Modelling the effect of concrete cement composition on its strength and failure behavior

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ABSTRACT

Typical concrete is a mixture of Portland cement (20 wt%), water (10 wt%), and aggregates (70 wt%). While all these constituent phases affect the concrete strength and fracture behavior, the focus of the present study is on the hardened cement paste, which can be further divided into the unreacted core, inner and outer products.

In high strength concrete water-to-cement ratio is low, and thus the distance between cement particles is small. Also, the amount of unreacted (high strength) core is higher, and the porosity is low. When water-to-cement ratio is higher, both the distance between cement particles and the porosity due to capillary pores increases.

In the present study, we develop a numerical model to predict the effect of the water-to-cement ratio on the compressive fracture behavior of concrete. We assume that the three subphases of the hardened cement paste can be represented, for purely mechanical purposes, as a linear elastic fracturing material, where the fracture is described by the embedded discontinuity finite elements. The unreacted core and the inner reaction product, modelled as a strip of finite elements surrounding the core, fail according to the first principal stress criterion. Upon its violation, a discontinuity (crack) with a normal parallel to the first principal direction is introduced in a finite element. The third phase represents both the outer hydration product and the capillary space between cement particles. Therefore, the strength of the third phase decreases with increasing water-to-cement ratio. The failure of the “hairy-like” outer reaction products-is described by pre-embedded discontinuities, three in each triangular element in the mesh, aligned parallel to the element edges. An exponential type of traction-separation law governs the softening behavior of each discontinuity. Representative 2D numerical simulations demonstrate that the present method captures the major features of concrete fracture and, particularly, predicts the known effects of the water-to-cement ratio on concrete strength.

Keywords: concrete fracture, cement-to-water ratio, mesoscopic modelling, embedded discontinuities, finite elements