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ELECTROMECHANICAL PROPERTIES OF PIEZORESISTIVE POLYMER MATERIALS AS A FUNCTION OF THE POLYMER MATRIX

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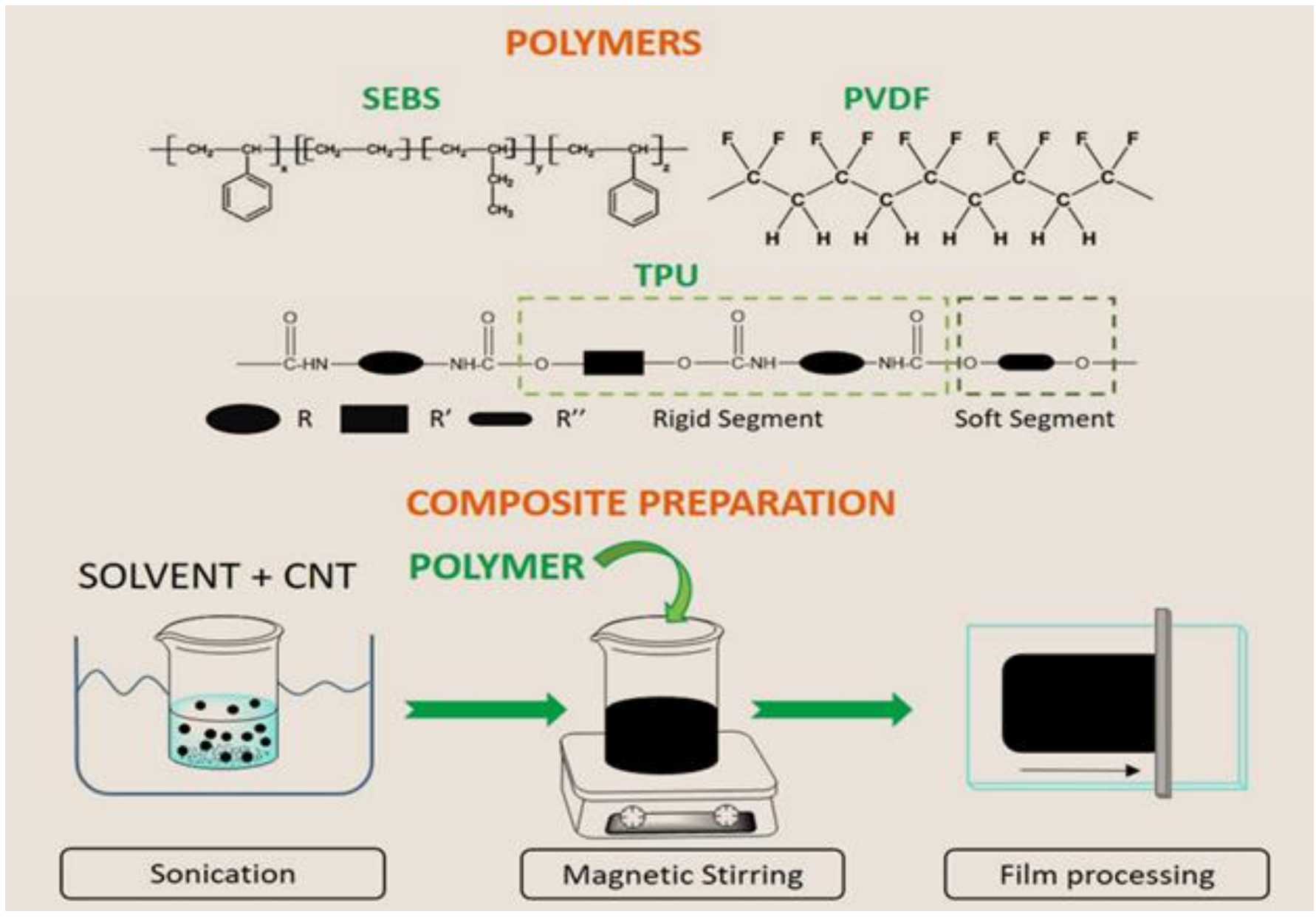
Introduction

Deformation sensors are among the most used in applications, particularly for the evaluation of force, pressure and deformation states of a given structure or structural part. Thus, materials with piezoresistive properties, resulting from the strain-induced variation of the electrical resistance of the material, are essential for the development of such devices. To date, commercially available piezoresistive sensors for industrial applications are mainly based on metallic films or silicon materials. Even if these types of sensors can exhibit high sensibility and/or accuracy, they show limited mechanical properties and integration into devices.

To overcome these drawbacks, polymer-based smart materials arise as a suitable alternative due to their flexibility, low cost and simple processing [1]. Moreover, their properties can be tailored for specific applications and they are easily integrated into devices. In this context, this work evaluates and compares the effect of the polymer matrix and different carbon nanofillers for the development of piezoresistive polymer-based materials[2].

Materials and Methods

- Conductive composites have been prepared by solvent casting based on: Poly(vinylidene fluoride) (PVDF), Styrene-b-(ethylene-co-butylene)-b-styrene (SEBS) and Thermoplastic polyurethanes (TPU).
- Polymer composite films were prepared (Figure 1) using cyclopentyl methyl ether (CPME) for SEBS and N,N dimethylformamide (DMF) for PVDF and TPU.



Matrices		
PVDF	TPU	SEBS
CNT content (wt.%)		
0		
0,25		
0,5		
1		
2		
5		

Figure 1- Materials and schematic representation of the experimental procedure for sample preparation.

Results and discussions

In all cases, the chemical and thermal properties of the polymers were preserved after the addition of the nanofillers. Good nanofiller dispersions were achieved for the three polymeric matrixes, and no significant variations on the mechanical properties with respect to the pristine polymers.

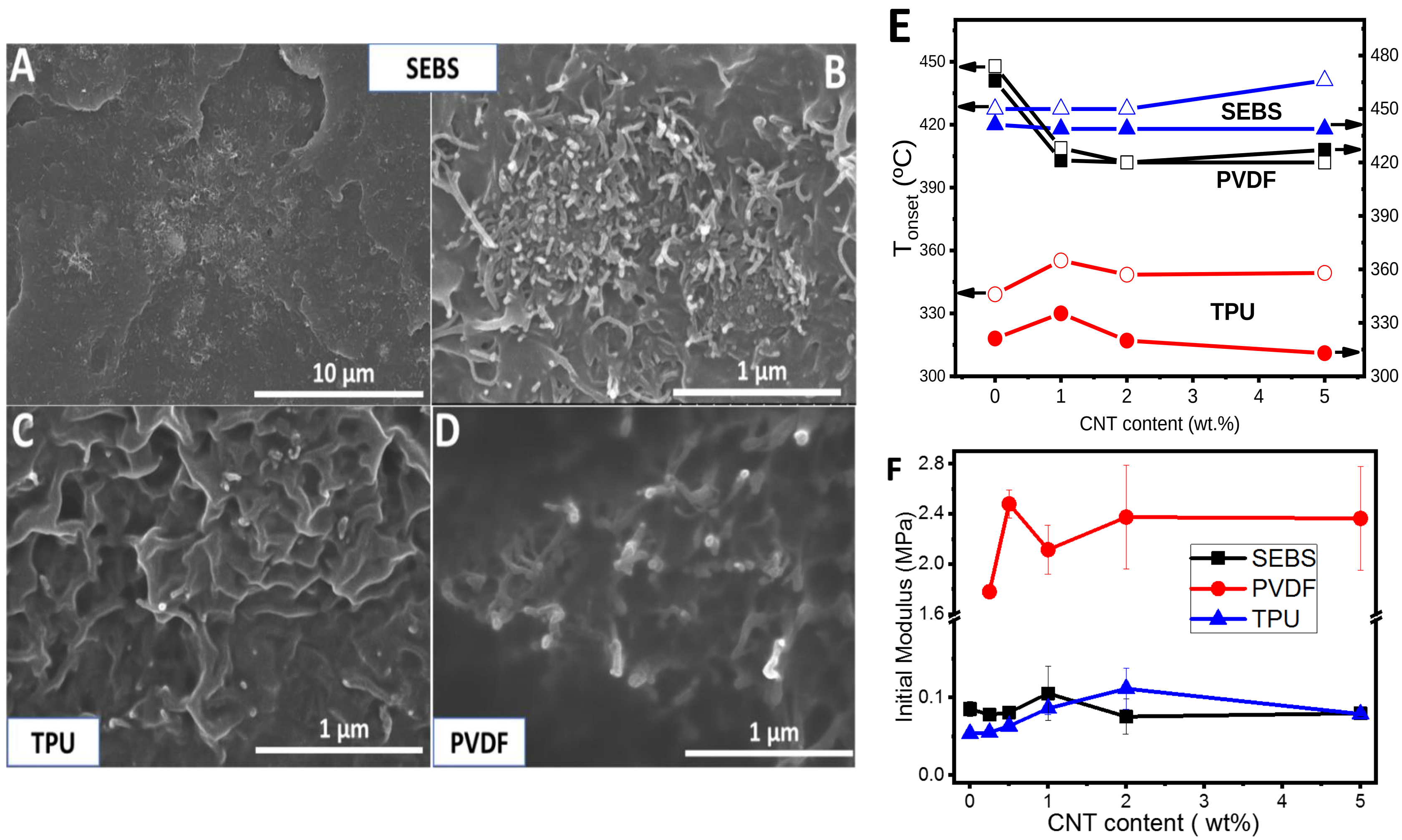
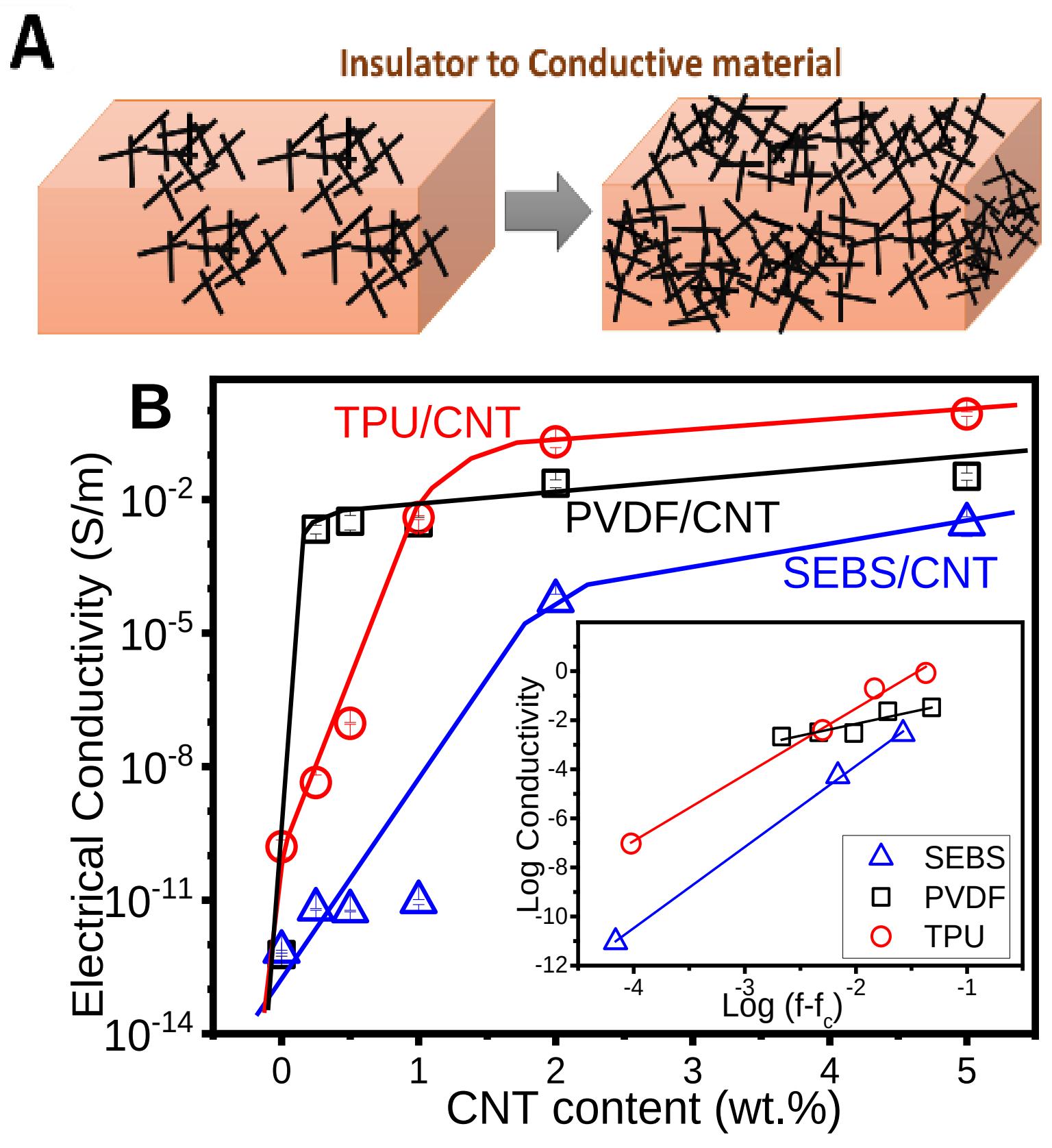


Figure 2
SEM cross-section images of the different composites materials with 5 wt.% of CNT, for A and B) SEBS, C) TPU and D) PVDF.
E) T_{onset} and $T_{maximum}$ of the PVDF, TPU and SEBS and the corresponding composites up to 5 wt.% CNT.
F) The initial modulus was calculated in the elastic region from the slope of the stress-strain curve (until 2% deformation).

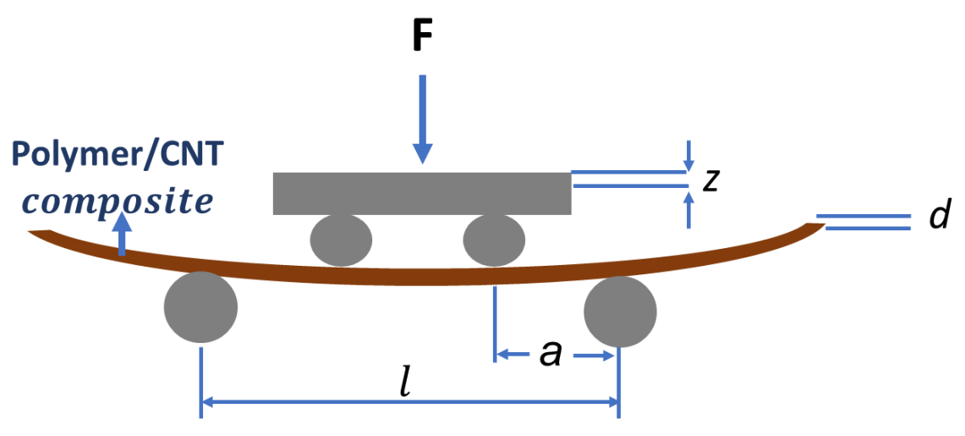
Electrical characterization of composites, the percolation in composites depends on the polymer materials, as the fillers or processing method used is similar for all composites.



C	SEBS	TPU	PVDF
PT (vol%)	6.9×10^{-3}	4.9×10^{-3}	3.5×10^{-4}
$\sigma_{maximum}$ (S/m)	2.8×10^{-3}	8.4×10^{-1}	3.3×10^{-2}
t	3.3	2.7	1.0
R^2	0.998	0.989	0.784

Figure 2-
A) Schematic of a polymer/CNT network resistor model.
B) Conductivity of polymers filled with CNT up to 5 wt.%. The inset represents the linear fit used by percolation theory.
C) Theoretical values of PT, critical exponent and conductivity in composites.

Piezoresistive tests were performed by uniaxial pressure and 4-point-bending modes. The piezoresistive performance was quantified by the Gauge Factor (GF) in equation 1, with contributions from the intrinsic piezoresistive effect and from geometrical factors.



4-point-bending

$$GF = \frac{dR/R_0}{dl/l_0} = \frac{d\rho/\rho_0}{\varepsilon} + (1+2\nu) \quad (1)$$

$$\varepsilon = \frac{3dz}{5a^2} \quad (2)$$

R: electrical resistance
$dl/l_0 = \varepsilon$ relative deformation
ρ: electrical resistivity
v : Poisson ratio

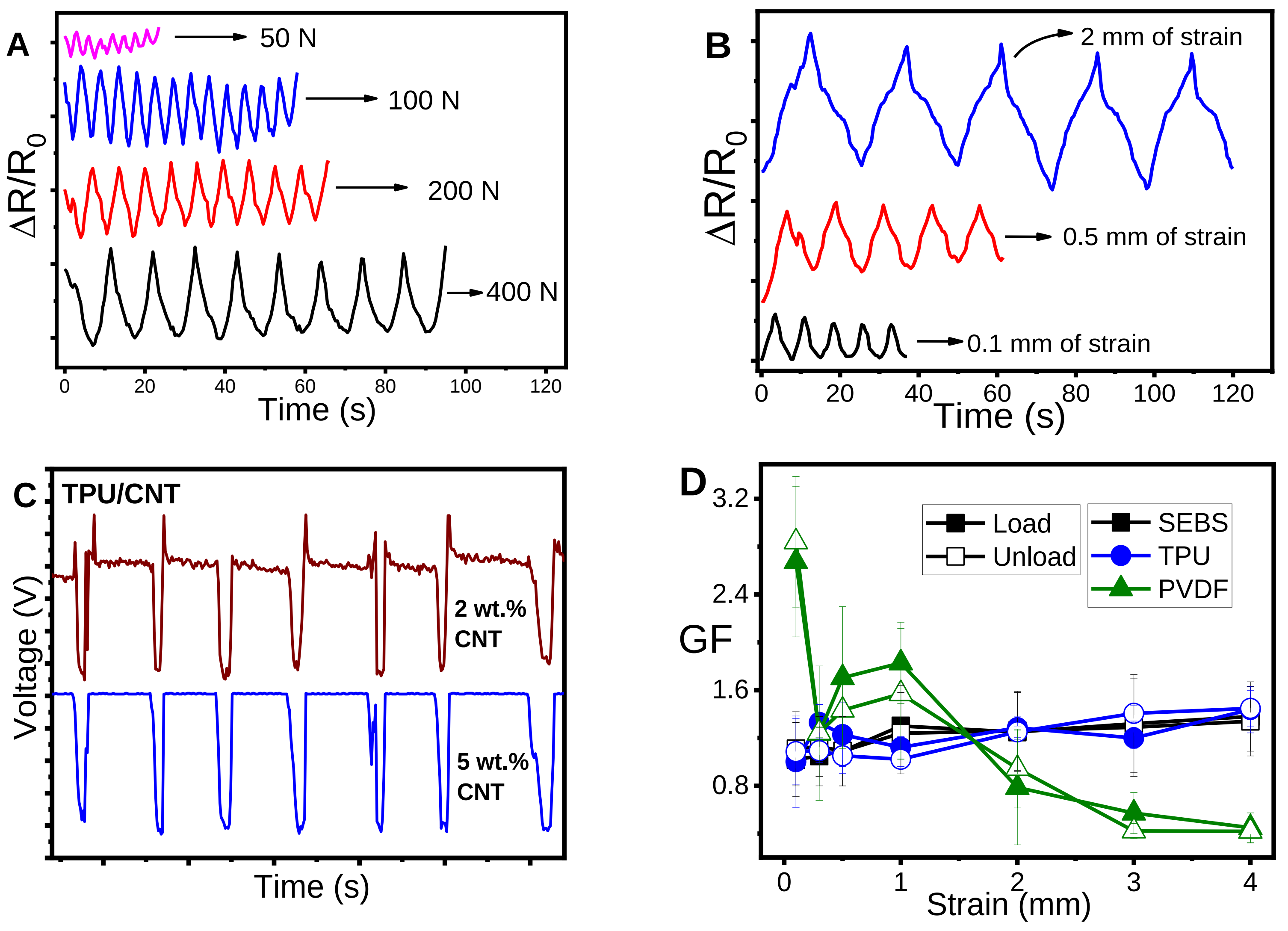


Figure 3- Piezoresistive response (A) PVDF with 5% CNT under uniaxial pressure. (B) PVDF with 5% CNT in 4-point-bending modes at different strain . C) Evaluation of the response of the sensor matrix with TPU with 5% CNT. D) Relative electrical resistance variation with applied load and unload cycles for the composites with 5 wt.% in 4-point-bending deformations.

Conclusions

Polymeric matrix composites from rigid (PVDF) to stretchable (TPU and SEBS) reinforced with CNT allow the development of piezoresistive materials.
Chemical and mechanical properties of the composites with different fillers contents up to 5 wt.% are similar to the pristine polymer for all polymer matrices. But the electrical and piezoresistive response of the composites depend on the polymer matrix.
As piezoresistive sensors for pressure applications, PVDF is an excellent material, essentially do to the low percolation threshold. PVDF/CNT composites with 0.5 wt.% CNT can measure and support larger pressures. For stretchable applications the materials should be TPU or SEBS due their stretchability and easy recovery.

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