PREDICTION ALGORITHM FOR TRANSVERSE PERMEABILITY OF UNIDIRECTIONAL FIBER REINFORCED COMPOSITE USING FLOW NETWORK

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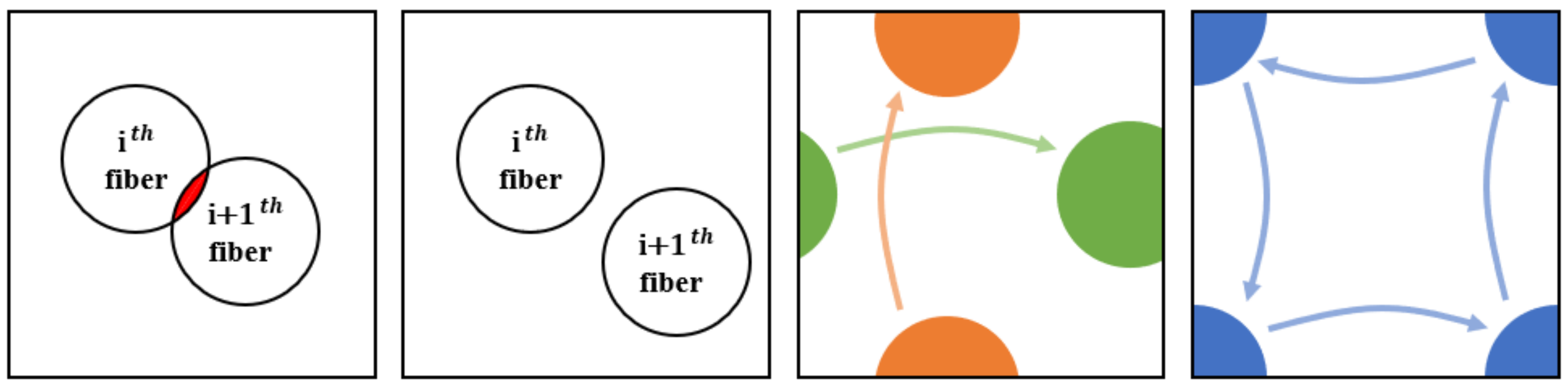
Introduction

Demand for composite materials is increasing in various fields. However, defects such as voids, inclusions, and delaminations may be introduced in composites during processing and fabrication, which causes variations in the physical properties of the composite material. In particular, the difference in the flow rate of the resin during the fiber impregnation process is one of the most dominant factors in the occurrence of defects. As shown in Fig. 1, entrapped air between the resins results in voids. Therefore, understanding the composite material manufacturing process is essential for quality improvement. In this study, an algorithm for predicting permeability, which is an important variable in the design of a manufacturing process, is proposed. In order to validate the suggested algorithm, the predicted permeability was compared to the results obtained by calculating permeability based on Darcy's law using the velocity field simulated by an established commercial program. The calculation time was shortened compared to the commercial program by using the flow network algorithm in the permeability calculation process.

Algorithm

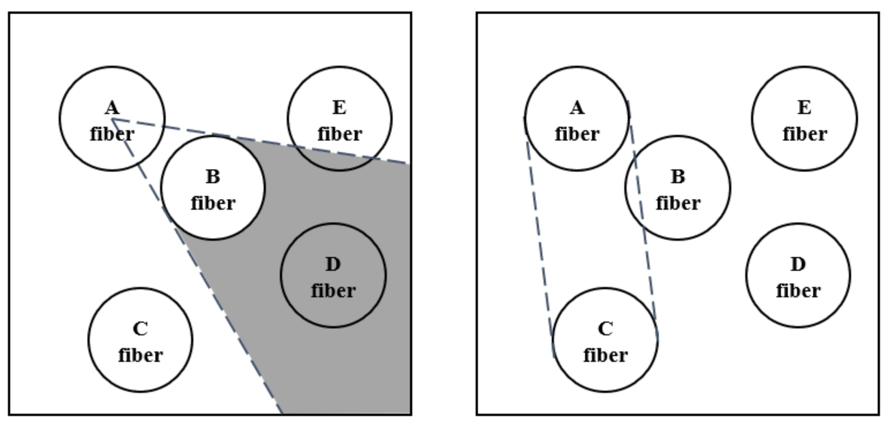
Representative Volume Element (RVE) Generation

◆ The RVE representing the internal shape of the continuous fiber-reinforced composite material was generated. The Nearest Neighbor Algorithm was implemented through MATLAB (MATLAB R2020b, Mathworks, USA). The periodic condition was applied to the edge.



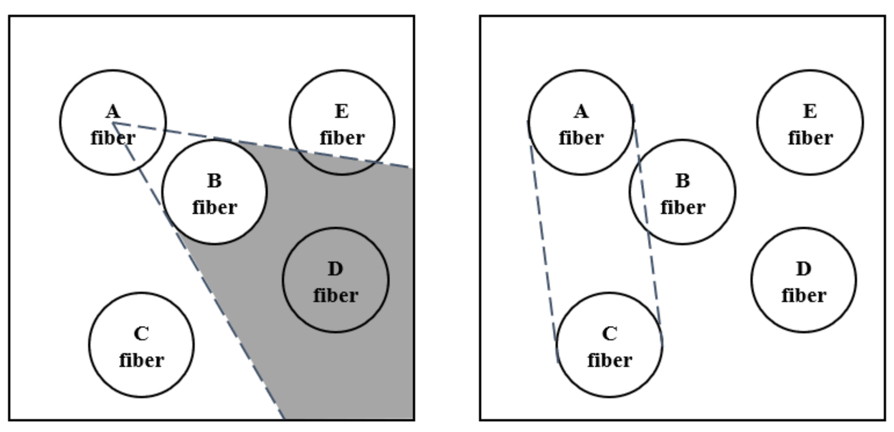
Selection of Valid Fiber Pairs

◆ The two rules were applied based on the angle and the exterior common tangent between the two adjacent fibers to select the fiber pair that resists resin flow.



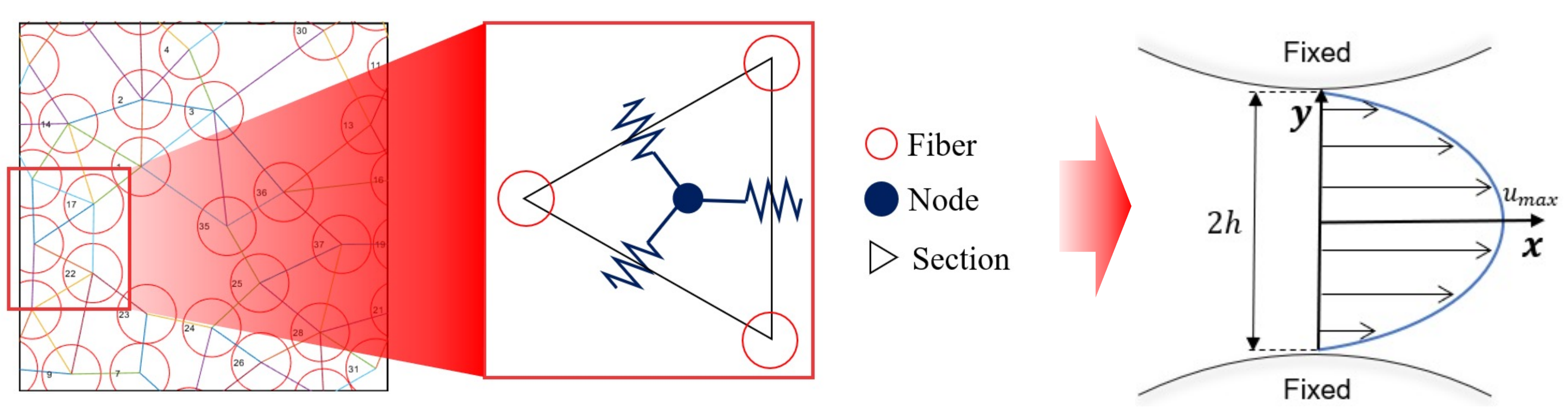
Section Dividing

◆ The interior space of RVE can be divided by polygon sections constructed by lines connecting the centers of valid fiber pairs. The section is the basis for defining the region when the pressure drop occurs.



Permeability Calculation

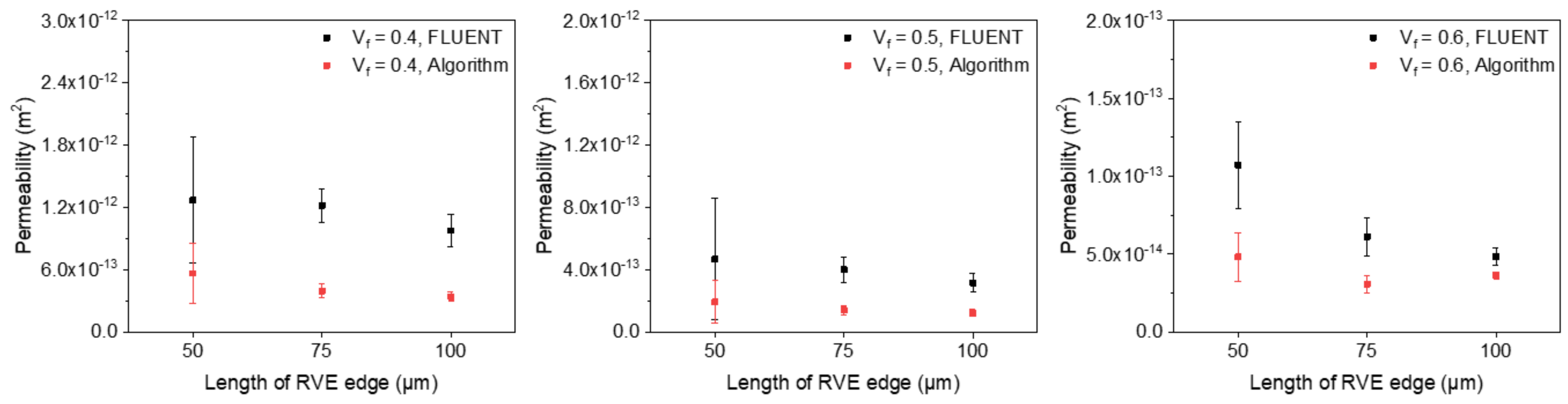
◆ The permeability was calculated by the flow network algorithm. The interior spaces and line segments of sections were treated as nodes and resistors in Nodal Circuit Analysis, respectively.



Algorithm

Equivalent length

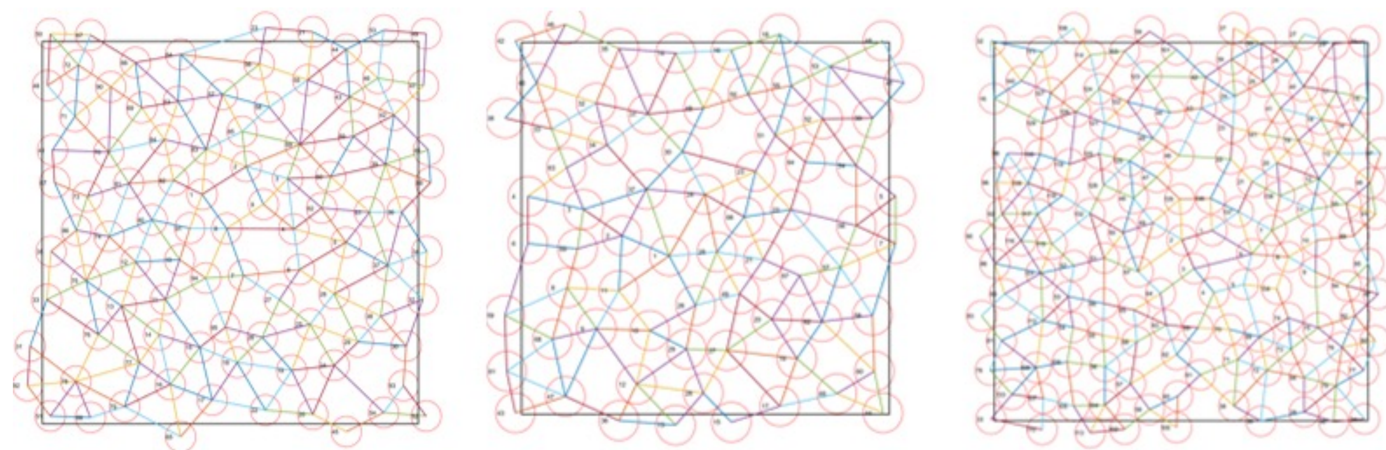
◆ The equivalent length is calculated by comparing the result predicted by Fluent (FLUENT 2020 R1, Ansys Inc., USA) and the prediction algorithm. The simulation was carried out with adherence to the conditions that satisfy Darcy's law, and the preservation of the no-slip condition was achieved by creating a suitable mesh configuration.



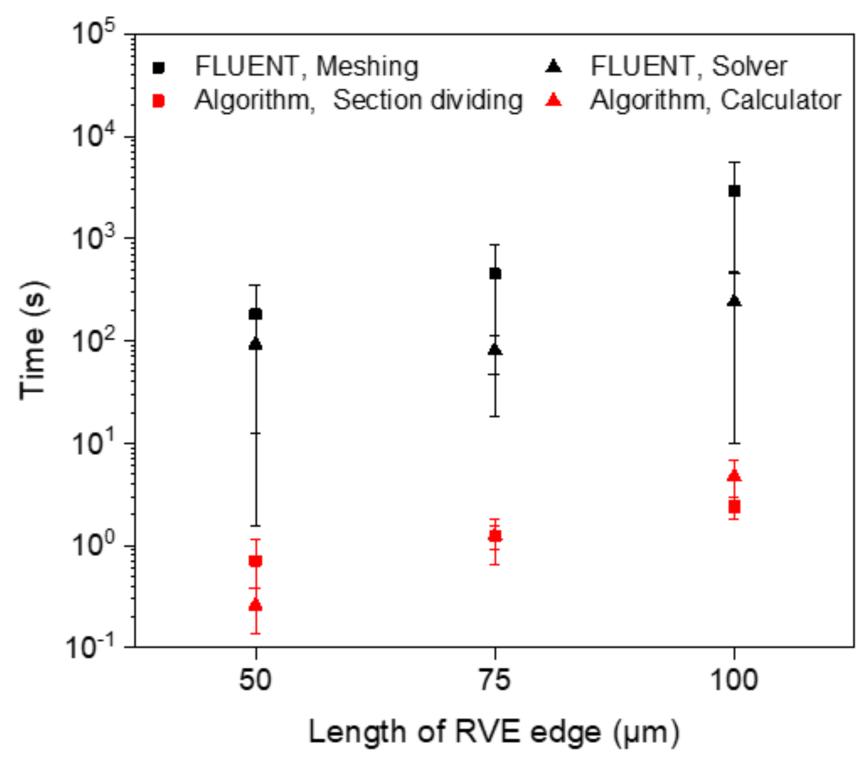
V_f	0.4	0.5	0.6
Equivalent Length (λ)	0.363	0.383	0.495

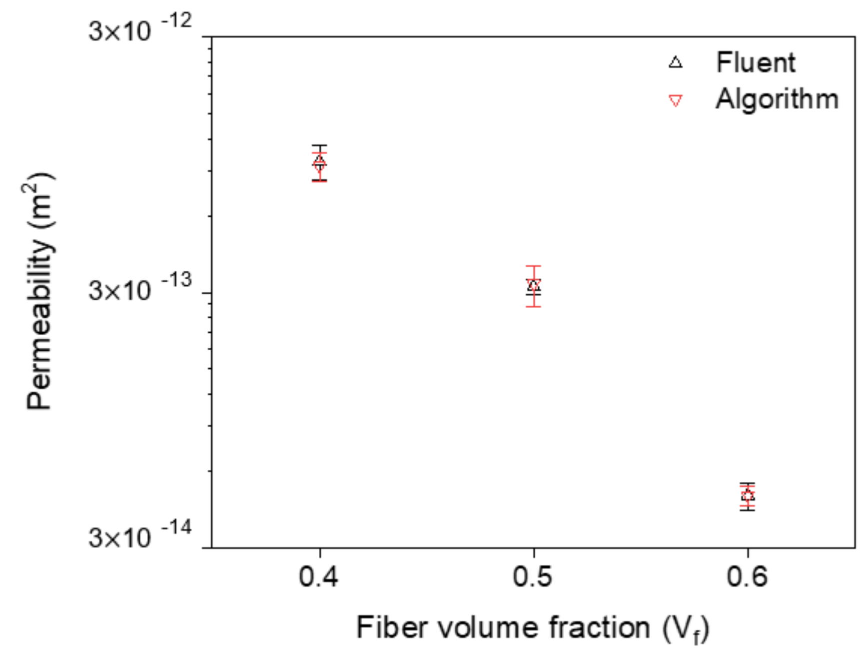
Results

RVE Generation & Section Dividing



Algorithm Result & Time Cost





Conclusion

This study proposes an algorithm for accurately predicting the permeability in transverse direction of continuous fiber-reinforced composites. The algorithm can take into account the porosity, internal fiber arrangement, and surface properties of the fiber, which collectively influence the impregnation properties of the reinforcement. Existing techniques struggle to incorporate all of these effects in their predictions of the permeability. To address this, the proposed algorithm considers the porosity and fiber arrangement through the shape of fibers within the RVE. Valid fiber pairs are selected based on two criteria, considering the flow resistance. The velocity field of the resin, influenced by the material's surface properties, is represented as a function of inter-fiber distance, and the non-slip condition is reflected through an equivalent distance showing similar trends as the fiber volume fraction. The algorithm's validity is verified by comparing the calculated permeability with those obtained using commercial simulation tools in newly created representative volume elements, demonstrating close agreement across various fiber volume fractions. Additionally, a notable distinction was observed in the computational time between the algorithm and the commercial simulation tool.

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