STATIK DYNAMIK

RUB

COMPUTATIONAL MODELING OF EXTRUSION-BASED 3D-CONCRETE-PRINTING PROCESSES

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The flow mechanisms during the fabrication of components with 3D-concrete-printing (3DCP) have a strong influence on the printed layer shape and fiber orientation, and thus dictate the quality of the final product. This thesis is devoted to the development of computational tools for 3DCP processes to analyze layer shapes, deformations, forces and fiber orientation states on the scale of a few layers for fresh concrete during the first tens of minutes after deposition. The development of the computational tools and the conducted numerical investigations are organized in three parts:

The first part of the thesis focuses on the analysis of extrusion and deposition processes using the Particle Finite Element Method (PFEM) with a viscoplastic regularized Bingham formulation to model the response of fresh concrete. The proposed computational model is validated by comparing the simulated shapes of one printed layer with experimental results. Further parametric studies reveal the influence of the process parameters on the layer shapes and the forces acting on the substrate. Results indicate that the forces generated under the extrusion nozzle during printing are several times larger than the self weight of a layer and can lead to deformations in the substrate. The Bingham model used in the first part of the thesis is unable to accurately predict the deformations in substrate layers, which can result from plastic and also elastic strains, and a more sophisticated material formulation is required.

The second part of the thesis is dedicated to the development of a thermodynamically consistent elasto-viscoplastic constitutive model for fresh and aging concrete based on a multiplicative split of the deformation gradient. A novel evolution equation for the "age-induced" strains is derived, allowing the adoption of a hyperelastic potential with evolving elastic constants to account for structural build-up. A convenient stress update scheme is derived and implemented in a computationally more efficient edge-based smoothed PFEM model. After validation using the same experiment as in the first part of the thesis, simulations of multiple printed layers were carried out to analyze the layer shapes, forces and deformations in substrate layers. The proposed constitutive model represents the first step towards a unified constitutive formulation that can be used for any concrete age and production step. The adoption of fibers in 3DCP improves the performance of the printed components significantly.

The third part of the thesis is attributed to the development of a fiber orientation model to analyze the flow-induced fiber orientation during printing. The model is based on a probabilistic representation of the fibers and an anisotropic Bingham constitutive model. A novel PFEM implementation of this model is presented and validated with experimental results from the literature of a fiber-reinforced 3DCP process of one printed layer. Further parametric studies show that the fiber orientation state, to some extent, can be controlled by the process parameters.

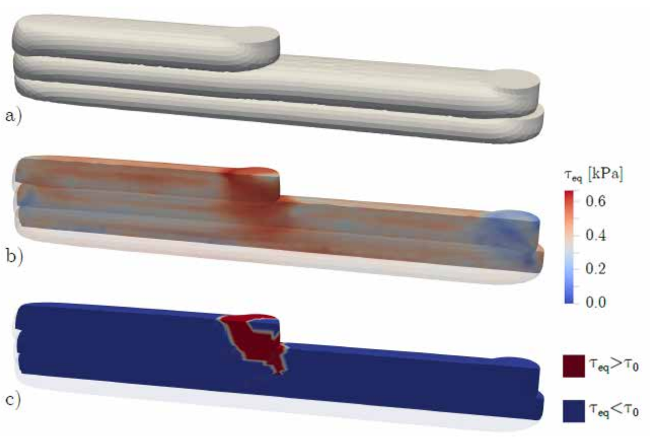

Fig: 3D-concrete-printing simulation of three layers during the time instance when printing the third layer. a) Side view on the printing process. b) Equivalent Kirchhoff stresses on the symmetry plane of the printed layer. c) Yield criterion on the symmetry plane of the printed layer.

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