# IMPREGNATION PROCESS OF VISCOUS FLUID IN WOVEN FIBRE BUNDLES DRIVEN BY PRESSURE DIFFERENCE

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## Introduction

In order to realize high-efficiency and high-quality resin transfer molding processes, it is of great importance and indispensable to understand impregnation and void formation processes within the fibre bundles by the viscous fluid. The characteristics of void formation has been discussed as a function of capillary number in the systems of unidirectional stitched fibres [1,2] and woven fibres [3] and so on. The mechanism of void formation in the resin transfer molding processes has been proposed [4,5], and was investigated by numerical approaches [6]. Arai et al. [7] investigated effect of stitching yarn as well as the substrate on which a single-layer fibre bundles are settled via three-dimensional numerical simulation. In the present study, we focus on the impregnation process in a single layer of woven fibre bundles settled between in-parallel smooth walls via experimental and numerical approaches.

## Experiments and numerical simulations

In the experiment, we prepared a cuboid as a mold. There existed two taps; the one is connected to the pump (DA-60D, ULVAC Kiko, Inc.) to reduce the pressure inside the mold. The pressure regulator (NVR200-01, KOGANEI) and pressure meter (VPC-A4-S-A-1, VALCOM Co., Ltd.) were installed between the pump and the tap to control the pressure difference exposing to the mold. The other tap was connected to the reserver of the test fluid. Silicone oils of 350 cSt in kinematic viscosity (Shin-Etsu Chemical Co., Ltd) were employed as the test fluid. The woven glass fibres of 17 μm in diameter and 550 g/m$^2$ in areal weight or area density were used as the test fibre. Behaviours of the contact line of the test fluid and generated bubbles were observed by a charged-coupled devise (CCD) camera (C9300-024, Hamamatsu Photonics, K.K.). The frame size and the frame rate were of 640×480 pixel$^2$ and 33.3 frame/sec (fps), respectively. We measured local pressure of the mold at three different points along the centre line in parallel to the pressure gradient with the piezo pressure censors installed to the top wall. The pressure difference $\Delta P$ was ranged from -5 kPa to -90 kPa in the gauge pressure. In prior to each experimental run, sucking of residual air was conducted for more than 60 min for degassing.

In the simulation, we employed moving particle semi-implicit (MPS) method for solving the fluid behaviour consisting of deformable free surface. We prepared the CAD data of the woven fibre bundles as the target geometry. A single-layer fibre bundles was set between the smooth rigid surfaces as the top and bottom walls. A uniform initial velocity was assigned to the fluid at the inlet. Periodic boundary condition was applied to the both sides.

## Results

Figure 1 indicates a typical example of the impregnation of the silicone oil under $\Delta P$ = -5 kPa in the middle region of the bundle obtained by the experiment. The liquid penetrates the fibre bundles from left to right in the figure. The edge of the test liquid (or, free surface of the silicone oil) proceeds along the warps, and then follows between the warps.

Figure 2 indicates a numerical result of the impregnation under the contact angle against the fibre $\theta_f$ = 0 deg. Impregnation process similar to that observed by the experiment is well reproduced. In the presentation, quantitative discussion on the temporal variation of the impregnation with the velocity profiles will be made.

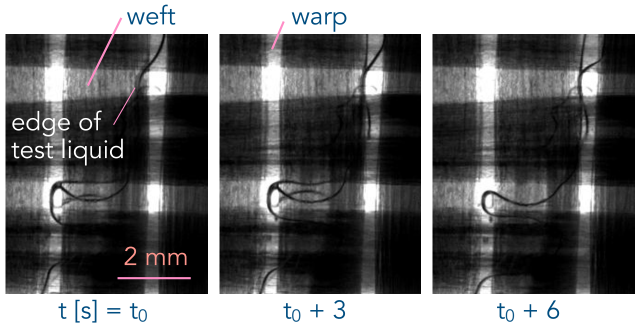


**Figure 1:** *Top view of impregnation process of silicone oil of 350 cSt in woven fibre bundles under $\Delta P$ = -5 kPa.*

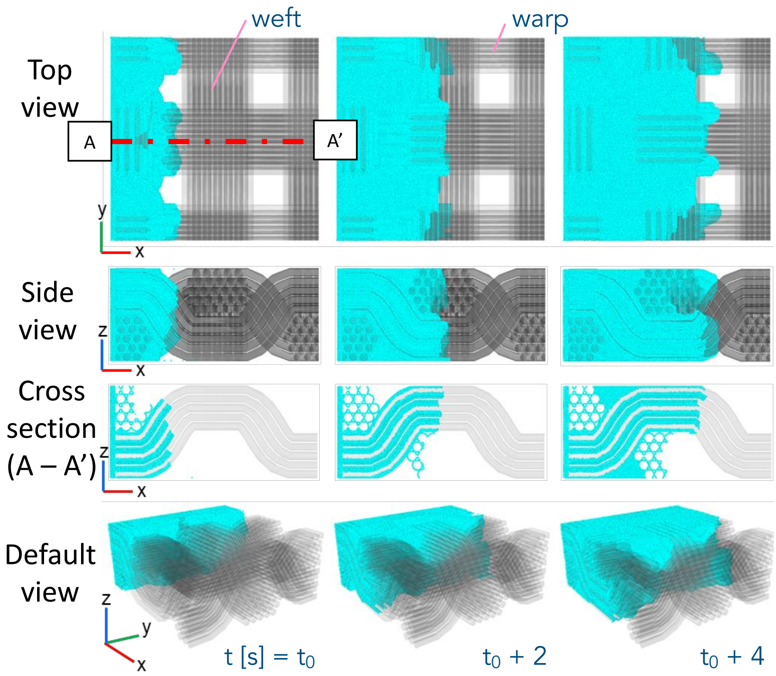


**Figure 2:** *Temporal variation of impregnation in woven fibre bundles under $\theta_f$ = 0 deg by MPS method.*


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