On the Performance of FBG Sensors During a Fatigue Tests of the Carbon Composite Specimens

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Abstract: The article is focused on the experimental research of fatigue behaviour of optical FBG (Fiber Bragg Grating) sensors in comparison with strain gauges. Both surface-mounted and embedded sensors were investigated. Possible influence of embedded optical fibers on fatigue life of carbon composite specimens was tested as well.

Keywords: FBG Sensor; Fatigue Properties; 3D Structure.

1 Introduction

FBG sensors have become known and widely used, but there are still some questions that need to be answered. One of them is behavior of such sensors during the fatigue loading in comparison to traditional resistive strain gauges. Because FBG sensor is inseparable part of the optical fiber, contrary to strain gage which is composed of parts, one might assume better fatigue resistance. In [1] we have shown that FBG sensors are comparable to strain gauges in case of the low-cycle fatigue combined with high strain (up to 1.3 %). In this article an experimental research on high-cycle fatigue properties of FBG sensors is described, as well as influence of embedded optical fiber on fatigue strength of two types of carbon composite.

2 Specimens and Experimental Method

2.1 Experimental Specimens

Experimental specimens were made from carbon composite in the shape of a 700 mm long beam, with cross section 20 x 30 mm. Two composite lay-ups were used – 3D and UD. So-called 3D structure specimens were made from combination of the uniaxial fiber tows (Nipon Granoc Yarn CN-80) with over-winding created from Toray T700 high-strength carbon fibers, with the orientation to the longitudinal axis in the range from 85 to 86 degrees. For more details about the 3D structure see [2]. Second type of specimen (UD) was made from unidirectionally oriented T700 fibers. The matrix was made from the Hybtonite anhydride resin in both cases.

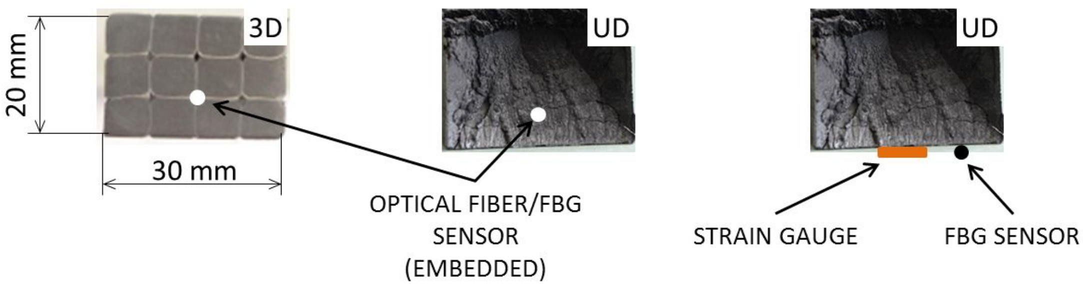


Fig. 1: Cross sections of specimens with locations of strain sensors.

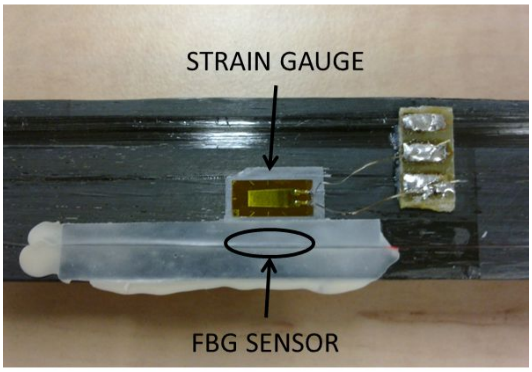


Fig. 2: Location of surface-mounted strain sensors.

Locations of particular strain sensors are shown in Fig. 1. DTG-LBL-830 FBG sensors with ORMOCER® primary coating (ø0.195 mm) were placed parallel to the longitudinal axis of specimens in three configurations:

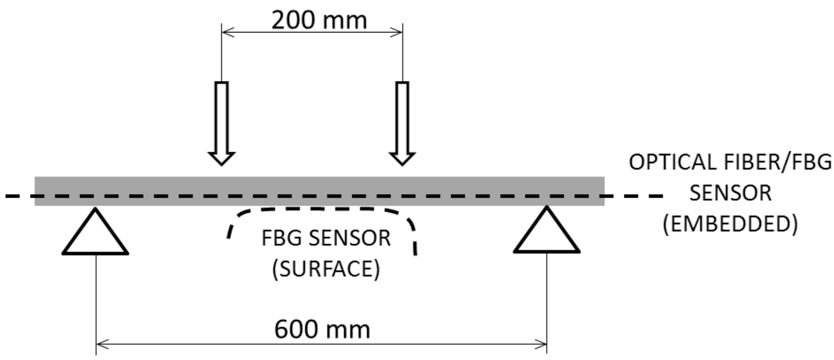
- glued on the surface in the central part of the UD specimens (see Fig. 2),
- embedded into the 3D structure specimens (into the resin areas between the cells),
- embedded between the unidirectional carbon fibers in the UD specimens.

HBM 1-LY11-6/350 strain gages were placed next to the FBG sensors in the central part of the specimen and were used for comparison. All surface-mounted sensors were glued using the HBM X60 two-component adhesive.

2.2 Experimental Equipment

Fatigue experiments were carried out using a standalone hydraulic actuator IST-PL40N with the 40 kN load cell and the displacement range up to 125 mm (see Fig. 3a). Specimens were loaded using the 4-Point Bending (4PB) loading device. The passive part has the support span of 600 mm and the loading part with the span of 200 mm (see Fig. 3b). The specimens were loaded by force controlled load with the frequency of 5 Hz and asymmetry of the loading cycle near of R = 0.1 until the final fracture.

(a) hydraulic actuator set-up



(b) specimen and sensors configuration

Fig. 3: Experimental set-up for 4PB testing.

The loading levels were derived from the preceding quasi-static 4PB tests and fatigue properties were measured in a range from 65 % to 85 % of static strength.

Loading force, actuator displacement, and signal from strain gauges and temperature of specimen surface were measured using the HBM Spider8 PC-based data acquisition device.

FBG sensors were connected to Safibra FBGuard 850 multi-channel interrogation device.

3 Experimental Results

3.1 Influence of Optical Fibers on the Carbon Composite Integrity

Fatigue S-N curves are pictured in Fig. 4 (UD specimens) and in Fig. 5 (3D specimens). Specimens with or without embedded optical fibers are compared on the basis of number of cycles to final fracture. It is shown that embedded optical fiber with outer diameter of 0.195 mm has no influence on fatigue life of both 3D and UD carbon composite specimens. Of course, the total number of specimens tested is quite low (which is because of high costs of such long term fatigue tests), but it is obvious that scatter of results is small.

3.2 Fatigue Performance of the FBG Sensors

Comparison of fatigue behavior of surface mounted strain gauges and FBG sensors and embedded FBG sensors is shown in Fig. 6. The limit sensor life was defined as achieving a 5 % (or higher) difference between the relative strain range (measured by strain gauge or FBG sensor) and the relative linear displacement range (measured on hydraulic actuator). It is obvious that surface-mounted FBG sensors can withstand higher strain range compared to strain gauges. Monolithic construction of FBG sensor is much less sensitive to fatigue than strain gauge, which is assembled from parts. Performance of embedded FBG sensors is limited not by their mechanical durability (all of them remained functional even after specimen failure) but by the integrity of surrounding resin material.

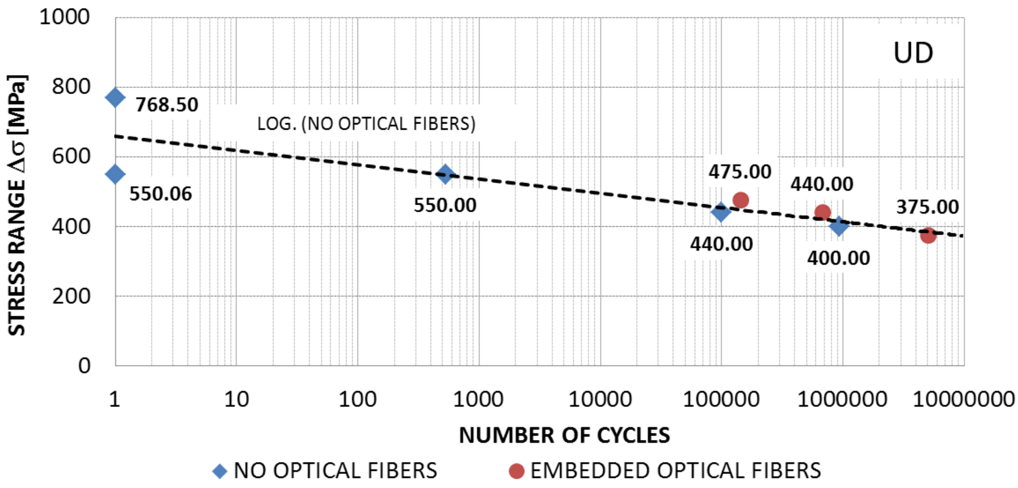


Fig. 4: Fatigue S-N curve for UD Carbon/Epoxy specimens.

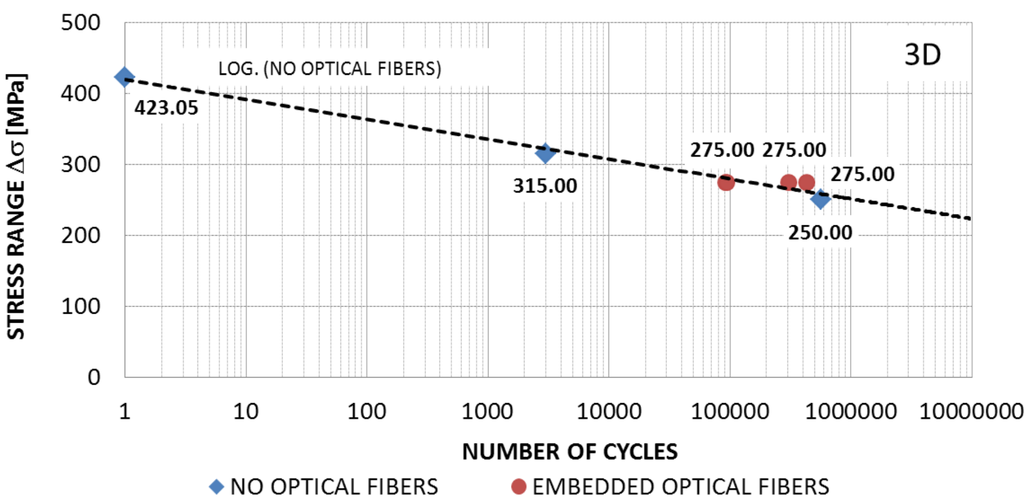


Fig. 5: Fatigue S-N curve for 3D Carbon/Epoxy specimens.

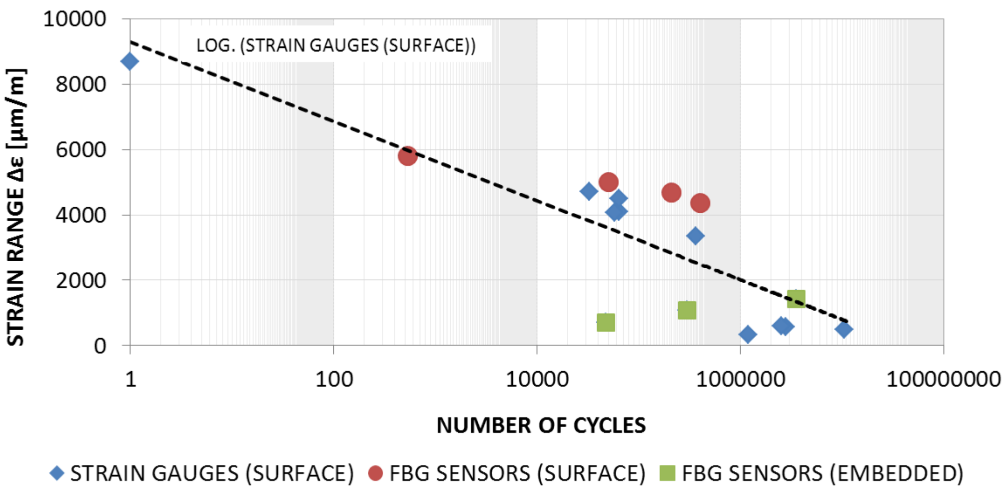


Fig. 6: Fatigue S-N curve for Carbon/Epoxy specimens with surface-mounted strain sensors.

4 Conclusion

Our experimental research showed that the tested FBG sensors have better fatigue durability than the conventional resistive foil strain gauges.

- FBG sensor with the ORMOCER® primary coating can withstand higher strain range at the same numbers of cycles, compared to standard foil strain gage.
- It was found that embedded optical fibers with ORMOCER® primary coating and outer diameter 0.195 mm has no influence on the UD and 3D Carbon/Epoxy composite and its fatigue behavior.

Acknowledgement

The authors would like to thank the Technology Agency of the Czech Republic for supporting this research with project no. TA04031450.

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