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A PARTICULE FLUID DYNAMICS MODELLING APPROACH TO DESIGN 3D CONCRETE PRINTING MATERIALS AND PROCESSES

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Abstract. The development of 3D-printable concrete is a multifaceted challenge, requiring careful tuning of both material and process parameters to ensure successful fabrication. This study proposes an integrated methodology that combines experimental testing, numerical modeling, and data-driven techniques to systematically optimize the printability of cementitious composites, with a focus on improving control and quality of the layer geometry. The process begins with an initial rheological assessment of the selected mix, performed in the laboratory using the flow table test, a rapid and practical method for estimating key rheological properties, particularly static yield stress. To investigate how key rheological properties, such as static yield stress and plastic viscosity, interact with process parameters including nozzle diameter, nozzle height, printing speed, and extrusion velocity, a series of numerical simulations were carried out using an in-house developed code. The tool is based on the Particle Finite Element Method (PFEM) and has been previously validated across various 3D printing scenarios, demonstrating both accuracy and computational efficiency in simulating extrusion and layer deposition processes. The code enables systematic variation of both material and process parameters to predict the resulting filament geometry with high fidelity. Simulation results have been consolidated into a prototype design chart and a generalized, dimensionless map that classifies possible filament cross-sections into five distinct printing regimes: quasi-Newtonian flow, round deposition, spread deposition, filament tearing, and layer-pressing. Once the optimal material and printing parameters are identified, a carefully designed Artificial Neural Network (ANN), trained on diverse datasets compiled from existing literature and encompassing a wide range of concrete mixtures, is employed to bridge the gap between rheological performance and potential mix design constituents and dosages.

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