Movement of Uncured Ultraviolet-Curable Resin during Curing

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Abstract. The movement of uncured ultraviolet (UV)-curable resin during curing was investigated using a particle image velocimetry (PIV) technique. The specimen consisted of a mold and UV curing resin in liquid form with acrylic powder. The mold consisted of glass and acrylic plates. The specimen was irradiated with UV rays downwards from above the specimen. Images of the resin during the curing process were then captured at a constant time interval using a digital camera. Results indicated that the movement of uncured resin during initial curing occurred in the upper part of the resin, and the movement of the uncured resin in the initial stage of curing determined the subsequent movement of the resin. The initial movement was inferred to be due to the shrinkage of the resin.

Introduction

Ultraviolet (UV)-curable resin is currently used as a material in many products. This is because the curing speed, ease of molding and storage, and safety of UV-curable resin are superior to those of other resins. However, UV-curable resin is known to shrink during curing. The shrinkage is considered to generate residual stress in products, which is thought to reduce the reliability of their mechanical strength.

To improve the reliability, the residual stress in products must be minimized. To achieve this, it is important to understand how UV-curable resin is cured and shrinks during irradiation with UV rays (curing process) and how stress is generated in UV-curable resin in relation to the curing and shrinkage.

The distribution of stress can be measured by a photoelastic technique [1]. However, it is difficult to directly observe the shrinkage of resin. To observe the shrinkage indirectly, the authors previously investigated the flow of UV-curable resin during curing from stream patterns obtained by a particle image velocimetry (PIV) technique and particle trajectory patterns obtained by a particle tracking velocimetry (PTV) technique [2]. It was found that the flow of uncured resin was affected by the resin being curred. However, the movement of uncured resin was not investigated in detail.

In this study, we investigated in detail the movement of uncured UV-curable resin during curing from the stream patterns obtained by PIV.

Experimental Procedure

Figure 1 shows details of the specimens, which consist of a mold and UV-curable liquid resin. Pentaerythritol triacrylate was used as the monomer in the resin, which has a shrinkage of 7.7%. The mold consists of glass plates, acrylic plates and black vinyl tape. Acrylic powder with a mean particle diameter of 50 μm was mixed with the liquid resin to visualize its flow. The volume fraction of the powder was 2%. The liquid resin with the acrylic powder was poured into a cavity (5 mm thick, 15 mm high and 20 mm wide) surrounded by glass and acrylic plates. The vinyl tape placed on the left and right sides prevented UV rays from irradiating the left and right sides of the resin, respectively, and the irradiated area was 5×10 mm^2.

Figure 2 schematically shows the system used for measuring the movement of the UV-curable resin during curing. The system consists of a green laser source with a wavelength of 532 nm, a digital camera for obtaining images of the resin, which are used to observe its movement, a personal computer for analyzing the

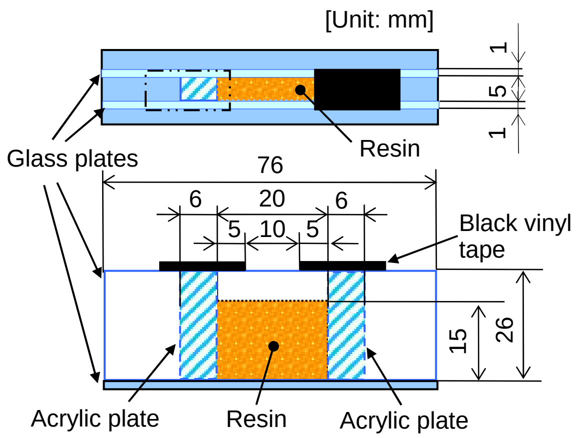


Fig. 1 Shape and dimensions of specimen

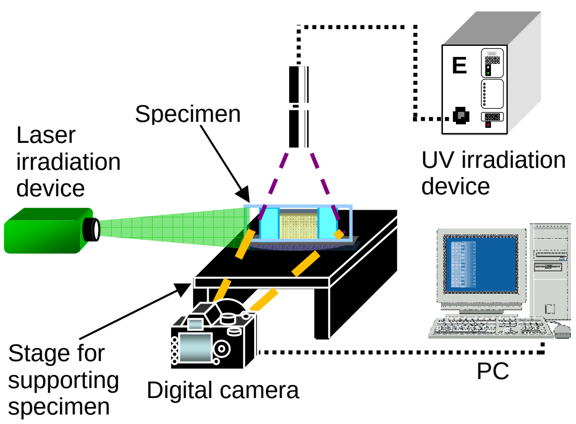


Fig. 2 Experimental setup

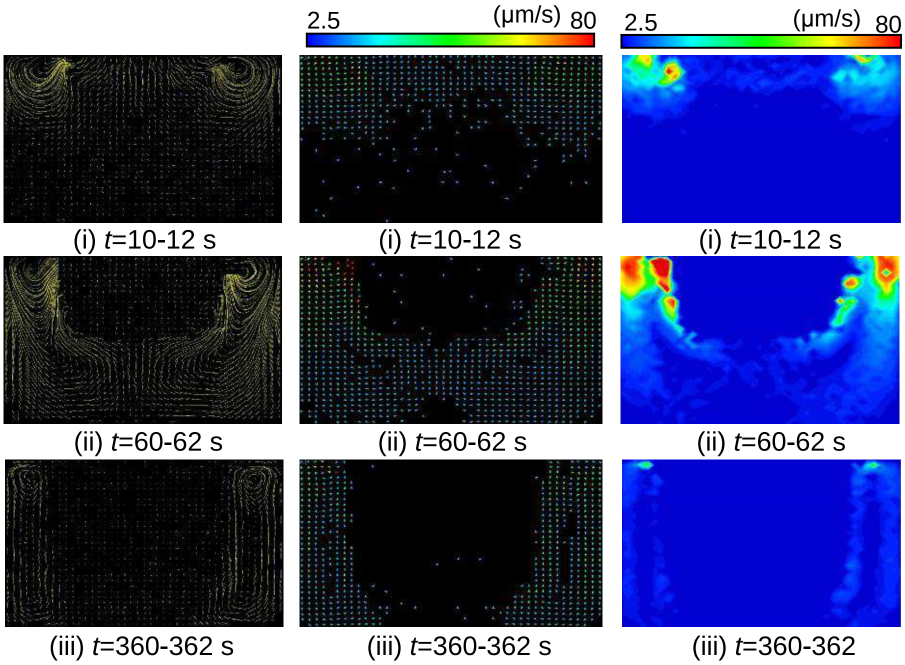
captured images and a UV irradiation device. The laser was used to irradiate the specimens from the left side. Stream patterns (quasi-streamlines) were drawn on the basis of the velocity of the resin obtained from the captured images using PIV software.

The specimens were placed on a stage and irradiated from above with UV rays with a light intensity, E, of 10.0 mW/cm^2 at the top surface of the resin for t=420 s. Images of the UV-curable resin during curing were obtained at time intervals of 1/3 s from 0 to 16 s and at time intervals of 2 s from 20 to 420 s using the digital camera for flow analysis. To draw the stream patterns (quasi-streamline and velocity vectors) using the PIV software, two images obtained at time intervals of 1 s from 0 to 16 s and 2 s from 20 to 420 s were used. A correlation area of 25×25 pixels was used, which was determined on the basis of the results of a preliminary experiment. The spatial resolution of the images was 17.54 μm/pixel.

Experimental Results and Discussion

Figure 3 shows the quasi-streamlines, velocity vectors and speed of the UV-curable resin during curing. In the interval t=10-12 s (Fig. 3(a)(i)), the uncured resin in the upper left part moved downward slightly and rotated counterclockwise toward the left side of the curing resin. The resin in the upper right part moved downward slightly and rotated clockwise toward the right side. The resin under the curing resin was drawn upward. In the interval t=60-62 s (Fig. 3(a)(ii)), the resin on the left and right sides of the cured resin markedly rotated counterclockwise and clockwise from the upper part to the lower part, respectively. The resin under the cured resin was drawn upward. In the interval t=360-362 s (Fig. 3(a)(iii)), the resin on the left and right sides of the cured resin slowly rotated counterclockwise and clockwise, respectively. The movement of the resin in the upper part was faster than that in the lower part.

Figure 4 shows an enlargement of the quasi-streamlines in the upper left part of the resin. In the interval t=3-4 s (Fig. 4(a)), the resin in the upper left part moved downward slightly, rotated counterclockwise around point C shown in Fig. 4 and moved toward the curing resin. In the interval t=5-6 s (Fig. 4(b)), the resin moved downward and formed two parts, one rotating counterclockwise around point C and the other moving toward the resin being cured. This movement was inferred to be due to the shrinkage of the resin.



(a) Quasi-streamlines (b) Velocity vectors (c) Speed

Fig. 3 Time variations of movement during curing

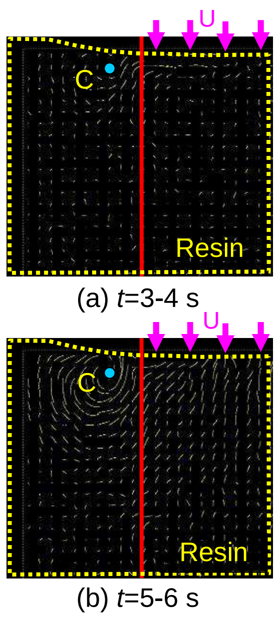


Fig. 4 Quasi-streamlines in the upper left area

Conclusions

The results obtained are summarized as follows.

(1) The movement of the uncured resin in the initial stage of curing determined the subsequent movement of the resin.

(2) The speed of the uncured resin varied as the curing progressed. The speed of the uncured resin not irradiated by UV rays was greater than that of the resin irradiated by UV rays.

References

[1] E. Umezaki and M. Abe: *Stress and movement of ultraviolet curing resin in curing process*, J. JSEM, Vol. 9, Special Issue (2009), p. 106-111.

[2] R. Odagiri, H. Ishibashi and E. Umezaki: *Flow and thermal analysis of ultraviolet-curable resin during curing process*, J. JSEM, 12**,** Special Issue (2012), p. s75-s80.