Effect of the Arrangement of Carbon Fiber Sensor in the Composite Layup in Regard to the SHM

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Abstract: This paper reports part of the complex study of the aspects, which can influence the possibility to detect impact damage of long fiber composite parts using integrated Carbon Fibre Sensors (CFSs). CFSs were prepared from carbon fiber tow and integrated in three different positions in relation to the composite lay-up. It was shown that the location of the CFS in the composite layup influences the possibility of the impact detection. The influence of the mechanical loading to the signal of the integrated CFSs is small compared to the effect of impact damage.

Keywords: carbon fibers; electrical properties; cyclic loading; composites; impact behavior.

1 Introduction

Structure Health Monitoring (SHM) of composites is a widely discussed and investigated topic. Impact damage detection of composite structures is one of the important tasks of SHM. in aerospace, automotive and other industries. One of the possible sensors for damage monitoring are Carbon Fiber Sensors (CFSs). CFSs are prepared from carbon fiber tow. It was reported that CFS can be used for strain monitoring [1–4], detection of microcracks [5,6] and also detection of impacts [7]. Cyclic loading of the CFS can also influence the measured signal [8]. In this paper part of a broader study of the effect of mechanical loading and impact loading on sensors will be presented. Possibility of impact damage detection using integrated CFSs is investigated. Influence of the arrangement of the CFS in the composite layup will be discussed (close to the top, close to the bottom of the specimen, in the middle of the lay-up). Relationship between number of loading cycles and electrical resistance change of the CFS integrated in different positions in the layup is also presented.

2 Experimental procedure

2.1 Specimen preparation

For the specimen preparation laminate lay-up [+45/0/-45/90]sym was used. Prepreg material made of woven fabric with epoxy resin HexPly 1454 GM/50%/1035 was used. The carbon fiber sensors were placed between the firstand second layer, between the fourth and fifth layer and between the seventh and eighth layer. Overview of the specimens is given in Tab. 1.

The following curing process was used: 125 °C for 90 min, 6 bar. All specimens which were investigated were manufactured using the peel ply – the thickness of the specimens was 1.3 mm.

2.2 Carbon Fiber Sensors (CFSs)

The CFSs used in the presented investigation were manufactured from the carbon fiber tow type PAN, producer Toray, label T300 1000-50A. CFSs were prepared in the length of 70 mm. The preparation of CFS has been described in [1], and the same procedure was used here. A nickel electrolyte coating was applied to the ends of each roving. Then electrical contacts made of thin copper wire were soldered to the ends.

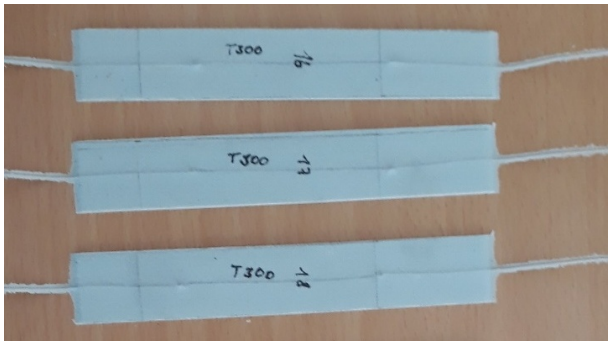

Fig. 1: Specimens with integrated CFSs.

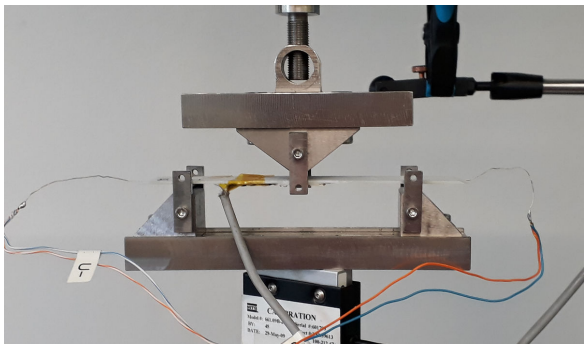

Fig. 2: Configuration of 3-point-bending test.

Tab. 1: Overview of the manufactured specimens.

Speciment Nr.	Placing of CFS between layers		Impact energy
30	1	2	2 J
31	1	2	2 J
32	1	2	2 × 2 J (first impact outside the area of the CFS)
33	1	2	2 × 2 J (first impact outside the area of the CFS)
34	4	5	Not impacted
35	4	5	Not impacted
36	4	5	2 × 2 J (first impact outside the area of the CFS)
37	4	5	2 × 2 J (first impact outside the area of the CFS)
16	7	8	2 J
17	7	8	2 J
18	7	8	2 J

2.3 Loading and damage preparation

All specimens were exposed to cyclic flexural loading. The configuration of the three-point bending (3PB) test was chosen in order to prevent damage in the area of electrical contacts. Hydraulic testing system MTS Mini Bionix (MTS, USA) was used for the load controlled procedure. The configuration of the 3PB test is shown in Fig. 2. Specimens were loaded with a compressive force in the range 1.5–15 N at a frequency of 0.1 Hz. The maximal compressive force 15 N was determined so that the longitudinal strain in the middle of the specimen on the bottom surface was 3,200 μm/m. The mechanical strain in the area of electrical contacts is then 960 μm/m. The applied strain was determined using strain gauge on one of the specimens. Total 200 load cycles were applied for each specimen to investigate the change of el. resistance depending on the mechanical loading before impact loading.

Drop weight impact test was used to test the ability of the CFSs for impact damage detection. Configuration of the impact test is depicted in Fig. 3. For the impact test, we used hemispherical impactor with the diameter of 16 mm with the weight of 410 g. The height for the drop impact test was 0.5 m, so the impact energy was 2 J. After the 2 J impact, there were no signs of damage on the impacted side of the specimen (mold side of the specimen was impacted). There were signs of damage on the opposite side observed on some specimens.

2.4 Electrical resistance measurements

Measurements of the changes in electrical resistance were performed using 344401A Agilent multimeter. The 4-wire ohms method was used in order to eliminate test lead resistances and contact resistances. The relative change in the electrical resistance of each specimen was determined according to Eq. 1. The value was used in the subsequent evaluation, and is marked $\frac{\Delta R}{R}$.

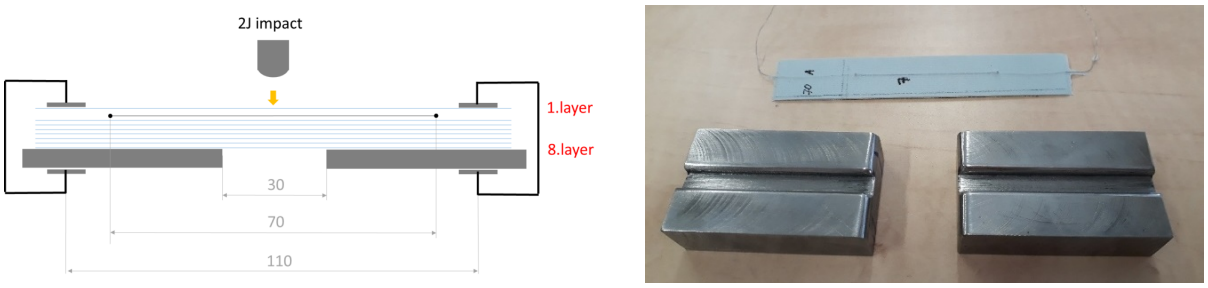

Fig. 3: Configuration of the drop weight impact test.

$$Relative\ change\ in\ electrical\ resistance = \frac{\Delta R}{R}\,[\%] = \frac{R - R_0}{R_0} \cdot 100. \tag{1}$$

3 Results and discussion

For the purposes of SHM and impact damage detection the following two factors are of great interest:

- the change in the electrical resistivity of the CFS due to the mechanical loading,
- the change in the electrical resistivity of the CFS due to impact loading.

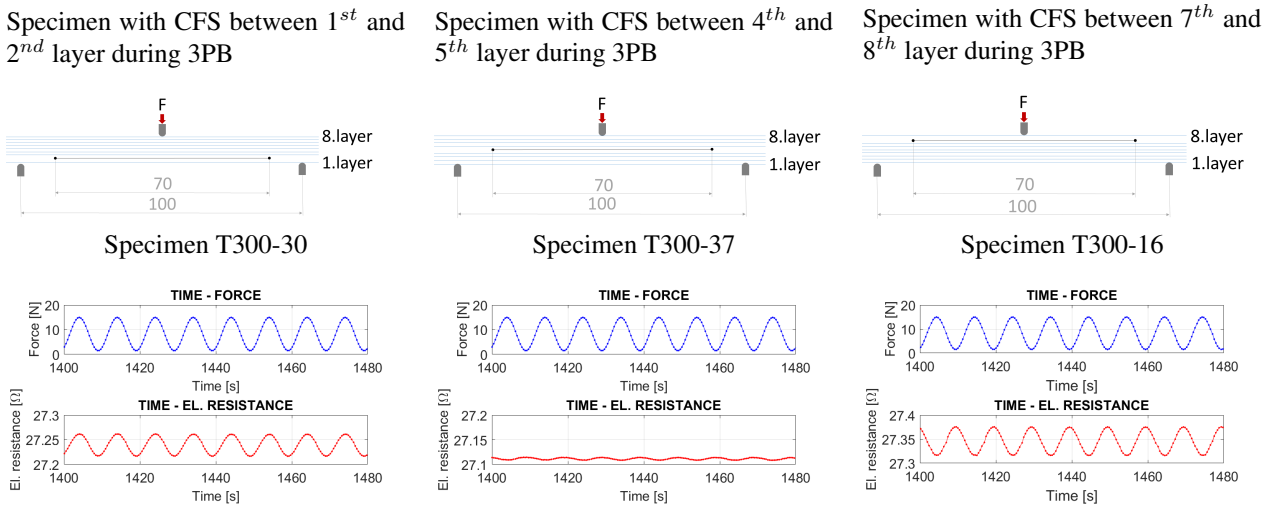

Fig. 4: Configuration of the 3PB test and measured signal from the integrated CFS.

Smooth dependence of the measured relative resistance of the fiber on the loading was measured, see Fig. 4. In order to determine the influence of the number of cycles to the change of electrical resistance the range value of the electrical resistance for the first and the 200th cycle of the mechanical loading was calculated. The results are shown in Fig. 5.

The influence of the placing CFS in different positions regarding the lay-up is shown on measured data in Fig. 4. For compressive loading the change in electrical resistivity is opposite to the change for tension loading. Small changes in electrical resistivity due to the mechanical loading was observed also for the sensors, which were placed in the middle of the lay-up.

The influence of impact loading to the measured electrical resistivity is shown in Fig. 6. In Fig. 5 is given peak-to peak relative electrical resistance change of measured signal in first and 200th cycle. It can be seen that the influence of number of cycles to measured electrical resistance is relatively small, compared to change in electrical resistance caused by the mechanical loading. According to measured data the sensors show stable behavior regarding the mechanical loading. In Fig. 6 is compared relative electrical resistance measured for maximal mechanical strain befor impact during 200th cycle and relative electrical resistance measured after impact. It can be seen that the change in measured el. resistance caused by the impact is much higher than the change in el. resistance caused by the mechanical loading. The measured change in electrical resistance

between specimens with sensors placed in the same configurations differs a little bit. A big difference in measured electrical resistance change can be seen for specimen 33 (CFS placed between first and second layer same as for specimens 30,31,32). There was probably problem during the impact loading. More experiments are needed to clarify this behavior.

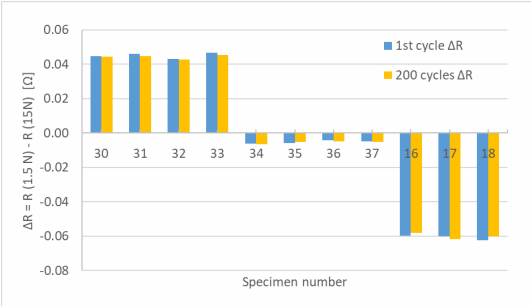

Fig. 5: Influence of the cyclic loading on the measured signal from CFSs.

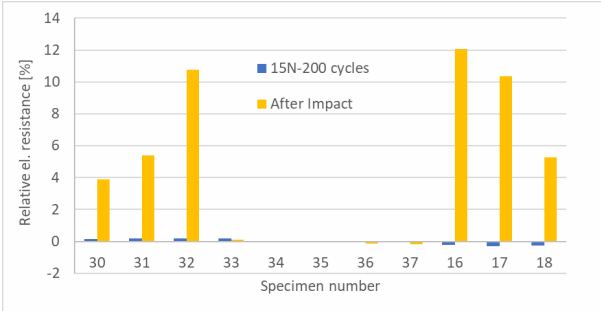

Fig. 6: Influence of the cyclic loading and impact damage on the measured el. resistance of the CFSs.

4 Conclusion

All tested CFSs show consistent dependency between applied load and measured electrical resistance. Investigated type of fiber tow used for integrated CFS shows stable behavior regarding cyclic loading. The influence of the mechanical loading to the change of electrical resistance of the integrated CFS is small compared to the effect of impact damage. For impact damage detection, it seems promising to place the CFS sensors close to the top or bottom of the composite lay-up.

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