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MICRO-BRAIDED YARN AS INTERMEDIATE MATERIAL SYSTEM FOR CONTINUES FIBER REINFORCED THERMOPLASTIC COMPOSITE

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SUMMARY: 'Micro-braided yarn' has been proposed as a means of overcoming the difficulty of impregnation of thermoplastic resin into fiber bundle in manufacturing long-fiber reinforced thermoplastic composites. In the Micro-braided yarn, a reinforcement fiber is covered by a matrix resin fiber. In this study, unidirectional carbon-fiber/PA6-Nylon composites manufactured from Micro-braided yarn as an intermediate material with different strand diameter were molded in order to examine the effect of the molding conditions on impregnation mechanism. A microscopic observation was performed with optical microscopy to understand the impregnation mechanism of thermoplastic resin into the fiber bundle. From the result of microscopic observation, impregnation state of thermoplastic resin was progressed along with holding time. A parameter for the impregnation property was proposed based on the impregnation volume. 3-point bending test was carried out to investigate the effects of diameter of reinforcements strand in Micro-braided yarn and molding condition on the mechanical properties. According to result of bending test, Micro-braided yarn with smaller diameter exhibited better bending performance. Finally, relation between mechanical property and impregnation parameter was clarified.

KEYWORD: Carbon/PA6, Micro-braided yarn, Thermoplastic composite, Impregnation

INTRODUCTION

Thermoplastic composite material has large problem in manufacturing the structural parts. Because molten viscosity of thermoplastic resin is extremely high compared to thermoset resin, it is difficult to impregnate the thermoplastic resin into the fiber bundles. To overcome these difficulties, various intermediate material systems have been developed; for example, co-woven fabric, commingled yarn, powder coated yarn [1-6]. However, these materials are very special materials, so that combination of reinforcement fiber and matrix is limited, for example Glass/PA6 and Glass/PP, and the cost is expensive. If we can have our own high impregnation materials by using normal reinforcements and matrix in appropriate costs, it would be very useful for extending usage of thermoplastic composites. Therefore, we have proposed Micro-braided yarns using braiding technique as intermediate material system for long fiber reinforced thermoplastic composite. In our previous study, Micro-braided yarns were applied to GF/PA6 braided composite material and fine impregnation quality was achieved [7,8]. Micro-braided yarn is mentioned in detail in the next chapter.

In this study, Micro-braided yarn was applied to carbon-fiber/PA6-Nylon system. And CF/PA6 unidirectional composites were molded with that Micro-braided yarn. Microscopic observation performed to understand the impregnation mechanism. Next, 3-point bending tests were carried out to investigate the effects of reinforcement strand diameter in Micro-braided yarn and molding condition on the mechanical properties.

MICRO-BRAIDED YARN

The dimensions of the braided fabric depend on volume of fiber bundle, the number of fiber bundles to fabricate the braided fabric and the fiber orientation angle. Various dimensions of the braided fabric can be fabricated by selecting these factors. Fibrous shaped braided yarns are fabricated and the yarn can be treated as a single fiber bundle so that textile processed goods can be easily fabricated using the yarns. The braided fabric can be dealt as an intermediate material for next fabrication process is called 'Micro-braided yarn' in this study.

Figure 1 provides a photograph of Micro-braided yarn. Continuous fiber reinforced thermoplastic composites may be realized through use of Micro-braided yarns that consist of reinforcing fibers and thermoplastic resin fibers. The thermoplastic resin fibers become the matrix for the thermoplastic composite through appropriate processing techniques. Micro-braided yarn is expected to overcome the difficulties of impregnation when thermoplastic precursors are impregnated into the long fiber reinforcements, because the reinforcing fibers contact directly with the matrix fiber in one Micro-braided yarn.

Non-braiding yarn can be inserted within the center of the Micro-braided yarn ('axial fiber'), as shown in Fig. 1. The number of braiding-fiber bundles and axial fiber can be also changed. The materials used in this study were Carbon-fiber bundles (T300, TORAY., Ltd.) as the reinforcement and PA6-fiber bundles (TORAY., Ltd.) as the matrix. Two kinds of Micro-braided Yarn were fabricated. Type A consists of 3000 filaments of carbon fiber and a PA6 fiber with 210denier, and Type B are 12000 filaments of carbon fiber and a PA6 fiber with 840denier. The differences of these two yarns were the strand diameter and the diameter

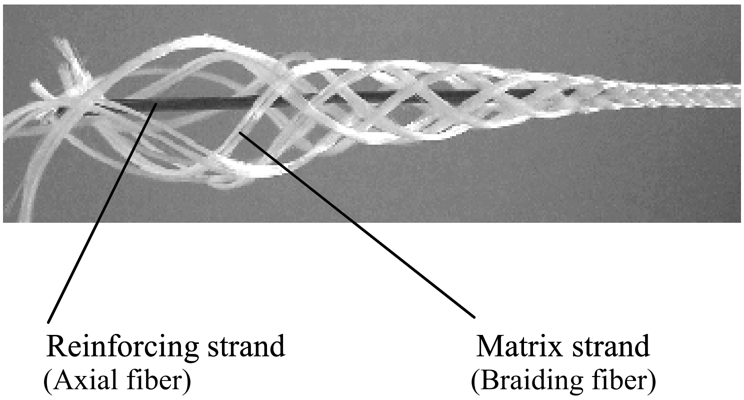

Fig.1 Photograph of Micro-braided yarn

MATERIALS AND EXPERIMETAL PROCEEDURE

of Type B (12k) is four times of the diameter of Type A (3k). The fiber volume fraction of each micro-braided yarn was the constant. Micro-braided yarns were wound onto a metallic frame in order to apply tension and it was set on preheated die, the unidirectional composite plates were molded by compression molding technique. The molding temperature was 260℃ which is above the melting temperature of PA6 polymer matrix, and pressure of 2MPa was applied. Here, the time during pressure was given, was defined as holding time. The holding time was varied from 5 minutes to 30 minutes in order to understand the effect of the holding time on impregnation state and the mechanical properties of composite. The composite was then rapidly cooled down in a water bath.

A microscopic observation was performed with optical microscopy to understand the impregnation mechanism of thermoplastic resin into the fiber bundle. 3-point bending tests were carried out to examine the effects of reinforcement strand diameter in micro-braided yarn and molding condition on the mechanical properties.

RESULT AND DISCUSSION

IMPREGNATION MECHANISM

Figure 2 shows photographs of cross-section for products in the case of Type A (3k). From the photographs, the circular region was observed from the surface of fiber bundle to the inside of fiber bundle. The circular region was increased with increasing holding time. Impregnation of thermoplastic resin was completed in this circular region, and inside of this circular region, the void was observed. In the case of 5 minutes of holding time, thermoplastic resin was impregnated to the midpoint of fiber bundle but the void existed inside of that circular region.

From that reason, the impregnation of thermoplastic resin into fiber bundle was not completed. The same case was observed in the case of 10 minutes and 15 minutes of holding time. In the case of 20 minutes of holding time, it is considered that impregnation of thermoplastic resin was completed since neither circular region nor the voids were observed.

Figure 3 shows a schematic drawing of the impregnation mechanism that is based on Fig. 2. In the first step, matrix resin around the carbon fiber strand was impregnated into the carbon-fiber bundle from the outside to the center. The area of the impregnated circular region increased with holding time. In this study, the area of the impregnation region is called perfect impregnation area. On the other hand, the inside of the perfect impregnation area has the void in the fiber bundle and the region is called imperfect impregnation area.

In the case of type B (12k), the void existed in fiber bundle still at 30 minutes of holding time. This means impregnation was not completed until 30 minutes. In the case of type A (3k), at 20 minutes of holding time, impregnation was completed, furthermore, carbon fiber monofilaments spread out along with impregnation process.

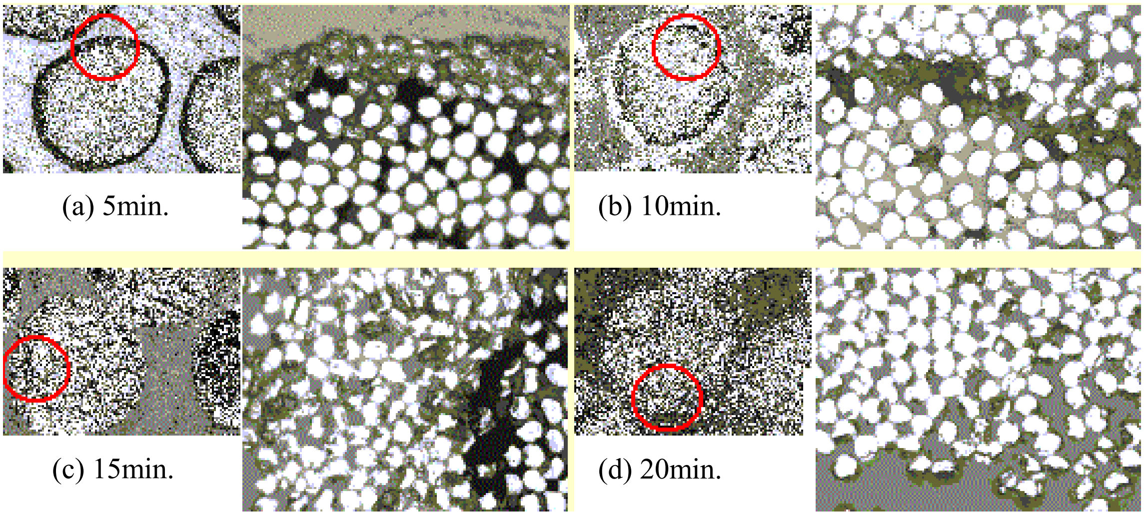

Fig.2 Photograph of cross-section for product in the case of type A (3k)

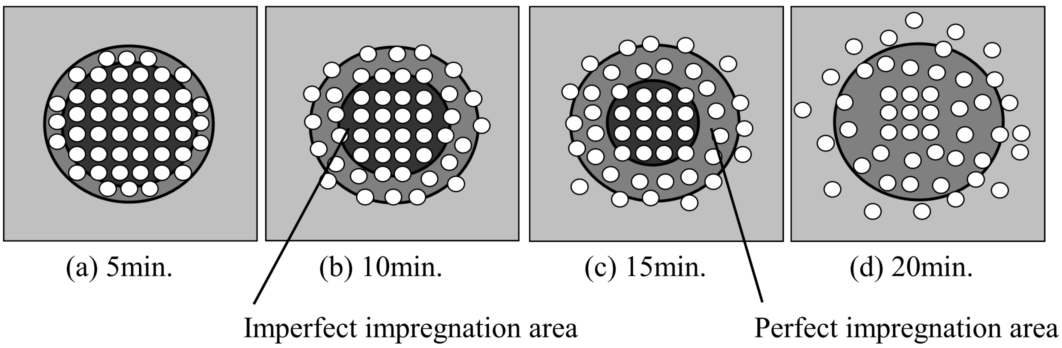

Fig.3 Schematic drawing of impregnation mechanism

In order to examine the impregnation state quantitatively, we propose a parameter for the impregnation property based on the volume. The volume of the fiber bundle region at 5 minutes of holding time is defined as a reference, V_0, the volume of the imperfect impregnation area in each holding time is V_i, and the volume of the fiber bundle area in each holding time is V_e. V_i decreased conversely with increase in the holding time and V_e increased with increase in the holding time because apparent fiber bundle increases due to the dispersion of the carbon fiber.

The parameters to represent the impregnation property are defined using above-mentioned volume as follows and shown in Fig.4; the difference between V_0 and V_i is defined as the impregnation volume, and the difference between V_e and V_0 is defined as the dispersion volume. Then, the sum of the impregnation volume and dispersion volume was defined as the total impregnation volume. Here, the volume for impregnation properties refers the volume of fiber bundle for five minutes as initial condition. The impregnation volume represents the amount of volume that the matrix resin was impregnated into fiber bundle. The dispersion volume shows the volume of the region in which carbon fibers disperse from the surface of the fiber bundle into the matrix resin. Each parameter was normalized with V_0 for type A (3k) and type B (12k).

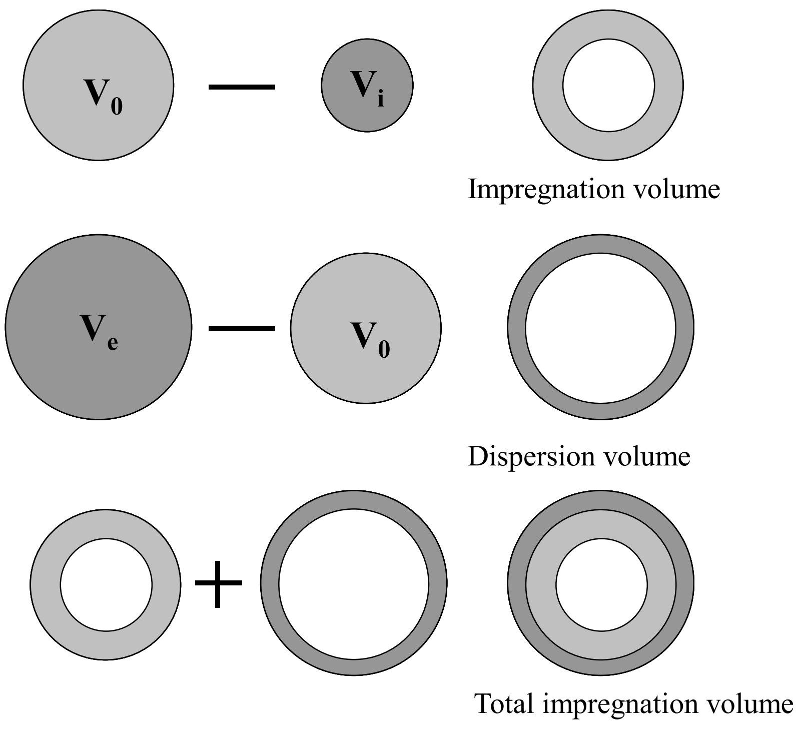

Fig.4 Definition of Impregnation parameter

Figure 5 shows relations between holding time and above-mentioned normalized parameters. In case of Type A (3k), impregnation volume became constant value because it reached V_0 in 20 minutes. It is represented that the impregnation was completed at 20 minutes of holding time. On the other hand, impregnation volume was continuously increased in Type B (12k), and this means that impregnation was not completed. Moreover, the dispersion volume of Type A (3k) increased after 20 minutes that the impregnation of the resin could be thought to be completed, while in the case of Type B (12k), the dispersion of the carbon fiber was hardly seen.

MECHANICAL PROPERTIES

The result of the bending test is shown in Fig. 6. This figure shows the relationship between bending modulus and holding time and bending strength and holding time. The bending modulus increased and the slope was gradually decreased with increase in holding time for both Type A (3k) and B (12k). In the case of Type A (3k), the bending strength linearly increased with increase in holding time, while the slope in bending strength was gradually decreased in the case of Type B (12k). The bending property of the Type A (3k) whose diameter of the fiber bundle is small was higher than that of the Type B (12k).

DISCUSSION

To relate mechanical properties with impregnation properties Fig.5 and 6 were re-plotted to Fig.7. Figure 7 (1) shows relations between bending modulus and bending strength and total impregnation volume of Type B (12k). Both bending modulus and bending strength linearly increased with increase in the total impregnation volume. Relations between bending properties and the total impregnation volume of Type A (3k) are shown in Fig.7 (2). The bending strength linearly increased with increase in the total volume. However, the bending modulus increased but the slope was gradually decreased with increase in the total impregnation volume. From these results, in case of Type B (12k), impregnation of resin was not completed. In case of Type A (3k), on the other hands, impregnation of resin was completed and dispersion of carbon fiber was observed. Therefore, the bending strength is considered to be affected by the dispersion of the carbon fiber in addition to the impregnation of the matrix resin. The bending modulus was affected by mostly impregnation of resin, on the other hand, was not affected by the dispersion of carbon fiber.

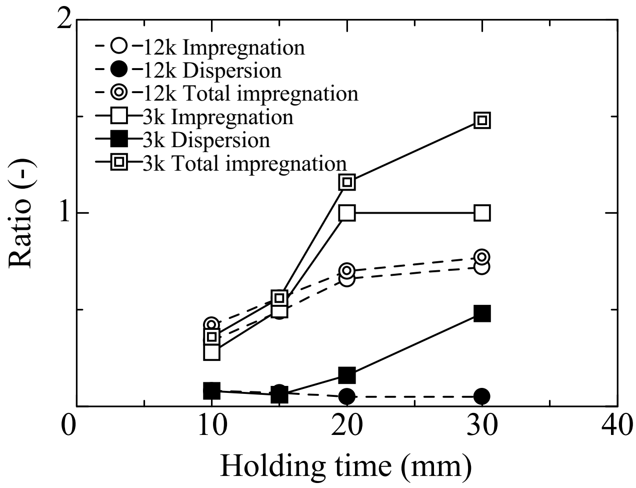

Fig.5 Impregnation parameters and holding time

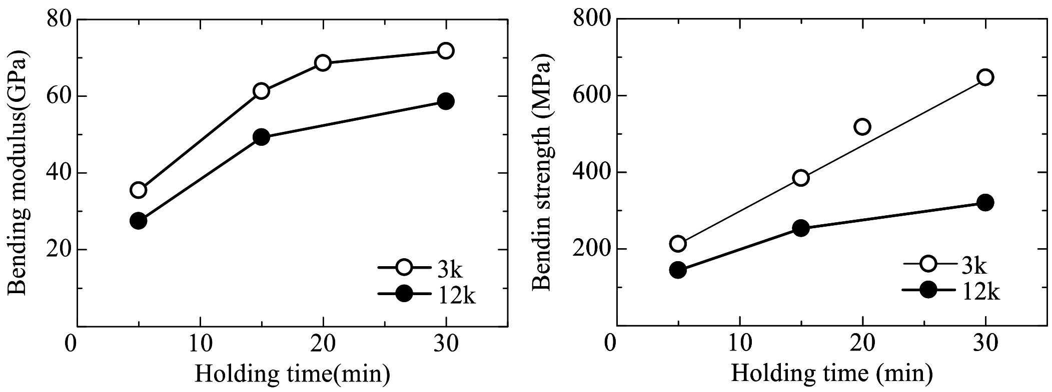

Fig.6 Bending properties and holding time

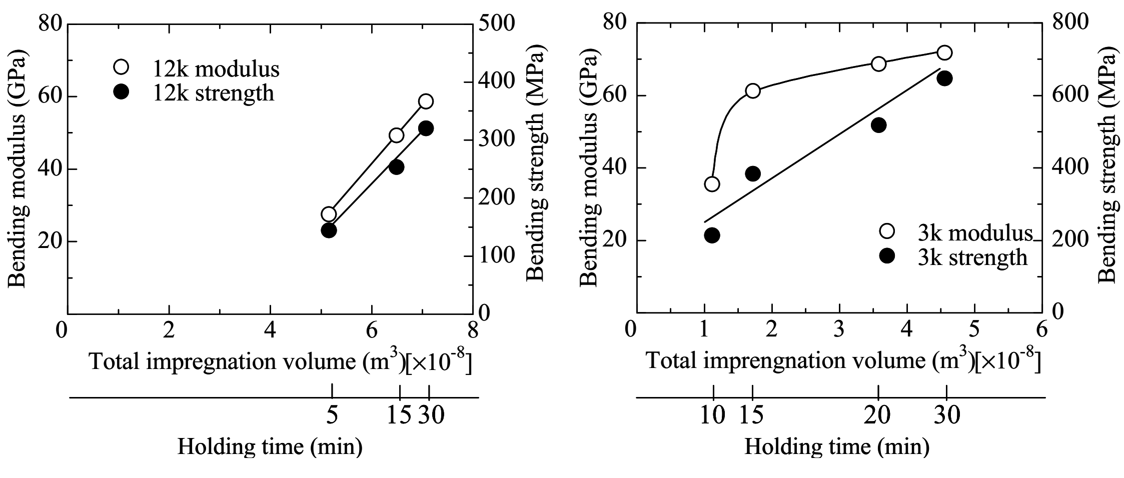

Fig.7 Bending properties and total impregnation volume

CONCLUSION

In this study, Micro-braided yarn was used to improve the impregnation of thermoplastic resin for long fiber reinforced thermoplastic composite. The effects of molding condition were investigated on impregnation property and mechanical properties of unidirectional composite by compression molding. As a result, relationship between impregnation property and mechanical properties were clarified.

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