PhD thesis (CIFRE) in partnership with Stellantis

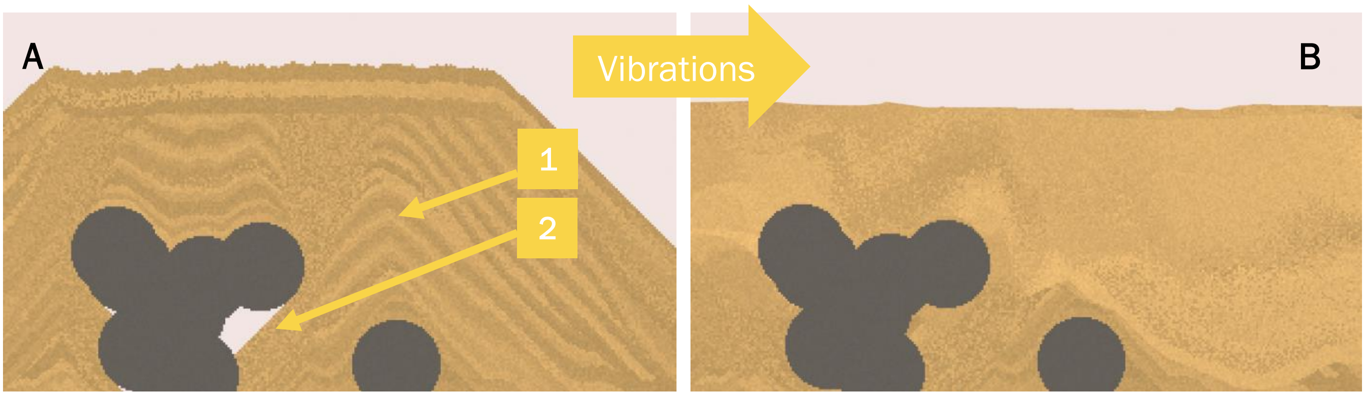
Rheological study and modeling of complex shaped molds filling process, with granular materials, used for foundry parts production

Context

Granular materials (sand, snow, grains, etc.) are media formed by a very large number of particles (typically > 100 µm in size) interacting via their contact forces, especially particle/particle friction. These media have an extremely complex rheology, as they present an apparent solid (sand heap), liquid (flowing grains) or gaseous state (*e.g.* at the surface of an avalanche) depending on the forces applied.

The foundry process used in the latest-generation engines manufacturing by Stellantis involves the immersion inside a grains bath of a template in the shape of the final part, creating a sand mold that perfectly matches this shape. The grains are continuously introduced by the top, in the form of a rain, with the aim of forming a dense continuum that perfectly matches the contours of the template.

Numerous filling and compaction defaults can occur if the template has unfavorable convexities (see figure). In order to avoid these defects, the filling process can be assisted by imposing vibrations at the base of the domain, designed to fluidize the granular medium thus formed and facilitate its flow, while ensuring a high level of final compactness. However, the energy supplied by vibration (mode, amplitude, frequency) needs to be carefully controlled, otherwise the granular packing may be in turn affected.



Schematic diagram of a grain stacking process (filled from the top) around a complex shape, before (A) and after (B) imposing vibrations. Illustration of structuration (1) and filling defects (2). *Drawn using Sandspiel.*

Goals and work program

The main aim of this thesis is to understand, predict and model the flow of a granular medium around complex shapes, in order to limit filling defects (loss of grain/shape continuity) and maximize its compactness. The approach will be essentially experimental. Part of the work may involve the use of numerical tools to simulate the process.

Initially, a simplified approach (experimental and theoretical) will be used to understand all the unitary mechanisms at play when a shower of grains forms a dense medium in the vicinity of simple shapes (sphere, prism...). The experimental set-up will consist of a combination of 3D visualization methods, local density measurements (using capacitance variations) and image analysis to track the filling front.

Secondly, we will study the fluidizing and compacting effect of different types of vibration, by controlling the level of local compactness of the medium throughout the whole domain.

The modelling of the front and compactness evolution will then be implemented in a numerical simulation code. Our approach will then be extended to more complex geometries and finally applied to real industrial processes.

The project will take place at the Centre de Mise en Forme des Matériaux (CEMEF) of Ecole des Mines de Paris - Université PSL, located on the Pierre Laffitte Campus in Sophia Antipolis (France). Numerous visits and interactions are also planned with Stellantis, the project's industrial partner. The candidate will be part of the CEMEF Computing and FLuids (CFL) research team.

Required skills and education

Master's degree or Engineering degree in Physics, Soft Matter Physics, Fluid Mechanics or Materials Science. Strong experience in physical measurements and experimental set-up design will be appreciated.

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