CHARACTERIZATION OF CEMENT-BASED PIEZOELECTRIC COMPOSITE SMART MATERIAL

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Summary: With increasing sophisticated civil engineering structures and tall buildings, structural health monitoring (SHM) becomes even more necessary. Among the materials used for non-destructive analysis (NDA), piezoelectric material is one the most interesting because it has actuator and sensor properties. An efficient technique for NDA is the acoustic emission (AE) detection, which gives accurately information about the structural conditions before the defect causes irreparable damage. The sensing element is usually embedded or surface mounted in the structure and therefore the impedance matching between the sensor material and the structure is an important parameter. In this work a cement-based piezoelectric composite with 1-3 connectivity was manufactured and characterized. Electromechanical measurements show that the presence of cement left the dielectric constant of both composite and concrete materials very close. The longitudinal piezoelectric constant ($d_{33}$) obtained was around 200 pC/N for a 1.2 MeV/m poling electric field. Ball bearing and pencil lead break tests indicate the sensor’s ability to detect acoustic emission.

1 INTRODUCTION

With the increasing population growth, the constructions of large buildings for housing or for trade are increasingly required to meet demand. It is known that the structure of the buildings deteriorate over time by several factors and the security of the population depends on the constant monitoring of structural integrity, which is often expensive, time consuming and sometimes not very accurate and also not feasible satisfactorily [1 – 5].

In this context, accurate monitoring of structure, in real time and if possible in an automated manner is of considerable importance bearing in mind that the successful monitoring may prevent loss of life, lower maintenance costs and prevent extensive damage. For the structural integrity monitoring, the sensor is an essential component. Among the
techniques used in sensors, the piezoelectricity has appeared as one of the most efficient mechanism [6]. On the other hand, the acoustic emission (AE) has been important and accurate technique for non-destructive structural evaluation [7-8]. That way piezoelectric material like lead zirconate titanate (PZT) ceramic or polymer-based piezoelectric composites have been studied and proposed as AE sensor for “Structural health monitoring” [9-10]. However, for evaluation of structures in the civil engineering, which main material is the concrete, the polymer-based composites and the piezoelectric ceramics are not compatible due to the different properties as the dielectric constant [11].

To overcome this problem, in this work a cement-based piezoelectric composite was obtained mixing cement, polymer (PU) and PZT in the rod form. The connectivity of the composite is 1-3 [12]. The electroactive properties of the composite PZT/PU/Cement were determined and the preliminary results indicate that the material has potential application as AE sensor for structure evaluation in the civil engineering. The composite surface mounted in the concrete structure, detects the transient elastic mechanical waves provided by the AE source (damage growth, cracks, etc.) and transforms it into electrical signal, which can be observed by oscilloscope.

2 EXPERIMENTAL

I MATERIALS:
- Polyurethane (PU) – Aqueous dispersion provided by Chemtura S. A., named PUW320;
- Ceramic: Lead Zirconate Titanate (PZT) form American Piezo Ceramics (APC) – PZT 851;
- Cement: Cement Portland CPII Z32
- Silver adhesive MH Nano – MY 203

II COMPOSITE PREPARATION:
The PZT in the wire form was obtained using a mixture of 95 vol.% of PZT powder and 5 vol.% of PU, calculated through the equation below:

\[ M_c = M_p \rho_c \left( \frac{\Phi_c}{\rho_p (1-\Phi_c)} \right) \]  

Where:
M is the mass; \( \rho \) is the density and \( \Phi \) is the volume fraction; c and p is related with the ceramic and polymer, respectively.
The mixture with a paste consistency was extruded with a syringe onto a glass plate and dried in an oven at 70ºC Thereafter, the PZT wire was sintered at 1260ºC. Figure 1 shows the composite fabrication with 1-3 connectivity.
III CHARACTERIZATION

A) Piezoelectric spectroscopy: The longitudinal $d_{33}$ piezoelectric coefficient was measured using a Pennebaker model 8000 $d_{33}$ Piezo Tester. The parameters studied were: poling field, poling time and temperature of polarization.

B) Microscopy: Field emission microscopy (FEG-SEM) images of the PZT wire and of the composite was obtained with a JEOL model 7500F in collaboration with Laboratório Interdisciplinar de eletro-cerâmica at Instituto de Química de Araraquara – UNESP.

C) Dielectric spectroscopy: Dielectric measurement was carried out using the HP 4192A Impedance Analyzer.

3 RESULTS AND DISCUSSION

Figure 2 shows the PZT wire after sintering. It can be seen that the removal of the polymer phase those not provided the appearance of the porous and the material present good homogeneity. The PZT/PU/Cement composite is shown in Figure 3. There is no contact between PZT wires indicating the 1-3 connectivity.
Figure 3: FEG-SEM image of the composite surface

The dielectric behavior of the composite was studied by measuring the permittivity ($\varepsilon'$) and dielectric loss ($\varepsilon''$) at room temperature, in the frequency range of $1.0 \text{ kHz}$ to $10^4 \text{ kHz}$. Equations 2 and 3 provide the values of permittivity and dielectric loss, respectively [13].

$$\varepsilon' = \frac{LY''}{A\omega\varepsilon_0}$$  \hspace{1cm} (2)

$$\varepsilon'' = \frac{LY'}{A\omega\varepsilon_0}$$ \hspace{1cm} (3)

where, $Y'$ and $Y''$ are the real and imaginary parts of the complex impedance, respectively; $\omega$ is the angular frequency, $A$ is the electrode area of the sample and $\varepsilon_0$ is the vacuum permittivity and $L$ is the simple thickness. Figure 4 and Figure 5 shows the dielectric behavior of PZT/PU/Cement composite, PZT/PU and Cement/Sand for comparison. By adding cement, the dielectric properties of the composite become closer of the material used in the structure.

Figure 4: Dielectric permittivity of the materials at room temperature
Figure 5: Dielectric loss of materials at room temperature.

For the $d_{33}$ longitudinal piezoelectric coefficient measurement, the sample is stretched in the same direction of the polarization and the electric potential from the piezoelectricity is compared with the value obtained with a standard ceramic sample. Table I shows the result obtained for 3 samples, using different poling electric field and fixed temperature and poling time.

<table>
<thead>
<tr>
<th>Electric Field (MV/m)</th>
<th>Temperature (°C)</th>
<th>Time (min)</th>
<th>Sample 1 $d_{33}$ (pC/N)</th>
<th>Sample 2 $d_{33}$ (pC/N)</th>
<th>Sample 3 $d_{33}$ (pC/N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.45</td>
<td>60</td>
<td>30</td>
<td>86</td>
<td>91</td>
<td>101</td>
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<tr>
<td>0.60</td>
<td>60</td>
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<tr>
<td>0.76</td>
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<td>30</td>
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<tr>
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<td>30</td>
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<td>173</td>
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<td>1.21</td>
<td>60</td>
<td>30</td>
<td>183</td>
<td>199</td>
<td>226</td>
</tr>
</tbody>
</table>

Table I – Variation of $d_{33}$ with poling electric field.

The poling temperature and the poling time were determined making the experiment with a fixed electric field and 60ºC appeared as the better temperature. The $d_{33}$ value does not change appreciably for polarization time over 30 min.

To characterize the surface mounted composite as AE sensor, the concrete rectangular piece with (19 x 9 x 5) cm dimensions was excited using two simulated AE sources: ball bearing drop, producing large amplitude and low frequency stress waves and pencil lead break (Hsu-Nielsen source) [14] which produce low amplitude with high frequency waves. A digital storage oscilloscope (Agilent DSO6012A) collects the data from the sensor. Figures 6 and 6a and 6b show the response of the composite sensor to a ball bearing drop test. The amplitude in the oscilloscope was 100 mV/div.

Figures 7, 7a and 7b show the electrical response of the sample to a pencil lead break test. The scale of the oscilloscope was 50 mV/div.
4 CONCLUSIONS

Cement-based piezoelectric composite with 1-3 connectivity was fabricated and characterized. The piezoelectric coefficient of 226 pC/N was obtained when the composite sample was polarized with small electric field. FEG-SEM microscopy shows PZT wires without meaningful pores and shows no percolation between the PZT.

The inclusion of cement into the PZT/PU composite increased the dielectric constant in comparison with the PZT/PU, approaching the value of the dielectric constant of concrete. The PZT/PU/Cement composite has the ability to detect AE signal.

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6 REFERENCES


