CHAPTER 2 FIBRES FOR SPORTSWEAR

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INTRODUCTION

Fibres have a wavy undulating structure and contribute many characteristics to the fabrics that are significant for the performance of functional clothing and sportswear. Sportswear depict multitude of attributes, for instance, it provides functional support, enhances performance, protects athlete from strain/injury, promotes sporting activity, communicates fashion and style, and more importantly, it offers the wearer comfort. The most vital factor that fibres/filaments contribute toward wearer comfort is moisture and thermal balance leading to suitable micro-climate next to the skin. O'Mahony and Braddock (2002) highlighted that in the UK sportswear often refer to active, performance clothing designed and manufactured for sports related activities, however in the US it includes casual leisure wear. In this chapter, sportswear refers to those garments intended for professional sports. Fibres influence the overall comfort of the wearer, mainly in providing a balance between heat loss and body perspiration. In recent years, there had been a tremendous increase in the development of new fibres to cater for the fast growing sportswear and functional clothing market. The demand for performance sportswear drives innovation in fibres and fabrics (Rigby, 1998).

Nylon was the first synthetic fibre (made in 1935 by E. I. DuPont de Nemours, Wilmington, Delaware), and since then a number of fibre have been produced. Nylon was originally used in toothbrush bristles; and the first recognised textile product made of nylon was stockings replacing silk. Commercial nylon stockings appeared in the market in 1938 (Humpries, 2009). Polyester had been used in sportswear since the 1970s because of its dynamic properties resulting in fabrics that are resilient, dimensionally stable, easy care, durable, sunlight and abrasion resistant. These properties make it ideal for an array of sportswear applications (Kadoph, 2007). Synthetic fibres have been widely preferred for active wear due to the multitude of performance enhancements they offer compared to natural fibres (Kirkwood, 2013). Natural fibres are often blended with synthetic fibres to achieve an optimised performance. For example, cotton is used in apparel because it absorbs perspiration, but it saturates quickly causing discomfort due to fabric cling. Hence, cotton and polyester are often blended to gain comfort without cling.

Today, high-functional fibres (Hongu and Phillips, 1997), microfibers (Purane and Panigrahi, 2007), nano-fibres (Brown and Stevens, 2007), and smart fibres (Tao, 2001) have been used in functional clothing. Many claims have been reported particularly, moisture management, thermo-regulation and performance monitoring attributes. Fibres used in sportswear and functional clothing are multi-dimensional and require a number of characteristics apart from possessing a length to width ratio for making a yarn. In the fibre industry, the parameters that influence performance are fibre fineness, fibre shape, molecular structure, and adding finishes [Hongu and Phillips, (1997) and Kadolph, (2014)]. Typical properties of fibres for sportswear include durability, absorbance, high moisture regain, light weight, extensible, colour fast, dimensionally stable and washable. For instance, phase change materials are quite popular among athletes for thermal regulation as discussed in this chapter. Hence, textile fibres contribute toward moisture control, thermal regulation, and breathability, cooling effect, softness, stretch, and UV protection. Synthetic fibres are found in countless applications in apparel and functional clothing due to mechanical and chemical properties (Ravandi and Valizadeh, 2011) compared to natural fibres.

There is evidence that innovation in sportswear and performance products is limited in volumes and the leisurewear and sports related fashion clothing is on a rise, which drives the mass market and increases the consumption of fibres. Although this could be arguable in the sense that mass market reaches a broad population and whether mass customisation is either a follower or driver in sportswear. Rigby (1998) described a volume versus performance pyramid, which indicated how market volumes change as fabric/garment performance increase, hence the price of garments. However, volume of garments under production remains higher for low performance sports related street wear clothing, whilst volume decreases for high performance sportswear, but the price increases. Innovation is often linked with product branding and is not related to volume of production. Lenzing, a leading cellulose fibre manufacturer reported that during 2012, 84 million tonnes of fibre were produced. According to CIRFS (European Man-Made Fibres Association), the world production of cotton, wool and man-made fibres (1991-2012), the production of cotton and wool decreased. Cotton production decreased from 46% in 1992 to 31% in 2012, whilst wool production decreased from 5% in 1992 to 1% in 2012. However there were positive trend for production of man-made fibres which increased to 68% in 2012 from 49% in 1992. This indicates that the consumption for man-made fibres is increasing globally.

In this chapter, widely used fibre types are highlighted and their characteristics are critically appraised. Various technical terms which are used to ascertain the performance of fibres are also explained. During intense activity, human bodies generate heat and sweat and perspire, and it becomes essential to understand these physiological changes in the context of sports activity. Sportswear requirements differ from fashion apparel and fibres are often blended to utilise the combined effect of two or three fibres, a typical example, will be wool, polyester and elastomeric fibres. The effect of blending fibre types on the performance of fabrics is discussed. New developments in the area of fibres such as, Trinomax AQ, Outlast, Nilit Breeze, Trevira, and Tencel are reviewed. The market trend for new and smart fibres is ever increasing and is highlighted in the context of sportswear and functional clothing. The fibres used in the area of moisture management, wicking, and thermal regulation are discussed and evidence from a wide range of resources are also presented in the context of those garments which are worn next to the skin such as base layer, compression vests and trousers, thermal underwear and stretch tights. The information provided here should be regarded as essential for effective design and development of performance clothing particularly sportswear.

FIBRES PROPERTIES AND ITS MODIFICATIONS

Fibres possess a wavy undulating physical nature called *crimp* that can affect the **warmth** and **resiliency** of fabrics. Gupta and Kothari (1997) describe a textile fibre as a long thin material which has a high degree of fineness and outstanding flexibility. In addition, they added that fibres should have good dimensional and thermal stability, acceptable strength and extensibility. Fibres are broadly classified into natural fibres, regenerated and man-made fibres*. Wool fibres possess a natural three-dimensional crimp. In the case of synthetic fibres, *texturing process* can impart crimp to manufactured fibres or yarns. Fabrics made from crimped yarn or fibres tend to more *resilient, and have increased bulk, cohesiveness, and warmth*. *Cohesiveness* is the ability of fibres to cling together and is important in making yarns. **Fibre resiliency** is the capability of the material to spring back to shape after being creased, twisted, and distorted. **Thick fibres** possess greater resiliency because there is more mass to absorb the strain, in addition the fibre shape affects fibre resiliency.

*(see Textile Terms and Definitions for elaborate fibre classification, Denton and Daniels, (2002)).

US based Invista promoted its Coolmax fabric® which is a popular brand among athletes for its ability to wick moisture from the skin, to absorb, and spread moisture to enhance drying rates and to keep the wearer cool and dry. It is made of lightweight hydrophilic polyester, which is **channelled**. The perspiration wicks away from the skin due to capillary action of channelled fibres (tetra and hexa channel).

TERMS USED FOR ASSESING FIBRE PERFORMANCE

In order to understand the characteristic and performance of fibres, it is essential to be familiar with the following technical terms (Denton and Daniels, 2002, Collier et al. 2009):

Absorbency: It is ability to take in moisture (expressed as the moisture regain), which is the amount of water a dry fibre absorbs from the air under standard conditions of 21 ^{0}C and 65% relative humidity. Table 1 below presents some of widely used fibres and their moisture regain.

Table 1 Moisture regain of fibres

Fibre type	Moisture regain (%)
Acetate	6.5
Acrylic	1.5
Cotton	7.0
Nylon	4.5
Polyester	0.4
Rayon	11.0
Rubber	0
Spandex	1.3
Wool	13.6

Source: ASTM D 1909 - 04

- **Absorption:** It is a process whereby the liquid is fully absorbed by the fibre through its structure and is quite common among **hydrophilic fibres** (Figure 1).
- **Adsorption:** It is a process, where liquid is taken up between the fibres on their surface rather than being held within the fibre.

- **Wicking**: It is the ability of fabric to transfer moisture adsorbed on fibres from one section to another. Wicking can also occur if liquid is absorbed within the fibre. A smooth surface reduces wicking action. Cotton (a hydrophilic fibre) and Olefin (hydrophobic) both possess a good wicking action. Fine fibres with channels are capable of transporting liquids (eg. four channelled INVISTA coolmax fabric)
- **Moisture regain:** The ratio of the mass of moisture in a material to the oven dry mass, usually expressed in percentage. A dry fibre when placed in a humid atmosphere, will absorb moisture.
- **Hydrophilic** - a fibre that has high regain (that absorbs water) is also referred as "water loving"
- **Hydrophobic**– a fibre that does not absorb water; referred to as "water hating". Regarding the dimensional stability in water - hydrophobic fibres shrink less when washed than hydrophilic fibres. With regard to stain removal it is easier to remove stains from hydrophilic fibres because water and detergent are absorbed into the fibre.

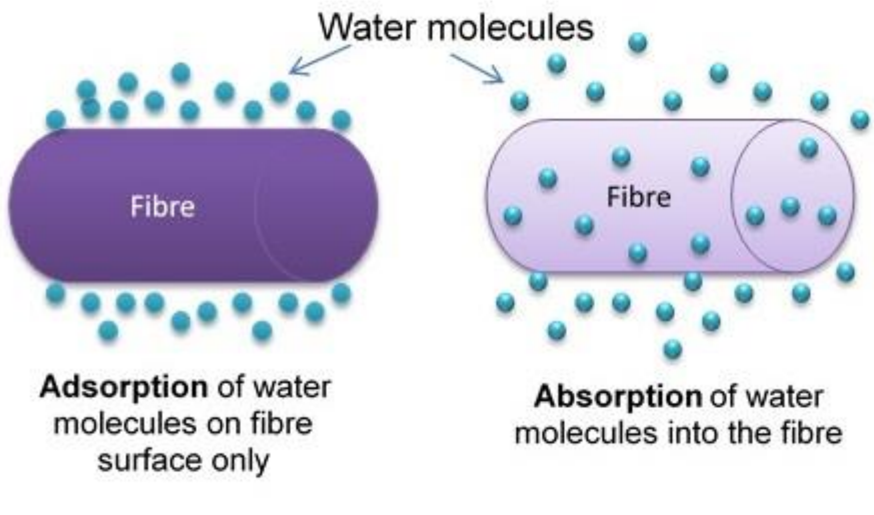


Figure 1 Mechanism of water adsorption and absorption

Fibre absorption affects the overall comfort of the wearer, and some of the terms are discussed below. **Skin discomfort -** little absorption or wicking and movement of perspiration – result in fabric clammy feeling. **Static build up** – the fabric clinging onto the body or sparks occur with fabric made of hydrophobic fibres, because no moisture content to help dissipate the built-up charge on fibre surface (dirt also clings on to the fibre surface). **Water repellency** – fibre that resists penetration of water or wetting but are not water proof. Non-absorbent fibres (polyester, acrylic) help repel water. Water repellent finishes (use of fluoro chemicals) on fabrics are popular. **Wrinkle recovery** - hydrophobic fibres possess better wrinkle recovery when laundered, as they do not swell or absorb water. **Hygroscopic**— fibres that absorbs moisture without feeling wet. **Thermo-physiological** – it is related to optimum balance between the heat loss and heat generated by the body. This depends on the body metabolism, thermal regulation mechanism and individual health condition. One of the important properties of fibres used for functional and active wear clothing is the elasticity and flexibility. **Fibre elasticity** refers to the ability to increase in length under tension (elongation) and return to original length when tension is released. Stretch and recovery of fibre/fabric makes a comfortable garment and causes less seam stress. Complete recovery prevents bagginess in fabric (knee, elbows), this can be noticed during a stretch and close fitting garments. Fibres that elongate 100% are *elastomeric fibres* typical examples are spandex, elasterell-p, lastol and rubber. **Fibre flexibility** refers to the ability of fibre to bend easily and repeatedly without breaking. Acetate fibre is a flexible fibre used in garments; glass fibre is a stiff fibre.

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

PHYSIOLOGICAL PARAMETERES

In this section three important factors that are vital for the designing of sportswear are discussed, namely '**body sweat patterns'**, '**thermal heating patterns**' and '**stretch and recovery'** requirements of an athlete. Smith and Havenith (2012) reported the body mapping of sweating patterns in athletes: the regional sweat rates were compared between thirteen aerobically trained females and nine aerobically trained males. For female participants the regional sweat rate (RSR) showed highest at the central upper back, heels, foot and between the breasts and lowest RSR were observed over the breast and middle and lower back. They further added that despite some differences in distribution, both sexes showed highest RSR on the central upper back and the lowest toward the extremities. Hence, whilst designing garments with various fabric components it is essential to consider the sweat patterns of the body. For instance, in the case of sports bra, it is necessary to have a fabric made of filaments/fibres that wick away the body perspiration particularly in the lower central back and facilitate breathability, whilst preventing fabric sticking to the body and inhibiting free movement.

During designing of functional clothing particularly active wear requires knowledge of heat patterns of body, designers can use the body mapping technology which W. L. Gore Associates have developed. The body mapping provides information on heat and moisture formation on various zones of the body (Hohenstein Institute, Performance Apparel Markets, 2012). According to the body mapping technology in the case of men (front side/anterior part), sweat zones are higher in central torso, shoulders, followed by limbs and arms. In the backside, central back, lower back, arms, shoulders are more prone to sweat formation. In the case of men the heat zones are neck, shoulders, chest, ribs, lower limbs, thighs. In the back part, upper back, shoulders, lower back, back thighs, and limbs.

In the case of women in the heat zones in the front part include, shoulders, neck, waist, lower limbs, and arms. In the case of the back side/posterior part, shoulders, central back, thighs, and lower limbs are affected. Hence, whilst designing garments for athletes care should be taken to ensure different needs of men and women are factored and at the same time thermo-physiological comfort is balanced by using appropriate fibre/fabrics in the clothing.

Swerev (2003) stated that comfort is not subjective feeling as it is as physiological process which the body attempts to balance between the heat loss and production. However, most researchers have defined comfort of clothing differently for instance, thermo-physiological comfort – the way the cloth helps to maintain heat balance during activity and skin sensational wear comfort – mechanical contact of fabric with the skin (Saville, 1999). Ravandi and Valizadeh, (2011) added that comfort of clothing can also affected by constituents, such as physical and chemical properties of fibres, filaments, yarns and fabrics.

MECHANISM OF BODY PERSPIRATION AND TEMPERATURE REGULATION

Human body perspires in two forms namely, insensible (in vapour form) and sensible perspiration (in liquid form), and to be in a comfortable state, the sports clothing worn next to the skin should allow both the type of perspiration to transmit from the skin to the outer surface (Das et al. 2009). Gleeson (1998), reported that during intensive activity, body heat production exceeds 1000 W. Some of this heat is dissipated and remaining raises the body's core temperature. This rise in temperature sensed by the skin's thermo receptors, which produces sweat to cool the body. Sweat evaporation and increased skin flow blood flow are some of the body's mechanisms to dissipate heat (Figure 2). Inappropriate clothing may affect the ability of the body to lose heat from the body.

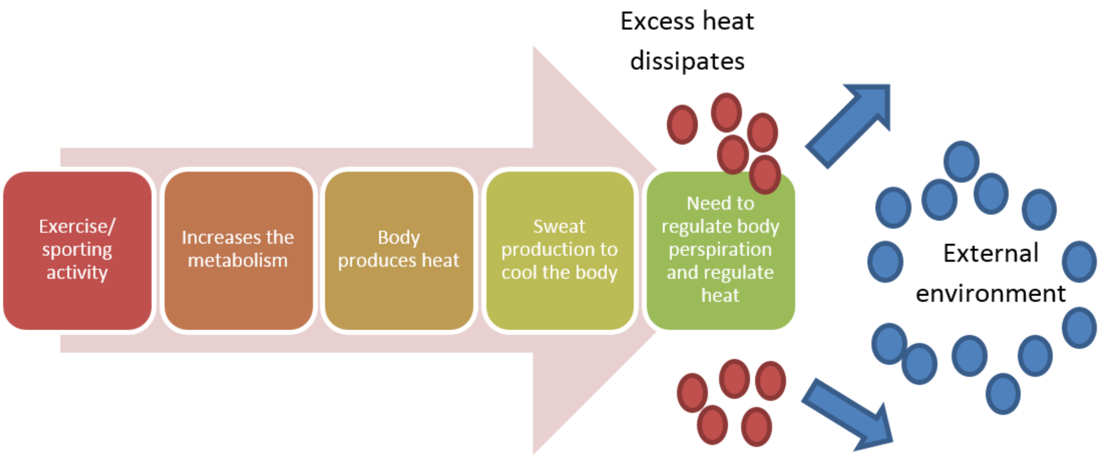


Figure 2 Mechanism of body perspiration and temperature regulation

Swerev (2003) reported that in order to feel comfortable thermo-physiologically there must be an equilibrium between production and heat loss, else the body's core temperature changes. Approximately, 10% of the human heat loss is due to breathing, the majority of heat through the skin. This can happen in the form of 'dry heat transfer' - through radiation and conduction and by 'moist heat flow' due to evaporation of perspiration. In both the above, heat is lost via clothing. He further added that how heat is dissipated depends on fibre composition, yarn and fabric construction, and cut of the garment. In addition, the micro-climate between the fabric and skin which can be circulated (convection) and exchanged with the surrounding air (ventilation). Outlast Technologies analysed the skin temperature in various parts of the body, which reported that the body's core temperature is 37°C and skin temperature is between 31°C and 35°C, where abdominal area (35°C), head 34.4, shoulders and upper thighs (34.3°C), wrists (31.4°C), hands (31.6°C), ankles (30.8°C) and feet (30.8 -31.6°C). A small fluctuation in temperature will lead to discomfort, and affects performance (Swantko, 2002). Hence, it can be inferred that designing functional garments with effective heat and moisture management depends on awareness on body heat and sweat pattern.

Gavin et al., (2001) investigated whether temperature regulation improved during exercise (running and walking) in moderate heat when wearing clothing (evaporative polyester fabric) which was supposed to promote sweat evaporation compared to conventional cotton garments. No differences were observed during and after exercise. It was concluded that clothing did not affect the thermo-regulation during exercise. However, recently Israel-based producer of nylon 6.6 yarns reported its Nilit Breeze (www.nilit.com) which promoted their products, maintaining the thermal balance. The filaments are made of flat cross section that quickly transfers body heat, the polymer contains inorganic particles that increases surface area and promotes cooling. Textured filament offers bulkiness for added ventilation and breathability. It further added that the NILIT® Breeze sleeve lowered the body temperature by 1°C compared to a standard sleeve when tested on a thermal sweated mannequin. Hence there is mixed reaction with regard to regulation of body temperature wearing clothing.

STRETCH AND RECOVERY

Stretch fabrics have become a staple in sportswear apparel due to the increased comfort and fit the highly extensible fibres offer. Voyce et al., (2005) explained how a person's skin stretches considerably with some key areas of stretch including 35% to 45% at knees and elbows and with sporting activities increasing such numbers, stretch of sportswear apparel is key for comfort. Although elastomeric fabrics are used to improve comfort, tighter compression garments are becoming more desirable in the market. Normal body movement expands the skin by 10 to 50% and strenuous movements in sports will require least resistance from garment and instant recovery. Stretch and recovery of garments depends on the fibre constituents (textured, elastomeric, micro fibre), yarn formation (ply yarn or core yarn), fabric structure (woven or knitted) and any fabric finishes. Elastane yarns are characterised by their ability to recover from stretch and is often used in stretch fabrics. Figure 3 illustrates various body postures that undergo stretch and require support.

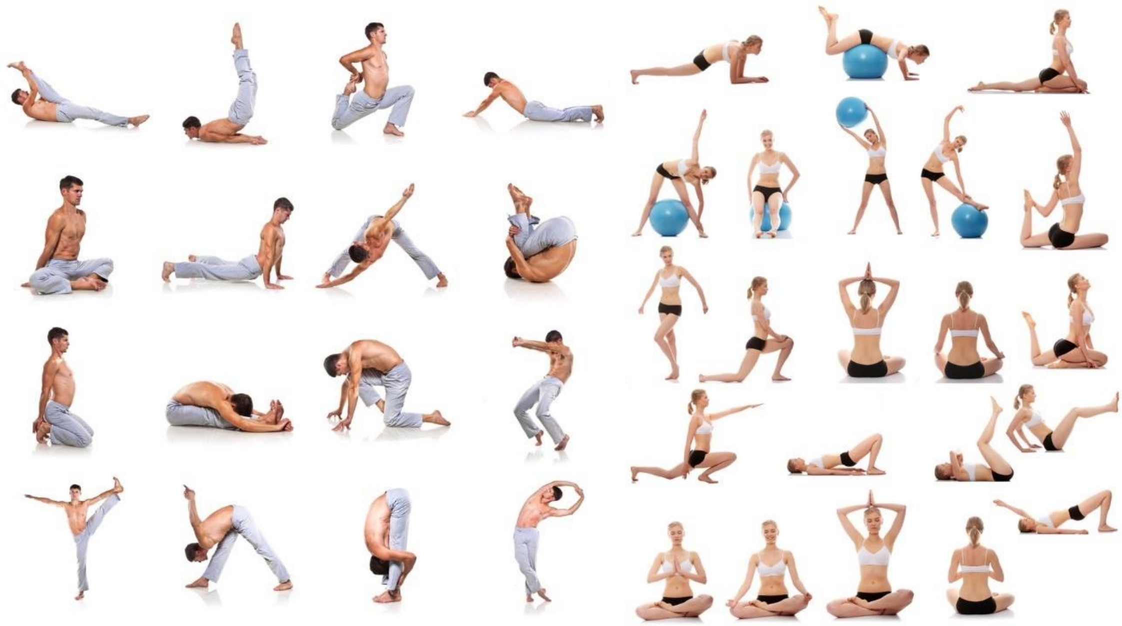


Figure 3: Different body stretch movements

(Source: Shutterstock)

BISFA, an international association of man-made fibre producers described elastane as "a fibre composed of at least 85% by mass of a segmented polyurethane which, if stretched to three times its un-stretched length, rapidly reverts substantially to the original length when the tension is removed" (BISFA, 2014). Widely used elastane, Lycra® developed by Invista. In its recent report Invista claimed that Lycra® SPORT fabric was specifically created to improve athletic performance and comfort. It added further that sportswear characteristics including compression, freedom of movement and comfort, are essential for athletes of all levels and in most sports from the fastest sprinters and cyclists in the world to swimmers, gymnasts or rugby players. INVISTA developed a three tiered, end-use performance standard for athletes: ‘Lycra® sport fabric’ for active performance, ‘Lycra ® sport beauty fabric’, combining performance with beauty and style, assists "looking in shape while getting in shape™" and ‘Lycra ® sport energy fabric’, innovated for compression fabrics used in high-intensity and high-energy-sports. Lycra sport energy provides 100% stretch in both directions, to maintain freedom of movement, as compression garments worn tight. Minimum recovery powers at 40% and 65% of fabric stretch and normal hysteresis for consistency in stretch and recovery (Lycra, 2012).

Elastane yarns are often covered with another fibre and is not used one its own. This provides more bulk and improves abrasion resistance. The main end-uses for the yarns are garments and other products, where comfort and fit are important. Typical examples are sports and leisure wear, swim wear, elastic fabrics and stockings (BISFA, 2014). Generally, casual garments are designed with 2-5% elastane for added comfort and stretch, however sportswear such as those used in tights have up to 10% elastane. However, compression garments that apply mechanical pressure uses up to 40% elastane. Hence, based on the end uses and desired stretch can be designed by varying the composition of elastane fibres.

Senthilkumar and Anbumani (2011) recently reported dynamic elastic recovery (DER) of elastic knitted fabrics intended for sportswear at different extension levels by determining the stress/strain of fabrics. They studied two types of fabrics with different types of yarn (spandex core cotton spun yarn, SCCS and spandex back-plated cotton yarn, SBPC) with identical fabric geometry (wales per cm, stitch density, loop length, etc.) and evaluated the DER behaviour. They added that at 20 – 30% extension the fabric loop deformation can take place with no change in the residual energy of elastane, however at 40 – 50%

extension fabric undergoes stretch, and may cause yarn slip in the structure. They concluded that SBPC fabric had higher DER value (higher stress) than SCCS fabric, claiming SBPC fabric had good elastic recovery which enhances the wearer's performance and supports in muscle recovery. It can be inferred that clothing intended for sportswear with strenuous activity require stretch and recovery particularly those that are worn skin tight (eg. compression garment) than leisure wear or basic sportswear. Careful planning and factoring the above parameters results in a garment that is fit for purpose.

FIBRES FOR SPORTSWEAR

The section discusses the importance of micro fibres, hollow fibres and bi-component fibres which have been used in functional garments, highlighting their characteristics and typical uses.

MICROFIBRES:

Fine diameter fibres less than one denier is often termed as microfibers and has valuable properties. They are soft, durable, drapeable and possess high absorbency and is used for high performance end uses, especially sportswear. It is produced through melt spinning – strict process controls, uniform high quality polymer. Fibres with <0.5 denier cannot withstand tensile forces of melt spinning. Commercially, nylon, polyester, acrylic and rayon are available in the market. Ultra-fine fibres are less than 0.3 denier per filament. Micro fibres are manufactured by producing bi-component process using two different polymers that do not mix, Collier et al., (2009) and Purane and Panigrahi (2007). Typical example is by producing a bi-component fibre in Islands-in-the-sea formation and dissolution of sea part of the fibre leaves the tiny micro-fibres.

HOLLOW FIBRES

Hollow fibres have been introduced in 1980s, whose cross-section is hollow and is available shapes - round, trilobal or square. The hollow fibres are resilient, has better recovery, bulky, and provides better thermal insulation by trapping air. Hollow polypropylene fibres are light weight, soft, and offers good thermal insulation used in thermal underwear (Ravandi and Valizadeh, 2011). Micro fibres are finer than delicate silk offers excellent drape, with luxurious handle, resistance to shrinkage, super-absorbent, and possess strength (Purane and Panigrahi, 2007). These properties enable to them to be used in a wide range of application.

Hollow fibres are made of sheath of fibre material with one or more hollow spaces at its centre (Figure 4). It is produced using *C shaped spinneret holes*, molten fibres relaxes after extrusion, open 'c form' closes to produce hollow fibre. There is also a spinneret hole with *solid core* around which polymer flows and produces hollow fibre. Increased absorbency, filters for kidney dialysis, carriers of carbon particles for safety clothing in contact with toxic fumes (Collier et al, 2009).

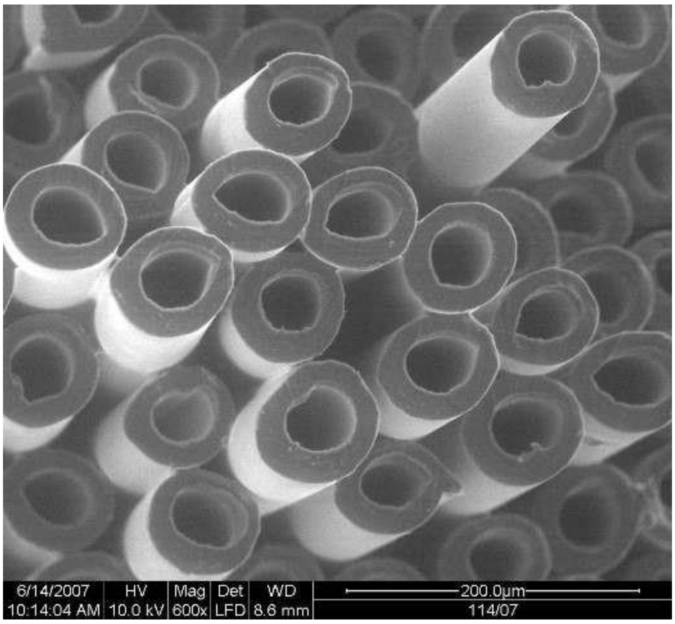


Figure 4 Hollow Fibres

Source: Institute of biopolymers and chemical fibres (IBWCH)

BI-COMPONENT FIBRES

Bi-component fibres have been in use technical textiles for quite some time. Fibre consisting of two polymers which are chemically or physically different or both. Bi-component fibres can be produced with two variants of same generic fibre two types of nylon, two types of acrylic or two generically different fibres polyester or nylon, nylon and elastane. Centexbel, based in Belgium which has an extrusion plant manufactures bi-component fibres. Different type of bi-component fibres are produced based on the end use (see Table 2). Bi-component fibres are made of two components distributed over the entire length of the fibre (Centexbel, 2014). Bi-component fibres are available in staple, filament and microfiber format. By extruding two polymers in one single fibre the different properties of both polymers can be extracted (Figure 5). Bi-component fibre are used in a wide range of functional products including sportswear.

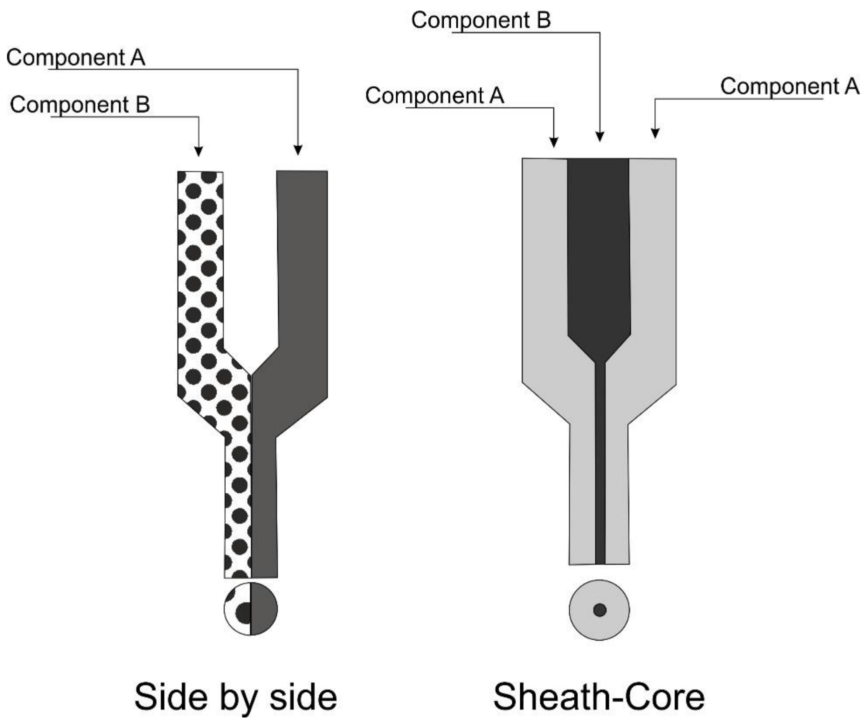
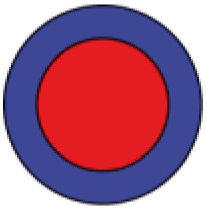
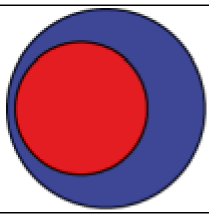
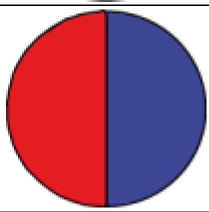
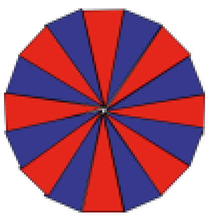
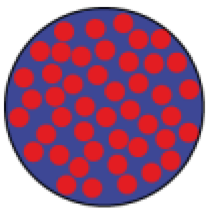


Figure 5 Bi-component filament extrusion

Puma recently developed sportswear including t-shirts, shorts, and sweatshirts which incorporates patented Celliant technology. Celliant is a brand name for bi-component fibre made from polyester which contains a blend of minerals and proprietary ingredients embedded in the core of the fibre (Performance Apparel Markets, 2013). Celliant Technology absorbs and stores the electromagnetic energy emitted from the body (in form of infrared light) and releases it to re-absorbed into the skin and tissue.

Table 2 Different types of Bi-component fibres

Name	Bi-component fibre	Characteristics and uses
Concentric sheath core		Used in melt fibres with sheath made from polymers with a low melting point around a core with high melting point. During heating the sheath will melt, consequent cooling will bind the structure. Used to produce fibres with expensive/quality polymer around a cheaper but resistant core.
Eccentric sheath core		As above two polymers are used, however the core is out of centre, due to different shrinking ratio of polymers the fibre will curl when heated in a relaxed state. It is possible to add crimp and volume.
Side-by-side		Both polymers share an equal part of fibre surface. Fibre can develop more crimp than the eccentric sheath/core.
Pie-wedges		It is made of sixteen adjoining pie-wedges. Each pie wedge of polymer is flanked by another polymer. Micro fibres (0.1 to 0.2 denier) are produced by splitting them by mechanical action. It is possible to provider a hole in the middle of the pie wedge to split the filaments more easily.
Islands/sea		In this type, one polymer represents the island (red ones) and the other polymer represents sea (blue). This structure allows to produce fine micro fibres by dissolving the latter, which is easier than extruding fine fibres directly.

Source: Centexbel© 2014 (Images reproduced with permission)

BLEND OF HOLLOW AND CHANNELLED FIBRES – ADVANSA THERMO-REGULATION FIBRES

ThermoºCool® is a combination of fibre shapes - channelled fibres and hollow fibres creates additional spaces within the fibres that allow a better circulation of air, improving significantly the fabric's evaporation capability (Giebel and Lamberts-Steffes, 2013). Outlast: Outlast PCM (phase change materials) are located in the fibre. The fibres are spun into yarns and are intended for those fabrics that are worn next to the skin. The outlast technologies uses the PCM that absorb, store and release the heat for optimal thermal comfort. Outlast® technology has the ability to continually regulate skin's microclimate. As the skin gets hot, the heat is absorbed, and as it cools, that heat is released.

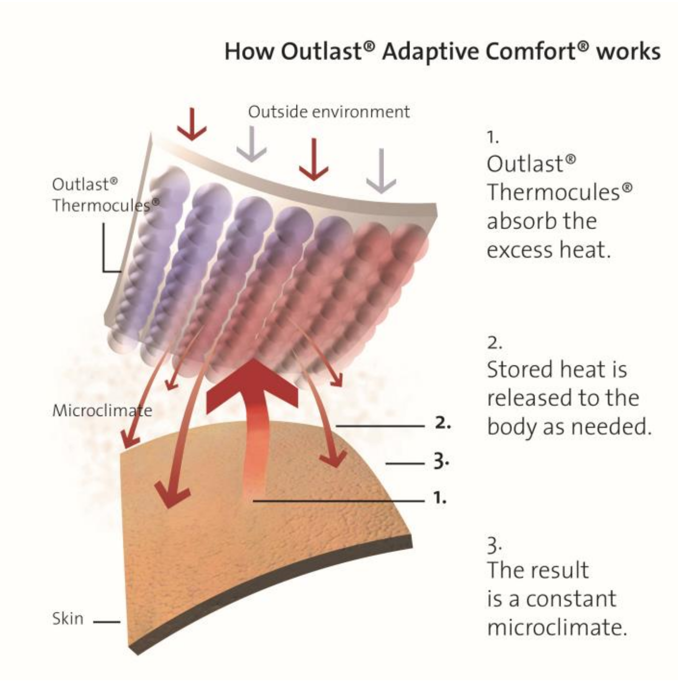


Figure 6 Adaptive comfort – Outlast Technologies here

Source: © Outlast Technologies LLC

As illustrated above (Figure 6) Outlast technologies works on the principle where excess heat generated by the body due to harsh external environment or intense activity is absorbed by the outlast micro thermal fibres. The stored heat is released back to the body as needed maintaining the temperature. The company claims that the fabric made of Outlast fibres offers constant micro-climate next to the skin. Figure 7 shows the thermo regulation process pictorially, highlighting three key stages.

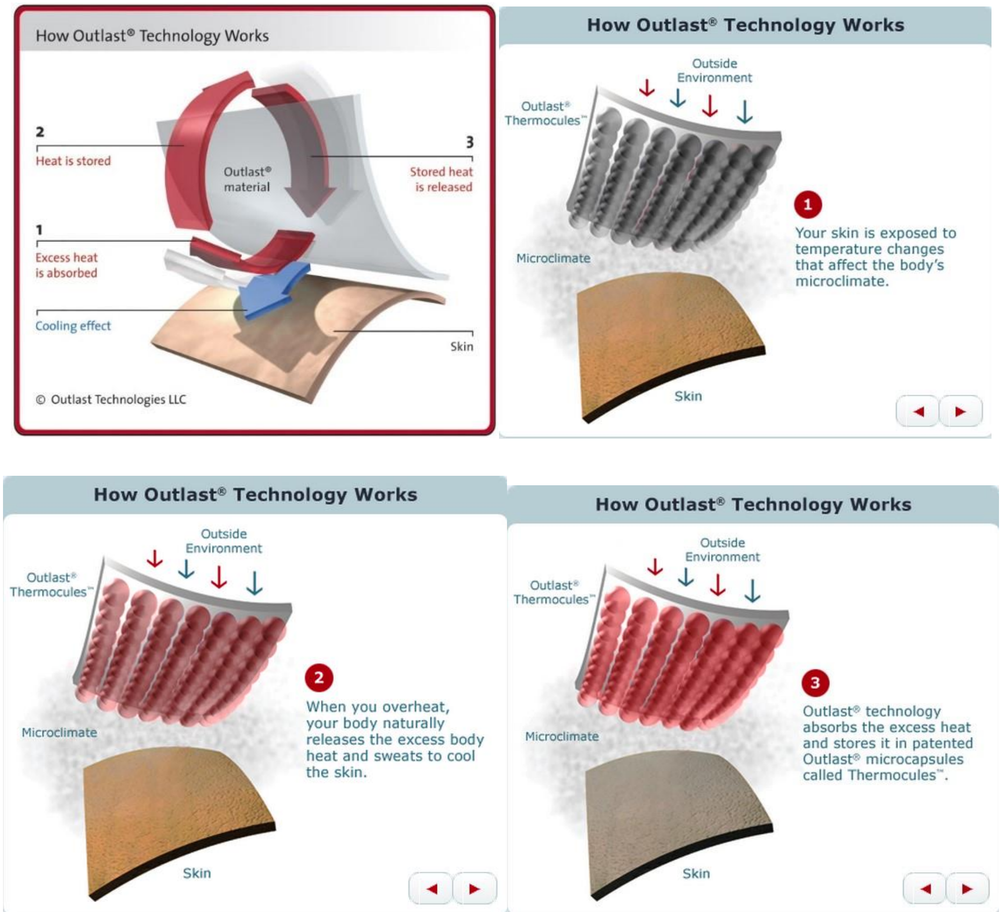


Figure 7 Outlast Technologies here

Source: © Outlast Technologies LLC

Recently Jockey, a US based apparel manufacturer incorporated PCMs developed by Outlast in its underwear to maintain good thermal comfort and keep the wearer comfortable by balancing the heat produced by the body. The PCMs melt when the surrounding heat rises and store surplus energy, when the physical activity decreases the body cools down the PCMs thermocules solidify and emits the heat, which was stored. This results in improving the comfort of the wearer. Jockey had introduced its product in men’s and women’s underwear (Performance apparel markets, 2011). Figure 8 illustrates the cross section of polyester fibre with thermocules; Figure 9 shows thermocules embedded/injected within the acrylic filament during production enhances durability and can be laundered many times without losing its performance (Swantko, 2002). Figure 10 illustrates Oulast® Technologies embedded within the viscose fibre.

Figure 8 Outlast® technology polyester fibre cross section with thermocules

[Images reproduced with permission from Outlast Europe GmbH]

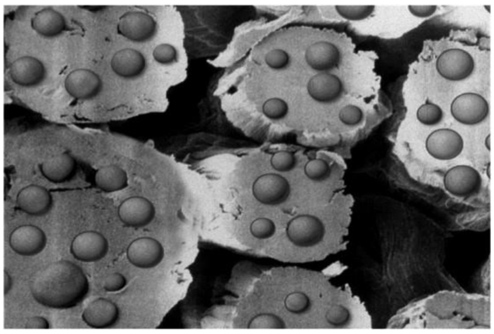


Figure 9 Outlast® technology - acrylic filament with thermocules

[Images reproduced with permission from Outlast Europe GmbH]

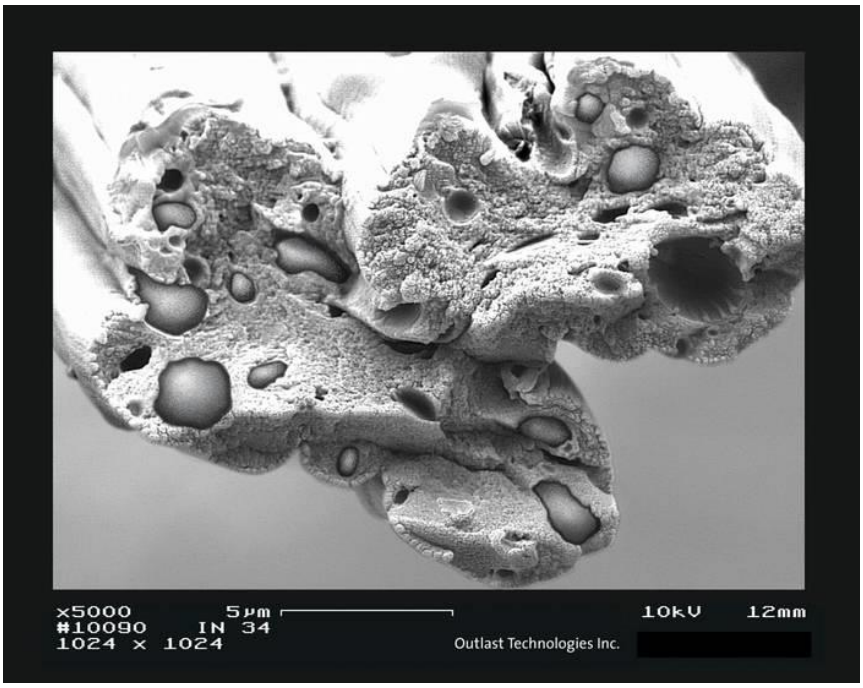


Figure 10 Outlast® technology - viscose fibre showing embedded thermocules

[Images reproduced with permission from Outlast Europe GmbH]

Celliant technology: Celliant® is a revolutionary, patented technology that absorbs and stores the electromagnetic energy emissions from the human body and re-emits them back to the body where they are re-absorbed into the muscle tissue (Future Materials, 2013) through the use of fibres, converts the body's natural energy (heat) into infrared (IR) light and emits it into the body's tissue and muscles. The result is a responsive textile clinically proven to benefit the human body, utilizing a blend of minerals and proprietary ingredients embedded into the fiber's core. Celliant technology is a blend of proprietary ingredients that recycles vibrant energy (heat) leaving the body into infrared light (IR) and sends it back to the body where it is absorbed by the tissue and muscles. IR waves are beneficial as they penetrate deep into the tissue. This energy causes the body to increase circulation and oxygen wherever it is applied. Celliant is a unique blend of 13 thermo-reactive minerals including titanium dioxide, silicon dioxide and aluminium oxide. Additional proprietary ingredients are blended with polyester fiber to create a variety of staple fibers, spun and filament yarns, and fabric blends (www.celliant.com). According to Hologenix, US based company, celliant technology have been shown to increase oxygenation in the body tissue and reduce body aches and pain. The technology uses electromagnetic energy emissions in the form of infrared light produced by the human body. Celliant technology harnesses the human body's natural energy and is clinically proven (clinical trials) to enhance tissue oxygen levels (Performance Apparel Markets, 2013).

CELLULOSE BLENDS

Generally cellulose fabrics tend to absorb water within its fibre structure and become heavy and take longer time to dry. This leads to stretching of fabric and clinging on to the skin. When the intense activity ceases fabric leave the wearer cold. However TENCEL® from lenzing is a synthetic fibre which is solvent spun from cellulose widely used in moisture management with improved aesthetics, and is used in sportswear. Firgo et al, (2006) reported that TENCEL® can be used effectively in performance sportswear provided the fabric is carefully designed using double layer fabrics that has better moisture absorption, moisture spreading, quick drying rate, reduced wet cling behaviour, better balance of water vapour permeability and thermal comfort and more importantly less synthetic appearance and handle. The two layer fabric strategy which was tested is based on the fact that the fabric is made of hydrophobic inner layer in contact with the skin where the sweat is pulled through the fabric by the hydrophilic layer which is the outer layer (made of TENCEL®). This outer layer is ideal for spreading (wicking) the moisture and evaporating it to the environment. The researchers also reported that having researched a number of blends with polyester, 30% TENCEL® and 70% polyester blended yarn fabric performed better in terms of absorbency, moisture spreading, drying rate, good wet cling index and intermediate water vapour permeability.

NEW DEVELOPMENTS IN FIBRE INDUSTRY

Trinomax AQ was recently developed by a joint collaboration between Nilit, an Israel-based manufacturer of nylon 6.6 and LincSpun yarns an Australian based developer of intelligent yarns and filaments. Trinomax AQ is made by twisting together three types of fibres namely merino wool, textured Nilit nylon 6.6 and Nilit Aquarius, using a proprietary LincSpun technology. The resulting yarn is lightweight, durable, soft and has the ability to regulate body temperature and wicks moisture. The company claims that performance is durable and lasts through repeated laundering and it intended for a range of products such as active wear, socks, and sportswear (Performance and apparel markets, 2011).

MARKET TREND AND OVERVIEW

According to Research and Markets report, the UK sportswear market grew 5.4% in 2012 with apparel accounting for 71% of the market value and footwear making up 29%. Among the retail stores, Pentland Group and Sports Direct have a majority of the market share after JJB sports entered administration in 2012. Among sportswear brands Nike and Adidas leading the market (WSA, 2013). Euromonitor International reported the global sales of sportswear are set to rise from US $245 bn in 2012 to US $300 by 2017 (Kondej, 2013).

Market drivers

Major sporting events are drawing attention of various sportswear brands including sports apparel and footwear companies to have a market share in the following events.

- Winter Olympics, Sochi, Russia, 7th – 23rd February, 2014
- FIFA Soccer World Cup, Brazil, 12th June – 13th July, 2014
- Summer Olympics in Rio de Janeiro, Brazil 5th – 21st August 2016

The above events also promote active wear and replica products among fans, supporters of sporting heroes and sports enthusiasts. In addition, market would drive by increasing demand in Brazil, China, USA and India (Kondej, 2013).

WIDELY USED FIBRE TYPES FOR SPORTSWEAR

In the past, cotton was widely preferred for a wide range of garments, however with the advent of synthetic fibres, such as polyester, nylon, polypropylene, acrylic, etc. During 1970s created pre-dominant use of polyester fibres in sportswear, which retained its prominence in 80s and 90s. **Polyester** is preferred in sportswear due to its light weight, cheap to produce, dye fastness, durability, easy care properties, quick drying, hydrophobic in nature, and wicking ability. In addition, the polyester filament fabrics can be given hydrophilic coating. Hence, polyester fibre based fabrics with its hydrophobic core and hydrophilic coating enables it to wick moisture away from its contact from the skin to outer surface to the environment. Polyester is often blended with other natural fibres mainly to extract its benefits to maintain moisture management and durability. European man-made fibres association reported that among man-made fibres polyester is a dominant fibre (WSA, 2012). Many sportswear brands are progressively moving toward recycled polyester, Adidas was one of the companies who carried out a life cycle analysis by conducting research on the environmental impact of polyester. Mechanically recycled polyester has better environmental profile than the chemical recycled, however chemically recycled fibres have a wide range of applications in the industry. **Elastane** is another synthetic fibre widely preferred for its elasticity mainly for stretch and recovery.

The elastic nature of filaments is used in sportswear to compress muscles, offer stretch for body movements, and support in recovering from muscle soreness.

A wide range of sportswear products such as foundation garments, swimwear, base layer products, compression tights, etc., are widely made of elastane. **Merino wool** is widely used in sportswear, for instance, superfine merino wool possess superior water vapour permeability and quick drying properties. Advansa's Thermo° Cool were blended with merino wool (50/50% or 70/30%), for better thermo regulation and comfort (Giebel and Lamberts-Steffes, 2013). Merino fibre can absorb up to 35% of its dry weight in moisture vapour. During strenuous exercise or hot conditions, a Merino wool garment closer to the skin actively transfers moisture vapour away from the body. This causes the micro-climate above the skin to become less saturated with vapour, thereby making the wearer less clammy and it is less likely for the vapour to form sweat droplets on the skin's surface. Recently Pearl Izumi a Japanese cycling and sports apparel promoted its cycling jersey with merino perform technology developed by Australian Wool Innovation using 19.5 micron wool that promotes comfort and warmth. (Pearl Izumi, 2010).

FIBRES TYPES AND BLENDS AFFECTING THE PERFORMANCE OF GARMENTS

The performance of fabrics is dependent on chemical and physical properties of constituent fibres, yarns, and finishes used. Blending different type of fibres enables to utilise the advantages of each fibre, which in turn facilitates to counteract the disadvantages other fibres, thus enhancing the appearance, durability, comfort, maintenance, cost, and overall performance. Typical blending include, polyester/cotton, cotton/lycra, polyester/viscose, nylon/lycra, wool blends, merino wool/acrylic, etc.

Polyester and viscose are quite often blended in apparel applications, since polyester has excellent durability and wrinkle resistant and easy to care and maintain. Viscose fibres have good absorbency and poor durability and wrinkle resistance. Das et al, (2009) who investigated the polyester and viscose fabric blends demonstrated that blending of fibres has an important role in moisture related comfort properties of clothing. The water vapour permeability and absorbency of fabric increases with the increase in hydrophilicity of material. However, the wicking decreases with the increase in viscose proportion. The higher hydrophilic material (viscose) provides better absorption, however, it reduces spreading resulting in moisture accumulation and sticky feeling. Hence, if an athlete produces a lot of perspiration, higher proportion of polyester fibres and smaller percentage of viscose will act as quick absorption of sweat from the skin, polyester filaments help to spread the moisture to the outer surface.

Sampath et al (2011) investigated the effect of filament fineness on comfort properties of knitted fabrics made of 150 denier polyester filament containing 34, 48, 108, 144 and 288 filaments. The fabrics were finished with moisture management finish and were assessed for wetting, wicking and moisture vapour transmission. They reported that when filament fineness increases wicking rate increases to a certain level. The yarn made of 108 filaments had higher wicking. The moisture vapour transmission was higher for finer fabrics than for fabrics made of coarser filaments. This study highlights the fact that number of filaments in a yarn and filament fineness should be at optimum level to promote moisture transmission. Filament fineness and number of filaments in a yarn play a vital role in determining the comfort characteristics of micro-denier polyester knitted fabrics.

MOISTURE MANAGEMENT

One of the main requirements of sportswear is moisture management and an optimum microclimate (including temperature and humidity) between the skin and clothing is necessary for an athlete to focus on the sports. To facilitate the moisture management, the breathability and body temperature should be regulated. Breathability is the ability of the fabric/garment to transport the moisture or perspiration from the skin to the environment. However, intense exercise or sporting activity increases body heat and sweat is produced to cool the skin's surface.

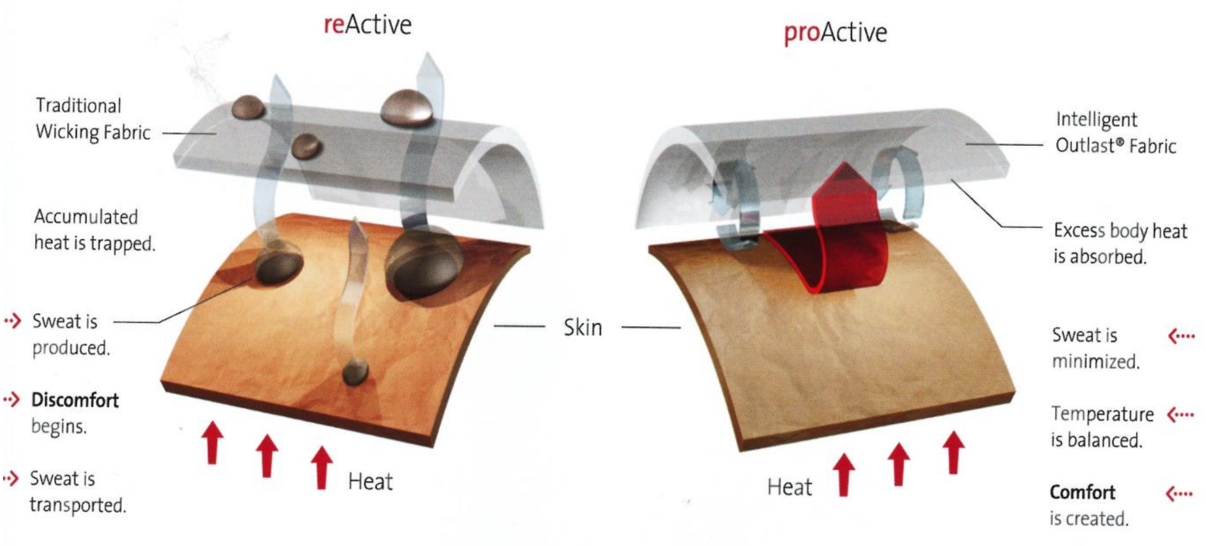


Figure 11 Moisture Management between re-active and pro-active materials

Source: © Outlast Technologies LLC

Figure 11 illustrates the conventional materials that 'reacts' to the body heat generation during intense activity, sweat is produced and transported, accumulated in the garment and results in discomfort. However, the outlast technologies is 'pro-active', which absorbs the excess heat generated by the body and sweat is minimised, temperature is balanced, resulting in better comfort. If excess body heat is not removed from the body, the athlete's performance decreases, in extreme cases it may result in fatigue, heat stress disorders or fainting. On the other hand if the excess body perspiration is not removed from the body then the fabric cling on to the body, the clothing saturated with perspiration may rub the skin resulting in blisters and rashes. Sections below highlight the importance of breathability and effect of wicking in sportswear.

Breathability is measured by determining **resistance to evaporative heat transfer** (RET), the lower the RET value the higher the fabric's breathability. Breathability can also evaluated by determining the **moisture vapour transfer rate** (MVTR), which is the rate at which a fabric allows the moisture vapour through the fabric. In other words determining the amount of moisture vapour in grams to pass through one square metre of fabric over a 24-hour period. Hohenstein Institute has produced results for RET values and physiological human comfort as ratings of wear comfort (Table 3).

Table 3 Resistance to evaporative heat transfer (RET)

RET value	Breathability	Wearer comfort
60 or less	Highly breathable	Very good
> 60 but ≤ 130	Highly breathable	Good
> 130 but ≤200	Breathable	Satisfactory
> 200 but ≤ 300	Slightly breathable	Unsatisfactory
>300	Not breathable	Unsatisfactory

Source: Hohenstein Institute, 2014

RET values for a nude person is zero and RET value increases if the clothing layers are increased decreasing the overall breathability of fabrics. It is necessary to know the breathability of materials whilst designing layering of garments which is often used in outdoor sportswear.

MOISTURE MANAGEMENT FIBRES

Trevira, a German based fibre company has developed a Trevira Moisture control with excellent moisture management properties. Fabrics made of these fibres are intended for work wear and sportswear. The fibre has a dual channel system (Figure 12) that accelerates transport of condensation molecules given off from the skin, from inner to outer layer. Moisture is wicked by the fabric surface quickly and it spreads the moisture and evaporates rapidly. The inner side of the fabric made of 100% Trevira in contact with the skin stays drier and prevents a chill effect. The following are some of the properties which the company claim:

- Very good moisture management
- Rapid dispersion and evaporation of moisture
- Quick drying
- Good pilling characteristics
- Easy care
- Washable with good fastness standards
- Pleasant handle
- Good electro-static properties
- Resistant to UV light and chlorine

Figure 12 Trevira fibres

(Courtesy of Trevira GmbH)

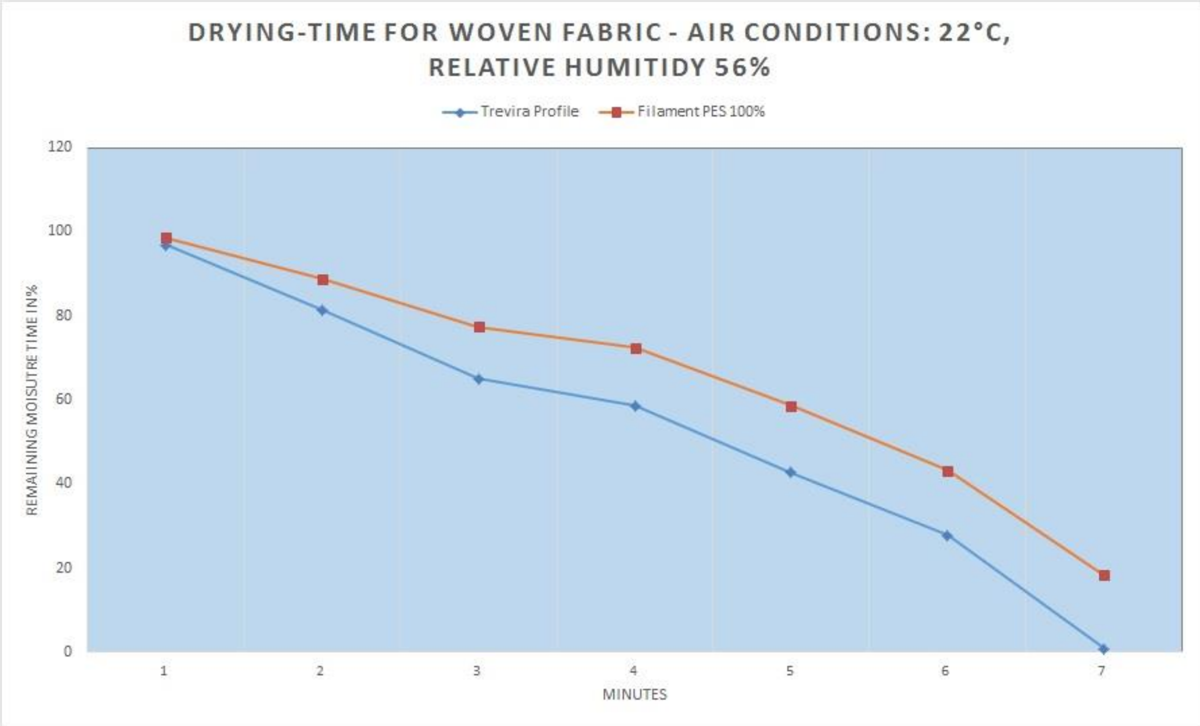


Figure 13 Drying Time for Trevira Profile

(Reproduced with permission, Trevira, 2014)

Trevira Perform moisture control, the dumb-bell shaped with its dual channel system accelerates the perspiration from the skin to transfer to fabric surface which evaporates rapidly and inner surface of the fabric remains dry (Trevira, 2014). The graph (Figure 13) above illustrates the drying time for woven fabric (at 22˚C and 56% RH) made of Trevira and 100% polyester fibre. The graph shows that the drying time of fabric made of Trevira Perform was better than the garment made of 100% polyester fibres. Moisture management using biomimetic pine-cone effect which is a bi-component yarn called Innotek (WSA, 2014).

Teijin fibres had recently reported its development of polyester fibres with enhanced moisture absorption and quick drying capabilities to prevent post-exercise chilling and stickiness from body sweat. The product had been recommended for sportswear (Teijin fibers, 2014) to be released in spring/summer 2014. The fabric made of Teijin fibers is made of three layer structure with a hydrophobic contact layer that has moisture repellent polyester fibres, moisture absorbent middle layer and outer moisture diffusion layer.

WICKING IN ACTIVE WEAR PRODUCTS

Wicking is the transmission of liquid through a textile by capillary action (Collier et al, 2009). Wicking or liquid transport properties depends on fibre type, yarn construction, fabric structure, density and structure of yarns, finishing treatment, viscosity, relative humidity of the atmosphere, and ambient temperature (Nyoni, 2010). The capillary channels in the inter-fibre spaces and size of the pores greatly determine the wicking. Various stages that involve during wicking process is given below:

1. Uptake of moisture from the skin surface.
2. Removal of moisture away from the skin and transport through the fabric surface.
3. Spreading of moisture within the fabric structure.
4. Absorption of moisture within suitable fibres: ʹdynamicʹ fabrics usually
5. Contain an ʹouter layerʹ of hydrophilic fibres to absorb and store sweat away from the skin surface.
6. Evaporation of the moisture from the fabric surface. (Nyoni, 2003)

During the last decade or so, there were developments in fibre size and shape, particularly introducing channels in filaments such as – hexa channel, tetra channel, (eg. Coolmax) where the capillary action enhances wicking action.

MAINTAINING BODY TEMPERATURE

Ultimate performance of sportswear lies in providing the optimum micro-climate next to the skin and this applies to those garments which are worn closer to the body, such as base layer products – sports vests, shorts, underwear, thermal wear, socks, etc. Beringer (2014) from Hohenstein Institute, an Independent laboratory from Germany recently reported the Innovative technology from Coolcore LLC a company from Portsmouth, US in providing cooling effect of textiles. Unlike the phase change materials or latent heat storage that exploit a change in phase from solid to liquid to absorb, store and release heat and is also free from chemicals. The finishes or chemicals that deteriorate over prolonged usage in conventional materials, however, Coolcore uses body own heat to achieve cooling.

US based Coolcore reported temperature regulating fibres, which are engineered to exploit the body's own sweat or added moisture to achieve cooling effect. The Coolcore technology which last for life of the garment works on three principles: wicking - moves sweat from the body, moisture transportation – to avoid saturation and accelerate drying, and regulated evaporation from the garment resulting in a cooling effect than conventional materials. In addition, company claims that garment does not cling on to the body due to quick wicking making it suitable for intensive sport such as cycling, running, etc. (www.coolcore.com).

DISCUSSIONS AND SUMMARY

The chapter had highlighted the importance of fibres in development of products designed for functional clothing, particularly sportswear. Fibres form the basic constituent of a garment and the performance of garment relies in choosing the right type of fibre composition by keeping up to date with the modern developments in this field. During the last decade or so the World production of man-made fibres increased from 49% in 1992 to 68% in 2012 and is bound to witness this trend as the demand for performance clothing increases. This is due to the fact that man-made fibres are engineered to meet specific requirements of the end use compared to natural fibres. The properties and characteristics of man-made fibres differ based on its fibre forming substance and it is essential to know the various technical terms used in the industry which had been briefly presented with examples. It could be argued that of the various developments in the fibre industry, fibre shape and fineness played a pivotal role in varying the performance of fabrics, for instance, it affected the moisture management, resiliency, bulkiness, warmth and overall comfort to the wearer.

During the selection of fibre types for sportswear it is essential to factor the physiological parameters particularly, sweat patterns, thermal regulation and stretch and recovery for parts of the body. This had been highlighted by critically reviewing evidence pertaining to this area and it offers new insight into development of sportswear. For instance, awareness of body sweat patterns and/or body mapping technology will enable designers to choose the most appropriate garment design. The design will elicit the usage of mesh fabric panels in central back where the athlete sweat the most compared to other zones that facilitates quick wicking and evaporation of body perspiration. In addition, it could be argued that multi-disciplinary collaboration among sports science practitioners, physiologists, textile engineers and garment designers will enable to develop products fit for purpose.

Mechanism of body perspiration and regulation of body temperature had been illustrated, the most heat is lost via clothing. The human body aims to balance between the heat production and heat loss, any imbalance results discomfort. Hence, careful consideration have to be given in regulation of body's temperature for sportswear. The rise in body temperature induces the body to produce sweat to cool the body. The garment should be able to allow moisture breathability and quickly transfer the moisture from the skin to the environment.

Athletes requires stretch and recovery during training and sporting activity. The stretch enables the athletes to move freely without restriction and offers support to the muscles, joints and prevents from strain on the tissue. The elastane fibres play an important role in providing 100% stretch, apply compression on to the muscle and prevent from soft tissue injury. Fine microfibers, hollow fibres and bi-component numerous possibilities to blend different characteristics of two different polymers and vary in shape, fineness and size to cater to demands of the end use.

Latent heat storage (phase change materials) products using thermocules in filaments to provide optimum thermo–regulation have been a breakthrough in technology in absorbing the body heat and releasing it when needed have offered possibilities for designers to tailor to the specific needs of the athletes. Newly developed cellulose fibres Tencel continued to provide new technologies particularly in moisture management and appearance and fabric handle. Widely used fibre types such as polyester, elastane, and wool blends will continue to be used in sports performance clothing, mainly due to their properties. Blending of fibres and filaments have been a practice in meeting the growing requirements of performance clothing. The blending of fibres enables to enhance the performance, durability, maintenance and reduce the overall cost of the product and this trend will continue to grow in sportswear.

Fibres that has dual channels to wick the perspiration, avoid condensation and accelerate drying and maintain body temperature using body heat will be implemented in various athletic wear such as vests, underwear, base layers, tights, etc. Hence, it becomes vital for apparel designers, technologists, and various stakeholders in the field of sportswear to carefully select different fibre types based on the end use and requirements. Innovations in fibre technology is fuelled by ever growing thrust among athletes to outperform in their respective field. Recent technological developments to utilise the energy produced by the body during an activity have been tested and resulted in production of smart products whose performance lasts lifelong. It is anticipated that textiles for sportswear will witness advance and smart developments in the years ahead that would fascinate athletes to wear smart garments which would meet their specific requirements and enhance their performance and appearance.

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