DESIGN OF BRAIDED FABRICS CONSIDERING INTERNAL STRUCTURE

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Keywords: Braided composite, Internal structure, Dimension, Geometrical Design

Abstract

The internal structures for the braided fabric was represented with 4 parameters; area and cross-sectional shape of braiding yarns, the braiding angle and distance between braiding yarns. However interrelationship between structural parameters has not been clarified. The purpose of this study is to clarify the interrelationship for braided fabrics. In order to investigate the internal structure, a distance between braiding yarns were changed by fabricating braided fabrics on a tapered mandrel with constant braiding angle, and effects of the distance on cross-sectional area and shape of braiding yarns were estimated experimentally and numerical model was constructed. Aspect ratio, major axis of fiber bundle and Gap between braiding yarns were a function of a distance between braiding yarns regardless of braiding angle. Consequently, it was suggested that predictions of internal structural parameters and mechanical properties for braided composites were possible by determining the dimension of fiber materials.

1 Introduction

The braided fabrics are one of the typical textiles and have been expected to be an excellent preforms for reinforcements of composite materials. One of the important features is the continuity of fiber bundles which oriented diagonally called braiding yarns, and braided fabrics have capability to change orientation angles of braiding yarns called braiding angles. Another feature is that fiber bundles called middle-end-yarns (MEYs) can be inserted into braiding yarns along the longitudinal direction, so that excellent mechanical properties are expected. In addition, braided fabrics can be fabricated by using various kinds of fibers and MEYs with different properties. Therefore, mechanical properties can be variously designed according to requirements. However it is very difficult to predict the internal structures of braided fabrics for determining mechanical properties. In previous study, it was clarified that internal structures of the braided fabric were decided by four structural parameters; braiding angles, a distance between braiding yarns, cross-sectional area and shape of the braiding yarn, and these parameters have interrelationship each other. For example, by changing a braiding angle, a distance between braiding yarns, area and cross-sectional shape of fiber bundles are automatically changed. Therefore a design of mechanical properties for braided composites is difficult.

The purpose of this study is to clarify the mechanism of determination for the internal structures of braided fabrics. In order to investigate the internal structure, a distance between braiding yarns were changed by fabricating braided fabrics on a tapered mandrel with constant braiding angle, and effects of the distance on cross-sectional area and shape of braiding yarns were estimated experimentally and numerical model was constructed.

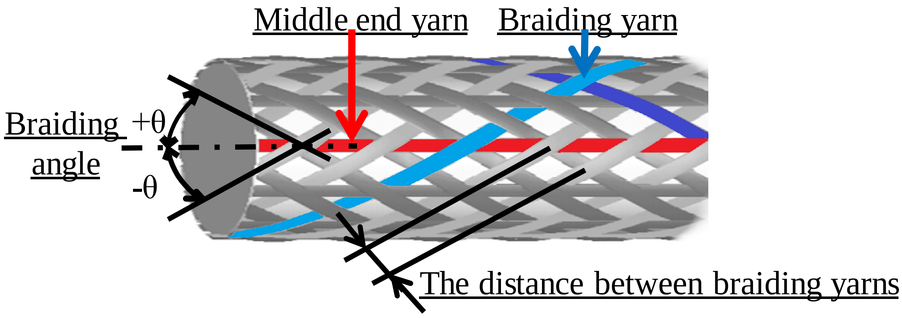


Figure 1. Structure of braided fabric with middle-end-yarn.

2 Materials and specimen preparation

The tubular braided fabrics were fabricated by using two types of carbon prepreg yarns with different filament numbers; one was with the number of 12000 (T700-12-RC38-SX3: Nippon oil corporation) called Type 12k and the other was with the number of 6000 (T700-6-RC38-SX3: Nippon oil corporation) called Type 6k. Impregnated resin was modified epoxy of 35wt%. One layer of braided fabrics was prepared on tapered mandrel with 1m length and the diameter was changed from 30 to 100mm. 48 of braiding yarns and 24 of MEYs were used for a fabrication and the braiding angle was constant with 65deg or 45deg. Each preforms were wrapped with PET tape with 25mm width and cured in an oven at 130℃ for 2 hours and 150℃ for 2 hours.

A picture of 45deg braided composite is shown in Fig.2. In the case of a braided composite with constant braiding angle, distance between braiding yarns was increased with increase in mandrel diameters as shown in the picture. The schematic images of the cross-sections of the braiding yarns at different diameters of tapered mandrel are also shown in Fig.2 below the picture. A width of fiber bundles was increased with increase in a diameter of the mandrel.

Figure 2. Braided composite on tapered mandrel with 45 deg of braiding angle,.

3 Testing methods

Procedure of cross-sectional observations was described as follows. The specimens were cut along the braiding yarn at each inner diameter (φ30, φ40, φ50, φ60, φ70, φ80, φ90, φ100). Each cut specimen was embedded into thermoset resin. The cross sections were polished and observed using an optical microscope (PME3: Olympus Corporation).

Schematic image of cross-sections along the braiding yarn is shown in Fig.3. Cross-sections of fiber bundles are represented by an elliptical shape in this figure. Gray elliptical shape

shows a braiding yarn and white one shows MEY. A distance between braiding yarns (L), area of fiber bundle (A), major axis (A_L) and minor axis (A_S) of fiber bundle were measured in each cross-section.
In this study, major axis A_L, aspect ratio of fiber bundle cross-sections, Gap between braiding yarns, were focused on to quantify internal structure of braided composites. Aspect ratio of fiber bundle cross-sections was calculated by A_S divided by A_L (Equation (1)), and corresponding to cross-sectional shape of the fiber bundle which is one of the structural parameters. Gap between fiber bundles (Gap) was calculated by subtracting the A_L from L (Equation (2)).

$$\text{Aspect ratio} = \frac{A_s}{A_L} \tag{1}$$

$$\text{Gap} = L - A_L \tag{2}$$

The relationship between quantified values of aspect ratio of fiber bundle or Gap between fiber bundles and distance between braiding yarns were investigated.

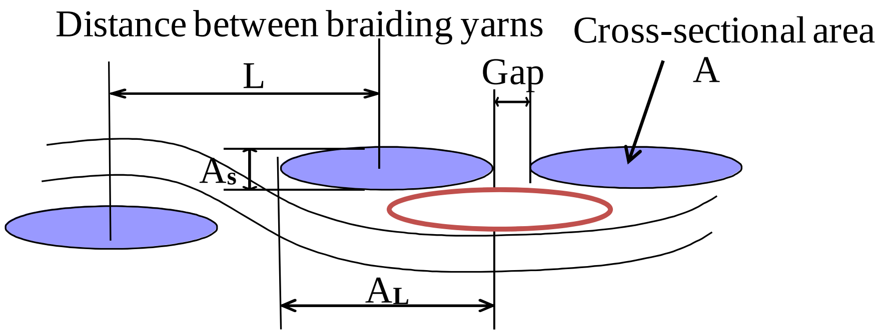
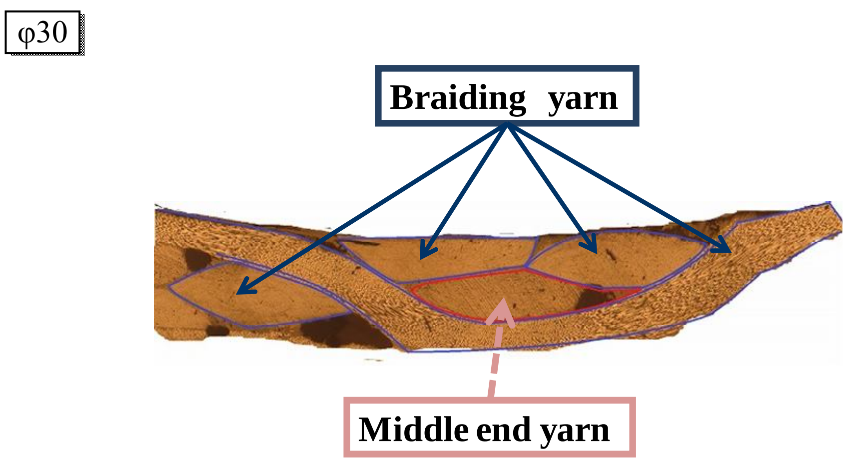


Figure 3. Schematic image of internal structure of braided composite.

4 Results

Cross-sectional photographs of type 12k in diameter of φ30, φ60, and φ100 are shown in Fig.4. With increasing the diameter corresponding to a distance between braiding fibers, cross-sectional shape of braiding yarns and MEYs should be flattened.



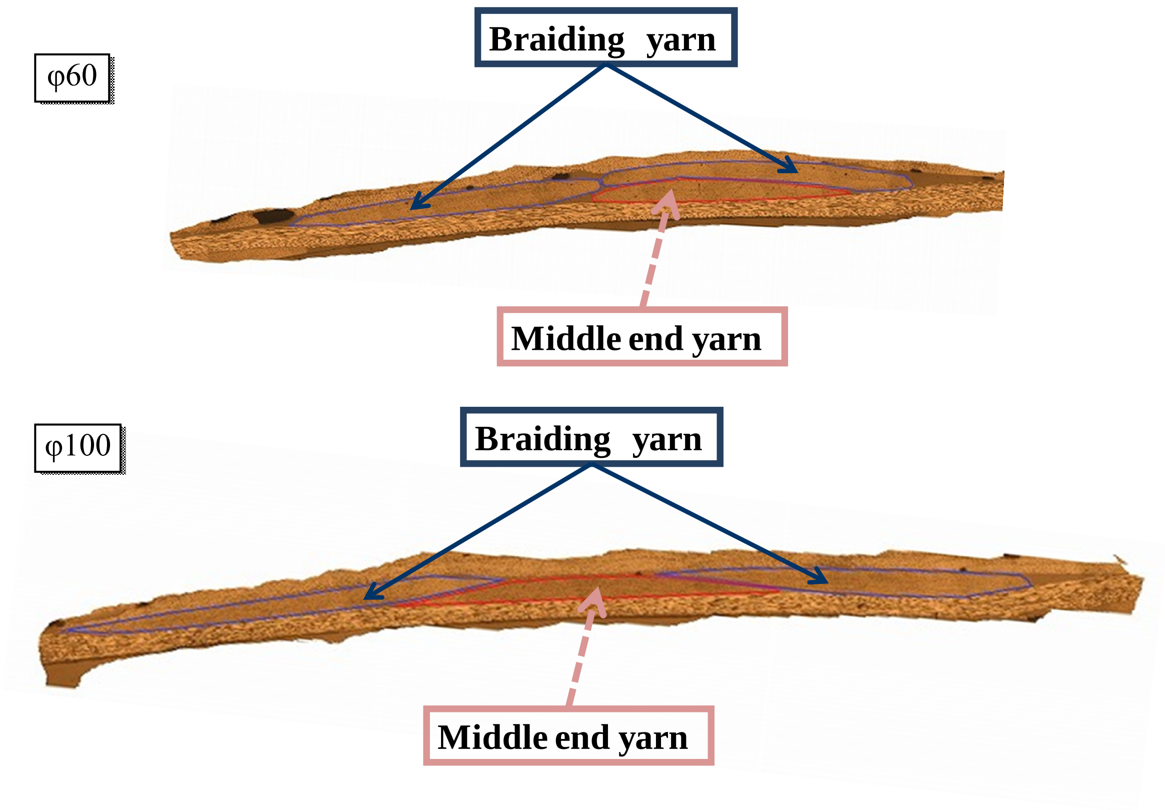


Figure 4. Cross-sectional photos at φ30, φ60, φ100 (12k)

4.1 Observation results and prediction of each parameter for 12k

Aspect ratio of type 12k with 65 and 45 braiding angles as a function of a distance between braiding yarns are shown in Fig.5. Each aspect ratio of 65deg and 45deg braiding angles was decreased with increasing a distance between braiding yarns, and these data seems to be continuous data and on a same curve. From this curve, a distance between braiding yarns converged on a certain value with increasing aspect ratio, and aspect ratio also verged on a certain value with increasing distance between braiding yarns. From this trend, relationship between aspect ratio and a distance between braiding yarns was approximated by fractional functions.

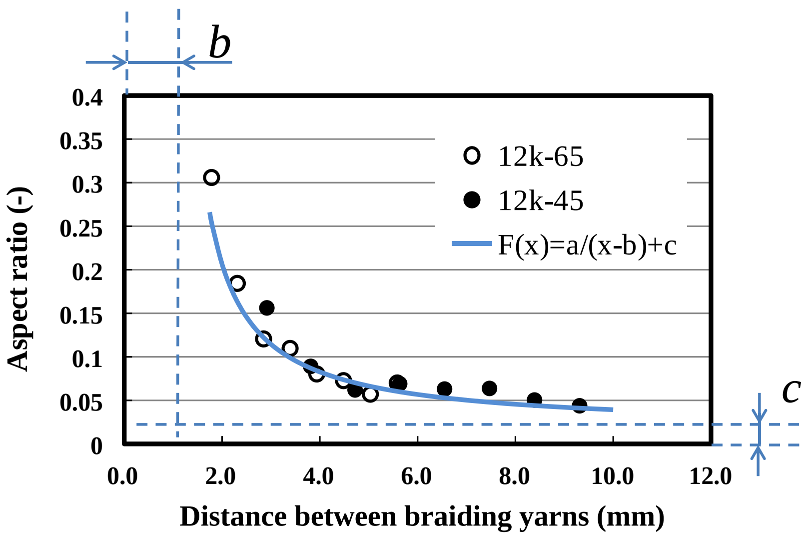


Figure 5. Aspect ratio as a function of a distance between braiding yarns. (12k)

This approximate expression was shown below:

$$F(x) = \frac{a}{(x-b)} + c \qquad \text{a = 0.200, b = 0.946, c = 0.018} \tag{4}$$

where *F(x)* is aspect ratio, *x* is distance between braiding yarns.
This expression shows that *x* converges on *b*, and F(x) converges on *c*. In other words, this expression shows minimum value of a distance between braiding yarns is *b* and maximum value of aspect ratio is *c*. The minimum distance *b* was decided when neighboring braiding yarns were contacted with each other assuming maximum aspect ratio of fiber bundle cross-section was 1. *a* and *c* were decided with constant number *b* by changing *a* and *c* to make approximate expression *F(x)* as close as possible to measured value.

Then, prediction of other parameters (Major axis of fiber bundle cross-section, Gap) was conducted. Major axis was calculated by following expression developed from a formula for area of an ellipse corresponding to cross-sectional shape of the braiding yarns.

$$A_L(x) = 2 \cdot \sqrt{\frac{A}{\pi \cdot F(x)}} \tag{5}$$

Measured and predicted major axis of fiber bundle cross-sections as a function of distance between braiding yarns were shown in Fig.6. Both predicted values and measured values had good agreement. These values was increased with increase in a distance between braiding yarns and converged on a constant value.

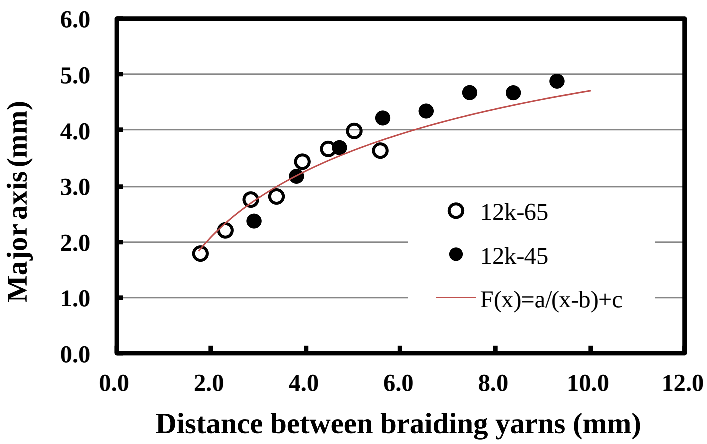


Figure 6. Major axis as a function of distance between braiding yarns. (12k)

Gap as a function of distance between braiding yarns was shown in Fig.7. Predicted values of Gap was calculated by subtracting the $A_L(x)$ from a distance between braiding yarns as follows,

$$\text{Gap(x)} = x - A_L(x) \tag{6}$$

Measured Gap of 65deg and 45deg also seems to be continuous data and on a curve. These values was increased with increase in a distance between braiding yarns. From these results, predicted value had good agreement with measured value.

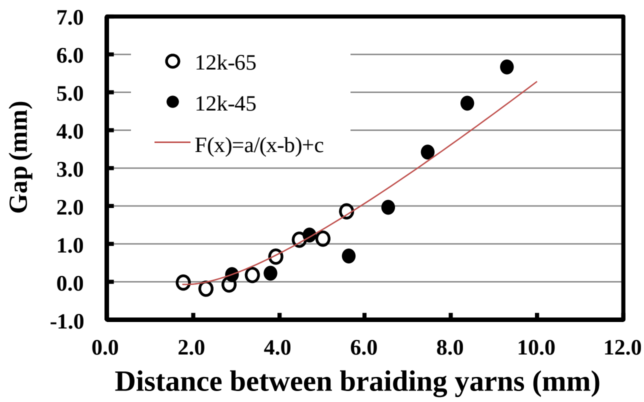


Figure 7. Gap as a function of distance between braiding yarnsfor 12k

4.2 Prediction of each 6k parameters from 12k approximate expression

Next, predictions of each structural parameter (aspect ratio of fiber bundles, major axis of fiber bundles, Gap between braiding fiber) of type 6k were carried out based on the approximate expression *F(x)* of 12k. Aspect ratio as a function of distance between braiding yarns is shown in Fig.8. Measured aspect ratio of 65deg and 45deg for 6k also seems to be on a same curved as is the case in 12k. These values was decreased with increasing a distance between braiding yarns and converged on a constant value. Here, assuming that the relationships between aspect ratio and a distance between braiding yarns in type 6k and 12k were same, approximate expression *F'(x)* of aspect ratio as a function of a distance between braiding yarns for 6k was derived based on *F(x)*.

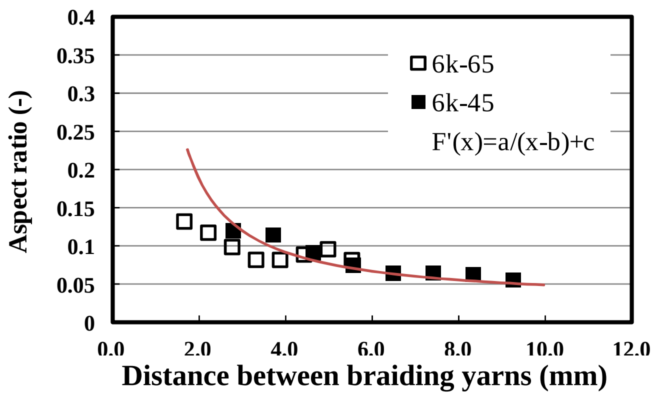


Figure 8. Aspect ratio as a function of distance between braiding yarns for 6k.

In other words, both major axis and minor axis of fiber bundle cross-section for 6k should be smaller than that for 12k, however, it was assumed that a ratio of these values was same ($A_S/A_L=A'_S/A'_L$). The cross-sectional area was decreased by half by changing 12k to 6k, minimum distance *b* between braiding yarns with aspect ratio of 1 in the case of 12k was changed to *b'* in the case of 6k. *a* and *b* in *F'(x)* were assumed to be same values as that in F(x).

$$F'(x) = \frac{a}{(x-b')} + c \qquad a = 0.200, b' = 0.617, c = 0.018 \tag{7}$$

A curve *F'(x)* is also shown in Fig.8. From these results, predicted values had good agreement with measured values. Next, major axis and Gap of 6k were derived from *F'(x)* as is the case in 12k. Measured and predicted major axis and Gap as a function of distance between braiding yarns for 6k are shown in Fig.9 and 10 respectively. From these results, predicted value had good agreement with measured value.

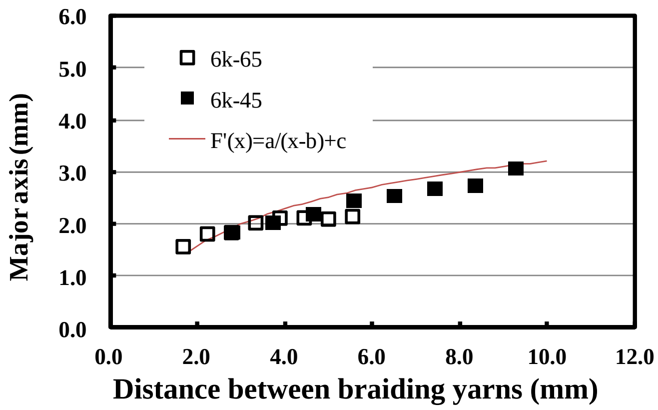


Figure 9. Major axis as a function of distance between braiding yarns. (6k)

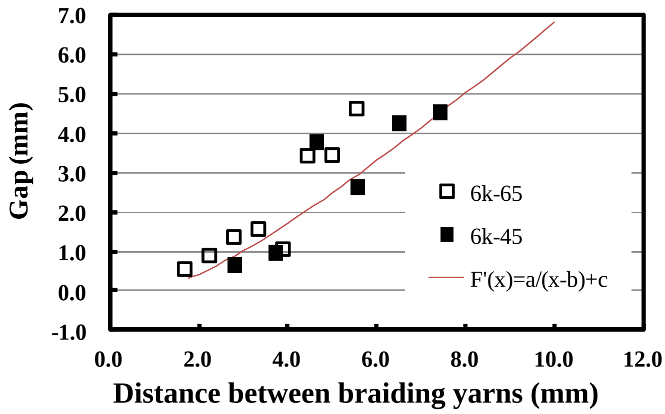


Figure 10. Gap as a function of distance between braiding yarns and distance between braiding yarns. (6k)

5 Conclusion

In this study, in order to clarify the interrelationship between internal structural parameters for braided fabrics, a distance between braiding yarns was changed by fabricating braided fabrics on a tapered mandrel with constant braiding angle. Effects of the distance on cross-sectional area and shape of braiding yarns were estimated experimentally and numerical model was constructed. Followings are the conclusion obtained in this study.

・Aspect ratio, major axis of fiber bundle and Gap between braiding yarns were a function of a distance between braiding yarns regardless of braiding angle.

・Aspect ratio as a function of a distance between braiding yarns could be approximated by fractional functions, and Gap and major axis could be also predicted based on the approximate expression of aspect ratio. In addition, aspect ratio, Gap and major axis of braided fabrics for fiber bundles with different filament number could be predicted.

・From the fractional functions of aspect ratio as a function of a distance between braiding fibers, it was suggested that aspect ratio of fiber bundle cross-section and a distance between braiding yarns had minimum value.

・It was suggested that predictions of internal structural parameters and mechanical properties for braided composites were possible by determining the dimension of fiber materials.