

# Nanotechnology in The Driver's Seat of Sportswear Industry: A Review of Current Trends and Future Applications



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## Abstract

Nanotechnology is considered as one of the most pioneering technologies of 21st century. The desire for sportswear with enhanced performance, efficiency and durability has existed for several years. Nanotechnological developments in textile industry has paved the way to fulfilling these desires. It has helped in overcoming the drawbacks of traditional processing techniques of sportswear industry. Introduction of nanotechnology has opened new opportunities of manufacturing functional and smart textiles that not only serve unique needs of sport activities but also aid athletes in achieving high performance with highest level of comfort and safety. Nanomaterials such as carbon nanotubes (CNT), silver nanowires, graphene and other 2D materials shall be used for incorporating electronic devices into clothing for the future development of wearable electronics for implementation in performance monitoring (in-situ).

The smart convergence of textiles, electronics and informatics shall harness improvements in sensors, flexible & printable electronics and energy devices. This shall open opportunities for much other new functionality such as energy storage and harvesting capabilities, biological functions, antimicrobial properties necessarily required for sportswear by way of integration of electronic components and sensors viz. heat and humidity with high strength, flexible and electrically conductive textiles. Taking a cue from the current trend of use of nanotechnology in the sportswear industry it is expected that a technological revolution is imminent soon. Some of the important properties imparted into sport-apparels by nanotechnology are thoroughly discussed. An overview of the recent developments and current trends pertaining to the use of nanotechnology in sportswear industry, its shortcomings and future perspective and current trends are given.

**Keywords:** Nanotechnology; Sportswear; Functional Textiles; Smart and Intelligent Textiles

## Introduction

Richard Feynman famously told an audience of the American Physical Society in 1959 that there was "plenty of room at the bottom" for exploration, discovery, and fame in the world of what we now call "nanotechnology": the study and application of very small things, in the size of less than 100 nanometers, by manipulating atoms and molecules. It is a multidisciplinary field that finds its usage in processing diverse range of products and materials by employing physical, chemical, biological, engineering

and electronic sciences. It has vast potential to create new materials with unique properties and improved performance. Due to this potential, nanotechnology is regarded as a key technology that will influence technological development soon and have economic, social and ecological implications Zhao, Boxman and Chowdhry [1], Chong [2], Ashish K Keshari [3]. Many researchers thus herald nanotechnology as the next industrial revolution, with unprecedented potential to revolutionize multiple sectors by

improving on existing technologies and introducing radical new tools and products Kaounides, Yu and Harper [4] Dutta, Ranu K [5].

Textile industry is one of the oldest industries of the world, and utilizes yarn, cloth and clothing derived from natural, synthetic, and chemical sources. Since the advent of nanotechnology, textiles industry has become one of the pioneering industries that have successfully implemented nanotechnology in developing innovative textile products for consumer usage [4]. A growing area of interest in the application of nanotechnology is use of nanoparticles on finishing textiles and developing fabrics with diverse practical applications and functions. Nano fabrics have better performance than conventional fabrics because they provide waterproof, stain-proof or odor-resistant properties which also have an edge over older products such as Teflon and Gore-Tex since nanoparticles-which are embedded in cotton, wool or other materials-do not alter the natural texture and feel of the original fabric. In fact, with the application of nanotechnology, textiles properties can be altered, improved or created with new or enhanced functionality without changing the comfort properties of the substrate Musante and White [6]. In this way, textiles can be nanoengineered to have specific properties such as hydrophobicity, antibacterial activity, conductivity, antiwrinkle, antistatic etc. Thus, treatment of textiles with suitable nanoparticles provide a new frontier of nanoengineered functional textiles [6-9], Dutta Ranu K, [10-12], and has paved the way for creating new textiles that were difficult to process through conventional techniques.

With an ever-increasing number of people getting involved in outdoor recreational sports, nanotechnology is receiving great attention in the global sportswear industry Choi, Lee & Yu [13], Kanat. Consumers now demand clothes that stay fresh and clean, smell pleasant, feel comfortable, require easy care, and look great Rajni Kumar. It is therefore important that sportswear industry employ newer technologies that improve functional properties of sportswear and nanotechnology will be the mainstay in these endeavors. As nanotechnology has opened new routes to produce functional textiles, researchers have found a wide range of applications of nanotechnology in sports clothing and equipment.

### Nanotechnology-based applications in textile industry

Nanotechnology-based textile can be produced by different techniques resulting in the development of:

a) Nanofibers, fibers with diameter of less than 100nm, large surface area (1000 times more than microfibers), and with excellent mechanical properties. They can be produced by interfacial polymerization, electrospinning and electrostatic spinning methods Huang [14] Ramakrishna [15]. Connected fabrics do provide extra convenience compared with wearable technology accessories, as they function both as sportswear and as biometric data collectors because their precision is greater, as the embedded sensors in connected fabrics are generally

closer to the central part of the body and its vital organs.

b) Nanocomposite fibers, produced by using nanofillers such as nanoclay, metal oxides and carbon nanotubes. These fibers have enhanced physical, mechanical, and abrasion resistance properties; and

c) Nano-finished textiles that deals with the use of nanoparticles on textiles, providing fabrics with diverse practical performance depending on the nanoparticles' properties Mongill [16] Montazer and Dehghani-Zahedani [17]. With nanoengineering, fabric with specific properties can be designed thus changing their appearance and/or improving their resistance to water, chemicals, biological agents, physical, mechanical, and general wear and tear Harifi and Montazer [18]. In fact, nanoparticle based nano finish and nanostructures can develop and enhancing advanced performance characteristics of conventional textiles, particularly in areas such as anti-microbial, antibacterial, water repellency, soil-resistance, anti-static, anti-infrared and flame-retardant properties. Therefore, nanotechnology can be used in engineering desired textile attributes, such as strength, softness, durability, comfort and breathability in fibers, yarns and fabrics.

### Nanotechnology-based applications in sportswear industry

Fabrics and products treated by nanotechnology-based material are being developed for a variety of active sports such as ballooning, parachuting, snowboarding, aerobics, athletics, running, cycling, hiking, mountaineering, swimming, sailing, windsurfing, and skiing etc. Considering the challenging conditions involved in these sports, it is important that sports apparel and gear possess' multifunctional properties. For example, advanced materials that provide viable solutions to bio-integrated wearable electronics have enabled recent advances in flexible and stretchable electronics. Taking a cue from it the textile manufacturers have brought sensor based smart textiles products to the market such as sensor tattoos and wearable motion charging devices as useful sportswear, mainly for the collection of biological-data (such as heart-rate, body temperature etc.). It is expected that all sports related clothing should at least serve basic functions such as comfort, protection, stretch ability, lightweight, and dimensional stability.

Smart sports are part of the broader phenomenon of the Internet of Things (IoT), Internet-enabled objects that connect to a network, gather and share data, and interact with their surroundings. With the help of IoTs, the Data collected thus becomes essential for measuring athletic performance, and therefore, smart sports technology allows users to capture and track their performance data. The equipment and devices collect and transmit information to smartphone apps or cloud systems that can then analyze it and provide diagnostics. Such data can also be used to create personalized "virtual coaching programs". Additionally, based on the nature of the sport, it is

important that “SMART” sportswear may serve some special functions, such as low aerodynamic and hydrodynamic drag force, compression, waterproofing, wind proofing, health-monitoring capabilities, and breathability etc. Kanjana and Nalankilli [19]. To meet these requirements, traditionally, several chemicals such as phthalates, dimethylformamide (DMF), nonylphenol ethoxylates, and nonylphenols etc. were used to impart varied properties and finishes. These chemicals were found to have deleterious side effects Greenpeace International [20] and after repeated laundering and wearing, sportswear start to lose those special properties and functionality Khan [21]. Asif and Hasan reported that nanotechnology-based finishing/treatment provides most durable finishes to fabrics. Nanoparticles have a large surface area-to-volume ratio and high surface energy, thus offering better affinity for fabrics and leading to increased durability of finishes and functions. At the same time application of nanoparticles on fabric’s surface will not affect hand (feel) of the fabric.

Hence, researchers in the past few years are focused on innovating new materials and techniques of treating/manufacturing textiles using nanotechnology that enable fabrics to retain enhanced properties longer and have advantages over conventional processes without any hazard. Harifi and Montazer [18] reported application of nanotechnology in incorporating properties in sportswear like, water-proof, anti-bacterial, UV-protection, self-cleaning, insulation, comfort, enhanced blood circulation and recovery of muscles, and electronic textile properties. Several nanomaterials were used in imparting these properties to textiles. The commonly used nanomaterials are metal oxide nano particles such as TiO<sub>2</sub>, ZnO, Cu<sub>2</sub>O, Fe<sub>3</sub>O<sub>4</sub>/Fe<sub>2</sub>O<sub>3</sub>, Al<sub>2</sub>O<sub>3</sub>; metal nanoparticles such as Ag, Au, Pd, Pt, Cu and Ni; carbon black nanoparticles; carbon nanotubes; and clay nanoparticles Harifi & Montazer [18].

### Recent Developments in Sportswear Industry

In the last decade, nanotechnology research in the field of sportswear is focused on two main areas. First, upgrading the present functions and performance of textile materials; and second, on addressing the development of intelligent textiles with new characteristics and functions Kaounides and Harper, Yetisen [22]. Towards this, textiles used in sportswear could be broadly classified as functional textiles, and smart/intelligent textiles.

### Functional Textiles

Functional textiles are specifically engineered to deliver a pre-defined performance or functionality to the user above its normal function Gupta [23]. These fabrics are mainly used in manufacturing textiles for active sports such as ballooning, parachuting, snowboarding, aerobics, hiking, mountaineering, swimming, sailing, windsurfing, and skiing. These are produced to have a minimum resistance against movement and provide maximum comfort with enhanced performance of the end user. Functional textiles may combine multiple functions, such as, heat-resistant, antibacterial, oil-water repellent, waterproof, windproof with good

breathability and moisture transport, into a single textile system to add more value. Thus, the current developments in functional textiles led to improved physiological comfort and performance of the end users. Some of the important properties incorporated in sportswear using nanoparticles/nanotechnology are listed below:

- a) UV protection:** Sportswear treated with nanoscale semiconductor oxides such as TiO<sub>2</sub> and ZnO efficiently absorb and scatter UV radiations, and are effective in protecting skin from UV radiations while retaining flexibility, weight and comfort properties of the fabric.
- b) Water proofing/repellency:** Water repellent sports textiles are manufactured by forming nano whiskers, which are three times smaller than a typical cotton fiber and give a peach fuzz effect (like the ‘Lotus effect’) to the textile. Fabric made with this nanomaterial contains high surface tension that allows water to remain on the surface. This is important in sportswear as it keeps the fabric clean and water proof.
- c) Antibacterial property:** To avoid the growth of bacteria and fungi due to sweating during sport activities, Ag, TiO<sub>2</sub>, and ZnO based nanomaterials are being utilized to impart antibacterial, odor-control, and fungicidal properties to sports textiles Throne-Holst [24], Charu Dwivedi [25,26].
- d) Electrical conductivity:** Textiles treated with nanoparticles that conduct electricity, such as ZnO, TiO<sub>2</sub> and ATO, can help disperse electric charge from fabric particularly synthetics such as polyester and nylon that tend to gather static charge. These fabrics are useful in creating textiles with sensors and actuators and are often used in manufacturing sports clothing Kathiervelu [27].
- e) Comfort:** Certain nanomaterial can enhance the comfort level of various sportswear. An example is the development nanomaterial by using atmospheric pressure non-thermal plasma technology followed by graft polymerization. This type of nanomaterial has proved to be an effective method in providing high performance by controlling moisture and odor during sport activities Manshahia and Das.

### Smart/Intelligent Textiles

Smart textiles are usually defined as textile materials or products that can sense and interpret changes in user’s local environment and respond appropriately Kanjana and Nalankilli [18]. For example, a lightweight, nanomaterial-based wearable system that can keep the wearer’s body comfortable in outside temperatures that ranges from – 50 °C to +50 °C (ClimaCon technology). The most commonly used materials in manufacturing smart/intelligent textiles are, phase change materials (PCM), shape memory materials (SMM), chromic materials (color change), conductive materials, and electronics incorporated textiles. The incorporation of smart materials and technologies into fabrics pave the way to

achieve numerous potential applications, such as, communication between devices, conduct electricity or energy, sense, react and protection from hazardous environments. According to functional activity of smart textiles, these can be classified in three categories:

- a) Passive Smart Textiles that can only sense the environmental conditions or stimulus.
- b) Active Smart Textiles that has both actuators and sensors. The actuators act upon the detected signal either directly or from a central control unit. Examples of active smart textiles are shape memory, chameleonic, water-resistant and vapor permeable (hydrophilic/non-porous), heat storage, thermo regulated, vapor absorbing, heat evolving fabric and electrically heated suits.
- c) Ultra-Smart Textiles that can sense, react and adopt themselves to environmental conditions or stimuli. A very smart or intelligent textile essentially consists of a unit, which works like the brain, with cognition, reasoning and activating capacities. The following are some of the materials/ technologies that have been developed to manufacture smart textiles:

### Insulation Effects

The sportswear with insulation properties against heat and cold are required especially for skiing, snowboarding, diving, mountaineering and cycling considering the relationship between human body heat, environmental conditions and physical activity. Thermo-regulated smart textiles, by incorporation of PCMs in textiles are of considerable importance in this aspect Harifi and Montazer [18]. In addition, shape memory materials (SMMs) are also useful in imparting special insulation properties to sportswear.

### Phase Change Materials (PCMs)

Thermally active materials made by PCM microcapsules coating can improve the wear comfort of the garment by active thermal insulation. PCM acts as thermal storage unit in the garments. It provides a thermal balance between the heat generated by the body while engaging in a sport and the heat released into the environment Kanjana and Nalankilli [19].

### Shape Memory Materials (SMMs)

These are polymeric smart materials that have an ability to return from a deformed state (temporary shape) to their original (permanent) shape following any external stimulus. Temperature, a magnetic field, an electric field, the pH value, UV light, and even the presence of water can trigger the shape change. Among the variety of available SMMs, shape memory polymers (SMPs) are most suitable in producing smart coatings for textiles Kanjana and Nalankilli [19]. SMPs can be incorporated in the form of films in multilayer garments for protective clothing, sportswear, or leisurewear. Using a composite film of SMM as an interlining (i.e. membrane) in multilayer garments, outdoor clothing can have an

adaptable thermal insulation and be used as performance clothing with variable adaptability and thermal insulation values Hu [28].

### Therapeutic Effects

Physical activities especially heavy sports such as bodybuilding, arm-wrestling and powerlifting may cause fatigue, injury or overworked muscles. This can be recovered using smart textiles with therapeutic effects. Textile materials that have close contact with skin are incorporated with germanium and ceramic powders such as alumina, titanium dioxide and silicon dioxide. These nanostructures with far-infrared radiation effect are applied in variety of therapeutic applications such as therapeutic knee bands, elbow bands and back-belts Chung and Lee [29].

### Electronic Properties

Clothing with electronic properties could be used for collecting vital information and therefore provides an important innovation in sportswear. These fabrics are being used in healthcare as well as in protecting athletes, especially in high-risk sports such as mountaineering. Their main purpose is monitoring biological and physiological body changes and recording vital body signs. Electronic textiles (e-Textiles) are particularly important in this respect. An electronic textile refers to a textile substrate that incorporates capabilities for sensing (biometric or external), communication (usually wireless), power transmission, and interconnection technology to allow sensors or things such as information processing devices to be networked together within a fabric. They usually contain conductive yarns that are either spun or twisted and incorporate with some amount of conductive material (such as strands of silver or stainless steel) to enable electrical conductivity. E-textiles can be broadly classified as; e-textiles with classical electronic devices such as conductors, integrated circuits, LEDs, and conventional batteries embedded into garments; and e-textiles with electronics integrated directly into the textile substrates. This can include either passive electronics such as conductors and resistors or active components like transistors, diodes, and solar cells. For example, Interactive Electronic Textiles (IETs) have been developed to detect blood pressure, time, distance, calorie and movement in active sportswear, even recording arm actions to improve golf or tennis swings Meoli and May-Plumlee [30]. A recent emphasis is on developing smart multifunctional sportswear for the overweight, called as diet-facilitating suit, using smart textile materials that monitor the change of waist circumference, body temperature and the time of exercise, and giving feedback to the wearer Hyun.

### Commercial products of Functional and Smart Textiles

Commercially, several textile companies have adopted nanotechnology to develop wide range of sports clothing and products for consumers. Some examples of commercialized products are summarized here. Scholler, a Swiss company, has developed a nano-based technology to produce clothing with optimal balance of comfort, air permeability, wind and water resistance, and self-cleaning property for extreme cold weather sports (mountaineering

and ski). JR Nanotech, a UK-based company, has developed 'Sole Fresh TM' socks treated with silver nanoparticles eliminating athlete's foot odor Mohapatra. Speedo, an Australian company, manufactures Fastskin swimsuit, which imitate the ridges present on the skin of a shark and allows a trouble-free gliding through the water thus increasing swimmers speed. Odegon Technologies, another UK-based company, produces nano fabrics that reduces unwanted odors. Adidas, in 2014, launched Climachill™, a sportswear collection that includes T-shirts, shorts, and shoes, made with smart fabrics that help to cool down the wearer's body temperature during sports related activity. The OM bra, a Canadian company, launched a smart sports bra that tracks the wearer's body signals, such as heart rate, breathing rate and calories burned. The data signals are transmitted to the OM signal mobile applications for visualization and implementation of effective strategies. US fitness apparel startup, Athos, launched a line of sportswear that records wearer's body metrics in order to help optimize training, and enables the real-time visualization and analysis of the muscles worked and the intensity of the workout. Another US sportswear company, Under Armour, had launched its Health Box connected-fitness system in 2016, a tracker that connects with all other Under Armour smart wearables and devices.

## Conclusion

Nanotechnology has revolutionized the production of sportswear globally. As nanotechnology-based finishing/treatment provide more durable finishes and functions to fabrics without affecting the inherent properties of the fabric, it has taken over the traditional methods of manufacturing sports fabric. Moreover, the customer demand of improved functionality and high performance has further motivated the development of nanotechnology-based textiles in the sports industry. It has not only affected individual's performance, but also have an impact on athlete's performance participating in world level games such as Olympics. With the development of smart textiles introducing new features on breathability, insulation and electronic properties in sportswear, athletes are now able to withstand high levels of activity for long durations while enhancing wearer's performance. Therefore, comparing the benefits of nanomaterial-based textiles over ordinary/conventional sport clothing, nanotechnology has brought many benefits to sports activities. In the coming years nanomaterial will be the mainstay in transforming textile industry and in general and sportswear. As with any emerging technology, a benefit-to-risk ratio needs to be calculated about the nanotechnology-based developments.

The negative effects of nanoparticles on wearer's skin and environment need an urgent attention. As textile products frequently come in direct contact of human skin, nanoparticles can be easily absorbed in the body and may pose a health hazard. In addition, there is a need to understand impact of the uncontrolled release of nanoparticles in the environments. Until recently, only very few

researches had been conducted on the effect of nanoparticles on health, safety risks and threats to the environment Harifi and Black [31], Montazer [18]. Besides, several nano-based products are increasingly available in the market. Therefore, policies and codes of conduct governing nanomaterial manufacturing, applications, and disposal warrants attention at the level of policy makers and manufacturers [31-43]. The regulations need to be fast enough to keep up with the pace of commercial applications of new product innovations driven by first-to-market competitive advantage. Therefore, it is recommended that future studies should focus on the production of nano-based sports materials while complying with safety regulations, minimizing the risks to health, safety and environmental hazards.

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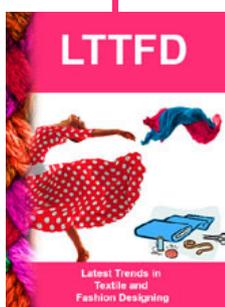
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