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An investigation of the relationship between compressive strength and dust generation potential of magnetite pellets

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ABSTRACT

Iron ore pellets should have sufficient mechanical strengths against degradation at all stages of pellet production in pelletizing plants. Besides the strength, pellets should have less dust emission during operation since the process efficiency and the pelletizing equipments are adversely affected by dust. Dust is also a problem for sintered (product) pellets since they abrade during transportation from pellet production site to the reduction facilities. Sufficient mechanical strength and low dust emission of pellets are necessary for better operation and handling of pellets. In this study, dust emission mechanism of sintered magnetite pellets produced with different binders was comparatively studied. The results showed that the dust is not produced by pellet breakdown for sintered pellets with sufficient strength. It was found that dust generation of sintered pellets is not directly dependent on the mechanical strength. One of the dust generation mechanisms of sintered pellets with sufficient strength is the roughness of pellet surfaces. The attrition and impact forces during transportation cause dust generation from pellet surfaces. The surface smoothness is more important since the pellets with high strength and rough surfaces produced more dust than those with smooth surfaces and low strength. Half of the fines generated due to pellet attrition or impact forces during handling of sintered pellets will become airborne and are considered as loss and operational/environmental problem. The percentage of particulate matter (PM_{10}) which is significant in health risk lied between 30% and 40% by weight of airborne pellet dust.

1. Introduction

Iron ore pellets should have sufficient mechanical strengths against degradation in all stages of pellet production. Besides having the strength, pellets should generate less dust during operation since the process efficiency and the equipments are adversely affected by pellet dust. Dust is also a problem for product pellets since they abrade during transportation to the reduction furnaces. Moreover, dust is considered as loss of product and environmental problem since they are becoming airborne in plant or during transportation. Therefore, sufficient mechanical strength and low dust generation of pellets are necessary for better operation and handling of pellets. Many researchers attempted to find suitable pellet production systems to achieve to produce stronger pellets using either alternative binders or new methods against the conventional ones.

The main strength indicators for product pellets are compressive strength and tumbling-abrasion indices. The compressive strength of pellets can be determined in accordance with the ASTM or ISO standards (ASTM E 382-07, 2007; ISO 4700:2007, 2007).with a compression test press by loading gradually with a constant cross-head speed. The maximum load required to break the sintered pellet is recorded. The tumbling and abrasion indices of pellets are primarily measured with a procedure (ASTM E279-97 (2010)) carried out in a drum with lifters revolving at a certain times with a certain speed. The latter test measures the resistance of the product pellets under certain abrasive condition in a standard test drum. However, this test is not adequate to evaluate the dust generation potential and mechanism of product pellets. Furthermore, this test method is not convenient to be applied in laboratory scale investigations since the amount of the test material is too much (11.3 kg pellet for single test). Moreover, in this method, no information can be obtained for ultra-fine particles (airborne particulates) formed during abrasion of pellets.

The breakdown of iron ore pellets at pelletizing plants and iron–steel facilities is a primary source of fine fraction and airborne dust generation. During breakdown, the pellets produce fine pellet fragments and an ultra-fine powder (airborne dust). To better understand the problem of airborne dust at iron ore facilities, the breakdown kinetics was studied by Copeland and Kawatra (2005) and Copeland et al. (2009). The researchers used a sieve-shaker with 3 mesh sieve on top and 35 mesh sieve on bottom to form and collect pellet fines. Dry pellets ranged from 100 to 1000 g were placed on 3 mesh sieve and the sieve-shaker was run for 15 min. The fines generated after

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test are reported and the particle size distribution analysis carried out on generated pellet fines. They concluded that the kinetics of dust generation is strictly dependent on the nature of the pellets, production process and handling conditions. Different pellet-breakdown properties lead to different PM_{10} (particles 10 μm in diameter or smaller) and $PM_{2.5}$ (particles 2.5 μm in diameter or smaller) quantities (Copeland and Kawatra, 2005).

Copeland et al. (2009) also used novel equipment called dust tower to evaluate how well a suppressant functioned in reducing airborne dust from iron ores and pellets. The procedure involved taking the treated pellets and fines (formed during pellet production at pelletizing plant) with different suppressants and dropping them through a counter-current air stream in an isolated column. The air stream was passed through a filter paper to remove airborne particles generated during dropping of pellets. The weight of the particles collected on the filter paper was reported as the amount of airborne dust generated. Pellet breakdown studies revealed that as much as 43% by weight of the airborne particles were 10 μm in diameter and smaller (material regulated by the U.S. Environmental Protection Agency (EPA)). A diagram of isolated column (dust tower) used in the research was given elsewhere (Copeland et al., 2009). This dust tower apparatus is unique in that it simulates material handling while allowing for direct airborne fine particles measurements.

In this study, pellets were produced using a magnetite concentrate in the laboratory and then they were sintered. Dust tower equipment was directly utilized to simulate the pellet breakdown (fine fraction generation potential) and pellet abrasion (dust generation potential) during dropping of product pellets by free fall through the dust tower. After dropping of all product pellets, fine fraction (−6.35 mm) was collected on the bottom pan and airborne dust fraction (vacuumed by air stream) was collected on filter paper and they were analyzed in terms of particle size. In order to see relationship between dust generation potential and compressive strength of sintered pellets, different binders were used to obtain pellets with varied compressive strength. The dust generation mechanism and correlation between dust generation potential and compressive strength of sintered pellets were discussed.

2. Experimental study

2.1. Materials

2.1.1. Magnetite

Magnetite concentrate obtained from a pelletizing plant located at Lake Superior district, MI, USA was used in the laboratory pelletizing experiments. Original sample was divided into representative samples with cone & quartering and riffling sampling methods. (ASTM E 877-03, 2003) Detailed representative sample preparation procedure was explained in the previous paper of the authors (Sivrikaya et al., 2013).

The moisture content of as received magnetite concentrate filter cake was 7.51%. Representative magnetite concentrate sample had a particle size of 96.53% passing 44 μm (325 mesh) with P_{100}:62.23 μm and P_{80}:27.60 μm. Specific surface area (Blaine number) was found 2212 ± 38 cm^2/g for magnetite concentrate according to ASTM standard (ASTM C 204-07, 2007). Specific gravity of magnetite concentrate was found 4.64 by pycnometer with both distilled water and acetone as liquid media. Elemental analysis of representative magnetite concentrate sample is shown in Table 1.

Bentonite clay, organic-based binders and colemanite mineral were tested as binders in order to compare the effect of different binders on both compressive strength and dust generation potential of product pellets.

2.1.2. Bentonites

Two different bentonite samples were tested. The particle size distribution analyses of bentonite samples showed that the minus 44 μm materials were 95.49% (P_{100}: 124.50 μm and P_{80}:13.11 μm) and 97.98% (P_{100}: 88.00 μm and P_{80}:16.13 μm) for bentonite-1 and bentonite-2, respectively. Elemental analyses of bentonite samples are given in Table 1. Mineralogical analyses of the bentonite samples revealed that they composed of montmorillonite, sodium/calcium aluminum silicate and potassium aluminum silicate hydroxide.

Table 1
Dry basis elemental compositions of raw materials, wt.%.

Component	Magnetite	Bentonite-1	Bentonite-2	Colemanite
Total Fe	65.52	–	–	–
Fe_2O_3	–	3.96	4.17	–
SiO_2	4.87	58.36	67.76	<6.50
Al_2O_3	0.09	21.14	16.86	–
CaO	0.44	1.43	2.19	27.00
MgO	0.37	2.98	3.62	–
Na_2O	<0.01	3.82	1.38	–
K_2O	0.02	0.58	0.73	–
S	0.03	–	–	<0.50
P_2O_5	0.05	–	–	–
TiO_2	0.01	–	–	–
B_2O_3	–	–	–	42.00
LOI	–	6.75	2.93	–

2.1.3. Organic-based binders

Three different organic-based binders were used; 1) technical grade CMC (carboxymethyl cellulose), 2) Ciba© DPEP06-0007 polymer and 3) Cytec Superfloc® A150LMW (low molecular weight flocculant). CMC is a cellulose derivative with carboxylmethyl groups ($-CH_2-COOH$) bound to some of the hydroxyl groups of the glucopyranose monomers that make up the cellulose backbone. The idealized chemical structures of cellulose and CMC were given elsewhere (Eisele and Kawatra, 2003). Technical grade CMC was purchased from the local chemical market. Ciba© DPEP06-0007 polymer is an anionic copolymer blend and Cytec Superfloc® A150LMW is an anionic polyacrylamide flocculant. They are intentionally synthesized for agglomeration and flocculation purposes in mineral processing industry. The former is manufactured and supplied by Ciba Specialty Chemicals Holding Inc. as a commercial agglomeration aid chemical. The latter flocculant is manufactured and supplied by Cytec Industries Inc. and generally used as dewatering aid. The manufactured organic based binders are identified by codes without identification of their chemical structure. Ciba© DPEP06-0007 polymer is described as 25–55% sodium carbonate in the material and safety data sheet (MSDS). However, no information about chemical contents of Cytec Superfloc® was given in its MSDS. These manufactured organic based binders were tested as binders alone or in combination with colemanite in the present study.

2.1.4. Colemanite

Colemanite (calcium–borate) is a natural borate mineral found in evaporite deposits of alkaline lacustrine environments. Colemanite is a secondary mineral that formed by alteration of borax and ulexite minerals. Colemanite has a chemical formula of $Ca_2B_6O_{11}\cdot 5(H_2O)$ and melting point of 986 °C (Tektaş, 2003). A colemanite concentrate sample in the size of −125 + 25 mm was taken from Eti Mine Bigadiç Concentration Plant, Balıkesir-Turkey. A typical chemical composition of colemanite sample is given in Table 1. The as-received colemanite sample was washed, dried and crushed down to 1 mm with roll crusher. The crushed sample was calcined at 550 °C to remove its chemically bonded water. The calcined colemanite was ground in a laboratory centrifuge ball mill to a particle size of 73.51% passing 44 μm (P_{100}: 176.00 μm and P_{80}:54.67 μm). The specific gravity of this calcined colemanite was measured to be 1.95 with acetone pycnometer.