Polymer-based nanocomposites with tailored electrical properties: Applications in aerospace and electrical power technologies

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Polymer nanocomposites based on carbon nanotubes (CNTs) and, more recently, on graphene and graphene oxide (GO) have attracted considerable attention over the last two decades. An in-depth understanding, and predictive capability of the key structure-property relationships governing the electrical/dielectric properties, has been established allowing the application of these novel materials in various technological areas. Two characteristic examples would be discussed in this presentation.

In the first part, an end application of CNTs incorporation in an aerospace grade epoxy resin is presented. The increased use of carbon fibre composites in aerospace components brings to the surface issues related to their poor lightning strike performance. Lightning strikes can induce severe damages due to the dielectric nature of the host matrix even in the case where the reinforcement is highly conductive e.g. carbon fibres. Metallic meshes or foils, co-cured within the outer layer of laminates, are currently used for protection. This solution comes at a cost in terms of weight and manufacturing complexity, presents difficulties in repair and most importantly does not provide full protection. The influence of CNTs on the lightning strike performance of carbon fibre composites is demonstrated.

In the second part, a method for the production of insulating materials with predetermined electrical/dielectric properties is discussed. The concept is applied on weak locations (typically interfaces) that are prone to failures due to electric field concentration in various medium and high voltage products. It is based on the controlled reduction (restoration of the graphitic lattice) of graphene oxide in GO-based composites, accompanied by a smooth transition from insulating to conducting behaviour. GO, produced by the oxidation of graphite, consists of a hexagonal ring-based carbon network bearing hydroxyl and epoxide functional groups on either side of the sheet, whereas the sheet edges are mostly decorated by carboxyl and carbonyl groups. These functional groups disrupt the sp^2 hybridization in the lattice leading to a significantly higher resistance compared to graphene, depending on degree of oxidation. Restoration of the lattice can be achieved by several chemical and electrochemical methods as well as by thermal treatment or even irradiation (laser, X-ray, UV, flash, e-beam). Depending on method and conditions, different level of restoration of the electronic structure of carbon plane is achieved leading to a broad band of conductivity values of the reduced graphene oxide (rGO). Two approaches were adopted to demonstrate the concept: I. A temperature gradient applied on a composite rod leading to a gradient in the conductivity along its length, and II. Surface treatment by a pulsed or a continuous laser on composite plates leading to a selective reduction at the targeted locations. The GO-based materials showed a very high bandwidth in their conductivity/permittivity upon the thermal or laser treatment (ranging from values the pure insulating matrix exhibits up to about 0.1 S/m), indicating that under optimal processing conditions conductivity can be tailored and graded irreversibly within these ranges.