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Numerical Simulation of Sand-Air Mixtures for the Casting Industry.

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ABSTRACT

Sand cores are widely used in the casting industry for casting complicated machine parts. They are produced by shooting a pressurized sand air mixture with high velocity in a core box, which has to be filled as homogeneously as possible. To obtain a homogeneously filled form, vents have to be drilled at appropriate positions in the core box to avoid blocking of the sand flow e.g. due to compressed air pockets. Simulation of the whole core shooting process will help to find the optimal positions for the vents depending on the geometry of the core box and the properties of the sand. During the process the dynamics of the sand-air mixture covers the whole range from rapid granular flow of the very compressible sand-air mixture to diffusion of compressible air in a nearly jammed sand geometry. For being able to cover the whole range of complex dynamic behavior of the sand-air mixture we used a nonlinear hydrodynamic modeling approach for the sand phase[1] and coupled the sand dynamics to the compressible Navier Stokes equation for air. The sand model is a hybrid model which combines results from kinetic theory of rapid granular flow with ansatzes from soil mechanics for dense slow flows. It reproduces known results from granular dynamics as e.g. dilatancy, existence of shear bands and solid like behavior. We consider the air phase to be isothermal and describe it by the general balance equations for mass and momentum, ie.

$$\frac{\partial \rho_a}{\partial t} + \nabla \cdot (v_a \rho_a) = 0, \tag{1}$$

$$\frac{\partial \rho_a v_a}{\partial t} + \nabla \cdot (\rho_a v_a v_a) = -\nabla p_a - \nabla \cdot (\eta_a \kappa_a) + \rho_a g - \beta(v_a - v_s), \tag{2}$$

where ρ_a, v_a, κ_a and p_a denote air density, velocity, rate of deformation tensor and pressure respectively. β is an effective friction coefficient, which depends in general on the local sand volume fraction and the particle Reynolds number. The system is closed with the ideal gas constitutive relation. The equations describing sand phase consist of the conservation of mass and momentum as well as an equation for the granular temperature, which quantifies the degree of fluctuations in the sand grain motion.

$$\frac{\partial \rho_s}{\partial t} + \nabla \cdot (v_s \rho_s) = 0, \tag{3}$$

$$\frac{\partial \rho_s v_s}{\partial t} + \nabla \cdot (\rho_s v_s v_s) = -\nabla p_s - \nabla \cdot (\eta_s \kappa_s) + \rho_s g + \beta(v_a - v_s), \tag{4}$$

$$\rho_s \left(\frac{\partial c_p T}{\partial t} + \nabla \cdot (c_p v_s T) \right) = -\nabla \cdot (\lambda \nabla T) + \eta_s \kappa_s : \kappa_s - \epsilon \rho_s T, \tag{5}$$

where ρ_s, v_s, κ_s, p_s and T denote sand density, velocities, rate of deformation tensor, pressure and granular temperature respectively. Equations (3-5) are closed with constitutive relations for c_p, η_s, λ and ϵ. The friction term $\beta(v_a - v_s)$ term appears with the opposite sign in the sand momentum equation to guarantee conservation of the total momentum. This term is responsible for the coupling of (2 and 4). We use a finite volume method to solve for air phase, as well as for sand phase. Equations (1, 2) are solved via pressure correction method for compressible flows [2]. The sand phase equation (3,4,5) are solved for ρ_s, $\rho_s v_s$ and T simultaneously. Due to diverging sand viscosity at sand concentrations close to random close packing, we treat the viscous term in (4) implicitly. Also time derivative contributions, the βv_s contribution from the coupling term in (4), as well as $\epsilon \rho_s T$ from (5) are discretized implicitly. All other terms are taken explicitly from the previous time step iteration. In the solution method we use a decoupled approach, that means that the problem is solved in two stages. The first stage involves solution of the air phase and the second one involves the solution of the sand phase within one time step. The model used in this work has been validated against experimental results. It has shown qualitative agreement for sand distribution during the filling process. One of the validations is presented in Figure 1, where we show the sand distribution in a simple core geometry [3]. In both simulations the same inflow sand and air velocities have been taken as inlet boundary condition. The difference lays in the vent location (indicated with arrows), ie. in the left plot vents are located symmetrically while in the right figure all left vents has been closed. The obtained results for the core shooting experiment shown in Figure 1, are consistent with the findings of the experiment in [3].

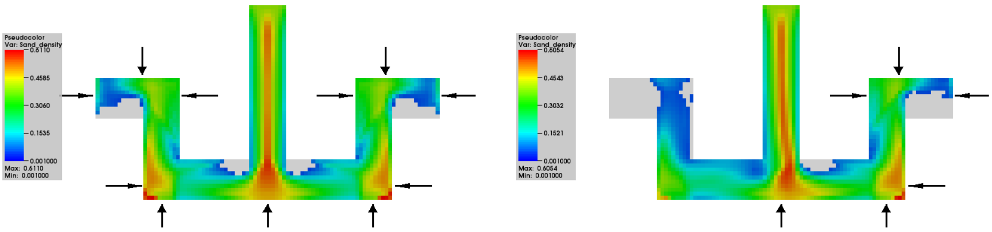

Figure 1: *Plot of sand distribution for a core shooting experiment with 11 vents open (left figure) and with all left vents closed (right figure). The arrows indicate the vent position. The results are consistent with the result of experiments [3].*

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