

A Novel Specimen shape for Fracture Characterization of 3D-Printed Hydroxyapatite

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Additive manufacturing enables the fabrication of hydroxyapatite (HA) scaffolds with complex geometries for bone regeneration. Experimental testing provides essential information on effective strength, but the local phenomena leading to fracture are still difficult to observe. Finite element modeling (FEM) equipped with phase-field fracture propagation represents a powerful tool to predict the mechanical performance of brittle porous scaffolds. The reliability of such models, however, strongly depends on accurate material parameters, particularly the critical energy release rate (G_c), which remains poorly documented for additively manufactured HA. Compact tension (CT) testing is widely used to characterize G_c , however, its application at the microscale introduces critical challenges, including displacements too small to be reliably tracked optically and high sensitivity to specimen misalignment and additional compliance introduced by external grips during tensile loading, all of which can reduce measurement accuracy and reproducibility.

In this work, the G_c of 3D-printed HA produced by vat photopolymerization (VPP) is investigated using newly designed miniaturized specimens, necessary for critical-size bone defects. An external frame is integrated within the classical CT specimen, allowing the load to be applied through flat plates in compression, which is then transformed into tensile opening at the specimen midsection via the internal connection between the frame and the crack mouth. FEM was used to optimize the geometry, ensuring efficient load transfer to avoid the need for external grips, such as wires or pins, typically required in classical CT tests. This configuration minimizes misalignment effects and improves experimental reproducibility, as compressive loading can be applied more reliably than tension at small scales. The resulting force-displacement response exhibits linear behavior, suggesting that parasitic deformations associated with external connectors are effectively removed. The experimental response was reproduced numerically using a phase-field, with the 3D printed geometry as model input, thus avoiding possible variation between designed and printed scaffold.

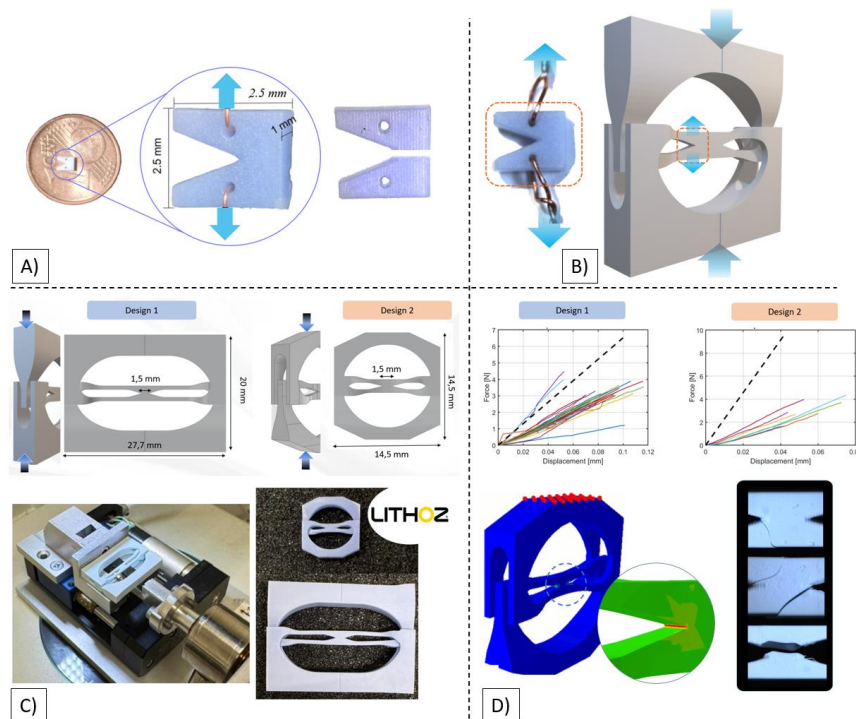


Figure 1. Novel miniaturized compact tension (CT) design. (A) Classical CT specimen scaled to critical-size defects and 3D Printed HA fractured specimen after experimental test. (B) Optimized design featuring an integrated frame to transform external compression into internal tensile opening. (C) Geometries and dimensions of two proposed designs and compression testing setup. (D) Up: Experimental force-displacement curves (colored lines) vs. preliminary linear elastic simulation stiffness (black dashed line). Bottom: FEM stress concentration regions and representative optical images of fracture patterns.