Characterization of the mechanical response of 3D-printed metamaterials under static tensile, compressive and bending loads

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This study examines the mechanical response of additively manufactured metamaterial specimens under tensile, compressive and bending loads. The analysis focuses on how cell orientation and internal topology affect the macroscopic performance of the structures. Two principal geometric concepts of regular lattices were considered (see Fig. 1): auxetic, composed of re-entrant concave cells and conventional, with convex unit geometries. Both variants were analysed in horizontal and vertical orientations of the unit cells.

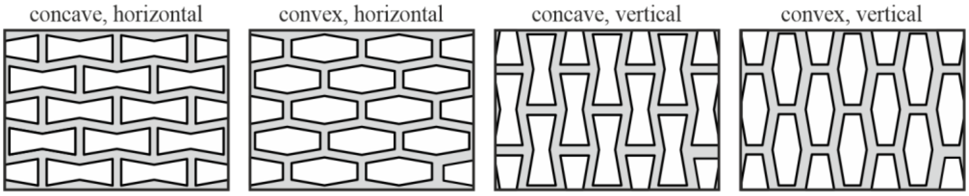

Figure 1. Metamaterial geometry concepts considered in the study.

Comprehensive experimental static tests were carried out using a universal testing machine integrated with a digital image correlation (DIC) system, enabling full-field deformation measurements. Based on the obtained results, a thorough quantitative and qualitative comparison of structural performance was carried out. From the tensile and compression data, effective elastic constants such as the Young’s modulus and Poisson’s ratio were derived, confirming that internal geometry plays a decisive role in tuning metamaterial stiffness. Bending tests further demonstrated that auxetic configurations are particularly sensitive to nonuniform stress distribution. Local damage effects caused by 3D printing imperfections were also observed. To complement the experimental work, numerical simulations of the laboratory tests were performed using the finite element method. The results exhibited good agreement with experimental data, confirming the reliability of the models. The combined experimental and numerical findings highlight the governing influence of geometrical design on the mechanical behaviour of additively manufactured metamaterials and validate the applied methodology as a reliable tool for predicting their load-bearing performance.

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