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APPLICATION OF NANOTECHNOLOGY IN TEXTILES: A REVIEW

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Abstract-*The word "nano" seems to be popping up everywhere now-a-days. Wall Street, Hollywood and major universities around the globe have all endeavored to associate their diverse enterprises with this word. "Nano" is a metric unit that means one billionth of a unit; as of late, it has been used most frequently in reference to nanotechnology. It is one of the latest innovations in this time that has shaped the today's lifestyle. One of the most widespread applications of nanotechnology is in textiles. The use of nanotechnology in the textile industry has increased rapidly due to its unique and valuable properties. The recent development of nanotechnology in textile areas including textile formation and textile finishing basically based on nanoparticles. Nanoparticles may consist of various elements and compounds and have a length of 1 to 100 nm. Nanoparticles are the most important elements which are now widely used to develop the textile materials and introduce new properties in textiles products. This review paper will be introduced by first discussing nanotechnology as a whole. Next, the paper will continue on to discuss nanofibers, its fabrication process- electrospinning, and applications. Finally, nanoparticles and some recent application of it in textiles have been presented. The economic and environmental aspect of nanotechnology has also been discussed here.*

Keywords: Nanotechnology, Nanoparticles, Nanofiber, Electrospinning, Surface area.

1. INTRODUCTION

Nanotechnology is an emerging interdisciplinary technology that has been booming in many areas during the recent decade, including materials science, mechanics, electronics, optics, medicine, plastics, energy, electronics, and aerospace. Its profound societal impact has been considered as the huge momentum to usher in a second industrial revolution [1, 2].

The "nano" in nanotechnology comes from the Greek word "nanos" that means dwarf. Scientists use this prefix to indicate 10^{-9} or one-billionth. A nanometer is one billionth of a meter that is about 100,000 times smaller than the diameter of a single human hair. The concept of Nanotechnology was given by Nobel Laureate Physicist Reichard Feynmn, in 1959. He said, "There's Plenty of Room at Bottom".

Nanotechnology can be used in engineering desired textile attributes, such as fabric softness, durability, and breathability and in developing advanced performance characteristics, namely, water repellency, fire retardency, antimicrobial resistance, etc., in fibers, yarns and fabrics. Enhancement of textile materials by nanotechnology is expected to become a trillion dollar industry in the next decade, with tremendous technological, economic and ecologic benefits. It was estimated that for the year 2003, the worldwide government funding for the research and development in the area of nanotechnology had increased to $3 billion annually, in addition to the millions of dollars invested by private industries. Although, textile industry is a small part of the global research in the emerging areas of nano-technology, the fibers and textiles industries in fact were the first to have successfully implemented these advances and demonstrated the applications of nano technology for consumer usage [3].

2. NANO FIBERS

The Nanofibers are defined as fibers with diameters less than 100 nanometers [4]. In the textile industry, this definition is often extended to include fibers as large as 1000 nm diameter [5]. They can be produced by interfacial polymerization, electrospinning, and forcespinning. Carbon nanofibers are graphitized fibers produced by catalytic synthesis.

With the production of nanofiber, nanotechnology extends its application to a vast area. Regarding production of nanofibers; conventional fiber spinning techniques were not able to produce polymer fibers with diameters in nanometer range. Several technologies have been developed that can potentially produce fibers less than one micrometer in diameter. Electrospinning is the process using electrostatic forces to form a fine filament from polymer solution.

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2.1 Fabrication Process - Electrospinning

Electrospinning is the most important method among the processes leading to nanofibers.

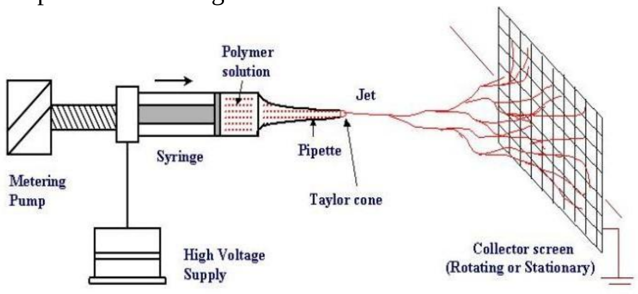

Fig. 1: Schematic of the electrospinning setup **[**6**]**

In the electrospinning process (Fig. 1) a high voltage is used to create an electrically charged stream of polymer solution or melt. A high voltage electrode is linked with the polymer solution. The solution is then spun through a capillary. Due to high voltage the electrode is linked with the polymer solution. The solution is then spun through a capillary. Due to high voltage electric field between the tip of capillary and a grounded collector, Taylor cone is formed at the tip of capillary producing sub-micron diameter fibers. Fibers solidify as the polymer solvent evaporates and create an interlinked fiber layer on the surface of collector. Many types of polymers were processed into nanofibers of 50 to 1000 nanometers in diameter.

2.2 Applications of Nano Fibers

An important characteristic of electrospinning is the ability to make fibers with diameters in the range of nanometers to a few microns. Consequently these fibers have a large surface area per unit mass so that nonwoven fabrics of these nanofibers collected on a screen can be used for example, for filtration of submicron particles in separation industries and biomedical applications [7], such as wound dressing in medical industry, tissue engineering scaffolds and artificial blood vessels. The use of electrospun fibers at critical places in advanced composites to improve crack resistance is also promising.

3. NANO-PARTICLES

There is no accepted international definition of a nanoparticle, but one given in the new PAS71 document developed in the UK is: "A particle having one or more dimensions of the order of 100nm or less". There is a note associated with this definition: "Novel properties that differentiate nanoparticles from the bulk material typically develop at a critical length scale of under 100nm". The "novel properties" mentioned are entirely dependent on the fact that at the nano-scale, the physics of nanoparticles mean that their properties are different from the properties of the bulk material. This makes the size of particles or the scale of its features the most important attribute of nanoparticles.

Some nano-particles currently available are as follows [8,9,10]:

1. Metals: Pd/Pt, Ag, Fe, etc.
2. Compounds:
    - Organic: Vitamins, DNA, Hydroxylapatite, Colour pigments.
    - Inorganic: TiO_2, ZnO, Fe2O3, MgO, SiO_2 etc.
3. Polymer:
    - Cellulose nano-whiskers
    - Carbon nano-whiskers.

Table 1: Nanoparticles and potential textile applications[11,12,13]

Sr. No.	Nanoparticles	Properties
1	Silver Nanoparticles	Anti-bacterial finishing
2	Fe Nanoparticles	Conductive magnetic properties, remote heating.
3	ZnO and TiO_2	UV protection, fiber protection, oxidative catalysis
4	TiO_2 and MgO	Chemical and biological protective performance, provide self-sterilizing function.
5	SiO_2 or Al_2O_3 Nanoparticles with PP or PE coating	Super water repellent finishing
6	Indium-tin oxide Nanoparticles	EM / IR protective clothing
7	Ceramic Nanoparticles	Increasing resistance to abrasion
8	Carbon black Nanoparticles	Increasing resistance to abrasion, chemical resistance and impart electrical conductivity, colouration of some textiles
9	Clay nanoparticles	High electrical, heat and chemical resistance
10	Cellulose Nano-whiskers	Wrinkle resistance, stain resistance, and water repellency

4. APPLICATIONS OF NANOPARTICLES IN TEXTILES

Due to the advancement of nanotechnology in the manufacturing of fiber or yarns including the development of fabric finishes, the applications and scopes are widespread in the area of textiles for the last few decades.

4.1 Self Cleaning Fabrics

In our everyday's life we are always concern about the cleanliness of our clothes and thus demand a lot of water, energy and time. With the development in science and technology, self cleaning clothes are no more the things of dreams. It's a brilliant application of nanotechnology that has made possible to obtain this properties on clothes and other materials as well. The technology uses nanocrystals treatment by controlling wettability and surface interaction.

The following two approaches are under investigation to produce self cleaning effects on clothes.

a) Self-cleaning effect of a textile material can be obtained by a photo-catalytically active (PCA) coating containing a photo-catalytically active oxide of a transition metal (MO) or (MO_2) such as titanium dioxide (TiO_2). Due to light absorption in the near UV, electrons are hoisted from the energy level of the valence band of TiO_2 into that of the conductive band, thus leaving a positively charged hole in the valence band. Titanium dioxide can also destroy pathogens such as bacteria in the presence of sunlight by breaking down the cell walls of the microorganisms. This should make self-cleaning fabrics especially useful in hospitals and other medical settings.

b) In other technique, self cleaning materials are based on nanocrystals making the surface oil or water repellent by controlling wettability and surface interaction. This is a concept that is completely different from that of the titanium dioxide coating.

Researchers have created a coating that can be integrated into virtually any fabric, allowing dirt to be released when water is applied. The patented coating allows clothing to be cleaned simply by spraying with water or wiping with a damp cloth and reduces the number of cleanings required. The coating -- a polymer film mixed with silver nanoparticles – is infused into fabric, creating a series of microscopic bumps that cause dirt and other substances to bounce off when water is applied.

“Self-cleaning” clothes are expected to be on the market within the next five years, according to the researchers. Self-cleaning fabrics could revolutionize the sport apparel industry. The technology has already been used to create t-shirts and underwear that can be worn hygienically for weeks without washing. More research is needed before self-cleaning clothes are available at high street shops, but manufacturers are said to be watching developments closely [14].

4.2 Water Repellency Property

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 [15,16,17]. 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. Lotus plants have super hydrophobic 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 [15].

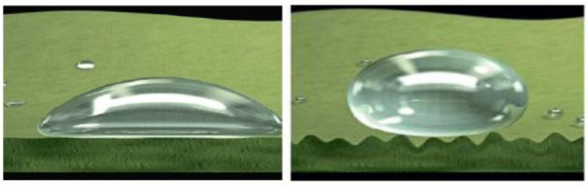

Fig.2:(a)Classic surface (b)Nano-sphere surface[18,19]

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. Super hydrophobicity was obtained due the roughness of the fabric surface, without affecting the softness and abrasion resistance of cotton fabric [20].

4.3 UV-Protection Property

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, TiO_2 [21,22,23,24] and ZnO [25,26] 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 [21,25]. This is due to the fact that nanoparticles 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 [22].

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 [21,27]. Apart from titanium dioxide, zinc oxide nanorods of 10 to 50 nm in length were applied to cotton fabric to provide UV protection [28]. According to the study of the UV-blocking effect, the fabric treated with zinc oxide nanorods demonstrated an excellent UV protective factor (UPF) rating.

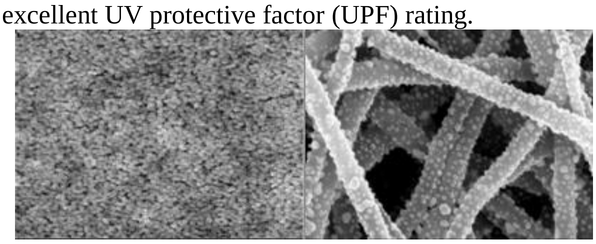

Fig. 4**:** Fabric coated with ZnO nanomaterials for

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UV-protected clothing (SEM-image) [13]

4.4 Anti-Bacterial Property

For imparting anti-bacterial properties, nano-sized silver [29,30,31,32,33], TiO_2 [23,24,34] and zinc oxide [25] 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 the metallic ion, thereby dissolving the organic substance to create a sterilising effect [25]. 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 [32,33,35]. 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', [24] and the mechanism is shown in Fig.5. 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 [27,36,37]. 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, TiO2: 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 [38,39,40].

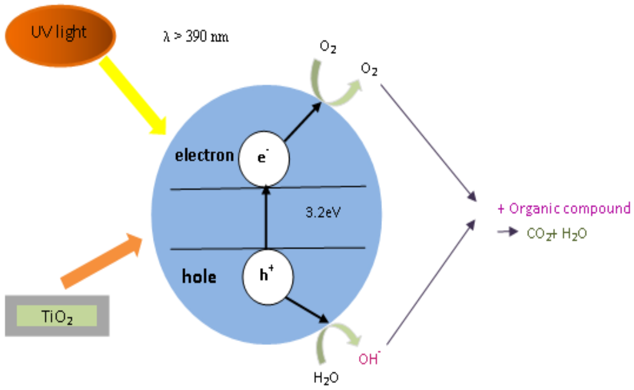

Fig. 5: Photocatalysis mechanism of titanium dioxide [13, 41]

4.5 Anti-Static Property

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 [42], zinc oxide whiskers [43], nano antimony-doped tin oxide (ATO) [44] and silane nanosol [45] 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 [46].

4.6 Wrinkle Resistance Property

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 [47,48] and nano-silica [49] to improve the wrinkle resistance of cotton and silk respectively. Nano-titanium dioxide was employed with carboxylic acid as a catalyst

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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.

4.7 Flame Retardant Finish

Nyacol nanotechnologies TM has been developed colloidal antimony pentoxide which has been applied for flame retardant finish in textile. Colloidal antimony pentoxide has been offered as fine particle dispersion, for use as a flame retardant synergist with halogenated flame-retardants (the ratio of halogen to antimony is 5:1 to 2:1). Nano antimony pentoxide is used with halogenated flame-retardants for a flame retardant finish to the garments [13].

5. ECONOMIC AND ENVIRONMENTAL ASPECTS

The unique properties of nano-materials have attracted not only scientists and research workers but also businesses, because of their huge economic potential. The national science foundation reports that nano-related goods and services will increase to a US$ 1 trillion market by 2015. This amount is larger than the combined businesses of the telecommunications and information technology industries. Several hundred billion Euros are forecast to be created by nanotechnology in the next decade [50]. The nano materials markets could expand to US$ 4 billion by 2007. It was believed that 2 million new employment opportunities would be created in order to meet the worldwide annual production demand of US$ 1 trillion in 10-15 years.

Nanotechnology may impart favorably on the environment as well. By using less resource without sacrificing performance, nanotechnology may save raw materials and also upgrade quality of life.

6. CONCLUSION

Textile industry has already impacted by nanotechnology. The development in the applications of nanoparticles has been very rapid in past years, particularly in the field of textile finishing. These nano-size materials are able to enhance the physical properties of conventional textiles in areas such as self cleaning fabrics, water repellence, uv-protection, anti-bacteria, anti-static, wrinkle resistance, flame retardant properties of textile materials. Nanofibers also come to occupy in the field of textiles and it has tremendous possibility. Research involving nanotechnology to improve performances or to create unprecedented functions of textile materials is flourishing. There is no doubt that in the next few years, nanotechnology will penetrate into every area of textile industry.

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