Spontaneous hydrogel gripper driven by free swelling

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Abstract. We investigate the morphogenetic process of ionic hydrogel with the semi-cylinder structure during the free swelling. From both an experimental and theoretical perspective, the results elucidated the feasibility of the hydrogel as a soft gripper dominated by local and global elastic instabilities. Furthermore, the gripper design was extended to the 4 claws structure.

Introduction

Autonomous shape transformation is common in biological systems, for example, Venus flytrap, seed pods, and octopuses. Such the morphogenetic process is of great significance for self-shaping materials for promising applications in soft robotics, biomimetic systems, drug delivery, etc. Besides, Swelling in liquid is a common phenomenon for hydrogel material. Regarding some published research, the swelling with ionic hydrogel and pre-defined structure can generate a controllable or programable surface with several types of elastic instabilities. Apart from the buckling in the annulus edge, wrinkling and creasing are also known on the flat surface. Here, we present the spontaneous shape transformation of hydrogel with the semi-cylinder structure and homogeneous property during free swelling, which enables instability morphology to be spatially distributed and generated in the hydrogel structure.

Experiment and Results

For fabrication of the hydrogel with acrylamide-co-sodium arylate network and semi-cylinder structure. The pre-solution including acrylamide and sodium acrylate of the hydrogel and curing agent were mixed and then injected into the 3D printed resin mould for gelation at room temperature. For carrying out the free swelling, the hydrogel sample was completely immersed into DI water/PBS solution. For characterization of the morphogenesis of the hydrogel sample, the sample was dyed by general food dye or marked by appropriate fluorescein so that could be directly observed by the camera, optical microscope or confocal microscopy.

The experimental results, as shown in Fig.1, illustrated 4 typical stages of the morphogenetic process during swelling. In the thickness direction, the decreasing gradient of the flow rate of absorbing water from the outer surface to the central area enabled the local and global instability morphologies which were characterized by the wrinkles and creases at the axial edge and thin layer of circumferential surface respectively. In the front view, due to local elastic instability at the axial edge, wrinkles occurred and then merged and finally, two edges were contacted. Meanwhile, through the back view, governed by global elastic instability, the creasing grid occurred on the circumferential surface, and then turned from the biaxial grid into the uniaxial grid and finally disappeared by the contribution of circumferential energy releasing. Besides, the flow velocities of all surfaces are consistent but the area of asymmetric surfaces are different resulting in the different flow rate and uneven expansion (high flow rate means high expansion factor). Therefore, by the two types of elastic instability and uneven expansion, the semi-cylinder exhibits the morphogenesis of a gripper during the expanding process. After that, as carrying on further swelling and balancing the internal distribution of flow rate, the sparse wrinkles also disappeared and the gripper reopened spontaneously. The geometry features were parameterized and the values of various parameters were measured by forwarding timeline or swelling ratio. The whole process is autonomous and a highly selective formation by predefined geometric confinement.

In further research of the structure, the morphogenetic process was simulated by FEM software. Since there was no commercial FEM software specialized in swelling analysis, the thermal flux module based on Fourier's law is applied to simulate swelling which is highly related to Fick's law and as shown in Fig.2, the morphological features including wrinkles at the axial edge, global closing/reopening process and corresponding timescale are successfully matched with the experimental results.
Based on the results in context, after a numerical analysis based on a specific theory, the high-quality phase diagram for stating the relationship between geometrical parameters and the fully-closed state has been worked out.

Furthermore, in order to use the hydrogel structure for universal application, the optimized flat 4 claws gripper which was composed of crossed double semi-cylinders has been tested to pick out a small object from water.

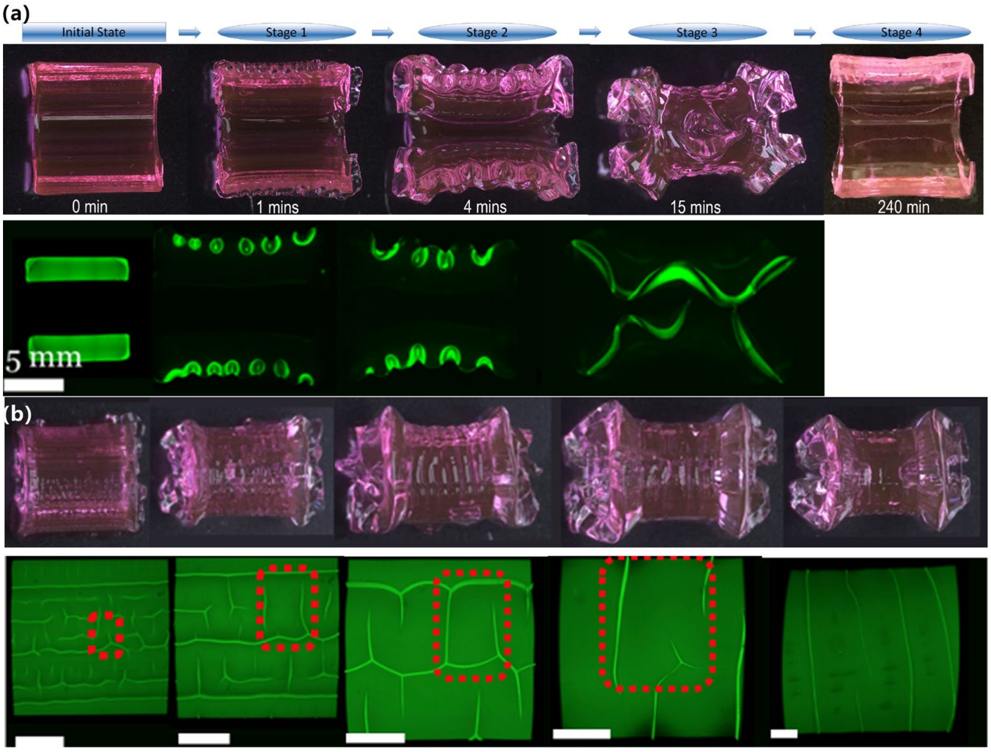

Fig. 1 Morphogenesis of the semi-cylinder at axial direction(a) and circumferential direction(b)

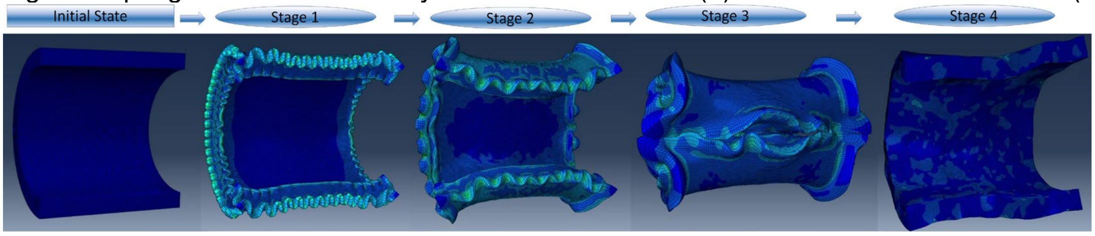

Fig. 2 FEM simulation results matched with 4 typical stages of morphogenesis in experiment

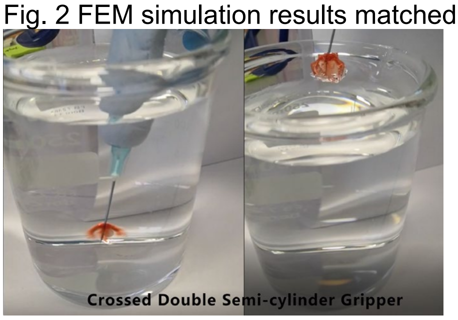

Fig. 3 Test of 4 claws(crossed double semi-cylinders)gripper

Conclusion

The free swelling induced liquid/solid interaction with predefined confinement of semi-cylinder structure can yield an autonomous soft gripper by specific dimensions. The morphogenesis and corresponding general strain-stress distribution have been demonstrated. Utilising the multi-stimuli responsive nature of the hydrogel, we recover the swollen gel part to its initial state, enabling reproducible and cyclic shape evolution. The described soft gel structure capable of shape transformation brings a variety of advantages such as easy to fabricate, large strain transformation, efficient actuation and high strength-to-weight ratio, which is anticipated to provide guidance for future applications in soft robotics, flexible electronics and off-shore engineering and healthcare products.