Binding effects in hematite and magnetite concentrates

S. Komar Kawatra *, Joseph A. Halt

Department of Chemical Engineering, Michigan Technological University, Houghton, Michigan 49931, United States

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A B S T R A C T

An industrial taconite facility, ‘Plant F’, processed both magnetite and hematite ores during the year. The concentrates were pelletized with a binder, bentonite. Plant personnel believed less bentonite was required to make hematite pellets. Thus, the authors intended to quantify in-plant observations through bench-scale pelletization tests. As-received magnetite and as-received hematite were pelletized and tested for wet-drop number and dry-crush strength. Hematite pellets exceeded industrial minimum wet-drop and dry-crush values of 5 drops and 22 N/pellet without bentonite addition, while magnetite pellets exceeded industrial minimum values at a bentonite dose of 6.6 kg/t (0.66%). It is known that finer particles increase pellet strength, so additional magnetite was ground to a similar particle size distribution as the as-received hematite. The ground magnetite was pelletized and tested for wet-drop number and dry-crush strength. Wet drop and dry crush values increased after grinding the magnetite concentrate. However, they were significantly less than hematite pellets at similar bentonite doses. Consequently, particle size effects were not the dominant cause for higher strengths in the hematite concentrate.

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1. Introduction

In the U.S., iron ore is predominantly used in blast furnace iron making. Approximately 53.6 Mt of ore was produced in the US in 2008; a majority of the ore was pelletized (Jorgenson, 2010). During pelletization, finely divided, moistened ore particles are agglomerated in a rotating drum with the aid of a binder. Moist, or ‘green’, pellets approximately 12 mm in diameter are dried and heat hardened to form durable pellets. Finished pellets are shipped considerable distances to iron making points-of-use.

Bentonite has historically been the standard binder for taconite agglomeration. Bentonite helps control water content during pelletization, and generally eases the agglomeration process. Bentonite doses of 0.5–1.0% by weight are usually added prior to agglomeration. These doses result in pellets with sufficient physical and metallurgical properties. However, bentonite contaminates iron ore pellets with unwanted silica and alumina (Ball et al., 1973).

Iron ore processors are interested in reducing bentonite dosages. Recently, personnel at a local iron ore concentrator and pelletizing plant have observed cyclical bentonite usages corresponding to the iron concentrate being pelletized (Plant F personnel, 2010). The facility, ‘Plant F’, processes hematite 6 months of the year; magnetite is pelletized the other 6 months. Smaller doses of bentonite are believed to be required for hematite pellets compared to magnetite pellets. Understanding why this occurs is important economically.

Promoting better bentonite bonding during magnetite pelletization could reduce Plant F’s, and other facilities’, bentonite usages. Bentonite production for iron ore pelletization—estimated at 574×10^3 metric tons in 2009—is a 31.6 million dollar burden (Virta, 2010).

It is well known that agglomeration performance, or ballability, and green and dried pellet strengths depend on characteristics of the particles being pelletized. Particle size (Jewett, 1958) and shape (Srb and Ruzickova, 1988) affect both wet and dry pellet strengths through changes in packing density and particle–particle interactions. As an example, increasing ultrafine particle content from 45 to 65 ppm per gram of taconite pellet increased dry crush strength from 2.27 to 6.80 kg (Stone and Cahn, 1968). In general, wider particle size distributions pack to greater densities. More dense, or less porous, pellets are stronger. Shape and roughness control particle surface areas, which increase contact and friction forces between particles after drying. Consequently, decreasing particle size can increase taconite pellet strengths.

Agglomeration performance also depends on the presence of surfactants on ore particles (Forsmo et al., 2008; Iwasaki et al., 1967). Hydrophobic coatings can influence particle wetting during the wet agglomeration process, reducing capillary forces required for particle cohesion. Air can become trapped within the structure, serving as nucleation sites for crack propagation.

Many factors could contribute to the pelletization differences observed at Plant F. The authors’ first objective is to pelletize unmodified hematite and magnetite concentrates. In other words, plant observations will be quantified experimentally. Additionally, the magnetite particle size distribution will be reduced to replicate that of
the hematite concentrate. The second objective of this study is thus to determine whether different ores will have similar pelletizing characteristics—if they have similar size distributions. Can particle size alone explain the different pelletization performance between a hematite concentrate and a magnetite concentrate?

2. Materials and methods

2.1. Materials

Two iron-ore filter concentrates were provided by local iron ore concentrators. Except for moisture adjustment, the concentrates were unmodified as-received. Concentrates were not washed to remove processing reagents remaining from the plant.

The hematite concentrate used was provided by Plant F. The concentrate was received dry and divided into approximately 2.5 kg samples using a riffle splitter. The hematite sample was 80% passing 30 μm; specific surface area (Blaine) was 4255 cm²/g. As indicated by XRD (Fig. 1), the hematite concentrate was fluxed with calcium carbonate and dolomite. Silica and magnetite were also present.

The magnetite concentrate used was provided by a taconite processing plant, Plant D. The concentrate contained ~8.5% moisture and was 80% passing 49 μm; specific surface area (Blaine) was 2250 cm²/g. The concentrate was divided into approximately 2.5 kg samples using a riffle splitter and sealed in plastic bags to preserve moisture content. The XRD spectrum of the magnetite sample is also shown in Fig. 1. The magnetite concentrate was fluxed, with silica as the main gangue constituent. The particle size curves of both the magnetite and hematite concentrate are shown in Fig. 2.

The bentonite used in these experiments was provided by Bentonite Performance Minerals, LLC. The bentonite was a sodium bentonite, with a PWA value of 850.

2.2. Pelletization

The development of the pelletization procedure used in these experiments was outlined in literature (Eisele and Kawatra, 2003). A brief description is included here.

The concentrate was placed in an orbital kneader-mixer and mixed slowly while moisture and binder were added. Magnetite concentrate was used as received, while the hematite concentrate was adjusted to 9% moisture with distilled water. The mixture was then mixed for 5 min at high speed, delumped through an 8-mesh screen and immediately pelletized. A small amount of concentrate/binder mixture was added to a pelletizing drum rotating at 25 rpm and lightly sprayed with distilled water to create pellet seeds. The seeds were lightly moistened with distilled water while adding additional material as they tumbled. Pellets were removed from the drum at 5 minute intervals and screened to control pellet diameter. Between 1 and 2 kg of green pellets were produced with diameters ranging from 11.2 to 12.7 mm. A portion of the finished pellets was immediately removed for wet pellet testing, and the remaining fraction dried at 105 °C for 24 h.

2.3. Pellet evaluation

2.3.1. Wet-drop number

The pellet wet-drop number was used to evaluate green pellet performance, and compared to an industrial accepted value of 5 drops to fracture. Individual pellets were dropped 18 in. onto a steel plate; the number of drops to fracture was recorded. Values reported are the average of 3 batches at 20 pellets per batch.

2.3.2. Dry-crush strength

Dry-crush strength was used to evaluate dry pellet performance. Individual, dry pellets were compressed between two plates at 40 mm/min and the load at fracture was recorded. Values obtained were compared to an industrial accepted value of 22 N/pellet. Values reported are the average of 3 batches at 20 pellets per batch.

2.3.3. Pellet porosity

Pellet porosity was found gravimetrically following an ASTM standard method (ASTM C914-09, 2011). Individual pellets were dried to constant weight, weighed, and coated with a thin layer of wax. Wax-coated pellets were then weighed in air and suspended in water to find the pellet envelope volume (Ve). Pellet porosity (ε) was thus calculated according to Eq. (1):

$$\varepsilon = 1 - \frac{m}{\rho V_e}$$

where m is the pellet dry weight and ρ is the powder density.

2.4. Magnetite particle size reduction

The inverse relationship between pellet strength and particle size is well known. Consequently, the magnetite concentrate was further ground to a similar size distribution as the hematite concentrate. 5 kg of dry magnetite was loaded into a ball mill and dry ground for 1 h. 15 min. This was repeated 3 times, producing 15 kg of material, which was mixed and rotary split into 12 representative samples. One sample was further split into 12 for particle size analysis (Fig. 2). The 80% passing size for the magnetite concentrate was reduced from 49 to 31 μm; the ball mill-ground magnetite particle size distribution replicated the hematite particle size distribution. Blaine analysis on the ground ore indicated specific surface area increased from...
2250 cm²/g to 3262 cm²/g. Before pelletization, the dry-ground magnetite concentrate was moistened to 8% moisture by weight.

3. Results and discussion

3.1. Pelletization of the as-received concentrates

Wet drop results from hematite and magnetite pellets are shown in Fig. 3. Wet drop values for both concentrates increased linearly with bentonite addition. The industrial minimum value of 5 drops to fracture is shown as a dashed line on the figure. As seen, hematite pellets exceeded the minimum value at all bentonite doses tested. Magnetite pellets were below 5 drops until 6.6 kg/t (0.66%) bentonite was added. Hematite pellets survived approximately 10–15 more drops to fracture than magnetite pellets, across all bentonite doses tested. However, the hematite pellets were not dropped more than 20 times; pellets at 4.6 and 6.1 kg/t bentonite survived 20 drops without cracking.

Hematite and magnetite pellet dry crush strengths are seen in Fig. 4. Pellet strengths increased linearly with bentonite addition for both concentrates. Similar to wet drop, hematite pellets exceeded the industrial minimum value of 22 N/pellet at all bentonite doses—even without binder. Magnetite pellets exceeded the minimum value at bentonite doses greater than 1.7 kg/t (0.17%). In the range of typical bentonite doses (0.5–1.0% by weight), both pellet types were strong enough to survive additional pellet handling required for heat-hardening. Across all bentonite doses tested, hematite pellets survived loads of 15–25 N/pellet more than magnetite pellets.

It is interesting that hematite pellets exceeded both industrial minimum values without binder; magnetite pellets were not sufficient until 6.6 kg/t (0.66%) bentonite was added. These results agreed with the industrial observation at Plant F. Less bentonite was required for hematite agglomeration.

3.2. Magnetite particle size reduction and pelletization

Pellets were produced from the ground magnetite concentrate at bentonite dosages of 0 and 6.1 kg bentonite per ton moist ore. Wet-drop and dry-crush strengths are shown in Table 1 and shown in Figs. 3 and 4, respectively. Values obtained from ground magnetite are compared to pellets produced from the as-received magnetite and hematite concentrates. Wet-drop and dry-crush values marginally increased after dry-grinding the magnetite concentrate. Wet drop increased from 3.5 to 4.0 drops, while dry-crush increased from 10.1 to 16.0 N/pellet. Hematite pellets survived 12.5 drops to fracture and a dry compression 28.6 N/pellet. All these results were obtained without binder. The significant decrease in particle size and increased surface area of the ground magnetite concentrate did not lead to greatly improved pelletizing performance.

At a bentonite dose of 6.1 kg/t, reducing the magnetite particle size from 49 to 31 μm had minimal observable effect on wet-drop and dry-crush performance. Hematite pellets were still much more durable than the ground magnetite pellets. Hematite wet drop was 20 compared to 6.2 in ground magnetite. Hematite dry crush was 79.1 compared to 55.4 N/pellet in ground magnetite.

Interestingly, the moisture content of green dry-ground magnetite pellets was nearly 1% less than the original magnetite pellets (7.8% compared to 8.7% moisture). Less distilled water spray was required for dry-ground magnetite pelletization. The dry-ground magnetite had a wider distribution than the original concentrate, which may have allowed particles to pack more densely during tumbling. However, as dry grinding may create hydrophobic particle surfaces (Sastry et al., 1977) and lead to air inclusions in green pellets, pellet porosity was measured. As seen in Table 1 and Fig. 5, the hematite pellets were more porous than the ground magnetite pellets, and significantly stronger. This indicates that air inclusions were not the cause for weaker magnetite pellets.

Combined, these results suggest that particle size alone cannot explain the initial pelletization differences between the magnetite and hematite concentrates. Magnetite pellets improved minimally on grinding to a similar size distribution as the hematite concentrate. Why then, was there such a large difference between the two types of pellets? The detrimental effects of processing reagents on magnetite

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**Fig. 3.** Wet drop values increased linearly with bentonite addition for hematite pellets and magnetite pellets. Typical bentonite doses would be 5 to 10 kg/t. Pellet size: 11.2–12.7 mm in diameter. Pellet moisture contents by weight: hematite ~ 9.3%, magnetite ~ 8.7%, ground magnetite ~ 7.8%. Bentonite: Na-bentonite from Bentonite Performance Minerals, LLC (850 PWA). Error bars not seen are smaller than the data point.

**Fig. 4.** Dry crush strength increased linearly with bentonite addition for hematite pellets and magnetite pellets. Typical bentonite dose would be 5 to 10 kg/t. Pellet size: 11.2–12.7 mm in diameter. Crosshead speed: 40 mm/min. Bentonite: Na-bentonite from Bentonite Performance Minerals, LLC (850 PWA). Error bars not seen are smaller than the data point.

**Table 1**

Test conditions comparing the effect of particle size reduction on pelletizing performance. The magnetite particle size was reduced by dry-grinding 5 kg dry concentrate in a ball mill for 1 h. 15 min. Individual ground batches were subsequently mixed together and rotary split to produce a concentrate for pelletizing. The bentonite sample was a Na-bentonite with a PWA value of 850. Finished pellets were 11.2–12.7 mm in diameter. Bentonite dosages are expressed as kg bentonite per ton moist ore.

<table>
<thead>
<tr>
<th>Concentrate</th>
<th># of replicates</th>
<th>Bentonite dose, kg/t</th>
<th>Wet-drop, N/pellet</th>
<th>Dry-crush, N/pellet</th>
<th>Porosity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean      P 95       Mean      P 95       Mean      P 95       Mean      P 95</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetite</td>
<td>3</td>
<td>0</td>
<td>3.5</td>
<td>8.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Ground magnetite</td>
<td>3</td>
<td>0</td>
<td>4.0</td>
<td>8.0</td>
<td>4.0</td>
</tr>
<tr>
<td>Hematite</td>
<td>3</td>
<td>0</td>
<td>12.5</td>
<td>28.6</td>
<td>12.5</td>
</tr>
<tr>
<td>Magnetite</td>
<td>2</td>
<td>6.1</td>
<td>5.0</td>
<td>15.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Ground magnetite</td>
<td>3</td>
<td>6.1</td>
<td>6.2</td>
<td>15.4</td>
<td>6.2</td>
</tr>
<tr>
<td>Hematite</td>
<td>3</td>
<td>6.1</td>
<td>20.0</td>
<td>29.8</td>
<td>20.0</td>
</tr>
</tbody>
</table>

\(^a\) 80% passing 40 μm, Blaine value = 2250 cm²/g.

\(^b\) 80% passing 31 μm, Blaine value = 3262 cm²/g.

\(^c\) 80% passing 30 μm, Blaine value = 4253 cm²/g.
pelletization are known (Forsmo et al., 2008; Iwasaki et al., 1967). Perhaps the hematite used here, processed by reverse flotation, is benefiting from starches applied during flocculation and flotation. However, the hematite concentrate should be analyzed for starch to make this hypothesis valid. Additional parameters such as flux quantities should be measured. The physical attributes of each concentrate should be as similar as possible before other causes are investigated.

4. Conclusions

Pelletization behaviors of hematite and magnetite concentrates were investigated. Hematite pellets required less binder than magnetite pellets to meet industrial minimum values for wet drop and dry crush strength. Hematite pellets exceeded 5 drops and 22 N/pellet without bentonite addition. Magnetite pellets exceeded 5 drops and 22 N/pellet at a bentonite dose of 6.6 kg/t (0.66%). These results agreed with industrial observations at Plant F; less bentonite was needed for hematite pelletization.

The magnetite concentrate was ground to a similar particle size distribution as the hematite concentrate (which increased particle fineness) in order to eliminate particle size as a factor affecting pellet strength. Grinding the magnetite minimally increased the pellet wet drop and dry crush strength values. However, the ground-magnetite strengths did not increase to be equal to the hematite pellet strengths. It was concluded that factors other than particle size were the dominant contributors to higher hematite pellet strengths. These factors could include effects of mineralogy (e.g. particle shape) and the presence of residual reagents from the concentrator.

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References

Plant F personnel (2010), personal communication.

Fig. 5. Pellet porosity as determined gravimetrically (ASTM C914-09, 2011). Ground-magnetite pellets do not appear to have increased air inclusions (leading to weaker pellets). Hematite pellets are the more porous pellets. Typical bentonite dose would be 5 to 10 kg/t. Pellet size: 11.2–12.7 mm in diameter. Bentonite: Na-bentonite from Bentonite Performance Minerals, LLC (850 PWA). Error bars not seen are smaller than the data point.