Recent Developments in Materials and Manufacturing Techniques Used for Sports Textiles

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Received 6 September 2022; Revised 1 February 2023; Accepted 3 February 2023; Published 22 February 2023

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In the recent era of development, the global market for the sportswear textile manufacturing industries has increased with the increase in consumption of active sportswear. The sportswear manufacturers not only focused on the market trends but also focused on material diversification with technology enhancement. The performance characteristics of active sportswear directly influence comfort level and athletic performance during sports activities. Different types of sportswear products require different performance characteristics. Appropriate moisture and heat management are the key factors for the endowment of the required physiological comfort level. In highly engineered textile-based sports goods, special characteristics are incorporated in the polymer/fibers/product manufacturing procedures/finishing techniques to obtain the maximum performance and comfort level. In this review paper current market trends, highly engineered polymers, fibers, fabrics, finishes, nanomaterials, and the recent developments in the manufacturing techniques of sportswear are illustrated.

1. Introduction

Sports are established, competitive, organized, causal, and all types of physical activities are played for the improvement of mental and physical health [1]. The clothing (gloves, T-shirts, jackets, trousers, caps, socks, shoes, etc.) and sports accessories (helmets, mouth guards, elbow/shoulder pads, Shin pads, etc.) that are required for a player/athlete have been termed sports textiles [2, 3]. Sports textiles play a vital role in the existence and performance of athletes.

In the early 19th century, sports persons used to wear grey linen fabric. At the end of the 19th century, dyed cotton shirts were introduced in the sports sector with different colors for team identification. With the invention of synthetic fibers, athlete uniforms were made from nylon, polyester, and spandex for better durability and elasticity. The fabric manufactured from these synthetic fibers was uncomfortable to wear. Therefore, different research has been conducted on properties optimization regarding the mechanical and comfort properties of sports textiles [4, 5]. With the increase in outdoor and indoor sports activities, the consumption of textile materials in sports textiles has also increased and evolved [6].

The market for textiles related to sportswear is growing massively in the last 20 years. This market includes sports fashion wear, basic sports clothing, leisure sportswear, and footwear. The global sports textiles market is forecast to grow from USD 40.68 billion in 2021 to USD 64.39 billion by 2030, at a Compound annual growth rate (CAGR) of 4.7% during the forecast period from 2021 to 2030 [7].

The activities, related to various kinds of sports, are reported as the basics of a healthier life. The increasing trend for participation in sports leads us to invent new sports for competition with world athletes and players. That’s why sportswear needs to have improved functionality so that the efficiency of the athletes can be enhanced [8]. The
performance sports textiles are those in which the functionality is enhanced, these are manufactured in low volume but have higher prices. In contrast to performance sportswear, basic sports clothing is cheaper and produced in bulk volume. Leisure sports clothing is just like performance sportswear but at cheaper prices and in bulk quantities [9].

The design of functional sportswear varies for different types of sports and also by weather conditions, type of sport, and the physical activity required for that specific sport[20]. The development of highly functional sportswear for various kinds of sports requires immense research by industries and academic professionals. To meet the demands for sportswear, there is a need to produce new fibers, fabrics, and textile finishing for the improvement of sport textile functions. In this field, the development of different man-made fibers contributed a lot to converting simple sportswear into high-tech sportswear. The fashion applicability and functional performance of sportswear can be judged during international games like the Olympics [10]. The scientific development of sportswear was aided by the manufacturing of specialty fibers by which advanced and smart sports clothing can be engineered for suitable end applications [11].

High-active sports are categorized as those in which games are played with high physical exertion like football, athletics’ jumping, and tennis. The comfort properties of clothing may adversely affect the performance of sports clothing [12]. In sports textiles, the performance of the clothing is indicated by the parameters like strength with light weight, extensibility, temperature regulations, overall moisture management capability, water and wind resistance, and smooth surface [13]. Sports clothing usually needs different characteristics for different end applications. Some of these requirements need to be discussed in detail.

The textile physiology mechanism of sports clothing is the interface between clothing and the human body to offer the information regarding physiological characteristics of that particular clothing [8]. Clothing physiology is generally expressed as the performance capability, health, and comfort of the wearer. The correct functionality of a garment decides whether it is physiologically appropriate or not. The body of a human has a temperature of 37°C and it should be maintained under all weather conditions. To avoid heat stress due to high physical activity, the heat produced by the body must be dissipated from the body through single or multi-layered fabrics. The hot and humid microclimate near the skin can cause problems in comfort. So, sports clothing must have some unique pathways for the removal of perspiration vapors from the body to the external environment. There are two types of textile/clothing comfort that are of enormous importance for sportswear:

1. Psychological comfort
2. Physical comfort (tactile, thermal, ergonomic).

2. Psychological Comfort

Psychological comfort is a state of mind, feeling the presence of pain and discomfort [14]. Human psychology, regarding clothing comfort, broadly depends upon many factors such as age, health, environment, weather, occasion, social status, economic background, profession, religion, and territory. Psychological comfort is very complex to explain because one thing which is comfortable for one, may or may not be comfortable for another. Physiological comfort is essential in all kinds of sportswear. It was the visual comfort that includes color, luster, design, style, and fashion. But this type of comfort does not have an active role in the functions of clothing.

2.1. Physical Comfort. Physical comfort is usually determined by the human skin. The normal internal body temperature of a human being is 37 ± 0.5°C under different environmental conditions [15]. When the temperature of the body changes from normal, the body releases or produces heat to maintain the normal body temperature [15, 16]. When the body temperature is at equilibrium, the human being performed activities at its maximum efficiency [18]. In this context, environmental conditions, physical activities, and clothing help in physical comfort as shown in Figure 1 [20]. Tactile comfort, thermal comfort, and ergonomic comfort are the types of physical comfort which are described below.

2.1.1. Tactile Comfort. The interaction of the wearer’s skin with the garment describes tactile comfort. Sportswear is usually worn right next to the skin. That’s why the feeling of a person towards a garment is of major concern. Tactile comfort is also categorized as sensorial comfort, it does not have any direct relation to thermal regulation. Factors affecting tactile comfort are shown in Figure 2. Fabric roughness, fabric softness, and fabric surface friction are directly related to tactile comfort. As tactile comfort is the interaction of the skin with the garment, so the rough fabric will irritate the skin, soft fabric provides comfort, and fabric surface friction will reduce the static charge properties.

When the body generates sweat, the feeling of wet or wet clinging is the main cause of discomfort. This could happen due to excessive accumulation of sweat on the body because of limited pathways for sweat removal. The low or no moisture transportation will cause wetness to the body and subsequently an unpleasant feeling, as the garment will tend to stick to the wearer’s body. In the human body, the skin is the largest organ acting as a shield to protect other sensitive organs of the body. Roughness, softness, and surface friction are the key factors of clothing for the determination of tactile comfort [20, 19]. Friction on the external surface of a human may result in skin injury. The ill-fitting sportswear and repeated abrasion are reported as the cause of Urticaria and hives [21]. Previous studies showed that the selection of low-friction and well-fitted garments can reduce these problems [22].

2.1.2. Thermo-Physiological Comfort. Thermo-physiological/thermal comfort depends upon many factors as shown in Figure 3. This comfort is mainly related to the thermal equilibrium of the wearer. The heat evolved by a high level of metabolic action in the body of athletes during high-active
sports like football can produce heat in the range of 800–1300 W. This amount of heat can cause an increase of 1.5–2°C in the core of the body. So, in this type of high physical activity, heat stress is of major concern. To counter this heat generated, the sweating of the body takes place and has an important role in decreasing the body’s core temperature to avoid heat stress. The sweating and its subsequent vaporization lead to a cooling effect [23]. The generation of sweat in an athlete’s body could be up to 2.5 L/hour, so a major technical requirement in this regard is the absorption of the body’s sweat and then it’s quick drying to provide a cooling effect [20].

Thermal equilibrium will be set up when the heat produced by the body’s metabolic action or physical activity is equal to the heat dissipated or heat lost from the body. But if the heat dissipation is improper, then there will be heat stress, and on the other hand, in case of excessive heat loss, wearer will experience cold stress [24]. So, it is necessary to develop the garments with an optimized transfer of moisture vapors and sustain the thermal insulation. There are four ways for the transfer of heat to regulate the human body’s temperature: conduction, convection, thermal radiation, and evaporation [25].

In hot climatic conditions, during active sports, 80% of energy can be converted into heat, and in a warmer atmosphere where the temperature of the air is higher than that of the body’s temperature, the phenomenon of convection can cause heat loads as shown in Figure 4.

In these cases, the only way of heat loss is in the form of evaporation, and the amount of dissipated heat depends on the rate of sweat evaporation. But the rate of sweat evaporation depends on the evaporative capacity of the environment. The amount of sweat generated is not equal in all areas of the body, back has more sweat generation than the chest area [26]. Thermo-physiological comfort can be estimated by the overall moisture management capability and breathability of a garment. The garments offer a microclimate between clothing and body, which behaves as a barrier for vapors and heat transfer to the environment as shown in Figure 5 [26, 27].

There are three modes of moisture transportation from the garment:

(i) The moving air close to the skin causes forced convection
(ii) Hydrophilic groups on the fabric (sorption–desorption) [29]
(iii) Diffusion of moisture vapors from the garment [30].

In severe perspiration, the garment next to the skin should absorb liquid quickly and need to transport it through the fabric’s thickness. Moisture transportation through fabrics takes place by wetting and subsequent wicking [31]. Wetting can be described as the spreading of sweat on the fabric. Wicking can be described by the molecular attraction of liquid to the fiber surface. This attraction depends on pore size distribution, pathways for effective capillary action, and surface tension [32]. The temperature of the body’s surface and the amount of moisture content in the microclimate mainly depend on the level of physical exertion and it is significantly affected by the fabric type [33]. Previous studies in this field showed that the comfort of sportswear during physical activity is determined by moisture accumulation and moisture vapor resistance [34]. The chill effect during sports activity can cause an accumulation of sweat within the garment, which results in a decrement of thermal insulation by 2–8% [35].

2.1.3. Ergonomic Comfort. In some sports, the ease of movement of different body parts is very essential. Higher efficiencies of athletes during a game require higher degrees of movement and flexibility. For this purpose, high volume or a high weight of the garment will adversely affect the flexibility. The stiffness of the fabric is also a significant factor in determining the ease of movement. So, sportswear should be lightweight and flexible to get high mobility. This comfort is also known as ergonomic comfort, which defines the ease of movement and fitness of sportswear or any other garment. It
mainly depends on the elasticity of the fabric, construction parameters, and fitness design [36]. Textile clothing for sports should not restrict the freedom of movement of the wearer, otherwise, unnecessary pressure on the body/garment will lead to discomfort for the wearer [37].

Some advanced and innovative products for sportswear are shown in Table 1.

Some sports like powerlifting, running, and jumping require improving the movement of an athlete to enhance the performance. The specially built garment for this purpose is known as compression athletic wear, which delivers the optimum compression and anatomic fitness to the player. Compression athletic wear is also called skin suits. By wearing these garments, athletes exhibited faster speeds of running over 10 km with reduced muscle soreness and lower heart rates [45].

3. Fibers and Fabrics Manufacturing Technologies Used in Sports Textile

Sportswear characteristics can be divided into functional and aesthetic requirements, both of which are essential in determining the clothing’s performance and consumer acceptability. Sportswear must meet aesthetic requirements (softness, surface texture, handle, luster, and color) and functional requirements (light weight, low fluid resistance, high tenacity, stretch-ability, thermal regulation, UV protection, vapor permeability, and sweat absorption and release).

The thermo-physiological comfort feature of the sportswear is crucial to ensuring the well-being of the athlete without compromising performance and effectiveness. Engineering materials with excellent moisture vapor and liquid moisture transmission create a dry microclimate for wearers involved in vigorous physical activity in hot, humid situations. Fabrics intended for activewear must take geometry, packing density, and the structure of the component fibers into careful consideration to effectively dissipate heat and moisture. Excellent moisture management characteristics can be found in sportswear made with particular fibers, yarns, and fabric structures.

As a result, sportswear designers experiment with different fiber cross-sectional shapes, shape factors, and specific surface areas, yarn variables like twist, linear density, structure, and packing coefficient, and fabric variables like loop length and porosity. They also use different knit structures like plated and elastane fabrics, as well as those created using bio-mimic concepts, to create sportswear intended for performance sports.

In recent years, with the invention of innovative functional polymers [46, 47], fibers, yarns, fabrics, and production techniques, the design of active sportswear becomes a subject of research to fulfill the requirements of the consumer. The performance characteristics of the sportswear are depicted by its fiber structure, inter-fiber interaction, yarn/fabric structure, and the chemical treatment applied during its development. The invention of synthetic fibers opened a new research area for their use in active sportswear fabrics. Active sportswear engineered with functionalized fibers exhibits excellent thermal performance and moisture management properties.

The properties of sportswear are directly influenced by its raw material. The correct raw material selection is a big challenge in the market for sports textiles. Different types of natural, synthetic, and special fibers are used in sportswear according to the end product applications.
Table 1: Some advanced and innovative commercial products for sportswear.

<table>
<thead>
<tr>
<th>Sr. #</th>
<th>Product description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Coolmax®, Thermolite, and Thermocool [38]. A blend of Coolmax and fine wool for particular functions [38].</td>
</tr>
<tr>
<td>2</td>
<td>Stunner QD® for quick absorption, dispersion, and evaporation of moisture [40].</td>
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<tr>
<td>3</td>
<td>Skin® A400, increased oxygen supply to muscles by dynamic gradient compression [41].</td>
</tr>
<tr>
<td>4</td>
<td>Field sensor TM® brushed inside for insulation and moisture management [42].</td>
</tr>
<tr>
<td>5</td>
<td>Coolmax® active, channeled polyester with superior OMMC [43].</td>
</tr>
<tr>
<td>6</td>
<td>INOTEK® biomimetic fiber, adoptive breathability in wet and dry conditions [44].</td>
</tr>
<tr>
<td>7</td>
<td>Sportwool® is a two-layered moisture management fabric [45].</td>
</tr>
<tr>
<td>8</td>
<td>(1) ThermoLite active—provides thermal insulation for high-energy activity and movement</td>
</tr>
<tr>
<td></td>
<td>(2) ThermoLite extra—provides warmthness and softness effect</td>
</tr>
<tr>
<td></td>
<td>(3) ThermoLite micro—exhibits warmth and water-resistance properties</td>
</tr>
<tr>
<td></td>
<td>(4) ThermoLite plus—provides warmth and comfort in wet conditions</td>
</tr>
<tr>
<td></td>
<td>(5) ThermoLite extreme—having substantial warmth and durability.</td>
</tr>
</tbody>
</table>

Among the parameters of the fiber, fiber cross-section is directly related to sportswear moisture management, better wicking, and quick-drying properties. A channeled structure like a tetra, Hexa, trilobal, triangular, or five-leaf fiber cross-section exhibits a large surface area for liquid sweat transmission in comparison with a circular cross-section. The chemical structure of fibers used in sports textile mostly contain hydroxyl, amide, and ester linkages. The presence of these functional groups provides the excellent thermal performance and moisture management properties. Detail of some special fibers having special characteristics is given below:

3.1. Coolmax Fiber. In 1986, the textile engineers of the Dupont Company developed a modified polyester fiber named Coolmax fiber. This fiber was specifically developed for the sportswear industry for the provision of cooling effects during active sports. The ester linkages present in the chemical structure will not absorb water but transport it in the environment through the surface. The cross-section of the fiber is a slightly oblong shape with lengthwise grooves on its surface rather than a round shape. The fibers were manufactured in tetra channel or Hexa channel cross-section. The channeled structure allows quick moisture-wicking from a wider surface area as shown in Figure 6. This will provide a cool, dry, and fresh feel to the wearer [45, 46].

3.2. Thermolite Fiber. Thermolite technology is warming technology that provides superior warmth without bulk in winter sportswear. The fiber has a unique hollow fiber design that provides thermal insulation by trapping the air inside and in between the fibers as shown in Figure 7. The fiber’s largest surface area spreads away the moisture from the skin for faster evaporation. The tiny air pockets in the fiber structure provide thermal insulation to the wearer [48, 49].

Five different types of thermolites with special features are available, which are given below:

3.3. Microfiber. Microfiber are man-made fibers that are synthesized at very fine linear density, i.e., 0.4–0.9 dtex, which makes them extremely lightweight fibers [54]. Microfiber-based textile products exhibit exceptional strength, durability, breathability, and softness effect [55]. Polyester, acrylic, polypropylene, and cellulose-based microfibers are generally available in the market. Microfibers provide a highly porous structure, improved water wicking, and excellent thermal control properties owing to the very fine fiber linear density.

3.4. Hygra Fiber. Highly active sportswear textiles require fabrics exhibiting highly moisture-absorbing and moisture-releasing properties. To fulfill this need, researchers have developed a core-sheath-based structure composed of the highly moisture-absorbing polymer as the core part and nylon as the sheath part. This fiber is known as Hygra fiber. The core hydrophilic polymer absorbs water 35 times its weight with quick water-releasing properties [56]. The nylon in the sheath provides high tensile strength, durability, and dimensional stability properties. Hygra fiber also exhibits antistatic properties even in low wet conditions [57].

3.5. Viloft Fiber. Advanced viscose fiber has a flat cross-section and crenelated surface exhibiting quick water-wicking and drying properties. The hydroxyl group in the chemical structure provides water loving group for moisture/sweat absorbance. Viloft fiber is used in sportswear by blending with some natural and synthetic fibers to achieve specific functional properties. It provides natural fibers with comfort properties, excellent moisture management, and temperature management characteristics [58]. Viloft spirit, viloft thermal, viloft micro, and viloft active functional fabrics are available in the market.

3.6. Killat N Fiber. It is a hollow nylon filament with a 33% hollow portion in the cross-section of each filament. The hollow structure provides excellent moisture absorption and thermal insulation properties. Nylon–polyester-based bi-component filament fibers were manufactured with soluble polyester-co-polymer as the core part and nylon as the sheath part. Then this bi-component filament was treated with an alkaline solution, the soluble polyester copolymer dissolve in the solution, and the hollow nylon filament was achieved [59].
3.7. Dryarn Fiber. Aquafil manufactured the recyclable polypropylene microfiber named Dryarn. Owing to its extremely lightweight and comfortable characteristics, it is used in many sports. Moreover, fiber also exhibits highly thermo-regularity and quick-drying properties. The highly smooth surface of the fiber resists the accumulation of bacteria on the fiber surface and avoids unpleasant odors during sports activities [17].

3.8. Thermo-Regulated Fibers. Thermo-regulated fibers regulate the body temperature from 30°C to 33°C according to the outside environmental temperature. The phase change materials (PCMs) are imparted in the fibers, which change their physical state upon heating or cooling [60]. Phase change materials exhibit the characteristics of absorbing or releasing a specific amount of energy in the form of latent heat [61]. Nowadays, more than 500 PCM materials are available in the market. Among them, paraffin-based PCM materials are used for textile applications [62]. Owing to their excellent thermo-regulatory properties, PCM-based thermo-regulated fibers are used in highly active sportswear.

Outlast fiber is a well-known example of thermo-regulated fiber. In Outlast technology, PCM microcapsules are incorporated into acrylic/viscose fiber that provides thermal comfort to the wearer by absorbing, storing, and releasing heat according to the requirement. During highly active sports activities or in hot climate conditions, the body produced an excessive amount of heat. This heat is absorbed by the Outlast fiber and provided to the body upon requirement as shown in Figure 8 [62, 64]. A brief description of the fibers is explained in Tables 2, 3, and 4.

3.9. Natural Fibers

3.10. Synthetic Fibers

3.11. Special Fibers

3.12. Pros and Cons of Regular Used Fibers in Sports Textile. Nylon is a synthetic fiber that is known for being durable and easy to care for. It is often used in sportswear because it dries quickly and does not hold onto sweat or odor like some other fabrics can. However, the breathability of nylon is not always the best and it can get sticky when humid out. However, this fabric does have some great features such as being lightweight, which makes for an ideal option if you are looking to stay cool during hot weather. That said, nylon is often blended with other fabrics to help offset these issues.

Polyester is a synthetic fabric that is known for being durable and easy to care for. It is often used in sportswear because it wicks away moisture, which keeps athletes cool and comfortable. However, polyester can also be quite hot.
and sticky when it’s humid out, and it does not provide much in the way of breathability. Microfiber is a synthetic fabric that is made from very fine fibers. It is known for being soft, lightweight, and absorbent. Microfiber is often used in sportswear because it dries quickly and does not hold onto sweat or odor like some other fabrics can. However, microfiber can be less durable than some other options and can pill over time.

Spandex is a synthetic fabric that is known for its stretchiness. It is often used in sportswear because it provides support and compression without being restrictive. However, humidity and heat can really take their toll on

![Diagram of OUTLAST material properties](image)

Figure 8: Working principle of outlast fiber [65].

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Properties</th>
<th>Sports textile products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>Absorbent, breathable, hypoallergenic, non-toxic, comfortable, biodegradable</td>
<td>Used as the inner lining in sportswear.</td>
</tr>
<tr>
<td>Hemp</td>
<td>Absorbent, UV protective, antimicrobial, durable, comfortable, good wet strength, biodegradable</td>
<td>Sails and ropes, caps</td>
</tr>
<tr>
<td>Bamboo</td>
<td>Absorbent, elastic, antibacterial, antifungal, natural deodorant, UV resistant, and biodegradable</td>
<td>Next to skin garments, knitted shirts, trousers</td>
</tr>
<tr>
<td>Wool</td>
<td>UV protection, antibacterial, stain resistance, antistatic, durability, and warmth</td>
<td>Used as an inner, mid, and outer layer for hiking, climbing, or skiing suits</td>
</tr>
<tr>
<td>Silk</td>
<td>Lightweight, breathable, elastic, absorbent, quick-drying, shiny appearance</td>
<td>Sports coats</td>
</tr>
</tbody>
</table>

Table 2: Natural fibers properties and their applications in sports textile products [66].
you when you are wearing spandex. The material is sticky, making it difficult to breathe in some situations if there's no air conditioning or other cooling device.

Bamboo fiber is a natural fiber that is made from bamboo plants. Bamboo fiber is known for being soft, absorbent, and antimicrobial. Bamboo fiber is often used in sportswear because it helps keep athletes cool and comfortable by wicking away moisture. However, bamboo fiber can sometimes be less durable than some other options and may pill over time.

There are a lot of different fibers/fabric options to choose from when it comes to sportswear. Each with its own set of pros and cons. The best option is that depends on your needs and preferences. For a garment that is durable and easy to care for, then polyester or nylon might be a good option. For that sportswear that dries quickly and does not hold onto sweat or odor, then microfiber might be a good choice. And if the need is something that provides support and compression without being restrictive, then spandex might be a good option. Ultimately, the best fabric for sportswear is the one that meets the specific needs in the most effective way.

4. Fabrics Used in Sports Textile

In sportswear and outdoor sports gear, there has been a significant increase in the development and use of high-performance fabrics. Many of these items' performance requirements necessitate a delicate balance of drape, thermal insulation, liquid barrier, antistatic, stretch, physiological comfort, and other factors. Over the last decade, research on this subject has resulted in the commercialization of a variety of novel products for high-functioning end uses. It is now possible to successfully combine the consumer requirements of aesthetics, design, and function in sportswear for various end-use applications by designing new processes for fabric preparation and finishing, as well as advances in technologies for the production and application of suitable polymeric membranes and surface finishes. Fabrics for activewear and sportswear are also designed with specific geometry, packing density, and structure of the constituent fibers in yarns, as well as fabric construction, to achieve the required heat and moisture dissipation at high metabolic rates. Many smart double-knitted or double-woven materials for sportswear have been designed so that the face closest to human skin has ideal moisture-wicking and sensory qualities, while the outside face has optimal moisture dissipation behavior.

4.1. Naiva Fabric. Naiva fabric was created by Unitika by mixing the Naiva yarn with a nylon microfiber. Naiva is a bi-component filament yarn made of Eval and nylon. Eval is an ethylene–vinyl alcohol copolymer resin. 55% Eval and 45% nylon constitute Naiva yarn. Many nylon microloops can be found on the surface of Naiva fabrics, which are generated by utilizing Naiva yarn's high thermal shrinkage feature. Naiva fabric not only has superior moisture permeability, but it also possesses lightweight, softness, and the capacity to be finished secondarily. Mountaineering and other active clothing benefit greatly from the fabric [68].

4.2. Field Sensor Fabric. Toray's field sensor fabric is a popular high-performance fabric with a layered construction that not only absorbs perspiration fast but also transfers it

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Properties</th>
<th>Sports textile products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polyester</td>
<td>Lightweight, wrinkle-free, durable, excellent elasticity, nonabsorbent,</td>
<td>Shirts, trousers, jackets, gloves, socks, undergarments</td>
</tr>
<tr>
<td></td>
<td>wicking properties</td>
<td></td>
</tr>
<tr>
<td>Nylon</td>
<td>Durable, excellent elongation, UV resistance, heat resistance,</td>
<td>Shirts, trousers, jackets, gloves, socks, undergarments, tracksuits</td>
</tr>
<tr>
<td></td>
<td>chemical resistance, mold and mildew resistance, quick-drying</td>
<td></td>
</tr>
<tr>
<td>Acrylic</td>
<td>Durable, excellent elastic recovery, good thermal stability, insect</td>
<td>Shoes, shoe lining, gloves, athlete wear</td>
</tr>
<tr>
<td></td>
<td>resistance</td>
<td></td>
</tr>
<tr>
<td>Polypropylene</td>
<td>Low density, tough, flexible, chemical resistant, lightweight, quick-</td>
<td>Shirts, trousers, undergarments</td>
</tr>
<tr>
<td></td>
<td>drying, and comfortable</td>
<td></td>
</tr>
<tr>
<td>Elastane</td>
<td>Soft, smooth, 50% stretch recovery, abrasion resistance, resistance to</td>
<td>Cyclist uniform, runners, athlete uniform, undergarments, swimmers dress, body fit garments</td>
</tr>
<tr>
<td></td>
<td>perspiration, body oil, and detergents</td>
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</table>

**Table 3: Synthetic fibers properties and their applications in sports textile products.**

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Properties</th>
<th>Sports textile products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hygra 20</td>
<td>Absorbs water 35 times its weight, is strong, dimensionally stable, antistatic</td>
<td>Athletic wear, skiwear, golf wear</td>
</tr>
<tr>
<td>Killat N23</td>
<td>Hollow nylon filament, good water absorbency, thermal insulation, lightweight</td>
<td>Shirts, trousers, undergarments, shoes lining</td>
</tr>
<tr>
<td>Elastane</td>
<td>Soft, smooth, 50% stretch recovery, abrasion resistance, resistance to</td>
<td>Swimwear, activewear, floor gymnastics</td>
</tr>
<tr>
<td></td>
<td>perspiration, body oil, and detergents</td>
<td></td>
</tr>
<tr>
<td>Dacron</td>
<td>4-channel polyester fiber, high-speed perspiration evaporation, excellent</td>
<td>Shirts, trousers, jackets, gloves, socks, undergarments</td>
</tr>
<tr>
<td></td>
<td>wicking, quick drying time, quick moisture absorption, and transportation</td>
<td></td>
</tr>
</tbody>
</table>

**Table 4: Special fibers properties and their applications in sports textile products.**
up to the fabric’s outer layer using the principle of capillary action. It’s made up of coarser denier yarn on the inside (in direct contact with the skin) and fine denier hydrophobic polyester yarn in a mesh construction on the outside to help sweat evaporate quickly [3].

4.3. Water Magic Fabric. Kuraray’s water magic works on the same premise as Naia’s for sweat absorption and quick-drying. Wrap’s water magic is a three-layered knitted fabric (67% polyester, 33% ultra-fine microfiber nylon). There are numerous random and minute pores in water magic. These micropores carry perspiration quickly from the skin to the outside air [67].

4.4. Gore-Tex Breathable Fabric. Gore-Tex is the original and most well-known waterproof breathable fabric. This is a polytetrafluoroethylene (PTFE) microporous membrane sandwiched between two fabric layers. According to the manufacturer, the polymer contains 1.4 billion microscopic holes per cm. These holes are significantly smaller than even the tiniest raindrops (23 g vs. 100 pro) but much larger than a water vapor molecule (40 × 10^6 m) [72].

4.5. Entrant G II. Entrant G II is a high-performance waterproof breathable fabric created by Toray. It’s a polyurethane microporous covering created with high water pressure resistance and moisture permeability in mind. The three-layered polyurethane coating membranes, which include two separate microporous layers, are the key to Entrant G II’s exceptional performance. Layer 1, layer 2, and layer 3 are the layers from the top fabric side, and each layer has the following properties: Layer 1: pores in the resin surface improve waterproofing and durability; layer 2: regularly designed micropores enhance moisture permeability; and layer 3: pores in the foam layer improve waterproofing and durability. Dew condensation is prevented by strengthening the covering surface [69].

4.6. Isofix Super. Kanebo’s “Isofix Super” is a coating that combines innovative processing and structural technology by fusing anti-sublimation and anti-migration coating processes to specific ceramics with numerous pores. Apart from the waterproof/moisture permeable property, the following are the main characteristics of “Isofix Super”. Anticondensation property: when the unique ceramics, which are formed of hydrophilic crystals with large numbers of microporous, reach a supersaturated state, condensation forms inside the garment, demonstrating their water-absorbing power to the hilt. This water-absorbing capacity can be as high as 100–200 times the weight of the coating’s unique ceramics. Because the ceramic particles protrude from the surface of the coated resin, none of the resin ever comes into contact with the body, providing wear comfort without a sticky feeling. Soft touch: “Isofix Super uses a softer resin than the polyurethane commonly used in waterproof/moisture permeable coatings” [70].

4.7. Sportwool™. It is a registered trademark of The Woolmark Company. Sportwool was invented in 1994 as a result of research into the physiological benefits of wool. It is a hybrid material made up of a fine Merino wool sublayer for insulation and a polyester exterior that draws moisture away from the wool layer and to the surface. The wool fiber next to the skin attracts and disperses perspiration vapor molecules before they condense into a liquid. The removal of vapor from the microclimate between the skin and the fabric decreases the formation of liquid sweat, leaving you drier and more comfortable. Sportwool’s unique natural thermal regulation and vapor management properties keep you cool in hot weather and warm in cold weather. So, whether the wearer is skiing on a cold winter morning or cycling in the heat of summer, Sportwool is the natural choice for maximum performance [71].

5. Influence of Different Factors on Comfort Properties

The parameters of textiles have an immense effect on the comfort properties of sportswear. The main parameters affecting the comfort of sportswear are fiber parameters, yarn parameters, fabric structures, biomimetic structures, and finishing treatments.

5.1. Effect of Fiber Parameters. Moisture management, water vapor wicking, quick-drying, and good elasticity are the features required for textile-based sportswear. The utilization of man-made fibers in sportswear garments showed performance improvement and an increase in comfort during physical activity [72]. Among the fiber parameters, the cross-sectional shape of fiber has a significant role in moisture management. The man-made filament fibers with higher shape factors have a higher surface area and consequently better wicking of moisture through the fabric thickness [73]. Polyester-made knitted structures were reported to have higher moisture transportation in sportswear [74]. The features of enhanced wick-ability and quick-drying can be imparted by using multi-channel fiber having more surface area for moisture transportation [75]. A large number of capillary forces are produced by the five-leaf cross-sectional shape of the fiber, which leads to better working [76]. The micro-denier fibers have capillaries of smaller sizes that increase the pressure. The increasing pressure drives the transfer of water to capillaries and results in enhanced wicking properties [77]. Katz. M studied that polyester/cotton blends having 10% and 15% cotton portions are better than the blends having 5% and 20% cotton portions. PC blended fabrics reduced the textured roughness as compared to pure polyester fabrics [44]. The blend of thermo-regulating viscose with polyester showed good wicking properties. Excellent liquid absorbency was observed with fabrics of nylon/polyester microfiber blend [78].

Stretch and recovery properties provide fabrics with ergonomic comfort. Elastane fibers were also used extensively in sports clothing to get superior stretch and recovery characteristics. The garment’s immediate response to the body’s movement can be estimated by dynamic elastic recovery. The elastane bare-plaited garments have a superior dynamic elastic recovery as compared to spandex core-spun yarns [79]. The previous research showed that the increasing
linear density of elastane resulted in poor thermophysiological comfort of the garment. In compression garments, lower elastane content leads to the superior moisture management and wicking properties [74].

Physical activities during sports also cause sweating formation, which causes bacteria on the fabric’s surface. In this context, sportswear also exhibits antibacterial properties. Polyvinyl Alcohol (PVA) nanofiber membranes with SiO$_2$ and germanium have quick healing and antibacterial activities for applications in sports textiles [80].

Collectively fiber cross-sectional shape, higher surface area, channeled structured fibers, micro-denier fiber, fiber elasticity, and fiber antibacterial properties directly affect the properties of the sports textile.

5.2. Effect of Yarn Parameters. Moisture management properties of sportswear can be influenced by yarn parameters. Yarn linear density and amount of twist are the main factors. The cotton yarns with higher linear density and twist are reported to have an effect of decreasing the spreading speed of moisture and the radius of the wet circle area [81]. Previous studies showed that increasing the twist factor resulted in decreasing absorbency and wicking height but increasing air permeability. It was observed that in comparison to spun polyester, PC, and 100% cotton, the knitted fabrics of micro-denier polyester yarn have rapid heat and moisture vapor transfer [82].

5.3. Effect of Fabric Structures

5.3.1. Single Jersey Knitted Structures. The honeycomb and pique knitted fabrics were observed to have inferior absorption and wicking as compared to single jersey due to the high cover factor [83]. Stiffness, porosity, thickness, pore size, and density are the parameters of fabrics having a significant influence on their comfort properties. Thin fabrics tend to have quick-drying [84]. The drying time of microclimate and vapor transfer is mainly affected by the permeability and thickness of the fabric [85]. Pique is an open knitted structure allowing for freedom of air through the fabric as shown in Figure 9. The moisture management capability of knitted fabrics was studied to be effectively controlled by the cover factor of the fabric. Fabrics with high cover factors were reported to have a smaller radius of moisture spread and higher wetting time, thus having lower overall moisture management capability [86, 93].

5.3.2. Two-Layered Structures. Two-layer knitted fabrics are very common for sportswear with uniqueness to each layer and entirely different performance parameters for both. The performance of layers regarding moisture transportation depends on the hydrophilic nature of both layers [83, 84, 94]. The outer layer of the fabric is made of hydrophilic fibers and the inner layer of hydrophobic fibers [89]. The knitted fabrics with an outer layer of cotton/viscose and the inner layer of polypropylene filaments showed better overall moisture management capability, liquid holding capacity, wickability, and moisture vapor transfer [90].

Two-layer fabric made of Polyester/Tencel (70/30) blend gives a superior balance of moisture vapor permeability, equal cling behavior and moisture spreading, better moisture absorption, and less synthetic-like touch compared to 100% polyester [91]. Fabrics with wool used as the inner and cotton as the outer layer showed enhanced dry feeling on the inner side and better moisture management properties [92]. Winter sports garments made with a blend of wool/polyethylene terephthalate (PET) and having loose construction of each layer diffuses more water moisture as compared to their wool/PET, and wool/bamboo blends exhibited better moisture management properties as compared to 100% bamboo and 100% wool [93].

5.3.3. Waterproof Breathable Fabrics. The protection from worse environmental conditions like rain, wind, and cold is delivered by the development of waterproof breathable fabrics [59]. Such sports fabrics provide complete permeation to moisture vapors and air but completely restrict the absorption and penetration of water in liquid form as shown in Figure 10 [94]. For this purpose, there is a need to develop some advanced textile structures and finishing techniques [95]. These types of fabrics could be developed by using high-density fabrics, polymeric coating, and film lamination [96].

5.3.4. Biomimetic Structures. These kinds of fabrics are those in which the structures or inspirations that existed in nature are replicated like in some applications fluid flow was mimicked [97]. One-way transfer and absorbency of water can be imparted by mimicking the structure of plants and this could be used in sportswear [98]. The flow of water in trees through channels was replicated in knitted structures. This type of knitted fabric has lower moisture vapor permeability but higher air permeability, one-way water transfer activity, and water absorption [99].

The garments were also engineered by replicating the structure of the pinecone as shown in Figure 11. These fabrics have several tiny holes throughout their surface, which
3 Layer

![Figure 10: Waterproof breathable fabric.](image)

would open to cool down the body in a hot environment and then flatten again to trap air in a cold climate [100].

5.3.5. Effect of Finishing Treatments. The functionality of sportswear could be enhanced by applying textile finishes to the fabric. The effective diffusion of perspiration with odor control can be achieved by using a technique of graft polymerization of acrylic acid on polyester fiber [101]. The incorporation of activated carbon on polyester fabric was also attempted to enhance moisture comfort by absorption of perspiration on carbon particles [102]. Due to delayed drying, this kind of fabric cannot be utilized in high-active sportswear [103]. The nano dry finish for Nanotex LLC could be smeared on sportswear to enhance the absorbency of perspiration [104]. In double-layer fabrics, the presence of either laminating substrate or microporous membrane enhances inner fabric temperature and vapor pressure build-up [105].

6. Use of Nanotechnology in Sportswear and Shoes

Multifunctional sports clothing can be manufactured by using nanotechnology in textile-like nanorods, nanofibers, and nano-finished textiles. Protection from extreme weather conditions can be developed by delivering garments with air and vapor permeability, wind, rain, snow, and liquid impermeability [106]. Table 5 describes the functional properties required for different sports goods.

For the elimination of odor from the socks of athletes, the company JR Nanotech U.K. has developed SoleFresh™ [107] socks treated with silver nanoparticles [108].

The Korea-based company, Hyosung has produced nanosilver nylon fibers having used in sportswear, jogging shoes, and sports bags [109]. A remarkable development in the manufacturing of slip-free shoe soles was made possible by the application of nanotechnology [110]. There are numerous applications of nanotechnology in sports clothing and shoes, which are discussed as follows.

6.1. Protection from Bacteria and UV. The perspiration from an athlete’s body provides suitable conditions for the generation of bacteria and consequently infection or odor formation [111]. Staphylococcus aureus is the most commonly occurring bacteria causing infectious diseases. For this purpose, the development of antibacterial clothing is a necessity for the sports industry [112–114]. It was reported that the use of chitosan fibers in sportswear and socks delivered the properties like antibacterial, fungicides, and moisture balance [115, 121]. Some researchers also applied zinc oxide nanoparticles on sportswear to attain antibacterial characteristics [117]. An antibacterial solution silverclear™ has been smeared for the manufacturing of antibacterial sportswear and shoes [118–120]. To avoid the risks involved with silver, the concentration of silver applied to fabric must be monitored carefully [121, 122]. Protection from UV is another domain in the field of sports clothing. The performance efficiency of UV-blocking materials could be enhanced by the uniform distribution of nanoparticles over the surface of fabrics [123].

6.2. Protection from Heat and Cold. Many sports like diving, cycling, snowboarding, and skiing require sportswear with insulating characteristics. These sports influence body heat loss with external factors and physical activity performed during that sport. For the development of thermo-regulating smart wear, the application of PCMs has grown in the textile industry [124–127]. PCMs are categorized as: (i) organic materials, non-paraffin such as alcohols, glycolic acid, and fatty acids; (ii) organic materials, paraffin such as alkyl hydrocarbons; (iii) inorganic materials and hydrated inorganic salts. To reduce the reactivity of PCMs with the external environment, these could be encapsulated into nanocapsules. Nanocapsules are capable of heat transfer at higher speeds as compared to microcapsules. Polystyrene, urea-formaldehyde, di-acid silicon, and poly(methylacrylate) are some of the shell materials for encapsulation. The PCM nanocapsule can be incorporated into textile material at the fiber spinning stage or as coating via using binders like polyurethane [65, 128–130]. The nanofibers produced by coaxial and composite electrospinning are the other ways to use PCMs in textiles [131].

6.3. Self-Cleaning by the Application of Nanotechnology. The manufacturing of sportswear with self-cleaning characteristics is one of the outstanding applications of nanotechnology in textiles. Photocatalytic nanoparticles like ZnO and TiO₂ were reported to produce a surface of textile fabrics with self-cleaning activity as shown in Figure 12 [132, 133]. These photocatalytic agents could be implanted into sportswear [134]. Nano-sphere™ was produced by a company named Schoeller Textile AG to manufacture self-cleaning fabrics for sports textiles [112]. Self-cleaning properties can be achieved through super-hydrophobic and super-hydrophilic surfaces as shown in Figure 13.

6.4. Multifunctional Characteristics Imparted by Nanotechnology. There is an increasing demand for sportswear with simultaneous
protective functions against hot, cold, water, wind, odor, and bacteria. These garments are very much required for sports being played in severe weather conditions like skiing, boating, and mountain climbing. For the development of such types of garments, nanotechnology plays a vital role. The characteristics of self-cleaning, UV-resistance, antibacterial, hydrophilic, hydrophobic, and photocatalytic in textiles can be incorporated by using metal oxide nanoparticles of ZnO, CuO, TiO₂, Al₂O₃, Cu₂O, Fe₂O₃, Mn₃O₅, MgO, GO, and Fe₃O₄ [137–147]. The properties of antifungal, conductivity can be incorporated by using metal nanoparticles of Ni, Cu, Pt, Pd, Ag, and Au [148–152]. It was reported that abrasion chemical resistance can be obtained by applying nanoparticles of carbon black [152, 161]. Carbon nanotubes were reported to have the capability of imparting thermal and electrical conductivity to textiles [147, 148, 162]. Biomass-based nanocomposites have also been used in sports textiles for rapid injured recovery during sports activities [155, 156].

![Figure 11: (a) Opening panel structure of pinecone. (b) Closing panel structure of pinecone. (c) Fabric with opening/closing panels mimicking the structure of pinecone.](image)

Table 5: Functional properties required for different sports goods.

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Sport type</th>
<th>Property required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All types of sports</td>
<td>Comfort, antibacterial</td>
</tr>
<tr>
<td>2</td>
<td>Running, referee gadgets</td>
<td>Electronic textiles</td>
</tr>
<tr>
<td>3</td>
<td>Back-belt, therapeutic knee band, an elbow band</td>
<td>Enhanced blood circulation</td>
</tr>
<tr>
<td>4</td>
<td>Diving, swimsuits, shoes</td>
<td>Waterproof</td>
</tr>
<tr>
<td>5</td>
<td>Mountaineering tents</td>
<td>Self-cleaning</td>
</tr>
<tr>
<td>6</td>
<td>Clothing for outdoor sports</td>
<td>UV protection</td>
</tr>
</tbody>
</table>
7. Use of Electronics in Sportswear

Another important domain is the continuous monitoring of physiological and biological changes in athletes involved in high physical and risk sports. Interactive electronic textiles have emerged as tools to detect arm action for improving the tennis or golf swing, movement of the body, calorie level, the pressure of blood, distance traveled, and time of activity [157]. Textile-based Piezo-resistive sensors were developed for monitoring breathing rate [158]. For monitoring chemical or physical changes, the heart rates of athletes [159], changes in waist circumference, time of exercise, and body temperature are useful in several applications of sports textiles [160, 161].

8. Effect of Sports Clothing on the Performance of an Athlete

Sportswear has a vital influence on the performance of athletes during physical activity or games. The amount of heat stress could be different from one clothing to another and depending upon the average temperature of the body, sweat loss, heart rate, and average skin temperature. It was studied that the pitching speed and performance of baseball players increased by using sportswear with higher absorption of moisture [162]. Along with the absorption of moisture, sportswear with superior moisture management properties was also reported to increase the cardiorespiratory fitness of athletes [163]. As compared to normal swimwear, the biomimetic swimwear was reported to have increased the speed of the swimmer and reduced overall active drag force [164].

The aesthetics of sportswear were also studied and found to have a good impact on the performance of athletes, like the performance increased by stimuli of testosterone dependent signal red color by using red color [165]. For high physical activity, functional sportswear could be used to reduce fatigue in the muscles. Far-infrared waves can be penetrated deeply into biological materials and it was reported that it has a positive effect on metabolism and blood circulation [166, 167]. Previous studies showed that compression garments resist fatigue because of reduced muscle oscillation during sports like jumping [168]. It has been reported that cardiovascular stress on athletes reduces due to enhanced cardiac input and venous return by wearing compression athletic wear [169]. The metabolic cost of energy can be reduced, and the submaximal running economy can be increased by using compression garments [170]. Previous studies also showed that athletes can run at faster speeds to enhance leg power [171] and increase lactate clearance by...
using compression garments [172]. Different characteristics of sportswear must be evaluated before its actual use. For this evaluation, we need to use standard methods. Table 6 represents the various test methods for the evaluation of sportswear.

### Table 6: Test methods for sportswear properties’ evaluation.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Standard test method</th>
<th>Brief description</th>
</tr>
</thead>
</table>

9. **Future Perspective**

A number of additional topics, such as respiratory water resistance, odorless clothes, and so on, are becoming related to sports textiles and are undergoing a few important technological breakthroughs as a result of alterations, improvement, and continuing research. The manufacture of breathable sportswear in a variety of combinations would surely improve sportswear comfort. These characteristics are necessary for players to remain dry and comfortable. Breathable textiles, along with features like UV protection, skins, and compression garments, are advancing in the realm of breathable sportswear technology, intending to improve athletic performance. Sports textiles are also performing more functional activities conveniently and smartly thanks to the use of smart textiles and wearable technologies.

9.1. **Sustainability Issues.** The expanding environmental concerns and their impact on the sportswear manufacturing business have prompted serious talks among all major companies about their goals for sustainable production and procurement of fabrics for sport and sportswear, as well as possible recycling solutions. With growing knowledge and education on the subject at the consumer, brand/retail, and mill levels, sustainability topics are becoming increasingly significant in the textile and clothing value chain. Polyester fiber already accounts for half of the global fiber market and is expected to continue to increase. Polyester yarn is manufactured from post-consumer recycled PET bottles, as well as fibers made from bio-polymer. Ingeo™ Polylactic acid (PLA) biopolymer is already employed in a variety of athletic applications.

The bio-based LYCRA should be developed and commercial quantities produced for the autumn/winter 2015 and spring/summer 2016 collections to aid the corporation in achieving the goals specified in its Planet Agenda sustainability program, which is centered on three primary goals:

1. Minimizing its environmental footprint at its manufacturing sites by saving resources, decreasing emissions, and eliminating waste.
2. Providing competitive goods that fulfill the needs of the garment markets while using fewer resources and improving the environmental performance of all fabrics.
3. Ensuring the health and safety of our employees and communities, as well as taking part in community stewardship programs.

Most worldwide giants in the sportswear manufacturing industry, such as Adidas and Nike, have made sustainability a strategic priority for their businesses. According to Adidas’ sustainability report, “As a global leader in the athletic goods sector and a responsible company, we express our commitment to the implementation of sustainable business practices in both our firm and our supplier chain.” We work hard to ensure that all aspects of our business, including our suppliers, have consistent values and that they are implemented. Our aim is clear: to raise the performance of our sites and those in our supply chain in the areas of social and environmental responsibility, and in this way to improve the lives of...
the people who manufacture our products, as well as the environment in which these products are manufactured.

Nike’s sustainability strategy is to create a portfolio of sustainable materials; materials account for around 60% of the environmental impacts of the average Nike shoe. Thus, using less or recycling more could make a big difference. Last year, for example, Nike used 7 million kg of organic cotton and included recycled polyester in more than 31 million products. Footwear and outdoor wear products from Timberland used 50 million post-consumer plastic bottles as recycled polyester in its footwear lines.

WL Gore has completed a project to eliminate perfluorooctanoic acid (PFOA) from all raw materials in the manufacture of its waterproof functional fabrics. On January 10, 2014, GORE, inventors of the GORE-TEX® brand product technology for comfort and protection, announced that it had completed a project to eliminate PFOA from all raw materials used in the manufacturing of weatherproof functional fabrics. This affects all membranes and long-lasting water repellency treatments used in finished products across a wide range of categories, including mountaineering, running, cycling, fashion and lifestyle garments, outdoor sports and casual wear footwear, and work wear for firefighters and police officers. GORE is one of the first firms in the industry to effectively switch its complete textile line to PFOA-free raw ingredients. The sportswear industry’s outstanding performance is due to a high degree of innovation, strong pricing, and increased customer concerns about health and well-being.

10. Conclusion

In the current era of development, high-active sports textile is a very challenging field that required functionality with comfort properties. Market growth of sports textiles was increased day by day owing to the increase in sports participation and consumption of sports goods. The performance of the sports athlete is directly associated with the proper moisture management property, air permeability property, and thermal insulation properties of the garment, which was worn by the player during sports activity. The suitable selection of raw material, fiber morphology, yarn, fabric structure, type of finish, and garment pattern will provide the required functionality. Researchers have engineered advanced polymers, fibers, yarns, and fabrics to meet customer demands and achieved the required performance characteristics. Performance characteristics of the sports-wear were also increased with the usage of highly elastic filaments (reduce drag forces in the garment), antibacterial finishes (reduce microbial growth due to sweating), and breathable fabrics (moisture management and temperature control). Moreover, functionalized new synthetic fibers were developed by changing the cross-section for moisture transport. In the field of sports textiles, various innovative products such as polymers, fibers, yarns, fabrics, and finishes were developed with maximum comfort characteristics. To produce sportswear exhibiting excellent thermal insulation properties, hollow structured thermo-regulated fibers are used. For the summer sportswear exhibiting moisture management properties, different types of functional fibers, yarns, blends of fibers, fabrics, and coatings were used in the structure of textile materials.

Data Availability

The data will be made available as per requirement.

Conflicts of Interest

The authors declare that they have no conflict of interest.

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