Smart Cement Response to Cyclic Loading

K. Elsayed and C. Vipulanandan Ph.D., P.E.
Center for Innovative Grouting Materials and Technology (CIGMAT)
Department of Civil and Environmental Engineering
University of Houston, Houston, Texas 77204-4003
CVipulanandan@uh.edu; Phone (713)743-4278

Abstract: In this study, the cyclic loading responses of smart Class-H Oil Cement and Ultrafine cement were investigated. The loading and unloading rate was 0.1 inches/minute. Smart cement carrying carbon fiber (CF) of 0.01% was developed, and their ability to sense an applied compressive cyclic load was tested. A series of cyclic loading tests with fixed load amplitudes were performed (95 psi = 0.65 MPa). In addition, a measurable change in piezoresistive strain was presented. For the cyclic experiments, the applied load was compared against fractional change in resistivity (FCR). Results showed that smart cement containing Class-H Oil Cement with 0.01%CF has higher performance for piezoresistive sensing under compressive cyclic load than Ultrafine cement with 0.01%CF.

1. Introduction:

Dynamic loading could be one of the main reasons for the destruction of concrete structures (Golewski, 2021). Hence, there are many ways for Structural health monitoring (SHM) of infrastructures to evaluate the structure safety and prevent failures. One of these sensors is using smart cement. Smart cement can provide real-time data of the structures using a network of sensory devices (Azhari et al., 2012). Carbon fiber is a conductive material that is usually used to obtain a piezoresistive smart cement. It can enhance the electrical resistivity of cementitious composites (Vipulanandan, 2021). In addition, it also can improve the mechanical properties of cement composite sensors. They have proven to be very effective in different sectors such as bridge monitoring, traffic monitoring, corrosion of pipelines, and asphalt pavements (Shi et al., 1999; Liu et al., 2011).

To improve the electrical resistivity of cementitious composites, different types of cement may use, including fiber materials. Ultrafine cement-based is a common type of grout that is used in many applications, including grouting technology. Ultrafine cement was used to improve oil and well production in many countries (Sarkar et al., 2001). Another type of cement (Class-H cement) is considered Oil-well cement that can be used for moderate to high sulphate resistance (Jefferis, 2003). In this study, Ultrafine cement and Class-H cement were used to enhance the electrical resistivity of smart cement under cyclic loading.

2. Objective:

The overall objective was to test and quantify the smart cement response to cyclic loading after 28 days of curing. The specific objectives of this study are the following:

1. Test the smart cement with 0.01% carbon fiber under cyclic loading of 0.1 inches/minute and peak stress of 95 psi.
2. Verify the repeatability of the resistivity measurement method.

3.Methodology:

One set of smart cement samples was prepared with 0.01% CF. Class-H Oil Cement and Ultrafine cement were used in this study. Four wires electrodes were attached to the cylindrical samples of 4-in. long and 2-

in. diameter as shown in Figure 1. Smart cement pastes were prepared by mixing the cement with water for 5 minutes after disturbing the carbon fiber in water. The water to cement ratio for cement was 0.4. After casting and vibrating for 10 s, all specimens were air-cured for at least 28 days before testing. Sensor specimens were subjected to compressive loading using a Sigma-1 Automated load test system (loading machine), as shown in Figure 2a. For each specimen, measurements of the resistance values using a commercial LCR device at 300 kHz were conducted, as illustrated in Figure 2b. Resistance measurements were made using alternating current (AC).

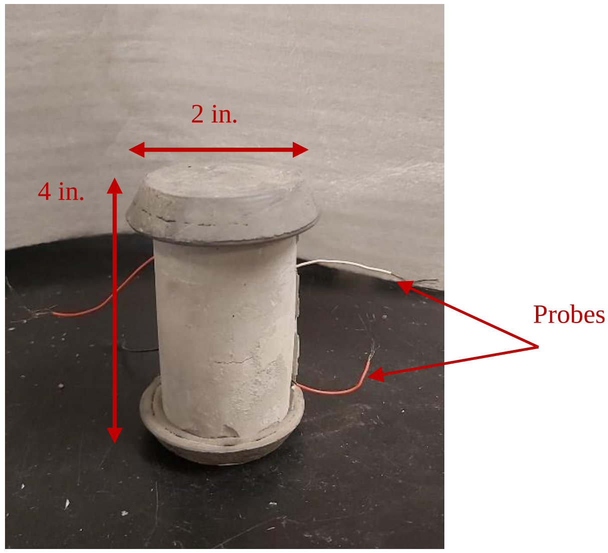

Figure 1: Probe configuration for electrical resistance measurements

Resistance measurements were calculated using the following equation:

$$R = k\rho \tag{1}$$

where R is the electrical resistance (Ω), ρ is the electrical resistivity (Ω m) which is a material property, k is an coefficient. A series of cyclic loading tests with fixed load amplitudes were performed (95 psi = 0.65 MPa). For the cyclic experiments, the applied load was compared against fractional change in resistivity (FCR):

$$FCR\left(\frac{\Delta\rho}{\rho}\right) = \frac{\rho - \rho_0}{\rho_0} \tag{2}$$

The loading rate was set so that each cycle took 72 s, leading to loading rates of 0.1 in./min.

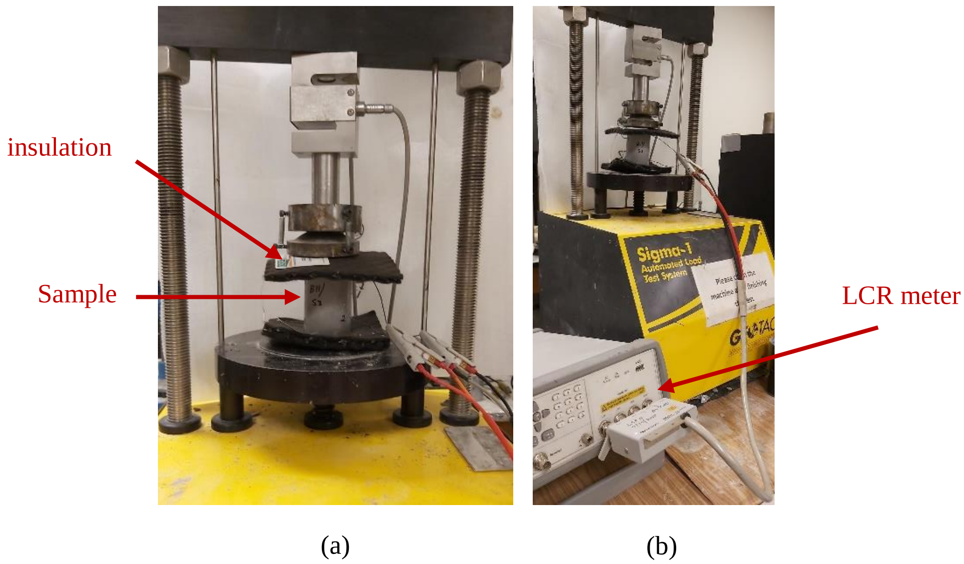

Figure 2: Sensing measurements of smart cement sample using (a) Testing Configuration and (b) LCR device

4. Results:

The piezoresistive behavior of smart cement with 0.01%CF was assessed by measuring their electrical response during cyclic compressive loading, as illustrated in Figure 3. During each loading cycle, the resistivity values increased with an increase in compressive load, resulting in a positive FCR, and then decreased to the initial value when the unloading branch of the cycle took place. The FCR values of Class-H cement were 54, 61, and 62, respectively, while they were 11, 14, and 16, respectively, for Ultrafine cement under the same loading of the three cycles. For a linear change in load with time, the entire response was nonlinear. This represents a higher strain sensing ability of Class-H cement with 0.01%CFs compared to the samples with Ultrafine cement with 0.01% CFs.

5. Conclusions

From this study, the following conclusions are advanced:

(a)Containing Class-H cement with 0.01% CF provides better piezoresistive strain, improved reliability, and increased sensitivity than Ultrafine cement with 0.01% CF under the applied compressive cyclic load.

(b)Smart cement showed a fully recover in piezoresistive characteristics at the end of each cyclic load.

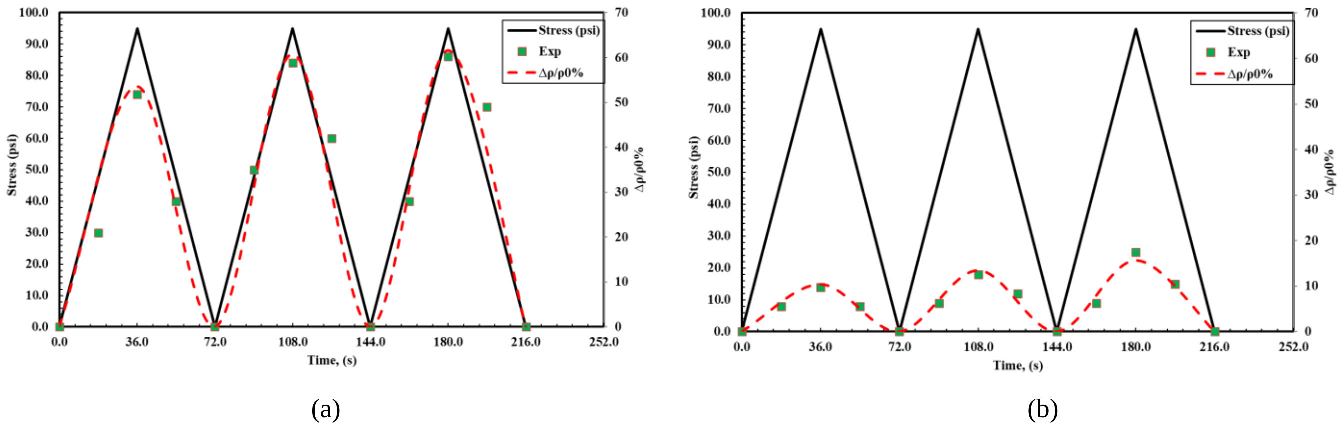

Figure 3: Stress and piezoresistive strain versus time of cement with 0.01% CF (a) Class-H cement, (b) Ultrafine cement

6. Acknowledgments:

This study was supported by the Center for Innovative Grouting Materials and Technology (CIGMAT)and Texas Hurricane Center for Innovative Technology (THCIT), University of Houston, Houston.

7. References:

Azhari, F., & Banthia, N. (2012). Cement-based sensors with carbon fibers and carbon nanotubes for piezoresistive sensing. Cement and Concrete Composites, 34(7), 866-873.

Golewski, G. L. (2021). On the special construction and materials conditions reducing the negative impact of vibrations on concrete structures. Materials Today: Proceedings, 45, 4344-4348.

Jefferis, S. A. (2003). Grouts and grouting. Advanced Concrete Technology Set, Elsevier, Oxford.

Liu, X. M., & Wu, S. P. (2011). Study on the piezoresistivity character of electrically conductive asphalt concrete. In Advanced Materials Research (Vol. 233, pp. 1756-1761). Trans Tech Publications Ltd.

Sarkar, S. L., & Wheeler, J. (2001). Important properties of an ultrafine cement—Part I. Cement and Concrete Research, 31(1), 119-123.

Shi, Z. Q., & Chung, D. D. L. (1999). Carbon fiber-reinforced concrete for traffic monitoring and weighing in motion. Cement and Concrete Research, 29(3), 435-439.

Vipulanandan, C. (2021), Smart Cement: Developing, Testing, Modeling and Real-Time Monitoring, Taylor and Francis, CRC Book, London, U. K. 402 pp.