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An explicit numerical scheme for soft Magneto Rheological Elastomers devices

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Abstract

Soft magnetorheological elastomers (MREs) are a class of smart active materials capable of undergoing large, reversible deformations when subjected to external magnetic fields. Due to their inherent softness, low weight, and high compliance, soft MREs have attracted significant interest for applications in soft actuators, soft robotics, biomedical sensing devices, and artificial muscle systems. Their ability to convert magnetic energy into mechanical deformation makes them particularly attractive for remotely actuated and controllable systems. In this study, an explicit numerical framework is developed to investigate the coupled magnetoelastic behavior of soft MREs exposed to magnetic loading. A thin circular MRE membrane is fabricated using a polydimethylsiloxane (PDMS) matrix embedded with uniformly dispersed iron particles. The fabricated membrane is circumferentially clamped, and a time-varying magnetic field is applied normal to its surface, resulting in pronounced out-of-plane deformation. To accurately characterize the material response, a comprehensive set of experimental tests, including uniaxial tensile testing and inductance measurements, is performed. The mechanical behavior of the MRE membrane is well captured using a nonlinear hyperelastic Ogden constitutive model, which provides an excellent fit to the experimental uniaxial stress–strain response. The experimentally calibrated material parameters are incorporated into a nonlinear magneto–hyperelastic numerical model. The proposed numerical framework demonstrates good agreement with experimental deformation profiles, validating its capability to predict the magneto-mechanical response of soft MRE structures. Building upon this validated framework, a soft cylindrical MRE actuator is numerically modeled to explore its actuation characteristics. Key performance parameters, including deformation range and actuation efficiency, are systematically analyzed. The results reveal that the actuation performance of cylindrical MRE actuators is strongly influenced by nondimensional geometric parameters such as membrane thickness and aspect ratio. Overall, the present study provides valuable insights into the design, modeling, and optimization of soft MRE-based devices and contributes to the development of advanced magnetically driven soft robotic systems.

Keywords:

Magnetoelastic Non linear elasticity Continuum Mechanics Soft Robotics