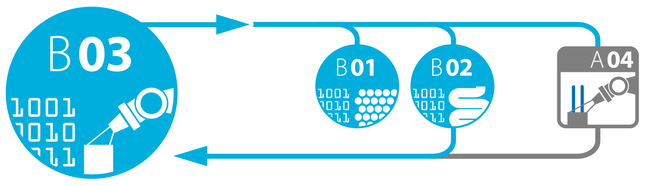
Modelling and Simulation of Shotcrete 3D Printing (SC3DP) Based on a Massively Parallel Multi-Phase, Multi-Component Coupled LBM-DEM Approach

Prof. Dr. Manfred Krafczyk
Jun. Prof. Dr. Martin Geier

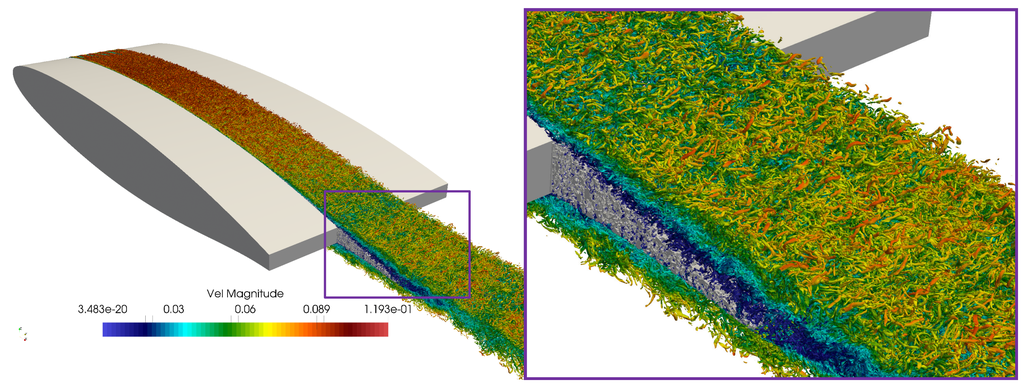
Institute for Computational Modeling in Civil Engineering, TUBS

Summary



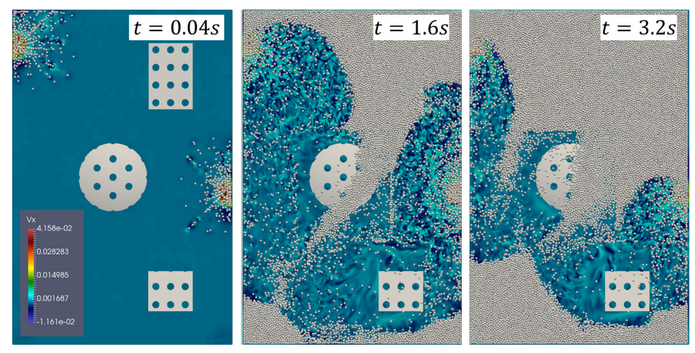
In this project we will develop a coupled simulation approach for the shotcrete process to predict the performance of a specific shotcrete nozzle geometry and the resulting jet dynamics as a function of the additive mixing within the nozzle and during the jet propagation. The model includes multiple components and phases as well as individual grains which are being advected with the mixture. A realistic stress-strain relationship will be developed to recover the correct non-Newtonian behaviour of the mixture including its thixotropic properties. The fully coupled simulation will serve to predict the behaviour of the shotcrete printer to be developed in A04.

Preliminary Work



The high performance computational fluid solver *VirtualFluids* is based on the cumulant lattice Boltzmann method (CLBM). It is developed for LES/DNS simulations of highly turbulent flows at high resolution. Due to its fourth order convergence, block structured grid refinement and its excellent parallel scalability on high performance computers, very challenging problems can be studied in unprecedented detail. The picture shows a wall resolved LES of a wing section at Reynolds number 1 000 000 including a fully resolved porous trailing edge.

Phase field models are used to simulate multi-phase flow. The picture shows the atomisation of a liquid jet. The applicants' conservative Allen-Cahn model overcomes the mass loss observed in the earlier Cahn-Hilliard models.



VirtualFluids can be coupled to a particle solver to capture the motion of solids interacting with the fluid. The picture shows snap shots of the simulation of an industrial filling process using up to 70000 spherical particles. The solid and the fluid are coupled via explicit momentum exchange requiring no inner iteration or implicit solvers.

Research Questions

- How homogenous is the mixing of the cement past within the accelerator and how can homogeneity be improved?
- What is the distribution of cement, solid fraction and air in the atomizing jet?
- What are droplet size distribution and the distribution of kinetic energy at impact and how do they spread over the jet's radius?
- How to model the high density ratio between air and cement in the atomising jet?
- How does the thixotropy of the cement paste influence the atomization?
- Is a meaningful simulation of the shotcrete process feasible?
- How to sustain a diffuse phase interface in the presence of turbulence?
- Can a model of such complexity be validated and verified to guarantee accuracy and convergence?

Methods

- Constitutive relations between stress and strain are incorporated via variable relaxation rates.
- The thixotropy of the cement paste is modelled by an advection-diffusion equation tracing the deformation history of the cement.
- A velocity-pressure formulation for the two phase problem is expected to overcome the density ratio restriction of current momentum pressure approaches. This can be combined with a velocity filter to sustain stability for high Reynolds numbers.
- An efficient coupling between solid particles and the fluids will be realized through an immersed boundary formulation (IBM).
- All model components as well as the coupled model will be verified as second order convergent.

Concept