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Effect of configuration in intermediate materials on textile processability by TFP technology

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Abstract. Continuous fiber reinforced thermoplastic (c-FRTP) has been focused on because of not only the excellent specific rigidity and strength but also the recyclability and the secondary workability due to a feature of the thermoplastic resin as the matrix. However, unlike the thermosetting resin, it is very difficult to impregnate thermoplastic resin into continuous fiber bundles because of its high melt viscosity. In order to solve this problem, various intermediate materials have been developed. On the other hand, Tailored Fiber Placement (TFP) is a textile manufacturing technology for continuous fiber preforming. Compared to other textile manufacturing processes, the continuous fiber material can be placed in any direction according to the requirement. From this characteristic, it is possible to change the local fiber orientation in the fiber reinforced composite material, so that mechanical properties of reinforcing fibers can be utilized to maximum. Applying fibrous intermediate material for c-FRTP to TFP technology, the high cycle c-FRTP molding with optimized fiber orientation can be achieved. However, in order to prepare a preform of c-FRTP, textile processability (flexibility) is needed for fibrous intermediate materials as dry fiber. Therefore, to develop fibrous intermediate material with both better impregnation property and flexibility for TFP technology is required. In this study, the effect of fabrication condition of newly developed fibrous intermediate material called PCY (Partially Impregnated Commingled Yarn) on preforming by TFP technology was investigated. The textile processability was evaluated by measuring the deformation resistance of various PCYs. The unidirectional (UD) preforms were prepared using PCY with better textile processability and impregnation property. In order to investigate the effect of stitch yarn on impregnation property during molding, the impregnation state was quantified by cross-sectional observation of various specimens. In addition, a tensile test using UD specimen was carried out to investigate the effect of stitch yarn on mechanical properties.

1. Introduction

Continuous fiber reinforced thermoplastic (cFRTP) has been focused on because of not only the excellent specific rigidity and strength but also the recyclability and the secondary workability due to a feature of the thermoplastic resin as the matrix. However, unlike the thermosetting resin, it is very difficult to impregnate thermoplastic resin into continuous fiber bundles because of its high melt viscosity. In order to solve this problem, various intermediate materials have been developed.

On the other hand, Tailored Fiber Placement (TFP) is a textile manufacturing technology for continuous fiber preforming. Compared to other textile manufacturing processes, the continuous fiber material can be placed in any direction according to the requirement. From this characteristic, it is possible to change the local fiber orientation in the fiber reinforced composite material, so that mechanical properties of reinforcing fibers can be utilized to maximum. Applying fibrous intermediate material for c-FRTP to TFP technology, the high cycle c-FRTP molding with optimized fiber orientation can be achieved [1]. However, in order to prepare a preform of c-FRTP, textile processability (flexibility) is needed for fibrous intermediate materials as dry fiber. Therefore, to develop fibrous intermediate material with both better impregnation property and flexibility for TFP technology is required.

In this study, the effect of fabrication condition of newly developed fibrous intermediate material called PCY (Partially Impregnated Commingled Yarn) on preforming by TFP technology was investigated. The textile processability was evaluated by measuring the deformation resistance of various PCYs. The unidirectional (UD) preforms were prepared using PCY with better textile processability and impregnation property. In order to investigate the effect of stitch yarn on impregnation property during molding, the impregnation state was quantified by cross-sectional observation of various specimens. In addition, a tensile test using UD specimen was carried out to investigate the effect of stitch yarn on mechanical properties.

2. Materials and Molding Method

2.1. Fabrication Method of PCY and Investigation of Fabrication Condition

The carbon fiber (TR50S-6L, Mitsubishi Chemical Corporation) was used as reinforcing fiber, and the polyamide resin (LEXTER8500, MITSUBISHI GAS CHEMICAL COMPANY, Inc.) was used as resin fiber. After commingled these fibers at the same rate (Vf =50%), surface of the fiber bundle was heated and melted by a heat roller to prepare PCY. The contact time between the fiber bundle and the heat roller was controlled by changing the production speed, and the impregnation state in PCY was changed.

The experiments measuring the resistance load when PCY passed through a thin hole to quantify the deformability were conducted for various PCYs with different initial impregnation states. Here, deformability is better as the load value is lower. The relationship between the resistance load and the heat roller velocity is shown in Figure 1. As shown in this figure, the resistance load decreased from 5 to 10 m/min in the heat roller speed, and showed almost constant value in the load over 10 m/min of roller velocity. This result means the textile processability greatly increases when the heat roller speed change from 5 to 10 m/min.

The relationship between Un-impregnation ratio obtained from cross-sectional observation of UD specimens and roller velocity is shown in Figure 2. As shown in this figure, the un-impregnation ratio increased with increasing roller velocity, and the rate of increase became larger after 15 m/min. Based on these results, PCY produced with a heat roller speed of 10 m/min was chosen for preform fabrication by TFP technology.

2.2. Stitching Conditions and Molding Method

Unidirectional preform having a length of 200 mm and width of 20 mm was produced and pressed to prepare a specimen. A preform with PCY was produced using the embroidery machine (TCWM101 Tajima Industries Ltd.). The effect of existence of stitch yarn on impregnation property after molding was examined by using polyamide fiber that be melted during the molding process and aramid fiber as stitch yarn. UD specimens were molded by using following molding conditions; the molding temperature was 260 ℃, molding pressure was 3MPa and molding time was 3 min. Furthermore, the effect of using the TFP technology on mechanical properties was examined by comparing the un-impregnation ratio and the mechanical properties with non-stitched specimens.

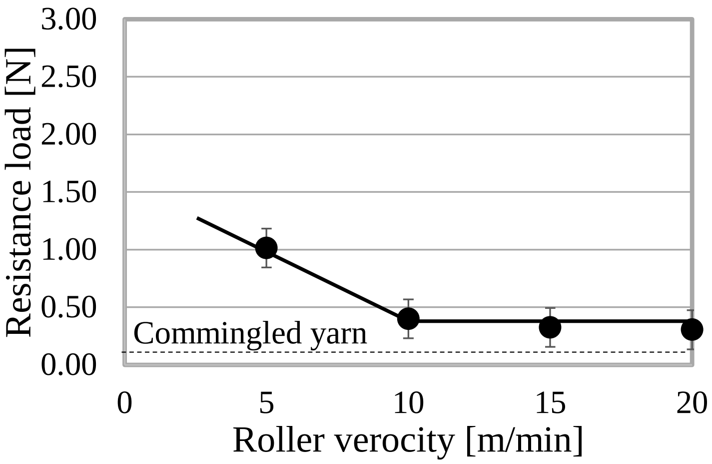

Figure 1. Relationship between resistance load of each PCY and roller velocity.

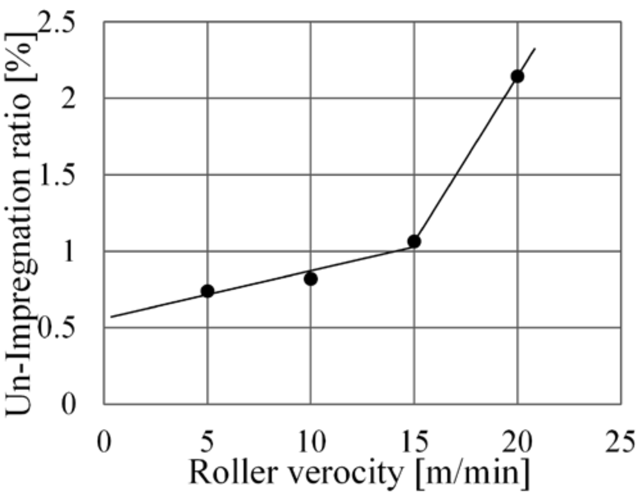

Figure 2. Relationship between Un-Impregnation ratio and roller velocity.

3. Results and Discussion

Un-impregnation ratio from the cross-sectional observation of each specimen is shown in Figure 3. The un-impregnation ratio in all specimens was less than 0.6%, but in the specimen with aramid stitch yarn, the un-impregnation ratio was slightly higher than the other specimens. From this result, unlike polyamide, the aramid stitch yarn does not melt by the heat during molding and remains in the specimen. Therefore, the impregnation state of the specimen would be affected by stitch yarn remaining in the specimen. As a result, it seemed that the waviness of PCY was generated, PCY was tied up and Vf in PCY was increased by the stitch yarn, as compared with the non-stitched one. Therefore, more molding time or molding pressure or molding temperature will be needed for better impregnation state for the molding with TFP preform due to the increase of Vf in the fiber bundle by stitch yarn.

In order to investigate the effect of stitch yarn on mechanical properties, a tensile test was conducted for various specimens. Achievement ratio of mechanical properties to the theoretical value of each specimen is shown in Figure 4. The achievement ratio is the ratio of measured value to the theoretical elastic modulus and strength in the 0 degree direction obtained from the rule of mixture with Vf set at 50%. As shown in Figure 4, achievement ratio of elastic modulus is more than 90% in all specimens.

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The achievement ratio of tensile strength for all specimens was also about 70% and the specimen showed a few percent difference. In previous studies, the unimpregnation ratio of less than 1% does not affect the strength of composite material. Consequently, the difference in structure of reinforcing fiber due to the stitch yarn does not affect the strength.

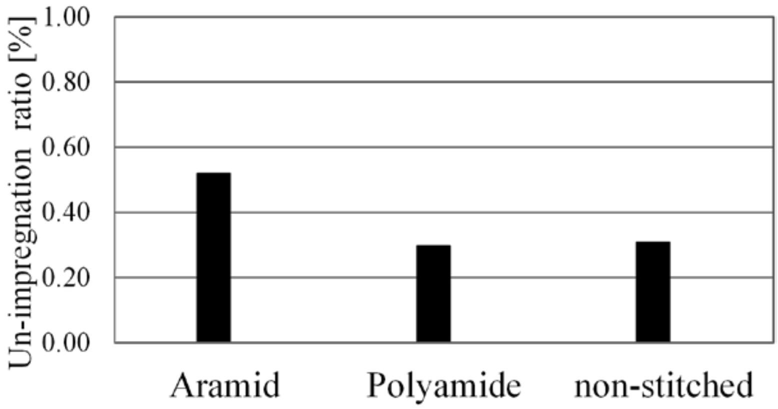

Figure 3. Un-impregnation ratio of various specimens.

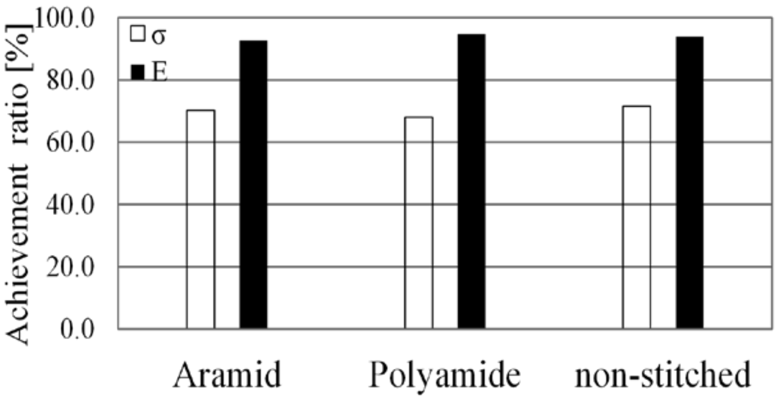

Figure 4. Achievement ratio of mechanical properties to the theoretical value.

References

[1] Mattheji P, Gliesche K, Feltin D, 1998, Tailored Fiber Placement-Mechanical Properties and Applications, *J. Reinforced Plastics and Composites*, **17**, 774-786.