# Fluid-solid transition in unsteady shearing flows

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## ABSTRACT

The discontinuous and inhomogeneous nature of granular materials leads to complex mechanical behaviours, even in case of simple flow conditions. In particular, granular systems can behave like either fluids, meaning that they yield under shear stress, or like solids able to resist applied stresses without deforming. If grains are widely spaced and free to move in any direction, interacting only through collisions, the medium behaves like a fluid and the stresses are proportional to the square of the strain rate under simple shearing (Bagnold scaling [1]). On the other hand, when particles are densely packed, a network of persistent contacts develops within the medium, and the granular material shows a solid-like, rate-independent behaviour. The mechanical response of the system during the solid-fluid transition, is still an open question [2], although several constitutive models have been proposed to this purpose in the literature [3, 4, 5, 6].

Whereas several numerical results have been obtained in the literature concerning steady, shearing granular flows, unsteady conditions have been less investigated. In this work, we investigate the fluid-solid transition in unsteady, homogeneous, shear flows of a collection of identical, frictional spheres, by particle simulations.

For steady, shearing flows, solid volume fraction larger (lower) than a critical value, indicates that a granular system is solid-like (fluid-like), i.e., rate-independent components of the stresses are present (absent). The critical volume fraction is the largest volume fraction at which a randomly collisional granular material can be sheared without force chains spanning the entire domain [7]. Simulations have been performed considering three volume fractions corresponding to fluid, solid and near-to-critical conditions at steady state.

The three systems follow very different evolutionary paths, in terms of pressure, shear stress and coordination number (the latter defined as the average number of contacts between all particles). The fluid-like behaviour is characterized by large fluctuations in stresses and coordination number, due to the continuous destruction/re-building of multi-particles aggregations, which, even if not spanning the entire domain, contribute to the structure of the system. Conversely, the fluctuations are much smaller when a contact network spanning the entire domain develops in the granular material (solid-like behaviour), since particles are more compacted and cannot easily abandon the own force chain. The fluid-solid transition is characterized by a critical value of the coordination number, independent of the volume fraction.

## REFERENCES

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