

Luminance change method for cure monitoring of GFRP

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Keywords: GFRP, Cure monitoring, Transmitted light

Abstract. Resin transfer molding (RTM) process is getting popular for fabrications of complicated commercial products made from Glass Fiber Reinforced Polymer (GFRP) at low cost. Cure monitoring is indispensable for RTM process. In the present study, polyester resin is adopted for matrix resin of the GFRP components. The polyester is usually adopted as matrix resin of the low-cost GFRP products. Existing methods for the cure monitoring are, however, expensive for the GFRP products. The polyester resin usually changes its optical property during curing. This enables us to monitor the degree of cure by means of measurements of luminance change of the transmitted light. Since the electrical circuit for measuring luminance change is not expensive, this system utilizes the luminance change for monitoring cure is not expensive system. In the present study, the sensing system employs a LED as a light source and plastic optical fibers as light paths. A photodiode is adopted as a light power sensor. This low-cost cure-monitoring system is applied to monitoring of degree of cure of polyester resin. Degree of cure is measured by means of commercially available dielectric sensors, and results are compared with the results of luminance change. The effectiveness of the method is confirmed experimentally here.

Introduction

Resin transfer molding (RTM) process is getting popular for fabrications of complicated commercial products made from Glass Fiber Reinforced Polymer (GFRP) at low cost. For the RTM process of complicated components, it is indispensable to do trial and error over and over to find the optimal fabrication process. The trial process is time consuming and that is one of the reasons of the high cost of composites. To overcome this problem, it is useful to monitor the degree of cure of the target GFRP products. By means of monitoring the degree of cure, the optimal resin flow process can be obtained without a large number of trial experiments.

In the present study, polyester resin is adopted for matrix resin of the GFRP components. The polyester is usually adopted as matrix resin of the low-cost GFRP products. Several methods for the cure monitoring have already been proposed. An exact measurement method uses a differential scanning calorimetry (DSC) to measure the degree of cure of polyester [1]. This method is limited to the small specimen and cannot be applied to actual RTM processes. A dynamic mechanical analysis (DMA), optical methods and dielectrometry method are applied to the actual cure monitoring [2]. However these methods are too expensive for the GFRP products, and the many of the sensors for the cure monitoring are not useful for other

objectives like strain monitoring or damage monitoring.[3]. Author's group has already published papers of damage and strain monitoring by means of the transmitted luminance of GFRP components [4, 5]. In the present study, therefore, the luminance change method is adopted for cure monitoring for the polyester. The polyester resin usually changes its optical property during the curing process. This enables us to monitor the degree of cure by means of measurements of luminance change of the transmitted light.

In the present study, the sensing system employs a LED as a light source and plastic optical fibers as light paths. A photodiode is adopted as a light power sensor. This low-cost cure-monitoring system is applied to monitoring of the degree of cure of polyester resin and glass/polyester composite (GFRP). The degree of cure is measured by means of commercially available dielectric sensors, and results are compared with the results of luminance change. The effectiveness is confirmed experimentally here.

Change of polyester resin during curing

Polyester resin is usually adapted as the matrix resin of GFRP. Several properties of polyester resin are changed during polyester resin curing. During polyester resin curing reaction, the chain length of the resin molecules grows through the cross linking reaction of factual groups, and the resin becomes more viscous. And volume shrinkage was occurred. In addition, heat of this reaction and change in optical property were occurred. In the present study, we propose to use this change in optical property during polyester resin curing. And, to know the degree of cure, we used a Dielectrometer to measure dielectric property change during polyester resin curing.

Optical property change of polyester resin. One of optical property change during polyester resin curing is the change of refractive index. The refractive index of polyester resin is increased with increase of degree of cure. This change of refractive index is effected on optical transparency. Therefore, in the present study, we proposed to use this change in optical transparency for cure monitoring.

Dielectric change of polyester resin. There are several methods for cure monitoring such as differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), and dielectrometry. Although DSC and DMA methods have been used widely, they are not employed for the on-line or in-situ cure monitoring during composite manufacturing except sample or specimen tests. Therefore, the dielectrometry has been most widely used for the on-line cure monitoring of thermosetting composite materials to describe the degree of cure qualitatively.

Many researches have been performed to obtain the relationship between the dielectric properties and the degree of polymerization [3, 6]. Dielectrometry is an only commercially available cure monitoring system. In the present study, we used the Eumetric100A (Holometric Micromet Inc., USA) as a dielectrometer.

Optical property change of GFRP. The refractive index of most of polyester resin is similar to that of glass fiber. Since the refractive indices of glass fiber and resin are nearly the same, GFRP have high optical transparency. Much of previous work has reported altering the refractive index of polyester resin and making a high optical transparent GFRP [7, 8]. In addition, the refractive index of polyester resin is increased with increase of degree of cure. Therefore, the optical transparency of GFRP is changed with increase of degree of cure of polyester resin.

Fig.1 shows the optical transparency change with the progress of cure of GFRP. In these pictures, the light is transmitted through glass fiber. In the left photograph, the transmitted light is little or nothing. However, the transmitted light was increased when polyester resin

infused, and changed during polyester resin curing.

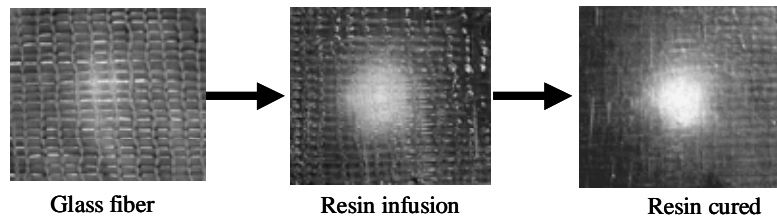


Fig. 1 Optical transparency change during GFRP molding

Cure monitoring system

A new cure monitoring system is proposed in the present study, and schematic image is shown in Fig.2. This system employs a LED as a light source, plastic optical fiber as a light paths and a photo diode as a luminance sensor. The data logger system composes of an amplifier, an A/D converter and a PC. Sensing area and optical fibers shown in Fig.2 change with applicable object. In this system, the light from the LED is transmitted in the optical fiber and the light is emitted into the target object. The transmitted light from the target object is received in the facing optical fiber and the luminance change is measured by the photo diode and recorded in the data logger.

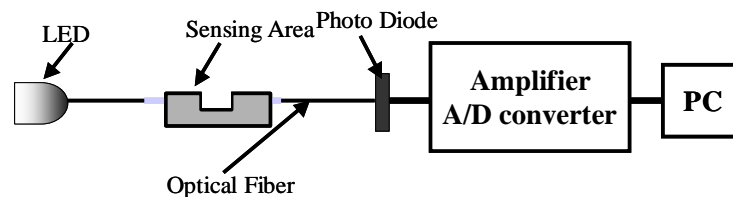


Fig. 2 Cure monitoring system with LED

Experimental method

Specimens and sensing area. In this study, polyester resin is Yupika 5100, and the curing agent is Permek. Permek is red color curing agent. Polyester resin and curing agent is mixed the rate of 100 to 1. Glass fiber shown in fig.3 is knit-fabric: WF800-127 made by FRP service Inc.

Sensing area configurations are shown in Fig.4. The sensing area of the optical fiber as shown in Fig. 4(a) is adopted for the measurements of luminance change due to the change in color during cure reaction of the polyester resin. For the GFRP specimen, the other sensing system without optical fiber is adopted as shown in Fig. 4(b). This system doesn't use plastic optical fiber, between a light source and a light sensor GFRP exists. The third sensing system for GFRP with plastic optical fiber is used as shown in Fig.4(c).

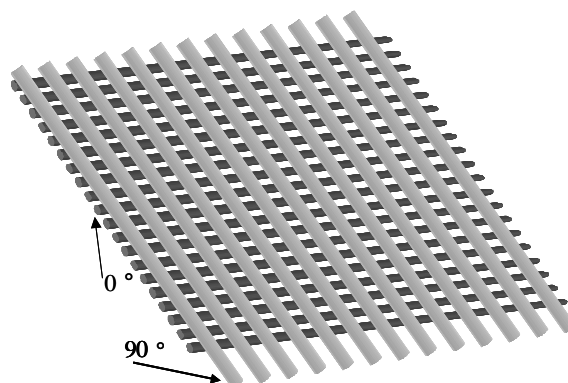


Fig. 3 Knitted fabric

Test procedure. Three kinds of tests are performed in the present study here. The first test is performed to investigate the luminance change of transmitted light owing to change in optical property of polyester resin during cure reaction. For this test, sensing area is the optical fiber sensing area. The second test without using optical fiber is performed to investigate the luminance change of transmitted light in GFRP during cure reaction. For this test, sensing area is the area between the LED and the photo diode. The last test is planned to monitor the luminance change of the transmitted light though the thickness direction for not only cure monitoring but also strain monitoring after curing.

Photo-diodes of BS500B by Sharp Co. are used for the optical sensors here. To measure the luminance of transmitted light using the photo-diodes, a luminance meter circuit shown in Fig.5 is employed. Using this circuit, change of luminance is converted to electric voltage change. The conversion rate from the luminance to the electric voltage is 1lx to 1mV. The increase of the output voltage, therefore, means the increase of the transmitted light power in the present study.

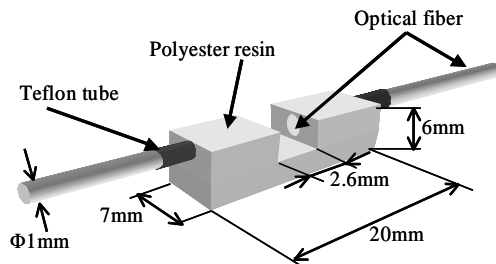


Fig. 4(a) Sensing area in polyester resin

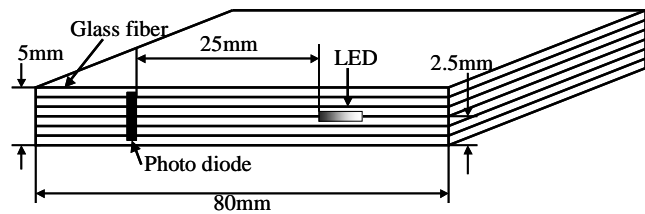


Fig. 4(b) Sensing area in GFRP

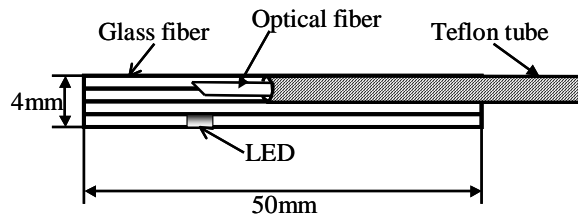


Fig. 4(c) Sensing area with optical fiber in GFRP

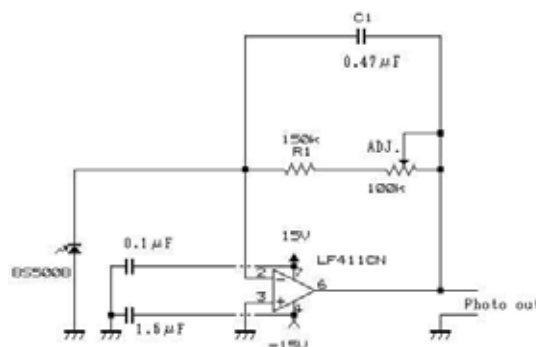


Fig. 5 Optical power meter circuit

Results and discussion

Polyester resin results. Fig.6 (a) shows the results of the luminance change during cure reaction in polyester resin. The left ordinate is the measured luminance change, the light ordinate is the measured cure index of the polyester resin and the abscissa is curing time. The

luminance of the transmitted light decreases with the increase of Cure Index. The light-intensity change of transmitted light converges after four hours. And the cure index is almost over 95% after four hours.

GFRP results. Fig.6 (b) shows the result of the luminance change during cure reaction in GFRP. The left ordinate is the measured luminance change, the right ordinate is the measured cure index of the polyester resin and the abscissa is curing time. The luminance of the transmitted light decreases in polyester resin with the increase of Cure Index. The luminance change of the transmitted light in GFRP, however, increases with the increase of Cure Index. This increase is supposed to be caused by the agreement the refractive index of polyester resin with the refractive index of glass fiber.

GFRP with optical fiber results. Fig.6(c) shows the result of the luminance change during cure reaction in GFRP with plastic optical fiber. The left ordinate is the measured luminance change, the right ordinate is the measured cure index of the polyester resin and the abscissa is curing time. The luminance of the transmitted light increases with the increase of Cure Index. This increase of the luminance is same as the luminance change shown in Fig.6 (b). The light-intensity change of transmitted light converges after 4 hours. And the cure index is almost over 95% after 4hours.

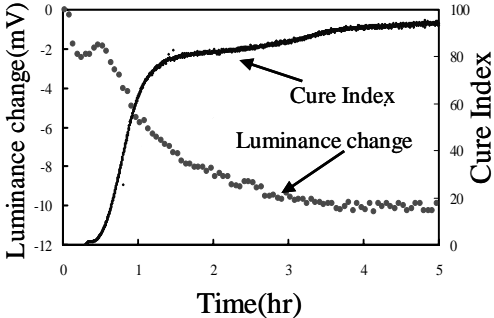


Fig. 6(a) Luminance change in polyester resin

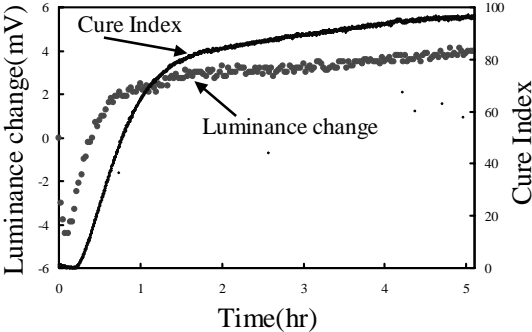


Fig. 6(b) Luminance change in GFRP

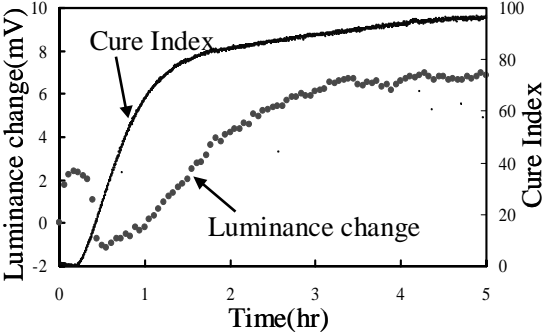


Fig. 6(c) Luminance change in GFRP with plastic optical fiber

Comparison of polyester resin results with GFRP results. The luminance change of polyester resin decreased with the increase of cure Index. In the polyester resin experiment, the light from LED is transmitted in the optical fiber and the light is emitted into the target object. As the refractive index of the polyester resin changes during cure reaction, the refractive index of the polyester resin leaves that of the core of optical fiber. As the refractive index of the polyester resin leave that of the core of optical fiber, the scattered light at boundary surface between polyester resin and core of optical fiber increases. Therefore, the luminance change of polyester resin decreased with the degree of cure of polyester resin.

However, the luminance change of GFRP increased with the increase of cure Index. As the refractive index of the polyester resin changes during cure reaction, the refractive index of the polyester resin approaches closely to the refractive index of the glass fiber. As the refractive index of the polyester resin approaches to the refractive index of the glass fiber, the degree of transparency of the entire GFRP increases. Therefore, the luminance change of GFRP increased with the degree of transparency of GFRP.

Conclusion

A new cure monitoring method with the luminance change of the transmitted light is proposed. This method is applied to simple polyester resin and glass/polyester composite. The luminance of the transmitted light in polyester resin decreases with the increase of cure index. The luminance change of the transmitted light in GFRP, however, increases with the increase of Cure Index. These systems can be used for cure monitoring.

The luminance change of the transmitted light in GFRP with plastic optical fiber increases with the increase of Cure Index.

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