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Review

Polymer/carbon based composites as electromagnetic interference (EMI) shielding materials

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ABSTRACT

The extensive development of electronic systems and telecommunications has lead to major concerns regarding electromagnetic pollution. Motivated by environmental questions and by a wide variety of applications, the quest for materials with high efficiency to mitigate electromagnetic interferences (EMI) pollution has become a mainstream field of research. This paper reviews the state-of-the-art research in the design and characterization of polymer/carbon based composites as EMI shielding materials. After a brief introduction, in Section 1, the electromagnetic theory will be briefly discussed in Section 2 setting the foundations of the strategies to be employed to design efficient EMI shielding materials. These materials will be classified in the next section by the type of carbon fillers, involving carbon black, carbon fiber, carbon nanotubes and graphene. The importance of the dispersion method into the polymer matrix (melt-blending, solution processing, etc.) on the final material properties will be discussed. The combination of carbon fillers with other constituents such as metallic nanoparticles or conductive polymers will be the topic of Section 4. The final section will address advanced complex architectures that are currently studied to improve the performances of EMI materials and, in some cases, to impart additional properties such as thermal management and mechanical resistance. In all these studies, we will discuss the efficiency of the composites/devices to absorb and/or reflect the EMI radiation.

Abbreviations: μm, micrometer; 3D, three dimensional; ABS, acrylonitrile-butadiene-styrene copolymer; Ag, silver; ASTM, American Society for Testing and Material; BR, butyl rubber; CB, carbon black; cm, centimeter; CNF, carbon nanofiber; CNP, carbon nanoparticle; CNT, carbon nanotube; CO_2, carbon dioxide; Db, decibels; DC, direct current; E, electrical field; EM, electromagnetic; EMA, poly(ethylene-co- methylacrylate); EMI, electromagnetic interference; EMT, Effective Medium Theory; EPDM, ethylene-propylene-diene monomer rubber; EVA, poly(ethylene-co-vinyl acetate); GFRC, glass fiber reinforced cement; GHz, GigaHertz; GS, graphene sheet; H, magnetic field; HDPE, high density polyethylene; HIPS, high impact polystyrene; LDPE, low density polyethylene; LLDPE, linear low density polyethylene; MHz, MegaHertz; mm, millimeter; MMA, methyl methacrylate; MWNT, multi-walled carbon nanotube; NBR, nitrile butadiene rubber; Ni, nickel; nm, Nanometer; P(Vac-co-VA), poly(vinyl acetate-co-vinyl alcohol); P3HT, poly(3-hexylthiophene); PANI, polyaniline; Pc, percolation threshold; PC, polycarbonate; PCL, polycaprolactone; PDMS, poly(dimethylsiloxane); PE, polyethylene; PEEK, poly(ether ether ketone); PEO, poly(ethylene oxide); PET, poly(ethylene terephtalate); PEtOc, poly(ethylene-co-octene); Pin, incident power; PLLA, poly(L-lactide); PMMA, poly(methyl methacrylate); PMTT, poly(trimethylene terephtalate); POSS, polyhedral oligomeric silsesquioxanes); Pout, transmitted power; PP, polypropylene; PPE, poly(phenylene ether); PP-g-MA, poly(propylene-graft-maleic anhydride); PPV, poly(p-phenylene-vinylene); PPY, polypyrolle; Pref, reflected power; PS, polystyrene; PUR, polyurethane; PVC, poly(vinyl chloride); PVDF, poly(vinylidene fluoride); PVOH, poly(vinyl alcohol); PVP, poly(vinylpyrrolidone); RAM, radar absorbing materials; RCS, radar cross section; RF, radio frequency; S, Siemens; SBR, styrene-butadiene rubber; SE, shielding effectiveness; SEA, shielding effectiveness by absorption; SER, shielding effectiveness by reflection; Sn, Tin; SWNT, single-walled carbon nanotube; VGCNF, vapor grown carbon nanofiber; VNA, vector network analyzer; wt%, Weight Percent; ε, dielectric constant; μ, permeability; σ, electrical conductivity.

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Contents

1. Introduction

Electromagnetic interferences (EMI) can be defined as conducted and/or radiated electromagnetic signals emitted by electrical circuits which, under operation, perturb proper operation of surrounding electrical equipments or cause radiative damage to living/biological species. The extensive development of gigahertz electronic systems and telecommunication devices has raised the electromagnetic pollution to a level never attained before, which justifies an active quest for novel and effective EMI shielding material solutions in a wide variety of applications. A large range of applications is concerned from commercial and scientific electronic instruments to antenna systems and military electronic devices. Another military application is stealth, devoted to the reduction of the detectability of target by canceling reflections of a radar signal incident to its surface. So-called Radar Absorbing Materials (RAM) can be processed under different forms: conductive paints or rubbers loaded with ferrite and/or carbon black particles were developed for stealth military planes by various countries (information is most often classified), while conductive foams and/or multilayered topologies are commonly used as liners for all enclosures in which reflection of waves has to be minimized, such as in anechoic chambers used as reference test environment for Electromagnetic Compatibility and ElectroMagnetic Interference (EMI) shielding certification measurements [1]. More generally, electromagnetic shielding is defined as the prevention of the propagation of electric and magnetic waves from one region to another by using conducting or magnetic materials. The shielding can be achieved by minimizing the signal passing through a system either by reflection of the wave or by absorption and dissipation of the radiation power inside the material.

Nowadays, the most common way to shield electrical circuits is by reflection owing to the use of metallic sheets. Such shielding is known since more than two centuries as the Faraday cage effect operating from DC to high frequency and based on the reorganization of electric charges in the shielding conductor in order to cancel the total electric field inside or outside the cage, depending on the position of the source. Faraday cage has no effect on magnetic field, but a similar shielding mechanism is obtained for the magnetic field at relatively low frequency when using a mu metal, that is a metal which has a very high relative permeability. As a consequence, such material is able to concentrate magnetic flux in the metal, preventing its expansion after the metal thickness [1]. Such solutions have the inconvenience of poor mechanical flexibility due to the high stiffness, high weight density, propensity to corrosion, and limited tuning of the shielding effectiveness (SE) [2]. Moreover, the electromagnetic pollution is not truly eliminated or mitigated since the electromagnetic signals are almost completely reflected at the surface of the metal sheets protecting the environment only beyond the shield. During the last two decades, a large amount of researches have been focused on the design of shielding materials which work by absorption, based on polymeric materials in order to take advantage of their lightness, low cost, easy shaping, etc. Nevertheless, most polymers possess intrinsic electrical insulating properties which make them almost transparent to electromagnetic waves. In order to circumvent this drawback, conductive nanoparticles are dispersed in appropriate concentrations within the insulating polymer matrix in order to induce the absorption of the radiation power via dissipation in the conductive particles while limiting the total reflection occurring at the surface.

Three main strategies have been investigated to process EM absorbing polymer based composites. The first one consists in the dispersion of metallic fillers, fibers [3–7] or nanoparticles [8–13] within a polymer matrix in order to increase the interaction with the electromagnetic radiation. Stainless steel fibers have been dispersed within polycarbonate [5], acrylonitrile-butadiene-styrene copolymer [14], polyphenylene ether (PPE) [4], and polypropylene [6] while the dispersion of copper fibers within an epoxy matrix has also been studied [3]. Bagwell et al. have shown that the smaller the fiber diameter, the higher the shielding effectiveness [3]. However, good dispersion, which is a