Modelling coupled magneto-mechanical growth in hyperelastic materials

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Abstract

Magneto-mechanical coupling in the growth of soft materials presents challenges due to the
complex interactions between magnetic fields, mechanical forces, and growth-induced deformations. While growth modeling has been extensively studied, integrating magnetic stimuli into growth processes remains underexplored. In this work, we develop a 3D governing system for capturing the coupled magneto-mechanical growth behaviors of soft materials. Based on the governing system, we implement a finite element framework using second-order hexahedral elements to simulate these interactions. The robustness and accuracy of the proposed framework are demonstrated through numerical simulations, including the uniaxial loading of a circular tube, a mesh convergence study, and surface pattern evolution. We also conduct experiments on surface pattern modulation in magneto-active soft materials. Specifically, we fabricate film-substrate samples and apply growth-induced instabilities combined with external magnetic fields to generate tunable surface patterns. To demonstrate the capabilities of our method, we apply our numerical framework to mimic the biological morphogenesis, such as the inversion process of the algal genus Volvox. Our study shows that integrating magneto-mechanical coupling with growth effects allows for flexible control over surface patterns, significantly enhancing the adaptability and responsiveness of soft materials. This work paves the way for innovative designs of adaptive and programmable soft materials, with potential applications in soft robotics, biomimetic structures, and tissue engineering

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