Cementitious Piezoresistive Structural Sensors (PRSS-CIGMAT (C))

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Abstract: Stress-strain relationships and sensing properties of cementitious piezoresistive materials were analyzed based on literature review. Piezoresistive performance of various cementitious materials was compared based on compressive stress, strain and resistivity relationships. Based on the current study, typical value for piezoresistive coefficient was estimated to be $3470*10^{-9}$ m^2/N while corresponding gage factor was 260.

1. Introduction

If a material's electrical resistivity changes with applied stress or strain, it is classified as piezoresistive. A Piezoresistive Structural Sensors (PRSS) can be developed, which is smart enough to sense its own properties depending on resistivity. PRSS can be used for stress and strain sensing, damage sensing, health monitoring, and thermoelectric sensing. Characterization of a cement based Piezoresistive Structural Sensor developed at CIGMAT (PRSS-CIGMAT (C)) for self-sensing is compared to the information in the literature.

2. Objectives

To compare the sensing characteristics of cementitious piezoresistive composites reported in the literature to material developed at CIGMAT.

3. Literature Review

Cementitious composites are commonly used in construction and maintenance of infrastructure. Fresh cement pastes conduct electricity electrolytically (non Ohmic conduction) and with addition of conductive filler, conduction occurs electronically (Ohmic). A model was proposed by Sett (2003) which defines the piezoresistive behavior of conductive filler reinforced polymer concrete which is given by,

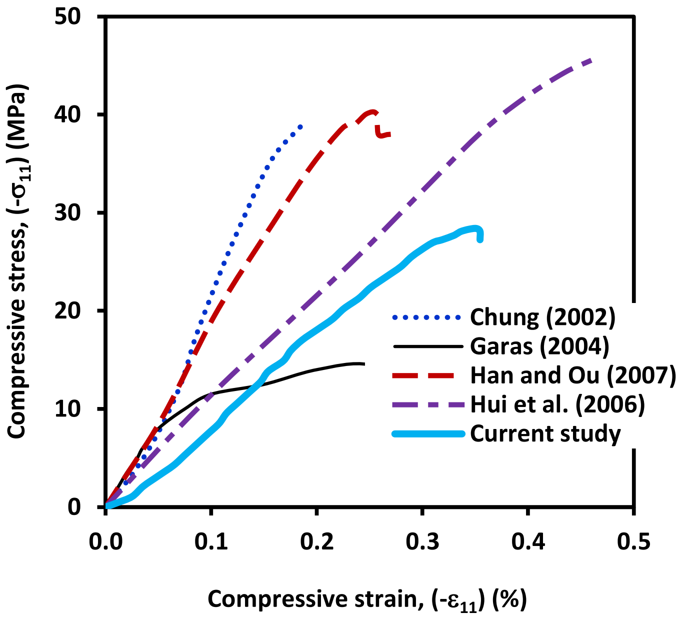
$$\left(\frac{\Delta\rho}{\rho_o}\right)_i = \prod_{ijk} \Delta\sigma_{jk} = \prod_{ijk} C_{jkmn}\, \Delta\varepsilon_{mn} = M_{ijk}\Delta\varepsilon_{jk} \quad \ldots\ldots (1)$$

where $\frac{\Delta\rho}{\rho_o}$ is fractional change in resistivity, $\prod$ is piezoresistivity coefficient, and M is gage factor. Both $\prod$ and M can be used to characterize the piezosensitivity by signifying the change in $\frac{\Delta\rho}{\rho_o}$ with stress and strain respectively. This model was used by Garas (2004) in characterizing the self-monitoring behavior of carbon fiber reinforced cement mortar under uniaxial compression. After a small reduction in resistivity at low stress values, a threshold was observed after which resistivity increased with compressive stress. The parameter $\prod$ was $-1.1*10^{-9}$ (initial) and $1*10^{-9}$ (post threshold) while M varied from -40 (initial) to 35 (post threshold) as reported by Garas (2004).

As reported by Chung (2002), in carbon fiber reinforced cement mortar, resistivity decreased under compression after 7 days of curing and it increased after 28 days of curing. Hui et al. (2006) studied carbon black filled cement pastes and reported a decrease in resistivity when subjected to compressive stress. Han and Ou (2007) also reported a decrease in resistivity of cement composite filled with carbon black and carbon fiber.

4. Results and Analysis

A conductive filler reinforced cementitious composite (coded MM) was used in current study. Stress-strain and stress-resistivity relationships are shown in Figures 1 and 2 along with some relationships found in literature. When compared to other relationships, it was evident that MM showed piezoresistive behavior, but at varying degree. It was noted that with compressive stress, resistivity increased in one case (Chung (2002)) and decreased in two other cases (Han and Ou (2007) and Hui et al. (2006)). In MM, a minimum threshold value (Garas (2004)) was observed and after that resistance increased with stress. Depending on base material properties, piezoresistive behavior can be different. Typical $\prod$ value for MM (post threshold) was estimated to be $3470*10^{-9}$ m^2/N and corresponding ***M*** value was 260. The piezoresistive parameters from this study were comparable to the values calculated from literature data.



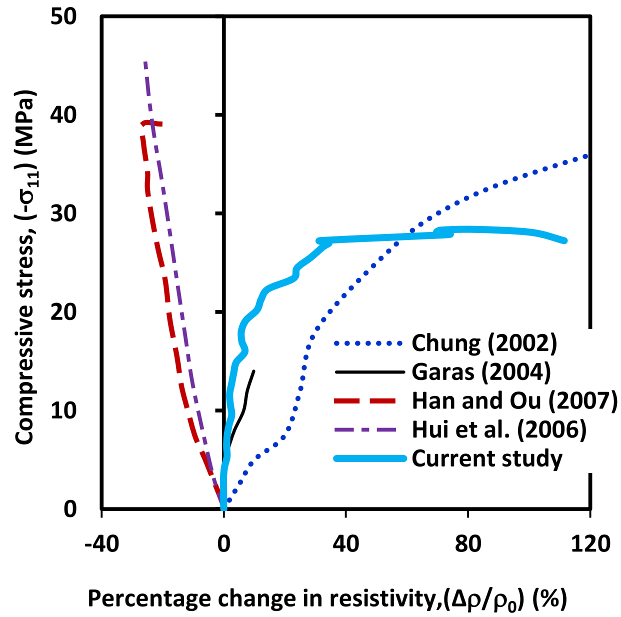


Figure1: Variation of compressive stress with strain for cementitious composites

Figure2: Variation of compressive stress with percentage change in resistivity

5. Conclusion

Based on the literature review and current study, the modified cementitious composites were piezoresistive and magnitudes of $\prod$ and ***M*** varied from $-600*10^{-9}$ m^2/N to $3470*10^{-9}$ m^2/N and -50 to 260 respectively.

6. Acknowledgement

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7. References

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