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Meso-scale computational modeling of the plastic-damage response of cementitious composites

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ABSTRACT

Concrete is considered as a 3-phase composite material; mortar matrix, aggregates, and interfacial transmission zone (ITZ). In order to investigate the contribution of each phase to the strength and damage response of concrete, 2-D and 3-D meso-scale simulations based on a coupled plasticity-damage model are carried out. The aggregates are modeled as a linear-elastic material, whereas the mortar matrix and ITZ are modeled using a coupled plasticity-damage model with different tensile and compressive mechanical behavior. Aggregate shape, distribution, and volume fraction are considered as simulated variables. The effect of the ITZ thickness and the strength of the ITZ and mortar matrix are also evaluated. It is shown that the behavior of concrete is merely dependent on the aggregate distribution and the strength of the mortar matrix, but dependent on aggregate shape, size, and volume fraction, and the thickness and strength of the ITZ.

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1. Introduction

Concrete can be considered as a three-phase composite material consisting of mortar matrix, aggregate, and interfacial transition zone (ITZ) between the aggregate and the mortar matrix. However, the majority of the conducted research on the inelastic and damage behavior of concrete materials and structures has been focused on treating concrete as a homogeneous material at the macroscopic scale which did not allow one to establish the microstructure–property relationship for designing better and superior fracture-resistant cementitious materials. Micromechanical modeling of the inelastic and damage behavior of each phase in the concrete material is not a trivial task since: [1] the properties of the ITZ, which plays a very important role in the concrete fracture behavior, are not easy to be measured experimentally; and [2] the computational cost is very high. However, due to the recent advances in understanding the chemical composition, thickness, and strength of the ITZ and the developments in computational power, one can effectively simulate the micromechanical behavior of concrete materials in order to get insights about the effect of various microstructural features (e.g. aggregate size, shape, gradation, and distribution, ITZ thickness and mechanical properties, the mortar mechanical properties, etc.). This will ultimately guide the design of better and superior fracture resistant concrete materials and structures. Therefore, this study is focused on conducting such a desirable micromechanical study using a recently developed coupled plasticity-damage model by Cicekli et al. [12].

The mesoscopic level analysis considering concrete as a composite material is the most practical and useful method for evaluating the composite behavior of concrete. The process of the mesoscale analysis can be categorized mainly into two steps. First step is to generate the 2-D or 3-D particles taking into account the shape, distribution, and volume fraction of aggregates, and second one is to perform a simulation with FE software applying constitutive models to each phase. The generation of the particles is one of the important research topics, and several modeling techniques have been proposed: [1] the random two-dimensional natural shape aggregate model [50]; [2] the random particle model [6]; [3] the beam lattice model [37,44]; [4] the random packing particle model [16]; and [5] the beam-particle model [53]. Although there is no doubt that the various particles generation techniques proposed until now made great progress to the simulation for concrete on mesoscopic level, the generation of the realistic 3-D random distributed actual shape of aggregates model is still a challenging task.

The random two-dimensional natural shape aggregate model proposed by Wittmann et al. [50] is a more realistic mesoscale analysis model than a circular shape aggregate model. The model, however, has a weak point that aggregates are generated one by one. Therefore, an advanced arbitrary shape aggregate generation algorithm, such as the Monte Carlo random sampling principle is proposed from a decade ago in order to overcome this shortcoming [15,22,49]. However, the important micromechanical properties, such as aggregate volume fraction was not included in their papers. The beam lattice model was widely adopted by several researchers in order to investigate the effect of the micromechanical properties on the tensile behavior of concrete [18,21,24–30,37]. Although concrete can be considered as a 3-phase particulate composite, and simplicity is one of the advantages of this

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