Powder Technology 270 (2015) 348–357

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

Bottom wall friction coefficients on the dynamic properties of sheared granular flows

Chun-Chung Liao, Shu-San Hsiau *, Pei-Sian Chang

Department of Mechanical Engineering, National Central University, Jhongli 32001, Taiwan, ROC

A R T I C L E I N F O

Article history:
Received 17 February 2014
Received in revised form 23 October 2014
Accepted 26 October 2014
Available online 31 October 2014

Keywords:
Sheared granular flows
Bottom wall friction coefficient
Tangential velocity
Granular temperature

A B S T R A C T

In this study, we used a two-dimensional annular shear cell to systematically investigate the dynamic properties of granular flow when it is subjected to varying bottom wall friction coefficients. A particle tracking method and image processing technology were employed to measure tangential velocity, slip velocity, local solid fraction, and granular temperature. The results demonstrated that the bottom wall friction coefficient played a crucial role in determining the dynamic properties of sheared granular flows, indicating that slip velocity is larger when a rougher bottom wall is applied. The results also indicated that the tangential velocity and granular temperature were reduced when the roughness of the bottom wall increased because of the strong frictional effect, which caused a larger dissipation of energy. The average granular temperature increased linearly when the solid fraction at each specific bottom wall friction coefficient increased.

1. Introduction

Granular materials are found in many industrial processes, such as in coal transportation, pharmaceutical manufacturing, food storage and transport, polymer production, pyrolysis of biomass, and metallurgical engineering, as well as in daily life, such as in sand, salt, sugar, and beans. The handling and processing of granular materials are of economic importance in many industries. Furthermore, to predict and prevent disasters caused by uncontrolled debris flows, avalanches, and landslides, it is crucial to understand the dynamic properties and rheology of these phenomena. However, the present understanding of the behavior of granular flows remains inadequate and a deeper study is necessary.

Granular materials do not flow homogeneously like a fluid because the external driven force does not exceed a critical value and energy dissipation resulting from the occurrence of inelastic collisions, as well as from friction between particles and between particles and walls. Therefore, a solid-like region and a liquid-like region (shear band region) can coexist in the same flow system. The thickness of a shear band is approximately four to ten particle diameters, which depends on the external driving conditions, solid fraction, and interstitial fluid viscosity [1–5]. The interactive collisions that occur between particles cause the random motions of these particles, which become the dominant mechanism influencing flow behavior in granular materials [6,7]. Random particle motion in granular flows is analogous to thermal molecular motion. The concept of granular temperature was first proposed by Ogawa [8] to quantify the mean-square value of fluctuation velocities. Granular temperature is defined as the specific fluctuation in the kinetic energy of particles that are present in granular flows, and it plays a role in granular flows that is similar to that of thermodynamic temperature in a gas. Granular materials behave more like a liquid or a gas when they have a higher granular temperature.

In the past few decades, shear cells have been widely used for investigating the dynamic properties and rheology of granular materials because they exhibit a relatively simple flow field, which makes them suitable for fundamental research [9–24]. According to the Reynolds shear dilatancy phenomenon, the packing structure of granular matter becomes diluted as a shear force is applied [25]. Mahmood et al. [17] investigated the micromechanics of granular flows by using a two-dimensional planar granular Couette flow. They determined that fluctuation velocity and granular temperature are related to the effective shear rate. They also indicated that the distribution of collision angles is anisotropic. Koval et al. [18] studied sheared granular flow by using a discrete element simulation in which an effective wall velocity was used to generate an inertia regime (shear band) near the rotating inner wall, whereas away from the wall a quasi-static regime prevailed, in which the granular material was in a solid or near-solid phase and particle motions were correspondingly slow and weak.

The wall friction effect exerts a significant influence on dynamic properties and flow behaviors in granular flows. Hsiau and Yang [15] indicated that the rougher the condition of a wall, the greater the stress that is induced, and the higher the shear rate in sheared granular flows. Jasti and Higgs [21] experimentally studied granular flows in an annular shear cell and observed that particle velocity and granular temperature increased with increasing shearing wall roughness. Marinack et al. [26] used different shearing wall surface materials to produce different coefficients of restitution between the granular and shearing

* Corresponding author at: No. 300, Jhongda Rd., Jhongli City, Taoyuan County 32001, Taiwan. Tel.: +886 3 426 7341; fax: +886 3 425 4501.
E-mail address: sshsiau@cc.ncu.edu.tw (S.-S. Hsiau).

http://dx.doi.org/10.1016/j.powtec.2014.10.043
0032-5910/

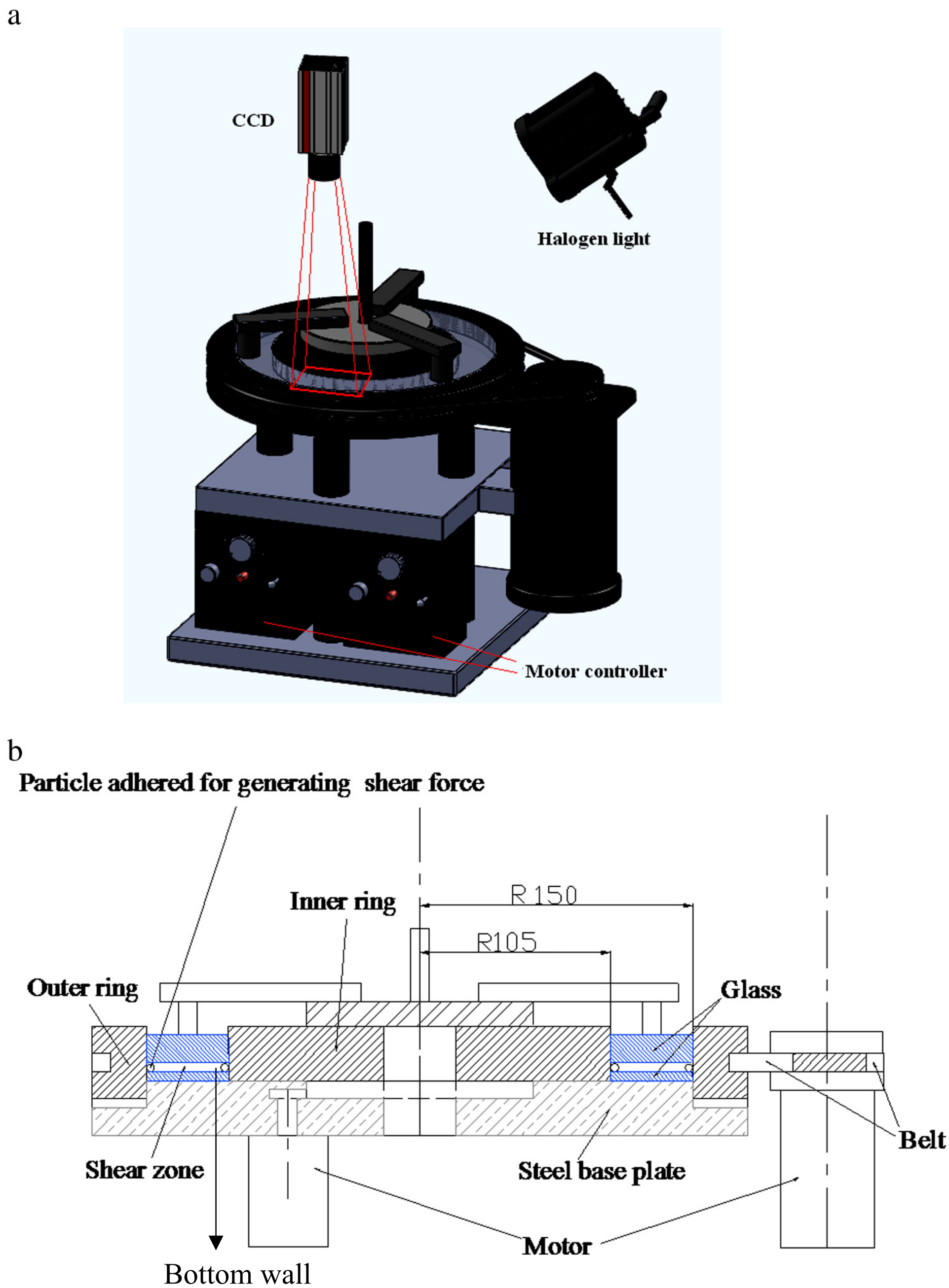

Fig. 1. Schematic drawing of (a) the shear cell experimental apparatus; (b) side view of the shear cell.

surface materials with the same shearing wall roughness and found that the velocity and granular temperature increased with the increase of restitution coefficient. Hsiau et al. [19] observed that convection and segregation rates increased with an increasing side wall friction coefficient in a vertical vibration bed. Kose et al. [22] experimentally investigated the rheology of particle–liquid mixtures by using both smooth and rough wall surfaces in sheared granular flows. They observed that the effective mixture viscosity is larger in cases involving rougher wall surfaces than in cases involving smoother wall surfaces. They demonstrated that wall slip substantially affects the apparent viscosity.

In the past, the effect of driving wall roughness on dynamic properties had received a lot of attention. The influence of bottom wall roughness on the dynamic properties in sheared granular flows has not been previously examined. Additionally, the bottom surface is usually uneven in most industrial and natural granular systems. Hence, it is important to study the effect of bottom wall friction coefficient on dynamic

Table 1
Parameters used in the current experiments.

Bottom wall friction coefficient (μ_w)	Inner wall velocity U_i (m/s)	Area solid fraction (ν)
0.384 (#220 (68 μm) sandpaper)	0.23 m/s	0.82
0.378 (#240 (61 μm) sandpaper)	0.34 m/s	
0.354 (#280 (51 μm) sandpaper)	0.45 m/s	
0.316 (#320 (45 μm) sandpaper)	0.57 m/s	
0.300 (#400 (38 μm) sandpaper)	0.68 m/s	
	1.02 m/s	
0.384 (#220 (68 μm) sandpaper)	1.02 m/s	0.78
0.378 (#240 (61 μm) sandpaper)		0.80
0.354 (#280 (51 μm) sandpaper)		0.82
0.316 (#320 (45 μm) sandpaper)		0.84
0.300 (#400 (38 μm) sandpaper)		