

Nanofinishing of Textiles for Sportswear

Nalankilli Govindan¹ Kanjana Subramanian²

¹Professor(Textile Chemistry Research and Innovation Centre) ²Lecturer(Apparel Production Research and Innovation Centre)

^{1,2}Ethiopian Institute of Textile and Fashion Technology, Bahir Dar University, Bahir Dar, Ethiopia

Abstract— Nanotechnology is a multidisciplinary and comprehensive frontier field. Application of nanotechnology in sports clothing and flooring for enhanced sport activities, performance, efficiency and comfort has increased tremendously during the last decade. The nanomaterial have been widely used in the stadium, sports turf, track, sports, apparel, sports equipment and sports supplements. With the coming of the nano era, nanotechnology will have far-reaching impact of human life. The desire for sport products with enhanced performance and efficiency has been known for many years and nanotechnology has opened new routes for the production of functional sportswear. An overview on the applications of nanofinishing in the making of different sportswear has been done exhaustively. Some of the important features imparted into sport apparels by nanofinishing are also thoroughly discussed.

Key words: Nanomaterials, Nanoparticles, Multifunctional, Antibacterial, UV-protection, Therapeutic effect, Comfort

I. INTRODUCTION

In textile industry, finishing stage is where the specific properties are imparted into fabrics, changing their appearance and/or improving their resistance to water, chemicals, biological, physical, mechanical and general wear. Nano-finishing, offering huge potential in a wide range of end uses, has opened up new insights for various applications difficult to proceed through conventional finishing, a growing area of interest in nano-finishing is use of nanoparticles on textiles, providing fabrics with diverse practical performance depending on the properties of nanoparticles. Over the years, research groups all around the world obtained variety of textile materials with multifunctional properties through incorporation of nanomaterials.

In sport clothing market, use of nanotechnology in textile materials including nanofibers, nanocomposite fibers and nano-finished textiles imparts multi-properties providing their application. A wide range of sports apparel utilizing nanotechnology have been developed by several companies. A nano-based technology to produce clothing with optimal balance of comfort has been developed by a Swiss company called Scholler, with air permeability, wind and water resistance and self-cleaning property for extreme cold weather sports such as mountaineering and ski. It has also the benefit from rain- and snow-repellent feature [1]. JR Nanotech, a UK-based company, has developed socks in the trade name of “SoleFresh™” which was treated with silver nanoparticles eliminating athlete’s foot odor. A Korean company, by name Hyosung has been producing Nano silver nylon fibers with application areas that include daily activities and sport, sportswear, sports bags and running shoes [2].

In the anti-slip properties of footwear soles, Nanotechnology has provided a real breakthrough [3]. Breathable clothing regulating body temperature in extreme

climates and increased wicking in sport clothing protecting mountaineer from the cold and rain, are some of the benefits of using nanotechnology in sportswear [4]. In this paper, some of the most important properties of nano-sport clothes and shoes are discussed exhaustively.

II. MULTIFUNCTIONAL PROPERTIES

Considering the severe conditions of several sports such as canoeing, skiing and mountaineering sportswear with multifunctional properties are always in demand, for instance, clothing with simultaneous protective properties against water, hot, cold, bacteria and unpleasant odors. Therefore, using nanotechnology in sportswear is beneficial in providing multifunctional sport clothing and shoes. Some of the main properties of sportswear incorporated with nanotechnology are briefly shown in Fig.1. The most common nanoparticles used in textile materials along with their main properties are summarized in Table 1.

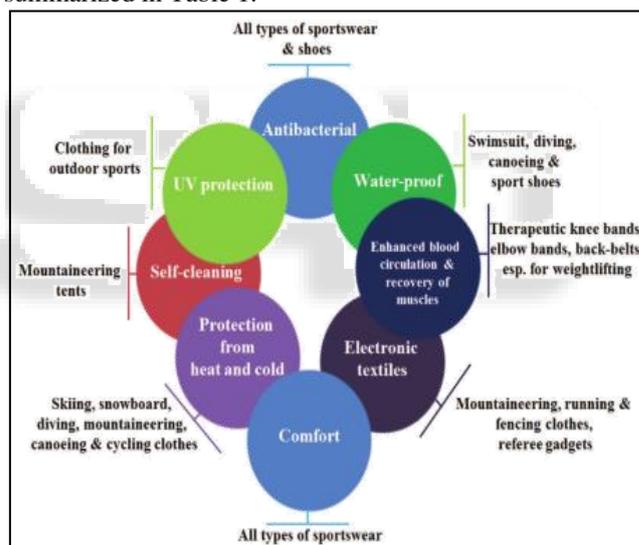


Fig. 1: Properties of sportswear and shoes incorporated with nanotechnology.

S.No.	Nanomaterials	Properties
1	Metal oxide nanoparticles such as TiO ₂ , ZnO, CuO/Cu ₂ O, Fe ₃ O ₄ /Fe ₂ O ₃ , Al ₂ O ₃ , ZrO ₂ , Mn ₃ O ₄ , MnO, MgO, GO	Photocatalytic, Self-cleaning, Antibacterial, UV-protection, Hydrophobic/hydrophilic properties
2	Metal nanoparticles such as Ag, Au, Pd, Pt, Cu and Ni	Antibacterial, Antifungal, Conductivity
3	Carbon black nanoparticles	Abrasion and chemical resistance, Electrical conductivity

4	Carbon nanotubes	Electrical and thermal conductivity
5	Clay nanoparticles	Flame retardant, UV shielding

Table 1. Common Nanomaterials used in textiles along with their main properties.

A. Water-proof

The development of sport clothing has come in to existence by water-proof breathable fabrics suitable for protection from wind, rain and loss of body heat. Water-proof fabrics prevent water from penetrating into the fibers but are breathable to allow water vapor to diffuse through fibers. Woven fabric, microporous membrane, coating and smart breathable fabric are the different types of classifications of breathable fabrics. The first water-proof breathable fabric was prepared by densely woven fabric or polymeric and resin coating. However, the nanotechnology has brought newer opportunities to develop water-proof breathable fabric [5]. Nanosilicate coated water-proof polyester fabric has been made to be kept dry after 2 months' immersion in water due to the decreased resistance between water and fabric, hence finds its application in swimsuits. Nano-membrane of TiO₂ and ZnO nanocomposites have been utilised in the making of Water-proof permeable antibacterial sport shoes called "LSMZ™" in which fluoronates and per fluoroalkyl substrate were used to obtain Lotus effect [superhydrophobicity] and water-vapor single-directed ability [6,7].

Ultra-thin membrane-like web with extremely fine fibers, high specific surface area, flexibility, light weight and desired porous structure can be produced by Electrospinning technique to impart barrier and comfort performance producing water-proof breathable apparel as sportswear [8]. Layered fabric systems, based on electrospun nanofiber webs with varying composite structures, substrate fabrics, and different levels of nanofiber web density have been prepared for outdoor sportswear and provide the wearer with high resistance to water penetration and high degree of moisture vapor and air permeability [8,9]. By depositing metal vapors such as Al on electrospun nanowebs [10], thermal comfort of the water-proof breathable layered fabric systems was improved.

B. Antibacterial

There is an increasing demand for antibacterial materials in many application areas including sport owing to the importance of public health awareness. Sweating during sport activities provides suitable environment for bacteria to grow and generate bad odor. Staphylococcus aureus is a common bacterium in athletic teams causing infectious diseases. Thus, antibacterial sport clothing can protect the athletes against microorganisms and unpleasant odors whilst preventing the fibers from damage and rotting [11,12]. Textiles from chitosan fibers with moisture controlling, antibacterial and fungicide properties were used in sport clothes and socks [13].

Generally the antimicrobial effect is obtained during the finishing stage through the application of nanomaterials, or through the incorporation of nanoparticles into fibers during spinning. Antibacterial sport apparels, sport shoes and insoles are widely prepared using silver nanoparticles although organic metals, quaternary ammonium compounds

and organic silicones have been used for antibacterial finishing of textile materials. The use of Zinc oxide nanoparticles have also been reported for antibacterial sportswear [14]. Small particle size and high-specific surface area of silver nanoparticles provide efficient antibacterial effect. The main antibacterial mechanisms are damage to the lipids, proteins and DNA of microorganisms [15-17].

A disinfectant and antibacterial solution "silverclear" has been applied for making antibacterial sport clothing and shoes [6,7]. Hohenstein Institute, Germany, based on the research carried out in fast onset action against bacteria, is required for antibacterial sportswear, and the efficacy should be permanent during sport activity. The skin reactions in the form of allergy, irritation or negative influence on skin microflora should also be considered [18]. The environmental risks of silver-containing clothes, and the silver concentration was found as the critical factor to be kept at a minimum range to avoid the involved risks [19]. If the function of the applied silver is not maintained at the low level, it has been reported that silver clothes usage should be minimized [18].

Silver ions attach themselves to the cell wall and inhibit the cell respiration and cell reproduction. Silver can be incorporated during extrusion [19], during electrospinning [20], or can be applied as a coating of nanosized silver colloidal solution [21]. Ultra Fresh® developed by Thomson Research Associates are based on a coating of ultrafine silver particles and are mainly used for polyester fabrics. AgION® technologies developed antimicrobials with silver particles in a zeolite carrier, which works on the ion exchange mechanism. In moist conditions, silver ions are exchanged with sodium and Silphure ions of sweat and control the bacterial growth [22]. Polymer nanocomposites with nanosilver particles are reported to have excellent antimicrobial action against both gram-positive and gram-negative bacteria. Hybrid [SiO₂/AG] coatings create good dispersion of silver nanoparticles in silica polymer matrix and have been found to have good antibacterial properties [23] TiO₂/AG nanocomposite synthesized by sol-gel technique showed excellent antimicrobial activity against gram-negative bacteria Escherichia coli [24]

C. Ultraviolet protection

UV-protection properties in sportswear with the application of nanoparticles has been developed because of the high risk of UV radiation-related skin lesion especially in outdoor sports. Semiconductors such as TiO₂, ZnO, SiO₂ and Al₂O₃, among the organic and inorganic UV-protective materials, have been receiving more attention due to their chemical stability, low cost, availability and non-toxicity. More than reflecting and/or scattering, the UV protection is mainly related to the potential of UV rays absorbance [25]. Through the uniform distribution of nanoparticles on fabric surface, the performance of UV-blocking agents can be efficiently increased [26]. With a very thin layer of functional zinc oxide polyurethane nanocomposite fibre web in a layered fabric system, UV-protection and antimicrobial properties were produced which is having potential application in outdoor sport clothing [14].

D. Insulation property

The sportswear with insulation property against heat and cold are required especially for skiing, snowboarding, diving, mountaineering and cycling considering the relation between

human body heat, environmental conditions and physical activity. Thermo-regulated smart textiles [27-30], by incorporation of phase change materials [PCMs] in textiles is of considerable interest in the recent past. PCMs are generally classified into organic materials including paraffin such as alkyl hydrocarbons [nonadecane and octadecane] and non-paraffin such as fatty-acids, alcohols and glycolic acids, and inorganic materials including hydrated inorganic salts [22]. The PCM nanocapsules with smaller particle size and higher heat transfer speed are more applicable than microcapsules. The materials used as shells for encapsulation of such PCMs are Melamine formaldehyde, urea formaldehyde, diacid silicone, polystyrene and polymethacrylate.

PCMs have been encapsulated into microcapsules or nanocapsules, reducing the PCM reactivity toward the outside volume changes of storage material during the period of phase change. The PCM nanocapsules can be added into fiber spinning stage or coated on textile materials during finishing process using a binder such as polyurethane [31-35]. The PCM nanofibers prepared by composite electrospinning and coaxial electrospinning are among the other methods of using PCMs in textiles [30]. The PCMs incorporated in sportswear can absorb the excessive body heat during sport activity and release the energy when necessary, decreasing thermal stress. The PCMs with specific temperature range that is less or more than body temperature are considered to be good for the application in sport products. The PCMs in sportswear absorb the heat immediately after temperature rise and release the energy when the temperature falls. Depending on the type and duration of physical activity, the required thermal insulation of clothing is imparted with the right amount of applied PCMs [27-30].

E. Comfort

The comfort level of the wearer is affected by the moisture transport property of sportswear which is dependent on wicking and evaporation rate [37]. The evaporation is improved by faster wicking of moisture through fabric due to higher surface area that leaves the wearer dry and comfortable [38]. If the moisture transport properties the fabric is good, they transfer moisture from the wearer's skin surface into the fabric surface, and release the moisture to the atmosphere. Sweat and moisture from the surface of the skin is transferred by these functional fabrics to the outer surface of the fabric that keeps the wearer's body dry and comfortable and prevents clinging of polyester fabric to the wearer's body [40]. The use of plasma technology which is an environmental friendly process is reported to give improved moisture management. To provide functional, intelligent and comfortable sportswear absorbing and immediately releasing sweat from the human body, functional sportswear with hydrophobic outer and hydrophilic inner sides have been developed [40]. These methods suffer from some drawbacks although fabric coating with hydrophilic/hydrophobic chemicals and weaving the inner and outer sides of the apparel with different hydrophobic/hydrophilic threads have been proposed for preparing functional sportswear,

As an effective method providing high performance in controlling moisture and odor during sport activities, atmospheric pressure non-thermal plasma followed by graft polymerization has been introduced recently [41]. Nanocoating with electro-spraying on a light-weight

multifunctional and monolayer fabric with hydrophobicity/hydrophilicity properties on opposite sides that was produced through plasma treatment, is reported to provide high-performance textiles with especial use in sportswear [42]. In comparison to the single-layer, dual-layer textiles have great potential to produce higher moisture transfer properties due to their components and structures that can be tailored independently [39]. The porous electrospun nanofibers can also be used to modify conventional textiles to boost the moisture transfer property developing advanced sportswear. Electrospun non-woven mats with thick layer of hydrophilic polyacrylonitrile nanofibers with a thin layer of hydrophobic polystyrene nanofibers coated with polydopamine is reported to have good moisture transfer potential [43].

F. Therapeutic effects

Heavy sports, especially that involves high physical activities such as bodybuilding, arm-wrestling and power-lifting may cause fatigue, injury or over-working muscles, which can be recovered using functional sportswear with therapeutic effects. It has been proved by researchers that far-infrared waves have the potential to be deeply penetrate into biological materials, and provide positive effect in terms of enhanced blood circulation and metabolism [44,45]. Far-infrared radiation effect on textile materials incorporated with germanium and ceramic powders such as alumina, titanium dioxide and silicon dioxide as nanostructures, in close contact with skin, can provide wide application areas including therapeutic treatment such as therapeutic knee bands, elbow bands and back-belts [46]. Far-infrared radiating materials absorb sunlight or heat from the human body, transform the energy into far-infrared rays within a specific wavelength range of approximately 6 to 14 mm and re-emit the energy to the human body [50], enhancing blood circulation and metabolism as well as promoting the recovery of fatigued muscles. Recently, PVA nanofibrous membranes containing germanium and SiO₂ have been introduced with antibacterial and fast-healing effects for sport applications such as medical supports worn during physical activities [46].

G. Self-cleaning

The production of sport clothing and mountaineering tents with self-cleaning property is considered to be one of the successful applications of nanotechnology in textile industry. Apart from engineering a superhydrophobic surface using the lotus effect, photocatalytic nanoparticles such as TiO₂ and ZnO have been used to produce hydrophilic surfaces with self-cleaning activity [47,48], and the photocatalytic self-cleaning fabrics could be applied for sportswear [49]. Due to the photo-excitation under light irradiation with energy greater than or equal to their band gap, through which an electron-hole pair is produced between the valence and conduction band by semiconductor nanoparticles results in photocatalytic activity. The photoinduced electrons could be further transferred to oxygen, generating superoxide, hydroperoxy [HO₂[•]] and hydroxyl [OH[•]] radicals. The holes or the produced hydroxyl radicals also have an oxidizing role in degrading stains, providing selfcleaning and anti-stain properties [50]. A German company by name Schoeller Textile AG has introduced "Nanosphere™" to produce self-cleaning fabrics for sport activities and mountaineering tents [1].

III. CONCLUSION

Multifunctional properties such as protective properties against water, hot, cold, bacteria and unpleasant odors can be incorporated in sportswear by Nanofinishing, and they are light-weight and flexible with high-impact strength. The wear comfort of sportswear is also positively affected by nanotechnology, enhancing the wearer's performance and efficiency. The athletes withstand high activity levels for a longer period of time due to the breathability of nanosportswear. Sportswear has emerged as a fast-growing textile sector with innovative materials and the latest technologies. Sportswear is a niche market, where price is not usually a considerable factor, because the strong emphasis is on performance enhancement. In highly competitive sports, when the human body reaches its upper limit of endurance, technology can play its part to provide that special winning edge. With special functionality and smart technologies, sportswear is considered as power skin instead of second skin. It may reduce the muscle fatigue and improve the physical endurance while maintaining the athlete's well-being in the toughest climatic conditions.

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