



Numerical simulation of compression breakage of spherical particle



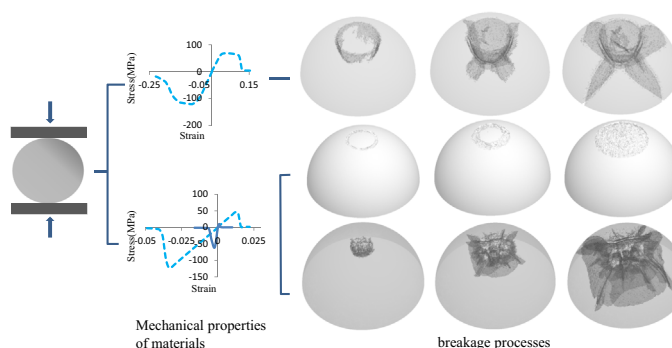
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HIGHLIGHTS

- A 3D numerical approach to particle breakage considering elastic-plastic is applied.
- Numerical results are validated with existing experiments.
- Different breakage patterns are obtained.
- The approach offers an effective way to study the breakage behaviour of granule.

GRAPHICAL ABSTRACT



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ABSTRACT

Understanding the breakage feature of granules has been an important study focus throughout the world for many years. The breakage mode depends on the extent of plastic flow, which cannot be explained by elastic solutions. In the paper, a numerical approach to particle breakage considering elastic-plastic behaviour is achieved using Finite Element Method (FEM). The numerical approach is validated by simulating the Brazilian test with a three-dimensional disk specimen. Then the breakage processes of spherical particle under compression are numerically modeled. The influence of different material mechanical properties is investigated and the consequences with respect to breakage processes are discussed. The predicted trends are in good agreement with experimental observations. The approach offers an effective way to investigate the breakage behaviour of granule, which would be helpful to make clear the whole process of the breakage mechanism.

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1. Introduction

Many industrial processes relate the storage, transport and mechanical disintegration of particle matter. During transportation and handling of particles, breakage and wear occur, which change the particles size/shape and deteriorate the product quality and sometimes may result to serious accidents. In other cases deliberate comminution is needed to achieve required size. It is important to understand the mechanisms of breakage under compression

conditions so that these wear and comminution processes can be properly controlled. However, there is a lack of exhaustive knowledge on the breakage process of compressed particles from the mechanical point of view.

At present, the breakage of aggregates has been studied experimentally (Li et al., 2013; Zheng et al., 2014; Shi and Zuo, 2014; Gupta, 2017). However, in these experiments the valid information obtained is limited to detecting the particle size distribution after breakage, so it is difficult to describe the breakage mechanism of agglomerates.

Recently, numerical simulations have been used to investigate the detailed evolution of agglomerate breakage due to compression

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or impact (Zheng et al., 2012, 2015; Cil and Alshibli, 2012; Duy et al., 2014; Dosta et al., 2016; Guo et al., 2017). However, fragments after breakage cannot typically be generated according to mechanical properties of materials in these numerical models.

As a basis of the particle breakage mechanisms, the deformation and fracture feature of individual spherical particles compressed between two rigid anvils have been investigated experimentally and numerically on different material which have included glasses (Arbiter et al., 1969; Shipway and Hutchings, 1993a, 1993b; Andrews and Kim, 1999; Salman and Gorham, 2000), polymers (Schoenert, 1972; Papadopoulos and Ghadiri, 1996; Gorham et al., 2003), ionic crystals (Yuregir et al., 1987), sand–cement (Arbiter et al., 1969), aluminium oxide (Salman et al., 2002), plaster (Chau et al., 2000), and agglomerates (Subero and Ghadiri, 2001; Fu et al., 2004). The stress distribution in loaded spheres is summarized in Shipway and Hutchings (1993a) and Chau et al. (2000), which provides a framework for the analysis of breakage mechanisms. Based on numerous research results, Salman et al. (2004) have given a descriptive classification of the impact failure modes of spherical particles. The configuration and nomenclature of the typical cracks are illustrated in Fig. 1. Some spheres exhibit shallow ring cracks near the contact circle passing into cone cracks. The cone cracks may evolve into divergent (“spalling”) cone cracks running to the free surface (Fig. 1(a)). The cone cracks can also proceed as convergent cone cracks (onion peels) (Fig. 1(b)) or gave rise to subsequent meridional cracks splitting the spheres in orange segment shaped fragments (Fig. 1(c)). Some spheres show in addition to ring cracks near the plastically deformed contact regions, lateral cracks giving rise to compression cones, and radial cracks evolving into meridional cracks (Fig. 1(d)). Overall, the importance of breakage during the granulation process has increased. A more detailed understanding of breakage mechanisms in the crushing process will allow better control and design of particulate product properties in the future.

In general, there are three modellings of particulate breakage: population balance modelling, discrete modelling and continuum modelling (Reynolds et al., 2005). Population balance modelling (PBE) is process scale. In the approach particulate systems are characterized by the birth and death of particles. For example, breakage process causes the increase of the number of particles and decrease of a particular size. Population balance is a balance on the number of particles of a particular state. The approach is to correlate the observed distribution of properties with the rates of the underlying processes that change those distributions (Hulbert and Katz, 1964; Hounslow, 1998; Qamar et al., 2009), which lacks of ability to describe the breakage process, such as debris geometry, internal force distributions, energy dissipation, load transmission and deformation are still beyond the scope of current test techniques. Although PBEs have been used in many aspects, PBEs need more experimental data for validation and fitting (Reynolds et al., 2004).

Discrete modelling is micro-scale which was initially proposed by Cundall and Strack (1979) aiming to compute the motion and effect of a large number of small particles. DEM is becoming widely accepted as an effective method of investigating granular and discontinuous materials (Yin, 1992), especially in granular flows, powder mechanics, and rock mechanics. DEM allows a more detailed study of the micro-dynamics of powder (Duy et al., 2014). For example, the force networks formed in a granular media can be visualized using DEM, which are nearly impossible in experiments with small and many particles. However, DEM need elaborately efforts to model realistic inter-particle bonds when simulating the deformation and failure of granule.

Continuum modelling is micro-scale also which considers granules as continuous bodies that can be expressed by material constitutive model representing the deformation and failure behaviour, and boundary conditions indicating the frictional and adhesive interactions (Adams et al., 2004).

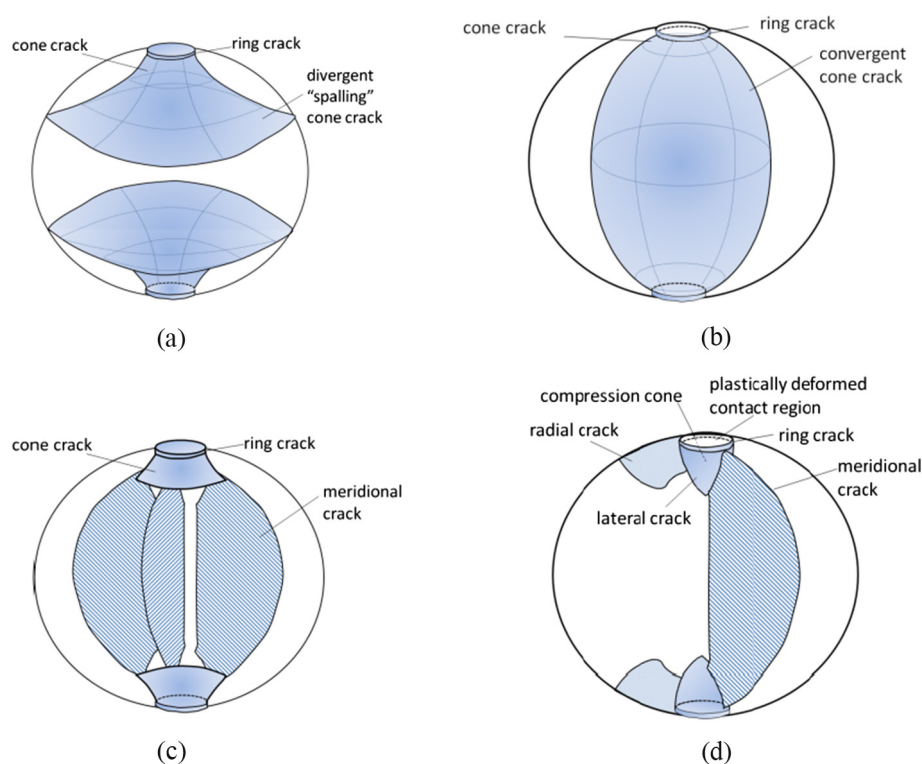


Fig. 1. The configuration and the nomenclature of the typical cracks.

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