A multiscale approach to localized damage indicators of a short-fibre reinforced high performance concrete

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ABSTRACT

By using a novel fibre-reinforced cement paste recipe in an additive manufacturing (3d-printing) method, a highly anisotropic material with vastly improved flexural and tensile strength can be created. Extruding the paste through a small nozzle results in unicorn fibre orientation. A fibre content of 3 vol.% results in static flexural strengths of above 100 MPa. High-strength fibre reinforced materials have great potential to be used as small, lightweight construction elements. In order to assess the service life and to be able to understand failure mechanisms, a combined experimental–simulation approach is necessary.

Structural members often show susceptibility to oscillating dynamic loads. Using a dynamic-mechanical analyser, miniature samples with a cross-section of 3 mm $\times$ 3 mm can be tested for their resistance towards cyclic loading in tests of up to 10 million cycles. Using an ex-situ method, micro-CT scans and optical microscopy are used to check for cracking and other damage indicators.

To investigate the tensile fatigue behaviour on macro scale, bone-shaped specimens under pulsating tensile stress with a cross section area of 50 mm $\times$ 50 mm are examined. In addition to standard methods, i.e. strain gauges, strain sensors and position sensors, modern and wide-range methods like fibre-optic sensors, photogrammetry (digital image correlation), acoustic emission analysis and ultrasonic based coda wave interferometry are used. The aim is to describe the local macro-crack development.

The numerical simulation of the mechanical behaviour of concrete, which is reinforced by short carbon fibres, requires a multiscale approach taking into account the scale of the carbon fibres besides the specimen scale. Pretests have shown that aggregates and pores do not need to be resolved separately on this scale for this material. Therefore, in the simulation, we consider the macroscopic workpiece and resolve the carbon-fibre scale by representative volume elements (RVE). The computational homogenization approach then requires the determination of the (local) material law in each macroscopic point with the help of the solution of cell problems posed in the RVE at that point. In particular, the macroscopic relation of the deformation gradient ∇u and the stress tensor σ is determined by averages of quantities determined in the RVE leading to a numerical material law of the form $\sigma = f(\nabla u)$, where the mapping f resolves the macro–micro–macro transition and represents the local effective material law. In order to be able to simulate the carbon-fibre-reinforced concrete realistically, the RVEs are taken from micro-CT data. For this purpose, the carbon fibres are identified in typical micro-CT data volume elements. The aspect ratio of the carbon fibres and the fact that they are (more or less) aligned requires the use of long cuboid representative volume elements.

The methods and current results will be presented at the conference.