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Bending Analysis of GFRP Composite Plate with a Hole Using Carbon Fiber Sensors

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Abstract: Glass fiber composite vessels are used for underground water storage and surface water treatment. Especially during the installation of such vessels damage occurs. This paper investigates possibility of utilization of integrated Carbon Fiber Sensors (CFSs) for Structural Health Monitoring (SHM) of such glass fiber composite vessels. In this study, a flexural analysis of a glass fibre-reinforced composite panel with a central hole was performed. The strain monitoring using CFSs near the hole was done. The obtained results confirm the possibility of using CFSs for SHM of GFRP vessels.

Keywords: Structural Health Monitoring; Carbon Fiber Sensor; Glass Fiber Composite vessel.

1 Introduction

A system of drainage channels and retention tanks is usually used for the collection and eventual subsequent treatment of surface stormwater from large, paved areas, allowing the water management cycle to be implemented from water capture, through treatment to final retention or recycling.

The cylindrical glass fiber composite wound vessels of interest are used to collect these waters and e.g. separate the oil from water. Vessels of various volumes are placed usually underground vertically or horizontally. Increased loads and stresses on the vessel walls, particularly localized loads, may occur during the placement of the vessels in the backfill and during actual operation, which may cause damage to the integrity of the vessel. It would therefore be desirable to develop a system for the possible indication of such local stresses, or of disruption of the vessel composite structure itself.

One of the critical areas of the vessel is the area around the mouth of the GFRP vessel. Sensors made of carbon fiber tow (Carbon Fiber Sensors - CFSs) integrated during manufacturing process can be used for structural monitoring of the vessel.

An initial measurement using CFSs were performed during bending test of the plate type specimen with a central hole.

2 Methods

2.1 Specimen Preparation

The specimens were manufactured using an automated filament winding procedure of glass fibre tows with polyester resin. The length of the specimen was 400 mm, width was 200 mm and thickness 9.76 mm. The central hole had a diameter of 80 mm. The specimens were cut out from a wound vessel. Total three specimens were manufactured for the measurement using CFS.

The CFSs were manufactured according to procedure published in [1] in a length of 80 mm. The CFSs were attached to the surface of the specimen after manufacturing and covered with a covering layer, see Fig. 1.

The three CFSs were placed along the longitudinal axes of the specimen according to Fig.1. The CFS sensors were positioned in such a way, that one sensor was installed closest to the hole. The second sensor was placed in the distance of 20 mm from the hole and the third sensor was installed in the distance of 40 mm from the hole. Total three CFSs were installed on each of two specimens 1 and 2. On specimen 3, 6 CFSs were installed, each three symmetrically on both sides of the hole (sensor group A, sensor group B).

Along with the CFSs was installed also optical fiber on each of the specimens. The optical fiber was used as a Distributed Fiber Optic Sensing (DFOS) system. Results from DFOS system will be described only briefly in this paper. More details can be found in Blaha et al. [2].

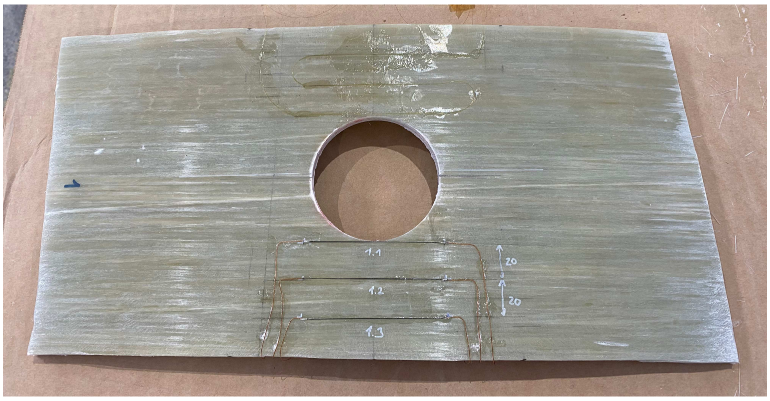
2.2 Sensors for Monitoring

The CFSs in this application are used for strain measurement, but they are meant to be used also for crack and impact monitoring in future as published in [1] and [3]. The change in measured electrical resistance of CFSs is recorded during loading. The change of measured electrical resistance is proportional to the extension of the sensor. Each sensor gives an integral information about its extension, which could be used for calculation of average strain along the sensor.

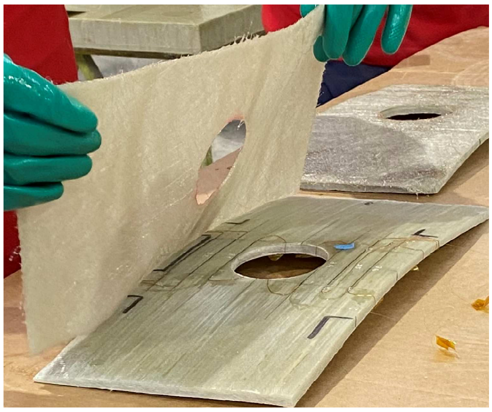
Measurements of the changes in electrical resistance change were performed using a Quantumx MX 1615B strain gauge amplifier, manufactured by Hottinger Baldwin Messtechnik GmbH. The output of the Wheatstone bridge was used to determine the changes in the electrical resistance of the measured carbon fiber sensors.

The change of measured electrical resistance of each CF sensor was converted to average mechanical strain using formula given in [3]. The strain sensitivity k of a CFS equal to 1.75 was used.

The second type of sensor, the DFOS sensors, enables measuring strain with high spatial resolution. It is used as a reference method. The method is based on the principle of Rayleigh scattering. Luna Odisi 6100 series was used for data recording from DFOS sensor.



a) prepared sample with optic and carbon fiber sensors installed on the plate



b) installation of covering glass mat layer on top of the sample

Fig. 1: Preparation of the experimental samples

2.3 Experimental Procedure

The bending test of the GFRP plate with a central hole was performed in the configuration depicted in Fig. 1. On the Heckert FPZ100/1 universal testing machine. The configuration of the performed 4-point bending test was as follows. The distance between lower supports was 320 mm, the distance between upper supports was 120 mm. The experimental procedure comprises of 5 loading cycles. The loading force varied from 0 to 1 kN.

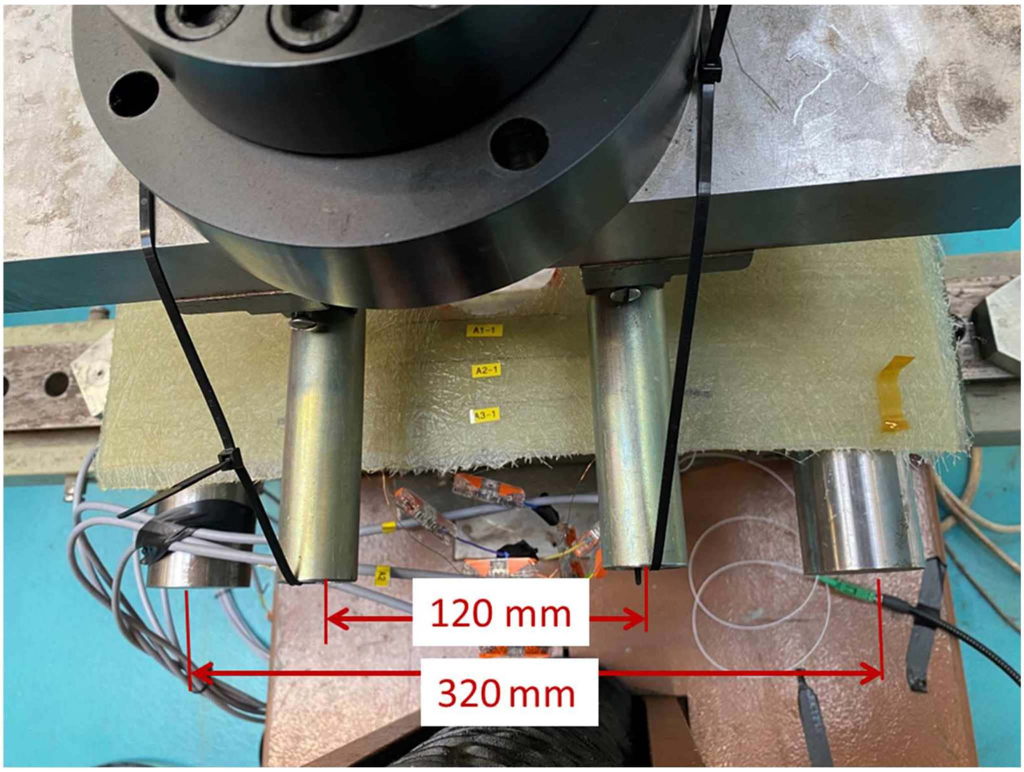


Fig. 2: Configuration of the bending test of the specimen with a central hole and integrated Carbon Fiber Sensors.

2.4 Analysis using Finite Element Method (FEM)

Numerical simulation of the 4PB text was performed using Abaqus software. The model of the specimen was prepared as a shell model according to specification of the specimens. The material properties were set according to used material (glass fibers, polyester resin). The data of mechanical strain was read from the FE model along the path, where sensors were placed, see Fig. 3.

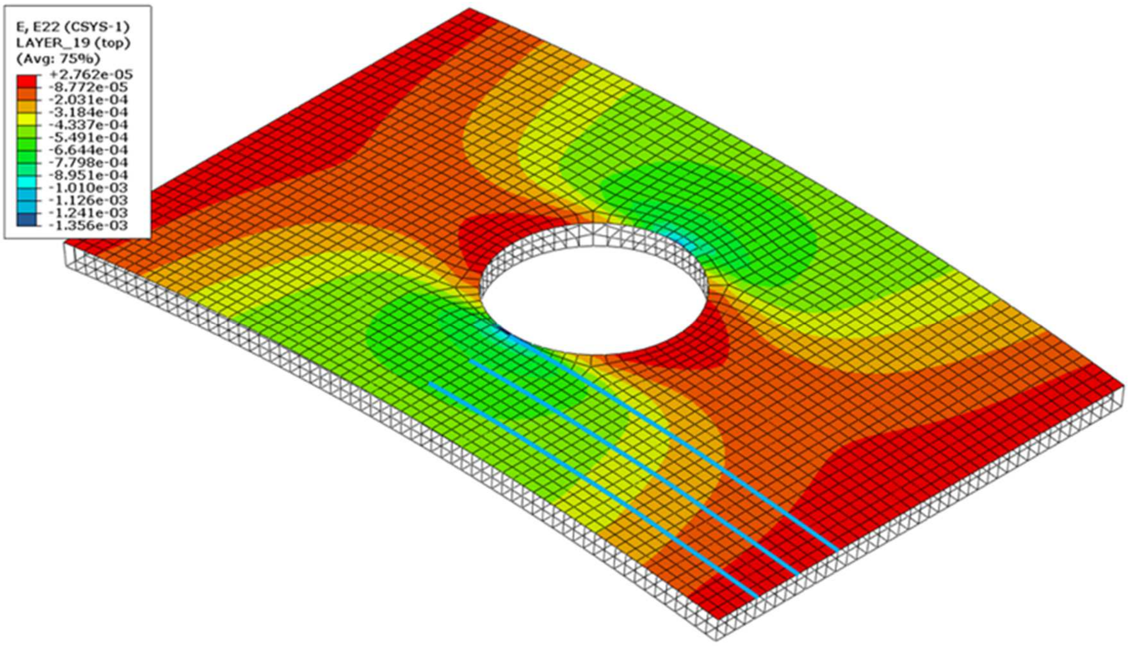


Fig. 3: Results of FE simulation of 4PB test.

3 Results and Discussion

The loading comprises of five loading cycles, measured data are given in Fig. 4.

Specimen 3 was loaded two times of 5 cycles, in order to measure DFOS sensors on both sides of the specimens, so for this specimen data for loading cycles 6 to 10 will be presented.

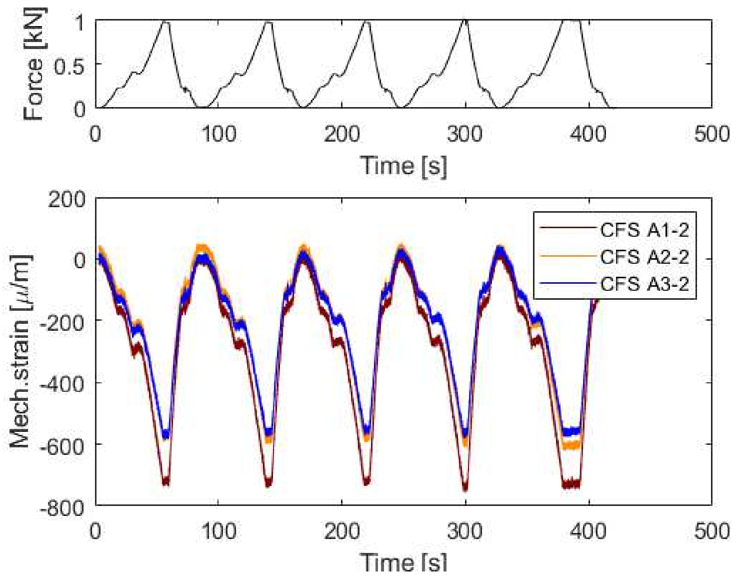
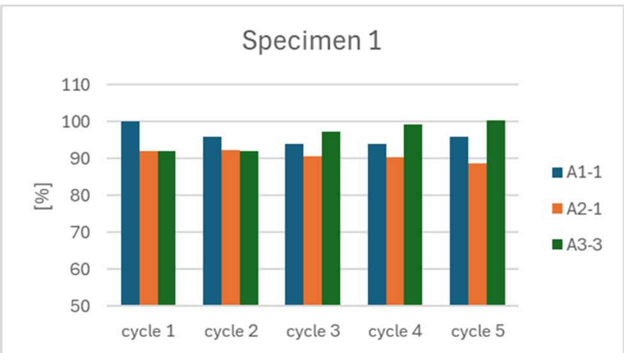
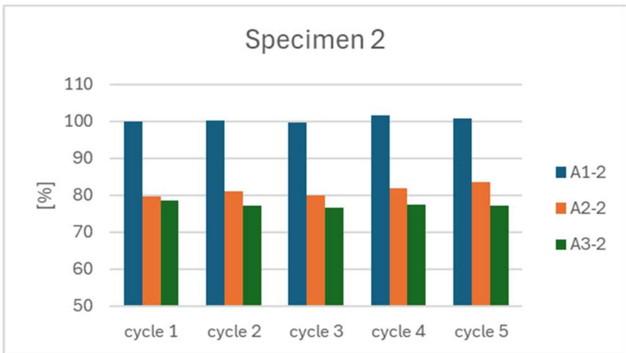


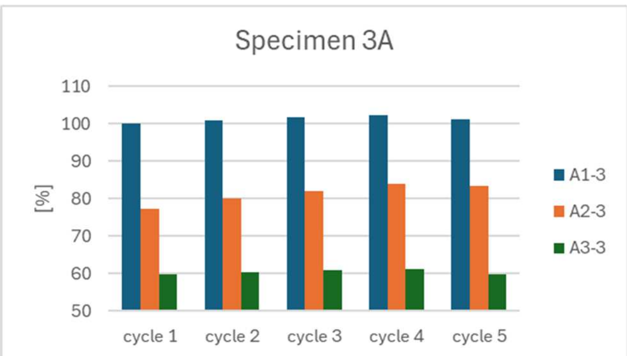
Fig. 4: Record of measured strain using CF sensors and applied force during 5 cycles of loading of specimen 2.



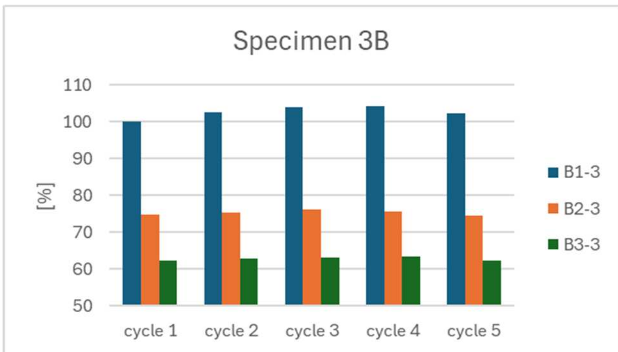
a) percentage change of measured strain on specimen 1



b) percentage change of measured strain on specimen 2



c) percentage change of measured strain on specimen 3 – group of sensors A



d) percentage change of measured strain on specimen 3 – group of sensors B

Fig. 5: Percentage change of measured strain using CF sensors on different specimens on different locations during five loading cycles.

Tab. 1: Comparison of measured data from CF and DFOS sensors and FEM simulation.

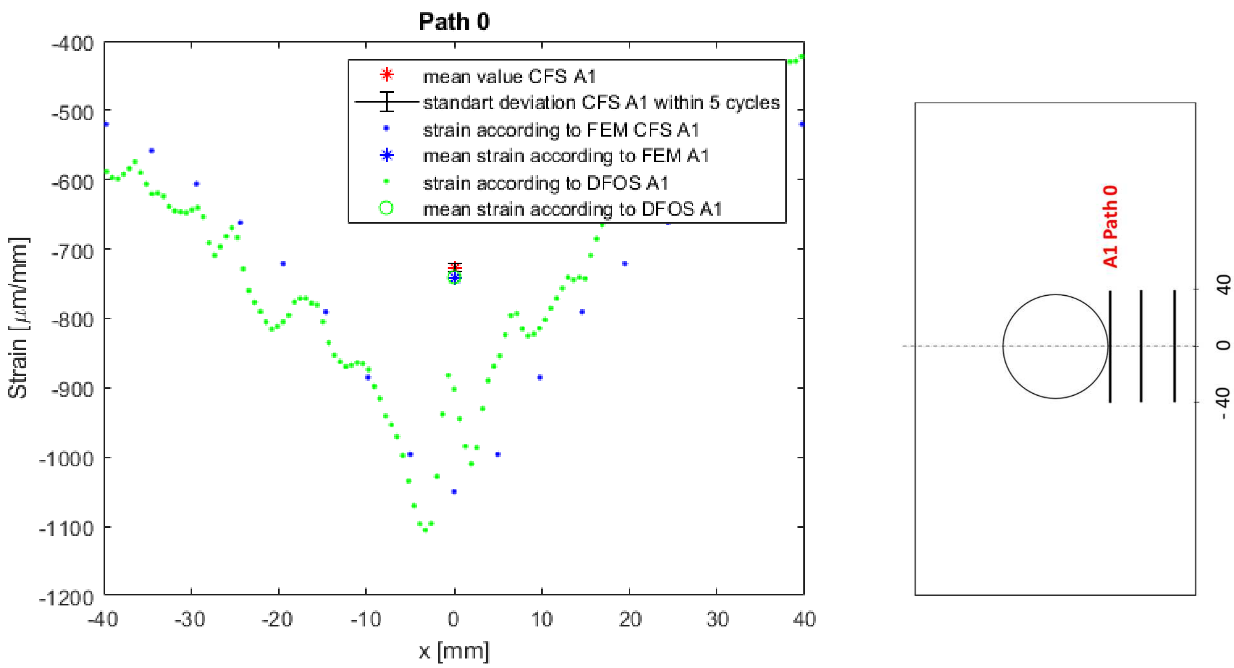
		Specimen 1		Specimen 2		Specimen 3A		Specimen 3B		Average all specimens	
Sensor location	**FEM [%]**	CFS [%]	OF av. [%]	CFS [%]	OF av. [%]	CFS [%]	OF av. [%]	CFS [%]	OF av. [%]	**CFS [%]**	**OF av. [%]**
Path 0	**100**	79	85	98	100	118	128	112	115	**102**	**107**
Path 20	**83**	75	80	79	89	98	-	86	92	**84**	**87**
Path 40	**74**	79	81	75	81	69	-	71	79	**74**	**80**

In Fig. 5 are given data of measured from CF sensors as relative values for better comparison. Measured strain for first cycle of sensor closest to the hole corresponds to 100 %. Change in measured data with the number of cycles is relatively small for sensors to all specimen with the exception of CF sensor A3 installed on specimen 1.

Measured data from CF sensors were compared to data gained from DFOS sensors and simulation using FEM. From each CF sensor only one value of average strain along the length of the sensor was obtained. Therefore, average strain value from measured strain along DFOS sensors was also calculated. Mechanical strain in longitudinal direction along paths corresponding to sensor localization was also read from the FEM analysis and average strain value was determined.

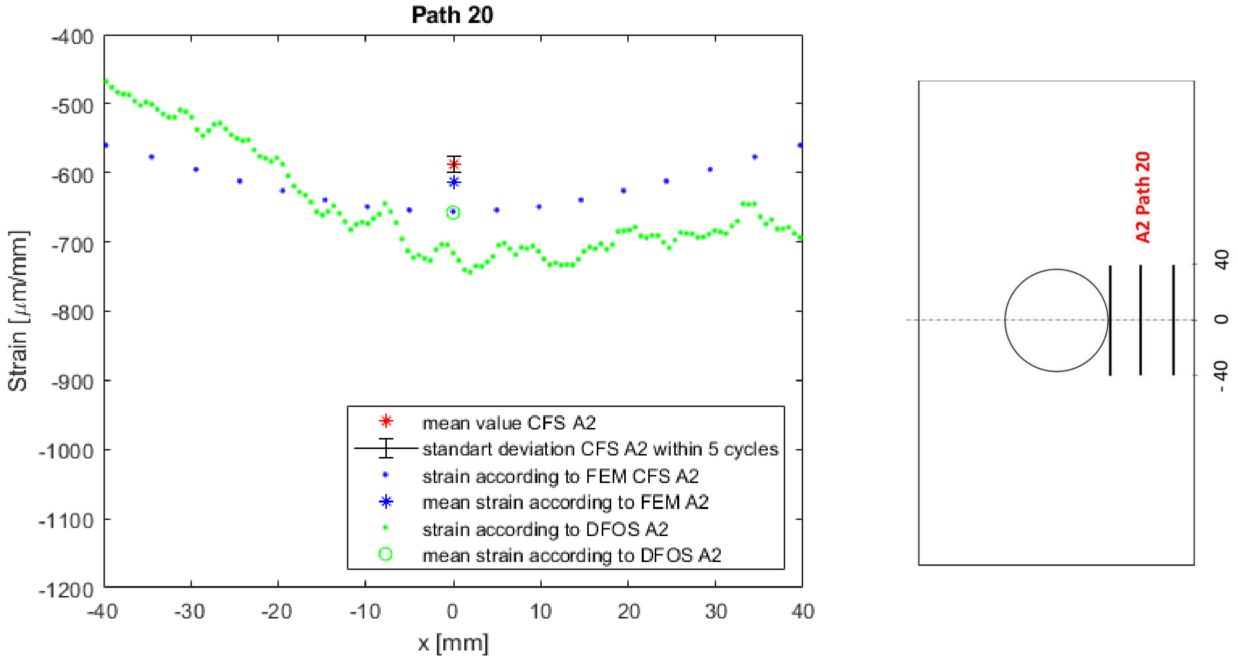
The data obtained from the simulation were compared with the measurement data from DFOS and CF sensors. Results of such comparison is given in Tab. 1. For better comparison the data are given as a percentage values, where 100 % corresponds to strain along sensor A1 (path 0) in FEM simulation.

In Fig. 6, Fig. 7 and Fig. 8 are compared data from CF and DFOS sensors and also FEM simulation for specimen 2.



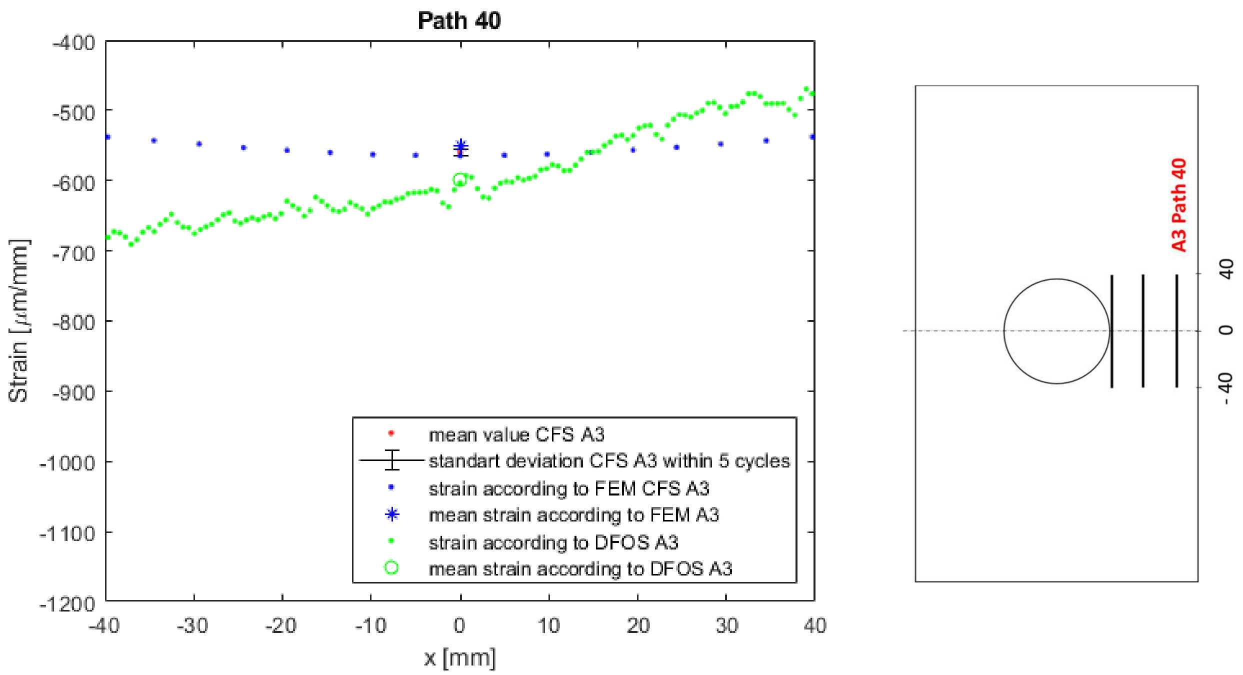
a) mechanical strain along path 0 at specimen 2 b) location of sensor A1

Fig. 6: Comparison of results for Specimen 2 along path 0 corresponding to CF sensor A1, DFOS sensor and FEM simulation.



a) mechanical strain along path 20 at specimen 2 b) location of sensor A2

Fig. 7*:* Comparison of results for Specimen 2 along path 20 corresponding to CF sensor A2, DFOS sensor and FEM simulation.



a) mechanical strain along path 40 at specimen 2 b) location of sensor A3

Fig. 8: Comparison of results for Specimen 2 along path 20 corresponding to CF sensor A2, DFOS sensor and FEM simulation.

4 Conclusion

The experimental campaign brought initial information about measurement strain on filament wound GFRP composite plate during repeated loading near the hole. Measured data were compared among CF sensors installed on different locations within one specimen and among several different specimens.

The results obtained from the strain measurements using CFSs show good repeatability and are in good agreement with the expected strain distribution based on the theory and FEM analysis. Measured average strain by CF sensors are in good agreement with the measured data from reference DFOS sensors.

The advantage of CF sensors and optical fibers is that they can be directly integrated into the composite structure of the vessel. The advantage of the usage of CF sensors over DFOS sensors is the significantly lower price of the measurement device, although we get only one average value of strain over the whole length of the sensor.

Acknowledgement

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