Characterization of Piezoresistive Structural Material using Impedance Spectroscopy

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Abstract
In this study, the self monitoring characteristics of carbon fiber reinforced polymer concrete (CFRPC) were investigated using compressive loading and Impedance Spectroscopy (IS). CFRPC showed piezoresistive characteristics and had a piezoresistive coefficient of 0.014/MPa and it is not affected by the change in AC frequency.

1. Introduction
Maintenance and rehabilitation of civil infrastructure by using self-monitoring materials is of increasing interest these days. Polymer is considered as the popular alternate binder for cement because of its rapid setting, high strength to density ratio and ability to withstand corrosive environment. Polymeric composites are being used as an alternate to cementitious composites in many engineering applications.

In this study, compressive properties of CFRPC were investigated using cyclic compressive loading and impedance spectroscopy. Carbon fiber was used as the conductive filler. Specimens were tested in compression to obtain the mechanical and electrochemical properties and self monitoring characteristics of CFRPC.

2. Objectives
The overall objective of this study was to characterize the piezoresistive material using compressive loading and the Impedance Spectroscopy (IS).

3. Preparations of CFRPC Specimens
Considering the workability and performance, in this study, polymer resin content chosen to be 20% by weight and Carbon fiber as 6% by weight. The sand used was well graded and had a coefficient of uniformity (Cu) of 5.8 and coefficient of concavity (Cc) of 0.9. In preparing the PC specimens, Cobalt Napthanate (CN) was first added to the polyester resin and the solution was mixed thoroughly and then Methyl Ethyl Ketone Peroxide (MEKP) was added. After further mixing, sand and conductive filler were added slowly and mixed long enough to obtain a uniform mix (CIGMAT PC 1-02). For the compression test, cylindrical specimens were prepared (CIGMAT PC 2-00). Specimens were cured at room temperature (about 25°C) for 24 hours followed by 80°C for 24 hours in an oven. Wires with conductors were embedded into the specimen during the preparation.

4. Impedance Spectroscopy
Impedance Spectroscopy (IS) is a very versatile electrochemical tool to characterize intrinsic electrical properties of any material and its interface. The basis of IS is the measurement of the impedance (resistance of Alternating Current (AC)) of the observed system in terms of the applied frequency and exciting signal. In this study, the frequency of the AC signal was varied from 0.1 Hz to 1 MHz and the coresponding impedances of the CFRPC specimen were measured.

5. Piezoresistivity Coefficient

In this study piezoresistivity coefficient (Π_{ijk}) is used to quantify the sensitivity of the CFRPC material to stress and it is defind as $(\Delta\rho/\rho_o)_i = \Pi_{ijk}.\Delta\sigma_{jk}$ where $(\Delta\rho/\rho_o)_i$ is the specific change in electrical resistivity and $\Delta\sigma_{jk}$ is the change in stress tensor. Under uniaxial stress condition the above equation simplified to $(\Delta\rho/\rho_o)_1 = \Pi_{111}.\Delta\sigma_{11}$.

6. Analysis and Discussions

During compressive loading test, the DC electrical resistance measurements were made along the stress (longitudinal) axis using Hewlett Packard 34420A Nano Volt / Micro Ohm Meter. Strain in the specimen was measured using the conventional strain gauge. Testing was performed in multiple cycles on loading up to a fraction of the failure stress . From figure 1(a) the piezoresistivity coefficient (Π_{111}) of CFRPC was obtained as 0.014/MPa above compressive stress of 3 MPa. During the IS test, the AC signals of different frequencies were applied to the specimen using a function generator and the impedances were measured using the same Nano Volt / Micro Ohm Meter. The bulk impedance is the impedance which remained unchanged after the frequency sweep. The piezoresistivity coefficient (Π_{111}) of the bulk impedance was obtained as 0.015/MPa.

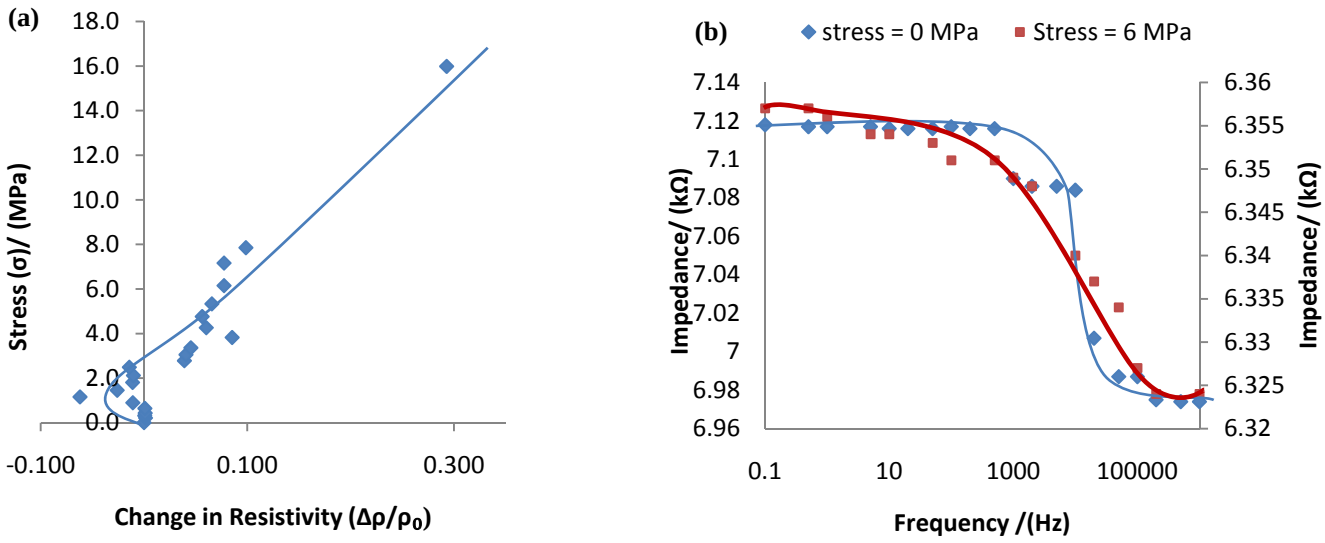

Fig. 1.(a) Variation of Stress with Change in Resistivity during compressive loading **(b)** Bode plots of CFRPC Specimen when compressive stress = 0 MPa and stress = 6 MPa.

7. Conclusions

The piezoresistive coefficients (Π_{111}) obtained using compressive loading and impedance spectroscopy methods were 0.014/MPa and 0.015/MPa respectively. These coefficients indicate the sensitivity of the CFRPC material. The sensitivity of the CFRPC material is not affected by the change in AC frequency.

8. References

1. Development and Characterization of Piezoresistive Smart structural Materials, Vipulanandan C and Sett, Kallol, Earth & Space 2004