Computational modeling of damage evolution in concrete due to cyclic loading

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ABSTRACT

Concrete is an archetypal quasi-brittle material that is characterized by a finite-sized fracture process zone (FPZ) in which various damage and toughening mechanisms play a significant role on crack development and propagation. According to Ritchie [1] these toughening mechanisms can be classified as *intrinsic* or *extrinsic* mechanisms. *Intrinsic* mechanisms are only material dependent, and thus independent of the geometry and size of the analyzed specimen. *Extrinsic* mechanisms on the other hand depend on the size of existing defects and the size and geometry of the specimen. *Intrinsic* mechanisms act in front of the crack tip and govern crack initiation and promote crack advance, whereas *extrinsic* mechanisms act mostly in the crack wake and retard crack propagation. In quasi-brittle materials such as concrete, extrinsic toughening mechanisms such as crack deflection and meandering due to the presence of large heterogeneities, contact shielding i.e., wedging due to debris and crack-roughness induced crack closure, crack face bridging due to tough aggregates and unbroken ligaments, crack trapping and pinning etc [1,2] are mostly governing fracture evolution. In cyclic loading these mechanisms play an even more important role, as their influence on overall degradation evolves with the number of cycles (e.g., the crack surface roughness decreases due to frictional sliding between crack faces, the traction carried by bridging ligaments decreases due to repeated loading and unloading etc.). Furthermore, during cyclic loading, many micro-cracks open but fail to completely close in unloading due to debris and roughness of the micro-crack surfaces. This generates residual stresses that accumulate and may contribute to additional damage [3]. Moreover, it is important to note that the loading conditions also play a dominant role in the degradation of concrete due to cyclic loading. As noted in Breitenbcher and Ibuk [4], the upper load limit K_{max} plays a decisive role in the evolution of deterioration process in comparison to the range of cyclic loads ΔK that is decisive in damage evolution in ductile materials. In order to accurately model these physical processes, a mechanistic material model based on experimental observations is proposed. To this end, we take as a starting point, a numerical model for damage and aggregate interlock in concrete [5]. This model captures ligament bridging and aggregate interlock in shearing by means of a cohesive law coupled with the crack-closure transition function. Moreover, under cyclic loading, especially when many cycles are considered, additional weakening of these bridging ligaments occur. As shown in numerous experiments, this weakening mechanism manifests itself through hysteretic behavior during loading and unloading. We enhance the model proposed by Jefferson and Mihai [5] by incorporating the effect of loading-unloading hysteresis that characterizes the physical mechanism of the polishing of crack surfaces due to repeated friction and weakening of the bridging ligaments. Within the scope of this contribution, we present selected numerical experiments on degradation of notched concrete prisms under monotonic and cyclic loading. Model predictions are compared with laboratory measurements.

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