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Non-crimp Tubular Preforming with Automation System and High Productivity

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Abstract: A new filament winding method developed in this study named MFW (multiple-supply FW) method. It performed a high productivity. In the MFW method, a large number of bobbins are used. Carbon fibers are arranged equiangularly above a mandrel, and they are wound and stacked on the mandrel simultaneously. Furthermore, CFRP pipes with non-crimp structure were made by MFW, and the torsional tests were performed in order to investigate mechanical properties comparing with braided CFRP pipes. These results made clear that the non-crimp structure by MFW was capable to improve torsional properties. The MFW machine produce non-crimp tubular preform with carbon fiber automatically. It is expected to produce non-crimp preforms for automotive parts which required high productivity.

Key words: Non-crimp structure, CFRP, filament winding, high productivity, automation.

1. Introduction

In recent years housing, automotive, civil engineering, and sporting goods have become important application fields. However, for continued expansion of the application of composite materials, they must offer not only light weight and high strength, but also functional properties and reduced costs. Researchers in applied mechanics have made progress in developing the anisotropic theory, the lamination theory, and the newer failure criterion, so that a design method has been established for large-scale panels made from unidirectional composites. When we consider the cost of composite materials, fabrication or manufacturing cost cannot be ignored. The selection of an appropriate manufacturing system is important, and research related to manufacturing will be needed [1-5].

Tubular elements have been widely used in structural application. Generally, the reinforcements are laminated in thick tube members by using filament winding method and conventional tubular braiding technique [6-8]. In conventional FW method, one or few strand is wound by one feeder, as shown in Fig. 1. In this research, this conventional FW method is named SFW (single-supply FW) method. In SFW, equipment must reciprocate many times for stacking one layer of CFRP. Therefore, SFW takes long manufacturing time, and it has a low productivity.

Textiles such as woven, knitted, and braided fabrics possess high potential for the fabrication of near-net-shaped composites [9-13]. This means that textile composites can reduce manufacturing costs greatly compared to the SFW method and unidirectional prepreg composites. Fig. 2 shows braiding process. Carriers with a bobbin move along a circular track and the mandrel moves in the perpendicular direction to the track plate. One group of carriers moves on the track in clockwise, and the other group of carriers moves in counter-clockwise. When the tubular braid is fabricated, a mandrel is used as a core at the center of the braiding machine. All fibers supplied from their small bobbins wrap around the surface of the mandrel. Fig. 3 shows a schematic of tubular braid preform. There are two groups of fiber orientation in clockwise and counter-clockwise directions. The tubular braid is formed by intertwining the fiber bundles of the two

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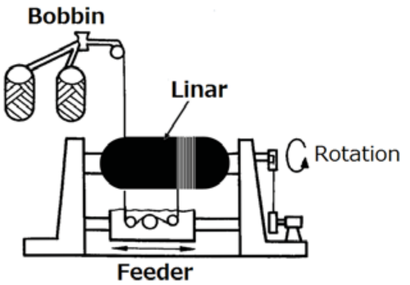

Fig. 1 Conventional filament winding machine (SFW).

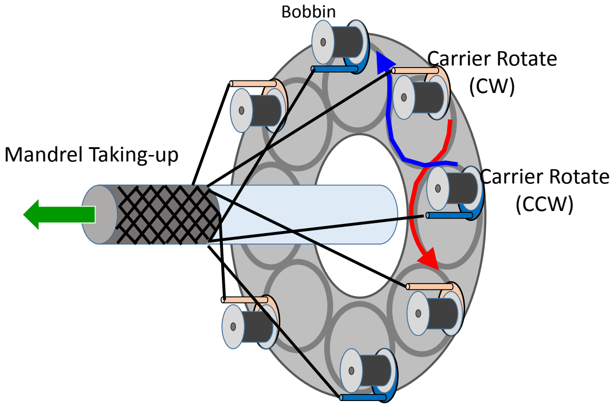

Fig. 2 Braiding mechanism.

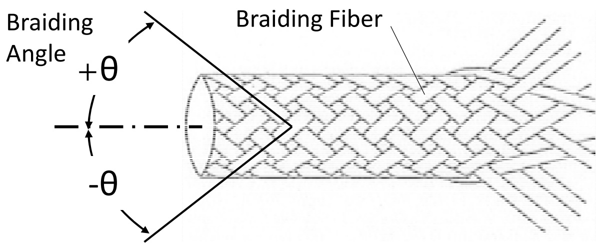

Fig. 3 Tubular braid preform.

groups. A braid has a $\pm\theta°$ biaxial structure. Braiding fiber crossing causes crimp. The low mechanical properties of textile composites are caused by the crimp. These characteristics currently limit the use of textile composites in many structurally critical applications. Accordingly, textile composites with high mechanical properties will be an important goal.

In this study, a new preforming mechanism was invented by improving the preforming method (MFW) to fabricate non-crimp tubular preform, firstly. Secondly, mechanical property of MFW CFRP pipes were investigated by comparing torsional property to braided CFRP pipes. Finally, an evolving MFW machine was introduced which had automation system.

2. Non-crimp PREFORMING

2.1 Concept of MFW (Multi-supply Filament Winding)

A new FW method developed in this research named MFW shown in Fig. 4. It performed a high productivity. In this MFW method, a large number of bobbins are used. Carbon fibers are arranged equiangularly above a mandrel, and they are wound and stacked on the mandrel. The mandrel reciprocated and rotated. All of the carbon fiber was used for making one layer, when a mandrel moved at one way. Therefore, MFW takes very short manufacturing time, and it has a high productivity. Fig. 5 shows an illustration of a tubular preform on a mandrel by MFW. The $+\theta$ fiber arrangement was made over the $-\theta$ layer on the mandrel with non-crimp fiber structure.

The winding angle is determined by the relative speed between rotating movement and reciprocating movement and diameter of the preform. The following relational expression holds by using reciprocating speed of the mandrel, rotating speed and diameter of the braid.

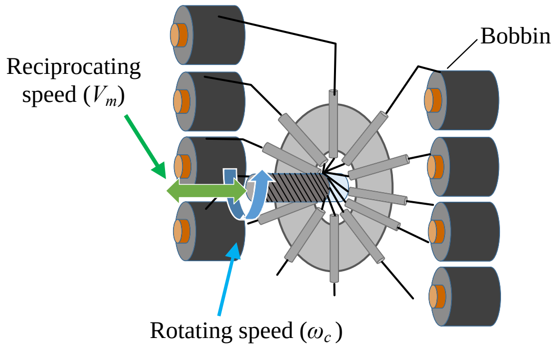

Fig. 4 Concept of Multi-supply FW method (MFW).

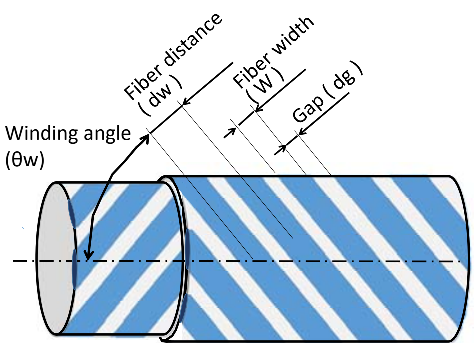

Fig. 5 Non-crimp fiber structure made by MFW.

$$\theta_w = \tan^{-1}\left(\frac{D}{2}\cdot\frac{\omega_c}{V_m}\right) \quad (1)$$

where, D is a diameter of preform, ω_c is angular speed of rotating mandrel, V_m is reciprocating speed of mandrel.

For a winding structure, changing winding angle causes the change of the distance between neighboring winding fibers (fiber distance). The winding fiber distance can be calculated by following equation,

$$d_w = \frac{\pi \cdot D}{N}\cos\theta_w \quad (2)$$

where, d_w is the fiber distance and N is the number of fibers. From Eq. (2), it is understood that the fiber distance is decreased with an increase in the winding angle. When winding structure is designed, it is necessary to consider the fiber distance. Too large fiber distance causes a decrease of fiver volume fraction and meandering of fiber orientation. Too small fiber distance dishevels winding fiber structure due to the overlapping the fiber substantially with the wound fiber.

2.2 Development of MFW

MFW machine named "MFW-48" was developed, shown in Fig. 6. MFW-48 has two axes, one linear axis and one rotary axis. It has 48 bobbins, and the maximum 48 carbon fibers are wound simultaneously. The number and disposition of carbon fibers can be rearranged in accordance with preform diameter or winding angle of ply.

3. Mechanical Properties of MFW CFRP Pipe

CFRP pipes with non-crimp structure were made by MFW-48, and the torsional tests were performed in order to investigate mechanical properties comparing with braided CFRP pipes. CFRP pipes were made with prepreg carbon tows. The prepreg carbon tows consist of carbon fiber (Torayca T700SC by Toray Industries, Inc.) and epoxy resin (SX3 by JX Nippon Oil & Energy Corporation). Three types of specimens, 30°, 45° and 60° fiber orientation angles, were made by each method. Table 1 shows the dimensions and fiber Vf (volume fractions). The dimensions of the pipes were 12 mm in inner diameter and about 17 mm in outer diameter. In this paper, the set of $+\theta$ and $-\theta$ layers is called one layer. When the fiber orientation angle is different, the number of layers is also different to make same thickness. In other words, with enlargement of fiber orientation angle, the distance between fibers was

Fig. 6 MFW machine, "MFW-48".

Table 1 Specimen list and their dimensions and Vf.

	BR			MFW		
NAME	BR-30	BR-45	BR-60	MFW-30	MFW-45	MFW-60
Fiber orient. angle deg.	30	45	60	30	45	60
Number of fiber	16			8		
Number of layer*	7	6	4	7	6	4
Inner diameter mm	12			12		
Outer diameter mm	16.70	16.88	16.60	16.54	16.82	16.72
Vf %	56.1	56.1	56.9	54.9	55.8	55.5

* A set + θ and - θ layer was called "one layer".

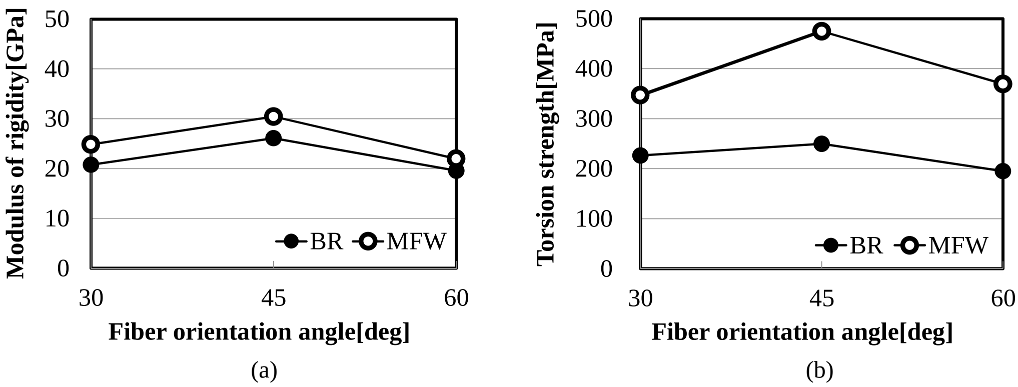

Fig. 7 Relations between modulus of rigidity, torsion strength and fiber orientation angle.

decreased, and the thickness of a layer became larger. Vf of all of specimens indicated 55% to 57%. The length of specimen was 300 mm. Metal tabs 60 mm long are bonded at the both of the ends. Torsional speed was 33.8 deg/min.

The relations between modulus of rigidity and fiber orientation angle of each specimen are shown in Fig. 7a. Regarding both MFW and BR, the 45° specimens indicated the highest modulus of rigidity in three fiber orientation angles. In the cases of all fiber orientation angles, the modulus of rigidity of MFW increased by 12% to 20%. The torsion strength of each specimen is shown in Fig. 7b. Regarding both MFW and BR, the 45° specimens indicated the highest torsion strength in three fiber orientation angles. In the cases of all fiber orientation angles, MFW increased much higher torsion strength than BR. Especially in the case of 45°, the torsion strength increased by 90% to BR. These results made clear that the non-crimp structure by MFW could improve torsional properties.

4. Large-Scale MFW Machine with Full Automation System

A MFW machine was also developed based on the concept of high productivity as shown in Fig. 8. One hundred and eighty original bobbins obtained from carbon fiber makers can be set directly. A mandrel can reciprocate in the longitudinal direction, and rotate at high velocities. The MFW machine produce non-crimp

Fig. 8 Automatic MFW machine with 180 bobbins.

tubular preform with carbon fiber automatically. It is expected to produce non-crimp preforms for automotive parts which required high productivity.

5. Conclusions

The new preforming mechanism, the MFW method, was invented with consideration for high productivity. Furthermore, CFRP pipes with non-crimp structure were made by MFW, and the torsional tests were performed in order to investigate mechanical properties comparing with braided CFRP pipes. These results made clear that the non-crimp structure by MFW was capable to improve torsional properties. Especially in the case of 45° specimens, MFW pipe indicated the higher torsion strength by 90% than BR specimen. The MFW machine produces non-crimp tubular preform with carbon fiber automatically. It is expected to produce automotive parts which required high productivity.

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