Experimental Evaluation on Fatigue Strength of Adhesive-Bonded Sandwich Panels with CFRP Faces and Honeycomb Cores

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Abstract. There is no existed standard testing method suitable to evaluate the fatigue strength of thick adhesive bonded structures like honeycomb sandwich panels. Fatigue strengths of adhesive-bonded sandwich panels constructed with aluminum honeycomb cores and CFRP (Carbon Fiber Reinforced Plastics) laminate faces were interested in this study. Fatigue experiments on sample cantilever beams of such honeycomb sandwich panels were carried out to validate the experimental method by improving the configurations of specimens, testing fixtures and instruments etc. Based on the improved testing method, influences of design parameters, such as specimen length and height, foil thickness and cell size of honeycomb cores, on the fatigue strength of adhesive bonded sandwich panels will be investigated in future experimental study.

1. Introduction

Honeycomb sandwich panels constructed with thin surfaces and honeycomb cores have characteristics like light-weight, higher stiffness and shock absorbency etc. Therefor they are usually developed for large-scale structure applications in various industrial fields, especially light-weight purpose desired fields like aerospace and architecture as shown in figure 1.

On the other hand, recognition on the durability of adhesive-bonded structure is very important for such honeycomb sandwich panels. Adhesive peeling between panel surfaces and honeycomb cores made from different materials such as light-weight FRP laminate surfaces and aluminum honeycomb cores need to be avoided to maintain the function of such sandwich panels [1]. Especially, the de-bonding problem caused by repetitive loading will cause the problem of strength degradation of honeycomb sandwich panel structures and lead to fractures. There is no existed standard testing method suitable to evaluate the fatigue strength of thick adhesive-bonded structures like honeycomb sandwich panels.

In this study, fatigue strengths of adhesive-bonded sandwich panels constructed with aluminum honeycomb cores and CFRP (Carbon Fiber Reinforced Plastics) laminate faces were interested [2]. Fatigue tests on sample cantilever beams of honeycomb sandwich panels were carried out. Improvements of configurations of specimens, testing fixtures and instruments etc. are executed to validate the experimental method.
2. Fatigue experiment of honeycomb sandwich panels

2.1. Specimen configuration
Sample honeycomb sandwich panels with 1.0mm thick CFRP laminate, and 1/8 inch cell size, 0.001 inch foil thickness and 30 mm height aluminum honeycomb core are introduced for fatigue experimental investigations. Two-liquid-component type, room-temperature cured adhesive consisting Epoxy and Polyamidoamine was introduced for bonding CFRP laminate faces and aluminum honeycomb cores, to minimize the residual stress caused by the linear thermal expansion during curing. The specimen configurations with panel shape and sizes are shown in figure 2 and table 1. Figure 3 shows the detail of honeycomb specification.

2.2. Experimental configuration
Cantilever bending fatigue tests on sample honeycomb sandwich panel specimens were introduced for experimental evaluations. Figure 4 shows the testing machine introduced for this study. This testing machine configuration are basically along the ASTM D 671-63 T standard (Standard Test Method for Flexural Fatigue of Plastics by Constant-Amplitude-of-Force). The left end of specimen is fixed and a repeated bending deflection is applied on the right end as shown in figure 5. Two strain gauges are installed on both sides of specimen surfaces for measurements. The deflections of cantilever bending tests are set from 2.0 mm to 6.0 mm with a number of loading cycle of $10^6$ for sample examinations. Test conditions are described in table 2.
2.3. Improved design of fixture for cantilever beam’s fatigue test

Based on the ASTM D 671-63 T standard, the testing configuration need to be improved because of the honeycomb sandwich panel’s thickness. Figure 6 shows the improved fixture for cantilever bending fatigue test. It has enough bending stiffness compared with the specimens and durability for the load occurred by bending deformation. By fixing the upper lid to not only the specimen but also the base of the fixture with two bolts, stability of fixing the specimen can be obtained. For the bending fatigue test, it is desirable that the center axis in the height direction of specimen and bending deflection are coincident. By using a height adjusting sheet material according to the height of panel specimen, it is possible to correct the deviation from the center of bending deflection with the specimen center line. Figure 6 shows an image diagram of the improved fixture in 3D CAD model with panel specimen fixed.

2.4. Evaluation on modulus of rigidity of honeycomb sandwich panel

Three-point bending test for honeycomb sandwich panels were carried out. Figure 7 and table 3 shows the three-point bending test and test conditions. Based on the result of three-point bending test, the modulus of rigidity G of honeycomb sandwich panel was calculated at 152.0 MPa using equation (1) and (2) [5, 6]. These results are needed for theoretical strain calculation used for comparison with experimental results in next section.

Table 2. Conditions of bending fatigue test of composite panels.

|                        |       |
|------------------------|-------|
| Rotating speed [rpm]   | 1700  |
| Sampling period [Hz]   | 500   |
| Number of data point [-]| 18000000 |
| Number of cycle [-]    | 10^6  |
| Bending deflection [mm]| 2.0–6.0 |
Table 3. Test conditions of three-point bending test.

| Parameter                              | Value       |
|----------------------------------------|-------------|
| Specimen size [mm]                     | 160×30×32   |
| CFRPThickness (t_f) [mm]               | 1.0         |
| Bending modulus (E) [GPa]              | 43.4        |
| Span (L) [mm]                          | 100         |
| Diameter of indenter [mm]              | 5           |
| Feed speed [mm/min]                    | 1.0         |

Figure 7. Three-point bending test.

\[
G = \frac{l^2}{12EI} \times \frac{t_c}{b(t_f + t_c)^2}
\]

(1)

\[
I = \frac{bt_f}{6} \left( 3t_c^2 + 6t_f t_c + 4t_f^2 \right)
\]

(2)

2.5. Experimental results

Measured strain results from the cantilever bending fatigue test of the honeycomb sandwich panels are analyzed using DIAdem software. Figure 8 shows firstly the typical close-up strain data obtained from data manipulation. Horizontal axis represents the number of loading cycle and vertical axis represents the strains obtained from the strain gauges. The accurate strain value with respect to the frequency can be obtained from the rain-flow counting analysis and sample result is shown in figure 9.

Figure 8. Example of analyzed strain data.  Figure 9. Result of rain flow counting.

The typical strain data measured from upper strain gauges (CH1) under 2.0mm, 3.0 mm, 4.0 mm and 6.0 mm bending deflections are shown in figure 10 with logarithmic representation of loading cycle number at horizontal axis. At the 6mm deflection case, the test was discontinued because fracture of core at the fixed-end was confirmed as shown in figure 11.

Figure 10. Compilation of upper surface strain data.
Further, the theoretical strain value of the panel surface corresponding to different bending deformations can be calculated from the equation (5) and the results are shown in Table 4 compared with experimental results. Equation (5) can be derived from equation (3) and (4), which are the basic formulas for strength of materials as function of bending deflection $\delta$ and modulus of rigidity $G$ [5, 6].

$$
\delta = \frac{PL^3}{3EI} + \frac{PL}{6U} \tag{3}
$$

$$
U = \frac{(t_r + t_c)^2}{t_c} Gb \tag{4}
$$

$$
\varepsilon = \frac{3U\delta y}{UL^2 + 3E}\tag{5}
$$

### Table 4. Theoretical and experimental value of bending fatigue test.

| Bending deflection [mm] | Bending moment [N-mm] | Strain [με] | Maximum strain (Theoretical deviation) [με] | Most frequent strain [με] | Minimum strain [με] |
|------------------------|-----------------------|-------------|-------------------------------------------|--------------------------|---------------------|
| 3.0                    | 0.73x10^5             | 1918.5      | CH1 1762.9 (-8.1%)                        | 1222.7                  | 975.5               |
| 4.0                    | 0.97x10^5             | 2558.0      | CH1 2144.4 (-16.2%)                       | 1144.0                  | 1072.2              |
| 6.0                    | 1.46x10^5             | 3837.0      | CH1 3746.7 (-2.4%)                        | 1251.6                  | 1048.3              |

Looking at the experimental strain data obtained from bending fatigue tests shown in figure 10, it can be confirmed the attenuation of strain due to bending deflections. From table 4, one can see that strain values immediately after test starts were close to the results calculated from theoretical formula, but they decreased sharply thereafter and gradually stabilized at about 1200με.

From sectional observation on tested specimens, no noticeable changes were observed at 2.0mm, 3.0 mm and 4.0 mm bending deflection cases. At 6.0 mm, honeycomb core near the fix end was found broken instead of fractures at adhesive bonds. From figure 10, it can be seen that the start point of attenuation differs with bending deflections. At relatively small bending deflection cases such as 2.0 mm, attenuation of strain value can hardly be confirmed until the number of load cycles exceeds $10^6$. However, as the deflection increases, the number of load cycles at attenuation beginning decreases. This can be considered to be caused by fatigue phenomenon due to the bending moment generated when bending the specimen. A reaction force of bending deflection acts on the fixed-end of the specimen and causes compression effects on honeycomb core. With repeated bending deflections, deformation and breakage of inner honeycomb core are considered to be occurred mainly in low cycle fatigue region up to $10^3$ times.

Utilization of the designed fixture for bending fatigue tests of thick honeycomb sandwich panels confirmed that the maximum strain value increased proportionally with the bending deflection increasing.

### 3. Summary

Testing method for the fatigue property evaluation on adhesively bonded honeycomb sandwich panels is investigated through experimental approach. Fatigue bending tests on sample aluminum/CFRP
honeycomb sandwich panels was carried out. From experimental results the following conclusions are obtained.

(1) By comparison, the deviation between experimental maximum strain and calculated static strain was mainly less than 10%, and the proportional relationship between bending deflection and measured maximum strain could validate the testing method proposed in this study. However, there are cases with deviation of more than 10%, which means improvement of installing strain gauges need to be done.

(2) Inner deformation or breakage of honeycomb core is considered to be occurred due to repeated compressive loads caused by large bending deflections. The destruction phenomenon can be confirmed from the decreased loading cyclic numbers with increased bending deflections.

(3) Based on the proposed fatigue bending test method, honeycomb cores at the fixed-end are deformed or broken before debonding of panel structure occurred. Therefore, thick adhesive structures can not be loaded stably. It is necessary to generate same bending strains with smaller bending moments by changing shape of panel specimens and reducing their bending rigidities.

4. Reference

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