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PROCEEDINGS

Inverse Design of Multifunctional Shape-Morphing Structures Based on Functionally Graded Composites

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ABSTRACT

Shape-morphing structures exhibit the remarkable ability to transition between different configurations, offering vast potential across numerous applications. A common example involves the transformation from a flat two-dimensional (2D) state to a desired three-dimensional (3D) form. One prevalent technique for fabricating such structures entails strategically cutting thin sheet materials (known as kirigami), which, upon the application of external mechanical forces, morph into the intended 3D shape. A method leveraging the non-linear beam equation has been proposed for inverse design, determining the optimal 2D cutting patterns necessary to achieve a symmetrical 3D shape. Central to this strategy is the manipulation of local bending stiffness.

This paper presents a novel inverse design approach that modifies bending stiffness by introducing distributed modulus within functionally graded composites (FGCs) [1]. To create FGC-based shape-morphing structures, a multi-material 3D printer is employed to fabricate graded composites using voxel-like building blocks. The longitudinal modulus of each cross-sectional slice is controlled via the rule of mixtures, aligning with the required modulus distribution along the elastic strip. Through this framework, a diverse array of structures with varying Gaussian curvatures is generated, validated through numerical simulations and experimental results, showcasing excellent agreement between the morphed structures and their targets.

Furthermore, the compressive rigidity and energy absorption properties of FGC-based hemi-ellipsoidal morphing structures with different aspect ratios are examined numerically and validated experimentally. Systematic numerical simulations illustrate the multifunctionality of modulus-graded shape-morphing composites, including their ability to blend distinct material advantages—such as high thermal conductivity with low electrical conductivity—and vice versa, to achieve combined effective properties within a single FGC structure.

This new inverse design framework opens avenues for creating shape-morphing structures using modulus-graded composite materials, applicable across various domains involving multi-physical environments. Moreover, it underscores the versatility of the approach, facilitating precise control over material properties at a localised level.

KEYWORDS

Functionally graded composites; shape-morphing structures; inverse design; additive manufacturing; multifunctionality

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