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Textile Sensor Applications with Monofilament of Poly(lactic acid) / Carbon Nanotubes

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KEY WORDS

Carbon Nanotubes; Polymer Composites; Smart Textiles; Liquid Sensing.

ABSTRACT

The aim of this work was to develop polymer matrix/carbon nanotube composite monofilaments to incorporate in textile products, to be used as sensors. The carbon nanotube polymer composite (CPC) monofilaments were produced with the required electrical and mechanical properties for the development of a textile sensor of water vapor. The monofilaments selected were formed by poly(lactic acid) (PLA), and were incorporated directly into the fabrics. The presence of water induced a variation on the electrical conductivity of the filaments.

INTRODUCTION

In order to provide people with personalized healthcare, technological advances should be brought closer to the subject by means of easy-to-use wearable interfaces between devices and human. A healthier daily life, safer and more comfortable may be possible thanks to through multifunctional fabrics. Textiles are being developed in numerous types with various functions. As a result the so called smart fabrics or e-textile are under development. The final result is expected to be a smart human-machine interface. Solutions based on textile materials are favourable for application in the medical field, or in applications where the sensors are in contact with the skin of people. A class of new materials that has been showing potential for application as sensors are carbon nanotubes. The superlative mechanical, thermal and electronic properties attributed to them was never observed in previous materials. Researchers have envisaged taking advantage of their conductivity and high aspect ratio to produce conductive plastics with low percolation thresholds. The diameter of the CNT varies from 1 to 100 nm and its length may reach the millimeter scale. Their densities range from 1.3 to 1.8 g/cm^3 and their Young's moduli are superior to all carbon fibers, with values near 1 TPa. Its strength reaches values of 63 GPa. The main objective of this work is to perform a smart textile which is able to respond with an intelligent answer when detecting humidity. Composite monofilaments formed by a specific polymer and CNT may change considerably their electrical response in the presence or absence of a conductive liquid. The action of humidity on the electrical resistivity of the monofilament should be detectable. The work presented includes the production of poly(lactic acid)/CNT monofilaments, their mechanical and electrical characterization, and testing for changes in electrical resistivity in the presence of water vapor. Other sensors, combining different polymers and CNT could be able to detect other parameters, like temperature or strain.

EXPERIMENTAL

Materials

The polymer chosen for the composite production was poly(lactic acid) (PLA). The CNT composition was 4%. The description of the materials used for the production of carbon/polymer composites (CPC) for monofilament is detailed in Table I.

Table I : CPC prepared by twin-screw extrusion

Materials	Origin	CPC prepared
CNT N7000	Nanocyl	-
PLA + 17% CNT	Nanocyl	PLA + 4% CNT by dilution with PLA

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Preparation of the CPC composites

The PLA + 4% CNT composite was prepared by melt processing, diluting the PLA/CNT masterbatch on a Coperion ZSK 27 MEGACOMPOUNDER modular co-rotating twin screw extruder fitted with the adequate screw configuration. The polymer was cooled in water through, dried with blown air and cut into pellets by a suitable cutter.

Processing of the CPC monofilament yarns

Monofilament yarn was processed in a prototype extrusion line, consisting of a Periplast (Portugal) single screw extruder and downstream equipment comprising die, water tank, 1st set of pulling rolls, 1st oven (for extrudate orientation), 2nd set of pulling rolls (for drawing the filament at the required stretching ratio), 2nd oven (for extrudate relaxation or further orientation). The set temperature profile was optimized according to the characteristics of the material to be processed. Setting appropriately the die temperature of the first oven was critical, as it determined the stretchability of the material. Whenever possible, the first set of rolls was adjusted to provide the same stretching ratio of the emerging extrudates. The draw ratio was maintained at minimum level, keeping $V_2/V_1=1,3$.

Table II : Processing Conditions for the Monofilament Yarn

Composition	Temperature profile (ºC)	Oven Temperature (ºC)
PLA / 4% CNT	185/185/180/175 (Die)	65 º C

RESULTS

Sensitivity to water vapor

The water vapor sensing ability of the filaments was tested on a climatic chamber “Fitoclima 150 EDT” from ARALAB manufacturer. The climatic chamber was programmed to perform cycles at 98% RH followed by drying at 30% RH. The experiment begins at the maximum saturation humidity and decreases the relative humidity until 30 %. Between each step the relative humidity is maintained during a stipulated period of time. During the entire test the current intensity is acquired as depicted in *Figure 1*.

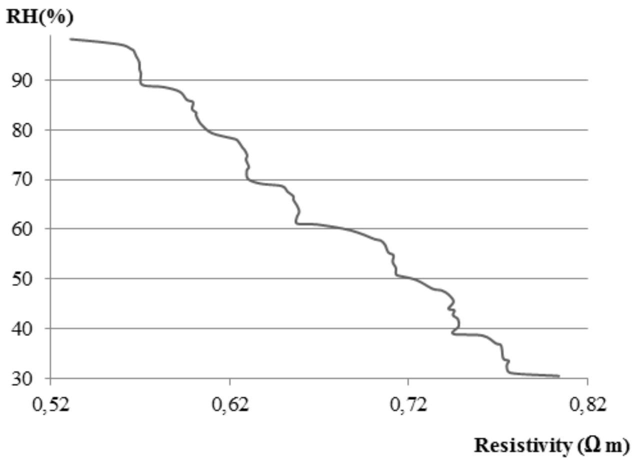


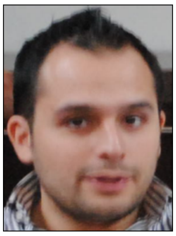
Figure 1 : Humidity Test Results

As it is possible to observe, the resistivity decreases as the humidity decreases, presenting good sensitivity to the changes in the external environment.

CONCLUSIONS

The monofilament of PLA / 4% CNT is sensitive to humidity as has been demonstrated. The target of this sensor is for textile applications (clothing or home textiles) where there is the need for early detection of humidity. Its application in textile materials are still the most complicated stage of the process. The stiffness of the monofilaments is a limitation for their textile processing, but may be circumvented if the weaving machines where they are produced can be adapted.

AUTHOR BIOGRAPHY



ALEXANDRE JOSÉ SOUSA FERREIRA was born in Setember 1982 in Martigny, Switzerland. In 2006 he was awarded the *Licenciatura* degree in Textile Engineering by the University of Minho. Since then he enrolled as a researcher at the 2C2T (Centro de Ciência e Tecnologia Têxtil), starting his PhD in 2008.