Towards minimal models for realistic granular materials: Tomographic analysis of bidispersed assemblies of ellipsoids

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Summary: In this paper, we report experimental results on granular compaction in a model system made of mono- and bidisperse ellipsoidal packings as well as sand packings. The packings are subject to vertical tapping of varying duration (number of taps) and their internal three-dimensional structure is obtained using x-ray computed tomography. The analysis of the vertical and horizontal local packing fraction profiles reveal a homogeneous densification in the ellipsoidal packings, however, sand packings exhibit radial density gradient.

1. INTRODUCTION

Microscopic (grain-scale) models for granular materials need to incorporate physical parameters that are pertinent at the particle scale such as friction coefficients, compressibility, etc. They also need to take into account distribution properties such as the variability in grain size and shape. In this paper, we aim to reduce the model complexity to essential ingredients by identifying the key mechanisms at play that govern the *granular compaction*. The key question we aim to address is the extension of the 'zero-th order' model –the spherical case– to model with first- and second-order complexity. Recent years have seen many studies addressing the effects of the particle shape while maintaining uniform particles. Ellipsoids [1, 2], tetrahedra and polyhedra, pear-shaped particles, etc. have all been investigated. There has also been substantial investigations into physical properties [1] that specifically change the compressibility [3]. Here, we focus on a different effect, namely the the compaction of bidisperse ellipsoidal & spherical particles via tapping. In addition, we study compaction in sand packings to better understand the effect of particle shape irregularity. We investigate the effect of mixtures of ellipsoids of identical aspect ratio but different size.

2. EXPERIMENTAL METHOD

To study the properties of bidisperse ellipsoid packings, we use two types of pharmaceutical placebo pills with an aspect ratio $\alpha \approx 0.57$ and large axis lengths of 8.9 mm and 10.2 mm, as shown in figure 1(a).

We start the preparation of the packing by poring the particles through a funnel into a cylindrical Perspex container of 144mm diameter. A set of steel wire grids has been placed at the bottom of the container before the fill. The circular grids have a square mesh size of $\approx$ 20mm, spatially separated by $\approx$ 25mm in height and their mesh orientation is rotated by 45degrees with respect to each other. During the filling process, the container is placed on a motorised, slowly rotating platform ($\approx$ 0.2 Hz) to create a homogeneous and isotropic packing. The grid is slowly pulled out to loosen packing before the experiments. This technique leads to a reproducible initial condition with a global packing fraction of 0.655± 0.02. This preparation method is similar to the technique used for the study of monodisperse ellipsoidal particles [1]. The resulting packings are imaged by helical x-ray tomography [4, 5, 6] and the particles positions and orientations are detected in the reconstructed image by a method based on a watershed algorithm [7, 8]. Particles close to the boundaries (cylinder walls, top and bottom) are removed from the analysis. The resulting packing is checked for spatial homogeneity in packing density. As a second dataset we show packings of Ottawa sand. The diameter of the sand grains is between 500 and 1000μm. Loose sand packings are prepared in the same way as the bidisperse ellipsoid packings, by pouring the particles in a cylindrical Perspex container of 24mm diameter and pulling a double grid through the packing to loosen it. The packings are again compacted by sinusoidal taps with peak acceleration of 2g. Figure 1(b)

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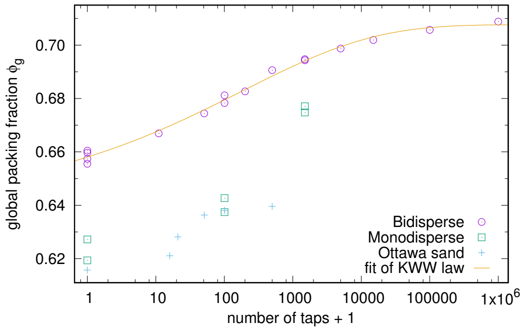
[a] 



(b)

Figure 1: Number of taps vs. global packing fraction. Data of monodisperse and bidisperse ellipsoids is shown, as well as data of Ottawa sand packings. Fitparameters for KWW law: $X_{\text{inf}} = 0.71$, $X_0 = 0.64$, $\tau = 181$, $\beta = 0.22$.

shows the global packing fraction vs. the number of applied taps for the bidisperse ellipsoid packing and the packings of Ottawa sand. As a reference, we include data for packings of monodisperse ellipsoids with approx. the same aspect ratio $\alpha = 0.59$ prepared with a similar preparation method, which was published elsewhere [1].

3. RESULTS

Figure 1(b) indicates that both systems show densification and density saturation, however, the ellipsoidal packing shows a very slow density saturation with a gentle change of densification starting at ≈ 10 taps and another transition to density saturation at $\approx$1,000 taps. The sand packing, however, exhibits a relatively sharp transition from the onset of densification (≈ 15 taps) to density saturation at ≈ 50 taps. The slow densification in the ellipsoidal packings is reminiscent of relaxation and compaction dynamics in glassy systems, which are commonly fitted by a stretched exponential law, the KWW (Kohlrausch, Williams, Watts) law [9, 10]

$$X_{\text{inf}} - (X_{\text{inf}} - X_0) * \exp\left[-\left(\#\text{taps}/\tau\right)^{\beta}\right] \tag{1}$$

Figure 1(b) shows a fit of the KWW law to our data of bidisperse ellipsoids, which is in very good agreement. In contrast, the global packing density in the sand packing, however, fully saturates at ≈ 50 taps.

References

[1] F.M. Schaller, M. Neudecker, M. Saadatfar, G.W. Delaney, G.E. Schröder-Turk, M. Schröter, Phys. Rev. Lett. **114**, 158001 (2015)

[2] F.M. Schaller, S. Kapfer, J. Hilton, P. Cleary, C.D.M. K. Mecke, T. Schilling, M. Saadatfar, M. Schröter, G. Delaney, G. Schröder-Turk, EPL (Europhysics Letters) **111**, 24 (2015)

[3] M. Saadatfar, A.P. Sheppard, T.J. Senden, A.J. Kabla, Journal of the Mechanics and Physics of Solids **60**, 55 (2012)

[4] A. Katsevich, SIAM Journal on Applied Mathematics **62**, 2012 (2002)

[5] T. Varslot, A. Kingston, G. Myers, A. Sheppard, Medical Physics **38**, 5459 (2011)

[6] A. Sheppard et al., Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms **324**, 49 (2014)

[7] M. Saadatfar, A.N. Shepard, M.K. Knackstedt, Advances in X-ray Tomography for Geomaterials pp. 269–276 (2010)

[8] F.M. Schaller, M. Neudecker, M. Saadatfar, G. Delaney, K. Mecke, G.E. Schröder-Turk, M. Schröter, AIP Conference Proceedings **1542**, 377 (2013)

[9] J.B. Knight, C.G. Fandrich, C.N. Lau, H.M. Jaeger, S.R. Nagel, Phys. Rev. E **51**, 3957 (1995)

[10] P. Philippe, D. Bideau, EPL (Europhysics Letters) **60**, 677 (2002)