

GNPs-Based Strain Sensors Derived from Recycled Cellulose Acetate: Fabrication and Analysis

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Summary:

Nanocomposites based on graphene nanoplatelets (GNP) were developed using recycled cellulose acetate from cigarette filters as the polymer matrix. Electrical conductivity measurements showed significant improvement with increasing GNP content, peaking at the saturation of the electrical network. The electromechanical performance of the sensors demonstrated a gauge factor (GF) near 20 at 3 wt% GNP content in the 0-2% strain range due to the tunneling effect. The new matrix ensures sensor sustainability and stability through cyclic testing.

Keywords: Recycled cellulose acetate, graphene nanoplatelets, strain sensor, nanocomposite, piezoresistive

Introduction

Strain sensors are essential for Structural Health Monitoring (SHM) in aerospace structures, providing real-time data on stress and deformation to ensure safety and integrity [1,2]. Carbon-based nanocomposites, particularly those doped with graphene nanoplatelets (GNPs), have shown great potential due to their high sensitivity and cost-effectiveness compared to traditional fiber optic sensors and strain gauges [3,4]. However, the increasing disposal of electronic sensors is leading to significant environmental problems due to the release of heavy metals and non-recyclable semiconductors, contributing to e-waste [5]. This issue has generated global interest in developing electronic sensors with longer lifespans and reduced e-waste. Numerous examples of electronic sensors with self-healing or recyclable properties have emerged in response to these concerns [6]. This study focuses on using recycled cellulose acetate (CA), derived from cigarette filters, as the polymer matrix for developing strain sensors based on graphene nanoplatelets (GNPs). The use of recycled materials helps reduce the demand for new raw materials and offers environmental benefits. The developed sensors, while innovative in their use of recycled polymer matrix, support green manufacturing pathways in response to environmental concerns.

Experimental Details

Materials

The nanocomposites used GNPs incorporated into recycled cellulose acetate, which was processed from discarded cigarette butts [7]. GNP powder was supplied by NANESA, Arezzo, Italy, with an average thickness of 14 nm, an average lateral size of 30 μm , and electrical resistivity of $10^{-5} \Omega\cdot\text{m}$. Acetone was used as solvent for GNP dispersion.

Fabrication of Nanocomposites

Conductive mixtures of GNPs/CA with three different graphene contents (3, 6, and 15 wt%) were prepared as reported in Fig. 1: Graphene nanoplatelets were initially dispersed in acetone by magnetic stirring and sonication for 1 hour in an ice bath while being simultaneously stirred.

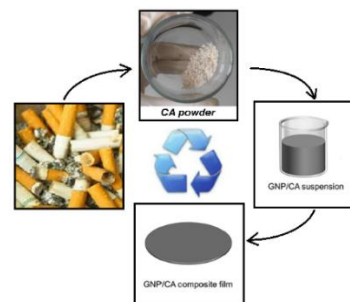


Fig. 1. Schematic illustration of the fabrication process.

The recycled CA was subsequently introduced into the solution under continuous stirring for 30 minutes at a controlled low speed. The final mixtures were then cast into molds and left at room temperature to completely evaporate the acetone and solidify.

Results and Discussion

Electrical Properties

The electrical conductivity of GNP/CA nanocomposites was investigated using the two-point probe method. The 3 wt%, 6 wt%, and 15 wt% GNP/CA sheets had conductivities of 0.001, 0.005, and 0.142 S/m, respectively. As predicted, being in the region between the percolation threshold and saturation point [8], increasing the GNP content resulted in higher conductivity.

Electromechanical properties

Tensile tests showed an increase in resistance with applied strain, confirming the piezoresistive nature of the sensors. Fig. 2 illustrates the relative resistance change over time as the sensor is stretched step by step and then released in the same increments. Each step corresponded to a 0.1% strain, up to a total strain of nearly 1%. The gauge factor (GF) of the sensors peaked at a value of approximately 20 for the 3 wt% GNP/CA content, while the 15 wt% GNP/CA content exhibited a GF of around 5 for strains up to nearly 2%.

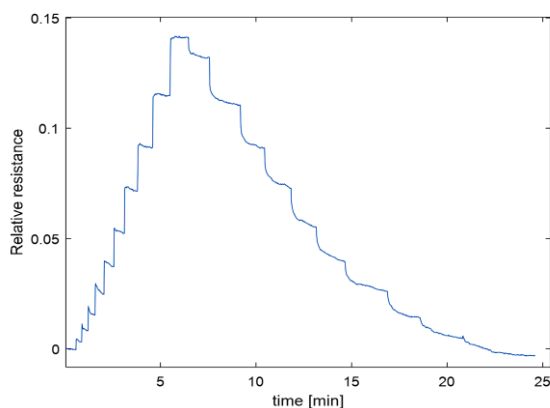


Fig. 2. Relative resistance changes of the sensor under strain for GNP/CA with 3 wt% graphene content (Each step: 0.1 % strain, totally 10 steps).

Long-Term Stability

Cyclic tests (100 cycles, 1% strain) confirmed the robustness of the sensors, demonstrating high durability and stable electromechanical responses with minimal signal degradation. The use of recycled cellulose acetate as the matrix provided excellent stability and compatibility with the conductive GNP network and produced robust sensors suitable for long-term applications.

Conclusion

In summary, this study demonstrated the successful fabrication of GNP/CA nanocomposites using recycled cellulose acetate from cigarette butts. The sensors exhibited piezoresistive properties with gauge factors peaking at 20 for 3 wt% GNP/CA content. Despite lower conductivity compared to other polymer matrices, the sensors showed improved performance over previous work. Cyclic tests confirmed their robustness and long-term stability, highlighting the environmental benefits and potential applications.

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