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A Multistable Origami-Inspired Magneto-Active Metamaterial

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Abstract

This study presents a magneto-active multistable metamaterial that leverages active-passive magnetic interactions for remote, rapid, and reversible shape reconfiguration. The metamaterial consists of stacked magneto-active layers, each inspired by a thick-panel origami design based on the square twist pattern. The integration of active and passive magnetic interactions facilitates the transition between multiple stable equilibrium states, including a flexible configuration with low stiffness, a load-bearable locked state at self-contact, and a fully unfolded configuration. A comprehensive theoretical analysis based on total potential energy calculations is conducted to explore the equilibrium states and deformation behavior of the metamaterial under varying external magnetic fields and mechanical loading conditions. The analysis incorporates elastic energy contributions from soft hinges and both active and passive magnetic interactions. The results reveal that the metamaterial exhibits tunable mechanical properties, with its compressive stiffness adjustable over two orders of magnitude through a combination of pre-assembly design modifications, such as hinge stiffness selection, and post-assembly magnetic tuning. Experimental validation confirms the accuracy of the theoretical predictions, demonstrating that the structure can maintain its load-bearable state even after the external magnetic field is removed due to the retention force provided by passive magnetic interactions. The proposed metamaterial provides a robust strategy for achieving programmable multistability and tunable mechanical response in a lightweight structure, offering promising applications in deployable structures, adaptive mechanical systems, and reconfigurable architectures.