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Review Article

Application of Nanotechnology in Modern Textiles: A Review

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Abstract

Nanotechnology is considered as one of the most promising technologies for the 21st century. Nanoscience along with nanotechnology encompasses the study and application of very small things and can be used across all the other science fields such as physics, chemistry, biology, materials science, and engineering. This technology overcomes the drawback of applying traditional methods to impart certain properties to textile materials. There is no hesitation that in the upcoming years, nanotechnology will break through into every vicinity of the textile industry. Application of nanotechnology in modern textile lies in areas where innovative principles will be combined into long-lasting, multifunctional textile structures without compromising the intrinsic textile properties including aesthetic, breathability, flexibility etc. The current condition of nanotechnological use in textiles arena is reviewed with an emphasis on improving various properties of textiles.

Keywords: *Nano-composite, e-textile, washing, graphene, medical textile*

Introduction

The perception of nanotechnology is not new-fangled; it was started over forty years ago.

Figure 1: Applications of nanotechnology in textiles by American Chemical Society

According to the National Nanotechnology Initiative (NNI) point of view, nano-technology is characterized as the exploitation of structures with at least one dimension of nanometre size for the manufacture of materials, devices or structures with original or significantly improved properties due to their nano-size (Wong *et al* 2006). Nanotechnology not only produces miniature structures, but also an expected mechanized technology which can offer thorough, inexpensive control of the structure of matter. Most importantly nanotechnology can be described as activities in the level of atoms and molecules which have applications in the real humankind. The nano-particles frequently used in profitable products in the range of 1 to 100 nm [Sawney *et al* 2008]. It goes without saying that, nano-science and nanotechnology together combined, have regenerated material science and led to the development and evolution of a new range of improved materials including polymers and textiles through nanostructuring and nanoengineering.

Nanotechnology is an emerging area which is expected to have wide ranging implications in all fields of science and technology such as material science, materials processing technology, mechanics, electronics, optics,medicine, energy and aerospace, plastics and textiles. Although this technology is still in its infancy, it is already proving to be a useful tool in improving the performance of textiles and generating worldwide interest. The novel application of nanotechnologies in textiles affords an expanded array of properties with potential for improved and new use in products [Musante *et al* 2012]. Changed or improved properties with nanotechnologies can provide new or enhanced functionalities. The information presented in this review article is not exhaustive, but does reflect current national and international research including commercial activities in nanotextiles. Use of nanotechnology and nanomaterials based processes is

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growing at an incredible rate in all fields of science and technology. Textile industry is also experiencing the benefits of nanotechnology in its diverse field of applications. There are various products produced form nanotechnology incorporated with textiles starting from nanocomposites and nanofibers to smart polymeric coatings are getting their way not only in high performance applications, but also successfully being used in different conventional textiles to provide new functionality and improved performance. The main advantages of nanotechnological advancements in textiles are incorporated with greater repeatability, reliability and toughness. Functionization of nanoparticles during various textiles processing like dyeing, finishing and coating enhances the product performance manifold and provides unachieved functionality.

The primary work on nanotechnology in textiles was commenced by Nano-Tex, a contributory of the US-based Burlington Industries [Wong *et al* 2006]. Afterward, other textile companies around the world began to invest for the development of nanotechnologies in various aspects. For example, coating is a common technique used to apply nano-particles onto textiles. The compositions of coating can modify the surface of textiles are usually composed of nano-particles, a surfactant, ingredients and a carrier medium [Joshi *et al* 2011]. Several methods can apply coating onto fabrics, including spraying, transfer printing, washing, rinsing and padding. Of these methods, padding is the most commonly used [Joshi 2005, 2008]. The nano-particles are attached to the fabrics with the use of a padder adjusted to suitable pressure and speed, followed by drying and curing. The properties imparted to textiles using nanotechnology include water repellence, soil resistance, wrinkle resistance, anti-bacteria, anti-static and UV-protection, flame retardation, improvement of dye-ability and so on. As there are various potential applications of nanotechnology in the textile industry, only some of the well-known properties imparted by nano-treatment are critically highlighted in this paper.

Nanotechnology in textiles

There are various types of newly developed coating techniques like sol-gel, layer-by-layer can develop multi-functional, intelligent, excellent durability and weather resistance to fabrics (Yetisen *et al* 2016). The present study primarily focuses on the improvement and potential applications of nanotechnology in developing multifunctional and smart nanocomposite based fibers, nanofibers and other new finished and coated textiles with nanotechnology based ideas. The idea of nano-materials in textile finishing and processing to enhance product performance is also discussed. Nanocoating is relatively a new technique in the arena of textile sector and currently under research and development stage. There are various polymeric nanocomposite coatings where nanoparticles are dispersed as polymeric media and used for coating applications is really a promising route to develop multifunctional and smart high performance textiles [Lam *et al* 2006]. The foremost researched area to produce multifunctional, intelligent fibers is the preparation of nanocomposite fibers where the exceptional properties of nanoparticles have been utilized to enhance and to impart several functionality on traditional textile based fibers. Investigation also revealed that, nanofibers which are sub-micron size in diameter are also gaining much more popularity in specialized technical applications such as filter fabric, antibacterial patches, tissue engineering and chemical protective suits.

Nano-finishes and coatings for advanced technical textiles

Nanotechnology has incredible commercial prospective for the textile industry. This is mainly due to the fact that, traditional methods which are used to impart different properties to fabrics often do not show the way to everlasting effects and sometimes may lose their functionality after repeated laundering or wearing. Therefore nanotechnology based advancement has opened tremendous possibilities in textile finishing techniques resulting into ground-breaking new finishes as well as new application techniques. The most important is on making chemical finishing more controllable, durable and significantly enhance the functionality by applying various kinds of nanoparticles or creating structured surfaces based on nanotechnology [Khan *et al* 2012].

Remarkable level of textile performances in nanofinishes such as stain resistance, antimicrobial, controlled hydrophilicity / hydrophobicity, antistatic, UV resistant, wrinkle controlled and shrink proof abilities can be exploited for a long range of technical textile applications such protective clothing, medical textiles, sportswear, automotive textiles etc. Finishing techniques incorporated with nanotechnology applied in nanoemulsion form also enables a more smart application on textiles surfaces. More importantly, nanotechnology based finishing can provide high durability for fabrics, this is due to the fact that, nano-particles have a large surface area-to-volume ratio and high surface energy, thus offering better affinity for fabrics and leading to an increase in durability of the function. Consequently a coating along with nano-particles on fabrics surface will not affect their hand feel properties. For that reason, the interest for scientists and technologists in using nanotechnologies in the textile industry is increasing.

Water repellence by nano-whiskers

Water-repellent property enhancement of fabric by creating nano-whiskers was developed by Nano-Tex, where hydrocarbons and 1/1000 of the size of a typical cotton fiber were added to the fabric to create peach fuzz like effect without lowering the strength of cotton fiber. The intermolecular spaces between the whiskers on the fabric surface are smaller than the typical drop of water, but larger than water molecules. Technically water remains on the top of the whiskers and above the surface of the fabric [Xin *et al* 2004, Draper 2003, Joshi*et al* 2006]. More importantly, liquid can still pass through the fabric, if certain amount of pressure is applied. The performance still at large remains permanent while maintaining breathability or hand feel property.

The most desired hydrophobic property can be imparted to a cotton fabric by coating it with a 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 [Windler *et al* 2012]. In addition, the hydrophobic property with marvelous attributes also obtained for the unevenness of the fabric surface, without affecting the softness and abrasion resistance of cotton fabric.

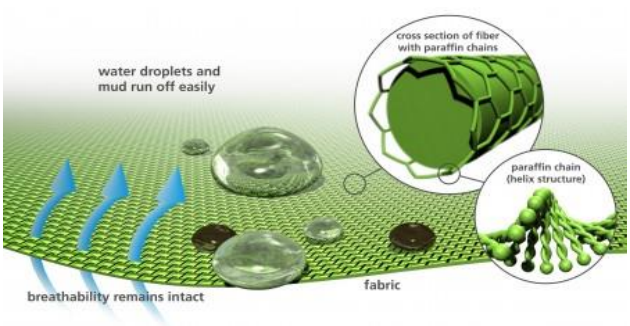

Figure 2: Mechanism of nanosphere on textiles applied by nano-sphere technology (Ecorepel®)

Nano-electronics in textiles:

Energy oriented textile based products that lead to wearable 'smart' technology can control integrated electronics along with sensors through conventional body movements; interwoven solar cells that turn T-shirts into power textiles; a wearable smart textile battery that can be recharged by sunlight; nano-electronics at the tip of a gloved finger; graphene yarns facilitate energy storage textiles; 'e-textile' coated with graphene detect noxious gases. Some researchers investigated that, electrical conductivity of conducting polymers and graphene, both of which are attractive for creating textiles enable the incorporation of sensors and actuators. Some scholarly works postulated about lightweight fabric carbon nanotube super-capacitor electrodes; stretchable graphene and PPy (Polypyrrole)-based super capacitors; triboelectric nanogenerators; flexible fiber and stripe batteries, stretchable PPy-based super capacitors for energy transfer. Adding digital components to these e-textiles would open up an entirely new area of functional clothing. OLEDs in fiber form could lead to revolutionary applications by integrating optical and optoelectronic devices into textile. Combined with nanoelectronic device, one day the whole world will see flexible optical sensors and display screens woven into shirts and other garments.

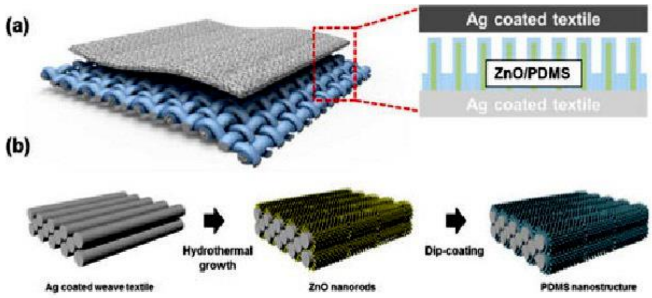

Figure 3: (a) Schematic illustration of a wearable triboelectric nano-generator (b) Fabrication process of the nano patterned PDMS structure by American Chemical Society)

UV-protection

Technically, inorganic UV blockers are far more preferable to organic UV blockers as they behave like chemically stable and non-toxic under constant exposure to high temperatures and UV. It is said that, semiconductor oxides such as TiO_2, ZnO, SiO_2 and Al_2O_3 are usually Inorganic UV blockers. Among these semiconductor oxides, titanium dioxide (TiO_2) [15-21] and zinc oxide (ZnO) [Saito 1993, Xiong *et al* 2003, Yasuhide *et al* 1997] are commonly used. It was observed that, nano-sized titanium dioxide and zinc oxide were more efficient at absorbing and scattering UV radiation than the traditional size and performs better to obstruct UV radiation [Xin *et al* 2004 and Saito 1993]. The main reason behind this, nano-particles has a larger surface area per unit mass and volume than the conventional materials, which leads to the increase of the effectiveness of blocking UV radiation.

Wrinkle resistance

In order to impart wrinkle resistance to fabric, resin is conventionally used. However, there are some limitations regarding to apply resin, including a decline in the tensile strength of fiber, abrasion resistance, water absorbency and dye-ability and breathability as well. For that reason, to overcome the limitations of resin application in textiles, some researchers employed nano-titanium dioxide [Xu *et al* 2005, Chien *et al* 2003] and nano-silica to improve the wrinkle resistance property of cotton and silk fabrics respectively. Apart from that, nano-titanium dioxide was employed along with carboxylic acid as a medium under UV irradiation to catalyze the cross-linking reaction between the cellulose molecule and the acid. Furthermore, application of nano-silica with maleic anhydride as a catalyst; results showed that the application of nano-silica with maleic anhydride could successfully develop the wrinkle resistance of silk [Wang *et al* 2005, Song *et al* 2001].

Application of nanosilver for antibacterial nano-finishes

There are wide ranges of antimicrobial textile finishes and products have been studied and quite a few of them have already been commercialized, which are based on to great extent superior antimicrobial properties of silver in nanoform. Nano silver particles containing antimicrobial dressings have been incorporated in wound care and have gained wide range of acceptability in medical applications, as secure, safe, harmless and effective means of controlling microbial growth around the wound, resulting in improved healing. Furthermore nano silver based medical textiles has also been developed and commercialized for health and hygiene security (Ali *et al* 2011).

Self-cleaning nano finishes

There are various plants around in nature including the Lotus leaf exhibit unusual wetting phenomena of super hydrophobicity. Technically a super hydrophobic surface is defined as one that can bead off water droplets completely along with exhibit water droplet advancing angles of 150 degree or higher at the surface area (Bozzi *et al* 2005). For that reason, a self-cleaning surface thus results since the rolling water droplets across the surface can easily pick up the dirt particles to leave behind a clean surface. By observing from the nature several marvelous approaches have been researched to generate super hydrophobic surfaces on textiles, which imitate the nanostructured Lotus leaf and therefore show signs of self-cleaning properties (Ali *et al* 2010, Bhattacharyya *et al* 2012).

Nano-finishes for antistatic property

An investigation revealed that, man-made fibers such as nylon and polyester are prone to static charge accumulation as they absorb a lesser amount of water. It also has been reported that nano sized TiO_2, ZnO whiskers, nanoantimony-doped tin oxide (ATO) along with silane nanosol could provide antistatic properties to man-made fibers; so that TiO_2, ZnO and TiO_2 nanoparticles are electrically conductive substances and help drive away the static charge in these fibers (Kathiervelu *et al* 2003).

Nano-coatings and electrochemical deposition

Nanostructured surfaces are of great interest, due to their large surface area, which might yield high functionality. Nanocoating refers to the covering of materials with a layer on the nanometer scale (10 - 100 nm in thickness) or covering of a nanoscale entity to form nanocomposite and structured materials. Nanocoatings on Textiles have recently been explored using mainly processes such as plasma-assisted polymerization, self-assembly, sol-gel nanocoating and electrochemical deposition (Zhang *et al* 2003, Wang *et al* 2004).

Conclusion and future trends

There is no denying of the fact that, nanotechnology has been emerged as the essential technology, which has revitalized the material science and has the prospects for development and advancement of new range of intelligent materials including polymers and textiles. To wrap up about application of nanotechnology in textiles, definitely has the potential to being revolution in the field of technical textiles. There is however a word of carefulness because industrial commercialization of the nanotechnology based products can become a commercial reality.

The issues are listed below:

- Mass production of nano particles and their cost of production.
- Practical implications on determination of mechanical suitability for use.
- Impact of uncontrolled release of nanoparticles in the environments and their effect on human health along with whole ecosystem widely covered under the realm 'nanotoxicology'.
- Develop and adapt test guidelines that ensure the comparability of research findings on the environmental impact and behavior of nano materials.
- Realistic viewpoint and ethics on the wide spread utilize of nanotechnology based products.

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