



Irradiation applications for polymer nano-composites: A state-of-the-art review



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ABSTRACT

In recent years, irradiation treatment has emerged as a popular technique for modification of nanostructures in fabrication of high performance polymer composites. The conventional modification methods typically involve expensive chemicals, difficult processing techniques and specialized chemistry. However, the irradiation treatment is considered simple, rapid and “green” technique that operates under ambient conditions and the product is free of residual initiators and modifiers. Such modifications develop strong interfacial matrix-nanostructure interactions and exhibit notable advantages as compared to chemical approaches. High energy radiations have beneficial effects for tailoring structure and properties of nano-systems with high precision. The irradiation processes, mechanisms, strategies and composites are reviewed in this article along with the potential applications and future challenges.

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Introduction

Study of interaction of radiations with materials has always been a popular scientific research domain. Broadly radiations can be classified as ionizing and non-ionizing depending on their ability to ionize materials. The ionization potential of isolated atoms ranges from a few eV for alkali elements to 24.6 eV for noble

gases [1]. Ionizing radiation can interact with material directly or indirectly and carry enough energy to ionize the medium it passes through. While non-ionizing radiation cannot ionize material due to its low ionizing potential. Fig. 1 presents the classification of radiations.

Irradiation treatment of reinforcement can be categorized into three general classes depending on the treatment stage: (a) pre-composite irradiation (b) irradiation grafting of nanostructures (c) post-composite irradiation. Nanostructures can be irradiated prior to their incorporation into polymer matrix. This treatment aims at modification of the surface and structural morphology of nanostructures. In second category, the nanostructures can be grafted with various modifier reagents or monomers under irradiation. The grafted nano-structures exhibit improved interactions with polymer matrices, and hence final composites are prepared with improved properties. The post-irradiation of reinforced composites is also found very interesting due to characteristics behavior of nanostructure within polymer matrices in nanocomposites under irradiation.

Pre-composite irradiation of nanostructures

Some non-functionalized nanostructures like carbon nanotubes (CNTs) and graphene show poor dispersion into polymer matrix due to stacking, agglomeration and other phenomenon. The poor polymer-filler interactions also limit the performance of filler

Abbreviations: AFM, atomic force microscopy; BET, Brunauer Emmer Teller; CB-D, chain breaking electron donor; CE, cyanate ester; CNTs, carbon nanotubes; CV, cyclic voltammetry; DNA, deoxyribonucleic acid; EA, elemental analysis; EB, electron beam; EIS, electrochemical impedance spectroscopy; EVA, ethylene-vinyl acetate; FE-SEM, field emission scanning electron microscopy; FTIR, Fourier transform infrared spectroscopy; GCD, galvanostatic charge discharge; GDVDP, glow discharge vapor deposition polymerization; HA, hydroxyapatite; HDPE, high density polyethylene; HPCS, allyl hydrido polycarbosilane; LDPE, low density polyethylene; MMT, montmorillonite; MWCNTs, multi-walled carbon nanotubes; NIR, near infrared; P(NMP), poly(*n*-methylpyrrole); P(Py), poly(pyrrole); PAN, polyacrylonitrile; PAN, polyacrylonitrile; PANI, polyaniline; PCL, polycaprolactone; PE, polyethylene; PEDOT, poly(3,4-ethylenedioxythiophene); PEO, polyethylene oxide; PET, polyethylene terephthalate; PMMA, poly(methyl methacrylate); PP, polypropylene; PSS, polystyrene sulfonate; PVA, polyvinyl alcohol; PVB, polyvinyl butyral; PVdF-HFP, poly(vinylidene fluoride-hexafluoropropylene); PZT, lead zirconate titanate; SHI, swift heavy ion; SM, Southern Michigan; SWCNTs, single walled carbon nanotubes; TEM, transmission electron microscopy; TGA, thermogravimetric analysis; UHMPE, ultra high molecular weight polyethylene; UV, ultraviolet; XPS, X-ray photoelectron spectroscopy; XRD, X-ray diffraction.

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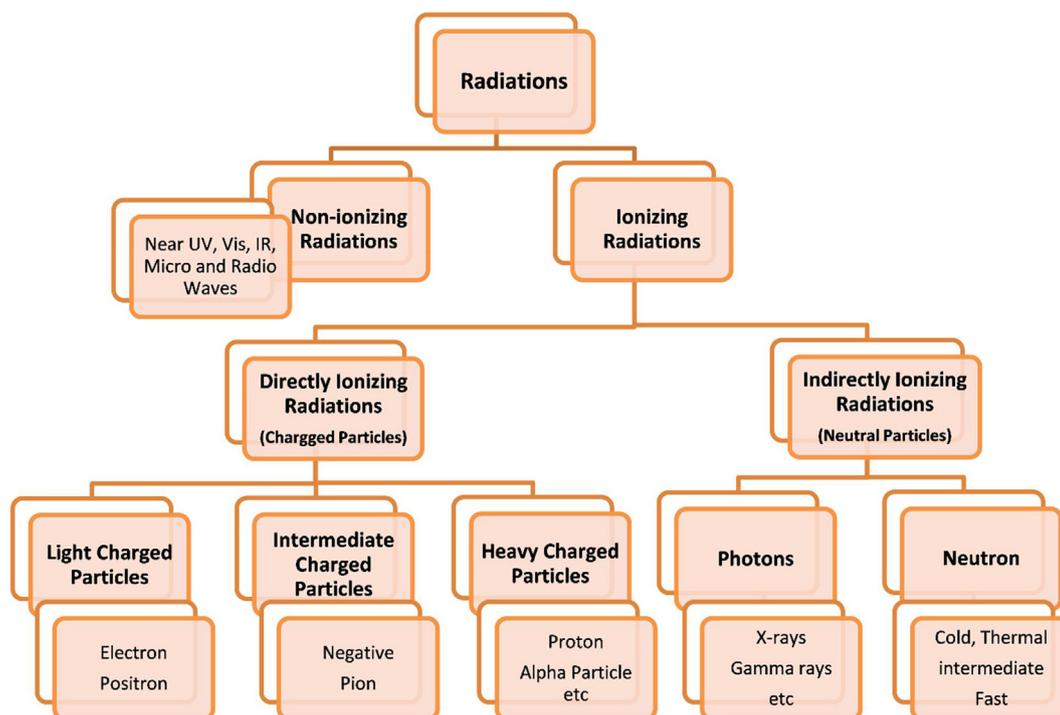


Fig. 1. Classification of radiations.

in polymer matrices. Environment friendly, economical and controlled irradiation treatments are the supposed answers of conventional, expensive and complicated chemical approaches to address these challenges.

Gamma irradiation

Gamma irradiation is a safer non-contact modification technique that has been used in chemical modification of nanoparticles. For example, various chemical methods are available for reduction of nanostructures. However, most of them involve toxic and explosive chemicals and require special precautions. Gamma irradiation has been successfully used to reduce graphene oxide to graphene [2–4]. In reduced graphene oxide/MWCNTs composite, gamma irradiation resulted in high conductivity and large surface area by limiting aggregation of graphene sheets and improved dispersability [5]. The reduced graphene oxide by gamma irradiation can be re-dispersed in organic solvents and resulting suspensions can stay stable for particular period of time depending upon the nature of irradiation medium and solvent. Its polymer

nanocomposites have shown a sharp transition from electrically insulating to conducting even at low weight loading of filler [3].

Performance of untreated SWCNTs (e.g., mechanical and electrical) usually deplete when incorporated in bulk materials as compared to treated SWCNTs due to weak intermolecular interactions among SWCNTs agglomerates [6]. Various studies are reported on modification of SWCNTs via irradiation treatment for polymer composites. For example, gamma irradiated SWCNTs and MWCNTs showed increased mechanical properties and electrical conductivity in air environment for various polymer matrices [6–9]. Studies suggest that gamma irradiation introduces active sites in lattice such as carbon defects and subsequently developing inter-tube crosslinking among CNTs at critical defects concentration [10]. Gamma-photons induced defects on MWCNTs surface are found favorable to improve hydrogen adsorption capacity [11]. Enhanced interactions between CNTs and matrix help in uniform dispersion and hence improving the mechanical and electrical properties. Oxygen concentration on CNTs had seen dramatically increased in O₂ atmosphere under ionizing effect of gamma irradiation and believed to contribute stronger interactions

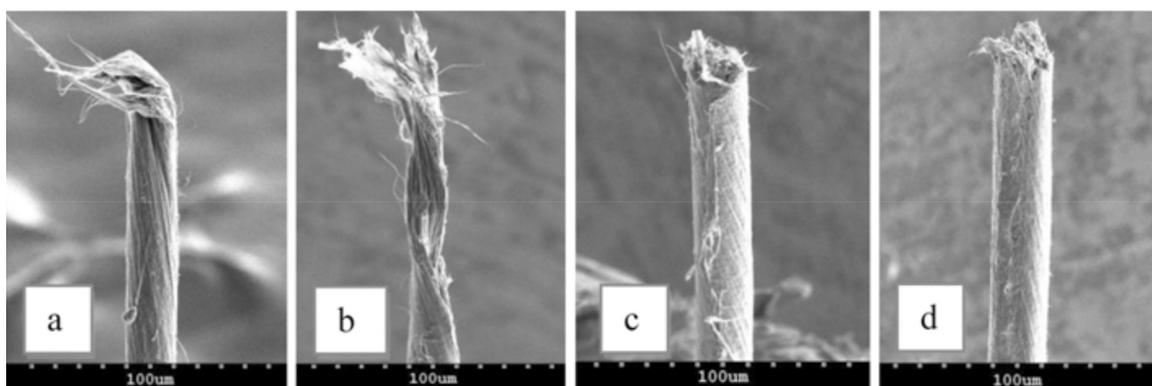


Fig. 2. Slipped broken ends of the untreated and γ -irradiated CNT yarns (a and b), and their epoxy composite yarns (c and d) after tensile breakage [12].

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