**Formation of electrical networks of multiwalled carbon nanotubes (MWCNT) in a polycarbonate (PC) matrix in oscillatory shear flows**

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**Abstract**

- Influence of molar mass (using a high-viscosity and a low-viscosity polycarbonate) on the formation of networks of multiwalled carbon nanotubes (MWCNTs) in shear was investigated.
- The formation of electrical and rheological networks proceeds more rapidly at higher temperatures and thereby a lower-viscosity matrix.
- Lower temperatures cause a larger stress-transfer and the breakup of the electrical network intensifies.
- Sinusoidal shear deformations give rise to oscillations in electrical conductivity.

**Motivation and Objectives**

- Especially in the field of conductive polymer composites, CNTs are ideal candidates for use as filler materials; due to their high length-to-diameter ratio in the 100-1000 range they can form percolated structures at very low filler concentrations.
- Electrical measurements can reveal the existence of a percolated network of conductive fillers in an isolating matrix [1-3].
- Oscillatory melt rheology is a sensitive tool to probe the structure of polymer melts.
- Simultaneous rheological and electrical investigations of polycarbonate composites are the focus of this study [4-5].

**Materials**

Two different batches of neat polycarbonate (PC) with different molecular weight distributions: Makrolon® M2200 and M2800. Composites containing 0.5, 1.0, 1.5, 2.0, 3.0 and 5.0 wt% Baytubes® (MWCNTs from Bayer MaterialScience AG).

Simultaneous rheological and electrical measurements were performed using a plate-plate geometry with electrically isolated tools.

**Results and discussion**

**Strain amplitude dependent behaviour**

Strain sweeps with increasing shear amplitude were conducted. Strain amplitude ranged from 0.4 to 300 % at a frequency of 0.1 rad/s.

**Dynamic mechanical analysis**

Dynamic mechanical analysis in the melt was performed at a frequency of 1 Hz and a deformation amplitude of 5 % at 280 °C.

- The addition of MWCNT leads to an increase in G’ for temperatures above Tg and particular for higher temperatures, solid-like behaviour is exhibited.
- The percolation threshold is situated between 0.5 wt% and 1.0 wt% for the PC M2200 composites and between 1.0 wt% and 1.5 wt% for the PC M2800 composites.
- According to frequency sweep (not shown) and strain amplitude sweep experiments, a lower matrix viscosity yields a lower percolation threshold for electrical conductivity.
- The electrically conductive networks persist below the glass transition temperature and thereby maintain in the glassy state of the PC composites.
- The formation of electrical conductivity is a degressive process facilitated by high temperature and low matrix viscosity and proceeds faster with higher filler content.

**Summary and conclusions**

Based on our experimental data, the existing models [1-3] can be extended.

This model illustrates the development of electrical conductivity by the incorporation of MWCNT into Polycarbonate. Partially bent nanotubes (black), forming agglomerates (circles) through entanglements and bonds. These clusters are embedded in the polycarbonate matrix. The clustering of agglomerates, leading to electrical conductivity, is highlighted by the contacting circles.

Observations in terms of electrical conductivity are interpreted as the superposition of three contributing phenomena:

- (i) Formation and reformation of percolated electrically conductive networks through agglomeration and clustering of nanotubes.
- (ii) Destruction / interruption of pathways of clusters leading to decreasing electrical conductivity at high shear amplitudes.
- (iii) Deformation of clusters / MWCNT-MWCNT bonds emerging in oscillations in electrical conductivity.

**References and Notes**