Effect of Granulation Condition and Property of Raw Material on Strength of Granulated Particle by Tumbling Granulation

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In order to clarify the factors on strength of granules for iron ore sinter, especially made of limonite iron ore, the effects of porosity, moisture and revolution speed of pelletizer on the strength of granules were examined with using reagent hematite. Moreover, using three kinds of commercial iron ores, the relationship between granule size and strength was examined. The strength measurement was undertaken before and after drying with a compression taster. The results obtained are follows:

1) In case of reagent hematite sample, the strength after drying became very low compared with that before drying. The compressive strength of sample just after granulation is determined by the adhesion force between hematite particles by liquid bridge of added water, but the strength after drying is maintained by the adhesion force by intertwined particles.

2) In case of commercial iron ores, the compressive strength after drying was very high compared with that in wet condition.

3) The cause for the different effect of drying on compressive strength between the commercial iron ore and reagent hematite seems to be the difference of gangue minerals that exist only in the iron ore and/or that of surface properties because the particle size distribution of reagent hematite and iron ores used is the same.

KEY WORDS: strength; raw material; granulation; limonite iron ore; iron ore sinter.

1. Introduction

Recently, the gradual depletion of high quality hematite iron ore in Western Australia have brought for an increase in limonite iron ores. The type of ores are inferior in sintering performance, and some of them such as Marra-mamba iron ore, have highly fine powder ratio and granulation property of them are inferior to other iron ores. Furthermore, limonite iron ores containing high combined water decrease the strength of sintered ores because many large cracks are formed during sintering. However, the increase in usage of limonite ore for raw material of sintering will cut down the cost of sinter since that ore is cheaper than other.

By the way, it is important to develop the method granulating the fine particle efficiently because the limonite iron ore have highly fine powder ratio. Moreover, the following properties are required for the particles charged into sintering machine; the quasi-particles, granules of coarse iron ore with fines adhered on them, must be hard not to break down when they are charged into feed hopper (drop strength) and inside the feed hopper (compressive strength) and the quasi-particles also keep their shapes during sintering, especially in dry zone (dry strength). In addition, it is well known that the structure and strength of the quasi-particles are influenced greatly by the porosity of iron ore, wettability between iron ore and water, adding moisture and characteristic of surface of iron ore.\(^1\)\(^-\)\(^{13}\)

Therefore, in this study, as the fundamental research for clarifying the factor on strength of quasi-particle granulated by using the limonite iron ore, the effects of porosity, adding moisture and revolution speed of pelletizer on the strength of granulated particle were examined by using reagent hematite. In addition, using three kinds of iron ore, the relationship between granulated particle size and strength was examined. The compressive strength of granulated particle before and after drying was measured.

In this study, the granulation experiment was carried out by using only fine iron ore and the strength of granulated particles were measured. It is based on the thought that the contribution of the nuclei particle for the collapse of the quasi-particle is small because the collapse happens to the adhesion fines layer, and that the dropping strength and compressive strength (wet/dry) of the quasi-particle depend on the strength of the adhesion fines layer.

2. Sample and Experiment

2.1. Samples

At first, hematite reagent was fired at 1,370°C and 1,115°C to make modeled iron ores of 5% and 15% porosity, respectively. Next, the firing hematite samples were crashed into powders under 150 μm and provided to granulation experiment. Table 1 shows the chemical composition of iron ores used in this study. Here, ore H is hematite iron ore, and ores W and R are limonite iron ores. All iron ores
were under 125 μm in size.

2.2. Experiments
The granulator was a disc type pelletizer featuring a rotating tire of 50 cm dia., 15 cm width. The speed of revolution in granulation was 20, 30 and 40 rpm, and granulation time was 8 min. In case of hematite, adding moisture was 40, 45 and 50 cc (7.4, 8.3, 9.1 mass%); In case of iron ore H, W and R, those were 45, 50 and 55 cc (11.4, 12.5, 13.6 mass%), 50, 55 and 60 cc (13.2, 14.3, 15.4 mass%), 55, 60 and 65 cc (16.7, 17.9, 19.1 mass%), respectively. The addition of moisture was conducted by the same method in previous study. The volume of sample used for the granulation experiment was 148 cc both reagent hematite and iron ores.

2.3. Evaluation Method of Strength for Granulated Particle
After granulation, granulated particle was screened to be the particle size /H11001/13.2 mm, 13.2–11.2 mm, 11.2–8 mm and 8–4 mm. As well as previous study, a screened particle was dropped from a place with a height of 50 cm and the falling numbers until it was fractured were measured. Moreover, the compressive strength of granulated particle just after granulation and after drying for 24 h at 120°C was measured by using a (tensile and) compression testing machine as shown in Fig. 1. Comparing the compressive strengths before and after drying could tell the effect of the adhesion force between particles by liquid bridge and the effect of the adhesion force by intertwined particles, and the effects of surface roughness, particle size distribution, gangue mineral and so on of raw material on the strength of granulated particle were separately discussed.

3. Results and Discussion
3.1. Reagent Hematite
Figures 2 and 3 show the overall view of granulated particles using reagent hematite samples with 5% and 15% porosity, respectively. As shown in Figs. 2 and 3, the granulation was completed in both samples regardless of moisture content and speed of revolution under the experimental conditions in this study. In the case of sample with 5% porosity adding moisture at 50 cc (9.1 mass%), a part of moisture had seeped to the surface of granules regardless of revolution speed. Consequently, 45 cc (8.3 mass%) is considered to be optimum for the sample with 5% porosity. In case of the sample with 15% porosity, the over-saturation occurred under the condition of 20 rpm and adding 45 cc moisture, the optimum moisture being 40 cc (7.4 mass%). Moreover, in the case of 30 and 40 rpm, the optimum moisture increased to be 45 cc because of the over-saturation at 50 cc. The particle size of granules generally increased with decreasing the revolution number of pelletizer regardless of sample porosity, as Figs. 2 and 3 show that the granules are large at 20 rpm, middle at 30 rpm and small at 40 rpm. Such tendency is probably due to the collapse of large granules caused by the impact energy and rotational kinetic energy which increase with increasing rotating speed.

Figure 4 shows the relationship between compressive

<table>
<thead>
<tr>
<th>Samples</th>
<th>T-Fe</th>
<th>FeO</th>
<th>CaO</th>
<th>SiO2</th>
<th>Al2O3</th>
<th>MgO</th>
<th>CW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ore H</td>
<td>63.60</td>
<td>0.10</td>
<td>0.04</td>
<td>3.28</td>
<td>1.88</td>
<td>0.01</td>
<td>3.06</td>
</tr>
<tr>
<td>Ore W</td>
<td>61.88</td>
<td>0.33</td>
<td>0.03</td>
<td>3.15</td>
<td>1.96</td>
<td>0.05</td>
<td>5.53</td>
</tr>
<tr>
<td>Ore R</td>
<td>57.29</td>
<td>0.05</td>
<td>0.36</td>
<td>5.46</td>
<td>2.66</td>
<td>0.20</td>
<td>8.10</td>
</tr>
</tbody>
</table>

Table 1. Chemical composition of iron ores (mass%).
strength and mean particle diameter in case of 20 rpm. Here, the mean diameter is calculated based on the arithmetic average of the screen mesh. This figure shows the compressive strength of granules decreased with increasing the mean particle diameter. Moreover, comparing the compressive strength by the same particle size suggested that porosity of sample and moisture content were ineffective on the compressive strength. The results of granulation experiment at 30 and 40 rpm will be omitted because almost the same tendency was obtained.

Figure 5 shows the same relationship for 40 cc moisture content. This figure shows the compressive strength of granules decreased with increasing the mean particle diameter. Moreover, comparing the compressive strength by the same particle size suggested that porosity of sample and revolution speed were ineffective on the compressive strength. The results of granulation experiment with 45 and 45 cc moisture content will be omitted because almost the same tendency was obtained.

From the results shown in Figs. 4 and 5, it was thought that the relationship between compressive strength and mean particle diameter just after granulation was hardly affected by the adding moisture contents, the number of revolutions and the porosity of samples. The compressive strength of granules decreased as the mean particle diameters of them increased.

Figures 6 and 7 show the relationship between compressive strength and mean particle diameter after drying was the same tendency before drying, that is, the compressive strength of granules decreased as the mean particle diameters of them increased. Moreover, the plots lay in a straight line. In addition, the compressive strength of sample with 15% porosity was larger than that of sample with 5% regardless of the particle size and the experimental condition.

Figures 8 and 9 show the relationship between compressive strength and mean particle diameter before and after drying at the revolution speed 20 and 40 rpm, respectively. In case of the reagent grade hematite, the compressive strength of sample at dry condition was proportional to that at wet although the data was a little scattered. The following equations between wet strength (Stw) and dry strength (Std) were obtained.

\[
\begin{align*}
20 \text{ rpm:} & \quad \frac{\text{Std}}{\text{Stw}} = 0.32 \times 10^{-0.32} \quad [\text{porosity: 15\%}] , \\
& \quad \frac{\text{Std}}{\text{Stw}} = 0.16 \times 10^{-0.16} \quad [\text{porosity: 5\%}] \\
40 \text{ rpm:} & \quad \frac{\text{Std}}{\text{Stw}} = 0.32 \times 10^{-0.32} \quad [\text{porosity: 15\%}] , \\
& \quad \frac{\text{Std}}{\text{Stw}} = 0.18 \times 10^{-0.18} \quad [\text{porosity: 5\%}] 
\end{align*}
\]

These equations mean that the dry strength was 0.32 times of wet strength in the case of 15% porosity and the dry strength was about 0.17 times of wet strength in the case of 5% porosity.

As mentioned above, the compressive strength of sample just after granulation doesn’t depend on the porosity of raw material and the granulation condition (moisture and revolution speed, etc.), but it depends on the granulated particle size. Consequently, it seemed that the compressive strength of sample just after granulation is determined by the adhe-
sion force between iron oxide particles by liquid bridge of water. On the other hand, it seemed that the compressive strength of sample after drying is affected by the adhesion force by intertwined particles, that is, surface roughness and particle size distribution of raw material.

Figure 10 shows the particle size distribution of sample with 5 and 15% porosity, with surface appearance observed by SEM. In the case of sample with 5% porosity, the peak of particle diameter is around 50 μm. On the other hand, in the case of sample with 15% porosity, the peak of particle diameter is around 50 μm and 3 μm. Moreover, the amount of particle under 10 μm in the sample with 15% porosity is about 2 times larger than that in the sample with 5% porosity, which seems to be a cause that the density of granules using the sample with 15% porosity is larger than that using the sample with 5% porosity. In addition, the SEM photographs in Fig. 10 show that the surface roughness of sample with 15% porosity is larger than that with 5% porosity. Consequently, the size distribution and surface roughness allowed the sample with 15% porosity to excel that with 5% in the dry strength because of the large adhesion force by intertwined particles.

3.2. Iron Ores

Figures 11 and 12 show the relationship between compressive strength and mean particle diameter in case of iron ore W with the effect of adding moisture content and revolution speed on the compressive strength, respectively. These figures show that the compressive strength of granules decreased as the mean particle diameter increased, but it hardly increased even if the adding moisture content and the revolution speed increased. The results for ore H and R were skipped here as the ores showed the same tendency. Figure 13 shows the relationship between compressive strength and mean particle diameter in case of ores H, R and W granulated with 55 cc moisture content and at 40 rpm. This figure shows that the compressive strength in-
creased in the order of iron ores \( W < R < H \) without regard to the adding moisture content, and the compressive strength of iron ore \( W \) was lowest at any mean diameter.

Figure 14 shows the relationship between compressive strength and moisture content in a granule under the experimental condition of 40 rpm. The moisture content in a granule was determined by weighing the sample before and after drying. This figure shows that iron ores \( W \) and \( R \) needed more moisture than \( H \) to give the same strength, and ore \( R \) needed the most.

Figure 15 shows the relationship between compressive strength and the falling numbers until a sample was fractured (FN). This figure shows that the falling numbers were proportional to compressive strength (Stw) although the data was a little scattered. The correlation was expressed as:

\[
\text{FN (—)} = 0.052 \times \text{Stw (kPa)}
\]

Figure 16 shows the relationship between compressive strength and mean particle diameter before and after drying at the revolution speed 40 rpm. This figure shows that the wet compressive strength and dry one had a positive relation. In case of iron ores, drying increase compressive strengths, the effect of which was different among the brand of iron ores, namely, the largest in case of ore \( R \) compared with ores \( H \) and \( W \). In addition, the relationship between the compressive strength at wet (Stw) and at dry condition (Std) was linear, although the data was a little scattered, giving the following equations.

\[
\text{[Ore R]: Std} = 7.82 \times \text{Stw (kPa)} \\
\text{[Ore H, W]: Std} = 4.01 \times \text{Stw (kPa)}
\]

These equations mean that the dry strength was 7.8 times of wet strength in case of iron ore \( R \) and the dry strength was 4 times of wet strength in case of ores \( H \) and \( W \).

3.3. Comparison Hematite Reagent and Iron Ores

The above-mentioned results summarized that the compressive strength was different among the brand of iron ores and that after drying was enhanced in case of iron ores. Such facts implied that the compressive strength depended not only on the adhesion force by liquid bridge of added water but also on particle size distribution of iron ore, surface property and gangue mineral.

Figure 17 shows the particle size distribution of iron ore \( R \) having the largest strength and iron ore \( W \) having the lowest strength. That for ore \( H \) was almost in the same tendency. This figure shows that the particle size distribution of iron ore used is almost same and also same as the reagent hematite sample with 15% porosity, which meant that the particle size distribution hardly contributed to the enhancement of compressive strength after drying in case of iron ore.

From the results obtained in this study, the cause for different effect of drying on compressive strength between the iron ores and reagent hematite seems to be the difference of gangue minerals that exist only in iron ore and that of surface properties because the particle size distribution of reagent hematite and iron ores used to granulation is the same. Whereas, a little difference among the iron ores was
lead by the small difference of gangue minerals and surface properties.

4. Conclusion

In order to clarify the factors on strength of quasi-particles for iron ore sinter, especially made of limonite iron ore, the effects of porosity, moisture and revolution speed of pelletizer on the strength of granulates were examined with using reagent hematite. Moreover, using three kinds of commercial iron ores, the relationship between granulate size and strength was examined. The strength measurement was undertaken before and after drying with a compression taster. The results obtained are follows:

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(3) In case of iron ores, the compressive strength of granules decreased as the mean particle diameters of them increased. The compressive strength after drying was very high compared with that in wet condition.

(4) The cause for the different effect of drying on compressive strength between the iron ore and reagent hematite seems to be the difference of gangue minerals that exist only in iron ore and/or that of surface properties because the particle size distribution of reagent hematite and iron ores used is the same.

REFERENCES