Polymeric Piezoresistive Structural Sensors (PRSS-CIGMAT (P))

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Abstract: Based on literature review and current study, stress/strain relationships and sensing properties of polymeric piezoresistive materials were analyzed. Piezoresistive coefficient and gage factor are regarded as indicators for such self-sensing materials and typical values were estimated to be in the range of 300-1600*10^{-9} m^2/N and 32-47 respectively for the selected polymeric composites.

1. Introduction

A material is piezoresistive if resistivity of that material changed under applied stress or strain. In contrast to the piezoelectric effect, the piezoresistive effect only causes a change in electrical resistance; it does not produce an electric potential. By improving material properties, a structural material can be made smarter to act as a Piezoresistive Structural Sensor (PRSS), which is self-sensing depending on resistivity.

2. Objectives

To compare the sensing characteristics of polymeric piezoresistive composites reported in the literature to the results from current study at CIGMAT.

3. Literature Review

Composites based on polymer, which are used in light weight structures such as aerospace and automotive, have long been studied. But very limited information was available in the literature on polymer based piezoresistive materials (Xu et al. (1996), Sett (2003) and Sevkat et al. (2008)). Polymer-matrix composites can be made electrically conductive with the addition of conductive filler.

Piezoresistive behavior of conductive filler reinforced polymer concrete was modeled by Sett (2003) as,

$$\left(\frac{\Delta\boldsymbol{\rho}}{\boldsymbol{\rho_o}}\right)_{\boldsymbol{i}} = \prod\nolimits_{\boldsymbol{ijk}} \Delta\boldsymbol{\sigma_{jk}} = \prod\nolimits_{\boldsymbol{ijk}} \boldsymbol{C_{jkmn}}\, \Delta\boldsymbol{\varepsilon_{mn}} = \boldsymbol{M_{ijk}}\Delta\boldsymbol{\varepsilon_{jk}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where $\frac{\Delta\boldsymbol{\rho}}{\boldsymbol{\rho_o}}$ is fractional change in resistivity, $\prod$ is piezoresistivity coefficient which relates specific change in electrical resistivity to change in stress tensor, and $\boldsymbol{M}$ is elasto-resistance tensor (known as gage factor) which signifies sensitivity of change in resistivity measurement to strain. Both piezoresistivity coefficient and gage factor were used to quantify piezosensitivity. This model is of interest as it can be used as a good indicator for stress/strain sensing.

Self-monitoring behavior of carbon fiber reinforced polymer concrete was studied by Sett (2003). Under compression, this material showed a decrease in resistivity at low stress values. The change in the trend was regarded as threshold. As reported, $\prod_{\boldsymbol{111}}$ was calculated to be -700*10^{-12} m^2/N initially and 650*10^{-12} m^2/N post threshold. Similarly $\boldsymbol{M_{111}}$ was found to be -8 and 7.2. Under tension, change in resistivity was always positive which yielded 650*10^{-12} m^2/N and 9.2 as $\prod_{\boldsymbol{111}}$ and M_{111} respectively.

4. Results and Analysis

A material which is polymeric in nature (coded LL) was used in the current study. Conductive filler reinforcement was adopted in order to develop piezoresistivity. Two different composites were made and tested under uniaxial compression. Composite-1 was loaded with 4% conductive filler (by wt.) while composite-2 was prepared with 0.7% modified conductive filler. Figures 1 and 2 show the variation of compressive stress with strain and fractional change in resistivity ($\frac{\Delta\rho}{\rho_o}$) respectively. It was evident that the LL composites showed piezoresistive behavior. For the same stress value, fractional change in resistance was way higher than strain for both composites. Hence measuring the electrical resistance proves to be worthy for stress/strain sensing of LL composites. A threshold value (Sett (2003)) exists after which resistivity increased. Formation of conductive network at lower stress values causes the electrical resistance to decrease and then breakage of conductive network causes an increase. Typical $\prod_{111}$ values for the LL composites 1 and 2 (post threshold) were estimated to be around $1600*10^{-9}$ m^2/N and $300*10^{-9}$ m^2/N respectively and corresponding M_{111} values were 32 and 47. These gage factors depict that sensitivity of PRSS is very high compared to conventional strain gages. When compared to the values reported by Sett (2003), dissimilarity is seen and this can be attributed to difference in constituent materials. However complete study is yet to be done to characterize the piezoresistive behavior of LL material. Furthermore, towards failure, resistivity increases very rapidly which proves to be good enough for damage sensing.

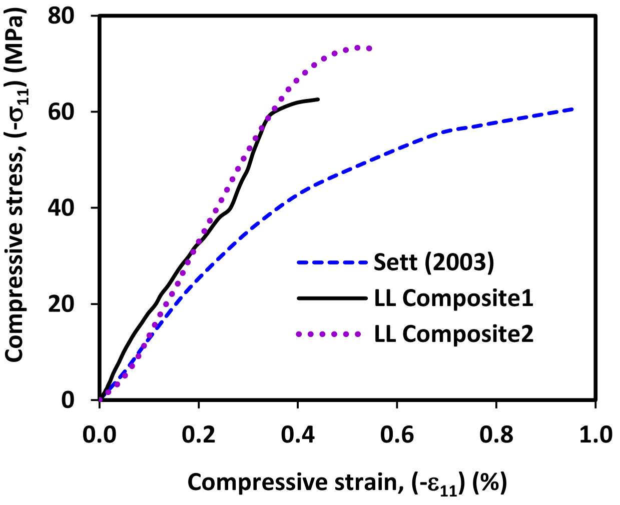

Figure 1: Variation of compressive stress with strain for polymeric composites

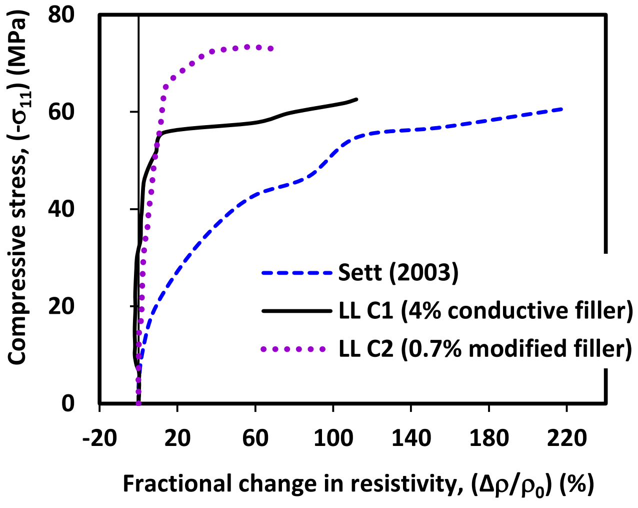

Figure 2: Variation of compressive stress with percentage change in resistivity

5. Conclusions

Based on the literature review and current study, magnitudes of piezoresistive parameters $\prod$ and M for the modified polymeric composites varied from $-700*10^{-12}$ m^2/N to $1600*10^{-9}$ m^2/N and -8 to 47 respectively.

6. Acknowledgement

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7. References

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