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EDITORIAL

Flow regimes and phase transitions in granular matter: multiscale modeling from micromechanics to continuum-editorial

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1 Introduction

The aims of this Granular Matter Topical Collection are to bring together the latest advances in constitutive and numerical modeling of granular media, with particular emphasis on coarse-grained discrete element simulations, micro-to-macro and phase transitions, and to improve our understanding of granular systems in view of large scale, practical applications.

This Topical Collection was inspired by some of the oral presentations that took place during the DEM8—8th International Conference on Discrete Element Methods that was held in Enschede, The Netherlands, on 21-26 July 2019 (conference website: https://mercurylab.co.uk/dem8).

All the articles belonging to this Topical Collection can be found on the website of the journal under the "Collection" section.

2 Themes of this special collection

Granular systems are different from 'classical' atomistic systems, in that they are neither fluid nor solid, but often behave as both at the same time. The macroscopic, collective behaviour of discrete, non-Brownian particles, which strongly depends on their interactions at the microscopic level, must be formulated as constitutive expressions in view of the solution of continuum models. Indeed, the final goal is to have models that contain information about the microstructure and the micro-mechanics, but can work on a larger, macroscopic scale. This can be achieved with the so-called micro-to-macro transition, starting from discrete data and translating the particle information into continuum fields.

From the discrete side, Discrete Element Methods (DEM) or coarse-grained DEM are ways to model assemblies of grains, keeping the focus on the microscopic properties and the discrete nature of the granular matter, while providing reference data for continuum models.

From the continuum side, however, there is no generally accepted continuum theory for industrial or geophysical applications on the large scale, although promising attempts have been proposed. Our understanding of the rheology of granular matter has greatly improved in the recent years; a remaining key question is how to extend the flow rheology to deal with different phases/regimes that naturally occur in many granular processes.

This article is part of the topical collection: Flow regimes and phase transitions in granular matter.

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3 Invited papers

This Special Collection comprises nine invited papers that cover a broad range of topics in the area of flow regimes and phase transitions. Three papers focus on the solid-fluid transition in granular materials. One paper investigates the role of moving intruders on the intermittent evolution of force chains. Three papers regard steady and unsteady flows of granular materials over erodible and rigid substrates. The remaining two papers concern the flow characteristics of non-spherical particles.

Xu et al. (2021) propose a criterion to identify the jamming/unjamming transition based on the vanishing of the *microscopic* expression of the second order work that in Geomechanics has been used to distinguish stable from unstable states. The authors prove that that criterion is able to successfully identify the jamming transition in DEM simulations of frictionless and frictional particles under different loading conditions.

Clerc et al. (2021) also focus on the second order work, although defined at the *mesoscopic* scale of grain-loops. They point out that its change in sign is a precursor of bursts of kinetic energy in quasi-2D DEM simulations of grains subjected to biaxial compression, leading to the possibility of predicting instabilities and solid-to-fluid transitions.

Berzi and Vescovi (2021) perform DEM simulations of identical spheres that are initially sheared at constant rate and then allowed to relax in the absence of shearing. They show that the system at the beginning of the relaxation can be shear jammed, fragile or unjammed and evolve into an anisotropic solid, an isotropic fluid or an anisotropic fluid, respectively.

Lehuen et al. (2020) employ a combination of experiments and discrete numerical simulations to show that the pull-off of an intruder from a granular medium, at least at very slow velocities, is governed by successions of loadings/rupture events occurring to a network of contacts bearing strong forces that emanates from the intruder.

Wu et al. (2021) investigate experimentally and numerically the collapse of a granular column over an horizontal, erodible substrate, while systematically changing the initial aspect ratio of the column and the density ratio between the particles in the column and those in the bed. They are able to obtain scaling laws for the morphology of the final deposit and the eroded region that should be reproduced by successful continuum models of granular materials.

Zhu et al. (2020) carry out DEM simulations of steady and fully developed inclined granular flows in channel of rectangular cross-section, with flat base and sidewalls. They confirm the existence of different regimes, with fascinating features such as longitudinal vortices or dense cores supported by gaseous layers, and are able to collapse their data to provide useful boundary conditions that can be employed in continuum models to try and reproduce the observations.

DEM simulations of gravity- and shear-driven flows confined between flat sidewalls are the subjects of the work of Richard et al. (2020). The authors highlight differences and similarities between the two configurations, in particular with respect to the stratification of different flow regimes. They also determine interesting scaling laws between the velocity fluctuations and the shear rate that pose a challenge to existing and future mathematical models of granular flows.

Wang et al. (2020) carry out DEM simulations of superquadric particles to investigate the effect of particle shape on the steady flow pattern inside a conical silo. They show that blockiness and aspect ratio play a non-trivial role in determining the flow regimes and the microstructure in granular flows of non-spherical particles.

Finally, the paper by Nadler (2021) includes the possibility of particle alignment into a rheological description of the behaviour of non-spherical particles and show promising comparisons against DEM simulations of steady, homogeneous shearing of frictionless, ellipsoidal grains.

These works are a meaningful indication of how deep is our current understanding of the fundamental mechanics of granular materials and how diverse and lively is the scientific community behind it.

They are also an indication on what we believe should be the future of the research on Granular Matter: implementation of reliable models of the jamming transition, to be included in continuum models of particle flows, that permit, e.g., to account for erosion/deposition of mass from/to a boundary; 2D and 3D mathematical models of flows in non-trivial geometry, capable of reproducing secondary flows and boundary effects; flows and transitions of particles of complex shape.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.