Concrete fatigue modeling and experimental characterization based on inter-aggregate cumulative sliding hypothesis of degradation

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A physically rigorous modeling of fatigue-induced degradation processes in the material structure of concrete is a paramount requirement for a significant improvement of existing, empirically based design concepts, particularly for reinforced concrete structures. In our recent work, we introduced a dissipative hypothesis ascribing the key fatigue driving degradation mechanisms to a cumulative measure of inter-aggregate shear strain. The hypothesis leads to a new formulation of a pressure-sensitive interface model [2], that can be embedded both in a discrete model of a material zone or in a tensorial formulation of a microplane model. An example of a microplane formulation (MS1) [3] including cumulative sliding as a dissipative mechanism has been introduced, showing the ability to capture the fatigue-induced tri-axial stress redistribution in the concrete material structure subjected to pulsating subcritical load.

To isolate the dissipative mechanisms and to validate the model, test configurations with controllable levels of combined compression and shear fatigue load are needed to cover the design-relevant range of stress configurations in a more appropriate way than the standard cylinder test. Alternative test setups have been developed recently, introducing a modified punch-through shear test (PTST) [1]. The combined experimental and numerical studies cover a wide range of stress configurations in the test ligament of the axi-symmetric punch-through shear test. The simulation with two different fatigue load amplitudes predicted larger number of cycles to failure for the lower amplitude, qualitatively complying to the Wöhler (S-N) curve of concrete.

Due to the thermodynamic formulation of the constitutive model, the energy breakdown of the individual inter-aggregate dissipative mechanisms could be quantified for a uniform shear fatigue loading at varied levels of confinement [4]. These studies reveal that plastic energy dissipation increases for lower fatigue amplitudes of the fatigue load leading to longer fatigue life, while damage dissipation remains nearly constant for loading scenarios with different amplitudes. Such conclusions stimulate the development of engineering design concepts that can realistically capture the fatigue life of high-performance reinforced concrete structures.

In addition to the uniform fatigue shear loading, also the effect of variable load amplitude has been studied and interpreted using the model MS1. Both experimental and numerical results have shown that the currently used Palmgrem-Miner design rule is not realistic, and needs to be refined to deliver reliable predictions of structural lifetime.

Besides the smeared representation of the dissipative process using the microplane model MS1, a discrete model employing the same inter-aggregate dissipative hypothesis will be presented, providing the possibility to study the localization processes and energy dissipation patterns due to fatigue loading within a representative dissipative process zone. A possibility to establish an energetic equivalence between both models will be discussed.

References

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