Mesoscale modelling and experimental validation of lightweight concrete mechanical behaviour

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Abstract

Lightweight concrete (LWC), characterized by its lower density achieved through lightweight aggregates, is an excellent material for improving sustainability in the construction industry. Compared to conventional concrete, LWC production generates fewer greenhouse gas emissions and requires less transportation energy. Constructions using this material may be an eco-friendly alternative to reduce environmental impact without compromising mechanical strength and durability. However, LWC exhibits complex behaviours at microscopic, mesoscopic, and macroscopic scales, requiring advanced analysis for better understanding and complete optimization of its performance.

This study assesses the mechanical performance of LWC at the mesoscopic scale, where it is modelled as a heterogeneous material consisting of mortar and lightweight aggregates. Using a MATLAB script, lightweight aggregates different in diameter are randomly positioned using Representative Volume Elements (RVEs) with the take-and-place method. This random distribution is based on the mix proportions used in the fabrication process of laboratory samples and the granulometry of the employed aggregates. Several geometries are generated to analyse different spherical aggregate distributions on a cubic specimen of 50x50x50 mm. The compressive strength of these geometries is evaluated using the Finite Element Method (FEM). Distinct material properties are defined for the mortar and the lightweight aggregates, applying a combined mathematical concrete model. This nonlinear model incorporates the Drucker-Prager material model for compression stresses and the Willam-Warnke material model for tension stresses to predict cracking and crushing failure modes. The developed numerical approach is validated with laboratory compression tests.

This advanced mesoscopic numerical model establishes a new methodology to assess LWC mechanical response, including deformation and fracture mechanisms, bridging the gap between mesoscopic and macroscopic scales. The applied hybrid methodology, combining numerical and experimental techniques, reduces costs and carbon footprint by optimizing the number of tests. The progressive replacement of laboratory tests by numerical simulations will enhance the sustainability of mesoscopic concrete behaviour studies, leading to more efficient and environmentally friendly research practices in the field.

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