

Emerging polymer-based nanocomposites

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Introduction

Polymer-based nanocomposites have received considerable interest in research for the last three decades. Besides improving the properties of parent polymer, the addition of low content of organic or inorganic nanofillers provides new properties to the nanocomposite material while maintaining almost the same processing properties as the starting polymers. Furthermore, the high surface/volume ratio of nanofillers and the interaction between polymer matrix and nanofiller at the molecular level leads to phase interfaces and notable changes in mechanical, optical, electrical properties, etc.¹ Therefore, polymer-based nanocomposites can potentially replace existing materials in different fields such as automotive and transportation,² biomedical,³ energy storage and generation,⁴ electronics,⁵ construction,⁶ piping,⁷ intelligent coatings,⁸ and environmental protection.⁹

Polymer-based nanocomposites represent one of the hottest topics in polymer technology with many application fields. Figure 1 shows the distribution of the scientific articles on polymer nanocomposites among the most crucial application fields in the last decade. Almost half of these application fields are covered by the energy, coatings, environment, sensors, biomedical, packaging, and aerospace sectors. More interesting, the temporal distribution of the scientific publications demonstrates a continuous growth trend reflected in this Special Collection on *Emerging polymer-based nanocomposites*.

Among the multifunctional properties of polymer-based nanocomposites are included anticorrosive, antibacterial, self-cleaning, and eco-friendly effects, which play a prominent role for surface treatments in the contribution of superior physical effects in products.

These outstanding properties are achieved when organic or inorganic materials at the nanoscale (nanofillers) are incorporated into polymer matrices. Figure 2 shows the most used nanofillers and polymer matrices in the last decade to prepare polymer nanocomposites among the different application fields. For example, in the case of nanofillers, carbon nanostructures such as carbon nanotubes, graphite, and graphene are primarily used in sensors and energy sectors. Also, metal nanoparticles such as silver and gold nanoparticles are primarily used in the biomedical sector. On the other hand, in the case of polymer matrices, biodegradable polymers such as cellulose, polylactic acid (PLA), and chitosan have relevance in the packaging and biomedical sectors.

Despite the infinite potential applications, the manufacturing of nanocomposites has still to overcome several challenges for an effective transition from macro-scale to the nanoscale. For example, a robust interdisciplinary interaction between scientists and engineers is still necessary to understand and optimize the structure-process-properties relationships, achieve a simpler and effective particle exfoliation and dispersion,¹⁰ and reduce manufacturing costs using more compostable and biodegradable polymers.

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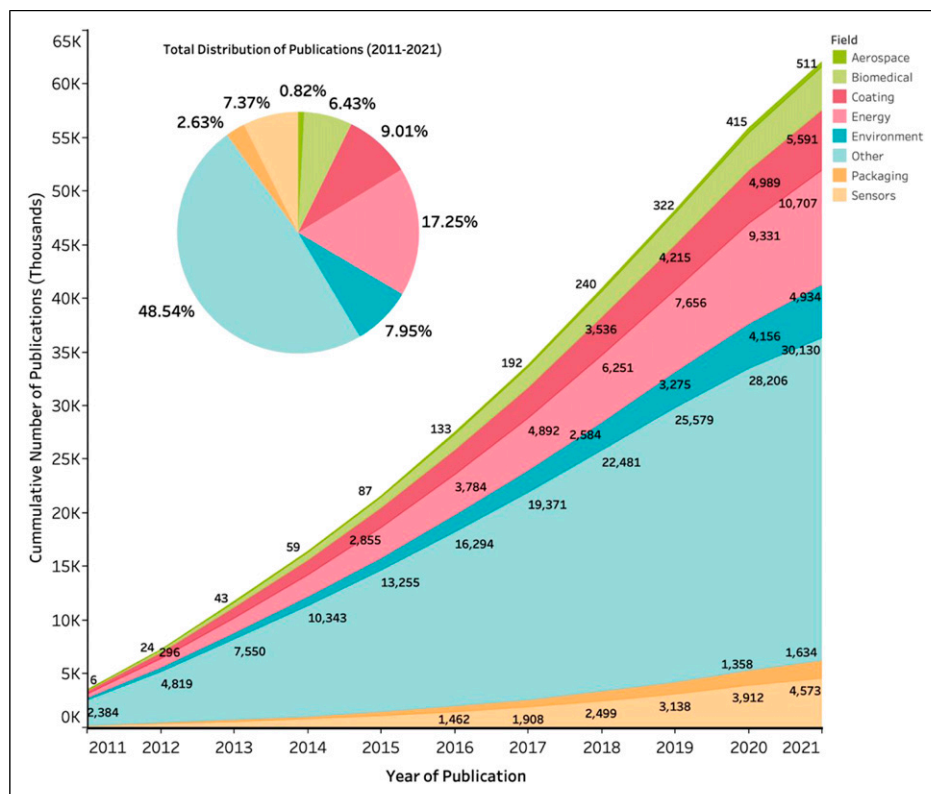


Figure 1. Trends in scientific publications on polymer nanocomposites and their distribution among the different application fields in the last decade (2011–2021). (Source data: Web of Science database accessed in November 2021).

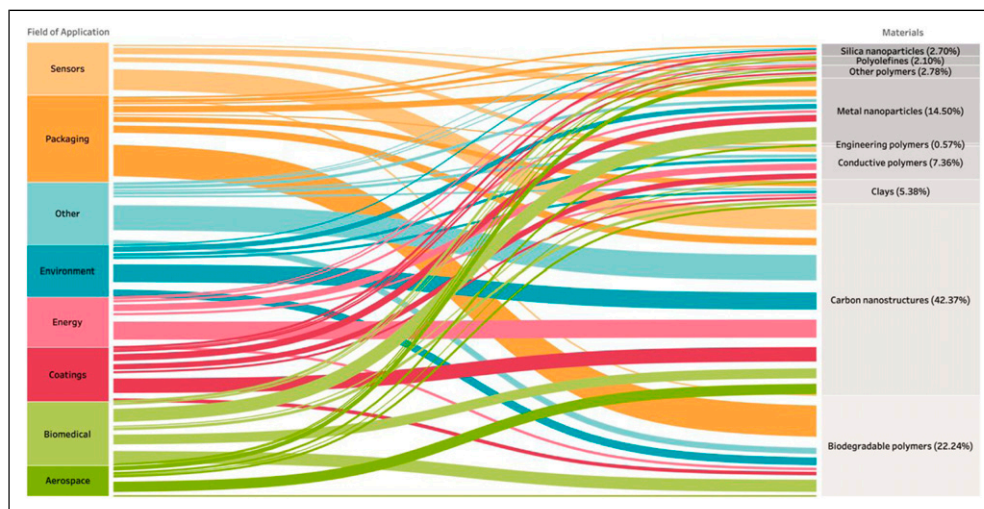


Figure 2. The flow of nanostructured materials and polymer matrices to prepare polymer nanocomposites for different application fields in the last decade (2011–2021). Thicker lines indicate a high relevance in the field of application. (Source data: Web of Science database accessed in November 2021).

This Special Collection was prepared during the coronavirus disease (COVID-19) pandemic, a situation that has changed all aspects of our lives. During this time, many research and academic activities were suspended. However, it has led to

thinking about how we can provide solutions for a healthy, safe, and more resilient society facing complex challenges to achieve a sustainable future. In this context, the role of polymer-based nanocomposites is of strategic importance.

The Special Collection on *Emerging polymer-based nanocomposites* collects eight research articles on the development and characterization of polymer-based nanocomposites in different fields encompassing chemistry, physics, biology, materials science, and engineering to highlight the latest achievements in this research field.

Contributions

The COVID-19 pandemic has made us more conscious about healthy eating habits, the quality of personal healthcare products, and how products are made.¹¹ This special issue contains various interesting articles that cover these issues. For example, docosahexaenoic acid (DHA), an omega-3 fatty acid present in fish oils, is known to have a protective effect against diseases including hypertension, myocardial infarction, Alzheimer's disease, and cancers. Usually, soft-gel capsules are the most common product formulation of DHA-containing fish oil; however, poor bioavailability owing to limited aqueous solubility limits its effective therapeutic delivery. The article titled "Formulation design and pharmacokinetic evaluation of docosahexaenoic acid containing self-nanoemulsifying drug delivery system for oral administration," presented by Alhakamy et al.,¹² presents a novel development of anhydrous nanoemulsions (without aqueous phase) using low-energy methods. These nanoemulsions comprise ultrafine droplets of DHA-containing fish oil and a mixture of surfactants and cosurfactants. This article relates how selected nanoemulsions can be diluted in gastric fluids, improving oral absorption and bioavailability.

During the hard times of the COVID-19 pandemic, as medical efforts focused on treating affected patients and protecting others from infection, the attention in hospitals of people with non-COVID-19-related diseases, such as cancer and diabetes, among others, was seriously compromised. This tragic experience showed that developing more efficient and prolonged drug-delivery systems are needed. The article "Preparation, characterization, and in vitro evaluation of amphiphilic peptide P12 and P12-DOX nanomicelles as antitumor drug carriers," presented by Song et al.,¹³ relates the synthesis of polymerized amphiphilic polypeptide nanomicelles as a novel carrier for doxorubicin (DOX), an antitumor antibiotic. DOX is chemically unstable; poorly soluble in water; and prone to hydrolysis, photolysis, and other changes, seriously limiting its clinical application and treatment efficacy. The polymerized polypeptide allows a higher drug-loading ratio, showing sensitivity to acid conditions like the acidic internal environment of tumor cells. Laser confocal microscopy surprisingly demonstrates the uptake of P12-DOX nanomicelles by tumor cells and normal cells.

On the other hand, the article "Dispersion of chitosan nanoparticles stable over a wide pH range by adsorption of

polyglycerol monostearate," presented by Kim et al.,¹⁴ describes the development of stable chitosan colloids by pulverization of bulk chitosan powder. Chitosan is a biodegradable cationic polymer as a carrier matrix for food ingredients and drug delivery; however, its poor solubility at a physiological pH limits its use in pharmaceutical and cosmetic applications. The authors of this article develop a novel mechanochemical modification of chitosan to obtain chitosan colloids stable even in an alkali solution and thermal stability upon storage at 50°C.

The abrupt changes in the global market and economic activities have invited us to reflect on the role of polymer nanocomposites in the post-COVID-19 society, particularly in the way materials are made. Various types of polymer nanocomposites are produced using fillers brought from other regions. The lockdown measures adopted to contain the COVID-19 pandemic have severely impacted import and export trade services. This situation has exposed the importance of using local raw materials as much as possible, encouraging the study of local sources and establishing local supply chains. The article "Comparative analysis of crystallization behavior induced by different mineral fillers in polypropylene nanocomposites," presented by Castillo and Barbosa,¹⁵ shows a detailed study on crystallization behavior of nanocomposites using talc from Australia and Argentina (with different origin and genesis), as well as sepiolite from Spain and Argentina. The authors found that talc from different origins and genesis present differences in nucleating capability, producing distinct morphological and thermal properties in a polypropylene matrix. This study demonstrates that mineral fillers from different regions can accomplish specific requirements for local industries.

The COVID-19 pandemic has pushed antimicrobial and photocatalytic coatings into the spotlight. During this confinement, household rooms became spaces for work rather than resting or playing. Hence, this trend brought the development of particular consumer preferences towards functional paints, aimed at developing a sense of well-being and safety. The article "Preparation of modified paints with nanostructured additives and its potential applications" presented by Solano et al.¹⁶ proposes a green ultrasound-assisted chemistry methodology using lemongrass extract to synthesize TiO₂ and ZnO nanoparticles with excellent morphological, optical, antimicrobial, anticorrosive, and photocatalytic properties. These nanofillers have been successfully used to give antibacterial, anticorrosive, and self-cleaning properties to commercial paints for metals, wood, and textiles. Anticorrosive properties are essential for the fabrication of paints, aimed at protecting structures exposed to chemical or electrochemical corrosion due to the pollution and marine atmosphere in large populated and coastal areas.¹⁷ Furthermore, through the photocatalytic activity of nanofillers, high hydrophobicity and self-cleaning ability

may reduce surface contamination by degrading pollutants to improve the quality and appearance of the structural surface.

The unprecedented pandemic crisis has made us realize with great force that climate and environmental challenges remain the primary threat to our planet and humanity as a whole. The clean hydrogen sector is approaching the pre-commercialization phase. It will play an essential role in decarbonizing our economies, enabling the realization of climate, environmental, and economic development goals. Developing low-cost and highly active fuel cells is one of the high-priority research directions for fuel cell commercialization, whereas durable electrodes and electrolyte membranes are keys for their optimization.¹⁸

The article “Novel nanocomposite membranes based on cross-linked eco-friendly polymers doped with sulfated titania nanotubes for direct methanol fuel cell application,” presented by Gouda et al.,¹⁹ describes a green alternative polyelectrolyte membrane for fuel cell application. The membrane is based on an eco-friendly polymer blend of poly (vinyl alcohol) (PVA) and iota carrageenan (IC) nanofilled with sulfated titania (SO₄TiO₂) nanotubes. The nanocomposite membrane exhibits a reduction in water and methanol uptake and increased thermal and oxidative stability compared to the undoped membrane and commercial Nafion membrane.

Polymer-based nanocomposites find novel applications in embedded sensors that can attract a tremendous technological interest for applications in various industrial sectors such as transportation, construction, and building. The article “Strain gauge properties of Pd⁺-ion-implanted polymer” presented by Di Benedetto et al.²⁰ describes the synthesis of metal-carbonaceous-polymer nanocomposites by palladium ion implantation in four different thermoplastic polymers: polymethyl methacrylate, polypropylene, polyethylene terephthalate glycol-modified, and polycarbonate. The ion implantation leads to forming a nanocomposite thin surface layer constituted by Pd nanoclusters embedded in a nanographite/amorphous carbon matrix. This nanocomposite layer is stable in time and adheres well on the polymer surface, increasing electrical conductivity and an extraordinary and linear electrical resistivity change by elastic deformation. By characterizing the strain gauge properties of the nanocomposite surface layers, gauge factors between 4 and 8, depending on the polymer kind, have been obtained.

Recently, carbon-based rubber nanocomposites reinforced with a low-volume fraction of nanofillers have attracted great interest due to the significant improvement in their overall mechanical and morphological properties. The article “Resistance-strain sensitive rubber composites filled by multiwalled carbon nanotubes for structure deformation monitoring” presented by Liu et al.²¹ describes multiwalled carbon nanotube/natural rubber composites with increased resistance-strain sensitivity prepared by the solution method. The composite is characterized by excellent electrical sensitivity (GF > 27) and large strain range (strain > 200%). It is

suited to application in strain monitoring of large deformation structures since the resistance-strain response is more stable when strain exceeds 100%. Analytical models based on tunneling and hopping effect have also been developed to investigate the resistance-strain sensing behavior.

Beyond what we can imagine, the advances in emerging polymer-based nanocomposites can help us improve our daily lives, facing new challenges for this post-COVID-19 society.

The Guest Editors are confident that this Special Collection of articles will benefit a large community in research and application of polymer nanocomposite materials to further advance along the pathway toward sustainability, performance, and competitiveness.

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