Embedded Fibre Bragg Gratings to Measure Shrinkage During the Early Age of Concrete.

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***Abstract*—The early-age shrinkage of concrete was investigated using optical Fibre Bragg Grating (FBG) strain sensors. Two methods were implemented – a tube and strut mechanical transducer using a FBG sensor and a surface embedded groove FBG sensor. The two sensor methods were compared with a conventional method (Venier caliper), showing that results correlate.**

Keywords—fibre Bragg grating, fibre optic sensor, early-age shrinkage, concrete shrinkage, fibre optic sensor embedment.

I. Introduction

Two important reasons for hardened concrete to shrink are drying shrinkage and autogenous shrinkage [1]. Any excessive shrinkage negatively affects the structural performance of the concrete. It is therefore necessary to quantify concrete shrinkage so that preventive or corrective measures can be taken to ensure proper structural performance. By developing a system to measure this shrinkage in concrete early on, it could aid in detecting and abetting unacceptable structural performance.

Much research has been performed on the use of optical sensors for structure condition monitoring. However the majority of this research has been focused on the long term health of the structure and thus investigates/monitors the properties of hardened concrete by measuring the strain. Banerji et al [2] used optical sensors for health monitoring of a concrete box-girder bridge. In this work optical fiber strain gauges were clamped to the surface of the bridge using grouted studs. Heininger et al [3] investigated the effects of pre-stressing concrete using optical sensors in which the sensors were glued on hardened concrete. Kerrouche et al [4] tested a concrete bridge to failure and monitored it with optical sensors. In this application the sensor network was embedded into Carbon Fiber Reinforced Polymer (CFRP) rods, fixed with low viscosity cyanoacrylate glue and then covered with an epoxy resin. The results form [2], [3], [4], [5] show that FBG sensors can be successfully embedded into and onto civil structures for quantitative measurement of concrete structure strain to assess structure health.

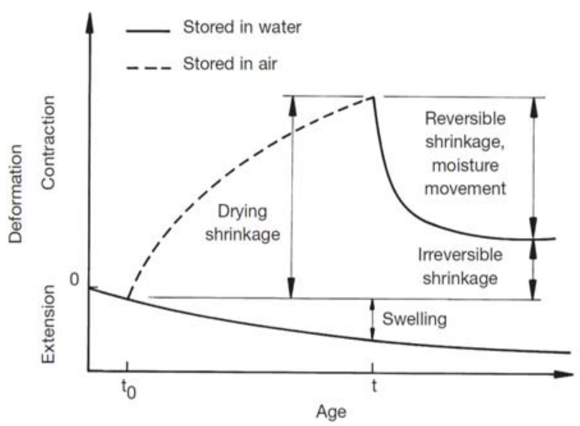

Figure 1 Moisture movement and deformation in concrete: concrete that dried from age t_0 until age t and was then re-saturated [14]

Very few investigation into embedding of sensors into early-age (fresh, green and first few days of hardened stage) have been done [6], [7]. This is possibly caused by the difficulty in the attachment of sensors to the fresh and green concrete however much of the total shrinkage of the concrete occurs during the early stage. From a practical point of view, it is difficult to attach displacement or strain gauges to a concrete specimen as most shrinkage measurements start form the time of demoulding the concrete specimen [7].

Conventional instruments used to measure shrinkage in concrete can be divided into contact, such as electrical strain gauges and mechanical strain gauges [8], [9], [10], and non-contact sensors such as digital photogrammetric methods [11], Moiré interferometry [12] and non-contact laser technology [9]. These instruments have some constraints such as: the requirement for frequent calibration, cumbersome to transport and operate, high cost, lack of electromagnetic immunity and most do not have the potential to perform as an integrated measuring device. Fibre Bragg gratings is a useful alternative as a measuring sensor for shrinkage and has the potential to perform as an integrated measuring system to statically and dynamically monitor parameters such as shrinkage, temperature and stress in concrete members from the early stage of concrete [13].

In this work a method and results are presented to measure shrinkage during the early stage/s of concrete by using fibre Bragg gratings. To overcome the difficulty of attaching a sensor during the fresh stage of concrete, a mechanical transducer was implemented.

II. Background

A. Concrete States

There are three stages in conventional concrete's life, namely fresh, green and hardened. Heat and water movement generated during these stages cause the concrete to experience shrinkage (see Figure 1). Shrinkage is moisture-dependent and normally altered by the cement composite.

The length of the fresh stage is dependent on, the type of cement used, the type of chemical admixture used, the relative humidity and the ambient temperature. This stage lasts for about 4 to 6 hours. In the fresh stage the concrete acts like a liquid and water moves to the top of the mixture. No heat is generated by the concrete [14].

The green stage lasts about 2 to 4 hours. During this time the concrete turns into a semi-solid, and water stops rising to the upper surface of the concrete [14]. It is during this time that the surface finish of the concrete is applied. The exothermic reaction of cement hydration happens during this time and heat is generated [14].

The third stage occurs when concrete hardens, and gains strength. A lot of heat is generated initially, but dissipates over time [14]. During this process the final volume of the concrete member is set. This means temperature effects must be compensated for in any strain measurements during the early stages of concrete shrinkage.

B. Fibre Bragg Grating (FBG) as an optical sensor

FBGs are intrinsic fibre elements in optical fibres where the refractive index of the fibre core is periodically modulated by illuminating it with UV light. The length of the FBG, which is an integral part of the fibre, is normally a few millimetres [15].

When light from a broadband source is launched in the fibre and propagates through this modulated structure, Bragg reflection causes one wavelength to be selectively reflected that satisfies equation (1), while the rest of the wavelengths are transmitted. The reflected Bragg wavelength is given by:

$$\lambda_B = 2n_{eff}\Lambda, \quad (1)$$

where n_{eff} indicates the effective refractive index with respect to the core propagating mode and Λ is the grating period.

As can be seen from equation (1), any change in the periodicity and refractive of the FBG will result in a change in the reflected Bragg wavelength. Therefore, any strain or temperature induced effect on the FBG, will produce a shift in the reflected Bragg wavelength.

III. Experimental Setup

Various methods to embed FBG sensors were employed to measure strain and temperature. Temperature was controlled and kept constant in all experiments in order to ensure that any temperature effects were caused only by the heat generated by the concrete and not from external sources.

A. Concrete Setup

The final concrete slab was 400 mm x 400 mm with a thickness of 80 mm. A concrete mixture of 1:2:2: cement, sand and stone with a 0.5 w/c ratio was used. All purpose 42.5N Afrisam cement, 22 mm stone size and crusher sand were used to produce the concrete specimen.

B. Optical Setup

A broadband source was fed into an optical circulator which directed the light to the fibre Bragg Grating. The reflected Bragg wavelenght was then measured by a spectrum analyser. See Figure 2 for the setup. Additional temperature FBG sensors were embedded, but not fixed to the concrete to measure temperature.

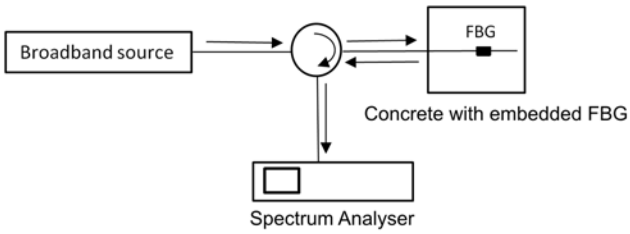

Figure 2 Optical system setup.

C. Embedding Methods

Tube and Strut: This device was embedded during the fresh stage of the concrete to measure shrinkage. The device is shown in Figure 3. The tube is made from 2 steel tubes of 4mm and 3.5 mm diameter that slides into each other. The end caps and strut are made from Perspex. Before using the tube and strut, a fibre is fed through the tube and glued to the end of each tube. When the strut is placed into the device the sensor will become tensioned.

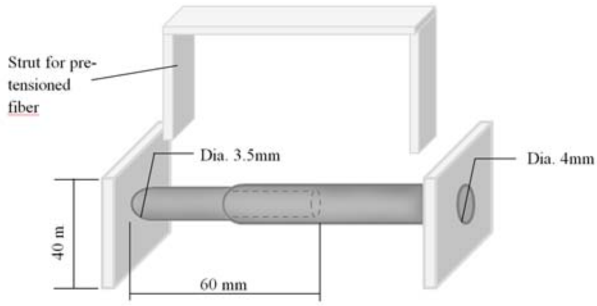

Figure 3 Tube and strut device.

An initial slab of 40mm thick was cast and compacted. The rod and tube strut device with the FBG sensor was then placed in the centre of the cast (Figure 4). The slab was then cast to its final thickness of 80 mm (Figure 5).

Figure 4 Tube and strut with FBG placed in wet stage concrete

Figure 5 Completed cast with the strut sticking out of the surface, before it was removed.

The strut from the tube and strut was then removed and the holes made by the strut were covered using grout (Figure 6).

Figure 6 Strut removed from the embedded tube sensor and the surface restored.

Groove: Once the green state of the concrete was reached, a groove, 1 mm deep, was cut into the surface of the concrete (Figure 7).

Figure 7 Groove application

The fibre was pre-stressed and fixed into the groove, using HBM X-60 epoxy. A 40 mm length of the ends/sides of the fibre were attached to the edges of the groove with the epoxy with the FBG in the middle of the attached fibre.

IV. Results and Discussion

After the cast was prepared, measurements were taken from the embedded FBG sensors. Vernier calipers were used in conjunction with the FBGs to confirm and compare results.

The measured results from the tube/strut device, placed in the middle and centre of the concrete slab, are shown in Figure 8. The results shown were taken over a period of 6 days.

Figure 8 shows that most of the shrinkage took place during day 1 of the curing process (almost 70%). Over the 6 day period a total shrinkage of 89 µm was measured.

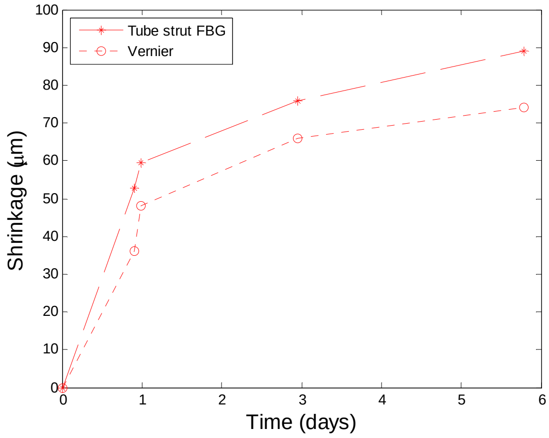

Figure 8 Shrinkage measured by the tube strut FBG sensor.

The results obtained from this method correspond well with the measured values from the Vernier caliper's.

The measured results from the groove sensor are shown in Figure 9.

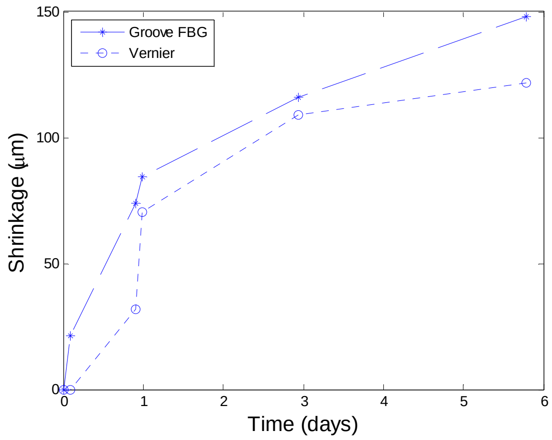

Figure 9 Shrinkage measured by the groove FBG sensor.

Although the measurements using this method were done during the green stage of the concrete, it can be seen that – like the tube/strut method – most of the shrinkage occurred during day 1.

The groove sensor, placed on the surface and 150 mm from the centre of the concrete slab, measured a total shrinkage of 148 µm over a 6 day period

The results obtained from this method, also correspond well with the measured values from the Vernier calipers. Measurements with the Vernier calipers were done by hand and the difference between the FBG sensor and the Vernier calipers measurements can be attributed to human error.

V. Conclusion

The experimental results of using embedded optical Fibre Bragg Grating sensors, to measure early stage shrinkage during most of the shrinkage of concrete takes place, were presented.

To embed the optical FBG sensors, two methods were implemented – a tube and strut device and a groove sensor on the surface of the specimen. Both optical sensor methods correlate with a conventional Vernier caliper measuring method.

The groove methods allows for easy installation of sensors during the green stage, without interference during the concrete casting.

The advantage of the tube and strut method is that it can be embedded during the fresh stage of concrete and therefore shrinkage can be measured from the beginning.

This method lends itself to many different types of applications. It could be used as an embedded sensor inside a structure and compared to an external sensor so that differential shrinkage could be measured between the inside and outside of a structure. This could provide valuable information about the early life and behavior of concrete, thus allowing engineers more insight and more control. The tube and strut sensor can also be used as a surface embedded sensor or sub-surface embedded sensor.

References

[1] J. Zhang, D. Hou and Y. Han, "Micromechanical modeling on autogenous and drying shrinkages of concrete," *Construction and bulding materials,* vol. 29, pp. 230-240, April 2012.

[2] P. Banerji, S. Chikermane, K. Grattan, T. Sun, F. Surre and R. Scott, "Application of fiber-optic strain sensors for monitoring of a pre-stressed concrete box girder bridge," 2011.

[3] H. Heininger, F. Mohr, U. Hannemann and R. Schmidt, "Observation of prestress loss in post-tensioned concrete with FBG and LVDT sensor," in *Proceedins of the IEEE Conference of Prognostics and Health Management*, 2012.

[4] A. Kerrouche, J. Leigthon, W. Boyle, Y. Gebremichael, T. Sun, K. Grattan and B. Taljsten, "Strain measurment on a rail bridge loaded to failure using a Fibre Bragg Grating-based distributed sensor system," *IEEE Sensors,* vol. 8, no. 12, pp. 2059-2065, 2008.

[5] D. Inaudi, N. Casanova, B. Glisic, S. Vurpillot, P. Kronenberg and S. LLoret, "International Journal for Restoration of Buildings and Monuments," *Lessons learned in the use of fiber optic sensor for civil,* vol. 3, no. 4, pp. 301-304, 2001.

[6] A. Wong, P. Childs, R. Berndt, T. Macken, G. Peng and N. Gowripalan, "Simultaneous measurement of shrinkage and temperature of reactive powder concrete at early-age using fibre Bragg grating sensors," *Cement and Concrete Composites,* vol. 29, pp. 490-497, 2007.

[7] V. Slowik, E. Schlattner and T. Klink, "Experimental investigation into early age shrinkage of cement paste by using fibre Bragg gratings.," *Cement & Concrete Composites,* no. 26, pp. 473-479, 2004.

[8] Civilers, "Civilers," 2014. [Online]. Available: http://www.civilers.com/articles/records/structures/type-strain-guages/. [Accessed 15 August 2014].

[9] C. Jiang, Y. Yang, Y. Wang, YZhou and C. Ma, "Autogenous shrinkage of high performance concrete containing mineral admixtures under difficult curing temperatures.," *Construction and Building materials*, vol. 61(0), pp. 260-269, 2014.

[10] Mayes Group, "The DEMEC mechanical strain gauge," 17 03 2009. [Online]. Available: http://www.geotecspa.com/documents/monitoraggi_strutturali/01C_Deformometro%20meccanico_Demec.pdf. [Accessed 04 06 2015].

[11] S. Kulur, B. Pekmezci and F. Yilmaztürk, "Measuring of shinkage in concrete samples by using digital photogrammetric methods," *The International Archives of the Photogrammetry, Remote Sensing and Spacial Information Sciences,* vol. 34, 15 05 2004.

[12] D. Post and B. Han, "Moiré Interferometry," in *Springer Handbook of Experimental SOlid Mechanics*, Springer, 2008, p. Part C/22.1.

[13] J. Miguel and Lopez-Higuera, "Handbook of Optical Fibre Sensing Technology," J. Miguel, Ed., Chichester, British Library Cataloguing in Publication Data, 2002, pp. 482-491.

[14] B. Addis and G. Owens, Fulton's Concrete Technology, Midrand: Cement and Concrete Institute, 2001.

[15] S. Spammer and P. Fuhr, "Concrete embedded optical fibre Bragg grating strain sensors.," in *IEEE International Symposium on Industrial Electronics.*, Pretoria, 1998.

[16] Cement & Concrete Institute, "Deformation and volume change of hardened concrete," in *Fulton's concrete technology*, C. &. C. Institute, Ed., Midrand, 2009, pp. 131-141.