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Multiwalled carbon nanotubes for microwave heating of polymers

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Efficient heating is achieved by optimizing the dispersion of microwave susceptor additives within a polypropylene matrix.

A large amount of energy is consumed in the plastic industry for the transformation of polymers into final goods and products. Indeed, depending on the particular transformation process, the energy consumption can vary from 1.5–4.0kWh/kg.[1] For environmental and economic reasons, there is thus an interest in looking for more effective heating techniques that would allow the energy consumption to be reduced.

Microwave heating is characterized as being a uniform, fast, and highly efficient technique. Unlike with conventional heating methods, microwaves heat the material from the inside first and are thus more effective because the surrounding air is not also heated. At present, the main applications of microwave heating in plastic processing activities are for polymer synthesis, drying of pellets, melting, soldering, selective heating, and curing of thermoset resins. In these processes, the microwaves do not interact with the majority of the polymeric materials because they lack a dipolar moment. For this reason, additives—known as heating susceptors—are often used in the preparation of materials so that they can absorb microwaves.[2,3]

In this work,[4] we have studied the effect of using multiwalled carbon nanotubes (MWCNTs) as microwave susceptors (dispersed in a polymeric matrix). We chose polypropylene (PP) as the matrix for our study because of its non-polar nature and microwave transparency. We prepared our thermoplastic composites with a melt-mixing procedure, in which we used a co-rotative twin-screw extruder. In addition, we applied different processing conditions so that we could obtain different dispersion qualities of the MWCNTs within the PP matrix. We then analyzed this dispersion and correlated it with the electrical conductivity and microwave heating effectiveness of the samples. We maintained a constant MWCNT content (1% w/w) for all of our nanocomposites.

To optimize the dispersion of MWCNTs in our samples, we evaluated different extrusion processing parameters. These factors included the screw configuration, screw speed, and feeding methodology (i.e., masterbatch or powder form).[4] For a first-order approach to evaluate the MWCNT dispersion, we used an optical microscope to calculate

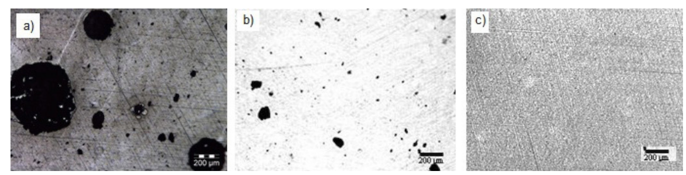

Figure 1. *Example optical microscope images of the multiwall carbon nanotube/polypropylene (MWCNT/PP) nanocomposite samples. These samples were produced under (a) high-shear, (b) mid-shear, and (c) low-shear conditions. Scale bars indicate 200µm.*

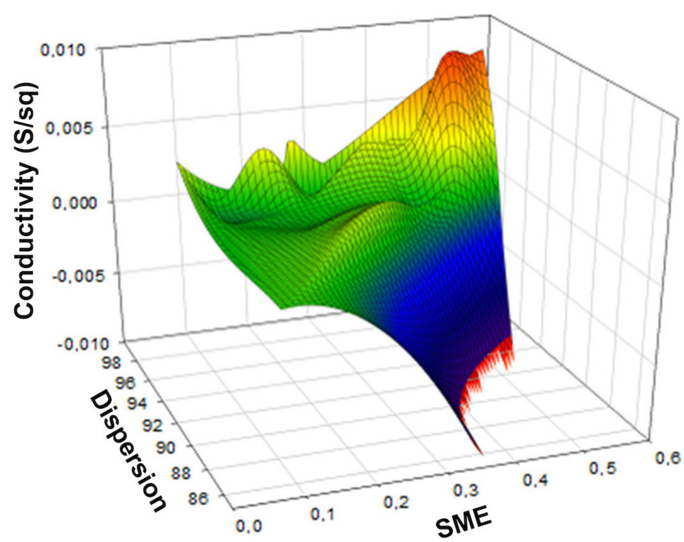

Figure 2. *Correlation between the specific mechanical energy (SME), dispersion factor, and surface electrical conductivity MWCNT/PP nanocomposites. S/Sq: Siemens/square.*

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the mean particle and agglomerate density. Our optical microscope images (see Figure 1) reveal that the dispersion and homogeneity of the nanocomposites improve as increasing levels of shear were applied during extrusion.

We achieved the best dispersion properties when we applied a high-shear screw configuration and a high screw speed, and when we introduced the MWCNTs in masterbatch form. Furthermore, the best dispersion factor was achieved when we produced the nanocomposites at high specific mechanical energies (which give rise to the best values of electrical conductivity), as shown in Figure 2. We find that the electrical conductivity can be improved by three orders of magnitude by optimizing the processing conditions.

For our experiments, we heated the samples in a multimode microwave oven (at 5.85GHz and 700W). We selected the frequency of 5.85GHz rather than the more common 2.45GHz because of our sample geometry, i.e., the higher frequency is more attenuated for thin geometries such as polymer pellets. The heating temperatures we achieved after 60s of microwave exposure are shown in Figure 3(a) and (b) for the nanocomposites that include the MWCNTs in powder form and in masterbatch form, respectively. Our results indicate that the influence of the processing conditions on the mean temperature reached in the microwave oven is more pronounced for the MWCNT-powder nanocomposites. In addition, we find that the electrical conductivity of the samples is improved at high screw speeds. This means that the heating effectiveness in the oven is also improved for these samples.

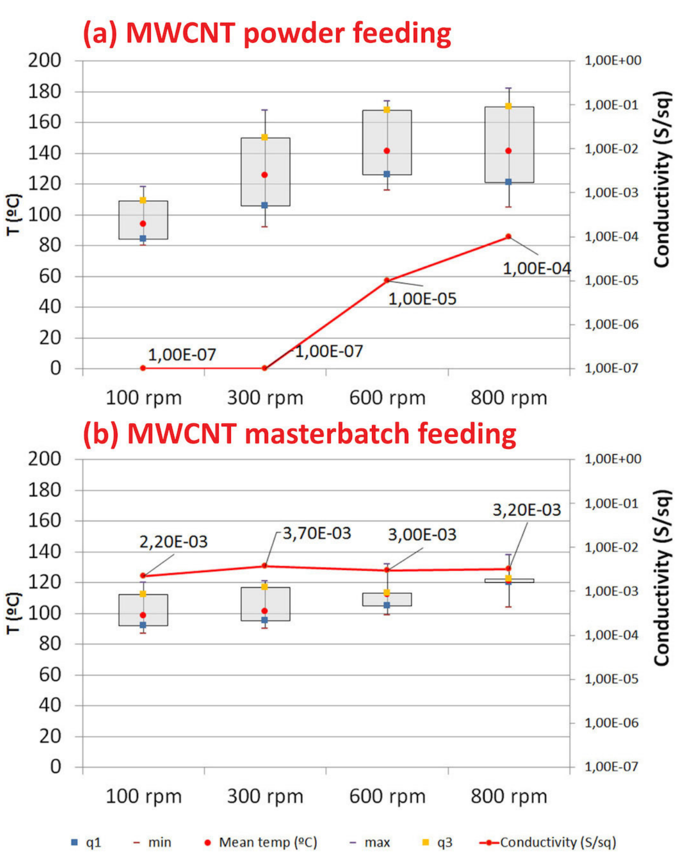

Figure 3. Temperature (T) and conductivity of the nanocomposites at different screw-speed extrusion conditions (after 60s of microwave heating). Samples were obtained by (a) direct feeding of MWCNT powder and (b) MWCNT masterbatch feeding. q1 and q3: First and third quartiles (i.e., 25 and 75% of the sample, respectively).

It is also important to note that the heating distribution in the powder-form nanocomposites is less homogeneous than for the masterbatch samples. Indeed, the difference between the maximum and the minimum temperatures is very high. This is caused by the presence of hot spots that arise because of poor MWCNT dispersion within the PP matrix. For the case of masterbatch feeding—see Figure 3(b)—the heating distribution is very homogeneous and the processing conditions have less of an influence on the nanocomposite performance. Nevertheless, we find that high-speed conditions are the optimum for realizing heating homogeneity.

In summary, we have investigated the use of multiwalled carbon nanotubes as microwave susceptors in polypropylene nanocomposites. Our results demonstrate the viability of using small MWCNT quantities to achieve microwave heating. Moreover, the MWCNTs can also be used as conductive fillers to achieve semiconductor properties in the final produced plastic parts. We also find that processing conditions strongly influence the characteristics of our nanocomposites during microwave heating. In particular, our results suggest that high-shear extrusion and the introduction of the MWCNTs in masterbatch format are the optimum processing conditions. In our future research we will focus on translating these results to the examination of other polymer materials.

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Begoña Galindo has a PhD in mechanical and materials engineering. She has been a senior polymer researcher in the Compounding Department of AIMPLAS since 2005. Her research is focused on the development of novel polymer formulations to achieve new functionalities in plastics. She also has experience working with nanocomposites for electrically and thermally conductive polymers.

Continued on next page

10.2417/spepro.006609 Page 3/3

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