Research and Development of Plastic Optical Fiber Based Smart Transparent Concrete

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ABSTRACT

Energy saving and safety evaluation are two key issues for infrastructure. In this paper, the development of a novel smart transparent concrete using plastic optical fiber (POF) and Fiber Bragg Grating (FBG) is discussed, along with its transparent and smart sensing properties. The experimental results show that an optical fiber can be easily combined with concrete and that the POF could provide a steady light transmitting ratio. Moreover, the FBG can be used as a sensing element for strain and temperature. This paper also discusses the mechanical effects of introducing POF into concrete specimens. Because the smart transparent concrete can be regarded as a "green" energy saving construction material and as a smart intrinsic sensor for long-term Structural Health Monitoring (SHM), it is a promising technology for field applications in civil infrastructure.

KEYWORDS: Energy Saving, Plastic Optical Fiber, Smart Transparent Concrete, Fiber Bragg Grating, Structural Health Monitoring, Green Construction Materials

1. INTRODUCTION

Due to economic development and space utilization requirements, high rise buildings and skyscrapers are mostly built downtown in metropolitan areas around the world, especially those countries with great populations. Those buildings are isolated biosphere only based on man-made lights to maintain people's optical activities. For example, China consumes 25% of global architectural energy and 13% of that energy is used to power lighting. At present, green structures focus greatly on saving energy with indoor thermal systems. However, in the area of illumination fields, there is very little research offering relevant solutions. Research on the intrinsic characteristics of the optical identity in construction materials is still at its infancy. Due to its outstanding light guiding and sensing advantages, such as anti-electromagnetic interference capability, small dimensions, distributed measurement and anti-corrosion characteristics, optical fibers have been widely adopted in the communication and sensing fields. It is considered to be one of the best sensor materials available and has been used widely since the 1990s. Hungarian architect, Aron Losonczi, first introduced the idea of light transmitting concrete in 2001 and then successfully produced the first transparent concrete block in 2003, named LiTraCon, shown as figure 1. However, his transparent concrete did not have smart sensing properties.

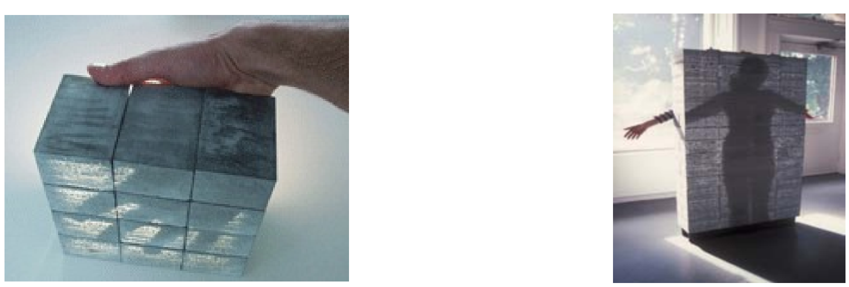


Figure 1: Picture of LiTraCon light transmitting concrete

(Courtesy of LiTraCon Bt 2001 – 2006)

Smart Sensor Phenomena, Technology, Networks, and Systems 2009, edited by Norbert G. Meyendorf, Kara J. Peters, Wolfgang Ecke, Proc. of SPIE Vol. 7293, 72930F · © 2009 SPIE · CCC code: 0277-786X/09/$18 · doi: 10.1117/12.816638

In this paper, a smart transparent concrete - novel construction material was manufactured with POF and FBG by drilling through the cement and mortar in order to utilize the light guiding ability of POF and the sensing properties of FBG, respectively. The main purpose was to use sunlight as a light source in order to reduce the power consumption of illumination. Meanwhile, the steady sensing offered by FBG allows detection of potential internal deformation of the concrete. Additionally, experiments to study the mechanical performance of the concrete infused with POF were carried out.

2. PHYSICAL MECHANISM OF POF BASED SMART TRANSPARENT CONCRETE

POF is an excellent media to transmit light at specific wavelengths since its refractive index is greater in core than in coating. As such, light can be transmitted through POF in the form of total reflection. As POF has a much larger core size and larger numerical aperture than common SiO_2- based optical fibers, it can absorb light at an incident angle as large as 60° and still provide a better light guiding system. POF has the advantages of greater ductility and good flexibility for a harsh environment. The light transmitted in POF is in the form of electromagnetic waves whose amplitude, phase, polarized state and frequency are affected by various physical parameters, such as temperature, pressure, stress, strain, electric field and magnetic field. By analyzing performance changes in those waves, the external physical conditions can be estimated. Such sensors offer unmatched advantages like high precision, quasi-distributed monitoring, relatively small volume, steady for structural identity, anti-electromagnetic interference, anti-corrosion, ease in handling and ruggedness, and some can even be used for absolute measurements, compared to the relative strain measurements after traditional resistance strain gauges have been installed. Based on the above mentioned features, POF with fiber grating in proportion with cement in concrete or a smart transparent concrete will provide a novel construction material that has both transparent appearance and structural assessment ability for long-term SHM.

3. FEASIBILITY STUDY WITH EPOXY RESIN BASED BLOCKS

The light guiding performance of concrete materials is completely determined by the internal POF's area ratio and surface roughness in certain sections. For this reason, epoxy resin was used instead of cement in order to reduce complexity as the first step of the experiments. Because epoxy resin is transparent, carbon black was used to simulate the opacity of a concrete environment; any detected light should be thus attributed to the POF. An epoxy resin block with 4% of the area occupied by POF was fabricated, as shown in Figure 2.

a) Fibers in an epoxy resin block mold

b) POF based epoxy resin block

Figure 2: Fabrication of a POF-based epoxy resin transparent block

The purpose of POF-based concrete is to transmit visible light. Therefore, visible light and infrared rays (wavelength varies from 400nm to 1100nm) were both used to test the transparent block's light transmitting and heat conduction functionalities. For quantitative analyses, the Newport 835 Optical Power Meter was applied as shown in Figure 3. The results for light transmitting are presented in Figure 4. It can be observed that the light transmitting average ratio of visible lights and infrared rays vary slightly from 0.529% to 0.535%. These results mean that the transparent block can not only transmit visible light steadily for optical activities but also thermal energy. It can reduce the consumption of both illuminating and thermal-based energy consumption. The test results shown in Figure 4 prove that developing a cement-based POF transparent block is feasible.

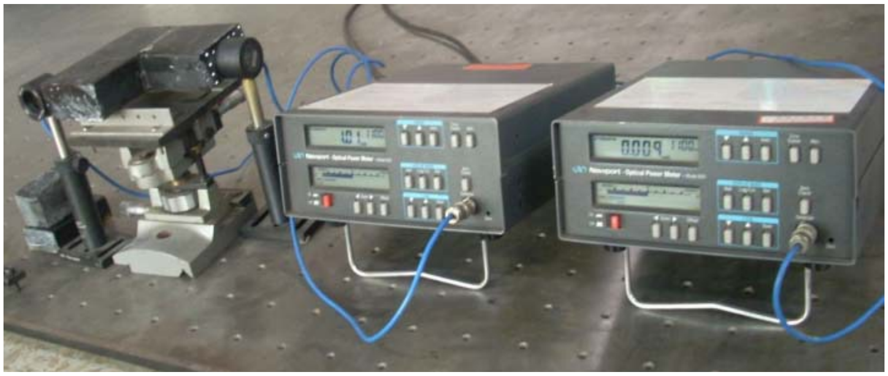
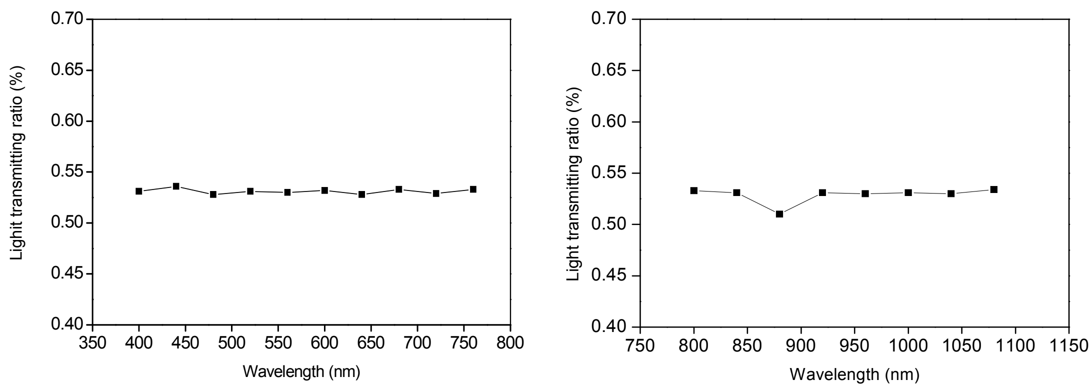


Figure 3: Test for POF based epoxy resin transparent block



a) Light transmitting ratio for visible light

b) Light transmitting ratio for infrared rays

Figure 4: Transparent features for the epoxy resin POF block

4. SMART TRANSPARENT CONCRETE BLOCK USING POF AND FBG

4.1 Fabrication of a smart transparent block

Four mortar specimens of 100×100×100 mm each was cast with a sand/cement/water ratio of 1:2:0.44. They had four various POF area ratios: 3.14%, 3.80%, 4.52% and 5.3 %. One smart POF-based concrete block is shown in Figure 5.

4.2 Transmitting performance of the smart transparent block

The transmitting performance of the smart transparent block was tested as shown in Figure 6 similar to that used for the epoxy resin-based block. The recorded data is presented in Figure 7. In considering the distribution of the light transmitting features of the transparent concrete block, it is observed that the light transmitting ratio becomes higher with a higher column proportion of POF and is stable at certain proportions of POF in concrete.

a) The mold for a smart concrete block

b) A POF-based smart concrete block

Figure 5: Fabrication of POF based smart transparent concrete block

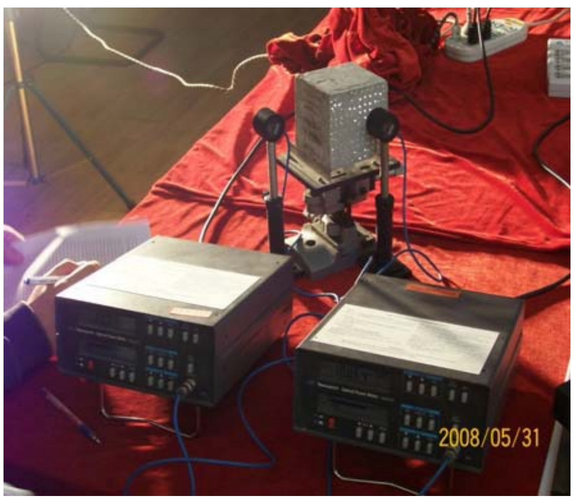


Figure 6: Test of a POF-based smart concrete block

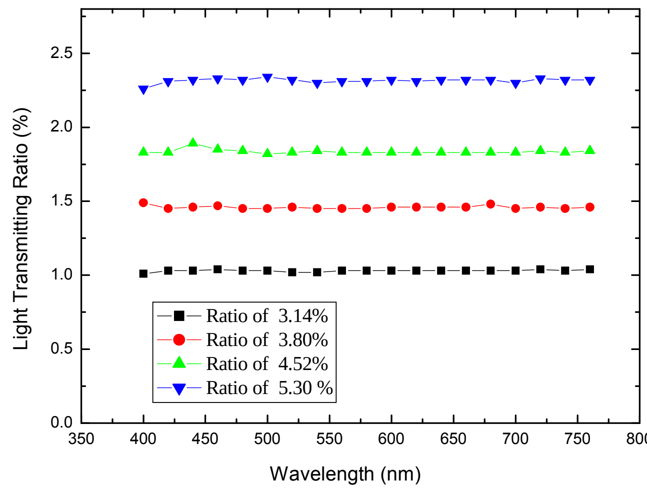


Figure 7: Transmitting performance of the transparent block

4.3 Mechanical performance of the smart transparent block

To investigate any influence of the POF on the strength of the transparent concrete block, a compression test was carried out for each specimen, as illustrated in Figure 8. The test data is shown in Table.1. It can be observed that the volume proportion affects the compression strength of the concrete block for less than 10% when the proportion ratio of the POF is less than 5 percent.

Table 1: Data of the compression performance of the transparent concrete block

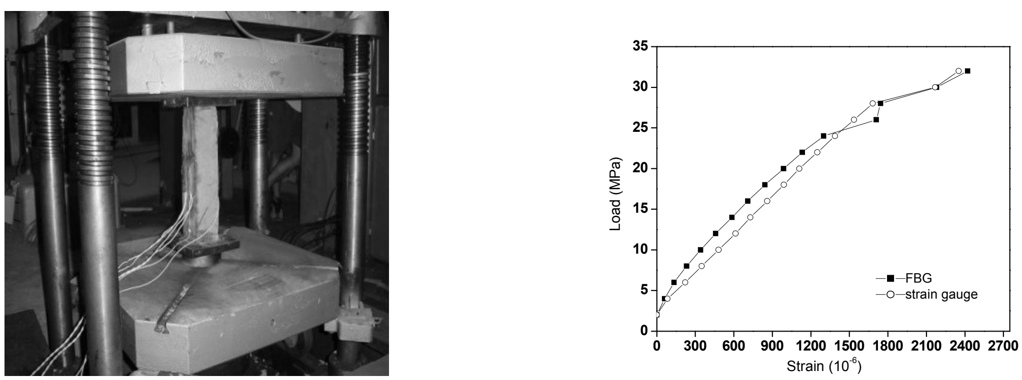
Proportion	0.0%	3.14%	3.80%	4.52%
Test data (kN)	190.5	190.0	219.0	180.5
	220.0	228.0	194.0	182.0
	195.0	185.0	174.0	184.0
Average	201.8	201.0	195.7	182.2

a) Test setup   b) Damage mode

Figure 8: Mechanical performance of the smart concrete block

4.4 Sensing properties of the smart transparent block

Along with the POF, FBG can be embedded in the smart transparent block to provide the block with the functionality of self sensing. Test results are shown in Figure 9. FBG works well to monitor strain as large as 2050με. The data agrees well with the traditional resistance strain gauge. Such experiments shows that the internal deformation can be monitored by fiber grating inside the specimen which will not be achieved by a traditional resistance strain gauge attached to the surface.



a) Test setup

b) Test data

Figure 9: Test of the sensing properties of the smart transparent concrete block

5. CONCLUSION AND REMARKS

A novel construction material named smart transparent concrete was developed using POF and FBG. The light transmitting, mechanical properties and self-sensing performance were cautiously investigated and the stated hypothesis of its light guiding capability was confirmed. FBG arranged in concrete can sense the inner deformation of concrete specimens under pressure and the changing tendency of the internal fiber grating is consistent with that shown in the electric resistance strain gauge tests. Such research and experimentation provides solid evidence for the intelligence of this system in structural safety assessment. With regard to the energy-saving aspect, POF-based concrete allows the use of sunlight for illumination; in the case of emergencies, transparent concrete will provide some relief in the case of daytime power outage for skyscrapers, making evacuation safer and more efficient. Additionally, a smart transparent concrete is aesthetically pleasing. POF-based transparent concrete could be regarded as an art which could be used in museums and specific exhibitions rather than just a construction material.

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