Porous piezoelectric materials for energy harvesting

Germán Martínez Ayuso*[1], Michael I. Friswell[1], Sondipon Adhikari[1], Hamed Haddad Khodaparast[1], and Carol A. Featherston[2]

[1]College of Engineering, Swansea University, Swansea, UK
[2]School of Engineering, Cardiff University, Cardiff, UK

Introduction

In this poster a new approach to energy harvester is done using composite material as porous piezoelectric material. This material is composed of two phases, being the matrix piezoelectric material as PZT-5A and its inclusions spheres of air.
In order to study this material for possible energy harvesting applications, in a previous step the porous material have to be homogenized for the different values of porosity. The method proposed to homogenize the material is the Mori-Tanaka approach. Lately the performance of this composite material is studied through an analytical simulation for different values of porosity, length and resistance. This results are validated with a FE model.

Homogenization: Mori-Tanaka approach

This methods is analytical solution for the homogenization of composite materials based on the Eshelby inclusion solution. The solution approximates the interaction between phases by assuming that each inclusion is embedded in an infinite matrix that is loaded remotely by an average matrix strain. Firstly, an influence tensor has to be calculated for every phase (A_i^0). These influence tensors will be averaged to obtain A_I, and finally C^*.
In this poster, E_I and E_M are the electroelastic properties matrix of the inclusions and matrix, respectively. The matrix and inclusion volume percentage are noted by c_M and c_I. The parameter A_i^0 is the influence tensor which relates the matrix strain tensor with the inclusion strain tensor. The Eshelby solution appears as S^* tensor and the homogenized material properties is denoted as E^*. I is the identity tensor.

$$A_I^0 = \left[I + S^* E_M^{-1} (E_I - E_M)\right]^{-1}$$
$$A_I = \left[c_I I + c_M (A_I^0)^{-1}\right]^{-1}$$
$$E^* = E_M + c_I (E_I - E_M) \cdot A_I$$

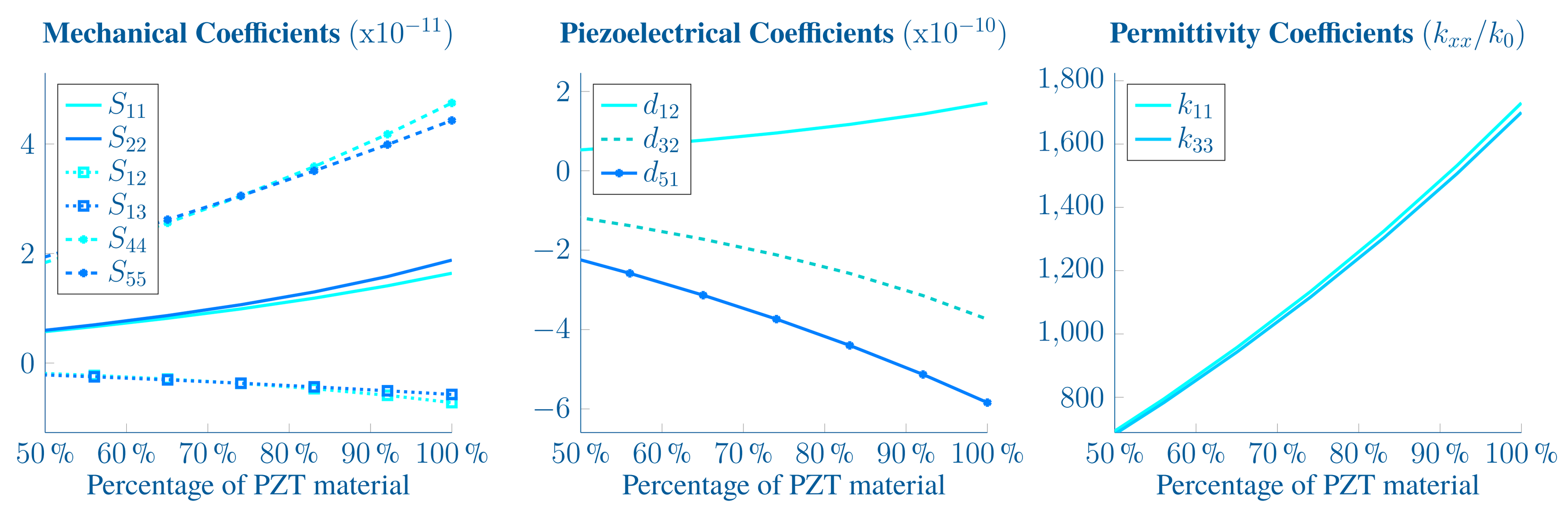


Figure 1: Mori-Tanaka Homogenization results for range 50%-100% of air inclusions

Theoretical Analysis: Mass constant energy harvester

A energy harvesting study over a cantilever bimorph beam made of porous piezoelectric material is performed using Euler-Bernouilly beam assumptions. Displacement and voltages are obtained doing a modal decomposition. In this energy harvester study, the mass of the piezo is constant for the whole range of porosity, hence the thickness of the piezoelectric layer increases to keep the amount piezoelectric material constant. The relationship between piezoelectric thickness and porosity increment are linear.

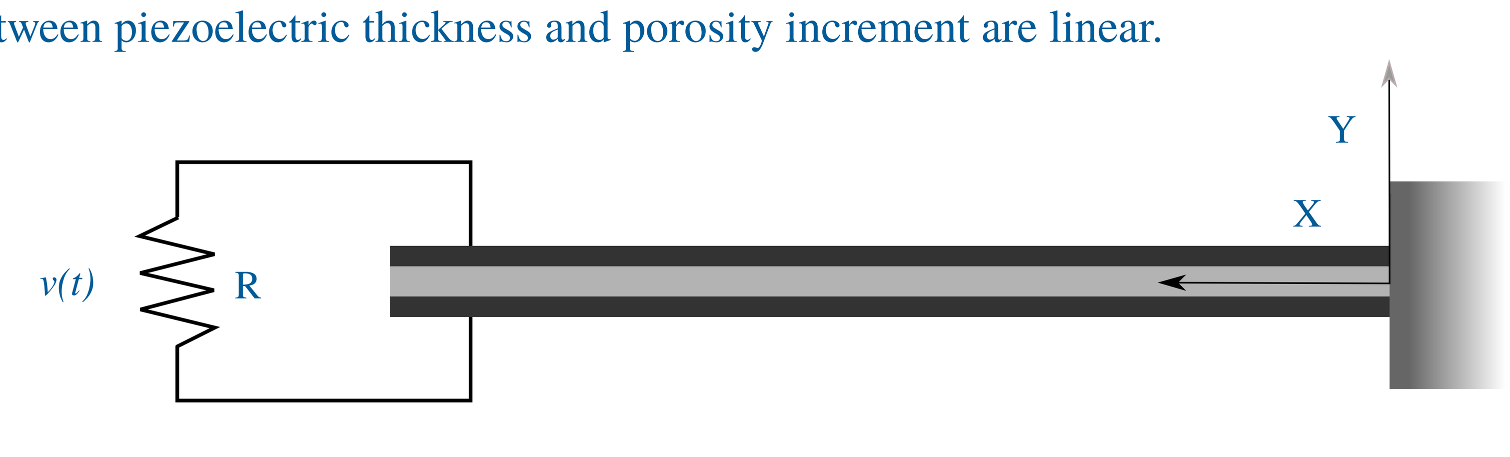


Figure 2: Energy harvester design.

$$\left.\begin{aligned} w(x,t) &= \sum_{n=1}^{\infty} \phi_n(x)\,\eta_n(t) \\ \frac{d}{dt}\left(\int_A D_i \cdot n_i \, dA\right) &= \frac{v(t)}{R} \\ D_i &= e_{imn}\epsilon_{mn} - k_{in}E_n \end{aligned}\right\} \Rightarrow V(\omega) = \frac{-\,\omega^2 W_0 \sum_{n=1}^{\infty} \dfrac{-\,j\omega\theta_n\sigma_n}{\omega_n^2 - \omega^2 + j2\zeta_n\omega_n\omega}}{\dfrac{1}{R} + j\omega C^{eq} + \sum_{n=1}^{\infty} \dfrac{j\omega\theta_n^2}{\omega_n^2 - \omega^2 + j2\zeta_n\omega_n\omega}}$$

Acknowledgment

The authors acknowledge the financial support from the Sêr Cymru National Research Network and Swansea University through a Postgraduate Scholarship.

***Main author. Email: 841238@swansea.ac.uk**

Results

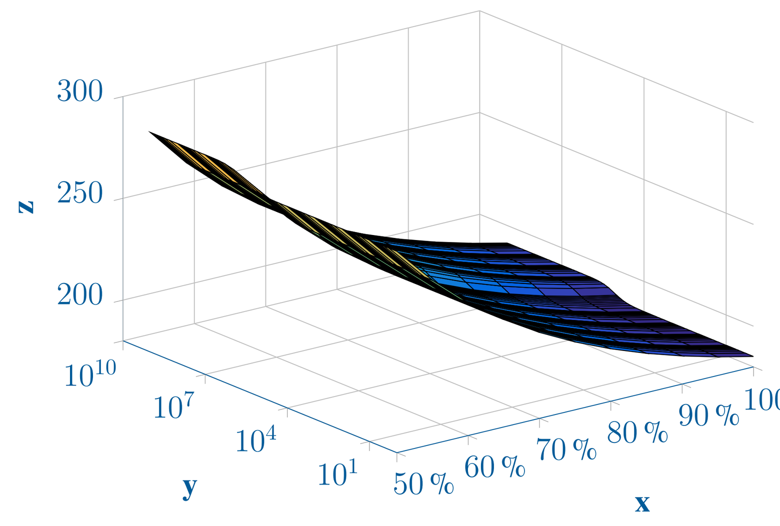


Figure 3

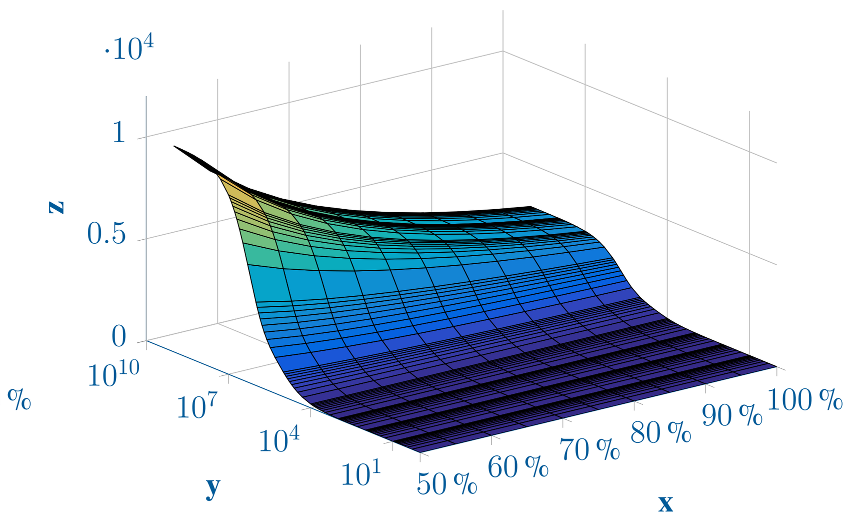


Figure 4

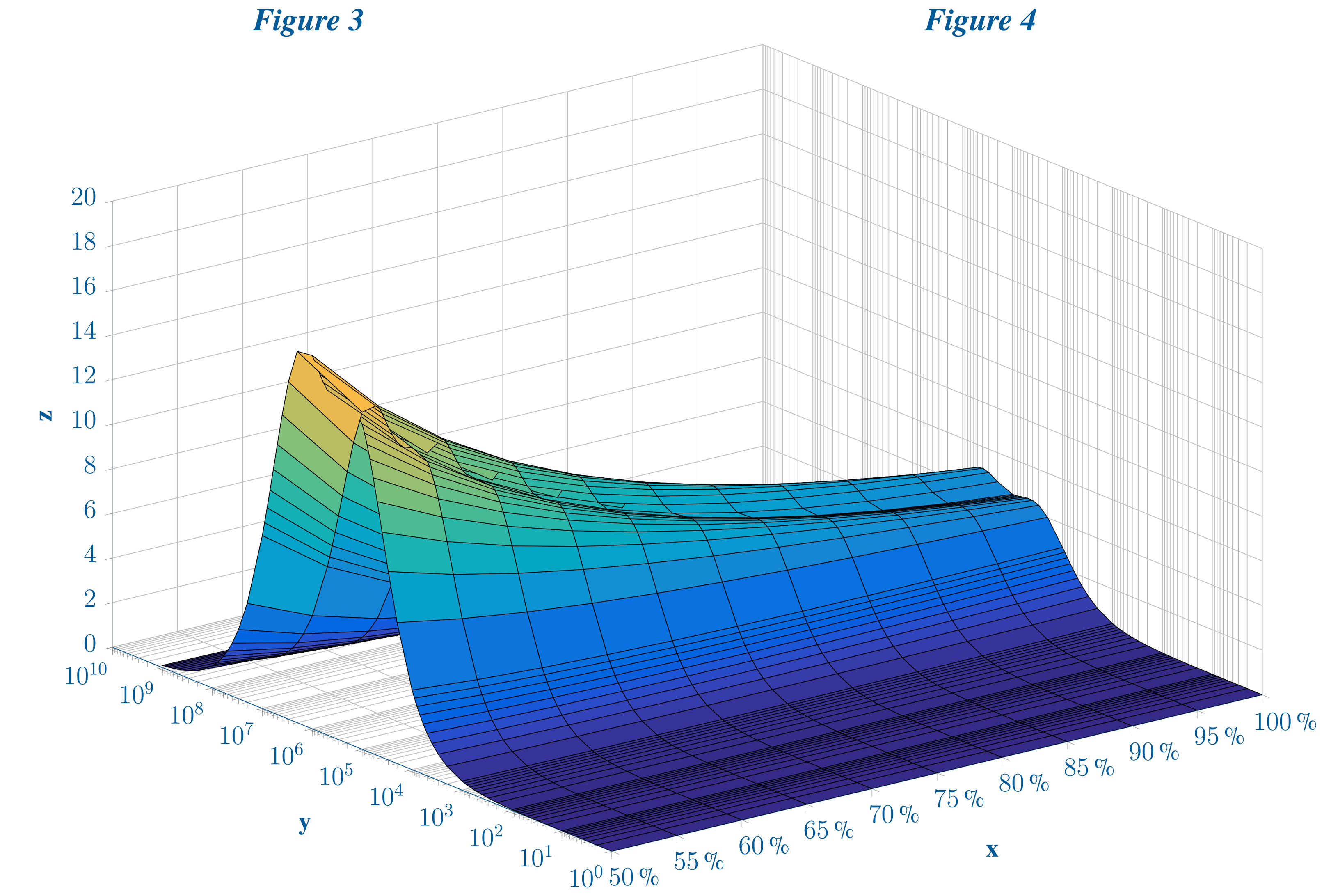
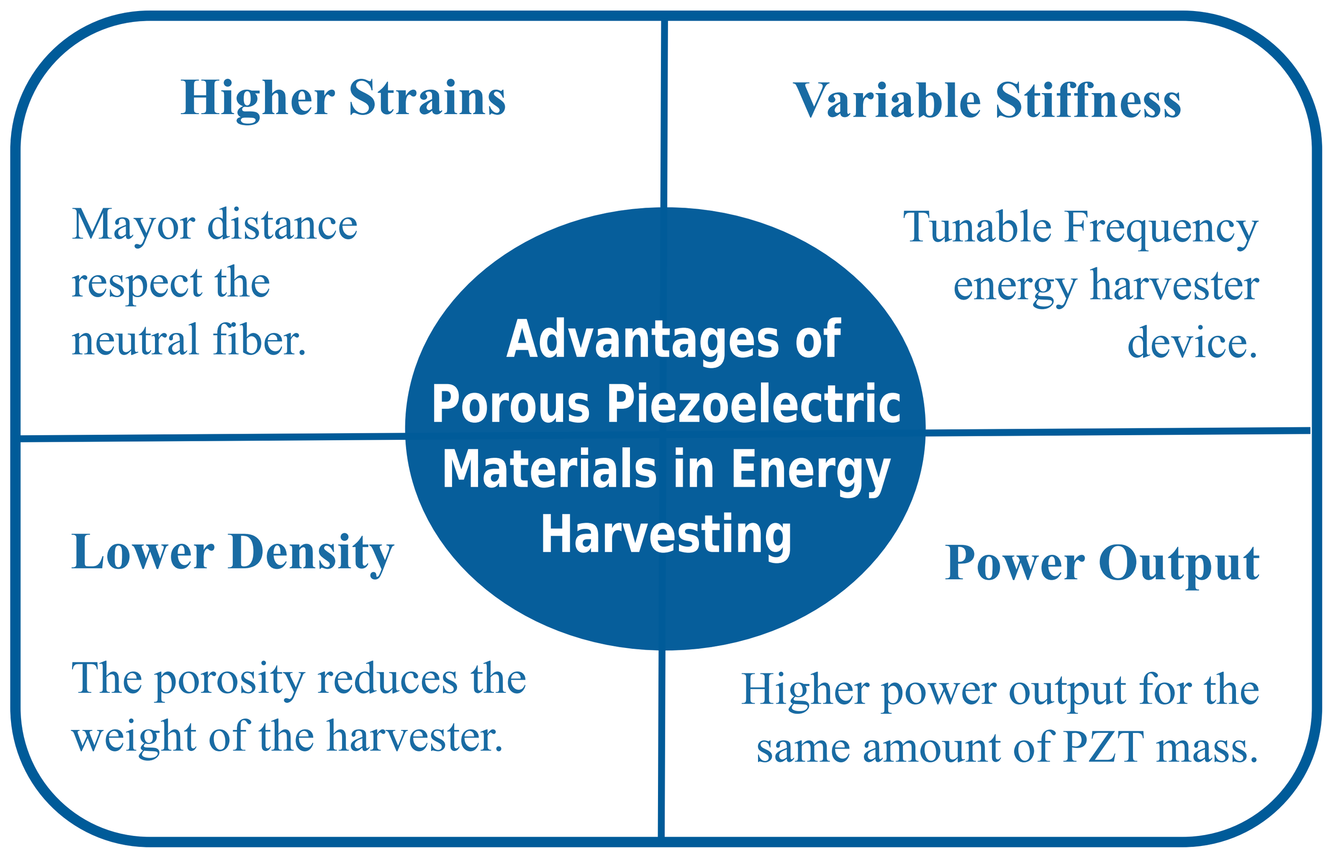


Figure 5

Figures 3, 4 and 5 show respectively the variation of the first natural frequency, the voltage and the power, for PZT material percentage between 50% and 100% and resistances range between $10^9\ \Omega$ and 1 Ω. The value measured Hertz, Volts and power (Watios), are in the z axis of the mentioned plots, while PZT material percentage is in the x axis and resistance is in the y axis. Figure 5 shows an increment of the power at the same time the PZT material percentage decreases, that means the porosity increase the power output. The present study shows that 75% of PZT material can leads up to 15 percent respect the non porous model. Also the natural frequency of the first mode increases as well up to 15 %.

Conclusions



Applications

- Design of sensor patch for plates and beams functionally optimised through thickness and length.
- Lighter and frequency tunable energy harvester designs.

Future research

- Experimental validation in a cantilever test.
- Optimized impacted piezoelectric energy harvester plate.