# Study of the Electrical Conductivity of Polyamide 66 and Carbon Nanofibers Composites by Dielectric Spectroscopy

J.C. Canalda*, A. Linares, M.E. Cagiao, T.A. Ezquerra
Instituto de Estructura de la Materia, CSIC, C/ Serrano 121, 28006, Madrid, Spain
* jccanalda@iem.cfmac.csic.es

## INTRODUCTION

▪Polymer composites based on high aspect ratio nanofillers such as carbon nanotubes (CNTs) and carbon nanofibers (CNFs) are receiving considerable attention[1] because of their unique multifunctional properties at very low filler loading.

▪Among the several factors that affect the properties of polymer composites, including dispersion and distribution of the filler within the polymer matrix, the filler aspect ratio is a crucial factor especially for electrical properties.

▪The electrical percolation threshold, which is the critical filler concentration that is required to initiate a conductive network within of the insulating matrix, is known to decrease with increase in the filler aspect ratio.

▪Although polyamide 6,6 (PA66) based composites are of great interest because of their excellent properties, the tendency to degrade in the presence of oxygen when melt processed it is a serious drawback.

▪The aim of this work is to obtain composites based on polyamide 6,6 (PA66) and different contents of CNF following a procedure described elsewhere[2] and study their dielectric behaviour.

## EXPERIMENTAL

▪From composites based on PA66 and CNF, at different compositions, samples of about 1 mm thickness were obtained by compression molding at 280 ºC for 4 minutes at 15 bar, and subsequently cooling down to room temperature under constant pressure.

▪The morphology of the nanocomposites was observed by scanning electron microscopy (SEM) in a Hitachi S-300N.

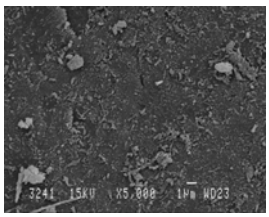
▪Wide angle X-ray scattering (WAXS) measurements were performed by means of a Seifert XRD 3000 θ/θ diffractometer, λ=0.154 nm at 0.02 º/s.

▪Differential scanning calorimetry (DSC) experiments were carried out using a Perkin-Elmer DSC7.

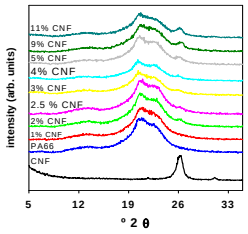
▪Dielectric studies were performed using a Novocontrol system integrating an ALPHA dielectric interface, in a frequency window of $10^{-2}$<F/Hz<$10^{-7}$ at room temperature.

## RESULTS

### SEM



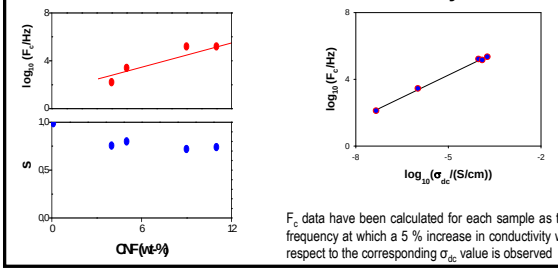
### WAXS



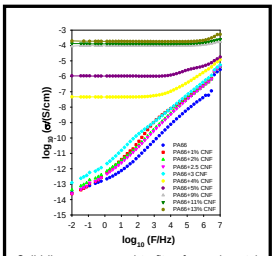

WAXS diffraction patterns of the nanocomposites showing the reflections of PA66 and the graphitic layer structure of the CNF

| SAMPLE | $T_m$ (º C) | ΔHm (cal/g) | $X_c^{DSC}$ (%) | $X_c^{WAXS}$ (%) |
|---|---|---|---|---|
| PA66 | 263.9 | 72.95 | 0.28 | 0.37 |
| PA66+1% CNF | 262.7 | 68.98 | 0.27 | 0.38 |
| PA66+2% CNF | 264.5 | 69.71 | 0.27 | 0.36 |
| PA66+2.5% CNF | 263.7 | 71.06 | 0.28 | 0.37 |
| PA66+3% CNF | 264.2 | 72.31 | 0.28 | 0.39 |
| PA66+4% CNF | 264.5 | 67.22 | 0.26 | 0.33 |
| PA66+5% CNF | 263.2 | 71.77 | 0.28 | 0.36 |
| PA66+9% CNF | 264.4 | 70.55 | 0.28 | 0.31 |
| PA66+11% CNF | 264.5 | 69.24 | 0.27 | 0.32 |

### AC Electrical Conductivity



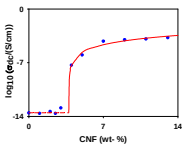

$F_c$ data have been calculated for each sample as that frequency at which a 5 % increase in conductivity with respect to the corresponding $\sigma_{dc}$ value is observed




Solid lines correspond to fits of experimental data to the equation:

$$\sigma(F) = \sigma_{dc} + \sigma_{ac} = \sigma_{dc} + A \cdot F^{s}$$

### DC Electrical Conductivity




percolation theory:

$\sigma_{dc} \approx (\Phi - \Phi c)^t$

t = 2.4 $\Phi_c$ = 3.8 %

## CONCLUSIONS

• Homogeneous mixtures are obtained, with good fiber dispersion in the polymer, as observed by SEM

• No significant changes are observed in melting point and melting enthalpies by the addition of nanofibers

•The degree of cristallinity achieved is around 30%, similar to that of the pure polymer. The values obtained by WAXS and DSC are the same order.

•The characteristic percolative[3] behaviour is observed, with Φc = 3.8 and t = 2.4

•$F_c$ increases in a linear fashion with CNF concentration.

• At low CNF concentration, S-exponent=1 corresponds to insulatinng specimens.

• As CNT concentration increases, S-exponent decreases. According to percolation theory, for three dimensional systems, S-values ranging from S ≈ 0.72, when polarization between particles is considered, to S ≈ 0.58 when anomalous diffusion in fractal clusters is considered[4].

## REFERENCES

[1]A. Linares, J.C. Canalda, M.E. Cagiao, M.C. García-Gutierrez, A. Nogales, I. Martín-Gullón, J. Vera and T.A. Ezquerra, Macromolecules 41, 7090 (2008)
[2] patent pending
[3] S. Kirkpatrick, Rev. Mod. Phys. 45, 574 (1973)
[4] Y. Gefen, A. Aharony, S. Alexander, Phys. Rev. Lett. 50, 77 (1983).