Particle Finite Element Simulation of Extrusion Processes of Fresh Concrete during Additive Manufacturing

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ABSTRACT

The trend of additive manufacturing, initiating in mechanical engineering and related industry sectors, has recently also found interest in the construction industry. Different techniques with high-performance concretes and mortars are under development, that allow for accurate and automated construction of complex concrete structures and components. Most of these manufacturing techniques can be categorized into selective-binding-like and more common extrusion-like techniques. Through the time dependent behavior of (fresh) concrete and uncertainties in machine and process parameters, properties of fabricated concrete structures are much more dependent on the manufacturing process as compared to conventional casting methods. Hence, numerical models can assist to understand the complex interactions between the printing process and the evolution of material and structural properties during the fabrication processes.

Accordingly, a numerical framework for the extrusion process in layered extrusion based additive manufacturing of cementitious materials is presented. Governing equations, like the balance of momentum and mass, are solved via the Particle Finite Element Method (PFEM) [1]. In PFEM the underlying equations are discretized by finite elements in an updated Lagrangian formulation, so that nodal positions are updated in each time step. In order to deal with large deformations and element distortions, the domain is frequently re-meshed every couple of time steps. Therefore, robust and fast re-meshing using triangular and tetrahedral elements in two and three dimensions, respectively, is fundamental.

From the family of non-Newtonian fluid models, the flow of homogenized fresh concrete is commonly described by the Bingham model. For these types of yield stress fluids, a certain yield stress must be exceeded to initiate viscous flow. The standard approach for modeling this behavior is based on regularized models, in which the regime below the yield stress is approximated with a large viscosity. These models have the advantage that no internal variables must be stored. A drawback of these method, however, is, that stresses at rest are still viscous and the material never really comes to rest. Consequently, a classical elasto-viscoplastic model is used to approximate the material behavior of fresh concrete. While the stresses below the yield stress are elastic, the stresses during yielding are approximated with an overstress function [2]. Hence, when the material is at rest, stresses can be assessed more accurately, which is important for analyzing initial stress states of additively manufactured concrete structures.

The presented numerical model is verified with different benchmark tests. In numerical examples of extrusion based additive manufacturing of fresh concrete, the effect of essential parameters is analyzed.

REFERENCES

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