Carbon Nanotube reinforced Textiles for Civil Protection Services

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Abstract

A research joint venture led by Foundation for Research & Technology-Hellas, partnered with KORDSA Global, is developing new processes and technologies to scale up the production of carbon nanotubes dispersed in polymers, to create textile fibers with enhanced performance and new functionality that cannot be provided by polymers or traditional composites.

Protective textiles are a field of intense research activity. Body armour materials have traditionally been designed to protect the wearer against any kind of weapon threats. Several new fibers and construction methods for bullet-proof fabrics have been developed besides woven Kevlar®, such as DSM's Dyneema®, Honeywell's Gold Flex® and Spectra®, Teijin Twaron'sTwaron® and Toyobo's Zylon®. These high performance fibers are characterized by low density, high strength and high energy absorption. However, to meet the protection requirements for typical ballistic threats, several layers of fabric are required. It is also frequently to improve the body armour with stab resistant materials. The resulting bulk and stiffness of the armour limits the wearer's mobility and agility. As a consequence, civil protection services are not used to wear the protection vest all the time, performing usual tasks such as patrolling or driving, since the models currently on the market are heavy, bulky & inflexible. There is an obvious need to develop flexible and lightweight protective body armour.

This gap can be filled by means of carbon based materials. Since Iijima's report on carbon nanotubes (CNT) in 1991[1], scientists have been attracted by CNT's unique atomic structure and properties. Because of the combination of low density, nanometer scale diameters, high aspect ratio, and more importantly, unique physical properties such as extremely high mechanical strength and modulus, CNTs are ideal as potential reinforcing filler without adding extra weight and contributing with excellent performance. The inclusion of CNTs in a polymeric matrix holds the potential to improve the host material's mechanical properties by orders of magnitude well above the performance of traditional fillers. The challenges for developing high performance polymer/CNTs composites include the dispersion of CNTs in the polymeric matrix and interfacial interactions to ensure efficient load transfer from the polymeric matrix to the CNTs. The challenge of achieving efficient CNT dispersion and orientation within the polymer composite poses a substantial obstacle to the development of relevant beyond the state of the art fabrics. In other words, the mechanical properties of CNT composites fibers are highly dependent on CNT loading, dispersion and orientation, as well as pertinent to the polymer matrix characteristic properties. Substantial research efforts have been undertaken toward preparation (in the lab-scale) and characterization of polymer nanocomposites.

Experimental methods: The MWCNTs (NTX1) used in this work were purchased from NanoThinx S.A. (Greece). Carboxyl (-COOH) functionalized MWCNTs (NTX5) were also purchased by NanoThinx. Chemical oxidation was carried out by two pertinent treatments, one mild by utilizing nitric acid followed by hydrogen peroxide and a second one, a mixture of nitric/sulfuric acid, significantly more aggressive.

The polymer used in this work is poly(ethylene terephthalate), PET (iv ≥ 1 dL/g). Nanocomposites of 0.5, 1 and 2 wt% were prepared by melt mixing under nitrogen atmosphere in a homemade batch mixer. Polymer films were prepared by melt pressing a small part of the master batch at 285°C followed by quenching in ice water.
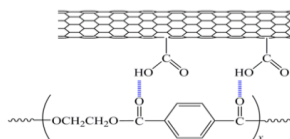

Fig. 1. *Scheme of CNT functionalization*

TGA in N_2 atmosphere was conducted for all MWCNTs shown. In the thermograms shown in Figure 2, the most thermally stable material is the as-received MWCNTs (NTX1), which does not lose weight after

being heated to 600°C. This is due to the low content of amorphous carbon in the as-received material. When a mild oxidation is conducted, the amount and rate of weight loss is very similar to that of the as-received material, indicating that no or very few amorphous carbon has been generated because of the acid treatment. The aggressive oxidation treatment, on the other hand, significantly degrades the graphitic structure of the MWCNTs by converting it to amorphous carbon, which is evident by the pronounced weight loss observed early in TGA curve.
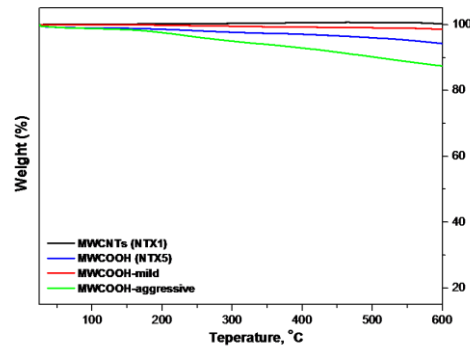

Fig. 2. *TGA curves of MWCNTs samples*

The tensile stress-strain curves of pure PET and the examined PET/MWCNTs composites at 0.5, 1, 2 wt% loading are presented in Figure 3. The absence of significant improvements in the mechanical properties of the NTX5 composites may be the result of aggregation, as well as poor interfacial interaction between the NTX5 MWCNTs and PET. Quite different properties are obtained for the composites that CNTs were oxidized by mild and aggressive treatment.

With respect to neat PET, these composites showed an increase in the strength and failure strain, although the improvement in elastic modulus may not be statistically significant. The large improvement in the tensile properties of these composites is attributed to the improved dispersion of MWCNTs inside the matrix and improved interactions between the MWCNTs and PET, mostly by hydrogen bonding, enhancing the interfacial bonding.
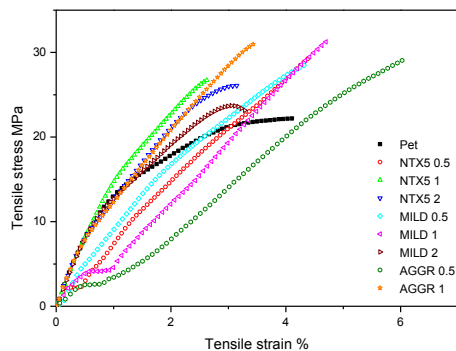

Fig. 3. *Representative stress-strain curves for PET and PET nanocomposites of all concentrations.*

Fabrication of PET/CNTs for textile applications both on laboratory and industrial scale needs to be optimized in terms of processing conditions that include pre-mixing parameters, feeding rate, temperature of extrusion die and screw speed in order to get new carbon nanotubes based materials with enhanced properties. Carbon nanotubes-PET monofilaments prepared at industrial scale (based on laboratory scale efforts) will be characterized and optimized for the required textile application.

References
[1] Iijima S., Nature, **354** (1991) 56-58.