The 10th International Conference on Flow Processes in Composite Materials (FPCM10)
Monte Verità, Ascona, CH – July 11-15, 2010

WETTING PROCESS OF FIBROUS POROUS MEDIA BY RESIN IN VARTM(VACUUM ASSISTED RESIN TRANSFER MOLDINGS) SYSTEM

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ABSTRACT: We focus on a flow of resin in fibrous porous as a fundamental study for vacuum assisted resin transfer moldings (VARTM) system. VARTM system realizes lower-cost process than other methods. We have inherent problem on VARTM, however, of the void formation in the resin transfer and hardening processes. It is very important to understand and control wetting process in the fibrous porous media to resolve the problems and to realize better FRP at lower cost. In the present study, the resin is driven by the pressure difference in the mold, where bundle(s) of the fibers are settled with a designated alignment. The resin flows above/beneath the bundles are simultaneously observed with two CCD cameras. Post image processing is applied to the original successive images to detect the leading edge of the resin advancing in the bundle(s). It is found that the resin does flow into the gap region between the bundles because of the capillary effect. This result indicates that the resin would penetrate into the gap in the bundle regardless of the net direction of the pressure gradient. It is also found that a counter flow against the direction of the net flow of the resin is always formed at the edge of the bundle. These flows result in collisions of the resin inside the bundles, which lead a formation of the voids in the composite material.

KEYWORDS: VARTM, glass fiber, resin, wetting process, visualization

INTRODUCTION

Fiber reinforced plastics (FRP) are one of composite materials that have been applied in a variety of industrial and engineering fields. The FRP is stronger in mechanical characteristics than the metals. The cost to process fine composite material, however, is significantly high, so that new processing schemes with higher producibility at lower cost have been desired. Vacuum assisted resin transfer molding (VARTM) is a potential processing method to realize low-cost-impact FRP with easier processes. Wetting in fiber bundles by the matrix is a key issue in the process to determine the dynamical features of the materials; if we have a poor wetting process, 'voids' where the resin does not bite the fiber surface emerge at the interface between the two. And, it is quite hard to predict positions where voids emerge in the bundle. These voids would lead most susceptible to failure. There should be no arguments on that the voids between the resin and the fibers would trigger unexpected and severe collapse of the products. There exist a large number of preceding research works to predict the flow patterns of the resin in the fiber bundles. We have little knowledge, however, on the wetting process of the fibers by the resin. In the present study, we focus on the wetting behaviors including the void formation in the resin-fiber bundle(s) system in which the resin is driven by the pressure difference.

EXPERIMENTS

Experimental Setup

Experimental apparatus is schematically shown in Fig. 1. In the present VARTM system, fiber bundles (as fibrous porous media) are placed on the glass mold, and the resin is supplied to the bundles by sucking through the mold (Fig. 1 (a)). Peel cloth and mesh are settled on the bundles to realize a flow path of the resin. Two tubes are positioned at both ends on the plate as the resin inlet and outlet. Vacuum-bag film is tightened on the whole system with sealant tape in order to seal the fiber bundles in the mold. The resin outlet is connected to vacuum pump through the resin pool. The present system realize the pressure difference up to 95 kPa between the mold and the atmosphere. We employ an epoxy resin JER 819, product of Japan Epoxy Resins Co., Ltd, as the test fluid. A bundle of glass fiber of (50 mm, 40 mm, 0.4 mm) in (length, width, thickness) is used as a unit of fibrous porous. We examine several cases of porous media in the present study as shown in Figs. 1 (b) and (c); (b) a single layer and (c) double layers of the bundles. We vary the direction of the bundle, parallel and perpendicular in the case of a single layer, and the combinations of those in the case of (c). Experimental materials are summarized in the Table 1.

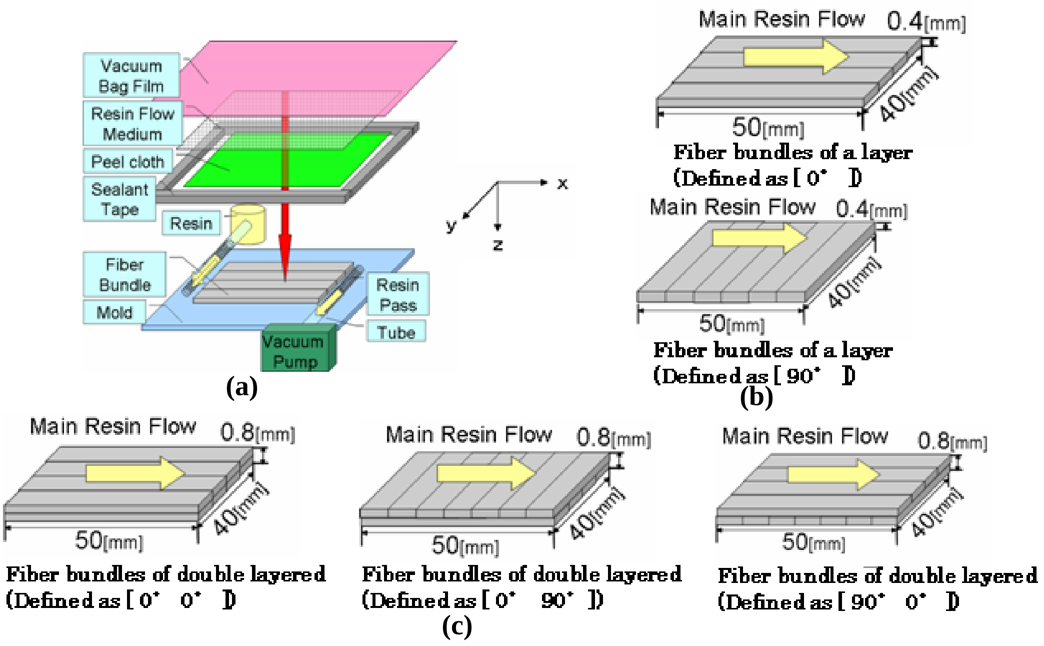


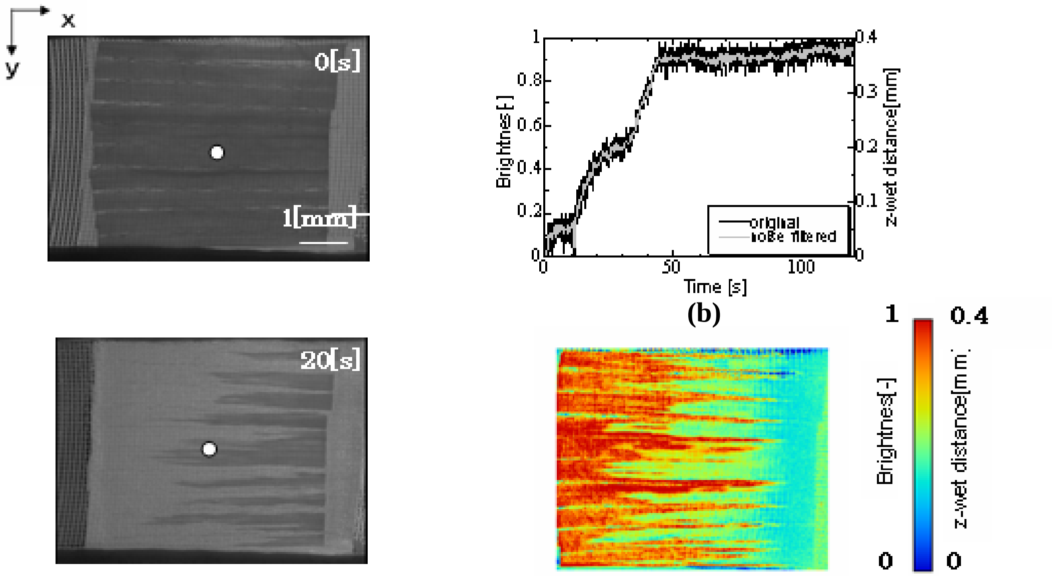
Fig. 1 (a) Schematics of experimental apparatus for vacuum assisted resin transfer molding, and fiber bundles as the fibrous porous media in the case of (b) a single layer and of (c) double layers.

Table 1 Experimental materials

Reinforcement	unidirectional glass knitted fabric
	mass : 684 g/m^3 stitching yarn : polyester diameter of fiber :10 µm
Matrix	epoxy resin
	viscosity(25 °C) : 375 mPa·s specific gravity(25 °C) : 1.10

Methods for Analyzing

Variation of the brightness of the detected images observed from the bottom corresponds to the advancement of the resin penetration in the fiber bundle. Through the careful observation, it is confirmed that minimum brightness before transferring the resin corresponds to 'perfectly dry' state, and the maximum after transferring the resin corresponds to 'perfectly wet' state. In the present study, we assume a linear correlation between the penetration depth of the resin (wet region) in the direction of the bundle thickness and the brightness in the detected image. Figure 2 indicates a typical example of the brightness variation at the bottom of the bundles in the case of a layer [0 °]; Figure 2 (a) shows the variation before (left) and at 20 s after the start of the resin transfer (right), and (b) a temporal variation of the normalized brightness at the measuring point as indicated in (a). Figure 2 (c) shows an evaluated resin penetration distribution from the image as shown on the right in Fig. 2 (a).



(a) (b) (c)

Fig. 2 Typical example of the brightness variation at the bottom of the bundles in the case of a layer [0 °] under he pressure difference of 95 kPa between the mold and the atmosphere. (a) The variation before (left) and at 20 s after the start of the resin transfer (right). The resin flows from left to right in the frame. (b) A temporal variation of the normalized brightness at the measuring point as indicated in (a). (c) Valuated resin penetration distribution from the image at t = 20 s as shown in (a).

RESULTS & DISCUSSION

Visualization on resin flow

Progresses of the resin penetration for different cases of the fiber bundles are shown in Fig. 3. Each column indicates temporal variation of the brightness detected from the bottom of the bundles. It is found that the resin does prefer flowing into the gap region between the bundles regardless of the pressure gradient. Noted here that areas enclosed with black circles indicate voids that have never wetted through the experiment in the present range of the pressure difference ΔP. Such voids never appear without any layer of the fiber bundles aligned perpendicular to the pressure gradient (90 °). Under the present experimental conditions, air would remain in the fiber bundles in the mold even though pre-sucking by the vacuum pump in the mold is made prior to the drawing the resin into the mold.

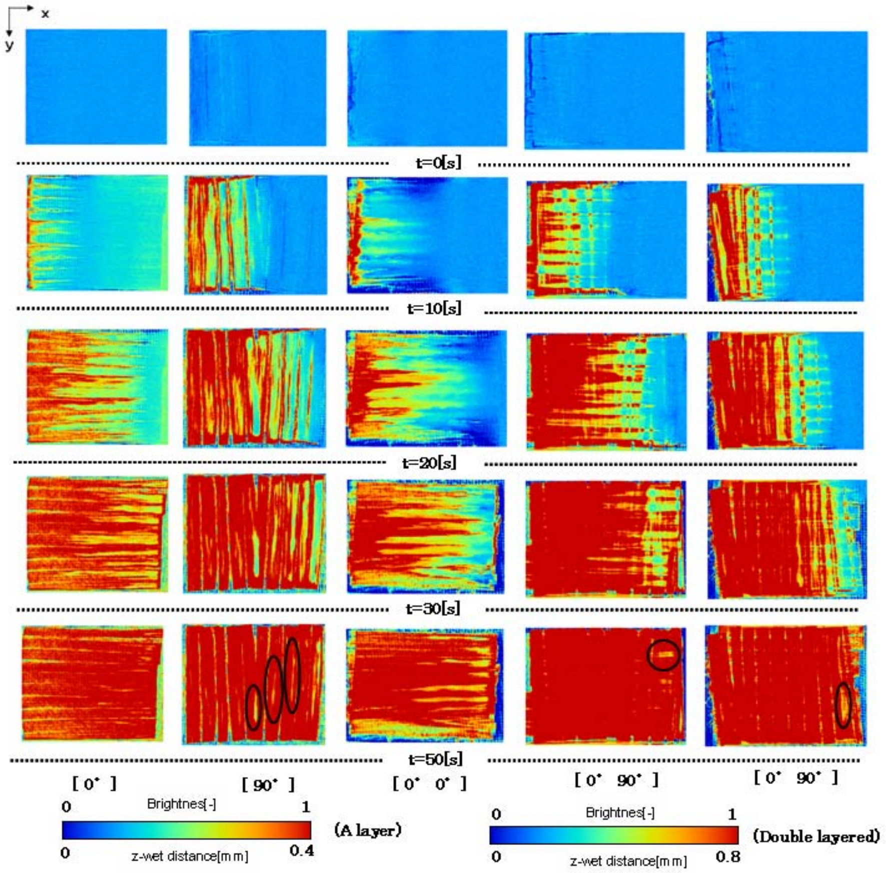
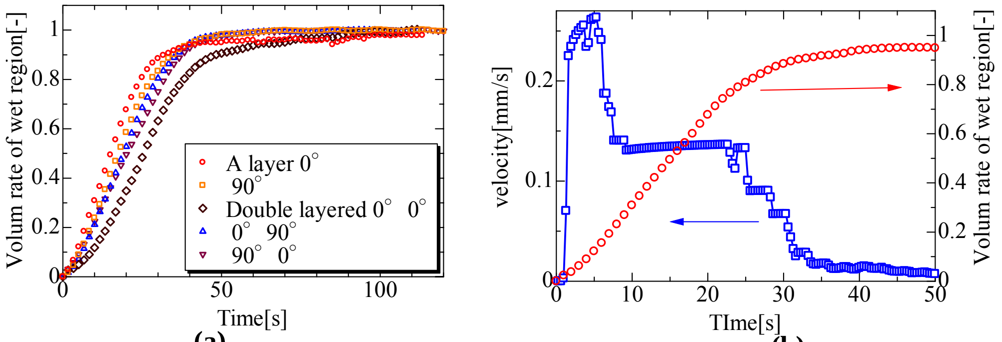


Fig. 3 Progresses of the resin penetration in the cases of a single layered [0 °], [90 °], and double layered [0 ° 0 °], [0 ° 90 °], and [90 ° 0 °] detected from the bundle bottom.

Volume of wet region

Figure 4 (a) indicates the growth of volume ratio of wetted region in the fibrous porous media of different alignments by the resin under ΔP = 95 kPa. The volume ratio of wetted region is defined as the ratio of the region where the resin penetrates in the fiber bundle to the whole volume of fiber bundles. In any case, the gradient is almost constant at 0.8 [-] of the volume rate regardless of the fiber bundle direction nor the layer numbers. Figure 4 (b) indicates the temporal variation of the mean resin velocity obtained from the temporal variation of the volume ratio of the wetted region under the assumptions aforementioned in the case of a single layer of [0 °] under ΔP = 95 kPa. When velocity is constant, the gradient of volume rate of wet region is constant. And the velocity falls, the gradient of volume rate of wet region become gradual.



(a) **(b)**

Fig. 4 (a)Temporal variation of volume ratio of wetted region in the bundles of different alignments by the resin under ΔP =95 kPa. (b) Mean velocity of the resin through the temporal variation of the volume ratio in the bundles (blue) obtained from the volume ratio of the wetted region (red) for a single layer of [0 °] under ΔP = 95 kPa.

CONCLUDING REMARKS

We carry out an experimental study on wetting process of the fibrous porous media by the resin; especially focusing on the resin flow in fiber bundles in vacuum assisted resin transfer moldings (VARTM). Through the visualization of the resin flow above/below the bundles, it is found that the resin does flow into the gap regions between the bundles because of the capillary effect regardless of the net direction of the pressure gradient.And it is also found that a counter flow against the direction of the net flow of the resin is always formed at the edge of the bundle. These flows result in encounter regions of the resin inside the bundle. This leads a formation of the voids in the composite material. We evaluate the temporal variations of the volume ratio of the wetted region and the mean resin velocity in the bundles. A part of this study is financially supported by Mitsubishi Rayon Co., Ltd.

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