SELF-ROLLING UP MICRO ASSEMBLY USING A TEMPERATURE-RESPONSIVE HYDROGEL SHEET WITH RIGID PLATE ARRAY

Novelty / Progress Claim(s)

We propose a micro self-assembling method using a self-rolling up deformation of temperature-responsive hydrogel sheet with rigid plate array. Our self-rolling up assembly is an assembling method for a micro three-dimensional (3D) structure performed by rolling up a two-dimensional (2D) flat sheet, like making a croissant, through continuous self-folding (Figure 1). The local curvature of the rolled up structures could be controlled by the length of rigid plate. Using our method, we assembled rotational symmetry 3D structures, such as cylindrical and croissant-like ellipsoidal structures. In addition, all the structures demonstrated repetitive deformation, forward rolling up and backward rolling.

Background / State of the Art

In the self-assembling method at micro scale, self-folding is an especially useful method to easily fabricate complex micro 3D structures from engineered 2D sheets [1,2]. Most self-folded microstructures are, however, limited to 3D structure with large hollow region [3]. It means that the folded structure is not solid 3D structure but consists only of surface of the 3D structure (for example, surface of cubic structure). Therefore, we developed 3D structures with small hollow region by self-rolling up 2D temperature-responsive hydrogel sheet towards micro soft robots or actuators.

Description of the New Method or System

Figure 2 shows the general principle of self-folding using a "hybrid hydrogel sheet" composed of pNIPAM-AAc (dot patterned region in Figure 2) and SU-8 (white region in Figure 2). Basically, the self-rolling up deformation of a hybrid hydrogel sheet occurs at the hinges between SU-8 plates. pNIPAM-AAc is known as a stimuli-responsive hydrogel with responsiveness to temperature and/or pH. SU-8 is an epoxy resin without responsiveness to these stimuli. In water under 28 °C, pNIPAM-AAc layer swells by absorbing water. The volume of pNIPAM-AAc layer at the top surface is increased, although volume at the bottom surface does not change because of obstruction caused by SU-8 plate. On the other hand, in water over 32 °C, pNIPAM-AAc layer shrinks and a difference in volume changes causes as well as swelling. As a result, the difference in volume changes leads to self-folding at the forward (under 28 °C) and backward (over 32 °C) angle as shown in Figure 2.

Experimental Results

Figure 3 shows the folding curvature using the hybrid hydrogel sheets. The hybrid hydrogel sheets with different SU-8 lengths L (from 100 μm to 1000 μm) were put into 20 °C cold water and 40 °C hot water, respectively (Figure 3(a)). As shown in Figure 3(b), controlling the self-folding curvature was possible by changing the length of SU-8 plate L. Based on this result, we could design and assemble not only a structure with small gaps between the rolled-up sheets (Figure 3(c)), but also a structure with large gaps by changing the local curvatures (Figure 3(d)).

In addition, time responses of the self-rolling were evaluated to confirm the repetitive deformation. A cylindrical hybrid hydrogel sheet kept in 20 °C cold water was dipped into 40 °C hot water. Similarly, the sheet kept in 40 °C hot water was dipped into 20 °C cold water. Figure 4 shows the measurement result of self-rolling up curvature. In case of increasing water (shrinking hydrogel), the time response resulted in approximately 2 times faster than that when decreasing water (swelling hydrogel).

Finally, we demonstrated micro 3D structures using self-rolling up deformation. Figure 5(a) shows a cylindrical structure with small hollow region in center and no gaps between the rolled-up sheet. In 40 °C hot water, the cylindrical structure had small internal hollow region with 180 μm in diameter. As shown in figure 5(b), our self-rolling method can also produce hollow structure, a croissant-like ellipsoidal structure, fabricated by changing the SU-8 plate length and width stepwise.

Word count: 594

References

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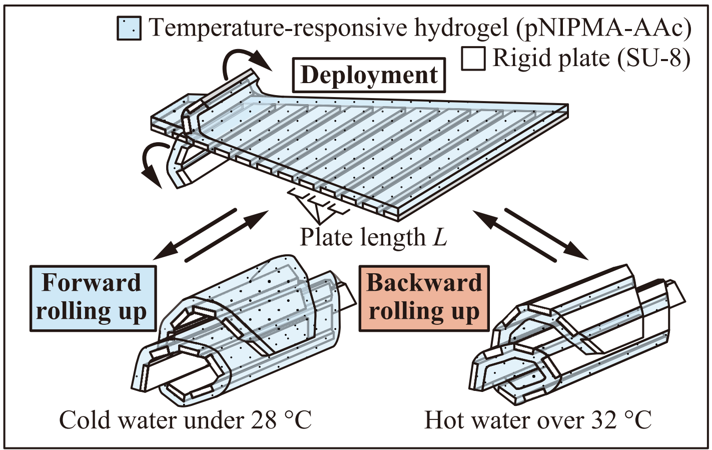

Figure 1: Concept of the self-rolling up deformation for micro 3D structures using temperature-responsive hydrogel sheet.

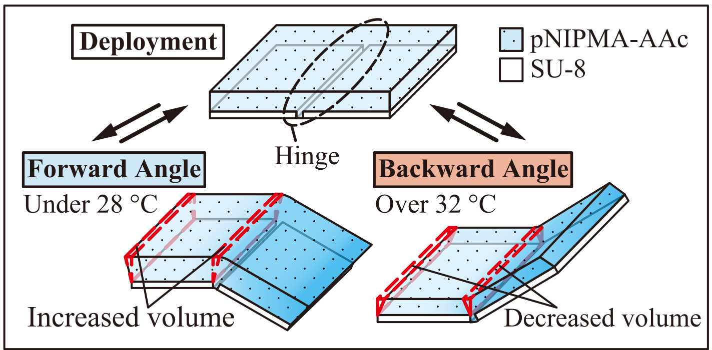

Figure 2: Principle of self-folding using hybrid hydrogel sheet.

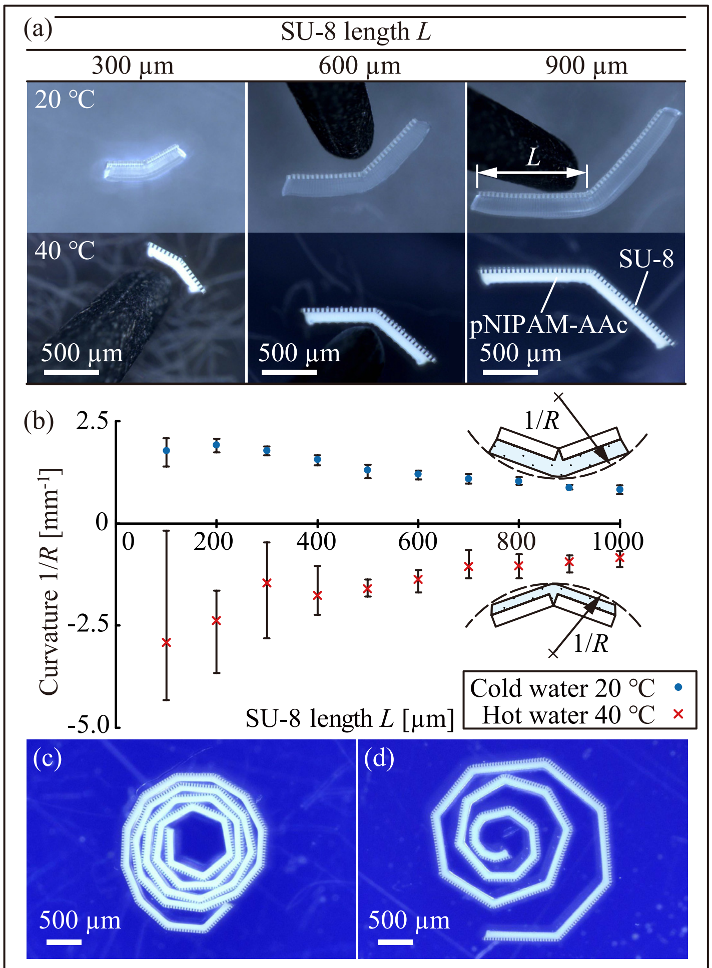

Figure 3: Basic characteristic of the self-folding. (a) Images of the fabricated hybrid hydrogel sheets during swelling and shrinking. (b) Characteristic of curvature produced by different length of SU-8 plate. (c) Small hollow structure. (d) Hollow structure with various curvatures.

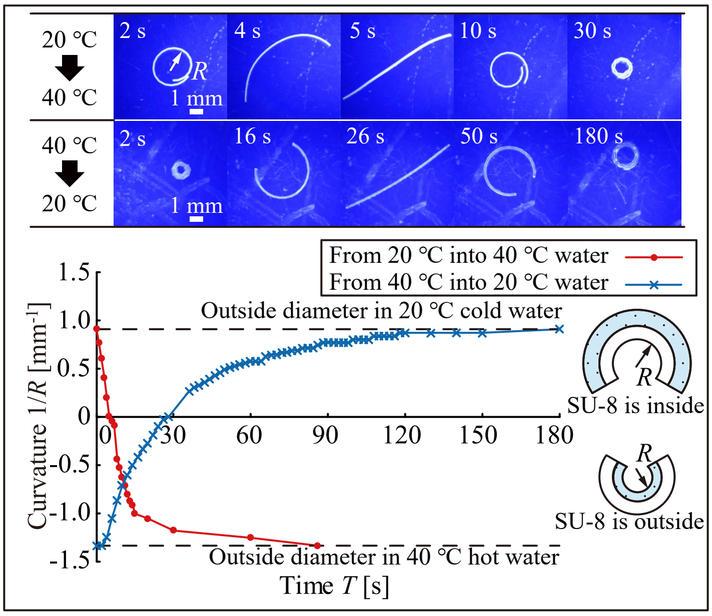

Figure 4: Time responses of the hybrid hydrogel sheet.

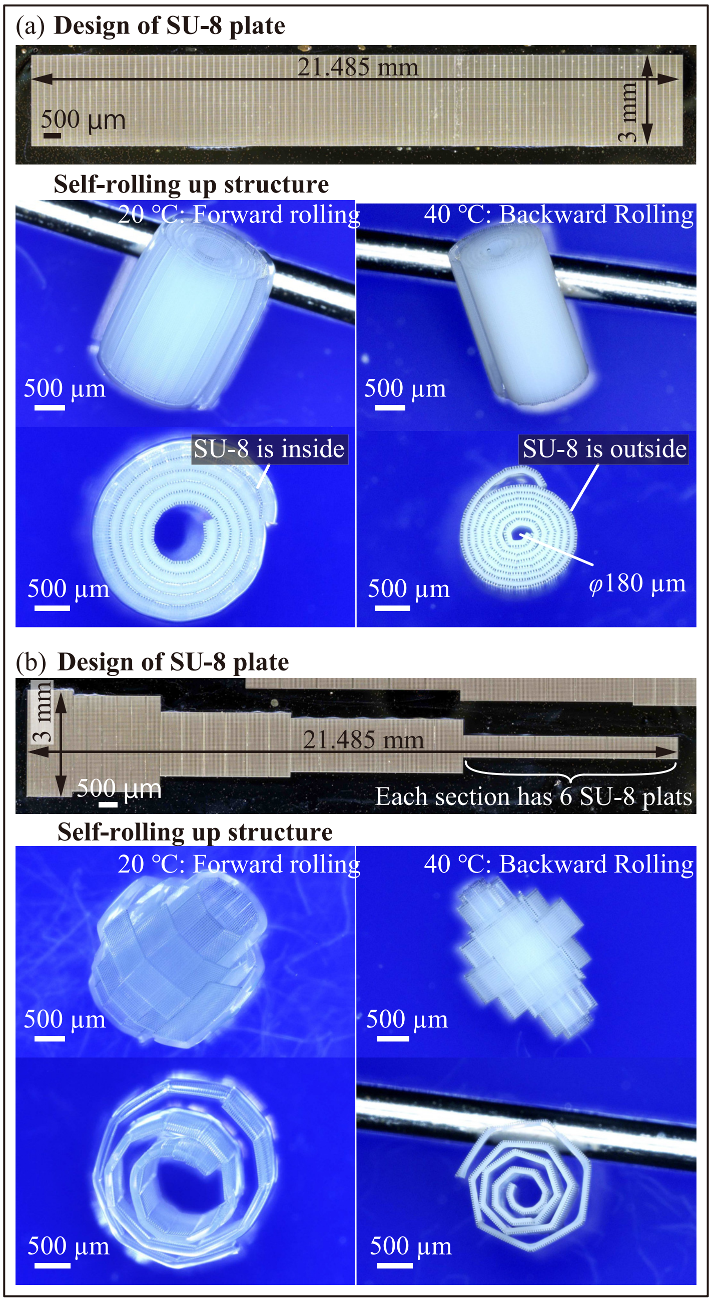

Figure 5: Designs and 3D structures fabricated using self-rolling up. (a) Cylindrical structure with small hollow region. (b) Croissant-like ellipsoidal structure with hollow region.