Mechanical Properties and Fracture Behavior of Hybrid Braided Composite Tube

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SUMMARY

In this study, matrix hybrid braided composite tube was fabricated. The effect of the position of flexible resin on the mechanical properties of the braided composite tube were investigated by and dynamic bending test. Moreover, the relationship between fracture length and the energy absorption was also clarified.

Keywords: textile composites, braided fabric, dynamic property, fracture aspect, matrix hybrid

INTRODUCTION

The braiding is one of the old traditional techniques in Japan. The braided fabrics have been expected to be an excellent preforms for the reinforcements of composite materials. The schematic drawing of braided fabric is shown in Fig.1. One of the important features is the continuity of the fibre bundle in the braided fabric. The all fibre bundles are continuously oriented, so that the excellent mechanical properties were expected. Other characteristic is capability of changing the "braiding angle". In the braided fabric, all fibre bundles are diagonally oriented, and the angle of the fibre bundle to the longitudinal direction can be adjusted freely. Also, the fibre bundle called the middle-end-fibre (MEF) can be inserted into the braiding yarns along the longitudinal direction. Therefore, the mechanical properties can be variously designed according to the requirements. Moreover, in braided fabric, various kinds of fibres can be adopted to each fibre bundles. So hybrid braided composites can be fabricated by using braiding technique.

For the hybrid composite, we have proposed 3 kinds of hybrid composite; Fibre hybrid, matrix hybrid and interphase hybrid. Fibre hybrid is defined as that some kinds of fibre bundles with different mechanical properties were used simultaneously in one FRP. Matrix hybrid is defined as the use of different kinds of matrix resin with different mechanical properties in one FRP simultaneously. Interphase hybrid is defined as the designing the mechanical properties of composite interphase with different surface treatment. Either hybrid composite has the possibility to add new function to the composite materials.

In this study, the braided composite tubes were fabricated by two types of prepreg yarns with different matrix resin, in other words the concept of matrix hybrid was adopted by using braiding technique. Prepreg yarns with matrix resin of general versatility (called type N) were used for braiding yarn, and prepreg yarns with matrix resin of flexibility (called type S) were used for MEF. The mechanical properties of Matrix hybrid braided composites tube were investigated by 3-point impact bending test. The effects of matrix hybrid on the fracture aspect were also evaluated by the cross-sectional observation.

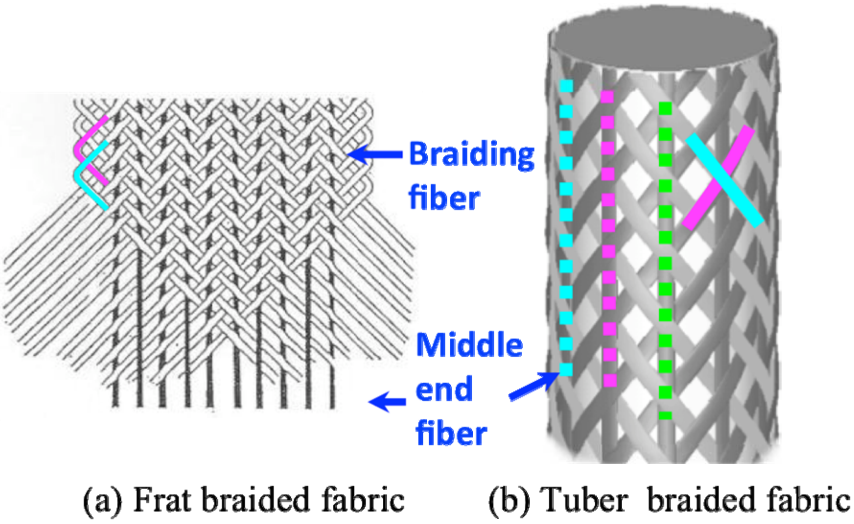

Fig.1 Schematic image of braided fabric

MATERIALS, FABRICATION AND EXPERIMENTS PROCEDURE

The tubular braided fabrics were fabricated by two types of prepreg yarns with different matrix; one is resin with general versatility (T700-12-RC38-SX3: Nippon oil corporation) called Type N and the other is resin with flexibility (T700-12-RC34-25HS-3: Nippon oil corporation) called Type S. Here, the flexibility means lower modulus and high ultimate strain. These two resins had same-based polymer.

Combination pattern of prepreg yarns were shown in Table 1. The six kinds of specimens were fabricated with two types of prepreg yarns. The schematic images of combination pattern were shown in Fig.2. 24 yarns for the braiding yarn and 12 yarns for the MEF were braided with a braiding angle of about 25 degrees. N12 specimen was fabricated by using only Type N. N6S6 and S12 were “MEF resin hybrid”. N6S6 was fabricated by using Type N and S alternately as MEF. All of MEF for S12were type S. InNoutS, NS Stripe, and NS A were “Braiding fibre resin hybrid”. For InNoutS, the two inner layers were fabricated by Type N and two outer layers were fabricated by Type S. For NS-Stripe, Three pair of Type N and S as braiding yarns appeared alternately. For NS-A Type N and S were used alternately as braiding yarns.

Prepreg yarns were braided around the mandrel with 20mm diameter. The number of stacking layers was 4 layers. Then PP tape was wrapped around the preforms for and it was cured in an oven at 130℃ for 2 hours and at 150℃ for 1 hour. The inner diameter of the specimens was 20mm. The outer diameter of the specimens was about 23.5mm.

Table1 Sample name

Sample name	Braiding fiber	Middle end
N12		N
N6S6	N	N6S6
S12		S12
In N Out S	Inner 2 layers N Outer 2lrayers S	N
NS Stripe	Stripe in N6S6	
NS A	Alternatenation N1S1	

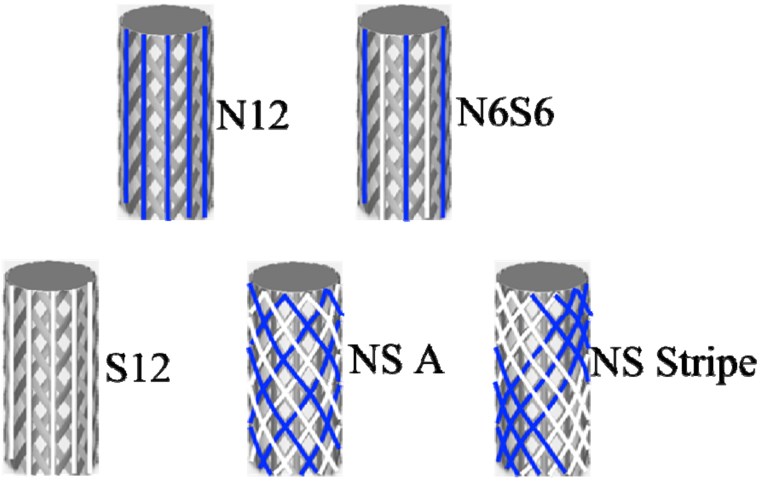

Fig.2 Type of specimen

The 3-point impact bending test was performed by INSTRON Dynatup 9250HV with a span length of 200mm and impact energy of 100J.

The procedure of the cross sectional observation was as follows.. The specimens were cut along the MEF and perpendicular to the MEF. And then, the specimens were embedded into thermoset resin and polished. The cross section was observed using an optical microscope (PME3: Olympus Corporation).

Fig.3 shows the typical cross sectional photographs along the MEF and perpendicular to the MEF. From these photos, MEF bundle of type S were observed as relatively black color. Resin of type S was softer than type N, so that resin of type S had a dent more than another area by polish.

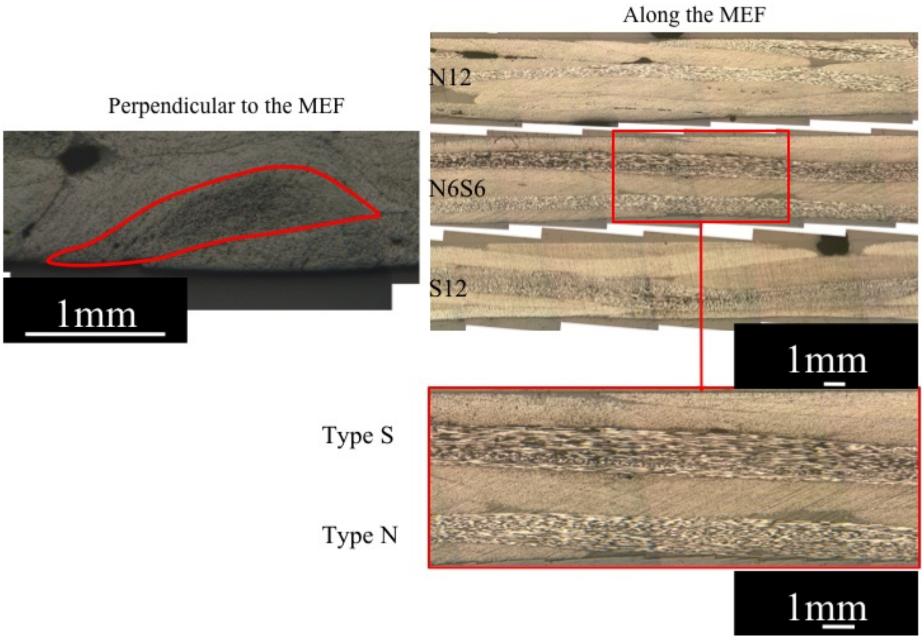

Fig.3 The photographs of the cross section along the MEF and perpendicular to the MEF

RESULTS AND DISCUSSION

3-Point Impact Bending Test

The absorbed energy was calculated from before and after max load and total energy. Total absorbed energy, load, energy to max load, and energy after max road of each specimen were shown in Table2.

For the total energy, NS Stripe and N6S6 were the highest value and NS A was the lowest. N6S6 showed the highest value in Max load,. N12 was the highest value in Energy to max load,. In energy after max load, N6S6 was the highest.

Fig.4 shows the representative fracture aspect with N12. Mainly two types of fractures were observed; delamination between fibre bundles and fibre fracture. Here, fibre fracture was classified into fibre fracture of Type N and S.

Table2 Results for 3-point impact bending test

		Total energy (J)	Load (N)	Energy to max load (J)	Energy after max load (J)
Hybrid Matrix in MEF	N12	29.2	2.97	5.56	23.6
	N6S6	30.4	3.33	3.00	27.4
	S12	28.6	3.13	4.08	24.5
Hybrid Matrix in braiding fiber	NS A	27.9	3.06	2.82	25.1
	NS Stripe	30.5	2.99	2.83	27.6
	inNoutS	29.0	3.21	3.12	25.1

The photographs of cross section of each specimen at the breaking point of tensile side along MEF were shown in Figs.5. The fibre fracture of Type N and the delamination between MEF and braiding fibre were shown in N12. The fibre fracture in MEF of N was observed and delamination between MEF and braiding fibre were shown in N6S6. Delamination in MEF bundle was not so observed.

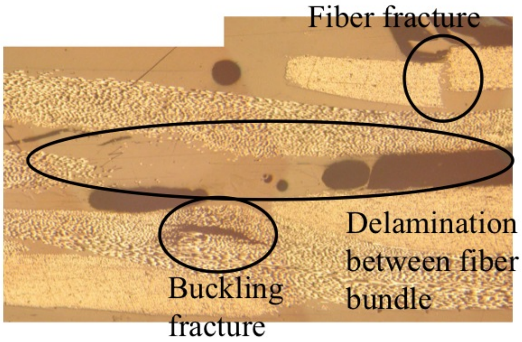

Fig.4 Photograph of cross section

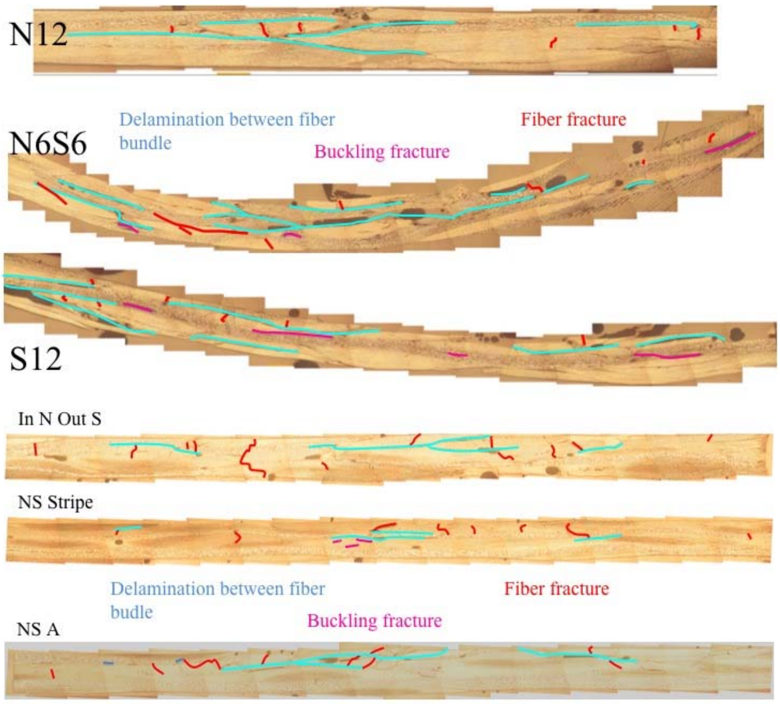

Fig.5 The photographs of cross section breaking point of tensile side along MEF

Here, in order to clarify the relation between fracture and absorbed energy, the fracture length were quantified.Each fracture length was shown in Table3 and the relationship between the energy after max load and the total fracture length was shown in Fig.6 Here the delamination length was much larger than the other fracture length.

However, the energy required for delamination between fibre bundles should be much smaller than the energy required for fibre fracture or buckling failure. So, the delamination length was not included into total fracture length in Fig.6. From load-deflection curves, energy absorption by destruction progressing was progressed after peak load. So, the relation between energy after max load and the length of destruction was examined.

	Sample name	Fiber fracture (mm)	Buckling fracture (mm)	Deramination between fiber bundle (mm)
	N12	4.8	3.6	25.7
Hybrid matrix in MEF	N6S6	9.9	5.6	35.0
	S12	6.4	5.1	34.5
Hybrid matrix in braiding fiber	inN outS	6.4	1.6	18.1
	NS-stripe	9.0	1.4	10.0
	NS-A	7.4	0.4	20.0

Table3 Length of each fracture

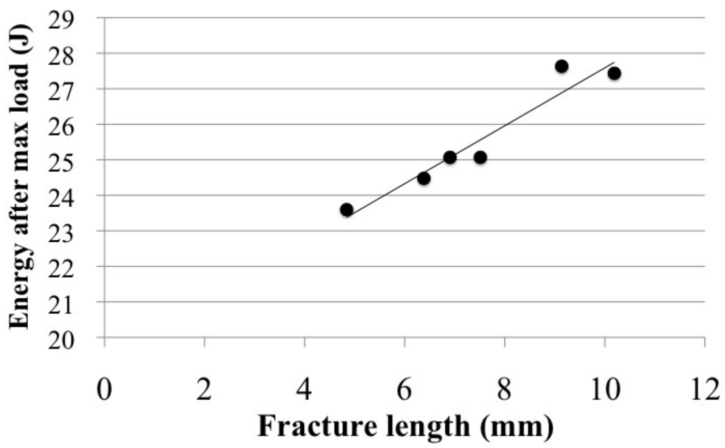

Fig.6 Relationship between total energy and fracture length

From this figure, The energy after max load was increased with increasing in the fracture length. Therefore it was clarified that the energy absorption and the fracture length was a linear relation.

Fig.6 can be expressed as

$$E = a \times l_f + b \quad \text{(Eq.1)}$$

where E was the energy absorption, l_f was the fibre fracture length. From Eq.1, “a” was 0.52 and “b” was 19.44. The carbon fibre “T700” had modulus 230GPa and breaking strain 2.1%. From these values, rupture stress of 1 filament was 1.95×10^{-3}J. And then, the volume fraction average in fibre bundle of braided composite tube was 61%, the energy of filament per unit length subsidiary fracture was 3.34J. This value was near the value of “a”, so absorption energy can calculate from carbon fibre material constant.

CONCLUSION

The mechanical properties and the internal structure of the matrix hybrid CF braided composites tube by using prepreg yarns of general versatility matrix resin impregnation and prepreg yarns of flexibility matrix resin impregnation were studied. From the 3 points bending tests, the absorption of energy was including when the MEF of S included in the specimen. But, the absorption of energy was decreasing when the MEF of S was excessively inserted.