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Hybrid Self-Sensing Cement Composite for Traffic Monitoring

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Abstract

This paper presents self-sensing cement-based composite adopted to control and monitor the traffic flow volume. In this work, cement was mixed with different percentages of carbon black (CB) and activated granulated ground blast furnace slag (GGBFS) (hybrid paste), by weight of cement. The aim was to fabricate an inexpensive and concrete friendly material whose piezo resistive properties helps to sense the axel pressure prompted by the vehicles passing over it. In experiment work, first of all the pressure sensitivity of various mix designs was examined in laboratory and the mix design which displayed more sensitivity to applied load was used on road testing for car detection. Mechanical and microstructural properties of hydrated cement sensor filled with CB and GGBFS as an active filler were also explored. X-ray diffraction (XRD) analysis and Scanning Electron Microscopy (SEM) as well as Energy Dispersive Spectroscopy (EDS) were carried out simulatiously to illustrate the hydration product development and microstructure of different specimens (cement sensors) correspondingly at different curing ages. Cement-based stress sensor hybrid with GGBFS and CB provided an extraordinary response to both compressive and vehicular loading with decent microstructure and mechanical properties. The findings of this research also clarified that the self-sensitive cement compound has a great potential to use as a device for traffic flow monitoring.

Keywords

Traffic monitoring, Piezo-resistive properties, Carbon black, Blast furnace slag

1. Introduction

Many researchers in the U.S. and Europe have started to integrate intelligent transport systems (ITS) into their transportation system to monitor and manage traffic flow and reduce congestion. These systems also provide transportation professionals with the tools to collect, analyze, and archive data that help in assessment and performance of these systems.

Traffic flow sensors are integral parts of modern intelligent transportation systems (ITS). Sensors provide real-time input data in support of a variety of ITS services and strategies, such as freeway ramp metering, traffic signal control, driver information and guidance. Therefore, the success of ITS depends to a large extent on the accuracy and reliability of traffic flow sensors (Faouzi and Klein, 2016). A large number of researchers have investigated different kinds of traffic sensing technologies. These sensors can be categorized into three major classes, in-road, on-road and over road sensors. Among these various sensors, inductive loop detectors have been the predominant traffic flow sensors, due to their mature technology, insensitivity to weather conditions, and relatively low costs. Inductive loop detectors can accurately measure occupancy, vehicle speed, and gaps. However, there are several limitations with inductive loop detectors. They need pavement cutting for installation, require lane closure for maintenance, and decrease the pavement life due to unfavorable compatibility with pavement in the highway. Recent advances in computing and communication technologies have led to the development of other detection technologies, such as microwave radars, infrared sensors, and video image processors. However, these sensors face the limitations of high sensor costs, high maintenance cost, and poor performance in inclement weather conditions (rain, snow and fog). Many of them also need additional mounting structures and time-consuming calibration (Klein et al. 2006).

To cope with this problem, researchers have developed a self-sensing cement composite material for traffic monitoring by filling cement with conductive materials to increase the sensing capability of cement composites. The reported conductive materials used in cement are carbon nanotubes (CNTs) (Han et al. 2009), carbon fiber (CFs) (Shi and Chung, 1999), nanographine (Radhika et al.2016), nickel-powder (Han et al., 2011), steel fiber (Banthia et al. 1992), carbon black (Wen and Chung, 2007). In experiments, they studied the response of the piezo resistive properties of this composite to compressive stress and also investigated with vehicular loading experiments to investigate the feasibility of using self-sensing cement composite for traffic monitoring.

Self-sensing CNT/cement composite presents sensitive and stable responses to repeated compressive loadings and impulsive loadings, and has remarkable responses to vehicular loadings. These findings indicate that the self-sensing CNT/cement composite has great potential for traffic monitoring use, such as in traffic flow detection, weigh-in-motion measurement and vehicle speed detection (Konsta and Aza, 2014).

The piezo-resistive response of carbon black cement-based composites was studied with the purpose to develop piezo-resistive cement-based stress sensor (PCSS) systems for traffic monitoring applications in contrast to other piezo resistive cement-based stress sensor (PCSS) studies, relevant specimen sizes for pavement embedding were considered. Low stress amplitudes up to 2 MPa were applied to evaluate whether the composite material had enough sensitivity to accurately monitor traffic-like loadings. Our results demonstrate that the low-cost carbon black (CB) filler provides a remarkably reproducible behavior with the average gauge factor, (i.e. fractional change in electrical resistance per unit strain) ranging from 40 to 60. While heating the specimens to 45℃ led to a decrease in sensitivity of about 30%, their linear response to applied stress was not affected (Monteiro et al., 2017).

The design and the feasibility of a self-sensing pavement for vehicle detection were also investigated by smart nickel particle filled cement-based sensors were embedded into a concrete pavement to set up the self-sensing pavement. Due to the high piezoresistive sensitivity of the smart cement-based sensors, the designed self-sensing pavement can accurately detect the passing vehicles (Han et al., 2011).

Self-monitoring concrete containing short carbon fibers (0.5% or 1.0% by weight of cement) is effective for traffic monitoring and weighing in motion. The resistance decreases reversibly with increasing stress up to 1 MPa and is independent of speed up to 55 mph (Shi and Chung, 1999).

Generally, the pressure of the tires on the ground caused by a passing vehicle is not very high, so a high sensitivity of detectors is beneficial and necessary for valid vehicle detection. Among the existing smart cement-based sensors, the nickel particle filled cement-based sensors have the highest sensitivity to compressive stress(Han *et al.*, 2011). Their sensitivity can reach 0.17/ MPa at a low compressive stress level, which is much higher than that of 0.03/MPa for the carbon fiber filled cement (Shi and Chung, 1999).

The resistivity and piezoresistive sensitivity of cement based nanocomposites reinforced with carbon nanotubes (CNTs) and carbon nanofibers (CNFs) was investigated. The application of 20 V appears to be the optimum amplitude for conducting reliable measurements of the electrical resistance of cement based materials, as results under this voltage were consistent. The appropriate oven temperature for specimen drying was explored, in order to eliminate from the resistivity testing the so-called polarization effect. It was shown that drying of the specimens at 95 C results in a significant water removal from the material's pores and greatly eliminates the polarization effect seen in specimens with higher internal moisture content (Konsta and Aza, 2014).

Resistivity measurements performed at 28 days old specimens containing different amounts of CNTs and CNFs showed that the addition of CNTs and CNFs was proven to induce a decrease in electrical resistance, with the nanocomposites containing 0.1 wt% CNTs yielding better electrical properties. Furthermore, a comparison between the resistivity values from composites reinforced with well dispersed carbon nanoscale fibers and those from composites reinforced with carbon nanoscale fibers ''as received'' indicated that resistivity measurements using the 4-pole method may provide a good correlation between the resistivity values measured and the degree of dispersion of the material in the matrix. Finally, conductivity measurements under cyclic compressive loading provided an insight in the piezo resistive properties of selected nanocomposites. Results confirm that nanocomposites reinforced with 0.1 wt% CNTs and CNFs exhibited an increased change in resistivity, which is indicative of the amplified sensitivity of the material in strain sensing (Konsta el al. 2014).

CNTs were effective to reduce the shrinkage of mortars, especially at early ages. The shrinkage reduction after 7 d was up to 62%, decreasing to up 21% after 1 year. Shrinkage was little affected by the type of CNT. >0.1% of CNTs was not effective to further reduce the long-term shrinkage (Li, Wang and Zhao, 2007).

The workability and density of concrete was little affected by the addition of up to 0.1%wtc CNTs. Durability properties of concrete were at this analyzed at 0.1% wt. regardless of the type of CNT and w/c ratio. The result shows modest improvements up to about 25%, suggest that greater amounts of CNTs are necessary to effectively increase the concrete performance, being fundamental to invest in the design of more efficient dispersion methodologies (Carriço et al., 2018).

Although a cement paste with 1.0 vol.% CFs had 10 times more electrical resistivity and 21.0% greater porosity than a paste with 0.5 vol.% CFs, the amount of incorporated CFs must be greater than 0.5 vol.% in order to produce an adequate piezo resistive sensing capacity. The percolation threshold of CFs is thus between 0.5 and 1.0 vol.% of the cement paste (Han el al., 2007).

Increasing the amount of MWCNTs in the paste increased the sensing sensitivity during cyclic compression tests. A 1.0 vol.% MWCNTs in the paste is sufficient for a strain sensor (Galao et al., 2014). The amount of MWCNTs incorporated with CFs should be at least 0.35 vol.% in order to produce sufficient piezo resistive sensing capacity. Also, the amount of incorporated CFs should be minimized to enhance sensing capacity (Wen and Chung, 2007).

It was also invested that, pozzolanic material having high amount of iron oxide (FeO) when replace with cement by 40% of cement weight, it also gives decent and linear response to compressive loading (Jia and Qian, 2012).

Hydration product development and microstructure of smart self-sensing cement based sensor filled with different conductive fillers was also studied by some researchers and they concluded that the conductive fillers have no harmful effects of the development of hydration products and microstructure (Liu el al. 2018).

Thus keeping in mind these benefits of cement sensors, this works proposes a self-sensing cement sensor filled with carbon black (CB) (Wen and Chung, 2007) and granulated ground blast furnace slag (GGBFS) (Jia and Qian, 2012) to detect the vehicles in intelligent transport system (ITS) as the carbon black shows stable response to compressive loading and is cheapest and easily available material throughout the world. Moreover, GGBFS used was to enhance the mechanical properties though it also acts as conducting material when replace with high amount by wt.% of cement (Xu et al., 2017).

2. Materials and methods

The following methods given below are used to investigate the required results.

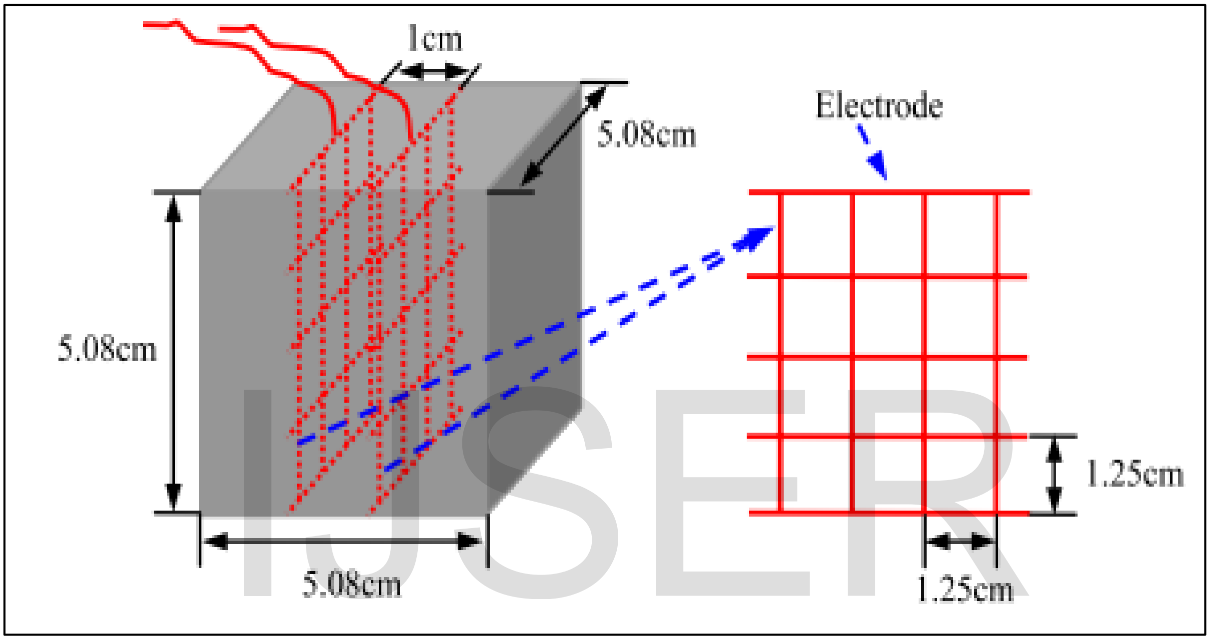

Figure 1: Structure of the self-sensing cement composite specimen and arrangements of electrodes.

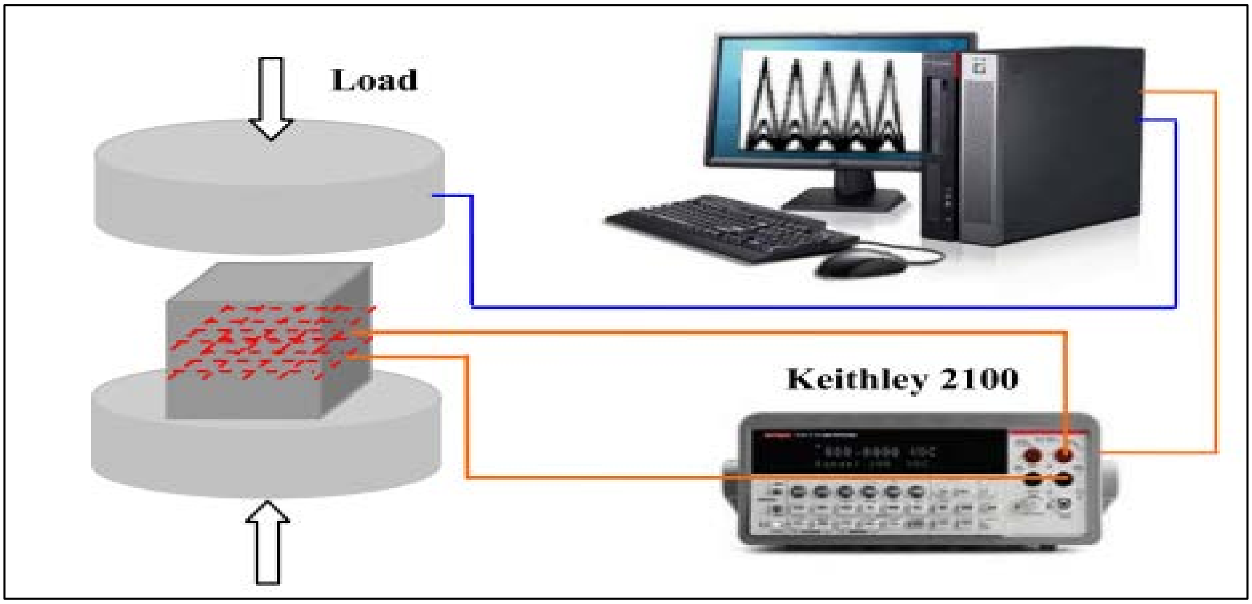

Figure 2: Sketch of experimental equipment for repeated compressive loading and impulsive loading.

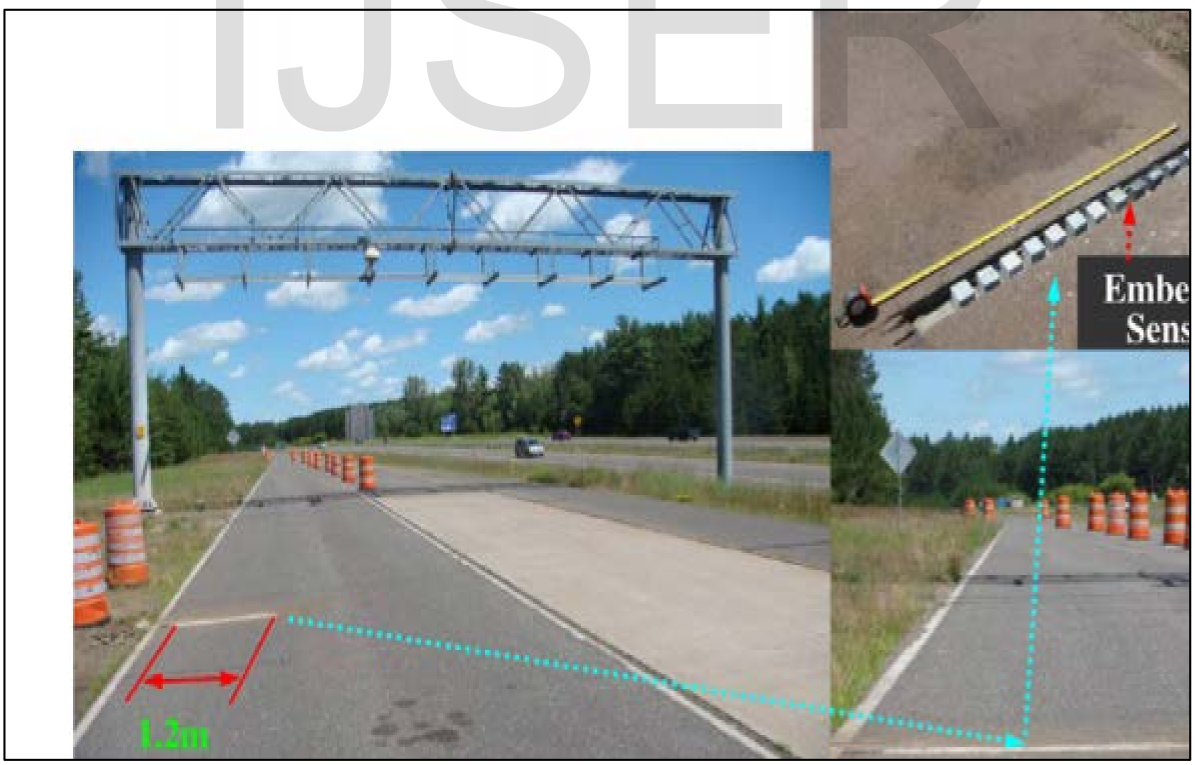

Figure 3: Self-sensing pavement embedded with smart cement based sensor array

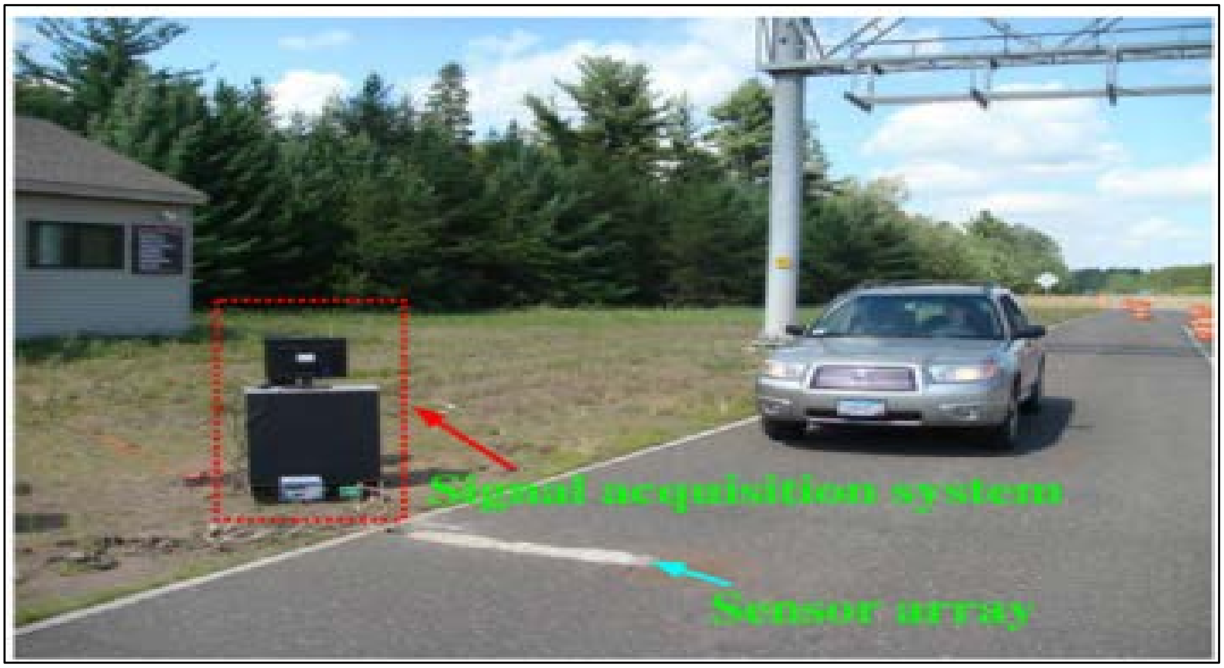

Figure. 4: Road test of self-sensing pavement

3. Results and discussion

The results of this research shows that the use of proposed material shows excellent response to repeated compressive loading and also on real road testing.

4. Conclusion

It is concluded from the results that smart self-sensing cement composite has great potential to be used as a device for traffic monitoring. It is also showed that the CB and GBFS based cement composite is very smart and cheap having several advantages over the conventional detectors in intelligent transport system (ITS), such as easy installation, low cost, easy maintenance, long service life and good compatibility with pavement structures and possessed excellent capability to detect the vehicles passing over it.

5. Recommendation

This work can be used for smart cities and structural health monitoring.

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