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Multifunctional polymer foams with carbon nanoparticles

Marcelo Antunes, José Ignacio Velasco*

Centre Català del Plàstic, Department of Materials Science and Metallurgy, Universitat Politècnica de Catalunya, BarcelonaTech (UPC), C/ Colom 114, E-08222 Terrassa, Barcelona, Spain

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ABSTRACT

Increasingly demanding industry requirements in terms of developing polymer-based components with higher specific properties have recently aroused a great interest around the possibility of combining density reduction through foaming with the addition of small amounts of functional nanosized particles. Particular interest has been given to the creation of lightweight conductive polymers by incorporating conductive carbon-based nanoparticles, related to processing improvements in attaining homogeneous nanoparticle dispersion and distribution throughout the polymer as well as new processes that enable a higher control and throughput of highly pure carbon nanoparticles, which could overcome some of the common problems of conductive polymers, such as high cost and poor mechanical properties. This review article considers the use of carbon nanoparticles in polymer foams, initially focusing on the important aspects of foam preparation, the main results found in the literature about conductive polymer composites containing carbon nanoparticles, as well as the main polymer foaming processes and types of foams. The main section is dedicated to the properties of multifunctional polymer foams with carbon nanoparticles, with special focus being given to the electrical and transport properties of these materials.

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* Corresponding author. Tel.: +34 937837022; fax: +34 937841827.
E-mail address: jose.ignacio.velasco@upc.edu (J.I. Velasco).

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1. Introduction

The increasingly more demanding requirements for polymers in terms of their specific properties in emerging sectors such as aerospace or leading sectors as electronics have led to the development of novel lightweight polymer nanocomposites by combining foaming with the addition of small amounts of nanosized fillers, and more recently by incorporating nanosized particles with functional characteristics, the combination of which resulting in what is known conventionally as multifunctional polymer foam.

Carbon-based nanoparticles and particularly carbon nanotubes and graphene have recently attracted a great deal of interest due to their inherently high mechanical and especially high transport properties, which have opened up a whole new set of possibilities in the electronics industry. Owing to their conducting-semiconducting structure-dependent electronic behavior, the incorporation of these carbon nanoparticles has been seen as a possible strategy to regulate the electronic transport of polymers, partially solving some of the problems related to the use of conducting polymers. Adding to all these possibilities, some of the synergies found between foaming and the incorporation of nanometric-sized particles could lead to new lightweight materials with improved transport properties for applications that could go from electrostatic discharge, ESD (fuel system components, packaging materials for ESD sensitive items) to electrostatic painting up till electromagnetic interference (EMI) shielding (fuel cells, gaskets for electronic devices, among others).

This review article considers the most recent results regarding the use of conductive carbon nanoparticles in the development of multifunctional polymer foams, initially focusing on the important aspects of polymer nanocomposite foam preparation, particularly on the types of carbon-based nanoparticles available and their intrinsic transport and mechanical properties, the main results found in the literature regarding conductive polymers based on these carbon nanofillers, as well as the main industrial foaming processes and types of polymer foams. The main section of the article is dedicated to the properties of multifunctional polymer foams with carbon-based nanoparticles, with great importance being given to the scarce investigation on the study of the electrical and transport properties of these materials.

2. Fundamentals and preparation of multifunctional polymer foams with carbon-based nanoparticles

Conducting polymers, which have attracted a great deal of interest in the most varied scientific disciplines, from printed circuitry to flexible electronics, can be classified into four basic types, each with its particular advantages and limitations: ionically conducting polymers, which, despite their high sensitiveness to moisture, are still vastly used in consumer electronic applications such as rechargeable batteries or fuel cells; conjugated polymers, mainly based on polyaniline (PANI) and used in conducting filled polymers; charge-transport polymers; and polymers with carbon-based or metallic conductive particles. Conducting conjugated polymers may be understood as polymers that display a semiconducting electronic gap that originates from the bonding and anti-bonding energy levels of σ-bonds between adjacent carbon atoms and the orthogonal π-bonds resulting from the linear combination of p_z orbitals from each repeat unit. This last band gap is the one responsible for their semiconducting properties [1].

Though in the past the preparation of conducting polymer composites had been limited due to difficulties resulting from non-homogeneous particle dispersion and distribution, as well as difficulties in controlling the final electrical properties of the composite and attaining a conductive behavior, special efforts have been made recently. These have mainly been related to the development of new processes that enable a higher control and throughput of highly crystalline conductive carbon nanotubes and the need to extend the applications of these materials, as common conducting polymers usually show a combination of high cost, low thermal and electrical stabilities, as well as poor mechanical properties.

Particular attention has been given to the use of carbon-based nanofillers, as the addition of low or even extremely low concentrations of these conductive nanofillers may significantly improve the electrical conductivity of non-conductive polymers. Carbon nanofillers can display, depending on their structural characteristics, either a fully metallic or semiconducting electronic behavior, which could result beneficial in the development of new conducting polymers for the most varied applications.

As lightness has gained considerable interest as a way to reduce costs, for instance in transportation, there is a great deal of interest in further reducing the density of polymers and increasing their possible range of applications by foaming the base material. As a consequence, the combination of foaming and incorporation of conductive nanoparticles could promote the development of novel multifunctional materials based on polymer nanocomposites (see some of the synergies and possibilities of combining the incorporation of functional nanoparticles with foaming in Fig. 1).

2.1. Carbon-based nanoparticles for multifunctional polymer foams

Carbon-based nanoparticles have generated a great deal of interest in the last decade, alone or in combination with other materials as polymers, direct consequence of their theoretically predicted combination of remarkable mechanical and other physical properties, such as extremely high thermal and electrical conductivities [2]. Alongside these very important intrinsic characteristics, carbon nanoparticles are low density materials, hence making them ideal candidates for the development of high performance polymer composites. Their geometric characteristics, where at least one of their dimensions is in the nanometer range, enables for a high theoretical specific surface interaction with polymer molecules, which could result in important mechanical or transport properties improvements at low or extremely low nanofiller concentrations.

However, some problems are still found when trying to combine these materials with polymers. One of