

Nanocomposites with Different Types of Nanofillers and Advanced Properties for Several Applications

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Polymer nanocomposites are an emerging technological field offering high-performance materials with unique and innovative properties, ideal for numerous advanced applications [1]. These include, among others, high-efficiency automotive and aerospace applications, food packaging, agriculture, printed electronics, biomedical applications, drug delivery, biotechnology, wastewater treatment, environmental protection, advanced energy-storage systems and electronic devices, gas/liquid barriers, fuel tanks, sensors, flammability reduction, chemical resistance, UV protective coatings, sports equipment, consumer goods, etc. [2–7]. The final properties of nanocomposites as well as their suitable applications directly depend on the polymer matrix used, the size and shape of the nanofillers, their functional groups, their amounts, their dispersion into the polymer matrix, and interfacial interactions [8]. The most effective properties are usually achieved when nanoscale fillers are added in small amounts, ranging from 0.5 up to 5 wt%. The individual properties of the nanofillers are also a crucial factor controlling the performance of the nanocomposites (improved mechanical strength, toughness, thermal stability, thermal conductivity, electrical properties, etc.) [9,10]. Some of these interesting applications of nanocomposites and their contribution to the enhancement of several polymer properties have been reported in the articles published in this Special Issue, along with descriptions of some new methods for nanocomposite production.

The addition of nanofillers improves the properties of nanocomposites and makes them more attractive than neat polymers. In Klonos et al.'s work, the effect of expandable graphite (EGr) at 5–55 wt % loading in the electrical and thermal conductivity of polystyrene (PS) and high-density polyethylene (HDPE) was evaluated [11]. From differential scanning calorimetry, it was found that the addition of EGr in PS can impose an increase in the glass transition temperature and a systematic decrease in the corresponding heat capacity change due to the formation of an interfacial rigid amorphous fraction (RAF). On the other hand, the presence of EGr in the highly crystalline HDPE matrix resulted in further elevation of the crystalline fraction (CF). Electrical conductivity (σ) values increase as the EGr amount increases for both matrices, up to 10^{-3} – 10^{-2} S/cm, resulting in a conductive percolation threshold for electrons at >8 wt % EGr. Simultaneously, the thermal conductivity (λ) of PS and HDPE were strongly increased, from 0.13 and 0.38 W·K⁻¹·m⁻¹ up to 0.55 and ~2 W·K⁻¹·m⁻¹, respectively. As can be seen, λ was systematically higher in HDPE than in PS, which was indicative of the additional contribution of HDPE crystals to heat transport.

In another recently published work, a face-centered cubic Ag nanoparticle (NP) was used to prepare a printable Ag ink, which was subsequently loaded in a user fillable pen and employed either by hand or by an in-house assembled printing machine to fabricate surface-enhanced Raman scattering (SERS) substrates [12]. Finite difference time-domain (FDTD) simulations showed a 155-times Ag NP electric field enhancement for Ag nanoparticle pairs with a particle spacing of 2 nm. By comparing the SERS substrate, made with different support matrices and fabrication methods, it was found that the poly(ethylene terephthalate) (PET)-printed substrate shows optimal performance, with an estimated sensitivity enhancement factor of 10^7 . These optimized SERS substrates show

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good stability (at least one month) and have been effectively tested in the detection of cancer drugs, including doxorubicin and metvan. Therefore, it was made clear that by using an inexpensive PET substrate printed with the Ag NPs ink through a scalable method, a highly sensitive, reproducible, and cost-effective method was developed to detect Raman active analytes on substrates with long-term stability.

Instead of using polymers as matrices, nanocomposites are also produced using nanoparticles or simple compounds. In such work, ZnO nanoparticles were mixed with three different drugs such as chloroquine, dipyrindamole, and lopinavir, and their chemical interactions were studied by molecular docking assay [13]. From the computational study, exergonic adsorption energies that ranged from 0.582 to 2.084 eV were obtained, which were dependent on the drug used. Lopinavir gave a higher energy adsorption, and a high occupied molecular orbital (HOMO) study demonstrated the electronic overlap between the ZnO-Np and the lopinavir, rendering it the most favored composite. That is because lopinavir contains N and O atoms on its structure, which promote binding with Zn metal. On the other hand, the binding energies demonstrate that the ZnO–chloroquine nanocomposite is the least favored, which can be due to the chloride group of the drug, which can change the electronic behavior of the entire system.

Another recent work demonstrated the feasibility of covert laser readable (CLR) surface structures as low-cost nanostructured flexible tags (n-CLRs) for tracking large-scale fabrication products [14]. The fabrication process of n-CLRs was described in detail. It combines a single lithography step of conventional metal coating to a single electrochemical step of template synthesis nanotechnology under ED masks and, finally, to the production of self-organized micro- and/or nanostructured surfaces. The study confirms that n-CLRs fulfil three rigorous criteria: marginal cost, simple identification, and numerous adjustable parameters.

Lately, it is also very common for several nanoparticles to be added in cosmetics. In such work, nanoadditives such as multiwall carbon nanotubes (MWCNTs), graphene oxide (GO), and lignin (LGN), in amounts of 0.5, 1, and 2% *w/v*, were used to enhance the antioxidant and UV stability of sunscreen emulsions [15]. All emulsions were prepared using the oil-in-water (O/W) technique and were pH- and viscosity-stable up to 90 days. It was found that emulsions containing LGN have excellent antioxidant properties, according to the 2,2-Diphenyl-1-picrylhydrazyl (DPPH) method, due to its phenolic groups. Additionally, the emulsions were evaluated for their ultraviolet (UV) radiation protection ability in terms of sun protection factor (SPF). It was reported that SPF values varied between 6.48 and 21.24 while the emulsion containing 2% *w/v* MWCNT showed the highest SPF index. Furthermore, UV irradiation tests showed that all emulsions exhibit great UV stability after 24 and 72 h of exposure. The overall results presented in this work could further expand the usage of organic additives in cosmetic applications in order to enhance some of their properties.

As described before, nanoparticle characteristics are essential to the process of tuning the polymer matrix properties, and for this reason, their production is of high importance. Likewise, the fabrication of different kinds of nanoparticles is also of great interest. In this sense, a new simple method for preparing confined copper and nickel nanoparticles by thermal treatment of their respective cations inside Mobil Composition of Matter 41 (MCM-41) hydrophobic nanopores was recently been developed [16]. Surface-modified MCM-41 hydrophobic materials were impregnated with copper II (Cu II) or nickel II (Ni II) aqueous solutions via a high-pressure treatment. After pressure release and washing, the remaining metal cations, confined exclusively within the nanopores, were heated, forming metallic nanoparticles. Fourier transform infrared (FTIR) and transmission electronic microscopy (TEM) evidenced the identification of copper and nickel spherical nanoparticles (NPs). Additionally, it was found via microscopy images that the NP was larger than the pores, suggesting that the NPs pushed through the pore wall.

All of the above work verify the advantages of nanocomposites in several applications as well as the benefits of using nanoparticles to reinforce the properties of polymer matrices.

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