Modelling of damage in 3D printed concrete: the role of interfaces and plasticity phenomena

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Abstract

3D printing of concrete is a promising construction technology, that offers the potential to build geometrically complex structures without the use of costly formwork. The layer-wise deposit of filaments during the 3D printing process results in an intrinsically orthotropic mechanical behavior in the hardened state. The overlapped layers of material can influence not only the overall mechanical properties, but also the failure modes. The presence of interfaces between subsequent layers represents a critical issue, as these areas are weaker than the homogeneous material, making them susceptible to initiation of damage mechanisms. In addition, the material behavior of each deposited filament- as commonly accepted for cementitious materials - is governed by a nonlinear behavior, characterized by irreversible deformations, strain hardening, strain softening and a degradation of the material stiffness. The aim of this work is to propose a numerical model to simulate the mechanical behaviour of 3D printed concrete (3DPC). A plasticity and non-local damage approach is developed to describe the mechanical behaviour of the solid filament. The evolution of the plastic strain is governed by the introduction of a suitable yield function. The stiffness degradation is described by introducing two scalar damage variables: a tensile and compressive damage. In particular, the growth of the compressive damage is governed by the nonlocal value of the accumulated plastic strain, while the evolution of the tensile damage depends on the nonlocal measure of the equivalent elastic strain. To overcome the analytical and computational issues induced by the softening constitutive law, an integral-type regularization technique is adopted. For the interfaces between the 3D printed layers, a cohesive interface law is considered, taking into account unilateral contact, damage initiation, and friction effects. The proposed numerical procedure is implemented in a finite element code.

Moreover, an experimental program has been conducted to investigate the mechanical behavior of 3DPC. Various tests, including compression and shear tests, were performed to characterize the mechanical properties and identify the different damage mechanisms. Furthermore, additional tests were carried out to compare the experimental data with the proposed numerical approach.

Overall, the proposed model provides a computationally efficient modeling approach that could be exploited for large-scale finite element simulations of 3DPC structures.

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