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Sensing damage in CFRP composite beam by electrical resistance measurement

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Abstract

This paper presents a study on electrical resistance (ER) measurement on unidirectional CFRP composite beam during cyclic flexural loading. ER measurement was conducted in the transverse direction to the fiber direction. Three measuring configuration, each in two copies were measured during shutdowns of loading. One measuring point was monitored by ER measurement also during cyclic loading. Artificial damage was created in a form of a cut in the middle of a specimen so that the cross section of the specimen was reduced. According to performed measurements further tests on possibility of damage detection during cyclic flexural loading by measuring ER in transversal direction must be performed. Possibility of fiber crack detection by presented type of measurement was confirmed.

Introduction

Carbon Fiber Reinforced Polymer (CFRP) composites are nowadays widely used for structural parts in aircraft and automotive industry, where high level of safety has to be ensured.

During the service composites are frequently exhibited to the dynamic loading. Damage detection can be conducted using NDT methods such as ultrasound or X-ray inspection, which is expensive and time-demanding. New approaches, which would enable also in-situ monitoring are being seeked. One of the possible method of Structure Health Monitoring (SHM) is electrical resistance measurement.

This method is based on a fact, that carbon fibers are electrically conductive but the matrix used for manufacturing CFRP is not. Carbon fibers in CFRP composite touch each other so that the material is conductive in all three directions. The conductivity changes depending on deformation and damage of the material. In previous work [1, 2] it was confirmed that it is possible to monitor damage during cyclic tension loading by electrical resistance measurement in the longitudinal and through-thickness direction. Damage was also monitored by this method during cyclic bending in both above mentioned directions.

So far no measurements on CFRP composite during cyclic bending were conducted in transversal direction (Fig. 1). Change in electrical resistance in transversal resistance might be also valuable indicator of damage in beams and other parts, where only some surfaces are accessible. This paper presents first set of measured data.

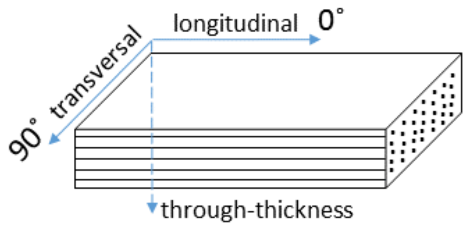

Fig. 1 Possible direction of resistance measurement on CFRP.

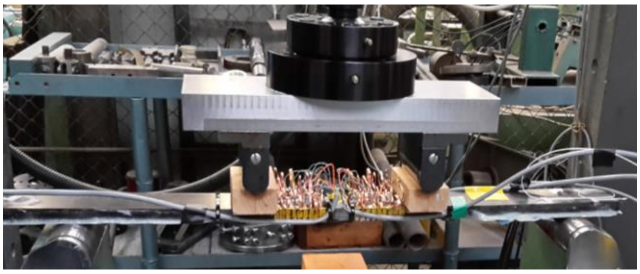

Fig. 2 Specimen during loading.

Experimental Methods

Materials. The specimen used for the experiment was prepared from the unidirectional carbon/epoxy prepreg sheets. The composite was processed by prepreg moulding in an autoclave (90 min at 125˚C and -80 kPa). Dimensions of the specimen are 800x60x13 mm. Electrical contacts were made using conductive epoxy resin and thin copper strips. Before preparing contacts specimen was sanded and cleaned with degreasing agent.

Measurement configuration. Configuration of the four-point bending tests is shown in Fig. 2 and Fig 3. A hydraulic testing system IST PL40N was used for four-point bending test of the specimen. Three types of electrode configurations were tested. Configuration of measuring points is shown in **Chyba! Nenašiel sa žiaden zdroj odkazov.**. To perform more accurate measurement, four-wire series comparison measuring method is used. Each measuring configuration (A, B, C) consists of two voltage contacts, which are between current contacts manufactured on the opposite sites of the beam. Each measuring configuration was prepared in two copies, so there were six measuring points. Measuring point was prepared in a such a way, that on one side of the specimen there was the voltage contact positioned closest to the top edge (depicted on the Fig. 4) and on the opposite side there was the voltage contact positioned closest to the bottom edge of the specimen. HP E3631A Current source was used for supply of 80 mA. Agilent 34461A device was used for voltage measurement.

Cyclic loading. Cyclic sinusoidal loading was applied to the specimen with the mean value of 2 kN and amplitude of 1 kN. This corresponds to the nominal value of the maximum stress on the sample surface 178 MPa. Before loading and during stops (shutdowns) between cyclic loading electrical resistance was measured at each measuring point under loading of 1, 2 and 3 kN. Besides this, electrical resistance at measuring point C2 was measured also during the cyclic loading. The temperature of the specimen was also measured during the loading using Pt-1000 sensor mounted to the top surface of the specimen.

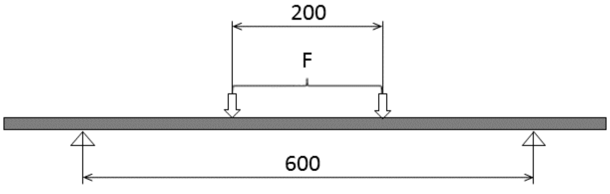

Fig. 3 Configuration during loading of the specimen.

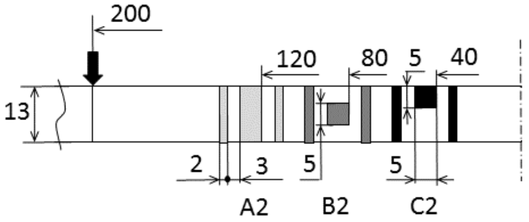

Fig. 4 Configuration of measuring points.

Results and discussion

Measuring during shutdowns. A change in relative resistance measured during stops between loading blocks for all measuring points is shown in picture Fig. 5**Chyba! Nenašiel sa žiaden zdroj odkazov.**. Relative resistance change is defined according to equation Eq.1.

$$\frac{\Delta R}{R_0} = \frac{R - R_0}{R_0} \tag{1}$$

In this formula R_0 is electrical resistance measured at load level 1 kN. It can be seen that measuring points C1 and C2 exhibit the biggest relative resistance change during loading. Because of this, measuring point C2 was chosen for measuring also during cyclic loading. When we compare measured data at the same measuring configurations, we can see that measuring points on the opposite halves of the beam have inverse dependence on loading. It is obvious that trend is similar for all measuring configurations on one side (A1, B1, C1 vs. A2, B2, C2). So we suppose that it is not caused by the method of preparing electrical contacts or measuring configuration. On the base of observed behavior of the beam there is an assumption, that it is caused by imperfection in the specimen itself. This hypothesis needs to be verified by further measurement.

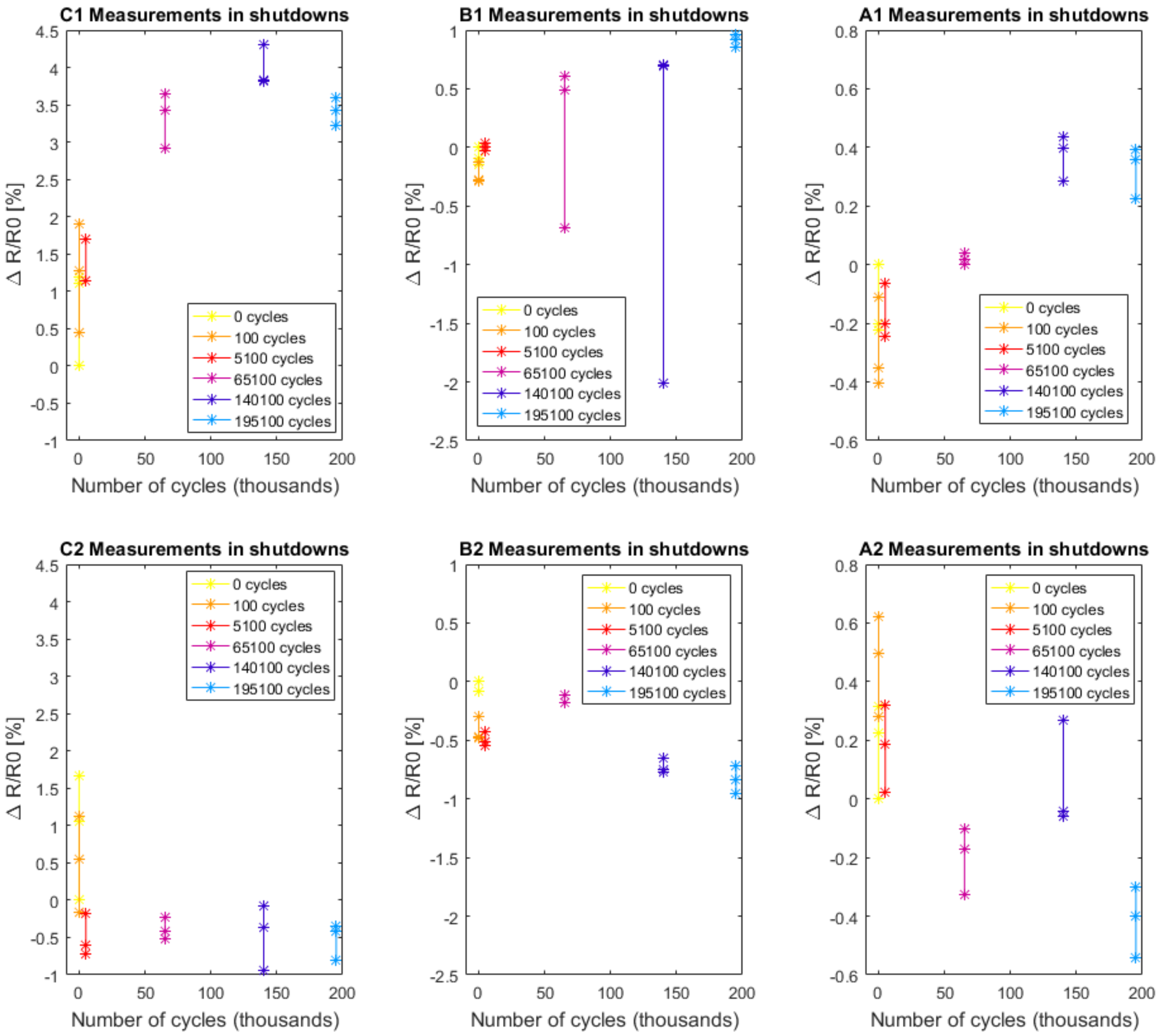

Fig. 5 Relative resistance change measured during stops between loading blocks for all measuring points.

After 195100 cycles artificial damage was created in a form of a cut in the middle of a specimen so that the cross section was reduced to 57x13 mm. So the depth of the cut was 3 mm and the width of the cut was 2 mm. After this weakening of the beam, measured electrical resistance significantly increased by more than 20 % in the measured point C2. Change in electrical resistance was observed in all measured points (Fig. 6). From this it can be drawn, that interruption of carbon fibers can be detected also by measurement in transversal direction.

Cyclic loading. Measured data at measuring point C2 are shown in figure Fig. 7. During first 2000 cycles we could observe significant change in measured electrical resistance, afterwards slight decreasing of electrical resistance can be observed.

In figure Fig. 7 temperature measured during cyclic loading is also depicted. On measured data during loading cycles 5100-15100 and 17820-195600 cycles it can be seen that at the same temperature of the specimen electrical resistance decreased. So the influence of the temperature on the measured resistance change doesn't need to be considered.

In figure Fig. 9 displacement under the load site is depicted. A small change in the value of displacement can be observed after the lowering of the specimen's cross section at 195100 cycles.

During the following loading cycles we can observe that measured resistance is decreasing, but it is not approaching its previous values, see data in figure Fig. 8.

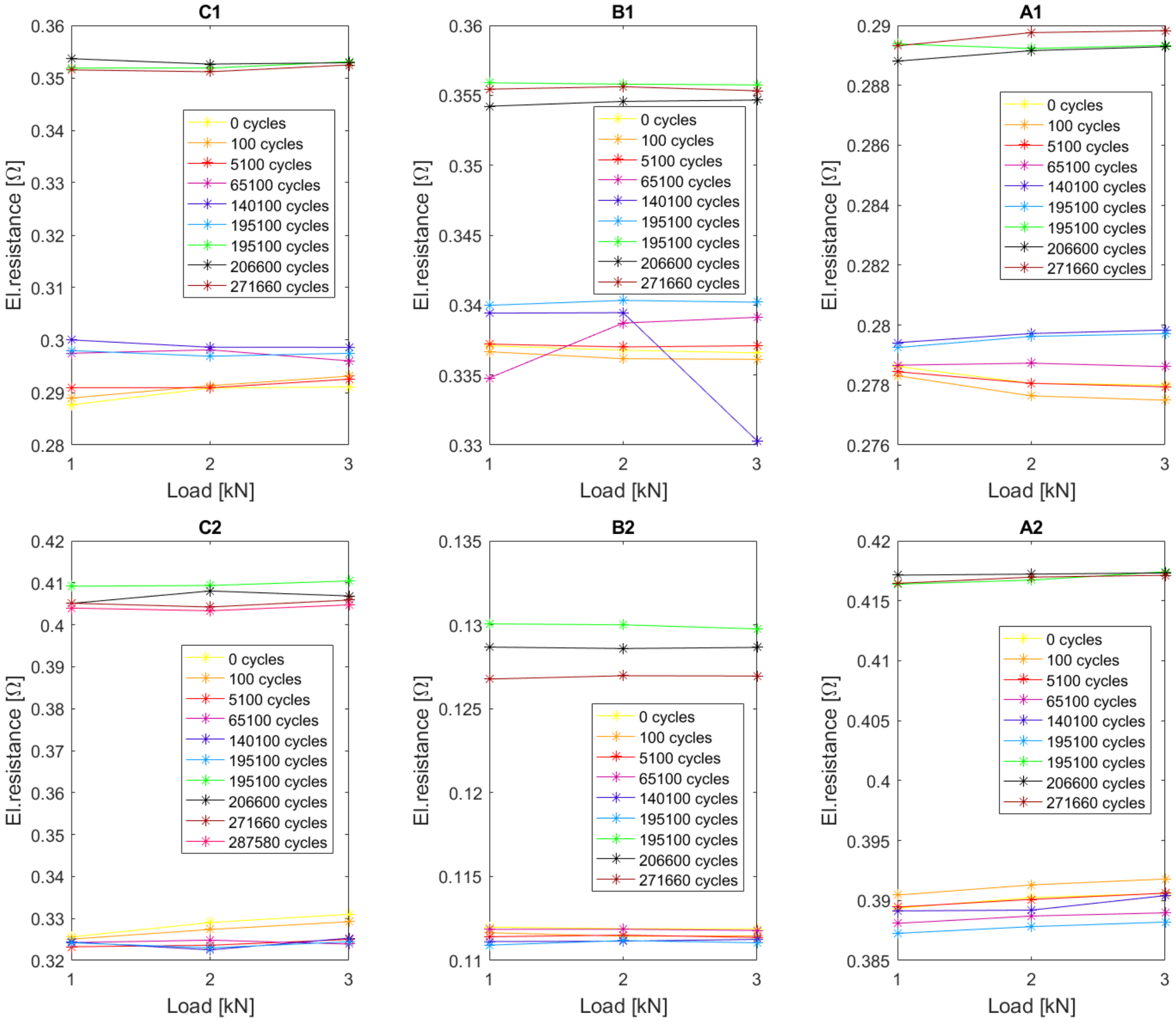

Fig. 6 Measured electrical resistance during stops between loading blogs before and after creating damage on the specimen.

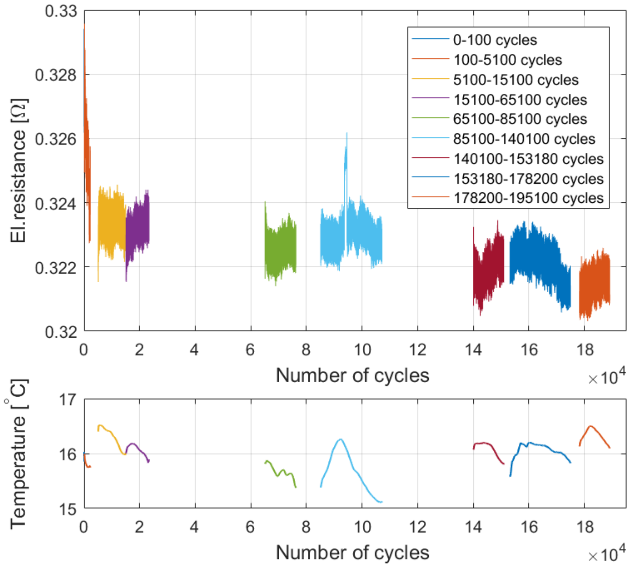

Fig. 7 Electrical resistance measured during cyclic loading at measuring point C2 and measured temperature of the specimen.

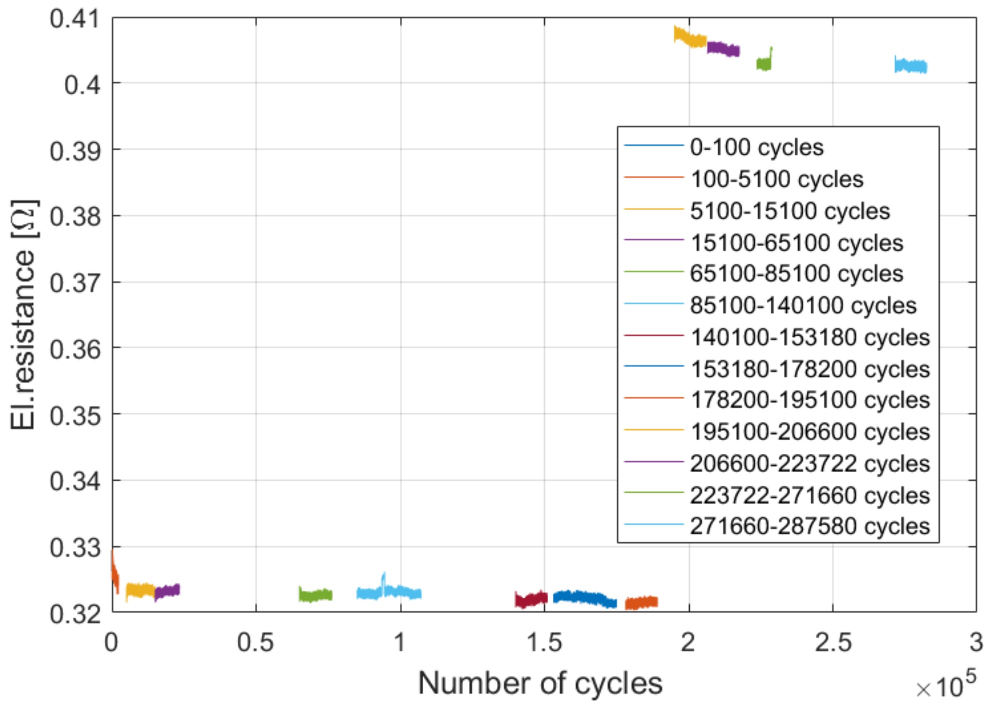

Fig. 8 Electrical resistance measured during cyclic loading at measuring point C2 before and after creating damage on the specimen.

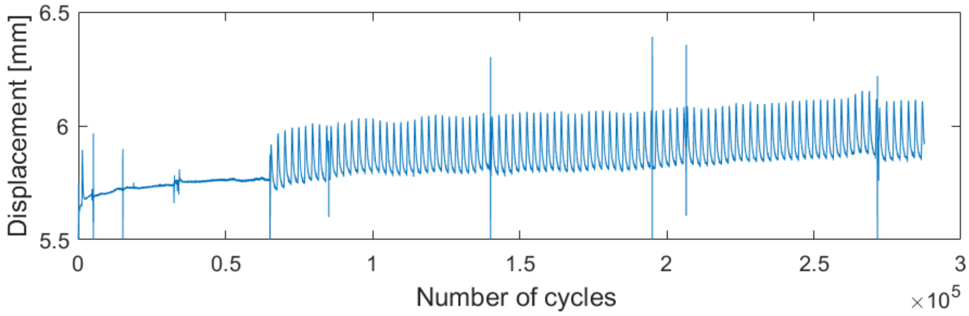

Fig. 9 Mean value of displacement (hydraulic actuator)during cyclic loading.

Conclusions

The performed study suggests that the best measuring configuration for transversal electrical resistance measurement is type C, because the average relative change in measured resistance before and after loading was the most significant. Regarding possibility of damage detection during cyclic flexural loading, so far no definite conclusions can be drawn. Experimental data measured during shutdowns at the same measuring configurations exhibit the opposite trend. On the base of observed behavior of the beam there is an assumption, that it is caused by imperfection in the specimen itself. By measuring electrical resistance during cyclic loading decreasing of electrical resistance especially at the beginning of the loading was observed. Artificial damage confirmed possibility to detect interrupting of carbon fibers in unidirectional composite also by measuring in transversal direction.

Acknowledgement

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