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Modeling and simulation of green iron ore pellet classification in a single deck roller screen using the discrete element method

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ABSTRACT

Bed permeability is a critical parameter in induration of green iron ore pellets in travelling grate furnaces. Its control and optimization must be pursued in order to achieve higher productivity, lower fuel consumption and higher quality and uniformity of fired pellets. One important method of improving bed permeability is to strictly control the size distribution of green pellets prior to feeding the induration furnace. Given the limited control that exists in the sizes of pellets that leave pelletizing drums or discs during balling, size classification by screening becomes of central importance. The work analyzes the performance of the main type of screen used in classification of green iron ore pellets, the roller screen, through simulations using the discrete element method. Recognition of the sticky nature of the material led to the choice of the Hertz-Mindlin model with JKR cohesion to describe the contacts. Material characterization tests were conducted that resulted in the estimation of detailed material and contact parameters for simulation. Finally, simulations using the discrete element method were used to analyze the sensitivity of the roller screen performance to selected material and operating variables.

1. Introduction

Roller screens are used worldwide in classification of green iron ore pellets. In Brazil, such devices started being used in the 1990s and rapidly replaced vibrating screens, given their higher separation efficiency and ability to preserve green pellets from damage and even breakage during classification.

Single-deck roller screens consist of a slightly angled deck in relation to horizontal (usually 10° to 19°) assembled with parallel rotating rolls meticulously gapped to separate fines, product (on-size) and coarse pellets (Fig. 1). Fines are removed on the first three quarters of the length of the screen through the gaps, typically wider than 9 mm [1], whereas in the last quarter, the product is classified by rolls with gaps that range from 14 to 18 mm. Coarse pellets are retained, being removed at the end of the roll discharge, while the product is the material passing the last quarter of the screen. In drum pelletizers, circuits are formed by coupling one roller screen to each drum, whereas in disc pelletizers such screens are typically used downstream from several discs. The circuits are closed by returning both the undersize and the oversize material back to the balling discs or drums.

Screening of green pellets impacts the productivity and fuel consumption of the induration furnace that is used downstream in heat-treatment of the iron ore pellets. In addition to that, screening affects the quality and uniformity of fired pellets, given its impact on bed permeability through control of the size distribution of pellets fed to the furnace.

Optimizing the operation of such devices is, therefore, worthwhile. Unfortunately, experimentation in full-scale plants, through measurements of size distribution of the feed and products, as well as the mass balance, is very challenging. First, collecting samples of streams that feed and leave the screen, and analyzing their size distribution is not straightforward given the low strength of the pellets, which can easily break during handling. The second challenge is related to the difficulty of properly measuring the flowrates of pellets in the different streams around the screen. This is often difficult to conduct online, since conveyor belts used in each balling line often do not have the required length to allow installing dynamic scales for continuously weighing the charge. Even when belts of sufficient length are available, the investment costs associated to such installation are not often justified. Finally, in the case of roller screens installed in plants that use balling discs, each screen is fed by the product of several discs. This creates a further challenge in industrial experimentation, since the impact of small changes on any variable in the screen may be difficult to measure, given the variability of the circuit owing to fluctuations in the operation of each disc. As such, computer simulation using the discrete element method (DEM) becomes a very attractive alternative for gaining insights into this important process.

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Fig. 1. Roller screen in operation.

The discrete element method (DEM) has been successfully used, for instance, to analyze particle motion [2,3], collision energies and amenability to produce wear in machines [4,5] used in a number of fields, with comparatively limited work dedicated so far to pelletization. For example, Lian et al. [6] investigated coalescence of agglomerates made from 1000 primary particles at different velocities and observed that more than half of the collision energy was dissipated by interparticle friction, followed by viscous damping of the liquid layer. Such simulation results were in close agreement with predictions using Liu's model [7]. Wang et al. [8] used Nonsmooth Discrete Element Method (NDEM) to simulate the discharge of green pellets from a rotary balling drum. This variant of DEM allows integration with much larger simulation step size than traditional DEM, so that impacts and friction stick-slip transitions are considered as instantaneous events making the velocities discontinuous in time. This makes the method potentially faster and, therefore, more capable of simulating longer times in the physical world. Mishra et al. [9] simulated the agglomeration process in a rotating drum mixer, capturing mill torque variations as well as breakage and nucleation mechanisms at different positions on the tumbler device.

Green iron ore pellets exhibit plastic deformation behavior, and the extent of this plasticity varies with the moisture content of the granule [7]. Describing such plasticity is therefore important in simulating using DEM. Recently Thornton et al. [10] demonstrated that ignoring the plastic deformation behavior of some materials when simulating using the discrete element method may lead to physically unrealistic results. In their studies on the elastic-plastic normal contact force model for solids with adhesion they concluded that linear models that ignore the permanent plastic deformation and assume the end of contact at a given relative approach are not physically sound. Indeed, this value is likely to be overestimated between 7 and 10 times. Mishra et al. [9] used in their simulations the elastic-plastic contact model, with values of interfacial energy varying from 0.5 to 1.5 J/m^2, being able to predict surging phenomena by capturing mill torque variations on the tumbler device.

While several simulation studies exist on vibrating screens, widely used in mineral and materials processing in general [11–14], no published work has been found exclusively dealing with the application of the discrete element method to simulate roller screens, representing an area of opportunity for optimization in the green balling process. The present work deals with the estimation of material and contact parameters of green iron ore pellets for simulation using DEM, followed by simulating a single-deck industrial roller screen operating under different conditions.

2. Materials and methods

2.1. Material and physical characterization

A pellet feed mixture was collected from an industrial plant in operation in Brazil. A summary of the physical and chemical characteristics of the feed to the pelletizing disc is presented in Table 1.

Green pellets were produced in a one-meter diameter disc pelletizer (Eirich Gmbh, model TR10) angled 68° from horizontal plane. Rotational speed of the disc was maintained constant at 16 rpm (37% of critical). The as-received mixture containing about 5% of moisture (wet basis) was placed in the disc and water spraying was carefully applied to promote agglomeration, so that pellets produced presented an average moisture content of 9.6% (wet basis). Once produced, pellets were hand-sieved for additional testing. Their bulk density was measured in a hydrostatic scale.

Green and dry compression strengths of pellets were measured according to ISO 4700:2015 [15]. Sieved between 10 and 12.5 mm, batches of 80 randomly selected pellets were subjected to testing under each condition. Green moist pellets were collected immediately after pelletizing in the laboratory. Dried pellets were obtained after placing a batch of pellets in a laboratory oven at 105 °C for 1 h. A compression testing machine (EMIC model DL1000), equipped with a 10 kN load cell, was used in all tests, during which deformations were also recorded. The advance velocity of the press piston was set to 10 mm/min. The compressive strength is the maximum peak force obtained before the first crack propagation which causes a drop of, at least, 10% in compressive force.

The standard drop number test [16] was carried out with 20 pellets sieved between 10.0 mm and 12.5 mm. They were individually and repeatedly dropped from a 46-cm height platform until either breakage or cracking occurred. The drop number is the average number of drops each pellet resisted.

2.2. Bench-scale handling tests

Two bench-scale tests were carried out in order to assist in the estimation of contact parameters for the DEM simulations: handling bench and tumbling tests.

Table 1
Chemical and physical characteristics of the balling feed.

	Measure	Value
Chemical composition	Fe_{total} (%)	62.2
	SiO_2 (%)	2.7
	CaO (%)	2.2
	Mn (%)	0.088
	MgO (%)	0.050
	P (%)	0.046
	TiO_2 (%)	0.101
	Binary basicity	0.82
Physical characteristics	Surface area (cm^2/g)	1,860
	<0.045 mm (%)	80.4
	LOI[a] (%)	4.75
	Bentonite dosage (%) – dry basis	0.56
	Anthracite coal (70.7 % C_{fix}) addition (kg/t)	17.1

[a] Loss on ignition.