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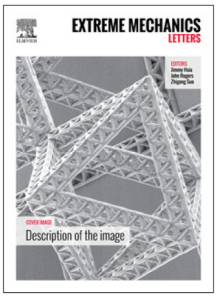

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Stimuli-induced bi-directional hydrogel unimorph actuators

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ABSTRACT

Stimuli responsive hydrogels may be promising materials for shape transforming structures due to their ability to deform significantly in response to an environmental stimulus without the need for external power. It is well-known that by laminating swelling hydrogels and non-swelling flexible materials, such as inert elastomers, bending actuation can be achieved. In this work, we report an improved hydrogel-elastomer bonding process and demonstrate the utility of the process with a stimuli-induced bi-directional hydrogel unimorph actuator. The actuator is comprised of polyacrylamide (PAAm) hydrogel, a humidity-sensitive gel that can swell to 17 times its original volume, bonded to polydimethylsiloxane (PDMS) elastomer, which is humidity insensitive. The unimorph actuator bends in one direction during swelling in an aqueous environment and in the opposite direction when drying in air, without any observed delamination between layers. We achieve the strong bonding between PAAm hydrogel and PDMS elastomer through both chemical and mechanical means, and quantify an order-of-magnitude improvement in interfacial bond strength relative to bonding through chemical means alone. We observe the bi-directional bending behavior of hydrogel unimorph actuators as a function of environmental humidity and prove that the structure's motion can be tuned by manipulating the thickness of the PDMS elastomer layer, as well as predicted using a simplified analytical approach. Lastly, we expand upon a simple rectangular unimorph structure to demonstrate more complex bending, wrinkling, and surface texture behaviors.

Keywords: hydrogel-elastomer, humidity-sensitive, interfacial bond, bi-directional

1. INTRODUCTION

Soft, intricate multifunctional structures seen in nature[1–4] have inspired the design of shape transforming materials capable of reconfiguration in response to environmental stimuli[5]. Various kinds of materials have been shown to exhibit shape changing behaviors, including shape memory alloys[6,7], electroactive polymers[8–10], shape memory polymers[11,12] and polymer gels[13,14]. Such materials have applications in microfluidics[15–17], biomedical devices[18–20], soft robotics[21–23], optical devices[24,25], microfabrication[26–28] and stimuli-responsive surfaces[29–31]. As a class of stimuli-responsive materials, hydrogels are able to change volume with reversible swelling and deswelling in response to environmental stimuli such as temperature[32–39], pH[32,40–43], light[44–46], enzymes[47], ion strength and solvent composition[48,49], electric and magnetic fields[14,21,50,51], elastic instabilities and surface oscillation[52,53]. The earliest published results on hydrogel actuation used the material for liquid flow control in microfluidic devices[17,38,39,54,55]. In these systems, hydrogels served as valves and underwent homogeneous expansion and shrinkage to control fluid flow. However, homogeneous swelling and deswelling only result in volumetric material changes. Shape change induced by inhomogeneous deformations, such as