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Monitoring of Composite Bicycle Components using Polymer Planar Bragg Gratings

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Summary:
This study demonstrates mobile load monitoring of a composite bicycle component using an application-customized polymer planar Bragg grating sensor, evaluated by a mobile interrogation unit. After a referencing procedure, the mechanical load of a seat post is monitored while cycling through a test track.

Keywords: Bragg Grating, Composites, Cyclic Olefin Copolymer, Micromilling, Load Monitoring

Introduction

The scientific impact of Polymer planar Bragg gratings (PPBG) based on Cyclic Olefin Copolymers (COC) has grown tremendously throughout recent years. Based on their outstanding material properties [1], these polymer-based optical sensors are capable of performing temperature-referenced, humidity-insensitive and multidimensional strain or shape sensing [2]. They can also be fully integrated into commercial-grade carbon fiber reinforced polymer (CFRP) workpieces [3], wherein structural health monitoring is especially vital [4]. This study follows a straightforward approach by adhesively affixing a COC-PPBG on a bicycle's CFRP seat post. In combination with a battery-powered mobile interrogation unit, which is also capable of wireless data transmission, it is possible to monitor the load status of the seat post in the field.

Sensor Fabrication

Injection-molded COC plates are cut to bulk sensor substrates with a length of 20 mm, a width of 10 mm and a thickness of 1.5 mm. Subsequently, a micromilling process (CNC Mini-Mill/4, Minitech Machinery) is used to fabricate a microstructure on the substrate's top surface. Afterwards, a waveguide comprising a Bragg grating structure is generated within the substrate by employing a sophisticated single-writing-step procedure [5]. Finally, the PPBG's bottom side is milled to a concave shape, whereas its radius of 13.6 mm matches that of the bicycle seat post. Fig. 1 depicts the final customized COC-PPBG. The microstructure on top of the substrate is filled with a UV-curable adhesive (NOA76, Norland). Subsequently, a single-mode fiber, exhibiting a polished 8° end facet, is inserted.

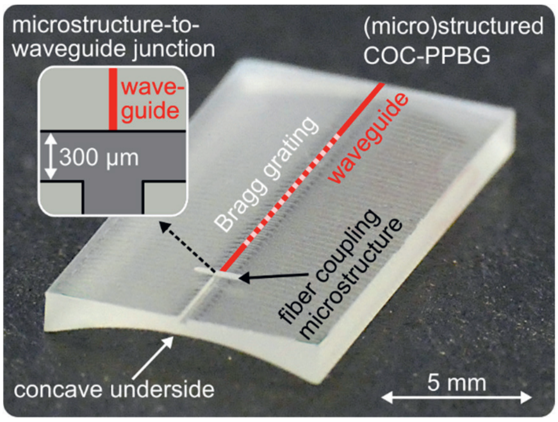

Fig. 1. COC-PPBG modified for affixation on a bicycle seat post (photonic structures are indicated).

After aligning the fiber with the integrated photonic structures, the adhesive is cured in order to obtain a durable physical connection of both components. Additionally, the optical adhesive serves as refractive index matching medium inbetween fiber end facet and polymer waveguide.

Interrogation and Referencing

A battery-powered interrogator (MOFIS M400, Redondo Optics) is used to monitor strain induced shifts of the PPBG's Bragg wavelength. The device uses the longer wavelength slope of a bandpass filter to convert Bragg wavelength shifts into intensity variations, quantified and transformed to a voltage signal by means of a photo receiver with appropriate electric conversion. After affixing the sensor at the seat post's front by means of an epoxy-based adhesive (DUOPOX AD840, DELO), the CFRP workpiece is mounted in a tensile testing machine (UD04, Step Engineering). This way, the resulting change in output voltage ΔV is referenced with the applied external load. An image of the setup is given in Fig. 2 a) while the determined reference function is shown in Fig. 2 b).

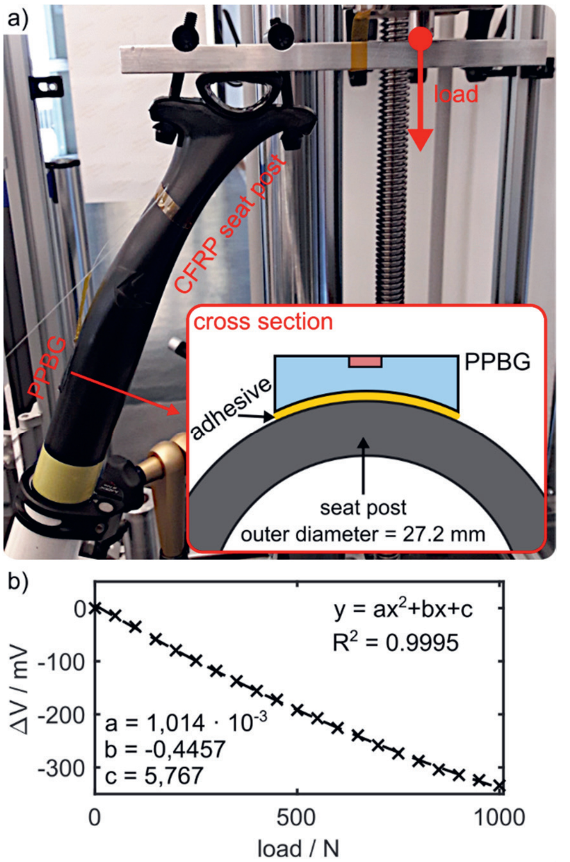

Fig. 2. a) Referencing setup. b) Voltage change ΔV as a function of the applied load.

The observed voltage change can be well-fitted with a quadratic function, whereas the nonlinear behavior is attributed to the bandpass-based wavelength shift to voltage conversion.

Field Experiments

The CFRP seat post with the affixed COC-PPBG sensor as well as the mobile interrogator are mounted on a bicycle, as shown Fig. 3 a). A cyclist with a weight of 82 kg rides the bicycle along a test track, while the load status of the seat post is monitored via the applied PPBG. Measurement data is transmitted wirelessly from the interrogator to a nearby evaluation station. Fig. 3 b) depicts the test track's pavement condition featuring four equidistant ditches. According to Fig. 3 c), which shows a time trace of the determined load, the mobile optical sensor setup is capable of quantifying the forces affecting the CFRP workpiece, whereas load impacts of the cyclist's pedaling movement as well as all ditches are discernible in the recorded data.

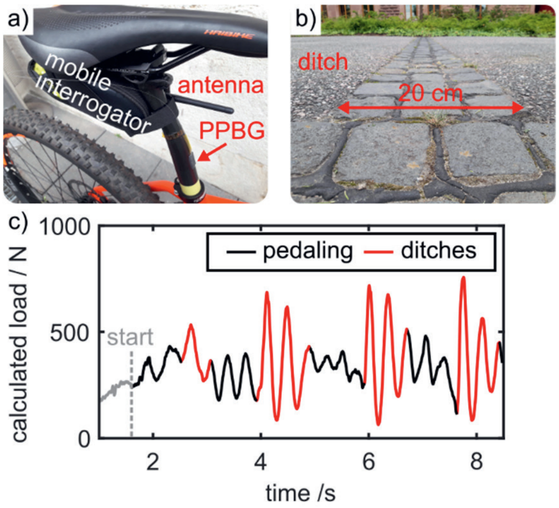

Fig. 3. a) Field experiment setup. b) Pavement conditions of the test track. c) Exemplifying time trace of the determined load profile.

Conclusion

This study demonstrates mobile load monitoring of a CFRP bicycle component by means of a shape-optimized polymer planar Bragg grating in combination with a battery-powered interrogator, which also features wireless data transmission.

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