Influence of Material Microstructure and Processing Characteristics on Extrusion-Based Printing: Linking Experiments and Modeling

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Abstract

The complexities and variabilities associated with cement-based materials pose real challenges in the layered extrusion process which is the most common method for 3D printing of cement-based materials. From a binder rheology standpoint, it is imperative that the material should flow cohesively though the extruder, but at the same time, be able to "set" fast enough once extruded so that it can maintain its shape and carry the weight of the overlaid layers. This requires control of particle shapes and sizes capable of retaining paste cohesion to enable flow as well as yield stress development, and adequate chemical reactions. Moreover, the processing techniques also influence the rheology – yield stress is a function of the compacting pressure that the paste is subjected to while being extruded, the geometry of the extruder, the surface roughness of the container walls etc. The efficiency of printing, thus is a function of a number of materials and processing related parameters, knowledge of which is essential in successful digital fabrication of cement-based binders.

Characterization of paste flow is important in ensuring rheological control during printing. The interaction between the rheological characteristics and processing parameters are better studied through a combination of experimental and simulation tools. For fresh pastes and concrete, discrete element method (DEM)-based simulations are appropriate to provide insights into the particle scale processes occurring during extrusion-based printing, and to relate them to the macro-scale response of the entire system. In this paper, we model the extrusion process of a plain ordinary Portland cement (OPC) paste using DEM, and outline the methodology adopted to evaluate the linkage between particle scale processes and extrusion process. An analytical model for a frictional plastic material undergoing ram extrusion is also used in conjunction with the DEM model to arrive at the yield stresses and shaping stresses that enable efficient extrusion process, as a function of the material microstructure.

Biosketch:

Narayanan Neithalath is a Professor in the School of Sustainable Engineering and the Built Environment at Arizona State University, Tempe AZ, USA. He obtained his Ph.D from Purdue University in 2004, specializing on cement-based materials. His research interests include materials science of infrastructural materials (cement and concrete), novel materials and systems for structural and functional performance in buildings and infrastructure, mechanics of Materials, and computational modeling and simulation of material performance. He has published more than 125 papers in peer-reviewed journal publications, and more than 150 papers in refereed conference publications. He is a Fellow of the American Concrete Institute (ACI) has received several awards for his research including the prestigious American Society of Civil Engineers' Walter L. Huber Civil Engineering Research Prize. He is the section editor for the ASCE J of Materials in Civil Engineering and an Associate Editor of Cement and Concrete Composites.