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The role of nanotechnology in modern textiles

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ABSTRACT

The use of nanomaterials- and nanotechnology-based processes is growing at a tremendous rate in all fields of science and technology. Textile industry is also experiencing the benefits of nanotechnology in its diverse field of applications. Nanoparticle application during conventional textile processing techniques, such as finishing, coating and dyeing, enhances the product performance manifold and imparts hitherto unachieved functionality. 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. The focus of this paper is to summarize recent applications of NT as they relate to textile fibers, yarns, and fabrics.

Keywords: Nanotechnology Nanomaterials Textiles Water repellent Dyeing

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INTRODUCTION

Nanotechnology is defined as the utilisation of structures with at least one dimension of nanometre size for the construction of materials, devices or systems with novel or significantly improved properties due to their nano-size. Nanotechnology can best be described as activities at the level of atoms and molecules that have applications in the real world. Nano-particles commonly used in commercial products are in the range of 1 to 100 nm. Nanotechnology is increasingly attracting worldwide attention because it is widely perceived as offering huge potential in a wide range of end uses. The unique and new properties of nanomaterials have attracted not only scientists and researchers but also businesses, due to their huge economical potential.

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. Nanotechnology can provide high durability for fabrics, because 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. In addition, a coating of nano-particles on fabrics will not affect their breathability or hand feel. Therefore, the interest in using nanotechnologies in the textile industry is increasing.

The first work on nanotechnology in textiles was undertaken by Nano-Tex, a subsidiary of the US-based Burlington Industries [1]. Later, more and more textile companies began to invest in the development of nanotechnologies. Coating is a common technique used to apply nano particles onto textiles. The coating compositions that can modify the surface of textiles are usually composed of nano-particles, a surfactant, ingredients and a carrier medium [2]. Several methods can apply coating onto fabrics, including spraying, transfer printing, washing, rinsing and padding. Of these methods, padding is the most commonly used [3-5]. 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. However there is some recent work done in nanotechnology based textile [6-12], in this paper we have made an attempt to give better understanding and clear overview of the concept of nanotechnology in the textile industry. 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 dyeability and so on has been reviewed thoroughly in this paper. 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.

ROLE OF NANOTECHNOLOGY IN TEXTILES

The textile industry certainly has the biggest customer base in the world. Therefore, the advances in the customer-oriented products will be the main focus for future NT applications, and the textile industry is expected to be one of the main beneficiaries. However, it goes without saying that there certainly are some limitations and unknown health risks pertaining to the rapid development and growth of NT and also their end-use products. For example, it isextremely difficult and complex to process carbon fibers of < 200 nm with traditional textile practices and procedures

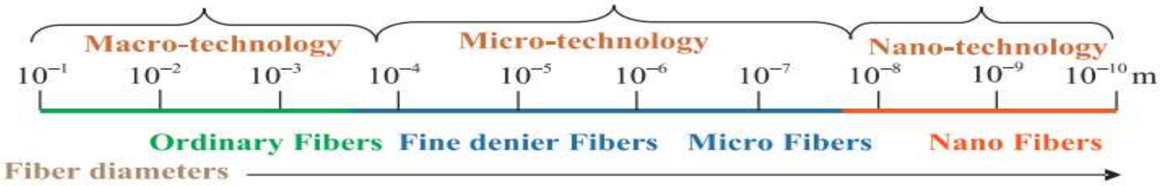

Figure 1 Fiber size and associated manufacturing/processing technologies

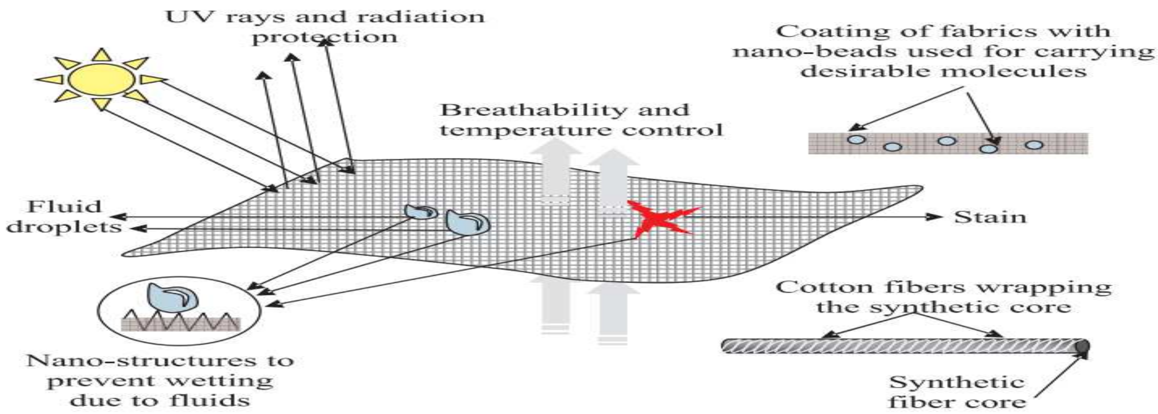

Figure 2 Fabric finishing for enhanced properties and performance

A wide range of fiber size or thickness can be utilized in textile processing (Figure 1). Ordinary and fine-denier textile fibers range from 1 to 100 µm in diameter and are produced by established dry wet-dry, jet melt spinning through spinnerets 1–100 µm in diameter. Nano-fibers of diameters in the nanometer range are mostly manufactured by electro-spinning process, although there are also other methods.

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 nanotechnology. A few representative applications of fabric finishing using NT are schematically displayed in Figure 2. NT provides plenty of efficient tools and techniques to produce desirable fabric attributes, mainly by engineering modifications of the fabric surface. For example, the prevention of fluid wetting towards the development of wateror stain-resistant fabrics has always been of great concern in textile manufacturing

1. Water Repellent Textiles

Finishing of coated textiles such as flame retardency, water repellency, antimicrobial, UV light ageing and encapsulated fragrances etc. has increased demand. Water and soil repellency has been one of the major targets for fibre and textile scientists and manufacturers for centuries. Water repellent textiles, by definition, repel water from the surface of the fabric. However, there are multiple methods by which water can be repelled from the fabric surface(Fig.3) The most commonly used chemicals for hydrophobization are fluoroalkylsilanes owing to their extremely low surface free energy and the simple reaction of the silane groups with the hydroxyl groups on coatings. Also, most superoleophobic surfaces are created by the hydrophobization of a perfluorinated material [13].

2. Wettability

Weattability is one of the most important properties of a solid surface and the contact angle has been commonly used to characterize the surface wettability. A surface with a water contact angle larger than 150° and a low sliding angle (the critical angle where a water droplet with a certain weight begins to slide down the inclined plate) is usually called a superhydrophobic surface. Superhydrophobic surfaces have attracted much interest because of their potential practical applications such as anti-sticking, anticontamination, and self-cleaning coating. The mechanism is similar to the lotus effect occurring in nature. Lotus plants have superhydrophobic surfaces which are rough and textured. Once water droplets fall onto them, water droplets bead up and, if 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 the lotus plant keep clean even during light rain [14].

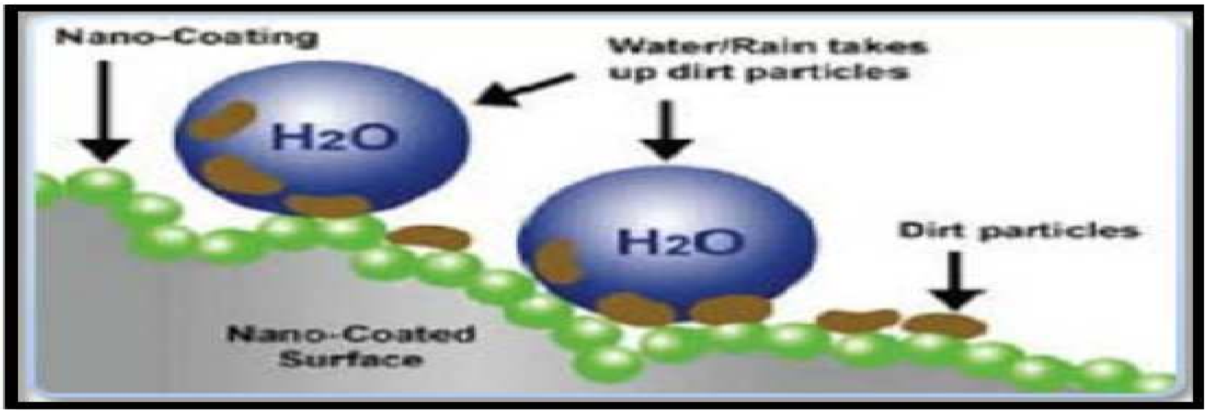

Fig. 3Nanocoatedself cleaning textile

3. Antibacterial Property

A range of antimicrobial textile finishes and products have been reported and quite a few have been commercialized, which are based on much superior antimicrobial properties of silver in nanoform. Nano silver particles containing antimicrobial dressings have been incorporated in wound care and have gained wide acceptance in medical industry, as a safe and effective means of controlling microbial growth in the wound, often resulting in improved healing. A range of nano silver based medical textiles for health and hygiene has been developed and commercialized.

4.**UV Protection**

It is also known that nanosized TiO_2 and ZnO particles are more efficient at absorbing and scattering UV radiation than the conventional size particles and thus were better able to block UV radiation as have much larger surface area to volume ratio. A lot of efforts have been made on the application UV bulking treatment to fabrics using nanotechnology. UV blocking treatments for cotton fabric has been developed using sol-gel method by Xin and coworkers. A thin layer of TiO_2 nanoparticle is formed, on the surface of treated cotton fabric, which provides excellent UV protection, the finish is durable up to 50 home launderings. Apart from TiO_2, ZnOnanorods of 10 to 50 nm in length were also applied to cotton fabric to provide UV protection. The rods exhibited excellent UV protection.

NANOSOLS

Nanosols are colloidal solutions of nanometre sized metal oxide particles in aqueous or organic solvents. Due to the very high surface area of such small particles the nanosols are metastable, thus, for example, during a coating process the particles will aggregate due to the evaporation of the solvent, easily forming a three-dimensional network. Nanosol particles exhibit diameters in the range from a few nanometres up to 100 nm, while coatings formed by nanosols can reach a thickness of up to several hundred nanometres. The length scale of a nanosol coating can therefore cover a broad range of the structural elements starting from molecules up to three-dimensional, large-scaled objects such as fibres forming a textile.

The basic nanosols can be modified in a wide range, leading to numerous new functionalities that can be applied to various surfaces in comparably simple coating processes. The nanosol coating is therefore a suitable tool for modifying a large number of materials, such as glass, paper, synthetic polymers, wood, metal and, of course, textiles. Coating textiles via the sol-gel process provides the textile substrate with a desired functionality while maintaining the physical properties of the textile. The application of sols containing metal oxides has the following benefits:

• Use of particles with diameters < 50 nm form durable transparent oxide layers.
• Heat, light, chemical and microbial stability.
• Augmented properties such as mechanical strength, wear and abrasion resistance.
• Oxide coatings can carry embedded functional additives such as biological compounds, inorganic particles, and polymers.
• Application can be carried out at room temperature and atmospheric pressure, and applied using conventional textile processes such as padding, and dip-coating [15]. Depending on the chemistry of the applied coating, surfaces can be modified to be hydrophilic or hydrophobic, and additional functionality can be added to a surface, such as flame resistance [15-19]

As a result of the particular properties of textile materials, e.g. high flexibility or low heat resistance, the nanosol process has to be adapted for the treatment of textiles.

1.Water-repellent property

1.1Nanowhiskers: Nanowhiskers [20] 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 [21]. However the liquid can still pass through the fabric if pressure applied [11].

1.2Nanospheres: 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 [22] 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 [23] 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 [24] was obtained due to the roughness of the fabric surface, affecting the softness and abrasion resistance of cotton

2.Anti-bacterial property

For imparting anti-bacterial properties, nano-sized silver , titanium dioxide and zinc oxide are used. Metallic ions and metallic compounds display a certain degree of sterilizing effect. 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.

2.1Silver nanoparticles
Silver nanoparticles when imparted on fabric kill bacteria [25] which makes clothes odor-resistant. Nanosilver particles have extremely large surface area thus increasing their contact with various microorganisms [26] and improving their bactericidal and fungicidal effectiveness. Nano-silver is very reactive with proteins. When coated with bacteria or fungus it will adversely affect the cellular metabolism, inhibits the cell growth [27] and suppress respiration, the basal metabolism of the electron transfer system, and the transport of the substrate into microbial cell membrane. Further inhibits [28] 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 [29] of bacteria

2.2Titanium 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 [30] 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 willcombine 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 [31] and water. This cascade reaction is called “oxidation-reduction” [32]. Through the reaction the photocatalyst is able to decompose common organic matters in the air such as odour molecules, bacteria and virus [33].

3. UV- Protection
Inorganic UV blockers are more preferable to organic UV blockers as they are non-toxic [34] and chemically stable under exposure to both high temperatures [35] and UV. Inorganic UV blockers are usually certain semiconductor [36.37] oxides such as TiO_2, ZnO, SiO_2, andAl_2O_3 [38]. 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. 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. Apart from titanium dioxide, zinc oxide rods of 10 to 50nm in length were applied to cotton fabric to provide UV protection. [39].

4. Dyeing and Surface treatment
Besides the use as dyes in a nano form, nanoparticles can be used also to improve dyeability. The dyeability of PP has been improved, for example, by mixing nanoclay with the PP Chitosan is cationic in acidic media, which makes it easy to absorb anionic molecules such as acid and reactive dyes. This property is useful in the dyeing of natural fibres such as wool and silk. An innovative technology for finishing recently developed, and still under refinement, is*inkjet printing*. It allows the application of dispersed dyes in nanoparticulate form, with significant advantaged, in terms of brilliancy of colours, storage stability, process economy (the overall set-up can be five times shorter) and wastes management.Among the processes of finishing described above, plasma treatments are getting a particular attention for their versatility and lower environmental impact.[40-46].

APPLICATIONS AND PERSPECTIVES
Textile Applications and perspectives As mentioned above, nanotechnology-related textiles products are already on the market and they refer essentially to textile clothing and furniture. In the case of clothing the attention is looking for fabrics having features of value for the customers/market, obtained without affecting their physical properties (colour, flexibility, breathability and weight), such as water repellence, stain and abrasion resistance, anti-bacterial activity, thermal insulation, wrinkle free, anti-static properties, dyeability. Three sectors, in particular, seem to be the candidate of choice: sport/outdoor textiles, medical textiles(shown in fig.4), military textiles, in the order which reflects also the order in terms of market volumes.[47-57]

1.Sports/outdoor textiles Most of the features of value for the clothing sector already mentioned are particularly attractive also in the sport/out door market. Textiles having anti-bacterial properties for the addition of silver nanoparticles that eliminate bad odours, providing better insulation or protection through surface treatments, or having improved mechanical or fludynamic properties by using nanocomposite fibres, can greatly improve physiological comfort and safety, both of garments and out door gears. These features are fashionable and the customer demand is high and therefore they can offer competitive advantage and gain of market shares

2. Medical textiles Nanotechnology-related textiles can play an important role also in the medical sector. Medical textiles can draw to all tools provided by nanotechnology in this field. Woven and nonwoven fabrics Anti-bacterial fabrics can be used to prevent infection or deodorise medical clothing, wound dressing, bedding. Fabrics can be functionalised at the surface for tissue engineering, drug delivery or topic treatments, such as the use of chitin for wound healing. Non-woven nanofiber cloths and filters can find application in a variety of medical equipment, from respiratory equipment to transfusion/dialysis machine.

3. Textiles for the military sector Also the military sector can have great advantages from textiles incorporating nanotechnology. An intense activity in this field is under way especially in US. At various US Universities as well as military research centres. But also industry is looking http://www.observatorynano.eu/ 32 to this sector as a possible outlet for its products. The need for textiles with, for example, very high anti-ballistic properties, anti-bacterial activity, flame retardant, colour modification for camouflage, RF shielding, protecting in biological warfare, to name some, is very high in this sector and nanotechnology can offer a vast array of solutions giving leading hedge products.

Fig.4.(a)Nonwovens Medical Market generates suit for medical surgery based on nanotechnology[57](b) sports socks using nanosilver particles involved[55]

CONCLUSION

Nanotechnology holds an enormously promising future for textiles. The development in functional finishes based on nanotechnology has endless possibilities and at present the application of nanotechnology merely reached the straight line. The new concepts exploited for the development of nano-finishes have opened up exciting opportunities for the further research and development. Nanotechnology does not affect other properties of the fabric which gets affected in other types of finishes. Nanotechnology involves a three-dimensional surface structure on the textile surfaces which is very beneficial and does not affect the properties of the substrate like the handle and breathability and does not add more extra weight to the treated textile. When nanosols technology is used for water repellency then finish involves a three-dimensional surface structure with gel-forming additives which repel water and prevent dirt particles from attaching themselves. The mechanism is similar to the lotus effect occurring in nature. With this technology we can achieve super hydrophobic surfaces which are rough and textured. 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. 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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