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Fabrication and Functions of Nanomaterials for Polymeric Textile Fibers

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Abstract

This review summarizes the fabrication and functions of nanomaterials for polymeric textile fibers. The electrospinning, nanofinishing, nanotransfer printing, layer-by-layer deposition, wet or dry-spinning, and sol-gel processes of the nanomaterials have been explored. The nanomaterials have induced the antibacterial, antistatic, water and oil repellence, wrinkle resistance, strength enhancement and UV blocking propertiesto polymeric textile fibers. The application of the nanomaterials for polymeric textile fibers offers the functionalityas well as the potential of improved processing techniques.

Introduction

Polymeric textile fibers are now widely used in the field of technical textiles including antibacterial properties, water and oil repellence, antistatic properties, wrinkle resistance, strength enhancement, UV blocking, and so on [1-5]. They originate from naturally occurring polymers such as cotton, flax, wool, chitosan, alginate, silk, feather keratin and wheat gluten as well as various synthetic polymers such as Poly Ethylene Terephthalate (PET), Polyester (PES), Polyamide (PA), Polypropylene (PP), Polyacrylonitrile (PAN) and nylon 66 [6-8]. Such materials may be in the form of surface coatings, voided patterns, fillers, or foams. To improve their properties, various nanoscale modifiers based on Ag Nanoparticles (NPs) Carbon Nanotubes (CNTs) Silica NPs, TiO_2 NPs, ZnO NPs or graphene oxide have been used in polymeric textile fibers [9-16]. In this paper, a brief review will be given regarding the fabrication and functions of nanomaterials for polymeric textile fibers.

Fabrication of nanomaterials for polymeric textile fibers

Electrospinning process

A direct approach for fabricating nanoporous polymer fibers via electrospinning had been demonstrated [19]. Polystyrene (PS) fibers with nanoporous structures both in the core and/or on the fiber surfaces were electrospun in a single process by varying solvent compositions and solution concentrations of the PS solutions. The schematic representations of the electrospinning setup and the electrospun nanoporous fiber evolution process were shown in Figure 1 [19]. Similarly, we investigated the electrospinning of biodegradable and biocompatible polymers and found the electrospunnanofibrous membrane [20-24].

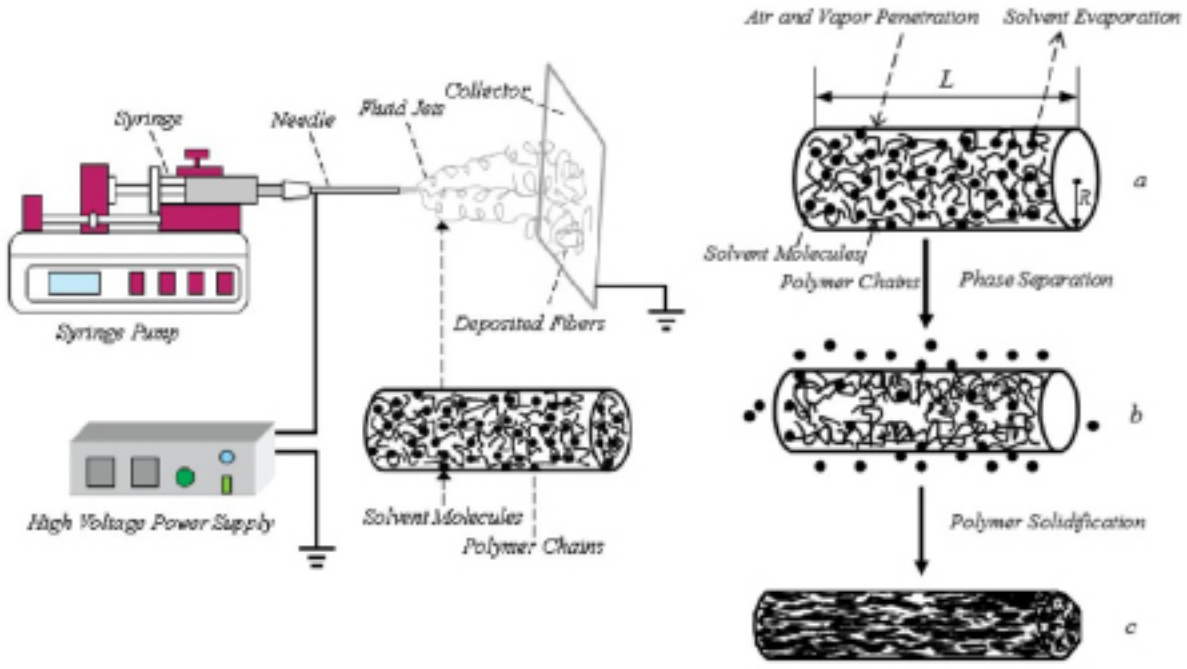

Figure 1: Schematic representations of the electrospinning setup and the electrospunnanoporous fiber evolution process [23].

Nanofinishing process

The advancement of polymeric textile nanofinishing requires implementing a sustainable technology for producing complex nanomaterials for enhancing the performance and extending the functions of the final product. Among the various aerosol processes, electrical discharges allow the high-yield synthesis of a wide range of well-defined NPs that can be directly deposited onto polymerictextile fibers by diffusion, in a green and universal manner [25]. The uniqueness of the proposed process lies in that diffusional deposition can be easily integrated into textile nanofinishing while providing a controlled loading profile within the textiles [25-27]. Since the NP synthesis method is fully compatible with commercial roll-to-roll textile production as illustrated in Figure 2, the nanofinishing process is amenable to upscaling [25].

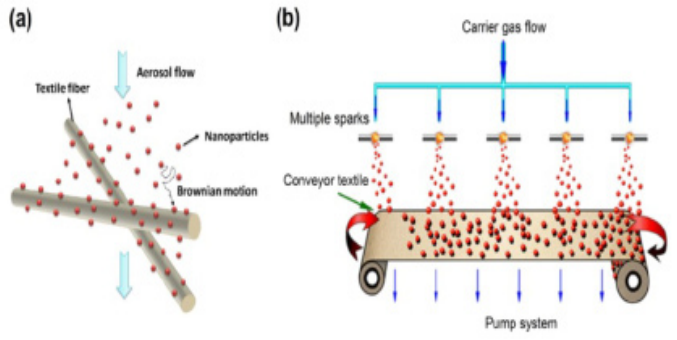

Figure 2: Schematic illustration of the nanofinishing process.

(a) An aerosol flow is passed through the textile, where the NPs collide and stick to the fibers by van der Waals forces. The NPs -fiber collisions are caused by the Brownian motion of the NPs.

(b) Conceptual design of a simple, scalable and green route for textile nanofinishing achieved by integrating electrical discharges for the synthesis of NPs into roll-to-roll textile production [25].

Nanotransfer printing process

The nanotransfer printing process using water-soluble polymer and the corresponding morphologies of the nanostructures fabricated on textiles are shown in Figure 3 [28]. Hyaluronic Acid (HA) was used as the donor substrate. Moreover, it could easily replicate the nanostructures by a molding process. First, a HA mold with a designed nanostructure pattern was prepared from a polymer mold. Second, various metals or SiO_2 were deposited on the patterned HA film. Finally, when the film was placed on a wet textile substrate, the designed nanostructures of functional materials were transferred onto the textile. Using this process, metal or nonmetal nanoscale patterns could be transferred onto the non-flat surface of the textile while retaining their shapes. The polymer mold fabrication process was used [29,30].

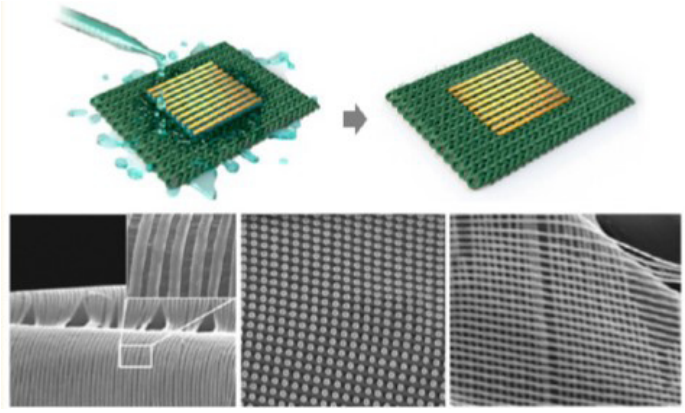

Figure 3: Schematic illustration of the nanotransfer printing process using water-soluble polymer and the corresponding morphologies of the nanostructures fabricated on textiles [20].

Layer-by-layer deposition process

Nanocoating Layer-By-Layer (LBL) is a powerful polymeric textile fiber [31]. In an effort to highlight the versatility of this coating system, flame retardant and conductive multilayer recipes were deposited onto a model cotton fabric substrate. Fire behavior and antistatic properties were evaluated using two

different nanocoating recipes. The automated system applied layer-by-layer nanocoatings by exposing sections of the fabric to deposition materials in a continuous, closed-loop fashion (Figure 4) [31]. This large-scale automated immersion device produced effective nanocoatings with consistent properties throughout the entire length of the coated fabric. Pairing these desired characteristics with the tailorability of the layer-by-layer assembly technique [32-34].

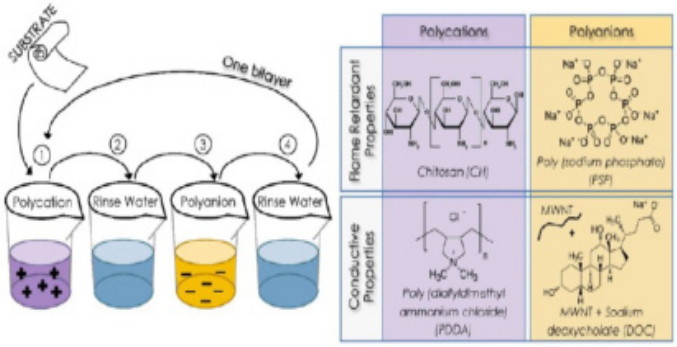

Figure 4: Schematic representations of the nanocoating layer-by-layer deposition process and the chemical structures used to produce the flame retardant and conductive behaviors [31].

Wet or dry-spinning process

Nanoporous wet-spinning process for polymeric textile fibers refers to extrusion of the spinning dope solution into a bath containing certain coagulant agent. Nanoporous dry-spinning is a process similar to wet spinning except that the solidification of fiber occurred not in a liquid environment, but in an air environment through evaporation of the volatile solvent or after a cooling process. Generally, Regenerated Silk Fibroin (RSF)/ Graphene Oxide (GO) hybrid silk fibers were dry-spun from a mixed dope of GO suspension and RSF aqueous solution [35]. Figure 5 was the schematic representations of GO sheets in the hybrid fibers during the drawing process [35]. By adding specific fillers including the carbon nanotube, cellulose nanocrystals and reduced graphene oxide into the spinning dope solution, different interactions occur between the silk protein and the fillers [36-38].

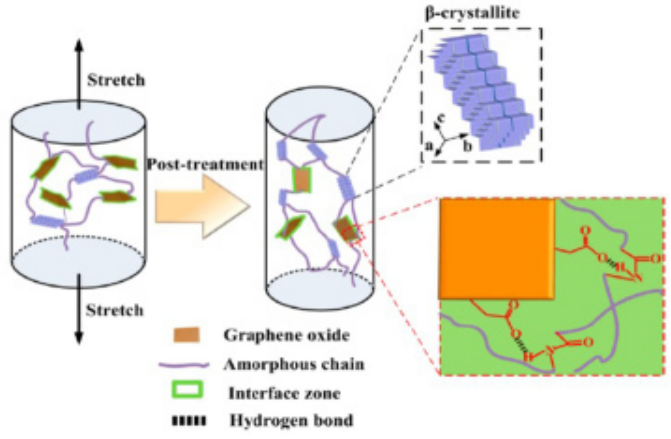

Figure 5: Schematic representations of GO sheets in the hybrid fibers during the drawing process [35].

Sol-gel process

A novel one-pot sol-gel process was a powerful polymeric textile fibers [39,40]. It incorporated Room-Temperature Ionic Liquids (RTILs) to synthesize Ag/TiO_2 nanocomposite powders [39]. The presence of RTILs was indispensable to the control of the size of the Ag particles. Highly dispersed, metallic Ag nano clusters were formed on the TiO_2 nanoparticle surface after calcination of the gel. As shown in Scheme 6 [39], the synthesis started with a single-phase solution containing homogeneously distributed precursors of Ag and TiO_2. Similarly, we investigated the polysaccharide-assisted incorporation of multi walled carbon nanotubes into sol–gel silica matrix for electrochemical sensing [41].

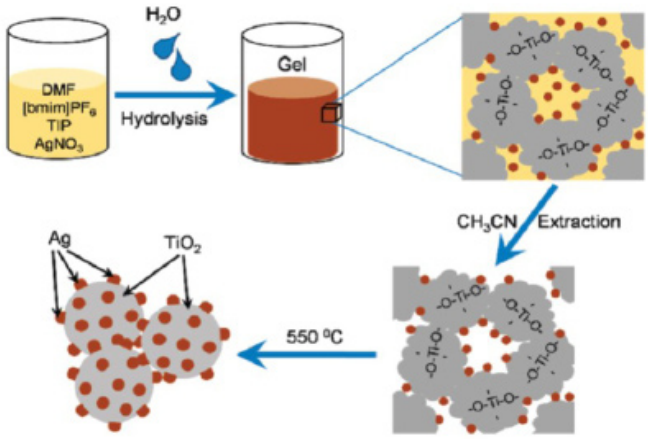

Figure 6: Schematic representations of Ag/TiO2nanocomposite powders in the sol-gel process [39].

Functions of nanomaterials for polymeric textile fibers

Antibacterial properties

Antibacterial properties of the nanomaterials for polymeric textile fibers are highly desired in applications that require a protective barrier against infection [42-44]. Several studies confirmed that Ag NPs possess excellent antimicrobial activity against a broad spectrum of microbes [45]. The antimicrobial efficacy of Ag additives depends on the concentration, surface area, and the release rate of the Ag+ ions [45]. When Ag NPs contact with moisture or bacteria, they adhere to the cell wall and membrane [46]. TiO_2 NPs can also be utilized to impart textiles with antibacterial properties. Furthermore, ZnO behaves similar to TiO_2 to produce antibacterial properties [47].

Antistatic properties

Antistatic properties of the nanomaterials for polymeric textile fibers are now widely used in the field of technical textiles. TiO_2 NPs, ZnO whiskers, and antimony (Sb)-doped tin oxide (SnO_2) particles were utilized to impart antistatic properties to synthetic fibers [48-50]. Additionally, silanenanosol enhances antistatic properties, as it absorbs moisture in the air through hydroxyl groups [51]. Antistatic charges with hydrophobicity could be achieved by treating polyester fabric with Ag NPs and fluorine water-repellent finish [52]. ZnO NPs, prepared by direct precipitation using Zinc Chloride ($ZnCl_2$), were immobilized on polyester fabrics through a pad-dry-cure process with an antistatic finishing agent [53].

Water and oil repellence properties

SiO_2 NPs in combination with water-repellent agents could be utilized to impart hydrophobicity to polymeric textile fibers [54]. SiO_2 NPs were synthesized via a sol–gel process. SiO_2 NPs could becoated over cotton in the presence of perfluoroocty-lated quaternary ammonium silane coupling agent to produce

hydrophobicity [54]. Oil-repellent textiles have also been produced. Polyester fabric could be coated with silicone nanofilaments and treated with plasma fluorination to impart superoleophobic properties to polymeric textile fibers [55].

Wrinkle resistance properties

Traditionally, fabrics are impregnated with resin to impart wrinkle resistance to textiles. To impart wrinkle resistance, NPs have been applied to polymeric textile fibers [56]. TiO_2 NPs with carboxylic acid as a catalyst were utilized to form cross-links between cellulose molecules and the acidic groups [57]. Dry and wet delay-wrinkle recovery angles of the treated silk were 267 and 250° compared to untreated fabric of 235° and 178°, respectively [58]. Additionally, SiO_2 NPs and maleic anhydrate as a catalyst have been applied to silk to improve wrinkle resistance [59].

Strength enhancement properties

CNT-reinforced polymeric textile fibers have been developed to improve strength and toughness and to decrease weight. These polymeric textile fibers could be produced through melt spinning of polypropylene and carbon particles [60]. The integration of CNTs into fibers has been shown to improve the strength and performance [61]. The tensile strength of the CNT-coated cotton fabrics was improved along the weft and warp directions, showing enhancement in both loading capability and flexibility [62].

UV blocking properties

Sol-gel method could be used to form a thin layer of TiO_2 on the surface of the polymeric textile fibers [63]. The UV protection effect may be maintained up to 50 launderings [63]. Furthermore, ZnO nanorods were incorporated in polymeric textile fibers to induce scattering at a high UV protective factor rating [64]. Additionally, ZnO NPs synthesized through sedimentation and peptization were immobilized on dyed polyester/cotton fabrics [65]. The resulting fabric absorbed the light in the UV region [65].

Future perspectives

Over the last two decades, numerous nanomaterials including Ag NPs、CNTs、Silica NPs、TiO_2 NPs、ZnO NPs or graphene oxide components have been deposited or woven into polymeric textile fibers. Despite the progress made in this field of nanomaterials for polymeric textile fibers, there still are many significant works to be done. In particular, the effects of nanoscale incorporation on the bulk and surface properties of polymeric textile fibers have not been explored in detail. Also, the ability to control and quantify nanoscale dispersion in such textile materials is an unresolved issue of fundamental importance. A molecular-level understanding of the interaction of nanoscale modifiers with polymeric textile fibers would be very useful for the design of new textile materials. Further research will focus on the design and preparation of novel nanoscale modifiers with multi- or “smart” functionalities for polymeric textile fibers [66,67].

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