PREDICTION OF PERMEABILITY IN RTM PROCESS FOR COMPOSITES BASED ON MULTI-SCALE APPROACH

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ABSTRACT

Composite material is an essential material for light-weight design as it shows high specific strength, and specific stiffness. Conventional composite material was costly. It was often used for the area which does not matter the price per weight. Today, as mass production method was introduced in composite material field, the cost of it is getting lower and lower, thus even automotive industry adopt to use composite for manufacturing car.

RTM(Resin Transfer Molding) is the well-known method for manufacturing composites and RTM has a benefit for manufacturing complexly shaped product. In RTM process, key material property is permeability that shows how well resin flows. Traditional method to gain permeability is performing experiment regarding flow velocity measurement. However because of anisotropic material property of composite material, design variation such as change of lay-up, and ply induce requirement for new experiment. It triggers additional cost of experiment and delay of design.

Therefore it is proposed to do virtual test using Multi-scale approach to derive permeability which was measured by experiment per each design change. Multi-scale approach is consisted of 3 step:Unit-cell(Micro-scale), Tow(Meso-scale), Woven(Macro-scale) analysis. By applying proposed virtual test method, number of measurement will be minimized and design process for composite will be shortened.

1 BASIC THEORY

1.1 Darcy's law

The governing equation for RTM permeation use Darcy's law used for porous media. 1 dimensional Darcy's law is like Eq.1 [1]

$$\mathrm{u} = \frac{K}{\mu}\frac{\Delta P}{L} \tag{1}$$

1.2 Mohr's circle for off-axis permeability

As Composite material shows anisotropic material property, ply angle should be considered in design. Mohr's circle can be used for describing anisotropic material property like Eq.2 [2]

$$K_{xx} = K_{11}cos^2\theta + K_{22}sin^2\theta \tag{2}$$

1.3 Permeability for laminate

Lay-up sequence for laminate should be considered as usual composite material is not provided in a single off-axis ply. For multi-ply lay-up permeability should be considered in averaged value like Eq.3 [3]

$$K_{xx}^{eq} = \frac{\sum_{i=1}^{n} K_{xx}^{(i)} \cdot t^{(i)}}{t} \tag{3}$$

2 NEWLY SUGGESTED APPROACH

2.1 Multi-scale approach for permeability of Unit-cell as micro-model

Introduced virtual test is new method which does not use traditional permeability measuring experiment. The method is down below. First, select the Unit-cell model consisted of one fiber and matrix like Fig.1. Flow analysis is performed for unit-cell model and flow velocity can be calculated as a result. Put flow velocity in to Darcy's laws, then Permeability can be inversely calculated.

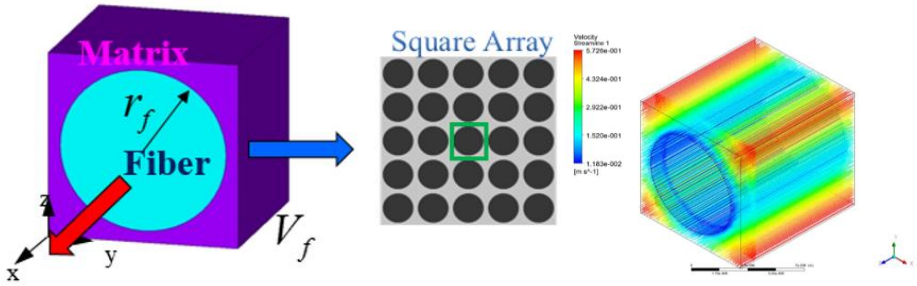

Fig. 1 Unit-cell model

2.2 Multi-scale approach for permeability of Tow as meso-model

Tow can be considered as porous media. Tow is consisted of bunch of fibers and vacant space like Fig. 2. In case of Tow model Berdichevsky method can describe longitudinal permeability by volume fraction, and diameter of fiber like Eq.4 [4]

$$K_l = \frac{d^2}{32V_f}\left(ln\frac{1}{V_f^2} - (3 - V_f)(1 - V_f)\right) \tag{4}$$

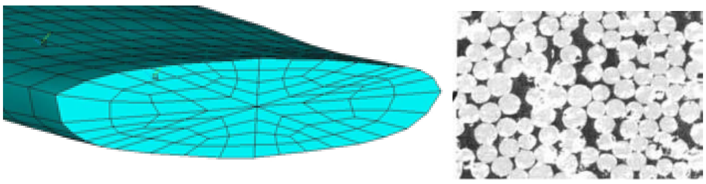

Fig. 2 Tow model

2.3 Multi-scale approach for permeability of Woven as macro-model

While tow is considered as porous media, inter-yarn is considered as channel flow as it is spacious comparing to intra-yarn like Fig3. Thus coupling of porous media with darcy's law and inter-yarn with stoke equation is required.

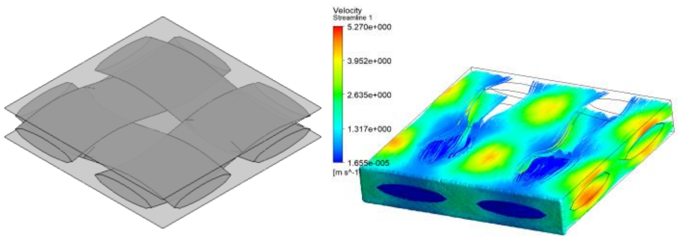

Fig. 3 Woven model

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