A Study on Bending Properties According to the FRP Composite Fiber Material

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ABSTRACT
The fiber reinforced plastic (FRP), which is an advanced composite material for aerospace structures such as aircrafts and space devices, is applied to many sectors that require lightweight materials for its high specific strength and stiffness. FRP is used for the materials for machinery and structures, and the fracture toughness evaluation is important to improve its soundness and reliability. In this study, the bending characteristics of three materials (Hybrid-C-GFRP, CFRP and GFRP) were examined to understand the bending characteristics of FRP. The results of the test showed that the maximum stress was highest in the CFRP test piece, and similar in GFRP and C-G Hybrid test pieces. This indicated that the stress is related to the strength. In addition, while GFRP and C-G hybrid had similar stress values, GFRP had higher bending strength than C-G hybrid because the stress of GFRP increased within a shorter displacement by the difference in the initial tangent line slope.

INTRODUCTION
Fiber-reinforced composites are widely used in many sectors for their excellent engineering characteristics, and many engineers proposed theoretical and numerical methods for the prediction of the characteristics of fiber-reinforced composites [1-3]. Because the fiber in the fiber-reinforced composites influences the complex behavior of the entire composites, the existing continuum mechanics, which is based on the continuous, isotropic and homogeneous materials, is not sufficient to predict the behavior of the heterogeneous materials. Accordingly, to structurally approach the composites via the micro mechanic approach and identify the composites in the micro mechanic and entire systems, micromechanics-based models have been proposed. As micro mechanic structural approaches, the elastic behavior [4-8] and elastic-plastic behavior [9-13] of the fiber-reinforced composites have been studied. Studies revealed that gradual damage in the fiber-reinforced composite is also an important phenomenon that must be considered in the analysis of composite materials, in addition to the elastic or elastic-plastic behavior [14-15], and relevant studies are being conducted [16-17]. In the study of Ju and Zhang (2001), the elastic-plastic behavior of the circular fiber-reinforced composite was predicted, but the damage between the fiber and matrix in the circular fiber-reinforced composite was not considered, and the study was conducted under the assumption that the fiber was completely bonded to the matrix regardless of the load history. In addition, for the behavior analysis of the circular fiber-reinforced composite, it was assumed that the initial circular fiber was completely bonded to the matrix in the circular fiber-reinforced composite and that with the increase in the load, part of the circular fiber was separated from the matrix and lost its role as fiber. In this study, different fiber materials were used to comparatively analyze the mechanical characteristics. A bending test was conducted to identify the mechanical characteristics of FRP; the mechanical characteristics of three materials (Hybrid-C-GFRP, CFRP and GFRP) in the bending test were examined; and the weaved-type Hybrid-C-GFRP, CFRP and GFRP test pieces were fabricated according to ASTM D790 to comparatively analyze the economics and reliability of different fiber materials.

Test Method:
Three test pieces (CFRP, GFRP and C-G Hybrid) were used for this test. The specification of
the test piece is described in Section 7.5 of ASTM D 790-3 [18]. In the bending test, the support span to depth ratio must be determined so that the damage occurs on the outside of the test piece. Generally, 16:1 or higher ratio is recommended, and if the test piece is longer, 32:1 or 40:1 is recommended. This ratio selection should remove the shear effect and leave only the pure bending force in the test by lengthening the span because composites have a low shear strength and a high tensile strength. Several highly anisotropic composites have a test method to ensure accurate bending measurement excluding the shear strength as much as possible according to ASTM 790 [18]. The test jig was set up according to the standard. Table 1 shows the specifications and quantities of test pieces.

Table 1: Specification and Quantity of Specimens.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Fiber Dir.</th>
<th>Support Span to Depth Ratio (L/d)</th>
<th>Specimen Size (mm)</th>
<th>Support Span (mm)</th>
<th>Crosshead Speed (mm/min)</th>
<th>Specimen Thickness (mm)</th>
<th>EA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFRP Woven</td>
<td>16 : 1</td>
<td>13.81 x 52</td>
<td>25.06</td>
<td>0.67</td>
<td>1.57</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>GFRP Woven</td>
<td>16 : 1</td>
<td>13.81 x 52</td>
<td>25.06</td>
<td>0.67</td>
<td>1.57</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>C-G HYBRID Woven</td>
<td>16 : 1</td>
<td>13.81 x 52</td>
<td>25.06</td>
<td>0.67</td>
<td>1.57</td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

CFRP, GFRP and C-G hybrid epoxy laminated composites with good static and dynamic mechanical characteristics were selected, and the three materials were used for the bending test. Test pieces were made by laminating carbon fiber, glass fiber and C-G hybrid prepreg (0.224 mm, 0.255 mm and 0.233 mm, respectively) in 7 plies into 1.57 mm. They were formed at 120°C and at a constant pressure for approximately 180 minutes using a vacuum bag. Table 2 shows the chemical and mechanical properties of the materials.

Table 2: Chemical Composition of CFRP, GFRP, C-G Hybrid Composite Materials.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Fiber Area Wt. (g/m²)</th>
<th>Resin Content (%)</th>
<th>Total Wt. (g/m²)</th>
<th>Thickness (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFRP</td>
<td>200</td>
<td>40</td>
<td>333</td>
<td>0.224</td>
</tr>
<tr>
<td>GFRP</td>
<td>308</td>
<td>34</td>
<td>467</td>
<td>0.255</td>
</tr>
<tr>
<td>C-G HYBRID</td>
<td>230</td>
<td>40</td>
<td>396</td>
<td>0.233</td>
</tr>
</tbody>
</table>

Fig. 1 shows the bending test piece for the measurement of the bending strength of CFRP, GFRP and C-G hybrid test pieces. Fig. 2 shows the dimensions and shapes.

(a)

(b)

(c)

Fig. 1: Bending Test Specimen of (a) CFRP and (b) GFRP and (c) C-G Hybrid.

Fig. 2: Sketch of Specimen.
The three-point bending test is generally conducted as a bending test because it is easy and simple [19]. In this study, a three-point bending test equipment in Fig. 3 was used. The support span jig had a shape of 10-mm-diameter semicircle, and the nose span jig was positioned in the center of the test piece. The support span was 25.06 mm.

The nose span jig and support span device were placed between the load cell and actuator of the universal testing machine (UTM). The test piece was placed on the support span device, and the nose span device was transferred in the load direction at a speed of 0.67 mm/min. The displacement was controlled within 5% strain according to ASTM 790 [18], and was verified using Eq. 1.

After the bending test, the bending strength and bending stiffness were calculated from the measured load-displacement curve using Eqs. 2 and 3.

\[
\sigma_f = \frac{3PL}{2bd^2} \quad \text{MPa} \\
P = N \\
L, b, d = \text{mm} \tag{2}
\]

\[
E_b = \frac{Lm}{4bd^3} \quad \text{MPa} \\
L, b, d = \text{mm} \\
m = \frac{P_{\text{max}}}{\delta} \tag{3}
\]

Where \(\sigma_f\) is the maximum strength, \(P\) is the load, and \(b\) and \(d\) are the width and length. \(EB\) is the bending elastic modulus, \(m\) is the initial tangent slope in the load-displacement graph from the test [19]. Table 3 shows the test conditions.

1. **Experiment Results and Discussion:**

The bending test was conducted with five test pieces for each material [18]. The test results were averaged for the three materials. Figs. 4-6 show the bending test results.

### Table 3: Experiment Condition for Bending Test

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Room Condition</th>
<th>Test Frame</th>
<th>Loading Rate (mm/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RT/Dry</td>
<td>20°C, 50% RH</td>
<td>Instron 5585</td>
<td>0.67</td>
</tr>
</tbody>
</table>

![Fig. 4: Stress-Strain Curve for CFRP Composite Specimen.](image)
In Fig. 4, the maximum stress values of the five test pieces were similar at 1000 MPa – 1026 MPa. The drop of the curve seems to indicate that CFRP is brittle and has no plastic deformation.

Fig. 5 shows the stress-strain curve from the bending test of GFRP. The stress stably and linearly increased to the maximum stress of 600 MPa to 644 MPa, but fiber fracture occurred at 3% strain and rapidly fractured. As in the case of CFRP, it seems that the curve drops because GFRP is brittle and has no plastic deformation.

Fig. 6 shows the stress-strain curve of the C-G hybrid material. The stress of the C-G hybrid material also stably and linearly increased to the maximum of 533 MPa to 570 MPa after the application of the load, and dropped at 3.5% strain with the fiber fracture. Unlike in the case of CFRP or GFRP, however, it decreased slowly. This seems to have been because fiber fracture in CFRP reduced the stress, but GFRP still did not fracture and showed strain hardening for a while before it finally fractured.
Fig. 7 shows the average stress-strain curve from the bending tests. In Fig. 7, the stress rapidly decreased after the maximum load, and that of C-G hybrid material gradually decreased. The maximum stress was highest in the CFRP test piece, and similar in GFRP and C-G Hybrid test pieces. This indicated that the stress is related to the strength. In addition, while GFRP and C-G hybrid had similar stress values, GFRP had higher bending strength than C-G hybrid because the stress of GFRP increased within a shorter displacement by the difference in the initial tangent line slope. Fig. 8 shows the test pieces after the bending test.

2. Conclusion:
   The analysis of the bending stress and bending strength of CFRP, GFRP and C-G hybrid materials resulted in the following conclusion.
   1. The curves for CFRP, GFRP and C-G hybrid test pieces increased and then dropped because the materials had brittle characteristic that abruptly fractured without plastic deformation.
   2. The C-G hybrid material fractured in somewhat ductile way after several times of repeated load increase and decrease after the maximum load application. This seems to have been because the maximum load led to the separation of CFRP and GFRP, and CFRP fiber immediately fractured, but GFRP endured the load longer before it finally fractured. This indicates that C-G hybrid material showed ductile bending behavior rather than improved strength.
   3. The maximum stress was highest in the CFRP test piece, and similar in GFRP and C-G Hybrid test pieces. This indicates that CFRP had the highest bending strength. In addition, while GFRP and C-G hybrid had similar stress values, GFRP had higher bending strength than C-G hybrid because the stress of GFRP increased within a shorter displacement by the difference in the initial tangent line slope.

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REFERENCES