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Applications of Nanotechnology in the Creation of Smart Sportswear for Enhanced Sports Performance: Efficiency and Comfort

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Abstract

IN RECENT years, nanotechnology (NT) has shown to be a multidisciplinary study area, increasing its range of applications in several spheres of human activity. Advancements in nanotechnology have been made in textile materials as a result of the quest for enhanced multifunctionality in engineering, industrial, technical, and medical textiles. Textile materials now have several uses thanks to the integration of cutting-edge technologies including photonic crystals, plasmonics, luminescence, architectural colorants, holography, LED displays, and metamaterials. The physicochemical behaviors of textiles, such as self-cleaning, UV protection, flame resistance, and antibacterial capabilities, have been enhanced by textile nanotechnology innovations such as nanoparticles (NPs) and sensor integration into textile materials. It is appropriate for use in health, medical, sporting, advanced engineering, pharmaceuticals, aerospace, military, automobile, food, and agricultural industries, among others since it offers flexible sensing capabilities, robotics, electrical conductivity, flexibility, and comfort. Metallic fibers that have been injected with nanoparticles, such as copper and silver NPs, have demonstrated antiviral and antibacterial activities. The purpose of this study is to give an overview of the uses of nanotechnology in several sports-related sectors, with a special emphasis on sports-related flooring, apparel, and footwear. Sport has been injected with several important factors. In-depth research is also done on garments made using nanotechnology. According to current trends, all types of sportswear will soon be impacted by the nanotechnology revolution.

Keywords: SMART textiles, Nanotechnology, Sportswear, Technical textiles, Protective fabrics.

Introduction

One of the most cutting-edge technologies of the twenty-first century is the usage of nanotechnology with smart clothes. [1, 2] Additionally, there is a constant need for sportswear with excellent performance, efficiency, and durability. As a result, the market for smart clothing may now meet these desires thanks to advancements in nanotechnology. [3, 4]

Nanotechnology has made it possible to create intelligent and practical clothing that not only satisfies the needs of athletic events but also helps athletes achieve the highest levels of comfort and safety. [5]

The use of smart clothing and materials is growing significantly in many industries. [4] Eventually, wearable technology will be as typical as a pair of jeans or a t-shirt. Because of the enormous technological, economic, and ecological advantages of nanomaterials, they are being employed more and more in clothing applications to improve performance and produce unequaled clothing functions. Nanomaterials will either provide garments with new

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characteristics or improve ones that currently exist. [6]

Nanotechnology is used in sportswear in a variety of ways, including anti-odor sports shoes, antibacterial and waterproof swimsuits, protective sportswear, and anti-odor swimwear. The safety and physical comfort of sportsmen are also increased when they wear Nano-sport clothing. Clothing with electrical sensors and GPS built-in can assist athletes in an emergency.

In this research, we tried to give a general overview of the main applications of nanotechnology in the textile sector, including sportswear like sportswear and shoes as well as floor coverings, while also listing the functional qualities of each. [1] Additionally, simple methods for summarizing the properties of sporting equipment have been provided. The information in this review study is entirely backed up by studies that have been documented in the literature. Each occasion has also featured samples of commercial goods, albeit this does not mean that the goods are acceptable.[6]

Smart Textiles Development

The modern textile industry faces incessant consumer demand for innovative applications of new technology and a constant stream of new and ever more innovative goods.

The "conventional" textile industries have experienced significant advancements in their products' mechanical strength and durability, surface texture and "feel," and capacity for a variety of color and pattern printing. Other advancements include aspects of personal care including antiperspirant and deodorant qualities in addition to flame-retardancy, self-cleaning and anti-microbial features. The development of so-called "smart textiles," which combine more traditional materials with clever nanoparticles, has occurred in recent years. [7]
"Smart textiles," which combine more traditional materials with clever nanoparticles, have occurred in recent years. [8]

Smart textiles are those that can perceive changes in their surroundings and react by changing one or more of their properties to carry out a specific purpose. The development of intelligent textiles has gone through three generations. [7]

Classification of Smart Textiles

Passive smart textiles-Active smart textiles-Ultra smart textiles

The first generation, or "passive," smart textiles can perceive changes in their environment but are unable to modify their features.

For instance, cotton impregnated with silver nanoparticles has anti-microbial qualities, and textiles coated with different metal oxide nanoparticles can generate clothing that is IR/UV resistant. Second-generation, or "active," smart textiles are made of materials that initially detect environmental changes or stimuli and then react appropriately. Examples include textiles with shape memory that can react to mechanical deformations and thermochromic fabrics that change color in response to temperature changes.[9]

Third-generation, Ultra smart textiles, sometimes known as "super-smart" textiles, include soft and smart electronics, including sensors, optoelectronic devices, Nano-generators, and energy storage systems. On-body electronics, for instance, can provide sensitivity to various contaminants, illnesses, or hazards. Nano-generators and energy storage devices may also be used to support eye-catching optical components on smart textiles.[10]

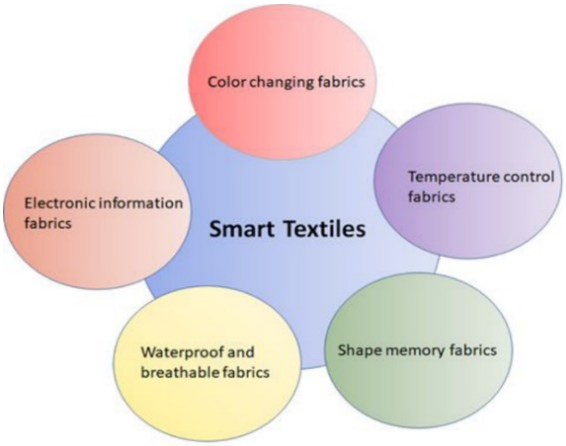

Fig. 1. Classification of Smart Textiles

Applications of Smart Textiles

The main applications for smart clothing with intelligent monitoring functions are in the fields of health care and sports monitoring. The elderly can benefit from self-reported health data, proactive disease prevention, and early disease detection, while athletes can monitor their physical condition and modify the intensity of their training.

Health

Wearable devices in "Telemedicine" allow body signals to be examined for healthcare purposes while engaging in daily activities.

It might eliminate the inconvenience of infrequent medical examinations that only provide a limited display of the patient's physical status, such as an ECG, EMG, and physical activity, or a dress with wireless fabric sensors implanted for continuous respiratory monitoring, etc. Using a 3-lead ECG shirt, a wearable sensitive garment measures heart rate and respiration. Knitting has entirely merged the sensors and conductive fiber net into the shirt. [11]

Life jacket and belt

The patient wears a life jacket as a dress for the examination device, which then tests the patient's

heart and blood pressure. Medical experts check the data from a life jacket after communicating it to a computer.

The life jacket might be used to process blood pressure without a cuff. A life belt is a trans-abdominally worn device for long-term health monitoring that provides techniques for monitoring the mother and unborn child. Pregnant women who live in remote areas, work while pregnant, or have particular fitness difficulties can all benefit from it. The life belt gives the obstetrician the ability to watch patients from a distance, automatically diagnose their condition by gathering and analyzing vital signs, constantly access the patients' medical information, and be alerted.[12]

The smart bra

Developed in Australia, the Smart Bra is designed to change its properties in response to breast movements. It can relax and stiffen its cups or loosen and tighten its straps to prevent breast pain and drop.[13]

A stretchable bra for breast cancer early detection is shown in Fig. **2**. An inflatable bra called Palpreast helps with an early cancer diagnosis.[12]

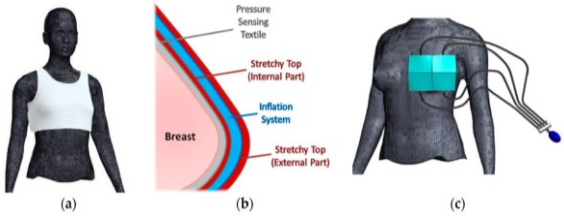

Fig. 2. (a) shows a stretchable bra for an early breast cancer diagnosis; (b) shows four separate air chambers positioned around the breast, and (c) shows a pressure-sensitive textile sensor. Reproduced from a source that was first released under a CC-BY 4.0 license

Fashion and entertainment

As technology becomes more nimble, many electrical components and garments are becoming portable appliances. Future technical clothing designs are being shown on the fashion runways using light-emitting textiles.[14]

e) Sports

Sportswear: Smart clothes or equipment can be used in sports that involve observation, computation of movement, stimulation of muscles, resistance training, recording of activity, and wound protection.[15]

Sports shoe: Global Positioning Systems are built into the shoes, allowing mountain rescue personnel to monitor the walker and find children. Gloves with warmers or LED lights that radiate energy are used to make it easier to see cyclists at night.[15]

Smart Materials and Fibers in Smart Textiles

In most cases, "Smart" or "Functional" materials are a component of "Smart Systems" that can perceive their surroundings and their effects and, if smart, can react to that external stimuli via an active control mechanism. A "Technology space," which also encompasses the fields of sensors and actuators, is where smart materials and systems are located, in addition to the use of electronic textile materials and engineered textiles in the smart clothing industry.[6]

Usage of SMART textiles

Shape memory textiles

Shape memory textiles are a sort of material having a shape memory function that is woven or finished into textiles. Textiles have exceptional qualities such as shape memory, high deformation recovery, good shock resistance, and flexibility under external circumstances such as temperature, mechanical force, light, pH value, etc. A "lazy shirt" was created by Corpo Nove, an Italian firm. When it's hot outside, the shirt's sleeves will automatically roll up from the wrist to the elbow in a matter of seconds; when it's cold outdoors, they can automatically recover and even iron themselves.[16]

Optical fiber

A type of optical composite fiber known as optical fiber can contain light energy and transport it in a waveguide mode. It also goes by the name "smart fiber," and it has outstanding transmission capabilities. It is made up of a core and cladding. The two types of fiber constructions that may now transmit a waveguide are step type and gradient type.

Optical fiber is frequently employed as a sensing material because it performs the combined roles of information transmission and perception. The technique for using it in optical fiber sensors is currently highly advanced. [17]

Color-changing textiles

Textiles that change color in response to changes in external environmental factors like light, temperature, pressure, etc. are referred to as color-changing textiles. Color-changing textiles are widely employed in many different industries due to their special characteristics. Military camouflage may be employed in the military, and civilians can utilize anti-counterfeiting materials to create stylish color-changing apparel and constantly-changing ornamental textiles, which are frequently used in bills, certifications, and trademarks. The following three techniques can be used to create fabrics that change color: Fabric can be dyed with color-changing

dyes, printed with color-changing paint, or added with color-changing fibers.[18]

The study and development of color-changing fiber technology are one of the three approaches that came later but have the most advantages. It offers a wonderful hand feel, good washing resistance, and a long-lasting discoloration effect in the fabric that is manufactured from it.[19]

Waterproof and moisture-permeable textiles

As practical materials that incorporate water-proof, moisture-permeable, windproof, and warmth retention characteristics, textiles that are waterproof and moisture-permeable are also referred to as "breathable fabrics". [20-22]

This type of fabric offers a wide range of growth possibilities and can satisfy people's demands for clothing during activities in difficult settings such as extreme cold, rain, snow, and wind. It can also satisfy people's wants for raincoats and other items needed in everyday life. It primarily consists of microporous membranes, non-porous membranes, intelligent waterproof and moisture-permeable textiles, and high-density fabrics that are waterproof and moisture-permeable.[18]

The idea behind high-density fabrics that are waterproof and moisture-permeable is that gas molecules diffuse through the spaces between the yarns from areas of high concentration to areas of low concentration. The basic method used by microporous membrane waterproof and moisture-permeable textiles to create waterproof and moisture-permeable properties is the difference between raindrop diameter and water vapor molecular diameter. To achieve the goal of waterproofing, the nonporous membrane waterproof and moisture-permeable fabric employs molecular hydrophilic properties to enhance the tension of the waterproof membrane surface.[23]

Self-cleaning textiles

Self-cleaning coatings are becoming more and more popular because they can eliminate both inorganic and organic impurities through two separate mechanisms: rolling water droplets and photocatalysis. [24]

As a result of the lotus- or cauliflower-shaped surface and low surface energy, rolling water droplets will produce dirt on the fabric's surface and roll off to absorb dust, soil, inorganic pollutants, and other pollutants.[25]

A contact angle of larger than 150° is necessary for this situation. Photocatalysis, which is readily eliminated after washing, is the destruction of organic filth by light.[26]

Electronic information SMART textiles

By mounting a GPS receiver on the collar, Sensatex of the United States created and developed smart positioning clothing. Using a remote control device mounted on a small display on the sleeve, the European Hewlett Packard laboratory has created smart clothing with a positioning system that is equipped with a personal area network, a global positioning system, an electronic compass, and a speed meter. When children or Alzheimer's sufferers are mistakenly lost, they can be quickly located if they are wearing this type of apparel. A ski suit with an integrated accelerometer, compass, and global positioning system sensors has been created by Lap-land University, Finnish Reima Tutta, and other organizations. This ski suit will be remote the monitoring terminal provides information including the current position coordinates and physiological measurement data for prompt rescue in the event of an accident by the wearer.[27]

Two teams of researchers from the Universities of Montreal and London created the intelligent emotion-sensing apparel. The windbreaker has a loudspeaker, sensors, and a body signal analyzer that can track the user's body signal and detect emotional changes in that person. The windbreaker will play some light music to lift your spirits when you're feeling depressed. This form of clothing can aid in the liberation of autistic individuals as well as the communication with their relatives for older people who live alone. More useful goods are continuously being created and developed, while emotion-aware apparel is still in the testing phase.[28]

Coating with Nano-particles

To increase a fabric's performance and utility, nanoparticle coating is frequently used in the textile industry. Nanotechnology can create durable textiles and provide long-lasting effects. While retaining the fabrics' breathable and tactile qualities, coating with nanoparticles can provide them attributes like anti-bacterial, water-repellence, UV protection, and self-cleaning. A variety of Nano-tex products use these coatings to repel and remove stains, resist spills, and resist static.[29, 30]

Nanotechnology

Nanotechnology is the science that deals with the study of matter manipulation on the atomic and molecular scale. Nanotechnology is concerned with creating new technologies and methods whose dimensions are measured in nanometers, which is a thousandth of a micrometer, that is, a millionth of a millimeter.

When manufacturing Nano-sized materials, the chemical and physical composition of the raw materials used in manufacturing play an important role in the properties of the resulting Nano-meter material, and there are two ways to manufacture a nano-size of the material.[31]

The first method is from top to bottom, in which the building units are reduced to the nanometer level.

The second method is from bottom to top, up-bottom, in which the building blocks are enlarged by entering individual atoms or molecules in reactions to form chemicals and biological materials, and then introducing these materials into building nanoscale components [32], as shown in Fig. **3**.

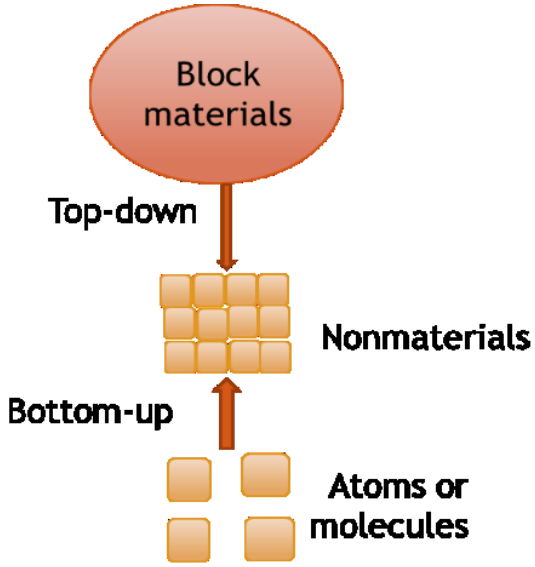

Fig. 3. Method of manufacturing the nanoscale size of the material

Nanomaterial shapes

Unlike when producing regular materials, the physical composition and chemical concentration of raw materials employed in production have a significant effect on the qualities of the final nanomaterial. [32]

These forms are listed in order of importance:

Nanoballs
Nanotubes.
Nanowires
Quantum dots.
Nano Fibers
Nano Particles

Nanoparticle characteristics

Electrical conductivity, hardness, color-changing capability, and transparency.[33]

Uses of nanotechnology in textiles:

UV protection [34]
Dust resistance
Flame resistance [35, 36]
Control humidity
Antibacterial resistance [37]
Static electricity resistance [30, 38]

Nanotechnology in the textile industry

As illustrated in Fig. **5**, there are three categories of nanotechnology used in the textile industry: nanofibers, nanocomposite fibers, and nano-finishing of textile materials. These categories are completely covered in the sections that follow.[4]

Advantages of nanotechnology in the textile industry:

Improving mechanical properties such as adding protection to military clothing and increasing resistance to chemicals, microbes, and wetness, as the colloidal solution contributes to 2-5 nanometers of silver increases the resistance of cotton clothes to bacteria, and nano-metric silicon dioxide improves the water-repellent property of clothes, as well as increasing the resistance of Clothes for flammability and high temperature, as some nanomaterials are characterized by resistance to ignition, and one of the advantages of nano is also to improve protection from ultraviolet radiation, as nanoparticles of titanium and zinc oxides are used to prepare clothes for protection from ultraviolet rays of the sun. As well as self-cleaning clothes, where nanoparticles of titanium dioxide are used as a light agent to break down organic dirt and microorganisms on the surface of cotton clothes.[39]

Fig. 4. Applications of nanotechnology in textiles[40]

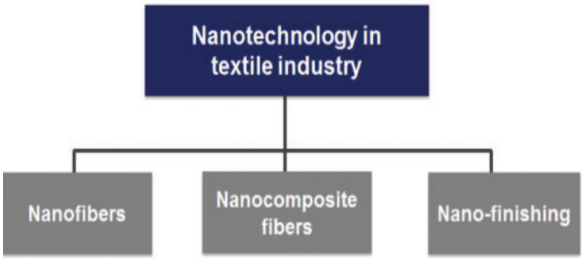

Fig. 5. Nanotechnology in the textile industry. [3]

Nanofibers

Nanofibers with diameters less than 100 nm, a vast surface area (1000 times more than microfibers), and outstanding mechanical qualities have a wide

range of uses in sports footwear and gear, including waterproof and windproof sportswear for mountaineering, canoeing, and cycling. Interfacial polymerization, electrospinning, and electrostatic spinning techniques can all be used to make them.[41]

Electro spun nanofiber webs are excellent choices for offering water resistance, breathability, and water vapor penetration due to their porous structure, wide surface area, high flexibility, and light weight. Based on electro spun nanofibers, porous membranes may be laminated onto knit fabric to give different kinds of sportswear wind and water resistance. For sportswear, particularly for mountaineers and bikers, where resistance to liquid penetration and simultaneous excellent water vapor transport combined with windproof qualities are required, the multi-layered electro-spun nanofiber mats-equipped fabric known as (MENMEF) is suited.[42]

Additionally, lightweight, bendable flexible vault poles have been created using carbon nanofibers.[43]

Running shoe insoles have been replaced by ultra-fine, high-strength polyester nanofiber, or "NanofrontTM." Because of the sole's superior slip resistance and high moisture absorption, it delivers outstanding frictional qualities.[44]

Nano-fibrous structures are distinct due to their improved mechanical performance (such as stiffness and tensile strength), larger surface-to-volume ratio, smaller pores, increased porosity, flexibility, and surface functions. Nano-fibrous structures have substantially greater moisture-wicking than regular fiber structures.[45]

Nanocomposite fibers

Nanofillers such as nano-clay, metal oxides, and carbon nanotubes have been generally used for preparing nanocomposite fibers.

The primary benefit of nanostructured composite fibers is their improved mechanical, physical, toughness, and abrasion resistance capabilities as a result of interactions between the polymer matrix and nanoparticles' large surface area and high aspect ratio. With the use of nanoparticles as fillers, fibers may be given multifunctional features including conductivity, antimicrobial, and anti-static qualities. Although there is experimental support for the impacts of nanoparticles on fibrous materials, the chemistry of the polymer matrix, the kind of nanofiller, and the technique of production all have a significant impact on the characteristics of nanocomposite fibers.[46]

The uniform dispersion of nanofillers in the polymer matrix is an important prerequisite for desirable mechanical and physical characteristics that can be improved by the use of organic surfactants and compatibilizers.[47]

Nano-finishing

A growing area of interest in nano-finishing is the use of nanoparticles in textiles, providing fabrics with diverse practical performances depending on the properties of the nanoparticles. Moreover, the finishing of fabrics with nanocomposites will provide several features producing multifunctional textiles.[48-54]

The two primary approaches of nano-finishing are as follows:

Ex situ: The fabric is treated with a nanoparticle precursor, or ex-situ finishing approach, in several nanostructured finishing processes. Therefore, traditional finishing techniques including fatigue, spraying, cushioning, foaming, and printing can be used. Ex-situ nanoparticle finishing typically involves three steps: preparation of the nanoparticle dispersion, textile application, and final fixing. Ex-situ procedures often need for the pretreatment of textiles to promote nanoparticle adsorption. Fabrics have been pretreated with plasma to boost the loading of nanoparticles such as nanosilver for increased antibacterial effectiveness.[55]

Following several treatments, such as hydrophobic sol-gel finishing, improved coating adherence was noted. Surface roughness results from plasma treatment's induction of wettability changes together with surface morphological changes. Depending on the kind of plasma gas, the surface may also acquire the ability to resist water. Fluoro-based compounds like CF4, C2 F6, SF6, and NF3 are used to treat plasma under vacuum, reducing surface energy and improving water repellency.[56]

In-situ: Finishing textiles using in-situ nanostructures has just lately been recognized as a viable alternative to the time-consuming and labor-intensive ex-situ approach.[57]

Nanoparticles are created in the presence of the textile material using the in-situ nanostructures finishing method, offering a one-step process without the need for a final fixing step. Other textile qualities, such as improved mechanical properties, are also favorably impacted by the physical and/or chemical interaction between the nanoparticles and fibers. Through the inclusion of nanoparticles, research teams from all around the world have developed a range of textile materials with multifunctional qualities throughout the years. In-situ synthesis of various nanoparticles, including silver, TiO2, ZnO, TiO2/Ag, and ZnO/Ag nanocomposites, has been the subject of numerous studies by Montazer and his research team over the past ten years to give textiles multifunctional properties, such as self-cleaning and antibacterial properties.[58]

On various textiles, copper and copper oxide nanoparticles have been created, giving them antibacterial, conductivity, and chemical sensing capabilities.[58]

Textiles that are magneto, photo, and bioactive have been created using in-situ synthesis of iron oxide nanoparticles and TiO2/Ag/iron oxide nanocomposites on polyester fabric.[59]

Additionally, there has lately been an increase in interest in the application of sonochemistry as a novel method for the in-situ deposition of nanoparticles onto textile surfaces. Abramov was a pioneering researcher who created a variety of concepts in the ultrasonic sector and was interested in the synthesis of materials using ultrasound.[60, 61]

Additionally, several teams under the direction of Gedanken and Suslick produced publications on the sonosynthesis of nanomaterials. Wool fabrics with self-cleaning, antibacterial/antifungal, hydrophilicity, enhanced tensile strength, low cytotoxicity, reduced alkaline solubility, and photo-yellowing properties were created through sonosynthesis of TiO2, ZnO, and N-doped TiO2 nanoparticles on cotton fabric using an ultrasonic bath at low temperature.[61, 62]

There are several sports applications for nano-finished fabrics, including swimwear, diving suits, sports socks, outdoor sports gear, climbing tents, and anti-stain Harifi and Montazer 1151 stadium floor coverings. When developing sportswear, it's crucial to take into account a variety of distinct qualities. For instance, strong moisture transfer qualities are essential to keep the body dry during physical exercise, and nano finishing is useful to change the fabric's moisture transfer capabilities.[63, 64]

Sportswear

Sportswear is the most diversified and fastest-growing group in the functional clothing market, as it raises the performance rate of the players while achieving a sense of comfort. It also qualifies the sport to compete to the highest level of performance, by using modern and developed materials technology and creating a good design that supports the athlete with the physiological comfort he needs. While practicing exercises and ease of movement without adding an extra burden on the player. Recently, the proportion of sales of sportswear increased, which led to the interest of textile developers, manufacturers, and designers of sportswear to introduce greater improvements and innovations in these clothes. Newly used high-tech manufacturing fibers, which are characterized by their strong performance and provide comfort and luxury, as well as the design of modern sportswear deals with the physiological aspects of the behavior of the body, where the aspects of comfort and function are extremely important.[65]

The body's physiological responses to exercise include adjustments to the heart rate, blood pressure, and body temperature. Thus, there are several aspects that influence the physiological state of the body and must be considered when choosing sportswear, including the impact of various textile materials used to make sportswear on the condition of the body. The material used in the sportswear must allow for the evacuation of this perspiration to regulate body temperature because the amount of sweat rises with exercise intensity and as a result of the high body temperature. Along with the fabric's thickness, the height of the body temperature increases with cloth thickness.[66]

Functional Requirements Of Sportswear:

Allow freedom of movement for athletes.

- To resist tearing.
- It should be suitable for the body.
- It must be appropriate to the climate.
- It should be compatible with the type of game.
- To allow permeability and release of heat generated during training.
- The pressure should not increase on the shoulders, elbows, and knees.
- It should be flexible and light in weight.
- It should be well-ventilated and have high pores.[66]

The materials used in sportswear

Natural cotton clothes

The majority of people still use cotton underwear today (cotton flannels and shorts). Cotton is certainly a comfortable material for the body and does not irritate the skin, but it is not suitable at all for practicing sports in the conditions in which it exists.

High levels of moisture, as it absorbs and retains huge amounts of moisture, increase its weight, and the wearer feels very cold, and cotton fabrics cling to the skin causing discomfort. According to sports medicine, the body's reaction to cold is Closing its arteries, which leads to a slowdown in blood circulation and malnutrition of the organs and areas of the body with their blood needs, and the obvious result of this is the deterioration of muscle performance and the general physical performance of the body, just as the coldness of the body, in general, can harm the kidneys in particular, and inhibits the capabilities of the immune system in general And infect people with colds. That is why the producers of sportswear, not long ago, began looking for fabrics that do not get wet and are characterized by a high ability to regulate temperature, meaning that the body maintains an acceptable temperature.[67]

Industrial clothes

Industrial textiles in a variety of forms, mainly polypropylene and polyester, were embraced by the producers.

Polyester is incredibly useful for sportswear due to its outstanding dimensional stability, excellent resistance to dirt, alkali, decay, and mildew, excellent heat resistance, good moisture transfer properties, low moisture absorption, ease of care, and low cost. All of these features are significant to consumers.

Sportswear constructed from these materials soon gained popularity among consumers when the required adjustments were made to their industrial composition. This is because the fabrics are nearly impermeable to liquids, dry fast, are lightweight, and exhibit good insulation, and softness, also characterized by moisture management so that they can regulate body temperature, improve muscle performance, and delay burnout. It has also recently become very similar to natural cotton tissue.[68]

Smart Sportswear

The terms "sports" and "health" are now intimately intertwined, and smart sportswear effectively blends these two ideas by integrating sensors that can track a person's physical state in real-time into their sportswear to improve their ability to exercise and better understand their bodies. Additionally, smart sportswear incorporates materials such as local heating systems, ultra-flexible fibers, and scientific heart rate monitoring of elite athletes as well as soft textiles that are better suited for individuals to exercise in a variety of settings. However, in general, four primary categories may be used to categorize the usage of smart clothing in sports: remote monitoring, frequent monitoring, comfort and ease of use, and the possibility of the fitting.[69]

An athlete who is being monitored remotely is free to go about his or her daily activities and workouts, and no medical personnel is necessary for the process of gathering data on parental health status and clinical results.[70]

Smart clothing's constant monitoring enables the identification of organ dysfunction and the identification of the elements influencing workout outcomes. Good injury prevention is provided by smart clothing. Additionally, it guards against weariness in a special way that enables early identification of functional abnormalities. When a routine checkup is insufficient, it aids in recognizing the initial symptoms of pathological disorders. The functional state of a person's body may be assessed during different stages of stress and rest.[71]

Nanotechnology in smart sports clothing and sports shoes

The use of nanotechnology in textiles, including nanofibers, nanocomposite fibers, and Nano finished textiles, imparts a variety of qualities that make them suitable for use in the market for athletic wear. Numerous textile businesses have used nanotechnology to create a variety of sports gear. For severe cold weather activities like climbing and skiing, Scholler, a Swiss business, has created a Nano-based technology to make garments with the ideal mix of comfort, air permeability, wind and water resistance, and self-cleaning characteristic.[72]

The sportswear that is developed also has a function that repels snow and rain

A UK-based business called JR Nanotech has created "SoleFreshTM" socks that have been coated with silver nanoparticles to get rid of athlete's foot odor.[73]

Hyosung, a Korean corporation, created nano silver nylon fibers with applications in daily life, sports, sportswear, sports bags, and running shoes.[74]

A significant improvement in the anti-slip capabilities of shoe soles was made possible by nanotechnology.[75]

Some advantages of adopting nanotechnology in athletics include increased wicking in clothing that protects mountaineers from the cold and rain and breathable gear that regulates body temperature in harsh climes.[76]

Characteristics of nano-sport apparel

In the section that follows, some of the most crucial characteristics of nano-sport apparel and footwear are covered in detail.

Water-proof

Water-proof, breathable textiles that offer protection from the wind, rain, and loss of body heat have helped to advance sportswear.

Water-proof textiles are breathable such that water vapor may diffuse through the threads while also preventing water from seeping into the fabric. Closely woven fabric, microporous membrane, coating, and smart breathable fabric are a few of the several forms of breathable textiles that have been identified.[77]

Although tightly woven fabric or polymeric and resin coating were used to create the first water-proof breathable fabric, nanotechnology has opened up new possibilities for fabric development[78].

Due to the lowered resistance between water and fabric, a water-proof polyester fabric coated with nano silicate has been developed and is rapidly being used for swimsuits.[42]

To impart barrier and comfort performance and create water-proof, breathable clothing for sportswear, electrospinning creates an ultrathin membrane-like web with incredibly tiny fibers, high specific surface area, flexibility, light weight, and appropriate porosity structure. For outdoor sportswear, layered fabric systems based on

electrospun nanofiber webs with varying composite structures, substrate fabrics, and levels of nanofiber web density have been developed. These fabrics offer the wearer a high level of moisture vapor and air permeability as well as high resistance to water penetration.[79] Moreover, by adding metal vapors like Al to electrospun nanowebs, the thermal comfort of the water-proof breathable layered fabric systems was enhanced.[80]

Ultra-violet protection property

Due to the significant risk of skin lesions caused by UV radiation, especially in outdoor activities, nanoparticles with UV protection capabilities have been created for use in sportswear. Due to their chemical stability, low cost, availability, and non-toxicity, semiconductors like TiO2, ZnO, SiO2, and Al2O3 have been receiving more attention and are more applicable among organic and inorganic UV-protective materials.[81] UV protection is primarily related to the potential of UV rays' absorbance rather than reflecting and/or scattering. The homogeneous dispersion of nanoparticles on fabric surfaces can effectively boost UV-blocking agents' efficacy.[82, 83]

Layered fabric systems with a very thin layer of functional zinc oxide polyurethane nanocomposite fiber web were created, and they have potential use in outdoor sports wear due to their UV protection and antibacterial qualities.[84]

Anti-Bacterial Property

In several application sectors, including sports, there is a rising need for antibacterial materials due to the significance of public health awareness.

Exercise that involves sweating creates a favorable environment for bacteria to flourish and produce foul odors. Infectious illnesses caused by Staphylococcus aureus are frequently found in sporting teams. Sports apparel that is antibacterial can therefore shield athletes from microbes and foul smells while reducing fiber deterioration.[85]

Sports apparel and socks have been made with chitosan-based textiles that have antifungal, antibacterial, and moisture-controlling qualities.[86]

Typically, nanoparticles are applied at the finishing step to provide an antibacterial effect, or they are spun into fibers to produce an antimicrobial effect. Although quaternary ammonium compounds, organic silicones, and organic metals have all been employed as antimicrobials Silver nanoparticles are frequently used in the finishing of textile fabrics, antimicrobial sports gear, sports shoes, and insoles. Additionally, several papers have discussed the use of zinc oxide nanoparticles in antibacterial sportswear.[84]

Silver nanoparticles' high specific surface area, tiny particle size, and metal ions all contribute to their antibacterial effectiveness. The primary antibacterial Harifi and Montazer 1153 mechanisms are damage to the lipids, proteins, and DNA of microorganisms.[87]

Antibacterial sportswear and shoes have been created using the disinfection and antibacterial solution "silverclearTM".[42]

According to studies done at the Hohenstein Institute in Germany, antibacterial sportswear must have a quick antibacterial effect and its effectiveness must last throughout physical exercise. Consideration should also be given to excluding skin responses (allergy, itchiness), as well as adverse effects on skin microbiota.[88]

According to publications evaluating the environmental concerns associated with wearing clothing containing silver, the silver content must be kept within a certain limit at all times.[81]

If the function of the applied silver is not kept at a low level, it has been underlined that the use of silver clothing should be minimized. [88]

Self-cleaning

One of the successful applications of nanotechnology in the textile industry is the production of sports clothing and mountaineering tents with the self-cleaning properties. In addition to exploiting the lotus effect to create superhydrophobic surfaces, photocatalytic nanoparticles like TiO2 and ZnO have been employed to create hydrophilic surfaces with self-cleaning activity.[89]

The photocatalytic self-cleaning textiles may be used to create athletic apparel.[80]

The photo-excitation of semiconductor nanoparticles under light irradiation with energy larger than or equal to their band gap, via which an electron-hole pair is formed between the valence and conduction band, is what gives semiconductor nanoparticles their photocatalytic activity. As a result of the photoinduced electrons being transported to oxygen, superoxide, hydroperoxy (HO2), and hydroxyl (OH) radicals might be produced. Additionally, the holes or the hydroxyl radicals created have an oxidizing function in the degradation of stains, offering self-cleaning and stain-removal characteristics.[90]

The "NanosphereTM" brand of self-cleaning textiles for sporting events and climbing tents was developed by Schoeller Textile AG Company.[91]

Protection from heat and cold

Sportswear with insulation against heat and cold is necessary for activities like skiing, snowboarding, diving, mountaineering, and cycling, especially when taking into account the relationship between human body heat, ambient circumstances, and physical activity. The use of phase change materials (PCMs) in textiles to create thermo-regulated smart textiles has recently attracted increasing interest.[92, 93]

PCMs may be broadly divided into organic and inorganic components, such as hydrated inorganic

salts and fatty acids, and non-paraffin components, such as alcohols, glycolic acids, and octadecane and nonadecane alkyl hydrocarbons.[94]

PCMs have been placed inside micro- or nanocapsules, which lessens their reactivity to the environment outside and regulates the volume changes of storage materials during phase transitions. Compared to microcapsules, PCM nanocapsules have smaller particle sizes and faster heat transmission. Some of the materials that have been employed as PCM encapsulating shells include polystyrene, polymethacrylate, diacid silicone, urea-formaldehyde, and melamine formaldehyde. Using a binder like polyurethane, the PCM nanocapsules can be introduced during the fiber spinning stage or coated on textile materials during the finishing process.[95, 96]

Among the alternative ways to use PCMs in textiles are the PCM nanofibers created by composite electrospinning and coaxial electrospinning.[97]

The PCMs used in sportswear may collect extra body heat generated during physical exercise and release the energy as needed to reduce thermal stress. Sports goods are an excellent fit for PCMs with a defined temperature range (less or more than body temperature). When temperatures rise, PCMs in sportswear rapidly absorb the heat and release it when the temperature drops. The kind and amount of physical activity determine the necessary level of garment thermal insulation and PCM application.[92, 98]

Comfort

An essential feature of sportswear is the moisture transport property, which is influenced by wicking and evaporation rate and affects the wearer's level of comfort.[99]

Due to the increased surface area and quicker draining of sweat through the fabric, the user is kept dry and comfortable.[100]

Fabrics with moisture transport characteristics allow moisture to be transferred from the wearer's skin surface to the fabric surface and then released into the atmosphere. These practical textiles help keep the wearer's body dry and comfortable by transferring perspiration and moisture from the skin's surface to the fabric's outer surface. This also helps keep the polyester fabric from sticking to the wearer's body.[101]

Plasma technology has reportedly improved moisture control and is an environmentally beneficial procedure.[102-105]

Functional sportswear with hydrophobic exterior and hydrophilic inner sides has been designed to provide intelligent, pleasant, and functional sportswear that quickly absorbs and releases perspiration from the human body, although approaches for creating functional sportswear, such as treating fabrics with hydrophilic/hydrophobic chemicals and weaving the inner and outer sides of the clothing with various hydrophobic/hydrophilic threads, have been suggested, these techniques have certain limitations. An efficient technique offering good performance in regulating moisture andodor during sporting activities has recently been introduced: atmospheric pressure non-thermal plasma followed by graft polymerization.[106]

An efficient, monolayer, and multipurpose through plasma treatment and nanocoating with electro-spraying, high-performance textiles with a focus on sportswear were created, featuring hydrophobicity/hydrophilicity qualities on different sides of the fabric.[107]

As a result of its components and structural design, dual-layer textiles have a greater ability to provide higher moisture transfer qualities than single-layer textiles. May be individually adjusted, additionally, the porous electrospun nanofibers be utilized to change traditional fabrics to increase the moisture transfer property generating innovative sportswear.[108]

Electrospun non-woven mats with a thick layer of hydrophilic polyacrylonitrile nanofibers and a thin layer of hydrophobic polystyrene nanofibers coated have been found to have good moisture transfer potential containing polydopamine.[108]

Methods of assessing sportswear properties

Standard methods are required for assessing the different properties of sportswear incorporated with nanotechnology, which are briefly summarized in

TABLE **1**. Water-proof breathable fabrics are studied based on spray test ISO 4920:2012, in which the fabric resistance to surface wetting is investigated by spraying a specific amount of distilled water and comparing the sample with standard pictures.[109] Determination of resistance to water penetration based on hydrostatic pressure is also important and is conducted by subjecting the fabric sample to a steadily increasing pressure of water on one face until penetration occurs (ISO 811: 1989, BS EN 20811: 1992).[110, 111]

The resistance to water-vapor permeability is also studied according to ISO 15496: 2004, in which fabric weight change is related to breathability, and a value of more than 20,000 g/m2 per day is regarded as a sample with high breathability.[111]

Determination of water repellency of fabrics by bundesmann rain-shower test (ISO 9865: 1991 and BS EN 29865: 1993) and AATCC 35-2006 and BS 5066: 1974 rain tests are among the other standard methods associated with water-proof breathable fabrics.[112, 113]

The antibacterial property of fabrics is generally evaluated using quantitative and qualitative tests based on AATCC100 and AATCC 147, respectively. The most common Gram-positive and Gram-negative bacteria are Staphylococcus aureus and

TABLE 1. The most common standard methods for assessing the properties of sportswear.

Property	Standard No.	Title
Water-proof and breathability	ISO 811: 1989 BS EN 20811: 1992 ISO 4920:2012	Textile fabrics, determination of resistance to water penetration, hydrostatic pressure test Textiles, determination of resistance to surface wetting (spray test) of fabrics
Water-proof and breathability	ISO 15496: 2004	Textiles, measurement of water vapor permeability of textiles for the purpose of quality control
Water-proof and breathability	BS 5636: 1990, ASTM D737-04: 2012, BS EN ISO 9237: 1995	Textiles, determination of the permeability of fabrics to air
Water-proof and breathability	BS EN 29865: 1993 ISO 9865: 1991	Textiles, determination of water repellency of fabrics by the Bundesmann rain-shower test
Water-proof and breathability	AATCC 35-2006 BS 5066: 1974	Method of test for the resistance of fabrics to an artificial shower
UV protection	AS/NZS 439 9:1996	Sun protective clothing, evaluation and classification
UV protection	AATCC 183: 2014 ASTM D6544: 2012	Transmittance or blocking of Erythemally weighted ultraviolet radiation through fabrics
Antibacterial	AATCC 100: 2004	Antibacterial finishes on textile materials
Antibacterial	AATCC 147: 2004	Antibacterial finishes on textile materials
Self-cleaning	ISO 27448: 2009	Test method for self-cleaning performance of semiconducting photocatalytic materials. Part1: measurement of water contact angle
Hot and cold protection	ISO 20344: 2004	Personal protective equipment, test methods for footwear
Hot and cold protection	ISO 15831: 2004	Clothing, physiological effects, measurement of thermal insulation by means of a thermal manikin

Other microbes, such as Escherichia coli, can also be employed, such as Klebsiella pneumonia. The quantitative approach is based on determining the decrease percent of bacteria from the inoculation treatment test specimen and control sample at zero contact time and after 24 hours (with no antibacterial agent).

The antibacterial activity of the specimen is shown in the qualitative test by a visible region of interrupted growth beneath and along the side of the test material.[113, 114]

A grading system for clothing called the ultraviolet protection factor (UPF) shows how well materials protect skin from UV radiation. The degree of UV protection that a garment gives increases with the UPF value. Any cloth with a UPF 50 rating enables less than 2% of UV transmission. The procedures for determining an item's UPF factor are described in AATCC 183 and ASTM D6544, respectively.[115]

Although ISO 27448-2009 uses measurements of the change in water contact angle of a surface under UV irradiation to test the self-cleaning ability of ceramics coated with nano photocatalysts, no standard approach has yet been established for textile materials.[76]

Although ceramics coated with nano photocatalysts are tested for their capacity to self-clean using measurements of the change in water contact angle of a surface under UV irradiation in ISO 27448-2009, there isn't yet a standardized procedure for textile materials.[116]

The most common method for assessing the self-cleaning ability of textiles owing to the integration of nano photocatalysts is to stain the samples with dyes or coffee and watch the stain disappear under various light irradiations.

Using a thermal manikin, the ISO 15831:2004 standard technique is used to test the thermal insulation of garments. The approach is based on calculating the temperature differential per unit area between the wearer's skin surface and the surrounding air. The manikin either travels steadily or at regular intervals.[117]

By evaluating the thermal changes in innersoles and footwear, ISO 20344:2004 and EN 12784:2000 standard techniques establish the insulation quality of shoes against heat and cold.[116, 118]

Concluding remarks and future trends

Numerous facets of sportswear have been changed by nanotechnology.

Sports apparel made with nanotechnology has multipurpose features including resistance to water, heat, cold, bacteria, and bad odors. They are also light and flexible with great impact strength.

Nanotechnology also has a favorable impact on the comfort of sportswear, which improves the wearer's effectiveness and performance. Sportsmen can engage in intense exercise for extended periods because of the breathability of nano-sportswear. To sum up, nanotechnology has several advantages over conventional sports apparel and equipment. These advantages include:

- Improved athletic performance
- Improved athletic safety
- Improved athletic comfort
- Higher strength and less weight
- Flexibility
- Multifunctional properties such as water-proof, antibacterial, anti-odor, anti stain, UV protection, heat, and cold protection, etc
- -Breathability

The need for creating new techniques and concepts for manufacturing sporting goods that use nanotechnology is emerging as a result of the expanding role of nanotechnology and the abundance of studies in this field. 1160 Journal of Industrial Textiles 46(5) Sportswear has had tremendous market expansion in recent years, and cutting-edge items are always being created with performance, quality, and design as key considerations. Sportswear with both practical performance and stylistic appeal will command a higher price from consumers, giving athletes a significant competitive edge. The future approach will be focused on fulfilling multifunctional requirements including temperature regulation, friction reduction, moisture management, high strength, elastic recovery, lightness, wind, and water resistance, and wear comfort along with other characteristics depending on the nature of the sport, climatic conditions, and physical activity, to develop enhanced performance products.

It's important to take into account how harmful nanoparticles might be to the environment and the skin of wearers.

The impact of nanoproducts on the environment and human health remains a mystery. Future research will concentrate more on high-performance sportswear that complies with safety rules, reducing the dangers from nanomaterials' health, safety, and environmental problems. The dangers associated with nanofibers and nanocomposite fibers are minimal, however, the surface coating of textiles with nanoparticles during nano-finishing processes may carry a higher hazardous risk. Therefore, in the garment industry, the longevity of nano-treatments will be crucial. The negative health and environmental dangers posed by nanoparticles are reduced through the durable nano finishing of textiles.

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تطبيقات تقنية النانو في ابتكار ملابس رياضية ذكية لتحسين الأداء الرياضي: الكفاءة والراحة

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الملخص

في السنوات الأخيرة ، أظهرت تقنية النانو (NT) أنها منطقة دراسة متعددة التخصصات ، مما يزيد من نطاق تطبيقاتها في العديد من مجالات النشاط البشري. تم إحراز تقدم في تكنولوجيا النانو في مواد النسيج نتيجة السعي إلى تعزيز الوظائف المتعددة في المنسوجات الهندسية والصناعية والتقنية والطبية. تمتلك مواد النسيج الآن العديد من الاستخدامات بفضل تكامل التقنيات المتطورة بما في ذلك البلورات الضوئية ، والبلاسمون ، والتلألؤ ، والتلوين المعماري ، والصورة الثلاثية الأبعاد ، وشاشات LED ، والمواد الخارقة. تم تعزيز السلوكيات الفيزيائية والكيميائية للمنسوجات ، مثل التنظيف الذاتي ، والحماية من الأشعة فوق البنفسجية ، ومقاومة اللهب ، والقدرات المضادة للبكتيريا ، من خلال ابتكارات تكنولوجيا النانو النسيجية مثل الجسيمات النانوية (NPs) وتكامل أجهزة الاستشعار في مواد النسيج. إنه مناسب للاستخدام في مجالات الصحة والطب والرياضة والهندسة المتقدمة والأدوية والفضاء والعسكرية والسيارات والأغذية والصناعات الزراعية ، من بين أمور أخرى لأنه يوفر إمكانات استشعار مرنة ، وروبوتات ، وموصلية كهربائية ، ومرونة ، وراحة. أظهرت الألياف المعدنية التي تم حقنها بالجسيمات النانوية ، مثل النحاس والفضة NPs ، نشاطًا مضادًا للفيروسات والبكتيريا. الغرض من هذه الدراسة هو تقديم لمحة عامة عن استخدامات تقنية النانو في العديد من القطاعات ذات الصلة بالرياضة ، مع التركيز بشكل خاص على الأرضيات والملابس والأحذية المتعلقة بالرياضة. تم حقن الرياضة بعدد من العوامل المهمة. يتم إجراء بحث متعمق أيضًا على الملابس المصنوعة باستخدام تقنية النانو. وفقًا للاتجاهات الحالية ، ستتأثر جميع أنواع الملابس الرياضية قريبًا بثورة تكنولوجيا النانو.

الكلمات الدالة: المنسوجات الذكية ، تقنية النانو ، الملابس الرياضية ، المنسوجات التقنية ، الأقمشة الواقية