RESIN IMPREGNATION BEHAVIOR IN THICK CARBON FIBRE COMPOSITE WITH A CORNER DURING VARTM PROCESS

H. Nakatani[1*], K. Adachi[1], K. Osaka[1]

[1] *Department of Mechanical & Physical Engineering, Osaka City University, 3-3-138 Sugimoto, Sumiyoshi, Osaka 558-8585, Japan.*
*Corresponding author (hayatonakatani@imat.eng.osaka-cu.ac.jp)

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Introduction

Vacuum assisted Resin Transfer Moulding (VaRTM) process impregnates resin to fiber preform using difference in pressure between atmosphere and vacuum, and attracts attention as a method to mould FRP at relatively low cost. Resin impregnation behavior in the fiber preform during the process is not understood exactly, and the formation of dry spots is a problem that should be avoided. It is said that a resin distribution media which is incorporated on the fiber preform as a surface layer has a significant effect on resin impregnation behavior by adding resin flow in out-of-plane direction [1,2]. The further investigation of resin impregnation behavior can be expected by evaluating the amount of resin supplied by the out-of-plane flow. In this study, multipoint measurements using embedded fiber optic sensors and numerical analysis for resin flow during VaRTM process for thick CFRP with corner are carried out to understand the resin impregnation behavior in the corner where dry spots can easily occur due to change in local cross-section area for resin flow.

Experimental procedure

40 plies of plain woven carbon fiber fabric (100 mm x 40 mm, T300, Toray) were stacked on an aluminium mould with a right angle corner and were covered by resin distribution medium (GREENFLOW 75, Airtech) as shown in Figure 1(a). The numbers 1 to 8 in the figure indicate position of fiber optic sensors inserted in the fiber preform. During the resin infusion arrival time of resin at each sensor was detected by recording change in intensity of Fresnel's reflected light from edge of optic fiber.

Numerical simulation

A simulation package based on control volume / finite element (CV/FEM) method approach was employed to numerically evaluate the resin flow with a cross-sectional view. In this approach governing equations based on Darcy's law and equation of continuity are solved by using finite element method to obtain fill factor for each node, then arrival time of resin or flow front can be then plotted. Figure 1(b) shows the analytical model using triangular elements with the definition of direction for anisotropic coefficient of permeability in fiber preform. Here K_{DM}=6.78×10^{-9} [m^2], K_{f1}=5.83×10^{-11} [m^2] and K_{f2}=1.56×10^{-12} [m^2] were used.

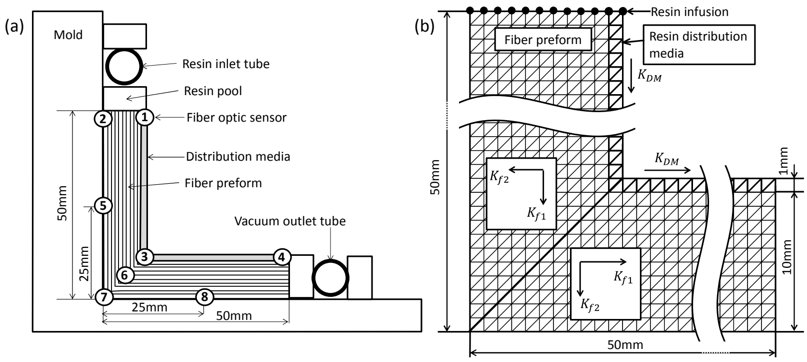

Figure 1: *Schematic of (a) experimental setup and (b) analytical model for resin impregnation.*

Results and discussion

Experimentally obtained arrival times of resin are shown in Table 1 with the start time of 0 s when the impregnation of resin was detected by sensor 1. Arrival times for sensor 1, 3 and 4 indicate that the resin proceeded in the distribution medium completely within 20 sec. On the other hand, much more time is required for resin to arrive at the bottom of the fiber preform near the tool side especially for the deepest region of the corner, and this can result in formation of dry-spot. It should be noted that resin cannot yet fill the corner part even if the impregnation seems to be finished by visual inspection from surface since arrival time of resin at sensor 4 is much faster than that of sensor 7.

Figure 2 shows simulated results for flow front shape for every 100 sec after the initiation of resin infusion. It is obvious that predicted time to fill the part near the corner and the bottom tool side is much longer than that for other parts. The predicted arrival times of resin at corresponding sensor locations of the infusion experiments are also provided in Table 1. Overall, the predicted times are shorter than those obtained by infusion experiment. Even for the surface part near the resin distribution medium additional 9 seconds are required for resin to reach the sensor 4 in the experiment. These results suggest that high permeability of the distribution medium cannot be maintained due to not only nesting with the preform and bag compliance but also collapse at the corner. One can see that there is a significant difference in the arrival times at the corner (sensor 7) and the bottom tool side (sensor 8). Possible reasons for those are that clearance gaps between fiber fabrics due to the waviness are occurred at the corner since stiffness of the vacuum bag prevent atmospheric pressure to be appropriately applied to the surface. As a result out-of-plane flow of resin through the distribution medium, which has a great effect on the impregnation behavior, was not produced.

Conclusion

Resin impregnation behaviour in thick CFRP laminates with a corner under VaRTM process was evaluated by experiments using multiple fiber optic sensors and numerical analysis. Compared to the resin flow near the surface with resin distribution medium, the arrival of resin at the bottom of corner was much delayed. Decrease in permeability of the distribution medium due to the collapse and clearance gaps between fabrics at the corner should be modelled to achieve an agreement of the numerical prediction of resin impregnation behaviour and the experimental results.

Table 1: *Arrival time of resin.*

Sensor No.	1	2	3	4
Experimental results [s]	0	2.5	14.0	18.7
Numerical results [s]	0	0	2.3	9.9
Sensor No.	**5**	**6**	**7**	**8**
Experimental results [s]	267.9	293.4	1254.3	1178.6
Numerical results [s]	64.3	121.1	222.0	333.6

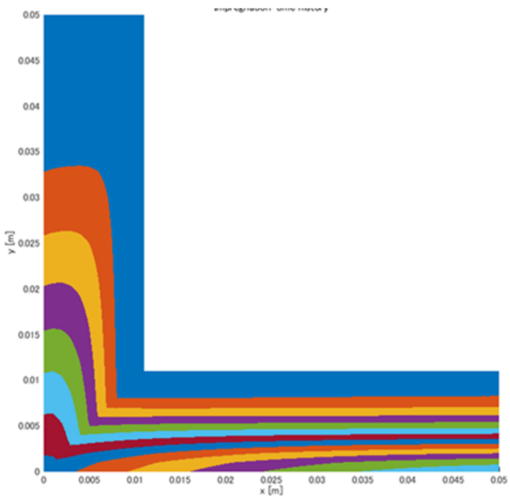

Figure 2: *Simulation results for resin impregnation in the thick CFRP with a corner.*

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References

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