ESTIMATION OF MECHANICAL PROPERTIES FOR FIBER REINFORCED COMPOSITES WITH WASTE FABRIC AND POLYPROPYLENE FIBER

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1 Introduction

In Japan, the amount of waste fabric is not less than 2 million tons, however, the recycling rate is only 10% which is remarkably lower than that of other materials. As a result, the effective use of the waste fabric has been required recently. In this study, the waste fabric is used as the substitute for wood materials with the aim of increasing the effective use of the waste fabric. The composite materials are manufactured with the waste fabric and polypropylene (PP) fiber by heating compression process. The proposed material is expected to alternate wood and constructional member, because it has similar characteristics like a wood, which can drive the nail and cut. In our previous studies [1][2], the glass rod and steel fiber had been used as the reinforced materials to improve the stiffness and strength of the waste fabric. However, the materials have several problems such as high density, high cost, low biodegradability, and so on.

In this research, two types of composites with waste fiber are proposed to improve the mechanical properties. One is the composites with shellac resin and bamboo fiber. The shellac resin is one of typical materials of biodegradability. And, the composites with thermosetting plastic are difficult to recycle and the environmental impact is high. In recent decades, the application of natural fiber to composites is investigated [3], and the bamboo fiber as the reinforced materials is applied with the waste fiber. Another is the composites with MAPP (maleic anhydride treated polypropylene) in order to improve the interfacial properties between waste fiber and resin. It has been known that the maleic anhydride can enhance the adherence property of interfacial. In order to estimate the mechanical properties, the micro compression test, the interlaminar shearing strength test and three-point bending test have been carried out. The experimental results are described in the paper.

2 Material and experimental method

2.1 Materials

A waste fabric was produced with polyester fiber. Figure 1(a) shows the felt of waste fabric, and the shellac resin to powder form is shown in Fig.1(b). The shellac is a natural, biodegradable resin from insect origin and thermosetting resin. The shellac resin is a substance that is widely used in many industrial applications such as coating and addition agent. In this research, shellac resin (GIFU Shellac Co. Ltd., Japan GH-24) was used two patterns. One is paste form, and another is dried form. Moreover, bamboo fiber with great mechanical properties, even in the natural fiber was used as reinforcing material [4], [5]. The bamboo has a large production volume in the world, moreover, it was used as building products due to combine the features of flexibility and toughness. In the present study, the bamboo sheet (Ban Co. Ltd., Japan) was produced for blasting treatment and blend with low melting point polyester (30 wt%). The maleic anhydride is a substance that is used in many industrial applications such as coating, additives, and surfactants.

![](image)

(a) Waste fabric (b) Shellac resin

**Fig.1 Waste fabric and shellac resin**

2.2 Test specimens

The waste fabric is chopped and mixed with PP fiber as a felt sheet. The symbols of materials are F, SFp, SFd, SBF and MF as listed in Table 1. Figure 2 shows the surface images of the materials. One is ‘F’ type which means the specimens using PP fiber, and the other is ‘MF’ type with MAPP fiber, which is
crossly-laminated with 6-sheets. The ‘SF’ type is laminate with three-layer, and shellac sheet was sandwiched in the middle of felt sheet as reinforcing material. Moreover, SF p was applied shellac in paste form and SF d was applied with shellac dried fiber. The ‘SBF’ type is five-layer structure, bamboo sheets was applied in outer layer as reinforcing material. Figure 3 shows the geometry of stacking sequence of SF.

<table>
<thead>
<tr>
<th>Table 1 Material properties</th>
<th>(a) F, SF_p, SF_d, SBF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Types of material</td>
<td>Waste fabric H_wt%</td>
</tr>
<tr>
<td>F</td>
<td>65</td>
</tr>
<tr>
<td>SF_p</td>
<td>61</td>
</tr>
<tr>
<td>SF_d</td>
<td>43.16</td>
</tr>
<tr>
<td>SBF</td>
<td>35.75</td>
</tr>
</tbody>
</table>

| (b) F, MF |
|-----------------------------|-------------------------|
| Types of material | Waste fabric H_wt% | PP fiber H_0 wt% | MAPP fiber H_0 wt% | Density ρg/cm³ |
| F | 65 | 35 | 0 | 0.74 |
| MF | 65 | 0 | 35 | 0.972 |

2.3 Production of SF specimens
Figure 4 shows scheme of production of SF_p and SF_d, and the observational result of surface of SF_d in Fig.5. As shown in Fig.4, the shellac paste form was set in interlaminar of the felt homogeneously and the shellac dried fiber was set in interlaminar of the felt as interval which the shellac dried fiber spread homogeneously. As shown in Fig.5, it was also confirmed that the shellac dried fiber spread homogeneously.

2.4 Experimental methods
The micro compression test has been carried out by MCT (SHIMADZU Co. Ltd., Japan, DUH-W201). Three-point bending test and interlaminar shearing strength test have been carried out by AUTOGRAPH (SHIMADZU Co. Ltd., Japan, DSC10-T). Figure 6 shows the geometry of test specimens for micro compression test. Figure 7 shows the geometry of test specimens for three-point bending test. Figure 8 shows the geometry of test specimens for interlaminar sharing strength test. In the micro compression test, the compression force is 1000 (mN), holding time is 10 (s), loading speed is 41.48 (mN/s), and the reduced elastic modulus, Y is estimated as:

\[ Y = \frac{E}{1 - V^2} \] (1)

where E is elastic modulus, V is poission ratio of specimens. In the bending test, the loading speed is
2.0 (mm/min), and the bending elastic modulus, $E_b$ and strength, $\sigma_b$ are estimated as:

$$E_b = \Delta \sigma_b / \Delta \varepsilon_b$$  \hspace{1cm} (2)

$$\sigma_b = 3P_b L / 2bh^2$$  \hspace{1cm} (3)

$$\varepsilon_b = 6hd / L^2 \times 100$$  \hspace{1cm} (4)

where $L$ is the distance of fulcruims, $b$ is the width of specimens, $h$ is the height of specimens, $P/\delta$ is the grade of linear portion of the load-deflection curve, $P_b$ is the applied load to the specimens. In the interlaminar shearing test, the tensile load ($P$) was applied to both ends of the specimen with tensile speed 1.0 (mm/min). When the tensile load increased, the interlaminar fracture appeared and the share force, $\tau$ can be expressed as:

$$\tau = P / L_{db} b$$  \hspace{1cm} (4)

where $L_{db}$ is the distance of cracks. The surface of specimens is also investigated with In-site observation by CCD microscope. In accordance with the shearing test proposed from the JHPC-B.

3 Experimental results

3.1 Waste fabric with shellac resin

3.1.1 Three-point bending test

Figure 9 shows load-flexural strain curves of F, SF$_p$, and SF$_d$. Figure 10 shows the results of three-point bending test. The colored bars mean the bending strength and the solid line shows the coefficient of variance. The number of test specimens is 5. The bending property increases by applying the shellac resin as reinforcing to waste fabric. The bending stiffness of SF$_p$ is about 2.7 times higher than that of F. The bending strength of SF$_p$ is about 1.93 times higher than that of F. On the other hand, the coefficient of variance of SF$_p$ is higher than that of F. There are several reasons for high coefficient of SF$_p$. One of them is the decay of ratio of impregnation for paste form. The other is the crack in the outer layer. The observational results of cross section of SF$_p$ are shown in Fig.11, and it is found that many voids interlaminar. The void was made for vapor from water generated heating process. The average value of bending elastic modulus of SF$_d$ is about 16.04 times higher than that of F. The bending strength of SF$_d$ is about 8.5 times higher than that of F. On the other hand, the coefficient of variance of SF$_d$ is lower than that of F. The reason of this phenomenon is due to the ratio of impregnation for dried form. Figure 12 shows the outer layer after the bending test. However, the crack by high tensile loaded in the outer layer.
Fig. 9 Load-flexural strain curves

(a) F
(b) SFp
(c) SFd

Fig. 10 Result of three-point bending test

Fig. 11 Cross section of interlaminar of SFp

Fig. 12 Outer layer after the bending test
3.1.2 Reinforcement with bamboo fiber

In order to reduce the crack of the outer layer, the bamboo fiber sheets are applied. Figure 13 shows load-deformation curves, and Figure 14 shows result of three-point bending test. The colored bar means the result of bending stiffness and strength and the black square shows the coefficient of variance. The number of test specimens is 5. The bending stiffness increases by applying bamboo sheets to SF. The average value of bending elastic modulus of SBF is about 21.6 times higher than that of F. Furthermore, the bending strength of SBF is about 9.05 times higher than that of F. On the other hand, the coefficient of variance of SBF is lower than that of F. As the reason, it is considered that the development of the crack is reduced in the outer layer due to applying bamboo fiber sheets.

3.2 Waste fabric with maleic anhydride PP

3.2.1 Thermal analysis

Thermal analysis was carried out using thermogravimetric (TG) analysis and differential scanning calorimeter (DSC). The DSC8270 was used for the measurements. The weight of test specimens of F and MF is 0.9(mg) respectively, and the specimens are heated from room temperature to 400(°C) at 5.0(°C/min) in a nitrogen atmosphere to melt them. The TG8120 was used for the measurements, and the weight of test specimens of F and MF evaluated is 0.6(mg). And the specimens are heated from room temperature to 800(°C) at 5.0(°C/min) in an air (200ml/min) atmosphere to melt them. Figure 15 shows the DSC curves and the TG curves. A melting point was observed in the DSC curves. All samples showed an endothermic peak due to PP melting around 160(°C). The onset of weight losses of F and MF are at about 200(°C). The decomposition appeared at low temperature because the increased surface area of the sample is the fibrous. The weight loss of F and MF up to 60(°C) is of the order of 92% and 98%. However, there was not observed effect of maleic anhydride owing to too low amount.
Fig.15 Results of heat analysis

3.2.2 Micro compression test
As the experimental results of micro compression tests, Figure 16 shows load-displacement curves. Figure 17 shows the result of reduced elastic modulus with changing the testing points along to the thickness direction (Z-direction). The colored bar means the average value of reduced elastic modulus and the black square shows the coefficient of variance. Test point was set up 5 locations 2.5mm between from center line to thickness direction. As shown in Fig.17, despite of the results of each test point is very widely, the reduced elastic modulus of MF is 2.64 times higher than that of F. On the other hand, the coefficient of variance of MF is lower than that of F.
3.2.3 Interlaminar shearing test
Figure 18 shows the result of the interlaminar shearing strength test. The colored bar means the average value of interlaminar shearing force and the black square shows the coefficient of variance. The number of test specimens is 5. The shearing strength of MF is 2.7 times higher than that of F. On the other hand, the coefficient of variance of MF is lower than that of F.

3.2.4 Observation of cross-section
Figure 19 shows cross-section of specimens after laminar shearing test. In the case of MF, the dissolution of the maleic anhydride is observed and fiber debonding is appeared due to the strong adhesive strength between waste fabric layers. The ratio of void area is measured by image process, and the value of the ratio is also shown in Fig.19. The ratio of F is 2.39 times higher than that of MF. From the results shown in Fig.19, it is obvious that MAPP fiber contributes the improvement of the mechanical properties to composites materials with waste fabric.

3.2.5 Three-point bending test
Figure 20 shows load- flexural strain curve. Figure 21 shows the result of three-point bending test. The colored bar means the average value of interlaminar shearing force and the black square shows the coefficient of variance. The number of test specimens is 5. The bending elastic modulus compared increases by applying maleic anhydride to PP. The average value of bending elastic modulus of MF is about 1.75 times higher than that of F. The bending strength of MF is about 2.14 times higher than that of F.

Figure 22 shows outer layer after bending test. As shown in Fig.22, the crack of the outermost layer was not shown. The reason why that reinforcing outer layer was caused by maleic anhydride was melted and exuded to outer layer.
4. Conclusion
In this study, the mechanical properties of fiber reinforced composites based on waste fabric with PP fiber were investigated. Moreover, the effect of reinforcement of shellac resin, bamboo fiber, and maleic anhydride on the mechanical properties was investigated. As the experimental results of micro compression test, interlaminar sharing test, In-site observation and bending test, it is found that the adhesive strength between waste fabric layers is improved due to the effects of reinforcing materials and MAPP fiber, and the coefficient of variance can be reduced.

References