Effect of Processing Method on Mechanical Properties of PC/ABS-MWCNT Nanocomposites

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Summary: Nanocomposites of commercial PC/ABS matrix filled with multi-walled carbon nanotubes (MWCNT) suspended in ethyl alcohol were compounded on twin-screw co-rotating extruder and subsequently injection molded varying injection speed and temperature. Optical microscopy (OM) and scanning electron microscopy (SEM) were used to characterize the morphology of nanocomposites. A presence of fine agglomerates of carbon nanotubes was observed. The elastic modulus and stress at yield point increased with MWCNT content for all nanocomposites. However, higher values of yield stress were obtained for lower injection velocities, due to more homogeneous dispersion at mild injection molding conditions.

Keywords: blends; carbon nanotubes; mechanical properties; morphology; nanocomposites

Introduction

Nanocomposites of polymer matrix and multi-walled carbon nanotubes are recently getting more importance due to their excellent properties.[1] Similar mechanical and electrical reinforcement is difficult to achieve with other filler in comparable loads. Improvement is often disturbed by non-homogeneous carbon nanotubes distribution or agglomeration in thermoplastic matrix, which usually can be controlled by correct selection of processing method and parameters. Literature related to this field shows research concentration mainly on industrial processes, such as melt compounding.[2] Injection molding brings more difficulties in achieving homogeneous morphology due to lower specific mechanical energies (SME) and higher pressures during the process.[3] Different nanofiller concentration with the respect to injection gate appears along with re-agglomeration of carbon nanotubes well-dispersed in the process prior to injection molding.[4]

Mechanical reinforcement requests higher degree of carbon nanotubes dispersion. Nanofiller load along with its orientation, achieved by sheet stretching, influences properties of PP-MWCNT obtained in extrusion process.[5] Fu et al.[6] report crystalline structures obtained on MWCNT nucleus as a morphological reason for reinforcement. Similar conclusions appear for polyurethane elastomers, suggesting a stress-induced crystallization changing the morphology. The mechanical properties of semi-crystalline polycarbonate-based nanocomposites with multi-walled carbon nanotubes also showed dependence on morphology.[7] Oriented nanofiller after injection molding gave improvement of mechanical properties, on the contrary to compression molding.

In this work we present PC/ABS-MWCNT nanocomposites processed on twin-screw co-rotating extruder with carbon nanotubes feeding in the form of suspension in ethyl alcohol and subsequently injection molded. The effect of varying injection speed on the morphology and mechanical properties was investigated. The morphology of nanocomposites was investigated by optical microscopy (OM) and scanning electron microscopy (SEM). Thermal properties and mechanical

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properties were determined by thermogravimetric analyses (TGA) and tensile testing, respectively.

Experimental Part

PC/ABS Bayblend® T85 used in this work was produced by Bayer MaterialScience AG. Multi-wall carbon nanotubes (MWCNT) NC7000 of 90% purity were supplied by Nanocyl. Material was produced by catalytic carbon vapor deposition (CCVD) with average diameter of 9.5 nm and average length of 1.5 μm. Absolute ethyl alcohol with 99.9% purity was supplied by Panreac Quimica.

Nanocomposites of PC/ABS with multiwall carbon nanotubes (MWCNT) were prepared by melt compounding with throughput of 1 kg/h on twin-screw corotating laboratory extruder Prism Eurolab 16 with L/D 25. Screw speed was adjusted to 400 rpm and barrels temperature between 220 °C and 280 °C.

Multi-walled carbon nanotubes suspension in ethyl alcohol (5 mg of MWCNT per 1 cm^3 of ethanol) was obtained with ultrasound probe (Bandelin UV 2200) and maintained with magnetic stirrer during the feeding process. Suspension was supplied to the machine with peristaltic pump. Nanocomposites between 0.5 wt% and 2.0 wt% MWCNT concentrations were produced. Such obtained material was injection molded on BOY machine at temperatures between 260 °C and 280 °C and with injection velocities ranging between 10 mms^{-1} and 100 mms^{-1}.

Results and Discussion

Morphology

Figure 1 shows the optical micrographs of PC/ABS-MWCNT nanocomposites with 1.0 wt% of carbon nanotubes processed with extruder screw speed of 400 rpm at various temperatures. The presence of fine agglomerates of carbon nanotubes was observed in all nanocomposites, although the number of agglomerates was significantly reduced when the temperature was increased up to 260 °C. It is related to the decrease of melt viscosity and higher mobility of carbon nanotubes.[2] According to the side experiments, the agglomeration density was decreased with the increase of screw speed, though above 400 rpm there is only a little change in the final morphology.

Polymer blend used in this study is immiscible (Figure 2). Polycarbonate (PC) having smooth surface is distinguishable from rough poly(styrene-*co*-acrylonitrile) (SAN) with spherical structures of polybutadiene. SEM micrograph shows the presence of carbon nanotubes, mainly in PC and polybutadiene rather than in SAN,

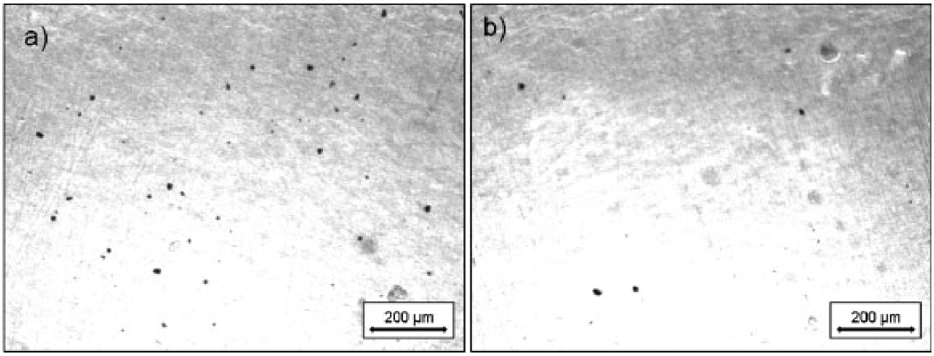

Figure 1.
Optical microscopy images of PC/ABS-MWCNT nanocomposites of 1.0 wt% processed at various temperatures; a) 220 °C, b) 260 °C.

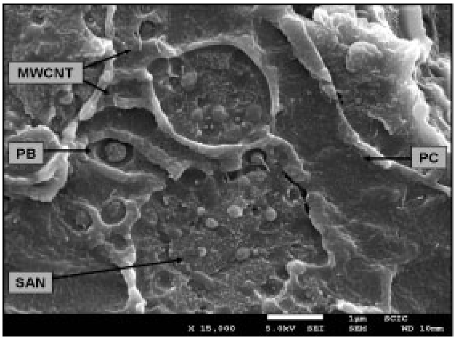

Figure 2.
SEM micrograph of PC/ABS-MWCNT nanocomposite of 1.0 wt% processed with MWCNT-ethyl alcohol suspension feeding; *PB* - polybutadiene.

due to the high affinity between polar groups along polycarbonate chains with the MWCNT surface. However, a good dispersion was observed in different polymer phases.

Thermal Properties

Figure 3 shows dependence of MWCNT on thermal stability of PC/ABS-MWCNT nanocomposites investigated by thermogravimetric analyses (TGA). Thermal stability in all investigated nanocomposites is reduced with MWCNT content. Peak maximum temperature values from the first derivative (DTG) of weight loss show decrease in PC region for all nanocomposites (from 523.4 °C for matrix to 516.3 °C for 1.0 wt%). It can be associated with the higher thermal conductivity of nanofiller and the following better distribution of heat in the sample. According to the study of morphology, majority of nanofiller is located in polycarbonate. This is confirmed by only little differences of thermal stability between PC/ABS and nanocomposites in ABS region, around 450 °C.

Mechanical Properties

Young's modulus of injected PC/ABS-MWCNT nanocomposites at different temperatures and with various nanofiller loadings are showed in Figure 4. Elastic modulus increases with MWCNT content for all nanocomposites. The increase is greater for high melt temperatures, in particular for the nanocomposites processed at 280 °C. Low melt viscosity at higher temperatures improve flow abilities of matrix and gives more homogeneous dispersion of nanofiller. This influence of melt temperature is analogous to agglomerates reduction effect showed in Figure 1.

Figure 5 shows stress at yield point dependence on with injection velocity and nanofiller content for PC/ABS-MWCNT nanocomposites. Changes of yield stress of nanocomposites with nanofiller content were similar to those obtained with elastic

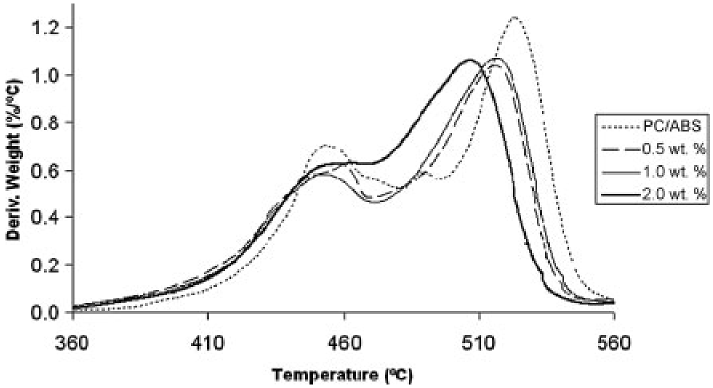

Figure 3.
Weight loss derivative as a function of temperature for PC/ABS-MWCNT nanocomposites with various carbon nanotubes loads.

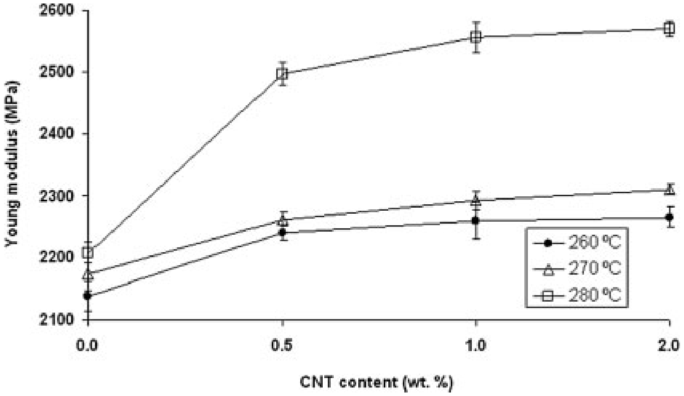

Figure 4.
Dependence of Young modulus on melt temperature in injection molded PC/ABS-MWCNT nanocomposites.

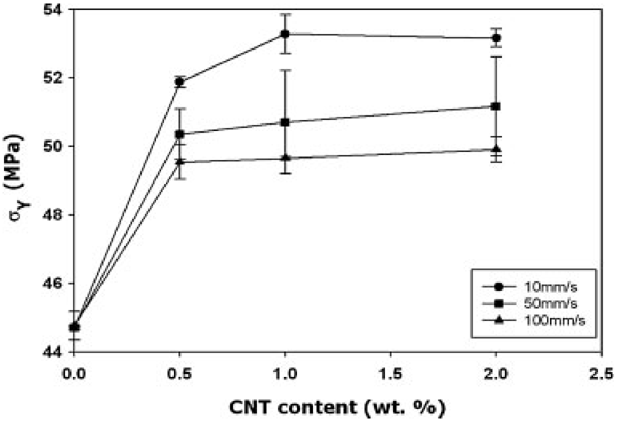

Figure 5.
Relation between stress at yield point and MWCNT content for PC/ABS-MWCNT nanocomposites injection molded at 270 °C with various velocities.

modulus. However, in this case, higher values of yield stress appear for lower injection velocities and clear decrease seems to appear above 10 mms^{-1}. This effect was opposite to what might be expected if the effect of the molecular orientation is studied on the polymer alone.[8] This is probably related to lower pressures applied to material during processing. Matrix melt and carbon nanotubes have different flow abilities giving more homogeneous nanocomposites at mild injection molding conditions. After significant increase between matrix and nanocomposite of 0.5 wt% MWCNT, plateau until 2.0 wt% can be observed.

Conclusion

It has been showed, that feeding multi-walled carbon nanotubes to twin-screw extruder in the form of ethyl alcohol suspension is sensitive to processing parameters. Increase of processing temperature during injection process gives better nanofiller dispersion. Majority of MWCNT is located in polycarbonate component of the blend. Thermal stability of nanocomposites decreases with respect to polymer matrix. Young's modulus increases with injection temperature, which is related to lower melt viscosity causing higher degree of homogeneity. Higher values of yield stress were obtained for lower injection velocities, due to a more homogeneous dispersion at mild injection molding conditions.

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