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Influence of Temporal Strain Evolution on Distributed Strain Sensing with OTDR in Polymer Optical Fibers

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Summary:
To measure strain in ground and earthworks, polymer optical fibers (POF) applied to geotextiles can be used. In case of an optical time domain reflectometry (OTDR) measurement, the backscattered intensity increases in strained areas. The increase of backscattering (IOB) has been characterized by gradual elongation of the fiber up to 5% with different elongation levels and holding times. A dynamic behavior of the IOB has been proved. It could be shown that for the tested elongation patterns the IOB varies around 0.3% up to 0.9% for absolute strain less than 2.2% and up to 5%, respectively.

Keywords: optical time domain reflectometry, structural health monitoring, strain sensing, geotextiles, polymer optical fiber

Background

Condition monitoring of critical earthworks as for example dams, dikes and disposal sites is a challenging yet not satisfactorily solved measuring task. A possible sensor consists of a polymer optical fiber (POF) applied to a geotextile [1]. Geotextiles are fabrics made of polymer fibers, which are used to absorb stress within the soil and therefore, are ideal to provide friction.

When straining the POF, the level of optical backscattering within the fiber increases along strained sections [2, 3], as shown at the Insert in Fig. 1. Therefore, a spatially resolved measurement of strain by OTDR is in principle possible. The increase of backscatter (IOB) is also affected by side effects like temperature and humidity [4].

However, a more dominant side effect is the relaxation processes that may result from adaptation of the POF material to external force. Hence, IOB is not stable over time, even at constant strain. Therefore, different strain profiles over time may result in varying IOB, even at the same amount of strain applied to the POF. In this work, this effect is characterized to quantify resulting uncertainties and potentially diminish them in field measurements of strain by OTDR in POF.

Method

An automated measurement program strained a standard PMMA-POF with 1 mm diameter (Mitsubishi GH-4001-P) and a total length of 15 m. Afterwards, at constant time steps OTDR measurements were taken using a commercially available POF OTDR (Luciol LOR-220) at 520 nm wavelength. In order to transfer the strain to the fiber, two rods were sticked to it using a two-component epoxy glue, were motorized linear drives apply the elongation.

Three fibers were treated identically besides the strain to time pattern. Strain was applied at the position 10 m - 11 m increasing over time from 0% to 5% in steps of 0.1%. For fiber 1 each 0.1% step was maintained for 10 minutes, for fiber 2 for 1 hour and for fiber 3 for 10 hours, respectively.

To check whether the relaxation takes place within one strain step and if the total testing time does compromise the results, two more fibers were tested. The fibers were strained at the position 40 m – 41 m. Both fibers were elongated from 0% to 5%. The step size of fiber 4 was 0.1%, maintained for 1 hour, each. In contrast, the step size of fiber 5 was 1% maintained for 10 hours, each. The total measurement time was the same, for fiber 4 and 5.

The IOB is calculated for each fiber at the center of the elongated length, as shown at the Insert in Fig. 1. Therefore, an average over a range of measurement points at the center is compared to two equally spaced areas before and after the elongation.

Results

Fig. 1. compares the IOB to strain dependence of fiber 1, fiber 2 and fiber 3. It is noticeable that

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faster strained fibers reach a higher IOB above a level of 2.2% total strain. However, the overall plot looks similar. Up to 2.2% the IOB remains almost the same and all measurements are reaching a similar slope between 3% and 5% strain.

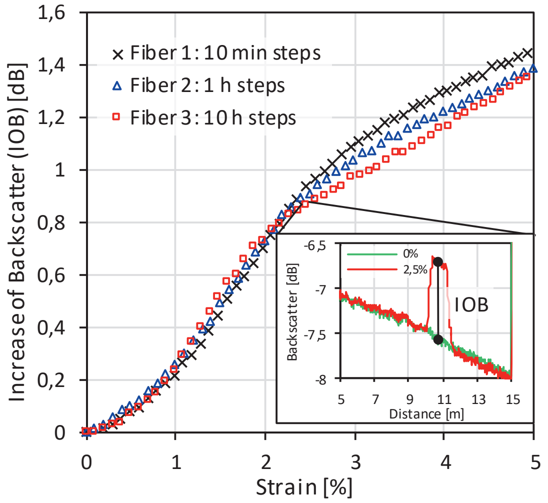

Fig. 1. Strain to IOB dependence of three fibers elongated in steps of 0.1% with different holding times. Insert: Example of an OTDR reflectogram at 2.5% strain and visualisation of increase of backscatter (IOB)

Strain for fiber 4 and fiber 5 was increased at the same rate. However, the step size has changed. Interestingly, at any particular strain step, the IOB is identical as shown in Fig. 2.

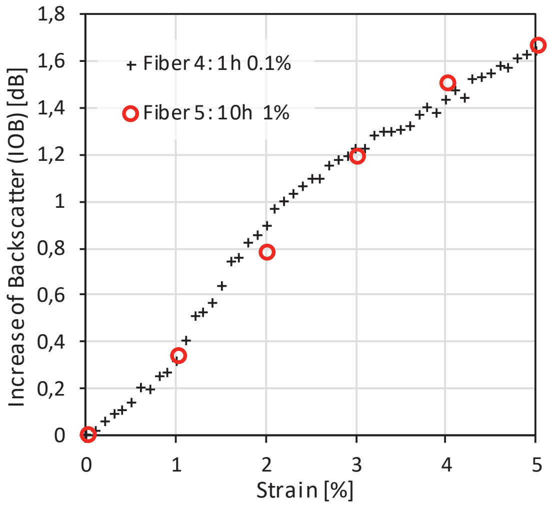

Fig. 2. Strain to IOB dependence of two fibers elongated with identical total testing time and different elongation step sizes and hold times.

A quick comparison of Fig. 1 and Fig. 2 shows a greater IOB at maximum strain in Fig. 2. This is caused by pulse dispersion over length in POF and the two measurements are therefore not comparable.

Conclusion

On the observed time scale from min 10 minutes to max 10 hours, the specific course of increase in strain up to 2.2% has no influence on the measured IOB. The temporal slope of the strain increase IOB for further measurements above 2.2%.

Due to the high linearity of fiber 3 above 2.2% strain, we assume it is close to the IOB after relaxation. The nonlinearity of fiber 2 and fiber 1 above 2.2% strain would then be a side effect of the underlying relaxation process. One way to test this hypotheses is to investigate on the hysteresis of IOB by strain above and beyond 2.2% strain.

The alteration due to different elongation speeds and levels is 0.3% in the IOB for strain less than 2.2% and 0.9% alteration between 2.2% and 5% strain.

Furthermore, Fig 2 shows that the step size does not affect IOB for identical overall relaxation times.

In our future work, we will improve our IOB calculation for better cross comparability through fiber length. Therefore, we will investigate on using puls energy instead of IOB.

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