Temperature characterisation of LPG sensors for monitoring deterioration in reinforced concrete

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Published version

O'FLAHERTY, Fin, GHASSEMLOOY, Zabih, MANGAT, Pal and DOWKER, K. (2003). Temperature characterisation of LPG sensors for monitoring deterioration in reinforced concrete. In: ILCDES 2003: Integrated Lifetime Engineering of Buildings and Civil Infrastructures. Rotterdam, In-house, 1001-1006.

Temperature Characterisation of LPG Sensors for Monitoring Deterioration in Reinforced Concrete

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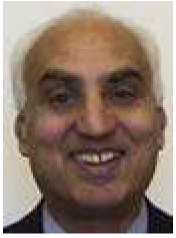

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Summary

Optical fibre technology is increasingly being used to monitor stresses and strains in structural members, thus leading to the development of intelligent structures. A research project is currently underway to further expand on the development of optical strain sensors by developing sensors for deterioration monitoring in reinforced concrete. A prototype sensor based on long period fibre gratings (LPGs) is being produced that will detect chemical changes within the concrete and on the steel reinforcement surface, thus indicating initiation of corrosion. Novel coatings will be adhered to the surface of the LPG which react with chemical changes and corrosion inducing substances at the steel/concrete interface thus changing the optical properties of the LPG.

The paper presents the results of preliminary tests to characterise the LPG for temperature variations. The purpose of the tests is twofold: firstly, to determine if the LPG is sensitive to a varying external medium and secondly, to compensate for the effects of temperature in the working sensor. It is shown that the temperature coefficients for the LPGs considered do not vary too much if water is used as the external medium instead of air. It is also shown that the temperature response of LPGs can be both positive and negative. Low order resonance bands are shown to be as sensitive to temperature changes as high order bands. Finally, the importance of keeping LPGs taut when testing is emphasised as results are affected by bend-induced spectral changes.

Keywords: Long period gratings, sensors, temperature, concrete deterioration

1 Introduction

Optical fibre technology involves the transmission of light through a transparent fibre waveguide of plastic or glass. By controlling the light source, a signal representing information is transmitted through the optical fibre from the signal source to the receiver. The optical signal features distinct amplitude, phase, frequency or polarisation characteristics. Generally, an optical fibre consists of a glass fibre core surrounded by some form of cladding and protective coating and may carry one (single-mode) or many modes (multi-mode) of lightwave (Figure 1). Typical core diameters range from 5 to 50 µm, with cladding and coating diameters of 125 and 150 µm respectively [1].

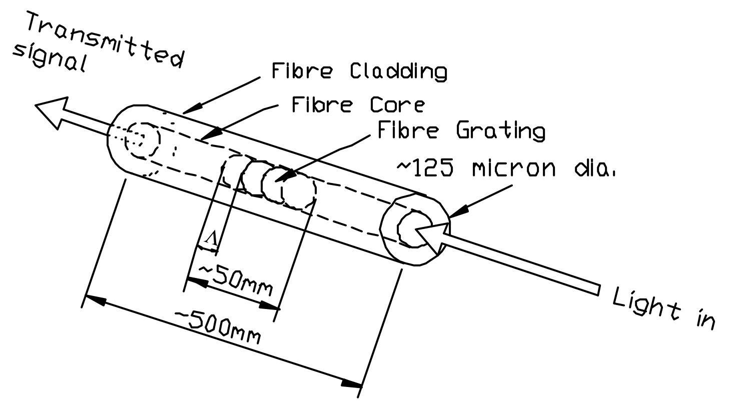

Figure 1 Schematic diagram of the LPG fibre sensor

Optical fibres are classified as *intrinsic* if the effect of the measurand on the light being transmitted takes place in the fibre. The sensor is considered *extrinsic* if the fibre carries the light from the source and to the detector, but the modulation occurs outside the fibre. Fibre optic sensors may be divided into two main categories: intensiometric and interferometric. *Intensiometric* sensors are simply based on the amount of light detected through the fibre [2]. An *interferometric* sensor is based on the detection of changes in the phase of light emerging out of a single mode fibre.

Long period gratings written in optical fibres are becoming increasingly important in fibre optics communications and optical sensing. LPGs were first presented by Versangkar et al [3] as optical filters in 1995. LPGs are made by illuminating photosensitive fibres with intense UV light in order to create a periodic increase in the refractive index of the core along the length of the fibres. The fundamental mode travelling in the core is diffracted by the gratings and is excited to cladding modes which are quickly attenuated. Hence, loss bands or resonance bands are observed in the transmission spectrum. For an LPG of a given periodicity and index modulation, the wavelengths at which the loss bands appear depend on the ambient temperature among other factors. Hence, the temperature characteristics of LPGs are very important in both communication and sensing applications.

Optical fibre technology has been used extensively in the past for structural strain monitoring, partly due to the size of the fibre which does not affect the properties of the concrete in which they are embedded [2]. The ability to interrogate numerous sensors multiplexed along a single fibre permits an entire structure to be fitted with sensors with a manageable number of leads routed to central points.

2 Applications to Date

There is widespread use of optical fibre technology in infrastructure monitoring to date, mainly for strain monitoring but more recently, they have been used to monitor corrosion in reinforced concrete structures. For example, fibre optic sensors have been embedded in several newly constructed civil structures, including bridges, buildings and dams yielding information about static and dynamic strain, temperature, wind or water pressure and structural health [2]. A multiplexed Bragg grating optical fibre monitoring system was designed and integrated at the construction stage in an experimental full scale laboratory bridge. The network of sensors was used to measure the strain throughout the bridge, with sensors bonded to the tension steel in the slab, and attached to the bottom flange of the girders [4].

With regards to corrosion monitoring, a multiple parameter sensing fibre optic sensor was embedded into roadway and bridge structures to provide an internal measurement and assessment of its health. The presence of corrosion was determined via colour modulation of the broadband. The input light emerges from the fibre at its end and if the fibre is in close proximity (<10 mm) to the corroding rebar, the light signal illuminates the rebar, is colour modulated with respect to the surface colour of the localised region of the rebar, and is reflected with some of the reflected signal injected back into the optical fibre. The colour modulated signal then travels back down the fibre and is sensed via standard spectroscopy. A colour shift in the input signal indicates that corrosion is present [5]. However, a significant downside to the effectiveness of this sensor is that it is difficult to ensure that the fibre is in the proximity of the rebar and the exit light is not obstructed by the constituents of the concrete. The fibres are small in size (typically less than 100 nm in diameter) and they present very small entrance and exit apertures. As such, it is difficult to launch and receive significant amounts of light when using these multimode optical fibres.

3 Experimental Procedure

In this paper, 3 different LPGs were tested to establish their temperature characteristics. The LPGs are referred to as fibres A, B and C and the specifications of each are given in Table 1. Fibres A and C each exhibited one loss band at 1551.2 and 1566.6 nm respectively when tested at 24°C, whereas two loss bands were observed at 1304.0 and 1557.3 nm for Fibre B. The temperature response of the LPGs was determined with either air or water as the ambient medium. In both cases the wavelength shifts was determined using an optical spectrum analyser (HP 86140A) which had two built-in LEDs centred at 1310 nm and 1550 nm.

Table 1 Specification of LPGs

Fibre	Type of Fibre	Grating Period, Λ (μm)	Resonance Wavelength in Air 24°C (nm)
A	Corning	700	1551.2
B	"	410	1304.0 & 1557.3
C	"	700	1566.6

3.1 Temperature Response in Air

To determine the temperature response in air, the set-up shown in Figure 2 was adopted. Fibres A, B and C were each tested in turn. The fibres were held straight between two holders with the gratings passing through an oven in the set-up (Figure 2). The temperature of the oven was controlled by varying the applied voltage using a stabilised power supply. The oven temperature was increased to 64°C and the corresponding locations of resonance bands were periodically recorded as the temperature dropped. A decrease in temperature was achieved by reducing the applied voltage to the power supply. Results are given in Section 4.

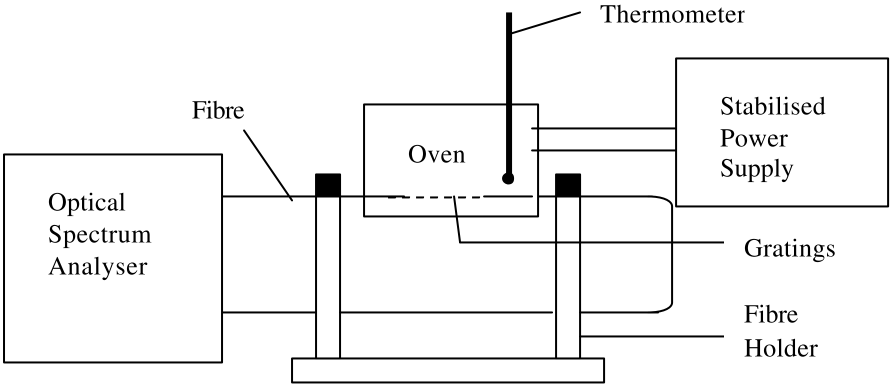

Figure 2 Experimental set-up for temperature response of LPGs in air

3.2 Temperature Response in Water

The temperature response of the fibres in water was determined through the use of a water bath as shown in Figure 3. Again, the LPG was kept taut between two clamps with the gratings submerged in the hot water (maximum temperature 40°C). The resonance wavelengths were recorded as the water cooled to room temperature. Cold water was added to further reduce the temperature to 8°C. The wavelengths of the resonance bands were again periodically recorded using an optical spectrum analyser (OSA) as the temperature decreased and are presented in Section 4.

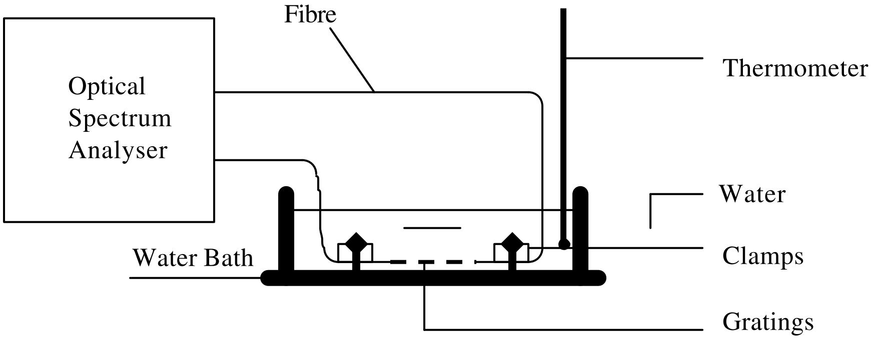

Figure 3 Experimental set-up for temperature response of LPGs in water

4 Experimental Results and Discussions

4.1 Temperature Sensitivity in Air and Water

The datum resonance wavelength for Fibre A was 1551.2 nm at 24°C (room temperature). The maximum air temperature employed was 64°C and the minimum was 24°C. The shift in wavelength due to a reduction in air temperature was recorded and is shown in Figure 4 (Graph α). A temperature coefficient of -0.2569 nm/°C was obtained for Fibre A from the best fit equation of the line (the negative temperature response is explained later in the paper).

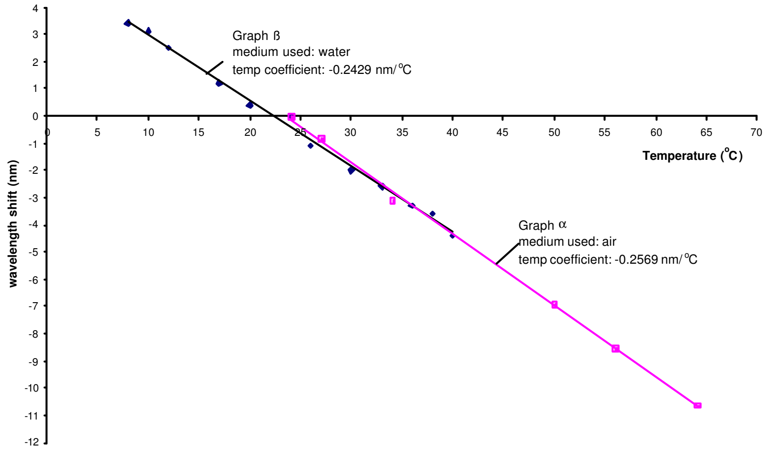

Figure 4 Wavelength shift in Fibre A due to temperature variations

The same fibre (LPG A) was tested for temperature response with water as the ambient medium instead of air. The temperatures ranged between a high of 40°C and a low of 8°C. Graph ß (Figure 4) shows the temperature response of the LPG. The temperature coefficient was found to be -0.2429 nm/°C which is similar to the temperature coefficient when tested in air. In practice, the index of refraction of most fluids reduces with an increase in temperature. Since LPGs are sensitive to external index changes [6], a wavelength shift due to the thermal-induced refractive index will occur and this will add to the temperature sensitivity of the grating. Therefore, a higher temperature coefficient for water would be expected. However, the change in temperature involved in this experiment was too small too cause any significant change in the two temperature coefficients.

4.2 Positive and Negative Temperature Responses

The temperature experiment using air as a medium was repeated using LPG B and testing was performed in the 1550 nm region to allow comparisons to be made with the test results in air from LPG A. The air temperature ranged between 63.5°C and 24°C as shown in Figure 5 and Table 2. The temperature coefficient obtained from the best fit line in Figure 5 was +0.0595 nm/°C. This positive temperature coefficient implies that the grating is operating in the normal region. However, the temperature coefficient obtained for LPG A (Figure 4, Graph α) was negative (-0.2429 nm/°C) and this implies that LPG A was operating in the anomalous region at the wavelength considered [7].

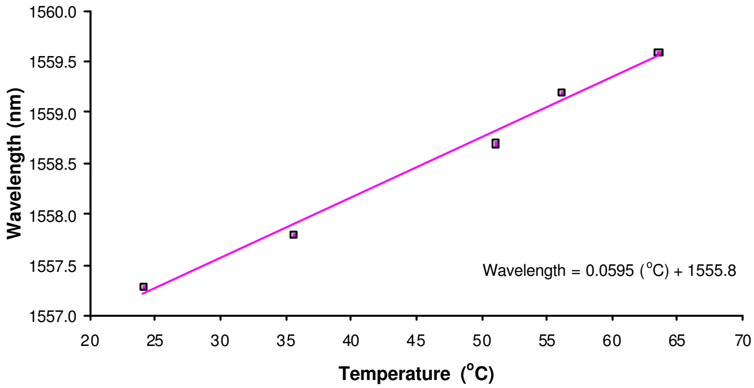

Figure 5 Temperature profile of LPG B in air (1550nm region)

Table 2 Temperature results for LPG B in air (1550nm region)

Temperature (°C)	Resonance wavelength (1550nm region)
63.5	1559.6
56	1559.2
51	1558.7
35.5	1557.8
24	1557.2

Hence, it is shown that the temperature profile of LPGs can be both positive and negative depending upon the characteristics of the gratings at the wavelength considered. The temperature coefficient for LPG B (+0.0595 nm/°C) is one order of magnitude lower that that for LPG A (-0.2569 nm/°C). Hence, LPG B is less affected by temperature variations and can therefore be used for purposes which require the LPG to remain unaffected by small changes in temperature.

4.3 Temperature Sensitivity of Different Resonance Bands

A major advantage of LPGs is the presence of multiple resonance bands which can be used for multi-parameter sensing [7]. In the current investigation, LPG B exhibited two resonance bands at 1304.0 and 1557.3 nm and their response to variations in air temperature is presented. The temperature coefficient for LPG B when tested in air in the 1550nm band is +0.0595 nm/°C as shown in Figure 5. Figure 6 shows the shift in the resonance wavelength at 1304 nm for the same fibre (LPG B) when also tested in air. The temperature coefficient obtained was +0.0505 nm/°C (Figure 6) which is very similar to that obtained for the 1550nm resonance band (+0.0595 nm/°C, Figure 6). This shows that lower order bands can be as sensitive to temperature variations as higher order bands. Hence, in multi-parameter sensing, lower order bands can be used to monitor temperature changes while higher order bands can be used to detect external index changes [7].

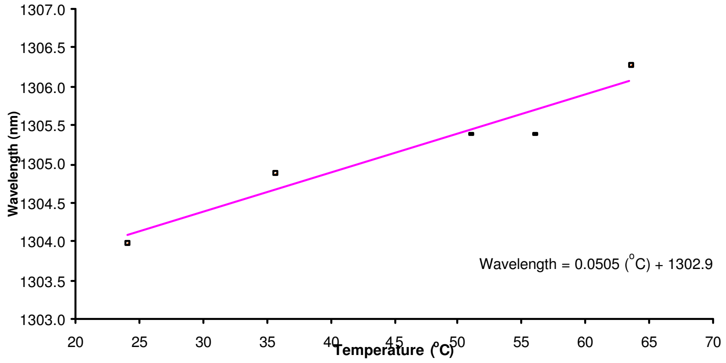

Figure 6 Temperature profile of coupling wavelength of LPG B in air (1310nm region)

4.4 Bend-Induced Spectral Changes

LPG C was used in the water bath to determine the response to temperature variations. The water temperature ranged between 27 °C and 48 °C. In this test, the LPG was not tensioned by the clamps. The response to temperature variations is shown in Figure 7. Referring to Figure 7, a linear relationship was evident at higher temperatures (between 33 °C and 48 °C). However, at lower temperatures (27 °C to 33 °C), two dips were observed on the spectrum analyser and the temperature response was no longer linear (Figure 7). This is probably due to bend-induced spectral changes which occurred when testing at lower temperatures. This depicts the importance of keeping the fibre taut when using LPGs.

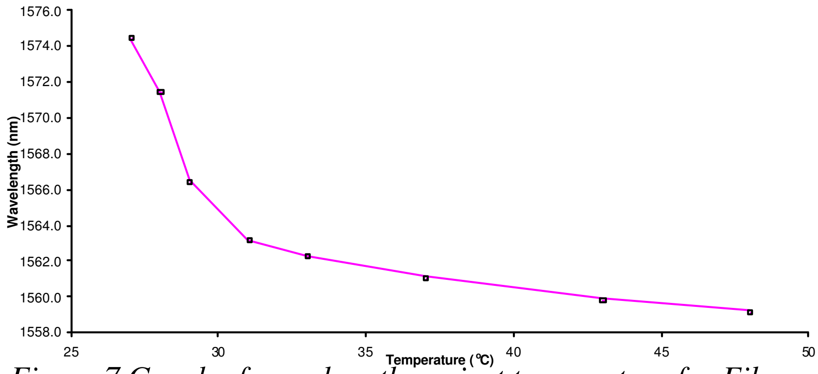

Figure 7 Graph of wavelength against temperature for Fibre C when tested in water

5 Conclusions

The following conclusions are obtained from laboratory tests to characterise LPGs for temperature variations:

- the temperature coefficients for water and air are similar
- LPGs can exhibit both positive and negative temperature profiles depending on whether they are operating in the normal or anomalous region
- LPGs can be used for multi-parameter sensing since low order bands are as sensitive to temperature as high order bands
- LPGs should be taut when testing as bends in the fibre influence the measured wavelength

6 Acknowledgements

The information presented in this paper is from a research project entitled 'Utilisation of LPG sensors for monitoring deterioration processes in reinforced concrete'. The authors wish to acknowledge the financial support provided by The Engineering and Physical Sciences Research Council (EPSRC).

7 References

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