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Numerical and experimental studies of corn particle properties on the forming of pile

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ABSTRACT

Slope angle and porosity are two important parameters to describe granular stockpile which is related closely to some phenomena in nature and various industries. In order to study influence of particle physical parameters to the shape, slope angle and porosity of the pile, corn pile experiments and calculations were investigated. The results showed that once physical parameters are chosen properly, simulation results are in good agreement with experimental ones. Particle density, Young's modulus and Poisson's ratio have little influence on the shape, slope angle and the porosity of the pile. Coefficient of restitution has some effects on the slope angle and porosity, which both decreases with the increase of restitution coefficient. Furthermore coefficient of static and rolling friction have obviously effects on the shape, slope angle and porosity of the pile and all this properties are more sensitive to the former.

1. Introduction

Granular stockpile is a very common phenomenon and it is of significant in nature and many industrial situations [1], such as sandpile in the desert in nature, grain pile in agriculture, capsule formation in pharmaceutical process, metallurgical sintering, pelletizing, blast furnace process. In blast furnace (BF) ironmaking, stockpile properties and structures of the lump zone have great effect on the void in burden layers which determines gas distribution and the chemical reactions between raw material particles and the gas. Furthermore the permeability of burden distributions (stockpile properties) will influence the BF smooth operation and stability in a long run. In the field of material preparations, including the shaping of granular particles in ceramics, powder metallurgy and composite synthesis, the densification of powder mass in stockpile form is also especially crucial [2,3]. Therefore, a further knowledge and understanding of the phenomena of granular stockpile is necessary [4] for many industries, even though many investigators [2–12] have studied granular stockpile in the past. Properties of granular particle pile are divided into two categories [5]: macro and micro ones. The former includes repose angle [6], slope angle, bulk density [7–9], stress distribution [3,6], porosity distribution [2,10] and pressure distribution and the latter means particle density, coefficient of rolling friction [11], coefficient of static friction [12], Poisson's ratio, coefficient of restitution and Young's modulus. The latter parameters have a heavy influence on the former properties, and the former accurate predictions can be calculated if the latter are selected appropriately [5].

A large number of studies have been investigated for granular stockpile. However, due to complexity of the stockpile structure and the opaque of the forming mechanism in three dimensions, it's difficult to fully understand stockpile properties merely by laboratory experiments [13–16]. In the past decade, with the development of computer technology and the improvement of computing speed, numerical simulations, including Monte Carlo (MC), cellular automaton (CA) and discrete element method (DEM), can be used to study many granular matters which are difficult to achieve in experiments. In particular, Monte Carlo algorithms are extensively used by scientists for a long time. However, these algorithms contain various assumptions about particle motion and stability criteria which simplify or ignore some physical truth (phenomena) of granular matter [17,18]. DEM has become an option for scientists and engineers to explore, validate and optimize the design of granular material handling system [19–21].

Early studies mainly focus on spheres or discs in DEM, because mathematical models of sphere-sphere and sphere-wall interactions are well-known [22–24] and a low computing effort for discs or spheres [25]. However, actual granular particles in our daily life are usually non-spherical and more complex. So it's necessary to study properties of non-spherical particles in granular stockpile, which most researchers used are ellipsoid, super-quadrics [26,27], glued-sphere clusters and polygon. For example, Yu et al. [2] and Xu et al. [28] have researched coordinate number and radical distribution of pile by ellipsoid with different sides and aspect ratio of particles. Höhner D et al. [25,29,30]

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Fig. 1. The size of corn particles.

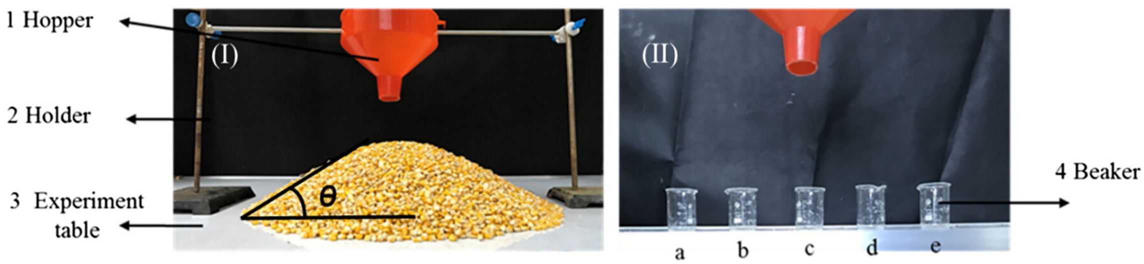

Fig. 2. Experimental apparatus of piling (I) and porosity measurement (II).

mainly investigated the movement of ellipsoid, super-quadrics, polygon and cylinder in the pile. The above studies of non-spherical particles concentrate on the properties on the forming of the pile, but there is no investigation of porous (void) distribution in the pile which is significant for chemical reactions between gas and particles in porous bed.

Slope angle in the paper has a little difference with the repose angle [31] which other researchers has been investigated. Exactly, the slope angle is a dynamic repose angle, which is the angle of the slope of the free surface of a flowing granular material [32], and is closely related to many phenomena and include piling [5,33], self-organization [34], avalanching [35], stratification [36,37], and segregation [38]. It's also a parameter to character the flowability potential of a pile. It has been found that the slope angle strongly depends on material properties such as sliding and rolling frictions and material density [39]. The investigations of Elperin et al. [40] and Coetzee et al. indicate that the slope angle increases with the increase of friction coefficient and

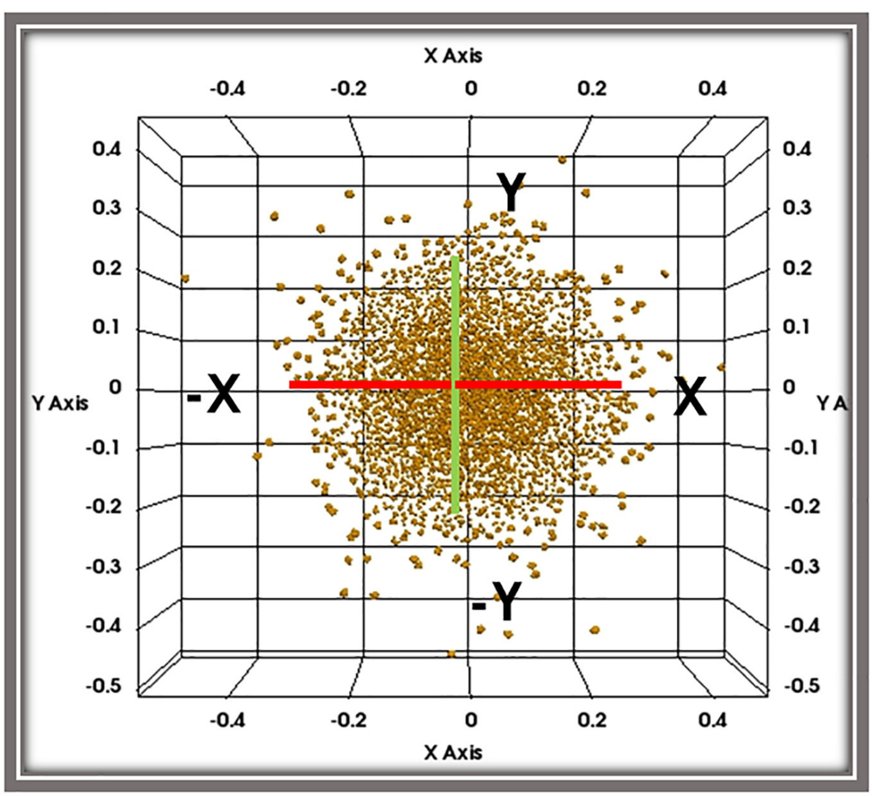

Fig. 3. Illustration of direction for data processing of slope angle (top view of pile in simulation).