INVESTIGATION OF FIBRE BRAGG GRATING RESPONSE UNDER INHOMOGENEOUS DEFORMATIONS

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1. Introduction

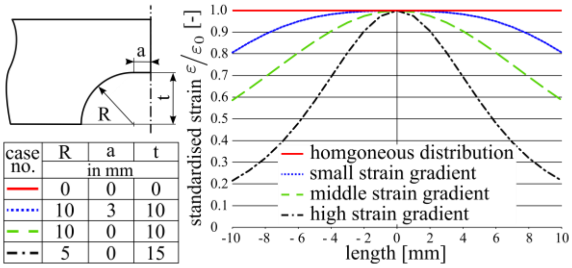
By the usage of strain sensors, the assumption is often that the strain is measured at one point. In reality, the sensors are often exposed to variations of strain state along its dimensions. This fact is observed for electrical strain gauges e. g. in [1]. We know that the strain gauges display an integral value of the deformation over the strain gauge area.

For the analysis of fibre-Bragg-grating (FBG) sensors a narrowband reflected peak, which arises from homogeneous deformation, is assumed [2]. This requirement is rarely satisfied by grating length of 2 to 8 mm. Thereby, the questions raise: What happens with the reflected wavelength peak of the FBGs and how is the degenerated wavelength peak to be evaluated?

2. Layout of specimen

For the investigation of the FBG response of inhomogeneous deformations, a well-defined strain state is applied. Different opportunities exist to generate an inhomogeneous strain state in a component. In this abstract, the inhomogeneous strain is generated by a bending test with different notched aluminium beams.

In this paragraph, the shape development of the different notched beams are described. To display the influence of the inhomogeneous strains, different geometries of the notch causes a different strain gradient, whereby the notch geometries are selected in this way that the strain gradients are differed considerably. To evaluate the strain gradients, numerical simulations are performed with the tool Ansys®. The beam is a symmetric 2D half model and the strain gradient is determined by a path on the unnotched side of the beam. For the comparison, an unnotched beam is also investigated, which occurs homogeneous strain. In Fig. 1, the different notch geometries and the strain distributions in longitudinal direction of the beam are displayed.



case no.	R	a	t
	in mm		
—	0	0	0
······	10	3	10
– –	10	0	10
–·–	5	0	15

Fig. 1. Geometries of used notches and corresponding strain distributions.

Besides the FBG sensor, which are draw tower gratings with 8 mm length, an electrical strain gauge is applied on the surface of the bending beam. This strain gauge is installed in central position above the notch. On the right and left side, two FBG sensors are applied. One FBG sensor is positioned above the centre of the notch position (centric FBG) and one sensor aligns with the centre of the notch (eccentric FBG). The realised application of the different sensors is shown in Fig. 2.

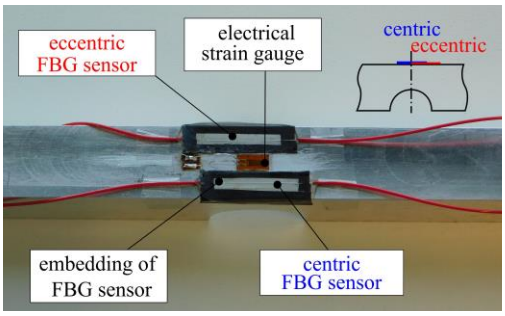


Fig. 2. Application of strain gauge and FBG sensors.

3. Experimental setup

In the following, the notched beams are investigated in a four point bending test, which is similar to the test setup explained in [3]. The experimental setup is depicted in Fig. 3. Therefore, the upper and lower bearings are pivot-mounted rolls to apply a defined load conditions.

The experimental sequence starts with a small preload. Afterwards, the system is reset and a given displacement of the upper bearings is reached. At the given displacement, the strain at the surface amounts approximately 2000 µm/m. This value is determined by a simulation of the specimen with the largest strain gradient and ensures that the beam is loaded only in the elastic range. Thus, the beams can be investigated several times as well as in different directions e. g. tension and compression.

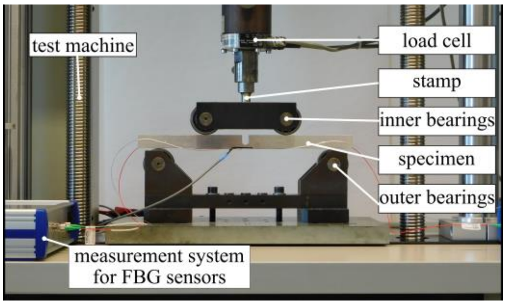


Fig. 3. Setup of four-point-bending test.

4. Analysis of experimental data

Expectedly, the FBG responses of the homogeneous beam show no significant changes during the loading. The peak stays narrowband and has a high reflectivity. The peak fulfils the Bragg conditions and a reflected wavelength can be detected. This reflected wavelength is required to calculate the strain in the fibre. In Tab. 1, the calculated strains of centric and eccentric FBGs are compared with the strain of the strain gauge for tension loading. A very good reproducibility is recognisable.

Table 1. Experimental results of homogeneous beam with tension load

case no.	**force [N]**	**strain of strain gauge [µm/m]**	**strain of centric FBG [µm/m]**	**strain of ecc. FBG [µm/m]**
1	5492	1929	1924	1938
2	5496	1931	1932	1946
3	5496	1931	1930	1946
AVG	5494	1931	1929	1943
STD	2	1	4	4

For the notched beams the peaks get an expanded shape, whereby a strain can be calculated by the peak shift. The strain analysis fails if the peak splits, which occur by the loaded beams with middle or high strain gradient. One example is shown in Fig. 4, where distribution of the FBG response of the beam with high strain gradient is shown. First, the enlarging of the peak and the decreasing of the reflectivity can be observed and up to 950 µm/m the central, centric peak splits and enlarges more and more. This peak splitting is reversible and vanishes if the beam is unloaded.

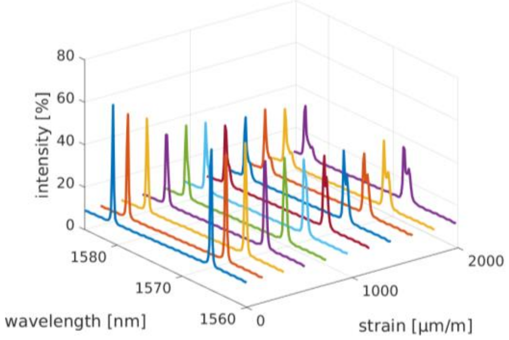


Fig. 4. Distribution of FBG spectra above the strain.

5. Challenges and conclusions

In this abstract, a four-point-bending test of notched aluminium beams is presented. This bending test is used to introduce inhomogeneous strain in FBG sensors. Thereby, the FBG response of an unnotched beam is as expected. For the notched beams, the reflected peak enlarges and decrease in the reflectivity. For a critical value of inhomogeneous strain, the reflected peak splits. At this point, the analysis of FBG signal collapses.

In literature, it is described to reconstruct a FBG spectra with e.g. the T-matrix method [4] which can be specified as a mathematical forward model. The challenge is to determine strain distributions from measured FBG spectra with splitted peaks by the solution of the inverse problem.

Acknowledgements

This work is part of a measure which is co-financed by means of taxation on the basis of that of the deputies of the Saxon Parliament decided budget. The financial support is gratefully acknowleged.

References

[1] Hofmann, K. An Introduction to Stress Analysis using Strain Gauges. *www.hbm.com*, 03.05.2019

[2] Kersey, A., Davis, M.A., Patrick, H., Leblanc, M., Koo, K., Askins, C.G., Putnam, M.A., Friebele, E. Fiber Grating Sensors. *J of Lightwave Technology*, 1997, Vol. 15, pp. 1442-1463.

[3] VDI/VDE/GESA 2660, Optical strain sensor based in fibre Bragg grating – Fundamentals, characteristics and sensor testing. 2010.

[4] Peters, K., Pattis, P., Botsis, J., Giaccari, P. Experimental verification of response of embedded optical fiber Bragg grating sensors in non-homogeneous strain fields. *J Optics and Lasers in Engineering*, 2000, pp. 107-119.