Investigation of Particle Arrangements in Polymer Nanoparticle Composites

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Polymer nanoparticle composites (PNC) have gained a lot of scientific and technological interest in the last decade. They can offer improved macroscopic properties compared to neat polymers or polymers filled with micron-sized particles [1].

Several aspects are believed to make major contributions to the changed material`s behaviour. One relates to particle related microstructure, i.e. the arrangement of the particles throughout the polymeric matrix and the interparticle distances. Good particle dispersion, whatever it might mean, is considered as a prerequisite for property improvements [1].

Unfortunately, there is a lack of reliable information concerning this point, probably owing to difficult sample preparations and suitable measuring methods. Often, Transmission Electron Microscopy (TEM) is used to state that the particles are homogeneously distributed, although TEM micrographs always show projections which must lead to incorrect values. On the other hand, simple unrealistic models are applied to calculate mean interparticle distances. These assume for example uniform cubic particle arrangements even for low particle fractions [2] .

But how to handle this problem?

TEM with its brilliant resolution provides valuable data about particle sizes and morphology emerging from samples thicker than about 50nm. Scanning probe techniques like Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM) in contrary are capable of reducing information depths considerably to several nanometers if properly used [3,4], thus providing data closer to 2D. Moreover, both techniques are of complementary character [5].

Classical stereology relates 2D data taken from cross-sectional areas to 3D properties [6]. It is well-known for several decades in different scientific domains like e.g. materials science, biology, medicine, and astronomy, but seems to be unnoticed in polymer science. Nearest neighbour distance distributions are one simple possibility to quantify particle arrangements. In this context, spatial particle distributions can basically be categorized as clustered, random or uniform [7] with an increasing mean nearest neighbour distance assuming equal particle fractions. Mixtures of the basic arrangements might be possible as well.

We report about first results concerning particle arrangements and interparticle distances in PNC composed of DGEBA/DETA (diglycidyl ether of bisphenol A cured with diethylene triamine) epoxies filled with different contents of silica nanoparticles. Microtoming, mechanical polishing, and ion etching as well as combinations of them has been tested for cross-section preparations. SEM micrographs of fields-of-interest have been done for further stereology based calculations with AFM used to investigate topographies. The results indicate a development of the particle arrangements with respect to volume

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fractions from random towards more uniform arrangements via a transition region characterized by lognormal distributed distances.

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