FATIGUE BEHAVIOR OF HONEYCOMB SANDWICH COMPOSITES UNDER FLEXURAL AND BUCKLING LOADING

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This study experimentally investigated the fatigue behaviors of honeycomb-sandwich composites under buckling and three-point bending loads. The ASTM C 365 and ASTM C 393 standards were used as references to prepare test specimens and conduct experiments. The investigation looked at how the cell diameter, core thickness and thickness of the skin material affected the fatigue behavior. It was observed that the most significant parameter affecting fatigue under buckling loads was the cell diameter, and the least significant parameter affecting fatigue under three-point loads was the thickness of the skin material.

Keywords: honeycomb, sandwich composites, fatigue

INTRODUCTION

Honeycomb-sandwich structures are formed by putting thick cell structures between thin, tough plates. Bonding between the plates and the honeycomb cells is provided by an adhesive, as shown in Figure 1. Honeycomb structures are known to have low weight and high flexural rigidity, and they are widely used under tensile and bending loads. The use of honeycomb structures in place of conventional materials under high loading has increased (Allen, 1969).

Aluminum alloys 3003, 2024 and 5052 are commonly used. The 5052 aluminum alloy is commonly used in aerospace applications, while the 2024 alloy is preferred for high-temperature uses. Although different methods are used to form honeycomb cells, the most common one is to use adhesive bonding (http://www.flightglobal.com).

Honeycomb composites are used for airfoils, spoilers, passenger floors and shells. Critical loads in airplanes can be created by bird impact, hail damage and other foreign objects. It is important to determine the damage caused by impacts to the airfoils and to the airframe. The resistance of sandwich composites to high-velocity impacts is low due to their thin layers and easily deformable core materials. The damage types most often observed – matrix cracking, separation and fiber damage – can be seen occurring individually or occurring in combination.

If the velocity of the impact is low, sandwich cells can absorb the load by being bent. If the kinetic energy of the impcat is lower than the elastic strain energy of the plate, the impact results in light damage (Bitzer, 1997). In high-velocity impacts, when the local contact stress exceeds the local strength, honeycomb cells may suffer from skin bending, debonding between skin and core and crush damage to the honeycomb cells (Aktay *et al*., 2008). Thus, energy absorption abilities of honeycomb composites depend on core damage and deformation (Abrate, 1998).

Because honeycomb composites have been developed and extensively used, many researchers have studied them to determine and enhance their mechanical properties. Yamashita and Gotoh (2005) investigated quasi-static behaviors of aluminum honeycomb composites under flatwise impact load. Miller *et al*. (2011) experimentally investigated and calculated the effects of eight different cell structures on buckling behaviors in composites. They determined that the conventional model had a buckling strength 13% less than the recessed model. Giglio *et al*. (2012) experimentally investigated and numerically determined the strength of honeycomb sandwich composites that consisted of aluminum surface layers and nomex cells by using three-point bending tests. Numerical and experimental results were compared using curves of load-shape changes and detailed photographic images of cell crushing under loads. They determined differences of 1.8% and 0.29% between numerical and experimental results for the energy absorption and maximum load respectively, and reported that the numerical and experimental curves of the load-shape change showed a similar tendency. Belouettar *et al*. (2009) experimentally investigated mechanical and fatigue behaviors of honeycomb composite structures consisting of aramid fibers and aluminum cells under static loads by using four-point bending tests. They determined that the damage formation in the cell structure was due to the decrease in rigidity and stated that an aluminum L model was more suitable in terms of structural lifetime. Solmaz and Topkaya (2012) experimentally and numerically investigated critical buckling loads of sandwich composites having ellipsoid cells. Copper and aluminum were used as the core materials and it was found that aluminum cells had greater buckling strength.

The fatigue behavior of sandwich composites with aluminum honeycomb cells were experimentally investigated in this study by investigating the effects of different cell diameters (D), cell heights (T) and thicknesses of skin material (h) under different loads.

MATERIALS AND METHODS

In the study, skin plates were produced using the 5754 aluminum alloy. The 3003 aluminum alloy was used as the honeycomb cell material. The 3M 2216 gray branded two-component, epoxy-based adhesive was used to bond honeycomb cells to skin materials. To enhance the quality of the bonding, skin material surfaces were ground using 180 grid sand paper (P180) and materials were cleaned by acetone to remove grease, dirt and impurities. The 3M 2216 gray can be cured at room temperature. However, to cure the adhesive faster, models were kept at 93°C for 30 minutes. The sandwich composite model is shown in Figure 1.

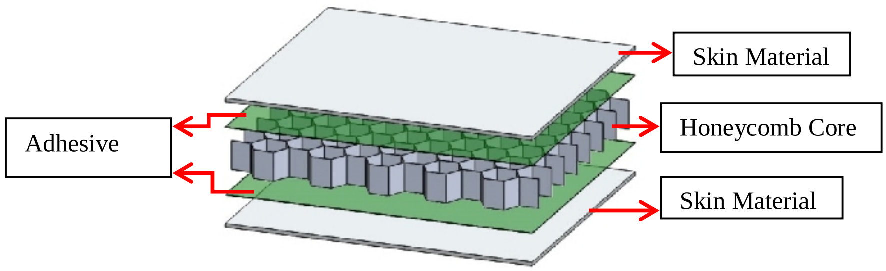

Figure 1. Sandwich Composite Model

The mechanical properties of materials used in the study are shown in Table 1. The basic reason for using honeycomb sandwich composites is that they have high strength values despite their low weights. Low weight values can be achieved by using large cell diameters and small cell heights; however, this results in strength decreases. The parameters used to determine strength decreases with respect to weight decreases are shown in Figure 2. Dimensions of the specimen – W and L values – were set to be 80 and 135 mm respectively. The cell diameter of the honeycomb was 6.35 and 9.525 mm respectively; cell height (T) was 10, 15, and 20 mm respectively; the thickness of skin material was 0.5, 1 and 1.5 mm respectively.

Table 1. Material Properties

Material	Density [kg/m^3]	Young's Modulus [MPa]	Poissons Ratio
AL 5754 Alloy	2670	70300	0.33
Adhesive 3M 2216	1296	565.6	0.47
AL 3003 Alloy	2730	68900	0.33

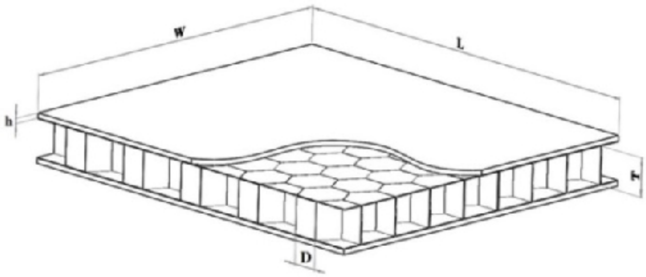

Figure 2. Dimensions of Model

Before conducting the fatigue experiments, static tests were performed to determine the specimen strengths. Three-point bending and buckling loads were used in the tests. Experiments were conducted using Shimadzu Universal test equipment with a load cell capacity of 250 kN.

After determining the static strength values of specimens, they were subject to fatigue experiments. During fatigue experiments, R=Fmin/Fmax was set to 0.1, and the test frequency was 5 Hz. Maximum load values were 90, 85, 80, 75, 70, 60, and 50% of the static damage loads (ultimate strengths) of specimens. Loads were applied to specimens under three-point bending and buckling. The ASTM C 365 and ASTM C 393 standards were used to determine specimen and boundary conditions. The specimens placed in the test equipment to undergo buckling and three-point bending loads are shown in Figure 3.

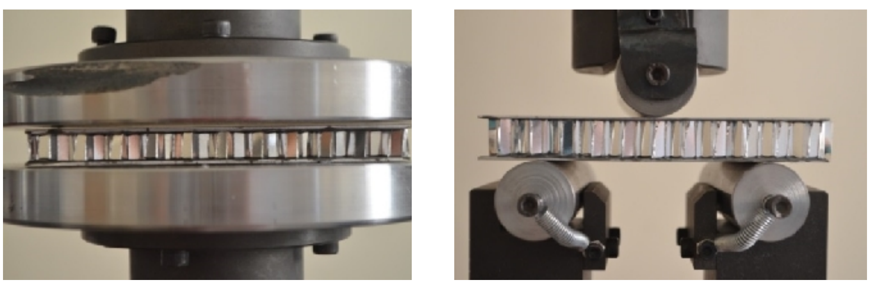

Figure 3. Application of Load: a. Buckling b. Three Point Bending

RESULTS AND DISCUSSION

Static strengths were found before the fatigue experiments. For buckling, maximum fatigue loads were applied as 90, 85, 80, 75, and 70% of the ultimate strength; for three-point bending, maximum fatigue loads were applied as 90, 80, 70 and 50% of the ultimate strength. Fatigue cycle numbers, with respect to buckling loads, are shown in Figure 4.

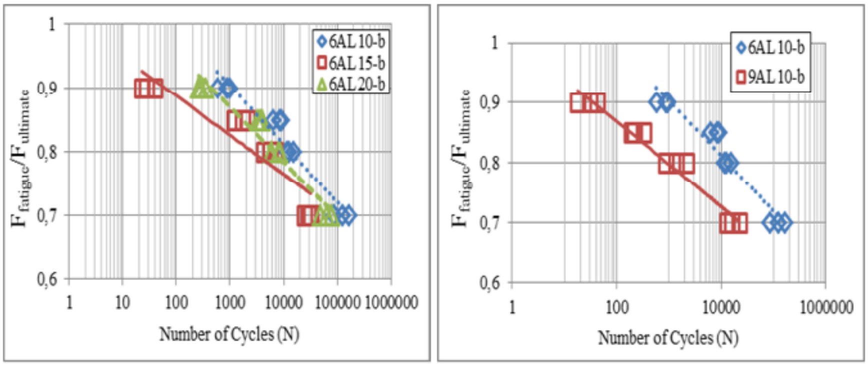

Figure 4. Applied Force-Number of Cycles Graphs for Compression Loading

It was observed that the lowest cell height (10 mm) had the highest fatigue cycle number, while the lowest fatigue cycle number was seen in the specimens with a cell height of 15 mm. As the ratio of applied load to static load decreases, fatigue cycle numbers were closer to each other. Increasing the cell diameter decreased the fatigue strengths.

Fatigue curves for three-point bending loads are shown in Figure 5. Increasing the thickness of the honeycomb core material increased the bending fatigue strengths of the specimens. Decreasing the $F_{fatigue}/F_{ultimate}$ value caused cycle numbers to be closer to each other. Increasing the thickness of the skin material increased the fatigue strengths, as in the case of static loading. When the thickness of the skin material was increased from 0.5 mm to 1 mm, the increase in the cycle number was more pronounced than increase from 1 mm to 1.5 mm. When the effects of cell diameter on fatigue strengths were examined, it was observed that higher cell diameters had lower fatigue cycle numbers for all loads.

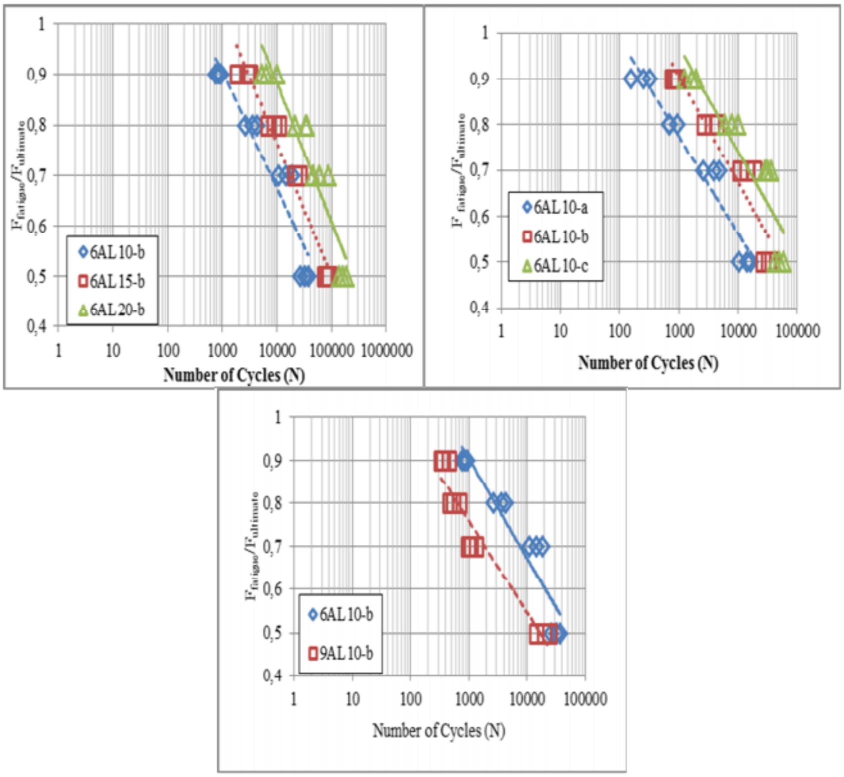

Figure 5. Applied Force-Number of Cycles Graphs for 3 Point Bending Loading

Damaged specimens having different cell thicknesses under three-point bending loads are shown in Figure 6. It was seen that the damage to the specimen having 10 mm cell thickness was a complete bending of the composite structure, as shown at the top of the figure. Partial local buckling damage was observed in the model with 15 mm thickness, while the damage in the model with 20 mm thickness was a complete local buckling (wrinkling).

Figure 6. Damaged samples after three point bending test

CONCLUSIONS

In this study, the fatigue behaviors of honeycomb sandwich composites were experimentally investigated under buckling and three-point bending loads and the results are shown below:

- Increasing cell diameter decreased the strength of specimens under both buckling and three-point bending loads. However, it was observed that it was more pronounced under buckling loadings.
- Increasing the thickness of the skin material increased the fatigue strength of specimens under three-point bending loads. The effect of the thickness of the surface material was not seen under buckling loads, where the load was carried only by the honeycomb core.
- Increasing the thickness of honeycomb cells decreased the fatigue strength of specimens under buckling loads, but increased it under three-point bending loads. The inertia increase occurring in specimens was considered the reason for this phenomenon.
- The greatest difference observed because of increasing cell thickness was in the damage-type and the damage in the specimen with 10 mm cell thickness resulting in a complete bending of the structure. This was partially local in the specimen with 15 mm thickness but only local in the specimen with 20 mm thickness.

Acknowledgement

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