VISUALIZATION OF FLOW OF VISCOUS FLUID AND SUSPENDED PARTICLE DEPOSITIONS IN IMPREGNATION PROCESS IN ONE-DIRECTIONAL FIBERS IN VARTM

Takuya ARAI[1*], Satoshi NAGAI[1], Nazurah Binti SHEIKH OMAR[2], Hiroshi SHINDO[2], Hiroki SUGIOKA[1], Toshihiro KANEKO[2,3], Ichiro UENO[2,3]

[1] *Div. Mechanical Engineering, Graduate School of Science & Technology, Tokyo University of Science*
[2] *Dept. Mechanical Engineering, Fac. Science & Technology, Tokyo University of Science*
[3] *Research Institute for Science & Technology (RIST), Tokyo University of Science*
[1~3] *2641 Yamazaki, Noda, Chiba 278-8510, JAPAN*
[*] Corresponding author (7512002@alumni.tus.ac.jp)

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Introduction

Vacuum assisted resin transfer molding (VARTM) is one of the manufacturing method to make fiber reinforced plastics (FRP). In this method, the resin is driven by a pressure difference within fiber bundles. In order to prevent void formation within fiber bundles, and to predict and control suspended particle distribution, it is necessary to elucidate the behavior of the resin impregnation into the fibers and deposition of fine particles in a complex geometry. In the present study, we focus on the impregnation process to the one-directional fiber bundles by the viscous fluid and deposition of fine particles suspended in the viscous fluid in VARTM method by a series of the experiments and the numerical simulations with the particle method.

Experiment

In our experiments, we employ epoxy resin and silicone oils (2 cSt, 20 cSt and 350 cSt) as the test fluids, and one-directional glass fiber bundles as the test fibers. The diameter of the fiber is of 23 μm. We vary the pressure difference ΔP of 30 kPa, 60 kPa and 90 kPa to drive the test fluid to the fiber bundles in a mold. We evaluate impregnation time and void rate at upstream, midstream and downstream. In order to visualize the flow patterns and deposition of the fine particles, we mix fluorescent particles of 13 μm in diameter as the test particles as done by Sugioka et al. [1]. Through the experiments, we monitor temporal variations of the impregnation and particle behaviors (Fig. 1). The impregnation time is evaluated as functions of the pressure difference to drive the fluids and the viscosity of the test fluid.

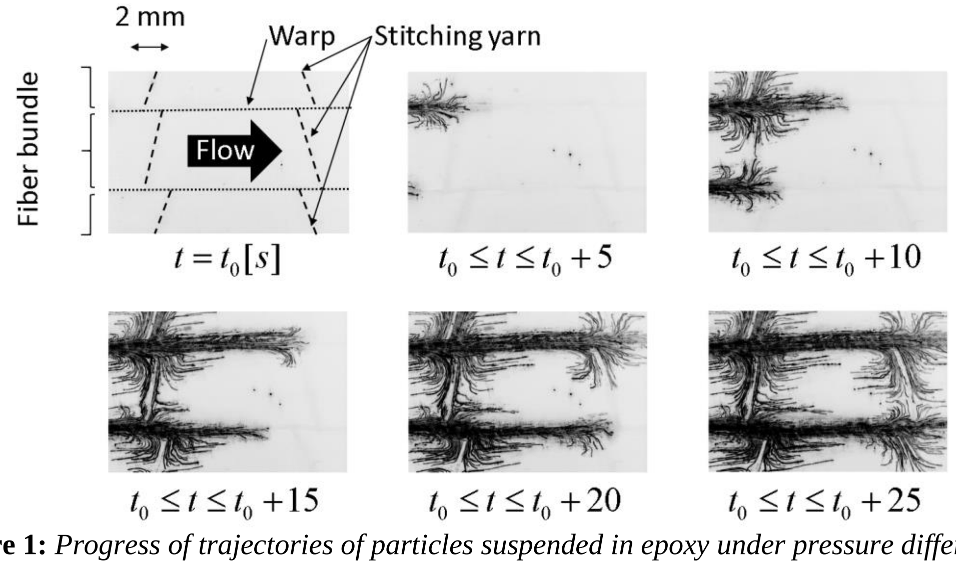

Figure 1: *Progress of trajectories of particles suspended in epoxy under pressure difference ΔP= -90 kPa.*

Numerical simulation

In this numerical simulation, we employ the particle method, especially moving particle semi-implicit (MPS) method [2]. We conduct a series of simulations with three components in two phases, in which non-compressible viscous fluid with or without spherical particles is injected into the fiber bundles. Fibers, warps and stitching yarn are modeled to have perfect wetting characteristics. Fiber volume fraction is kept about 60 %, and the ratio of the diameters of fiber and spherical particle is decided to follow the experimental condition. We employ Reynolds number Re and capillary number Ca as the governing parameters.

Results and discussion

Through the experiments, we reveal that voids are easily generated around stitching yarn as indicated with multilayer systems by Ref. [3] even in the system of single-layer one-directional fiber bundles on the substrate. Further we reveal that mixed particles are easily deposited along the stitching yarn because of the flow opposite to the net flow affected by warp and stitching yarn. We show temporal variation of impregnation time, and voids fraction by changing a driving pressure difference and viscosity. Through the numerical simulation, we illustrate the behaviors of viscous fluid and suspended particles behavior in the fiber bundles and around stitching yarn. We reproduce a phenomenon of particles deposition around stitching yarn, and discuss correlation among the pressure fields, velocity fields and particle deposition.

References

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