MONITORING AND SIMULATION OF DISTRIBUTION OF DEGREE-OF-CURE OF CFRP BY REFRACTIVE INDEX MEASUREMENT

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Introduction

It is very important to optimise cure condition of large and complex-shaped FRP for reduction of manufacturing cost. Recent technology of real-time in-situ process monitoring may help to develop a real-time control system of cure process. In the present paper, the optical fiber sensor which can measure refractive index was used to estimate degree-of-cure of CFRP in real time. The experimental results were compared with results of cure process simulation.

Experimental methods

The cure monitoring system developed by our laboratory has a SLD light source, optical fiber sensor with distal end and an optical circulator. The intensity of reflection light at the boundary between glass and resin was measured for calculation of degree-of-cure.

For manufacturing FRP, epoxy resin (ARALDITE LY5052, hardening: ARADUR 5052 CH) was employed as matrix resin, carbon cross of thickness 0.2mm and grass cross of thickness 0.1mm, as reinforcement.

In the present study, we prepared two kinds of configuration for the experiments. Figure 1(a) shows the configuration of single-point measurement of CFRP. The preform consisted of 10 carbon cloths and the sensors were embedded in the center layer. The experimental configuration for measuring distribution of degree-of-cure of GFRP is shown in Figure 1(b). The preform consisted of 60 glass cloths and the sensors were embedded in the bottom, center and top layers. Large temperature gradient was generated due to the large thickness and low thermal conductivity of GFRP.

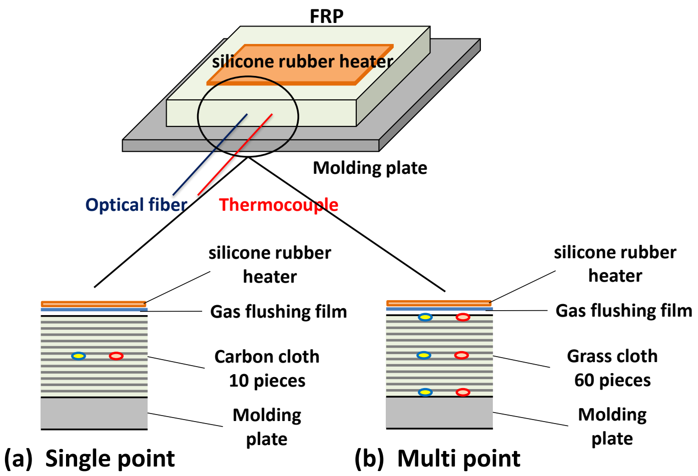

Figure 1: *Experimental set-up and stacking configurations for cure monitoring of CFRP and GFRP.*

Results and discussions

In the present paper, we propose the method of real-time estimation of degree-of-cure using combination of real-time measurement and simulation of degree-of-cure. Figure 2 shows relationships between degree-of-cure curves measured by the single-point measurement of CFRP, temperature and curing time. In the graph, simulation results of degree-of-cure using a kinetic model (Kamal model) were also plotted. When the degree-of-cure is more than 0.2, degree-of-cure was estimated using the kinetic model where the initial value of degree-of-cure is measured by the optical fiber sensors. It was shown that the estimated degree-of-cure curve agreed very well with the measured curve. From this result, it appeared that degree-of-cure could be estimated precisely at real-time by an accurate kinetic model for cure reaction and in-situ monitoring result of degree-of-cure. Using this method, we can control molding temperature so that degree-of-cure becomes 1.0 at the time we desired. For example, the temperature control using this method was demonstrated in Figure 2. It is shown that cure reaction finished at 110 minutes by changing heating rate and isothermal temperature.

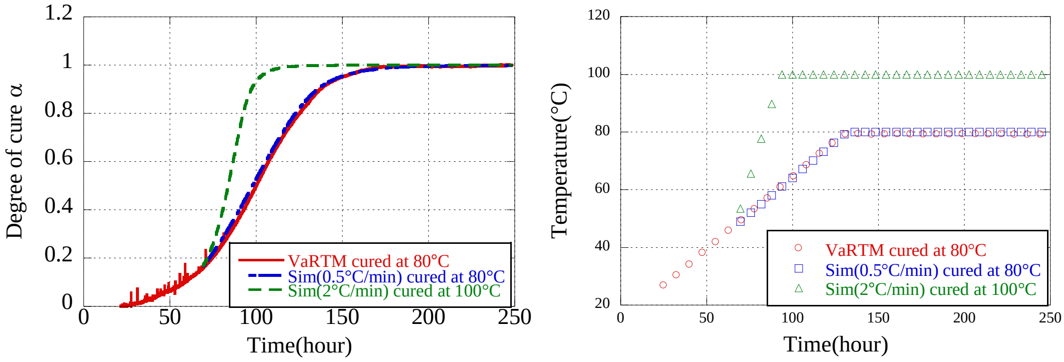

Figure 2: *Experimental and simulated degree-of-cure curves and temperature of CFRP*.

Figure 3 shows relationships between degree-of-cure curves measured by the multi-points measurement of GFRP, temperature and curing time. In the left graph, simulation results of degree-of-cure were also plotted. From the right graph, it was found that large temperature gradient occurred during cure process. Final temperatures of the upper, middle and lower parts were 78°C, 65°C and 53°C, respectively. Since FRP of thickness was 5.6mm, temperature gradient was 4.5 °C/mm.

The left graph shows that he estimated degree-of-cure curve agreed very well with the measured curve. Therefore, it appeared that the simulation model made using data measured by optical fiber sensors had good accuracy to predict degree-of-cure. However, it was found that accuracy of the model at the lower part, that is, when the temperature was 53ºC, was lower than the other parts. Improvement of the model at lower temperature should be tried for conducting more precise prediction.

From the degree-of-cure curves, it can be seen that cure process delayed due to the large temperature gradient. The completion times of curing reaction of the upper and middle parts were 2 and 3 hours. The degree-of-cure curves at the lower part shows that the cure reaction did not complete after 4.5 hours. These information obtained by our system is useful to control cure process of FRP apparently.

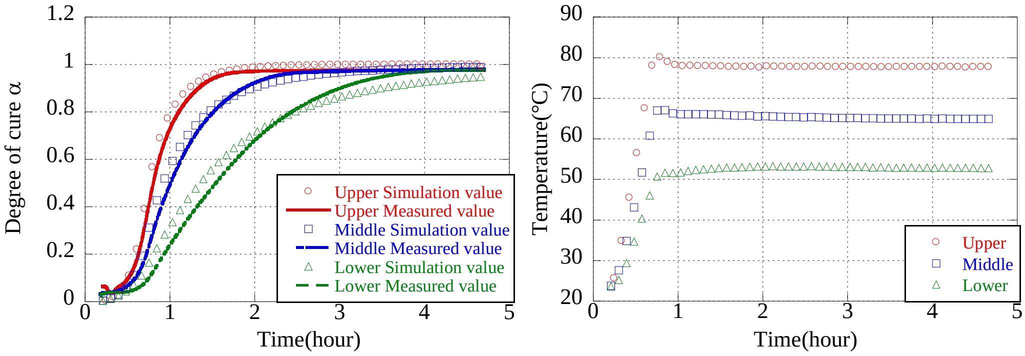

Figure 2: *Degree-of-cure and temperature curves of the thick GFRP measured by multi-points measurement system.*

References

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