A pilot Study: Evaluation of sensor system design for optical fibre humidity sensors subjected to aggressive air sewer environment

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***Abstract*—Research has identified that humidity plays a fundamental role on the conversion of hydrogen sulphide into sulphuric acid during corrosion of concrete in gravity sewers and that potentially minor reductions in humidity can reduce corrosion rates. The high levels of hydrogen sulfide and the high relative humidity (typically > 98%) that leads to condensation in sewer air makes humidity measurement within such environment difficult. The work presented here aims to tackle this issue by applying a more durable packaging that could withstand the harsh environment. The humidity monitoring element in the probe is based on a moisture-sensitive polymer coated fibre grating in series with an uncoated grating for temperature compensation. To optimize the device to be operational, two designs of the probe assembly were configured using different material, thus aiming to provide long term durability. The aim of the probe design evaluated was to achieve both a good sensitivity to humidity and to protect the sensing elements from the aggressive environment and which had rendered ineffective the electrical sensors placed in the sewer and used for cross-comparison. The packaged sensors were trailed in situ over a period of 5 months, during which the sensors were constantly subjected to the prevailing high, but varying levels of humidity and hydrogen sulfide gas. The results show the significant promise for tailor made packaging which will protect the sensor element from the harsh environment while retaining good sensitivity. These outcomes show a promising future for optical fiber sensors to be employed for the measurement of humidity in the long term in harsh environmental applications.**

Keywords—Optical Fiber Sensor; Fiber Bragg Grating; Fibre sensor packaging; Polyimide; Polyether ether ketone

I. Introduction

Concrete sewer corrosion depends on humidity which, although variable, is high in the overhead space of gravity sewer pipes. The link between moisture and corrosion is also supported by various literature reports [1,2]. In order to be able to predict corrosion rates (and thus schedule maintenance more efficiently) it is necessary to have reliable humidity measurements on or near the surface of the concrete. The influence of humidity on corrosion of sewer concrete is over-looked, mainly due to the lack of sensors that can withstand the aggressive and fouling conditions of gaseous hydrogen sulfide (H_2S) that is present. The aggressive sewer environment rapidly destroys electronic sensors that have been evaluated previously in this environment because they corrode in the constant high humidity and acidic environment. An important alternative technology has been developed in recent years - there has been enormous growth in-fibre optic sensor technology as new applications open up and the technology matures. Optical fibre-based sensors possess a number of advantages over conventional electrical/electronic sensors in general, such as immunity to electromagnetic interference, chemical inertness, light weight and low mass (which facilitates 'drying' after use), multiplexing capability, high thermal stability and remote sensing ability, all of which make them well suited to both general and remote sensing. In light of the deficiencies of conventional technologies for this particular application, these advantages make them ideal candidates for measurement applications where such conventional electrical/electronic sensors are found to be inappropriate or simply would not function. Thus considerable research effort on fibre-optic (FO)-based techniques for humidity sensing has been seen [3,4], much of it by the authors, and this provides the basis for the approach taken in this work.

The most critical element of the work is the design of the sensor system – in particular the 'packaging' of the device so that the sensor element is well protected from the chemically aggressive and fouling environment but is exposed to measure humidity adequately. Although optical fibre itself is less likely to be attacked by gaseous H_2S as they are made of glass, the moisture sensitive polymer that is used for the measurement of humidity could potentially react with the acidic environment and therefore would need protection. This paper discusses system performance and the main sensing mechanism used, especially two types of sensor packaging designs that were utilised to meet the task.

II. Sensor Element Mechanism

For this particular application optical fibre Bragg gratings (FBGs) were fabricated using phase masks illuminated by light from a 248 nm KrF excimer laser with a pulse energy of 12 mJ and a pulse frequency of 200 Hz. Subsequently the gratings were annealed at 200°C for 3 hours to avoid any thermal drifting of the FBGs. An in-house dip-coating system was used for coating the FBGs with commercially bought Polyimide (PI 2525 from Hitachi Chemical DuPont MicroSystems).

Following the above process, four different sensor elements were fabricated for evaluation – to allow for breakage or damage during installation. In each, the sensor as packaged in the system contains two FBGs in series, one for temperature measurement only and the other a FBG coated with a thin layer of moisture sensitive polyimide for RH measurement. This is shown in Fig. 1. More information on fabrication and sensor element basic design can be found elsewhere [5].

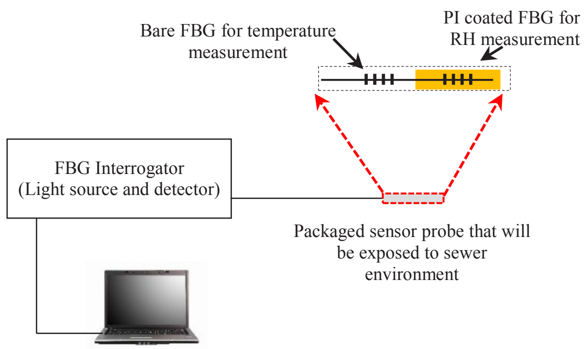


Fig. 1. Sensor interrogation setup.

III. Sensor System Designs

Following the fabrication and calibration of the sensors, two different sensor packaging types were considered. Several potentially suitable packaging designs were evaluated to optimize performance in the known aggressive environment. Ultimately, two different packaging options that were seen to be the best candidates for the evaluations to be carried out were explored:

A. 3D printed Epoxy

This approach inexpensive, quick to fabricate and could be done 'in-house'. The design comprised a 3D printed epoxy rod, with a small grove in the middle into which the fiber containing the sensors were inserted. The region of the fiber containing the sensing regions was exposed to air on one end which is protected with a 3D-printed perforated cap, which could easily be removed for inspection. This sensor packaging is illustrated in Fig. 2 where a comparison to the commercial electrical sensor can also be seen.

B. PEEK (Polyether ether ketone)

A second approach to the sensor design was used, based on a PEEK packaging design that has been introduced by some of the authors [6]. This was a more complex design to implement, but potentially more robust and chemically resistant. The sensors were embedded into a tube made of PEEK and perforated at the tip. The perforated tip ensures that the sensing element is exposed to water vapour. For further protection, the perforated tip was then covered using a permeable Polytetrafluoroethylene (PTFE) membrane to protect the sensor against the sewer environment. Finally the PTFE membrane and the PEEK tube were covered again using a perforated PEEK rod with a centrically bore hole. A schematic of this design can be seen in Fig. 3. This creates a robust configuration for the sensor system for the aggressive environment and the exterior view of this packaging can be seen in Fig. 4.

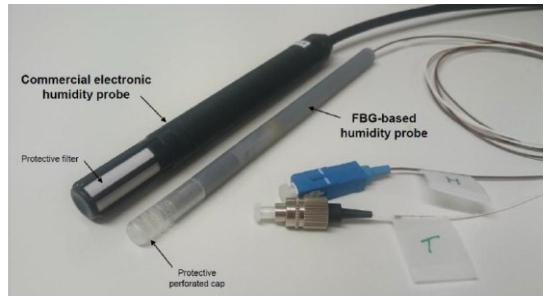


Fig. 2. Sensor system designed using 3D-printed epoxy packaging and for comparison a conventional commercial electronic humidity probe (left).

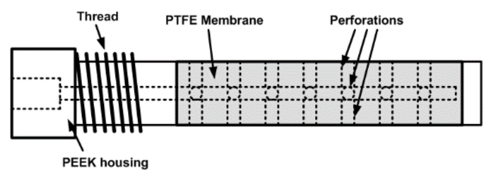


Fig. 3. Illustration of the sensor using the PEEK sensor housing.

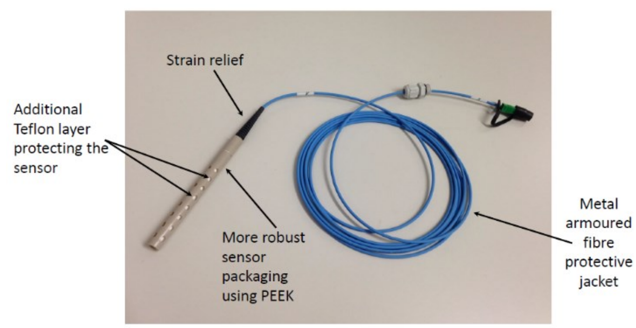
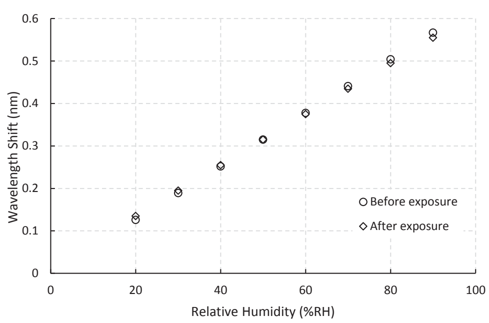


Fig. 4. Sensor system designed using PEEK packaging (with fiber optic connections to the interrogation system).

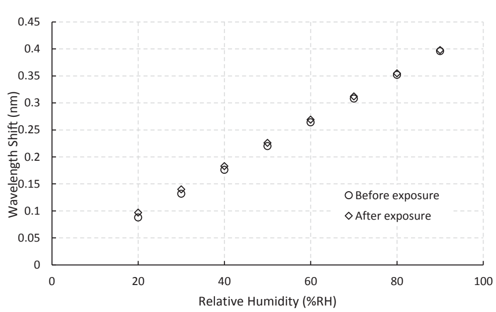
IV. Results after Test Period

The sensor systems which were configured as shown above were calibrated before and after the exposure to aggressive sewer environment (5 months continuous exposure). The visible observations of the deterioration of both the PEEK and Epoxy packaging could be seen from Fig. 5. Following the calibration tests performed on the sensor probes after the trial, they were compared with that of the calibration results prior to exposure. This can be seen in Fig. 6. As can be seen, the PEEK and Epoxy packaging designs have protected the sensing element and therefore the sensors were still performing well with an acceptable level of sensitivity (~4 pm/%RH for the Epoxy sensor and ~6 pm/%RH for the PEEK sensor).

Fig. 5. Visible inspection of the PEEK (above) and epoxy (below) packaging after extended exposure in the sewer environment.



(a)



(b)

Fig. 6. Calibration results before and after exposure to the sewer environment for 5 months; (a) PEEK packaging and (b) epoxy packaging.

V. Discussion and Conclusion

The sensor schemes chosen, using a coated fibre optic humidity sensor approach works well but the packaging plays a vital role in increasing the durability of the sensor as the sensing element needs to be effectively protected against harsh environment. In this work the performance of two packaging schemes around a similar fibre optic based humidity sensor itself and operated in an aggressive sewer environment is reported. The evaluation verified that both the packaging choices made are able to protect the sensor against the effects of the gaseous H_2S that was present over the period of the tests and proved superior to the performance of conventional sensors. The moisture sensing element shows a linear response to humidity and is calibrated, with compensation included to allow for temperature variations. Although both the fully packaged sensors survived well, the PEEK packaging is recommended for even longer periods of exposure. Both the nature of the material and the use of the Teflon layer meant that the sensor element is very well protected, with the outer material showing less effect due to fouling (Fig. 5). Work is ongoing to evaluate the sensor packaging design for extended test periods.

Acknowledgment

The authors would like to acknowledge the technical discussions with J. Gonzalez and L. Vorreiter from Sydney Water. The support of the Edinburgh Napier University Early Career Researcher's fund, the Royal Academy of Engineering and the George Daniels Educational Trust is greatly appreciated.

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