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Research paper

Study and Characterization of Polystyrene/Titanium Dioxide Nanocomposites (PS/TiO_2 NCs) for Photocatalytic Degradation Application: a Review

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Abstract

Synthetic polymer/TiO_2 composite such as Polystyrene/TiO_2 has become recent highly research materials due to its potential and significant application in various fields. we can tune the polymer and nanoparticles by different techniques such as change the materials concentration, Exposure of materials to laser radiation, Exposure of materials to laser radiation, especially in tuning the polystyrene/TiO2 composite energy band gap. In this review, several methods of preparation are briefly explored such as pan-milling, precipitation, melt compounding, dip-coating, solution cast, and sol-gel method. Some recent advancement that focuses on the two basic elements: polymer and TiO_2 are also included especially discussing on photocatalytic degradation that introduces photon as manipulate parameter to tune the polymer/TiO_2 composite energy band gap. Scanning electron microscope (SEM) analysis of various polymer/TiO_2 (type n concentration) and Polystyrene/TiO_2 (concentration and nanoparticles sizes) are the focus of the discussion before exposure to laser radiation as photodegradation source.

Keywords: *Laser Irradiation; Nanocomposite; Photocatalytic Degradation; Polystyrene; Titanium Dioxide.*

1. Introduction

Currently, one important aspect as for polymer is to obtain functional properties and high mechanical performances by the introduction of inorganic nanomaterial used as an additive. For many years, researchers worldwide have done a lot of work on polymer stress reactions conducted in polymer solutions, polymer melts and polymer solids [1, 2]. The first polymer/metals work as a polystyrene/TiO_2 with pan milling process started at 1996 [3]. The sturdy interaction between the additive and the polystyrene could be obtained because of the small size of the nanoparticles [4] as is shown in fig. 1, with a great surface area. It can combine the inorganic nanoparticles properties, such as solidity and Suitable thermal features, with the properties of the polymer such as toughness, and easy processability to get composites with suitable properties [5].

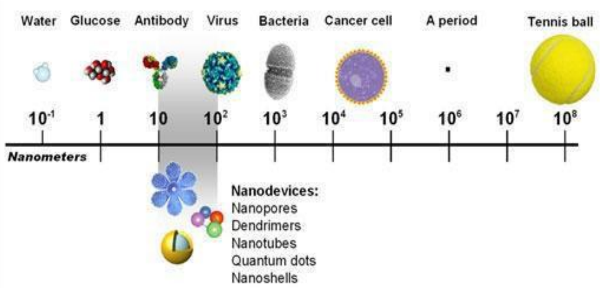


Fig. 1: Nanoscale integration of nanoparticles and biomolecules [4]

Thinking about the disposal of polymer waste, such as polystyrene (PS) has become part of the most stately issues facing researchers working in the environment field. Although there are sundry techniques for reuse of polystyrene (PS), these solutions are not considered a long-duration solution [6]. Furthermore, even getting biodegradable and photodegradable (by aiding the organic photosensitizer addition) polystyrene cannot fix the problem because these polymers have the fixing of long-duration degradation and because of the different kind of environmental issue by the stabilizers inserted in their preparation [7].

1.1. Polystyrene/Metal Oxide Nanocomposites

Metal oxide NPs such as TiO_2, ZnO, Cu_2O, CuO, and Fe_3O_4 have a large range of current and proposed applications and rank among the highest production volume NPs. They are also used as fillers for the PS structure, due to their motivating optical, electrical, chemical, and antimicrobial properties. For example, TiO_2 is inexpensive and non-toxic material with unique electrochemical and photocatalytic properties, widely used as UV-resistant material and in the field of chemical fiber production [8], plastics [9], printing ink [10], coatings [11], self-cleaning glasses [12], self-cleaning ceramics [13], antibacterial materials [14], foods packing material [15], chemical industry [8], cosmetics [16], gas and moisture sensor [17, 18]. Cu_2O and CuO NPs have special physical and chemical features such as chemical activity and thermal resistance, catalysis, antimicrobial, magnetic and optical properties which make them good candidates for optoelectronic devices and solar cells, gas sensor, ceramic resistors, magnetic storage media, photoconductive and photothermal applications, high-tech superconductors, etc. [19, 20]. ZnO NPs have high chemical constancy, low dielectric constant, great electromechanical conjugation coefficient, high luminous transmittance high catalysis activity, excellent electrical and optical properties, intensive ultraviolet and infrared absorption, and they are widely used in various fields such as UV-shielding [21], photocatalysis [22], field emission display [23], gas sensing [24], and thermoelectricity [25], for the production of voltage-dependent resistor, image recording, antimicrobial and self-cleaning hygiene ceramics, floor tile, paints, and plastics [26, 27] Magnetic Fe3O4 NPs are currently intensely discussed for medical applications in vitro diagnostics because of their biocompatibility and for spintronics devices due to their half-metallic properties [28, 29]. Introduction of metal oxide nanoparticles (MONPs) into PS matrix, some of the above-mentioned properties of these NPs can be used to improve or enhance properties of PS.

1.2. Properties of Polystyrene/TiO_2 Nanocomposites

When the TiO_2 Nanospheres [30, 31] or nanotubes [32] were incorporated in PS by in situ bulk radical polymerization, the obtained PS/TiO_2 NCs showed higher transitional glass and better in thermal and thermo-oxidative constancy than the pure polystyrene (PS). Sang et al., obtained the optimal properties, tensile performance and thermal constancy of the PS/TiO_2 NCs at 1.0 wt.% of TiO_2 loading, with the tensile strength increase of reaching to 43.6% compared to the purity of PS [33]. The onset temperature at which 10% mass is lost is increased by 10 ºC. On the other side, the presence of TiO_2 NPs in PS films greatly promotes the photocatalytic degradation to the NCs, much faster than the simple photolysis of a pure PS sample, through its oxidative reaction with the active oxygen radicals [34, 35]. addition to that, the adsorption with photocatalytic features of the PS/TiO_2 NCs are active for the degradation in methylene blue dye solutions by UV irradiation [36]. moreover, Wang et al. showed that HIPS/TiO_2 NCs have a satisfactory antibacterial effect against Escherichia coli with Staphylococcus aureus and better rheological behavior than bulk PS [37]. In another investigation of HIPS/TiO_2 NCs, the snick impact strength with tensile strength, and tensile elastic modulus increased to the maximum when nano-TiO_2 content was 2% [38]. The TiO_2 NPs have both toughening and reinforcing effects on HIPS at 2% loading. heat distortion temperature (HDT), flame retardancy, mechanical properties, and comprehensive performance of HIPS/TiO_2 NCs are better than that of HIPS alone, so the nanocomposites (NCs) are useful for a vast range of applications. In another study, the effect of PS/TiO_2 NCs dielectrics on thin film transistor performance has been explored [39]. These results stock a better comprehension of how the dielectric/semiconductor idler and especially the permittivity of dielectric impact the transport features of organic thin film transistors.

2. A Review of Literature

Photocatalysis on TiO_2 appears a promising alternative technology for degradation of organic such as polystyrene (PS) [40]. It is built on the photogeneration of discrete electrons and the holes in the particles of semiconductor [41]. These carriers of charge either recombine inside the particle or shift to the surface of it where they can interact with adsorbed molecules [42]. the positive holes usually oxidize organic compounds, induce their oxidative degradation, whilst electrons at most reduce molecular oxygen into superoxide radical anions [43]. Recombination of photogenerated holes and electrons into the particles of the semiconductor is responsible for the comparatively low quantum crop of photocatalytic degradation [44].

latterly, a lot of researches are achieved to develop improve TiO_2 photocatalysts that show a high pep under the visible light irradiation in order to make the best use of the sunlight. Metal ion-grew TiO_2 photocatalysts with several transition metals like V, Mn, and Cr ions and polystyrene as a polymer have been inspected, which allow some photocatalytic reactions for proceeding under visible light [45-48]. TiO_2 powder managed by hydrogen peroxide (HP) or chelating agent also shows higher photocatalytic activity under visible light [49, 50]. TiO_2 doped with nonmetal elements like C, S, and N anions is supported to absorb visible light [51-54]. Dye sensitization of TiO_2 can dilate its absorption to the region of visible spectral due to the mutual function of photosensitization and TiO_2 semiconductor.

As a normal plastic material, a big amount of polystyrene (PS) is used in food serving and retail industry. Moreover, the foam of polystyrene (PS) packaging is exceedingly used to get electronic instruments, household appliances, auto parts, and other fragile goods from damage. Due to its subsidence, PS and concerned plastic products are non-biodegradable in the normal environment. The waste polystyrene plastics don't mold in landfills, causing an earnest environmental problem, called "white pollution" It is well known that TiO_2 will produce electron-hole pairs under illumination of UV-light. TiO_2 photocatalyst has been swimmingly used to sanitize water and air, to humiliate the organic pollutants and to kill the bacteria [55, 56]. Previous studies to the TiO_2 polymers photocatalytic degradation at most dealt with liquid stage reactions like polyvinyl chloride (PVC) photocatalytic degradation of particles in TiO_2 suspension waterly solution [57]. Recently, there are a few studies on the solid-stage photocatalytic degradation of polymer–TiO_2 composite. just one reference is got [58]. They scrutinized the photocatalytic degradation to PVC–TiO_2 composite films. Their PVC–TiO_2 composite was synthesized by directly embedding TiO_2 into PVC. By the viewpoint of solid-stage photocatalytic degradation, a well-dispersed and uniformly mixed microstructure of polymer–TiO_2 composite is highly desired.

Usually, TiO_2 particles will aggregate significantly in the low polar medium, if there is not enough steric hindrance [59, 60]. The TiO_2 nanoparticles joined into the polymer matrix manifest in the shape of vast agglomerates, whose size dilates up to a slight micrometer. The micrometer-sized agglomerates decrease the photodegradation efficiency safely in two mechanisms [58] (a) detraction the interface area between the polymer and the agent of photocatalytic, and (b) induce rapid whitening. The photoinduced whitening rapidly shortens the light permeation depth inside of the composite film, which stops further photodegradation. Nanoparticles as well generate nanocavities, which waste out little forthcoming light, if the TiO_2 nanoparticles could get a pretty dispersion in the polymer, the efficiency of photocatalytic degradation. Due to the scholastic significance of the topic of study of polystyrene (PS)/metal oxide (MO), research on (PS/MO) development has been throughout the time such as (PS/CuO), (PS/ZnO), (PS/TiO_2). However, we focused in this review on the (PS/TiO_2), Because of its importance in thermal and electronic applications in solar cells and photocatalytic degradation others.

3. Review of various fabrication techniques

3.1. Pan-Milling method

Milling is a significant unit operation in powder processing technology [61]. It depends on mechanical forces to get stress within a particle, leading to size reduction of the particle. There are several kinds of mills, like roller mills [62], ball mills [61], and impact [63] and jet mills [64].

3.2. Precipitation technique

The precipitation technique is making a solid material in the solution through a chemical reaction, precipitate is a name of that a solid formed and the supernate is a name of that a liquid materials remaining over the solid materials, salts like ammonium is used for proteins to precipitate, organic solvents methanol used to deposit dextrans, chilled ethanol, and acetone used for protein precipitation, nonionic polymer such as polyethylene glycol used in precipitation [65].

3.3. Melt Compounding process

Compounding [66] is a process of melt blending polymers as the polystyrene with other additives as TiO_2. This process changes the physical, thermal, electrical or aesthetic characteristics of the plastic. The final product is called a compound or composite [67, 68].

3.4. Dip-coating method

The dip-coating method is a widespread technique of applying a covering, decorative, or functional polymer vinyl coating on an assortment of metal parts. Exemplary applications supply a protective layer against sharp or rough materials, a protective plastic layer to prevent corrosion or just a beautiful and soft coating to enhance the product's appearance, It has cost effective to make a one-step dunk to coat an output [69], for example, a tool grip than it is to injection mold a sleeve and then enforce it to the lug. The coated grip is softer, has no vortex lines, and agglutinates better to the production to be coated.

3.5. Solution Cast Method

Solution Cast Method is a manufacturing technique used to get flexible plastic such as polystyrene [70] components which are typically in the shape of a single or multi-lumen tube ordinarily hired in the medical instrument industry. This industrialization technology is individual in the product does not need conventional throwing or injection casting technologies, yet it easily incorporates components and features traditionally produced by these processes.

3.6. Sol-Gel method

Sol-gel is a chemical method used to make glass and ceramic materials in the thin films form, fibers, or powders [71]. the first part of that phrase (sol-gel) is a colloidal (the sparsed phase is so small that gravitational forces do not exist; only Van der Waals and surface charges are present)or molecular suspension of solid particles of ions in a solvent. the second part of that phrase (sol-gel) is a semi-hard cluster that establishes when the solvent starts to steam and the ions or particles left behind begin to join together in a continuous network, the sol-gel technique [72] is a damp-chemical mechanism that which uses either a chemical solution (sol short for solution) or colloidal materials (sol for nano-scale particle) to get an incorporated network (gel).

4. Surface analysis

Scanning Electron Microscope (SEM) analysis shows the morphologies of PS and PS-TiO_2 samples. The polystyrene film surface morphologies, PS–TiO_2 and PS–Grafting-TiO_2 composite materials, it can be spotted from Fig. 2(a), (b) and (c) Respectively that the G-TiO_2 nanoparticles materials were well strewn in the composite film. contrasted to the unmodified TiO_2 particles, the size of G-TiO_2 particles materials inside of the film are 100–300 nm, but with the non-grafted TiO_2 particles materials are in the range (500–600nm) in the same condensation range of TiO_2 [73, 74].

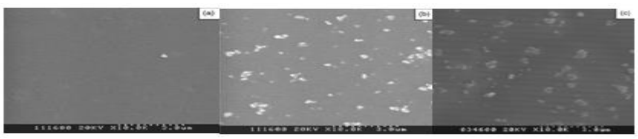
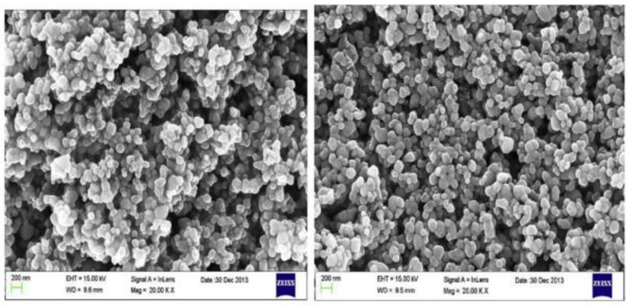


Fig.2: SEM images of composite films: (a) pure PS film (b) PS–G-TiO_2 (1.0 wt.%) film (c) PS–TiO_2 (1.0 wt.%) composite film [73].

Yonglin Lei et al., [44], showed the typical SEM images of TiO_2 and Hindered amine modified Aromatic polyamide Dendrimer/ Polystyrene-Grafted-TiO_2 (HADPG-TiO_2) particles are displayed in Fig. 3 (a, b). It enables to be spotted the plain TiO2 nanoparticles are smooths, spherical, and strong aggregation. The moderate size of the TiO_2 nanoparticles is approximately 100 nm. The morphology of HADPG-TiO_2 particles materials does not different much from the plain TiO_2 and the moderate particles size is near to the plain TiO_2. However, the HADPG TiO_2 particles materials appear with less gathering and the HADPG-TiO_2 particles surface is rougher than plain TiO_2.



(a) (b)

Fig.3: SEM images of TiO_2 (a) and HADPG-TiO_2 (b) [44]

The dispersion of TiO_2 nanoparticles in polystyrene was rated by SEM (Fig. 4). It can be clear by Fig. 4 (a) that the untreated TiO_2 aggregates industriously and has the pauper stampeding in the polymer of PS. However, the iron (II) phthalocyanine Titanium Dioxide (FePc-TiO_2) particles demonstrate a drastically different morphology in the polymer matrix (Fig. 4b). Actually, the revised nanoparticles stampede well unless a few singular particles materials under the same instrumental setting When we look to the grafting material such as (TiO_2/CuPc) [75], it's looking like (FePc-TiO_2) in technique. This result sanctifies that prepared treating of the TiO_2 nanoparticles may amend the stampeding of the nanoparticles in the polymer, which can well enhance the photocatalytic influence of nano-TiO_2 under UV irradiation. [66,76], the particles of TiO_2 are ''grafted" on the polystyrene and even a potent stirring in the water for 1 h could not strip them from the Expanded Polystyrene (EPS) surface.[77] The spherical shape with a smooth in a colloidal polymer with TiO_2 is very clear [78], as it in fig. 5 (a, b, c).

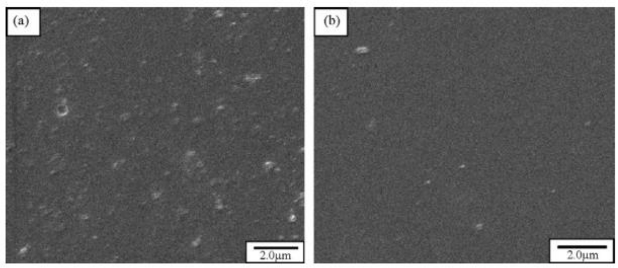


Fig.4: the SEM images of the PS-TiO_2 (a) and PS-FePc-TiO_2 (b) films [66]

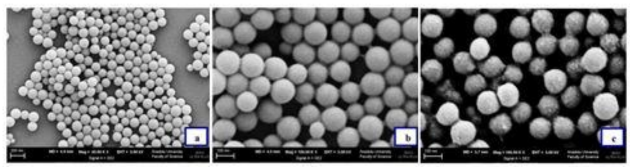


Fig.5: SEM images of the nanocrystalline titania-coated polymer particles: (a, b) PS; (c) PS/TiO_2-4h [78].

The films PS-g-TiO_2 (TiO_2: 2%) of morphology and purred PS film irradiated for 0hour and 200 hours in the air, respectively showed in Fig. 6. Both the pure film are soft before irradiation and PS-g-TiO_2 composite film surface and (Fig. 6a and b). After irradiation of 200 hours (1 mW/cm^2), the composite film [67] was clearly decomposed (Fig. 6d). The large cavities created not only on the surface of the film but also into the film, with the chalking phenomenon catching place. further, the pure PS film varied only little after 200 hours irradiation (Fig. 6c) [35].

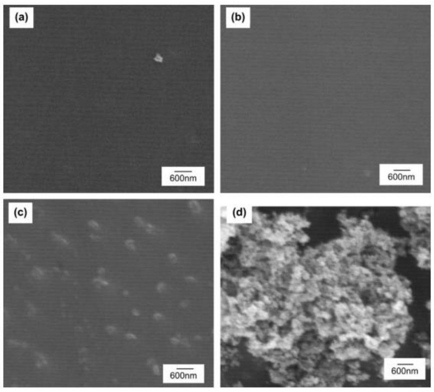


Fig.6: SEM images of: (a) pure film (0 h), (b) composite film (TiO_2: 1%, 0 h), (c) pure film (200 h), (d) composite film (TiO_2: 1%, 200 h). [35]

5. Conclusion

The thin films of PS/TiO_2 can be obtained through several methods. The photocatalytic degradation technique of PS-TiO_2 composite material sample much better than the pure PS sample simple photolysis. The existence of TiO_2 particles in polystyrene films greatly enhances the flexibility of the material; using laser irradiation is an enhancement of the band gap tuning.

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