

A proposal of conventional FE-modeling for layered braided composites: comparison of numerical results with experimental results

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Abstract. A new FE modeling system for braided tube has been proposed. The input data are the shape of section of a braid, the braided angle, and the number of layers and the diameter of tube. The generated model has been verified by comparison with the experimental results and numerical ones. The mechanical properties for the tube have been analysed by the generated model and FEM code. On the other hand, the rigidity and the strength for the tube have been measured by three point bending and torsion tests. The experimental results have agreed with the numerical results. The agreement has encouraged that the proposed procedure can be applied to generate FE models for braided tubes with complex geometry.

1. Introduction

Braided tubes made of carbon fiber reinforce plastics (CFRP) have been widely used for various structures in automotive, civil engineering, sporting goods etc. due to their superior productivity and excellent features as performs [1, 2]. Moreover, they have a good feature that their mechanical properties can be controlled arbitrarily by several designing parameters such as braiding angles, tex of yarns, number of yarns and number of layers etc. (See Figure 1).

Controlling mechanical properties in practice, however, takes much effort because of many trial productions required under broad possibilities for the designing parameters. To ease the difficulty, finite element (FE) analysis has been invoked revealing relativity between the designing parameters and the mechanical properties such as stiffness, strength and internal stress etc. [3, 4]. We also have proposed a procedure to make braided models for FE analysis, whose structure of yarns is more precise than former models, presenting undulations by braiding and stacking of layers [5]. Further, we have implemented the procedure to software named “Composites Dream” which designers can operate easily.

This paper has reviewed the procedure for braided tubes and presented validation of a FE model generated by the procedure in virtue of comparing numerical results of the model and experimental results. A golf shaft with four layered triaxle braided has been modeled by the procedure. Cross-sectional observations of the model and the golf shaft have confirmed the similarity of structure of yarns. Further, comparing some tests (three-point bending and torsional tests) and FE analysis of them have validated the similarity of mechanical properties.



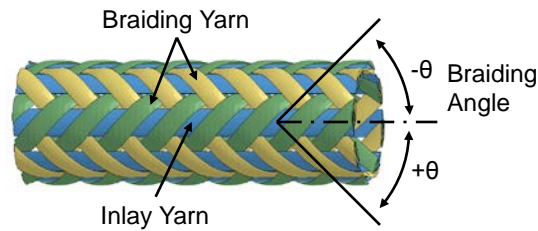


Figure 1. Structure of braided tube

2. Proposal model

2.1. Procedures

The modeling process is divided into three steps. The first step is to prepare shell elements and to determine the shape of cross-section of a bundle (Figure 2(a)). Width and thickness of the cross-section are estimated from thickness of each layer.

The next step is to duplicate the shell elements, and to generate solid elements for bundles by sweeping the shell elements along an axial direction of the tube with certain braiding angles (Figure 2(b)). In addition, the crimp can be represented by the sweeping trajectories whose radii change with a (periodic) spline curve with crimp height expected from thickness of each layer.

Finally, the generated FE-model packs up to the designed thickness of the tube (Figure 2(c)). The surfaces of solid elements contact with each other if some layers are applied. To preserve the tex of bundles in the calculation, the solid elements have an orthotropic material, and Poisson's ratios of them are 0.5. In order to remove redundant lengths generated by the compression of the packing, the thermal strain applies to reduce the lengths of bundles.

As example, Figure 3 shows several patterns of bundles that the procedure can generate. Figure 3(a) is for changing braiding angles, the degrees are 30, 45 and 60. And Figure 3(b) is for changing number of braiding bundles, the number are 4, 8 and 16.

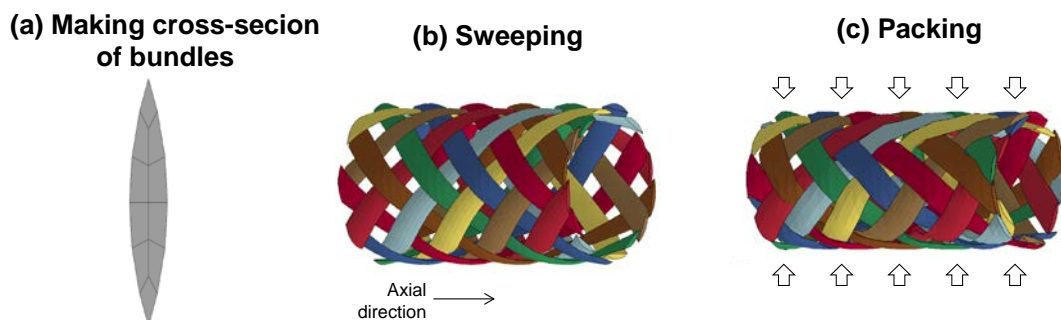


Figure 2. Proposal procedures to generate finite model of braided tube

2.2. Specimen

Figure 4 shows a golf shaft of braided CFRP tube used for validation. The length is 160 mm and the outer and inner diameters are 15.46 mm and 11.26 mm, respectively. The shaft consists of four layers and the specification is summarized in Table 1. A FE model of the tube generated by the proposed procedure is shown Figure 5.

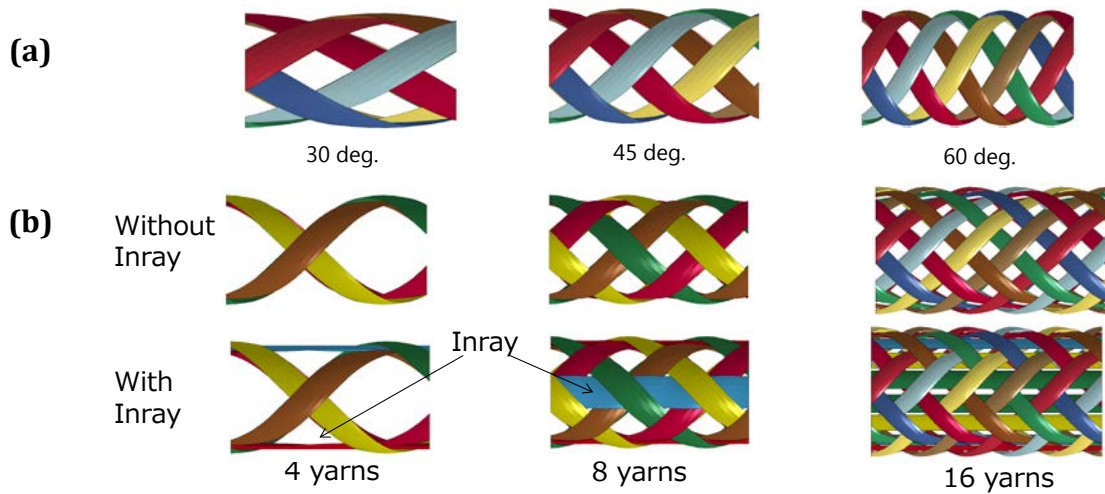


Figure 3. Examples generated by Composites Dream with some designing parameters (a)Changing braiding angle and (b)changing number of inlay

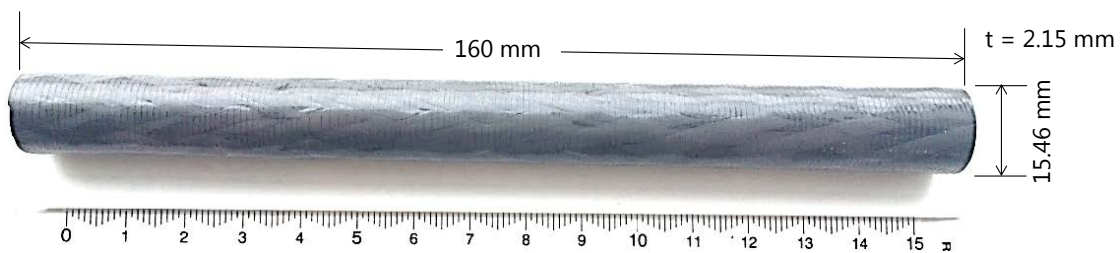


Figure 4. Golf shaft

Table 1. Specifications of the golf shaft

Position	No. of Ply	Tex	Number of Yarns		Braiding Angle
			Braiding Yarn	Inlay Yarn	
Inner layer ↓	1	12K	16	0	46 deg.
	2	12K	16	0	39 deg.
	3	12K	16	4	30 deg.
Outer layer	4	24K	16	8	19 deg.



Figure 5. Generated finite model of the golf shaft

3. Results and discussions

3.1. Cross-sectional observation

In order to validate the modelling procedure, the shape of bundles in a cross-section of tube is compared. Figures 6(a) and (b) show the cross-section of the golf shaft. They have two types which are perpendicular and parallel sections to longitudinal direction, respectively.

The cross-sections for each direction of generated FE-model are shown in Figures 6(c) and (d).

From Figure 6(a), it is revealed that the cross-section is filled with bundles closely. Figure 6(c) shows the generated model and also reveals that the bundles are in existence without gaps. From these figures, it is recognized that the initial shape of section of bundle like a lens can't keep anymore after the packing, and that the trend of geometry change of each bundle deformed agree well. However, the explicit evaluation will be necessary to the quantitative evaluation.

Figure 6(b) indicates the section for axial direction. The bundles exist in section area without gap. Figure 6(d) is the generated model by the proposed procedure.

Comparing the golf shaft and FE model by the procedure confirms that the shape of section of bundle is similar. Consequently, we can conclude that the proposed procedure can generate FE models for layered braided tubes.

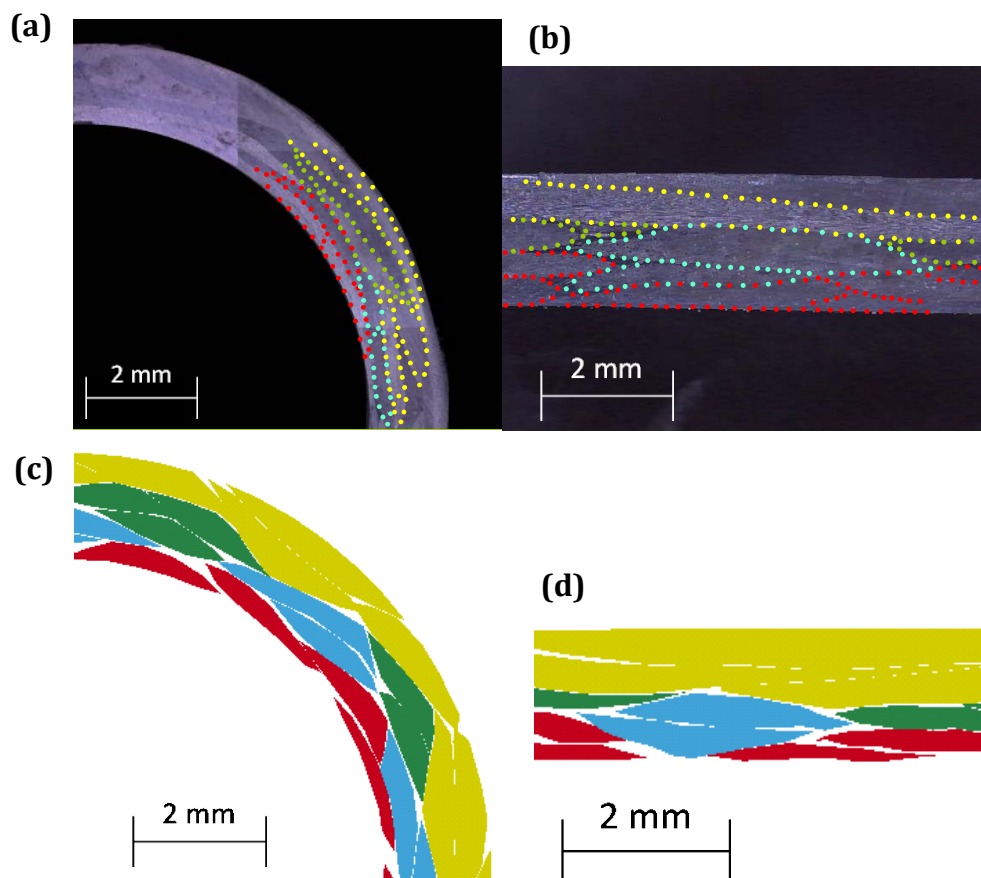


Figure 6. Cross-sectional images of the golf shaft and the finite model

3.2. Three-point bending test

Figure 7 shows the numerical and the experimental results for the three-point bending test. The span of bending test has been 120 mm, and the shapes of supporting and loading parts have been cylinder with 10 mm radius.

The analysis under three-point bending has been carried out by LS-DYNA. The engineering constants of CFRP bundle for analysis is shown in Table 2. The moduli have been estimated by Uemura's equation [6] with carbon fiber volume fraction $V_f = 54\%$ (experimental) and epoxy resin. As the strain criteria of compression, $F_{ec} = 0.25\%$ has been employed.

The experimental result in the Figure 7 shows elastic response by 0.5 mm of displacement and failure response after that. The numerical result has a good agreement with it.

Figure 8(a) shows the top view of the specimen after test. The position of loading nose is the line connected to triangles in Figure 8(a). Figure 8(b) shows the numerical results concerning the failure elements and the displacement d is 1.0 mm. The damage propagations of both results have similar situation.

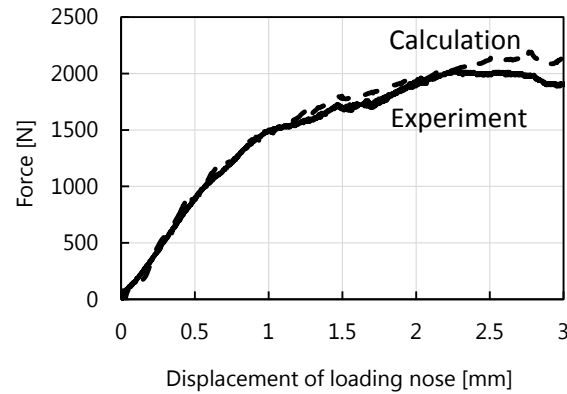


Figure 7. Load-displacement curves of the three-point bending test

Table 2. Engineering constants for bundles

Engineering constants			Description
E_1	140 GPa		Modulus of longitudinal (fiber) direction
E_2	6.91 GPa		Modulus of transverse direction
G_{12}	2.41 GPa		Shear modulus of longitudinal and transverse directions
G_{23}	2.74 GPa		Shear modulus of transverse directions
ν_{12}	0.427		Poisson's ratio of longitudinal and transverse directions
ν_{23}	0.263		Poisson's ratio of transverse directions

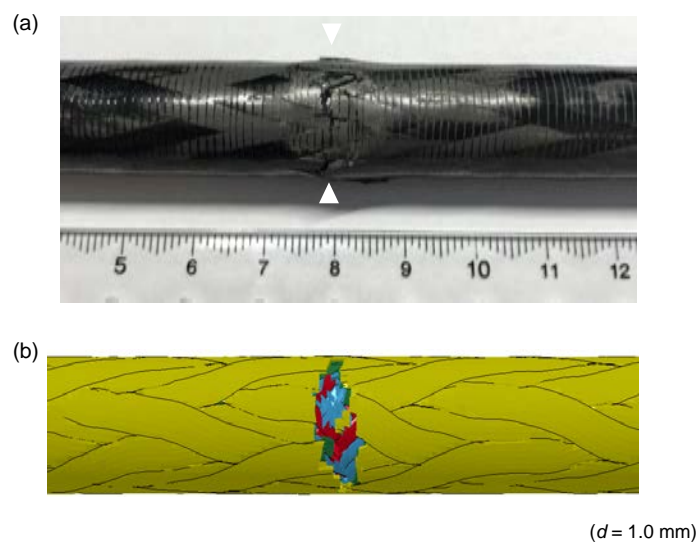


Figure 8. Status of damage propagation after the three-point bending test (a) Experimental result and (b) Numerical result

3.3. Torsion test

Figure 9 shows the torsional stiffness around the shaft axis obtained by torsion test and FE analysis. Four specimens are prepared. The scatter of experimental data is a little. But the numerical result is about 15% higher than the experimental ones. As the end of specimen must hold by the torsion testing apparatus, the both ends of specimens have been supported by GFRP. The support of GFRP did not consider to the numerical simulation. The torsional stiffness of GFRP is lower than that of CFRP. From these points, it is recognized that the numerical result has good agreements with the experimental ones.

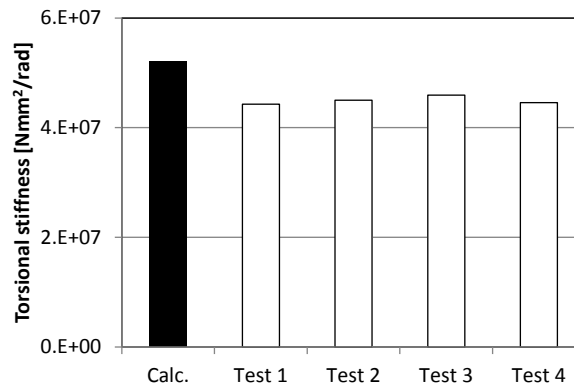


Figure 9. Torsional stiffness

4. Conclusions

The procedure to generate FE model of the layered braided tubes with complex architecture has been proposed. In order to verify the procedure, the similarity of shape of bundles has been confirmed by comparing the cross-sections of the real CFRP golf shaft and FE model generated by the proposed procedure. The proposed system is acceptable as a design tool, because the numerical results of mechanical properties such as the stiffness and failure behaviour with the FE model have agreed well with the experimental results.

We have implemented the procedure to the software named “Composites Dream” in which some designing parameters for a braided tube can generate a FE model readily (See Figure 10). Providing the verified procedure with ease, the software should contribute designing of braided tubes.



Figure 10. Analysis procedures for braided composites tubes using Composites Dream

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