Comparing the Initial Curing of Smart Oil Well Cement to Smart Ultrafine Cement Using the Vipulanandan Curing Model

K. Elsayed and C. Vipulanandan Ph.D., P.E.
[1]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, one-day curing of Class-H Oil-well cement was compared to the Ultrafine cement by monitoring the resistivity from the time of mixing to 1 day of curing. Based on the mixing process, the initial resistivity of Class-H cement with a water-to-cement ratio (w/c) of 0.4 and Ultrafine cement w/c ratio of 0.8 was 1 Ω m. With the addition of 0.01% carbon fiber, the initial resistivity decreased. After 1 day of curing, the resistivity of Class-H cement with 0.01% fibers increased by 55% and for Ultrafine cement by 145%. Vipulanandan curing model predicted the curing of the smart cement very well.

1. Introduction:

Smart cement has many advantages, including higher sensitivity and higher durability. Highly conductive smart cement is reflected by electrical resistivity changes in response to the damage under applied load conditions (Dong et al., 2022). Oil-well cement is usually made from blended hydraulic cement or Portland cement clinkers (Vipulanandan, 2021). Class-H cement is considered one type of Oil-well cement that can be used for moderate to high sulphate resistance (Jefferis, 2003). Ultrafine cement is another type of cement composed of a finely ground mixture of Portland cement, pumice pozzolan, and dispersant (Sarkar et al., 2001). Ultrafine cement has an average particle size of 3 to 4 microns, which reduces permeability. It can be used to seepage in mines, dams, and tunnels.

The mixing of cement with water and fibers can be characterized using different monitoring methods. These methods can help to assess the quality control of cement. Electrical resistivity is a non-destructive and less expensive test that can be a practical method to determine cement properties. The initial resistivity of cement slurry will be affected by not only the type of cement but also the curing time and amount of fibers. In this study, the sensitivity of resistivity in determining the quality control of the mixing of cement was investigated.

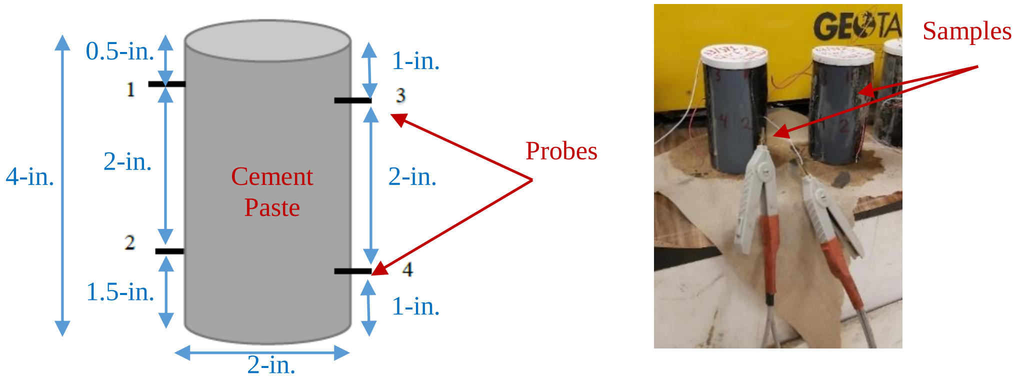
2. Objective:

The overall objective was to compare the curing of smart Class-H cement with the Ultrafine cement. The specific objectives of this study are the following:

a) Experimentally characterize the Class-H and Ultrafine cement with 0.01% fibers.
b) Model the curing behavior using Vipulanandan curing model.

3. Methodology:

Commercially available Class-H and Ultrafine cements were used in this study. Smart cement pastes were prepared by mixing the cement with water for 5 min after disturbing the carbon fiber in water. A cylindrical mold of height 4 inches and 2 inches in diameter was used, as shown in Figure 1. Four insertions were made on the curved surface of the mold, two on each side and the other two on the diametrically opposite side, for wire probes to be inserted. One mix with fixed carbon fiber content (0.01%) by weight of cement mass was prepared. The water to cement ratio for Class-H and Ultrafine cements are 0.4 and 0.8, respectively. A conductivity meter was also used to measure the conductivity of the specimen during casting. After casting and vibrating for 10 s, all specimens were cured in the molds for 24 h. For each specimen, measurements of the resistance and reactance values using a commercial LCR device at 300 kHz were conducted. In this experiment, readings were taken during the first day of curing.



(a) (b)

Figure 1: Probe configuration for electrical resistance measurements (a) Schematic and (b) Test samples

Vipulanandan curing model (Vipulanandan et al.,1990) was used to predict the electrical resistivity of cement during hydration of the cement. The proposed model is as follows:

$$\frac{1}{\rho} = \frac{1}{\rho_{min}}\left[\frac{\frac{t+t_o}{t_{min}+t_o}}{q+(1-p-q)*\left(\frac{t+t_o}{t_{min}+t_o}\right)+p\left(\frac{t+t_o}{t_{min}+t_o}\right)^{\frac{p+q}{(p)}}}\right] \quad (1)$$

where ρ is the electrical resistivity (Ω- m); ρ_{min} is the minimum electrical resistivity (Ω- m); t is the curing time (min), t_{min} is the time corresponding to minimum electrical resistivity (ρ_{min}); parameters p, t_o, *and q* are model parameters. Figure 2 shows Vipulanandan curing model parameters and the changes in the resistivity during the hydration of cement with time.

4. Results:

(a) Initial Resistivity

i. Class-H cement with 0.01% fibers:

The experimental results indicate that electrical resistivity is significantly influenced by adding 0.01% CF. The initial resistivity of Class-H cement with 0.01% carbon fiber was 1.02 Ω-m immediately after mixing. The minimum resistivity was 0.93 Ω-m and the time taken to reach the minimum resistivity was 150 minutes.

ii. Ultrafine cement with 0.01% fibers:

The initial resistivity of Ultrafine cement mixed with a w/c ratio of 0.8 was 1.00 Ω-m. The time taken to reach the minimum resistivity was 15 minutes, which is lower than Class-H cement and the minimum resistivity was 0.98 Ω-m.

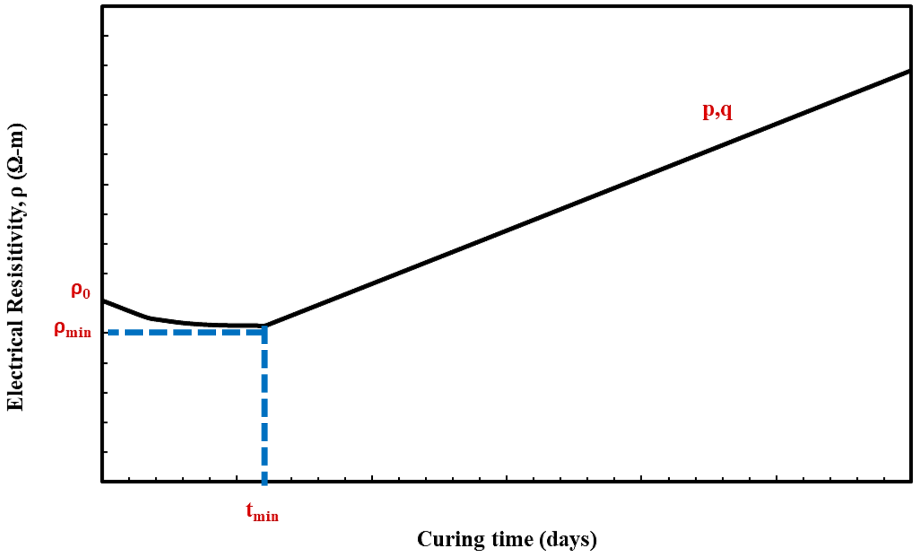


Figure 2: Typical changes in the resistivity during the hydration of cement with time

(b) <u>1-day curing</u>

i. <u>Class-H cement with 0.01% fibers:</u>

After 24 hours of curing, the resistivity was 1.58 Ω-m, which is more than the initial resistivity by 55%. The Vipulanandan curing model parameters p,q, and t_o are summarized in Table 1. The parameter ratio (q/p) was higher than that for Ultrafine cement. The coefficient of determination (R^2) was 1, and the root-mean-square error (RMSE) was 0.44 Ω-m after one day of curing.

ii. <u>Ultrafine cement with 0.01% fibers:</u>

The resistivity after one day of curing was 2.45 Ω-m, which is more than the initial resistivity by 145%. Vipulanandan curing model predicted the measured resistivity very well. The coefficient of determination (R^2) was 1, and the root-mean-square error (RMSE) was 0.72 Ω-m after one day of curing. The resistivity of Ultrafine cement after one day of curing is higher than that for Class-H cement by 55%.

Table 1: Vipulanandan curing model parameters

Cement Type	Minimum resistivity at t_{min} (Ω-m)	Minimum Time (t_{min}) (min)	Time constant (t_o) (min)	Model Constant $q=E_s/E_i$	Model Constant (p)	Constraint (p+q)	q/p	R^2	RMSE
Class-H	0.93	150.00	110	0.11	0.10	0.21	1.16	1.00	0.44
Ultrafine	0.98	15.00	153	0.21	0.22	0.43	0.95	1.00	0.72

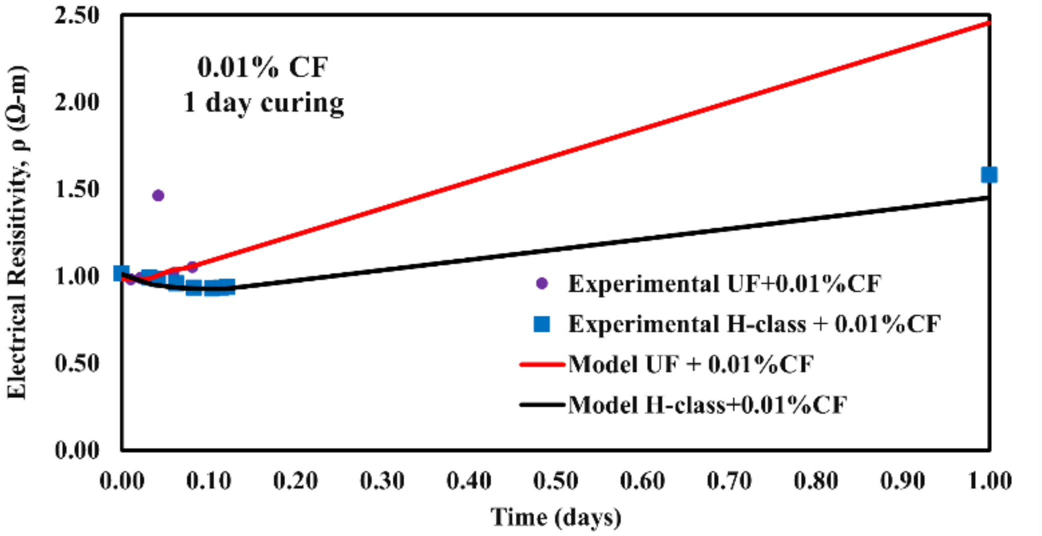


Figure 3: The effect of curing time on the electrical resistivity of Class-H cement and Ultrafine cement with 0.01% CF at 1-day curing

5. Conclusions

From this study, the following conclusions are advanced:

(1).Vipulanandan curing model predicted the measured resistivity very well.

(2). Smart cement with Ultrafine cement has higher performance in resistivity than Class-H cement after one day of curing.

(3).The resistivity sensitivity depends on the type of cement and the amount of additive.

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:

1. Dong, W., Li, W., Long, G., Tao, Z., Li, J., & Wang, K. (2019). Electrical resistivity and mechanical properties of cementitious composite incorporating conductive rubber fibres. Smart materials and structures, 28(8), 085013.
2. Dong, W., Li, W., Sun, Z., Ibrahim, I., & Sheng, D. (2022). Intrinsic graphene/cement-based sensors with piezoresistivity and superhydrophobicity capacities for smart concrete infrastructure. Automation in Construction, 133, 103983.
3. Jefferis, S. A. (2003). Grouts and grouting. Advanced Concrete Technology Set, Elsevier, Oxford.
4. Sarkar, S. L., & Wheeler, J. (2001). Important properties of an ultrafine cement—Part I. Cement and Concrete Research, 31(1), 119-123.
5. Vipulanandan, C., and Paul, E. (1990), ‘Performance of Epoxy and Polyester Polymer Concrete’, ACI Materials Journal, 87(3), pp. 241– 251.
6. Vipulanandan, C. (2021), Smart Cement: Developing, Testing, Modeling and Real-Time Monitoring, Taylor and Francis, CRC Book, London, U. K. 402 pp.