APPLICATIONS OF NANOTECHNOLOGY IN TEXTILES AND COTTON NONWOVENS: A REVIEW

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Introduction

Nanotechnology is a science that deals with the understanding, manipulation, transformation, control, and efficient utilization of matter at nanometer dimensions or, say, near molecular levels. The term *nano* refers to a linear dimension that is a billionth of a meter or, say, one thousandth of a micron, which is a millionth part of a meter. Although the underlying concept of nanotechnology or the formerly so-called *sub-micro* is several decades old, the recent couple of decades indeed have seen significant spurs in the developments and innovations of the technology in many industries and manufacturing sectors, including fibers and textiles (woven, knitted and nonwoven fabrics). The reason for the recent spurs and rapid growths in applications of the technology is the successful commercial demonstration of the underlying fact that a matter at or near its molecular level or dimension exhibits considerable improvements in some of its classical physical, mechanical, chemical, biological, light spectrum, electronic energy, and the like properties. And that when the matter at its nano dimensions, even in small quantity, say 2 to 5% by weight of the bulk material, is integrated with a compatible bulk matter/substrate, the former's improved characteristics efficiently enhance desirable attributes of the latter's ultimate end-product. For example, nano particles of certain materials, when somehow impregnated into or embedded in cotton fiber, yarn or fabric, can significantly improve the latter's durability, softness, stain resistance, dye-ability, thermal resistance/stability, wrinkle resistance, dimensional stability, abrasion resistance, fluid absorbency or repulsion, antimicrobial/biocide effects, or the like. Textiles in general and cotton textiles and nonwovens in particular are expected to be the major beneficiaries of the rapidly growing nanotechnology.

Transformation of Bulk Matter into Nano-Size Particles

There are several methods or processes to transform a bulk matter or material (in any of the three forms, viz., solid, liquid and gas) into its nano-size particles. The most popular or promising are:

1. ***Electro-spinning***: In this process, the bulk material in fused/molten or in a solution form is subjected to a very high electric potential (up to 60 KV), while being extruded through a spinneret of nano-size pores/orifices and laid on to a grounded plate. The nano fibers/whiskers thus produced have significantly improved properties, such as strength modulus, electric resistivity, electronic energy, light spectrum, absorbency, and the like, compared to its parent bulk material.
2. ***Coagulation-based carbon-nano-tube spinning method***: This is an advanced electro-spinning process in which composite nano fibers are produced from synthetic nano fibers. Nano-yarns comprised of Multi-Walled CNT (MWCNT) that consist of 7 to 20 concentric cylinders of Singled-Walled CNT, can be produced by *simultaneous reduction of fiber diameter* and increase in twist up to 1000. These nano materials extend extra strength, toughness, energy-damping capability, etc., and can be deployed to produce electronic textiles for supporting multi-functionalities, including capability for actuation, energy storage capacity, radio or microwave absorption, electrostatic discharge protection, textile heating, and/or wiring for electronic devices.
3. ***Ionization of polymeric materials in very low concentration/viscosity solutions***: In this process, the dissociation of certain materials in solution form into their nano-size cationic and anionic groups of molecules which is utilized to alternatively and repeatedly deposit nano-scale layers of the nano ionic components of the materials. Unlike the application of free radicals of the materials, this repeated cationic-anionic assembly or the so-called Layer-by-Layer (L-b-L) deposition of nano particles of certain polymeric components on a cotton substrate, whether woven or nonwoven, can exhibit significantly improved functionalities of the end-product. For example, deposition of silver in nano format on a cotton fabric provides satisfactory antimicrobial and wound-healing features, while integration of a cotton substrate with nano particles of silicon oxide or a ceramic may as well offer the desired thermal stability to the cotton end-products.

Applications of Nanotechnology in Textile Processes and Products

Nanotechnology today provides a plenty of efficient tools and techniques to develop desirable fabric functionalities and attributes. By changing the surface structures of fibers, several diverse fiber functionalities can be obtained for profitable exploitation of functional fabrics for special applications. One of the possibilities to develop desired functionality is by embossing the surface of synthetic fibers with nano structures. Integration of nano-sized antimicrobial particles into textile fibers leads to the development of superior wound dressings. Similarly, by incorporating ceramic nanoparticles into a spinning solution, polyimidoamide fibers can be produced in which SiO_2 nano-particles are present. Such a "nano treatment" can also produce antistatic polyacrylonitrile (PAN) fibers consisting of electrically conductive channels, which not only possess antistatic properties but also have good mechanical properties. Chemical modifications of synthetic fibers using nano particles can enhance the fibers' porosity and absorption properties, which are very useful to produce thermal-resistant and flame-resistant fabrics. Desirable thermal properties as well as enhanced fiber tenacity can also be obtained by modifying the surface of the fibers with other (nano) matters such as diamine (diaminodiphenyl methane), montmorillonite, and silica nanoparticles, etc. Specific functionality in fibers can also be achieved by another leading chemical oxidative deposition technology, which deals with the deposition of Conducting Electroactive Polymers (CEP), i.e. polyaniline, polypyrrole, polythiophene, and their derivatives (in nano form) onto different kinds of synthetic fibers, resulting in special composite fibers with high tensile strength and good thermal stability. Surface polymerization of CEP (by Graft copolymerization) of polymer fibers has a potential to increase the fibers' conductivity almost 10 times by decreasing their electrical resistivity. These so-called coated polymeric composite fibers can be used in microwave attenuation, EMI shielding, and dissipation of static electric charge. They can also be useful in developing fabrics intended for military applications, e.g., camouflage, stealth protection, and the like. It may be mentioned that the polymer deposition techniques can be further improved to obtain many other desirable characteristics of CEP coated textiles. In the melt-spinning process, polypropylene/nano-carbon fiber composites with significantly enhanced modulus, compressive strength, and dispersion properties can be produced. Through optimal orientation and crystallization of nanofibers, excellent properties of composite fibers can be achieved and successfully used for the micro-filtration applications in the medical field.

Finishing of fabrics, made with natural and synthetic fibers, to achieve desirable hand, surface texture, color, and other special aesthetic and functional properties has been a primary focus in textile processing. In the last decade alone, the advent of nanotechnology has spurred significant developments and innovations in this field of textile technology. Fabric finishing has taken new routes and demonstrated a great potential for significant improvements by applications of nanotechnology. The developments in the areas of surface engineering and fabric finishing have been highlighted in several manuscripts. There are many ways in which the surface properties of a fabric can be manipulated and enhanced by implementing appropriate surface finishing, coating, and/or altering techniques, using nano-technology. A few representative applications of fabric finishing using nanotechnology include the UV rays and radiation protection; breathability; temperature control; wetting prevention; coating of fabrics with nano-beads used for carrying desired chemical molecules; development of water- or stain- resistance; etc.. Most successful developments in this regard can be attributed to a US-based company, Nano-Tex™. By using nano-technology, they have developed several fabric treatments to achieve certain enhanced fabric attributes, such as superior durability, softness, tear strength, abrasion resistance, and durable-press/wrinkle-resistance. In fact, this company is a pioneer in the development of several fabric coatings and treatments, which are capable of providing the above-stated high-performance fabric attributes. For example, their trademark *Nano-Pel* technology for stain-resistance and oil-repellency treatments utilizes the concept of surface engineering and develops hydrophobic fabric surfaces that are capable of repelling liquids and resisting stains, while complementing the other desirable fabric attributes, such as breathability, softness and comfort. Basically, this sort of surface treatment attaches small nano-whiskers, which are nano-structures to provide roughness to the fabric surface so that fluid-surface interaction and consequently fluid penetration can be avoided and the treated fabric has permanent water- and stain- resistant properties. The same company has also developed several other fabric treatments and trademarked technologies. *Nano Touch* is a trademark for one of their nano technologies for treating a "core-wrap" type of fabric. In a core-warp yarn or fabric, a core of usually synthetic fibers is wrapped with natural fibers, such as cotton. The (nano) treated core component of a core-wrap bi-component fabric provides high strength, permanent anti-static behavior, and durability, while the traditionally-treated wrap component of the fabric provides desirable softness, comfort, and aesthetic characteristics. *Nano Care* technology is offered to produce wrinkle-free/resistant and shrink-proof fabrics made of cellulosic fibers, such as cotton. *Nano Dry* technology, on the other hand, provides hydrophilic finishing to synthetic fabrics. This nano-based finish allows the fabric to quickly wick away the contact body's moisture/sweat, which quickly evaporates to provide comfort to the wearer. This company has also developed a technology in which *Nanobeads* are used into the textile substrate for carrying bioactive or anti-biological agents, drugs, pharmaceuticals, sun blocks, and textile dyes, which subsequently can provide desired high performance attributes and functionalities to the treated fabrics.

Very recently, Beringer and Hofer have demonstrated that by combining the nano-particles of hydroxylapatite, TiO_2, ZnO and Fe_2O_3 with other organic and inorganic substances, the surfaces of the textile fabrics can be appreciably modified to achieve considerably greater abrasion resistance, water repellency, ultraviolet (UV) resistance, and electromagnetic- and infrared- protection properties. For example, the titanium-dioxide nanoparticles have been utilized for the UV protection. Similarly, by using nano-sized silicon dioxide as an additive in coating materials, significant improvements in the strength and flame-resistance of textile fabrics can be achieved. For cotton fabrics, wrinkle resistance can be developed by using the nano-engineered cross-linking agents during the fabric finishing process. Besides the wrinkle resistance, such finishing is also capable of eliminating toxic agents, while maintaining the desired comfort properties of cotton. It has also been shown that a wide range of so-called functional finishing of fabrics can be obtained by using micro encapsulation technique, which is widely used in the pharmaceutical industries, as well. This technology enables to carry out several liquid or solid agents (fragrant, flame-retardant agents, etc.) that are encapsulated in phase-changing materials acting as binders (e.g., wax). This technology, for an example, can be used to develop odor-eliminating finishes of fabrics. Fire-retardant and anti-microbial agents can also be microencapsulated for advanced fabric finishing. These advances in the application of nanotechnology are expected to further improve fabric finishing for the next generation of fabrics. The following are a few representative textile products that have been modified by using nanotechnology:

- Military and combat outfit
- Camouflage and tents
- Jackets and gloves
- Sportswear
- Hygienic underwear
- Composite fabrics and other materials
- UV-protective clothing
- Medical fabrics & tissue engineering
- Climate control garments
- Electronic textiles

Recently, a Swiss company Scholler has also developed a nano-based technology to produce a new line of brand name fabrics, such as "Soft-Shells," functional stretch multi-layer fabrics. The fabrics and the garments made there-from are capable of dynamic climate control, which provide optimal balance of comfort, air permeability, wind and water resistance through their "soft inner layer" and "tough and durable outer layer." The technology is being used in the manufacture of apparel for extreme cold weathers and for out-door, mountain sports, ski sports, and various other sportswear applications. The company has also developed an innovative "Nano-Sphere™" finishing treatment of the fabrics, which provides self-cleaning feature and resists stains. The company's Schoeller®-PCM technology offers moisture management features and provides comfort and protection at the same time. The combination of NanoSphere™ finish and "Soft-Shell" technology is capable of producing fabrics/garments that repel rain and snow. Several fabric and garment manufacturing companies have utilized these advanced technologies in developing a wide range of special-purpose apparel. For example, ski-wear and jackets with 3XDRY® Moisture Management System by Allsport; extreme performance jacket and pants by Mammut, Mountaineering; and cliff pants and jackets by Millet; abrasion- and tear- proof footwear that is light, breathable and air permeable is offered by Schoeller®-Keprotec® (material provided by Springboost); and gloves by Reusch and Swany. Similar lines of products have also been designed by several other companies, as well. For example, Germany's Franz-Ziener has introduced ski jackets, which feature Nano-Tex coatings to make them windproof, waterproof, and breathable. With the help of advanced finishing products, UV protection can also be obtained, in addition to the good durability, good air permeability, and soft hand feel.

Significant advances are envisioned towards the development of military and combat uniforms and apparel, using nanotechnology. One of the largest and perhaps unique research centers in the world, whose main focus is on the development of next generation of materials for soldiers, is the Institute for Soldier Nanotechnologies (ISN). This institution is a consortium of research collaboration among the US Army, the Massachusetts Institute of Technology (MIT), and several industrial organizations. The research conducted by this consortium is dedicated to developing, mainly for the military, advanced textile materials and products by utilizing nanotechnology. The main focus is to develop a variety of textile fabrics and other products/materials that are light weight (so that the overall load on soldiers can be reduced significantly), strong, abrasion/wear resistant, durable, waterproof, capable of changing color (to improve camouflage), energy absorbent (to be bullet proof), temperature sensitive (for different climate controls), and embeddable with multi-purpose micro/nano sensors. In addition, several antimicrobial textile treatments are currently being produced that can play very significant roles in protection against a wide range of physical/chemical/biological threats. To produce battle-ready smart textiles, several disparate technologies, such as micro capsulation, biotechnologies, and information technology, are being utilized. Quantum Group Inc., in its recently patented technology, has shown that the combination of "nano-fibrils" (0.4-1 nano meter, produced by electro spinning process with reinforcing, strong fibers or filaments) can be used for producing yarns as well as nonwoven fabrics that can be utilized in tissue engineering. Otsuka Kagaku has developed new electro conductive (nano) fibers that can be used for the protection against radiation emitted by electronics. Several other technologies for producing fabrics to shield radiations are also being investigated. Hanes, USA, has developed some anti-cellulite shaper wear fabrics, which utilize the micro-encapsulation techniques to modify the appearance of cellulite. Cellulose from a variety of very cheap sources, such as grass, kenaf, cotton fiber, cotton plant material, etc., may be used. These composites improve the thermal stability of the cellulose and, therefore, may lead to the development of certain flame-retardant, end-products, such as nonwovens, special-purpose papers, filaments, coatings, etc.

In addition to the development of improved textile fabrics and materials, several advances in the area of textile processing have also been made. For example, the textile dyeing and finishing processes use dyes and other chemicals that are expensive and cause a serious environmental concern when the effluents after processing are discharged into public waterways. Nano-filtration membrane technology developed in recent years is being aggressively investigated to try to recover the dyes for economic and environmental benefits and, at the same time, conserve precious water. Nanofiltration technology consists of a separation process in which relatively small organic molecules along with some ionic components are retained by a nanoporous membrane. These grafted membranes are capable of removing the dye molecules, so that the dye can be recovered and the processed water can be recycled and reused. A novel, Spiral-wound membrane technology also exists for the treatment of textile effluents, using nano and ultra filtration units. Nanotechnology is also widely applied in the developments of pigment particles used for dyeing and printing of textile fabrics. Recently, the researchers at the Technical University of Liberec have invented and patented Nanospider™ technology to mass produce nano-fibers for textile applications.

References

(Please note that a complete list of references on the subject can be found in the following reference)
Sawhney, A.P.S., Condon, B., Singh, K. V., Pang, S.S., Li, G., and Hui, D. Modern Applications of Nanotechnology in Textiles. Text. Res. J. 78 (8), p. 731-739. (2008).

Endnotes

1. The Southern Regional Research Center (SRRC) is one of the major research facilities of the Agricultural Research service of the U. S. Department of Agriculture.

2. Mention of companies and their commercial products and trade names in this publication is solely for the purpose of providing specific information and does not imply any recommendation and/or endorsement of them by the U.S. Department of Agriculture.