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# Rapid Compression-Based Mechanical Characterization of Hydrogels Using Soft Magnetorheological Elastomers

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**Abstract**

Hydrogels are versatile, biocompatible materials with tunable crosslinking, swelling, and mechanical properties, making them valuable for biomedical applications such as drug delivery, wound healing, bioelectronics and tissue engineering. However, developing and optimizing hydrogels for specific uses necessitates precise adjustments to their mechanical properties, highlighting the need for efficient mechanical testing methods. Despite significant progress, the current techniques for mechanical characterization, such as atomic force microscopy (AFM), nanoindentation, osmotic compression, micropipette aspiration and capillary micromechanics are slow, low-throughput, complex, and expensive, sometimes require prolonged fabrication duration and consume large amounts of hydrogel samples, limiting their suitability for noninvasive and high throughput measurements essential in hydrogel development and quality control. One promising approach is the use of adequately soft stimuli-responsive actuators to apply tunable loads to hydrogels without damaging them in the process. In particular, magnetorheological elastomers (MREs), which are soft smart multifunctional composites consisting of magnetizable particles embedded in an elastomeric matrix, have attracted significant attention due to their magnetically tunable mechanical response. When exposed to an external magnetic field, MREs deform in a reversible and controlled manner, allowing them to serve as programmable actuators. The coupling of magnetic and mechanical behavior in these composites enables remote and controllable tuning of their mechanical properties via the magnetorheological (MR) effect. Compared to other actuation strategies, magnetic actuation offers advantages such as remote control, contactless activation, rapid response, and continuous tunability, making MREs especially suitable for dynamic mechanical stimulation of soft viscoelastic materials. Depending on the nature of the magnetic particles, MREs can be categorized as soft, hard and hybrid MREs. In soft magnetorheological elastomers (s-MREs), soft magnetic particles with almost negligible remanence and low coercivity are embedded in the carrier matrix while in hard MREs (h-MREs), hard magnetic particles with relatively high remanence and high coercivity are infused into the compliant polymeric matrix. Hybrid MREs (H-MREs) contain both soft and hard magnetic particles. In this study, s-MREs comprising carbonyl iron particles (CIP) and Ecoflex 00-30 in varying mass proportions were fabricated and characterized both magnetically and mechanically. Ionically-crosslinked alginate hydrogels in the millimetric scale with polymer concentrations between 0.5% and 2% were prepared using an extrusion technique. s-MRE consisting of 30 wt.% CIP was used as an actuator to conduct the mechanical characterization of the prepared hydrogels via compression testing. The results showcase a direct proportionality of the stiffness of hydrogels to their polymer concentrations. Notably, the consistency between results from AFM and MRE-based testing validates the proposed characterization approach. Moreover, this characterization technique offers simplicity and cost-efficiency in comparison to existing methods. Based on the collected experimental data, a simple user-friendly prototype for rapid mechanical characterization of soft gels has been designed, fabricated and demonstrated. This device can potentially serve as a tool for the efficient evaluation of bulk hydrogels and other soft biomaterials in tissue engineering, drug delivery, mechanobiology research and industrial applications.

**Keywords:**

magnetorheological elastomers (MREs) multifunctional composites magnetoactive elastomers hydrogels Young’s modulus soft actuators biomaterials