EAN 2018
56th conference on experimental stress analysis

Monitoring of Delamination Growth on the MMB Specimens using FBG Sensors and Electrical Resistance Measurement Method

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Keywords: Carbon Fibre-Reinforced Polymer (CFRP) composites, FBG sensors, MMB specimens, electrical resistance measurement.

Abstract. This paper report results of damage monitoring on carbon fiber-reinforced polymer composite specimens loaded simultaneously by mode I and mode II loading (Mixed-Mode Bending - MMB specimens). The delamination propagation during fatigue loading was monitored by the embedded FBG sensor and by electrical resistance measurement method. The measurement of the electric response was carried out in the through-thickness direction of the specimen. Presented data confirm possibility to detect delamination by mixed-mode loading using embedded FBG sensor and also using the presented electrical measurement.

Introduction

Carbon Fibre-Reinforced Polymer (CFRP) composites are widely used in the aerospace industry, automotive and civil engineering because of their outstanding ratio of high strength to low density. For a reliable long-term operation, it is necessary to develop procedures of a damage monitoring. The damage often appears inside the material without visible signs on the impacted surface unlike to conventional materials such as steel and aluminum. A delamination is one type of such a damage. It often appears after the impact loading and then it can growth during the shear loading. Ultrasonic testing is the most common inspection method to reveal such damages, but it is costly and time demanding. Other methods are also under investigation [1] such as the acoustic emission [2], the electro-magnetic interference, the monitoring using FBG (Fiber Bragg Grating) sensors [3] or the comparative vacuum monitoring.

Methods based on the electrical potential or resistance measurement [4, 5] are also intensively investigated because they have a great potential to be developed to the form of automated systems. The electrical potential/resistance measurement can be used for an impact monitoring or a delamination growth monitoring.

Extensive tests with a large number of samples must be carried out to evaluate a method for the structural health monitoring. For this reason, we decided to study two methods on the same specimens. Specimens loaded simultaneously by mode I and mode II loading (Mixed-Mode Bending - MMB specimens) were used for the evaluating purpose. Optical fibers with FBG sensors have already proven its ability for the delamination detection under a pure mode I loading (tested on Double Cantilever Beam - DCB specimens) [3]. The possibility to detect delamination crack in advance also under a mixed mode I and II was examined in this study. The second studied method was a less known method based on the electrical resistance measurement. The work by Zappalorto et al. [5] described change in measured electrical resistance on DCB specimen for delamination propagation when delamination cracks already passed the area of electrical contacts. On the contrary, in presented work, electrical resistance was measured in the area of electrical contacts to bring more details about electrical response in this area. We also used a slightly different configuration of the electrical contacts in order to avoid possible influence of the contact resistance on the measurement. So called voltage change method was used instead of the potential method [6].

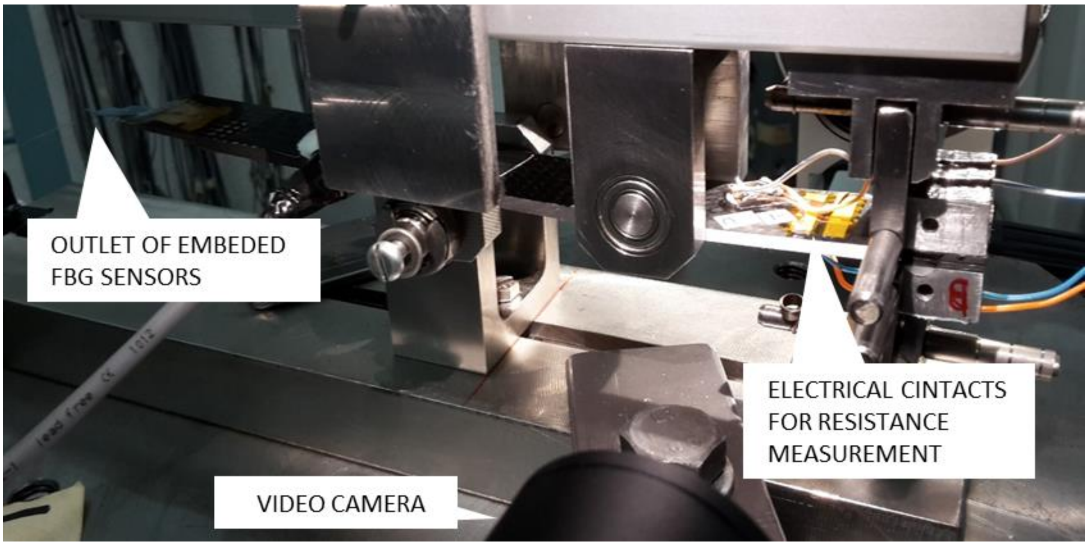


Fig. 46 Configuration of the test

Experimental Procedure

Material and Specimen Preparation. The MMB specimens were extracted from CFRP composite made of 16 layers of the material Hexply AGP 193PW/8552S RC40. The lay-up $[45/0]_{4S}$ was used. Dimensions of the specimens are 185 x 25 x 3.3 mm. A 25 mm long non-adhesive plastic foil sheet was inserted to the plate edge during manufacturing to the neutral axis to initiate the delamination growth between the 8th and 9th layer. Total number of five MMB specimens was tested.

A pair of aluminum alloy blocks with dimensions of 25 mm x 20 mm x 10 mm was bonded using R 21 MP-2 instant cyanoacrylate adhesive to the end of each specimen on the side with non-adhesive insert. These blocks are used to apply the load to the specimens (Fig. 1). Then a white paint marker was applied on the specimen edges to reveal the crack front during loading. Both edges of the specimen were marked using black lines with an interval of 25 mm.

The optical fiber with two FBG sensors was embedded also between the 8^{th} and 9^{th} layer during manufacturing. Distance of the first FBG sensor from the specimen edge was 50 mm and second FBG sensors was 75 mm from the specimen edge. The positions of the FBG sensors are shown in Fig. 47.

Electrical contacts were manufactured after the curing of the specimens. Surface of the specimens was first slightly sanded and carefully cleaned with a degreasing agent. The electrical contacts were prepared using a conductive epoxy and thin copper strips on the top and bottom surfaces of the specimens. The configuration of the electrical contacts used for electrical resistance measurement are shown in Fig. 2. Two electrical contacts served for injecting duty current of 80 mA. The voltage difference was measured on the second pair of electrodes.

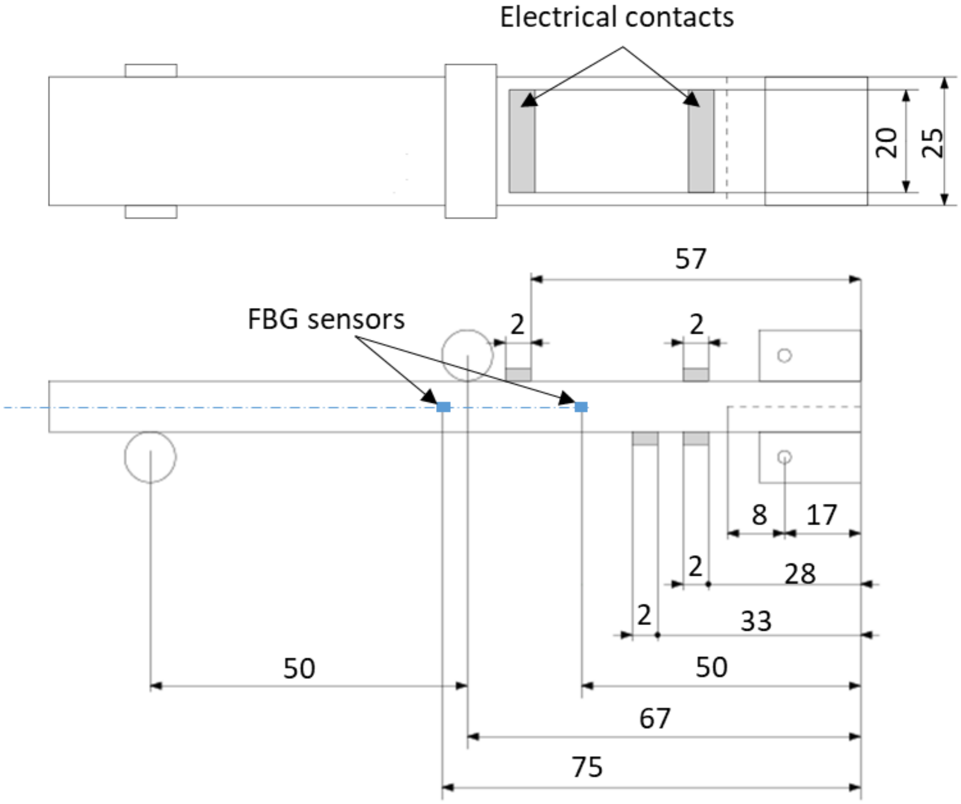


Fig. 47 Configuration of the electrical contacts and FBG sensors location

Test Configuration. The specimens were loaded by mixed-mode bending according to ASTM D6671M-06 standard. The configuration of the loading is shown in Fig. 48. MMB specimens were clamped using bonded aluminum blocks into INOVA ZUZ 50 loading machine, with a LTC-116-0.1 load cell, which has a capacity of 1 kN. The crack propagation during the loading was monitored using the cameras at 12.5 frames per second. Sinusoidal loading with displacement control set to δ_{max} = 7 mm and δ_{min} = 0.7 mm, and a frequency of 5 Hz was applied. The cycling was stopped for each measurement.

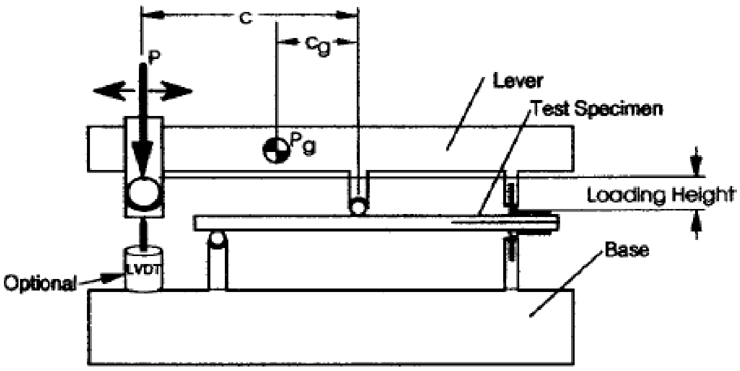


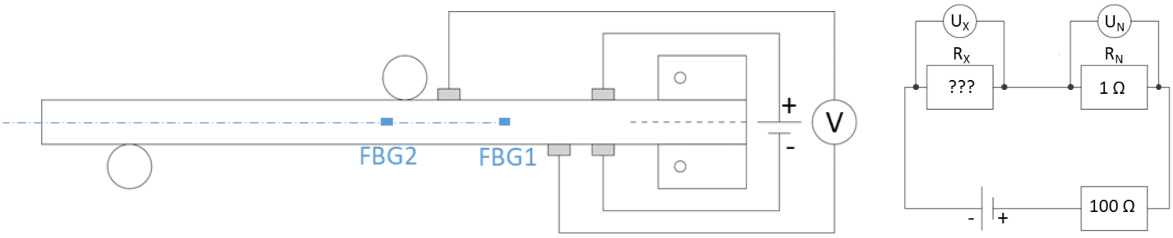
Fig. 48 MMB test configuration [7]

Measurement procedure. The Safibra FBGuard 1550 DAQ device was used to capture the signal from FBG sensors. Bragg spectra during two static load cases (loaded / unloaded specimen) were recorded after each cyclic loading block. Mechanical strain from FBG sensors versus time was also measured with data sampling frequency of 50 Hz.

Electrical resistance measurement was performed using the HP E3631A current source and two Agilent 34461A multimeters (Fig. 49). The change in electrical resistance was determined using the series comparison measurement method according to the following equation:

$$R_X = \frac{U_X}{U_N} \cdot R_N \quad (1)$$

The electrical measurement was performed also in two static load cases (loaded /unloaded).



(a) (b)

Fig. 49 Measurement procedure of the electrical resistance measurement - configuration of duty current injection and voltage change measurement on the specimen (a), schematic of the series comparison measurement method (b)

Experimental Results

FBG sensors. Experimental data from FBG sensors were evaluated using the procedure, which is described in Ref. [3]. Delamination evaluation method was based on the peak distortion detection in measured spectrum of each FBG sensor (see Fig. 5). For the number of cycles, where FBG sensor has detected damage, the actual damage length from camera was obtained. Damage detection advance was then calculated as a difference between the position of the FBG sensor (50 or 75 mm, measured from the specimen's front edge) and the value from camera reading. Results are shown in the Table 1. It can be seen that in cases of MMB02-05 the first FBG sensor (50 mm from specimen edge) was able to detect damage in composite before it reaches sensor's position, with advance in range from 0.9 to 6.9 mm. In a single case of specimen MMB01, where only small crack growth was found until the last 5000 cycles, damage was detected with more than 3 mm latency after the visual method. Second FBG sensor wasn't able to detect any damage in all cases.

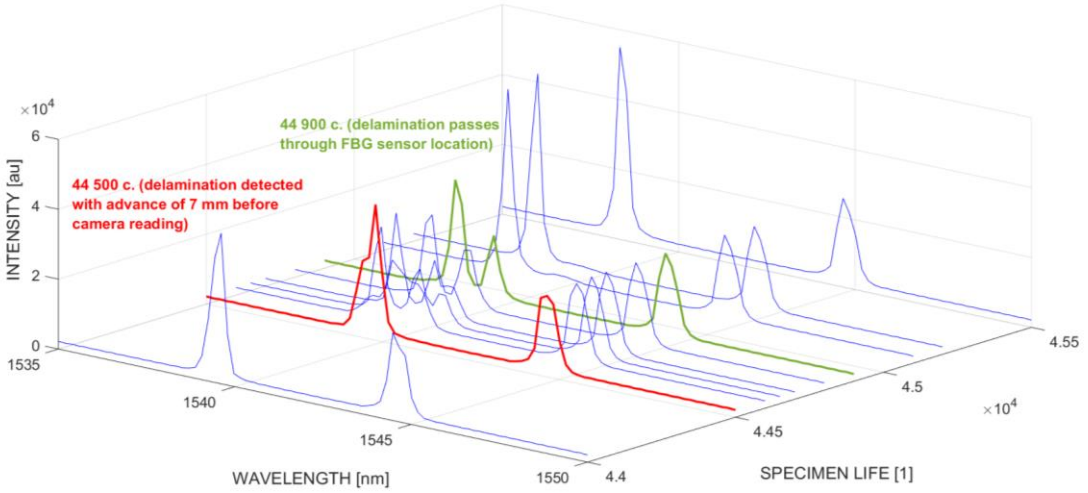


Fig. 50 Specimen MMB04 Bragg spectra reading, loaded state

Tab.1 Summary of results for specimens MMB01-05.

	distance from specimen edge [mm]	50
MMB01	damage detection advance (FBG sensor vs. camera reading) [mm], loaded / unloaded condition	-3,3
MMB02		0,9
MMB03		1,0
MMB04		6.9 / 4.6
MMB05		6.3 / 1.8

Electrical resistance change measurement. The results for electrical resistance change measurement are given in Fig. 51 and Fig. 52 for all five specimens. The Δ*R* value in the graph is measured electrical resistance normalized by its initial value R_0. Electrical resistance was measured in two states – loaded/unloaded – opened crack/closed crack. Measured values for both states are given in Fig. 51.

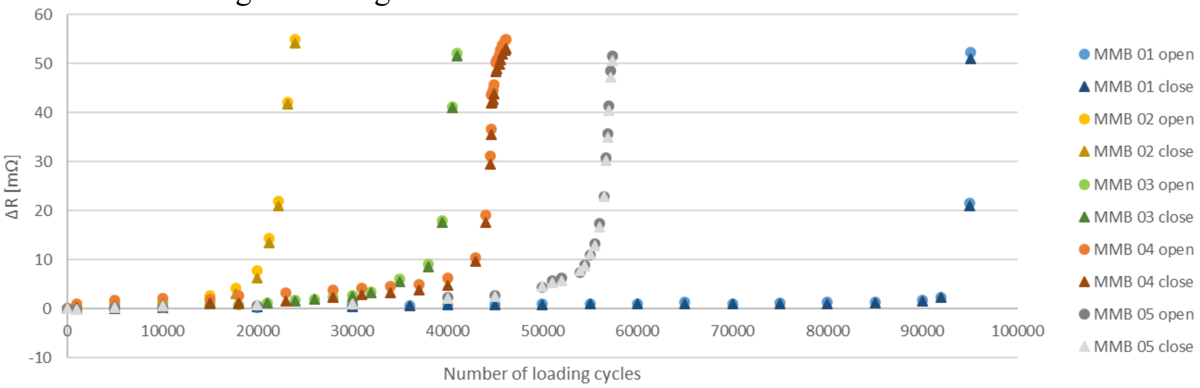


Fig. 51 Change in measured electrical resistance vs. number of cycles of all tested MMB specimens for states loaded/unloaded – opened/closed crack

The differences between measured values for loaded/unloaded state are small, the maximal difference between electrical resistance measured for open and close state was 1 mΩ for all tested specimens.

Relative change of measured electrical resistance was calculated according the following equation

$$\frac{\Delta R}{R} = \frac{R - R_0}{R_0} \cdot 100 \ \ [\%]. \qquad (2)$$

R is the actual electrical resistance and R_0 is the initial electrical resistance measured before cyclic loading of the specimen. The relative electrical resistance as a function of measured delamination length is plotted in Fig. 52. Delamination length was determined using the video-cameras. The initial length of delamination was given by the inserted 25 mm long non-adhesive plastic foil sheet.

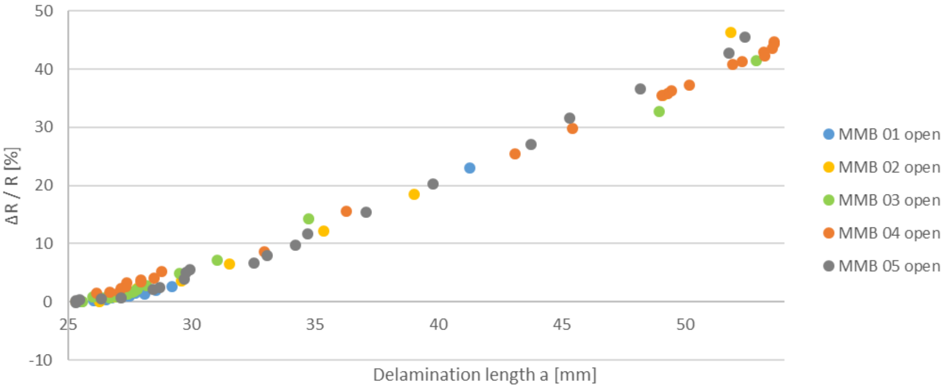


Fig. 52 Relative electrical resistance change vs. delamination length

Conclusions

In this work two methods for damage monitoring of CFRP composite were studied on the MMB specimens during fatigue loading. Possibility to delamination monitoring of such specimens was confirmed by means of the embedded FBG sensors. The electrical resistance measurement in the area of electrical contacts can be also used for delamination monitoring. Further work will be done on in the area of finite element analyses and the temperature influence evaluation.

Acknowledgement

The authors would like to thank the Technology Agency of the Czech Republic for supporting this research with project no. TE02000032 and Grant Agency of the Czech Technical University in Prague for supporting this research with grant No. SGS18/175/OHK2/3T/12.

References

[1] Gardiner, G. (2015). Structural health monitoring: NDT-integrated aerostructures enter service. CompositesWorld, http://www.compositesworld.com/articles/structural-health-monitoring-ndt-integrated-aerostructures-enter-service.

[2] L. Michalcová, M. Kadlec, Carbon/epoxy composite delamination analysis by acoustic emission method under various environmental conditions, Engineering Failure Analysis. 69 (2016) 88–96.

[3] M. Dvorak, N. Schmidova, M. Kadlec, M. Ruzicka, Use of FBG Sensors for Delamination Growth Measurement under Mode I Loading, EAN 2017 - 55th Conference on Experimental Stress Analysis 2017. (2017) 102-107.

[4] A. Todoroki, New analytical method for electric current and multiple delamination cracks for thin CFRP cross-ply laminates using equivalent electric conductance, Advanced Composite Materials, 25 (2016), 87-101, DOI:10.1080/09243046.2014.985420.

[5] M. Zappalorto, F. Panozzo, P.A. Carraro, M. Quaresimin, Electrical response of laminate with a delamination: modelling and experiments, Composite Science and Technology. 143 (2017) 31-45.

[6] L. Shen, J. Li, B.M. Liaw, F. Delale, J.H. Chung, Modeling and analysis of the electrical resistance measurement of carbon fiber polymer-matrix composites, Composite Science and Technology. 67 (2007) 2513-2520.

[7] ASTM Standard D6671M-06. Mixed Mode I-Mode II Interlaminar Fracture Toughness of Unidirectional Fiber Reinforced Polymer Matrix Composites. ASTM International, West Conshohocken, PA, 2006.