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Numerical study of agglomerate abrasion in a tumbling mixer

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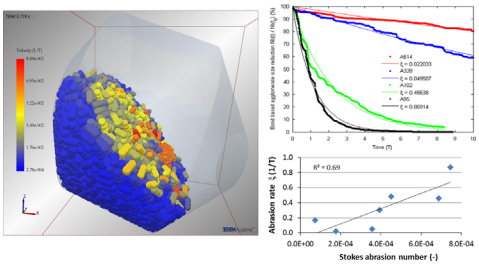
HIGHLIGHTS

- Abrasion of dry agglomerates in dry powder blends was investigated using DEM.
- Size reduction mode varies with agglomerate's mechanical properties, bond strengths.
- Size reduction rate varies with blend condition: filler size, mixer size, mixing rate.
- Stoke abrasion number gave good prediction of agglomerate abrasion behavior.

GRAPHICAL ABSTRACT



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ABSTRACT

A numerical simulation using the Discrete Element Method (DEM) was performed to investigate the phenomena concerning the abrasion and breakage of agglomerates in a diffusion powder mixer. Agglomerates were created by defining a single structure of particles with bonds of different strengths using the Bonded Particle Model (BPM). By comparing the agglomerate size reduction calculated by intact and broken bonds with that agglomerate size calculated by particle number, it was possible to differentiate abrasion and breakage behavior of the agglomerate in the system. The DEM simulations gave support to earlier investigations which concluded that definition of a Stoke abrasion number is a valid approach to predict agglomerate abrasion in a powder blending system.

1. Introduction

Production of powder blends is an important operation in many industries. A common operation in mixing is to make a blend consisting of a small amount of a cohesive powder and a non-cohesive bulk material. A typical example is a cohesive micronized drug that has to be mixed with a free-flowing filler. In such blending processes, it is essential that the cohesive material becomes well-distributed in the powder blend. Because a cohesive powder generally forms aggregates or lumps (Willemsz et al., 2010; Lachiver et al., 2006; Saunders, 1991), fracture of the lumps is needed. Previous reports showed that the time to achieve a sufficiently uniform blend (the "mixing time") is dominated by the rate of abrasion of the lumps (Loveday and Naidoo, 1997; De Villiers, 1997; Llusa et al., 2009b; Llusa et al., 2009a; Willemsz et al., 2010). In fact, the blending process is basically dominated by a rate of abrasion or rate of breakage issue.

Experimental work done earlier (Willemsz et al., 2012a, 2012b, 2013) showed that it is possible to define a Stokes number that relates the strength of agglomerates to the mixing intensity of the moving

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powder. In these studies, lumps were designed and made as brittle calibrated test particles which showed porosity dependent abrasion behavior (Willemsz et al., 2010). The particle velocities on the surface of a powder beds were determined by high speed camera imaging and an in-house developed image processing algorithm (Willemsz et al., 2012c). Results of these studies gave strong indications that the impact intensity and frequency encountered by the aggregates is a determining factor in this process.

Discrete Element Method (DEM) is a numerical method that is gaining increasing interest in academics as well as in industry to study powder behavior in processes. Introduced in 1979, DEM was first used to study rock mechanics (Cundall and Strack, 1979). Later on, the use of DEM has been extended to different types of particulate systems which find applications in different industries e.g. chemical, food and pharmaceutical industry. In DEM, lateral and rotational motions of every particle are calculated by integrating Newton's equation of motion. For further details about the method, readers are referred to other reviews (Luding, 2008; Zhu et al., 2008).

To obtain a better understanding of the processes occurring in the bulk during blending of aggregates in a bed of inert fillers, it has been decided to perform a number of Discrete Element Analyses. These give the possibility to obtain information of processes occurring in the bulk of the mixture. The experimental tests were able to obtain information of particle speed at the surface of the powder bed and lump properties can only be obtained off-line. The aim of this study was to obtain more background information concerning the mechanism of aggregate attrition or breakage.

2. Methods

DEM simulations were performed using a commercially available 3D DEM package, EDEM (DEM Solutions, 2014). EDEM treated particles as soft spheres. Particles deform elastically and do not suffer from permanent deformation (DEM Solutions, 2012a). Two different types of particles were used in this study: fine cohesive 'API' particles and coarse 'filler' particles. Fine particles ($r=30\ \mu m$) were used to form an agglomerate using the Bonded Particle Model (BPM) (DEM Solutions, 2012b; Potyondy and Cundall, 2004). Coarse particles with rod like shape, more or less similar to many fillers in pharmaceutical blends, were constructed of three overlapping spheres ($r=70\ \mu m$) as described earlier in literature (DEM Solutions, 2012a; Hare and Ghadiri, 2013). The length/width ratio was 2.

The overall particle–particle interaction followed the Hertz-Mindlin contact model in which the contact mechanics can be considered as 'spring-dashpot' configuration (DEM Solutions, 2012b). Only in case that a bond exists between fine particles, the fine particle–fine particle interaction follows the Bonded Particle Model (BPM) which over rule the Hertz-Mindlin contact model (DEM Solutions, 2012b).

The container mixer used in this simulation has the geometry of a tumbling mixer in which the particles are mixed by 'tumbling'

Table 1
Hypothetical bond parameters and agglomerate properties.

Agglomerate	Spring constant of bond (F/L)	Critical stress of bond (F/L^2)	Modulus of agglomerate (F/L^2)	Fracture strength of agglomerate (F/L^2)
A514	7.1×10^{-1}	1×10^{4}	108	514
A328	7.1×10^{-1}	5×10^{3}	95	328
A102	7.1×10^{-2}	1×10^{4}	16	102
A95	7.1×10^{-2}	5×10^{3}	15	95

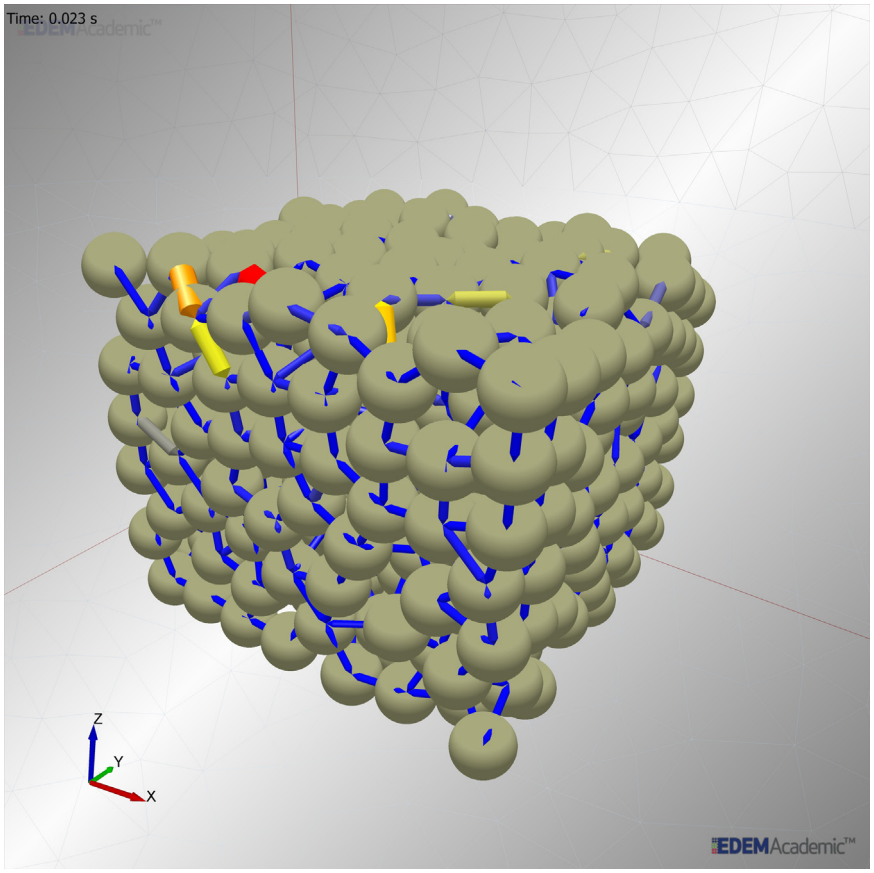

Fig. 1. Agglomerate creation.