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Monitoring of Concrete Structures with Integrated Bragg Grating Sensors

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1. Introduction

Worldwide a lot of research is carried out concerning the (remote) monitoring of civil engineering structures to improve their durability and safety. This paper focuses on the use of optical fiber sensors for the purpose of remote monitoring. The main advantages of optical fiber sensors are their insensitivity to corrosion and electro-magnetic interference and their small size. Some optical fiber techniques even have the possibility to use more than one sensor in one fiber which enables quasi-distributed sensing or even continuous measurements. The sensor used for the tests reported in this paper is a Bragg grating sensor which consists of a periodical change in refractive index written in the core of part of a single mode optical fiber. When broadband light is coupled into the fiber one will receive a small reflection peak centered around a certain wavelength called the Bragg wavelength. This wavelength depends on the period of the grating which will change due to mechanical and/or thermal loading. This paper shows the results of tests to determine the temperature effect on the sensor and will give a comparison between strains measured with an electrical strain gauge and strains measured with Bragg sensors. The executed tests are tensile tests on steel rods and a bending test on a concrete prism with an integrated Bragg sensor. In order to demonstrate remote measurement capabilities, as required in many civil engineering applications, a remote monitoring test set-up has been implemented. In this set-up the optical spectrumanalyser (used to measure the reflection peak), the test object and the monitoring PC are connected to each other via optical links of about 200 m. The exact location of each element is basically irrelevant as long as they are linked to each other. It is clear that such a set-up is an essential step towards a permanent remote monitoring system of civil engineering structures in combination with a novel method of strain measuring.

2. Temperature sensitivity of a Bragg grating sensor

When a Bragg grating is subjected to strain the peak wavelength will change linearly. This enables us to use a Bragg grating as a sensor. However a change in temperature will change the refractive index of the grating and will also cause a linear change of the peak wavelength. In order to be able to distinguish both types of wavelength shift during a strain measurement on a test object in an environment with changing temperature, it is necessary to determine the shift of a free Bragg sensor caused by temperature effects. Tests were performed on free Bragg gratings as well as on a Bragg grating attached to a rebar. By determining the shift of the free grating caused by a changing temperature the coefficient of thermal expansion of the rebar could be checked. The test gave a coefficient of thermal expansion of $10.2 \cdot 10^{-6}$ /°C, which is in good agreement with the normally assumed coefficient of thermal expansion for steel of $10 \cdot 10^{-6}$ to $11 \cdot 10^{-6}$ /°C.

3. Tensile tests on steel rods

In order to compare strains measured with a Bragg grating to strains measured with electrical strain gauges simple tensile tests on steel rods were performed. In order to have a controlled manner of attaching the fiber to the rebars a groove of 1 mm width and 1 mm depth was milled in the rebars. The sensor could easily be put in this groove and the groove was then filled with epoxy resin. Attention should be paid that the resin shows no visco-elastic behavior and no hysteresis. An example of a tensile test (loading and unloading) is given in figure 1.

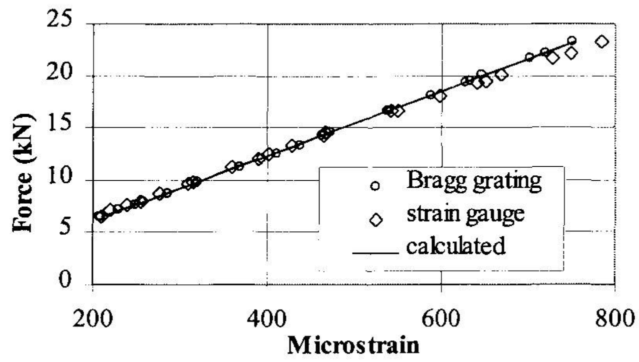

Fig.1 Tensile test on a rebar (ϕ = 14 mm)

4. Bending test on a concrete prism

After performing a tensile test in the elastic zone, a rebar was integrated in a concrete prism of 600 × 150 × 150 mm. The prism was subjected to a 4 point bending test. The strains measured by the grating and the ones measured by the electrical strain gauge were almost identical during the load cycle. A slight difference occurred when the prism was unloaded. The prism was subjected to several loading cycles. The signal of the Bragg grating after each loading cycle was constant while the signal of the strain gauge varied within a range of a 110 $\mu\varepsilon$. The first load cycle is shown in figure 2.

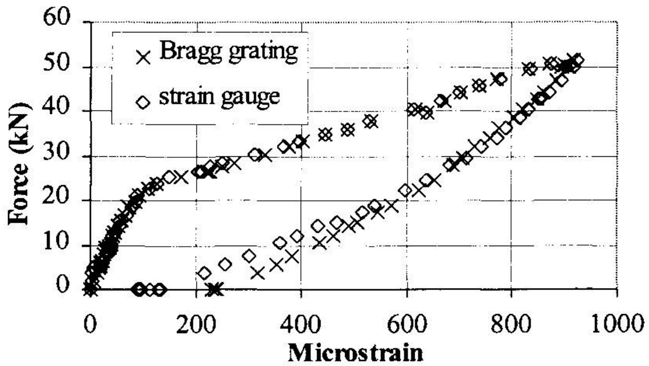

Fig.2 Four point bending test on a concrete prism

5. Conclusion

This paper has shown the results of tests to determine the temperature sensitivity of a Bragg sensor. The results of strain measurements with Bragg gratings during tensile tests on steel rods and a bending test on a concrete prism show that gratings are adequate strain sensors allowing integration in concrete structures. All test were performed in a remote monitoring set-up.