The Pelletizing of Industrial Acceptable Magnetite Pellets with Bentonite Clay as Binding Agent

PJ Pieters, Frans B. Waanders, and Elvis Fosso-Kankeu

Abstract—Magnetite fines, resulting from the beneficiation of iron ores are used in pelletized form in the steel making process. Due to the environmental aspects associated with the fines lying on the waste dump heaps, magnetite green pellets are produced by pelletizing moist fines. In the pelletizing industry the produced green pellets are then dried, sintered, cooled and lastly sent to the steel production industry. The pelletizing of iron oxide fines is a solution to the dust formation problem caused by fines which are fed to steel production blast furnaces. Research which has been conducted in the past was mainly focused on the understanding of the importance of forces emitted by a viscous binder during deformation strength tests of agglomerated magnetite pellets. Most of the total binding force is controlled by a network of cohesive forces. The lesser of the total compressive strength can be attributed to capillary forces. During the pelletizing process the plasticity of the green pellets is a very important green pellet property and a certain degree is thus required to sustain a healthy growth rate of the green pellets. The aim of the present research study was to investigate whether bentonite clay will suffice as an appropriate binding agent for magnetite fines, to yield industrial acceptable strength magnetite pellets. Special attention has been paid to determining an optimal firing temperature and an optimal bentonite dosing percentage, while the pellets was exposed to relevant industrial pelletizing conditions. The results points out clearly that there is an increase in the load at maximum load and the load at break strength of the pellets with an increase of both the binder dosing and an increase in the firing temperature. The formation of duplex structures within the pellets was observed on the load at maximum load and the load at break strengths results obtained for firing temperatures which ranged between 350°C to 500°C. The 1 wt.% bentonite dosage yielded sufficient compressive load at break and load at maximum load strengths.

Keywords—Magnetite, green pellets, iron ore, agglomeration, pelletizing, compressive strength.

I. INTRODUCTION

IRON ore global reserves are associated with the formation of magnetite and hematite ores. The origin of magnetite and hematite ores is mainly attributed to its metamorphic property. The global reserve deposits are represented by fine-grained beneficiated ores which is composited out of magnetite and hematite. The practice of pelletizing that is currently in use was developed in the 1950’s [1]. The pelletizing of beneficiated iron oxide fines during the steel making process is the primary consumer of binding agents. In general, a binding agent is anything that causes particles to adhere together into a mass [2]. Adhesion is the binding strength between the binding agent and the iron oxide particle. Bentonite clay quickly established its dominance as a binding agent. Bentonite clay is still one of the most common and competitive binding agents in use today. Bentonite owns a big deal of its success to its effectiveness and relative low cost [1]. Mined iron ore contain a large amount of gangue materials, such as silicates. It is absolutely of the essence that iron oxides need to be concentrated from these mined ores. During the first step of beneficiation the mined iron ores must first be grinded. The grinding process step ensures that the particle size distribution of the iron ore is suitable for the moist ore to be pelletized [3]. During the steel making process, the blast furnace process step is of utmost importance. Iron oxide fines which are unpelletized, are not suitable to be fed to the blast furnace. If unpelletized fines should be fed to blast furnace, a non-permeable bed of iron oxide fines will form. During operation of blast furnace with a non-permeable bed, the iron oxide fines will be blown out of the furnace as dust. This occurs due to high flow rates of gas through the non-permeable bed [2]. The iron oxide fines must be agglomerated into larger particles before it can be used in the steel industry. The pelletizing of moist iron oxide fines is one of the most common techniques used to agglomerate fines back to lump ore size. The binding agent used during the pelletizing process, ensures that the moist iron oxide fines binds into high-strength green pellets during the pelletizing process step [2]. The agglomerated green pellets have a productions size which range between 9 and 16 mm in diameter. The green pellets are sent to a kiln for sintering [3]. The sintered pellets should be able to withstand forces in excess of 22 N per pellet, for the pellets to be able to survive transports and firing [1]. The pelletizing of iron oxide fines is implemented with great success in cases where the fines need to be transported a great distance between the mine and the blast furnace. The pellets are fired to ensure that the pellets are durable and can be handled with ease [2]. The pelletized iron oxide fines can be fed to the blast furnace for processing. The pellets form a permeable bed of iron oxide
material inside the furnace. The permeability of the pellet bed ensures that the fast flowing gas will be able to pass through the bed in a uniform fashion. The permeability burden is thus improved by feeding pellets instead of fines to the blast furnace. The rate of reduction increases with an increase in the permeability of the bed inside the blast furnace. The amount of iron oxide materials that are blown out of furnace is minimized by the pelletizing of iron oxide fines [2].

II. METHODOLOGY

A. Malvern Mastersizer

The Malvern Mastersizer 2000 analyses the particle size by implementing the basic principle of laser diffraction. The particle size distribution (PSD) of a certain sample is determined by laser diffraction, through the measuring of the sharp deactivation of the intensity of the scattered light. The laser beam is passed through the dispersed sample to achieve this setup. The light will be scattered at large angles by small particles, while the light scattered by large particles will have smaller angles. The PSD of the sample is determined by the Malvern Mastersizer which reports it as the volume of the equivalent sphere diameter.

B. Mössbauer spectroscopy analyser

The Mössbauer spectroscopy analyser was used to analyse the magnetite and bentonite clay which was used during the experimental procedure. This is to determine the amount of magnetite, hematite or other species of iron present within the representative samples. The Halder Mössbauer spectroscopy analyser used a proportional counter, which was filled at 2 atm. to be capable of operating in constant conventional acceleration mode. The spectroscopy analyser was calibrated through the implementation of \( \alpha \text{Fe} \) as the reference. The \( \gamma \)-rays were produced by a 50mCi \(^{57}\text{Co} \) source which was plated into an Rh-foil. The data was collected with a multi-channel analyser (MCA), while the sample was analysed at room temperature. The MCA obtained the spectrum of count rate against the velocity of the source.

C. Muffle furnace

The muffle furnace was used to heat the pellets up to predetermined appropriate firing temperatures and to keep the temperature constant for the prescribed period of time. The temperature was ranged between 250°C and 500°C, in temperature increments of 50°C.

D. LRX Plus pressure machine

The Lloyd LRX Plus pressure machine was used to determine the load at break and the load at maximum load strengths of the pellets. The LRX Plus pressure machine can apply forces in excess of 5 kN. This force is equal to a pressure of approximately 38 MPa being exerted on a 13 mm diameter pellet.

E. Scanning Electron Microscope

The scanning electron microscope (SEM) was used to investigate the surfaces of the magnetite, bentonite and the fired pellets individually. The break fractures and structures will be observed. The analysis with regards to the pellets will be carried out post the firing process at different temperatures. The FEI Quanta 200 ESEM Scanning Electron Microscope with an integrated Oxford Inca 400 energy dispersive x-ray spectrometer was used during the SEM analysis.

F. X-ray diffraction

The starting material for the X-ray diffraction (XRD) analysis was characterized by conventional powder X-ray diffraction. The XRD analyses were carried out at room temperature and a subsequent Rietveld analysis was also done. The equipment used to record the patterns is a Panalytical X’pert MPD diffractometer which is equipped with a Panalytic X’celerator detector.

G. Calculations

Calculation for the conversion of the load at break and load at maximum load forces, in N, to pressures, in kPa, was done according to Equation 1.

\[
P = \frac{\text{Crushing load} \times 1000}{\text{cross sectional area of plane of fracture}} \quad \text{[kPa]}
\]  

Equation 1 has the following constants:

\[\text{Cross sectional area of plane of fracture} = \pi \left( \frac{D}{2} \right)^2\]

\[D = 0.013 \quad [\text{m}]\]

III. RESULTS AND DISCUSSION

A. XRF analysis

The XRF analysis was done to determine the mass percentages of the elements present, as presented in Table 2 and 3.

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Table 2 provides the XRF analysis of the magnetite, during which the weight percentages of elements present within the undisclosed location magnetite sample were compared to the percentages of the elements present within the theoretical synthesized magnetite. The XRF analysis of the bentonite clay sample with a low moisture content, is shown in Table 3.

<table>
<thead>
<tr>
<th>Elements present within sample</th>
<th>Weight percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>50.24</td>
</tr>
<tr>
<td>Si</td>
<td>26.73</td>
</tr>
<tr>
<td>Al</td>
<td>8.61</td>
</tr>
<tr>
<td>Fe</td>
<td>6.73</td>
</tr>
<tr>
<td>C</td>
<td>3.11</td>
</tr>
<tr>
<td>K</td>
<td>1.54</td>
</tr>
<tr>
<td>Mg</td>
<td>1.07</td>
</tr>
<tr>
<td>Ca</td>
<td>0.84</td>
</tr>
<tr>
<td>Na</td>
<td>0.61</td>
</tr>
<tr>
<td>Ti</td>
<td>0.52</td>
</tr>
</tbody>
</table>

A. Particle size distributions

The magnetite PSD plot the cumulative mass percentage which passed through each sieve expressed in micro meters. The results of the magnetite PSD can be seen in Fig. 1.

The magnetite fines consist of small particles, smaller than 1 mm. The results of the bentonite clay PSD can be seen in Fig. 2.

The bentonite clay consists of small particles, smaller than 0.1 mm.

B. Mössbauer spectroscopy

The analyses of the Fe containing components are shown in Fig. 3 and 4 respectively.

In Fig. 3 the spectrum of pure magnetite with less than 1% iron hydroxide is visible and the spectrum consists of the typical 2 sextets with hyperfine magnetic fields of 49 and 46 T respectively.

In Fig. 4 the spectrum for the clay consist of only one doublet with one typical Fe$^{3+}$ component.

C. X-ray diffraction

The X-ray diffraction patterns of both the magnetite and bentonite clay will be discussed. Fig. 5 shows the results obtained during the x-ray diffraction analysis on the magnetite which was used during the experimental procedure of this investigation.
According to Fig. 5 the magnetite which was used during the experimental procedure of this study exhibited the same XRD behaviour as would be exhibited by a sample of 100% pure magnetite. Fig. 6, shows the results obtained during the x-ray diffraction analysis on the bentonite clay which was used as binding agent during the experimental procedure of this investigation.

![Fig. 6: XRD results for bentonite clay](image)

According to Fig. 6 the bentonite clay which was used during the experimental procedure of this study exhibited the same XRD behaviour as would be exhibited by a sample which contains high amounts of both quartz and smectite. The percentage of montmorillonite is low at the room temperature analysis due to the fact that it only becomes visible on the XRD patterns at temperatures in excess of 20°C.

**D. Load at break compression strength tests**

The minimum industrial acceptable compressive strength with which dried pellets should comply is in excess of 22 N per pellet [1]. This force translates to a pressure of 165.75 kPa per pellet. Fig. 7 and 8, show the load at break strength results obtained during the compression strength tests on the magnetite pellets with the addition of bentonite clay as binding agent.

![Fig. 7: Load at break strength versus weight percentage bentonite dosage](image)

![Fig. 8: Load at maximum load strength versus firing temperature](image)

![Fig. 9: Load at maximum load strength versus weight percentage bentonite dosage](image)

The 1 wt.% added bentonite curve recorded 342 kPa, its lowest compression strength at 250°C. The 1 wt.% bentonite addition thus suffices as the optimal bentonite dosing to satisfy the minimum industrial acceptable compressive strength. Binder dosing leads to large financial expenses for a pelletizing plant, the addition of the binding agent thus needs to be minimized. By implementing the 1 wt.% bentonite clay...
dosage the compression strength of the pellets will comply at any firing temperature.

E. Scanning electron microscope

The SEM was used to investigate the break structures and fractures present on the surfaces of representative pellets formed during firing. Fig. 12, shows the micrograph obtained during Scanning electron microscope analysis. The results show the surface of a pellet which contains 3 wt.% bentonite clay which remained at room temperature for the drying process.

Fig. 12: Micrograph for pellet fired at 500°C

From the micrograph, Fig. 12, it can be seen that there are no loose particles visible which indicate that completed binding occurred and agglomeration occurred completely.

IV. CONCLUSION

Due to the increase in application costs of higher binding agent dosage and the 1 wt.% bentonite dosage yielding sufficient compressive load at break and load at maximum load strengths, the 2 wt.% and 3 wt.% bentonite dosages will not be taken into consideration for pelletizing of the magnetite fines. It is thus concluded that the 1 wt.% bentonite clay dosage to the magnetite fines, when dried at room temperature, does yield magnetite pellets of sufficient compressive strengths to survive both transport and handling on the pelletizing and steel production plants. The 1 wt.% bentonite dosage is low enough to induce a positive net cash flow, through the pelletizing and the recycling of the magnetite fines on the waste dump heaps. The fact that room temperature drying yielded sufficient compression strength, a further decrease in the expenses with regards to the firing of the green pellets can be expected.

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