THE EFFECT OF KNIT FABRIC PARAMETERS ON ACTIVE SPORTSWEAR'S MOISTURE MANAGEMENT AND THERMAL COMFORT PROPERTIES- A SYSTEMATIC REVIEW

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ABSTRACT

Recently, there has been a global surge in involvement in sports. The highly competitive world of sports has increased the number of professional athletes. Additionally, individuals view sport as an integral component of their daily activities, since it directly contributes to their fitness. Globally, both the quality and quantity of active apparel used have grown dramatically. Activewear is clothing designed to perform some actions to maintain the desired characteristics of specific sports. Thermal physiological comfort is a critical component of sportswear, particularly when sporting activities take place in difficult atmospheric circumstances for an extended length of time. Proper clothing choices can considerably minimize athletes' kinetic and thermal demands. The technology innovation is focused on the preparation of fibers with superior and unique characteristics for a variety of applications. This article discusses the functional requirements for sportswear, aspects of comfort, classification, and the raw material used for sportswear, the influence of factors such as form and geometry, yarn and fabric parameters, and finishes, also the newest advancements in sportswear.

Keywords: Moisture management, comfort, thermal comfort, knit fabric, active wear, vapor permeability, thermo physiological comfort

1. INTRODUCTION

Functional textiles are employed initially for their functional and performance features, rather than for their aesthetic qualities. [1]. Sports textiles are a subfield of functional textiles that target the fabrics utilized in sports [2]. Clothing is critical for both general customers and active sportsmen in the twenty-first century [3]. The expansion of the activewear and sportswear markets has had a considerable influence on textile manufacturers [4, 5]. The sports sector has the largest market share of smart textiles [6, 7]. The innovation of novel textile fibers and innovative technologies adds to the market's active growth. The sports tech market in India is booming, owing to rising popularity and quick changes in design and clothing. [8]. Between 2015 and 2023, the expected growth in demand for sports textiles and fitness equipment has been boosted by 33%[9,10]. The U. S controls 35% of the overall sportswear market, China controls 10%, Japan controls 7%, Brazil controls 5%, Germany, Great Britain, and France each control 4%, and the remaining 28% is accounted for by all other nations [11,12]. To assure comfort, clothes must be made to maintain the body's thermal balance throughout a broad spectrum of climatic circumstances. Moisture management is the technique of controlling the transport of sweat and vapor from the skin surface to air via the fabric [13]. The most critical element that fibers/filaments provide to the wearer's comfort is moisture and temperature balance, which results in an appropriate microclimate close to the skin. There is a remarkable surge in the creation of novel fibers in few years to meet the rising demand for athletic and functional apparel [14]. Today, functional clothing incorporates high-functional fibers, microfibers, nanofibers, and smart fibers [15-18]. This article discusses the characteristics of active clothing, as well as the various fibers and knit fabric structures. Additionally, several approaches for improving moisture management, thermal comfort characteristics, moisture management parameters, and innovative materials for active wear are discussed.

2. SPORTS TEXTILES: PROPERTY AND FUNCTION

The aspects of sports textiles will place different demands on fibers and fabrics, while also meeting client needs for fit, drape, and ease of motion. Sportswear affects a sportsperson's performance, making it a significant factor. They must provide comfort, optimal heat, and moisture regulation, good air permeability, wicking ability, dimensional stability, durability, ease of care, low bacteria count [3], UV resistance, and good perspiration fastness [19, 20], as well as being lightweight, and producing a cooling effect. Generally, these characteristics are influenced by fiber properties [21]. Synthetic fibers are utilized in a broad number of applications in clothing and functional wear due to their excellent mechanical and chemical properties. [22- 24]. While athletes sweat throughout various activities, the ability of the fabric to wick away sweat from the body is critical for the wearer's comfort [25]. In high-intensity sports, heat pressure increases dramatically due to abnormal conditions of metabolism, resulting in a heated fury of between 800 and 1300W. This measure of warmth has been shown to raise the body's core temperature by 1.5–2oC. To regulate the body's core temperature, sweating occurs and the heat generated by water vaporization provides the cooling effect. Sweat rates can reach 2.5L/h [20].

3. TEXTILES IN SPORTS

Textiles utilized in sports may be roughly classified into three types:

• Sportswear,

- Athletic clothes, athlete clothing, football jerseys and apparel, cricket dresses, game shorts, swimming dresses, sweatshirts, and tennis attire.

• Sports equipment and

- a football, a volleyball, a rugby ball, a pair of hockey sticks, and a golf club

• Recreational equipment.

- Turf, nets, and rings, among other things, offer the necessary playing conditions [24]

4. SPORTSWEAR FIBERS

The following are the fibers used in sportswear.

4.1 Natural Fibers

4.1.1 Cotton

Cotton is a hydrophilic fabric that retains 8.5% of its moisture. It possesses little elasticity, with a maximum elongation of 3–10% at the breaking point. The strength is adequate, with a tensile strength of 3–5 grams that rises by 10% when wet [26]. Cotton fibers are the most comfortable and softest textiles available. SASMIRA's wicking tests on cotton treated with hydrophobic finishes demonstrate good wicking performance. Cotton is not advised for use as a foundation layer since it absorbs moisture and sticks to the body. [4,19, 27]

4.1.2 Wool

Wool is a hydrophilic fabric that retains 13% of its moisture. It possesses good elasticity, with a breakpoint elongation of 20%–40%, the best wicking characteristics, the highest moisture recovery, and the finest insulating properties when wet. At constant temperature and RH, wool fibers have the greatest moisture resorption of any fiber. Additionally, wool is naturally water repellent, which contributes to comfort properties. By contrast, wool dries slowly and has better friction when wet. [28]

4.1.3. Rayon Viscose

It is a man-made fabric comprised of regenerated cellulose and is extremely absorbent and hydrophilic fiber with a moisture recovery rate of 13% and a great elasticity of 15–30% at the breaking point. Although viscose has a greater amount of amorphous material. This increases its absorbency over cotton. Additionally, the viscose fibers' somewhat uneven surface contributes to their comfort against the skin while worn [28]. It is not recommended for use near sportswear because of its moisture content [19].

4.1.4 Lyocell

This is a cellulosic fabric that is completely biodegradable. The absorbency of Lyocell can be significantly modified by chemical treatments. It has a high wet and dry strength is absorbent and has a Nano-fiber structure [4]. Additionally, because of its high strength, it is utilized in many mechanical and chemical finishing operations.

4.1.5 Bamboo

It is a regenerated fiber and has intrinsic microbiological and degradable qualities; higher water absorption capacity, smoothness, and brilliance, also Ultraviolet protection properties; bamboo textile products are gaining popularity in the textile sector. Bamboo fiber is extremely comfortable in several applications due to its high water uptake and quick-drying capabilities resulting from its distinctive structure [29].

4.2 Synthetic Fibers

Synthetic fabrics are generally utilized in athletic apparel [4]. Hydrophobic or hydrophilic surfaces can be found on man-made fibers. Man-made fabrics are generally considered as the superior choice for athletic apparel due to their ideal mix of insulation, softness, lightness, moisture regulation, and quick-drying characteristics. [3].

4.2.1 Polyester

This fiber has excellent dimensional stability, heat stability, and is resistant to dirt, alkalis, mildew, rot, and organic solvents. Polyester is utilized as a foundation fabric in sportswear because of minimal moisture absorption, low cost. While polyester is naturally hydrophobic, on treating with certain chemicals, it turns hydrophilic and may be utilized as a base layer in active sportswear. Because polyester is durable, lightweight possess flexible and has a soft hand. The polyester can be changed by adding free hydroxyl groups, this show in the de-structuring of water and therefore wetting [4, 19, 27].

4.2.2 Polypropylene

Polypropylene fibers have risen in popularity in active wear; the market share is still relatively modest. Polypropylene fibers have excellent wicking and vapor permeability but lower perspiration absorption. When wet, polypropylene provides excellent insulation and melts at a moderate temperature in home dryers. Polypropylene is suitable for sportswear because of its ability to transport moisture from the body without being absorbed. Polypropylene is touted as a superior moisture-wicking material because of its excellent thermal properties and hydrophobic nature, which maintain the user's body temperature in cold conditions and body temperature in hot regions [4, 19].

4.2.3 Fibers elastomeric

Elastomeric fiber is a synthetic fiber made of at least 85% segmented polyurethane. It features a low absorbency, a hydrophobic fabric, and a moisture recovery rate of 0.75–1.3 percent. Elastomeric fibers are commonly utilized to improve the stretch and support of clothing. Swimwear, for example, may include between 15% and 40% elastomeric fibers, whereas knitted sportswear may contain between 3% and 10%. The Thermo physiological properties of clothing containing elastomeric fibers are unaffected. [28]

4.2.4 Hollow Fibers

Hollow fibers were launched in the 1980s; they have a hollow cross-section and come in round, trilobal, or square configurations. Hollow polypropylene fibers are soft and lightweight and offer better thermal insulation when used in thermal underwear. The presence of air in the fiber core enhances the fabric's heat resistance, while the convoluted fiber surface and increased surface air created by using a fine fiber improve the fabric's wicking capabilities [4, 16, 30].

4.2.5 Microfibers

They are extremely light and fine, have a good drape, resistant to shrinking, are super absorbent, and are strong; this makes them both pleasant and useful. Advanced textile innovation for performance wear has resulted in the improvement of very fine deniers, including high-performance microfibers and ultra-micro fibers for a second skin. Microfibers can be made to be anti-static, anti-stress, UV resistant, and be thermally insulating. [21]. Microfibers are produced using a bi-component method involving two different polymers that do not combine [16, 30].

4.2.6 Fibers made of polyamide

They absorb high moisture than polyester and have a better wicking capacity but a slower drying rate. Polyamide fibers are strong fibers with a better degree of elasticity, flexibility, abrasion resistance, and abrasion resistance. Polyamides are air-texturized to impart a soft handling and natural appearance; fast-drying can result in easy-care clothing. Polyamide and elastane can be combined to create a fabric that is both comfortable and water and stain-resistant [4].

4.2.7 Fibers with two Components

Bi-component fibers can be composed of two variants of the same generic fiber, like two types of nylon or two types of acrylic, or two generically separate fibers, such as polyester or nylon, or nylon and elastane. [31]. Bi-component fibers are classified into three types: staple, filament, and microfiber. It is feasible to get the unique properties of two polymers by extruding them into a single fiber. (Figure1). Bi-component fibers are used in many functional goods, including athletic apparel.

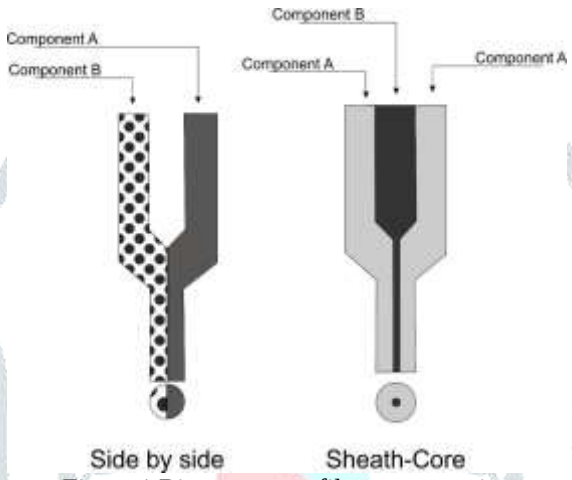

Figure 1 Bi-component filament extrusion

4.3 Advanced fibers

4.3.1 Hygra 20

Unitika Limited introduced Hygra, a sheath-core filament yarn made of hydrophilic material and nylon. Because of its perfect network structure, this hydrophilic polymer fiber absorbs thirty-five times its weight in water and also possesses a fast release capability that other hydrophilic polymers lack. Additionally, this fiber displays antistatic characteristics even under dry circumstances. This is used to produce a variety of garments, including golf clothing, athletic wear, and skiwear. [19].

4.3.2 N23 Killat

Kanebo introduced the nylon hollow filaments used in Killat N23. This fiber is very hydrophilic and retains heat well, owing to the existence of a 33% hollow region in the cross-section of the filament. This is a bi-component spun filament with a polyester copolymer core and a nylon skin. [19]

4.3.3 Dacron

This is a 4-Channel Polyester that refers to high-performance material wicks away moisture and expedites perspiration evaporation. This kind of fabric dries quickly, has excellent wicking qualities, and has good moisture absorption properties [19].

5. YARNS FOR ATHLETIC WEAR

Staple fiber textiles are more absorbency than filament yarn fabrics with the same composition and yarn diameter looser packing of the yarn. Loosely packed yarns enhance the available surface area for absorption while increasing the distance between the yarns improves vapor permeability. Because staple fiber yarns contain a higher amount of air, they offer excellent thermal insulation. Additionally, they may provide additional sensory comfort by giving a warmer sense to the hand. Crimping man-made yarns increases the bulkiness of the fibers in yarns and yarns in textiles, therefore enhancing their water vapor permeability and thermal comfort. However, staple fiber yarns are more decumbent to pilling or shedding lint. [4].

6. DIFFERENT FABRIC CONSTRUCTIONS

Generally, knitted textiles are favored for sportswear due to a greater degree of flexibility and stretchability than woven fabrics, allowing for unfettered movement and the transfer of body vapors to the next layer of the apparel [3]. Dense pile textiles play an important part in sports apparel, as they trap air for insulation and are extremely absorbent. Multi-layer textiles created using the warp and weft knitting method have become popular for activewear. Compared to single-layer textiles, layered fabrics perform significantly better in thermo-physiological regulation. Each layer performs a different role; the one close to the body must swiftly wick away sweat to the outermost layer that rapidly disperses it to the environment via evaporation. [4].

7. FINISHES FOR ATHLETIC APPAREL

The materials coated with silicone retain their form after multiple washings; also non-shrinking and crease-resistant. Moisture management treatments that aid in quick-wicking and drying and provide significant value to casual wear and sporting will increase the wearer's comfort level. Numerous moisture management methods are utilized to promote moisture absorption

[4]. Microencapsulation technology has enabled the improvement of textiles containing a variety of health-promoting and well-being chemicals floating in bubbles along their threads. When the garment is worn, the bubbles rupture and gradually discharge their contents onto the wearer's skin. PCMs are being advanced for active sportswear. These materials transform from liquid to gel and help keep the body temperature stable. This alters the fabric's insulating characteristics, allowing for the creation of clothing that keeps the body at a given temperature. Phase change technology makes use of materials that change in response to both internal and external temperatures. PCM stores heat energy; when the temperature decreases, the materials solidify and gradually release the stored heat. [3,4,32]. Shape memory polymers can recall and keep their shape or revert to a prior shape. Clothing composed of shape memory polymers is capable of sensing changes in the external environment and intelligently estimating and controlling its reaction to the greatest level of comfort. Additionally, this polymer is unique in that the temperature at which micro-Brownian motion occurs may be adjusted arbitrarily. This shows that the activation point may be acquired in the context where the garment will be worn. [3].

8. MOISTURE TRANSPORT MECHANISMS

Moisture is transferred through fabrics in a way similar to how a liquid wicks through capillaries. Two characteristics govern capillary action:

• Diameter

• The surface energy of the fiber.

The wicking ability of cloth rises as the space among the threads decreases. Moisture is easily absorbed by fabric structures because they efficiently generate tiny capillaries. Capillary action, on the other side, ends when all areas of the cloth are equally saturated. Hydrophilic materials have excellent surface energy, therefore, they absorb moisture faster than hydrophobic fibers, Numerous factors influence moisture transport in fabric, including the fiber type, the fabric's weave, weight, and the presence of chemical coating. It is well known that materials with moisture-wicking properties aid in temperature regulation, delay fatigue, and enhance physical activity. Therefore, natural materials are suitable for the clothing worn during periods of inactivity; synthetic materials are best suited for periods of intensive activity [14,33].

9. BODY PERSPIRATION AND THERMOREGULATION MECHANISMS

The human body perspires in two ways: insensible and sensible perspiration, and to be comfortable, sports clothing close to the body should allow for both types of perspiration to be transmitted [34]. During strenuous exertion, the body generates more than 1000 W of heat. While some of this heat is clear away, the remainder elevates the core temperature of the body. This increase in temperature is detected by the skin's thermo-receptors, which leads the body to generate perspiration to cool itself. Sweat evaporation and increased blood flow to the skin are two methods by which the body dissipates heat (Figure 2).

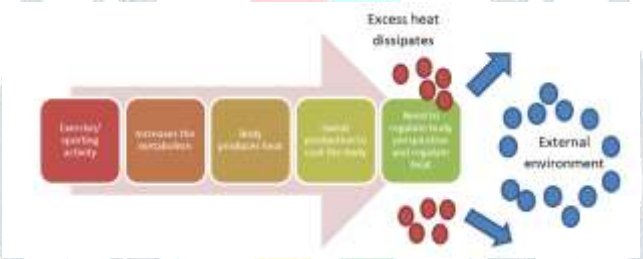

Figure 2 Mechanism of body perspiration and thermoregulation

To be thermo-physiologically comfortable, there must be equity between heat generation and heat loss; otherwise, the body's core temperature would fluctuate. Around 10% of human loss of heat is due to breathing, with the bulk loss of heat occurring via the skin. This is due to dry heat transfer- by radiation and conduction or moist heat flow caused by sweat evaporation via clothes. Additionally, dissipation of heat is concerned by fabric composition, and garment construction, a slight change in temperature causes pain and impairs function [35, 36].

10. ASPECTS OF SPORTSWEAR THAT PROVIDE COMFORT

Users' perceptions of comfort in sportswear may be classified into four categories: thermo-physiological, psychological, skin sensory, and ergonomically wear comfort [37].

• Psychological comfort: This metric reveals that individuals require particular clothes, materials, and design aspects to feel at ease. When textiles are worn during hard exercise, psychological comfort occurs when the material is extensible and does not restrict flexibility. [4]

• Thermal comfort: it is decided by thermal, moisture, and air permeability characteristics. This entails the transfer of thermal and vapor via the garment and has a legitimate effect on an individual's thermoregulation. [3,6]. During the working condition, the body maintains a temperature of 37oC, which enables it to adapt to changing situations. The body creates significant quantities of heat energy during vigorous exertion, and the temperature rises. Thus, to maintain the temperature of 37oC, heat must be transferred to the environment. The body perspires to regulate its temperature. [4,10]

• Thermo-physiological comfort: this is decided by the breathability and moisture management capabilities of the fabric [38]. Thermo-physiological comfort is categorized into two different stages, during which the body generates insensible sweat constantly. Therefore, constant heat and moisture vapor fluxes are generated, which must progressively dissipate to sustain thermoregulation and a sense of thermal comfort. In this case, clothing becomes a part of the steady flow thermoregulation system [49].

• Sensorial comfort: Sensorial comfort attributes to the mechanical feelings caused by a textile during contact with the skin. The perception may be pleasant, such as smoothness or softness, or it may be unpleasant, such as scratchiness, excessive stiffness, or clinging to sweat-soaked skin [40, 41]. Sensorial pain associated with wetness and stickiness can be a significant cause of discomfort in circumstances of excessive perspiration [42].

Moisture transmission happens in three ways via fabric: moisture diffusion owing to the moisture vapor gradient across the fabric, moisture sorption-desorption by hydrophilic sites on the fabric, and moisture transmission via convection via moving air near the body [43,44].

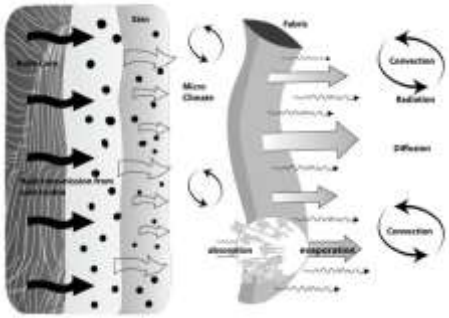

Figure 3. Heat and moisture vapor is transferred from the human body to the environment via textiles.

11. COMFORT CHARACTERISTICS ARE NECESSARY FOR SPORTS APPLICATIONS

11.1 Permeability of the air

It is a biophysical property of textiles that affects the fabric's capacity to conduct air. It largely depends on fabric characteristics like porosity, thickness. The dimension and distribution of pores in a textile are decided by the fabric's shape. The loop length contributes to the pore size of knitted fabric. When the loop length is increased, the air permeability of the loop increases as well. When the loop length is increased, the stitch density space increases, therefore increasing the size of the pores through which the airflow permeates. Other significant parameters impacting the porosity of material include yarn diameter, knitting structure, stitch density, and yarn linear density [45]. The fabric structure has a major effect on air permeability. Higher fabric density was associated with lower air permeability values. Because of the fabric's reduced thickness and fiber shape, it has greater air permeability. [46].

11.2 Conductivity of Heat

Thermal conductivity is the amount of heat that flows through a fabric of a certain area and thickness per unit time while its opposite faces a temperature difference of one Kelvin. Thermal conductivity, thermal insulation, and thermal absorptivity are used to quantify thermal comfort [46]. Human clothing provides thermal comfort by transporting heat via fabric and by keeping the user dry at a skin temperature of 37°C [47]. Individual fiber properties, yarn spinning processes, and fabric manufacturing variables all add significantly to a material warmth or coolness. [48] The roughness and hairiness of the clothing surface influence its thermal comfort qualities. Rough textiles have a lower area of skin contact, whereas fabrics with greater hairiness give space for air to circulate while yet providing a warm sensation [49]. Fabrics with finer yarns and longer stitch lengths provide greater comfort in humid circumstances due to their increased permeability to air and perspiration [50].

11.3 Proprieties for managing moisture

Cloth worn close to the body should have two qualities. i) The clothing should wick away perspiration from the skin. ii) To maintain the wearer's comfort, moisture should be taken by the material and dissipated into the atmosphere. Moisture management is a secondary characteristic of a textile that must constantly be weighed against comfort. This can be achieved in a variety of ways, including changing the fiber's surface chemistry, using modified cross-sectional fibers, fabric engineering, yarn engineering (blending), chemically coated [8, 25]

11.4 Permeability of Water Vapor

Two processes occur when vapor travels across a fabric layer: diffusion and sorption-desorption. The rate of diffusion through material is dependent on the porosity of the material characteristics. The diffusivity of a material increases as its moisture regains and hygroscopicity increases. Factors associated with fibers, such as cross-sectional shape and moisture absorption capabilities, have no significant effect. [46] Additionally, the cross-section of the fiber increases the barrier to vapor passage across the fiber surface, lowering the permeability of water vapor. The greatest fabric densities resulted in the lowest water vapor transfer rate indices.

Clothing constructed from a microporous membrane attached to knitted fabric exhibits excellent water-tightness and low perspiration permeability via the composite system, resulting in notably advantageous sanitary qualities and great user comfort. [51]. Surface porosity affects water vapor permeability, whereas contrast has an on affect air permeability [52].

11.5 Absorbency of water

The fabric's porosity, also the fiber and yarn utilized, are the primary determinants of water absorption. The raw material, the stitch density, and the knitting pattern all influence the dynamics of liquid spots. [45, 53]

12. TECHNIQUES FOR MOISTURE MANAGEMENT ADVANCEMENTS

However, opinions on how to attain optimal moisture control vary among textile producers. To attain the various effects, either the appropriate fiber material is utilized or a secondary finishing is performed. Additionally, specific fibers and finishes can be united. Textiles that are

12.1 Hydrophobic: Absorb a little quantity of moisture, which might result in inadequate moisture transfer leads to an uncomfortable sense of wetness. While hydrophobic fibers like polyester are inefficient at absorbing moisture, they have a better chance of transporting it due to limited binding sites for water.

12.2 Hydrophilic textiles: Water repellent fabrics are characterized by a higher ability for humidity absorption. The newly formed liquid is rapidly absorbed and transferred to the atmosphere. Because of the existence of hydrogen-bonding sites for water molecules, hydrophilic fibers are excellent at absorbing moisture but inefficient at transporting and releasing it.

12.3 Hydrophobic-Hydrophilic textiles: Hydrophobic-Hydrophilic fabrics are intended to swiftly transfer and evaporate perspiration from the body [25].

12.4 Special fibers: Special fibers are meant to improve capillary attraction and moisture transfer through the use of unique profiles. Additionally, the greater surface area of these fibers aids in evaporation.

12.5 Breathable Textile: Waterproof fabric fully stops liquid water from penetrating and absorbing. The word "breathability" defines the fabric's ability to breathe itself. Breathable textiles allow water vapor to flow passively through them while preventing liquid water penetration.

12.6 Spacer Fabrics: They are manufactured with two distinct fabric webs that are linked by spacer yarns or fibers of different stiffness. The middle zone generates an air layer that acts as an insulator and thermoregulator. A significant benefit is it's lightweight relative to its enormous capacity. At the moment, it is mostly utilized in practical apparel like athletic shoes, bra cups, shoulder padding, knee protectors. [54].

12.7 Phase change materials: They have variable freezing and melting points, when combined in a microcapsule, retain and emit thermal energy, maintaining a temperature range of 30-34 °C, which is fairly comfortable for the athlete. When the layers' temperatures approach the PCM phase transition, PCM microspheres can offer transitory heating and cooling effects. [55].

13. THE EFFECT OF VARIOUS PARAMETERS ON THE COMFORT OF ATHLETIC CLOTHING

13.1 Fiber Type and Geometry

The cross-sectional form of the fiber influences the fabric's moisture transfer characteristics [56]. Tetrachannel and Hexa channel cross sections provide a greater surface area for the liquid to flow across, resulting in improved wicking ability and quicker drying [57]. Polyesters with trilobal and triangular cross-sections were also proven for improved moisture transfer when contrasted to polyesters with circular cross-sections. Filaments with a higher form factor have a quicker wicking rate due to an increased specific surface area. The wettability of various textile fibers may be measured in terms of their surface-free energy. The higher a fiber's surface free energy, the more wettable it is [58].

The existence of polar or non-polar groups determines whether fibers are hydrophilic or hydrophobic. Water absorption of fiber is governed by its crystalline structure, the size, orientation, and distribution of crystallites, also the presence and size of amorphous areas [59]. Microfiber polyester knitted textiles have superior moisture-related comfort aspects such as absorption and drying. Micro denier yarn's small capillary size raises capillary action, which promotes water transport into the capillaries and leads to increased wicking [60]. Split nylon/polyester (N/P) microfiber fabric creates densely packed and aligned fine capillary columns of water between the fibers, resulting in exceptional absorbency. The micropores expand by generating dense and even cracks, allowing for rapid absorption of large amounts of fluids.

13.2 Parameters for Yarn

Moisture transfer is influenced by yarn twist and linear density of the yarn. Moisture transfer parameters like absorption, spreading time, and maximum wet area circle radius are found to decrease with an increased soaking time of fabric when cotton yarns have a greater twist coefficient and linear density. According to certain reports, a higher twist coefficient improves permeability to air and water while decreasing wicking height and absorption [55].

Micro denier polyester yarn has a higher moisture vapor transmission rate, a quick heat transfer rate, and a cooler first touch than spun PET, PP, and 100 percent cotton [61]. Plain knitted textiles with mixed, core, or coated material that include solely profiled polyester and no cotton exhibit a poor potential for water absorption. Compared to traditional P/C blended yarns, core and coated yarns combining cotton and profiled polyester fibers demonstrate superior vapor absorption and release.

13.3 Fabric Structure

Single jersey (SJ) fabric has been shown to have excellent wicking and absorption properties over other knitted constructions. Because the SJ structure is composed entirely of knit loops, the loop legs are oriented only toward the wale direction, which aids in wicking in contrast to alternative structures composed of a combination of knit and tuck loops [62].

The structural parameters of the fabric, such as thickness, porosity, pore size, density, tightness factor, and stiffness, have a substantial effect on the fabric's comfort qualities. It is stated that a thin and porous knit construction has great moisture vapor dissipation characteristics [63]. The cover factor of material is a critical structural characteristic affecting the knitted fabric's moisture management ability. Textiles with a greater cover factor take longer to wet, and moisture distributes in a narrower radius, resulting in a decreased total moisture management capability.

14. BIOMIMETIC STRUCTURE

Biomimetic is the technique of copying or emulating natural mechanisms [64]. Biomimicry of plant structure in the fabric may significantly increase the fabric's water absorption and one-way transport properties, which can be quite beneficial in sporting applications. In this structure, bigger loops are created on the backside and smaller loops on the face side, resulting in a lower loop density at the rear and a greater inter yarn space at the face, replicating the taper of water conduits in trees. The loops on the back are made up of two yarns grouped around each other on every other needle of the weft knitting tool, which aids in the transfer of water from the back to the face by mimicking the plant's 'cohesion-tension' method [65], but their vapor permeability is smaller than that of control material because of increased fabric thickness [66].

15. INFLUENCE OF CHEMICAL PROCESSING

Caustic treatment has been shown to increase the overall moisture management capacity of single-jersey knitted polyester/cotton (52:48) textiles. Increases in the NaOH concentration improve the absorption, high wetted radius, and complete

moisture management capacity. The change has been connected to improvement in the fineness of polyester fibers caused by alkaline hydrolysis and improvement in the swelling of cotton fibers caused by caustic treatment [67]. Additionally, the plasma technique improves the absorbency of polyester interlock textiles [68,69]. Nanotex LLC's nano dry finish is also utilized in sportswear to increase sweat absorption. The incorporation of a microporous membrane or a laminating substrate in the double fabric assembly enhances vapor pressure build-up and prolongs the surface temperature of the inner fabric [70].

16. INNOVATIVE SPORTING GOODS

Advanced Fiber Technology (ADVANSA) offers several high-performance fibers like Coolmax®, Thermolite, and Thermocool for many sportswear applications [71]. Coolmax® active is a high-tech fiber composed of specially developed four- and six-channel polyester fibers that construct a transport network with a larger region that evaporates moisture from the skin and into the fabric's outer layer, keeping the athlete cool and dry. Thermolite® is extremely popular for activewear in cold climates. Hollow-core fibers trap air and give excellent insulation, also heat, and comfort. The high surface area promotes rapid dispersal of sweat, ensuring that the athlete is dry 50% faster than cotton. In Coolmax® all season, a channeled surface is coupled with a hollow core to drain the moisture when the user is hot and to offer warmth for extra comfort on colder days [72]. Toray provided a variety of moisture-wicking textiles, including Stunner QD® and Field sensor®, first one is a woven nylon fabric that rapidly absorbs, and dissipates sweat to promote rapid drying. The raised ends inner side of Fieldsensor TM® adds insulation and moisture control, making it ideal for winter athletic sportswear.

Inotek® fiber is a cutting-edge biomimetic fiber. On absorption of sweat, it contracts to a very thin structure, allowing air pockets to open and improve breathability. This reaction is reversible, and fibers revert to their normal dimensions when exposed to dry air. The Skin® 400 series is an elastane-infused warp knitted revolutionary compression athletic clothing that utilizes dynamic gradient compression to enhance oxygen supply to busy muscles. Speedobiomimetic ®'s swimsuit Fastskin is inspired by shark skin. The denticles of shark skin and the fabric's super-stretch properties can help swimmers perform better by retaining their shape, compressing their muscles, and reducing their drag coefficient [20]

17. SPORTSWEAR DESIGN

Today, several tools and software for 3D clothing design and simulation are accessible. Clothes can be replicated using a virtual mannequin. This enables the simulation and evaluation of garment fit.

3D scanning of the body has been used in the apparel business for the previous two decades but has lately improved in efficiency. Commercially accessible three-dimensional scanning devices may be categorized into five broad categories [73, 74]:

1. Laser scanning technologies that make use of lasers as a light;
2. 3D scanning systems that utilize structured light, mostly white light;
3. 3D scanning systems that utilize LEDs and infrared detectors;
4. Shadow 3D body scanning systems, which include two-dimensional pictures of video silhouettes (body contours) in various body postures and transform them into a 3D model;
5. Systems that employ radio waves to scan the body via clothes

When it comes to sports that need a close fit, the critical characteristics to consider when designing apparel is the elastic capabilities of fabrics, particularly tensile and elastic recovery. When tight-fitting clothing is placed over a curved part of the body, radial pressure is created. The pressure is measured by the elasticity modulus of the embedded textile fabric, the curvature of the human body, the circumference of the garment about the circumference of the body part, and the contact surface. Based on compression force measurements at specific points on the body and awareness of the material tensile properties, a relation between the elastic characteristics and the realized clothing model can be established for it to adapt to the size and shape of the human body part on which it will be worn. Additionally, the ergonomic comfort of fitness athletic apparel was assessed. The mechanical characteristics of knitted textiles are defined by a tension map which contains values (gf/cm) for the tension exerted by clothing on the body of a virtual mannequin. The tension map gives insight into simulated clothes by depicting the values of stretching, tightening, and distance between fabric and a virtual model in a color-coded map. These results were compared to those obtained using Pico Press pressure measurement equipment [75].

Conclusion

Textiles are utilized in many games and recreational activities. Due to growing interest in sports activities, textile consumption in such items and equipment has increased steadily. The sports and recreation industries have benefited significantly from the rising value addition of their goods. The functionalities needed by athletic textiles differ depending on the sport, ambient circumstances, and type of activity. Sportswear is manufactured by combining several types of polymers and fibrous materials, changing the structure of a material, laminating, finishing, and manufacturing technologies. When creating athletic textiles, parameters such as protection and safety from severe weather, comfort, exercise to improve an athlete's performance, and attractive clothing and high fashion abilities are considered.

References

1. Horrocks, A. Richard, and Subhash C. Anand, eds. Handbook of technical textiles. Elsevier, 2000.
2. McCarthy, B.J. An overview of the technical textiles sector. *Handbook of technical textiles*, pp.1-20, 2016.
3. Uttam, D. Active sportswear fabrics. *International Journal of IT, Engineering and Applied Sciences Research*, *2*(1), pp.34-40, 2013.
4. Özdil, N. and Anand, S. Recent Developments in Textile Materials and Products Used for Activewear and Sportswear. *Electronic Journal of Vehicle Technologies/Tasit Teknolojileri Elektronik Dergisi*, *8*(3). 2014
5. Chidambaram, P., Govindan, R. and Venkatraman, K.C. Study of thermal comfort properties of cotton/regenerated bamboo knitted fabrics. *African Journal of Basic & Applied Sciences*, *4*(2), pp.60-66, 2012
6. Nayak, R.K., Punj, S.K., Chatterjee, K.N. and Behera, B.K. Comfort properties of suiting fabrics. Indian Journal of Fiber and Textile Research, vol 34, pages 122-128, June 2009.
7. Abreu, M.J.A.M., Catarino, A.P., Cardoso, C. and Martin, E. Effects of sportswear design on thermal comfort. AUTEX Conference, France, June 8-10, 2011

8. Mayur, B., Mrinal, C., Saptarshi, M. and Adivarekar, R. Moisture management properties of textiles and its evaluation, Curr. Trends Fashion Technol. *Text. Eng*, *3*(3), pp.50-55, 2018
9. Kandhavadivu, P., Rathinamoorthy, R. and Surjit, R. Moisture and thermal management properties of woven and knitted tri-layer fabrics. *Indian Journal of Fibre & Textile Research (IJFTR)*, *40*(3), pp.243-249, 2015
10. Özdil, N., Marmaralı, A. and Kretzschmar, S.D. Effect of yarn properties on thermal comfort of knitted fabrics. *International Journal of Thermal Sciences*, *46*(12), pp.1318-1322, 2007.
11. Rumyantsev. The History of sportswear. *Textile Space*, 13-20, August 2017
12. Nigmatova, F., Maksudov, N., Kasimova, A. and Shin, E., Compression Clothes for Sports-Critical. International Journal of Advanced Research in Science, Engineering and Technology, 5(12), 7525-7533, 2018
13. MMT Testing instrument SDL Atlas, Machine manual, available at Wool Research Association (WRA), Thane
14. Rigby, D. Development of performance fibers and fabrics–A proactive approach. *World Sports Activewear, WSA, pp13-17*, 1998.
15. Hongu, T. and Phillips, G.O. New fibers, second edition, Woodhead Publishing Ltd., 1997
16. Purane, S.V. and Panigrahi, N.R. Microfibers, microfilaments and their applications. *AUTEX Research Journal*, *7*(3), pp.148-158, 2007.
17. Brown, P. and Stevens, K. Nanofibers and nanotechnology in textiles. Elsevier. 2007.
18. Tao, X. ed. Smart fibers, fabrics and clothing: fundamentals and applications. Elsevier. 2001
19. Geetha. S. Textiles in Sports, International Journal of Science, Technology & Management, Volume No 04, Special Issue No. 01, March 2015
20. Manshahia, M. and Das, A. High active sportswear–A critical review. Indian Journal of Fiber & Textile Research Vol. 39, December 2014, page no. 441-449.
21. Venkatraman, P. Evaluating the performance of fabrics for sportswear. *Materials and technology for sportswear and performance apparel*, pp.272-299, 2015.
22. Ravandi, S.H. and Valizadeh, M. Properties of fibers and fabrics that contribute to human comfort. In *Improving comfort in clothing* (pp. 61-78). Woodhead Publishing. 2011
23. Chugan, P.K. Diversification into technical textiles: a forward momentum for Indian textiles industry. *Nirma University Journal of Business and Management Studies*, *6*(1), pp.19-34, 2012.
24. Tarafder, N., Textiles in Sportswear, Sports Goods and Sports Equipment-A. Journal of Mechanical Robotics, 4(3), 1-10, 2009
25. Senthilkumar, M., Sampath, M.B. and Ramachandran, T. Moisture management in active sportswear: techniques and evaluation—a review article. *Journal of the Institution of Engineers (India): Series E*, *93*(2), pp.61-68, 2012
26. Gioello, D.A. Understanding fabrics. Fairchild Publications, 1982
27. Chaudhari, S.S., Chitnis, R.S. and Ramakrishnan, R. Waterproof breathable active sportswear fabrics. *Man-made textiles in India*, *5*, pp.166-171, 2004
28. Higgins, L. and Anand, M.E. Textile Materials and Products for Activewear and Sportswear. *Textiles Intelligence Limited, ReinoUnido:* 2003
29. Erdumlu, N. and Ozipek, B. Investigation of regenerated bamboo fiber and yarn characteristics. *Fibres & Textiles in Eastern Europe*, *16*(4), p.69, 2008
30. Tortora, P.G. and Collier, B.J. *Understanding textiles*. 1997
31. Naeimirad, M., Zadhoush, A., Kotek, R., Esmaeely Neisiany, R., Nouri Khorasani, S. and Ramakrishna, S. Recent advances in core/shell bicomponent fibers and nanofibers: A review. *Journal of Applied Polymer Science*, *135*(21), p.46265, 2018.
32. Arjun, D. and Hayavadana, J. Thermal energy storage materials (PCMs) for textile applications. *Journal of Textile and Apparel, Technology and Management*, *8*(4), 2014
33. Azeem, M., Boughattas, A., Wiener, J. and Havelka, A. Mechanism of liquid water transport in fabrics; A review. *Fibers and Textiles*, *24*(4), pp.58-65, 2017
34. Das, B., Das, A., Kothari, V., Fanguiero, R. and Araujo, M.D. Moisture flow through blended fabrics–Effect of hydrophilicity. *Journal of Engineered Fibers and Fabrics*, *4*(4), 2009
35. Hayes, S.G. and Venkatraman, P. eds. Materials and technology for sportswear and performance apparel. CRC Press. 2018
36. Swantko, K. Adaptive comfort, Knit Americas, Fall, pg.20-21, 2002
37. Bartels, V.T. Physiological comfort of sportswear. In *Textiles in sport* (pp. 177-203). 2005
38. Saville, B.P. Physical testing of textiles. Elsevier. 1999
39. Yoo, S. and Barker, R.L. Comfort properties of heat-resistant protective workwear in varying conditions of physical activity and environment. Part I: Thermophysical and sensorial properties of fabrics. *Textile Research Journal*, *75*(7), pp.523-530, 2005
40. Shishoo, R. ed., Textiles in sport. Elsevier. 2005.
41. Li, Y. and Wong, A.S. Clothing biosensory engineering. Woodhead Publishing. 2006
42. Kothari, V.K. and Sanyal, P. Fibres and fabrics for active sportswear. *ASIAN TEXTILE JOURNAL-BOMBAY-*, *12*(3), pp.55-61, 2003.
43. Parson, K.C. Heat transfer through human body and clothing system Protective clothing system and materials. *Maral Sekkar, New York*, 1994
44. Zimniewska, M., Laurentowska, M., Bogacz, E., Kryściak, J., Domaszewska, K. and Zimniewska, O. Influence of sportswear made from polyester and man-made cellulosic fibres on the energy cost of physical effort. *Fibres & Textiles in Eastern Europe*, (3 (80)), pp.94-99, 2010.
45. Bivainytė, A. and Mikučionienė, D. Investigation on the air and water vapor permeability of double-layered weft knitted fabrics. *PES*, *8*, p.29., 2011.
46. Onofrei, E., Rocha, A.M. and Catarino, A. The influence of knitted fabrics' structure on the thermal and moisture management properties. *Journal of Engineered Fibers and Fabrics*, *6*(4), 2011.

47. Özen, İ., Çinçik, E. and Şimşek, S. Thermal comfort properties of simulated multilayered diaper structures in dry and wet conditions. *Journal of Industrial Textiles*, *46*(1), pp.256-278, 2016.
48. Pac, M.J., Bueno, M.A., Renner, M. and El Kasmi, S. Warm-cool feeling relative to tribological properties of fabrics. *Textile Research Journal*, *71*(9), pp.806-812, 2001.
49. Sampath, M.B., Aruputharaj, A., Senthilkumar, M. and Nalankilli, G. Analysis of thermal comfort characteristics of moisture management finished knitted fabrics made from different yarns. *Journal of industrial textiles*, *42*(1), pp.19-33, 2012
50. Jhanji, Y., Gupta, D. and Kothari, V.K. Moisture management and wicking properties of polyester-cotton plated knits. *Indian Journal of Fibre & Textile Research (IJFTR)*, *42*(2), pp.183-188, 2017
51. Brzeziński, S., Malinowska, G. and Nowak, T. High-tech sports clothing with high comfort of use made from multi-layer composite materials. *Fibres & Textiles in Eastern Europe*, *13*(4), p.52, 2005
52. Wilbik-Halgas, B., Danych, R., Wiecek, B. and Kowalski, K. Air and water vapor permeability in double-layered knitted fabrics with different raw materials. *FIBRES and TEXTILES in Eastern Europe*, *14*(3), p.77, 2006.
53. Gopalakrishnan. K . Comfort Properties of Knitted Fabrics for Sports Applications. *International Journal of Advanced Research in Science and Engineering*, 5(3), 582-587, 2016
54. Bagherzadeh, R., Gorji, M., Latifi, M., Payvandy, P. and Kong, L.X. Evolution of moisture management behavior of high-wicking 3D warp-knitted spacer fabrics. *Fibers and Polymers*, *13*(4), pp.529-534, 2012.
55. Wang, S.X., Li, Y., Tokura, H., Hu, J.Y., Kwok, Y.L. and Au, R . Effect of phase change materials on temperature and moisture distributions in clothing during exercise in a cold environment. *Journal of Fiber Bioengineering and Informatics*, *1*(1), pp.29-40, 2008
56. Manshahia, M. and Das, A. Comfort Characteristics of knitted active sportswear: liquid water transportation. *Research Journal of Textile and Apparel*. 17(30, 38-49, 2013.
57. Fangueiro, R., Filgueiras, A., Soutinho, F. and Meidi, X. Wicking behavior and drying capability of functional knitted fabrics. *Textile Research Journal*, *80*(15), pp.1522-1530, 2010
58. Černe, L. and Simončič, B. Influence of repellent finishing on the surface free energy of cellulosic textile substrates. *Textile research journal*, *74*(5), pp.426-432, 2004
59. Peršin, Z., Stana-Kleinschek, K., Sfiligoj-Smole, M., Kre, T. and Ribitsch, V. Determining the surface free energy of cellulose materials with the powder contact angle method. *Textile research journal*, *74*(1), pp.55-62, 2004.
60. Srinivasan, J., Ramakrishnan, G., Mukhopadhyay, S. and Manoharan, S. A study of knitted fabrics from polyester micro-denier fibers. *Journal of the Textile Institute*, *98*(1), pp.31-35, 2007
61. Özdil, N., Süpüren, G., Özçelik, G. and Pruchova, J. A study on the moisture transport properties of the cotton knitted fabrics in a single jersey structure. *Textile and Apparel*, *19*(3), pp.218-223, 2009
62. Patil, U.J., Kane, C.D. and Ramesh, P. Wickability behavior of single-knit structures. *The Journal of The Textile Institute*, *100*(5), pp.457-465, 2009
63. Prahsarn, C., Barker, R.L. and Gupta, B.S. Moisture vapor transport behavior of polyester knit fabrics. *Textile Research Journal*, *75*(4), pp.346-351, 2005
64. Saha, S.K. and Celata, G.P. Advances in modeling of biomimetic fluid flow at different scales. *Nanoscale research letters*, *6*(1), pp.1-11, 2011.
65. Sarkar, M., Fan, J., Szeto, Y.C. and Tao, X. Biomimetics of plant structure in textile fabrics for the improvement of water transport properties. *Textile Research Journal*, *79*(7), pp.657-668, 2009.
66. Chen, Q., Fan, J.T. and Sarkar, M.K. Biomimetics of branching structure in warp knitted fabrics to improve water transport properties for comfort. *Textile Research Journal*, *82*(11), pp.1131-1142, 2012.
67. Nazir, A., Hussain, T., Zia, Q. and Afzal, M.A. Improving thermo-physiological comfort of polyester/cotton knits by caustic and cellulases treatments. *Autex Research Journal*, *14*(3), pp.200-204, 2014.
68. Karaca, B.E.T.Ü.L., Demir, A.S.L.I., Özdoğan, E.S.E.N. and İşmal, Ö.E., Environmentally benign alternatives: plasma and enzymes to improve moisture management properties of knitted PET fabrics. *Fibers and Polymers*, *11*(7), pp.1003-1009, 2010.
69. http://www.nano-glide.com
70. Kim, J.O. Dynamic Moisture Vapor Transfer Through Textiles: Part III: Effect of Film Characteristics on Microclimate Moisture and Temperature Changes. *Textile Research Journal*, *69*(3), pp.193-202, 1999
71. www.advanca.com
72. www.coolmax.invista.com
73. Chowdhury, H., Alam, F. and Subic, A. Aerodynamic performance evaluation of sports textile. *Procedia Engineering*, *2*(2), pp.2517-2522, 2010.
74. D'Apuzzo, N. and Gruen, A. Recent advances in 3D full-body scanning with applications to fashion and apparel. *Optical 3-D measurement techniques IX*, *2*, 2009.
75. Jariyapunya, N., Musilová, B., Geršak, J. and Baheti, S.S. The influence of stretch fabric mechanical properties on clothing pressure. Vlakna a Textil 24(2):43-48, 2007