EFFECT OF THERMAL CYCLING ON COMPOSITE HONEYCOMB SANDWICH STRUCTURES

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1. INTRODUCTION

Composites sandwich structures offer features like higher bending stiffness, light weight, superior dimensional stability, low thermal conductivity and acoustic insulation, which makes them an attractive option for aerospace applications. There is a significant demand in spacecraft industry to reduce structural weight, thus choosing materials with higher strength-to-weight ratios which also satisfy other operational requirements such as the ability to withstand extreme temperature in space, is of primary importance. During a spacecraft's operation, it can experience temperature variations as high as ± 185 °C. Therefore, materials used in its structure such as solid laminates and sandwich structures with honeycomb core are likely to experience major problems, notably microcracking in resin [1], and delamination at the interfaces due to the freeze-thaw mechanism [2] which could result in premature failure.

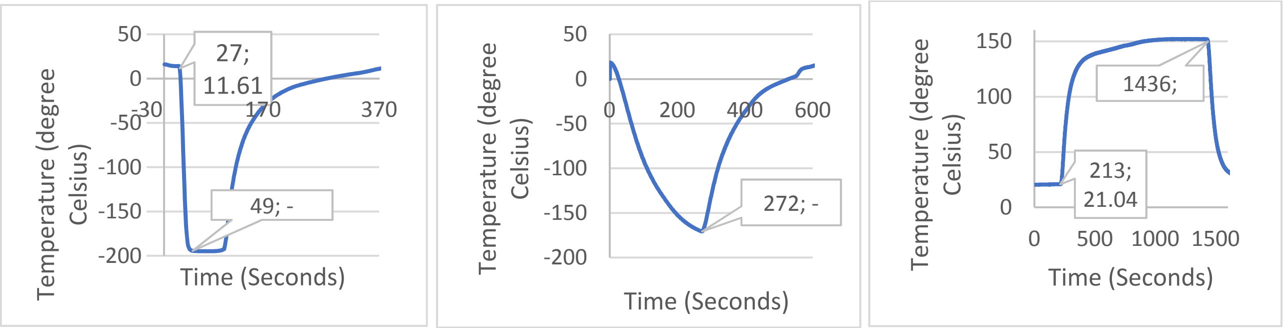
This paper is focused on studying the effect of thermal cycling on composite honeycomb sandwich structures. Samples were subjected to a space-like thermal cycling, and crack formation and growth were monitored and quantified after repeated thermal cycles.

2. MATERIAL AND TEST PLAN

The sandwich panel was made of 6.4 mm (0.25inch) thick phenolic resin coated Kevlar honeycomb core with 0.25 mm thick facesheets made of 5HS carbon fiber fabric with cyanate ester resin. The facesheets were cured at the laminate level and are then bonded to the core using a structural film adhesive (FM300). The cure cycle was 90 minutes at 120 °C under autoclave pressure of 1.5 atm. There were no voids present in the facesheet when the sample cross-sections were observed under the optical microscope.

Test Plan

Four sandwich samples were cut into 25.4 mm by 25.4 mm pieces and then subjected to thermal cycling. To achieve cold case condition temperature, liquid nitrogen was used. The test samples were placed in a convection oven to achieve hot case condition. Two test setups were developed for the cold case. The first setup involves direct dipping of samples in LN2 (Liquid Nitrogen, for higher rate of cooling), which is comparable to the condition experienced by sandwich materials used in cryogenic fuel tank [3], where the cryogenic fuel is in direct contact with the material. The second setup involves non-contact cooling, where samples are subjected to cryogenic temperature environment, without direct contact with LN2. This condition simulates the thermal environment (lower rate of cooling) experienced by the materials used in spacecraft primary structures and support brackets in eclipse region of the orbit. A thermocouple was installed inside the core of a spare sample to monitor the change in temperature.



(a) *(b)* *(c)*

Fig. 1: Time vs temperature profiles of sample for direct dipping in LN2 (a), non-contact cooling (b) and hot cycle (c).

The change in temperature with respect to time for the thermal conditioning is shown in Fig. 1. It can be noted from Fig. 1 (a), that it takes 20 seconds for the samples to reach -194 °C when directly dipped in LN2, and approximately 5 minutes to reach -170 °C for samples subjected to non-contact cooling. For the hot case condition, it takes approximately 15 minutes to reach +150 °C, however the cycle time was extended to 20 minutes, which serves as buffer. One complete cycle consists of one cold and one hot cycle. Out of four, two samples were subjected to direct dipping in LN2 followed by hot cycle. The second set of two samples were subjected to non-contact cooling followed by hot cycle. This was done to simulate the condition as described in the test plan.

3. MICROSCOPIC INSPECTION

The samples were observed under the microscope after every half cycle, to investigate the part of the cycle (hot or cold) that contributes more towards the formation and propagation of microcracks. As the honeycomb sandwich material consists of both geometric and material anisotropy, the microscopic inspection was done on two cross-sectional sides perpendicular to each other, one on ribbon direction side (the side where the cut was made along the ribbon), and the other on transverse ribbon direction side of the core. The results after subsequent cycles are as shown below.

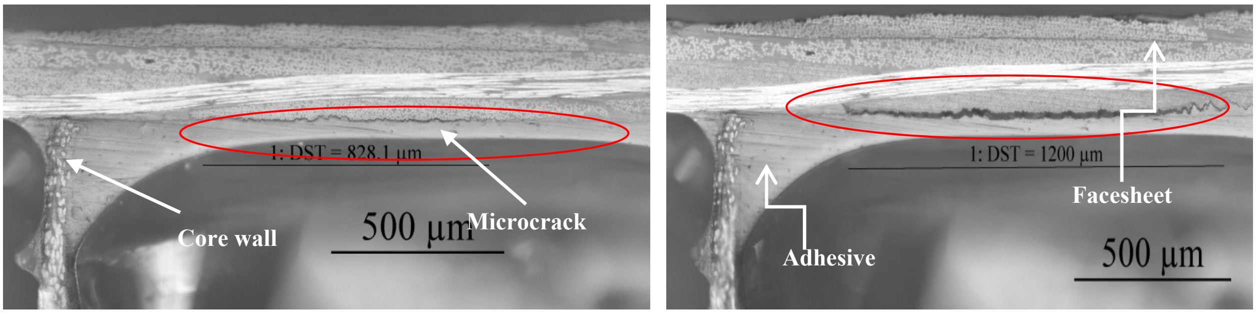


Fig. 2: Microscopic images of sandwich cross section taken after 2nd cycle (left) and 10th cycle (right).

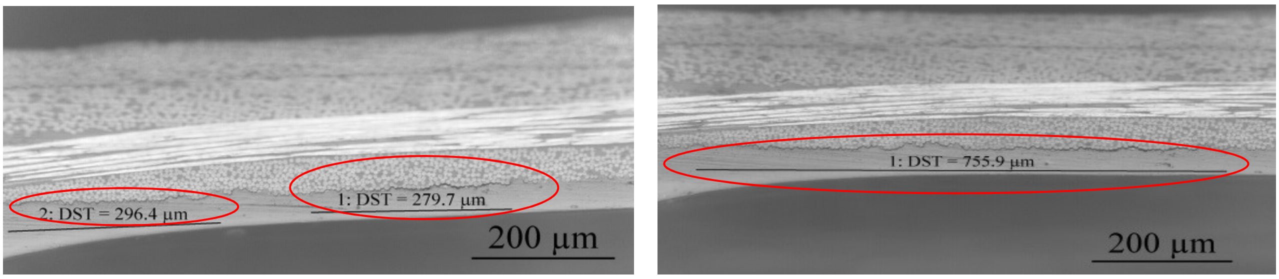


Fig. 3: Magnified microscopic images of sandwich cross section taken after 1st cycle-hot cycle (left) and 1.5 cycle- cold cycle (right).

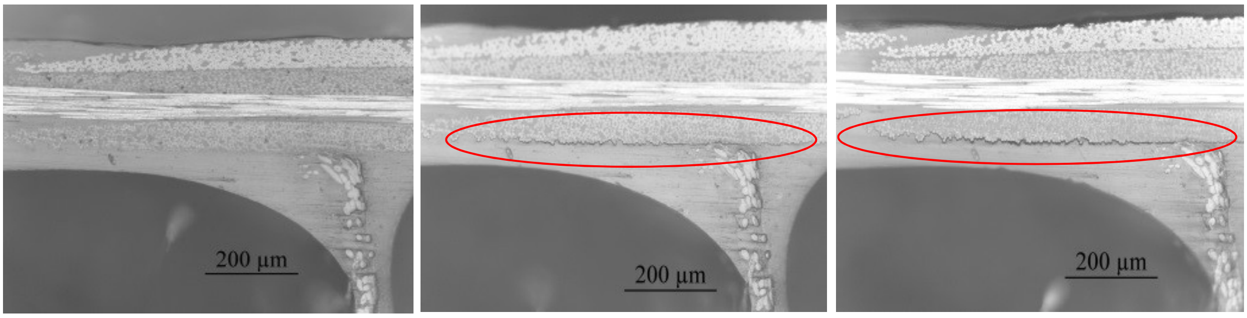


Fig. 4: Images taken after 0.5 cycle-cold cycle (left), 5th cycle (middle) and 10th cycle (right).

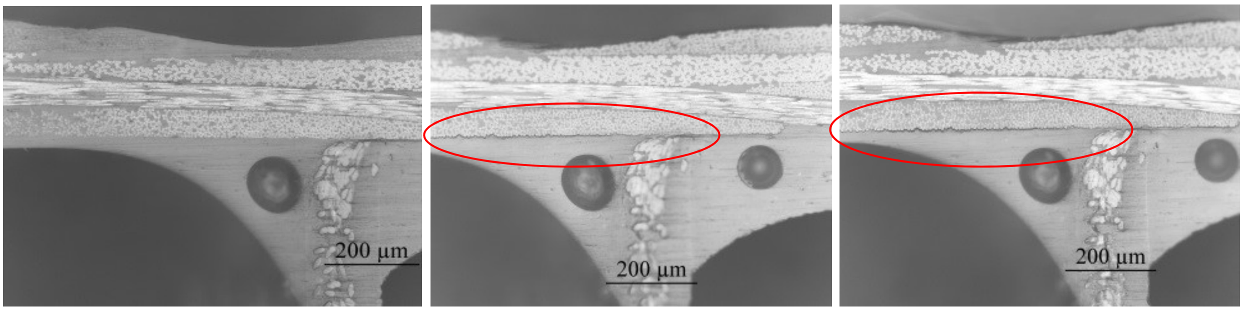


Fig. 5: Images taken after 0.5 cycle-cold cycle (left), 5th cycle (middle) and 10th cycle (right).

Microcrack Formation and Propagation

Fig. 2 clearly shows various aspects of honeycomb sandwich composite such as core wall, facesheet, adhesive fillet area and an example of a microcrack. Fig. 3 shows examples of magnified images of crack progression. The microscopic image as shown in Fig. 4 (left) was captured after cold cycle (0.5 cycle), the same position was again observed under microscope after subsequent cycles. A facing delamination crack was found at the interface between the adhesive layer and facesheet. Most cracks appeared after hot cycle which indicates that the influence of hot cycle is more severe for crack formation, in the first two thermal cycles. It is also interesting to note that crack formation in cold cycle is lower, however thicker cracks grows in length (propagates) as shown in Fig. 3 (right, after cold cycle). Multiple cracks were observed at different part of sample with similar patterns as shown in Figs. 4 and 5, most cracks form between 90 degree tow and adhesive layer.

4. QUANTIFICATION OF CRACKS

Cracks were quantified using parameters such as crack density [1] and crack length, the former corresponds to number of cracks per unit area (cracks/mm^2) per sample and the later corresponds to summation of length of all the cracks observed per sample. The plot of change in crack density with respect to number of cycle is shown in the image below. Crack density was higher on ribbon direction side compared to transverse ribbon direction side as indicated by the plots in Fig. 6. This is mainly due to the anisotropic behavior of the sandwich core. The core's ribbon direction coefficient of thermal expansion is higher compared to the transverse ribbon direction CTE [5].

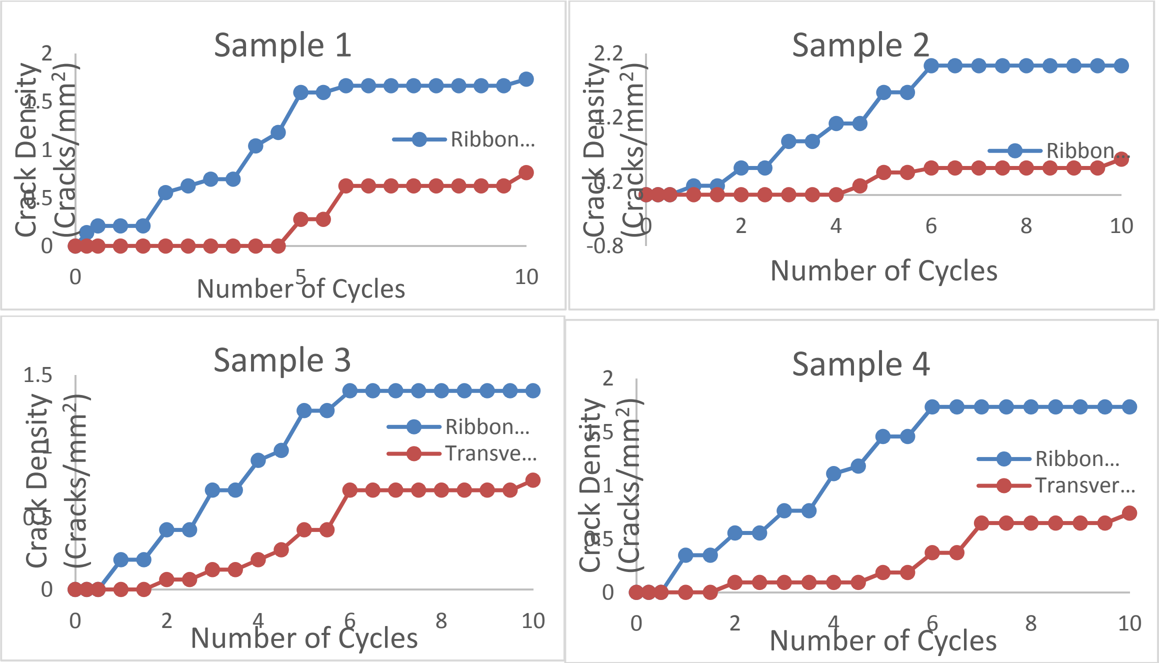


Fig. 6: Variation in crack density with respect to number of cycles of the four samples.

5. CONCLUSION

A methodology of quantifying microcracks on sandwich composite material subjected to thermal cycling is developed. For statistical significant data, four samples were observed after hot and cold cycles, with two samples each for different rate of cooling. Longitudinal microcracks were observed at the region between facesheet and core, indicating that the adhesive layer is the weak link. The variation in crack density with cycles is almost constant for all samples, with slight variance owing to the minor difference in local geometry of observation. A model is being developed to correlate the crack density vs number of thermal cycle.

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