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Fatigue fracture of fiber reinforced polymer honeycomb composite sandwich structures for gas turbine engines

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Abstract. Fiber reinforced polymer honeycomb composite sandwich structures are commonly used in different industries. In particular, they are used in the manufacture of gas turbine engines. However, fiber reinforced polymer honeycomb composite sandwich structures often have a manufacturing flaw. In theory, such flaws due to their rapid propagation reduce the durability of fiber reinforced polymer honeycomb composite sandwich structures. In this paper, bending fatigue tests of fiber reinforced polymer honeycomb composite sandwich structures with manufacturing flaws were conducted. Comparative analysis of fatigue fracture of fiber reinforced polymer honeycomb composite sandwich specimens was conducted before and after their bending fatigue tests. The analysis was based on the internal damage X-ray observation of fiber reinforced polymer honeycomb composite sandwich specimens.

1. Introduction

Application of fiber reinforced polymer honeycomb composite sandwich (FRPHCS) structures is constantly growing. Currently FRPHCS structures are used in the aircraft, ships, cars, bridge construction and wind energy systems. The FRPHCS structures application in the aviation industry, specifically in gas turbine engine manufacture has the greatest interest. This is because that FRPHCS structures have a high fatigue resistance and stiffness, high strength-to-weight ratio and low acoustic conductivity [1, 2]. The last two features is most important due to the current trend of gas turbine engine weight reduce.

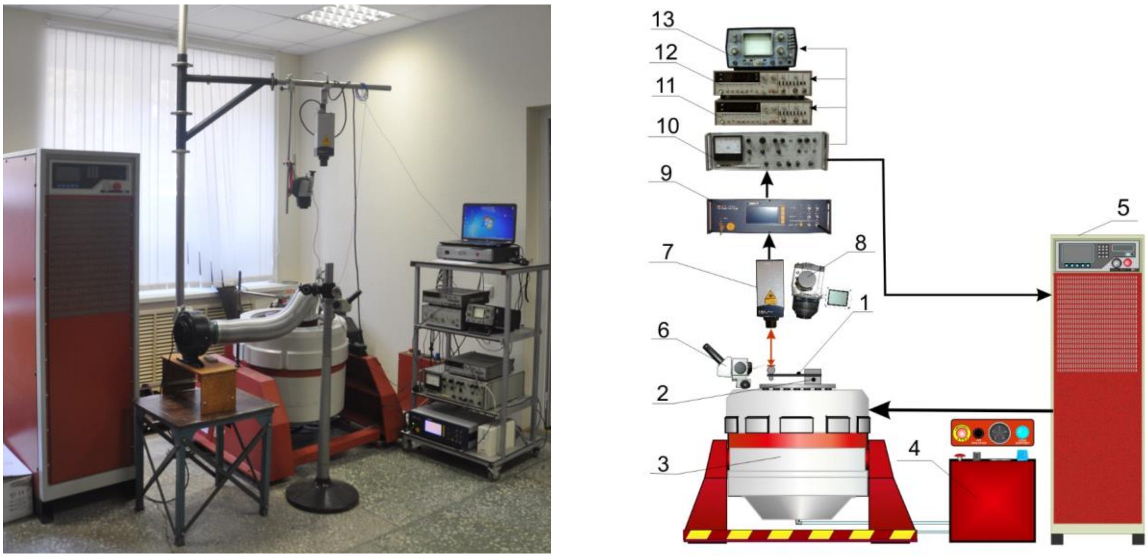
However, FRPHCS structures can have internal manufacturing flaws due to imperfect manufacturing technique. Such flaws can significantly reduce the static and fatigue life of FRPHCS structures.

Some authors [3,4] note that the durability of damaged FRPHCS structures under fatigue bending is lower than that of undamaged ones.

Theoretically, manufacturing flaws reduce the FRPHCS structures durability due to the fact that their propagation is rapid. Therefore, fracture pattern comparative analysis of FRPHCS specimens before and after their bending fatigue tests is the purpose of this paper. The analysis was based on X-ray observation of internal FRPHCS damage.

2. Method and materials

The cantilever bending fatigue tests are conducted on V-850-400 electrodynamic shaker with a power amplifier and APM-4M power regulator (Figure 1).



a) b)

Figure 1 – Experimental unit: external appearance (a) and scheme (b). 1 – Test specimen, 2 – Fixing spot, 3 – Electrodynamic shaker V850-400, 4 – Pneumatic control unit, 5 – Power amplifier, 6 – Microscope MBS-9, 7 – Sensor head of a laser vibrometer OFV-525 8 – Infrared camera, 9 – Laser vibration sensor OFV 5000, 10 – APM-4M power regulator , 11 – Frequency indicator, 12 – Cycle counter , 13 – Oscilloscope.

Fatigue tests are based on the ASTM C393/C393M standard [5]. This standard regulates the static bending tests of three-honeycomb-layer sandwich panel. In this study the cantilever bending fatigue tests, as opposed to static bending tests, involve cyclic load applying.

FRPHCS cantilever bending fatigue tests were conducted by fully reversed cycle on first flexural own shape. Initialization and maintenance of the cycling stress amplitude are carried out by the control point oscillation amplitude which is located at the free end of the specimen. The amplitude and frequency of bending is controlled by one-dimension laser vibration sensor OFV5000. Indirect monitoring of amplitude is carried out by microscope MBS-9. To reduce the testing frequency the weigh is fastened to the free end of the specimen.

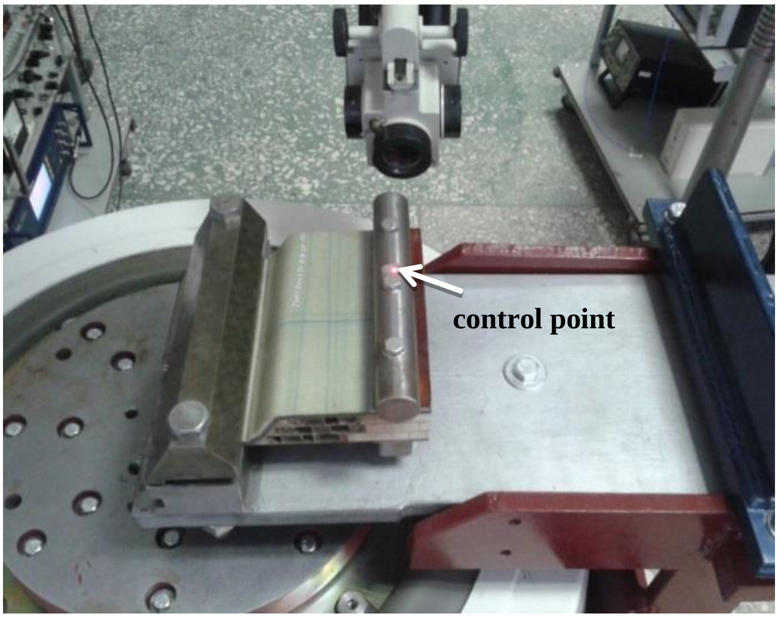
In this study, the control point oscillation amplitude of the FRPHCS specimen is 1 mm. The tests are stopped after the 10^5 cycles.

The test specimens are subjected to X-ray detection based on the Nikon Metrology XT X 450 (Figure 2), which includes a microfocus X-ray tube with a minimum focal spot diameter of 30 µm (at 80 kW) and a plane-parallel detector Perkin Elmer XRD 1621 with a pixel size of 200 µm. X-ray photography of the specimen was carried out before and after the tests in the same plane and with an equal step.

Figure 2 – Nikon Metrology XT X 450

As test specimens, two three-honeycomb-layer sandwich have been used (Figure 3a). Specimens have a carbon fiber reinforced skin and glass fiber reinforced skin. One of the ends of the panels is filled with foam. The test specimen was fixed

a)



b)

Figure 3 –Three-honeycomb-layer sandwich specimen (a); fixed specimen on the electrodynamic shaker (b)

cantilever on the electrodynamic shaker (Fig. 3b).

3. Results

Figure 4 shows the testing frequency relative change of the FRPHCS specimens during cantilever bending fatigue tests. The Table1 shows the FRPHCS specimens actual frequencies. The testing frequency, reducing of the first specimen was 3.8% and the second one is 8.65%.

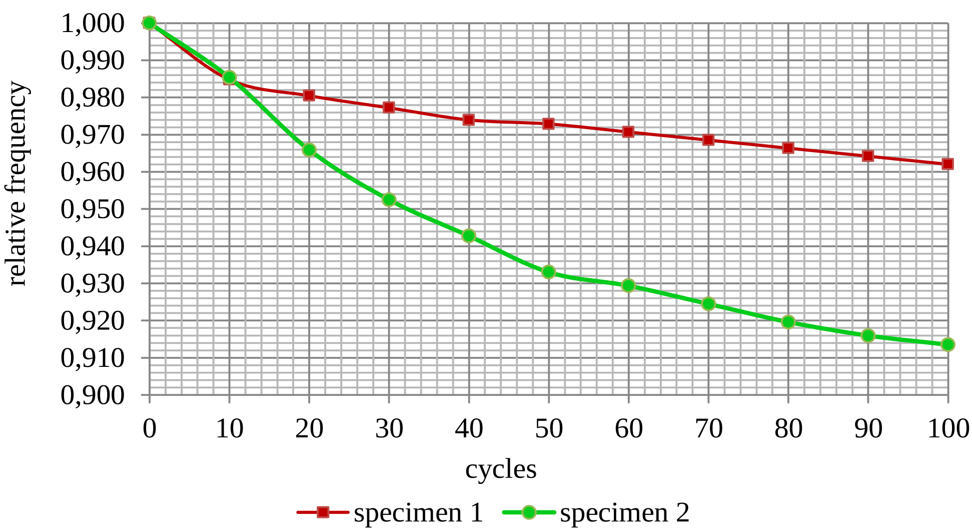


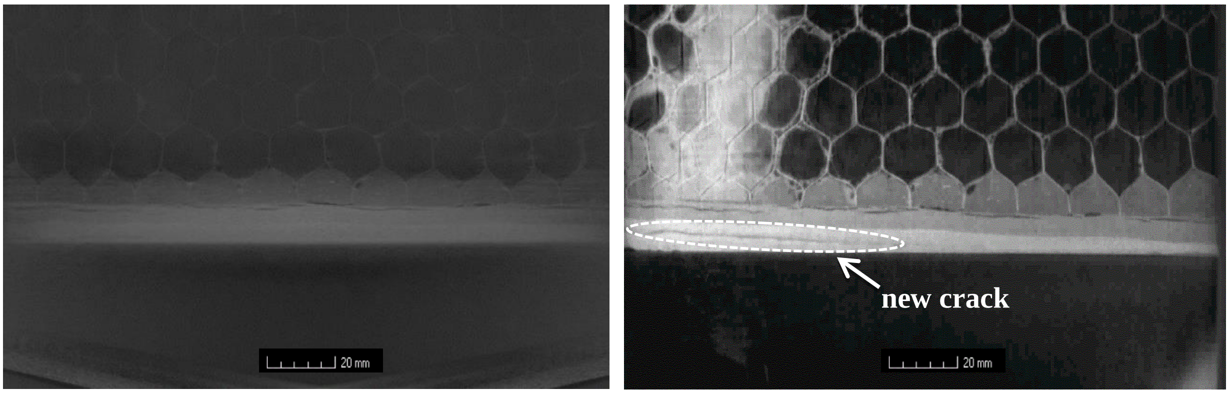
Figure 4 – Frequency relative change of the FRPHCS specimens during cantilever bending fatigue tests

Table 1 – Specimens frequencies, Hz

Cycles, 10^3		0	10	20	30	40	50	60	70	80	90	10
Specimen number	1	92,2	90,8	90,4	90,1	59,8	89,7	89,5	89,3	89,1	88,9	88,7
	2	82,1	80,9	79,3	78,2	77,4	76,6	76,3	75,9	75,5	75,2	75

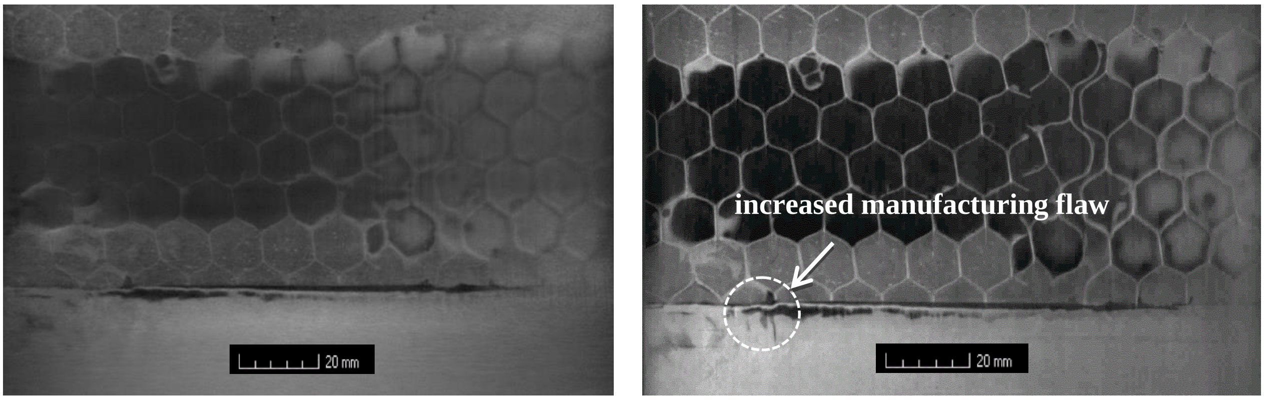
Figures 5a and b show X-ray shadowgraphs of the first specimen before and after the test. It can be seen from the figures that there is no significant fatigue failure. The size of the flaws remained at about the same level. However, a new crack formation occurs in the glass fiber reinforced shell.

When X-ray shadowgraphs of the second specimen was examined (Fig. 6a and b), it can be noted that there is no significant fatigue failure. However, a flaw size slight increase is observed after 10^5 loading cycles.



a) b)

Figure 5 – X-ray shadowgraphs of the first specimen before (a) and after (b) the test



a) b)

Figure 6 – X-ray shadowgraphs of the second specimen before (a) and after (b) the test

4. Conclusion

The assumption that manufacturing flaws due to their rapid propagation reduce the fiber reinforced polymer honeycomb composite sandwich structures durability led to the following results. No significant fatigue failure has been observed after cantilever bending fatigue tests of polymeric honeycomb sandwich panels with manufacturing flaws. The flaws sizes light increase occurs on a par with newly crack. Therefore, one cannot reliably state that manufacturing flaws propagate rapidly.

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However, in this paper, there was no comparison of the fatigue fracture of fiber reinforced polymer honeycomb composite sandwich specimen with manufacturing flaws and specimens without them.

In addition, the selected number of cycles of load may not be enough to cause significant fatigue damage.

Therefore, further investigation of this problem requires fatigue testing of fiber reinforced polymer honeycomb composite sandwich structures with manufacturing flaws and without them by more than 10^5 cycles.

5. References

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