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METHODOLOGICAL ADVANCES IN DEM-BASED BULK SOLIDS HANDLING SIMULATION FOR PREDICTING PARTICLE DEGRADATION

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Abstract. Mechanical degradation during bulk solids handling can significantly affect the performance of mineral processing and ironmaking operations by generating fines and reducing product quality. Although Discrete Element Method (DEM)-based approaches combined with mechanistic breakage models have been successfully applied to predict particle degradation, important limitations remain regarding the representation of energy transfer mechanisms and impact-angle effects, particularly for irregular particles. This work proposes methodological improvements to the Advanced Bulk Solids Handling Simulation framework by introducing algorithms capable of calculating impact angle, effective energy transfer through contact networks, and the minimum energy required for abrasion. Laboratory degradation tests were performed using charcoal briquettes subjected to screening and tumbling conditions representative of industrial handling operations. DEM simulations were conducted using EDEM and collision histories were post-processed through Monte Carlo procedures coupled with mechanistic breakage models. The proposed methodology accurately reproduced impact-angle measurements and significantly improved degradation predictions compared with previous approaches developed for spherical particles. The model successfully predicted fines generation in both screening and tumbling tests, achieving relative errors below 3% during the initial stages of degradation. Results demonstrate the potential of the methodology for predicting mechanical degradation of irregular granular materials in industrial bulk handling systems.

1. Introduction

Bulk solids handling operations are widely employed in mining and metallurgical industries through conveyors, transfer chutes, silos and stockpiles. During transport, particles are subjected to repeated compressive and shear stresses that may induce breakage and abrasion. Several empirical and mechanistic approaches have been proposed to estimate degradation during handling operations; however, no universally accepted methodology currently exists.

The development of DEM-based breakage models has substantially improved the understanding of particle degradation mechanisms. In particular, the Tavares breakage model has been successfully applied to a wide range of granular materials [1,2]. More recently, the approach named as Advanced Bulk Solids Handling Simulation [3] has enabled degradation prediction without explicitly replacing particles after breakage, significantly reducing computational requirements. In work by Cavalcanti et al., the impact angle in collisions was estimated indirectly from dissipated collision energies for spherical particles [4]. While this simplification proved adequate for iron ore pellets, its applicability to irregular particles remains uncertain. Therefore, the objective of this work is to develop and demonstrate an improved methodology capable of accurately describing degradation mechanisms of irregular particles through explicit impact-angle obtained from DEM and energy-transfer calculations.

2. Methodology

2.1. Advanced Bulk Solids Handling Simulation Framework

The proposed methodology is based on a hybrid approach combining DEM simulations and mechanistic breakage modelling [5]. In this approach, DEM is employed exclusively to reproduce particle motion and record collision histories, while degradation calculations are performed during a subsequent post-processing stage.

For each collision registered during DEM simulation, relevant variables are extracted, including particle and geometry identities, relative velocities, energy losses and collision geometry.

Since this approach preserves the original particle population during DEM calculations, the computational burden associated with explicit breakage models that continuously generate fragments during simulation is avoided. Consequently, large industrial handling systems can be analysed while maintaining physically based degradation predictions.

In a post-processing step outside DEM environment, virtual particles are created and then subjected to a particle breakage model based on Tavares and King work [6-8] as shown in Figure 1. The collision may result in either particle damage and surface breakage or complete disintegration of the particle, generating a distribution of fragments.

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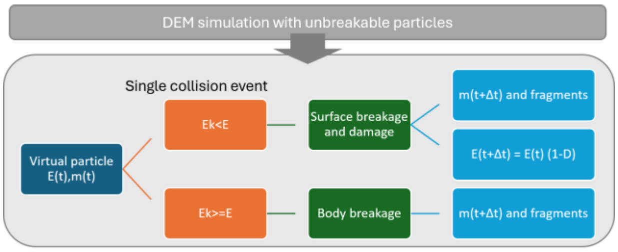

Figure 1. Model framework for breaking virtual particles outside DEM environment.

2.2. Explicit Determination of Impact Angle

Previous approaches estimated impact conditions indirectly through relationships between dissipated energy and collision orientation. While adequate for spherical particles, such approximations become unreliable when irregular particle geometries are considered.

In the present work, the impact angle is calculated directly from the collision normal vector and the relative velocity between colliding bodies. The procedure provides a geometrically consistent description of the collision event and remains independent of particle orientation and shape.

Because the formulation is derived directly from contact kinematics, the methodology can be applied to spherical, non-spherical and multi-sphere particle representations without additional calibration. The approach has been tested with controlled simulation of particle drop against inclined planes (Figure 2).

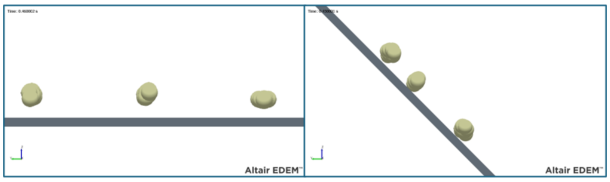

Figure 2. Snapshots of DEM simulations of multiple particle drop against a plane at two angular positions.

2.3. Energy Transfer Through Contact Networks

Conventional approaches typically associate breakage exclusively with the kinetic energy of particles directly involved in a collision. However, in confined systems such as silos, stockpiles and packed beds, energy may propagate through contact networks and induce breakage in particles that possess little or no individual kinetic energy.

To represent this phenomenon, a new algorithm was developed to evaluate energy transmission through overlapping contact events. The approach allows impact energy to propagate through neighbouring contacts, similarly to the behaviour observed in Newton's cradle systems. As a result, particles can receive fracture-inducing energy indirectly through the granular assembly, providing a more realistic representation of degradation in dense particle systems.

2.4. Abrasion Modeling

While impact breakage has been extensively studied, abrasion mechanisms depend on local contact conditions and generally require a minimum level of stress or energy before material removal occurs. In the recent application of the model, Cavalcanti et al. [4], the abrasion model was proportional to collision energy losses. In this scenario, particles would still generate fragments, even in the case of very low energy losses. In the proposed framework, abrasion is activated only when the energy associated with a collision exceeds a minimum threshold value.

This concept introduces a mean for distinguishing ineffective contacts from contacts capable of producing measurable surface degradation.

3. Demonstration of Application

The methodology was evaluated using 22.4 mm x19.2 mm charcoal briquettes subjected to controlled degradation experiments. Two handling environments were considered: Ro-Tap screening and tumbling tests in a 30x60 cm (length x diameter) drum.

The corresponding experimental systems were reproduced in DEM using EDEM 2025 and are shown in Figure 3. Collision histories extracted from the simulations were processed using the proposed framework and subsequently used as inputs for mechanistic degradation calculations.

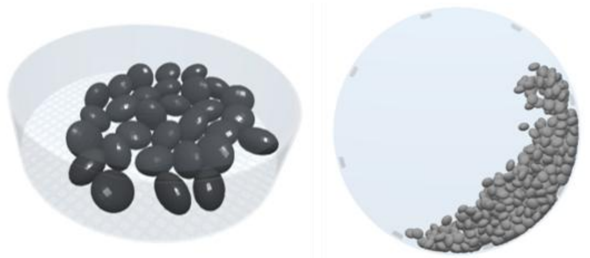

Figure 3. Snapshots of DEM simulations of Ro-tap (left) and Tumbling test (right).

The developed impact-angle formulation accurately reproduced collision geometry over a wide range of impact conditions. Furthermore, the incorporation of energy-transfer mechanisms enabled the identification of degradation events that would not be captured using conventional approaches.

Simulations results considering different values for the minimum abrasion energy are showed in Figure 4 for both systems. A common fitting factor of 0.25 J/kg has been found for both systems considering the 5 minutes mark as reference.

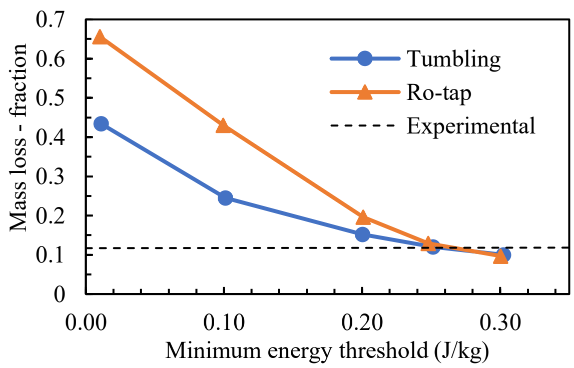

Figure 4. Mass lost due to abrasion at 5 min mark as function of the minimum energy threshold.

Finally, predictions of fine generation over time are presented in Figure 5. It was observed a good agreement to the experiments results, especially at the five-minute mark for the two different systems, being the Ro-tap the most intensive in terms of collision frequency, while the tumbling test the one with the highest collision energies. For longer times, the number of surviving particles reduces, so the original DEM simulation no long represents the actual hold-up of the systems. At some point a new DEM simulation would be required in order to generate new collision histories to be used with the breakage model.

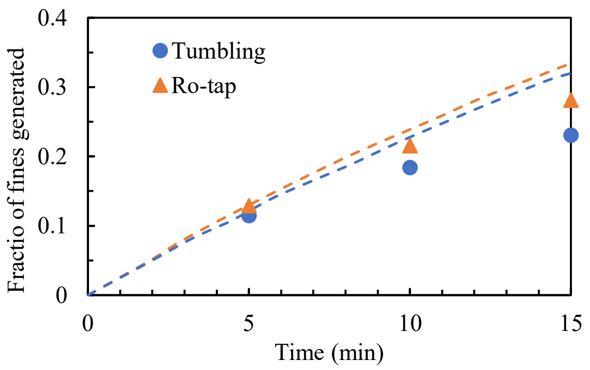

Figure 5. Evolution of mass lost due to abrasion for Ro-tap and tumbling. Dashed lines represent simulation results.

Fortunately, breakage levels exceeding 10% are uncommon in most bulk solids handling operations. Therefore, the results demonstrate the applicability of the proposed Advanced Bulk Solids Handling Simulation.

4. Conclusions

The results demonstrated that the methodological improvements proposed for the Advanced Bulk Solids Handling Simulation framework increased its capability to predict the mechanical degradation of irregular particles. The algorithm developed for impact angle calculation provided consistent results, while the incorporation of energy transfer between particles and the concept of a minimum energy required for abrasion allowed the representation of additional physical mechanisms associated with degradation during handling operations.

These developments extend the applicability of the methodology to irregular particles and dense granular systems where limited breakage occurs, addressing limitations associated with previous approaches originally developed for spherical particles. Furthermore, the proposed framework preserves the computational advantages of methodologies based on collision history while introducing descriptors that can be coupled with mechanistic breakage models.

Application of the methodology to tumbling and oscillating system such as Ro-tap screening using charcoal briquettes showed agreement with the main degradation trends observed experimentally, indicating its applicability to the prediction of degradation of granular materials during bulk solids handling operations.

Acknowledgement

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