Prediction and validation of mechanical properties of high fiber volume fraction composites using virtual random fiber generator and in-situ material testing

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1. Introduction

The importance of the identification and prediction of mechanical properties of composite materials is increasing in the automotive and aerospace industries. Through numerous experimental, analytical, and computational studies, the prediction of mechanical properties in the longitudinal direction of fiber reinforced composites has been already proved to be highly accurate. However, many prediction methods are currently being studied due to poor accuracy in the prediction of properties of the transverse direction of the composite [1]. This work predicts the mechanical properties of the representative volume elements (RVEs) for high fiber volume fraction composites made by various virtual random fiber generators and validates the prediction method by comparing them with in-situ material test results.

2. FE modeling of RVEs with interphase

According to our previous studies [2], we predicted the effective elastic properties of the RVEs of unidirectional fiber reinforced composites using random sequential expansion (RSE) and random fiber removal techniques (RFR), and as a result, we found that a prediction with RFR algorithm was closest to the actual test value than the predicted results using other existing algorithms.

However, there is still about 10% underestimation in the prediction of the transverse elastic properties —this is because the RVEs as seen in Fig. 1(a) consists of fiber and matrix. Instead of that, recent studies have predicted the properties of composite by adding a thin layer between fiber and matrix, termed interphase [3, 4].

This work also predicts the effective elastic properties and strength in the transverse direction with the RVEs of unidirectional composites consisting of fiber, interphase, and matrix, as shown in Fig. 1(b), and verify the prediction methods by comparing with the test result. To evaluate the properties of interphase properly, an in-situ material testing device was manufactured, simulating a four-point bending test, and its test results were used to figure out the strength and elastic modulus of interphase by inverse analysis.

3. Prediction of the interphase mechanical properties by inverse analysis

Effective elastic properties of interphase were predicted by comparing effective elastic properties of RVEs modeled with fiber, interphase, and matrix with the test results.

Given that the interphase is transversely isotropic, it was assumed that among five independent elastic properties ($E_1, E_2, \nu_{12}, \nu_{23}, G_{23}$) of the interphase, three interphase properties (E_1, ν_{12}) corresponding to the longitudinal direction are the same as those of matrix, and the remaining properties (E_2, ν_{23}, G_{23}) were assigned as independent variables. Then, among prediction results of effective elastic properties of RVEs using various independent variable values, interphase elastic properties that predict closest results to test results was identified.

However, due to the lack of close results to test results from various interphase properties, the interphase thickness was also assigned as an independent variable.

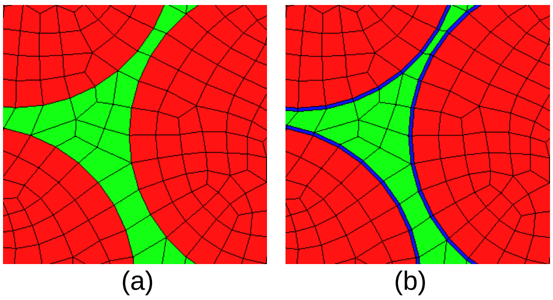

Fig. 1 Configuration of FE models consisting of (a)fiber/matrix, (b)fiber/interphase/matrix

Table 1 Mean value of the predicted effective elastic properties of E-glass/MY750 composites (V_f = 60%)

Methodology	E_1 (GPa) (Error %)	E_2 (GPa) (Error %)	G_{21} (GPa) (Error %)

Random fiber removal [2]	45.881 (0.62%)	13.814 (-14.73%)	5.257 (-9.83%)
RSE [2]	45.876 (0.61%)	13.161 (-18.76%)	4.966 (-14.82%)
Mori-Tanaka	45.8 (0.44%)	11.019 (-31.98%)	4.318 (-25.93%)
Measured(ref.)	45.6	16.2	5.83

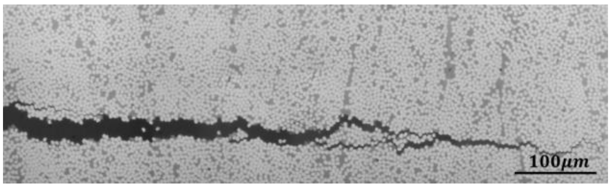

Fig. 2 A micrograph image of the fractured unidirectional composite

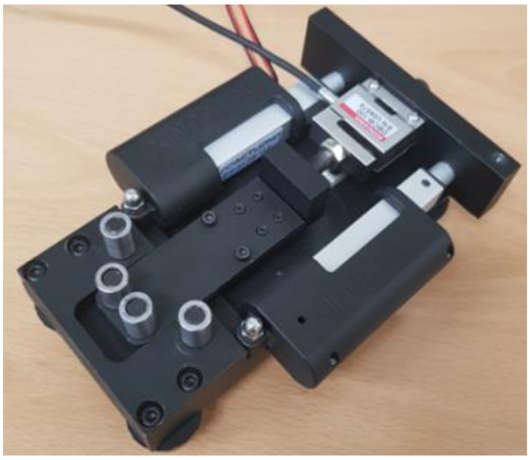
Fig. 3 In-situ 4-point bending tester

4. Prediction and validation of the fracture strength

The fracture strength in the transverse direction of the RVEs of composites was predicted using finite element simulation. To simulate damage behavior of material, the cohesive zone model (CZM) of interphase was employed. Equivalent displacement boundary conditions acting on the specimen in the 4-point bending test were gradually applied to observe progressive damage behavior of the RVE of composites.

In addition, the prediction scheme of this work is validated by comparing with in-situ four-point bending test of the actual composite material.

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