

Electrical properties of nanostructured polypropylene: a matter of morphology?

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ABSTRACT

This work investigates an alternative view on the mechanisms behind the modification of electrical properties in a filled dielectric, based on the variation of morphological properties of materials.

The case of a nanostructured polypropylene-based blend will be analysed, highlighting the morphological changes observed in the bulk of the material with modifications of electrical properties such as space charge accumulation, dielectric strength and conductivity.

Results show that nanofillers help inducing an enhanced morphology of the bulk material, with a reduction of phase separation. This in turn results in better breakdown voltage and lower conductivity, but also an increase in space charge accumulation characteristics to unacceptable levels.

On the other hand, functionalization of nanoparticles has been proven to be able to reduce charge accumulation to levels lower than the neat base material, despite a similar polymeric morphology. This must be due to the improved filler dispersion observed, clearly showing the added value carried by nanostructuring.

KEYWORDS

Insulation, Morphology, Nanofiller.

INTRODUCTION

Nanostructured dielectrics are a fascinating technological solution since their first proposal by Lewis in 1994. The modification of trap density and depth by nanoparticles and their surface functionalization affects several electrical properties in ways that are hard to control or predict [1],[2]. Space charge accumulation, breakdown properties and conductivity are only some of the several properties potentially modified by nanofillers.

Tailoring a material with selected improved characteristics should be possible by carefully selecting fillers with an adequate nature and dispersion [3] but hard to achieve in a cost-effective way, given the high level of precision and control this production would require.

Polymers featuring certain characteristics can be interpreted under a certain level or ordering of its micro and macroscopic structure. The structure that forms during polymerization critically defines the properties of the final material, and having, for example, the right range of molecular length is crucial for achieving thermomechanical integrity with the desired properties of thermoplasticity and rheological characteristics of a product.

Other works experimented the possibility to achieve enhanced properties through blending, after the addition of different grades of polymers, with good results [4],[5].

An alternative way of providing materials with improved characteristics might come from the modification of internal morphology that fillers introduce during the polymerization

processes [6].

CRYSTALLIZATION PRINCIPLES

Among the possible levels of order a polymer can exist, crystallinity is the most important concept, as with metals.

The two factors mainly influencing the physical properties of solid polymers, once the basic chemical composition of chains is selected, are defects and the set of parameters chosen during the crystallization stage. This work will focus on the first aspect.

All polymers have defects, to some extent. The most common type of defect comes from the geometrical placement of moieties within the monomer along the polymer backbone, differentiating three possible structures of a polymer: isotactic, syndiotactic, and atactic.

Branches, impurities in the structure, end of chains and inclusions are considered defects. Those irregularities deeply influence how a polymer will be able to solidify. Indeed, from a thermodynamic point of view, the Gibbs Thomson equation (Equation 1) links the melting temperature T_m with enthalpy of melting ΔH_v , surface free energy σ_e , and crystal dimensions l . T_m^0 is the temperature at which infinitely large crystals will melt.

$$T_m = T_m^0 \left(1 - \frac{2\sigma_e}{l \Delta H_v} \right) \quad (1)$$

Since crystals always start growing from secondary nucleation, starting from a defective site in the melt, crystal dimensions will also be limited by the presence of defects. In other words, the theoretical dimension of a crystal, l , is limited in practice by the distance between nucleation sites (i.e. defects). A high concentration of defective molecular structures will result in a final morphology characterized by smaller crystals, in turn decreasing the temperature that they form at.

Therefore, it is possible to gather a lot of control over the way crystallization occurs when control over defective regions is also allowed (e.g. purposefully introducing a certain concentration of irregularities).

It must be said that this opportunity is always limited by the fact that polymers are statistical entities (molecular length or defect size and concentration is not a constant but rather a distribution of values). The statistical process of polymerization is then not always perfectly defined *a priori*.

INCLUSION OF ADDITIVES: MORPHOLOGICAL EFFECTS

The theory of Keith and Padden [7] indicates that a high concentration of weak and defective material is found in boundaries after crystallization, and therefore, when large structures are formed, bigger highly defective regions will also be formed in the solid. Those are the regions that will most likely cause a mechanical or electrically failure.