 3- 0, 1, 2, 3
E-P line				
	Ore A	12.91	12.90	12.88
	Ore B	8.61	8.60	8.59
	BF-dust	0.52	0.52	0.52
	Quicklime	0.80	0.60	0.40
	Subtotal (E-P)	22.84	22.62	22.38
	Ore B’	0.0, 0.7, 1.1, 1.6		
D-D line				
	Ore B	14.12	14.10	14.08
	Other SFs	47.43	47.39	47.32
	Fluxes	14.81	15.09	15.41
	Quicklime	0.80	0.80	0.80
	Return fine	20.00	20.00	20.00
	Coke breeze	5.50	5.50	5.50
	Subtotal (D-D)	102.66	102.88	103.11
	Total	125.50	125.50	125.50

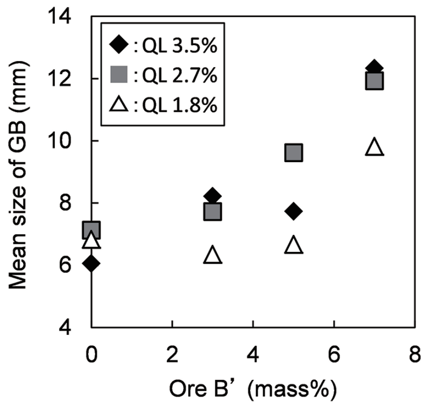

Fig. 9 Effect of micro-particle binder on granulation at E-P line[9]

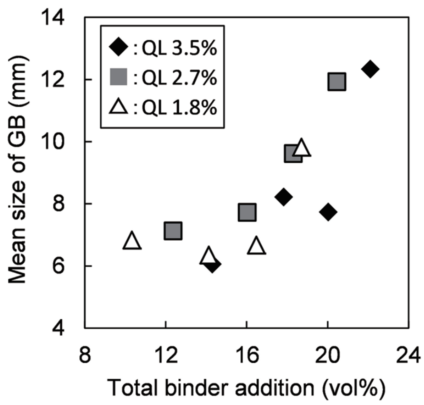

Fig. 10 Effect of total binder on granulation at E-P line

productivity started to decline in all three levels of the quicklime addition ratio. However, the extent of the deterioration of the sinter productivity in the case of the addition of Ore B' 7 mass% differs depending on the quicklime addition ratio, and the smaller the addition of quicklime, the more remarkably the sinter yield and the sinter productivity deteriorated (**Fig. 11**).

The mean size of GB at Ore B' 7 mass%, although it depends on the amount of quicklime added, is from 9.8 mm to 12.3 mm, and does not exceed the upper limit of 15 mm of the large granulated substance in the MEBIOS method referred to in the introductory chapter. However, despite that, the sinter yield dropped significantly, the reason of which is considered to be attributed to, as examples, the shortage of the amounts of CaO component and carbon. Regarding the material behavior in sintering when large-size particles are arranged, Kawaguchi et al.[16] report that; when the Marra Mamba granulated balls are arranged as large particles, the sintering condition affects the sinter yield significantly. Therefore, mixing the material that contains low-melting point components of high fluidity (high CaO content, high FeO content) and high fuel carbon is considered to be effective. The Marra Mamba granulated ball used for the study by Kawaguchi et al. is 10–15 mm mixed with the 6.2 mass% of the −1 mm of quicklime, and the amount of the mixed CaO is considered to be about 3.5 mass% of the ball. To this effect, as GB of Case 3-3 wherein the drop of the yield was remarkable in this test contained CaO of 1.8 mass% with the GB mean size of 9.8 mm, the strength after sintering is considered to be deficient.

From the above, the quicklime that has been used conventionally as a binder contains the CaO composition, and is able to increase the GB particle size while maintaining the strength after sintering. However, in producing larger GB by employing additionally the micro-particle binder made of ground iron ore, it is desirable to prepare separately for respective GB particle size the means to secure the strength after sintering, or to control the amounts of the addition of binders so that the GB particle size is controlled to an appropriate size to maintain the strength after sintering. For the long run test in the E-P line of the Wakayama No.5 Sinter Machine, based on this result, it was decided that the production and the addition of Ore B' is below 7 mass% with respect to the E-P line, and a grinding mill conforming to the above specification was introduced and evaluation based on the production sinter machine was conducted.

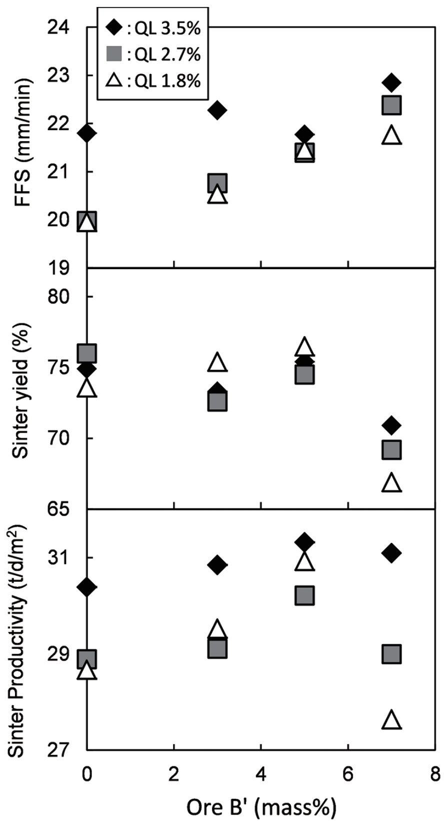

Fig. 11 Effect of micro-particle binder on sinter productivity

As a means to secure the strength of GB after sintering, in addition to the abovementioned CaO component and carbon, magnetite ore is considered to be effective. Matsumura et al.[17] reported in the workshop of the Iron and Steel Institute of Japan that, in the pot test of the separate type granulation process that employed GB which mainly employed magnetite concentrate and suppressed the proximate arrangement of CaO and carbon based on the knowledge of the academic contingent that studied the utilization of magnetite ore,[18–20] the enhancement of strength was promoted by the oxidative heat generating reaction of the magnetite ore, and both the cold strength and the reducibility of sintered ore were improved. The addition of the iron ore micro-particle binder to the magnetite concentrate is a subject for future study.

3.3 Summary of sinter pot tests

Simulating the granulation flow of the Wakayama No.5 Sinter Machine, a pot test of adding micro-particle binder to the simulated E-P line was conducted, and the following results were obtained.

(1) In the simulated E-P line granulation, the effect of the addition of the micro-particle binder on the granulation improvement was confirmed. The mean size of GB grew, being correlated with the total sum of the volume-based amount of addition regardless of the type of binder particle.

(2) The sinter productivity shows the peak value at a certain value of addition. In the case where 7.0 mass% of the micro-particle binder Ore B' was added to the simulated E-P line, the sinter productivity deteriorated.

4. Long Run Test in Production Line

In this chapter, the production of the iron ore micro-particle binder in the Wakayama No.5 Sinter Machine, and the result of the long-term evaluation of the effect of the addition thereof on the effect of the granulation improvement are described.

4.1 Features of the Wakayama No.5 Sinter Machine

In 2008, the production capacity of the Wakayama No.5 Sinter Machine was expanded to cope with the blast furnace volume expansion from 2700 m^3 of the No.4, 5 Blast Furnaces production structure to 3700 m^3 of the new No.1, 2 Blast Furnaces production structure. At the expansion, a P-type separate granulation line was introduced intended for the production of the large and thick granulation substance proposed by the MEBIOS method (**Fig. 12**).[5]

The E-P line of the Wakayama No.5 Sinter Machine is capable of handling materials at 150 t/h (about 20% of the entire material (sinter mix), about 25% of the entire new material of the sinter mix). For the E-P line, five material hoppers were allotted (one of them is for the exclusive use of the pneumatic transport of quicklime), three hoppers were used for ores (standard arrangement: one for fine ore, two for concentrate), one for blast furnace dust and one for the quicklime as described above. The mixing ratio of the powder ore and the concentrate (PF/SF ratio) is set at 1/1 or higher and 3/1 or lower based on our past study.[21]

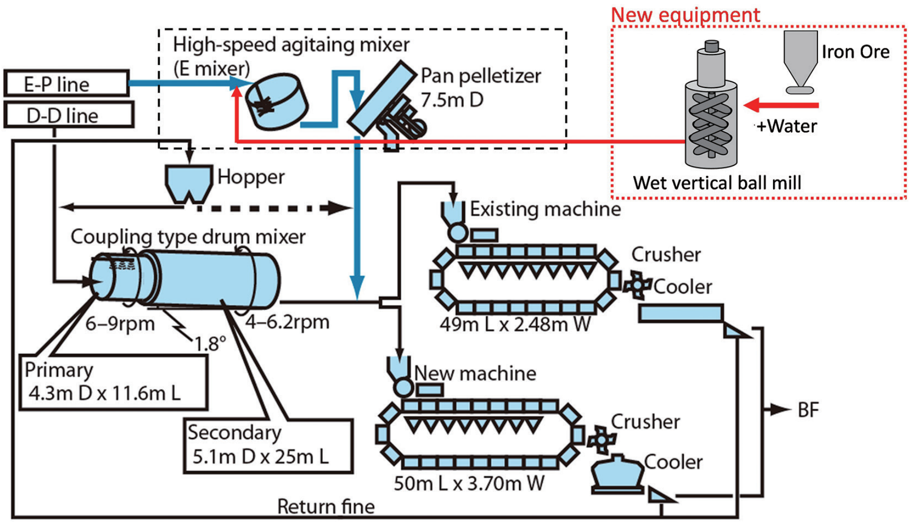

Fig. 12 Granulation process of the Wakayama No.5 Sinter Machine

The rest of the entire material (sinter mix) of 80% is processed by the drum mixer (hereinafter referred to as the D-D line). In the Wakayama No.5 Sinter Machine, the primary mixer and the secondary mixer are of the coupled type without any conveyor in between (to provide sufficient staying time in the secondary mixer under a layout restriction).

Finally, on the conveyor carrying the granulated material after the granulation in the D-D line, the granulated material from the E-P line is overlaid and both granulated materials join each other. The granulated materials are lightly mixed via several relays, and charged to the surge hopper and via the drum feeder segmentation, and then charged into the sinter machine.

4.2 Introduction of wet vertical ball mill

With respect to the abovementioned E-P line, various grinding processes for continuous production and the addition of micro-particle binder were compared and studied, and the wet vertical ball mill (hereinafter referred to as mill) was selected. The reason for not selecting the dry grinding method but the wet grinding method is that, as the micro-particle binder is considered to move with water and be positioned in between concentrate particles during the granulation process as shown in Fig. 2, and by charging to the high-speed agitating mixer in the form of slurry wherein grinding of iron ore (crushing to the size of micro-particle binder) and the suspension of the micro-particle in the aqueous suspension state have been simultaneously promoted, the arrangement of the binder is expected to be efficiently performed. Furthermore, because of the high specific surface area, it is difficult for the micro-particles of the dry-ground iron ore to get wet in spite of the addition of water, and further, the particles locally become wet and condensed, readily forming an unmixed-in lump of particles. The selection was made taking into consideration the prevention of this problem also.

The schematic structure and the grinding process are stated hereunder (**Fig. 13**). The tower-like mill installed with a screw at its inside center is packed to a predetermined quantity with abrasion-resistant steel balls as the grinding media. The iron ore to be ground and water are charged, the content is agitated by the rotation of the screw and the content is ground by the compressive force and the shearing force. Accordingly, this mill is a type of ball mill in a broad sense, however, specifically, it is considered to be a type of media-stirring mill.

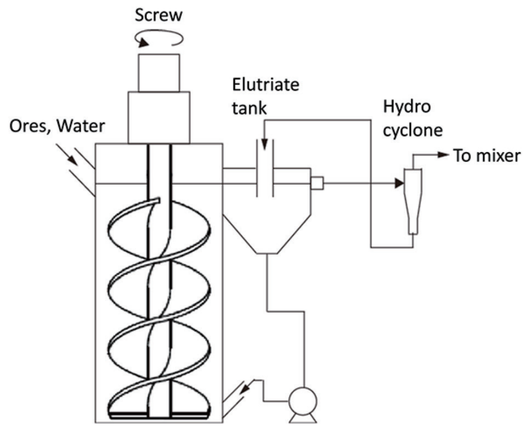

Fig. 13 Schematic diagram of wet vertical ball mill

The slurry of iron ore thus ground in the mill is classified by gravity in the accompanying elutriate tank and classified by centrifugal force in the hydro-cyclone. The coarse particles are returned to the mill and the fine ore particles are fed into the high-speed agitating mixer of the next step in the form of the finished particle slurry. The main specification of the mill is: maximum amount of material to be supplied is to be 7.3 t/h to ensure the volume of the slurry particles of -10 μm is at the target 60 vol% or above, maximum water supply amount to be 9.6 t/h and the slurry concentration to be 40–43 mass%.

4.3 Test condition in production line

The test operation was started at first without mixing concentrate. The concentrate of about 13.3% of the entire new material of the entire sinter material (sinter mix) was mixed, and the base operation was continued for about 3 days (such base operation hereinafter referred to as Base). Then the mill was started and the grinding amount and the concentration were gradually increased, taking a day to reach the target values, and then the test was started (such test hereinafter referred to as Test).

The same material mixing ratio was applied to the Base and the Test although the actual value varied slightly due to the slight adjustment of the sintered ore compositions and variations in the recycled material compositions. For the Test, a portion of the Australian pisolite ore that was referred to in the preceding chapter was ground.

Table 3 Blending conditions of commercial plant test (mass%)

		Base	Test
E-P line	Concentrate	13.3	13.3
	Pisolite SF (Australia)	8.9	8.8
	Others	0.6	0.7
	Quicklime	0.8	0.8
	Micro-particles	0.0	0.5
	Subtotal	23.6	24.0
D-D line	Pisolite SF (Australia)	17.2	16.6
	Marra mamba SF (Australia)	19.5	19.4
	Hematitle SF (Brazil)	17.7	17.6
	Others	11.1	11.5
	Limestone	10.5	10.7
	Quicklime	0.3	0.3
	Subtotal	76.4	76.0
Total		100.0	100.0

The slurry of the ground ore was transported to the high-speed agitating mixer by pumping and charged. To maintain a constant moisture level of granulation in the Base, water to be added to the high-speed agitating mixer was replaced by the slurry. The amount of the new material ground in the test was about 0.5 mass% of the entire material (sinter mix), which is equivalent to about 2.1 mass% of the E-P line. In the D-D line, ordinary fine ores, auxiliary materials, carbonaceous materials and the like were mixed (**Table 3**).

During the test, samples were taken from the E-P line granulated substance (at the exit of the pan-pelletizer), D-D line granulated substance (at the exit of the drum mixer) and the mixed granulated substance after joining of both and right before charging to the sinter machine (ore feeding site), and the granulation state was evaluated. For evaluation of the granulation state, the pseudo particles were evaluated. After the sample reduction, the samples were dried thoroughly by a dryer (maintained for 2 hours or longer at 105°C), shaken for 12 s by a rotation-tap type shaker without the tapping motion and then classified into the size divisions of 8.0, 4.0, 2.0, 1.0 and 0.25 mm. In particular, the amount of −0.25 mm powder that is produced through the separation and/or collapse, and reported by a past study as having a high correlation with the material layer permeability,[22] was evaluated as the inadhesive powder ratio (−0.25 mm%).

4.4 Result and examination

The property of the slurry is described. The concentration reached the target value of about 40 mass% 24 hours after the start of the mill, and the average concentration stayed at 40.8 mass% during the subsequent Test period. Based on the measurement by the laser diffraction and scattering method, the ratio of the −10 μm particles was about 71%, and the grinding performance for the target particle size was confirmed (**Fig. 14**).

An example of the evaluation of the granulated substance is shown. From among the samples taken from the E-P granulated substance during the Base period and Test period and already evaluated, one sample from Base and another from Test, both having the same moisture level, were selected and compared, and as the ungranulated powder ratio decreased, the effect of the addition of the micro-particle binder on the improvement of granulation was confirmed (**Fig. 15**[10]). From the result of the observation of the polished sample surface of the granulated substance of the E-P line, in the adhering layer of the granulated substance sampled during the Test period, the porosity decreased as compared with that of the Base, and it was confirmed that the voids were filled by the micro-particle binder (**Fig. 16**).

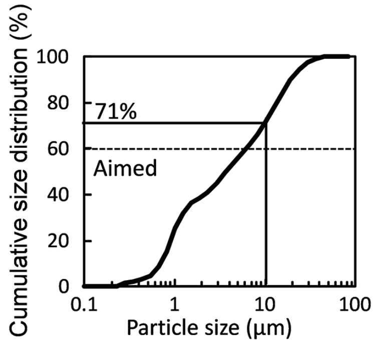

Fig. 14 Size distribution of slurry

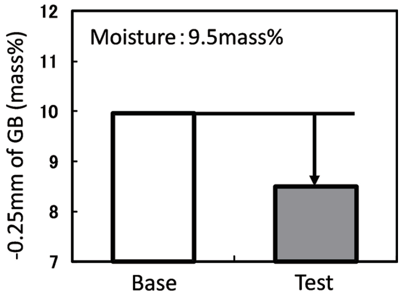

Fig. 15 Effect of total binder on granulation at E-P line[10]

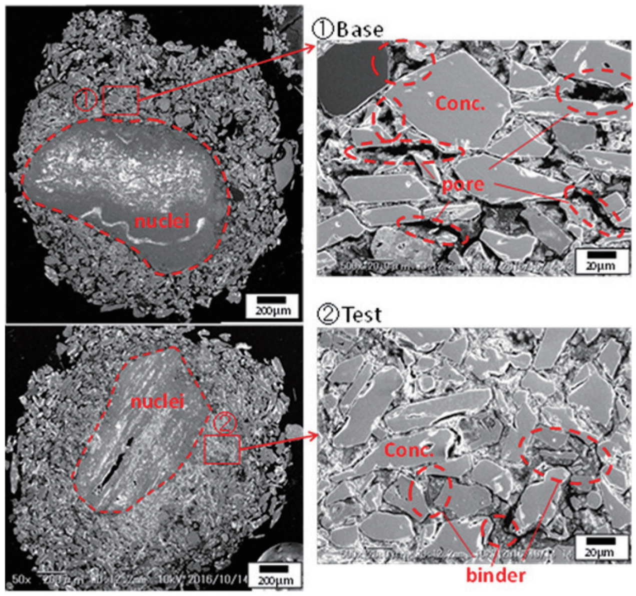

Fig. 16 Effect of micro-particle binder on adhering layer structure

Furthermore, the "unmixed-in lump of particles" that looks like the self-condensation of the sole iron ore micro-particles reaching up to the size of several hundred μm was not recognized from the section surface observation. It is considered that, by mixing and agitating the added wet-ground micro-particle slurry by the high-speed agitating mixer, the micro-particle binder dispersed sufficiently in the concentrate voids. Thus, the wet-grinding method is judged effective as a method for producing and supplying the micro-particle binder to realize the improvement of granulation when concentrate

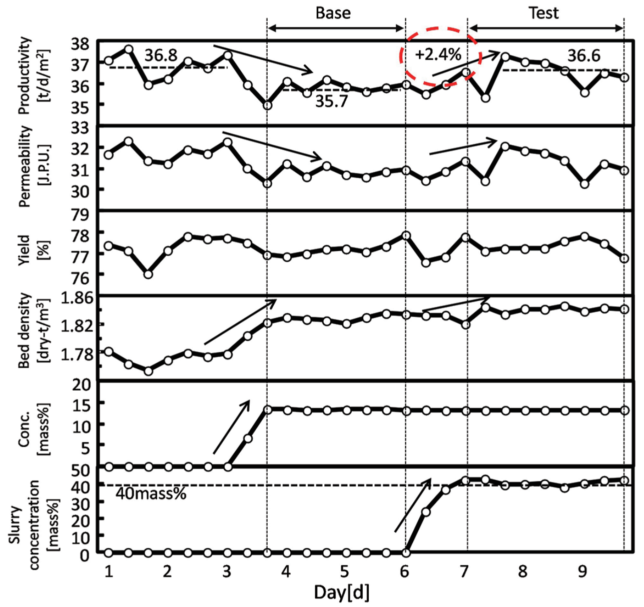

Fig. 17 Effect of micro-particle binder addition on sintering operation at the Wakayama No.5 Sinter Machine[10)]

is used in a large quantity.

During the transition from before the Base period where concentrate was not mixed to the Base period, the permeability and the productivity deteriorated. During the transition from the Base period to the Test period, the sinter productivity was enhanced by 2.4%, namely by the addition of the micro-particle binder (**Fig. 17**[10)]).

5. Conclusion

A wet vertical ball mill was introduced to the E-P line of the Wakayama No.5 Sinter Machine, and by producing and adding a micro-particle binder continuously, the following results were obtained.

(1) The improvement of the granulation by continuously adding the wet-ground iron ore micro-particle binder in the form of slurry was confirmed.

(2) By the improvement of granulation by the addition of the iron ore micro-particle binder, the enhancement of the productivity in the case of the use of fine powder iron ore in a large quantity in the P-type separate granulation line was confirmed.

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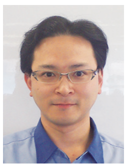
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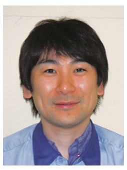
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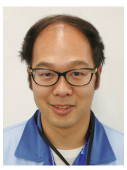
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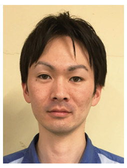
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