

ELECTRICAL AND THERMAL PROPERTIES OF CARBON NANOFIBER AND MICROFIBERS

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Introduction

Nanofillers such as carbon nanofibers (CNFs) and carbon nanotubes (CNTs) are suitable for preparing polymeric composites, especially for films applications because of their very small diameter ($<0.1 \mu\text{m}$), high aspect ratio (~ 1000) and extraordinary electrical, thermal and mechanical properties when compared with traditional carbon fibers (CFs). In other words, the use of nanofillers could improve the poor transport properties of the matrix without deteriorating its mechanical properties [1]. In an earlier study, we have also shown that the morphology of the filler affects both the filler-matrix interfacial bonding and the filler interconnectivity [1, 2]. Therefore, the use of twisted/coiled-shaped nanofillers could enhance the final composite properties. For that purpose, MJ carbon nanofibers (MJ CNFs) were included as nanofillers in this work along with traditional CFs [3]. In this study, the electrical and thermal properties of LLDPE composites are presented.

Experimental

The following three types of fillers were used: (i) mesophase pitch-based carbon fibers P-55; (ii) carbon nanofibers PR-19 Applied Science Inc., and (iii) research grade MJ carbon nanofibers, synthesized at Myongji University (Korea) [3]. Poly(ethylene-co-1-octene) (Dowlex 2045 LLDPE) from Dow Chemical was used as matrix, which has a density of 0.920 g/cm^3 , DSC melting point of $122 \text{ }^\circ\text{C}$, and Vicat softening point of $108 \text{ }^\circ\text{C}$.

A Rheomix 600 mixer was used to prepare 1, 3 and 10 wt% P-55 CF/LLDPE composites at 190°C and three different batches were prepared at 20, 30 and 60 rpm, respectively. A DSM Xplore Micro twin screw compounder was used to mix the LLDPE and CNFs at 1, 10 and 30 wt% at $190 \text{ }^\circ\text{C}$.

The electrical resistivity was measured using a digital megaohmmeter ACL 800, which complies the ASTM D257 and EOS/ESD standards. A controlled humidity and temperature chamber Electro-Tech Systems, Inc. 506A was used for constant relative humidity (RH) and temperature ($\sim 25 \text{ }^\circ\text{C}$). For the P-55 CF/LLDPE composites processed at 20 rpm, the static decay time was measured using a static decay meter Electro-Tech Systems, Inc. 406D that complies with the Federal Test Method 101D, Method 4046 and Mil-B-81705C, and from these measurements, the electrical relaxation time was calculated.

For thermal testing, a NETZSCH Laser Flash Analyzer LFA 447 was used to determine the thermal conductivity of the composites according to ASTM E1461.

Results and Discussion

Initially, the electrostatic dissipation (ESD) and resistivity of the P-55 CF/LLDPE composites were analyzed. For 1 and 3 wt% composites, there was a smooth decrease in the electrical relaxation time (i.e. a measurement of ESD). However, for 10 wt% content the electrical relaxation time decreased drastically, from approximately 200 seconds for pure LLDPE down to 0.0008 seconds for 10 wt% P-55 CF/LLDPE. This implies that at 10 wt% the material became electrostatic dissipative. The electrical resistivity of the P-55 CF/LLDPE composites, presented in Fig. 1, shows that the dispersion level increased by increasing the energy of mixing for all three compositions. The resistivity of 10 wt% P-55 CF composites processed at 20 and 30 rpm was $\sim 5 \times 10^8 \Omega\text{-cm}$, but at 60 rpm was $\sim 3 \times 10^9 \Omega\text{-cm}$, which is almost one order of magnitude higher. Therefore, the resistivity is not only affected by the filler content, but also by the dispersion level reached.

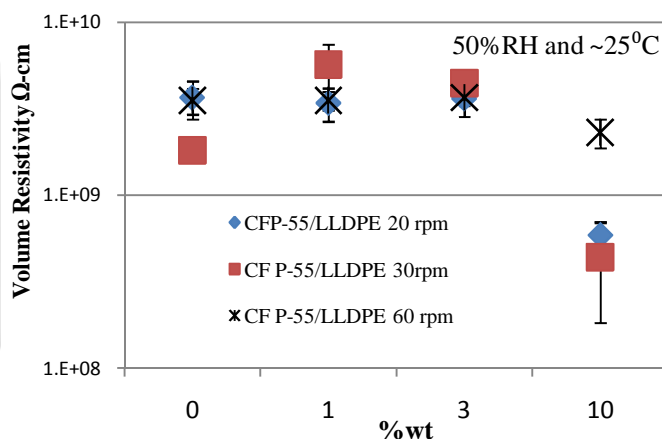


Fig. 1 Volume resistivity for pure LLDPE and P-55 CF/LLDPE composites processed at 190°C for 20 min. Measurements at 50%RH and $\sim 25 \text{ }^\circ\text{C}$. Error bars represents 95% confidence intervals.

To assess the effect of the filler content, the resistivity of composites processed at $190 \text{ }^\circ\text{C}$ and 20 rpm for 20 minutes is shown in Fig. 2. For PR-19 CNF, the composition was varied up to 30 wt% and a gradual decreasing of the resistivity was observed; however, percolation threshold was not reached. In our earlier study [1], carried out with PR-19 CNFs in LLDPE, we found a percolation threshold of $\sim 25 \text{ wt\%}$ with a lower mixing rate. This difference comes from the fact that when the dispersion increases the filler is more distributed, decreasing the probability of forming networks. The data for P-55 CF processed at 20 rpm is also shown in Fig. 2.

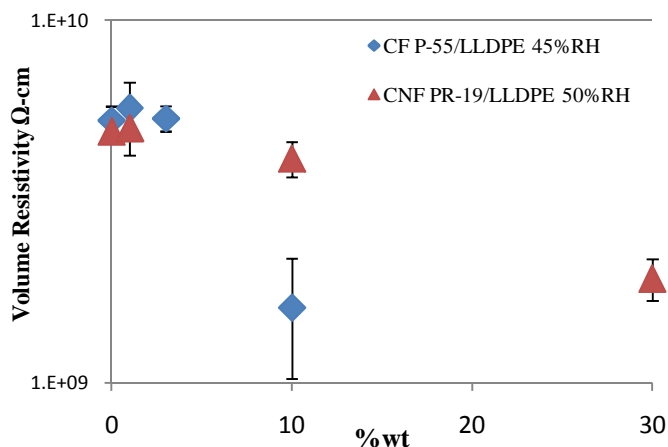


Fig. 2 Volume resistivity for pure LLDPE and its composites processed at 190°C and 20 rpm for 20 min. Measurements at ~25 °C. Error bars represents 95% confidence intervals.

The thermal conductivity for P-55 CF, PR-19 CNF and MJ CNF in LLDPE composites is shown in Figure 3. From the results, a very small increase of this property can be seen, however it is very evident that thermal conductivity increases as the composition increases, but is also affected by the type of filler, since for 30% wt the thermal conductivity of PR-19 CNF (0.52 W/m·K) was higher than that of the MJ CNF (0.46 W/m·K). This small improvement in thermal conductivity compare to the one in electrical conductivity is due to the fact that heat and electron transfer are carried out by different mechanisms.

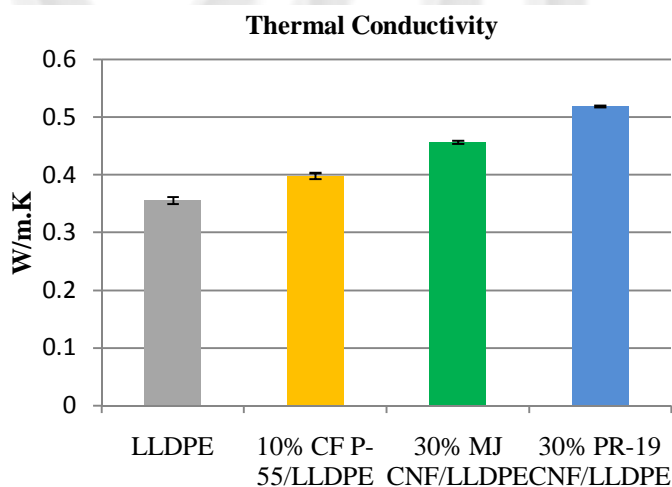


Fig. 3 Thermal conductivity for pure LLDPE and its composites processed at 190°C and 20 rpm for 20 min. Measurements at ~25 °C. Error bars represents 95% confidence intervals.

Conclusions

The electrical and thermal properties of linear low density polyethylene composites reinforced by mesophase pitch-based carbon fibers and carbon nanofibers were studied. Melt-mixing was used to intimately blend the matrix and the filler by using intensive batch mixing and twin-screw extrusion. The electrostatic dissipation of the P-55 CF/LLDPE composites increased with increasing CF content, and an ESD percolation threshold was found between 3 and 10 wt%. Their electrical resistivity decreases with increasing CF content, but no percolation threshold was observed for P-55 and PR-19 nanocomposites. On the other hand, thermal conductivity not only increases as the composition increases but also, is affected by the filler type.

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References

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