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A study on the transition between neighbouring drum segregated bands and its application to functionally graded material production

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ABSTRACT

The composition transitions between two neighbouring segregated bands in a rotating drum were studied using binary glass beads of 6 different size ratios. The concentration gradient of the coarser particles in the transition zone increased dramatically when the particle size ratio increased from 1.68 to 2.01 and then gradually decreased as the particle size ratio increased from 2.01 to 3.37. The concentration gradient profile could be explained by the differences of the dynamic angles of repose between the two components of the binary mixture. A novel, convenient and particulate-level composition controlled FGM processing method is proposed based on the transition zone structure between two neighbouring segregated bands. A $Cu/Al_2O_3/Cu$ functionally graded material was successfully produced based on the proposed method using binary mixture of Cu and Al_2O_3 powders.

1. Introduction

Rotating drums are commonly used equipments for powder mixing operations in the food, ceramics and pharmaceutical industries. Williams and Khan reported that when particles of different sizes, densities, surface roughness, or elasticities were tumbled in a rotating drum, the blends might perform segregation [1]. During the mixing process, particles with different physical properties may not uniformly distribute in the drum and the particles with similar physical properties may stay together and cause segregation at certain operating conditions.

The size-induced segregation occurred when the particle size ratio of a binary blend is greater than 1.2 [1]. When binary mixture of particles differing only in sizes is tumbled in a rotating drum, high concentrations of the finer particles are collected around the centre of the bed after few revolutions and form a segregated core in the radial direction. Cores of different shapes have been reported. Hill et al. investigated the formation of wavy striped core (sun pattern) and reported that the wavy striped core was associated to the wave-breaking of the semi-circular radial segregation core (moon pattern) [2]. The finer grains may migrate from one strip to another strip through the central core and hence some strips could be coarsened or be eliminated, causing the formation of the final wedge-shaped segregation pattern [3]. Zuriguel et al. studied the core formation mechanism based on the uphill wave of the particles and predicted the petal number of the striped core [4].

Oyama initially reported the formation of the axial segregated bands when binary mixture of particle differing in sizes was tumbled in a rotating drum [5]. In the axial direction, the alternative coarser-particle-rich bands and finer-particle-rich bands were formed at the bed surface and more complicated segregated patterns were also reported [6]. The numbers of the bands are functions of the rotational speed, fill level, rotating time and drum geometry [7,8]. The mechanism of the axial segregated band formation is still not very clear although some researchers have proposed reasonable band formation mechanisms. Kuo et al. reported that the formation of the axial bands always began in the end wall shear zone, where the particle bed experienced shear dilation and formed the radial segregation core easily [7]. Chen et al. reported an onset mechanism for the axial band formation also close to the two end walls. While both finer and coarser particles departed from the particle bed upstream, less finer particles reached the particle bed downstream due to percolation. The accumulations of coarser particles close to the two end walls initiated the band formation [9]. Some researchers attributed the band formation by the so-called core-thickening mechanism [10] and others considered the formation of the bands due to the differences of the dynamic angle of repose between the coarser particles and the finer particles [11]. The segregated band structures are dynamic. Choo et al. showed that the bands might be formed, merged, or vanished, but finally the band structure reached a steady state [12]. The bands and cores are co-existing. The finer-particle-rich cores can be found in the interior of the coarser-particle-rich bands [13,14]. The exchanges of the particles in the bands were

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through the connected cores, which caused the band coarsening and merging at the bed surface [15].

Most previous studies of the rotating drum segregation focused on the formation and the evolution of the segregated bands and cores. No work studied the transitions of the particle compositions between two neighbouring segregated bands. The segregation patterns in Fig. 1 (a), (b) and (c) are obtained from the bed surface in a half filled drum rotating at 10, 20 and 30 rpm, respectively using a binary mixture of 350 μm white glass beads and 700 μm grey glass beads. The distributions of the finer and coarser particles in the transition zone between the neighbouring bands are apparently very different in the drums of different rotational speeds. In this work, we focused on the study of the distributions of the two components of the binary mixtures in the transition zone between two neighbouring bands using the binary mixtures of six different size ratios.

Because the concentration of the key component of the binary mixture (say the coarser particles of the binary mixture) is gradually changed in the axial direction in the transition zone as shown in Fig. 1, the self-assembly particle distribution in the transition zone between two neighbouring bands is initially applied for the production of the functionally graded material (FGM) in this study. A FGM is a composite material in which the composition of the key component is gradually increased or decreased in certain dimension [16]. The conventional FGM production method includes, at least, the following steps: (1) different particles are mixed to prepare particle mixtures of different compositions; (2) particle mixtures of different compositions are stacked in the order that the concentration of the key component gradually changes from 100% to 0% in a *stage wise* manner; (3) the stack is compressed and sintered [17]. The concentration gradient of the key component in a FGM depends on the numbers of the particle mixtures. The more the numbers of the particle mixtures are, the smoother the concentration changes of the key component in a FGM [17]. Since the concentration of the key component can be controlled at particulate level as the illustrations shown in Fig. 1, a novel FGM production method is proposed in this study based on the distributions of the particles in the transition zone between two neighbouring bands.

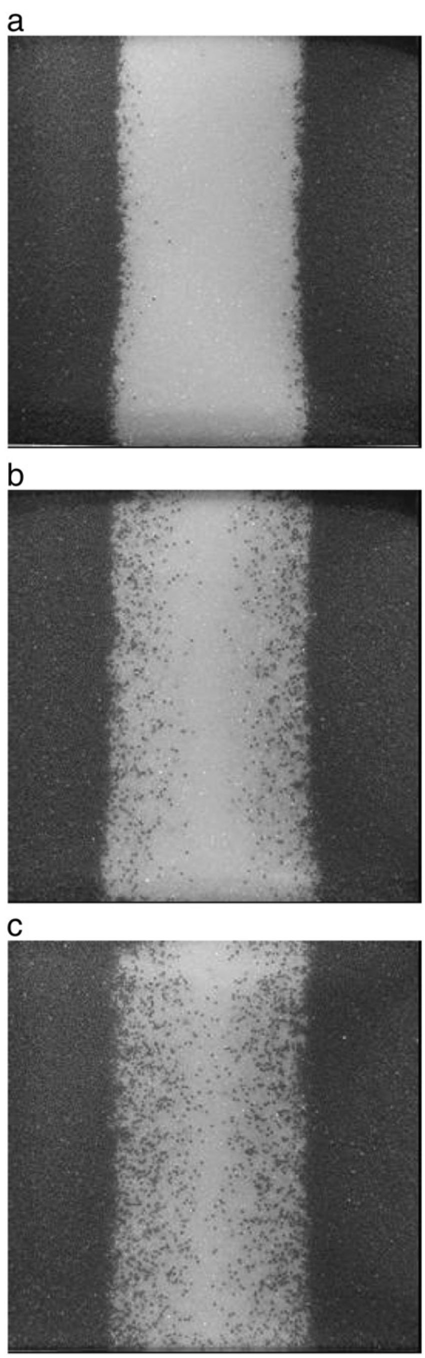

Fig. 1. The segregated band structures at the bed surface in a 50% fill rotating at (a) 10 rpm, (b) 20 rpm and (c) 30 rpm. The white and grey particles are 350 μm and 700 μm glass beads, respectively.

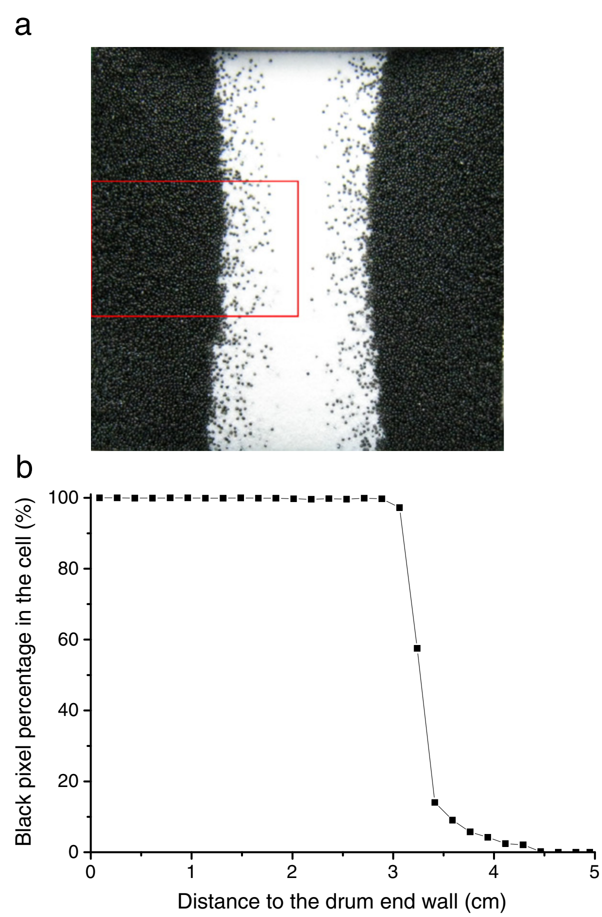

Fig. 2. (a) The segregation pattern at the surface of the bed using binary mixture of the particle size ratio = 3.37. (b) The percentage of the black pixel in the analysed cell along the drum rotating axis analysed from the frame shown in (a).