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Fibers for Sportswear and Influence of Smart Materials on Sports Performance

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Abstract

The progression of fibers developments has gone through the phases of conventional fibers, highly functional fibers and high-performance fibers. Polyester is the single most common fibers used for sportswear and active wear. Other fibers suitable for active wear are polyamide, polypropylene, acrylics and elastane. Wool and cotton fibers are still finding applications in leisurewear. Synthetic fibers can either be modified during manufacture, e.g. by producing hollow fibers and fibers with irregular cross-section, or be optimally blended with natural fibers to improve their thermo-physiological and sensory properties. Synthetic fibers with improved UV resistance and having anti-microbial properties are also commercially available for use in sportswear. New technologies for producing micro fibers have also contributed towards production of high-tech sportswear."

Keywords: Fibers, polymers, smart materials, micro fibers, sportswear

1. Introduction

Sportswear depicts a multitude of attributes; for instance, it provides functional support, enhances performance, protects athlete from strain/injury, promotes sporting activity, communicates fashion and style and, more importantly, offers the wearer comfort. The most vital factor that fibers/filaments contribute toward wearer comfort is moisture and thermal balance leading to a suitable microclimate next to the skin. Fibers influence the overall comfort of the wearer, mainly in providing a balance between heat loss and body perspiration. In recent years, there has been a tremendous increase in the development of new fibers to cater to the fast-growing sportswear and functional clothing market [1]. Today, highly functional fibers [2] microfibers [3], nanofibers [4] and smart fibers [5] have been used in functional clothing. Many claims have been reported, particularly moisture management, thermoregulation and performance-monitoring attributes. Fibers used in sportswear and functional clothing are multidimensional and require a number of characteristics apart from possessing a length-to-width ratio for making a yarn. In the fibers industry, the parameters that influence performance are fibers fineness, fibers shape, molecular structure and adding finishes [2, 6]. Typical properties of fibers for sportswear include durability, absorbance, high moisture regain, and lightweight, extensible, colorfast, dimensionally stable and washable." The aim of this chapter is to provide an overview of current smart and intelligent textile technologies. It commences with a broad definition of smart textiles and then explores how such garments can be powered and how information can be collected and transmitted. The chapter will then further present how smart textiles can respond to the changes within the body and adapt to these to enhance comfort and performance, with specific reference to sportswear applications.

2. The Definition of Smart Materials

It is generally considered that the term 'smart material' refers to a material that is able to sense changes in its surroundings and react to these changes accordingly. However [5], suggests that smart materials can be subcategorized into three divisions as follows:

- Passive smart materials can be thought of as sensory devices; that is, materials of this type can sense changes in the environment, but do not have the capabilities to react to these changes.
- Active smart materials are able to both sense external stimuli and react accordingly.
- Very smart materials are able to sense, react and adapt themselves according to the changes in their surroundings.

There has been much work on the development of smart materials in the medical industry, where major innovations have been noted in the monitoring of patients. Similarly, the military have found smart materials extremely useful in the monitoring of soldiers in combat, enabling medical aid to be targeted to those whose need is greatest [7]. The major part of these developments can be used and adapted to enhance the use of smart materials in the sportswear industry. As the potential applications of smart materials are so diverse, there are many solutions offered to the issues of power supplies, conductive yarns and integrated sensors."

3. Terms Used for Assessing Fibers Performance

In order to understand the characteristics and performance of fibers, it is essential to be familiar with the following technical terms.

Absorbency: Ability to take in moisture (expressed as the moisture regain), which is the amount of water a dry fibers absorbs from the air under standard conditions of 21 °C and 65% relative humidity.

- **Absorption:** A process whereby the liquid is fully absorbed by the fibers through its structure that is quite common among hydrophilic fibers.
- **Adsorption:** A process where liquid is taken up between the fibers on their surface rather than being held within the fibers.

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- **Wicking:** The ability of fabric to transfer moisture adsorbed on fibers from one section to another. Wicking can also occur if liquid is absorbed within the fibers. A smooth surface reduces wicking action. Cotton (hydrophilic) and olefin (hydrophobic) fibers both possess a good wicking action. Fine fibers with channels are capable of transporting liquids (e.g. four-channeled INVISTA Coolmax fabric).

- **Moisture Regain:** The ratio of the mass of moisture in a material to the oven dry mass, usually expressed in percentage. A dry fiber placed in a humid atmosphere will absorb moisture.

- **Hydrophilic:** A fiber that has high regain (that absorbs water); also referred to as 'water loving'.

- **Hydrophobic:** A fiber that does not absorb water; referred to as 'water hating'. Regarding the dimensional stability in water, hydrophobic fibers shrink less when washed than hydrophilic fibers. With regard to stain removal, it is easier to remove stains from hydrophilic fibers because water and detergent are absorbed into the fibers.

Fiber's absorption affects the overall comfort of the wearer, and some of the relevant terms are discussed below:

- **Skin Discomfort:** Little absorption or wicking and movement of perspiration, resulting in a fabric clammy feeling.

- **Static Buildup:** Fabric clinging to the body or sparks occurring with fabric made of hydrophobic fibers because of no moisture content to help dissipate the built-up charge on fibers surface (dirt also clings onto the fibers surface).

- Water Repellence: Fibers that resists penetration of water or wetting but that is not waterproof. Nonabsorbent fibers (polyester, acrylic) help repel water. Water-repellent finishes (use of fluorochemicals) on fabrics are popular.

- **Wrinkle Recovery:** Better wrinkle recovery by hydrophobic fibers when laundered as they do not swell or absorb water.

- **Hygroscopic:** fibers that absorb moisture without feeling wet.

- **Thermo Physiological:** related to optimum balance between the heat loss and heat generated by the body. This depends on the body metabolism, thermal regulation mechanism and individual health condition. One of the important properties of fibers used for functional and active wear clothing is the elasticity and flexibility.

• **Fibers Elasticity:** the ability to increase in length under tension (elongation) and return to original length when tension is released. Stretch and recovery of fibers/fabric makes a comfortable garment and causes less seam stress. Complete recovery prevents bagginess in fabric (knees, elbows), which can be noticed during a stretch and when wearing close-fitting garments. Fibers that elongate 100% are elastomeric fibers and typical examples are spandex, elasterell-p, lastol and rubber.

• **Fibers Flexibility**: The ability of fibers to bend easily and repeatedly without breaking. Acetate fibers is a flexible fiber used in garments; glass fibers is a stiff fiber widely used in technical textiles.

Hence, in order to understand the performance of fibers, their characteristics and properties-particularly in the design and development of functional clothing and sportswear-it is necessary to be familiar with various technical terms used in the industry as well as to utilize them during communication.

4. Widely Used Fibers Types for Sportswear

"In the past, cotton was widely preferred for a wide range of garments until the advent of synthetic fibers such as polyester, nylon, polypropylene, acrylic, etc. During the 1970s use of polyester fibers in sportswear predominated, continuing in the 1980s and 1990s.

Microfiber: fine-diameter fibers less than 1 denier are often termed microfiber and have valuable properties. They are soft, durable and drape able, possess high absorbency and are used for high-performance end uses, especially sportswear. They are produced through melt spinning with strict process control, resulting in a uniform and high-quality polymer.

Hollow Fibers: hollow fibers are made of a sheath of fibers material with one or more hollow spaces at its centre are resilient, have better recovery, are bulky and provide better thermal insulation by trapping air. Hollow polypropylene fibers are lightweight and soft and offer good thermal insulation used in thermal underwear [7] .

Bicomponent Fibers: Bicomponent fibers can be produced with two variants of the same generic fibers, two types of nylon, two types of acrylic or two generically different fibers of polyester or nylon, nylon and elastane. By extruding two polymers in one single fibers, the different properties of both polymers can be extracted. Bicomponent fibers are used in a wide range of functional products including sportswear.

Polyester: is preferred in sportswear because it is lightweight, cheap to produce, dye-fast, durable, easy to care for, quick drying, hydrophobic in nature and has wicking ability.

Elastane: is another synthetic fiber widely preferred for its elasticity (mainly for stretch and recovery). The elastic nature of filaments is used in sportswear to compress muscles, offer stretch for body movements and support in recovering from muscle soreness. A wide range of sportswear products, such as foundation garments, swimwear, base layer products, compression tights, etc. are made of elastane.

Merino Wool: is widely used in sportswear; for instance, superfine Merino wool possesses superior water vapour permeability and quick-drying properties. During strenuous exercise or hot conditions, a Merino wool garment closer to the skin actively transfers moisture vapour away from the body.

5. **Smart Materials**

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- Active smart materials are able to both sense external stimuli and react accordingly.

- Very smart materials are able to sense, react and adapt themselves according to the changes in their surroundings. The major part of these developments can be used and adapted to enhance the use of smart materials in the sportswear industry. As the potential applications of smart materials are so diverse, there are many solutions offered to the issues of power supplies, conductive yarns and integrated sensors.

5.1 Power Supplies

A limiting factor in the development of smart textiles has been the amount of power required to allow the textile 'system' to operate. The issue of current supply was met by the batteries of mobile phones and power supply from an AC/DC source. As technology has developed, solar energy was harvested using photovoltaic (PV) cells have been used along with lithium ion batteries which have long life span.

5.2 Conductive Yarns

In order for smart garments to progress from those which cleverly hide wiring within the garment structure, the textile itself needed to become the 'wiring system'. Early work focused on metallic fibers and yarns, such as copper, steel, nickel and silver, which were known for their conductive properties.

However, issues were quickly found with the flexibility of these fibers, thus impacting on the drape and handle and ultimately the comfort of the textile. Further developments involved polymer-based filament yarns. These yarns can be created by the traditional method of melt spinning, with the active conductive polymer component being added. Another approach to integrating the electronic circuit into the textile is the use of embroidery techniques. Various researchers have explored this field and have used the yarns for embellishment as well as functionality. Another possible solution to the issue of integrated conductivity is that of conductive ink printing. This allows specific circuits to be printed as required, but there is still much development required in this field to ensure such circuits are completely effective and reliable [8].

5.3 Integrated Circuits

Sensors as part of a garment need to be innocuous, particularly in sportswear, so as to not distract wearers from their activity, which could be detrimental to performance. Developments in textile technology mean that the textile itself can now be considered as the sensor, rather than trying to discreetly house an external sensor within the body of the garment or textile structure. Using a colorimetric pH indicator, an LED detector and a wireless transmitter, it is able to monitor the rate of fluid loss from the body. Such a system could be useful for athletes to monitor hydration levels (which have a profound effect on performance), particularly in environments where the temperature and humidity are markedly different from that in which the athlete normally trains and competes. Piezoelectric fibers (those which generate an electrical potential when under strain) are considered the best types of fibers for this end use. Natural fibers such as silk can display these properties to some degree, but synthetic polymers such as polyvinylidene fluoride (PVDF), polypropylene (PP) and polyethylene terephthalate (PET) can be engineered to display piezoelectric properties [9].

6. The Influence of Smart Materials on Sport Performance

Health monitoring has been a key area for the development of smart textiles. Placing textiles directly against the skin and hard wiring them to a monitor has been a technique used for several years in the monitoring of vital signs such as heart and respiratory rates. However, more recent developments have seen advancements in wireless technologies, eliminating the need for hard wiring to an external piece of equipment and thus increasing the potential for mobility of the patient, in turn improving patient comfort and therefore, as some research suggests, decreasing recovery times [10]. These technologies are easily transferrable to the field of sportswear. Incorporating the sensors within the body of the garment and wirelessly transmitting information can provide critical information on vital signs and thus the performance of the athlete. This can provide valuable information for the athlete during the preparation phase of the competitive season and training sessions can be tailored to enhance

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performance, without impeding activity. Similarly, the performance of the athlete can be monitored during competition with analysis of data providing a platform with which to build a strategy for future events. However, it is critical that the sensors cannot be detected by the athlete as this could cause distraction or discomfort and ultimately cause a reduction in performance."

7. Automatic Adjustments

The definition of a true smart material is that it is one able to detect and respond to external stimulus, adapting itself accordingly. There are various types of materials that could fall into this category.

7.1 Shape Memory

Shape memory textiles exhibit the ability to be deformed by external stimuli (usually temperature) into a temporary form and then return to their original shape [11]. Such materials are manufactured from polymers that are heated to a specific temperature (the temperature of deformation) at which they are set into shape. The material is then allowed to cool. During use, if the material is heated to its temperature of deformation, it will then lose its set shape and thus change the properties it imparts. This process is entirely repeatable as the changes are within the morphology of the structure and not due to the degradation of the polymer [12]. In sportswear applications, such textiles can be useful in the thermoregulation of the body. The fabric structure opens as the body temperature rises, allowing heat and moisture to travel away from the body and facilitating cooling. As the environment and body cool, the structure closes, thus trapping air between the garment and the body and allowing thermal insulation to occur [13] ."

7.2 Phase Change

Phase change materials are those which have the ability to change state when absorbing or releasing thermal energy, thus acting as thermo regulators in fabric and garment form. Typically, these materials are based on a wax type of compound encapsulated within a fibers, although this is not the only type of material and technique that can be used. Alongside paraffin waxes, compounds such as hydrated inorganic salts, linear long chain hydrocarbons and polyethylene glycols have been considered in the development of textiles with enhanced thermoregulatory properties, with techniques such as lamination and coating being explored by researchers as alternatives to fibers encapsulation. The critical factors required for a phase change material to be effective in a textile clothing application are as follows:

I) A melting point between 15 °C and 30 °C.
II) II) A small difference between melting and solidification points.
III) III) Stability during repeated melting and solidification.
IV) IV) Excellent thermal conductivity.

Additionally, health and safety factors such as low toxicity, resistance to flammability and effects on the environment are key considerations. Ultimately, for the mass market, cost is the deciding factor [14]. As body and environmental temperatures rise, the compound absorbs the thermal energy and, as it does so, changes state from solid to liquid, drawing heat away from the body and allowing cooling to occur. Conversely, as temperature drops, the compound emits thermal energy and it transforms from liquid to solid state, allowing heating of the surrounding area. Careful engineering of the garment is required to ensure it is the body that benefits from the movement of thermal energy and not the surrounding atmosphere15. Currently, the amount of phase change material that can be incorporated into textile weights common in garments (approx. 150-400 g2) is such that only approximately 15 minutes of effectiveness can be achieved. However, this could be of use in sportswear applications for garments worn immediately after warm-up to ensure muscles are not allowed to cool before activity. There has been some development using this technology in heavyweight garments such as those used in extreme sports in colder climates; gloves for snowboarding and skiing have successfully used phase change materials to impart thermal comfort [16].

7.3 Chromic Effects

Materials experiencing a change of color due to external stimuli are known as chromatic. The specific category of chromatic function is dependent on the stimulus as follows:”

- Photo chromatic-color change due to light
- Electro chromic-color change due to electrical currents
- Piezo chromic-color change due to mechanical deformation
- Solva chromic-color change due to moisture
- Thermo chromic-color change due to heat

Thermo chromic textiles have been used to some degree in the medical industry in the monitoring of body temperature and could be used in sportswear in a similar way and aid performance monitoring. Similarly, solva chromes could aid sportswear performance, being used to monitor the production of perspiration and thus advise the wearer on necessary rehydration.

8. Specific Applications in Sportswear

8.1 Athletics Professional athletes require perfect conditions in both their own bodies and the external environment to perform at their optimal level [17] . Smart textiles can offer monitoring techniques in the training environment which are noninvasive and therefore do not distract wearers from their performance [18] . However, monitoring of the body's response to exercise is not in demand exclusively by professional sportspeople. Sport as a recreational activity is commonplace, with many participants having a keen interest in monitoring their performance. Many companies have recognized this 'High Street demand' for such monitoring devices and several are now available for use in both the leisure and professional sportswear market. The T-shirt type garment is constructed from a knitted fabric base containing elastane to improve fit and comfort properties. In the front portion of the garment, ECG electrodes and a respiratory monitor are knitted into the fabric structure alongside the circuitry, which is created from silver-coated polyester yarns. The vest can provide real-time monitoring and data output, which can enable athletes to understand and adapt their performance and training regimes [19]. In a similar way, NuMetrex has developed the 'sports bra'. The sensors and conductive components are all inherent in the garment, thus minimizing any distractions that could be caused by the monitoring equipment." The information is transmitted wirelessly to a watch via a clipon transmitting device, enabling the wearer to monitor heart rate in real time.

8.2 Ski Wear

The sport of skiing involves periods of high activity (skiing downhill) followed by those of relative inactivity (resting at the end of the ski run, or the lift climb to the top of the slope). Ski wear therefore must be thermoregulatory-supplying the wearer with both cooling and insulating properties. Phase change materials lend themselves perfectly to the shorter ski runs associated with recreational skiing. "Where the downhill ski runs and lift climbs are short (less than 10-15 minutes), enough phase change material can be incorporated into the clothing to allow effective thermoregulation to take place. Ski clothing is generally thicker than every day wear; however, the wearer still requires clothing that is flexible enough for normal body movement, thus restricting the amount of phase change materials that can be incorporated into clothing covering the arms and legs (and torso to some degree). Areas of the body where heat loss due to conduction is known to be greatest in cold climates are the hands and the feet. In the case of the feet, less apparel flexibility is required; thus the textiles used can be thicker and more phase change materials can be incorporated, increasing the length of the effectiveness of the material. A degree of manual dexterity is still required in skiing; however, more phase change material can be incorporated in the body of the glove to improve insulation without compromising movement. A critical factor in mountain sports is protection from the wind, which can cause accelerated heat loss and hypothermia if the body is not sufficiently shielded. Coupled with this, it is essential that moisture produced by the body is allowed to escape through the garments to allow cooling when required. This moisture must be allowed to escape and not held either on the skin or within the textile structure as this can again accelerate the cooling effects of the surrounding environment." Shape memory polymers, discussed above would serve a useful purpose in this case, with the structure being closed if wind chill is a threat, whilst opening up to allow moisture out if the temperature of the body begins to increase.

9. Discussion

The market for smart textiles is growing, particularly in those industries, such as sportswear, in which there is a need for the wearers to be monitored and the information collected to be analyzed. "The fashion industry has yet to find a real use for such technology, and smart textiles are still frequently used as novelty items. There is a danger that the fashion industry will continue to see such developments as a 'gimmick' using the technologies to support structures such as those with LEDs. Improvements in the flexibility of the fabrics which incorporate the componentry to enable operation of the smart garment are also allowing designers to create garments more easily. In early developments the wiring of the components was the deciding factor in the garment design (as seen with the ICD + jacket), which led to smart garments being heavy and bulky. Conductive yarns, componentry and sensors are now all readily available in flexible forms off the shelf, enabling lighter weight garments to be produced, which are more comfortable to wear [20] . The apparel industry still encounters problems with power sources for smart textiles and as such is limited in the progression of the technology until a viable option is found [21] . Some encouragement should be taken from the mobile phone industry where much work is being done to improve battery life whilst reducing battery size. Companies such as Apple and Samsung are market leaders in the smart phone arena where their products are providing an increase in functionality with no increase in battery size [22] . Alternative power sources should not be disregarded. Traditional recharge-able batteries, which draw their charge by being plugged into the mains supply for a period of time, could be replaced with more sustainable alternatives. Solar power has seen great leaps forward in the last few years, with solar cells decreasing in size and, as discussed in the previous section, increasing in flexibility. The 'charge whilst you wear' concept would be appealing to consumers, who are quick to highlight their frustrations with the traditional methods of recharging batteries. In order for the smart textile to become a reliable product for the diagnostic and medical aspects of the sports industry, improvements in wireless integrity still need to be made. There is a perception that wireless technologies are still not as reliable as their hard-wired counterparts and, in order for such textiles to gain credibility, absolute reliability of data transmission is critical [23]. Whilst this is based largely on perception rather than hard fact, wireless technologies do have room for improvement. Finally, the environmental impact should be considered. In a world where a conscious effort is being made to reuse and recycle, is there really a place for textiles which contain added technology? And what shelf life do these garments have? It could be suggested that in terms of performance sportswear, there will always be a need to monitor athletic performance-be that through heart rate, blood pressure, respiratory rate or one of the other functions discussed previously in this chapter. However, as the technologies are developing at such a rate, will this mean garments can be upgraded as the technology develops, or will current garments be deemed obsolete in a couple of years' time? In this case, does this mean that garments now will go to a landfill site or can they be recycled? An argument could be put forward that, as the garments are the sensors and are transmitting the raw data, it is the processing software that will change and, as such, the garment will have a longer life than that initially thought. This issue will only be brought to light as the smart textile market widens.

10. Conclusion

Fibers form the basic constituent of a garment and garment performance relies on choosing the right type of fibers composition by keeping up to date with modern developments in this field. "During the last decade or so, the world production of man-made fibers increased from 49% in 1992 to 68% in 2012 and this trend is bound to continue as the demand for performance clothing increases. This is due to the fact that, compared to natural fibers, man-made fibers are engineered to meet specific requirements of the end user. Smart materials have an important part to play in the future of sportswear. There have been many developments since the integration of electronics into a garment in the late 1990s and, although the novelty factor of this garment was quickly dismissed by the consumer, it served as a basis for innovation. Developments in military and medical applications easily translated into sportswear products." Sports performance monitoring was the first to be considered and the development of integrated sensors and piezoelectric fibers enabled professional athletes to monitor their activity in real time, recording their data for analysis and enabling training sessions to be adapted accordingly. In addition to performance monitoring, smart textiles have also been developed to enhance comfort, with shape memory and phase change materials being used. These technologies have allowed apparel with exceptional thermo-regulatory properties to be established which adapt in line with wearers' individual needs.

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