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Computational modelling and characterization of non-Newtonian visco-plastic cementitious building materials

Mareike Thiedeitz[1], Jithender J. Timothy[2] and Thomas Kränkel[3]

Technical University Munich, Centre for Building materials,
[1] mareike.thiedeitz@tum.de, [2]jithender.timothy@tum.de, [3]thomas.kraenkel@tum.de

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Cementitious building materials like Ultra High Performance concrete (UHPC), Self-Compacting Concrete (SCC) or concrete with low clinker content (Green Concrete) possess a complex rheological behaviour due to high packing densities and the use of various additives and chemical admixtures. Existing rheological models such as the visco-plastic BINGHAM or HERSCHEL-BULKLEY model do not fit the actual flow behaviour of strongly non-Newtonian cementitious materials: Depending on the paste mix design of a concrete, a huge range of non-Newtonian flow characteristics from shear-thinning to shear-thickening and visco-elastic material behaviour can appear. Computational modelling of transient concrete flow therefore requires accurate knowledge of the rheological properties, followed by a meaningful choice of both the rheological model for computational fluid dynamics simulation (CFD) and the associated boundary conditions. The authors present a test program of four cementitious pastes with low ($\phi = 0.45$) and high ($\phi = 0.55$) solid volume fraction ϕ each with low and high flowability. A rheological analysis will serve as input for the numerical modelling of concrete flow. CFD analysis using OpenFoam is conducted for a mini-L-Box test using the yield stress function incorporating BINGHAM- and HERSCHEL-BULKLEY equations and viscosity-related Cross- and adapted shear-thickening equations. Experimental mini-L-Box tests are compared with CFD results. With increasing non-Newtonian behaviour, numerical instabilities and deviation from actual flow behaviour is shown. This is especially valid at the transition from visco-plastic to visco-elasto-plastic material behaviour. The results provide new insight into computational modelling of complex cementitious building materials and serves as basis for further advanced CFD based modelling and characterization of time-dependent non-Newtonian concrete flow.