Piezoresistive Behavior of Smart Cement Cured under High Pressure and High Temperature (HPHT) Conditions

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Abstract

In this study, piezoresistive behavior of smart class G Oilwell cement cured under a pressure of 3000 psi (20 MPa) and temperature of 300°F for three days and was tested under uniaxial compression. The change in resistivity was positive under compressive loading and the response was nonlinear. The compressive strength at failure was 5200 psi (36 MPa) and the change in resistivity at maximum load was 160%.

1. Introduction

There have been many damages and failures in cement based infrastructures both onshore and offshore. Hence, long-term structural health monitoring (SHM) of cementitious materials is essential to ensure the durability and safe performance. This is especially critical when cementing casing in oil wells, where the cement is expected to last for decades if not longer while performing its intended purpose under the harsh downhole environments. Hence, there is a need for a robust sensing method that is reliable for as long as the well remains in service. In this study carbon fiber was added to class G Oilwell cement to enhance its sensing properties without altering the mechanical and chemical properties of the final mixture. Carbon fibers have been used to test the resistivity and conductivity of cement-based materials with negative piezoresistivity (change in resistivity) (Wen, 1999. In recent years, highly sensing smart cement has been developed with positive change in resistivity under compressive loading (Vipulanandan et al. 2015-2016).

2. Objective

The specific objectives of this study were to experimentally investigate the piezoresistive characteristics of smart cement cured under high pressure and high temperature.

3. Materials and Method

The materials and methods used in this study are summarized as follows:

- Class G cement with water to cement (W/C) ratio of 0.44. The additives are summarized in Table 1.
- The cylindrical specimen size was 2”X 4” demolded after 3 days of curing under HPHT (300 °F and 3000 psi confining pressure).
- After 3 day of curing period under HPHT (300 °F and 3000 psi confining pressure in the autoclave) the cement specimens were tested.
- The impedance was measured using the two probes with the LCR meter using alternating current (AC) with 1 Volt and the frequency was varied from 20 Hz to (300 kHz.
- Uniaxial compressive strength tests were performed after capping the specimens..

Table 1. Cement Additives by Weight of Cement (BWOC)

Additive	BWOC %
Silica Flour	35
Fluid Loss	0.63
Carbon Fibers	0.05
Dispersant	0.096

4. Results and Discussion

(i). Material Characterization

It is important to identify the critical electrical property of the HPHT cured smart cement so that it can be easily monitored in the field. In this study, LCR meter (L= Induction, C= Capacitance, R= Resistance) with ac current (1 volt) was used to measure the impedance with the frequency. The response of the smart cement is shown in Figure 1. The impedance reduced with the frequncy and at very high frequechy it was approaching limited value, identified as CASE 2 using the Vipulanandan Impedance Model and resistance was the bulk cement material property. The bulk resistance of the smart cement was approximately 40 kΩ at 300 kHz.

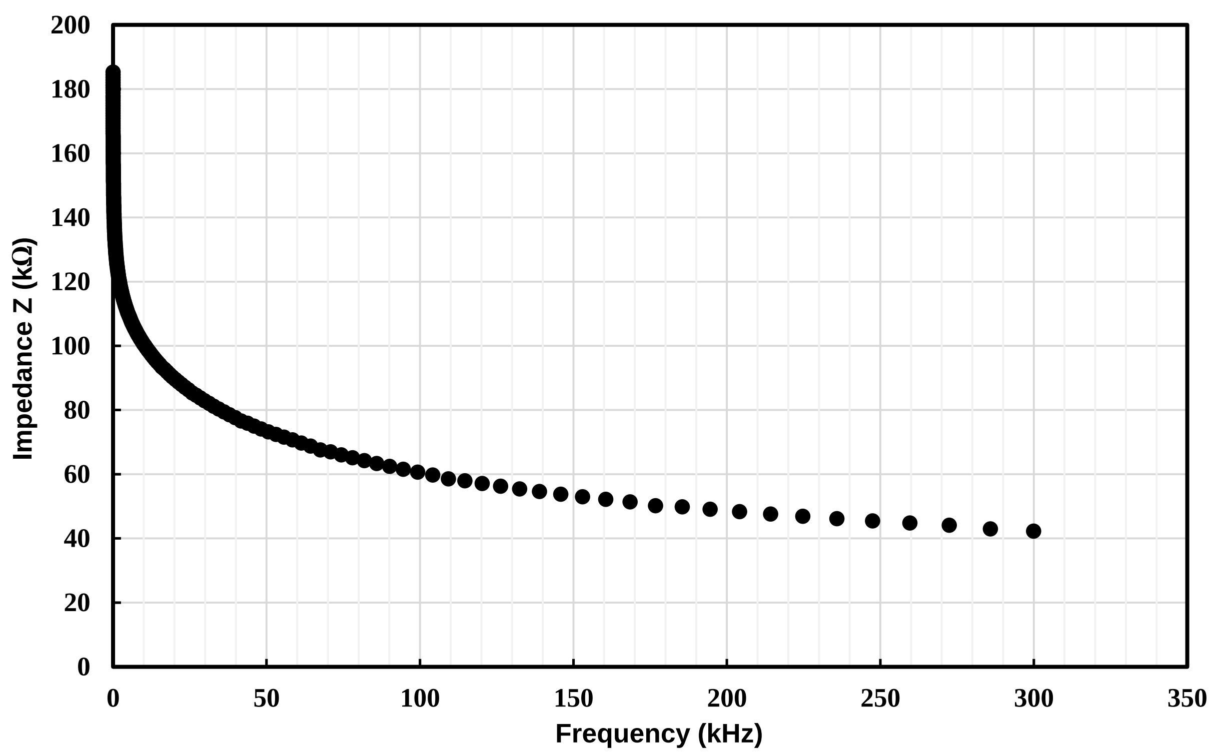

Figure 1. Impedance versus Frequency Response of Smart Cement Cured under HPHT

(ii). Compressive Piezoresistive Behavior

The piezoresistive response of the smart cement under compressive loading is shown in Figure 2. The electrical resistivity increased with the applied compressive stress nonlinearly. The smart cement was very highly responsive at very low stress indicting the sensitivity of the material. The compressive strength of the smart cement was 5200 psi (36 MPa) and the failure resistivity strain was 160%, which is 900 times (90,000%) higher than the compressive failure strain of cement.

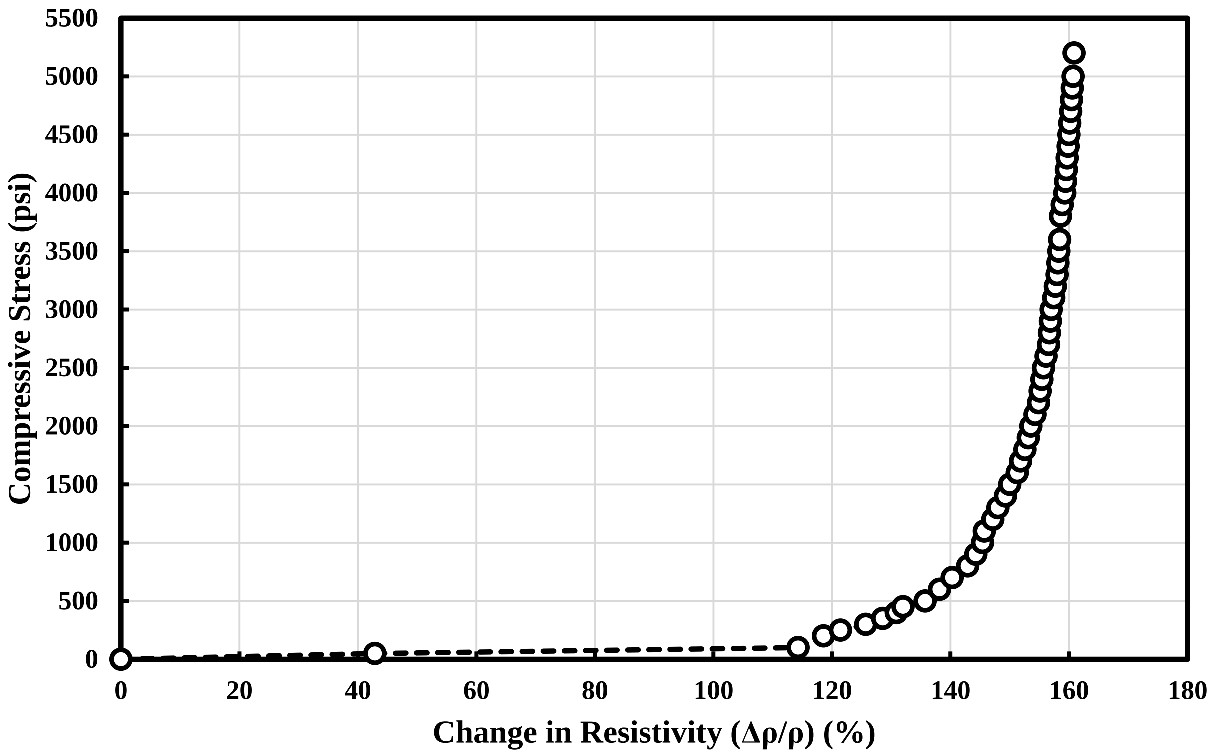

Figure 2. Compressive Stress Versus Change in Resistivity Response of Smart Cement

5. Conclusions

Based on the experimental results following conclusions are advanced regarding the response of the smart cement:

1. Material characterization identified resistivity as the critical parameter to monitor.
2. The electrical resistivity increased with increasing applied compressive load.
3. Maximum change of resistivity at the failure load was 160%, which is 900 times (90,000%) higher than the compressive failure strain of cement.
4. Smart cement cured under HPHT was highly sensitive and can be used for structural health monitoring.

6. Acknowledgements

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7. References

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