EMBEDDED OPTICAL FIBRE STRAIN GAGES FOR CIVIL ENGINEERING : APPLICATION TO CONCRETE MONITORING

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1. INTRODUCTION

Intrinsic Optical Fibre Sensors (OFS), in which the fibre is the transducer, are now recognized as good candidates for distributed or quasi-distributed sensing applications. In the particular field of Civil Engineering, this concept will provide powerfull means for global and real time monitoring of the structure integrity. Natural phenomena like earthquakes, wind, atmospheric pollutions but also more insidious internal effects such as chemical attack (Alkali problem) yield consequent internal damages for which the embedment of sensor arrays could be of great interest.

In our application, the transducer scheme is based on a polarimetric approach in which the two modes of a high birefringent fibre are used to measure a phase shift proportional to the strain state. A quasi-distributed measurement is performed by using the low coherence "White Light Interferometry " (WLI) to separate the information provided by a linear sensor arrangement. Along the fibre, the sensors are separated each others by intrinsic mode couplers [1,2].

In this paper, we report some experimental results of strain states obtained with concrete test structures. The sensors were embedded in the structure during its manufacturing and tests of elongation and compression were performed.

2. PRINCIPLE

The WLI is used to multiplex the different signals coming from the sensors. A schematic drawing of our arrangement is depicted in Figure 1. A pigtailed SLD light source, emitting at 830 nm, is launched into one of the polarization modes of the sensing fibre. In order to control the input polarization state, an optical fibre polarizer is added between the light source and the sensor. At the output of the sensor, an analyzer oriented at 45° with respect to the fibre axes allows to get the polarization condition necessary to recover the interferences after passing through a Michelson interferometer. The Optical Path Difference (OPD) associated to the sensing zones defined along the fibre are greater than the coherence length of the light source in order that the low coherence demultiplexing method may be used [3,4]. For demultiplexing, we use a specific multi-mirror Michelson [5] designed to generate several OPDs simulteneously which match the OPDs provided by the sensor zones localized along the fibre. In our experiment, the OPD between two adjacent mirrors is 150 µm. These developments have been achieved in the frame of the European Project *OSTIC BRITE N° RI1B0173-C(CD).*

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The intensity of the detected signal coming from the i^{th} coupler (i^{th} sensor zone) is given by :

$I=I_0(1+K_i\ m_0\ \cos\Phi_i)$ with :

K_i : amplitude coupling coefficient

m_0 : interferometer efficiency

Φ_i : phase corresponding to the i^{th} sensor zone

The expression of the phase is :

$\Phi_i=2\pi/\lambda(OPD_r-\Delta_n\ l_i)$

λ : wavelength (0.83 µm)

Δ_n : birefringence ($5.5\ 10^{-4}$)

l_i : length between the i^{th} coupler and the fibre end

OPD_r : Optical Path Difference in the receiver

When the interferometric receiver matches all the signals generated by the sensing fibre, the phase delay $\Delta\phi_i$ between two successive signals (corresponding to couplers i^{th} and $i\text{-}1^{th}$) can be measured :

$$\Delta\Phi_i = 2\pi/\lambda\ \Delta_n\ (l_i - l_{i-1})$$

and provides information upon the variations of the sensing zone lengths that are directly related to the strain distribution along the OFS.

3. SENSOR DESCRIPTION

The optical fibre used for our application is a Polyimide coated Hi-Bi fibre from FIBERCORE. For these trials, the optical sensor is limited to a single sensing zone defined between two coupling points, separated by a length L. The fabrication of the couplers consists in modifying locally the birefringence, by controlled heating using a standard splicer. It could be obviously possible to use photoinduced gratings to get the same effect [6].

The length between two couplers is defined by the following relation ship : $L = OPD_r/\Delta_n$ L = 272 mm.

The optical fibre must be protected by a sheath before embedment into concrete. The purpose of this protection is to reinforce the mechanical strength of the embedded fibre, to prevent from chemical agression, and to avoid the creation of parasitic coupling points which may be generated by the material grain. This mechanical protection of the fibre has been made by using a stainless steel thin tube.

The mechanical bond between the fibre coating and the metallic tube has been made by gluing. The Figure 2 shows the sensor structure.

4. TEST STRUCTURES DESCRIPTION

Two types of test structures have been manufactured. The first one of rectangular shape has been used for strain measurements. A schematic drawing of this test structure with armatures is shown in Figure 3. The length of the test structure was 800 mm and the optical fibre sensor was placed in the center of the test structure at 50 mm of its bottom.

The second one, of cylindrical shape, does not contain any armature. It has been used for pure compressive measurements. The optical fibre sensor is placed in the center (Figure 4).

The concrete used for the test structure fabrication has a breaking resistance of about 30 MPa. During their process, the test structures have been vibrated with a needle. Trials have been started after a delay of 28 days (time necessary for concrete drying).

The test structure have been intrumented with classical strain gages bonded on the surface, to get reference measurements.

5. EXPERIMENTAL RESULTS

5.1 Three point bending

Mechanical sollicitations have been applied through a 3 point bending configuration, the distance between points being about 500 mm. Because the OFS is located in the bottom part of the test structure, the measurements that we describe here after are related to an elongation of the sensor.

Several load rises have been performed with this test structure. For a load of 160 kN, the strain value given by the reference strain gage was 1035 $\mu\varepsilon$ and the differential phase variation provided by the OFS was 10.55 rd. The derived optical sensor sensitivity is 10.2 mrad/ $\mu\varepsilon$. For four successive load rises, the sensitivity repeatability was ± 0.22 mrad/ $\mu\varepsilon$.

Considering the measure integration on a length of 272 mm (length of one sensing zone), we can deduce a linear sensitivity of 37.5 mrad/ $\mu\varepsilon$/m.

The Figure 5 shows compared responses of the reference conventional electrical strain gage and of our optical fibre sensor. The good linearity of both gages is to be underlined.

5.2 Compression

The results for three successive compressions were the following. Under loading of 400 kN the value of strain provided by the strain gage was 263 $\mu\varepsilon$, and the phase variation was 6.61 rad. The derived sensitivity of the optical sensor was then 25 mrad/ $\mu\varepsilon$. For three successive load rises, the repeatability was ± 1.6 mrad/ $\mu\varepsilon$. The linear sensitivity was 92 mrad/ $\mu\varepsilon$/m. The Figure 6 shows the responses of both electrical and optical strain gages.

6. EXPERIMENTAL RESULT ANALYSIS

It is to be noted that the sensitivity of the OFS calculated from the three point bending experiment is 2.5 times lower than that found for compressive tests. This difference in sensitivity can be explained by the fact that, in the case of the bending test, the test structure is inhomogeneous due to the reinforcement. Consequently, the strain imposed to the mean fibre of the test structure, the strain imposed to the OFS and the strain measured by the reference strain gage bonded on the bottom surface were not physically identical.

In the compressive test case, the sensitivity of the OFS derived from the measurements is comparable to the one obtained with composite materials (*OSTIC*, 100 mrad/ $\mu\varepsilon$/m).

7. CONCLUSION

These first trials have shown it is possible to get information of concrete structure strain by using embedded OFS. The use of a thin metallic tube as sensor sheathing has been experimented with success. Further experimentations devoted to cracking analysis over several multiplexed sensing zones are now in progress and the corresponding results will be presented in the oral communication.

8. ACKNOWLEDGEMENTS

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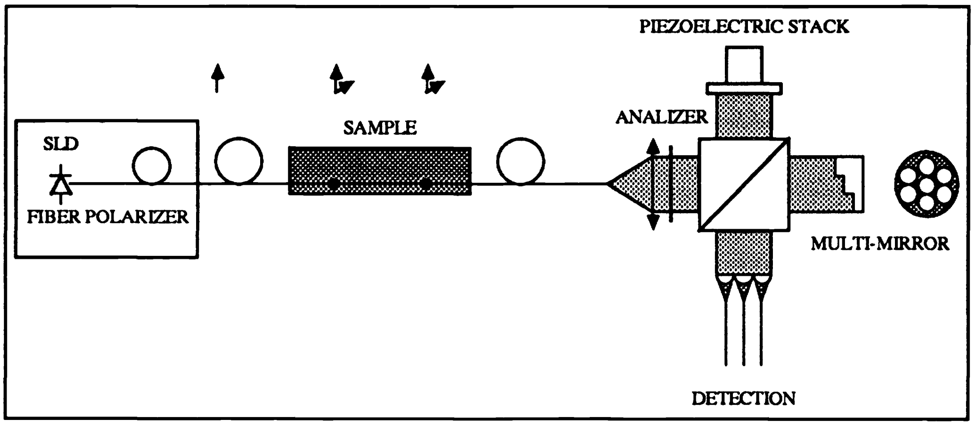

FIGURE 1 : Experimental setup

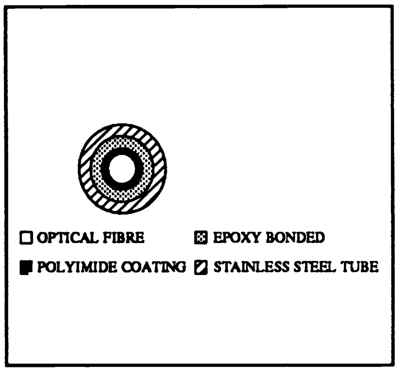

FIGURE 2 : Optical fiber sensor with tube

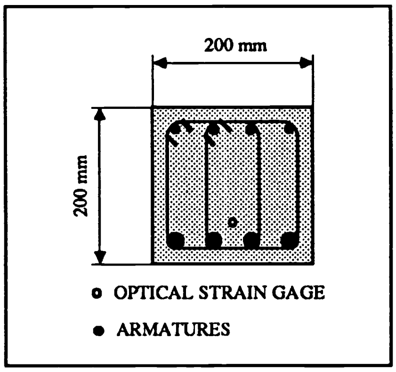

FIGURE 3 : Test structure for elongation

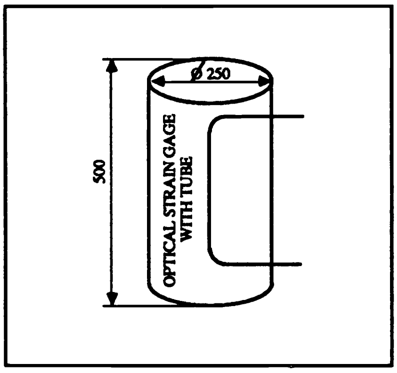

FIGURE 4 : Test structure for compression

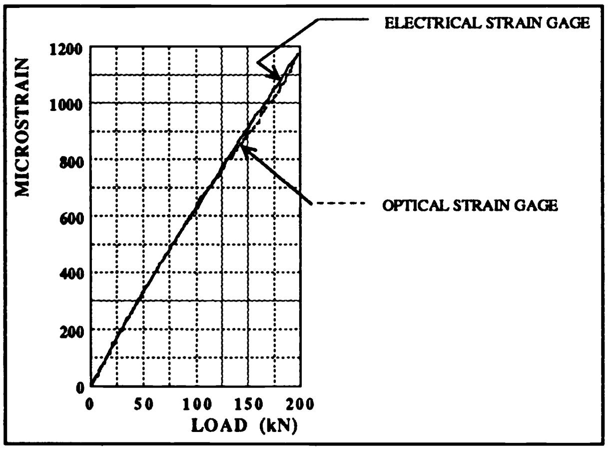

FIGURE 5 : Optical and electrical strain gages in extension

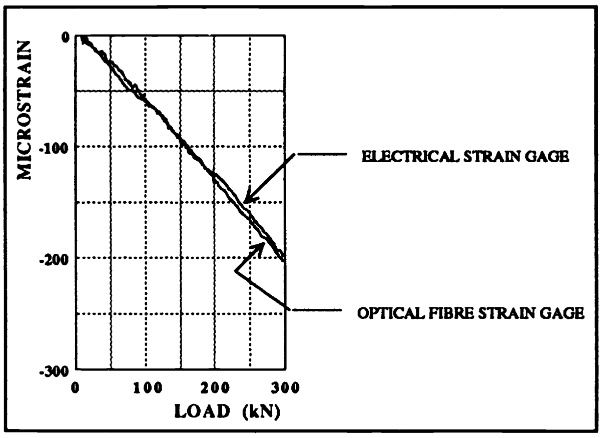

FIGURE 6 : Optical and electrical strain gages in compression

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