Mechanical Performance of GFRP Sandwich Panels with Stiffen Webs

Ming-Ji Fang, Wenhao Wang and Yingjie Fu

ABSTRACT

This paper presents the details of a research program that was conducted to evaluate the one-way bending behavior of glass fiber reinforced polymer (GFRP) sandwich panels. The panels consist of GFRP skins and a foam-GFRP web core. An experimental study was carried out to study the effect of the skin and web thickness, the web height and the web space. The results demonstrate that compared to the only foam-core sandwich panels, a maximum of approximately 230% increase in the ultimate bending strength can be achieved. Meanwhile, the bending stiffness and energy dissipation can be enhanced respectively. On the other hand, an analytical model was built. The finite element analysis, conducted to simulate the bending behavior considering the bond performance of the face sheets and foam core, accurately predicted the ultimate bending strengths and deflections of the panels under four-point bending in comparison with the experimental results.1

KEYWORDS

GFRP sandwich panels; Stiffen webs; Foam core; Bending behavior.

INTRODUCTION

Sandwich panels have been commonly used in the aerospace and automotive industries due to their high strength-to-weight ratio and energy absorption characteristics. This sort of structure has gained often-time use in civil engineering

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1 Ming-Ji Fang, Yingjie Fu, School of Civil Engineering, Shanghai Normal University, Shanghai, China
Wenhao Wang, School of Civil Engineering, Shandong University, Jinan, China
in approaching years. Typical sandwich panels used in structural applications consist of two thin face skins which are attached to each other by a thick and relatively flexible core. The skins provide the flexural rigidity of the panel while the core provides the shear rigidity. Skin materials include aluminum, fiber reinforced polymer (FRP) composites and reinforced concrete. Core materials commonly include polymeric foams, balsa wood or lightweight honeycomb structures.

Extensive experimental and analytical studies[1-8] on sandwich flexural members with a foam core have been conducted in the past few years. In the majority of the studies, sandwich panels were usually fabricated by a pultrusion or bonding process. However, in this study, all panels are manufactured by vacuum-assisted resin infusion process.

![Figure 1. The composite sandwich panel with web stiffeners.](image)

**EXPERIMENTAL RESULT**

**Test Specimen And Material Properties**

In this study, six sandwich panels were manufactured by means of vacuum assisted resin infusion process. The GFRP and unsaturated polyester resin were used for the face sheets and webs. The polyurethane foam (PU foam) with 40kg/m³ density was used for the filled core. All the specimens had the identical length of 3300mm and some different face sheet and web thicknesses were tried in the study. Details of the tested specimen are given in Table I and Figure 1, where $L$ is the panel length, $B$ is the width, $S_w$ is the web spacing, $t_w$ and $t_s$ are the thickness of web and face respectively. The panel of B1-70-con is only made of the face sheet and foam core. Its web has no stiffness and the panel itself is used to evaluate the mechanics behavior of the reinforced ones.

Mechanical properties are summarized in Table II and Table III.
TABLE I. DETAILS OF SPECIMENS.

| Specimen        | L (mm) | B (mm) | h (mm) | S_v (mm) | t_v (mm) | t_s (mm) |
|-----------------|--------|--------|--------|----------|----------|----------|
| B1-70-con       | 3300   | 600    | 70     | -        | -        | 3.0      |
| B1-70-1-1-1     | 3300   | 600    | 70     | 200      | 3.6      | 3.6      |
| B1-70-1-1-2     | 3300   | 600    | 70     | 200      | 3.6      | 3.0      |
| B1-70-2-1-2     | 3300   | 600    | 70     | 150      | 3.6      | 3.0      |
| B1-70-3-1-2     | 3300   | 600    | 70     | 100      | 3.6      | 3.0      |
| B1-85-2-1-2     | 3300   | 600    | 85     | 150      | 3.6      | 3.0      |

TABLE II. MATERIAL PROPERTIES OF GFRP FACE SHEET AND WEBS.

| Material Property | Facing sheet | Web |
|-------------------|--------------|-----|
| Tensile strength (MPa) | 219.6        | 296.3 |
| Tensile modulus (GPa)   | 20.14        | 8.84 |
| Compressive strength (MPa) | 100.1        | —    |
| Compressive modulus (GPa) | 6.7          | —    |
| Shear modulus (MPa)     | —            | 299.64 |

TABLE III. MATERIAL PROPERTIES OF FOAM.

| Material Property   | Value  |
|---------------------|--------|
| Compressive strength (MPa) | 0.25   |
| Compressive modulus (MPa)   | 8.65   |
| Shear strength (MPa)        | 0.22   |
| Shear modulus (MPa)         | 3.14   |

TEST SET-UP AND LOADING PROCEDURE

The four-point bending test was conducted in the Structure Research Center of Shanghai Normal University, using hydraulic loading system. Clear span (L) between the two roller supports was 900mm, which was shown in Figure 2. After the 0.5kN pre-loading, the load was applied gradually with a rate of 6 mm per min.

EXPERIMENT OBSERVATION

As was shown in the testing process, the collapse of panels can be classified into these conditions,
1. Delamination occurred in the panels, which especially took place in the panels that was not reinforced (B1-70-con).
2. Another sort of failure displayed as local buckling, happened near the loading point of the upper plate, was likely to occur in the plate with a thickness of 3.0 mm.
3. One was the plate buckling appeared at the upper plate. The 3.6-mm-thick plate ended up with this kind of failure.

The buckling deformation of the latter two classification would result in the penetrate fracture of the upper panel afterwards.
All modes above belong to brittle failure. The stiffness of the specimens were lost instantaneously as soon as reaching the ultimate bearing capacity, and there is no stiffness degradation before the failure. Figure 3 shows one failure mode of the specimens.

![Figure 2. Loading layout.](image)

![Figure 3. Failure mode.](image)

![Figure 4. Load-displacement of specimens.](image)

**EXPERIMENTAL RESULTS AND DISCUSSION**

As is depicted in Figure 4 and Table IV, it lists the results of comparison in the mid-span force and deformation experiment of distinctive models. Pu stands for the ultimate capacity, $\Delta u$ is the mid-span deformation while Ke accounts for the initial rigidity of each plate. Additionally, Pu,con serves as the bearing capacity of plate that contain no reinforcement, $\Delta u$, con plays its midspan deformation and Ke, con illustrates its initial rigidity.

Compared to the pure foam sandwich panel, B1-70-con, without any stiffening, the bearing capacity and stiffness of all kinds of stiffened composites are significantly improved. All specimens resulted in brittle failure during the process of loading and no shear failure of foam core was observed. The load-displacement curve of each specimen did not degrade.
NUMERICAL STUDY

In this study, finite software ABQUS was used for finite element simulation analysis. The solid element C3D8I is used to simulate GFRP sheet and foam core. GFRP material is considered as an elastic material in modeling. As a result of the different modulus of elasticity of GFRP assumed, the upper and lower panels of the composite panels are modeled respectively.

Fig. 5 shows the comparison of experimental and numerical results and the ABQUS finite element analysis can simulate the mechanical properties of the composite sandwich panels very well.

| Specimen | $P_u$ (KN) | $\Delta_u$ (mm) | $K_e$ (KN/mm) | $P_u/P_{u,con}$ (%) | $\Delta_u/\Delta_{u,con}$ (%) | $K_e/K_{e,con}$ (%) |
|----------|------------|----------------|---------------|-------------------|-----------------|-------------------|
| B1-70-con| 11.3       | 111.9          | 0.10          | --                | --              | --                |
| B1-70-1-1-1 | 30.0       | 133.1          | 0.23          | 265.5             | 118.9           | 209.1             |
| B1-70-1-1-2 | 18.6       | 115.2          | 0.16          | 164.6             | 102.9           | 160.0             |
| B1-70-2-1-2 | 24.8       | 142.8          | 0.17          | 219.5             | 127.6           | 154.5             |
| B1-70-3-1-2 | 28.3       | 161.1          | 0.18          | 250.4             | 144.0           | 163.6             |
| B1-85-2-1-2 | 36.0       | 138.9          | 0.26          | 318.6             | 124.1           | 236.3             |
CONCLUSIONS

Based on the experimental research reported in the paper, the following conclusions can be drawn within the limitation of the research.

(1) Compared to solely foam core sandwich panels, B1-70-con, without any reinforcement, setting of longitudinal and lateral stiffeners can significantly improve the bearing capacity and stiffness of sandwich panels. All specimens acted as brittle failure during loading, and no shear failure of foam core was observed. The force-deformation curve of each specimen did not perform stiffness degeneration.

(2) Along with the decrease of spacing between longitudinal stiffeners, the ultimate bearing capacity of each plate showed distinctive improvement by contrast. The test witnessed an apparent rise of the specimens’ ultimate bearing capacity through changing the longitudinal reinforce web spacing, but it also saw the reduction of the stiffening web spacing place limited influence on the bending stiffness.

(3) The mechanical properties of sandwich panels can be obviously improved by increasing the thickness of face sheet and the height of the sandwich panels.

(4) The ABQUS finite element analysis can somehow perfectly simulate the mechanical properties of the composite with an average error of about 5%.

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