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Surface modification of inorganic nanoparticles for development of organic–inorganic nanocomposites—A review

Sarita Kango^a, Susheel Kalia^{b,c,*}, Annamaria Celli^b, James Njuguna^d, Youssef Habibi^e, Rajesh Kumar^a

^a Department of Physics and Materials Science, Jaypee University of Information Technology, Wanknaghat 173234, Dist. Solan, H.P., India

^b Department of Civil, Chemical, Environmental and Materials Engineering, University of Bologna, Via Terracini 28, 40131 Bologna, Italy

^c Department of Chemistry, Bahra University, Wanknaghat (Shimla Hills) 173234, Dist. Solan, H.P., India

^d School of Applied Sciences, Cranfield University, Cranfield, Bedford MK43 0AL, United Kingdom

^e Laboratory of Polymeric & Composite Materials, University of Mons, Place du Parc, 20 B-7000 Mons, Belgium

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ABSTRACT

Nanoparticles and nanocomposites are used in a wide range of applications in various fields, such as medicine, textiles, cosmetics, agriculture, optics, food packaging, optoelectronic devices, semiconductor devices, aerospace, construction and catalysis. Nanoparticles can be incorporated into polymeric nanocomposites. Polymeric nanocomposites consisting of inorganic nanoparticles and organic polymers represent a new class of materials that exhibit improved performance compared to their microparticle counterparts. It is therefore expected that they will advance the field of engineering applications. Incorporation of inorganic nanoparticles into a polymer matrix can significantly affect the properties of the matrix. The resulting composite might exhibit improved thermal, mechanical, rheological, electrical, catalytic, fire retardancy and optical properties. The properties of polymer composites depend on the type of nanoparticles that are incorporated, their size and shape,

Abbreviations: ABS, Acrylonitrile butadiene styrene; AIBN, 2,2'-azobisisobutyronitrile; AM, Acrylamide; APS, Aminopropyltrimethoxysilane; APTES, 3-aminopropyltriethoxysilane; APTMS, 3-aminopropyltrimethoxysilane; ATCC, American-type culture collection; BA, Butyl acrylate; CLIO, Crosslinked iron oxide nanoparticles; CTE, Coefficient of thermal expansion; DBSA, Dodecylbenzene sulfonic acid; DMA/DMTA, Dynamic-mechanical analysis /Dynamic mechanical thermal analysis; DNA, Deoxyribonucleic acid; DSC, Differential scanning calorimetry; DTA, Differential thermal analysis; GC, Glycol chitosan; HDA, Hexadecylamine; ICP-MS, Inductively coupled plasma mass spectrometry; IPTMS, 3-Isocyanatopropyltrimethoxysilane; LEDs, Light-emitting diodes; LDPE, Linear low density polyethylene; MAA, Methacrylic acid; MION, Monocrystalline iron oxide nanoparticles; MMA, Methyl methacrylate; MNPs, Magnetic nanoparticles; MPC, 2-methacryloyloxyethyl phosphorylcholine; MPS, 3-(trimethoxysilyl)propyl methacrylate; MRI, Magnetic resonance imaging; Ms, Saturation magnetization; MTX, Methotrexate; NMR, Nuclear magnetic resonance; NPs, Nanoparticles; OA, Oleic acid; PA 6,6, Polyamide 6, 6; PAAM, Polyacrylamide; PANi, Polyaniline; PBA, Polybutylacrylate; PC, Polycarbonate; PCEs, Power conversion efficiencies; PCL, Polycaprolactone; PCL-g-AA, Acrylic acid grafted polycaprolactone; PEG, Polyethylene glycol; PEGMA, Polyethylene glycol methacrylate; PEN, Poly(ethylene 2,6-naphthalate); PET, Polyethylene terephthalate; PHEA, Poly(hydroethyl acrylate); P3HT, Poly(3-hexylthiophene); PI, Polyimide; PINCS, Polymer inorganic nanocomposites; PMMA, Poly(methyl methacrylate); PP, Polypropylene; PPG, Poly(propylene glycol); PPGMA, Poly(propylene glycol) methacrylate; PPS, Polyphenylene sulphide; PPy, Polypyrrole; PS, Polystyrene; PTES, n-propyltriethoxysilane; PU, Polyurethane; PVA, Poly(vinylalcohol); PVP, Polyvinyl pyrrolidone; QDs, Quantum dots; RI, Refractive index; RNA, Ribonucleic acid; SI-ATRP, Surface-initiated atom transfer radical polymerization; SMA, Styrene-maleic anhydride copolymer; Spp, Syndiotactic polypropylene; SPR, Surface plasmon resonance; TEM, Transmission electron microscopy; TEOS, Tetraethoxysilane; TG, Glass transition; TGA, Thermogravimetric analysis; TGA-MS, Thermogravimetric analysis-mass spectrometry; THF, Tetrahydrofuran; TLI RP, Thiol-lactam initiated radical polymerization; TMA, Thermomechanical analysis; TOPO, Trioctylphosphine oxides; TTIP, Tetra isopropyl ortho titanate; UV, Ultra violet; VTES, Triethoxyvinylsilane.

* Corresponding author at: Department of Chemistry, Bahra University, Wanknaghat 173234, Dist. Solan, H.P., India. Tel.: +91 9418604948; fax: +91 1792 247462.

E-mail addresses: susheel.kalia@gmail.com, susheel.kalia@yahoo.com (S. Kalia).

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their concentration and their interactions with the polymer matrix. The main problem with polymer nanocomposites is the prevention of particle aggregation. It is difficult to produce monodispersed nanoparticles in a polymer matrix because nanoparticles agglomerate due to their specific surface area and volume effects. This problem can be overcome by modification of the surface of the inorganic particles. The modification improves the interfacial interactions between the inorganic particles and the polymer matrix. There are two ways to modify the surface of inorganic particles. The first is accomplished through surface absorption or reaction with small molecules, such as silane coupling agents, and the second method is based on grafting polymeric molecules through covalent bonding to the hydroxyl groups existing on the particles. The advantage of the second procedure over the first lies in the fact that the polymer-grafted particles can be designed with the desired properties through a proper selection of the species of the grafting monomers and the choice of grafting conditions.

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1. Introduction

Development of organic–inorganic nanocomposites, often achieved by grafting synthetic polymers on inorganic particles or by adding modified nanoparticles (NPs) into polymer matrices, is intended to produce composite materials with improved mechanical and other properties. Nanocomposites made up of inorganic nanoparticles and organic polymers represent a new class of materials that exhibit improved performance when compared with their microparticle counterparts [1]. Surface modification of inorganic nanoparticles has attracted a great deal of attention because it produces excellent integration and an improved interface between nanoparticles and polymer matrices [2–5].

Polymer matrices reinforced with modified inorganic nanoparticles combine the functionalities of polymer matrices, which include low weight and easy formability, with the unique features of the inorganic nanoparticles. The nanocomposites obtained by incorporation of these types of materials can lead to improvements in several areas, such as optical, mechanical, electrical, magnetic, rheological, and fire retardancy properties [6,7]. However, the nanoparticles have a strong tendency to undergo agglomeration followed by insufficient dispersal in the polymer matrix, degrading the optical and mechanical properties of the nanocomposites [8,9]. To improve the dispersion stability of nanoparticles in aqueous media or polymer matrices, it is essential that the particle surface modification involving polymer surfactant molecules or other

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