Novel Reentrant Composite Structure: A Potential Material for Orthopaedic Applications

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Introduction

It was hypothesized that the nonlinear load-displacement relationship displayed by bone could be conferred on an implant by tailoring its structure, yielding an enhanced mechanical stimulation of the tissues. These composite structures were designed to also feature piezoelectric properties that could additionally stimulate osteogenesis. Preliminary mechanical and electromechanical investigations of such porous structures are presented.

Materials and Methods

Bowtie specimens with various aspect ratios (Small, Medium, Large, Extra-large, Extra-extra-large) were made from Nickel powder via a solid free form process and from stainless steel shim stocks using a plastic forming technique. Poled Barium Titanate plates were sandwiched between the stainless steel bowtie cells to create electromechanical composite structures. The bowtie structures were positioned between self-aligning platens in a MTS system (Mini Bionix 858, MTS, Eden Prairie, MN) and subjected to both cyclic and quasi-static compression to investigate their strain-stress and behaviors. Non-contact sensors (MTI) were used to measure transverse deformation. The voltage signals delivered by the piezoelectric composite structures were monitored along with the axial deformation, axial force and transverse deformation signals. The apparent modulus, yield strength, plastic strength, resilience and compressive strain ratio were derived from the mechanical signals. Voltage measurements yielded current values generated by the electromechanical systems.

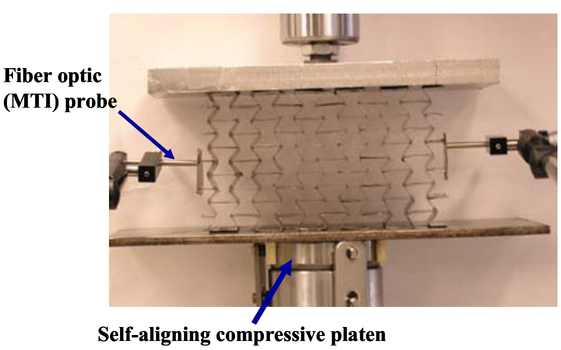

Figure 1. Bowtie reentrant structure under test. The non-contact probes measure the transverse deformation of the structure during its cyclic axial compression

Results

Under quasi-static compression, the structures displayed a nonlinear mechanical behavior at small strains and an overall strain-stress relationship similar to bone. Under cyclic compressive tests to 0.6 percent strain, all structures presented a repeatable nonlinear strain-stress behavior. The curves were fitted by a second-order polynomial expression whose coefficients are function of the relative density of the structure to a power 'C_i'.

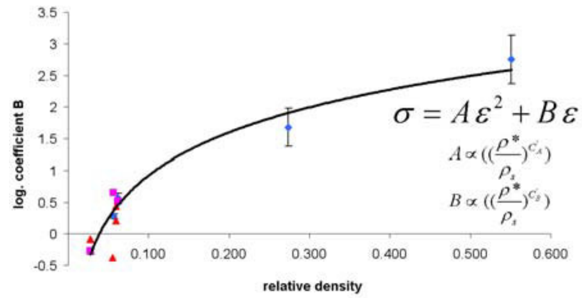

Figure 2. Logarithmic relationship between the relative density (ρ^*/ρ_s) and the logarithm of the second coefficient of the stress (σ)-strain (ε) polynomial relationship

Results from testing composite stainless steel / $BaTiO_3$ bowtie structures confirmed that their electromechanical properties vary with the relative density of the structure and the strain level, and can thus be tailored (Figure 3).

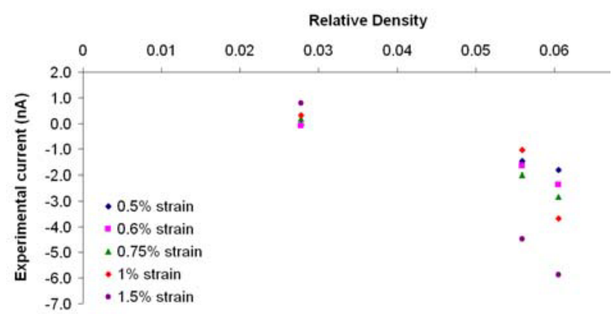

Figure 3. Graph of the experimental current values versus the relative density at all strain levels

Discussion

Some patients present metabolic conditions that impede bone healing. A ductile and tough structural material with piezoelectric properties such as the new composite structures in development presents the potential to address those limitations. Implants made of these porous materials may reduce the needs and risks linked to the use of electrical stimulators and BMPs. This initial study utilizes crude manufacturing techniques to show initial proof of concept; more refined techniques are available to make implant quality materials. Future studies would include analysis of the mechanotransduction potential of these implant quality materials in biological systems.

Acknowledgements: Funded by NSF Project 0600555.