Mesoscale modeling of high-performance fiber-reinforced concrete under monotonic and cyclic loading

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Concrete is one of the most commonly utilized building materials and has a significant environmental impact due to the high energy needed for cement production. Over the past decades, significant progress has been made in developing high-performance and ultra-high-performance concretes and incorporating fiber reinforcements in structural concrete resulting in material savings and improved durability.

However, to fully realize the potential benefits, better models and design approaches must accompany these material improvements. This work focuses material behavior aspect of fiber-reinforced high-performance concrete, investigating damage processes and mechanisms occurring at small scales, which are not readily observable during loading tests. To this end, it presents a framework for generating mesoscale concrete models based on virtually created aggregate and fiber distributions [1], as well as from Computational Tomography (CT) images. A finite element model utilizing zero-thickness interface elements is applied to simulate the fracture behavior of mesoscale specimen models. The zero-thickness interface elements are equipped with a cohesive-frictional traction-separation law that includes dilatancy due to aggregate interlocking and a model for hysteresis occurring due to incomplete crack closure during loading-unloading cycles. The steel fibers are considered explicitly and modeled as elastoplastic Timoshenko beam elements. The 3D elastoplastic constitutive law with isotropic and kinematic hardening is adapted for beam elements by iterative solution of zero stress constraints via Newton's method [3]. The embedment of fibers into the cement matrix is facilitated via a penalty-based tying algorithm that enables flexible placement of fibers without needing to conform with the background mesh. The bond between the cement matrix and fibers is modeled via an elastoplastic bond-slip law proposed in [2], whose parameters are calibrated based on single-fiber pullout experiments. All model components are implemented into the open-source Finite Element program ”Kratos Multiphysics” [4].

The capabilities of the proposed model are demonstrated by reanalyzing several experimental scenarios, such as notched prismatic specimens under uniaxial tension [5], small cylinders under uniaxial compression, and fiber-reinforced high-performance concrete beams under three-point bending and comparing results with the available experimental data.

The presentation is closed with a discussion of implementation, the benefits and limitations of the proposed modeling approach, and potential ways to improve the model further.

References

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