SELECTED APPLICATIONS OF NANOTECHNOLOGY IN TEXTILES

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Abstract

The use of nanotechnology in the textile industry has increased rapidly due to its unique and valuable properties. The present status of nanotechnology use in textiles is reviewed, with an emphasis on improving various properties of textiles.

Key words:

nanotechnology, water repellence, UV-protection, anti-bacteria, anti-static, wrinkle resistance

Introduction

The concept of nanotechnology is not new; it was started over forty years ago.According to the National Nanotechnology Initiative (NNI), 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 not only produces small structures, but also an anticipated manufacturing technology which can give thorough, inexpensive control of the structure of matter. 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.

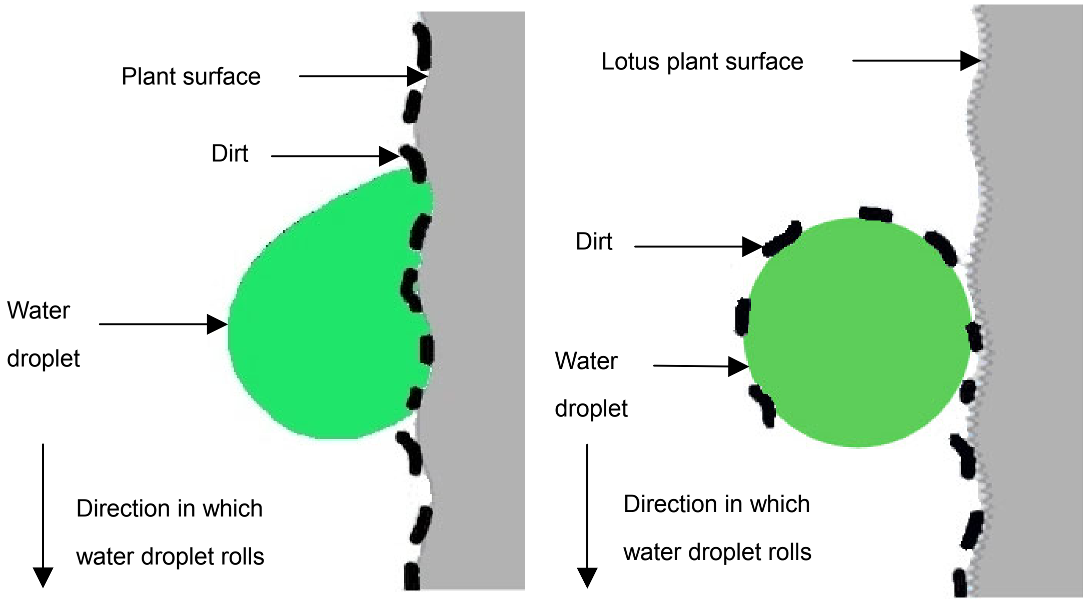
The first work on nanotechnology in textiles was undertaken by Nano-Tex, a subsidiary of the US-based Burlington Industries [1]. Later, more and more textile companies began to invest in the development of nanotechnologies. Coating is a common technique used to apply nano-particles onto textiles. The 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. 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. 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.

Water repellence

Nano-Tex improves the water-repellent property of fabric by creating nano-whiskers, which are hydrocarbons 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 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 [1, 6, 7]. However, liquid can still pass through the fabric, if pressure is applied. The performance is permanent while maintaining breathability.

Apart from Nano-Tex, the Swiss-based textile company Schoeller developed the NanoSphere to make water-repellent fabrics. NanoSphere impregnation 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, as demonstrated in Figure 1. 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 [1].

On the other hand, a 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. Superhydrophobicity was obtained due the roughness of the fabric surface, without affecting the softness and abrasion resistance of cotton fabric [8].



(a) (b)

Figure 1. Mechanism of NanoSphere on textiles applied by NanoSphere technology; (a) water droplet rolls down a plant, (b) water droplet rolls down a lotus plant

UV-protection

Inorganic UV blockers are more preferable to organic UV blockers as they are non-toxic and chemically stable under exposure to both high temperatures and UV. Inorganic UV blockers are usually certain semiconductor oxides such as TiO_2, ZnO, SiO_2 and Al_2O_3. Among these semiconductor oxides, titanium dioxide (TiO_2) [4, 9-11] and zinc oxide (ZnO) [12, 13] are commonly used. It was determined that nano-sized titanium dioxide and zinc oxide were more efficient at absorbing and scattering UV radiation than the conventional size-[[?]], and were thus better able to block UV [4, 12]. This is due to the fact that nano-particles have a larger surface area per unit mass and volume than the conventional materials, leading to the increase of the effectiveness of blocking UV radiation. For small particles, light scattering predominates at approximately one-tenth of the wavelength of the scattered light. Rayleigh's scattering theory stated that the scattering was strongly dependent upon the wavelength, where the scattering was inversely proportional to the wavelength to the fourth power. This theory predicts that in order to scatter UV radiation between 200 and 400 nm, the optimum particle size will be between 20 and 40 nm [9].

Various research works on the application of UV-blocking treatment to fabric using nanotechnology were conducted. 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; the effect can be maintained after 50 home launderings [4, 14]. Apart from titanium dioxide, zinc oxide nanorods of 10 to 50 nm in length were applied to cotton fabric to provide UV protection [15]. According to the study of the UV-blocking effect, the fabric treated with zinc oxide nanorods demonstrated an excellent UV protective factor (UPF) rating.

Anti-bacteria

For imparting anti-bacterial properties, nano-sized silver [3, 5, 16-18], titanium dioxide [9, 10, 19] and zinc oxide [12] are used. Metallic ions and metallic compounds display a certain degree of sterilising effect. It is considered that part of the oxygen in the air or water is turned into active oxygen by means of catalysis with the metallic ion, thereby dissolving the organic substance to create a sterilising effect [12]. With the use of nano-sized particles, the number of particles per unit area is increased, and thus anti-bacterial effects can be maximised.

Nano-silver particles have an extremely large relative surface area, thus increasing their contact with bacteria or fungi, and vastly improving their bactericidal and fungicidal effectiveness. Nano-silver is very reactive with proteins. When contacting bacteria and fungus, 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. Furthermore, it inhibits the multiplication and growth of those bacteria and fungi which cause infection, odour, itchiness and sores. Hence, nano-silver particles are widely applied to socks in order to prohibit the growth of bacteria. In addition, nano-silver can be applied to a range of other healthcare products such as dressings for burns, scald, skin donor and recipient sites [16, 17, 20].

Titanium dioxide is a photocatalyst; once it is illuminated by light with energy higher than its band gaps, the electrons in TiO_2 will jump from the valence band to the conduction band, and the electron (e^-) and electric hole (h^+) pairs will form on the surface of the photocatalyst. The negative electrons and oxygen will combine into O_2^-; the positive electric holes and water will generate hydroxyl radicals. Since both are unstable chemical substances, when the organic compound falls on the surface of the photocatalyst it will combine with O_2^- and OH- respectively, and turn into carbon dioxide (CO_2) and water (H_2O). This cascade reaction is called ‘oxidation-reduction’, [11] and the mechanism is shown in Figure 2. Through the reaction, the photocatalyst is able to decompose common organic matters in the air such as odour molecules, bacteria and viruses.

Several papers have discussed the use of the photocatalytic property of TiO_2 in the field of textiles [14, 21, 22]. It was determined that a fabric treated with nano-TiO_2 could provide effective protection against bacteria and the discoloration of stains, due to the photocatalytic activity of nano-TiO_2. On the other hand, zinc oxide is also a photocatalyst, and the photocatalysis mechanism is similar to that of titanium dioxide; only the band gap (ZnO: 3.37eV, TiO_2: 3.2eV) is different from titanium dioxide. Nano-ZnO provides effective photocatalytic properties once it is illuminated by light, and so it is employed to impart anti-bacterial properties to textiles [23-25].

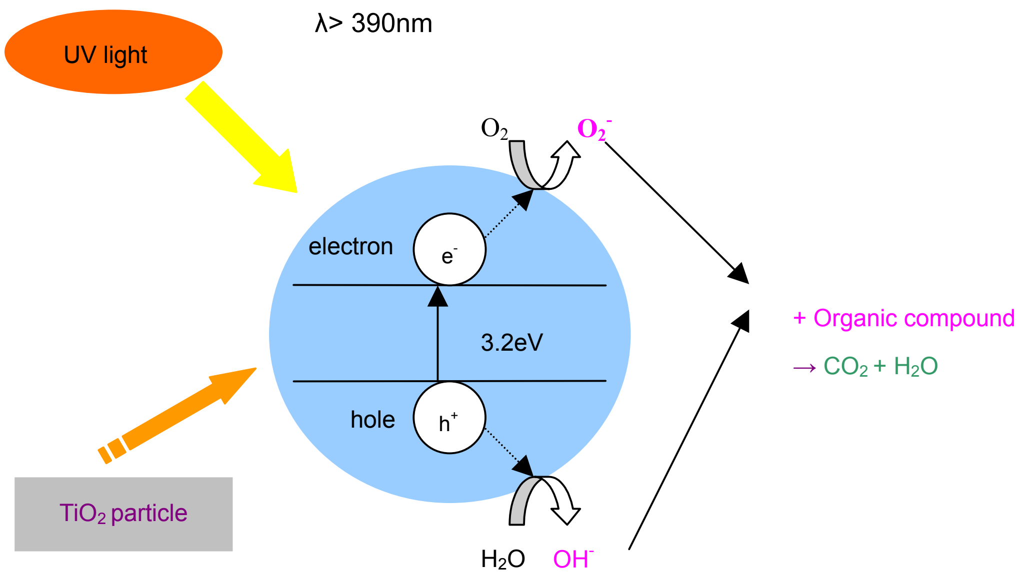


Figure 2. Photocatalysis mechanism of titanium dioxide

Anti-static

Static charge usually builds up in synthetic fibres such as nylon and polyester 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 textiles by using nanotechnology were conducted. It was determined that nano-sized titanium dioxide [26], zinc oxide whiskers [27], nano antimony-doped tin oxide (ATO) [28] and silane nanosol [29] could impart anti-static properties to synthetic fibres. TiO_2, ZnO and ATO provide anti-static effects because they are electrically conductive materials. Such material helps to effectively dissipate the static charge which is accumulated on the fabric. On the other hand, silane nanosol improves anti-static properties, as the silane gel particles on fibre absorb water and moisture in the air by amino and hydroxyl groups and bound water.

Nanotechnology has been applied in manufacturing an anti-static garment. W.L. Gore and Associates GmbH used nanotechnology and polytetrafluroethylene (PTEE-Dupont's Teflon®) to develop an anti-static membrane for protective clothing. Gore-Tex® I Workwear protects the wearer from electrostatic discharges. Electrically conductive nano-particles are durably anchored in the fibrils of the Gore-Tex® I membrane of Teflon, creating an electrically conductive network that prevents the formation of isolated chargeable areas and voltage peaks commonly found in conventional anti-static materials. This method can overcome the limitation of conventional methods, which is that the anti-static agent is easily washed off after a few laundry cycles [30].

Wrinkle resistance

To impart wrinkle resistance to fabric, resin is commonly used in conventional methods. However, there are limitations to applying resin, including a decrease in the tensile strength of fibre, abrasion resistance, water absorbency and dyeability, as well as breathability. To overcome the limitations of using resin, some researchers employed nano-titanium dioxide [31, 32] and nano-silica [33] to improve the wrinkle resistance of cotton and silk respectively. Nano-titanium dioxide was employed with carboxylic acid as a catalyst under UV irradiation to catalyse the cross-linking reaction between the cellulose molecule and the acid. On the other hand, nano-silica was applied with maleic anhydride as a catalyst; the results showed that the application of nano-silica with maleic anhydride could successfully improve the wrinkle resistance of silk.

Conclusion

Five properties imparted to textile materials using nanotechnology have been highlighted 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.

Acknowledgement

The authors would like to acknowledge Specialized Technology Resources (H.K.) Ltd for their financial support of this work.

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