TWENTY-THIRD INTERNATIONAL CONFERENCE ON COMPOSITE MATERIALS (ICCM23)

CONDUCTIVE SMART NANOCOMPOSITE MATERIALS FOR STRUCTURAL HEALTH MONITORING AND STRAIN DETECTION

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ICCM 23 BELFAST 2023

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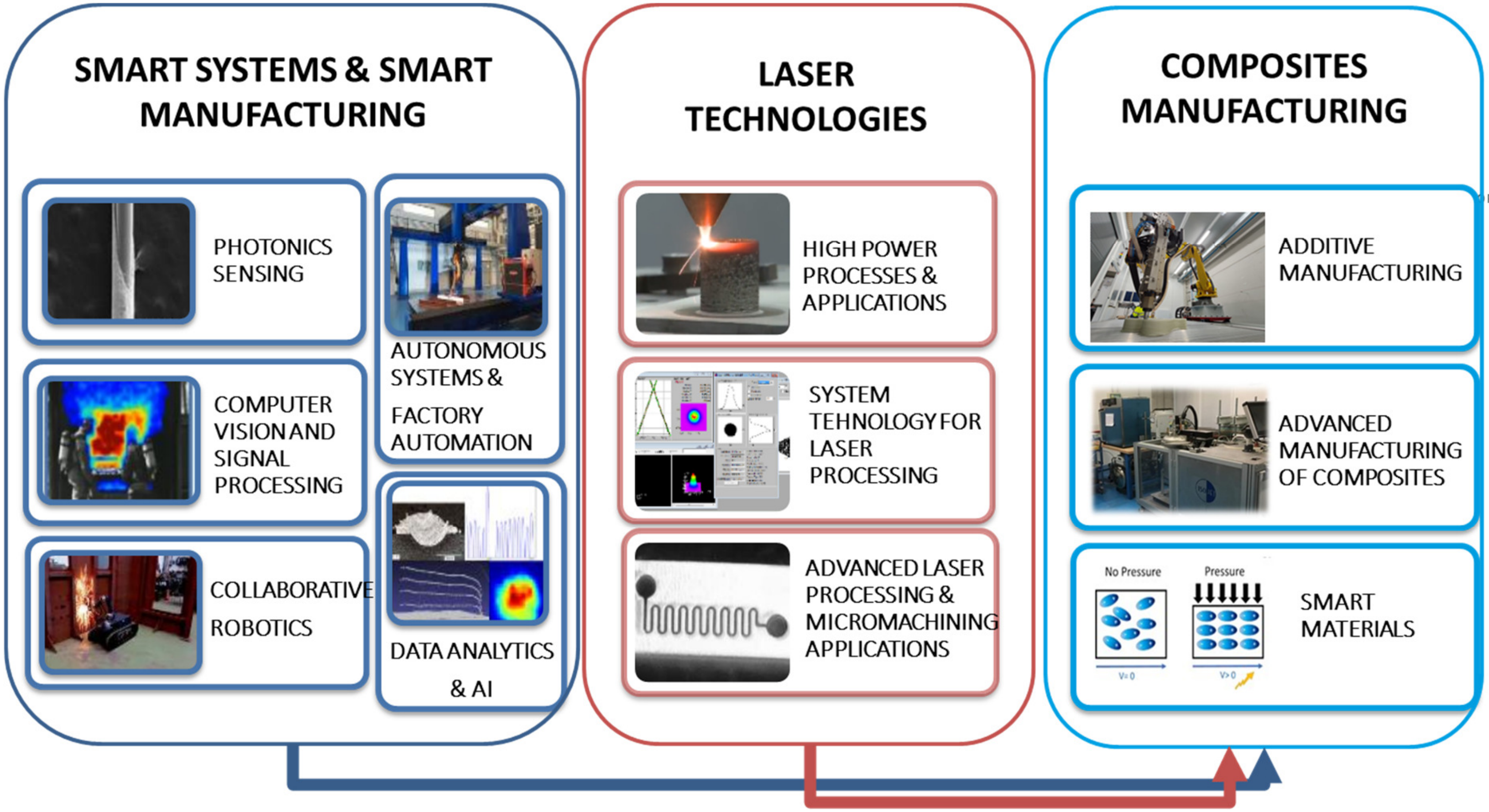

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CONDUCTIVE SMART NANOCOMPOSITE MATERIALS FOR STRUCTURAL HEALTH MONITORING AND MOTION DETECTION

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Structural Health Monitoring & Strain Detection

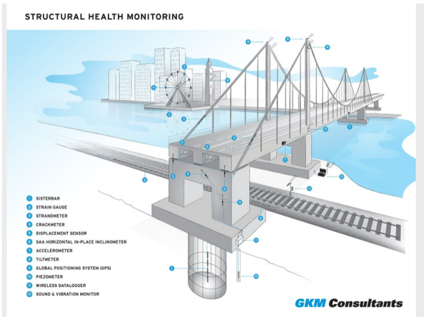
- A ***Structural Health Monitoring (SHM)*** system evaluates the structural health of a material and warns if something fails.

- ***Predictive models*** to develop ***digital twin*** and ***machine learning*** that allows predicting the effect of different stresses applied to materials and structural behaviour in service meaning significant savings in the plans and maintenance tasks of the structures.

WIND

Structural Health Monitoring for Wind Turbines (foundation, tower and rotor, blades…

- *Dynamic changes*
- *Eigenfrequency*
- *Mechanical displacement*
- *Corrosion*
- *Impacts*
- *Erosion of the sea floor, "Scour"*
- *Etc…*

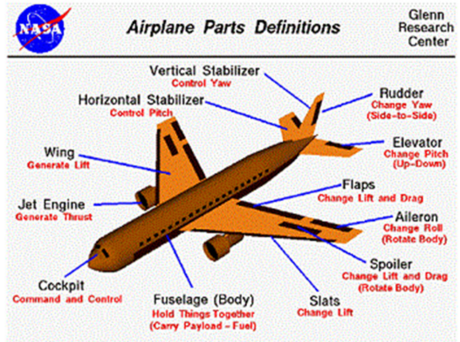


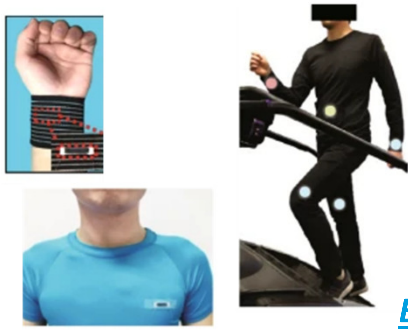
BRIDGES

- ***a crack ini****tiates or grows*
- *a suspension wire or cable breaks*
- *an accidental impact occurs*
- *dislocation or deterioration takes place*
- *active corrosion propagates*

AERONAUTICS

- *Fatigue*
- *Corrosion*
- *Overload*
- *Wear*
- *High-temperatura corrosion*
- *Creep*





BIOMEDICAL SECTOR

- ***Wearable strain sensors*** *have great potential for* *motion detection*, *thus they are of great interest in fields such as personal and* *public health care, future entertainment, human-machine interaction, artificial intelligence, etc.*

- *Within the medical applications, body movement detections stand out:* ***muscle movements, facial movements, pulse, heartbeat****...*

Types of SHM systems

Main type of sensors for SHM

The most common methods for SHM consist of integrating, inside or on the surface of the structure to be monitored, devices that measure changes in different physical parameters due to the appearance of structural damage or mechanical deformations.

- *Passive acoustic sensors*. Measures changes in strain
- *Strain gauges*. Measures changes in conductivity (from the gauge)
- *Accelerometers.* Measure accelerations.
- *Fiber optic sensors*. Measures reflected optical signals
- *Ultrasonic sensors*. Measures reflected ultrasonic signals

DISADVANTAGES

- *Fragile*
- *Difficulty seeing through several inches of the structure*
- *Placement near the place where the damage occurs (which is not known a priori)*
- *Interpreting the signals can be difficult*
- *Prone to long-term failure*
- *They are disturbed by environmental noise*
- *Lack of sensitivity to detect microcracks*
- *High cost*

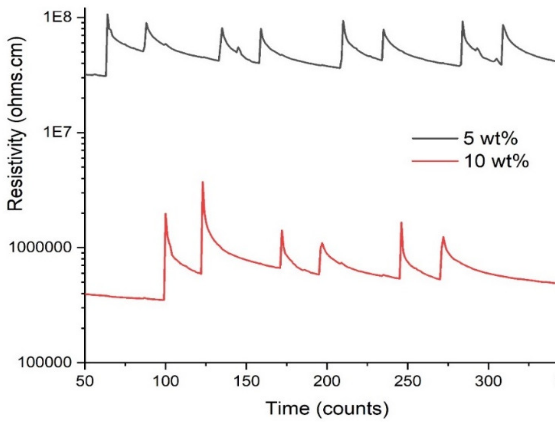
Alternative plan

The ***smart materials*** that allow applications in both SHM and strain detection are the same: ***Conductive polymeric nanocomposites***.

Integrating carbon based Nanomaterials (CNTs, graphene, carbon black…).

Structural Health Monitoring & Strain Detection

Piezoresistivity is defined as the coupling phenomenon between a mechanical stimulus (strain, ε) and a change in electrical resistance (ΔR, where R is the electrical resistance)



Resistivity change corresponding to rubber filled with CNT when manually fold and unfold (AIMEN graph, not the picture)

- When piezoresistive materials are stretched by an external force, the material resistance varies to a certain extent.

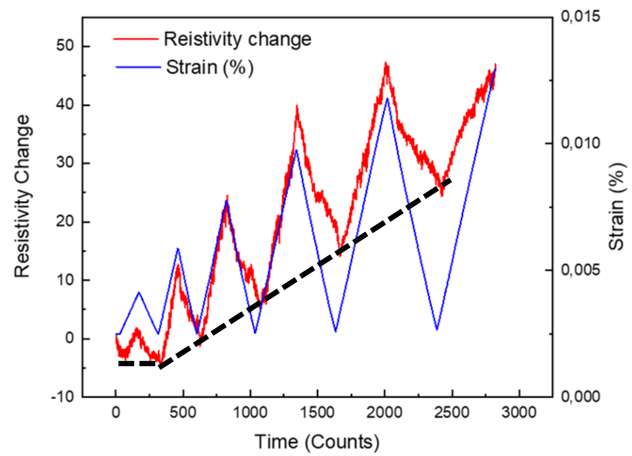
STRAIN detection

- When firmly attached to a deformable object, piezoresistive elements stretch as the object experiences strain, resulting in variable resistance.

Structural Health Monitoring:
Conductivity change Method Δσ

Conductivity

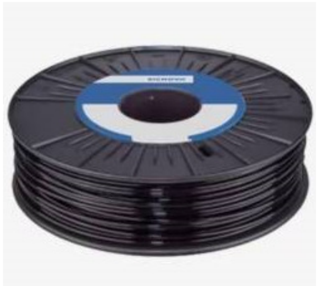
σ=1/ρ=1/R*0,02 (S/m)

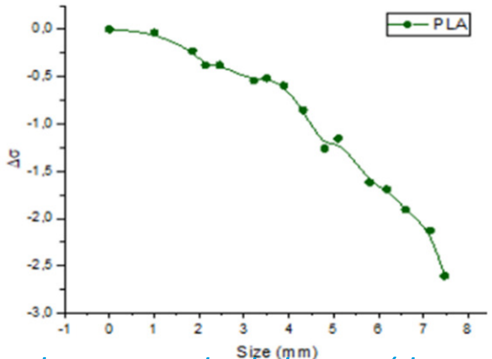


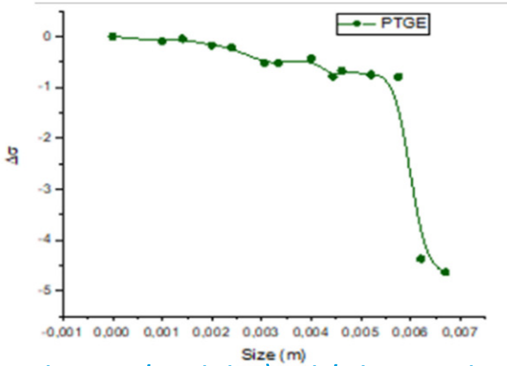
Commercial Conductive Filaments: Structural Health Monitoring

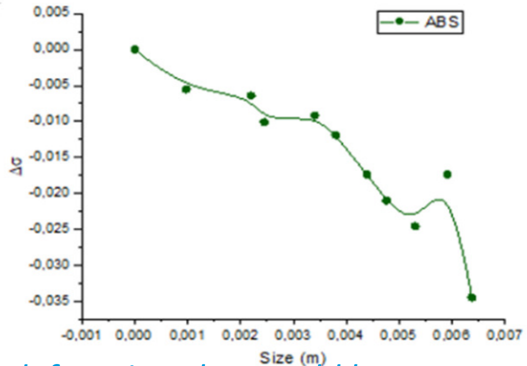
Commercial Conductive 3D Filaments: **Thermoplastic Polymer + Carbon-Based Nanoadditives**

Coupon	Description	Resistance
PLA	Carbon Black (20%)	0,588E3 ohm
ESD safe ABS	Unknown load of MWCNTs	0,464E6 ohm
CNT PETG	Unknown load of CNTs	0,346E9 ohm
PEKK-ESD	Unknown load of CNTs	48.5E6 ohm









- *All materials show a gradual change (decrease in conductivity) with increasing defect size: they could be proposed for SHM.*

Conductivity change Method Δσ

$$\sigma=1/\rho=1/R*0,02\ (S/m)$$


Functional Composite Materials

RESEARCH Open Access

Evaluation of conductive smart composite polymeric materials for potential applicationsin structural health monitoring and strain detection

Olalla Sanchez-Sobrado, Daniel Rodriguez, Ricardo Losada and Elena Rodriguez

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Commercial Conductive Filaments: Structural Health Monitoring

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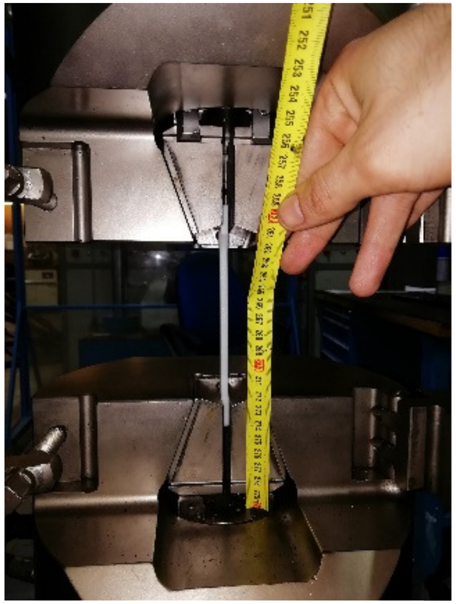
Simultaneous measurements of mechanical deformation and electrical conductivity during a tensile test, using acquisition equipment.

- For all materials, the resistivity increases during deformation, and as soon as the deformation ceases and the material returns to its original state, the resistivity also decreases.
- When polymers reach their breaking point, the resistivity curve collapses.



Sanchez-Sobrado et al. Functional Composite Materials (2023) 4:2
https://doi.org/10.1186/s42252-023-00039-x

Functional Composite Materials

RESEARCH Open Access

Evaluation of conductive smart composite polymeric materials for potential applicationsin structural health monitoring and strain detection

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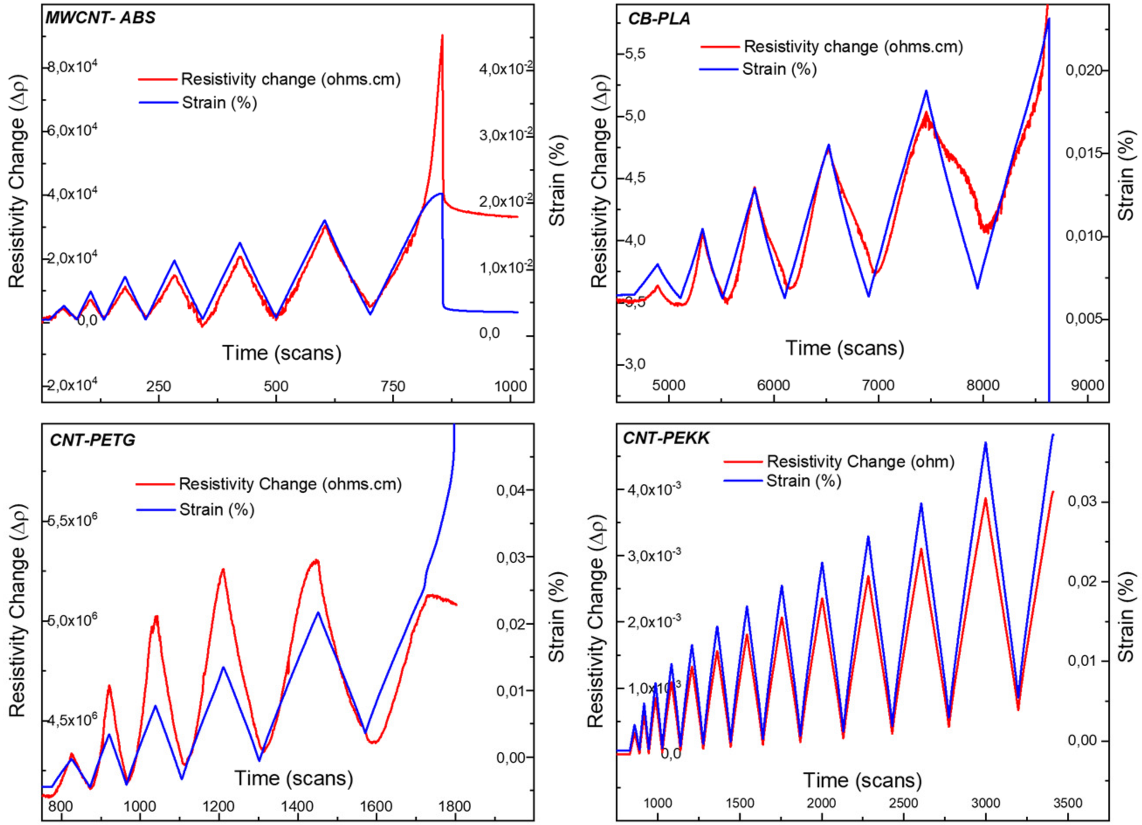

RT NANOCOMPOSITE MATERIALS FOR STRUCTURAL HEALTH MONITORING AND MOTION DETECTION

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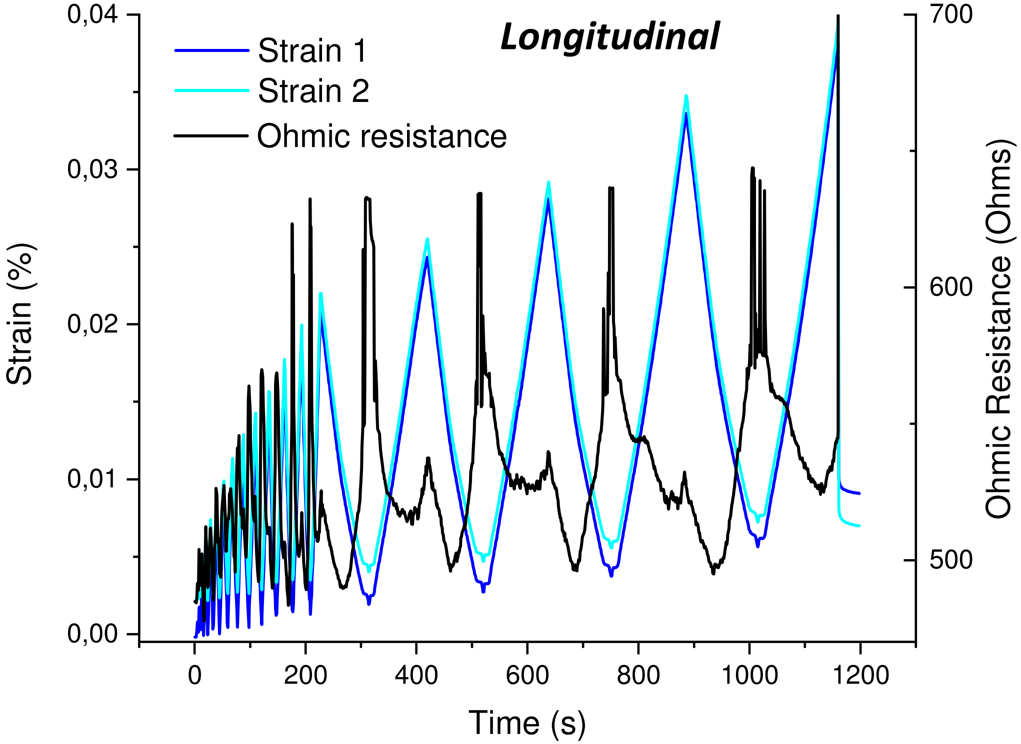
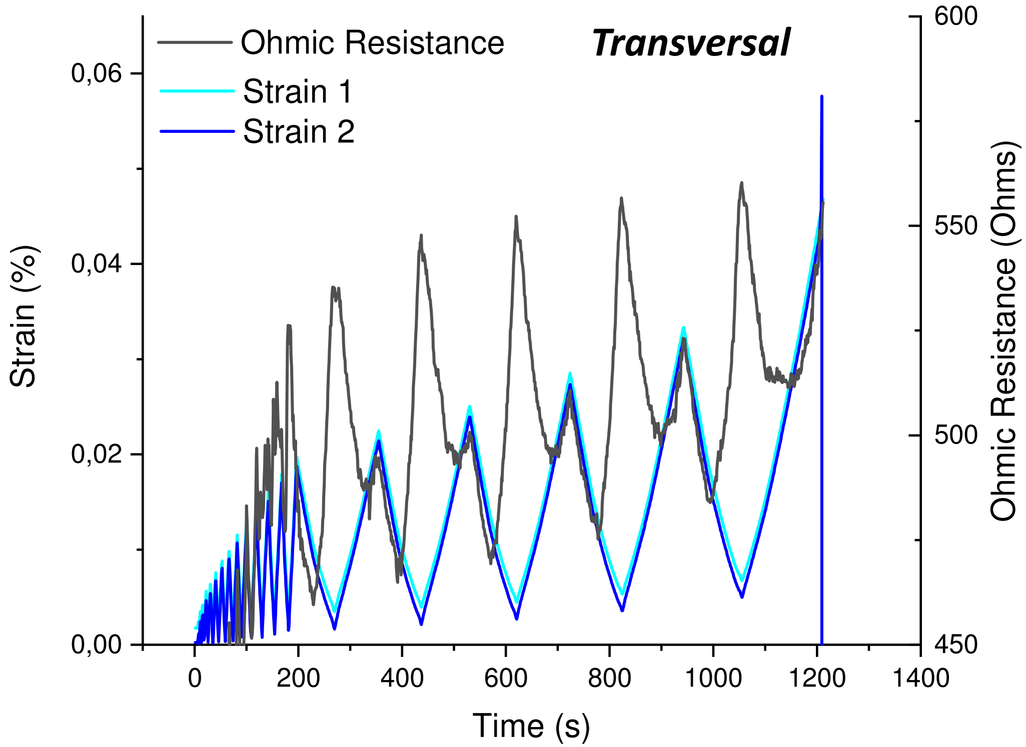
PEEK based 3D printing filament including ***CNTs*** and ***graphene***

Polymers **2018**, 10, 925; doi:10.3390/polym10080925





CONDUCTIVE SMART NANOCOMPOSITE MATERIALS FOR STRUCTURAL HEALTH MONITORING AND MOTION DETECTION

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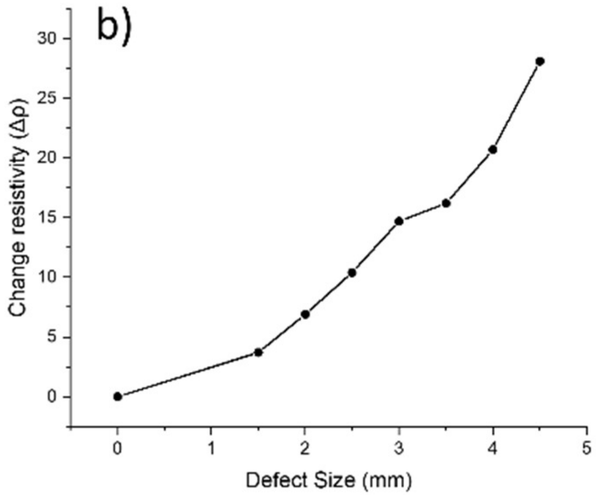
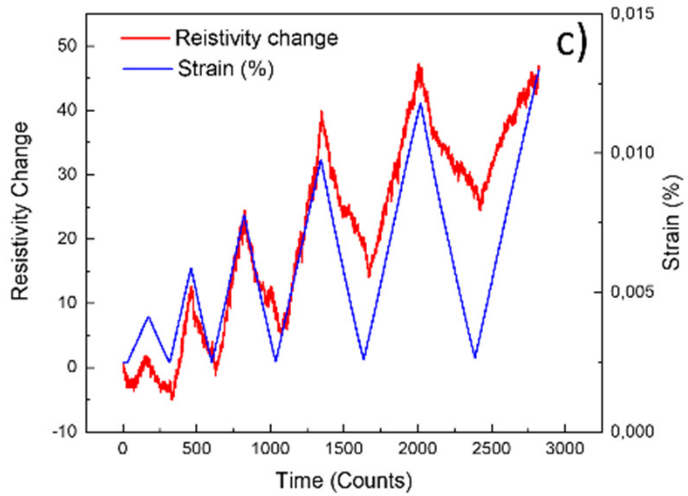
Carbon Nanotube based epoxy resin & elastomeric composites

Epoxy resin + CNTs

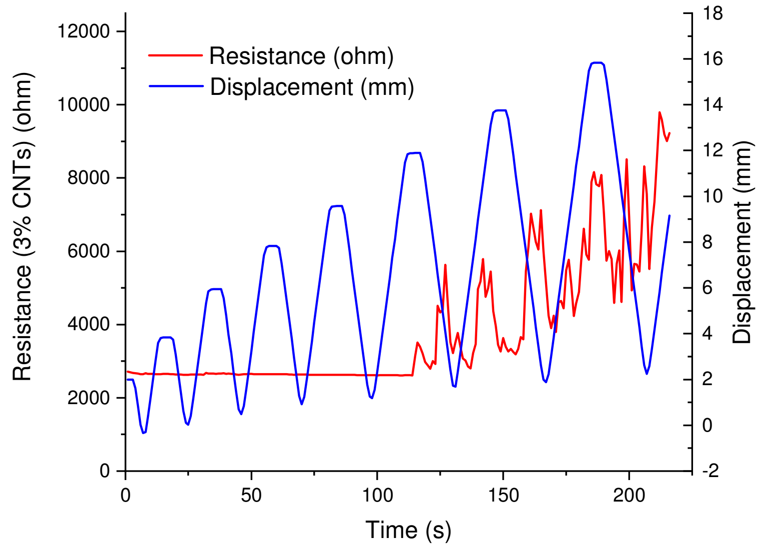
Rubber+ CNTs



Evolution of change of the resistivity with defect size



Simultaneus measurements of resistivity change (red lines) and strain (blue lines) for conductive epoxy resin



- Resistivity increases during deformation, and as soon as the deformation ceases and the material returns to its original state, the resistivity also decreases.
- Material shows a gradual change (decrease in conductivity) with increasing defect size: it could be proposed for SHM

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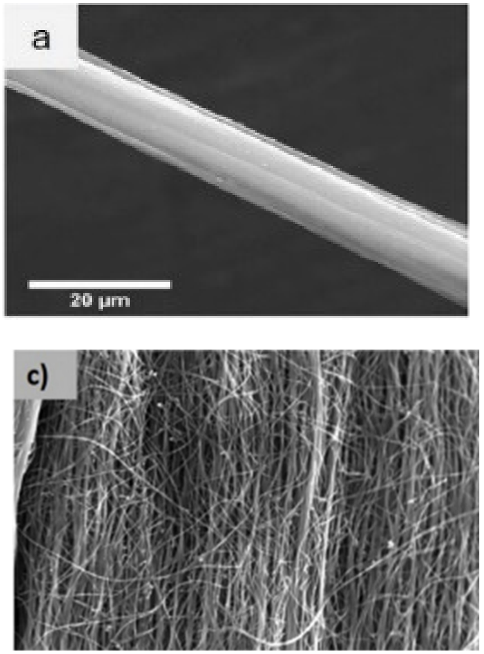
Continuous CNT fibres :
- Exhibit piezoresistive behaviour
- Are easily embeddable in composites

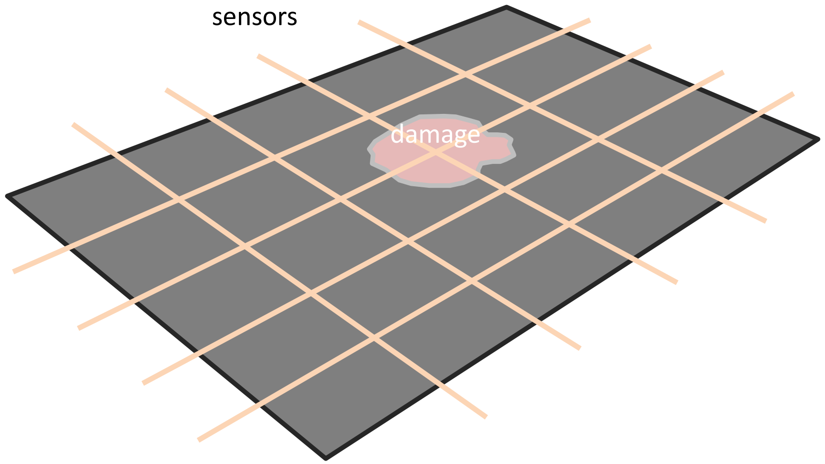
A grid on sensors allows to monitor strain and to relate its changes to the mechanical properties of the laminate panel

CNT fibres



SEM image of the densified CNT fibre

CNT fibres as embedded strain sensors

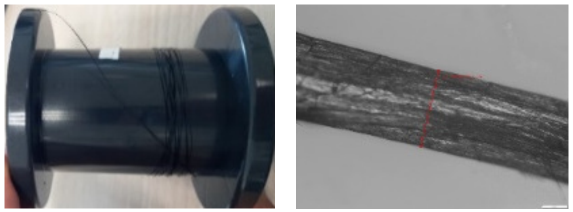


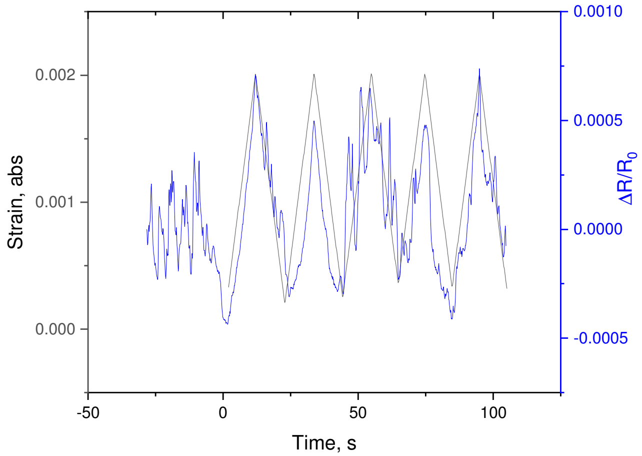
Scheme of the arrangement of a grid of embedded CNTs fibre sensors in a rectangular panel

Zarzoso, M., Mikhalchan, A., Vilatela, J.J. and Gonzalez, C.
Carbon nanotube fibre-based sensors for strain monitoring of CF/PAEK composites (In preparation)

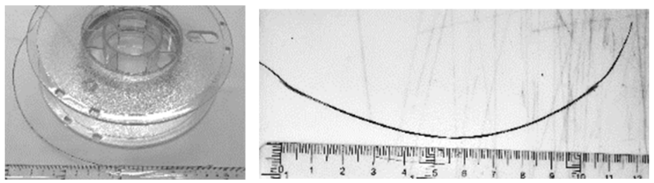
3D printed filaments with continuous CNT fibres

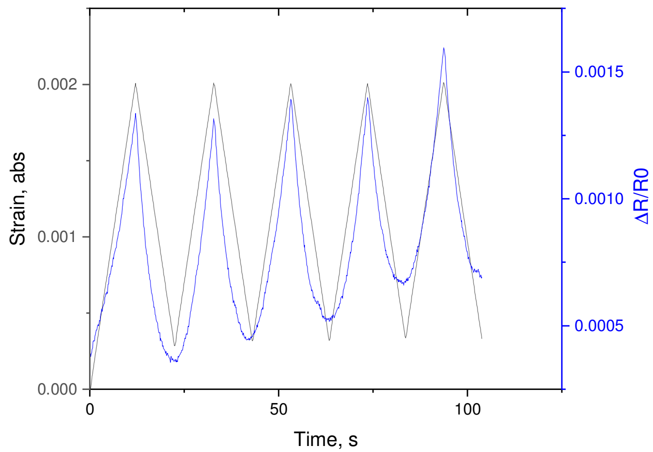
dry cCNT fibre



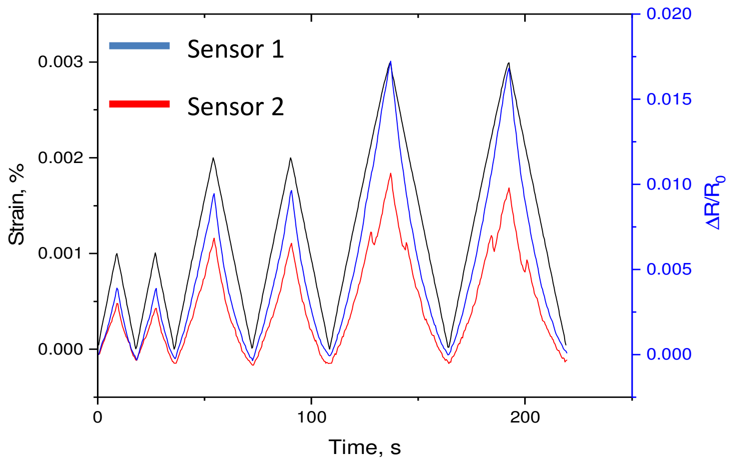


3D printed cCNT fibre





CNT fibres as embedded strain sensors



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CONCLUSIONS

- In the presented work, electrical properties, and both damage and strain dependent electrical resistance characteristics of several different carbon-based/polymer composite and nanocomposite materials were investigated: (a) CNTs reinforced RTM6 Epoxy resin, (b) different carbon-based nano additives thermoplastic composite for 3D printing technologies prepreg composite: PLA/CB; ABS/CNTs; PETG/CNTs and PEKK/CNTs and (c) long carbon fiber composite laminates.
- All polymeric conductive composite and nanocomposite materials evaluated in this work present response to the formation of structural damage, being nanocomposite based in small amount of nanomaterials like CNTs the most sensitive and promised for applications in SHM.
- All polymeric conductive composite and nanocomposite materials evaluated of different nature (thermoset and thermoplastic) have been proved suitable for applications in strain and motion detection. Long carbon fiber-based composites, allow to detect the production of microcracks during tensile tests.

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