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Magnetically induced mechanical anisotropy in ultra-soft hMREs

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Abstract

The use of magnetorheological elastomers (MREs) has expanded in recent years due to the wide range of possibilities offered by these novel materials for the development of new intelligent systems, for example for applications in soft robotics. From enabling the design of actuators [1] to modifying and even reprogramming the mechanical properties of a structure [2], the magneto-mechanical problem has attracted considerable interest, particularly in the last few years, and various constitutive models have been proposed to describe the behaviour of these emerging materials. However, these theoretical frameworks and experimental developments generally assume relatively soft matrices that allow the large deformations characteristic of such structures, where the presence of hard magnetic particles leads to isotropic changes in the material properties. When the stiffness of the soft matrix falls below a certain threshold – such as an ultra-soft matrix with a stiffness of approximately ≈3 kPa – these models fail to accurately capture the behaviour of the material and structures. During the fabrication of the MREs by using hard magnetic particles (hMREs), and specifically after the induction of magnetic remanence in the material, the particles undergo slight displacements and form chain-like structures. This effect causes the mechanical properties of the material to deviate from isotropy and result into an anisotropic mechanical response. Due to the nature of this phenomenon, variables like particle concentration and magnetization play a key role. Consequently, it becomes

necessary not only to develop new constitutive models capable of reproducing these anisotropies, but also new numerical models that can predict and optimize the material response [3]. In this study, we demonstrate how such ultra-soft matrices exhibit anisotropic behaviour in contrast to the classical assumption of isotropy, drawing on experimental characterization, advanced constitutive modelling, and experimental validation.

Keywords:

Magneto-mechanics Magnetorheological elastomers Multifunctional materials Soft robotics

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