ESR5: Steady State Rheology from Homogeneous and Locally Averaged Simple Shear Simulations
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Introduction

Granular materials and particulate matter are ubiquitous in our daily life and they display interesting bulk behaviors from static to dynamic, solid to fluid or gas like states, or even all these states together. The challenge of bridging the gap between the particulate, microscopic picture towards their continuum description (via the so-called micro-macro transition) is one of today's challenges of modern research. An improved rheological model for granules under shearing is proposed for macroscopic friction, volume fraction, coordination number and granular temperature [1]. In addition, the results are compared with the locally averaged data from inhomogeneous steady state shear bands in a split bottom ring shear cell [2] as well as homogeneous volume conserved simple shear and pure shear [3].
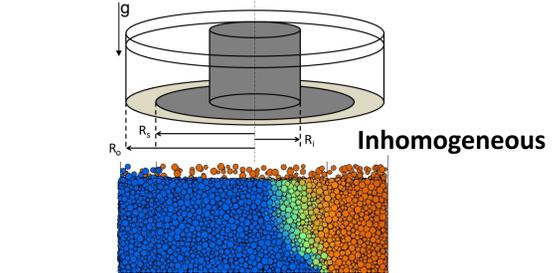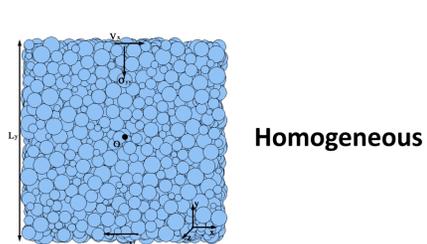
Simulation Methods

Homogeneous

Fig.1. Simulation consider a 3D system of polydispersed particles under normal stress controlled simple shear with Lees-Edwards periodic boundary using MercuryDPM software [1].

Inhomogeneous

Fig.2. 3D Schematic representation of split bottom ring shear cell (top) and side view of shear band formation in the simulation (bottom).

Dimensionless Quantities

- Softness from pressure p: $p^* = \dfrac{p \cdot d_{median}}{k_1}$

- Shear Stress: $\tau^* = \dfrac{\tau \cdot d_{median}}{k_1}$

- Macroscopic Friction: $\mu = \dfrac{\tau^*}{p^*}$

- Inertial Number: $I = \dfrac{\dot{\gamma} d}{\sqrt{p/\rho}}$

Rheological Models

Classical μ-I Rheology [4]:

$$\mu(I) = \mu_0 + \frac{\mu_\infty - \mu_0}{1 + I_\mu/I}$$

Improved and Extended Rheological Model:

$$\mu(I,p^*) = \mu_0 f(I) f(p^*) = \mu_0 \left(1 + \frac{(\mu_\infty/\mu_0 - 1)}{1 + I_\mu/I}\right)\left(1 - \left(\frac{p^*}{p^*_\sigma}\right)^{0.5}\right)$$

$$\Phi(I,p^*) = \Phi_0 f(I) f(p^*) = \Phi_0 \left(1 - \frac{I}{I_\Phi}\right)\left(1 + \frac{p^*}{p^*_\Phi}\right)$$
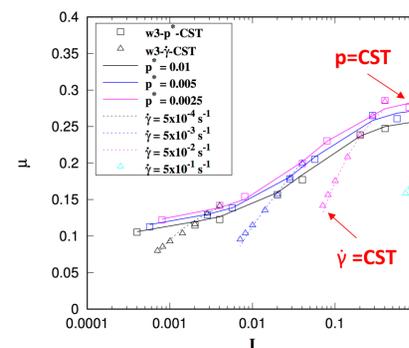
Results

Fig.4. Macroscopic friction, μ, plotted against inertial number, I, using stress controlled simple shear. Two paths are chosen here: (i). softness p^* = constant, vary shear rate $\dot{\gamma}$; (ii). $\dot{\gamma}$ = constant, vary softness p^* as shown in the legend, different colors refer to different shear rates or confining stresses. The inter-particle friction μ_p = 0 and polydispersity w = 3. Lines are the fitting using our extended model.
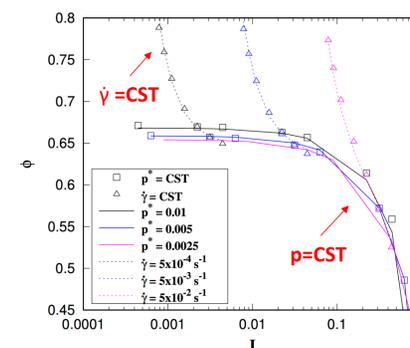

Fig.5. Bulk density (volume fraction), ϕ, plotted against inertial number, I, using stress controlled simple shear for inter-particle friction μ_p = 0.01 and polydispersity w = 2 (in order to match the initial particle size distribution as in [2] for comparison). The same paths are chosen as in Fig. 4 and lines are the fitting using our extended model.
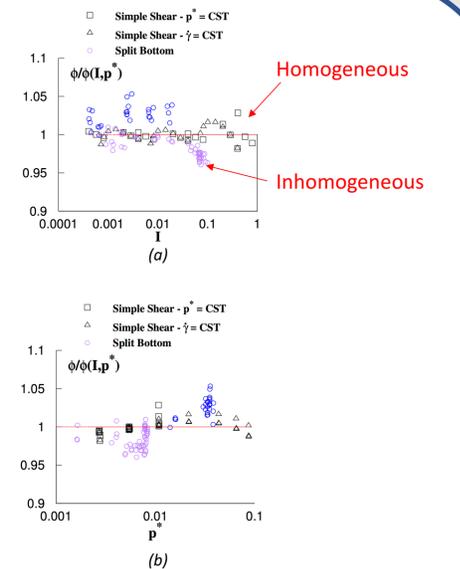

Fig.6. Quality factor using actual data divided by fitted $\phi(I,p^*)$ function viewing from two dependencies: (a) inertial number, (b) softness. Simple Shear (homogeneous, black) are compared with the center of shear bands in split bottom ring shear cell (inhomogeneous, color). Different colors for split bottom shear cell data refer to the low softness ($p^*< 0.01$, purple) and high softness ($p^* > 0.01$, blue) respectively.

Conclusion & Future Challenges

- In low to moderate inertia regime ($I < 0.1$), our improved and extended rheological model is able to describe the rheological behavior in a 3 variables space.

- Good agreements between globally averaged homogeneous simple shear data and locally averaged inhomogeneous split bottom ring shear cell data.

- Further verification/improvement of our extended model on the coordination number C and granular temperature T is needed.

References

[1] Shi, H., Luding, S. and Magnanimo, V. (2017) Steady state rheology from homogeneous and locally averaged simple shear simulations. in Powders & Grains 2017, submitted.
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[4] Jop, P., Forterre, Y., & Pouliquen, O. (2006). A constitutive law for dense granular flows. Nature, 441(7094), 727-730.