RHEOLOGICAL IMPACT OF NANO-SIZE FILLERS IN POLYCARBONATE

M.Maier*, C.Martínez, C.König, J. Nolte, D.Nemec, I.Kolaric
Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), Stuttgart, Germany
*E-Mail: Mathias.Maier@ipa.fraunhofer.de

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Introduction

Aim of this study is to investigate, if a composite with a mixture (hybrid compound) of carbon nanotubes (CNT) and carbon black (CB) can achieve the same electrical conductivity as a CNT composite but with a lower melt viscosity.

Carbon nanotubes (CNTs) are a promising filler material for polymers to impart the electrical conductivity and enhance the mechanical behaviour. These particles however, are known to increase the melt viscosity of thermoplastics significantly. In the moulding process high melt viscosities can cause various complications.

Carbon black (CB) is a common filler used for antistatic and conductive polymers. In comparison to CNTs, much higher amounts of CB have to be used to create a conductive network, which can be attributed to its spherical structure. However, CB does not increase the melt viscosity as greatly as CNTs.

Experimental

Materials used for this study are polycarbonate *Makrolon 2405* from Bayer AG, Multiwalled nanotubes *Ctube 100* from CNT Co., Ltd. and high conductive carbon black *Printex XE2* from Evonik AG.

Compounding was done by a co-rotating twin screw extruder HAAKE Polylab OS PTW16. Using a flat die the samples were directly prepared.

For electrical measurements rectangles were cut. These rectangles were temperature treated for 1 h at 423 K and cooled slowly. After this, electrical contacts were created with silver paint. The electrical measurement was done by a 4-wire setup (Agilent 34420A Micro Ohm Meter).

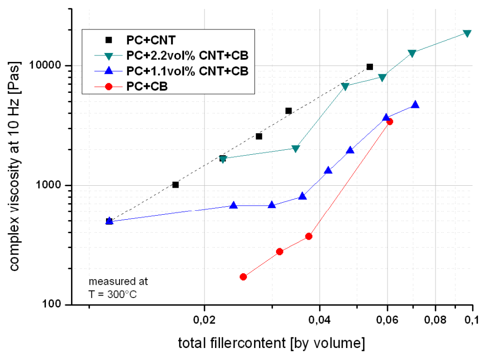
For rheological characterisation a rheometer HAAKE Mars 2 was used. Measurement setup was a 20mm plate-plate geometry with 0.9mm constant gap. The measurement was operated in oscillation mode. First the linear visco-elastic region was determined with a amplitude sweep. With this evaluated shear stress at 573 K a frequency sweep was performed.

Results

Complex viscosity of polycarbonate-compounds in dependency of the nanofiller-type and -content

The CNT compounds show for all filler contents the highest viscosity, the CB composites the lowest. For the two CNT+CB hybrid series the addition of small amounts of CB results in a viscosity lower than CNT composites at the same filler concentration.

With higher contents the slope of the curve become similar to the CNT compound.



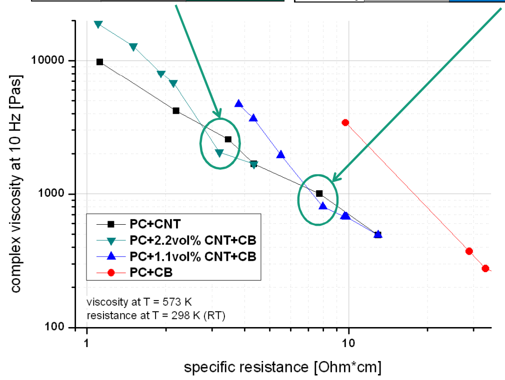
Interpretation:

The hybrid compounds do not show a significant change of viscosity below 2.5 vol% additional CB load. Below this threshold the free volumes between the CNT fibers are filled up with the spherical CB. After these gaps are saturated with CB, the viscosity rise, with a higher CB Load.

Complex viscosity as function of specific resistance for different filler contents

	CNT compound	CNT-CB-hybrid compound
Filler amound	**2.8vol% CNT**	**2.2vol% CNT + 1.3vol% CB**
Complex Viscosity at 10Hz	2550 [Pas]	2050 [Pas]
Resistivity	3.5 [Ω*cm]	3.2 [Ω*cm]

	CNT compound	CNT-CB-hybrid compound
Filler amound	**1.7vol% CNT**	**1.1vol% CNT+ 2.5vol% CB**
Complex Viscosity at 10Hz	1000 [Pas]	800 [Pas]
Resistivity	7.8 [Ω*cm]	8.0 [Ω*cm]



Comparing the viscosity and the resistance, addition of small amounts of CB to an constant amount of CNT the resistance decreases with only small influence on the viscosity.

By adding higher amounts of CB the electrical properties of the compound are dominated by the CB conductivity. For this cases the viscosity at the same resistance becomes larger compared to a pure CNT compound. This is caused by the lower conductivity of the CB.

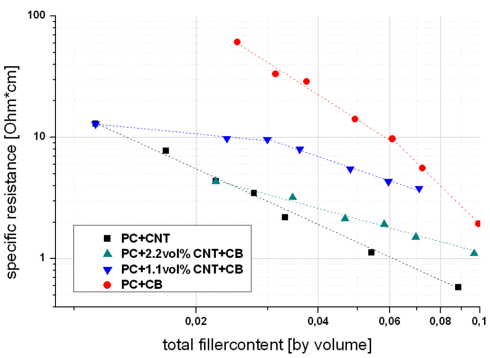
Specific resistance of polycarbonate compounds in dependency of the nanofiller type and content

All compounds were well above percolation threshold.

The lowest resistance measured for a filler content was for the pure CNT compound, the highest for the CB compound.

Interpretation:

The resistance of the CNT compound and 2.2vol% CNT+CB compound can be fitted to the equation $y = a*x^t$.



Whereas the pure CB and 1.1vol% CNT+CB hybrid compounds show a discontinuity at approximately 10 Ohm*cm.

After this discontinuity both hybrid compounds show nearly the same slope, which is lower in absolute value than for the CNT compound.

This reduction of resistance for both hybrids is mainly based on the resistivity and contact resistance of the CB, which is higher than for CNT.

Conclusion

- **We achieved comparable electrical properties between CNT-CB- hybrid compounds and pure CNT compounds.**

- **We get lower viscosities for a CNT-CB-hybrid compound in comparison to a pure CNT compound with same total filler concentrations.**

- **A reduction of 20 % in viscosity is possible by adding small concentrations of CB to a CNT compound in comparison to a CNT compound of same resistance.**