# ANALYSIS OF AN AXIALLY LOADED COMPOSITE TUBE MEASURED BY DISTRIBUTED FIBER OPTIC SENSORS

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**Abstract**

This work shows an axially loaded composite tube that represents a rod body with a wrapped joint. For the experimental analysis, distributed fiber optic sensors installed on the surface of the rod were used to analyse axial, and radial deformations and local changes in the joint region under tensile loading until failure.

## 1. Introduction

The composite parts designed for a specific usage needed to be verified experimentally, especially in fields with high safety standards such as the aircraft industry, where each part must be tested to prevent early collapse.
This article presents an experimental approach to failure development using a distributed fiber optic sensing system (DFOS). The system is based on scattering principle in fiber optics, reflecting the strain changes along the optical fiber. This can be helpful for detecting weak spots in the rod. Therefore, the composite rod is tested and evaluated until failure.

## 2. The DFOS system for strain measurement

Distributed fiber optic sensing system for strain measurement works on the backscattering principle caused by small impurities in fiber optics, which are created during fiber optic production. The DFOS method uses tunable laser as a coherent light source that sweeps through the optical path to the sensor, reflecting scattered light to the orthogonal detectors. Then, the signal obtained from the loaded fiber on the structure is cross-correlated with the reference signal, and the strain change at all points along the optical fiber is calculated from the correlation shift. The same process can be used for temperature change detection along the optical fiber.

## 3. Preparation for testing, sensor installation

The composite rods were produced by the Compo Tech PLUS, spol. s.r.o. company using winding technology. The rod was made of XN60 or T700 carbon fiber, and an epoxy matrix. One end of the rod contained holes for attaching a metal insert, while the other end of the rod was reinforced with fiberglass for testing purposes only. All rods were intended for tension and compression tests. Due to the uneven distribution of material of the composite rod, two sensor configurations were developed. The main problem was the strength of the tie rod, and additional information was required to locate the damage.

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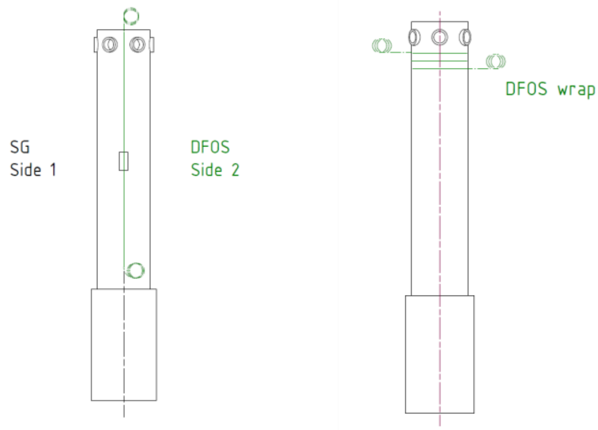


Fig. 1. The DFOS sensor layout. The first – a) axial installation of DFOS sensor together with a strain gauge, the second – b) radial installation of the DFOS sensor on rod.

Figure 1 shows the DFOS sensor layout for the two sensor configurations: a) axial configuration on the left, and b) radial configuration on the right. In the axial configuration, the DFOS sensor is placed on the surface along the rod in the same direction as strain gauge, and both sensors can be compared in the plane of strain gauge. In this configuration, the DFOS sensor can also be used to obtain the strain distribution along the composite rod, which can be useful in locating the concentration of strain along the tube. In the radial configuration, the DFOS sensor is wrapped on the surface around the top of the tube below the metal insert attachment holes. This sensor arrangement can analyse the stress under the holes and show if it is evenly distributed under load.

Fig. 2. Testing setup for composite tube with the DFOS sensor and strain gauges installed in axial configuration.

## 4. Composite tube testing

The composite tube with prepared sensors was tested using the servo-hydraulic testing machine Heckert UFP 400 until failure. Both types of tubes, made of high-modulus and high-strength carbon fibers XN60 and T700, were tested in tension and compression. The testing setup can be seen in the Figure 2.
Loading was displacement controlled and quasi-static for all tests. After each sample was broken, a visual inspection was performed to determine the location and extent of damage.

## 5. Results

All the tests were performed until failure, and all specimens broke in the hole section. The tensile tests broke off the wrapped fibers around the holes (see Figure 3), whereas in the compression tests, the samples broke below the holes, at the end of the metal flange due to strut failure.

Fig. 3. The composite tube after the test.

The results are splitted into two configurations for greater clarity: axial and radial configurations.

a) Axial configuration

In this configuration, the results from T700 fiber type were more consistent compared to XN60 type. All specimens in this configuration were tested only in tension. The material curve is linear until failure. After that, most of sensors stopped measuring or peeled off partially from the sample. Figures 4 and 5 show the sample with a working sensor after breakage.

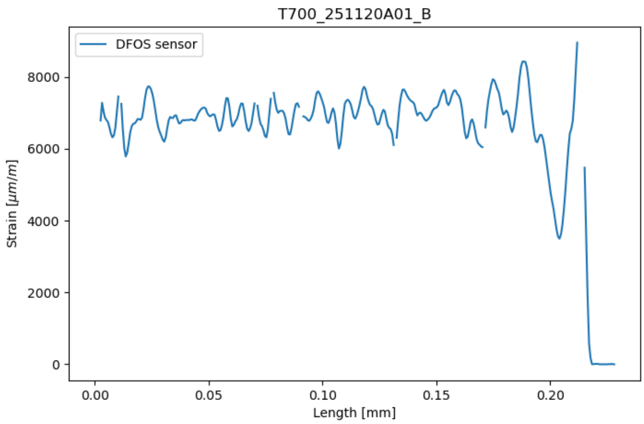


Fig. 4. The DFOS sensor at the defined load level along the tube in axial configuration.

In Figure 4, the results from the sample with the DFOS sensor installed in axial direction along the composite tube are shown. The distribution along the tube is not constant, which could be caused by uneven composite winding – uneven surface layout of carbon fibers. There is also strain concentration near the hole for attaching the metal end due to a reduction in the volume of fibers wrapped around the holes.
Figure 5 shows the graph of the relationship between the load force indicated by the load-cell and the strain from the sensors. Only a single point in the plane of strain gauge was chosen from the DFOS sensor for comparison with two strain gauge (SG) sensors.

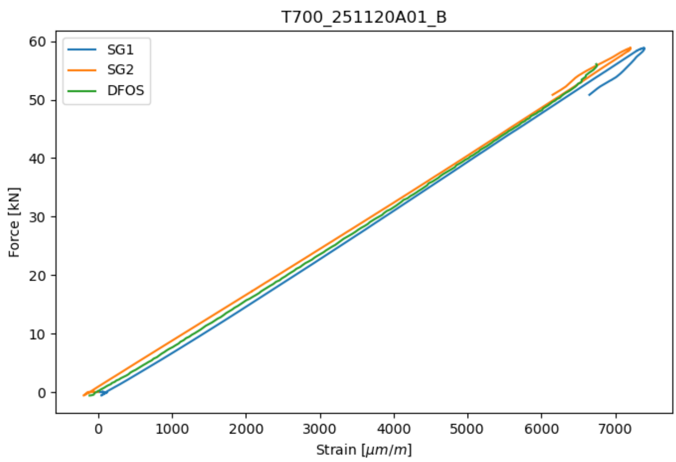


Fig. 5. The DFOS sensor with the strain gauges compared in relation to the machine force.

There is no significant difference between the sensors, according to Figure 5. The axial arrangement has the advantage of measuring in the direction of testing.

b) Radial configuration

In the radial configuration, the DFOS sensor was wrapped around the tube below the holes. The specimens in this configuration were tested in tension and compression. For the T700 type samples, the results were similar to the previous configuration - a linear trend until failure, but the XN60 type cracked gradually. For better understanding, the display of the results was adjusted so that the course of the deformations along the length, respectively along the circumference, and the course of the force over time were displayed simultaneously. In this view, the impact changes occurring during loading can be seen.
Figure 6 shows two time states during loading, the first at the peak of the maximum force (left part), and the second after this peak (right part). The drop in force caused a significant change in the strain distribution around the tube.

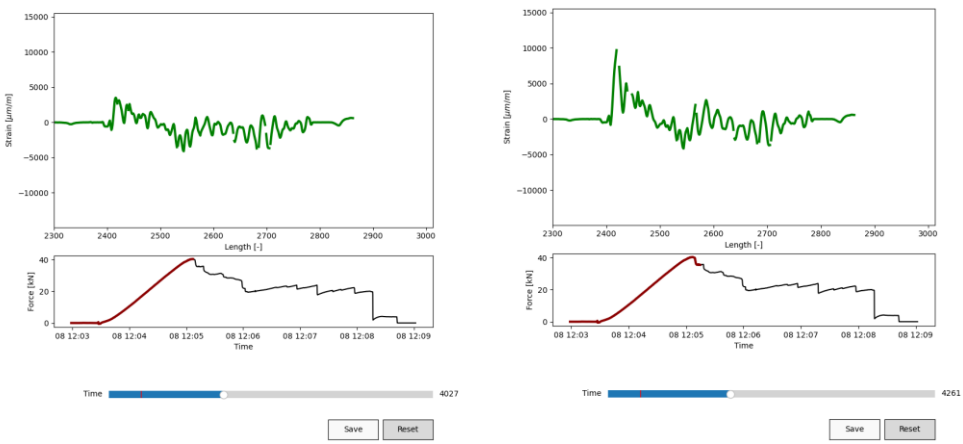


Fig. 6. A comparison between two time states during loading. On the left side – the strain distribution at the peak of the maximum force, on the right side – the strain distribution after the first load drop. A significant change in strain distribution can be seen before and after the force drop.

## 6. Conclusion

By using a distributed optical sensing system to measure strain, much more information can be obtained, especially when dealing with an atypical tube with a wrapped end and where analytical calculation cannot be used to predict the results. Several conclusions can be drawn from the results.
The first conclusion is that the composite tubes were tested in tension in two types of materials, with T700 type achieving higher strength but sudden damage, unlike XN60 type achieving lower strength but gradual damage. In compression tests, the damage was gradual for both types of materials.
The second conclusion is that the DFOS method can be used to measure strain on composite tubes compared to strain gauges. The results showed no significant difference between these methods. The DFOS method can measure at a lower frequency compared to strain gauges, but the optical fiber can be installed in small areas and measured distributedly.

The last conclusion is that two DFOS sensor configurations were installed and presented. The first configuration (axial) showed the advantage of the DFOS method by measuring along the length of the composite tube. This makes it possible to obtain much more detailed information about the strain distribution on the measured components. The second configuration (radial) showed a non-uniform strain distribution around the tube under the wound holes. Significant changes in strain are evident when the force decreases under load. This can help identify the critical point of damage when it occurs.
To identify the point of initiation of damage, more experiments with more detailed installation and configuration of the sensors, especially their location, must be performed, otherwise the results will not be valid.

## Acknowledgements

Financial support was provided for this study by the Grant Agency of the Czech Technical University in Prague; grant no. SGS21/151/OHK2/3T/12, and by the Technology Agency of the Czech Republic, grant no. TJ02000252, FW01010450

## References

[1] Mark Froggatt and Jason Moore. High-spatial-resolution distributed strain measurement in optical fiber with rayleigh scatter. Appl. Opt., 37(10):1735–1740, Apr 1998.
[2] Christian Boller, Fou-Kuo Chang, and Yozo Fujino, editors. Encyclopedia of structural health monitoring. Wiley-Blackwell, Hoboken, NJ, January 2009.
[3] P Fernández Díaz-Maroto, AF LÓPEZ, and JA Güemes. Distributed fibre optic sensors for stiffened skin panels strain monitoring and failure mode detection. Structural Health Monitoring 2015, 2015.