Mechanical Properties Analysis of Carbon Fiber Panels Sandwich Structure Containing Aluminum Alloy Corrugated Core

Shijie Liu and Jiumei Xiao

ABSTRACT

Carbon Fiber Reinforced Polymer (CFRP) is widely used in industry and construction. In this paper, three-point bending test was used to analyze the mechanical properties of CFRP by introducing aluminum alloy corrugated core. The numerical simulation is fairly consistent with the experimental analysis. We found that more than 95% of energy consumption comes from corrugated cores. The attenuation of bending failure stress is 38.83%. It fully shows that corrugated core has outstanding buffer capacity for objects hitting. In addition, two kinds of material are bonded by the adhesive. We also found that increasing the thickness of the adhesive will reduce the contact stress, enhance the stability of the structure and promote elastic-plastic damage deformation.¹

INTRODUCTION

CFRP has been widely applied in various engineering fields, thus a lot of mechanical properties have been analyzed by relevant scholars. Literature [1,2] pointed out that CFRP provided high stiffness and strength, but its strain was small. Some scholars started from raw materials to improve the weakness of CFRP [3], and others enhanced the impact resistance of CFRP through structural design. Sandwich structure was used to strengthen material properties by introducing foam-core, honeycomb aluminum, prism and truss structure [4, 5]. Abrate.S [6] showed that the strength and stiffness of corrugated sandwich structure were better than those of

¹Shijie Liu, Jiumei Xiao Department of Applied Mechanics, University of Science and Technology Beijing, Beijing, China, 100083
Corresponding author: Jiu-mei Xiao, E-mail: jiujiu@sas.ustb.edu.cn
pyramid and foam-core sandwich structure. S. H. Song [7] thought that aluminum alloy corrugated plates had strong plastic shape, which enlarged the deformation process of structure and slowed down the instability time of carbon fiber sheet. In 2013, Hou [8] studied the optimal design of sandwich corrugated core under compression and impact load by experimental and numerical simulation. In 2016, in the analysis of bending and buckling of corrugated plates, the improvement was found to be more significant in the case of trapezoidal corrugation than that of sinusoidal one [9]. He et al. [10] investigated the low velocity impact behavior of hybrid sandwich structures consisting of CFRP face sheets by experimental and numerical method in 2016, Boorle and Mallick considered geometric parameters and laminate construction on the global bending response of composite sandwich structure with corrugated core [11].

This paper aims to study the variation of the stress with time at the contact surface between indenter and CFRP face sheets, and analyze the contribution of structural deformation under three-point bending test to the energy consumption about aluminum alloy corrugated core. By means of numerical simulation and experimental analysis, we investigate the effects of aluminum alloy corrugated core and different thickness of the adhesive on the mechanical properties of CFRP. It would provide a reference for the design of carbon fiber hybrid panels with aluminum alloy corrugated core.

**EXPERIMENTAL AND SIMULATION DETAILS**

**Specimens and Methodology**

The inclination angle of aluminum alloy corrugated core(AL-5052-O) is 55 degrees [8], and the prepared specimens were made according to ASTM D790 standard, as shown in Fig.1. A high strength construction adhesive (YUE-SHEN) was used to bond the face sheets and the core. The mechanical properties of each part are shown in Tables 1, and the cell sizes are shown in Fig. 2 and Table 2. The thickness of optimum plates is Ha (Ha=H+2* (T1+T2+T3).

Three-point bending test was carried out at a low-speeding of 4mm/min as shown in Fig.1. The sizes of the experimental scheme are shown in Table 2. The type A0 was used as a reference. The specimens labeled A1, A2 and A3 correspond to the optimization scheme A; and the specimens labeled B1, B2 and B3 correspond to the optimization scheme B.

![Figure 1. Specimens and loading machine.](image)
**Numerical Simulation**

Referring to the C-C Composite Model, the composite failure analysis of sandwich panel was carried out. St-PierreL[12] explained that the response of corrugated plates under a low-speeding impact was similar to that under quasi-static compression. Thus, the mechanical response of CFRP and aluminum alloy could be considered rate-independent of loading rate. Therefore, the three-point bending test of carbon fiber-aluminum alloy corrugated laminated structure is simulated by a low-speeding collision.

**RESULT ANALYSIS**

**Analysis of Experimental Results**

When the displacement at the contact surface of scheme A0 was 4.24mm, the maximum load was 1668N, and the surface of the structure stayed intact. With the increase of deformation at the contact surface, the carbon fiber sheets began to fracture, separated in interlayer and were crushed at the upper surface. At the point, \( H_a=3.75 \text{mm} \), according to Hertz theory, the failure stress of the panel is 533.76MPa.
In scheme A, when the maximum load was 1814N and the displacement was 4.756mm, aluminum alloy corrugated core underwent elastic-plastic deformation. When the deformation reached 5.98mm, the carbon fiber sheets stayed intact. When the sheets were broken, Ha=5.0mm, the failure stress of the panel is 326.54MPa. The loading process of Scenario B is similar to scheme A’s. When the vertical displacement of scheme B reached 5.91 mm, the maximum load was 1908 N, and the face plate began to undergo the buckling deformation. At this time, Ha=5.2 mm, the ultimate stress is 317.52MPa.

Comparing A, B with program A0, the energy consumption of A, B increased by 121% and 164%, respectively. The structural absorption energy and residual energy are shown in Fig. 3 and Table 4. The simulation curves of panel energy absorption under time history are shown in Fig. 4.

**Simulation Results**

In numerical simulation, time history curves of stress at the contact surface are shown in Fig. 4. The peak stresses of scheme A0, A and B are 569.89 MPa, 328.59 MPa and 314.54 MPa, respectively. Compared with the scheme A0, the peak value dropped by about 40%. This is a generally good agreement with the experiment as shown in Table 4. In addition, considering experimental phenomena, we find that scheme A0 is tension-bending failure, and scheme A and B are shear failure after structure compaction. That means, the corrugated core changes the failure process of structure, which is beneficial to protect the panels and improve the stability of sandwich panels.

In Fig. 5 (a), the energy absorption of CFRP face sheets is about 3Jof the total energy consumption; in Fig. 5 (b), the elastic-plastic deformation energy absorption of aluminum sheet is about 9.19J, accounting for 99.57% of the total energy consumption; the bonding layer hardly absorbs energy, and the elastic deformation of carbon fiber sheet occurs, while the deformation is too large, then shear failure occurs; in Fig. 5 (c), the structural response is similar to that of (b). Aluminum plates absorb about 11.27J, accounting for 99.30% of total energy consumption. In
addition, increasing the thickness of the adhesive will reduce the contact stress, strengthen the stability of the structure and promote elastic-plastic damage deformation.

Figure 4. (a) Time history of internal energy curves in numerical simulation; (b) Response relationship between effective stress and time.

Figure 5. Energy absorbing characteristics of different parts (A0, A and B) to time curves.

TABLE III. CONSISTENCY ANALYSIS BETWEEN EXPERIMENTAL RESULTS AND NUMERICAL SIMULATE.

<table>
<thead>
<tr>
<th>Schemes</th>
<th>Peak value of energy absorption in quasi-static collisions (J)</th>
<th>Quasi-static collision remnant (J)</th>
<th>Peak value of structural stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Experi</td>
<td>Simul</td>
<td>Error (%)</td>
</tr>
<tr>
<td>A0</td>
<td>4.71</td>
<td>5.08</td>
<td>7.86</td>
</tr>
<tr>
<td>A</td>
<td>12.10</td>
<td>12.50</td>
<td>3.31</td>
</tr>
<tr>
<td>B</td>
<td>14.90</td>
<td>15.02</td>
<td>0.81</td>
</tr>
</tbody>
</table>

CONCLUSIONS

In this paper, we studied the variation of stress with time at the contact surface between indenter and CFRP face sheets, and analyzed the contribution of structural deformation under three-point bending test to the energy consumption about
aluminum alloy corrugated core. Aluminum alloy corrugated core played an important role in the energy absorption of sandwich structure.

The yield stress of Al-5052-O corrugated carbon core is much lower than the stress of carbon fiber plates on compression, bending and tensile. Therefore, when carbon fiber plates are impacted, the elastic-plastic deformation of aluminum alloy corrugated core occurs first, then buckling deformation is appeared, which avoids the rapid increase of stress of carbon fiber plates. The energy absorption characteristics of sandwich structures are improved. In addition, increasing the thickness of the adhesive will reduce the contact stress, strengthen the stability of the structure and cause further elastic-plastic damage deformation.

REFERENCES