Progress in Polymer Science 80 (2018) 1–38

Contents lists available at ScienceDirect

Progress in Polymer Science

journal homepage: www.elsevier.com/locate/ppolysci

Recent advances and remaining challenges for polymeric nanocomposites in healthcare applications

Sandeep Kumar[a,*], Sarita[a], Monika Nehra[a,b], Neeraj Dilbaghi[a], K. Tankeshwar[a,c], Ki-Hyun Kim[d,**]

[a] Department of Bio and Nano Technology, Guru Jambheshwar University of Science and Technology, Hisar, Haryana, 125001, India
[b] Department of Electronics and Communication Engineering, Guru Jambheshwar University of Science and Technology, Hisar, Haryana, 125001, India
[c] Department of Physics, Panjab University, Chandigarh, 160014, India
[d] Department of Civil & Environmental Engineering, Hanyang University, 222 Wangsimni-Ro, Seoul 04763, Republic of Korea

ARTICLE INFO

Article history:
Received 14 August 2017
Received in revised form
12 November 2017
Accepted 20 March 2018
Available online 23 March 2018

Keywords:
Polymer nanocomposite

ABSTRACT

Remarkable advancements in material technologies have accelerated the use of many new materials and their hybrids and composites in diverse applications. Among such available options, polymer nanocomposites are recognized to have the potential to bring future revolution, especially because of their flexible functionalities and related advantages (e.g., good strength, large surface area to volume ratio, large flame retardancy, high elastic modulus, enhanced density, and thermo-mechanical/optoelectronic/magnetic properties). These nanocomposites have been successfully incorporated into diverse fields of applications such as drug delivery, tissue engineering, gene therapy, food preservation, biosensing, and bioimaging. Thus, the primary focus of this review is placed to give an integrated overview of polymer nanocomposites

Abbreviations: AG, agarose; AIs, active ingredients; AP, aminopyrene; AGET, activators generated by electron transfer; AgNPs, silver nanoparticles; ATRP, atom transfer radical polymerization; AuNPs, gold nanoparticles; *B. subtilis*, *Bacillus subtilis*; BD, bismaleimide; BG, bioactive glass; BGLs, blood glucose levels; BMP, bone morphogenic protein-2; *C. jejuni*, *Campylobacter jejuni*; CAGR, compound annual growth rate; CCDP, 2-chloro-30,40-dihydroxyacetophenone; CD, α-cyclodextrin; CG-VV-PRN-LDH, chitosan-glutathione-valine-valine-pirenoxine sodium-layered double hydroxides; CL, chemiluminescence; CLPE, cross-linked polyethylene; CNTs, carbon nanotubes; CT, computed tomography; CTAB, cetyltrimethylammonium bromide; CTCs, circulating tumor cells; DMBIM, 5,6-dimethylbenzimidazole; DPED, diphenylethylenediamine; DSS, disuccinimidyl suberate; *E. coli*, *Escherichia coli*; ECM, extra cellular matrix; EMI, electromagnetic interference; EOC, expanded organoclay; Eos, essential oils; EVOH, ethylene-vinyl alcohol; FDA, food and drug administration; FI, fluorescence imaging; FL, fluorescence; FTIR, fourier transform infrared spectroscopy; GA, gallic acid; GCE, glassy carbon electrode; GONS, graphene oxide nanosheets; GOx, glucose oxidase enzyme; GSH, glutathione; HA, hydroxyapatite; HBCs, hyperbranched chitosan; HEMA-MAC, hydroxyethyl methacrylate methacryloyl-L-cysteine methyl ester; HF, hydrofluoric; HM-HPMC, hydrophobically modified-hydroxypropyl methylcellulose; HMME, hematoporphyrin monomethyl ether; hMSCs, human mesenchymal stem cells; HNTs, halloysite nanotubes; HPAEK, hyperbranched poly(aryl ether ketone); HPMC, hydroxypropyl methylcellulose; HPC, high performance concrete; HMW, high molecular weight; IL-CPE, ionic liquid-carbon paste electrode; KC-PPyAuNPs, kappa-carrageenan-polypyrrole-gold nanoparticles; *L. monocytogenes*, *Listeria monocytogenes*; LCP, liquid crystalline polymers; LDHs, layered double hydroxides; LDPE, low-density polyethylene; LMW, low molecular weight; MFH, magnetic fluid hyperthermia; MIP, molecularly imprinted polymer; MMT, montmorillonite; MnTPP, manganese tetraphenyl porphyrin; MPEG, monomethoxy polyethylene glycol; MR, magnetic resonance; MRI, magnetic resonance imaging; MWCNTs, multi-walled carbon nanotubes; *P. aeruginosa*, *Pseudomonas aeruginosa*; PA, polyamide; PAHs, polycyclic aromatic hydrocarbons; PAM, polyacrylamide; PAMAM, polyamidoamine; PANI, polyaniline; PBAT, poly(butlene adipate-co-terephthalate); PBE, poly(Bisphenol A-co-epichlorohydrin); PC, polycarbonate; PCA-HPAEK, carboxylic-functionalized hyperbranched poly(aryl ether ketone); PCL, poly(ε-caprolactone); PCGA, poly(ε-caprolactone-co-glycolic acid); PDA, polydopamine; PDLLA, poly(D,L-lactide); PDMAEA, poly(2-(dimethylamino) ethyl acrylate); PDMAEMA, poly[(dimethylamino)ethyl methacrylate]; PDMS, polydimethylsiloxane; PE, polyethylene; PEA/PAN/CB, polyethlene/polyaniline/carbon black; PEI, polyetherimide; PEG, polyethylene glycol; PEGMA, poly(ethylene glycol) methacrylate; PEM, patterned electrospun membrane; PET, poly(ethylene terephthalate); PEVA, poly(ethylene-co-vinyl acetate); PFA, polyfurfuryl alcohol; PFV, polyfluorene-vinylene; PgL, polyaniline grafted to lignin; PLA, poly(lactic acid); PLA-b-p(MAA-PBA), poly(L-lactide)-b-poly(methacrylic acid-co-phenylboronic acid); PLGA, poly(D,L-lactide-co-glycolide); PLL, poly(L-lysine); PLLA, poly-L-lactic Acid; PMAA, poly(methacrylic acid); PMMA, poly (methylmethacrylate); PMMA–BSA, poly(methyl methacrylate)–bovine serum albumin; PMPC, poly(2-methacryloyloxyethyl phosphorylcholine); PNIPAM, poly(N-isopropylacrylamide); P(NIPAM-co-AAD), poly(*N*-isopropylacrylamide-*co*-acrylic acid); P(NIPAm-*co*-MAA), poly[(N-isopropylacrylamide)-*co*-(methacrylic acid)]; POC, point of care; Poly(HEMA-MAC), poly (hydroxyethyl methacrylate methacryloyl-L-cysteine methyl ester); POP, polymer optical preform; POSS, polyhedral oligomeric silses-quioxanes; PP, pure polyethylene; PPA, poly(pyrrole propylic acid); pPANI, plasma polyaniline; PPF, poly(propylene fumarate); PS, polystyrene; PS-PDMS, polystyrene-block-poly(dimethylsiloxane); PSAN, poly (styrene-*co*-acrylonitrile); PtNPs, platinum nanoparticles; PVA, poly(vinyl alcohol); PVB, polyvinyl butyral; PVC, poly(vinyl chloride); PVDF, poly(vinylidene fluoride); $PVF^{+}ClO4^{-}$, polyvinylferrocenium perchlorate; PyOx, pyranose oxidase; PVP, polyvinylpyrrolidone; P4VP, poly(4-vinylpyridine); QCS, quaternized chitosan; QDs, quantum dots; RAFT, reversible addition-fragmentation chain transfer; RGD, Arg-Gly-Asp; rGO, reduced graphene oxide; RNA, ribonucleic acid; *S. aureus*, *Staphylococcus aureus*; SBS, poly(styrene-butadiene-styrene); SI-ATRP, surface initiated atom transfer radical polymerization; SIP, surface-imprinted; SMAh, poly(styrene-co-maleic anhydride); SPCE, screen-printed carbon electrode; SPE, screen printed electrode; SPECT, single photon emission computed tomography; SPR, surface plasmon resonance; TC, tetracycline; TEM, transmission electron microscopy; THA, total hip arthroplasty; ThermoDOX, doxorubicin; TNB, trinitrobencene; UA, uric acid; UCL, upconversion luminescence; UHMWPE, ultra-high molecular weight polyethylene; UPE, unsaturated polyester; XPAA, cross-linkable poly(acrylic acid).

* Corresponding author.
** Corresponding author.
E-mail addresses: ksandeep36@yahoo.com (S. Kumar), kkim61@hanyang.ac.kr (K.-H. Kim).

https://doi.org/10.1016/j.progpolymsci.2018.03.001

Biomedical application
Biosensing
Bioimaging

along with their synthesis routes, surface treatment strategies, and applications in the healthcare sector (e.g., drug delivery, 3D bio-implant, bioimaging, food processing, and other miscellaneous biomedical applications). Our discussion also highlights future directions for this emerging field of research.

Contents

1. Introduction

At present, nanotechnology is flourishing in all disciplines of science and engineering. Nanomaterials and nanocomposites have been introduced in diverse applications, including medicine, food packaging, tissue engineering, cosmetics, textiles, agriculture, optoelectronic devices, automotive industries, and aerospace engineering. Nanocomposites are popular at both the academic and industrial levels due to their unusual properties, unique design capacity, eco-friendly nature, easy fabrication, and cost-effectiveness. The incorporation of nanoparticles into a matrix of particular materials (either polymer, metal, or ceramics) further upgrades their novel properties such as excellent mechanical stability (in terms of strength, toughness, flexibility, Young's modulus, dimension stability, etc.), good optical features, flame retardancy, low water/gas permeability, and high electro-thermal conductivity.

Basically, nanocomposites are multiphase solid materials, embedding one material with reinforcing phases (involving diverse forms such as particles, sheets, and/or fibers) into other materials [1]. The properties of the nanocomposites are prominently dependent on the toughness of the matrix and the potency of the reinforcement [2]. Among the different nanocomposites, polymer nanocomposites have attracted significant interest of numerous researchers in the healthcare sector because of their significant potential to advance engineering applications. The properties of polymer nanocomposites are derived from the type of nanomaterials that are dispersed into the polymer matrix including the concentration, size, shape, and interaction of nanomaterials with the polymer matrix [3–5]. The polymer nanocomposites have thus been utilized in diverse applications such as waste water treatment [6,7], tissue engineering [8], electrochemical sensors [9,10], drug delivery [11,12], food processing [13], transparent thin films [14,15], and biomedical applications [16,17].

With the recent development in nanotechnology, the potent role of nanomaterials has been explored widely in various fields such as electrochemical sensing applications for the detection of a variety of analytes including heavy metal ions [18–21]. In this respect, the polymer nanocomposites-modified electrodes offered unprecedentedly low detection limits (or high sensitivity) as well as good selectivity for diverse analytes (e.g., cadmium, lead, arsenic, and mercury) [22,23]. Along with such sensing applications, the nanocomposites are also found to be very promising for the effective removal of various pollutant species. Because of many outstanding features (such as large surface area, free adsorption sites, good interfacial reactivity of nanofillers, and outstanding physical/mechanical properties), their enhanced capabilities are also recognized for effective removal of heavy metals and metalloids,