Mechanical Properties of Jute Composite by Spray up Fabrication Method

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Abstract

In this study, the jute fiber was used to fabricate ecologically friendly composite by spray up molding technique. As the primal investigation, motion analysis of spray up method process was conducted, to obtain fixed quantity of expert's skills default value which is not actualized. Furthermore, dynamic characteristics and dimensional stability measurement was carried out of a specimen, and studies about a relation with an expert's operation was conducted. Thereby, the suitable education and technical tradition to advanced management engineering and inexperienced person are attained. The results suggested that 1) expert's motion data can be feed to jute/carbon spray up robot. And it is able to minimize the errors during fabrication of jute composite panels etc., 2) it is expected that the mechanical property and working efficiency could be improved with the improve of the advanced spray up method and 3) by making the combination of the optimal materials (jute fiber, kind of resin, etc.), high productivity and good elastic modulus are realized. Finally, spray up molding equipment is very flexibility, so it can make various composites easily.

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1. Introduction

Spray up is a method used for composite moulding. Resin matrix was sprayed out by the compressed air through the spray gun. The fiber/yarn as the reinforcement was cut simultaneously. The sprayed resin touched the cut fiber/yarn and both of them fall into the board/mold. The process might repeat to get the designed thickness. That is why the work process is efficient and can easily cope with design changes. Thereby, the quality of the material moulded by spray up method is closely related to the workers 'skill.

Nowadays, natural fibres reinforced materials have gained extensively interests. In particularly, the use of natural fibre reinforced composites has continuously increased due to their low density, low cost and environmental friendliness. Moreover, these natural fibres are also helpful to reduce both the oil dependency and carbon dioxide emission.

Additionally, in this study, motion analysis was used to compare the differences between spray up techniques by an expert and a non-expert. Motion analysis can record people in motion. A MAC 3D System was used since it is the most powerful tool available for motion capture and analysis. The sampling rate was 60 Hz. As described above, the spray up method relies on the skill of the craftsman. therefore, material quality depends on the generation of air bubbles, required consistent quality, advanced management engineering and passing on of the skills. For this reason, motion analysis of an expert applier’s skills was conducted to obtain objective data during spary up process. Furthermore, dynamic characteristics and dimensional stability measurements were made, and an investigation of the correlation to an expert's application techniques was conducted. In this way, suitable training and communicating technical skills can be passed on to advanced management engineering and inexperienced appliers. Also, the degree of master craftsmanship (called takumi in Japanese) needs to be quantified so that more advanced technology will become manageable. The objective of this research is to record the motion analysis of the spray up method and the mechanical properties of Jute-FRP using the spray up method.

2 Measuring Method

2.1 Subjects

In this study, two people were tested: an expert spray up craftsman (male, 42 years old, 19-year work career) and a non-expert (male, 37 years old, 1-year work career). The biological data of the subjects is shown in table 1. Both subjects were right handed, and didn’t have physical handicaps or a disease that restricted their work.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age</th>
<th>Years experience</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Dominant hand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expert</td>
<td>42</td>
<td>19</td>
<td>162</td>
<td>65</td>
<td>Right</td>
</tr>
<tr>
<td>Non-expert</td>
<td>37</td>
<td>1</td>
<td>166</td>
<td>70</td>
<td>Right</td>
</tr>
</tbody>
</table>

2.2. Analysis object

The object of analysis was to evaluate the work done for fabricated composites using the spray up method. The size of the mold was 1820 mm high and 910 mm wide. A blue rectangle (1250 mm x 800 mm) was drawn on the 1 square meter spray region. In addition, in this experiment, it was presupposed that the process of degassing (pressing down with a roller after completely spraying on the resin and the roving) would not be done. Since the surface smoothness and thickness distribution vary greatly through control of a roller, in this research only spray up skills were evaluated.
2.3. Spray up method

For motion analysis, in particularly in this study, unsaturated polyester resin with a sprayed amount at 2,044 [g/min] and continuation filament with sprayed on: 1,080 [g/min] and cut into 1 inch strands were used through spray out machine (made in Japan).

2.4. Three-dimensional motion measurement

Three-dimensional motion measurement was performed using an optical real-time motion capturing system (Fig. 2), the MAC 3D System (Motion Analysis Corporation). For data processing, the coordinate data from the 19 markers attached to each joint was obtained using EvaRT Ver. 5.0.4 software (Motion Analysis Corporation).
2.5. Dimensional stability

To compare the dimensional stability of the expert and non-expert, the surface coarseness of the plane of the acquired molded product was measured. A micrometer was used for measuring thickness. All samples (1250 mm x 800 mm) obtained in the experiment were cut and divided into 16 sections. Moreover, the thickness of the cross section of each area was measured every 10 mm. About 1,110 data points were obtained per subject.

2.6. Mechanical property

For tensile strength testing of the jute composite using the spray up method, 10 specimens were processed. The form of the specimens is shown in Fig. 3 (based on ASTM D3039). The tab part uses 50 mm emery paper. A strain gauge was attached to the middle of a specimen. Test conditions were a crosshead speed of 1 mm/min.

![Fig.3. Specimens for tensile testing](image)

3. Results and Considerations

3.1 Process analysis

First, each motion under work was defined, and could be divide into two motions: first the “stroke” and second the “process.” The “stroke” was defined as the reciprocating movement of the spray in the height direction of the mold and the “process” was defined as the movement one way in the horizontal direction of the mold by repetitive “strokes” (Fig. 4).

![Fig.4. Definition of “stroke” and ”process”.](image)

Both the expert and non-expert started spraying from the upper left. For both, the number of times of the “process” was three times. Process 1: From the left to the right; Process 2: From the right to the left; Process 3: From the left to the right. The number of “strokes” in each process is compared (table 2).
In process 1 and 2, the expert took 7 strokes and the non-expert took 5 and 6 strokes. In process 3, the expert took 6 strokes, while the non-expert took 9. The number of strokes made by the non-expert in each process varied while it is relative constant by the expert.

Next, the mean work time of the stroke in each process was compared (Fig. 5). The mean work time of the expert and non-expert shortened with the increase in process. The expert’s mean work time was short by 19.5%. On the other hand, the non-expert was short by no less than 31.5%. That is, the spray per stroke gradually became faster.

### Table 2. The number of strokes

<table>
<thead>
<tr>
<th></th>
<th>Expert</th>
<th>Non-expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process 1</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Process 2</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Process 3</td>
<td>6</td>
<td>9</td>
</tr>
</tbody>
</table>

**3.2. Motion analysis**

The operations at spraying up by the expert and non-expert were compared. Attention was paid to the motion (toe tips, knee and greater trochanter) of the lower half of the body. The difference in motion was especially noted (Fig. 6).
Here, the x, y and z axises are defined as the direction perpendicular to the spray, the spray direction, and the height direction (Fig. 7), respectively.

Fig. 7. Coordinate axes

To understand the series of motions better, the “crookedness expansion movements” of the expert and non-expert were compared. Next, the angle variations between the knee, greater trochanter and shoulder (right side) are shown in Fig. 8.

The expert had a wide angle variation (wide arc) and it is a stable angle variation. Moreover, it is clear that the expert is further “crooked” by about 20 degrees, and it turns out that the “crookedness expansion movement” for each stroke by the expert was performed smoothly. That is, the expert is performing the “crookedness expansion movement” efficiently while on tiptoes. An image of an angle variation is shown in Fig. 9. The difference in the angle variation can be clearly seen from this figure. Moreover, the motion of the non-expert placed a burden on the body, preventing a smooth motion.

Fig. 8. Angle between knee, greater trochanter and shoulder

Fig. 9. Angle variation
3.3. Dimensional stability

The dimensional stability (thickness distribution) of the expert and non-expert are shown in Fig. 10,11. The expert's average thickness was 3.52 mm and the coefficient of variation (CV) value was 11.4%. On the other hand, the average thickness for the non-expert was 2.47 mm and the CV value was 16.2%. As the theoretical thickness of this study was 3.50 mm, the non-expert’s thickness distribution was thin and the CV value was also large. Also, the horizontal cross-sectional thickness and the cross-sectional thickness in the height direction were observed. The CV value of the horizontal cross-sectional thickness for the non-expert was especially high. This thickness came from overlapping strokes or an inconsistent speed. Moreover, the ends of the horizontal sections were extremely thin.

The thickness distribution of the superior extremity and the lower end shows that the expert had precise thickness control. In addition, to refine the spray up method, there needs to be a consistent coefficient of variation of less than 10%. Improving the spray up technology would substantially contribute to dimensional stability and reduced waste.

3.4. Mechanical property of jute spray up

In this study, Jute fibers were cut into about 4 mm pieces and then sprayed onto the mold with the resin. Here the volume fraction of fiber of the obtained Jute-FRP board was about 20%. Ten specimens were extracted from one Jute-FRP plate made using the spray up method.

The mechanical properties of Jute-FRP by spray up method are shown in Table 3. The tensile strength and elastic modulus are also shown. Coefficients of variation (CVs) of the tensile strength and the elastic modulus had high numerical values. That is, the variation in the measured value between the specimens was large. A subject for future study would be how to reduce this coefficient of variation. Therefore, creating a sample with high reproducibility would be indispensable.
Fig. 10. Horizontal cross-sectional thickness (upper: expert, lower: non-expert)

- **expert (horizontal direction)**
  - Average: 3.26 mm
  - C.V.: 14.7%

- **non-expert (horizontal direction)**
  - Average: 2.46 mm
  - C.V.: 32.7%

Fig. 11. Cross-sectional thickness of height direction (left: expert, right: non-expert)

- **Expert**
  - Average: 3.39 mm
  - C.V.: 10.8%

- **non-expert**
  - Average: 2.90 mm
  - C.V.: 14.6%
Table 3 Mechanical property

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Tensile strength [MPa]</th>
<th>Elastic modulus [GPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17.8</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>18.5</td>
<td>4.22</td>
</tr>
<tr>
<td>3</td>
<td>14.4</td>
<td>4.07</td>
</tr>
<tr>
<td>4</td>
<td>16.5</td>
<td>4.41</td>
</tr>
<tr>
<td>5</td>
<td>16.2</td>
<td>4.01</td>
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<td>6</td>
<td>16.6</td>
<td>4.34</td>
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<tr>
<td>7</td>
<td>15.7</td>
<td>4.47</td>
</tr>
<tr>
<td>8</td>
<td>18.2</td>
<td>4.14</td>
</tr>
<tr>
<td>9</td>
<td>13.2</td>
<td>4.22</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>16.3</strong></td>
<td><strong>4.28</strong></td>
</tr>
<tr>
<td><strong>C.V.</strong></td>
<td><strong>10.1%</strong></td>
<td><strong>4.4%</strong></td>
</tr>
</tbody>
</table>

4. Conclusion

Analysis of the spray up method revealed the following:
1) The “crookedness expansion movement” was efficient because it was performed on tiptoes.
2) The “crookedness expansion movement” for each stroke was performed smoothly by the expert.

Jute fiber reinforced composite molded by spray up method was tested to discuss the mechanical property. It is found that although the elastic modulus show stable values, the tensile strength with relative large variation. Further study will be carried out to find the relationship between the operator’s skill and the quality of the products.

References

