Effect of Thermal Fatigue on Performance of Composites Honeycomb Sandwich

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ABSTRACT

A spacecraft during its operation will be subjected to thermal fatigue ranging between -185°C to +150°C. One of the most common types of damage arising due to thermal fatigue is microcracking. This paper is focused on the studying the effect of thermal fatigue on the mechanical property of composite honeycomb sandwich structures. Different facing and core thickness configuration of the composite honeycomb sandwich structure made of same material were studied. Mechanical test was performed to evaluate the deterioration of bond line strength between facesheet and core. Experimental results indicate that the sandwich panels with thin facesheet and thick core have the least performance after subjection to the thermal fatigue.

KEYWORDS: *Sandwich structure***,** *microcracking, thermal fatigue.*

1 INTRODUCTION

Application of polymer based composite materials into primary and secondary structures has been a subject of considerable interest for space and aerospace industry. Particularly composite honeycomb sandwich structures are widely used as it offers higher flexural stiffness to density ratio, as opposed to metal counterparts and solid laminates. One of the problems associated with the use of such structures for space applications involves thermal fatigue. As a result, it is of utmost importance to be aware of the margin of degradation.

Matrix microcracking is one of the most common defects arising due to thermal fatigue. When the process temperature deviates from the stress-free temperature, residual stresses increase, resulting in matrix microcracking and debonding between fiber and matrix. This problem for solid laminates has been investigated by many researchers (Timmerman et al., (2002), Garnich at al., (2011), Gupta and Hojjati (2018), Mahdavi (2017). The thermal fatigue induced microcrack initiation and propagation mechanism varies significantly between solid laminates and sandwich structures due to the composition. Damage in the form of delamination, fiber-matrix debonding and matrix microcracking are commonly observed in sandwich structures subjected to thermal fatigue (K. Pannkoke and H.J. Wagner (1991), Laurent et al., (2017), Hegde and Hojjati (2018), Islam et al., (2016)). This paper compares the effect of thermal fatigue on the mechanical properties of sandwich structure made of the same material but with different facesheet and core thickness configuration.

2 MATERIAL AND MANUFACTURING

Sandwich samples with different core and facesheet thickness were chosen for this study. Table 1 provides information related to the different sample configuration under investigation. The facesheets were made of 5-harness satin carbon fiber woven fabric with cyanate ester resin. The facesheets were cured separately at the laminate level and then bonded to the core using modified epoxy film adhesive. The core chosen was a perforated Kevlar honeycomb core coated with phenolic resin. The cell size of the core was 3 mm with core wall thickness of 46 micrometer and density of 48 kg/m3. The volume fraction of (±45) and (0/90) fabric plies within samples was kept the same (50%) for all configuration to have almost the same in-plane stiffness properties and thermal expansion coefficients.

Table 1 Sample configuration

Sample ID	**Configuration**
Sample A	$[(\pm 45),(0/90),\text{core}]_S$ with 6.25 mm thick core
Sample B	$[(0/90),(\pm 45)_2,(0/90)_2,(\pm 45)_2,(0/90),\text{core}]_S$ with 6.25 mm thick core
Sample C	$[(0/90),(\pm 45)_2,(0/90),\text{core}]_S$ with 12.5 mm thick core
Sample D	$[(0/90),(\pm 45)_2,(0/90),\text{core}]_S$ with 19 mm thick core

2.1 Test plan

The samples were cut to 25mm by 25 mm size from a large panel using diamond saw cutting tool. Care was taken to achieve tolerance of ±0.5 mm between the sample sizes to achieve consistent results. The plates cutting direction were aligned in ribbon and transvers ribbon directions as shown in Figure 1. Then the samples were preheated to 70 °C for a period of three hours to remove moisture content. The free edges of the samples were polished for microscopic observation.

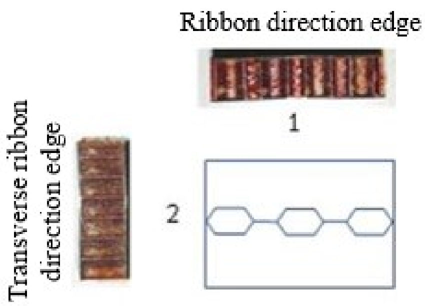


Figure 1: Sides observed under the microscope

A test setup was developed to expose the samples to induce thermal fatigue. The samples were submerged in liquid nitrogen (LN_2) in order to expose them to cryogenic temperature (-194 °C). To take them to the elevated temperature (+150 °C), the samples were placed in a convection Owen. A T-type thermocouple was mounted inside the core of one of the samples to monitor the temperature with time. As soon as the temperature at the core reached the desired value, sample were taken out of the conditioning chambers. One complete thermal cycle involves one cryogenic and one hot case conditioning. Samples were observed for microcracks at the cross section using optical microscope after each thermal cycle until 10 cycles, furthermore, the observation interval was increased.

2.2 Microscopic observation

Microscopic observation was performed on two free edges of the sample. The ribbon direction edge and transverse ribbon direction edge (Figure 1). No voids were observed on the facesheet for any samples. Longitudinal microcracks in the form of delamination were observed between the facesheet and core-facesheet adhesive. The 90 degree tow and adhesive region interphase were most sensitive. Up to 10 thermal cycles, cracks were formed. Thereafter, old microcracks started to grow in length and eventually joined each other. After 20-30 thermal cycles microcracks grew longer and the gap became wider and transverse cracks initiated from the longitudinal cracks. Figure 2 shows the evolution of microcracks for Sample A between zero thermal cycles and 60 thermal cycles. Microcracks are the result of mismatch in coefficient of thermal expansion (CTE) between the constituents (Grimsley et al., 2001). Residual stresses increase as the temperature drops below stress-free temperature (Cure temperature) when the samples are subjected to cryogenic conditioning. Cracks form primarily between the facesheet and core-facesheet adhesive as the difference in CTE is higher between facesheet and adhesive. Similar cracks were observed in other configuration of the samples. Sample A and Sample D were found to be more sensitive to thermal fatigue. This is discussed elaborately in the next section.

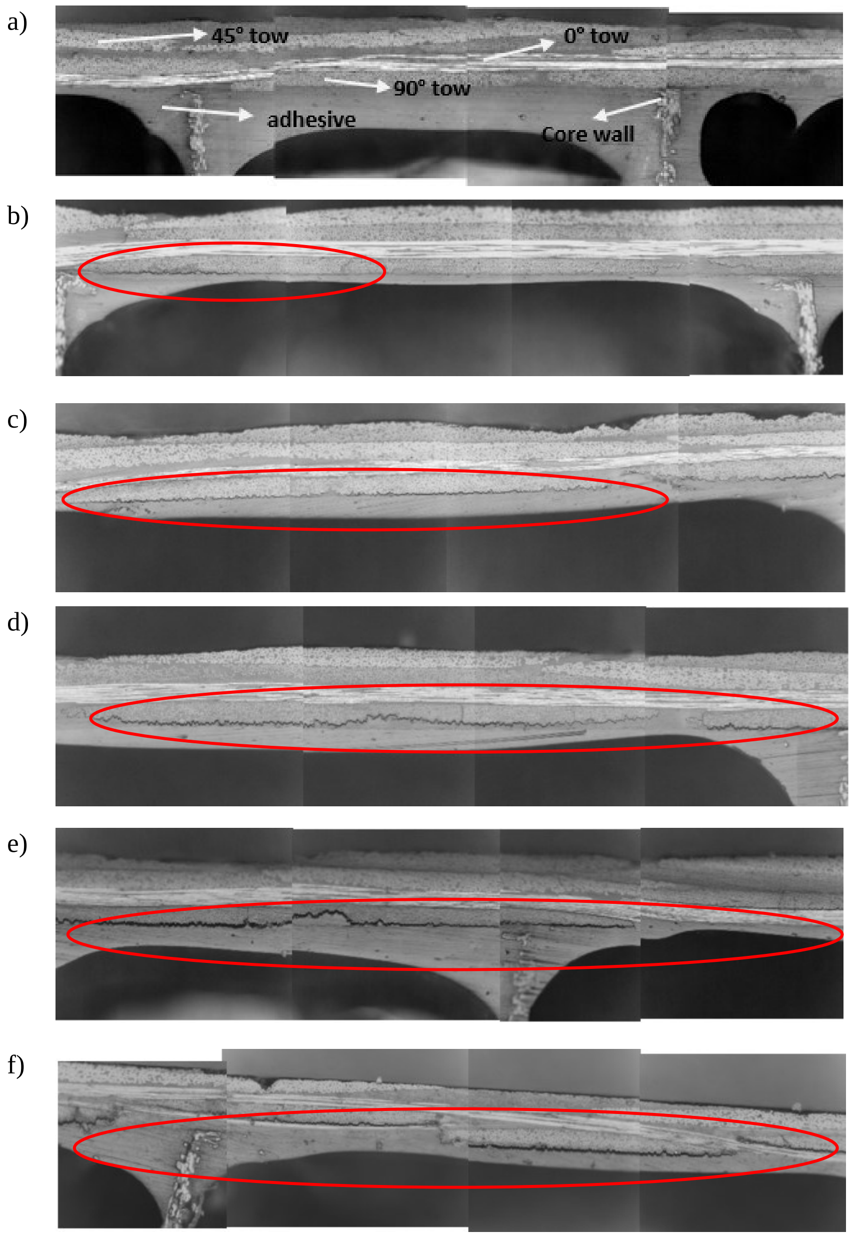


Figure 2: Evolution of microcracks a) No thermal cycle, b) after 10 thermal cycles, c) after 20 thermal cycles, d) after 30 thermal cycles, e) After 40 cycles, f) After 60 thermal cycles.

3 MECHANICAL TEST

As mentioned before, longitudinal microcracks between core/facing adhesive and facesheet were observed, thus affecting the bond-line strength of facesheet and core (Hou et al., 2001). Of all the ASTM standard test methods for sandwich panels, flatwise tensile test (ASTM C297) was chosen which is the most suitable test method to measure the bond line strength. Prior to performing thermal fatigue, the sample size was decided based on the requirements of ASTM standard for flatwise testing. After following surface preparation procedures on the samples and loading blocks, the samples were bonded using a 2-part adhesive named Loctite 9392 QT aero. The adhesive was cured as per manufacturer recommended curing cycle. The tests were performed on displacement control mode with the rate of 0.5 mm/min and the force values are recorded at a sampling rate of 3 readings per second. For each specimen destructive test was performed and the load at failure which is the flatwise tensile strength (FWT) was recorded.

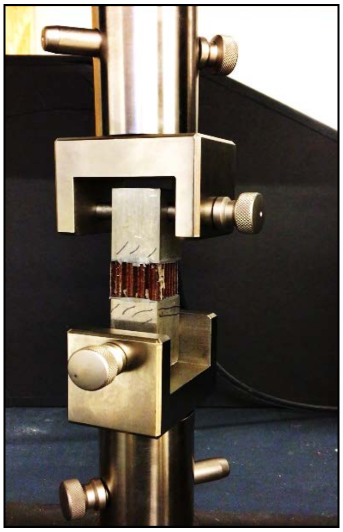


Figure 4: Sample loaded to flatwise tensile test fixture.

3.1 Test results

Samples were tested after 0, 10, 20, 30, 40 and 60 thermal cycles. Three samples were tested for each case to obtain statistically significant data. The following graphs shown in Figure 4 illustrate the correlation between the mechanical strength and thermal cycles for the four configurations of samples under investigation. Trend lines were added in order to best-fit a linear curve and the slopes were then calculated. There is significant reduction in FWT strength for all the samples with increase in cycle. It is interesting to note a slight increase in flatwise tensile strength for Sample B and C after 10 thermal cycles. The possible cause for this could be the post curing of adhesive upon thermal fatigue (David et al., 1997). As mentioned in the test plan, the thermal cycle involves conditioning at elevated temperature of +150 ºC which can cause post-curing. In all the cases the cracks saturate after 30-40 thermal cycles and so does FWT strength. It can be seen that samples A and D have the lowest FWT. Therefore, panels with thinner facesheet or thicker core will be more susceptible to damage under thermal fatigue.

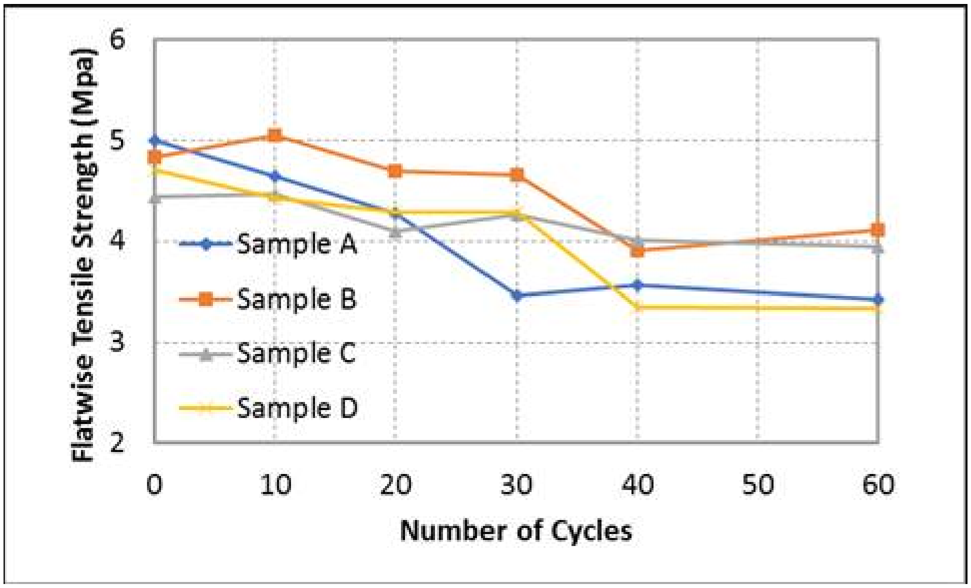
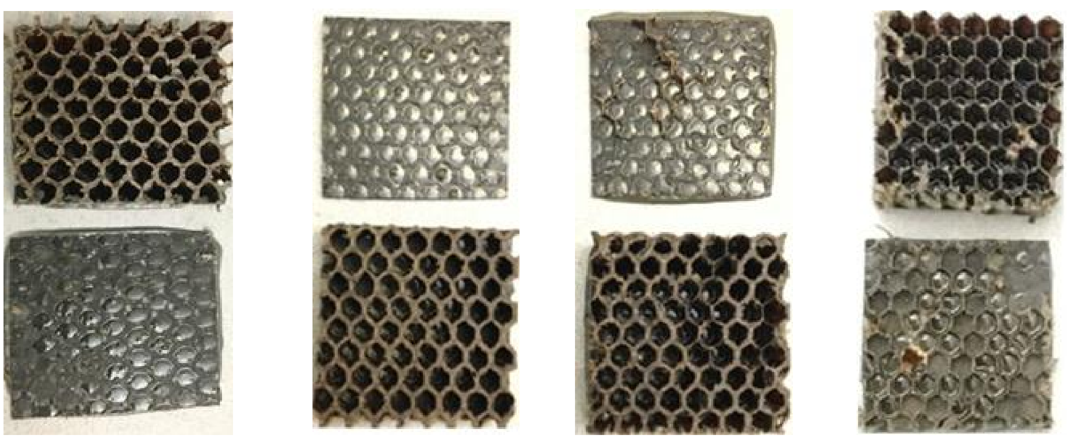


Figure 4: Change in mechanical strength with increase on thermal cycle for different samples

3.2 Failure mode

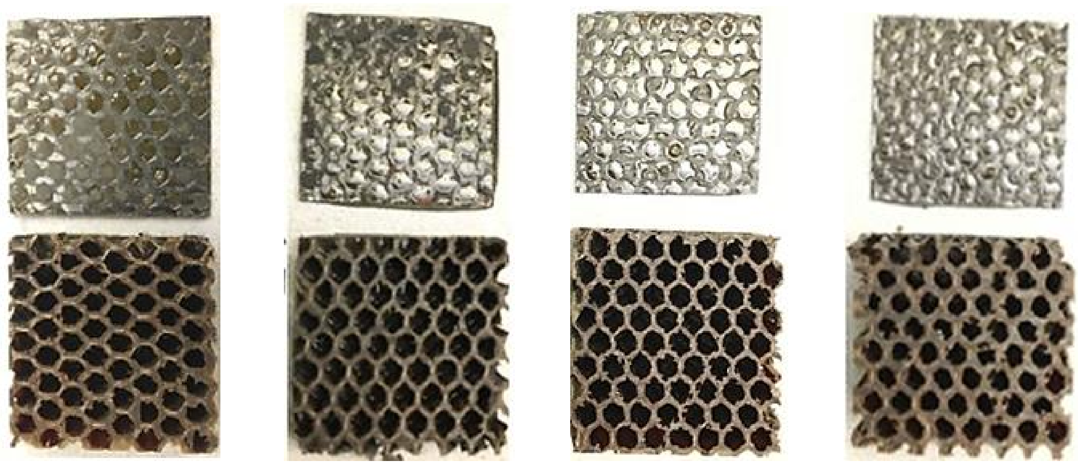
The only acceptable mode of failure is the failure within the sample and not the adhesive failure between the sample and loading block. Figure 5 presents the post FWT test pictures of samples at zero thermal cycles. Following the application of ultimate load to each specimen, it was evident that except sample D that underwent 100 percent core failure, samples A, B and C experienced adhesive failure of core facing adhesive. Figure 5 shows the failure modes of samples A, B, C and D before applying any thermal cycles.



(a) (b) (c) (d)

Figure 5: Images of samples after flatwise test without any thermal cycle for, (a) Sample A, (b) Sample B, (c) Sample C and (d) Sample D.

The failure modes of samples A, B, C and D after 60 thermal cycles are presented in Figure 6. Although the failure modes of samples A, B and C are the same for 0 cycle and 60 cycles, the drop in FWT strength of samples are quite significant. Retention of adhesive on the core side of the sample is clear after observing the detailed view of the failed samples subjected to 60 thermal cycles. The reduction in FWT strength values and the retention of adhesive on the core side of thermal cycled samples shows the effect of microcracks. The 100 percent adhesive failure of core facing adhesive at 60 thermal cycles as shown in figure 6d as opposed to 100 percent core failure at 0 thermal cycles for sample D (Figure 5d) is a clear indication of deterioration of mechanical strength upon thermal fatigue



(a) (b) (c) (d)

Figure 6: Images of samples after 60 thermal cycles followed by flatwise test for, (a) Sample A, (b) Sample B, (c) Sample C and (d) Sample D.

4 CONCLUSION

The effect of thermal fatigue on the mechanical property of composite honeycomb sandwich structures were studied. Different facing and core thickness configuration of the composite honeycomb sandwich structure made of the same material were investigated. Mechanical test was performed to evaluate the deterioration of bond line strength between facesheet and core. Adhesive failure of the core facing adhesive was the most common type of failure observed. Significant drop in debonding strength were recorded with increase in thermal cycles. The flatwise tensile strength also saturated after 30-40 thermal cycle. Sample A and sample B with the same core thickness but different facesheet thickness were compared. The higher sensitivity to thermal fatigue for sample A is possibly due to the unsymmetrical laminates on one side of the facesheet as opposed to sample B. Unsymmetrical laminates are known to exhibit coupling effect due to thermal load. Sample C and sample D with different core thickness but same facesheet thickness were compared. Both microcrack formation and FWT test results prompted sample D was more sensitive to thermal fatigue. It was found that between two samples studied for comparison made of the same material and volume fraction of plies, the one with higher core to facesheet thickness ratio was more sensitive to microcracking.

5 ACKNOWLEDGEMENTS

The authors would like to thank Dr Daniel-Iosif Rosca, at Concordia Centre for Composites, for support while performing the experiment. This research work was conducted with financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC), Consortium de Recherche et D’innovation en Aerospatiale au Quebec (CRIAQ), MDA Corporation and Stelia North America.

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