Filler structure anisotropy and electrical conductivity enhancement in electrified carbon nanotube/thermoplastic polymer composites

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Carbon nanotube-filled polymer composites constitute a class of emerging, value-added materials that are expected to make an enormous technological and commercial impact in applications where electrical conductivity, superior heat conduction, and mechanical robustness are desired material attributes [1]. Examples of existing or proposed applications include flexible electronics, antistatic films, electromagnetic interference (EMI) shielding, coatings for electrostatic painting, automotive parts, reinforced aerospace materials, and sporting goods [2]. In addition to the advantages these composites present in their isotropic form, research over the last decade has shown that their counterparts containing aligned MWCNTs can exhibit an enormous improvement in their electrical, thermal, and mechanical properties along the direction of MWCNT alignment [3]. Moreover, desired property values can be attained at significantly lower filler content [4]. In view of the fact that alignment and structuring of MWCNTs in the polymer matrix during processing is possible through the use of various external force fields (electric, magnetic, or mechanical) [5], the enticing prospect of producing engineering polymer composites with superior properties, higher commercial value, and possibly lower production cost due to filler conservation, begins to emerge.

This work examines the characteristics of network formation of multiwall carbon nanotubes (MWCNTs) inside a polyolefin matrix melt under the influence of an externally applied alternating current (AC) electric field. The conditions under which dramatic improvements in the composite's electrical conductivity can be achieved are also investigated. Two types of composites are used in this study: MWCNT/ethylene-octene copolymer (EOC), in which fine MWCNT dispersion during melt compounding is achieved by means of a novel non-specific, noncovalent functionalization method and MWCNT/poly(ethylene succinate) (PESu), which is prepared by *in situ* polymerization.

Using TEM, SEM, and impedance spectroscopy, it is found that the electrified composite films exhibit nanotube assembly into columnar structures parallel to the electric field (Fig. 1), accompanied by dramatic increases in electrical conductivity up to eight orders of magnitude. By combining static and dynamic electrical resistivity measurements, we are able to derive correlations between the characteristic insulator-to-conductor transition times of the composites and process parameters, such as electric field strength (E), polymer viscosity (η) and nanotube volume fraction (ϕ). Finally, a criterion for the selection of (η, E, ϕ) conditions that enable MWCNT assembly under an electric field controlled regime (i.e., minimal Brownian motion-driven aggregation effects) is developed. The correlations presented herein not only provide insights in the MWCNT assembly process, but can also guide the experimental design in future studies on electrified composites or assist in the selection of process parameters in composites manufacturing.

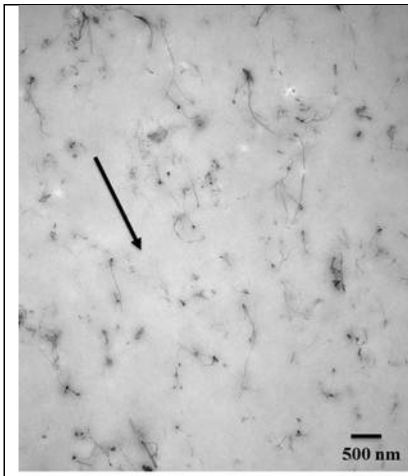

Figure 1: TEM image showing MWCNT alignment along the direction of an electric field (arrow) inside a polyolefin matrix [6].

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