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Folding behavior study of polystyrene sheet activated by light

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ABSTRACT

The polystyrene (PS) sheet is contracted to 50% when it approaches the glass transition temperature. As the black-colored line pattern is printed to the PS sheet and the rays is lighted to the sheet, the localized thermal absorption causes the folding behavior. Such folding behavior of the PS sheet can be easily controlled by its just line pattern printing. Also, the PS sheet folding behavior using the non-contact activation energy such as light can be employed in the various industrial fields. In this study, the 3-dimensional shape deformations from PS sheet folding behavior are manufactured, and this folding deformation process is analyzed by the cohesive interface line element method.

1. INTRODUCTION

Recently, as it is known that the polystyrene (PS) sheet with black-colored line pattern is folded by the light, the PS sheet is thought as a self-folding material (Liu, et. al., 2012). The folding behavior of the PS sheet is easily materialized by printing the black-colored line pattern, so the PS sheet can be extensively utilized. Especially, the PS sheet folding behavior can be used as the non-contact control technique, because the folding deformation of the PS sheet is activated by the light.

The folding behavior of the PS sheet is based on its thermal contraction reaction. The contraction phenomenon of the PS sheet occurs when it approaches the glass transition temperature(about 102 ℃). The contraction ratio is about 50~60%, but, this is limited on the contraction in-plane direction. However, by printing simple line pattern to the PS sheet, the selectional contraction control is possible. Such localized contraction control is a key of the PS sheet folding behavior. When the PS sheet gets light, the light penetrates the transparent area of the sheet, and the light is almost absorbed in the black-colored area. Thus, the depth-dependent thermal absorption in

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the line pattern causes the folding deformation. The folding of the PS sheet is activated by the light, so it needs not to be directly connected to the power source. Also, the folding behavior is determined by the line pattern, so the deformed shape is easily controlled through the line pattern design. In the case of the more folding behaviors, the more line patterns are required in the PS sheet, but this may cause the unexpected deformed shape due to its excessive thermal absorption. Accordingly, the non-uniform thermal absorption should be covered in the folding behavior design of the PS sheet, so the sequential folding technique using collar faces is employed in this study. As the collar faces are applied to the edge lines of the PS sheet, the PS sheet can be deformed to the planned shape.
The folding behavior of the PS sheet is recently found, so the experiment related on the folding deformation has not much progressed (Liu, et. al., 2012). Accordingly, the properties about the folding deformation by the light are obtained from the experiment performed in this study. Especially, we centrally studied the relation between the line pattern shapes and the folding deformation. Based on the measured properties about PS sheet folding deformation, some self-folding origami structure is designed and manufactured.

2. Discussion

2.1 Folding deformation of PS sheet by light

At the glass transition state of the PS sheet, the thermal deformation reaction occurs in the overall area. Due to its pre-strained state, the PS sheet contracts in plane, and it thickens as Fig. 1 a).

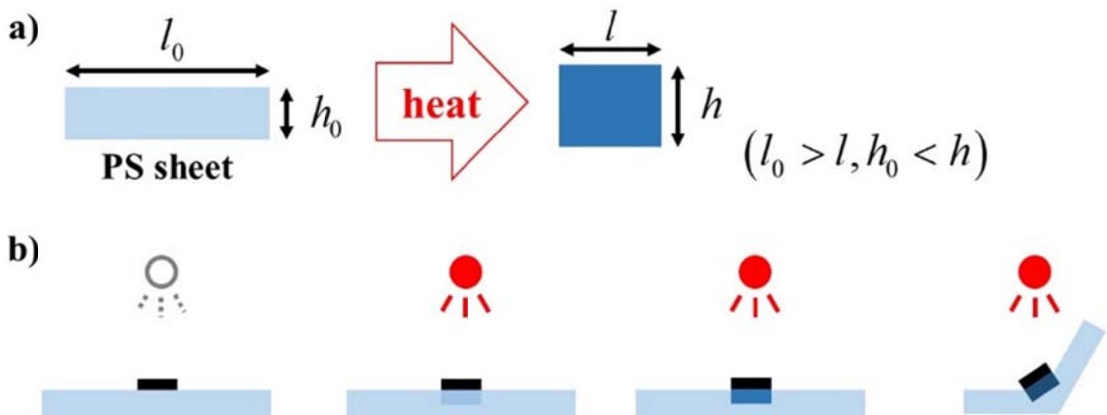

Fig. 1 Thermal deformation and folding deformation of PS sheet

a) Thermal deformation of the PS sheet b) Folding deformation of PS sheet by light

In Fig.1 (a), the heat is uniformly distributed to the PS sheet, so the thermal contraction overall in all area of PS sheet. Through the black-colored line pattern printed in the sheet, the light passes most of the PS sheet except the printed area. From the localized light absorption, the depth-dependent thermal deformation occurs and causes to the folding deformation.
The PS sheet starts thermal contraction reaction without any external force, when it approaches the glass transition state. Although the constitutive models for the shape

memory polymer material have been developed and proposed and they can exactly predict the thermal deformation of the polymer material (Nguyen, et. al., 2008), they are not appropriate for the folding deformation due to their limitation concentrated to the three-dimensional or one-dimensional properties of the material. As the alternative, the bending moment-rotation angle curve is modified by the heat as

$$\begin{aligned} & f = M - \left(M_y - M_T(Q)\right) & & \\ & M = D\theta & & (\text{elastic}). \\ & M = \frac{DK}{D+K}\left(\theta - \theta_y\right) + \left(M_y - M_T(Q)\right) & & (\text{plastic}) \end{aligned} \tag{1}$$

In the no-light state, the PS sheet without any external force does not show any deformation behavior. When the PS sheet absorbs light, the temperature of the line pattern increases due to its absorbed heat, and the plastic curve descends. The folding deformation occurs at the glass transition state, and this means the x-intercept of the plastic curve is generated by the heat. This explains how the PS sheet is folded by light without external force.

2.2 Self-folding structure design

Through the line pattern design of PS sheet, the folding behavior is controlled. Accordingly, the self-folding origami structure using the PS sheet can be achieved without difficulties, and we designed and manufactured a self-folding structure using this technique.

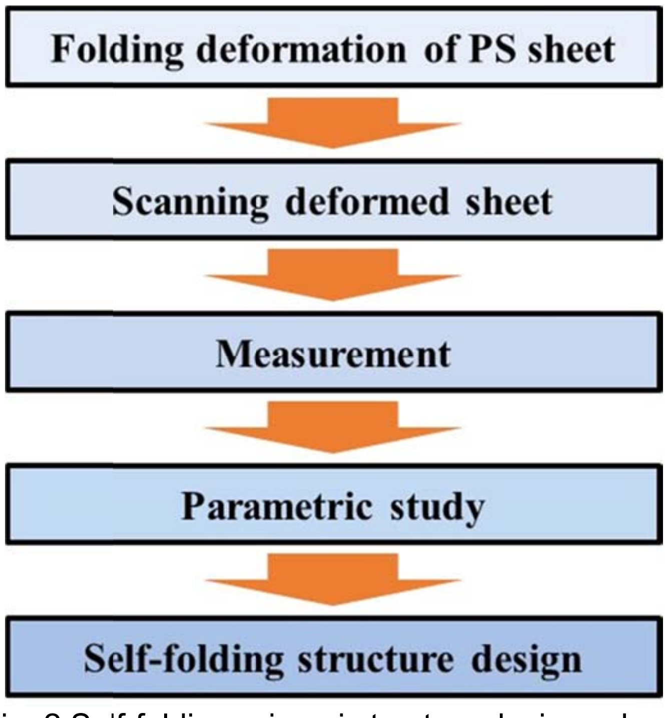

Fig. 2 Self-folding origami structure design scheme

In Fig. 2, the PS sheet is folded by light, and the deformed shape of the PS sheet is observed by the 3D scanning. From the PS sheet folding experiment, the folding properties about the line pattern is identified, and this is utilized in the self-folding origami structure design. We expect that the folding technique of PS sheet activated by light can be applied in various self-folding systems.

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