Abstract

Improved understanding of the rheology of fresh concrete can help optimize its flow properties. This thesis presents a comprehensive Discrete Element Method (DEM)-based framework for analysing the flow behaviour of fresh concrete. The focus is on the effect of meso-geometric features such as particle size and shape, and meso-material properties such as bond strength and damping. The critical role of the material fabric in determining flowability is examined. A meso-structure-based yield stress is proposed to address the shortcomings of existing analytical/empirical relations. The meso-structure-based yield stress is seen to be invariant with respect to specimen size and test type, and shows good agreement with experimentally determined yield stress values. This is seen to be true for stiff as well as highly flowable concrete mixes. Next, the influence of material fabric on slump flow is investigated. This study reveals the critical role of fabric anisotropy in controlling the rate of flow. The findings suggest the existence of two distinct flow regimes: a fabric-dominated flow regime and a momentum-dominated flow regime, with the two demarcated by the peak in the fabric anisotropy history. To further analyse the meso-mechanics governing flow, the meso-structural stress is decomposed into isotropic and anisotropic components. This enables the fabric-dependent stress tensors that control the mobilization of pre-peak anisotropy to be identified. It also enables the determination of the fabric-dependent stress tensors that exert a dominant influence on the yield stress. In the final phase of the study, a meso-structure enriched constitutive model for fresh concrete is developed. This requires a procedure to compute the meso-structural strain from the DEM results. A mesh-free Smooth Particle Hydrodynamics (SPH) based approach is adopted, which enables accurate computation of the meso-structural strain despite the very large deformations that occur during slump flow. The meso-structure-enriched constitutive model is then used to yield insights on the role of meso-geometry and meso-material properties in determining the macro flow parameters. It also helps elucidate the mechanism responsible for the variable effect of viscosity-modifying agent (VMA) dosage on viscosity and yield stress of self-compacting concretes. Overall, the thesis establishes that meso-scale analysis provides a rich fund of information on the processes that determine the flowability of fresh concrete. It also suggests that further work resulting in automation of the calibration procedure can enable the use of the proposed modelling framework for determining optimum design mixes for high-performance self-compacting and 3D printed concrete.