MODELING THE STRESS-STRAIN BEHAVIOR OF TRIAXIALLY BRAIDED COMPOSITES

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Introduction

The architecture of textile reinforcement affects the deformation and failure behavior of the textile reinforced composites. Constitutive laws derived from homogenized equivalents, whether through analytical solutions [1-3] or multi-scale schemes [4-6], have often been used in finite element analysis (FEA) where the meso structures of the textile composites are not represented explicitly. Although these approaches are sufficient in obtaining the elastic response of the structures, their effectiveness in predicting the progressive failure behavior of textile composites is not satisfactory.

The meso structure can be represented by detailed FE models where fiber tows and the matrix are represented explicitly using solid elements and modeled with respective material properties [7,8]. So far the computational cost is too high for detailed FE models to be used in design applications.

The meso structure can also be considered in FE models by a sub-cell approach [9-12]. Similar to the "Mosaic model" in micromechanics analysis [2], the sub-cell FE models consider the meso structure of textile composites through simplified RUC representations. However, instead of homogenizing the RUC, the sub-cells are preserved and represented explicitly in FE models such that each sub-cell has its distinctive property. In this way, an RUC FE model with explicit meso structure can be constructed with a small number of elements. The technique has also been demonstrated in impact simulation of braided composite plate structures [11].

The construction and property of the sub-cell may be established through a variety of techniques such as micromechanics analysis [9], equivalent [10,11], or idealized laminate [12]. In the idealized laminate approach, the sub-cell is represented by a laminate with plies representing fiber tows and matrix, and the fiber tows are modeled by a UD composite. For triaxially braided composites, a simple straight line model has been developed to obtain the volume fraction of axial tows and braider tows in the sub-cells [12], Fig.1. This paper examines the use of this approach in the analysis of three triaxially braided composites, namely 0/±30, 0/±45 and 0/±60.

Results and Discussions

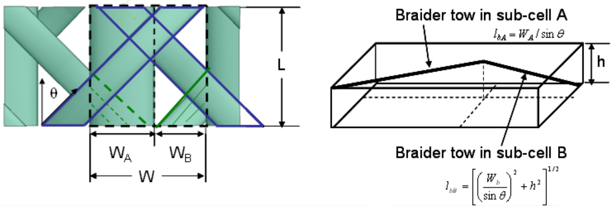
The carbon fiber braided composite was fabricated with 80k Fortafil axial tows, 12k Grafil braider tows, and Ashland Hetron 922 matrix [6].

Composite fiber volume fraction

In addition to obtaining the fiber tow volume fractions in a sub-cell, the procedure in Fig.1 yield a prediction for the overall fiber volume fraction in the composite. A comparison between prediction and experimental data can be made, which provides a mean to validate the straight line model.

Fig.2 compares the predicted and experimentally measured composite fiber volume fraction for the three types of braided composites in three geometrical shapes, a plaque, a square tube and a circular tube. The RUC width W increases with the braiding angle. For the same braiding angle, W varies with the geometrical shapes. The plaque had the smallest W value, i.e. a relatively tight braid, and hence yielded a highest composite fiber volume fraction. The tubes had much larger W values. Further more, square tubes are tighter than the circular tubes. The overall comparison between the predictions and experimental data is rather good with the exception of 0/±30 circular tube.

The above results clearly indicate that using the properties measured in specimens from the plaques,



	Sub-cell A	Sub-cell B
Axial tow	$V_{f,aA} = \frac{\pi d_a^2}{4} n_a L$	0
Braider tow	$V_{f,bA} = \frac{\pi d_b^2}{4} n_b 2 l_{bA}$ $= \frac{\pi d_b^2}{2} n_b \frac{W_A}{\sin\theta}$	$V_{f,bB} = \frac{\pi d_b^2}{4} n_b 2 l_{bB}$ $= \frac{\pi d_b^2}{2} n_b \left[\left(\frac{W_b}{\sin\theta}\right)^2 + h^2\right]^{1/2}$

Fiber fraction in a sub-cells
$V_{kl} = \frac{V_{f,kl}}{V_{f,UD} W_l h L}$ $k=a, b, l=A, B.$
Matrix fraction in a sub-cell
$V_{m,l} = 1 - \sum_k V_{kl}$
Fiber fraction in unit cell
$V_f = \frac{\sum_k \sum_l V_{kl}}{WhL} = \frac{\sum_k \sum_l V_{kl}}{W^2 h \tan\theta}$

Fig.1 Determine the volume fractions of axial tow, braider tow and matrix in sub-cells A and B based on a straight line model [12].

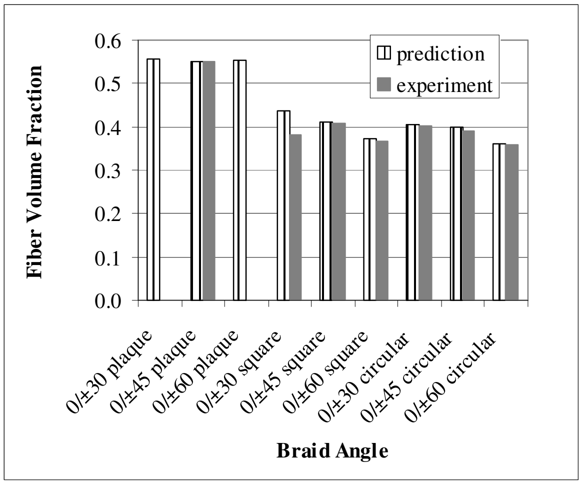
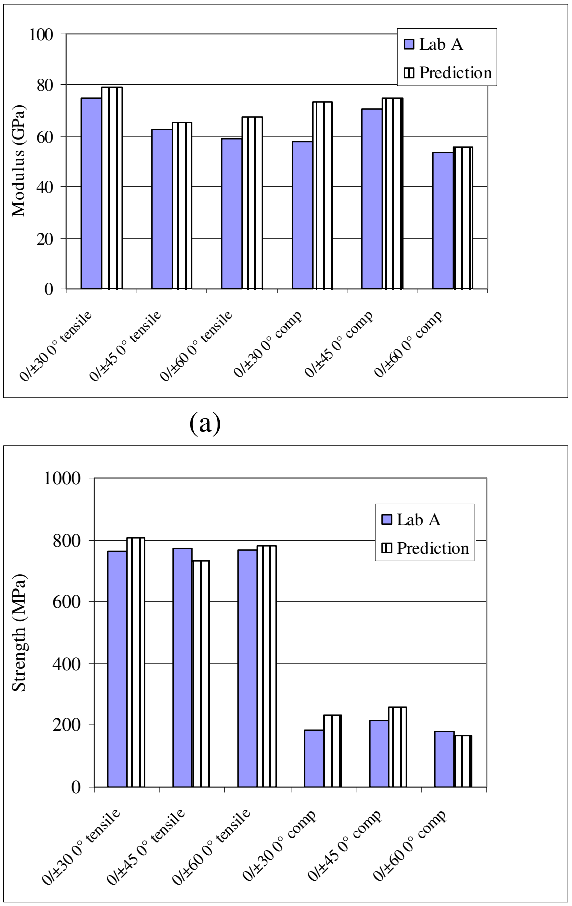


Fig.2. Comparison of the predicted and measured composite fiber volume fraction.



(a)

(b)

Fig. 3 Comparison of the predicted and measured tensile and compression (a) moduli and strengths (b) in the 0° direction for the three types of braids.

a common place in current FEA including crash and impact [13-15], can lead to significant errors in the analysis of braided structures.

Stress-strain responses

The FE models for tensile and compression experiments using specimens taken from braided were developed for the three types of braided composites. To investigate the behavior of three types of braids under tensile and compression loading along 0º and 90º directions, a total of 12 FE models were built.

As an example, Fig. 3 provides comparisons between the predicted and measured properties for the 0º direction for the three types of braids. The predictions were excellent for 0/±45 composite. The prediction for other two types of braided composite is good for 0º tension and fair for 0º compression. The predictions in the 90º direction provided the correct trend for the three types of braided composites. The predicted values, however, are generally higher.

Conclusion

The stress-strain responses of three triaxially braided composites were studied using a sub-cell approach. The predicted composite fiber volume fraction is in excellent agreement with experimental values. For the stress-strain properties, the predictions were excellent for 0/±45 composites, and good for 0/±60 and 0/±30 in the 0º direction. The prediction for the 90º direction for 0/±60 and 0/±30 are generally higher. This requires further investigations.

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