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Review Article

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Nanotextiles- A Broader Perspective

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Abstract

Nano Technology means optimizing performance and providing smart solutions for the future. It means configuring molecules to change in size and properties for enhancement as in the case of smart fabrics. Smart fabrics can help manufacturers and designers with the increased emphasis on lifestyle, aesthetic appeal and form demanded for technological products. Nanosize particles can exhibit unexpected properties different from those of the bulk material. The basic premise is that properties can dramatically change when a substance's size is reduced to the nanometer range. Nanotechnology has versatile applications in Textile Chemicals industry in manufacturing garments with stain resistance, flame retardant finishes, wrinkle resistance finishes, moisture management, antimicrobial qualities, UV protection, and soil release properties. Incorporating nanomaterials into a textile can affect a host of properties, including shrinkage, strength, electrical conductivity and flammability. Nanotechnology has also made a tremendous impact on functionality and performance. Nano-treated textiles may lead to many inventions as the science develops in future.

Keywords: Nanotechnology; Nanoparticles; Cotton; Textile industry; Nanowhiskers; Superhydrophobicity; Anti-bacterial properties; Nano-silver; Anti-microbial

Abbreviations: GNF: Graphite nanofibres; CNT: Carbon nanotubes; TiO2: Titanium dioxide; ZnO: Zinc oxide.

Introduction

Nano's (Greek) means dwarf [1]. One nanometer is defined as 1 billionth meter i.e.1×10^{-9}m and involves developing materials or devices within that size. Nanotechnology is defined as the precise manipulation of individual atoms and molecules to create layered structures [2]. Nanosize particles can exhibit unexpected properties different from those of the bulk material. Small size of nanoparticles leads to particle–particle aggregation hereby making physical handling of nanoparticles difficult in liquid and dry powder forms. The basic premise is that properties can dramatically change when a substance's size is reduced to the nanometer range. In bulk form, gold is inert; [3] however, once broken down into small clusters of atoms it becomes highly reactive. It's the application of functional systems in the sub-μ range. Based on the use of sub-units nanoparticles are systematically arranged [4]. In the field of textiles, nanotechnology has been used in synthesis of quantum dot [5,6] called semiconductor nanocrystals [7]. Dye molecules are used to make fibers. In nanocrystals, the color changes with increase in particle size thus it is possible to create different size particles from a single material having different optical properties that cover the entire visible region [8]. There are many possible routes for nanotechnology [9] to be incorporated into fabrics which provide excellent performance [10]. Nanofinishing in textile technology is very promising due to various end uses like protective textiles for soldiers, medical textiles and smart textiles [11,12].

Cotton is the most commonly used popular clothing material [13,14]. It is the only renewable resource but also biodegradable [15] and readily available. Cotton is composed mainly of cellulose [16] molecules, adding functionalities to cotton fibers [17] is a challenging endeavor as physical and chemical heterogeneities need to be overcome. By assembling metal nano-particles on to the cotton several applications can be envisioned [18].

Nanotechnology also has the real commercial potential for the textile industry [19]. This is mainly due to the fact that conventional methods impart different properties [20] to fabrics which often do not lead to permanent effects, and will lose their functions after laundering or wearing. Nanotechnology can provide high durability for fabrics, because nano-particles have a large surface [21] area-to-volume ratio and high surface energy, thus presenting better affinity for fabrics and leading to an increase in durability of the function. In addition, a coating of nano-particles on fabrics will not affect their breathability or hand feel [22]. Nanofibres have smaller pores and higher surface area than regular fibers which show enormous applications in nanocatalysis, tissue scaffolds, protective clothing, filtration, and optical electronics. The electrospinning process is the one which uses a high voltage electric field to produce electrically charged jets from polymer [23] solution or melts, which on drying by means of evaporation of the solvent produce nanofibres [24]. Fabrication processes for nanomaterials [25] is complex but sometimes hazardous and distant from "green manufacturing" [26].

Nano-materials when engineered at the atomic and molecular level and are integrated into fabrics can exhibit certain properties which alter the physical properties of a textile. Nanotechnology also has real commercial potential for the textile industry. This is mainly due to the fact that conventional methods used to impart different properties to fabrics often do not lead to permanent effects, and will lose their functions after laundering or wearing. This technology provide high durability for fabrics because nanoparticles [27] have a large surface area-to-volume ratio and high surface energy thus presenting better affinity to fabrics and increase in durability of the function [28]. The nanoemulsions particles have given a characteristic property of being easily absorbed by the skin which is sought beneficial in textile industry [29].

Nanotechnology to textiles involves

- Manufacturing composite fibers

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• Dyeing and printing

• Textile finishing (Coating nano-particles)

• coating

Manufacturing composite fibers

Nano-structured composite fibers are in the area where we see early booming of nanotechnology. Those composite fibers employ:

• Nanosize fillers(clay nanoparticle, metal oxide nanoparticles, carbon black)

• Graphite nanofibres (GNF)

• Carbon nanotubes (CNT) [30,31]

Dyeing and printing

Currently available technology for manufacturing of dyeable polypropylene relies mainly on copolymerization [32] polyblending and grafting technologies and plasma treatment [33]. The dyeable polypropylene can be produced via nanotechnology. At present pigments are widely used as colourants in textile printing and dyeing [34].

Textile finishing

Discrete molecules or nanoparticles of finishes can be brought individually to designated sites on textile materials in a specific orientation and trajectory through thermodynamics, [35] electrostatic or other technical approaches.

• Upgrade of chemical finishes and resultant functions

• Nanoparticles in finishing

• Self assembled nanolayers

Coating

Coating is common technique used to apply nano-particles onto textiles. Methods used for coating on textiles:

• Spraying

• Transfer printing

• Washing

• Rinsing

• Padding

Properties that are imparted on to the textiles include:

• Water repellence

• Soil resistance

• Wrinkle resistance [36]

• Antimicrobial [37,38]

• Anti-bacteria [39]

• Anti-static

• UV protection

• Flame retardation

• Improvement of dyeability

Current Nanotechnology Applications

Water-repellent property

Nanowhiskers: Nanowhiskers [40] are hydrocarbons and1/1000 of the size of a typical cotton fiber that is added to the fabric to create a peach fuzz effect without lowering the strength of cotton. The spaces between the whiskers on the fabric are smaller than the typical drop of water, but still larger than water molecules; water thus remains on the top of the whiskers and above the surface of the fabric [41]. However the liquid can still pass through the fabric if pressure applied [11].

Nanospheres: Impregnation involves a three dimensional surface structures with gel-forming additives which repel water and prevent dirt particles from attaching themselves. The mechanism is similar to the lotus leaf effect occurring in nature. Lotus plants [42] have super hydrophobic surfaces which are tough and textured. Once water droplets fall onto them, water droplets the surface slopes slightly, will roll off. As a result, the surfaces stay dry even during a heavy shower. Furthermore the droplets pick up small particles of dirt as they roll, and so the leaves of lotus plant keep clean even during light rain. This hydrophobic [43] property can be imparted to a cotton fabric by coating it with thin nanoparticulate plasma film. The audio frequency plasma of some kinds of fluorocarbon chemical was applied to deposit a nanoparticulate hydrophobic film onto a cotton fabric surface to improve its water repellent property. Superhydrophobicity [44] was obtained due to the roughness of the fabric surface, affecting the softness and abrasion resistance of cotton.

Anti-bacterial property

For imparting anti-bacterial properties, nano-sized silver [45], titanium dioxide and zinc oxide are used. Metallic ions [46,47] and metallic compounds display a certain degree of sterilizing effect [48]. The part of oxygen in the air or water turned into active oxygen by means of catalysis with metallic ions thereby dissolving the organic substance to create a sterilizing effect [49]

Silver nanoparticles

Silver nanoparticles when imparted on fabric kill bacteria [50] which makes clothes odor-resistant. Nanosilver particles have extremely large surface area thus increasing their contact with various microorganisms [51] and improving their bactericidal and fungicidal effectiveness [52,53]. Nano-silver is very reactive with proteins. When coated with bacteria or fungus it will adversely affect the cellular metabolism, inhibits the cell growth [54] and suppress respiration, the basal metabolism of the electron transfer system, and the transport of the substrate into microbial [55] cell membrane [56]. Further inhibits [57] the multiplication and growth of those bacteria and fungi which cause infection, odour, itchiness and sores. Hence nano-silver particles can be applied to socks in order to prohibit the growth [58] of bacteria.

Titanium dioxide

TiO_2 is a photocatalyst. It was determined that fabric treated with nano-TiO_2 could provide effective protection against bacteria and discoloration of stains due to the photocatalytic activity. Once illuminated by light energy higher than its band gaps, the electrons [59] in titaniumdioxide will jump from the valence band to the conduction band and the electron (e^-) and the electric hole (h^+) pairs will form on the surface of the photocatalyst. The electrons and the oxygen will combine into (O_2-), the positive electric holes and water generate hydroxyl radicals. Since both are unstable when an organic compound falls on the surface of photocatalyst it will combine with the both and turn in to carbondioxide [60] and water. This cascade reaction is called "oxidation-reduction" [61-63]. Through the reaction the photocatalyst is able to decompose common organic matters in the air such as odour molecules, bacteria and virus [64,65].

UV- Protection

Inorganic UV blockers are more preferable to organic UV blockers as they are non-toxic [66] and chemically stable under exposure to both high temperatures [67] and UV. Inorganic UV blockers are usually certain semiconductor [68,69] oxides such as TiO_2, ZnO, SiO_2, and $Al2O_3$ [70]. Among these semiconductor devices titanium dioxide (TiO_2) and zinc oxide (ZnO) were more efficient at absorbing and scattering UV radiation than the conventional size and were thus able to block UV. This is due to their large surface area per unit mass and volume [71]. UV-blocking treatment for cotton fabrics was developed using the sol-gel method [72]. A thin layer of titanium dioxide is formed on the surface of the treated cotton fabric which provides excellent UV-protection; the effect can be maintained after 50 home launderings. Apart from titanium dioxide, zinc oxide rods of 10 to 50nm in length were applied to cotton fabric to provide UV protection. The fabric treated with zinc oxide nanorods proved an excellent factor (UPF) rating.

The functions depicted here are the main functions of the nano particles on to the fabric. The use of the silver and gold particles [73] enables the odour resistance and anti bacterial and antifungal properties [74,75]. The titanium dioxide is for the uv-protection and nano whiskers for the water repellent property. The commercial products which are already in the market show these great features.

Commercially Available Products

Nanotechnology [76] is research-intensive and mostly relies on public as well as on private R&D funding. Using nanotechnology in consumer products is growing at rapid phase and the market for nanotechnology products is being predicted to grow at a very rapid rate [77].

Nano-Tex

Nano-Tex in Emeryville calif, founded in 1998, [78] has been one of the leaders in nano-treatments designed specifically for textiles, which has developed a new fabric that is showing up in Brookes Brothers shirts, travelsmith sports jacket. Today, more than eighty textile mills around the world are utilizing Nanotex's patented nanotreatments. Nanotreated fabrics can be spill resistant, stain proof, wrinkle resistant and static proof. Nano-Tex is already in stores, but now it may be coming to a soldier or police officer.

Resists

Resists Spills was one of the first nano treatments offered by Nano-Tex. It can be applied to cotton, polyester, [79] wool, silk or rayon. Stain release was designed to mimic the natural characteristics of a plant's leaves. The surface of most leaves is hydrophobic. In a rain shower, water droplets roll off the leaf's surface carrying away contaminants. A leaf's surface is also rough, decreasing the surface's ability to soak up water. Like a leaf's surface, treatments have been developed to make the fabric ultra-hydrophobic. Self-cleaning fibers might eventually replace conventional fluorochemical based finishes currently used to provide water repellency.

Sensatex

Sensatex, based in Bethesda, is working with the military, emergency workers and doctors to develop what they call it a "smart shirt" clothing featuring tiny microscopic wires interwoven into fabric itself [80]. By turning garments into communication devices, this kind of technology that could help outfit of the soldier of the future keeping track of vital signs, and even heat up or cool down depending on the weather. The technology could remotely monitor home-bound patients who wear these shirts, capturing vital data and then beaming it wirelessly to a doctor, a hospital, a family member wherever it needs to go. Sensatex continues to search for investors. There are many advances in this field of nanotextiles.

The future of nanotextiles can be [81]:

1. Supersensitive bio-filters made of fibers capable of filtering out viruses, bacteria, and hazardous particles and microorganisms [82].
2. Nanolayers when applied to natural fibers showed certain properties and then these are made into protective clothing for firefighters, emergency responders, and military personnel that selectively blocks hazardous gases and minuscule contaminants but allows air and moisture to flow through.
3. Lightweight smart textiles which are more comfortable for hikers, athletes, and environmentally sensitive individuals [80].
4. Fibers that control the movement of medicine to administer time released antibacterial [83] and antiallergenic compounds; for example gloves that deliver arthritis medicine or antibacterial sheets in hospitals.
5. Magnetic nanoparticles [84] when embedded inside a garment or paper document to create a unique signature that can be scanned to detect counterfeit currency or fake passports.
6. Sensors that could swab a food or surgical preparation surface to immediately detect the presence of hazardous bacteria.
7. Biodegradable fibers saturated with time-released pesticides that could be planted with seeds as an alternative to spraying pesticides.
8. Doilies, seat cushions, or wall hangings used in airplanes that would continually absorb particles or gases or other airborne biohazards.

Conclusion

Cotton continues to be the most commonly used and popular clothing material. It is the only renewable but also biodegradable and readily available. Since cotton is composed mainly of cellulose molecules, adding functionalities to cotton fibers is a challenging endeavor as physical and chemical heterogeneities need to be overcome. By assembling metal nano-particles on to the cotton several applications can be envisioned. So to this context the development of the nanotextiles came in to existence.

Five properties imparted to textile materials using nanotechnology have been heilightined in this paper. As mentioned, nanotechnology overcomes the limitations of applying conventional methods to impart certain properties to textile materials. There is no doubt that in the next few years nanotechnology will penetrate into every area of textile industry.

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