CHAPTER 3 FABRIC PROPERTIES AND THEIR CHARACTERISTICS

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1.0 INTRODUCTION

A confident understanding of fabric behaviour and characteristics are vital in the design and development of a functional garment. For instance, a warp knit mesh fabric made of 100% polyester designed to wick moisture away from the skin, with the quick dry ability, making it ideal for everyday wear and preferred in extreme performance requirements. On the other hand, Georgette is a balanced plain-woven fabric generally made of 100% polyester with high twist yarns giving the fabric less smooth appearance used in fashion apparel. Textile materials have evolved in recent times and fabrics play a significant role in the development of sportswear industry. In fact, it reflects the quality of a brand and its identity. The primary focus of this chapter is to present the essential and the desirable properties suitable for performance apparel especially for sportswear. Various sportswear applications are discussed to enable the reader to understand the rationale for such parameter. Generally, garments intended for fashion apparel will have to fulfil the following characteristics: durability, strength, colourfastness, aesthetics and so forth. These properties are mandatory for everyday use and maintenance for fashion apparel. However, in the case of performance apparel the requirements are functional and application-specific properties, such as moisture transmission, thermal resistance, wicking, water proof, and flame resistant. The reason for requirements of such properties is because functional apparel are subjected to a wide range of end uses such that a garment will be affected by internal (fibres, yarn fineness, warp/weft movement, fabric density, thickness, fabric count) and external factors (external environment – exposure to sunlight, wind, rain, cold weather conditions and during use). These factors affect the performance and behaviour of functional apparel which are discussed in the sections with examples. In addition, the interaction between the human body and garment is significant; this is true for those close-fit garments such as, base layer garments, where thermo-regulation plays a vital role in the performance of an athlete. Fabrics for sportswear are either woven or knitted and is often blended with synthetic and natural fibres with varying linear density to provide an optimum performance. The heavy weight fabrics for outerwear are multi-layered (coated or laminated) and their properties differ from light weight fabrics. Parameters of these fabrics due to structural difference are highlighted here with specific focus on functional apparel. Fabric behaviour will be affected by its composition and this is presented with examples. This chapter will empower the reader to understand the properties of fabrics for various performance application, and how these parameters will affect the overall performance of the garment.

2.0 FABRIC PROPERTIES AND THEIR INFLUENCE ON PRODUCT PERFORMANCE

A number of fabrics are used in performance and sportswear apparel include – smart fabrics which has intelligent approach to high body or ambient temperature – the warmer the material gets the faster the moisture management system functions – Burlington's smart fabric temperature management. The technology uses micro-encapsulated phase change materials called Thermocules® to absorb and release heat to enhance comfort. Light weight, stretchable and soft waterproof or breathable fabrics; fabrics made of fine micro-fibres with breathability; soft shell or three layer fabrics which are bonded as well as laminated made of tricot warp knits or woven fabric for wind insulation or water proof; knits – with synthetic or natural fibre blends and up to 30% elastane fibres for stretch and recovery, fleece and brushed knit made of synthetic fibres that has a natural feel, stretchy and smooth surface; woven shirts with varying fabric weight (160 to 400 g/m^2); eco-friendly fabrics include recycled polyester; fancy fabrics with patterns, designs and finishes, laser or etched burnt out, 3D knits, honey comb patterns and work wear and protective wear fabrics include durable rugged finish, cut resistant, flame retardant, resistance to abrasion, reflective facings, etc. Figure 1 illustrates the type of fabrics used for fashion apparel which include woven, knitted fabrics, braids, interlining, bonded fabrics and felt. It should be noted that fabrics – woven and knitted will perform differently due to their structural variation which is summarised in Table 1. Functional apparel have a combination of fabrics made of woven and knitted to suit various application.

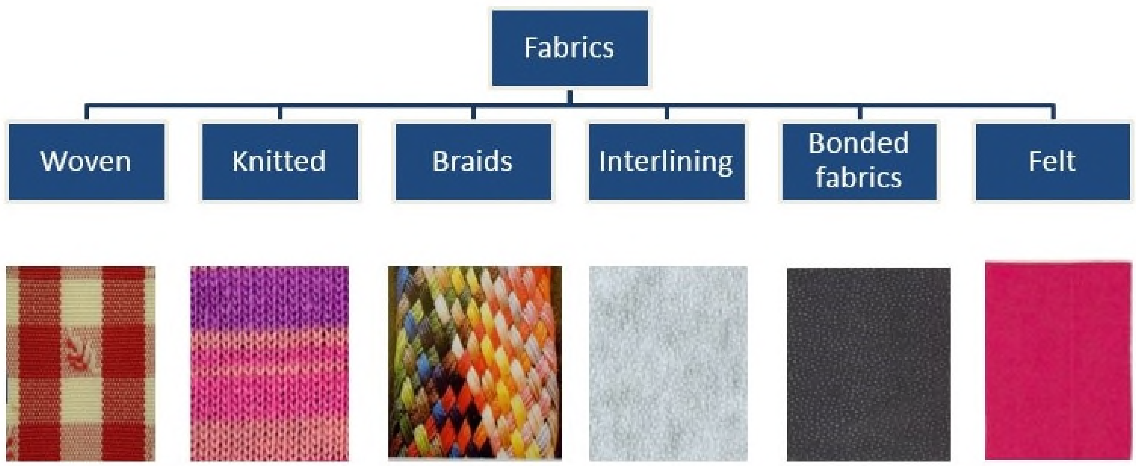


Figure 1: Common fabric types for apparel end use

Table 1: Fabric characteristics

Knitted fabrics	**Woven fabrics**
• Series of interconnected loops made with one or more sets of yarns. • Can be ravelled from top to bottom. • Warp knits cannot ravel. • Fabric can snag and run, bowed or skewed. • Usually heavier because more yarn is used.	• Two or more sets of yarns interlaced to form the fabric structure. • Yarns interlace at right angles. • May be bowed or skewed. Can be ravelled from any cut edge. • Usually lighter in weight because less yarn is used
• Possess stretch and elasticity, adapts to body movement. • Good recovery from wrinkles, air permeable. • Possess open spaces between yarns and bulky.	• Possess limited stretch and adaptability to body movement • Bulkiness and recovery from wrinkle depends on weave structure • Stable to stress, less air permeable, especially with dense fabric.
• Porous and less opaque	• Provides maximum hiding power and cover

• Less stable in use and care. Higher shrinkage unless heat-set	• More stable in use and care. May shrink less than 2%

In order to understand the fabric properties of garments designed for active wear it is necessary to explore the sports trend - type of sports preferred, frequency of activities, and garments frequently purchased. In the UK, a number of sporting activities are preferred, amongst many, swimming, running, cycling, tennis, golf and aerobics are widely preferred (Mintel, 2011). Population involved in sports are generally younger group whose age range from 16 to 24 and this trend can noted across various sports. However, population in the age range 25 to 34 and 35 to 44 were also active particularly in swimming, using gym, running, cycling and tennis.

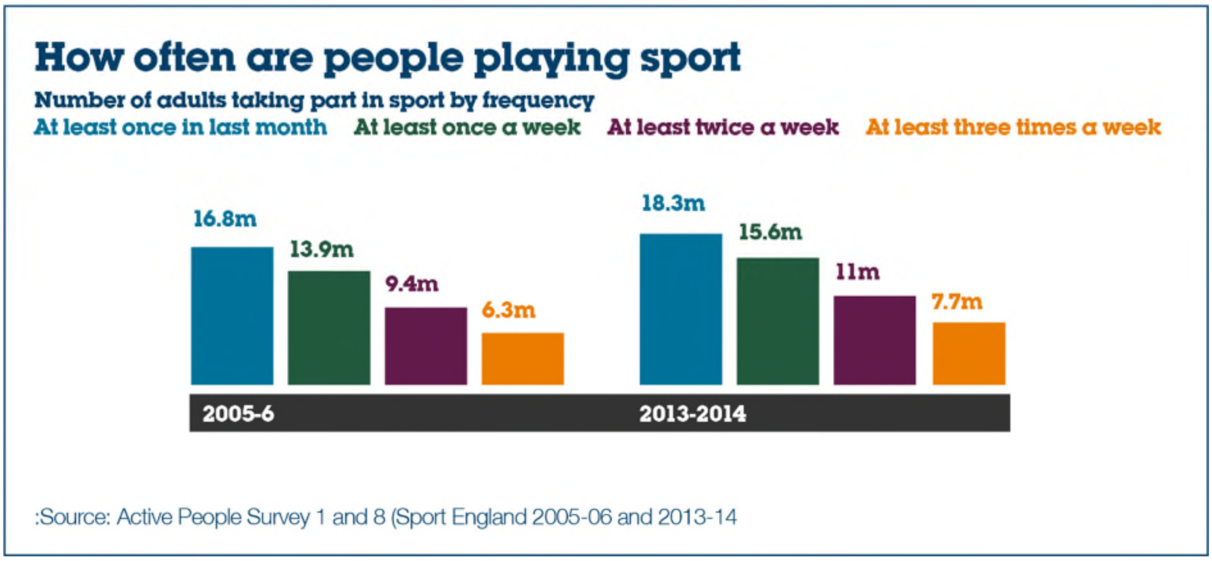


Figure 2: Number of adults taking part in sports 2005/6 and 2013/14

(Source: Sportengland.org)

There is a gradual and consistent increase in the number of people who involve in sporting activities over the last eight years (Figure 2). This includes adults who take part once a month, once a week, twice and three times a week.

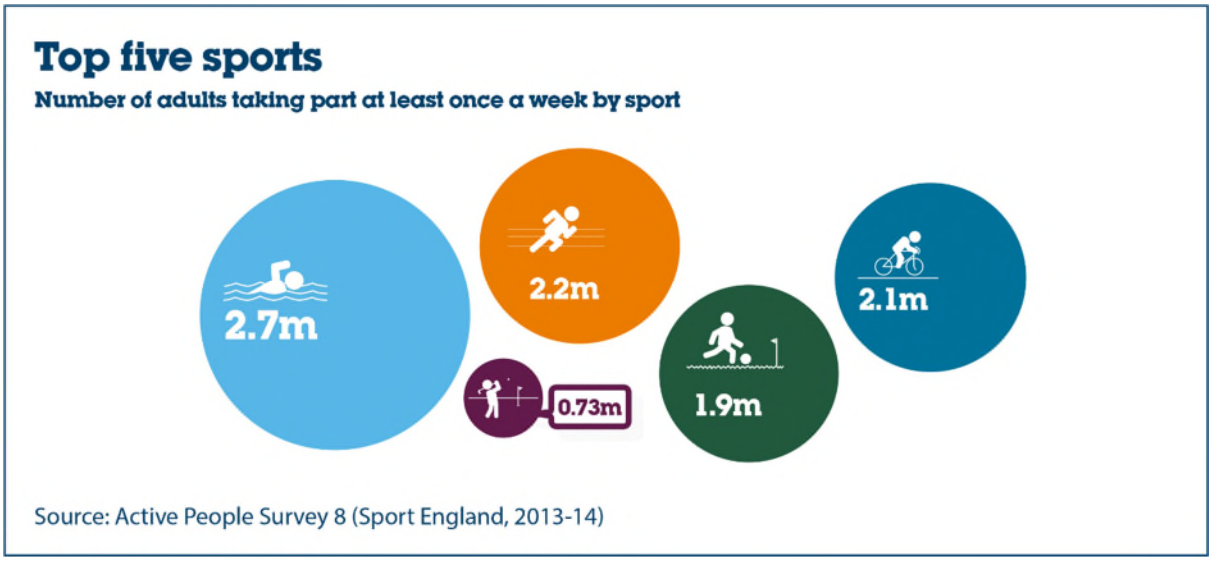


Figure 3: Top five sports played

(Source: Sportengland.org)

Sport England survey on the most frequently preferred sports in the UK reported that swimming was mostly preferred to stay fit and as a sporting activity (Figure 3), followed by athletics, football, cycling and golf (www.sportengland.org). In this chapter, specific focus will be given to those fabrics which are used in the manufacture of garments for these sport activities.

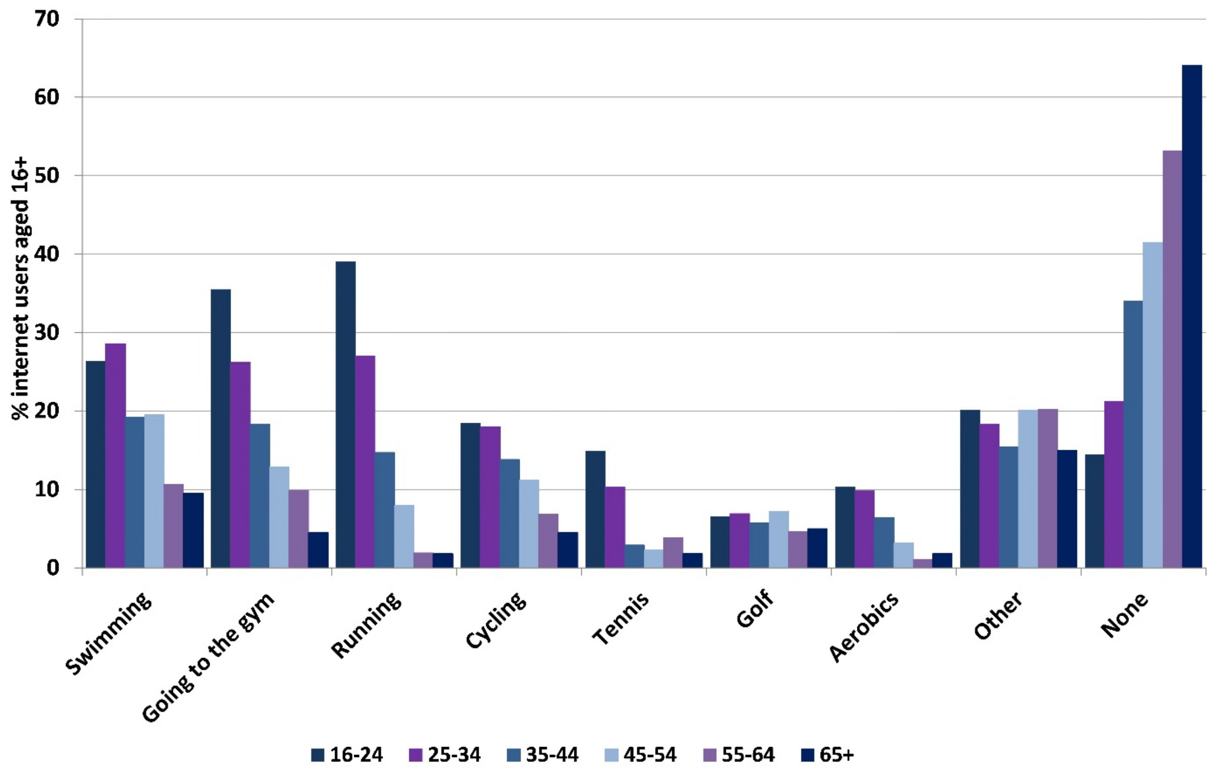


Figure 4: Sports clothing purchased during 2010/11in the UK

(Source: Mintel, 2011)

It can be noted that most of sport loving population purchase garments for casual end uses or as fashion apparel than for sporting activities. This trend was observed across all forms of garments from trainers to fleece. It should be noted that survey was based on internet users (n=2000) who were above 16 years and among them trainers, jogging trousers, t-shirts, shorts, football shirts, sweat shirts and sports jackets are popular among consumers. In addition, at the lower end of the segment, replica rugby shirts, waterproof jackets, fleece, leggings and vests were also popular (Figure 4). Mintel (2011) recently in its report stated that 33% of consumers purchased sportswear as a comfortable leisure wear; 21% consumers stated they would prefer branded sportswear and 46% of consumers purchased sportswear clothing to stay physically active and to enhance their performance. This finding is interesting that the sportswear market has a good base, particularly among younger age group and most prefer garments to stay fit and support in their performance.

It is also necessary to note that sports active adults prefer functional garments for leisure activities.

2.1 Essential and desirable properties of fabrics

A fabric property is a characteristic of a material, which it should possess for it to be used in a desired application satisfactorily. In other words, it can also be termed as the requirement of a textile material for a certain purpose. In this section, various fabric properties mandatory for performance and sportswear are highlighted. In order to identify the desirable and essential property it is necessary to know the requirements of a specific sport (Table 2). Essential properties are those that are necessary for a particular sport either due to regulations or user requirement. On the other hand, desirable properties are those which are preferred by users for aesthetics and appearance. Let us explore the some of the widely preferred sports. It should be noted each and every sport has different requirements based on the nature and intensity at which they are played. However it is assumed these are at professional level and include those fabrics that are used for casual, fitness and sporting activities.

Table 2 : Major sports and parameters required

TYPE OF SPORT AND GARMENTS USED		ESSENTIAL PROPERTY OF FABRIC	DESIRABLE PROPERTY OF FABRIC
Football	Typical garments include tops, trousers, base layer tights, socks, compression tops and shorts, soft shell jacket, and knee support	• Moisture (sweat) management • Breathable • Anti-cling • Anti-static • Light weight fabric • Anti-odour • Durable • Washable • Colour fastness	• Aesthetics • Sensorial comfort • Soft next to the skin
Golf	shirts, trousers, jackets, water proof jackets and socks	• Comfort • Moisture management • Thermal insulation • Durable	• Colourfastness • Smooth to skin • Aesthetics – crease recovery and stiffness • Soil resistant

Cycling	Bib shorts, cycling shoes, short sleeved jersey, base layer vests, fingerless gloves, socks, and cap	• Stretch and recovery • Sweat absorption • Wicking • Compression • Breathable • Wind proof • Anti-odour • UV protection	• Long lasting fit • Durable (good bursting strength) • Fabric stability
Swimming	swim suit, board shorts, jammers, racer back suits, swim briefs, body suits, and soft-shell jackets.	• Chlorine resistant fabric • Low moisture absorption rate • Colour resistant • Quick drying • Improved elasticity • Drag-resistant • Four-way stretch	• Soft feel to the skin • Shape retention • Improved comfort • Support in garment fit • Anti-bacterial • UV protection
Athletics	Body suits, tops, t-shirts, shorts, track suits, leotards, sports bra	• Light weight • Keep cool • Sweat management (wicking) • Breathable • Sustainable (natural fibres) • Water proof (jackets) • Thermal insulation (fleece) • Compression (base layer)	• Snag resistance • Aesthetics • Colourfastness • Water repellent

Some other properties of fabrics/garments required in performance apparel

- Absorb moisture readily
- Appearance
- Attractive
- Bend repeatedly without breaking
- Conceal or protect
- Dimensionally stable
- Easy to dispose
- Easy to maintain
- Fabric hangs freely
- Good surface texture
- Impact protection
- Lustre
- Non-absorbent

- Protect the body
- Resilient
- Resistant to insect damage
- Resistant to mildew
- Shrinkage resistant
- Soft-next-to-skin
- Stretch without breaking
- Transfer electric charges
- Transfer or maintain heat
- Wick moisture readily
- Withstand degradation from sunlight
- Withstand pulling force
- Withstand use

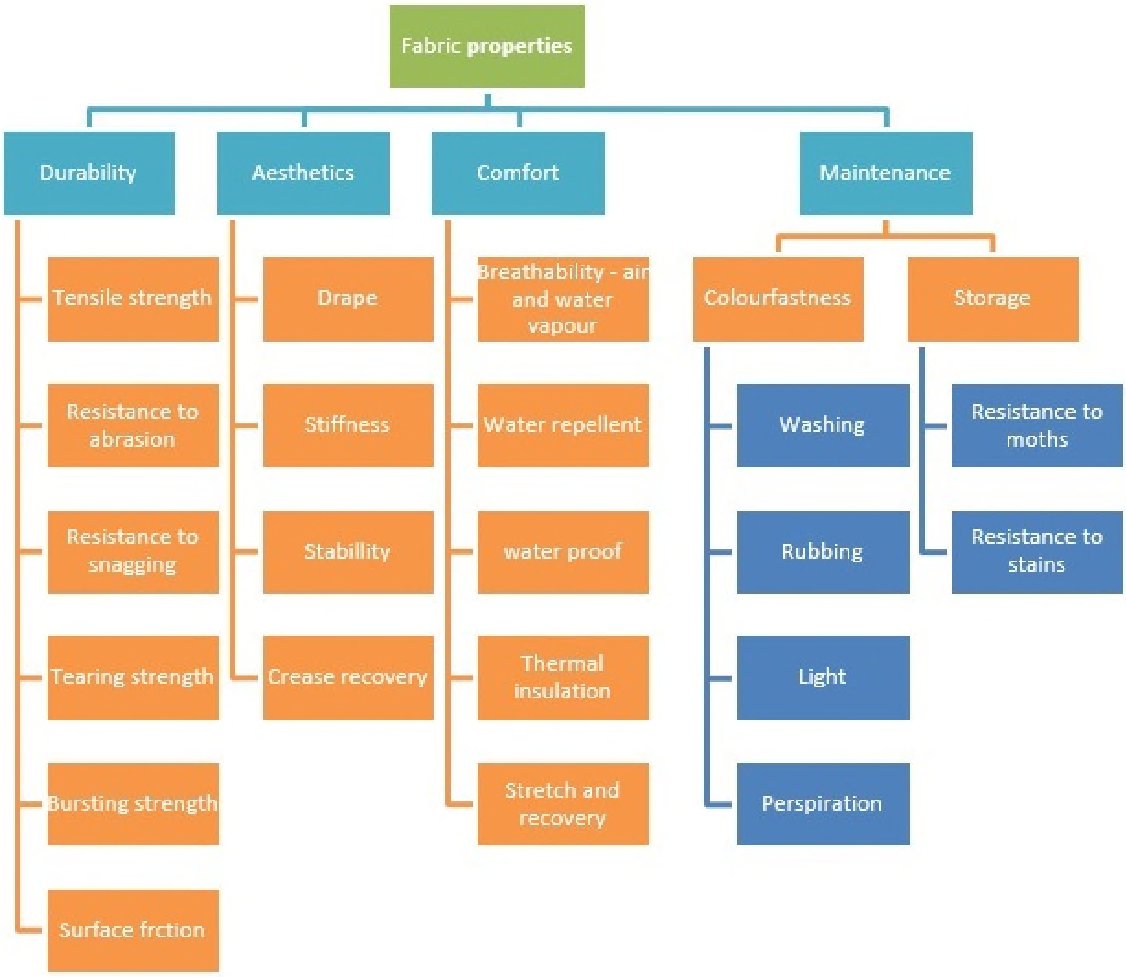


Figure 5: Fabric properties

Figure 5 illustrates the properties of fabrics which are classified into four sections, durability, aesthetics, comfort and maintenance of a garment on a day-to-day basis. The terminology of various fabric properties are presented in Table 3 with specific application.

CASE STUDY: A cycling enthusiast- fabric requirements

A cross-country cyclist* illustrated in the picture is a regular cyclist who uses bike training twice a month. Each occasion can involve from five to seven hours of intensive cycling. The garments that the cyclist uses include bib-shorts and tops. In addition, elbow support and shinbone protection for the lower limb is part of the kit. Some of the properties that the cyclist prefers in their garments are:

1. Light weight
2. Economical
3. Durable
4. Washable
5. Easy to wear
6. Soft next to the skin
7. Breathable
8. Moisture absorbent
9. Practical (fit for purpose)
10. Economical

It could be noted that the cyclist who is a professional who wants to involve in the sport as a recreation as well as to keep fit. The cyclist pays significant attention to the clothing gear and desires to wear garments that allows free movement as well as protect from injuries.

Table 3: Fabric properties and their application			
Category	**Textile parameter**	**Definition**	**Suitability**
Durability	Breaking strength	Force required to break a fabric when it is under tension	Woven fabric
	Tearing strength	Force required to continue a rip already started in the fabric	Woven fabric
	Bursting strength	Amount of pressure required to rupture a fabric	Knitted fabric, felts, nonwoven fabric, lace
	Abrasion resistance	Resistance to wear away of any part of material when rubbed against another material	All fabric and applications
	Pilling resistance	Formation of pill or fuzz on the surface of the fabric	Hydrophobic fibres and fabrics with inferior yarn quality
	Surface friction	Ability to offer resistance to rubbing force or sliding action	Fabrics with low yarns per inch
Aesthetics	Fabric drape	The ability of the fabric to drape or to hang on its own weight to follow the body contours and graceful folds/curves.	Woven and knitted fabrics
	Stiffness (Fabric handle)	It determines the bending length of the fabric or ability of the fabric to bend under its own weight at a specified angle	Woven, nonwoven fabrics in both directions
	Crease recovery	Ability of the fabric to resist creasing	Wool/silk - high resistance to creases, cellulose fibres poor resistance

	Dimensional stability	The ability of the fabric to remain stable without change in its dimension after washing	Woven and knitted fabrics
comfort	Air permeability	Ability of the fabric to allow passage of air through its surface at a specified pressure difference over a certain period.	Dense woven fabric
	Moisture permeability	Ability of the fabric to allow moisture vapour to pass through its structure	Fabric with finishes with certain coating for water penetration
	Thermal conductivity	Ability to conduct heat (K m/W); implies the quantity of heat that passes in unit time through a plate of particular area and thickness	Garments for outer door wear
	Water proof	Resistance to water penetration	Fabrics with film/membrane coating
	Stretch and recovery	Ability of the fabric to stretch under deformation and recover to its original position after removal of deformation	Knitted fabrics with elastane composition
Maintenance	Colourfastness to washing	It is a measure of how permanent a colour remains on the fabric during washing	Mild to dark colour/shaded woven/knitted fabrics
	Colourfastness to Rubbing	To determine the effect of colourfastness in wet and dry rubbing action	Woven and knitted fabrics that bright or dark coloured
	Colourfastness to Light	To determine the effect of colourfastness during continuous exposure to light source	Woven and knitted fabrics that bright or dark coloured – outdoor /swimwear
	Colourfastness to Perspiration	To determine the resistance of the colour of textiles to human perspiration	Woven and knitted fabrics that bright or dark coloured worn next to the skin – socks, tights, etc.
Storage	Resistance to moths/insects	Ability of fabric to resist from moth and insects during storage	Fabrics with animal fibre composition

Resistance to stains	Ability of the fabric to staining during long term storage	Woven / knitted fabrics

3.0 FACTORS THAT INFLUENCE FABRIC BEHAVIOUR

Functional apparel will be subjected to a wide range of end uses such that a garment will be affected by internal (fibres, yarn fineness, warp/weft or course/;wale movement, fabric density, thickness, fabric count) and external factors (external environment – exposure to sunlight, wind, rain, cold weather conditions, fabric/human body interaction). These factors affect the performance and behaviour of functional apparel which are discussed in the sections with examples.

3.1 Internal factors influencing fabric performance

Fabric is either interlaced with one or more set of yarns or interconnected with loop of yarns, which are composed of fibres and filaments, and it is the fundamental element. In performance apparel a wide range of synthetic filaments such as nylon, polyester, elastane, acrylic and so forth are widely used. Fabric behaviour is affected by fibre blends and their fineness (McGregor and Naebe, 2013). Similarly, yarn quality (count) is pivotal in producing a uniform fabric texture. Some of the yarn quality parameters such as yarn twist, number of folds, and yarn count affect fabric characteristics. For instance, a fine quality yarn made of fine denier filament will possess a supple and pliable fabric that has low drape coefficient. On the other hand, a coarse yarn will produce a stiff fabric that has high drape. There is effect of fibre type, yarn quality and fabric attributes on fabric performance. McGregor and Naebe (2013) reported the comfort properties of 81 single jersey knitted fabrics with varying fibre, yarn and fabric attributes. The research studied the comfort properties of wool knitted fabrics with 27 types of fibre blends, 16 types of yarn and 30 different fabrics. Authors reported that tighter fabrics were less comfortable and progressive blending of cashmere with wool progressively increased comfort assessment. The tactile comfort properties were assessed using WCM – wool comfort metre. They further added that fabric thickness, yarn elongation and yarn quality (thick and thin places) affected fabric comfort properties (Figure 6).

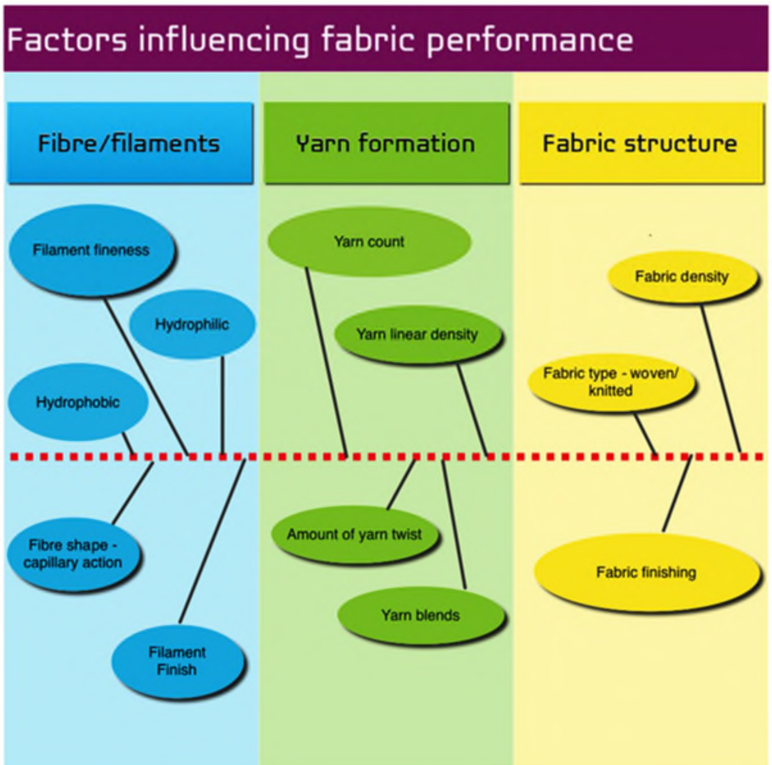


Figure 6: Internal factors affecting fabric performance

It should also be noted that finer fibres (linear density) influence the behaviour of fabric and its performance especially in sportswear. A fabric is also termed as micro-fabric when it is made of filaments whose fineness is less than 1 decitex. The term micro-denier fibre is widely used in Asia and US. Micro-denier fibres have excellent flexibility and yarns are of better regularity. This parameter enables yarns to be knitted and resulting fabric is soft and pliable (Chattopadhyay, 1997). In addition, knitted fabrics with micro-denier fibres have better dimensional stability and wick the moisture, resulting in better comfort. This makes the micro-fabric ideal for sportswear. Srinivasan et al. (2005) investigated the performance of polyester micro-denier knitted fabrics and compared with normal polyester. The study reported that micro fibre fabrics possessed excellent drape, moisture transmission property, wicking and were dimensionally stable. Such property makes it ideal for active sportswear (Figure 7).

In addition, fibre fineness and yarn quality, affects the fabric behaviour particularly the comfort characteristics – wicking and moisture vapour transmission. Such a parameter is essential in maintaining comfort levels of an athlete wearing a base layer. 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. Mori and Matsudaira (2000) highlighted that fabric density was an essential factor in determining fabric handle of wool fabrics.

Fabric density greatly affects the performance, for instance, a high fabric count has good abrasion resistance, fabric cover, and dimensional stability. In addition, the fabric has excellent resistance to wind and reasonable strength. Such a property is widely preferred in work wear and trousers. On the other hand, low count fabrics possess poor abrasion resistance, low fabric cover, low stability leading to shrinkage, and low resistance to wind.

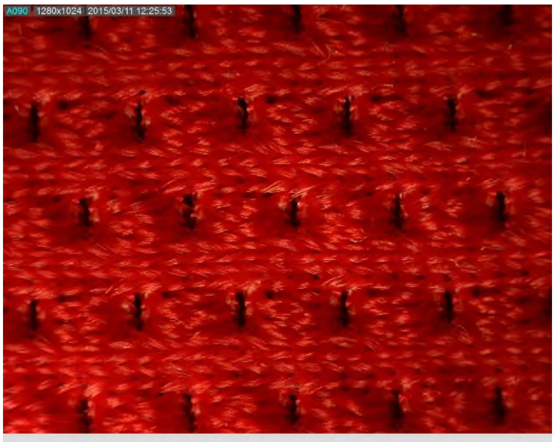
a.  b. 

Figure 7a and 7b Knitted fabric with vents

Matsudaira et al. (2009) investigated the effects of weave density, yarn twist, yarn count on fabric handle of polyester woven fabrics by using objective evaluation method. Plain-woven fabrics made of polyester used for women's wear such as Tafetta, Dechine, Georgette 1, Pongee, Yoryu, and Georgette 2 were selected. Various fabric handle properties such as stiffness, ant-drape stiffness, crispness, scroopy feel and flexibility with soft feel were studied. Stiffness increased with increase in weft yarn density (2000 to 5000 picks/m) for all fabrics; Anti-drape stiffness also increased with increase in weft yarn density (2000-5000 picks/m). Fabric soft feel decreased as the weft density increased from 2000-5000 picks/m. Hence, weft density is inversely proportional to fabric soft feel. Fullness and softness did not show any change with the variation in weft density. Larger weft density is needed to produce lower crispness. There was no difference in scroopy feel of the fabric with increasing weft density. The effect of yarn twist was noted in fabrics – Dechine and Yoryu. In the case of Dechine the stiffness and anti-drape stiffness decreased with the yarn twist, however in the case of Yoryu fabric a little change was noted in all the parameters. Effect of yarn count on was noted for Taffeta and Georgette where stiffness and anti-drape stiffness decreased with increase in yarn count.

Prakash and Ramakrishnan (2013) explored the effect of fibre blend ratio, fabric loop length and yarn linear density on thermal comfort properties of single jersey fabrics. Three yarn count quality (20s, 25s 30s: Ne) were produced with blends of cotton and bamboo fibres. Investigators reported that thermal conductivity was reduced as the proportion of bamboo fibre increased, as lowest thermal conductivity was observed with 100% bamboo yarns. For a given fabric of a certain composition, the air permeability increased as loop length increased. In addition, air permeability of 100% bamboo fabrics was 200% that of cotton fabric. Fabrics made of bamboo blended yarns had a lower thickness and fabric density than cotton fabrics. The water vapour and air permeability improved with the increase in the composition of bamboo fibre content. Water vapour permeability determines breathability of the clothing material. It is the transmission of water vapour through fabric from the skin to the outer surface by diffusion and absorption-desorption process (Das et al, 2009). As the yarn linear density increased, thermal conductivity decreased because fibres trapped more air. Finally, as the yarn linear density increased, relative water vapour permeability increased particularly for bamboo blended fabrics. Researchers noted that increase in water vapour permeability can be attributed to lower fabric density and thickness. When the yarn count is coarser, the fabric density and thickness increased resulting lower water vapour permeability. Karhan et al. (2006) stated that natural bamboo fibre provided functional properties due to its excellent moisture absorption, quick evaporation and anti-bacterial properties. This shows that a number of internal factors including fibres, yarn and fabric structure affect the fabric characteristics and designers/garment developers should pay particular attention in the selection of appropriate fabric. In the next section, evidence pertaining to external factors affecting the performance of the fabric are discussed.

3.2 External factors influencing fabric behaviour

Performance apparel is exposed to a wide range of external conditions including sunlight, rain, wind, cold/warm weather conditions or during intense physical activity interaction with the human body. Generally, fabrics meet common requirements such as strength and durability; however fabrics with special properties make them to be used in special applications intended for high performance apparel. Typical performance apparel for active wear involves wearing clothing layers and various requirements of fabrics is outlined below (Figure 8).

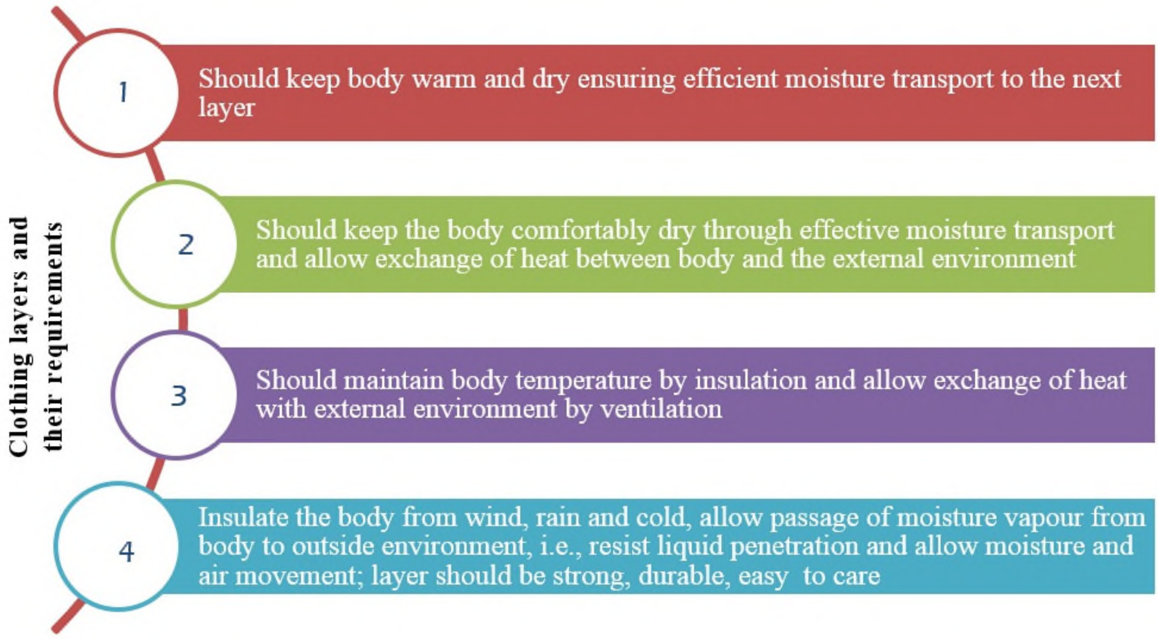


Figure 8: Clothing layers and their requirements

Wang et al. (2007) reported a wearer trial using clothing layers (four structures). They reported that the moisture management property of fabrics significantly affected the moisture diffusion and temperature distributions in the cold protective clothing systems, and influenced the thermal and moisture sensations, when the wearer was exposed to climate chamber maintained at -15°C.

Investigators Long and Wu (2011) reported a research on cotton fabric coated with nanoparticles made of compound of titanium dioxide and nitrogen breaks down dirt and kills microbes when exposed to light. In the past the invention was only applicable when fabrics were exposed to certain ultraviolet rays. But researchers reported that they intend to develop fabrics when exposed to ordinary sunlight. The fabric removes orange dye stain upon exposing to sunlight. Fabric coating is durable and remains intact after several wash and drying.

Some of the external factors can affect wearer, particularly when a wearer is exposed to long and continuous amounts of sunlight. Ultra-violet rays can cause damage to textiles as well as cause acute skin damage (Thiry, 2002). It should be noted that the earth's atmosphere absorbs harmful wavelengths, and only 5% reach the earth's surface (Rajendrakumar et al, 2006 and Xin et al, 2004). Researchers Sundaresan et al. (2011) recently investigated the UV protection using nano TiO_2 as well as the anti-microbial and self-cleaning properties of cotton fabrics. The fabrics treated with 12nm nanoparticles exhibited higher UPF values than the fabric treated with 7nm nanoparticles. The durability of the imparted function was in the range of 32–36 washes for antimicrobial activity and UV-protection property. In the case of self-cleaning activity, the smaller nanoparticle size TiO_2 derived using sol-gel technique; exhibited better self-cleaning activity as compared to large nanoparticles of nano-sol TiO_2.

A garment when it is in the wet condition, the comfort is affected and this depends on thermal properties, moisture vapour resistance of clothing and the percentage of moisture accumulated inside the clothing. Hence, during wet conditions the physiological comfort depends on the thermal resistance in wet state and the active cooling resulting from the moisture evaporation from skin through the clothing and from the direct evaporation of sweat from the fabric surface.

Onofrei et al., (2011) reported the thermal comfort properties of elastic knitted fabrics produced with functional yarns (Coolmax® and Outlast®) that has thermo-regulating effect. The measurements were made at dry and wet states, and the moisture transfer between the fabrics and a wet skin was assessed. Thermal parameters such as thermal resistance, thermal conductivity and absorptivity were reported. Two knitted fabrics were assessed - Polyester (Coolmax®)/ Elastane (Creora) and Viscose (Outlast®)/ Cotton/Elastane (Creora).

Measurements at dry state: The air permeability of Coolmax® fabric was lower than that of Outlast® fabric. This was due to the higher thickness of the fabric. The higher surface area of the Coolmax® fibre increased the resistance to air flow, which resulted in lower air permeability. Thermal conductivity of a fabric represents the ability of the fabric to transport heat and resulting due to combination of fibre conductivity and structural characteristics of the fabric. In dry state, the Coolmax ® fabric exhibited higher thermal resistance, lower thermal conductivity and lower thermal absorptivity when compared with the Outlast fabric. Outlast knit fabric exhibited higher thermal absorptivity values giving a cooler feeling at first contact with the skin.

Measurements at wet state: The rate of air flow through the wet fabric decreased when the fabric moisture increased. The authors reported that decrease in fabric porosity due to fibre swelling (Outlast fabric) and replaced air spaces with moisture. Both fabrics in wet state had higher values of thermal conductivity than in dry state. The thermal conductivity and thermal capacity of water is much higher than those of the fibres and air entrapped within the fabric, which lead to a higher heat conduction. For the Coolmax® fabric, the effect of increasing moisture content above the 'sweating sensation' was not significant for thermal conductivity and resistance. In the case of Outlast, the increase in moisture content significantly raised thermal conductivity and decreased the thermal resistance. Researchers reported that Outlast® fabrics were more prone to significant thermal properties changes due to moisture uptake than the Coolmax®. In addition, 60% moisture content acts as a threshold to major changes on Outlast® fabrics thermal properties. Hence, it can be noted that influence of moisture can affect the thermo-physiological comfort of the wearer and this is applicable to those functional yarns – that has therm-regulating effect. Outlast® is a thermally active material (Phase change material with viscose fibre structure and thermo-regulating effect depends on heat absorption and heat emission of PCM www.outlast.com. Thermo-regulation of Coolmax® depends on moisture management due to shape of fibres (multi-channel) that depends on capillary theory – absorb sweat and moisture away from the skin and transport it to the fabric surface and leading to evaporation www.coolmax.invista.com.

Commercial examples – fabrics for outer wear

Table 4 below outlines some of the recent developments in fabrics with specific properties that prevents or protects the wearer from exposure to extreme weather conditions.

Table 4: Fabric with specific properties

Sunlight protection	Sun reflector - UV protection From Schoeller – Solar+ and cold black www.coldblack.ch	Coldblack® with a special finish reduces absorption of heat rays and provides a minimum of 30 UPF protection without affecting the appearance and sensation.
Rain/water repellent	Ecorepel® for outdoors from Schoeller www.ecorepel.ch water repellent and breathable	Ecorepel is biodegradable and offers natural protection from stain and water. The fabric is breathable and soft. Made of fibres with long paraffin chains that wrap themselves spiral like around filaments and reduces surface tension of water droplets and even mud runs-off.
Water resistant and thermal insulation	Primaloft fibres – thermal insulation and water resistant www.primaloft.com	PrimaLoft fibres adsorb 100 – 250% weight in water and insulates under wet conditions. It is resistant to wind and compressible. The fibres trap large volume of air resulting in superior thermal performance.
Extreme cold weather	Extreme cold conditions – Polartec Alpha®	The fabric is made of three layers: protective outer layer that is breathable, middle lofty layer which traps air and smooth inner lining fabric. Dries quickly to minimize heat loss. Insulates even when wet. Appropriate for a broad range of activities as a mid- or outer-layer. Wind resistant and machine washable

3.3 Fabric and human body interaction

Clothing physiology is the interaction of clothing and human body in various environments. Fabrics used for performance clothing should possess a reasonable fabric handle to facilitate the ease of wear. The interaction of fabric/clothing with the skin is regarded as a comfort factor by experts in this field. Human body remains comfortable at 37°C ± 0.5 °C and under normal conditions human body produces heat continuously. Physical activity (exercise) may rise body core temperature by 3°C while exposure to cold may lower core temperature by 1°C. Beyond these limits, the human body is susceptible to hypothermia (when the skin or blood is cooled enough to lower the body temperature, metabolic and physiological process slows down, heart rate is slow and blood pressure low, and consciousness is lost) which is life threatening.

Normally, when the core temperature increases, which is higher than what it can disperse, the body reacts by producing perspiration from the skin. The evaporation of sweat results in a cooling effect. The body shell and core temperature in a warm environment remains at 35˚C, however in cold environment inner most core body temperature remains at 36˚C; the boundary of core temperature shrinks to preserve the heat in the brain, thorax and abdomen, temperature of the limbs falls (Pocock and Richards, 2009) especially those in distal regions. Smith and Havenith (2011) investigated the sweat patterns of nine male Caucasian athletes during exercise in warm conditions. They reported that sweat rate increased significantly with exercise intensity in all regions except the feet and ankle. Lower back (posterior torso) consistently showed the highest sweat rates over the whole body. Highest sweat rates were observed on the central and lower back (posterior torso) and forehead whilst the lowest values were observed towards the extremities. These sweat pattern data would facilitate in designing thermo-regulatory clothing particularly for athletes providing a comfortable micro-climate through adequate ventilation, sweat absorption and moisture evaporation. When the surrounding temperature is below the core temperature, the body may lose heat and such heat losses be supplemented by wearing a garment with good insulation properties that can trap air and prevent heat loss.

Base layer clothing which is often termed as ‘second skin’ interacts with the body and a number of parameters were investigated relating to physical, psychological and tactile sensation. These include fabric softness (Zhang et al., 2006); fabric-skin friction property (Wang et al. 2010); tactile properties and subjective measures for next-to-skin knitted fabrics (Mahar et al. 2013). The fabric softness generally depends on fineness of filaments, finishes applied on fabric and the ability of fibres/filaments to transport or wick moisture away from the skin. Mahar et al., (2013) conducted a survey on descriptors of fabric handle of approximately 50 next-to-skin knitted fabrics. The following bi-polar descriptors were identified to describe the fabric handle:

- Smooth - rough (surface property)
- Soft - hard/harsh (Flexural property)
- Heavy/Thick – Light/thin (mass/bulk property)
- Clean – hairy (surface property)
- Cool – warm (perceived temperature)

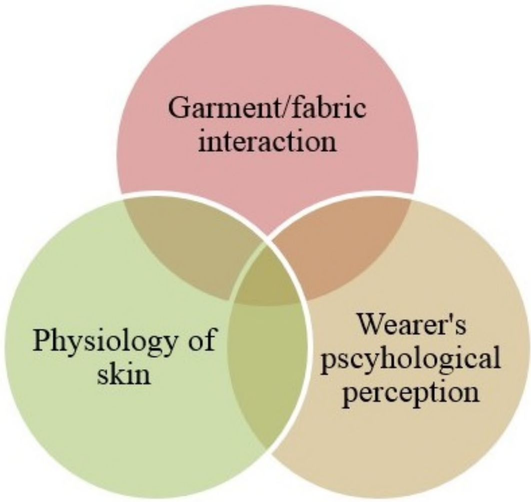


Figure 9: Fabric/human body interaction

Yao et al. (2011) investigated the interaction of skin and clothing using four cotton/polyester pajamas (underwear) conducted for three weeks under mild cold conditions. The wearer trial measured skin physiological parameters, subjective sensory response, stress level, and physical properties of clothing fabric. Fabrics were treated with hydrophilic or hydrophobic treatment. Subjective sensations were obtained from a questionnaire by rating six sensations (dampness, coldness, itchiness, softness, breathability, and overall comfort). A framework was established and researchers reported that fabric properties influence skin physiology, sensation, and psychological response. They further added that physiological effects from overall comfort sensations, sleep quality, and stress also influenced skin physiology in terms of skin surface pH and sebum. They explained the relationships among fabric, skin physiology, and psychology (Figure 9).

A garment plays a vital role in providing physical comfort to the wearer and to offer a micro-climate air cushion between the skin and garment. When a garment surface is not uniform this may result in tickling sensation, or blistering in severe conditions where there is constant rubbing between the skin and garment. Pan et al., (2005) presented a simulated model for physical and psychological interactions between skin and fabric including contact and friction as well as during motion such as walking or running. They reported that the primary factors contributing to comfort and well-being of the wearer include, fabric friction, fabric density, space between skin and fabric and elastic modulus of the fabric.

Investigators Qian and Fan (2006) reported the interaction of surface heat and moisture transfer from sweating/non-sweating manikin under varying climatic conditions and walking speeds. The researchers reported that surface thermal insulation was not affected by moisture transfer. The surface moisture vapour resistance at isothermal conditions were greater than those under non-isothermal conditions at wind velocity less than 2.0 m/sec.

The moisture accumulation due to condensation or absorption in sportswear clothing is a concern when worn during cold conditions. Hence, it is necessary to know the underlying cause of moisture accumulation while constructing multi-layer assembly of garments, which can maximise moisture transmission and minimise condensation and moisture retained by the clothing. As this will cause discomfort due to chill effect. Wu and Fan (2008) established a theoretical model of heat and moisture transfer for multi-layer assembly of fabrics. After investigating two multi-layer fabric assemblies (1) Goretex inner fabric - multiple ply wool battings - multiple ply polyester battings – Goretex outer fabric and (2) Goretex inner fabric - multiple ply polyester battings - multiple ply wool battings- Goretex outer fabric. It was reported that garment assembly which had wool batting in the inner region closer to the body and polyester batting in the outer region (away from the body) reduced moisture accumulation within and the total heat loss through the clothing assemblies. The information from this research is very useful to designing of multi-layer padded jackets for cold weather conditions.

4.0 Fabric structure and their characteristics

Structural variations of the fabric can affect the performance of fabrics, particularly in facilitating the thermo-regulation of human body. This include, yarn quality, fabric design, fabric layers, and coating on its surface. Özdil et al (2007), highlighted that knitted fabrics made from varying yarn count (linear density), yarn twist and processing (combed/carded) of fibres can affect the thermal properties of 1x1 rib fabrics. 1 × 1 rib knit fabrics produced from finer yarns (yarn count) have lower thermal conductivity and higher water vapour permeability values, these fabrics have warmer feeling property. As the yarn twist increased the thermal absorptivity and water vapour permeability also increased, resulting in a cooling effect. But thermal resistance values decrease as the twist coefficient of yarn increases. Thermal resistance values of fabrics knitted with combed cotton yarns are lower than the fabrics knitted with carded cotton yarns. It was reported that fabrics knitted with combed yarns displayed higher thermal absorptivity values. Because the hairiness of this yarn was less and these samples gave the coolest feeling.

4.1 Structural influence and their effect on performance

Phase change materials (PCM) have the ability to change their state within a temperature range that was intended for astronauts to be used in their space suit to provide thermal protection against extreme climate fluctuation (Mondal, 2008). PCM absorbs energy during heating process as the phase change takes place, or this energy can be transferred to the environment in the phase change range during a reverse cooling process. Textiles containing phase change materials react to the changes in the environment, when a rise in temperature occurs, the PCM micro-capsules react by absorbing heat and storing this energy in the liquid state. When the temperature falls the micro-capsules release this stored heat energy and phase change material convert to solid state (Mondal, 2008). The PCMs are used in the thermo-regulation of performance apparel where synthetic fibres containing PCM micro-capsules are extruded (eg., **Schoeller®-PCM™**). The melting point of PCM is 28°C. PCM are also incorporated in the form of lamination, coating, bi-component fibres or foam. Researchers Wang et al., (2006) reported the effect of integrated application of PCM and conductive fabrics in clothing using a bionic skin model. Clothing assembly of various thickness consisting of (A) nonwoven fabric plus conductive fabric without heating; (B) nonwoven fabric coated with PCM plus conductive fabric without heating; (C) nonwoven fabric with conductive fabric with heating and (D) nonwoven fabric with PCM and conductive fabric with heating. Conductive fabric was controlled in such a way that it switches on when the temperature of the second layer (B) falls below 27°C and when temperature increases above 29°C it switches off. They reported the use of conductive fabric can enhance the thermal insulation of the clothing and keep the wearer warm, by preventing the heat loss from the body while using clothing assembly coated with PCM.

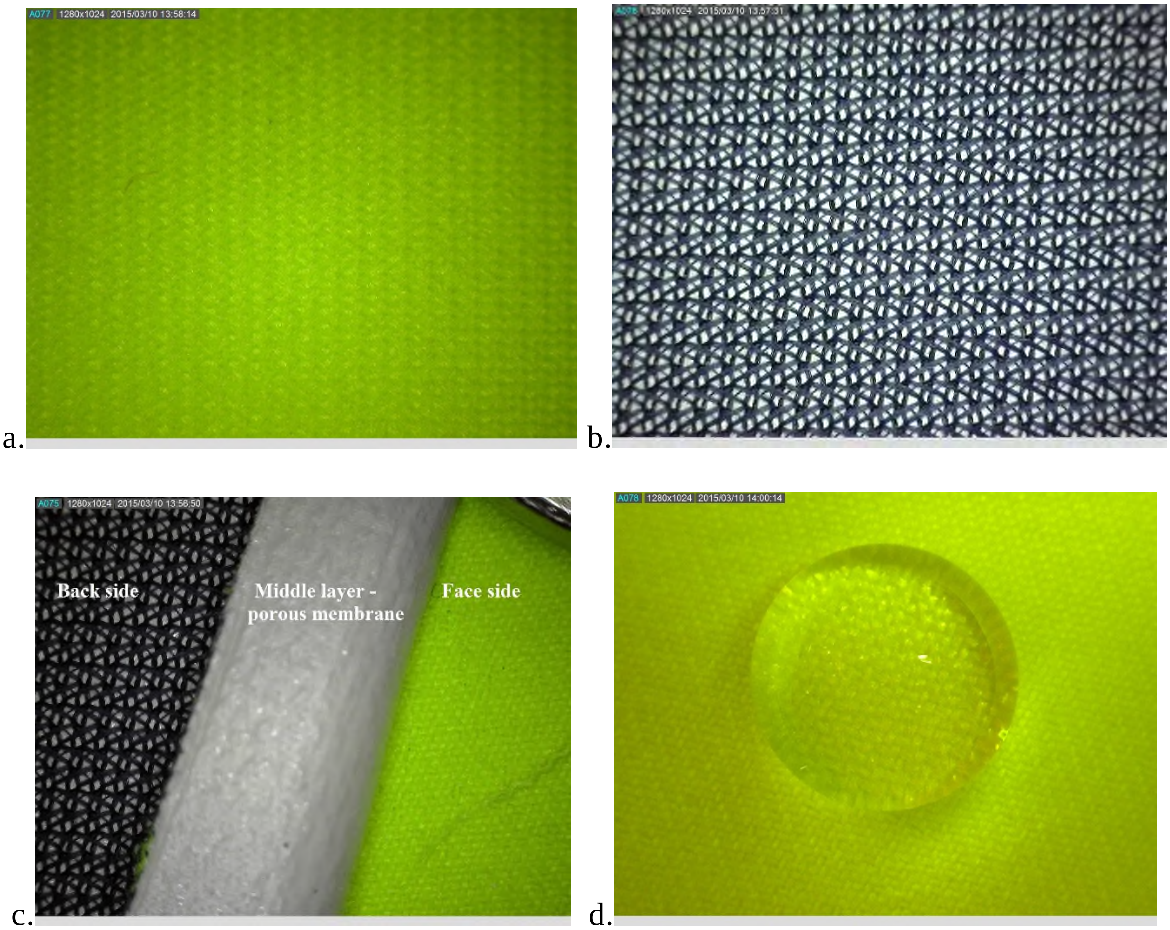
4.2 Special multi-layer fabrics for protection

The following section (Table 5) highlights different type of fabric formation will have varying response and outcomes under different climatic/weather conditions (Figure 10a to d).

Table 5: water proof breathable fabrics with specific fabric properties

Densely woven fabrics	Fabrics constructed using hydrophobic and non-absorptive fibre/yarns with high weave density and inter yarn spaces should be small to protect against wind/rain	Ventile, fabrics from micro-fibres
Micro-porous membranes and coating	Micro-porous membranes have pore size much smaller 2-3 μm than the size of rain drops 100 μm and water vapour 40x10^{-6}μm. Coated fabrics are composite materials whereby a polymer coating is applied on to fabric surface. Polyurethane, poly-tetrafluroethylene (PTFE), acrylic, polyamino acids, whose pore size range from 0.1 to 50 μm. PU coating is widely preferred due to its flexibility, durability and ability of film to suit various end uses.	Goretex, sympatex
Hydrophillic membrane and coatings	This is based on chemical chain reaction between moisture molecule and non-porous film. The property is obtained by incorporating hydrophilic backbone in the coating material which increases the affinity of polymer to water molecule and with good breathability	Durable, possess good strength, resistant to chemicals, can be designed to higher breathability than micro-porous material. Eg. Sympatex film
Biomimetics	Mimicking the analogy of leaf stomata which has the ability to open to increase the moisture vapour transmission and closes to reduce it.	Stomatex is used in conjunction with Sympatex for water proof insulating barrier.

	Stomatex is closed foam made of neoprene with a series of convex domes vented by a tiny aperture at the apex. Domes mimic the transpiration process similar to a leaf providing a control release of water vapour enhancing comfort.	
Source: Mukhopadhyay and Midha, 2008		

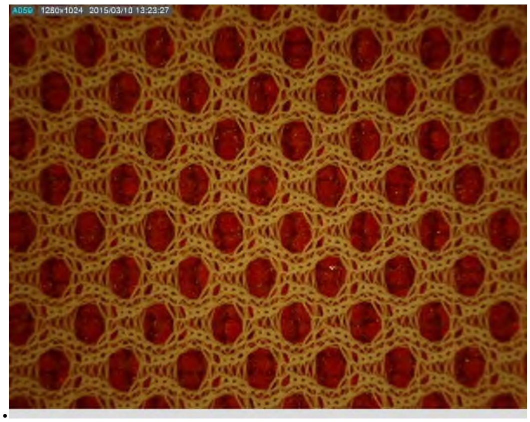


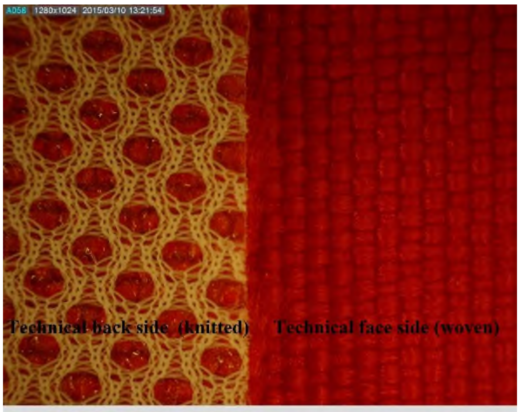
a. b. c. d.

Figure 10 a – 10 d Micro-porous membrane fabric – Gore-Tex®.

The section below highlights some of the range of coated/laminated fabrics from Frizza Group, which are suitable for work wear and outer layer jackets. For instance, Venti Bi-stretch is a lightweight fabric with a dry film Teflon lamination and has the ability to offer stretch for added comfort. Cordura 1100 is a woven fabric with Teflon lamination, which is water repellent, intended for work wear (Figure 11 a to c).

a. 

b. 

c. 

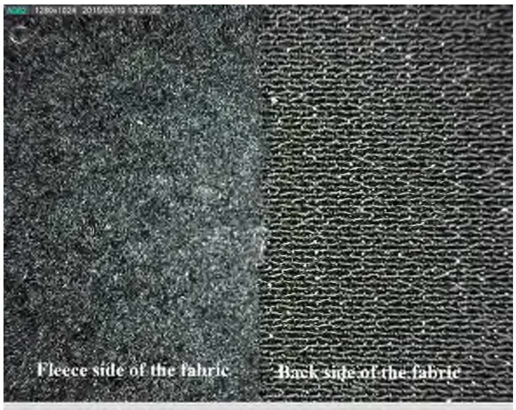
d. 

Figure 11 a, b and c: Multi-layer fabrics

1. Venti Bi-stretch – dry film S + Teflon 72 gsm; 65% nylon; 11% Elastane and 24% polyurethane
2. Cordura 1100 – Dry film bonded to woven fabric with Teflon coating – 410 gsm 80% polyamide (nylon) and 20% polyurethane (Figure 11 a to 11c)
3. Polystretch – micro-pile fabric with Teflon coating 346 gsm; 85% polyester, 14% polyurethane and 1% elastane
4. ASPEN - dry film + Teflon – 245 gsm, 82% nylon, 7% spandex; 11% polyurethane

5.0 FABRIC COMPOSITION AND THEIR EFFECT ON SPORTSWEAR PERFORMANCE

Fabric behaviour and their characteristics are influenced by its composition. Some of the fabric properties that are affected are thermo-physiological comfort in the form of water vapour permeability, moisture absorption, wicking and air permeability. The hydrophilic property of fibres also influences its moisture absorption and transmission (wicking). The section below presents some of the recent findings along with commercial examples of natural and synthetic fibre blends.

5.1 Importance of fabric composition in sportswear

Troynikov and Wardiningsih (2011) investigated the liquid moisture management properties of knitted fabrics made of different fibre blends – wool/polyester and wool/bamboo of varying ratio for base layer sportswear. The researchers reported that blending wool fibres with polyester or wool with bamboo had improved the moisture management properties of the fabrics in comparison to 100% wool and 100% bamboo fabrics.

Generally, blending of fibres in clothing is to offer an optimum balance between durability and comfort properties. Investigators Das et al. (2009) explored the effect of fibre blends (polyester/viscose) on the moisture flow of eight different plain woven fabrics (varying the blend ratio of polyester/ viscose). Air permeability, water vapour permeability, moisture regain, absorptive capacity, horizontal and vertical wicking was measured. They reported that as the viscose proportion increased the absorbency of the material increased linearly, much similar to the effect of moisture regain. They further added that as the fabric structure (cover factor, porosity) was similar among the test samples, the increase in the moisture absorption and regain can be attributed to the increase in amount of hydrophilic fibres. Air permeability of all the test fabrics was similar which confirms that the fabrics were similar in their construction. It was also reported that in the case of wicking, a small proportion of polyester fibre (hydrophobic – fibre does not bond with the absorbing group of water molecules) in the fabric increased the vertical wicking due to capillary flow. In the case of 100% viscose fabric which is hydrophilic in nature, (has good affinity to water when water molecule reaches it forms bond with absorbing group of fibre molecules) the wicking was less due to the fact that fibres swell due to absorption resulting in the inhibition of capillary flow along its surface or between inter-fibre spaces. This resulted in less movement of moisture along the fabric surface.

This confirms the fact that when the hydrophilic proportion of fibres is increased the fabric will offer quick absorption from the skin, however, the hydrophilic nature causes poor wicking which accounts for moisture accumulation and resulting in dampness and wet sensation next to the skin. Hence, in the case of active wear, where sweating levels are high, a higher proportion of polyester fibres will wick away the moisture and keep the wearer dry and a small proportion will facilitate in quick absorption from the skin (typical fabric composition 80% polyester and 20% viscose).

5.2 Natural fibres and their effect on fabric performance

Wool fibres have been in use for outdoor apparel for its warmth, comfortable handle and superior performance. Some of the advantages of merino wool include wrinkle recovery, water repellent, anti-static, durable and resilient. Advansa Thermo°Cool® from Südwolle group recently reported its high performance fibre offered by Advansa a leading fibre producer in Europe. They added that for high intense sports activity the wearer can benefit from its Duoregulation™ with Merino Wool.

The combination of Advansa Thermo°Cool® with Merino wool offer the possibility of light, breathable, exceptionally soft fabrics with warmth, natural, luxurious feel, and good comfort. Advansa Thermo°Cool® is made with smart fibre cross-section. Fabrics from this blend do not absorb moisture as much as the pure merino wool and is well suited for aerobic sports. The blend of Advansa Thermo°Cool® with Merino wool is suitable for warm and cold conditions are ideal for layering garments, socks, mid layer fleece. Wool fibres also provide natural odour control when the sweat levels are high. The wearer feels fresh, as the fabric (Advansa Thermo°Cool®) wicks the moisture away from the skin and dry quickly compared to 100% wool fabric. During intense activity, Advansa Thermo°Cool® evaporates moisture faster than other materials and allows enhanced air circulation focussing energy on the evaporation process. On the other hand, in the case of low activity, Advansa Thermo°Cool® acts as a buffer which protects the wearer from changes in external temperature. This supports the wearer from post exercise cooling and allowing excess heat to dissipate into the air. Some of the brands by Südwolle group are given below.

- Yarn in motion
- Biella Yarn

Thermo°Cool® has a blend of channelled fibre cross-section and hollow fibres, which creates inter-fibre spaces which enables better circulation of air and channelled filaments wick moisture away from the skin. The improved air permeability allows vapour to reach the exterior preventing condensation, which affects evaporative cooling and avoiding excess heat.

5.3 Synthetic and smart fibres used in sportswear

Dyneema® from DSM, is a polyethylene fibre with ultra-high molecular orientation which has high breaking strength and is reported to be 15 times stronger than steel (on a weight for weight basis), resistant to cuts, as well as light weight and extremely tear resistant (Henssen, 2013).

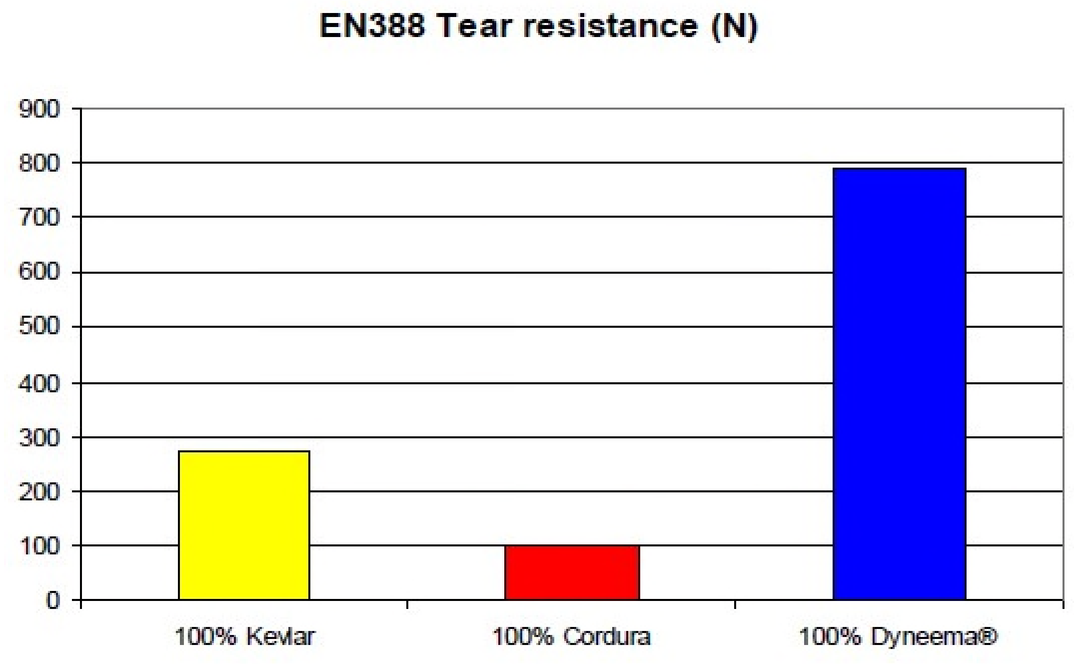


Figure 12: Tear resistance of fabric made of 100% Dyneema®

Figure 12 reveals that Dyneema® is approximately eight times resistant to tearing compared to Cordura (high tenacity nylon) and three times stronger compared to Kevlar (para aramid).

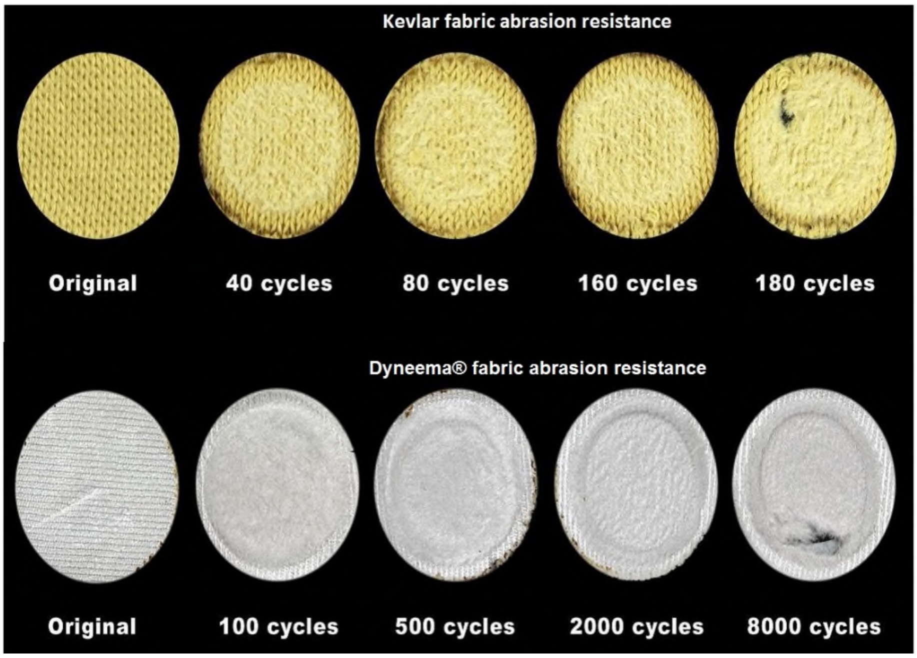


Figure 12: Abrasion resistance fabric with Dyneema®

(Source: Dyneema).

Abrasion resistance results at various cycles of rub are presented for Kevlar and Dyneema® (Figure 12). The fabric surface distortion is less for Dyneema® at 8000 cycles compared to Kevlar, whereas Kevlar fabric reveals thread breaks at 180 cycles. The illustration (Figure 13) shows that Dyneema® fabric is repellent to water**.**

Figure 13: Dyneema® Hydrophobic

(Source: Dyneema)

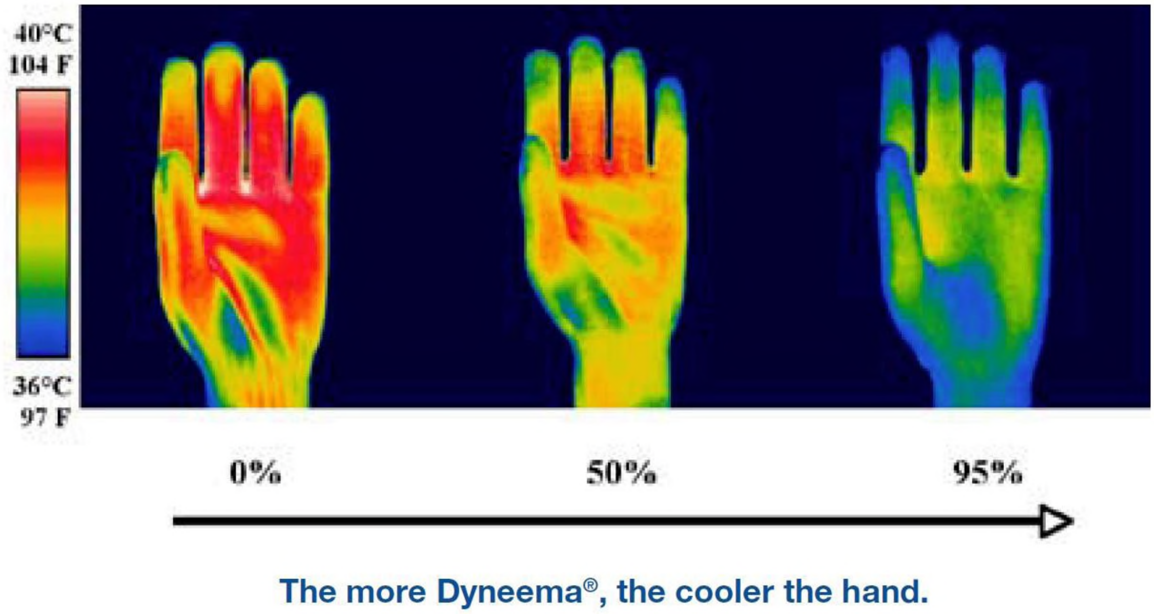


Figure 14 Glove with Dyneema®: High Thermal conductivity

(Source: Dyneema)

Finally, Figure 14 reveals that fabric made of Dyneema® offers better thermal conductivity and comfort helping to keep the body cool while exercising, if more proportion of Dyneema® is used in the fabric. Hence, the fabric made of Dyneema® is a high performance material made of synthetic fibres which is resistant to tearing, light weight, abrasion resistant, soft, and supple next to the skin, hydrophobic, fatigue or bending resistant and offers better thermal conductivity which makes it ideal to be used in high performance sportswear and performance work wear.

6.0 DISCUSSIONS

This chapter has highlighted the importance of fabric characteristics in the design and development of performance apparel particularly for sportswear. Recent developments in technology have resulted in the development of high performance fibres/fabrics. Fabrics for performance apparel include, water proof or breathable fabrics, multi-layer fabrics, knitted fabrics, fleece or brushed knits, smart fabrics, eco-friendly and hardwearing fabrics for work wear. Fabric behaviour varies during use and manufacture. It should be noted that there are numerous requirements from a user perspective using high performance apparel, and it is not possible to incorporate every possible need. In this context, the chapter have highlighted essential parameters that should be fulfilled in addition to desirable parameters. Widely played sports in the UK were chosen and various essential and desirable properties were presented. The case study also revealed that garments for cycling are multi-dimensional and functional. Market trend for sports garments are on a rise, as there is increase in the number of adults involving in sports over the last few years, highlighted through Mintel's report. There are a number of reasons behind this increased participation, but among many it is due to health benefits, which Sport England have stated that physically active adults have a reduced risk of chronic illness such as heart disease, diabetes or musco-skeletal concerns. Five major sports were identified as most preferred sports – swimming, running, football, cycling and golf. Most of these sports require specific clothing gear to support their performance.

A number of internal and external factors were highlighted with evidence and examples to facilitate a better understanding of fabric parameters. Some of the internal factors including, fibre type, blend, fineness, yarn quality, fabric density, thickness, and structure were presented. It was highlighted that in the case of wool blend knitted fabrics, tighter knit fabrics were less comfortable. Fabrics made of synthetic micro-fibres were ideal for sportswear particularly for athletics, as they had excellent moisture transmission property, wicking and dimensionally stable. In addition, the micro-fibre fabrics have excellent fabric handle, soft and pliable. The fineness of filaments influenced wicking and moisture transmission. In the case of woven fabrics, increase in the yarn density (weft) increased the stiffness of the fabric and the fabric was not smooth. The fabric stiffness decreased with the increase in the yarn fineness. It was also highlighted that fabrics with bamboo yarns had low thermal conductivity. Air permeability for knitted fabrics with bamboo fibres was much better than fabrics with cotton fibres. Hence, it can be inferred that fabric structure affects its performance, particularly with regard to thermal and/or moisture related comfort.

Various external factors were highlighted including exposure severe cold conditions, exposure to continuous sunlight, measurements of fabric properties in wet and dry state. The fabric properties differ when exposed to cold conditions especially thermal and moisture sensation. Durable fabrics with TiO_2 nano-coating with self-cleaning ability and protection from UV rays were also presented intended for high performance outdoor apparel such as mountain climbing or cross-country biking. It was also interesting to note the comfort measurements in the wet and dry state, and variations were presented. In the wet state, fabric porosity was reduced resulting in low air permeability. A number of commercial examples were also presented with regard to UV protection, water repellent and thermal insulation.

The effect of fabric and human body interaction should be accounted during the design and development of performance clothing particularly for sportswear. It had been shown that a garment should be able to absorb sweat level (particularly from central and lower back), wick the moisture away from the skin, allow moisture evaporation, prevent excess heat loss from the body, avert condensation due to accumulation of moisture and body heat, provide an optimum micro-climate between the skin and clothing, and most importantly provide tactile comfort to the wearer. It was also highlighted that fabric properties influence the psychological well-being of the wearer and tactile sensation.

These fabric properties are critical in the selection of appropriate fabrics taking into consideration the fibre blend, quality, yarn structure, fabric density, fabric structure and lamination or coating techniques used to optimise thermo-regulatory comfort of the wearer.

Various type of fabric structures used in sportswear was also presented with commercial examples and illustration. Materials such as phase change materials, biomimetics, micro-porous coatings and membranes are getting popular among professional garments. Fabric composition in the form of fibre blends also influenced the comfort properties such as moisture regain, water vapour permeability, air permeability, and wicking. The fabric moisture absorptivity is influenced by the proportion of hydrophilic fibre blended with hydrophobic fibres. Natural fibres such as Merino wool have also been reported to possess properties suitable for active wear. Pure merino wool have been blended with varying fibre cross section to regulate absorption, wicking, air circulation, insulation, and enhance comfort of the wearer. Synthetic fibres with ultra-high molecular orientation with superior performance (high breaking strength, light weight, abrasion resistant, tear resistant) were also highlighted with illustration and its application was presented. It is anticipated that the reader will benefit with this review of fabric properties, which has presented the research relating to fabric properties for sportswear.

7.0 SUMMARY AND CONCLUSIONS

Fabric properties refer to a set of requirements fulfilled by a material intended for a specific application. The fabric knowledge is essential in the selection, designing and developing of a garment range for performance apparel and is highlighted in this chapter with examples and visual illustration. Fabric properties and characteristics vary based on their texture, pattern, design, and structure. Fabric knowledge is important for those involved in the textile design, garment manufacturing, fashion design, product development, fashion buyers, merchandising, quality control, fabric supply and sales. It also becomes a unique selling point for marketing and promoting various claims of a new technology. Garment manufacturing involves a combination of processes, for example while sewing; various settings have to be carried out to prevent seam distortion or puckering. Fabric properties also affect cutting, laying-up of fabric layers and slip caused while handling fine denier or micro-fibre fabrics. Understanding fabric behaviour and their characteristics will enable the technicians, technologist and designers alike to produce a garment, which is fit for purpose and with the desired aesthetics.

Hence, if a company/designer prefers to design a range of base layer garment, the choice of a fabric will be based on a number of factors as highlighted in this chapter, internal and external factors, fabric structure, fibre blend ratio, fabric composition, and moreover the interaction between the garment and skin. The typical fabric choice will be lightweight, made of micro-fibres, with a uniform yarn quality, knitted fabric (medium to fine gauge); which has the ability to wick the moisture from the skin, allow air transmission, and at the same time prevent excess body heat loss. However, for an outdoor garment, the fabric choice is heavyweight, coated or laminated or multi-layered woven/knitted fabric sometimes quilted and possibly phase change material, which has the ability to resist wind penetration, water repellent and at the same time allow moisture vapour transmission. In addition, the designer should also assess the fabric/skin interaction under dynamic conditions (running, walking) and climatic conditions (wind/extremely cold/warm) to verify its suitability. Therefore, it becomes mandatory for the designers to have a wider understanding of fabric properties and characteristics as highlighted in this chapter so that they produce a performance garment, which is ideal for the chosen application. It is anticipated that the reader after reviewing this chapter will be equipped with new ideas and be motivated to further their vision in designing functional and performance apparel for the future generation.

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