

Influence of Piezoresistive Material and Thickness on the Electromechanical Response of Flexible Pressure Sensors

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Summary:

Flexible piezoresistive sensors based on carbon-filled polyethylene (PE) and thermoplastic polyurethane (TPU) were compared. TPU sensors were fabricated by fused filament fabrication, enabling thickness control from 0.2 to 5 mm. Electrical resistance was measured under cyclic loading up to 250 kPa. TPU shows improved repeatability and a sixfold reduction in drift (35 Ω vs 330 Ω). Increasing thickness reduces sensitivity but limits saturation, enabling tuning of the sensor response. TPU provides a more stable and configurable alternative to PE.

Keywords: piezoresistive sensors, flexible sensors, thermoplastic polyurethane, polyethylene, pressure sensing

Background, Motivation and Objective

Flexible piezoresistive sensors are widely used for pressure sensing, but performance depends on materials and fabrication, affecting sensitivity, repeatability, and stability [1,2]. For motion analysis and health monitoring, reliable sensors are required. This study compares carbon-filled PE and TPU sensors under cyclic compression, focusing on TPU thickness (0.2-5 mm).

Sensor Architecture and Materials

All sensors share a multilayer architecture composed of polyimide encapsulation layers, copper electrodes, and a piezoresistive layer (Fig. 1). The electrical response is measured under a normal compressive force applied over a 1 cm² area.

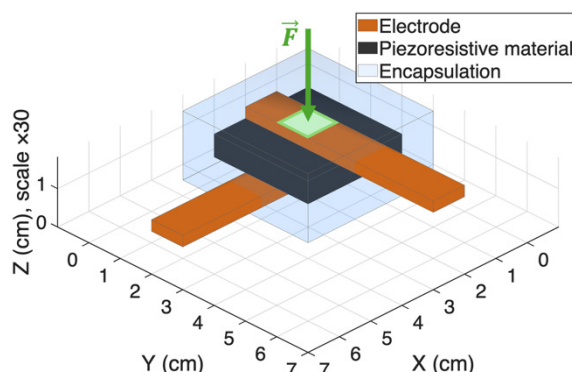


Fig. 1. Multilayer architecture of the piezoresistive sensor under a normal compressive force $\vec{F}$ applied over a 1 cm² area.

Two materials were investigated: carbon-filled polyethylene (PE, Velostat®, 3M, USA, thickness of 0.1 mm) and carbon-filled thermoplastic

polyurethane (TPU, Recreus, Spain). PE-based sensors (PC-PE) were fabricated by assembling polyimide (P) layers, adhesive copper (C) electrodes, and a PE film. For TPU-based sensors (PC-TPU), the piezoresistive layer was first fabricated by fused filament fabrication (FFF) with full infill (100%), then assembled with polyimide encapsulation and copper electrodes. The TPU thickness was varied from 0.2 to 5 mm to study its influence on the electrical response, the lower limit being set by the printing resolution of the FFF process and the upper limit by the loss of flexibility at higher thickness. PC-PE sensors were developed in previous work [3].

Electrical Characterization Methods

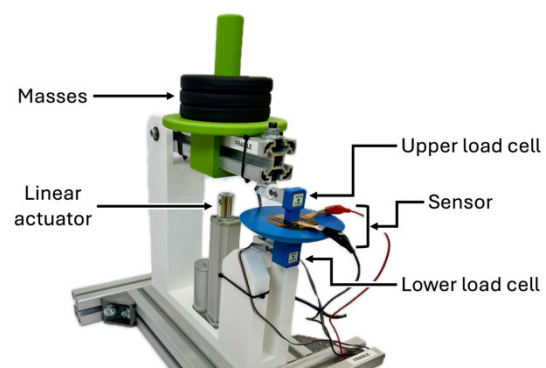


Fig. 2. Experimental setup for electromechanical characterization with force and resistance measurements under calibrated loading.

Electrical characterization was performed using a custom test bench applying controlled normal loads to the sensors (Fig. 2). The load was generated by calibrated masses. Three types of tests were conducted: (i) short-term cyclic tests

(3 cycles, 1 min without load / 1 min under load) to evaluate repeatability; (ii) reproducibility tests on three samples per configuration; and (iii) long-term cyclic tests (1 min period) to assess conditioning effects. Resistance was recorded continuously at a 300 ms sampling interval.

Results and Discussion

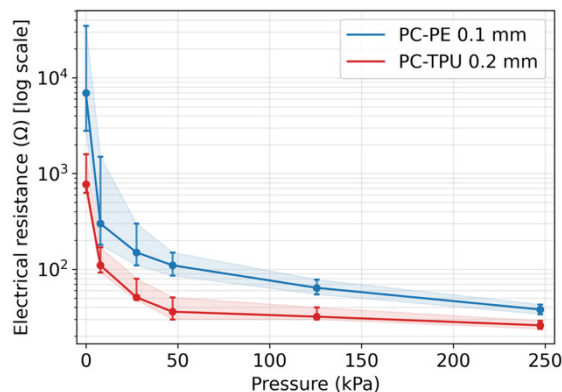


Fig. 3. Electrical resistance as a function of applied pressure for PC-PE and PC-TPU 0.2 mm sensors. Shaded areas represent the min-max range, and markers indicate median values.

Figure 3 compares the electromechanical response of PC-PE (0.1 mm) and PC-TPU (0.2 mm) sensors. The PC-PE sensor exhibits a higher initial resistance and a larger dispersion, as highlighted by the wide min-max range (over repeated cycles and across different samples), particularly at low pressures. In contrast, the PC-TPU sensor shows a more stable and reproducible response, with reduced variability across measurements. As the applied pressure increases, the difference between both materials decreases. At higher pressures (>100 kPa), the electrical resistance tends to converge, indicating a saturation of the piezoresistive effect and reduced sensitivity for both materials.

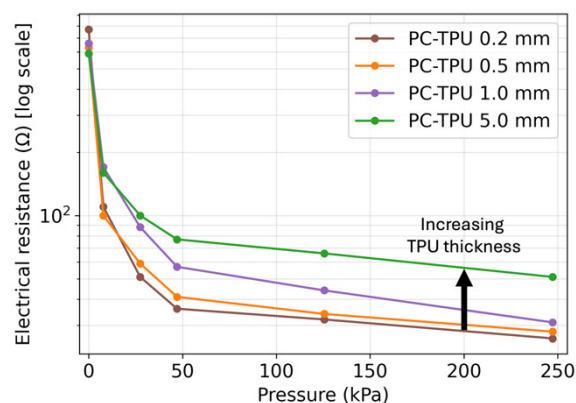


Fig. 4. Electrical resistance as a function of applied pressure for PC-TPU sensors with varying TPU thickness (0.2 to 5 mm). Median values are shown for each configuration.

Figure 4 highlights the influence of TPU thickness on the sensor response. Increasing the

thickness from 0.2 mm to 5 mm leads to a systematic increase in resistance between 25 kPa and 250 kPa. At these pressures, the curves exhibit nearly constant spacing on a logarithmic scale, indicating a similar relative sensitivity across all thicknesses. However, in absolute terms, thicker layers show a reduced slope of the resistance-pressure response, corresponding to a lower sensitivity. Thinner layers exhibit a sharper response and earlier saturation, while thicker layers provide a more gradual response and an extended usable pressure range up to 250 kPa. This demonstrates that TPU thickness governs a trade-off between sensitivity and dynamic range.

Tab. 1: Electrical resistance drift (ΔR) measured after stabilization. The stabilization cycle number corresponds to the cycle from which ΔR measured between 0 and 27.5 kPa no longer shows significant evolution.

Sensor	ΔR (Ω)	ΔR (%)	Cycles
PC-PE [3]	330	110%	500+
PC-TPU	35	117%	330

Table 1 shows the electrical resistance drift (ΔR) after stabilization. While both sensors exhibit comparable relative variations (~110-117%), the absolute drift is substantially reduced for PC-TPU, indicating improved stability and more reliable electrical behavior under repeated loading.

Conclusion

TPU improves repeatability, reproducibility and reduces drift compared to PE. Thickness tuning enables a trade-off between sensitivity and dynamic range: increasing thickness raises resistance and reduces absolute sensitivity while extending the usable pressure range. TPU-based sensors thus provide a stable and configurable approach for flexible pressure sensing. A thickness-dependent model may apply at moderate pressures, with deviations at low pressures.

References

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