OPTICAL FIBER SENSORS IN CIVIL ENGINEERING APPLICATIONS FOR STRUCTURAL HEALTH MONITORING

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Introduction

Bridges, tunnels, dams and a wide range of buildings, large and small, require maintenance to keep them in operation and the planning and scheduling of such maintenance is critical to optimize the use of the resources needed. To date only a limited range of measurement systems have become available to monitor parameters such as stress and strain, vibration and temperature and there is a need for better information on the chemical changes that occur in structures as a result of ingress of chemicals from the environment. For example, failure of our civil infrastructure caused by corrosion of the structural members, costs in excess of $1 billion annually in the US alone in terms of repair, rehabilitation and replacement and can be a danger to us all. To achieve better usage of our current and future civil structures, there is a real need to have a clear knowledge of the status of these structures as they age.

Structural Degradation and Monitoring Strategies

Structural Health Monitoring (SHM) is defined as the use of metrology techniques and sensors to provide a continuous assessment of the state of engineering structures. Structural degradation tends to be statistical in nature, rather than deterministic, and there is particular value to be gained from reliable *in situ* integrity monitoring, that can be achieved through the design and the implementation of suitable instrumentation to yield data at all stages during the lifetime of a structure, including prior to and post repair. To do so effective instrumentation is needed to give the requisite data: devices installed for such assessment should be capable of providing the means to implement ongoing condition maintenance and overall lifetime prediction, including post-repair lifetime and design verification for new structures. Addressing this is the use of new, calibrated monitoring devices applied both during the damage phases and additionally during repair procedures, to allow the effects of degradation and of repair on a range of structures to be evaluated .

Experimental

Sensor Systems and SHM

Fibre optic sensors (the focus of the work) have enormous potential for structural monitoring: they offer advantages over the electrical systems in a number of ways, namely they are small and lightweight, non-electrical in operation and are immune to electromagnetic interference. A number of sensor types and systems are often considered, including strain and temperature sensors, chemical sensors for pH (to detect carbonation), chloride attack and water (moisture) ingress, as prime examples. Two specific examples of the innovations in these areas are given below.

Mositure Sensing in Concrete Structures

The Fiber Bragg Grating (FBG)-based moisture sensor used in this work has been discussed before by some of the authors [1] and has been used successfully to evaluate the time taken for water to permeate concrete samples. In summary, the operation of the FBG-based moisture sensor is based on the swelling of a moisture-sensitive polymer coated on the sensing element which is formed by periodic refractive index modulation of a photosensitive optical fiber [2]. The expansion of the coating layer, as a result of the moisture absorption, induces a secondary strain effect on the polymer-coated FBG, causing the optical fiber to stretch. Since an FBG is inherently sensitive to the applied strain and temperature change, it perturbs the effective refractive index and the period of the sensing element, consequently causing the central wavelength of the resonance peak or dip (known as the Bragg wavelength) to shift. The change in wavelength of the sensor is thus calibrated under standardized conditions against the humidity/moisture level and this sensor is then mounted in standardized concrete samples.

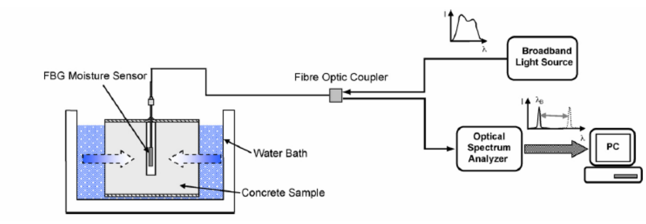

Figure 1 Moisture ingress test set up

The calibration of the sensor is shown in Figure 2 below, illustrating the change in the Bragg wavelength with relative humidity at constant temperature (23°C).

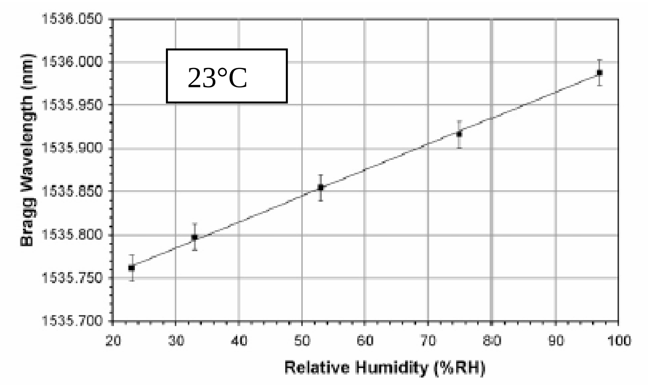

Figure 2 Calibration of the relative humidity sensor

Two different samples were tested: they were prepared at the same time and showed some small variations in their response, as shown in Figure 3. The results show the ability of the sensor to measure the porosity of the concrete sample through the time taken for the water to transit the sample and to reach the sensor placed at its centre (Figure 1). At the end of the test their compressive strengths were measured and found to differ by only a small margin (Sample 1: 11.9 N/mm^2; Sample 2 12.9 N/mm^2). Results have been taken on a wide range of samples: the exposure of the samples to repeated 'freeze-thaw' cycles (not shown here) has given useful information on the porosity changes of the samples under similar tests.

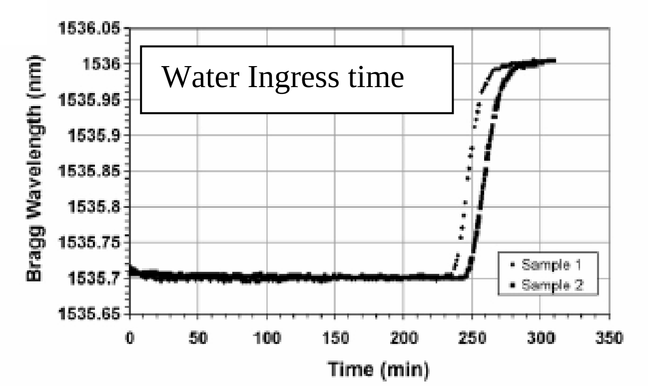

Figure 3 Water ingress time as a function of calibration wavelength (proportional to RH) for 2 samples tested

pH monitoring in concrete samples

pH sensors have been created to measure changes in this key parameter in concrete samples exposed to carbonation through absorption of atmospheric carbon dioxide: this has implication for the degradation of the structure through the enhanced corrosion of the metal reinforcement (the 'rebar'). The system developed [3] used a visible light source, a miniature spectrometer, and a fiber optic sensor using an indicator dye encapsulated in a sol-gel, as shown in Figure 4.

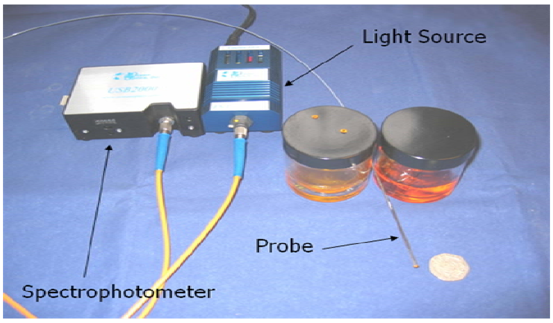

Figure 4 Experimental set up for pH monitoring probe for concrete samples

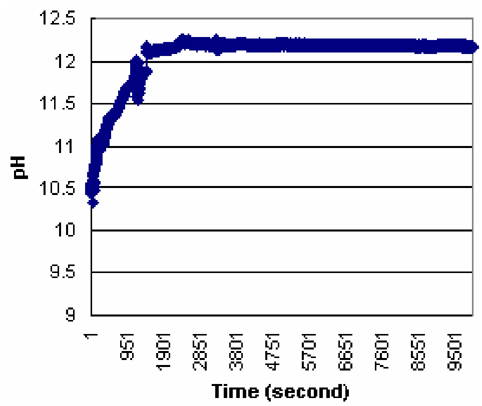

Figure 5 pH measurements – concrete pore fluid

Figure 5 shows result taken from extracted pore fluid of a concrete sample and illustrates the ability to measure the very high pH present – the long stabilization time of the sensor (as seen from the x axis) is a reflection of the design of the sensor to promote high durability (hardness) to overcome the very alkaline conditions of the sample.

Further results on these and other fiber optic sensors used for structural monitoring will form the basis of the paper.

References

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2. T.L. Yeo, D. Eckstein, B. McKinley, L.F. Boswell, T. Sun, K.T.V. Grattan, Demonstration of fibre optic sensing technique for the measurement of moisture absorption in concrete, *Smart Materials and* , 15 (2006) N40–N45.
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