Near-Infrared Light Responsive-Behavior of Shape Memory Polymer on the Water Surface

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Keywords: shape memory polymer, photothermal conversion, near-infrared light, meniscus climbing

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Abstract

A leaf beetle larva can climb up the surface of the water to land by bending its body with minimum energy, which is called “meniscus climbing”. The larva climbs the meniscus of the water surface by matching its body to the meniscus curve. We have prepared shape memory polymers (SMPs) for artificial meniscus climbing. In this study, the SMP was coated with polypyrrole (PPy) which shows a photothermal conversion effect. PPy-coated SMP (PPy-SMP) is locally heated by near-infrared (NIR) laser irradiation. The meniscus climbing of PPy-SMP was evaluated on the water surface.

1. Introduction

A leaf beetle larva uses surface tension to move on the surface of the water[1)]. It usually lives on land, but when it falls to the surface of the water near the shore of the pond, it can reach the shore without swimming. This ability is called "meniscus climbing". Meniscus climbing is a phenomenon in which the shape of the body is matched to the shape of the meniscus to advance on the water surface with less energy and climb the meniscus. Meniscus climbing occurs due to the change in surface tension on the water surface. In this study, we performed meniscus climbing artificially using a shape memory polymer triggered by an external stimulus. The shape memory polymer (SMP) becomes a rubber state above its glass transition temperature (T_g) and can be deformed. If it is reduced to T_g or less while being deformed, its shape is fixed. When heated to T_g or higher again, it returns to its original shape. To perform meniscus climbing using SMP, local heating of SMP is required. Therefore, local heating by near-infrared light (NIR) irradiation was examined[2)]. In order to heat SMP above T_g with NIR, a photothermal conversion material that can absorb NIR and convert it into heat is required. It has been reported that polypyrrole-coated triiron tetroxide[3)] and gold nanoparticles[4)] convert NIR to heat with high conversion efficiency. Therefore, polypyrrole (PPy) was used as the photothermal conversion material. As a shape memory polymer, a polymer in which stearyl acrylate (SA) and methyl acrylate (MA) were crosslinked was prepared[5)]. The surface of the SMP was coated with polypyrrole by performing oxidative polymerization of pyrrole on the surface of the obtained shape memory polymer. After that, heat generation and shape change due to NIR irradiation of the

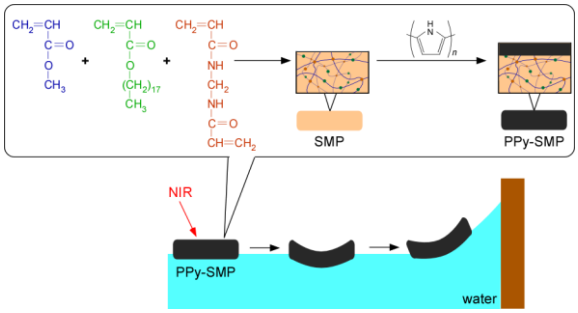

Figure 1. Conceptual illustration of meniscus climbing of polypyrrole-coated shape memory polymer (PPy-SMP).

polypyrrole-coated SMP (PPy-SMP) were observed. NIR was applied to a plate-shaped PPy-SMP floating on the water surface in a petri dish. At this time, our study aims to confirm whether the PPy-SMP was deformed into a curved shape by the heat generated by the photothermal conversion and moved toward the petri dish wall by meniscus climbing.

2. Experiment

An SMP was prepared with cross-linking SA and MA with methylene bisacrylamide (MBAA) by radical polymerization using azobis(isobutyronitrile) (AIBN) as an initiator. SMP was coated with PPy by chemical oxidative polymerization. PPy-SMP was irradiated by NIR and the best concentration of pyrrole to change the shape of PPy-SMP was determined. Curved shape PPy-SMP was heated and changed to plate shape, then it was floated on the water surface. Meniscus climbing was observed upon NIR irradiation because the shape of PPy-SMP was changed from plate shape to curved shape. The curvature of PPy-SMP was changed and the relationships between the curvature of PPy-SMP and the acceleration and moving distance of meniscus climbing were investigated.

3. Results and discussion

PPy-SMP changed its shape upon NIR irradiation. The best concentration of pyrrole to change the shape of PPy-SMP was determined as 4 mM. PPy-SMP on the water surface moved to the wall of the petri dish by meniscus climbing upon NIR irradiation because PPy-SMP was changed its shape by heat generated from PPy due to photothermal conversion. The acceleration of meniscus climbing decreased with increasing curvature of PPy-SMP, whereas the moving distance was not changed. Therefore, the moving distance may be influenced by other parameters such as the shape of the meniscus, the hydrophobicity, and so on.

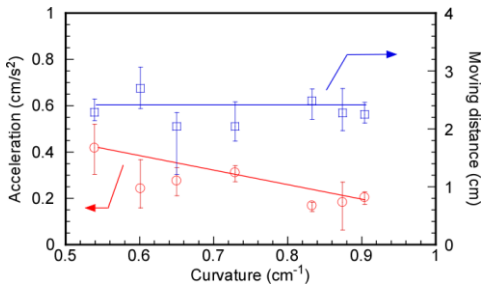

Figure 2. Acceleration (○) and moving distance to the edge of the petri plate (□) as a function of curvature of PPy-SMP.

4. Conclusions

Shape memory polymer was prepared and coated with polypyrrole. PPy-SMP moved to the wall of petri dish by meniscus climbing by upon NIR irradiation. In the future, if natural energy such as sunlight is used as an external stimulus, meniscus climbing of PPy-SMP can be expected to be applied to energy-saving transportation technology.

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