Elaboration and characterization of Ni/BaTiO 3 Functionally Graded Piezoelectric Material for active vibration control applications

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Elaboration and characterization of Ni/BaTiO$_3$ Functionally Graded Piezoelectric Material for active vibration control applications

Julie Cédelle[1], Damien Bregiroux[2], Johann Petit[1], Isabelle Bruant[1], Luc Davenne[1]

1 LEME, UPL, Université Paris Nanterre, Ville d'Avray, France.
2 LCMCP, Sorbonne Université, Paris, France.

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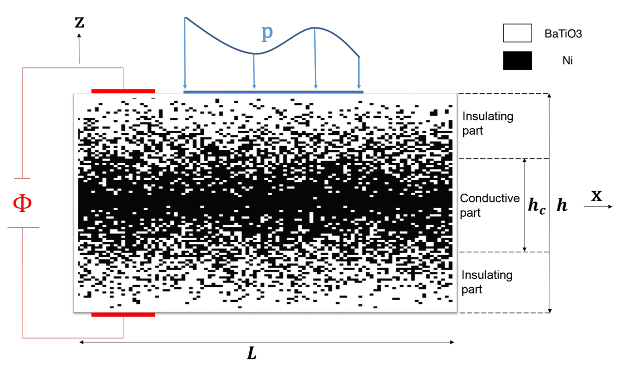
Context of the study : the active vibration control of smart FGPM structures.

The FGPM structures are new composite, designed to achieve a functional performance with mechanical (m) and piezoelectric (p) properties that gradually evolve along the transversal direction. Due to the piezoelectric effects, the vibrations of light-weight FGPM structures can be actively damped with a controller.



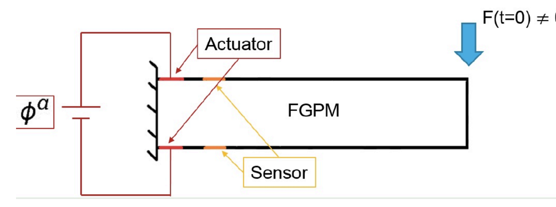
Homogenization law used for simulations: [1]

$$V^{(m)}(z) = 1 - \frac{2\,|\,z\,|}{h}, z \in [\frac{-h}{2}, \frac{-h}{2}]$$

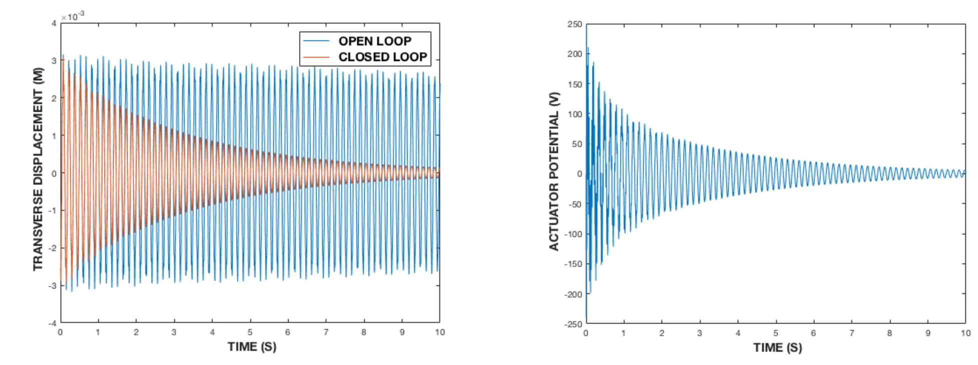
$$P(z) = (P^{(m)} - P^{(p)})(V^{(m)}(z))^k + P^{(p)} \quad \text{(eq 1)}$$

$P(z)$: effective material properties
k: fraction index

Numerical simulations of FGPM beam active control, with



1 x 0.01 x 0.01 m^3 beam
Eigenfrequencies for k=0.5 :
6,6 Hz, 41,7 Hz, 116,8 Hz, 229 Hz
Length of the electrode actuator: 0.1 m

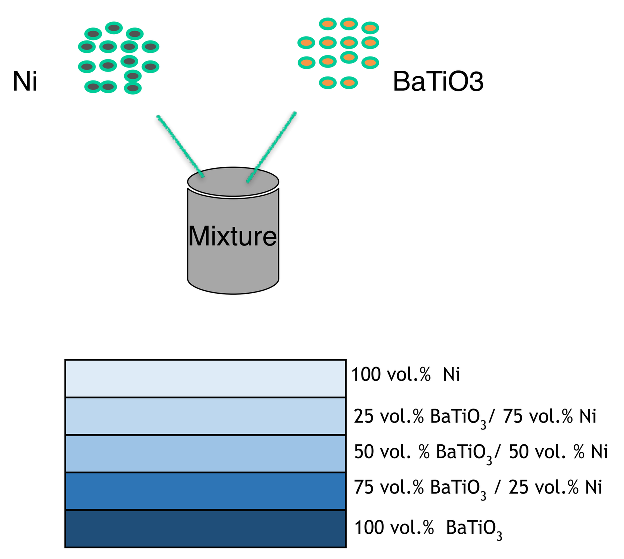


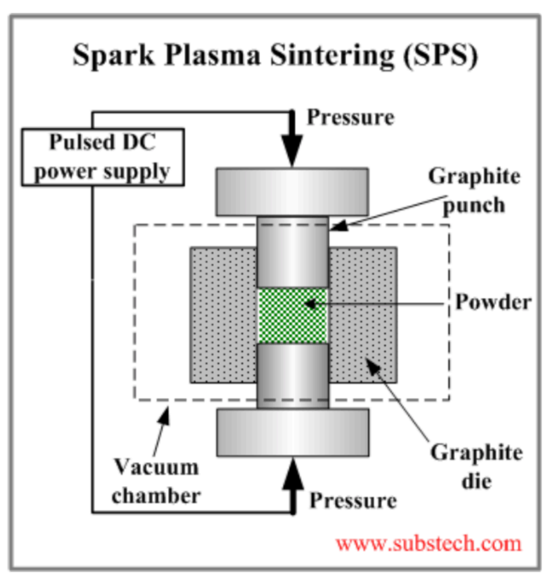
The simulations of the active control using LQR controller show the efficiency of this new concept [2]. Here, in the case of a release test, the vibrations are vanished in less than 10 s.

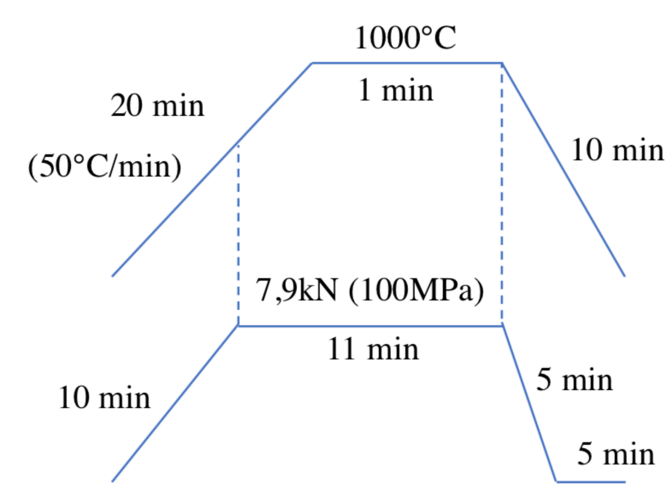
The drawbacks of these simulations are the use of a conceptual model. Does this model reflect the real behavior of FGPM?

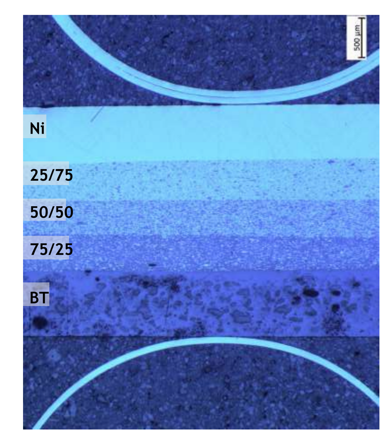
Main topics:
- **The elaboration of Ni/BaTiO$_3$ FGPM**
- **The experimental characterization of material properties.**

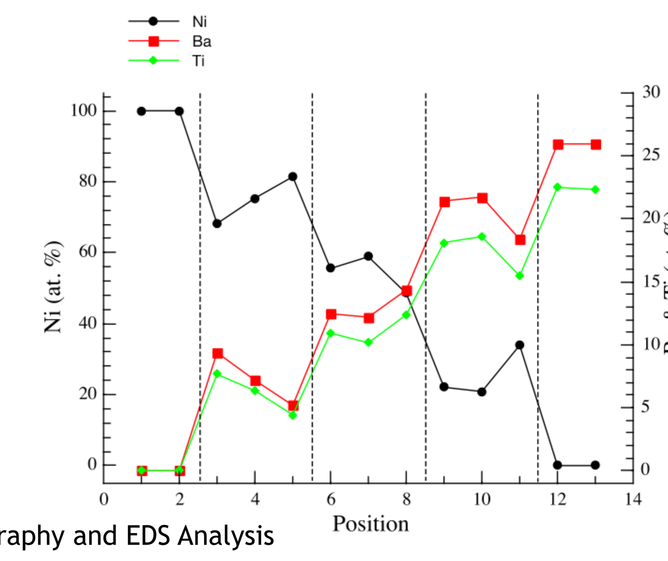
Elaboration of FGPM Ni/BaTiO3 pellet:









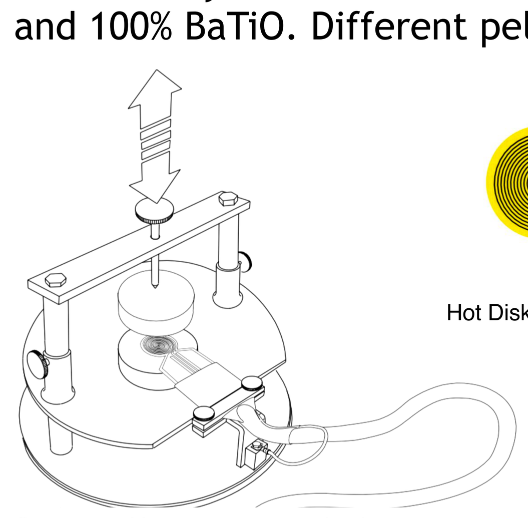


FGM sample micrography and EDS Analysis

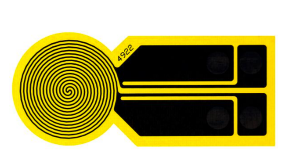
Ni/BaTiO$_3$ FGPM pellet has been elaborated by the Spark Plasma Sintering technique (Dr Sinter-Lab SPS-515S, SPS Sintex Inc.). SPS sintering consists of heating the sample very quickly while applying a uniaxial charge. Thus, it is possible to densify the material in very short time thus limiting both grain growing and the interdiffusion of different chemical species. We propose to sinter together layers of mixture of ceramic powder/metal with compositions ranging from 100% ceramic to 100% metal. Powders were sintered in a 15 mm diameter graphite die with a constant applied pressure of 100 MPa. The heating rate was fixed to 50°C.min^{-1}. The cooling rate was around 100°C.min^{-1}.

Experimental Characterization of materials properties *P*(*z*):

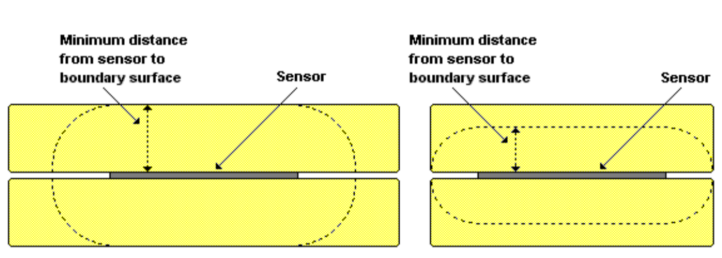
A first study is conducted to define the thermal and mechanical properties *P*(*z*). Five powder mixtures have been used and sintered (in vol.%): 100% Ni, 75% Ni/25% BaTiO$_3$, 50% Ni/50% BaTiO$_3$, 25%Ni/75% BaTiO$_3$ and 100% BaTiO. Different pellets (5 mm thickness, 15 mm diameter) were obtained in order to characterize independently and model the continuous nature of a smart FGPM.



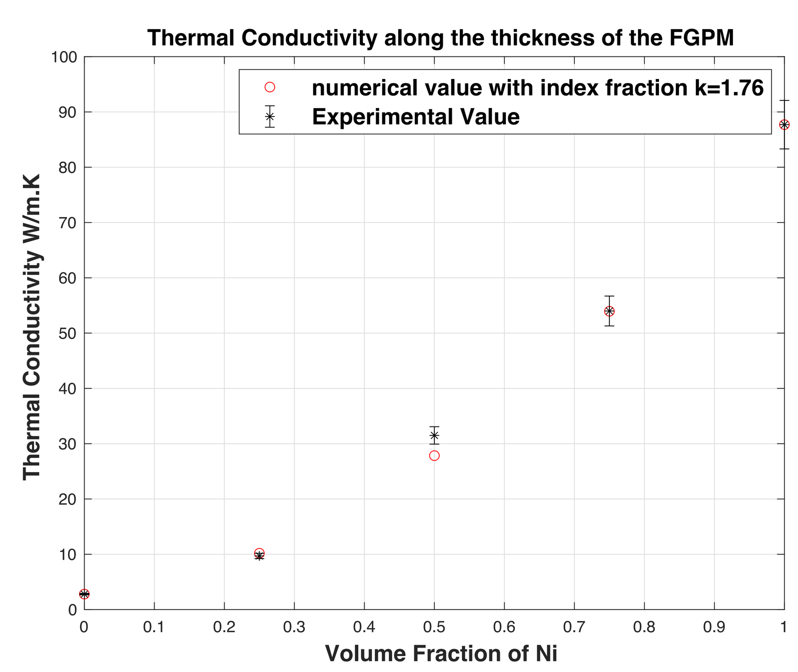
Sensor position between sample pieces.

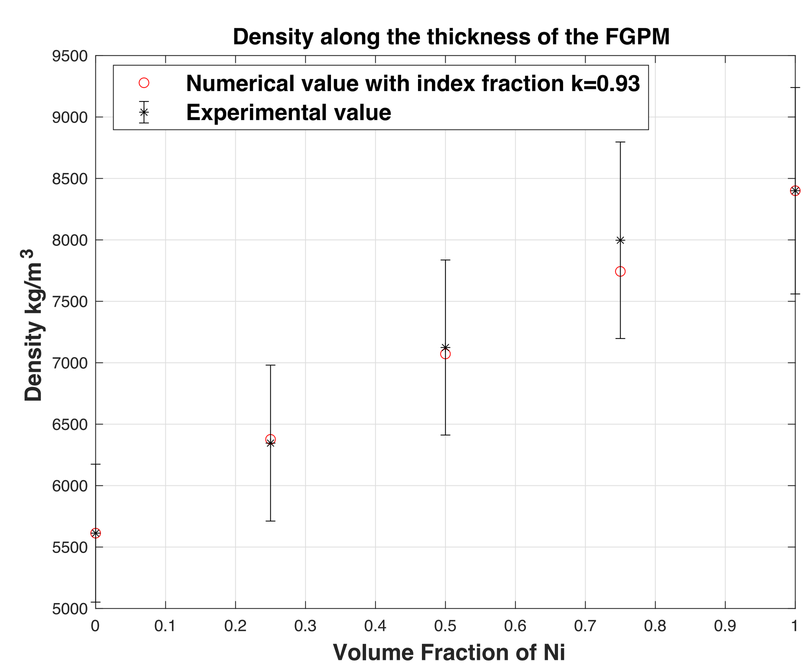


Hot Disk sensor with Kapton insulation

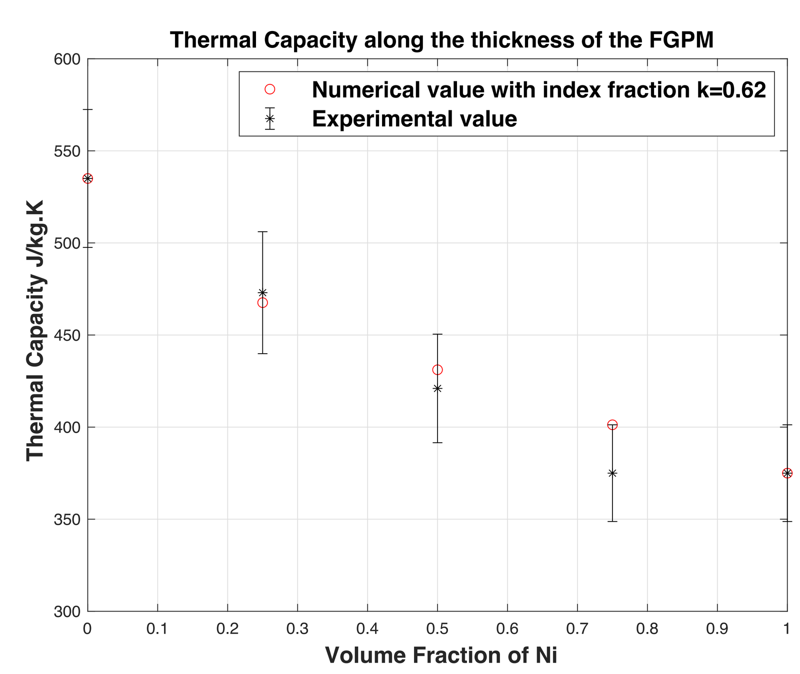


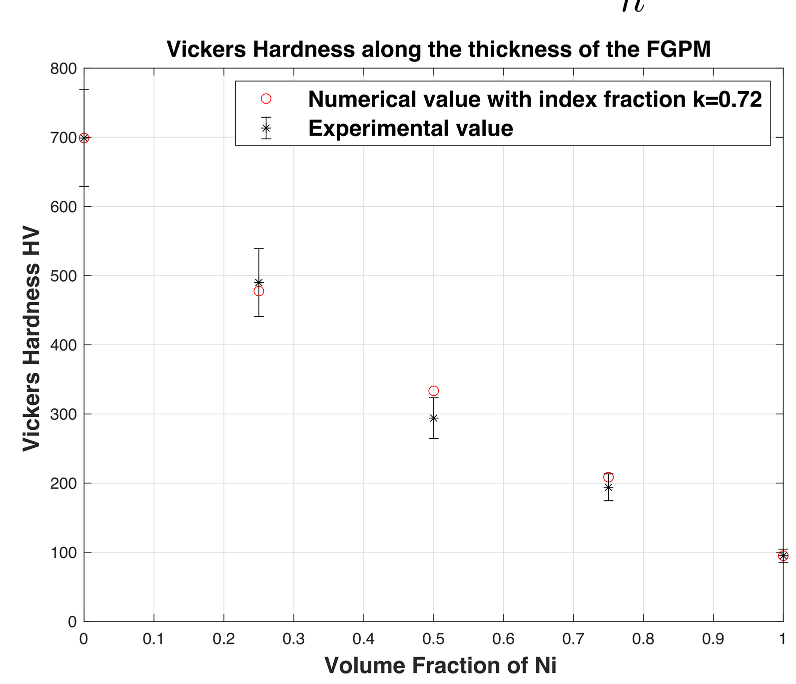
Minimum distance from sensor to boundary surface.

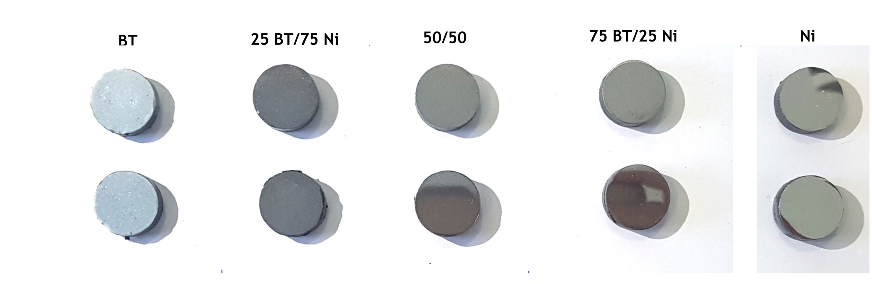


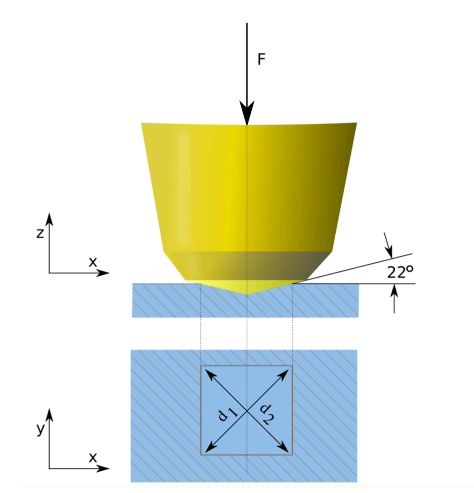


$$P(z) = (P^{(m)} - P^{(p)})(V^{(m)}(z))^k + P^{(p)} \quad \text{(eq 1)} \qquad V^{(m)}(z) = 1 - \frac{z}{h}$$









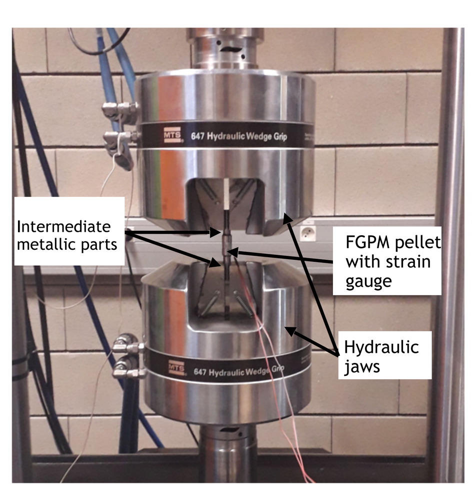
Vickers hardness test

The thermal conductivity was measured by the transient **plane source (TPS) technique, with a TPS 2500 Hot Disk thermal analyzer (accuracy of around 5%). The sensor is placed between two identical samples.**

ardness is a characteristic of a material.
t is defined as the resistance to indentation, and it is etermined by measuring the permanent imprint surface of a iamond pyramid pressed against the solid with a certain normal oad.

The first experimental results show on the one hand that the use of equation 1 seems to be adequate, and on the other hand that the fraction index *k* is not a constant value and depends on the nature of the measured property *P*.

Characterization of the Young's Modulus: as the thickness of FGPM pellet is very low, a compression test is implemented using two very hard and stiff intermediate metallic parts in STUB steel (100Cr6). The pellet is equipped with a small strain gauge (size 5x4 mm^2).
Unfortunately, the first results are not usable because of the difficulty in sticking gauges on tiny specimens. Next tests will be conducted with larger FGPM specimens. Work is in progress…



Compression test using an hydraulic Fatigue Testing System

Small strain gauge (size 5x4 mm^2) on Ni pellet

Conclusion and perspectives:

The first results show that the coefficient *k* is different for each characteristic, it will probably also be different for the mechanical and piezoelectric properties. It will be interesting to study the influence of *k* on the quality of active control : Which microstructural parameters are connected to *k*? Can we optimize this coefficient *k* at the elaboration stage in order to obtain better active control? Work is in progress !

References:
[1] Doroushi A, Eslami M and Komeili A (2011) Vibration analysis and transient response of an FGPM beam under thermo-electro-mechanical loads using higher-order shear deformation theory. Journal of Intelligent Material Systems and Structures 22(3): 231–243
[2] Maruani J, Bruant I, Pablo F, Gallimard L (2017) A numerical efficiency study on the active vibration control for a FGPM beam, Composite structures 182: 478-486