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Characteristics and application of nanomaterials on sportswear fabric

Yongho Choi[1], Sang-Duk Lee[2] and Shin Hwan Yoo[2, 3*]

[1] *Department of Materials Science and Engineering, Jungwon University, Goesan-eup, South Korea.*

[2]*Department of Physical Education, Hallym University, Chuncheon, South Korea.*

**Corresponding author*

[1, 2, 3]*Orcids: 0000-0002-4255-3709, 0000-0002-5160-5099, 0000-0002-0717-5802*

Abstract

Nanotechnology is becoming an essential key for special functions of sportswear and it has begun to be applied to sportswear industry for innovating performance. Impact of nanotechnology on the sportswear industry is getting bigger. Ultimate purposes of highly functional sportswear based on nanotechnology are to increase safety against mechanical, chemical, physical, optical, and thermal destruction and to improve water repellency, oil recovery and anti-fouling functions. Moreover, nanotechnology can improve functions sportswear such as reflection and absorption of UV and IR, shielding of electromagnetic waves, and etc. In addition, appearance, touch, and durability of color can be improved as well. Mostly used nanomaterials for functional sportswear are ZnO, TiO_2, Ag, SiO_2, Carbon black, and carbon nanotubes. In this paper, characteristics and applications of the above nanomaterials on textiles are reviewed.

Keywords: Nanomaterial, Textile, Functional textile, Sportswear, Fabric

APPLICATION OF NANOMATERIALS ON SPORTSWEAR

Recently, nanotechnology has received great interest in a global sportswear industry. Nanotechnology is becoming an essential key for special functions of sportswear. Concept of 'nano', a billionth of a billion, is not entirely new, but it has begun to be applied to sportswear industry for innovating performance. In other words, the nanotechnology is a future that allows consumers to actually get their dream sportswear.

Impact of nanotechnology on the sportswear industry is getting bigger. Ultimate purposes of highly functional sportswear based on nanotechnology are to increase safety against mechanical, chemical, physical, optical, and thermal destruction and to improve water repellency, oil recovery and anti-fouling functions. Moreover, nanotechnology can improve functions sportswear such as reflection and absorption of UV and IR, shielding of electromagnetic waves, and etc. In addition, appearance, touch, and durability of color can be improved as well. Mostly used nanomaterials for functional sportswear are ZnO, TiO_2, Ag, SiO_2, Carbon black, and carbon nanotubes. In this paper, characteristics and applications of the above nanomaterials on textiles are reviewed.

Zinc Oxide (ZnO) nanoparticles

The main characteristics of ZnO materials in textile applications are bio-safe, photo-oxidizing and photo-catalytic. ZnO nanoparticles are very small in size so the surface reactivity is greatly increased. ZnO nanoparticles have been extensively studied for UV-protection and antibacterial functions, and these two functions have been focused in this review.

It was experimentally demonstrated that the smaller size of nanoparticles can increase the efficiency of UV-protection of the coated textiles. [1] ZnO nanoparticles were prepared by reaction with 1,2-ethanediol at 150ºC and water reaction at 90ºC to get the smaller size. Moreover, the smaller size of ZnO nanoparticles improved the antibacterial and self-cleaning functions.[1]

In other study, ~40 nm ZnO nanoparticles were coated on cotton fabrics and it was shown that 2% contents of the ZnO nanoparticles blocked an average of 75% UV light. Air permeability of the coated cotton fabrics was improved as well. [2]

ZnO nanoparticles can be used to increase efficiency and lifetime of dye. ZnO nanoparticles were coated on polyester fabrics and the fading of dye on the fabrics was studied. However, the result showed that ZnO nanoparticles generated superoxide and hydroxyl radicals (Reactive Oxygen Species) when irradiated with UV lights. Addition of anti-oxidants to dyes may reduce the activity of ROS. [3]

The antibacterial behavior of the ZnO nanoparticles was studied. [4] As a result, it was shown that the particle size, concentration and adding of dispersants affect the antibacterial behaviors of ZnO nanoparticles. The antibacterial activity was increased with smaller size of nanoparticles and/or with higher nanoparticle concentration. However, the type of dispersants didn’t show great differences in their experiments.

The antibacterial effect of ZnO nanoparticles on *Campylobacter jejuni* was investigated. The *Campylobacter* *jejuni* was destroyed after exposure to 0.5 mg/ml of ZnO nanoparticles for 16 hours. [5]

The antimicrobial effect of ZnO nanoparticles (20-25 nm size) were tested against pathogenic bacteria such as *Staphylococcus aureus* (Gram positive) and *Salmonella typhimurium* (Gram negative) and two plant fungi. The result showed that ZnO nanoparticles have good antibacterial activity against those bacteria and fungi tested. [6]

The antimicrobial effect of ZnO nanoparticles embedded in polyurethane on different bacteria such as *Staphylococcus aureus*, *Escherichia coli* and *Pseudomonas aeruginosa* were investigated. [7]

Silver (Ag) nanoparticles

The antibacterial properties of Ag have been well studied and are being used in wide applications. Likewise, as the size of Ag became smaller, its properties are much strengthened. As other nanoparticles, the nano-size can bring significant improvements in the antibacterial activity of Ag.

The antibacterial activity of Ag nanoparticles at different concentrations against yeast was characterized. [8] In their experiments, the growth of yeast and *Escherichia coli* was inhibited in Ag nanoparticles even at low concentrations. They studied the inhibitory behavior of Ag nanoparticles with free-radical generation as well.

The antibacterial activity of Ag nanoparticles against Gram-positive *Staphylococcus aureus* and Gram-negative *Escherichia coli* was studied with field emission scanning electron microscopy. [9] They found that the minimum inhibitory concentration of Ag nanoparticles against *Staphylococcus aureus* and *Escherichia coli* was 100 µg/ml.

More studies have been conducted for characterization of the antibacterial activity of Ag nanoparticles at several different sizes, concentration, formation, and other factors. [10-14] Morones et.al found that antibacterial activity of Ag nanoparticles is size dependent and only nanoparticles interacted with the bacteria have a diameter of 1-10 nm.[15]

Super-hydrophobic property of Ag nanoparticles with *hexadecyltrimethoxysilane* treatment was experimentally demonstrated. [16] A super-hydrophobic surface was formed by coating Ag nanoparticle on textiles and it was examined by scanning electron microscopy. The coated cotton textiles showed conductive characteristic. Moreover, the coated textile showed a high antibacterial activity against the gram-negative bacteria, *Escherichia coli*.

Titanium dioxide (TiO_2) nanoparticles

TiO_2 is chemically stable and has durability against corrosion so it is one of the most applicable nanomaterials in textile industry. The band gap energy of TiO_2 is 3.2 eV which causes a reaction with ultraviolet light near 380 nm. However, ultraviolet light are only 5% of the sunlight, so pure TiO_2 is not enough for real life applications. In order to overcome the problem, photocatalytic materials reacting with visible light band such as TiO_2 composites have been actively studied.

Enzymes can improve adsorption of nanoparticles on textiles and its functionalities. [17] A textile was first treated with proteases and lipases and then coated with TiO_2 nanoparticles. The cross-linking agent, butane tetracarboxylic acid (BTCA), was added in a solution and it was cured to enhance the adsorption and stabilization of TiO_2 nanoparticles on the textiles. The self-cleaning, UV protection and antibacterial properties of the coated textiles were examined by scanning electron microscopy and energy dispersive X-ray spectroscopy. [17]

SiO_2-TiO_2 core-shell nanoparticles with different sizes were prepared with tetraethyl orthosilicate (TEOS) and tetraisopropyl titanate (TIPT). [18] And antireflective and self-cleaning properties of the core-shell nanoparticles were characterized. The core-shell nanoparticles were formed as raspberry-like shape. The properties of nanoparticles were characterized with many different methods such as scanning electron microscopy, transmission electron microscopy, thermogravimetric analysis, X-ray diffraction, Fourier transform infrared spectroscopy, and UV–vis spectroscopy. The result showed that the maximum transmittance of the nanoparticle coated glass was very high, up to ca. 97% and the glass showed good super hydrophilic, antifogging, photocatalytic, and self-cleaning properties.

The most efficient size of TiO_2 nanoparticles for UV protection was characterized. [19] Based on the Monte Carlo simulation, the most effective size of TiO_2 nanoparticles for UV-B protection was found to be 62 nm.

In other study, TiO_2 nanoparticles with 62 and 122 nm size were found to be the most effective for the protection of 310-410 nm wavelengths light. [20]

Poly(ethylene phthalate) (PET)/TiO_2 nanoparticle composite was prepared and its properties were investigated. [21] As results, UV transmittance the nanoparticle composite was lower than 10% in the UV-A band and lower than 1% in the UV-B band. The ultraviolet protection factor (UPF) of the composite was greater than 50.

In other study, polyester textile was modified with a natural polysaccharide alginate and colloidal TiO_2 nanoparticle, and its UV protection, photocatalytic and antibacterial activity was characterized. [22] The modified polyester textile showed a good antibacterial activity and UV protection efficiency even after several washing cycles. The result indicates an excellent laundering durability of the TiO_2 nanoparicles coated textile. Moreover, they showed that a photo degradation of the modified textiles by UV light was very slow.

Anatase TiO_2 nanoparticles with 3-5 nm size were prepared and coated on cotton fabrics. [23] The study showed a good self-cleaning and antibacterial activities of the textile.

Silica (SiO_2) nanoparticles

Many researches have been conducted on the super-hydrophobic properties of SiO_2 nanoparticles. A surface with a water contact angle higher than 150° is considered as a super-hydrophobic surface. The super-hydrophobic surface on cotton and polyester fabrics was demonstrated with SiO_2 sol nanoparticles. [24] The authors showed that the water contact angle on a coated cotton super-hydrophobic surface was as high as 155º and 143º for polyester super-hydrophobic surface. The super-hydrophobic activity was mainly due to a hydrolyzed hexadecyltrimethoxysilane and SiO_2 sol nanoparticles, and a roughness of the super-hydrophobic surface was further increased by SiO_2 sol nanoparticles. Also, they found that the super-hydrophobic surface was durable after several washing cycles. The super-hydrophobic surface was characterized by scanning electron microscopy.

A super-hydrophobic surface was achieved with SiO_2 nano-spheres. [25] The authors theoretically demonstrated that too large spacing between the SiO_2 nano-spheres can possibly deactivate the super-hydrophobic effects.

Super-hydrophobic surface on cotton fabrics was prepared using SiO_2 nanoparticles and ZnO nanorods.[26] The SiO_2 nanoparticles and ZnO nanorods coated cotton fabrics were subsequently modified by dodecyltrimethoxysilane (DTMS) to increase super-hydrophobic effects. They found that a water contact angle (WCA) was more than 150º for a 5 mL water droplet.

The mesoporous SiO_2 nanoparticles which were functionalized with tridecafluorooctyl-triethoxysilane were coated on cotton textiles. [27] The SiO_2 nanoparticles were spherical and average size was about 45 nm. They also showed high surface areas and large pore volumes on the coated cotton textiles which resulted in super-hydrophobic surface.

Amino- and epoxy-functionalized SiO_2 nanoparticles were coated on epoxy-functionalized cotton textiles and demonstrated super-hydrophobic surface. [28] A static water contact angle was about 170° for a 5 μL droplet.

Carbon nanotubes

Carbon nanotubes are attracting many attentions due to their excellent chemical, mechanical and electrical properties, and also their application in textile industry has been actively studied. Depending on number of walls of carbon nanotubes, they are categorized into single walled carbon nanotube (SWCNT) and multi walled carbon nanotube (MWCNT). SWCNT is composed with one wall and MWCNT is composed with more than one wall. MWCNT is electrically metallic material, but SWCNT can be either semiconducting or metallic material based on its structures such as diameter and chirality. Depending on its chirality, three types of SWCNT structures are possible such as armchair, zigzag, and chiral SWCNT. It is also known that the bandgap of semiconducting SWCNT is inversely proportional to their diameter. For textile application, electrical properties of carbon nanotubes have been importantly studied and developed applications.

MnO_2 which is a pseudocapacitor material was electrodeposited on carbon nanotubes forming conductive textiles. [29] It is well known that carbon nanotubes cab effectively decrease ion diffusion and charge transport resistance. The MnO_2 and carbon nanotubes composite in a form of textile was used as a positive electrode and it was reduced to be used as a negative electrode. Electrolyte was water containing 0.5 M of Na_2SO_4. The resultant electrodes can be used as the electrical energy storage for multifunctional wears.

Carbon nanotubes itself were used as fibers.[30] Mechanical and electrical properties of the carbon nanotubes fiber were examined and they experimentally demonstrated that it is promising material as a mechanical reinforcement and/or electrical conductive source in textiles. The carbon nanotubes fiber was about 4 times stronger than spider dragline silk and about 20 times stronger than steel wires.

An electrically conductive textile was demonstrated with carbon nanotubes by polyelectrolyte based coating. [31] The authors integrated humidity sensor in the electrically conductive carbon nanotubes textile and it was shown that the textile can be used to detect albumin and blood with high sensitivity and selectivity.

Carbon nanotube-polymer composite was fabricated as a strain sensor for health monitoring application. [32] The polymer acts as the interfacial bonding between the carbon nanotubes. Multi walled carbon nanotubes served as conductive material and used for improving a repeatability and linearity of the sensor. The authors also developed a neuron sensor for detecting large strains and cracking which is useful for health monitoring of large structures.

A core/sheath structured carbon nanotube fiber was demonstrated as a super capacitor for wearable electronics. [33] The carbon nanotubes were coated as thin layer onto a metal wires and which serves as current collector for long length super capacitor. The core/sheath structured composite showed excellent electrochemical properties. The fiber type super capacitor is suitable for wearable electronic applications.

A strain sensor using a thin film of aligned single walled carbon nanotubes was demonstrated for motion detectable textile. [34] The strain sensor using the carbon nanotube films could measure strains up to 280% which is 50 times larger than a conventional metal strain sensor. Also, it showed high durability, fast response and good ductility. They integrated the sensor on stockings, bandages and gloves and showed capability of detection for human motions such as movement, typing, and breathing.

Single walled carbon nanotubes were coated on conventional textiles to demonstrate electrically conductive textile. [35] Due to the incorporated carbon nanotubes, the textile had increased conductivity by four orders of magnitude and doubled capacitance. Also, they showed that the textile has good durability and strain sensing properties.

Aligned carbon nanotube fibers were fabricated and used as an electrode for super capacitor. [36] The carbon nanotube fibers were incorporated for a solar energy convertible wear.

Carbon nanotubes were used for mechanical reinforcement in conventional fibers and cotton fibers were coated with carbon nanotubes. [37] The cotton textile coated with carbon nanotubes showed excellent mechanical properties, flame retardancy, UV-blocking and super-hydrophobic properties.

Carbon nanotubes were coated on carbon fibers forming composite textile. [38] The composite was subsequently infiltrated with epoxy resin in which the carbon nanotubes were completely integrated into the carbon fibers. They showed that the carbon nanotubes and carbon fiber composites have ~30% enhanced interlaminar shear strength and significantly improved electrical conductivity. We summarized the applications of nanomaterials discussed in Table 1.

Table 1: Applications of nanomaterials in textiles

Material	Application in textile
ZnO nanoparticles	UV protection Antibacterial application Additive for dye
Ag nanoparticles	Antibacterial application Superhydrophobic surface
TiO_2 nanoparticles	Self-cleaning UV protection Antibacterial application Antireflective application(SiO_2-TiO_2 core-shell) Superhydrophobic surface Photocatalytic application
SiO_2 nanoparticles	Superhydrophobic surface
Carbon nanotubes	Conductive electrode Mechanical reinforcement Humidity sensor Strain sensor Super capacitor

CONCLUSION

Numerous studies have been conducted to apply nanomaterials to textile. Nanomaterials can be applied to textiles to impart antimicrobial, self-cleaning, anti-wrinkle, UV protection, waterproof and electrical conductivity functions. There have been many efforts to apply nanomaterials so far, but further researches and developments would be necessary in the future. In this paper, we have reviewed the major nanomaterials that have been studied for application to textile. Although a lot of researches have been conducted, more nanomaterials need to be discovered to realize novel functions, and it is necessary to expand its application for functional textiles such as sportswear, military wear, and etc.

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