REVIEW ARTICLE

Eleyon NANOSCALE REPORTS

DOI: 10.26524/nr1832

Applications of Nanotechnology for Textile Products: A Review

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Received : 12-10-2018
Accepted : 21-11-2018

ABSTRACT: The fundamentals of nanotechnology lie in the fact that the properties of materials drastically change when their dimensions are reduced to nanometer scale. Nanotextiles can be produced by a variety of methods. The use of nanotechnology in the textile industry has increased rapidly due to its unique and valuable properties. Changed or improved properties with nanotechnology can provide new or enhanced functionalities. Nanotechnology is a growing interdisciplinary technology and seen as a new industrial revolution. The future success of nanotechnology in textile applications lies in the areas where new principles will be combined into durable and multi-functional textile systems without compromising the inherent properties. The advances in nanotechnology have created enormous opportunities and challenges for the textile industry, including the cotton industry.

Keywords: Nanometer Scale, Nanotextile, Nanofibre, Nanofinish, Antibacterial.

Introduction

Nanotechnology is a growing interdisciplinary technology often seen as a new industrial revolution. Nanotechnology deals with materials **from 1 to 100 nm in length.** The fundamentals of nanotechnology lie in the fact that the properties of materials drastically change when their dimensions are reduced to **nanometer scale** [1]. Now-a-days, also the textile industry has discovered the possibilities of nanotechnology. Therefore, it is understood that nanotechnology in textiles is the understanding, manipulation and control of matters with the above mentioned length, such that the physical, chemical and biological properties of the materials can be engineered, synthesized and altered to develop the next generation of improved materials, devices, structures and systems. It is used to develop desired textile characteristics such as high tensile strength, unique surface structure, soft hand, durability, water repellent, fire retardant, antibacterial properties and many others.

Nanotechnology in **'nanotextiles'** can be produced by a variety of methods. The key differences among them is that whether synthetic nanoparticles are integrated into the fibres or the textiles, or are applied as a coating on the surface, and/or whether nanoparticles are added to the nanoscale fibres or coating [2]. However, information about manufacturing methods, the nanomaterials themselves and the quantities used as well as the life cycle of the nano treated textile for sale is largely unavailable to the consumers. The report of the author clarifies nanotextiles manufacturing processes and application areas and gives an overview about the potential effects on the environment and health.

Nanotechnology is an emerging technology that has been booming in many areas during the recent decades, including material science, mechanics, electronics, optics, medicine, plastics, energy and aerospace. Its profound secret impact has been considered as the huge momentum to the users in a second industrial revolution [3-4]. Although textile industry is a small part of the global research in the emerging areas of nanotechnology, the fibres and textile industry in fact were the first to have successfully implemented these advances and demonstrated the applications of nanotechnology for consumer usage [5]. Self-cleaning fabrics could revolutionize the sport apparel industry. The technology has already been used to create **T-shirts and under wears** that can be worn hygienically for weeks without washing [6]. For small particles, light scattering predominates at approximately **one-tenth of the wave length of the scattered light.** As the nanoparticles have a **larger surface area per unit mass and volume** than the conventional material, which ultimately lead to the increase of the effectiveness of the **blocking UV-radiation** [7]**.** For imparting anti-bacterial properties, nanosized sliver, TiO2, and zinc oxide are used. Nano-ZnO provides effective photo catalytic property [8]**.** Nanotechnology has been applied in the manufacturing of **anti-static garments.** TiO2, ZnO and ATO help to effectively dissipate the static charges which accumulate on the fabrics [9]**.** The unique properties of nanomaterials have attracted not only scientists and research workers but also businessmen, because of their huge economic potential [10]**.**

The application of nanotechnology to textiles affords an expanded many of the properties with potential for improved and novel use in materials and products. Changed or improved properties with nanotechnology can provide new or enhanced functionalities to reflect current national and international research and commercial activities of nanotextiles [11]**.** Many products use or with commercialization will use, chemical, physical or electronic technologies to respond passively or actively to thermal, chemical, biological, electromagnetic and mechanical stress. These products include warming and cooling textiles, conductive textiles, communication textiles, etc [12]**.** Nanofinished textiles are those that apply a nanoscale property added after the base treatment has been fabricated. This includes post-manufacture treatments and coatings to apply nanomaterials or create nanofibrous surfaces or fibre media [13]**.** Fibre fabrication for nanofibrous textiles typically would be new. Not only does initial fabrication of the fibre require a process that can create nanofibres such as electro spinning or force spinning, which are not conventional drawing methods, but all of the subsequent steps in the manufacturing process must accommodate these smaller fibres [14]**.** Production of nanomaterials may require advanced equipment not typical within the textile industry, for example treatment chemicals, polymer composites, and then film coatings. Nano-object generation may use advanced machines [15]**.** Testing and characterizing nanotextiles may pose challenges not found in regular textiles. Material specifications are critical in manufacturing. Nanomaterials have unique properties requiring close control of parameters so as not to alter performance [16]**.** Nanotechnology can provide high durability, because the nano-particles have **a large surface area-to-volume ratio and high surface energy,** thus presenting better affinity for fabrics and leading to an increase in durability of the function and in addition, a coating of nanoparticles on fabrics will not affect their breath ability or feel [17]**.**

Among the many applications of nanotechnology, textile industry has been currently added one of the most benefited sector. Application of nanotechnology in the textile industry has tremendously increased the durability of fabrics, its comfort and hygienic properties and has also reduced its production cost. Nanotechnology also offer many advantages as compared to the conventional process in terms of economy, energy saving, eco-friendliness, control release of substances, packaging, separating and storing materials in a microscopic scale for later use and release under controlled conditions [18]**.** The applications of nanoparticles to textiles have been the objects of several studies aimed at producing finished fabrics with different functional performances. The particle size also plays a primary role in determining their adhesion to the fibres. It is reasonable to expect that the largest particle agglomerate will be easily removed from the fibre surface, while the smallest particle will penetrate deeper and adhere strongly into the fabric matrix [19]**.** The use of nanotechnology allows textiles to become multifunctional and produce fabrics with special functions, including antibacterial, UV-protection, easy clean, water and stain repellent and anti-odour [20]**.**

It has been discovered that unique composite fibres were produced from synthetic nanofibres obtained through an advanced electro-spinning process, such as the coagulation based carbon-nano-tube. These composite fibres afford electronic textiles for super capacitors [21]**.** A nano-treatment can also produce anti-static polyacryonitrile **(PAN)** fibres consisting of electrically conductive channels, which not only possess antistatic properties but also have good mechanical properties [22]**.** Specific functionalities in fibres can also be achieved by another leading chemical oxidative deposition technology, which deals with the deposition of **conductive electroactive polymers (CEP),** i.e, polyaniline, polypyrrole, polythiophene and their derivatives on to different kinds of synthetic fibres, resulting in a special composite fibre with high tensile strength and good thermal stability [23]**.** Fabric finishing has taken new routes and demonstrated a great potential for significant improvement by application of nanotechnology. The developments in the areas of surface engineering and fabric finishing have been highlighted in several research works [24]. Nanotechnology based processes in textile fibres, yarns and fabric-finishing have led to the development of several new and improved textile products [25]. Nanotechnology brings the possibility of combining the merits of natural and synthetic fibres, such that advanced fabrics that complement the desire attributes of each constituent fibre can be produced.

Nanotechnology in textile Engineering

The vast development and changes in life style has attracted people towards a more comfort and luxurious life. People are moving towards small, safer, cheaper and fast working products which not only reduces the work load but also help them to carry out their works at a much greater pace with minimum efforts. There have been developments of gadgets that are much smaller in size like micro chips, nanocapsules, carbon tubes, memory cards, pen drives, etc which reduces the problems of transport and storage and are also much faster and reliable by which works can be carried out in lesser time. The concept of nanotechnology was given by **Nobel Laureate Physicist Richard Feynman in 1959.** Generally nanotechnology deals with structures that are sized between 1 to 100 nm at least on dimension and involves developing materials or devices possessing dimension within that size. Nanotechnology creates structures that have excellent properties by controlling atoms and molecules, functional materials, devices and systems on the nanometer scale by involving precise placement of individual atoms. Although nanotechnology is a relatively recent development in scientific research, the development of its central concepts happened to be over a longer period of time [18].

(a)Nanotechnology in textile industry and textile engineering- Application of nanotechnology in textile industry has tremendously increased the durability of fabrics, increased its comfort, hygienic properties and have also offers many advantages as compared to the conventional process in terms of economy, energy saving, eco-friendliness, control release of substances, packaging, separating and storing materials on a microscopic scale for later use and release under controlled conditions. The object of several studies for the application of nanotechnology to textile materials aimed at producing finished fabrics with different functional performances. A whole variety of novel nanotech textiles are already on the market at this moment. The areas where nanotech enhanced textiles are already seeing their applications include sporting industry, skincare, space technology for better protection in extreme environments. The use of nanotechnology allows textiles to become multifunctional and produce fabrics with special functions including anti-bacterial, UV-protection, easy-clean, water and stain repellent and anti-odour [19].

(b)Types of nanomaterials-Nanostructure composite fibres are intensively used in automotive, aerospace and military applications. Nanocomposite fibres are produced by dispersing nanosize fillers into a fibre mix. Due to their large surface area and high aspect ratio, nanofibres interact with polymer chain movement and thus reduce the chain mobility of the system. Being evenly distributed in polymer matrices, nanoparticles can carry load and increase the toughness and abrasion resistance [20]. Carbon nanofibres and carbon black nanoparticles are among the most commonly used nanosize filling materials. Filtration devices and wound dressings are just some of the applications of nanofibres. Medical stuff, fire fighters, the emergency services or military personnel could all be benefited from protective garments made of carbon nanofibre materials. Clay nanoparticles are resistant to heat, chemicals, and electricity and have the ability to block UV light. Nano composite fibres which utilize clay nanoparticles can be engineered to be flame, UV light resistant and anti-corrosive. Carbon nano tube is a tubular form of carbon with diameter as small as nanometer **(nm).** A carbon nanotube is configurationally equivalent to a 2-dimensional grapheme sheet rolled into a tube. The composite fibres have potential applications in safety harnesses, explosion proof blankets and electromagnetic shielding applications. Polymeric materials with nanosize porosity exhibit light weight, good thermal insulation as well as high cracking temperature without scarifying in mechanical strength. These are fully bio-degradable and relatively high strength.

Application of Nanoparticles in Textiles

(a)Self-cleaning fibres-Due to the advancement of nanotechnology in the manufacturing of fibres or yarns including the development of fabric finishes, the applications and scopes are wide spread in the area of textiles for years to come. With the developments in science and technology, self-cleaning clothes are no more the things of dreams. It is a brilliant application of nanotechnology that has made possible to obtain this property on the clothes and other materials as well. The technology uses nanocrystals treatment by controlling wet ability and surface interaction [03]. It can be done by two methods, namely, (i) by the coating material containing a photo-catalytically active oxide of a transition metal (MO) or (MO2), such as titanium dioxide (TiO2) and (ii) in the other technique, self-cleaning materials are based on nanocrystals making the surface oil or water repellent by controlling wet ability and surface interaction. Self-cleaning fabrics could revolutionize the sports apparel industry.

(b)Water repellent property-Nano-Tex improves the water repellent property of fabrics by creating nano-whiskers , which are hydro-carbons and 1/1000 of the size of a typical cotton fibre, that are added to the fabric to create a peach fuzz effect without lowering the strength of cotton. The space between the whiskers on the fabric is smaller than the typical drop of water, but still larger than the water molecules, water thus remaining on the top of the whiskers and above the surface of the fabric [04]. On the other hand, a hydrophilic 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 on to a cotton fabric surface to improve its water repellent property.

(c)UV-protection property-Various research works on the application of UV-blocking treatment to fabrics using nanotechnology have been conducted [05]. UV-blocking treatment for cotton fabrics was developed using the sol-gel method. A thin layer of titanium dioxide is formed on the surface of the treated cotton fabric, which provides excellent UV-protection and the effect can be maintained after **50 home washings.** Apart from titanium dioxide, zinc oxide nanorods of 10 **to 50 nm in length** were applied to cotton fabrics to provide UV-blocking effect and the fabrics treated with zinc oxide nanorods demonstrated an excellent UV-protection.

(d)Anti-bacterial property-For imparting **anti-bacterial** Nanosized silver, TiO2 and Zinc Oxide are used. Metallic ions and metallic compounds display a certain degree of sterilizing effect. It is considered that part of the oxygen in the air or water is turned into active oxygen by means of catalysis with metallic ions, there by dissolving the organic substance to create a sterilizing effect [06]. With the use of nanosized particles the number of particles per unit area is increased, thus the anti-bacterial effects can be maximised. Nanosilver particles have an extremely large relative surface area, thus increasing their contact with bacteria or fungi and vastly improving their bactericidal and fungicidal effectiveness. Nanosilver is very reactive with proteins. When contracting bacteria and fungus exist, it will adversely affect cellular metabolism and inhibit cell growth. It also suppresses respiration the basal metabolism of the electron transfer system, and the transport of the substrate into the microbial cell membrane. Nanosilver particles are widely applied to socks in order to prohibit the growth of bacteria. In addition, nanosilver can be applied to a range of other healthcare products such as dressing for burns, scald, skin donor and recipient sites. It was determined that a fabric treated with nano-TiO2, could provide effective protection against bacteria and discoloration of stains, due to the photo catalytic activity of nano-TiO2. On the other hand, Zinc oxide is also a photo catalyst and the photo catalysis mechanism is similar to that of titanium dioxide, as the band gap is different.

(e)Anti-static property- Static charge usually builds up in synthetic fibres, because they absorb little water. Cellulosic fibres have higher moisture content to carry away static charges, so that no static charge will accumulate. As synthetic fibres provide poor anti-static properties, research work concerning the improvement of the anti-static properties of the textiles by using nanotechnology were conducted [07]. It was determined that the nanosized titanium dioxide, zinc oxide, whiskers, nanoantimony-dropped and saline nanogel containing anti-static properties to synthetic fibres. Such materials help to dissipate the static charge which is accumulated on the fabric. Nanotechnology has been applied in manufacturing an anti-static ferment.

(g)Wrinkle resistance properties- To impart wrinkle resistance to fabric, resin is currently used in conventional methods. However, there are limitations in applying resin, including a decrease of the tensile strength of fibres, abrasion resistance and absorbency and dye ability as well as breaking load. To overcome the limitations of using resin, researchers employed nanotitanium dioxide and nanosilica to improve the wrinkle resistance of cotton and silk respectively [08].

(h)Flame retardant finish-The unique properties of nanomaterials have attracted not only scientists and researchers but also businessmen, because of their huge economic potential [10]. Nyacol nanotechnology TM has developed colloidal antimony pent oxide which has applied for flame retardant finish in textiles. Colloidal antimony pent oxide has been offered as fine particle dispersion for use as a flame retardant synergist with halogenated flame-retardant.

Modern Applications of Nanotechnology in Textiles

At the **National Nanotechnology Initiative (NNI),** nanotechnology is defined as the understand, manipulation and control of matter at the stated length of **1 to 100 nm (1 billion nm= 1m) scale,** such that the physical, chemical and biological properties of materials can be engineered, synthesized or altered to develop the next generations of improved materials, devices, structures and systems [21]. Being one of the largest consumer supported industries with significant impact on a nation's economy, advances in applications of nanotechnology to improve textile properties offer obvious high economic potential for the industries growth.

(a)Improvements in fibre/yarn manufacturing by using nanotechnology-A wide range of fibre size or thickness can be utilized in textile processing. Nanofibres of diameters in the nanomater range are mostly manufactured by electro-spinning process, although there are other methods also. Carbon nanotubes provide fibres of ultra-high strength and performance. It was shown that super-aligned arrays of **CNT** provide nanoyarns that **exhibit Young's modulus in the T Pa range,** tensile strength **equalled 200 G Pa,** elastic strain up to 5% and breaking strain of 20%. In electro spinning a charged polymer melt or solution is extruded through sub-micrometer diameter spinneret to arrest fibres on a grounded collector plate subjected to high potential difference between the spinnerets and the plate. The process is an established technique to generate fibres of extremely small diameters and enhanced properties. Further enhancement of fibre strength and conductivity is achieved with heat treatment [22]. It was discovered that unique composite fibres were produced from synthetic nanofibres obtained through an advanced electro-spinning process such as the coagulation based carbonnano-tube spinning method. During electro-spinning process, nanoyarns comprised of multi-walled CNT that consist of single walled CNT, can be produced by simultaneous reduction of fibre diameter and increase in twist in the electro spinning process. By changing the surface structures of synthetic fibres, several diverse fibre functionalities can be obtained for profitable exploitation of functional fabrics in special applications.

(b)Progress towards the fabric finishing by using nanotechnology-Nanotechnology provides plenty of efficient tools and techniques to produce desirable fabric attributes mainly by engineering modifications of the fabric surface. Researchers have demonstrated that by altering the micro and nanoscale surface features on a fabric surface, a more robust control of wetting behaviour can be obtained. They also have shown that such an alteration in the fabric's surface properties is capable of exhibiting the 'Lotus-effect", which demonstrated the natural hydrophobic behaviour of a leaf surface. This sort of surface engineering, which is capable of replicating hydrophobic behaviour, can be utilized in developing special chemical finishes for producing water and or stain resistant fabrics. The most successful developments in this regard can be attributed by a US-based company, NanoTex TM. By using nanotechnology 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 [23]. Their trade mark NanoPel technology for stain-resistance and oil-repellent treatments utilizes the concept of surface engineering and develops hydrophobic fabric surfaces that are capable of repelling liquids and resisting stains, while contemplating the other desirable fabric attributes, such as breath ability, softness and comfort. Nanocare technology is offered to produce wrinkle-free/resistant and shrink-proof fabrics made of cellulosic fibres, such as cotton. Nanodry technology on the other hand, provides hydrophilic finishing to synthetic fabrics. This nanobased finish allows the fabric to whisk away the contact body's moisture/sweat, which quickly evaporates to provide comfort to the wearer. Nanobeads are used into the textiles for carrying bio-active 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.

(c)Some textile products based on nanotechnology-In the recent past, nanotechnology based progress in textile fibres, yarns and fabric-finishing have led to the development of several new and improved textile products [24]. A **Swiss Company Scholar** has also developed a nanobased technology to produce a new line of brand name fabrics, such as soft-shells, functional stretch multi-layer fabrics. The fabrics made there from are capable of dynamic control, which provide optimal balance of comfort, air permeability and wind and water resistance, through their soft inner layer and tough and durable outer layer. Significant developments are envisioned towards the development of military and combat uniforms and apparel using nanotechnology. The main focus is to develop a variety of textile fabrics and other products/materials that are light weight, strong, abrasion/wear resistant, durable, water proof, capable of changing colour, energy absorbent, temperature sensitive and embeddable with multi- purpose micro/nano sensors [25]. Advanced nanofibres of nanosized particles are also being developed for efficient applications in wound dressings. In the development of improved textile fabrics and materials, several advances in the area of textile processing have also been made. Nanofiltration membrane technology developed is being aggressively investigated to try to recover the dyes for economic and environmental benefits and at the same time conserve precious water. In order to mass production nanofibres for textile applications, nanospider technology was invented and patented by the **researchers at Technical University of Liberec.**

Applications Area of Nanotechnology in Textile Finishing

Changed or improved properties with nanotechnology can provide new or enhanced functionalities. Nanoenabled properties associated with current and modification research for use in textile research include: aesthetic, shrink resistance, anti-microbial, stain resistance, electrical conductivity, static protection, fire resistance, UV resistance, fire resistance, water repellent, high strength, wrinkle resistance, moisture management and self-cleaning [11]. Many products use or with commercialization will use, chemical, physical or electronic technology to respond passively or actively to thermal, chemical, biological, electromagnetic and mechanical stress. These products includes warming and cooling textiles, conductive textiles, communicating textiles, textile sensors and actuators, digital fashion, chromatic textiles, etc with applications in the medical fields, sports and leisure, the military and first-responders market and intelligent application in buildings. Integration of nanotechnology into textile products is being realised in coatings, treatments, fibre material composites and nanoscale fibres. Nanotextiles have been subdivided into four major types namely, nanofinished textiles, nanocomposite textiles, nanofibrous textiles and nano enables nonwovens.

Types of Nano Textiles

(a)Nano-finished textiles-Nano-finished textiles are those that apply a nanoscale property added after the base textiles have been fabricated. Additive nanomaterials to date include metal nanoobjects or clay may include those roughened by treatments. Nanofinishing can provide accessible means for established textile manufacturers to engage with nanotextile [12].

(b)Nano-composite textiles-Polymer matrices are the most prevalent in nano-omposite fibres however, other matrices are also useful. Similar to nanofinished textiles, nanocomposite fibres may not require significant changes to the manufacturing process. If the fibre material is entirely changed by choosing a different matrix material or significantly altered by the composite properties, significant reconfiguration may be needed [13].

(c)Nano-fibrous textiles-nanofibrous textiles have fibres with nanoscale dimensions. These true nanofibres have a nano-scale cross-sectional area and may or may not have a nanoscale length. Fibre material may be either a single material or a composite. Nanofibres may also be nanofinished. These nanotextiles focus on fabricating fibres to exploit nanoscale properties. Fibre fabrication for nanofibrous textiles typically would be new. Not only does initial fabrication of the fibre require a process that can create nanofibres or force spinning, which are not conventional drawing but all of the subsequent steps in the manufacturing process must accommodate these smaller fibres. Research into nanofibrous textiles is wide spread, little has significant commercialization. Its development, however, may afford exciting applications and opportunities [14].

(d)Nano-enabled nonwovens-Nanotechnology in nonwovens may make use of improvements in properties to benefit textile processing, for example adhesive properties may be enhanced or conventional methods of securing layers replaced with adhering nanostructured surfaces. Other nanoscale functionalities may utilize nanofilms or coatings in layers or barriers, for example for antibacterial properties, energy production and luminescence [15]. Production of nanomaterials may require advanced equipment not typical within the textile industry, such as treatment chemicals, polymer composites, and film coatings. Nanoobjects generation may use advanced machines. For nanofinished textiles, one must consider the nanoobject being applied. Spraying techniques, chemical baths and electrostatic adhesion are a few general categories. Foe nanocomposites, the matrix must be produced first and then fibres are fabricated. Nanofibrous textiles will be more complex, requiring new processes from basic fibre fabrication to the finished textiles [16]. Nanotechnology is increasingly attracting worldwide attention, because it is widely perceived as offering huge potential in a wide range of end use. The unique and new properties of nanmaterials have attracted not only the scientists and researchers but also businessmen, due to their huge economical potentiality [17].

Conclusion

The potential of nanotechnology in the development of new materials in the textile industry is considerable. There is a huge potential for profitable applications of nanotechnology in cotton and other textile industries. Its applications can economically extend the properties and values of textile processing and products. The nanosized materials are able to enhance the physical properties of conventional textiles in the areas such as self-cleaning fabrics, water repellent, UV-protection, anti-bacterial, anti-static, wrinkle resistance and flame retardant properties of textile materials. By deploying nanotechnology, ultra strong, durable and specific-function-oriented fabrics can be effectively produced for a number of end-use applications, including medical, industrial, military, domestic, apparel, household furnishing and much more. Nanotechnology overcomes the limitations of applying conventional methods to impart certain properties to textile materials. It is expected that in the near future nanotechnology will penetrate into every area of the textile industry.

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