Cure monitor of concrete cylinder by using fibre optic sensors

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ABSTRACT: Embedded sensor protection system (ESPS) for fibre optic sensor (FOS) has been presented in this paper. Protected Extrinsic Fabry–Perot interferometric (EFPI) sensors nd Fibre Bragg Grating (FBG) have been used to monitor the cure progress and structural health status of concrete cylinders. The results indicate that the protected EFPI and FBG sensors are more sensitively to follow the change of environment temperature compared with commercial special strain gauges due to the special design of sensor protection system. The protected fibre optic sensors are suitable achieve the structural health monitoring in practical.

1. INTRODUCTION

The structural health monitoring (SHM) in-service is very important and definitely demanded for safely working of engineering structure such as concrete structures. It is very difficult to carry out by using conventional methods. New reinforced concrete construction would benefit greatly from in-situ structural monitors that could detect a decrease in performance or imminent failure, for example, variation in strain, temperature, corrosion, or crack formation. The ability to interrogate numerous sensors multiplexed along a single fibre permits an entire structure to be outfitted with sensors with a manageable number of leads routed to central access points. In response to the increased need, various techniques are being developed and some of the most promising are based on the use of fibre optic sensors (FOS).

Fibre optic smart structures are an enabling technology that will allow engineer to add a nervous system to their designs, enabling damage assessment, vibration damping, and many other capabilities to structures that would be very difficult to achieve by other means. The potential market for the application of smart civil structures can be quite large. The most probable candidates will be smart civil structures such as smart building and skyscrapers, smart bridge, dams, bridge decks etc. Fibre optic sensors (FOS) can offer many potential advantages for application to civil structural systems. In fact, a lot of fibre optic sensors have been developed for use in smart civil structure such as polarisation FOS, Extrinsic Fabry–Perot interferometric (EFPI), and fibre Bragg gratings (FBGs), multimode FOS, etc.. [1-3] These fibre optic sensors have been already used to monitor the structural health status of composite and concrete structures successfully. [4-7]

In this paper, cure monitoring of smart concrete cylinder had been performed using protected Extrinsic Fabry-Perot Interferometer (EFPI) and Fibre Bragg Grating (FBG) fibre optic sensors (FOSs) during 10-days. Both of EFPI and FBG sensors given correlation results with reference strain gauges. The results also indicate that the protected EFPI and FBG sensors are more sensitively to follow the change of environment temperature compared with commercial special strain gauges due to the special design of sensor protection system.

2. EFPI and FBG SENSORS

2.1 Extrinsic Fabry–Perot interferometric (EFPI) sensor

The basic principle of EFPI sensor is based on the multi-reflection Fabry-Perot interference between the two reflected mirrors. The schematic configuration of Extrinsic Fabry-Perot Interferometric sensor is shown in Figure 1. The EFPI sensor is made using a two single mode optical fibre as the two reflectors. The two fibres are inserted and fused into a quartz capillary tube with a larger diameter.
The two-components epoxy also been used to strengthening the bond between the bare fibres and capillary. In this EFPI sensor, a cavity comprising two reflectors that are parallel to each other and perpendicular to the axis of the optical fibres. The cavity length between the two surfaces of optical fibres is changed when an external load is applied onto this sensor. This can be measured by a CCD spectrometer through a 3dB 2x2 fibre coupler. The strain of the sensor is given according the following equation [4]

$$\varepsilon = \frac{\Delta d}{L} \qquad (1)$$

Where Δd is the change of the cavity length, L is the gauge length that is the distance between the two fusion spliced points on the micro capillary.

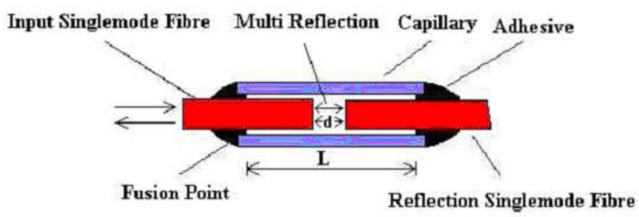


Figure 1 Schematic configuration of Extrinsic Fabry-Perot Interferometric (EFPI) sensor

2.2 Fibre Bragg grating (FBG) sensor

As far as we know the uniform fibre Bragg grating (FBG) includes a segment of optical fibre in which a periodic modulation of the core refractive index as shown in Figure 2. Usually, in-fibre FBG can be fabricated on the photosensitive (Ge-doped or hydrogen socked) single mode optical fibre by using the UV laser source in wavelength 240-248nm. Basically, the principle of the FBG sensor is based on the measurement of the changes in reflective signal, which is the centre wavelength of back-reflected light from a Bragg grating, depends on the effective refractive index of the core and the periodicity of the grating. According the Bragg condition, the Bragg wavelength can be expressed as [8] :

$$\lambda_B = 2n_{eff}\Lambda \qquad (2)$$

Where λ_B is Bragg grating wavelength, Λ is grating periodic spacing, n_{eff} is the effective reflective index of the fibre core. So the Bragg wavelength will shift with changes in either n_{eff} or Λ. When an external mechanical or thermal deformation is imposed onto the grating area, the effective reflective index will change as well as the periodic spacing.

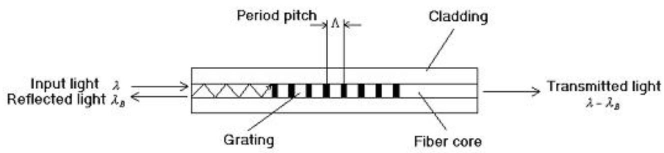
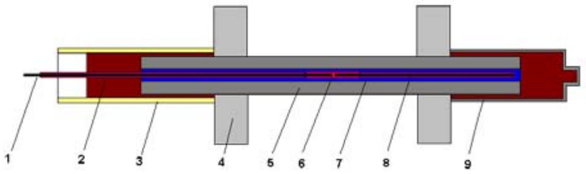


Figure 2 Schematic illustration of Fibre Bragg grating (FBG) sensor

3. EXPERIMENTS AND DISCUSSIONS

The inherent vulnerability of fibre optic sensors makes it difficult to protect the fibres from concrete aggregate in the pour duration and following service term. So these unprotected FOS can be damaged and corroded easily during the practical application of long term duration as the FOS normally contact with cements and aggregates directly. This disadvantage really limits the application of fibre optic sensors in concrete structures. Thus, the sensor protection systems are certainly demanded for the applications of fibre optic sensors in civil engineering. Previously, the protected FOS have been developed and used in concrete structures to perform the mechanical measurement [9]. Figure 3 shows the schematic illustration of the steel tube-based embedded sensor protection system (ESPS). Photograph of steel tube-based ESPS is shown in Figure 4. [9]



1 - Optical fibre 2- Silicone rubber 3- Thick PTFE tube 4 -Steel flange 5 - Steel tube 6 - FP sensor
7 - Epoxy adhesive 8 - Thin PTFE tube 9 - Fixed steel tube

Figure 3 Schematic illustration of the steel tube-based ESPS

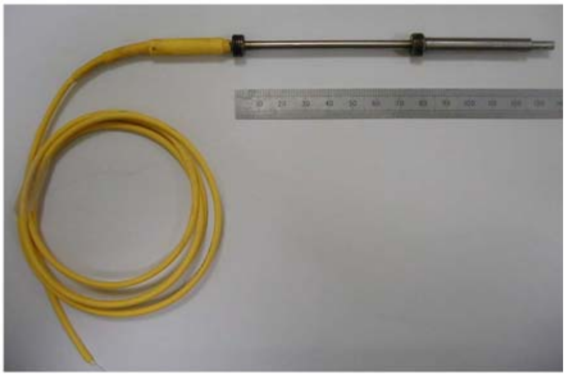


Figure 4 Photograph of the steel tube-based ESPS

The schematic diagram of experimental system of concrete cylinders with ESPS embedded EFPI and FBG fibre optic sensors for cure monitoring is shown in Figure 5. A conventional electrical resistance strain (ERS) gauge is surface bonded on the outside of steel tube to compare the strain transfer. A commercial special embedment ERS gauge from the Measurement Group that is normally used to monitor the cure of concrete materials is also embedded in the cylinder as a reference measurement. The thermocouple temperature sensors are put in the concrete cylinder and water tank to monitor the environment temperature. The cure development of concrete cylinders using EFPI sensor is shown in Figure 6. It can be found that the cure strain is increased to 60 $\mu\varepsilon$ during the first 48 hours at early cure age. Then the cure strain is going to constant with certain periodical perturbation during the following 10-days. It can be speculated that the periodical perturbations are caused by changed ambient temperature from day to night during the cure period. Thus, this leads to additional materials shrinkage deformation of cement mortar. As we can see that the perturbations given by EFPI and conventional ERS sensors are much bigger than that from commercial special strain gauge. The reason is that embedded sensor protection systems can strongly hold with surrounding cement and transfer the cure strain more effectively. At the same time, the perturbations also prove that the protected EFPI and FBG sensors are more sensitively to follow the change of environment temperature compared with commercial special strain gauges due to the special design of ESPS. It also emerged that the early age deformation is much bigger and is normally composed of the thermal deformation (swelling and shrinkage), endogenous shrinkage, carbonation shrinkage and the evaporation shrinkage. The deformation due to auto stressing provoked by stiffness of formwork can be considered as negligible [10]. Same phenomenon can be validated in Figure 7 when protected FBG sensor is used to monitor the cure progress. Obviously, it can be found that the FBG sensors can be used to monitor the cure strain and have very good agreement with conventional strain gauge sensors. This means there is very good strain transfer between the fibre optic sensor inside of steel tube and strain gauge mounted on the surface of steel tube.

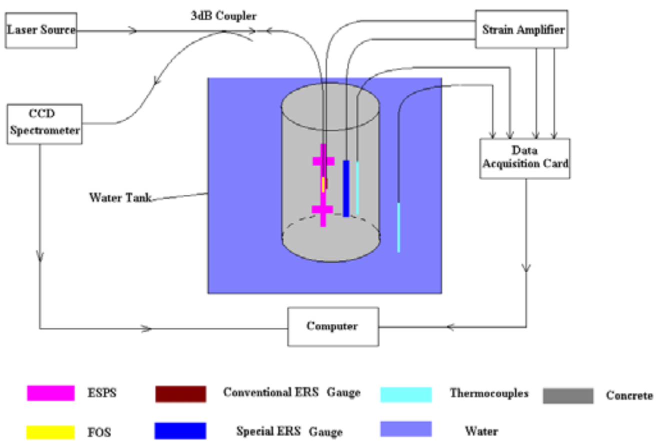


Figure 5 Schematic diagram of cure monitoring of concrete cylinders with embedded FOS

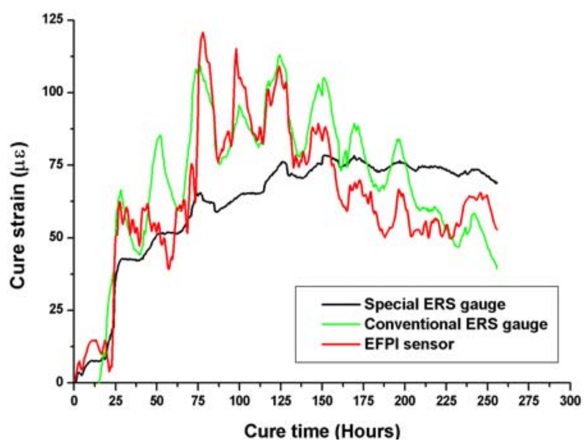


Figure 6 Cure monitoring of concrete cylinder using EFPI sensors

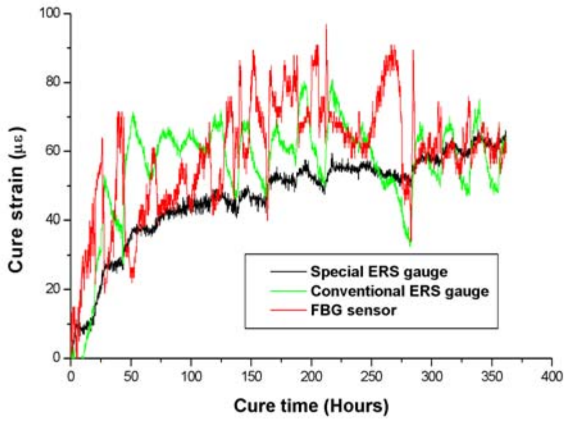


Figure 7 Cure monitoring of concrete cylinder using FBG sensors

4. CONCLUTIONS

In this paper, The ESPS with EFPI sensor then have been embedded in the concrete cylinders to monitor the cure development during 10-days duration. Some important conclusions can be obtained:

a. The Fibre optic sensors (FOSs) can be protected effectively by embedded sensors protection system (ESPS) in concrete structures.

b. The cure strain of concrete materials can be monitored from early cure age by using EFPI sensors. Better sensitivity is found using ESPS for comparison with commercial special strain gauge.

Therefore, the above mentioned ESPS are suitable achieve the structural health monitoring in practica such as smart bridge, smart highway, smart building in future for different type of the FOS such as Fibre Bragg grating, fluorescence-based temperature sensors, etc..

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