SURFACE TREATMENT OF CONTINUOUS FIBER FOR IMPREGNATION AND MECHANICAL PROPERTIES OF THERMOPLASTIC COMPOSITES

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1 Introduction

Continuous fiber reinforced thermoplastic composites have been attractive material system due to the recycle ability and secondary processing in recent years. The fabrication of continuous fiber reinforced thermoplastic composite involves two problems. The first one is that thermoplastics as matrices generally have high melt viscosity so that it is difficult to impregnate resin into reinforcing fiber bundle. To overcome this problem, intermediate materials with CF and thermoplastic fiber have been developed. Since thermoplastic resin is located close to reinforcement fiber bundle, impregnation performance of thermoplastics is excellent [1]. The other one is low interfacial properties between the fiber and matrix. It is considered that interfacial properties in continuous fiber reinforced thermoplastic composites can be characterized by the wetting ability and chemical interaction between fiber and matrix. Wetting ability would affect resin impregnation state during molding while chemical reaction affects composite strength. Therefore, interface design of CFRTP is very important to obtain composite materials with improved processability and mechanical performance.

The objective of this research is to improve the both impregnation state and interfacial properties by using surface treatment on carbon fiber. To achieve this objective, low molecular weight polypropylene (L-PP) were used for CF/L-PP composite, and low molecular weight polycarbonate (PC) were used for CF/PC composite.

1.1 MBY

Micro-braided yarn (MBY) is one of the intermediate materials. MBY with CF and thermoplastic fiber have been developed by using Japanese traditional braiding resin fibers around reinforcement fiber bundles as shown as Fig. 1. Braided fabric was Braided fabric consists of only diagonally-oriented braiding yarn as shown in Fig. 2. Braided fabric-MEY consists of diagonally-oriented braiding yarn and longitudinally-oriented middle–end-yarn as shown in Fig. 3. Using this character, MBY can be changed volume fraction of fiber (Vf) easily.

2 Surface treatment for carbon fiber by L-PP

2.1 Intermediate material

The materials used in this study were carbon fiber as the reinforcement (T700SC-1200, TORAY), and Polypropylene (PP) fibers as matrix resin.

The carbon fibers were treated by using L-PP with various conditions at 0.0, 2.1wt%.

To evaluate the impregnation state and mechanical properties were fabricated. Untreated and L-PP treated carbon fibers were braided with PP fibers to yield MBY [2,3]

2.2 Molding method

Prior to compression molding process for fabricating the composites, the MBYs was wound onto a parallel metallic frame with a 20 x 340 mm equipped with a spring mechanism to prevent thermal shrinkage during molding, as shown in Fig. 5. The wound flame was then placed into a preheated mold size 20×200 mm before performing
compression molding at 200 °C with a molding pressure of 10 MPa for 60 minutes. Cooling was subsequently performed by running water though the mold while keeping the specimens under constant pressure.

2.3 Cross-sectional observations

The cross section of each molding was observed with the optical microscope. For the observation on cross section, the samples were emery ground (#100–#2,000) and buffed (alumina particle, average particle size: 100 nm) after they were embedded in epoxy resin. Fig. 5(a) shows the impregnation state by cross-sectional photographs of composites by untreated. Fig. 5(b) shows the impregnation state by cross-sectional photographs of composites by treated with L-PP. Black region inside of fiber bundle was un-impregnated region without resin. Un-impregnation ratio of using un-treated CF is 0.0%, and un-impregnation ratio of using CF treated by L-PP is 3.0%. It is found from this that impregnation property became lower by treating by L-PP.

2.4 Interfacial adhesion properties

Micro-droplet test was performed to investigate interfacial adhesion and evaluated interfacial shear strength of the CF/PP inter face, the resin fiber was melted by using a hot plate at 220°C and a small droplet of resin was applied to a single fiber. micro-droplet test machine HM410 (Tohei Sangyo) was used with a fiber pull-out speed of 0.03mm/min. When the micro-droplet touches the knife edges, the interface is solicited in shear mode.

Fig. 6 show SEM photographs after micro-droplet test for un-treated and treated by L-PP. In the case of untreated, there is no resin. But in case of using CF treated by L-PP, the resin remains on surface of carbon fibers. This shows that interface intensity rose by the surface treatment.

2.5 Bending test for CF/PP

3 point bending test of unidirectional composites was performed by using an INSTRON universal testing machine (model 4206). As shown in Fig. 7 the specimen size was 50mm in length, 15mm in width and 2.0mm in thickness. The span length was 25mm and the test speed was 1mm/min.

Table1 shows bending abilities of composites. Value of strength and modulus of treated by L-PP are higher than un-treated one. It is find that tensile strength and tensile modulus improved owing to treatment by L-PP.

2.4 Conclusion

The surface treatment by L-PP was effective to advance surface adhesion and mechanical properties, but for impregnation properties, there is not effective. To wrap up, it is find that Impregnation and adhesiveness are not necessarily in agreement.

3. Surface treatment for carbon fiber by PC

3.1 Impregnated tape for CF/PC

Carbon fibers (T700-6000-SC, TORAY), and Carbon fibers (PYROFIL TR50S12L) were used as the reinforcing fiber. PC resin powder with low molecular weight (H-4000, Mitsubishi Gas Chemical Company Inc.) was used as the matrix resin. The powder was dissolved in methylene chloride with concentration of 5.0wt% and 3.3 wt%.

Pre-impregnated tape was prepared by dipping continuous fiber into the solution with sizing machine as shown in Fig.8. The resin content on fiber bundle was 4.6 wt% and 2.7wt%.

3.2 Molding method

3.2.1 For cross-sectional observations

In order to investigate the impregnation state of molding, unidirectional composite was fabricated as shown in Fig.9. Carbon fibers (T700-6000-SC, TORAY) treated by PC solution of 5wt% of concentration was used in this molding. Fiber bundles were wound 36 times unidirectional-aligned on metal flame. 3 types of composite were fabricated; sample-1 was fabricated by sandwiching dry carbon fiber with PC film (FE200B, 50 micrometer of thickness), sample-2 was fabricated only with pre-impregnated tape, sample-3 was fabricated by sandwiching pre-impregnated tape with PC film. 2 layers of films were inserted at both surface and 3 layers of films were inserted between fiber bundles.

It was molded by heating and compression molding method. Molding pressure was 7MPa, molding time was 10min, and molding temperature was 290 degree Celsius. Finally, unidirectional plate (20mm
in width, 200mm in length) was molded and cross-sectional observation was carried out.

3.2.2 For tensile test
Carbon fibers (PYROFIL TR50S12L) treated by PC solution of 5wt% and 3.3wt% concentration was used in this molding. Specimens for tensile test were fabricated by sandwiching pre-impregnated tape with PC film. 2 layers of films were inserted at both surface and 3 layers of films were inserted between fiber bundles. It was molded by heating and compression molding method. Molding pressure was 7MPa, molding time was 10min, and molding temperature was 290 degree Celsius. Finally, unidirectional plate (20mm in width, 200mm in length) was molded and cross-sectional observation was carried out.

3.3 Cross-sectional observations
Fig. 10 shows the photographs of the cross section. Then, un-impregnation ratio of each specimen was calculated. Un-impregnation ratio was defined as the area of un-impregnation area divided by the cross section of the molding. Table 2 shows un-impregnation ratio of each composite. Even the resin film was required as appropriate content of matrix, the impregnation state was greatly improved by using pre-impregnated tape.

3.4 Tensile test
Tensile3 test of unidirectional composites was performed by using an INSTRON universal testing machine (model 4206). The specimen size was 200mm in length, 20mm in width and 2.0mm in thickness. The distance between chuck was 100mm and the test speed was 1mm/min, as shown as Fig. 11.

Fig. 12 shows tensile abilities. Both strength and modulus are an almost fixed value. It is find that concentration of PC solution hardly influences.

3.5 Conclusion
In this study, in order to improve the both impregnation state and interfacial properties, surface treatment by using the resin with low molecular weight and same materials with matrix resin was proposed. According to the molding, it was clarified that the impregnation state was greatly improved by using pre-impregnated tape after sizing treatment.

But for mechanical properties, sizing treatment by using the resin with low molecular weight effect changes with resin.

Reference


Fig. 1 Fabrication of Micro-braided yarn (MBY)

Fig. 2 Structure of braided fabric

Fig. 4 Fabrication method of unidirectional specimens
(a) Cross sectional photographs of composites consist of un-treated CF and PP

(b) Cross sectional photographs of Composites consist of CF treated 2.1wt% L-PP and PP

Fig. 5 Cross sectional photographs of Composites consist of CF and PP
(a) Untreated
(b) Treated by L-PP

Fig. 6 SEM photographs of after micro-droplet test

Fig. 7 Size of specimens for bending test

Fig. 8 Sizing method.
Table 1 Results of three point bending test.

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<th>Un-treated</th>
<th>Treated by L-PP</th>
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<td>Strength (MPa)</td>
<td>110.05</td>
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<td>Modulus (GPa)</td>
<td>18.22</td>
<td>47.91</td>
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Fig. 9 Molding method of CF/PC

Fig. 10 Cross-sectional observation of CF/PC
Table 2 Un-impregnation ratio of CF/PC

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<th>Sample number</th>
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<td>Un-impregnation ratio (%)</td>
<td>40.1</td>
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Fig. 11 Fig. 9 Size of specimens for tensile test

Table 3 Results of three point tensile test.

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<th>Concentration of treatment (wt%)</th>
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<tr>
<td>Strength (MPa)</td>
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<td>1455.12</td>
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<td>Modulus (Gpa)</td>
<td>164.13</td>
<td>152.74</td>
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