Green piezoelectric for autonomous smart textile

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Abstract. In this work, the fabrication of Rochelle salt based piezoelectric textiles are shown. Structures composed of fibers and Rochelle salt are easily produced using green processes. Both manufacturing and the material itself are really efficient in terms of environmental impact, considering the fabrication processes and the material resources involved. Additionally Rochelle salt is biocompatible. In this green paradigm, active sensing or actuating textiles are developed. Thus processing method and piezoelectric properties have been studied: (1) pure crystals are used as acoustic actuator, (2) fabrication of the textile-based composite is detailed, (3) converse effective $d_{33}$ is evaluated and compared to lead zirconate titanate ceramic. The utility of textile-based piezoelectric merits its use in a wide array of applications.

1. Introduction
Textile-based sensors [1, 2] and piezoelectronics are have been recently utilized in the development of smart textiles for medical applications [3]. In this work, the development of a textile-based piezoelectric material based on large area, low-cost manufacturing is addressed. We first report on the actuation of cantilevers using pure crystals demonstrating the efficient and well-known [4] piezoelectric character of the pure material: Rochelle salt. Then the fabrication of the composite material composed of polypropylene (PP) fibers and Rochelle salt is described. Finally, the converse piezoelectric effect of the composite material is demonstrated and compared with a standard lead zirconate titanate (PZT) ceramic of similar size. Complementing that, impregnated PP textile has been used for the piezoelectric actuation of a PET-based cantilever.

2. Context
Sodium potassium tartrate tetrahydrate, KNaC₄H₄O₇·4H₂O also called Rochelle or Seignette salt is a ferroelectric and piezoelectric material that does not contain rare elements, therefore being intrinsically environmental friendly. Rochelle salt is the oldest and has been for a long time the only known ferroelectric and piezoelectric material [5, 6]. Nowadays Rochelle salt is used in chemistry for different reactions especially in organic synthesis [7] and it is massively produced as a food additive (E337) also called cream of tartar [8].

In order to demonstrate piezoelectricity of Rochelle salt (called PiezoSalt in this work), we used pure millimeter sized crystals as a piezoelectric actuator of a paper-based cantilever (Figure 1). A driving voltage was applied to the crystal and the cantilever displacement was measured using a laser

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vibrometer. The dynamic first resonant mode of the paper cantilever exhibited an out-of-plane amplitude higher than 200 pm. The decrease of the phase from 0 to -90° indicated that the out-of-plane displacement was the consequence of the driving signal applied to the crystal. During this experiment acoustic waves produced by the crystal were audible.

![Figure 1](image1.png)

**Figure 1.** (a) Array of paper cantilevers of several lengths actuated by acoustic waves produced by a Rochelle crystal fixed on a paper sheet. (b) Module and (c) Phase of the displacement of the cantilever (length 1.5 mm).

This experiment illustrates (1) the piezoelectric behavior of pure Rochelle salt crystals, (2) its ability to produced easily acoustic waves that could drive a cantilever-based structure, (3) a micro-actuator concept simply built-up with paper, Rochelle salt and aluminum. The next step was to functionalize some material with this piezoelectric crystal. Therefore this micro-actuator concept was tested again in section 3.4 with the composite PiezoSalt.

### 3. Fabrication and characterization

In this section we discuss how we manufacture the textile-base piezoelectric. Then, some micrograph highlights the polycrystalline structure obtained in between the fibers. Finally, the composite is actuated at low voltage and the out-of-plane displacement produced is measured. A Comparison between PZT ceramic and textile-base piezoelectric is performed in order to evaluate the converse effective $d_{33}$. Additionally the impregnated textile is used to actuate a PET cantilever demonstrating the micro-actuator concept within the textile.

#### 3.1. Fabrication

Polypropylene (PP) based absorbent tissue usually provided for cleaning floors and surfaces has been used as matrix. The thickness of the initial tissue is 3 mm. The textile has been impregnated into Rochelle salt solution and dried. Figure 2 illustrates the PP sample before and after impregnation. Stretchable silver-plated nylon supplied by Sparkfun were used as electrode and fixed on the PP textile before impregnation. After impregnation the stretchable conductive textile (cf. conductive textile on Figure 2) is naturally attached to the impregnated PP textile due to the presence of the salt. Impregnation and drying procedure were repeated two times in order to increase the loading of Rochelle salt inside the matrix. A Rochelle salt composite material has been formed using an absorbent textile composed of polypropylene (PP) fibers. The resultant PiezoSalt Textile is hard and stiff while the initial absorbent tissue was soft and compressible. The thickness of the impregnated textile is about 10% thicker than the initial tissue.
3.2. Material structure

The initial absorbent tissue is formed of random arrangement of polypropylene fibers as shown in Figure 3a. Micrographs have been taken using the Hirox KH-8700 digital microscope. After the impregnation, the fibers network is trapped into a polycrystalline structure clearly visible on the micrograph of Figure 3b.

3.3. Evaluation of the converse piezoelectric effect

The evaluation of the converse piezoelectric effect has been done by comparing the Rochelle salt impregnated textile samples (3 mm thick) and a standard PZT ceramic from PI (ref. PIC181, 1 mm-thick). The first easiest test was an audio sweep. Both materials emitted audible acoustic waves when applying a 3V periodic chirp defined from 10 Hz to 10 kHz. The exact same actuating conditions have been applied to the samples when placed under a laser vibrometer (MSA-400 from Polytec). Out of plane complex displacement of both piezoelectric devices were measured on the top planar electrode of the samples, the resulting spectrums being presented in Figure 4.
The comparison of displacement spectrums shows that the maximum displacement measured, in the range 1 to 10 kHz, was 14 pm for the PiezoSalt Textile while displacement reached 29 pm for the PZT sample. We could also notice that the sharpness of resonant peaks is deprecated in case of PiezoTextile due to the difference in the stiffness of the materials. Conductance spectrums shown in Figure 4-c and –d highlighted also an important difference in the electromechanical coupling factor: a narrow bandwidth indicating a high coupling factor (which was the case for PZT but not for PiezoSalt Textile). Uncalibrated effective $d_{33}$ and coupling factor $k$ obtained for the PZT and the PiezoTextile are presented in Table 1.

|               | Effective $d_{33}$ (pm/V) | $k_p$  |
|---------------|---------------------------|--------|
| PiezoTextile  | 45                        | 0.01   |
| PZT           | 94                        | 0.5    |

The PiezoTextile does not have the excellent and unbeatable piezoelectric properties of PZT. Nevertheless, these electromechanical tests have demonstrated high piezoelectric properties for a textile-based material.

3.4. Micro-actuator concept

A microcantilever composed of PET coated with aluminium has been fixed on top of the PiezoTextile. The dynamic first out-of-plane resonant mode of the cantilever has been measured. A drive oscillating voltage of 5V actuated the impregnated PP textile which induced the phase-shifted displacement of the PET cantilever. Module and phase of the cantilever displacement recorded with a laser vibrometer is shown on Figure 3. Any phase-shifted displacement and neither any sound production could be recorded on a non-impregnated reference device.
The microcantilever has been successfully actuated piezoelectrically with the PiezoTextile. This micro-actuator concept works identically that the one presented in Figure 1. Therefore Rochelle salt could stay piezoelectrically active when impregnated into the polypropylene-based textile.

4. Conclusion
In this work, the piezoelectric behavior of Rochelle salt crystal has been highlighted within a textile matrix composed of polypropylene fibers. We developed a method to functionalize textile with this piezoelectric material. Electromechanical properties of the piezoelectric textile have been evaluated. Finally the converse piezoelectric effect existing into the composite material has been demonstrated. A PET microcantilever could be successfully actuated piezoelectrically with the PiezoSalt Textile. This concept easily manufacturable could find application into many fields. Smart textile, large area functionalized surfaces, integrated sensors and actuators or even harvesting surfaces are some of the numerous potential applications that can be envisioned at low cost. In the future, wearable smart devices will be developed out of this PiezoSalt Textile.

5. References
[1] Morris, D., Coyle, S., Wu, Y., Lau, K. T., Wallace, G., & Diamond, D. (2009). Bio-sensing textile based patch with integrated optical detection system for sweat monitoring. *Sensors and Actuators B: Chemical*, 139(1), 231-236.
[2] Yang, Y. L., Chuang, M. C., Lou, S. L., & Wang, J. (2010). Thick-film textile-based amperometric sensors and biosensors. *Analyst*, 135(6), 1230-1234.
[3] Carpi, F., & De Rossi, D. (2005). Electroactive polymer-based devices for e-textiles in biomedicine. *Information Technology in Biomedicine, IEEE Transactions on*, 9(3), 295-318.
[4] Unsworth, J. (1992, January). Piezoelectricity and piezoelectric materials. In *Key Engineering Materials*, Vol. 66, pp. 273-310.
[5] Busch G., 1987, Early History of Ferroelectricity. *Ferroelectrics*, 74; 267-28.4
[6] Kanzig W., 1987, History of Ferroelectricity 1938-1955. *Ferroelectrics*:74; 285-291.
[7] Fieser, L. F.; Fieser, M., *Reagents for Organic Synthesis*; Vol.1; Wiley: New York; 1967, p. 983.
[8] Furia, T. E. (1973). *CRC handbook of food additives* (Vol. 1). CRC Press.