Study on 180° Peel Test of Interface Adhesive Honeycomb Sandwich Structure

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Keywords: Honeycomb structure, Peel strength, Adhesive interface, DIC.

Abstract. 180° Peel experiment was designed and performed to estimate the peel strength parameters and failure modes of the interface adhesive Honeycomb Sandwich Structure (HSS). The aluminum-lithium alloy honeycomb core and skin specimens were bonded with adhesive according to the adhesive bond strength test standards, and the honeycomb shape is hexagon. 180° peel test was conducted using the designed fixtures so as to compare the peel strength and failure form of the adhesive layer. The peel strength was calculated by recording the peel load-displacement curves and observing the destruction of the interface during the experiment. Simultaneously, local strain field, especially at the critical moment of the breakage point, was obtained by digital image correlation (DIC). The results show that failure mode of the HSS with interfacial adhesive is cohesion failure of the adhesive, and the results of numerical analysis are in good agreement with the experiments.

Introduction

HSS is a kind of special structural composite material, which is consisted of honeycomb core inserted between two thin skins or panels bonded with adhesive. Due to its good stiffness and strength, it has been widely used in aerospace structures, satisfying the special requirements on quality and performance. For example, honeycomb structures are commonly used in the primary structure of commercial aircraft, military fighter and helicopters [1]. In addition to the choice of the materials, mechanical property of the adhesive between the skin and the honeycomb core, the peel strength being a key indicator, is also important to assure the quality and bearing capacity of honeycomb sandwich structures [2-3]. The new aluminum-lithium alloy with low density, high strength, and good processing properties can significantly reduce the weight of the structure and improve the aircraft payload, so it's advantageous to employ aluminum - lithium alloy honeycomb sandwich structure used in aircraft, aviation and other structures [4].

Adhesive property between honeycomb core and skin is also crucial to the loading capacity of the HSS, and epoxy and polyimide are commonly used as adhesive materials [5]. When the external load applying on the sandwich structure exceeds a certain allowable range, the structure will be destroyed. Because of the fragile bonding between skin and honeycomb core, the interface damage is most likely to occur. In this failure mode, adhesive layer peel stress plays a dominant role, resulting in a substantial reduction of the loading capacity of the HSS [6]. Currently, standard methods for assessing peel properties between the skin and honeycomb core interface are roller peel test (ASTM D1781), float roller test (GB /T 7122) and 180° peel test (GB / T 2790). In general, it is appropriate to adopt the 180° peel method to detect peel strength when it comes to honeycomb aluminum plate with stronger bonding interfaces [7-8].

In this paper, aluminum-lithium alloy honeycomb core and skin samples were designed and manufactured according to the adhesive bond strength test standards. Then 180° peel test was conducted using the designed fixtures so as to compare the peel strength and failure form of the adhesive layer. The local strain field of the peel process was obtained by the DIC method. After that, the peeling stress can be used to characterize the adhesive properties of the interface. The experimental parameters can be used in the finite element analysis (FEM) to evaluate the bearing capacity of the whole structure.
180° Peel Test

The testing specimens were aluminum-lithium alloy honeycomb sandwich structure with an adhesive between the skin and the core. The fixture was designed and processed according to GB/T 2790-1995, as shown in Figure 1.

![Figure 1. Interface adhesive honeycomb sandwich structure model with speckles spraying on one side.](image)

Table 1 shows the geometric size of the specimen. The specimen was fixed with a fixture and installed with a testing machine for tension.

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th>Quantity</th>
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</thead>
<tbody>
<tr>
<td>L1</td>
<td>L2</td>
<td>L3</td>
<td>L4</td>
<td>B</td>
<td>t</td>
<td>t_1</td>
<td>t_2</td>
</tr>
<tr>
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<td>50</td>
<td>220</td>
<td>370</td>
<td>27.7</td>
<td>19.4</td>
<td>0.3</td>
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</table>

The micro-tensile testing machine (Instron 3345) with a maximum loading capacity of 5 kN was used to obtain the displacement-load curve. The experimental setup is shown in Figure 2(a). The specimen was loaded along the axial direction, while the load and displacement were measured during the loading process. The experimental data were converted into the load-displacement curves. One side of the specimen was filled with soft rubber and spayed with white and black speckles. A camera was used to collect images for monitoring the interfacial damages and deformation.

![Figure 2. (a) Experimental setup and (b) Filling details in honeycomb core.](image)

In order to collect the speckle images in peeling process using optical measurement, the hole in one side of the honeycomb core was filled with soft rubber, as shown in Figure 2(b). Because of its superior plasticity and soft texture, the soft rubber and spraying speckle treatment has little impact on the honeycomb core after filling, which makes it easy to collect the deformed images.

Finite Element Numerical Analysis

Numerical simulation is based on ABAQUS with the same boundary conditions. The shell element was used to simulate skins and honeycomb core, and there is a surface-based cohesive model inserted between the skin and honeycomb core. It totally has 13108 elements and 12796 nodes. The
FEM model is shown in Figure 3, and the structure uses S4R shell element. The honeycomb structure material parameters and relative interfacial fracture parameters were listed in Table 2.

Figure 3. Finite element model of debonding honeycomb sandwich structure.

Table 2. Material parameters of finite element model.

<table>
<thead>
<tr>
<th></th>
<th>Young’s modulus (GPa)</th>
<th>Yield stress (MPa)</th>
<th>Nominal stress (MPa)</th>
<th>Tangential stress (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Honeycomb core</td>
<td>70</td>
<td>410</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>skin</td>
<td>68</td>
<td>405</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Cohesive</td>
<td>—</td>
<td>—</td>
<td>2.885</td>
<td>0.995</td>
</tr>
</tbody>
</table>

Results and Discussion

The experiment specimens were in a manner of displacement loading with a rate of 100 mm/min. In order to ensure the accuracy of the experiment, 5 samples were used in each group. The load-displacement curve and typical failure mode of interface adhesive honeycomb sandwich structure were shown in Figure 4.

Figure 4. (a) Load-displacement curves for honeycomb structure and (b) failure photo.

The peeling started at its critical load. As time goes on, the load-displacement curve was serrated, as shown in Figure 4(a), and the loading stopped when the displacement reached about 130 mm. The average peeling stress is about 1.036 MPa according to the peel strength formula of GB/T 2790-1995 and the failure mode is the cohesion failure of adhesive, as shown in Figure 4(b).

The full-field strains at different times are shown in Table 3 during the debonding process of honeycomb sandwich structures.
Table 3. Full-field strains of specimen at different time.

<table>
<thead>
<tr>
<th>Strain</th>
<th>0 s</th>
<th>25 s</th>
<th>50 s</th>
<th>75 s</th>
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<td>$\varepsilon_x$</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
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<tr>
<td>$\varepsilon_y$</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
</tr>
<tr>
<td>$\gamma_{xy}$</td>
<td><img src="image9" alt="Image" /></td>
<td><img src="image10" alt="Image" /></td>
<td><img src="image11" alt="Image" /></td>
<td><img src="image12" alt="Image" /></td>
</tr>
</tbody>
</table>

It can be seen that the strain $\varepsilon_x$ at the peeling is negative. The maximum strain $\varepsilon_x$ moves along the peeling point and the interfacial crack of specimen was under the debonding force. Moreover, the strain $\varepsilon_y$ in the middle of the observation region gradually increased and the structure was bent, which was caused by the low bending stiffness of the honeycomb core. When the time is 75 s, the speckles on the surface of specimen were damaged due to excessive bending deformation. Among the three directions of strain, the strain $\varepsilon_y$ along the peeling direction was always the largest and the maximum value located at the tip of the peeling. However, the shear strain $\gamma_{xy}$ was very small during the loading process.

As shown in Figure 5(a), the FEM simulation indicates that the HSS was bent and deformed due to the low bending stiffness of the honeycomb core after the interface failure. The stress at the peeling point near the interface of the thin-walled core is large, which is consistent with the experimental results. Moreover, the load-displacement curve of numerical result is shown in Figure 5(b). After the critical peeling force is reached, the load decreases and then fluctuates with loading as same as the experimental curve.

Figure 5. (a) FEM simulation of peeling test of honeycomb structure and (b) load-displacement curve of numerical result.
Conclusions

The deformation and failure behaviors of the bonded honeycomb sandwich structure under the 180° peeling load was investigated experimentally and numerically. 180° debonding strength of the interfacial adhesive HSS is about 1.036 MPa and the failure mode is the cohesion failure of the adhesive layer. The maximum strain existed in y direction at the point of peeling, which plays a leading role in the loading capacity. The FEM results are in good agreement with the experiments.

Acknowledgement

The author is grateful to the National Basic Research Program of China (No. 2014CB046506) and the National Natural Science Foundation (Nos. 11472070, 11572070, 11772081).

References


