A PROPOSAL OF CONVENTIONAL FE-MODELING FOR LAYERED BRAIDED COMPOSITES

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ABSTRACT

A FE modeling procedure for layered braided composites tubes with a complex architecture has been proposed. The damage mechanics has been also introduced in the numerical analysis. The modeling procedure has been validated by comparing the bundle pattern of the generated model with one of the produced braided tube. In addition, the mechanical behaviour for braided tube with 4 layers under three-point bending test has been simulated by proposed procedure and has compared with the experimental result. It is recognized that the proposed procedure can be applied to the braided composites with the complex structure.

1 INTRODUCTION

Tubes fabricated by carbon fiber reinforced plastics (CFRP) are widely used for various structures in automotive, civil engineering, sporting goods etc. The production techniques are filament winding, sheet winding and braiding. The braiding will have superior productivity and braiding tubes will develop excellent features as performs [1, 2]. Moreover, the control of braiding angle (See Fig. 1) along axial direction can be designed the mechanical properties arbitrarily.

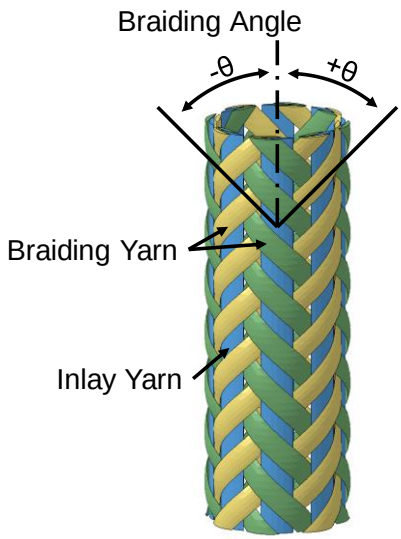


Figure 1: Schematic image of a braided fabric.

On the other hand, it has been pointed out that the crimps due to the braiding may drop the mechanical properties. We have some papers about the investigation of relation between the crimp force and the mechanical properties [1, 3].

Finite element (FE) analysis is an effective method for the investigation relations between the mechanical properties and the mesoscopic structures, because it is not easy to produce various type tubes and to measure experimentally. Ohtani et al. have reported about the relation between the

bending rigidity and the crimp for braided tube. The investigation has been carried out by FE analysis with the homogenized materials and the beam elements which present the crimps of bundles [4]. Picket et al. have investigated the rigidity of tubes numerically. The tubes have been designed and produced by the special braiding processes [5].

In this paper, a new method, which can generate FE model for the braided tubes with complex architecture, has been proposed. A FE-model for a tube with 4 layered triaxle braided has been generated by “Composites Dream”, and the crimp and the nesting of bundles due to braiding and stacking can be expressed in the model.

In order to verify, the cross section of the generated EF model has been compared with the produced braided tube. Further, the mechanical behaviours under three-point bending test have been simulated. The numerical result has been compared with the experimental result to validate the proposed method.

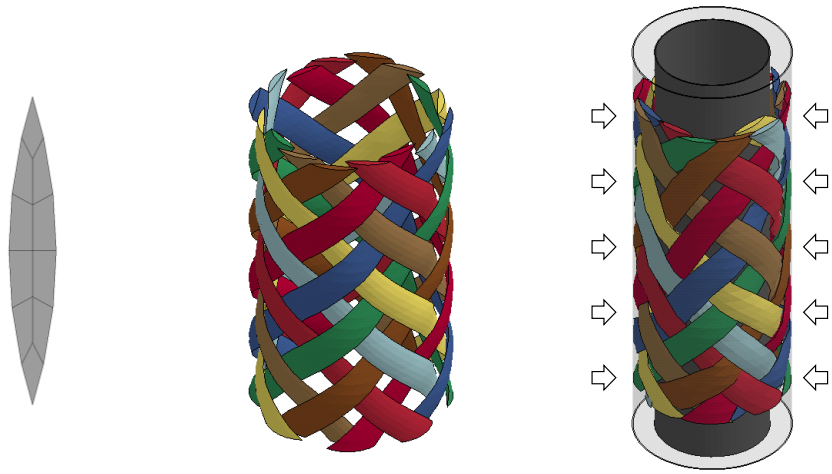
2 PROCEDURES

The modeling process consists of three steps. The first step is to prepare shell elements and to determine the shape of cross-section of a bundle (Fig. 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 (Fig. 2(b)). The crimp can be represented by the change of curvature of bundle. In addition, the trajectories are presented by 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 (Fig. 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.

FE model of a braided tube produced by the proposed procedure is shown in Figure 3. The braided tube is used for golf shafts. The tube consists of four layers and the specification is summarized in Table 1. The outer and inner diameters are 15.46 mm and 11.26 mm, respectively.



(a) Determination of section area of yarn (b) Braided yarn with arbitrary angle (c) Packing process

Figure 2: Generating procedure of a FE-model for a braided tube.

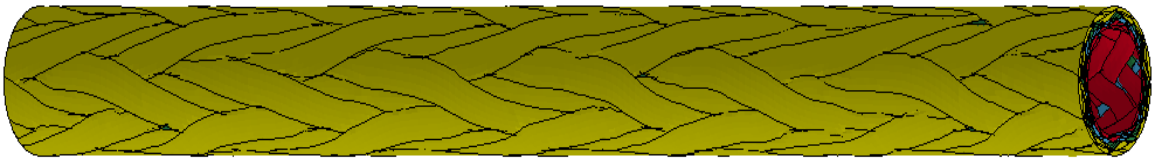


Figure 3: Generated FE-model for braided tube with four layers.

Table 1: Condition of production for a braided tube

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.

3 RESULTS AND DISCUSSION

3.1 Cross-sectional observation

In order to validate the modelling procedure, the shape of bundle in a cross section of tube is compared. Figures 4(a) and (b) show the cross section of the braided tube. 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 Figs 4(c) and (d).

From Fig. 4(a), it is revealed that the cross-section is filled with bundles closely. Fig. 4(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 cross-sections of each bundle deformed agree well. However, the explicit evaluation will be necessary to the quantitative evaluation.

Figure 4(b) indicates the section for axial direction. The bundles exist in section area without gap.

Figure 4(d) is the generated model by the proposed procedure.

By comparing both models, it is recognized 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.

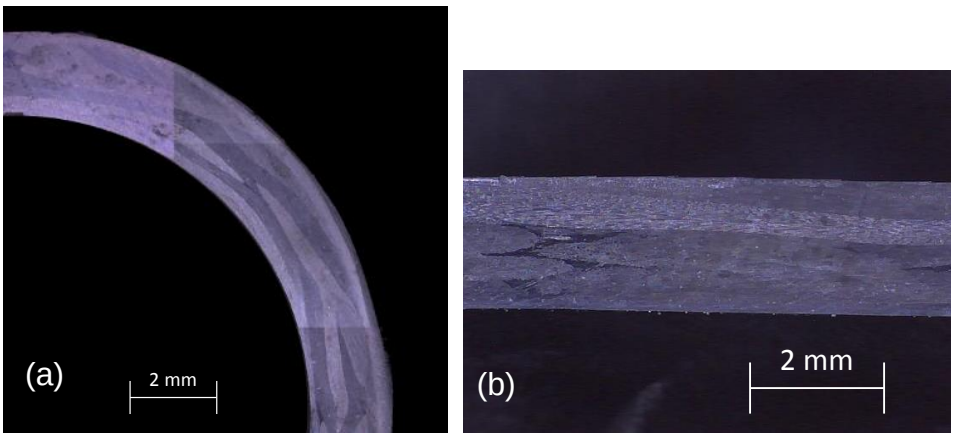


Figure 4: Comparison of cross-section between generated FE-model and braided tube.

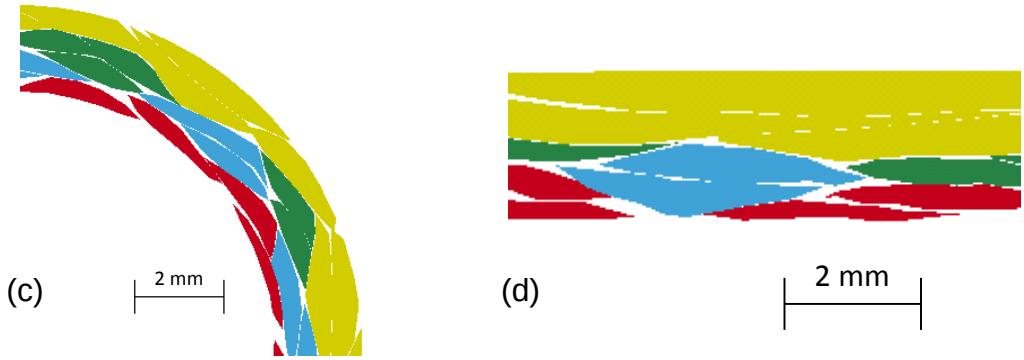


Figure 4 (continued).

3.2 Three-point bending test

Figure 5 shows the numerical and the experimental results for mechanical behaviors under the three-point bending test. The length of the tube tested is 160 mm and the span of bending test is 120 mm, respectively. The shapes of supporting and loading parts are cylinder with 10 mm radius.

FE-model is generated by "Composites Dream" and the analysis under three-point bending is carried out by LS-DYNA. The mechanical properties of CFRP bundle for analysis is shown in Table 2. The moduli of elasticity with carbon fiber volume fraction V_f = 54 % (experimental) and epoxy resin are estimated by the Uemura's equation [6]. As the strain criteria of compression, $F\varepsilon_c$ = 0.1 % and 0.25 % are employed.

From Fig. 5, it is revealed that the experimental result has a good agreement with the numerical one when the strain criterion $F\varepsilon_c$ is 0.25 %. The numerical results when $F\varepsilon_c$ is 0.1 % and $F\varepsilon_c$ is infinity (linear analysis) are also shown in Fig. 5. The effect of $F\varepsilon_c$ on the mechanical behaviours is grasped by Fig. 5.

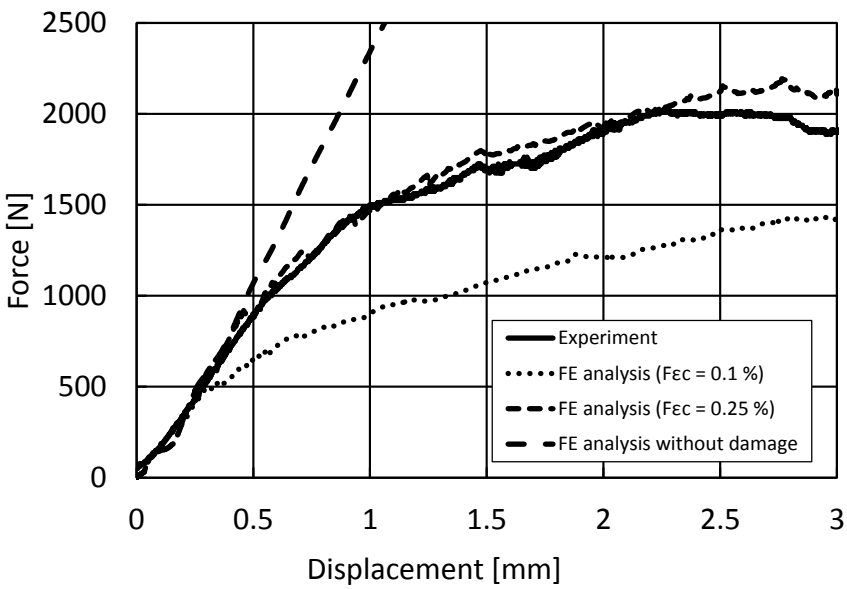


Figure 5: Comparison between numerical results and experimental result under three-point bending test.

Table 2: Mechanical properties of a bundle.

Mechanical properties		Description
E_1	240 GPa	Modulus of longitudinal (fiber) direction
E_2	15.3 GPa	Modulus of transverse direction
G_{12}	5.22 GPa	Shear modulus of longitudinal and transverse directions
G_{23}	5.20 GPa	Shear modulus of transverse directions
ν_{12}	0.2	Poisson's ratio of longitudinal and transverse directions
ν_{23}	0.47	Poisson's ratio of transverse directions

Figure 6(a) shows the top view of specimen after test. The position of loading nose with the radius 10 mm is the line connected to triangles in Fig. 6(a).

Figure 6(b) shows the numerical results concerning the failure elements when $F\varepsilon_c$ is 0.25 % and the displacement d is 1.0 mm. The damage propagations of both results have similar situation.

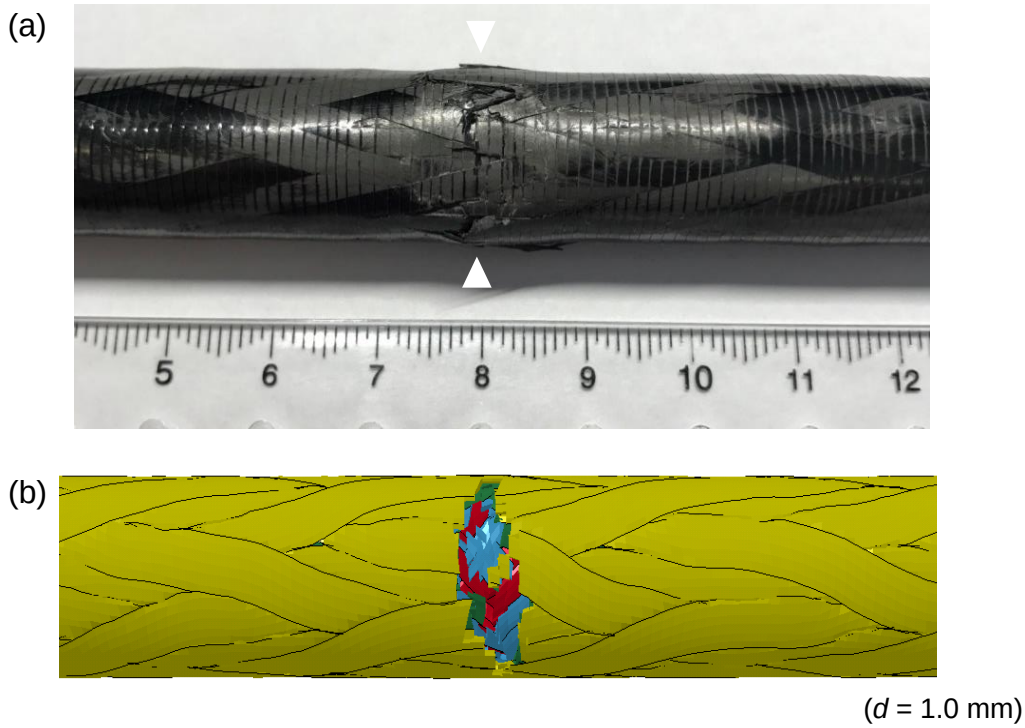


Figure 6: Status of damage propagation after three-point bending test
(a) Experimental result and (b) Computational result.

Figure 7 shows the axial stress distribution in the surface layer of bundle. The solid line shows the distribution to the loading side and the dotted line shows the distribution to the bottom sides. This result has really captured the braided structure, because the stress does not distribute symmetrical about the loading point.

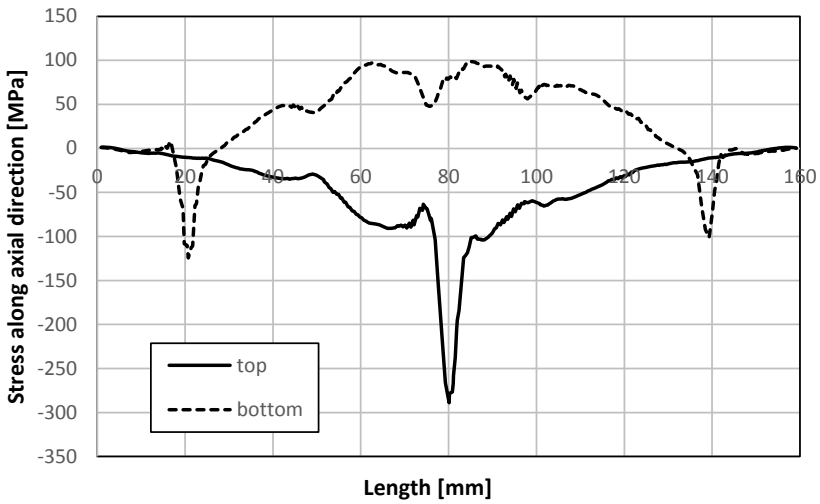


Figure 7: Stress distribution in surface layer along axial direction (at d = 0.40 mm).

4 CONCLUSIONS

The procedure to generate FE model and the numerical method to simulate the mechanical behaviour for the layered braided tube with complex architecture has been proposed. In order to verify, the cross section of generated model and the mechanical behaviour have been compared with the cross section of produced tube and the experimental result of three-point bending test. It is recognized that FE-model for braided tube with complex architecture can be produced easily, and that the damage propagation for tube can be also simulated by the proposed method. It is clear, from these results, that the proposed system named “Composites Dream” will be useful tool for the design of braided structure.

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