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DEVELOPMENT OF CONTINUOUS BRAIDED PULTRUSION PROCESS

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SUMMARY: In the pultrusion process, usually the unidirectional fiber reinforced composites are fabricated. One of the problems of the unidirectional fiber reinforced composites is the anisotropic of mechanical properties. In this study, the unidirectional fibers were covered with the braided yarns to reduce the anisotropic. Moreover, the new molding method which had continuity was established by combining braiding machine and pultrusion process. The impregnation states and the flexural properties of the pultrusion moldings in longitudinal and lateral directions were investigated. The fractured surfaces of the specimens after flexural tests were observed, in order to clarify the difference of the fracture mechanism between unidirectional moldings and braided one. As the result of the experiments, braided moldings with good impregnation state could be obtained in case that fiber volume fraction was enough high. It was clarified that specimens with braiding technique had high isotropic, because the braided moldings showed the much higher flexural properties in lateral directions than the only unidirectional moldings. Besides, it was found that the braiding layer restrained the development of the cracks.

KEYWORDS: pultrusion, braiding, isotropic, impregnation, flexural properties

INTRODUCTION

The pultrusion process has become increasingly broader use for the production of composite [1]. The pultrusion is an automated process for manufacturing reinforced materials into continuous, constant cross section profiles. The basic operation consists of pulling a continuous reinforcing fiber through a facility to impregnate the reinforcement with resin, and then shaping and curing the profile in various dies. In addition to producing complex sections, the pultrusion process has an operating flexibility enabling optimum efficiency of reinforcement to be realized at high speed. That is the advantages of pultrusion process are good moldability and high mechanical properties depend on continuous processing. These and other advantages make pultrusion such an efficient process that it has been said that, if possible, a composite should be designed so that it can be pultruded [2].

The unidirectional fibers are used as general reinforcement materials for pultrusion molding, because of their greatly mechanical properties of longitudinal direction. Normally, only longitudinal properties were considered, because the mechanical properties of other directions were very weak in compared with longitudinal direction. In other words, it is anisotropic material. Therefore, in order to extend further applications, the pultrusion moldings should design the stiffness at all other direction according to the requirements. To improve the mechanical properties, usually the mats were used as reinforcement form.

In this study, braided techniques were used instead of the mats. The schematic drawing of braided tube was shown in Fig. 1. In this figure, the braided angle means the bundle orientation of the braidings, and the middle end fiber means the unidirectional fibers which along the longitudinal direction in between braided fibers. The braiding is the textile technology which promises improvements in properties of composite material and being to meet requirements of automated fabrication [3]. Since brandings have fiber bundles which continued in longitudinal and circumferential direction, it can be expected that mechanical properties would be improved. In addition, the braidings can be designed their mechanical properties by changing the braided angle and applying the various kind of fiber to by one of the braiding fiber and the middle end fiber. Therefore, the purpose of this study is to improve anisotropic of the unidirectional pultrusion molds with braiding technique.

The schematic drawing of pultrusion processing line with braiding technique is shown in Fig. 2. The braiding machine was inserted between glass rovings and resin bath. That braiding machine can braid the cylindrical tube. Besides, continuous of molding line which is one of the advantages of pultrusion process was not lost in new molding line with braided technique. As it was shown in Fig. 3, unidirectional fibers were covered with braiding yarns. And then it was pulled into the die after providing the resin. The impregnation states and the flexural properties of the pultrusion moldings were investigated. Since the purpose of this study is to improve anisotropic, anisotropic parameter was introduced.

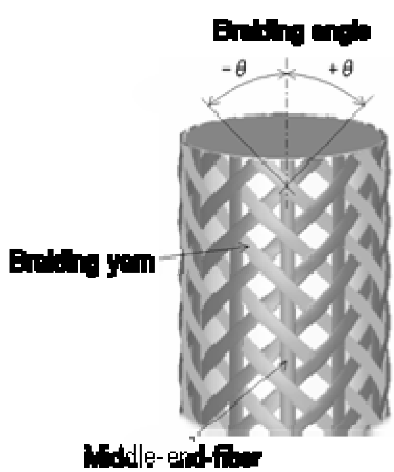

Fig. 1 The schematic drawing of braided tube.

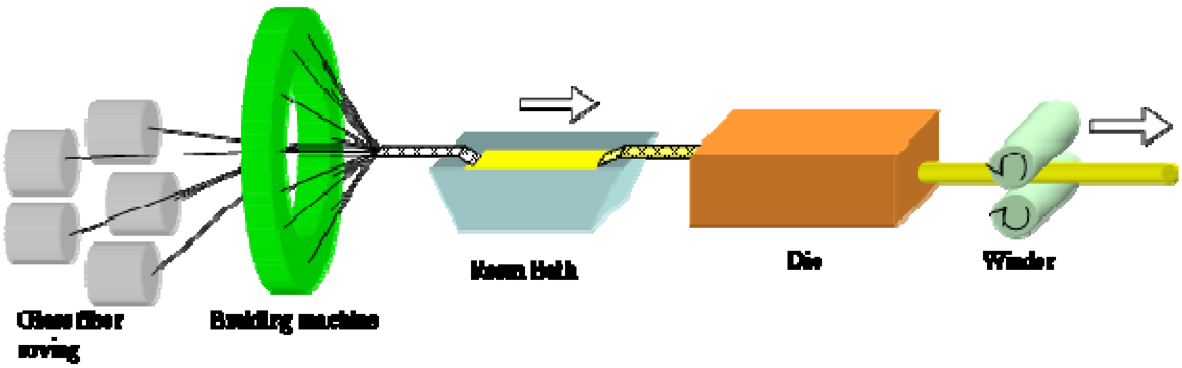

Fig. 2 The new pultrusion molding line with braiding

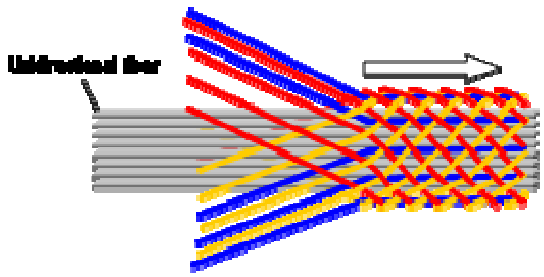

Fig. 3 The schematic drawing of braided molding.

EXPEREMENTAL PROCEDURE

Material and Molding Condition

As matrix, an unsaturated polyester (UP) resin was used. And as reinforcement fiber, the glass fiber (SAINT GOBAIN VETROTEX Ro99 4400 P122) was used. Same type of fibers was used both for unidirectional and braided fiber. The die had a rectangle section which size was 32×6 mm, length of die was 800 mm. The temperature of die was controlled every three parts, from entrance they were 80, 140, 160 degree Celsius. The pultrusion velocity was 200 mm/min.

Effect of Middle-end-Yarn on Impregnation State

Three types of moldings were manufactured. One was the braided molding without middle-end-yarn, next one was the braided molding with middle-end-yarn and last one was the only unidirectional molding. The braided moldings were compared with the unidirectional molding. The braided angles of two braided moldings were 30 degree. All moldings had 50% fiber volume fraction (V_f). In order to investigate the effect of middle-end-yarn on impregnation state, the surface and the cross section of the each specimen was observed.

Effect of Supply Method of Resin on Impregnation State

Two types of supply method of resin were examined for getting the good impregnation state. One was a single resin bath like Fig. 2. The other was double resin bath. In this method, two resin baths were inserted before and after braiding machine. Therefore, the unidirectional fibers were soaked in the resin before they were covered with braiding fibers, and then they were soaked in the resin again after braiding. Those braided angle was 25 degree, and Vf was 48%. In order to investigate the effect of supply method of resin on the impregnation state, the surface and the cross section of the each specimen were observed.

Effect of Fiber Volume Fraction on Impregnation State

To investigate the relationship between fiber volume fraction and impregnation state, the void contents of three specimens which had different fiber volume fraction were measured. The V_f of three specimens were 48%, 50% and 52%. In order to control the V_f, the number of the unidirectional fiber was changed, in this study these were 12, 14 and 16. The surface and the cross section of the each specimen were observed, and then the void contents were calculated by the cross section photos which were obtained by microscope.

Flexural Tests

To investigate the flexural properties, three point bending tests in longitudinal direction and lateral direction were performed by using Instron universal testing machine (Model 55R4206). The span lengths were 96 mm for longitudinal direction and 24mm for lateral direction. The crosshead speed was 1 mm/min.

Since the purpose of this study is to improve isotropy, an anisotropic parameter was introduced by dividing a characteristic in the 0 degree direction by the value in the 90 degrees direction. If this parameter is close to 1, that material is close to isotropic.

RESULTS AND DISCUSSIONS

Effect of Middle-end-Yarn on Impregnation State

The aspects of these moldings were shown in Fig. 4. From this figure, it was found that the width was decreased during molding in braided molding without middle-end-yarn, because when braided moldings was subjected to tension in longitudinal direction, it shrunk in lateral direction by changing braiding angle. In the case of braided molding with middle-end-yarn, a decrease in lateral direction did not occur since middle-end-yarns prevented the shrinking. It was clarified that the middle-end-yarns were essential for braided moldings. However that molding had many voids on the surface. In the case of unidirectional molding, the voids on the surface and the change in width did not occur.

The cross section of each molding was shown in Fig. 5. From this figure, it was found that there were big unimpregnated region in the middle of braided molding without middle-end-yarn, because the resin was pushed out from unidirectional fiber bundle by shrinking of braided bundles. Such big unimpregnated regions were not observed in the braided molding with middle-end-yarn and unidirectional molding. However, there were many voids in the braided molding with middle-end-yarn, especially they were observed in the resin rich regions which were in between unidirectional fibers which were shown in Fig. 5 as red area and braided yarns.

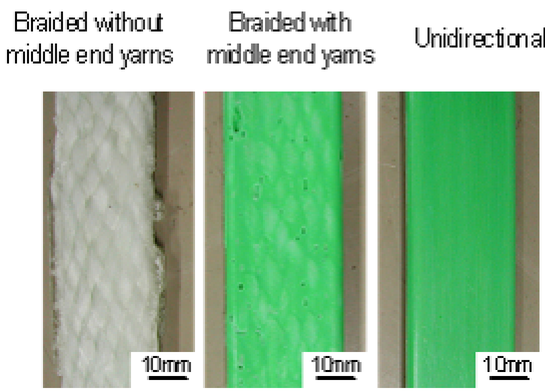

Fig. 4 The aspects of moldings.

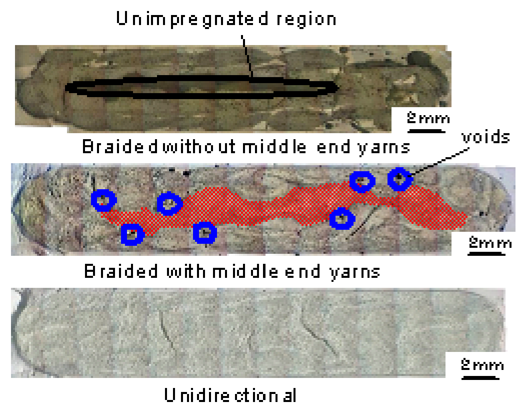

Fig. 5 The cross-section of each molding.

Effect of Supply Method on Impregnation State

In Fig. 6, the cross section photo of braided specimen with double resin bath was shown. From this figure, many voids were still observed and the impregnation state was not improved with double resin bath. The double resin bath was not effective, but by using double resin bath, different resin may be applied to unidirectional fibers and braiding fibers. That is to say, the possibility of materials design was increased.

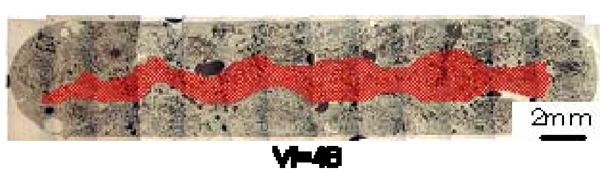

Fig. 6 The cross-section of molding with model A.

Effect of Fiber Volume Fraction on Impregnation State

The aspects of moldings which had different Vf were shown in Fig. 7. From this figure, it was found that the number of voids on the surface decreased as V_f increased. The cross section of moldings which had different V_f was shown in Fig. 8. From Fig. 6 and Fig. 8, void contents were calculated by dividing sum of area of voids by area of cross section. The relationship between voids contents and V_f was shown in Fig. 9. From this figure, the voids contents decreased linearly as V_f increased. Therefore, to increase the V_f improved the impregnation state.

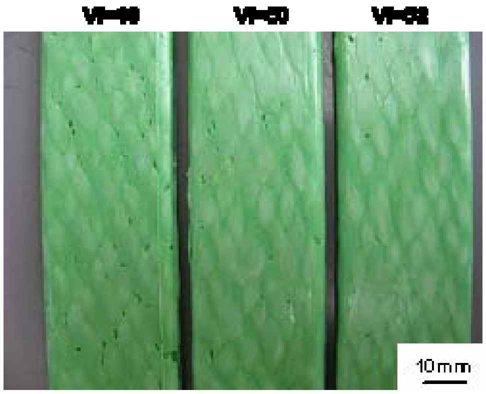

Fig. 7 The aspects of moldings with Method A, B.

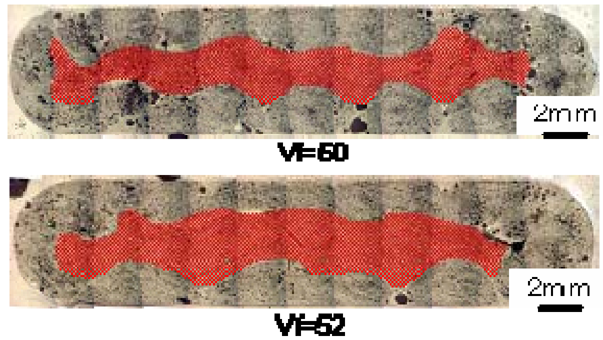

Fig. 8 The cross-section of moldings with Method B.

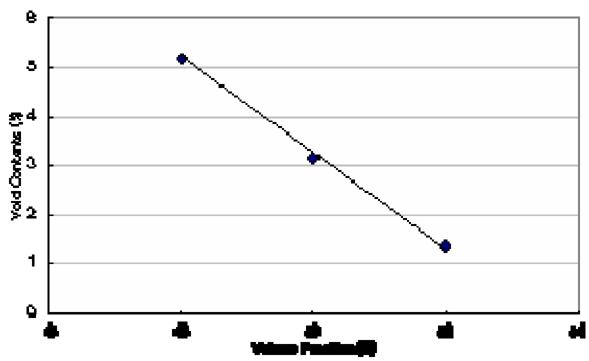

Fig. 9 Relationship between voids contents and V_f .

Flexural Tests

The relationship between flexural stress and deflection in longitudinal direction was shown in Fig. 10. In this figure, the stress of unidirectional specimen decreased sharply after the maximum stress, but the stress of braided specimens decreased gradually. The bending modulus, strength and theoretical modulus were shown in Table 1. Here, theoretical modulus was calculated with laminate theory, and the values in parenthesis were the achievement ratio of experimental modulus. The unidirectional specimen had higher modulus and strength than the braided specimens. The modulus and strength of braided specimen increased as Vf increased. The achievement ratio of the braided specimen was increased with increase in Vf and that with Vf of 52% was superior to the unidirectional specimen's one.

The relationship between flexural stress and deflection in lateral direction was shown in Fig. 11. In this figure, the stress of unidirectional specimen decreased sharply after the maximum stress, but the stress of braided specimens decreased gradually as same as results in longitudinal direction. The bending modulus, strength and theoretical modulus were shown in Table 2. The braided specimen had higher strength than the unidirectional specimens. The modulus and strength of braided specimen increased as V_f increased. The modulus and the achievement ratio of the braided specimen which had 50% and 52% as V_f were superior to the unidirectional specimen.

The anisotropic parameters of modulus and strength which were provided by the flexural tests were shown in Table 3. From this table, it was found that all braided specimens had higher isotropic than unidirectional specimen. In addition, as much as V_f rose, the anisotropic parameters of the modulus came toward 1. In other words, the braided technique improved the anisotropic of unidirectional pulustusion moldings. As it was mentioned in introduction, braidings can be changed the braided angle and be applied the various kind of fiber to by one of the braiding fiber and the middle end fiber, therefore the braiding plutrusion can control the anisotropic parameter of products.

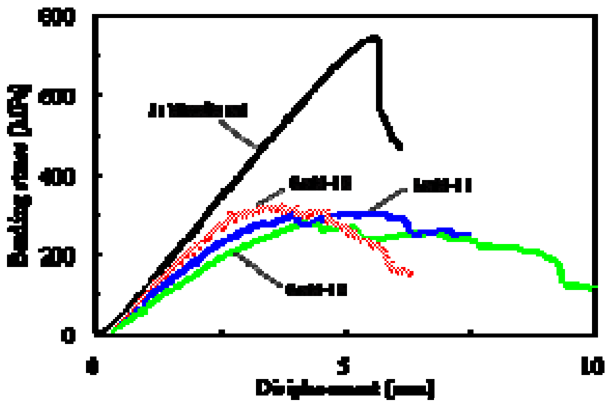

Fig. 10 The relationship between flexural stress and deflection of longitudinal direction.

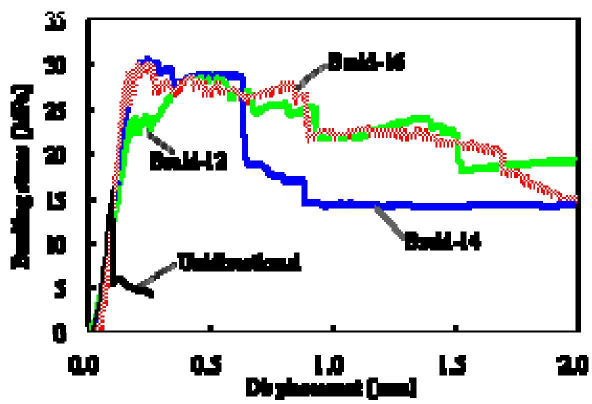

Fig. 11 The relationship between flexural stress and deflection of lateral direction.

Table 1 The bending modulus, strength and theoretical modulus

	Bending modulus (GPa) Exp.	Bending modulus (GPa) Cal. (%)	Bending strength (MPa) Exp.
Unidirectional	37.39	44.0 (85.0)	765.3
Braided- 12	21.14	29.7 (71.1)	273.7
Braided- 14	26.47	29.9 (88.7)	307.3
Braided- 16	28.73	30.0 (95.9)	320.4

Table 2 The bending modulus, strength and theoretical modulus

	Bending modulus (GPa) Exp.	Bending modulus (GPa) Cal.	Bending strength (MPa) Exp.
Unidirectional	3.74	12.29 (30.5)	16.1
Braided- 12	2.51	13.46 (20.7)	33.0
Braided- 14	3.56	13.50 (29.1)	34.5
Braided- 16	4.62	13.54 (37.8)	35.6

Table 3 The anisotropic parameters of modulus and strength

	E_0/E_{90}	σ_0/σ_{90}
Unidirectional	10.0	47.6
Braided-12	8.4	9.2
Braided-14	7.4	9.8
Braided-16	6.2	10.0

CONCLUSIONS

To improve anisotropic, unidirectional fibers were covered with braided yarns in pultrusion moldings. Besides, continuous of molding line which is one of the advantages of pultrusion process was not lost in new molding line with braided technique. The main results of the molding, the cross section observations and the flexural tests in longitudinal direction and lateral direction were shown blow.

・ For braided moldings, the middle-end-yarns were essential.

・ To obtain good impregnation state, Vf had to high enough, in this time it was 52%.

・ The braided technique improved the anisotropic of unidirectional pulustusion moldings.

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