Chapter 11 Evaluating the performance of fabrics for sportswear

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Introduction

Evaluation of fabrics for its performance is mandatory particularly during design and development of sportswear and performance apparel. By investigating the properties of fabrics through textile testing it is possible to determine its suitability for its intended application. Specific fibre types can be blended to meet consumer requirements, for instance, in sportswear stretch plays an important role in adapting to various body movements (Roy, 2014). Stretch can also controlled in specific directions which allows support to specific muscles. X-bionic bib tight (X-Bionic®, 2014) has the ability to apply pressure to specific muscles as well as to transport moisture during intensive nature of the sport. Such a product design could would not exist if properties of materials were not explored in the first instance. ISPO textrends 2015/16 categorises fabrics used in sports apparel into eight applications, base layer, second layer, outer layer, membrane and coatings, fibres for insulation, trims, accessories and soft equipment used in sports.

Evaluation of sportswear involve a series of tests to ascertain the performance of the garment and accessories and it varies based on the application and requirements (Table 1). The most important aspect in sportswear is moisture management and thermal balance.

Table 1 Various sports and their requirements			
Popular sports	Fabrics used	Frequently used product name	Specific properties
Cycling	Brushed knitted fabrics with stretch	Cycling tights	Three-way stretch Insulation during winter Soft next to the skin
Skiing	Warp knitted fabric	Base layer thermal	Thermal resistance Stretch and recovery Moisture permeable
	Single weft knit, napped technical back	Mid layer fleece	Thermal insulation
	Breathable coated woven fabrics (high density)	Outer shell jackets	Water proof Breathable Durable
Running	Warp/weft knitted fabric with bi-directional stretch	Compression tights –	Stretch and recovery Comfort
	Knitted fabric	Tops and leggings	
	Woven fabric	Jogging shorts	Light weight Quick drying
Football	Warp and weft knit	Tights	Stretch and recovery Moisture permeable
	Knitted fabric	Tops	Comfortable/moisture management
	Woven fabric	Trousers	Durable
Swimming	Woven and knit fabrics with elastomeric filaments	Female/male swim suits	Stretch and recovery Quick drying Durable
		Training jackets and trousers	

In this chapter, specific test methods relating to fabric durability, fabric handle, stretch and recovery, moisture transport, water vapour permeability and thermal resistance are discussed. The test methods are referred to British standards which provide definition of various parameters, examples are included to enable the reader to interpret the test results and explanation is provided on how those parameters affect garment performance and research relating to these parameters (Figure 1).

Different Type of sports

Figure 1 Different type of individual sport

Physical measurements for woven and knitted fabrics

Fabric's physical parameters play an important role in determining their characteristics which is widely used by professionals as 'specifications' whilst making decisions such as suitability for a particular end use or to communicate across the fashion supply chain. In this section, the following parameters will be discussed:

- Fabric area density or fabric weight
- Fabric thickness
- Fabric bulk density

- Fabric construction
- Fabric count
- Fabric cover factor

Fabric area density:

Fabric weight is mass per unit area, denoted in grams per square metre (g/m^2). It is an important fabric property that is often used in determining the fabric cost and quality. For woven fabrics it is calculated by preparing a fabric specimen to dimension 100 x 100 mm and weighing them in a scale. The resultant value is multiplied by 100 to calculate it for a metre. In industry, the fabric area density is also calculated using gsm cutter (Figure 2), which is circular in shape.

For knitted fabrics, $area\ density = (s\ x\ l\ x\ T)\ \div 100$

Where, s – stitch density per cm^2; l – stitch length is length of yarn in a knitted loop, and T – yarn count in tex (Anand, 2000).

Stitch density refer to the total number of loops and is obtained by determining the wales per cm (wpc) and courses per cm (cpc) in a measured area and multiplying both the values, which is 315 cm^2. For example wpc – 15 and cpc – 21 for single jersey fabric, the stitch density is obtained multiplying these values. A typical stitch length of 2.55 and yarn count 16 tex. The area density for a knitted fabric is obtained using the above formula 1, which is 128.5 g/m^2. Fabric weight affects the fabric stiffness especially the bending rigidity particularly in the warp direction (Mandal and Abraham, 2009). Table 2 classifies area density of fabrics based on the application.

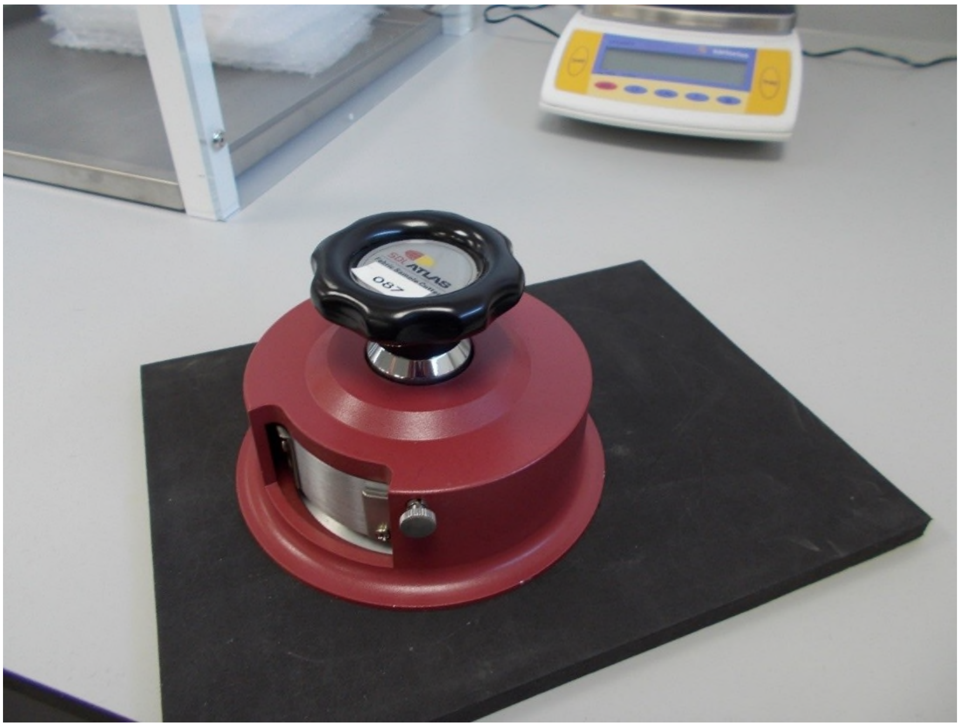


Figure 2 Fabric gsm cutter
(Image courtesy of MMU Textile Lab)

Table 2 Fabric weight for fabrics used in sportswear		
Fabric type	**grams/square metre (g/m^2)**	**Function /end uses**
Very light weight fabric	18	Base layer, light weight, moisture management smooth fabric worn next to skin
Light weight fabric	< 100	Mid layer fabric used for tops, trousers, trainers, etc.
Medium weight fabric	130 - 180	Soft shell fabrics used outer layer jackets, these are either laminated or coated with finishes
Heavy weight fabrics	250+	Hard shell heavy weight fabrics used for jackets, trousers, and high performance technical materials used for outdoor applications

Fabric Thickness:

It is the distance between the upper and lower surface of the fabric and is measured using a thickness gauge or tester (Figure 3). The test sample is placed between two reference plates which exerts a known pressure on the sample. The distance between plates is recorded in mm (BS EN ISO 5084). The fabric thickness affects garment production especially in adjusting the sewing machine settings. This could be selection of a needle or fabric feed system. Selection of needle depends on the stitch density (seams per inch) required. In sportswear stitch density is finer than for a jacket. For knitwear, a ball pointed tip is preferred which prevents from fabric damage (laddering effect). For instance, in the case of knitted stretch fabrics with fine thickness that slips during sewing due to slippage results in fabric being gathered or staggered, in this case, a differential feed system at the top and bottom will be used in sewing machine, one end will feed the fabric quicker and the other feeds slowly resulting in a good quality seam. Fabric thickness also affects the overall performance of a garment, especially, the abrasion resistance of fabrics, the higher the fabric thickness, the higher resistance to abrasive action (Özdil et al, 2012). Table 3 generally classifies the thickness of fabrics.

Figure 3 Fabric thickness tester

(Image courtesy of MMU Textile Lab)

Table 3 Fabric Thickness	
Type	Thickness (mm)
Thin	< 0.20
Medium	0.23 – 0.46
Thick	> 0.47
Source: Collier and Epps (1999)	

Fabric bulk density

Fabric bulk density takes into account the fabric weight and thickness. It represent the bulkiness of the fabric relative to its thickness. It is an important factor in determining the garment comfort. A thick fabric with an average weight is more comfortable in cold conditions or outdoor sports on the other hand a thin fabric of same weight will be ideal in warm conditions. It is generally expressed in g/cm^3. Bulk density is calculated using the equation given below.

$$Bulk\ density = \frac{fabric\ thicknesss\ in\ cm\ x\ fabric\ weight\ in\ g/cm^2}{10{,}000}$$

Fabric construction

The repeat of the design is presented by shading the box that represents the warp interlacing over the weft yarn (Figure 4 and 5). This is called ‘fabric design’ construction.

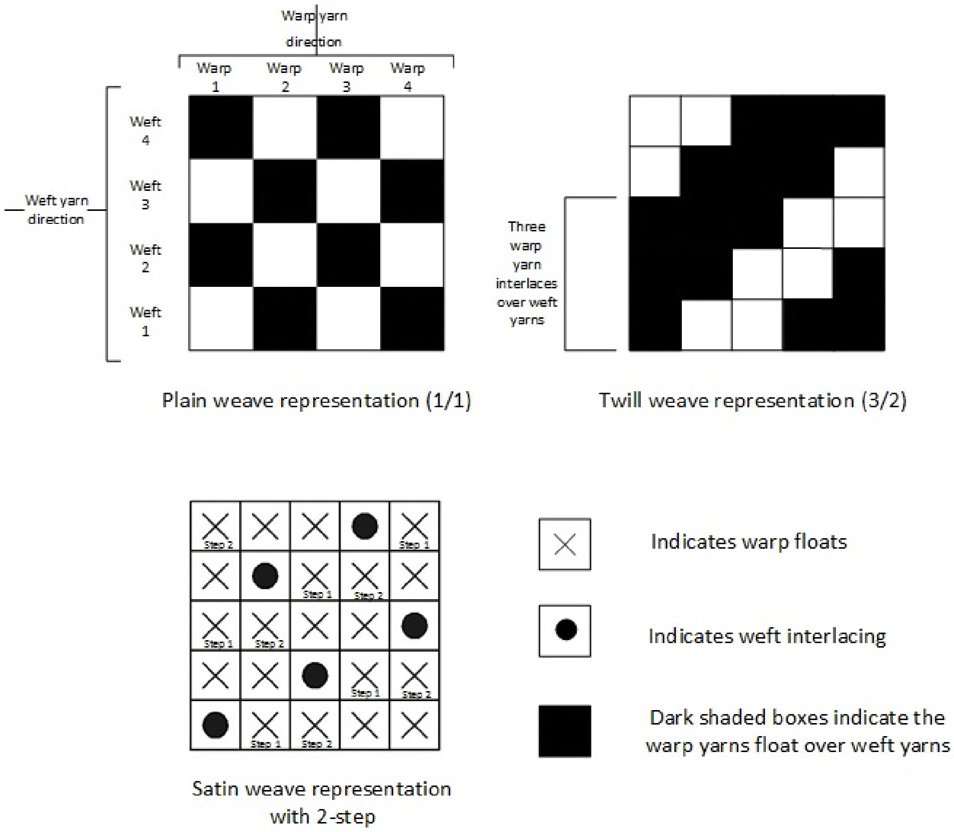


Figure 4 Woven fabric construction

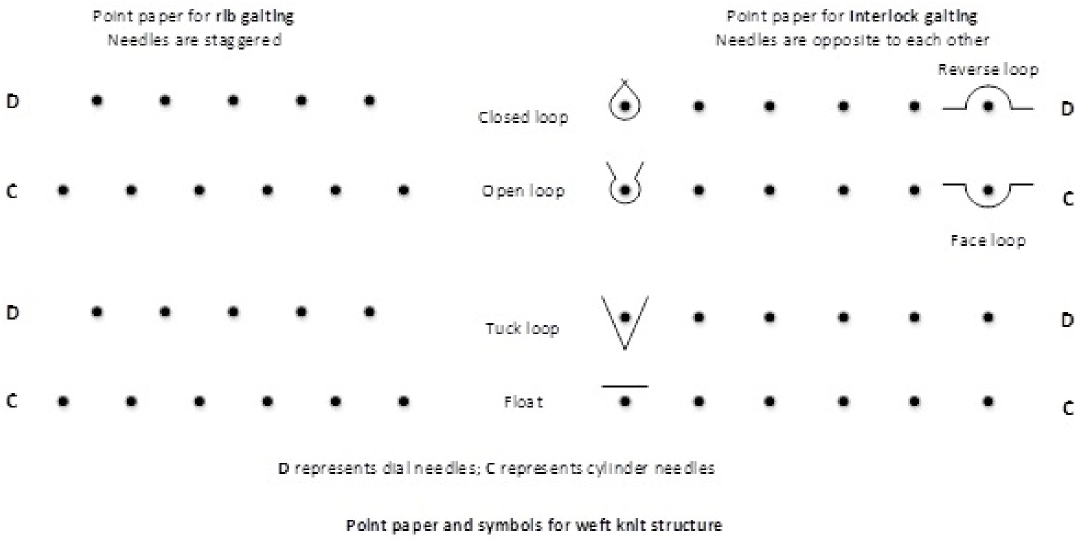


Figure 5 Point paper for weft knitted fabric representation

(Source: Taylor, 1999)

Fabric cover factor

Cover factor for woven fabrics indicates the extent to which a fabric area is covered by one set of yarns. In woven fabrics, cover factor is determined in warp and weft direction. In knitted fabrics cover factor is also termed as tightness factor. It is generally denoted by K.

It is calculated using the formula, $K = \frac{threads\ per\ cm\ \sqrt{tex}}{10}$ for woven fabrics

Tightness factor $K = \frac{\sqrt{tex}}{stitch\ length\ in\ mm}$ for knitted fabrics

Fabric count

A fabric counter or magnifying glass is used to determine fabric count. Fabric count is assessed by counting the number of warp or weft yarns in woven fabric (Figure 6b) and counting the number of courses and wales in knitted fabrics (Figure 6a). The fabric count plays an important role in determining the closeness of the weave or knit that affects various properties such as porosity, permeability, durability of the fabric.

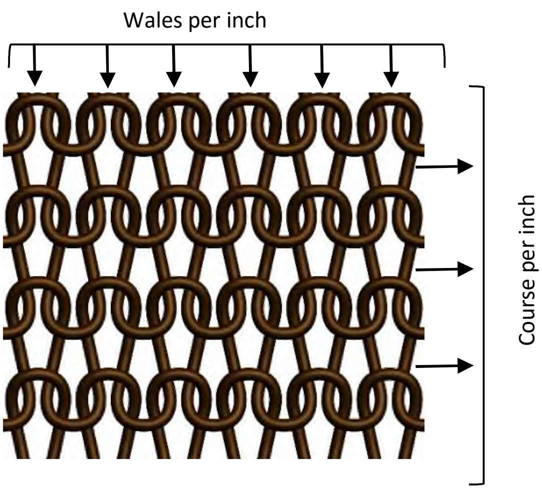


Figure 6 a Knitted fabric structure

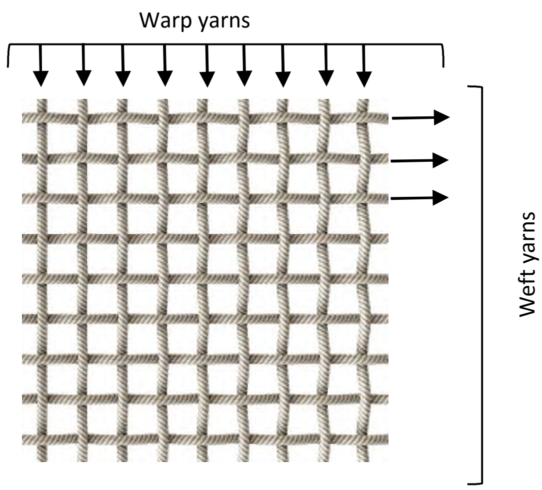


Figure 6b Woven fabric structure

(Source: Dreamstime)

Evaluating durability

Durability is one of the important parameter when selecting a fabric for a particular end use. Sports activity involves repeated body movements and sportswear can abrade in several ways, for instance fabric rubbing with another layer of fabric, fabric abrading in particular areas including, crotch, knee, and under arms; rubbing against another object due to trip or fall; garment abrasion while laundering; and abrasion can also occur between yarns and fibres when fabric is stretched repeatedly. The effect of fabric abrasion depends on various elements, fibre type and its properties; yarn quality and its structure; and fabric construction.

Factors that affect abrasion resistance of fabrics

- Presence of longer fibres in the yarn offer better resistance to abrasion than short fibres
- Increased in fibre diameter enhances resistance to a certain extent
- Optimum yarn twist offers good resistance to abrasion
- Increasing yarn linear density increases resistance with a constant fabric density
- Uniform yarn crimp in the fabric (warp and weft) enables even wear across the fabric
- Warp or weft floats are highly susceptible to abrasion
- Fabric weight and its relative thickness affects the abrasion resistance
- Abrasion also depends on fabric count (ends and picks per inch) the more threads per inch the lesser the wear
- Type of yarns also affects abrasion resistance, for instance, air jet spun yarn – high resistance to abrasion; ring spun yarn possess moderate resistance and open –end spun yarn possess low resistance to abrasion

Abrasion resistance

The usual method to evaluate fabric abrasion is Martindale abrasion tester, where the instrument (BS EN ISO 12947-2/2014) subjects specimen to a uniform rubbing motion (Lissajou's figure) and is repeated until two threads are broken (woven fabric). Various methods are used to determine the end of the test are the evaluation of change in before and after sample weight, change in colour using a colour change chart (ISO 105 A02) or examining whether the sample distortion or being rubbed away and completion of specified number of cycles (Johnson and Cohen, 2010). However, in this section Taber Abrasion tester is discussed (BS EN ISO 5470-1/1999) that works on the principle of rotary platform which tests flat abrasion and is intended for heavier woven and knitted fabrics as the abrading action is severe (Figure 7). In this method, the instrument uses a flat abrasive action in which the fabric is placed on a rotatory platform and is abraded by two abrasive wheels. Six samples of dimension 114 ±1 mm diameter with a central hole of diameter 6.35 mm is chosen and is conditioned. The load applied can be varied depending upon the type of abrasion required for instance from very gentle (2.5 N) to harsh action (9.8 N). Similarly, the rotary wheels can be either rubber and abrasive grain or vitrified version depending on the required abrasive action. The sample weight is measured prior to test in milligrams. To determine the average rate of loss in mass, the loss in mass for every 100 cycles should be recorded. The end of test is determined by change in colour of abraded portion, change in mass, or change in surface distortion.

Figure 7 Taber Abrasion Tester

(Image courtesy of MMU Textile Lab)

Laminated or coated or heavy multi-layered fabrics that are intended for jackets, trousers, back pack, footwear (Cordura ® Naturalle) are often subjected to this test to evaluate their resistance to abrasion. Three heavy weight woven fabrics that are intended for outer wear for jackets were randomly selected. Fabric 1 (282 g/m^2), fabric 2 (375 g/m^2) and fabric 3(245 g/m^2). Fabric 1 is laminated at its back side; fabric 2 and 3 are coated fabrics. The standard load of 7.35 N was applied and an abradant H18 (Non-resilient) vitrified surface that applied medium abrasive action.

Table 4 Percentage change in mass

Abrasion resistance		Fabric 1 (yellow)	Fabric 2 (green)	Fabric 3 (camo)
Initial weight (mg)		2530 mg	3260 mg	2080 mg
Average rate of loss in mass	100 cycles	4.74% (2410 mg)	1.84 % (3200 mg)	2.40 % (2030 mg)
	200 cycles	5.13% (2400 mg)	3.37% (3150 mg)	2.88 % (2020 mg)
	300 cycles	6.32 % (2370 mg)	5.52 % (3080 mg)	5.05 % (1980 mg)

	400 cycles	7.50% (2340 mg)	6.44 % (3050 mg)	5.76 % (1960 mg)
	500 cycles	7.90% (2330 mg)	8.58 % (2980 mg)	6.25% (1950 mg)
	Average	6.32 %	5.15%	4.46%

Figure 8 Taber abrasion test samples

It could be observed from Table 4 that in the case of fabric1, the specimen endured surface distortion between 300-500 cycles and rate of loss of mass is higher especially at 500 cycles. At 500 cycles, the top surface of the fabric had been lost leaving the coating exposed. In the case of fabric 2, the rate of loss of mass varied and the fabric surface was distorted and loss of colour was also noted. However, the fabric structure remained unaltered. The thickness of fabric 3 was less compared to remaining samples and fabric surface was distorted with change in colour and thread bare was also noted at 500 cycles. The samples are illustrated in Figure 8 which shows the material at the start and at the end of 500 cycles.

Fabric pilling

Pilling is a fault commonly observed in knitted woollen goods or fabrics made from soft twist yarns. Pilling occurs when rubbing action in wear causes loose fibres from surface of yarn coils/ loops and forms pills on the fabric surface due to brushing up with a surface (washing or daily wear). Formation of fuzz on the fabric surface due to:

- Brushing of free fibre ends from yarn structure
- Formation of fibre loops into fibre fuzz (Figure 9).

Figure 9 Typical knit fabric with surface fuzz (pill) (author's own image)

Fabrics with synthetic fibre content the pills are stronger and remain on the fabric surface causing unsightly appearance to the product.

In this method (BS EN ISO 12945-1: 2000), fabrics are subjected to constant rotation in a pill box (Figure 11) to tease the fibres to form pill and grading it against the original specimen. The method is suitable to wide range of fabrics. The test specimen is conditioned to a temperature of (20± 5) °C and a relative humidity of (65 ±2) % for at least six hours. Five specimens each 125x125 mm; two for machine direction and two for cross direction of the fabric; One specimen for comparing; specimen sewn to form a tube (see Figure 10). At the end of the set number of revolutions (18000) the test specimen is assessed visually using the pictures as shown (Figure 12). Pilling is graded visually using rating scale, where 5 indicates no change and 1 indicates dense fuzz (Table 5).

Figure 10 Preparation of sample for pilling test

(Author's image)

Figure 11 Pilling box used to measure pilling resistance of fabrics

(Image courtesy of MMU Textile Lab)

Figure 12 Pilling assessment photographs

(Image courtesy of MMU Textile Lab)

Table 5 Visual Assessment: Fabric pilling		
Rating	Description	Notes
5	No change	No visible change
4	Slight change	Slight surface fuzzing
3	Moderate change	Exhibits fuzzing and/or pills
2	Significant change	Distinct fuzzing and/or pilling
1	Severe change	Dense fuzzing and/or pilling covering specimen.

Fabric handle in sportswear

In fashion industry, a number of personnel handle fabrics for its suitability to an end-use especially during manufacturing. Fabric handle is an individual's response to touch when a fabric is handled. This could also refer to how a fabric drape. A number of subjective attributes have been used to refer fabric handle, for instance, smooth, rough, stiff, soft, crisp, silky, etc. Subjective grading is often not consistent, as what a person perceives as appealing may not be for the other person. In this section, various methods to determine the fabric handle are discussed which can be utilised to characterise the fabrics for its performance and determine its relevance to a particular end use. These are fabric stiffness, fabric drape and crease recovery. Fabric stiffness refers ability of the fabric to bend on its own weight. Stiffness refers to resistance to bending. In casual sports tops, the most widely preferred fabric is a single jersey which is not stiff compared to a tightly woven twill fabric.

Fabric stiffness

In this method (BS 3356: 1990), bending length is measured, in which a rectangular strip of material (200 x 25 mm) is slowly slid on a horizontal grip as shown in the diagram, until the edge of the fabric touches the marked line (Figure 13 b). The length of material protruding beyond the edge is recorded. The test is repeated separately in warp and weft directions over a number of times (n=5) and the average bending length is reported. Generally, a stiffer fabric possess a greater length compared to limp fabric. Care should be taken to ensure the test sample is conditioned and experiment conducted in standard atmosphere.

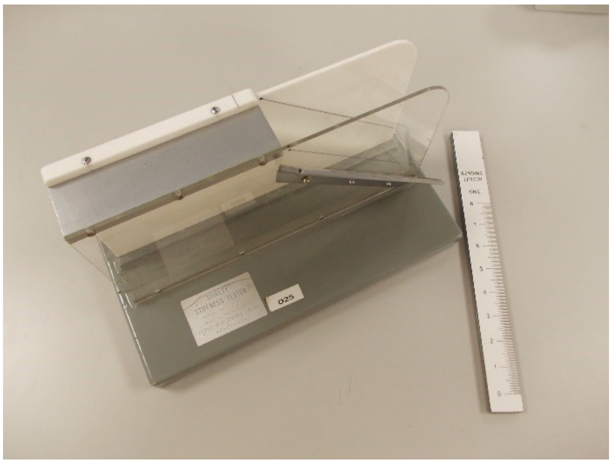


Figure 13a Shirley Stiffness Tester

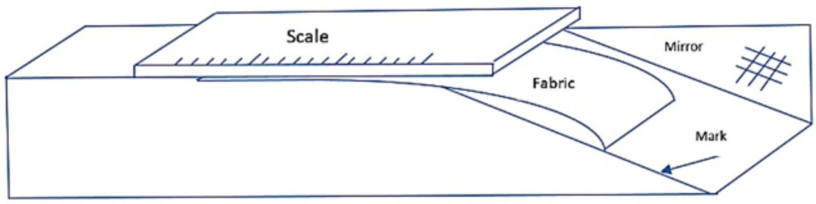


Figure 13b. Close-up view here >

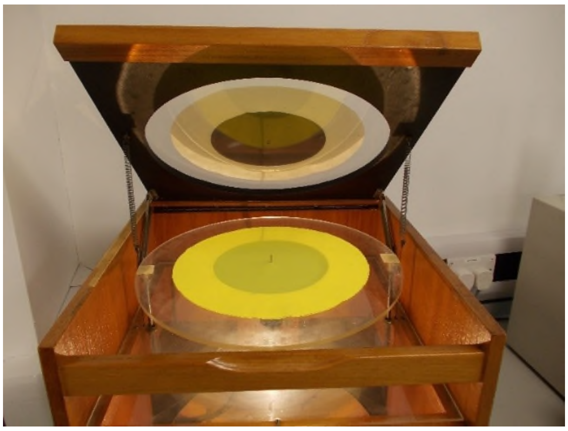
(Image courtesy of MMU Textile Lab)

Flexural rigidity (G) is calculated using the equation given below which determines the resistance of fabrics to bending by external forces. Flexural rigidity,$G = 0.1\ MC^3$ where, M is mass per unit area in g/cm^2 and C is bending length in cm. Flexural rigidity is reported in mg.cm.

Fabric drape

Drape is a characteristic of a material to freely fall or hang over a three dimensional form. This parameter is important to determine fabric handle. In this method, (BS 5058: 1973), a fabric specimen of diameter 30 cm for medium fabrics (24 cm diameter for limp fabrics; 36 cm diameter for stiff fabrics) is placed on a circular disc (Figure 14) and the specimen is allowed to drape on its own weight. Using a light source placed beneath the specimen, a shadow of the draped specimen is cast on a paper ring (Figure 14b). The outline of the fabric shadow traced on the paper (of known mass, W_0) and traced paper ring is weighed (W_1). Drape coefficient is calculated as the percentage of the total area of the paper ring obtained by vertically projecting the shadow of the draped specimen.

A fabric with a drape coefficient closer to 100% is stiffer, whilst a fabric with drape coefficient closer to zero is pliable and more drapeable. In woven fabric grain affects drape in garments. Figure 1 illustrates a plain single jersey fabric whose drape coefficient was 20% indicating a limp fabric.



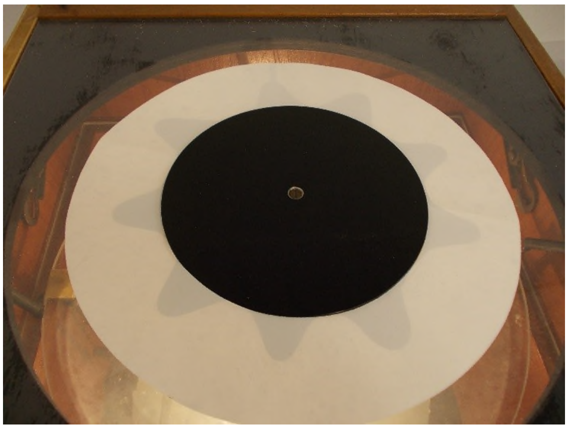


Figure 14a Drape meter **Figure 14b Shadow of the draped specimen**

(Image courtesy of MMU Textile Lab)

$$Drape\ coeffecient\ (\%) = \frac{W_1}{W_0}\ x\ 100$$

where, W_1 is weight of paper in the shadow region (g); W_0 is weight of paper ring (g). The experiment is repeated for six specimens and average is reported and is carried out in standard atmospheric conditions (BS 1051), i.e. a relative humidity of 65 ± 2 % and a temperature of 20 ± 2 °C. Limp fabrics are difficult to handle during the garment manufacture mainly during fabric laying-up, spreading and stitching. Stiff fabrics are difficult to form body form shapes particularly shoulder, arm hole, etc.

Fabric stretch and recovery

Importance of stretch and recovery was highlighted in Chapter 7. During wearing and removal of knitwear or certain sportswear stretch is an important parameter. BS 4294:1968 is commonly used to determine the stretch and recovery of woven and knit fabrics using the apparatus Fryma fabric extensiometer. It consists of two jaws (75 mm wide), a fixed and a movable jaw capable of holding the specimen without slippage (see

Figure 15). The apparatus is capable of applying a load of 6 kg. The conditioned test specimen is prepared to 200 x 75 ±1 mm in both warp and weft direction for woven fabrics and course and weft directions for knit fabrics. The number of test specimen is usually five in both directions.

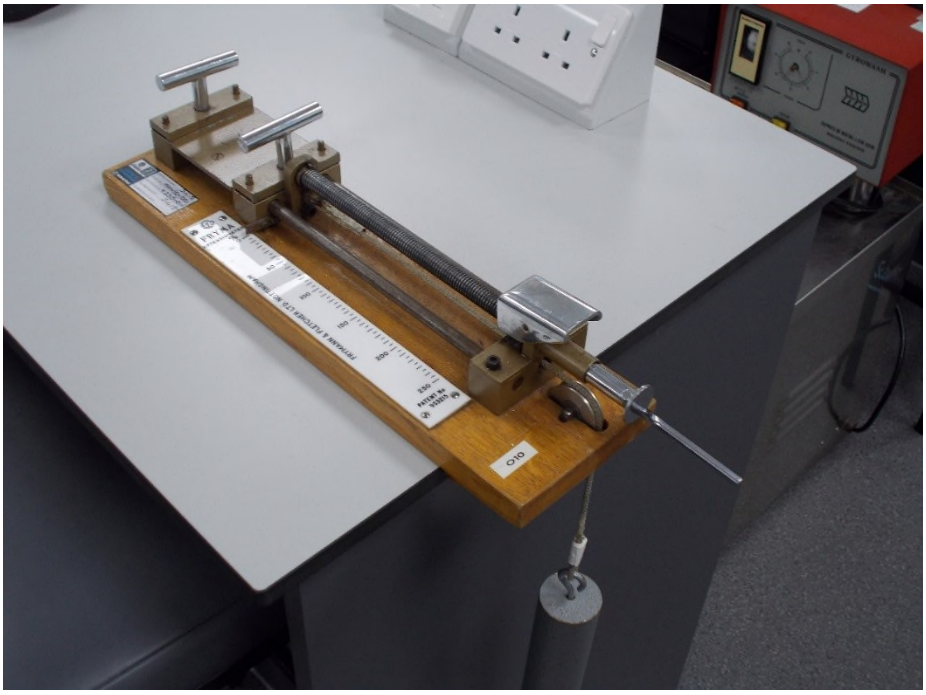


Figure 15 Fryma Extensiometer

(Image courtesy of MMU Textile Lab)

For most knitted fabrics, the distance between the inner edges of two clamps is set at 75 mm (L_1) and for 200mm for woven fabrics. A reference ‘mark’ is made on the fabric at the inner edges of the clamp using a marker. The load (eg. 6 kg for knits) is applied slowly for 10 seconds and immediately reduced within 7.5 seconds and test specimen return to original position. Immediately, the load is re-applied for 1 minute and the stretch of the fabrics is recorded (L_2). Now the load is reduced and clamps are brought to original position. The test specimen is removed from the apparatus and allowed to remain flat for one minute and the distance between the two reference mark is now recorded (L_3). Using the above values, the stretch properties of the fabric is calculated.

$$\textbf{Mean extension } (\%) = 100\ x\ \frac{L_2 - L_1}{L_1}\ ;\ \textbf{Mean residual extension } (\%) = 100\ x\ \frac{L_3 - L_1}{L_1}$$

On a general note, fabrics that offer stretch is expected to recover within 3% of its original extension (Saville, 1999). The stretch and recovery properties of fabrics are essential while designing garments for sportswear, particularly those that can stretch either in one direction (warp or weft) or in both the directions. In addition, it is very important to comprehend the amount of stretch required for different body movements. 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, 13-16% at the shoulder back and with sporting activities increasing such numbers, stretch of sportswear apparel is key element for comfort. Normal body movement expands the skin by 10-50% and strenuous movements in sports will require least resistance from garment and instant recovery. Hence, it is vital that stretch and recovery vales are taken into account while creating fabric panels for the garment manufacture particularly those that are intended for form fitting gear for swimming, cycling, etc. For a compression top made of warp knit structure with fibre composition 63% nylon, 23% Nylon and 14% elastane, the typical stretch and recovery values are, stretch in course direction – 95%; wale direction – 94%; recovery 96% in course direction and 95% in wale direction (Allsop, 2012). This indicates that the fabric can provide uniform stretch in both the directions which is ideal for compression sportswear.

Measurement of fabric comfort

Athletes perceive comfort as an important factor while making a purchase or selecting a garment for training or event. During intensive sport, the core temperature of the human body changes and perspires to balance the excessive heat (Pocock and Richards, 2009). The most important factor while designing sportswear is moisture management and wicking. Performance of fabrics are affected by a combination of fibre properties and composition, yarn formation, and fabric structure (see Chapter 3).

In sportswear, particularly athletic apparel fabrics chosen should have quick drying and good wicking property to handle excess sweat produced by the body. Zhou et al. (2014) highlighted that fibres with greater surface area has better wicking. Zhou et al. reported the comfort properties of six interlock knitted fabrics made from various blends of chemically and physically modified polyester filament (PET) with trefoil cross section and cotton fibres. Modified polyester fibre had enhanced moisture management particularly 35% PET and 65% cotton blend knitted fabric.

Wicking and its effect on fabric comfort

Wicking is the movement of liquid by capillary action, provided that the liquid wets the assembly of fibres so that it can move from its source to some distance against the gravitational forces by occupying the available capillary spaces. The smallest capillary possess greater capillary forces, hence the wickability. Wicking depends upon the surface properties of fibres, surface area, density, thickness and the capillary path through the fabric. Moreover, the rate of wicking is different along warp (wale) than weft (coarse) direction.

Moisture Management Tester (MMT)

The moisture management tester was developed by Hong Kong Polytechnic University and SDL Atlas Textile Testing Solutions to determine the dynamic liquid transport properties of knitted and woven fabrics. The test method is depends on the change in the contact electrical resistance of fabric during moisture transport (Yao et al., 2008). The apparatus is used to measure the liquid transport in multiple directions. MMT consists of upper and lower concentric moisture sensors (Figure 16). The pre-defined amount of saline solution (simulated sweat) is introduced on to the upper side of the fabric, which allows the saline to spread the fabric outer surface, through the fabric and lower surface of the fabric. The following six moisture management properties are measured:

1. Wetting time for (top (WT_t) and bottom surface (WT_b) in seconds
2. Absorption rate for top (AR_t) and bottom surface (AR_b) of the fabric in percentage per second
3. Maximum wetted radius (mm) for top (MWR_t) and bottom surface (MWR_b) of the fabric in mm
4. Spreading speed for top surface (SSt) and bottom surface (SS_b) in mm/sec
5. Accumulated one-way transport capacity in percentage
6. Overall moisture management capacity (OMMC)

MMT is connected to personal computer and software records the moisture transport through the fabric and produces various illustration including water content vs time; water location vs time (Figure 17); finger print of moisture management properties (Figure 18). McQueen et al. (2013) reported a development of a protocol to assess the fabric suitability for testing moisture management properties using MMT.

MMT grades fabric for six indices and classifies fabrics as, water proof fabric, water repellent fabric, slow absorbing and slow drying fabric, fast absorbing and slow drying fabric, fast absorbing and quick drying fabric, water penetration fabric and moisture management fabric (See Finger print). The moisture management equipment have been recognised by AATCC (American Association for Textile Chemists and Colourists) in its test method AATCC 195:2009.

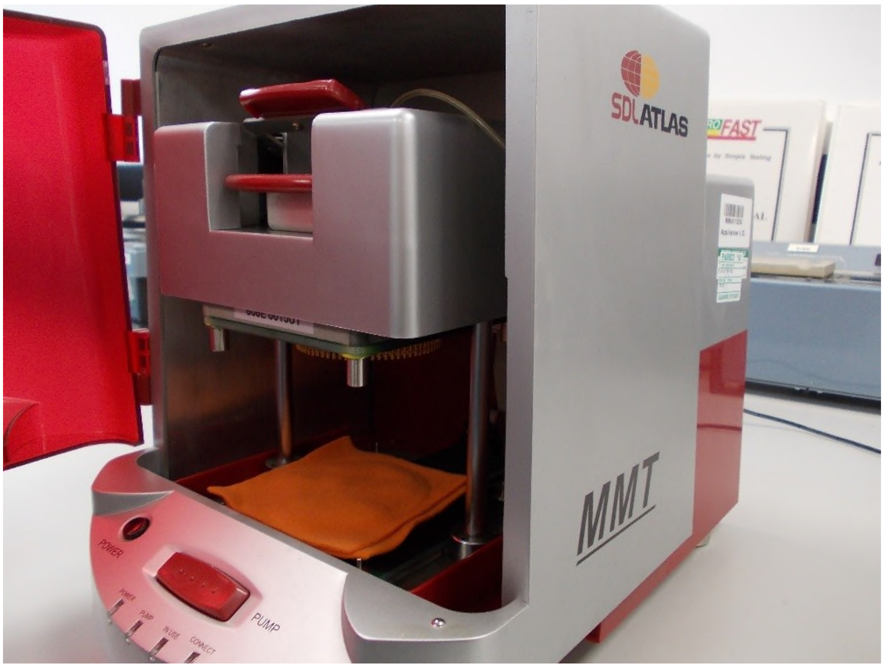
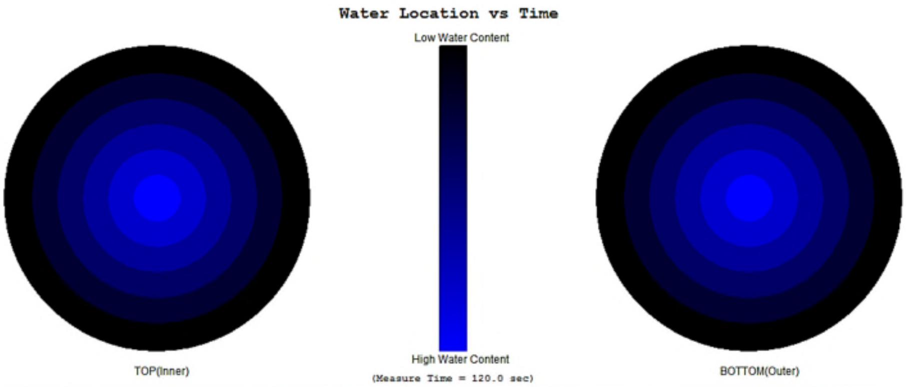


Figure 16 Moisture Management Tester (MMT)

(Image courtesy of MMU Textile Lab)



	Top Surface	Bottom Surface
Wetting time(sec)	1.64	3.484
Absorption rate(%/sec)	25.8923	10.559
Max wetted radius(mm)	25.0	25.0
Spreading Speed(mm/sec)	4.0073	1.6518
One way transport capability	528.2955	
Description	MMT-	

Figure 17 MMT output – water location Vs time

(Image courtesy of MMU Textile Lab)

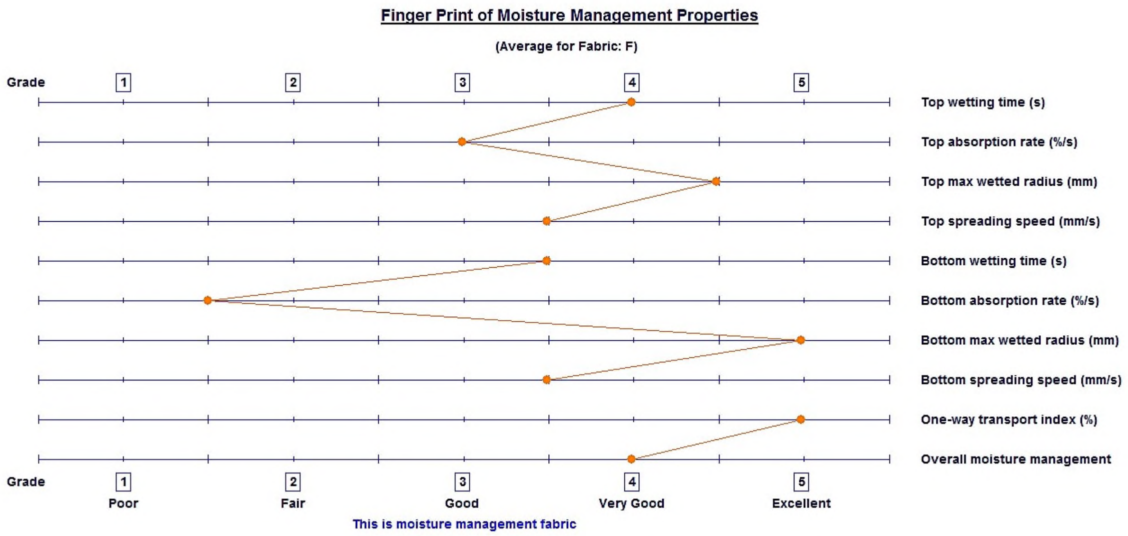


Figure 18 Finger print for moisture management properties

(Image courtesy of MMU Textile Lab)

MMT is suitable to determine the liquid transport in multiple directions and finger print (see Figure 16) is a useful and instant method to identify the moisture management of fabrics. For instance, in the sample as shown above, the top wetting time is *very good* (grade 4); absorption rate was good (grade 3); top surface wetting radius is *very good*; spreading speed was between grade 3-4 indicating good wicking capacity; It could be noted that top surface wicks and transports moisture better than the bottom surface. The one way transport of liquid was also *excellent*. The finger print also provides the overall moisture management as *very good* (grade 4). It could be observed the fabric is suitable for moisture management where one of its surface wicks the moisture than the other surface. The surface of the fabric that wicks away the moisture quickly would be in contact with the skin and helps to prevent stickiness due to excess perspiration during intense activity.

Influence of moisture transfer in functional clothing (Permetest)

Permetest was developed by Sensora Instrument, Czech Republic which measures water vapour resistance, relative water vapour permeability and thermal resistance of woven, knitted and nonwoven fabrics (Matsuiak et al., 2011). The equipment works on ISO 11092 standard that measures the thermal and water vapour resistance under steady state conditions (sweating guarded hot plate test). Bogusławska-Bączek and Hes, (2013) recently presented the working principle of Permetest as Skin Model that provides a reliable measurement of the water vapour permeability of fabrics in a dry and wet state. Permetest – often called as a 'skin model' where the instrument measures the water vapour permeability of fabrics. This instrument simulates the wet and dry human skin conditions in terms of thermal feeling and serves for the determination of water vapour permeability of fabrics (Figure 19). The instrument works on the principle of heat flux sensing. When water flows into the measuring head, some amount of heat is lost. This instrument measures the heat loss from the measuring head due to the evaporation of water in bare condition and while being covered by the fabric. The relative water vapour permeability of the fabric sample is calculated by the ratio of heat loss from the measuring head with and without fabric. Das et al. (2009) reported the water vapour permeability of blended fabrics using Permetest.

Figure 19 Permetest

(Image courtesy of MMU Textile Lab)

The results are presented in the equipment as well as via a software connected to a PC. The image below (Figure 20) illustrates a typical output from the Permetest. The instrument also allows to record the test and calculate simple statistical test, mean, median and standard deviation. The relative water vapour permeability (RWVP) is determined using the formula:

$$\text{RWVP} = \frac{Heat\ lost\ with\ the\ fabric\ placed\ on\ measuring\ head\ \ (u_1)}{Heat\ lost\ with\ bare\ measuring\ head\ (u_o)}\, x\ 100$$

Table 6 Outcomes from Permetest			
Type of material	Water vapour resistance (m^2 Pa W^{-1})	Relative water vapour permeability (%)	Dry thermal resistance (Km^2W^{-1})
Base layer knit 1 (Skins)	3.7	72.8	2.8
Base layer knit 1 (SUD)	4.0	75.3	2.8
Fleece	7.3	57.1	7.9
Coated fabric (grey woven fabric)	8.5	54.0	Not applicable as the fabric is very thin
Outer layer	4.2	67.1	Not applicable as the fabric is very thin

Table 6 highlights the results of widely used sports fabrics (base layer, fleece, coated fabric and outer layer) including dry thermal resistance, relative water vapour permeability and water vapour resistance.

Thermal resistance of fabrics

Celcar (2010) reported that as the fabric thickness increase, water vapour resistance and thermal resistance of the fabrics also increases.

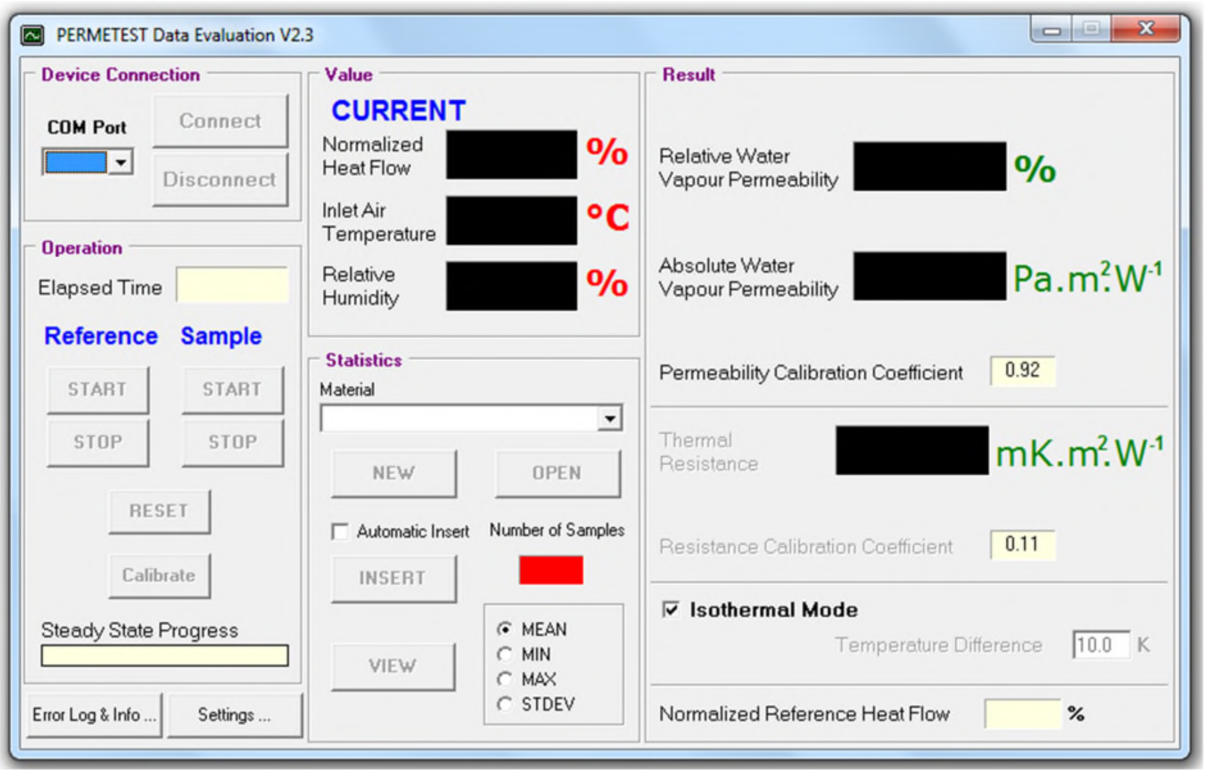


Figure 20 Typical output from Permetest

Fabric specifications and interpreting results

Table 7 presents the experimental values relating to fabric's physical characteristics, durability, aesthetics and fabric comfort which are some of the vital pre-requisites for a fabric to find its usage in sportswear and performance clothing. The woven material made of 100% polyester is a light weight fabric intended for mid-layer soft shell jackets that is water repellent whilst the knitted fabric is medium weight fabric with a water repellent finish intended to be used as a tops for men and women. The woven fabric has a 1/1 plain weave structure in which both sides of the fabric appear similar and the knitted fabric is a single jersey, which possess a distinct technical face and back. It is made of polyester and lycra. Fabric thickness of woven fabric is less than 0.20 mm whilst the knitted fabric is 0.66 mm. Fabric thickness plays an important role during joining of fabrics especially in maintaining the pressure at the presser foot of a sewing machine. Fabric cover factor determines the extent to which a set of yarn covers the area of a fabric. The warp cover factor 13.5 and weft cover factor 6.3 indicates that area covered

<table>
<tr><th colspan="7">TABLE 7 Example fabric specification</th></tr>
<tr><th colspan="3">Properties</th><th colspan="2">01 Woven fabric</th><th colspan="2">02 Knitted fabric</th></tr>
<tr><td rowspan="7">Fabric physical characteristics</td><td colspan="2">Area density (g/m^2)</td><td colspan="2">115</td><td colspan="2">255</td></tr>
<tr><td colspan="2">Bulk density (g/cm^3)</td><td colspan="2">0.64</td><td colspan="2">0.39</td></tr>
<tr><td colspan="2">Thickness (mm)</td><td colspan="2">0.18</td><td colspan="2">0.66</td></tr>
<tr><td colspan="2">Fabric cover (K) factor/stitch density</td><td colspan="2">13.5 + 6.3</td><td colspan="2">11.0</td></tr>
<tr><td colspan="2">Fabric structure</td><td colspan="2">1/1 plain weave</td><td colspan="2">Single jersey</td></tr>
<tr><td colspan="2">Fibre composition (%)</td><td colspan="2">100% polyester</td><td colspan="2">Polyester/lycra</td></tr>
<tr><td colspan="2">Yarn count (tex)</td><td colspan="2">Warp 5.0
Weft 12.0</td><td colspan="2">20.0</td></tr>
<tr><td rowspan="2">Fabric density</td><td colspan="2">Woven fabric (ends per inch x picks per inch)</td><td colspan="2">100 x 72</td><td colspan="2">NA</td></tr>
<tr><td colspan="2">Knitted fabric (courses per cm and wales per cm)</td><td colspan="2">NA</td><td colspan="2">22 x 15</td></tr>
<tr><td rowspan="4">Durability</td><td colspan="2">Fabric pilling (grade)</td><td colspan="2">5</td><td colspan="2">4</td></tr>
<tr><td rowspan="3">Abrasion resistance @ 10,000</td><td>Change in colour</td><td colspan="2">Very minor change</td><td colspan="2">Slight increase in shade</td></tr>
<tr><td>Rate of loss of mass</td><td colspan="2">Nil</td><td colspan="2">0.01</td></tr>
<tr><td>Thread bare</td><td colspan="2">No</td><td colspan="2">No</td></tr>
<tr><td rowspan="2">Aesthetics</td><td colspan="2">Fabric handle stiffness
Flexural rigidity (μNm)
Bending modulus (N/m^2)</td><td>Warp
12.0
0.4</td><td>Weft
4.3
0.1</td><td>Wales
2.8
0.1</td><td>Courses
0.5
0</td></tr>
<tr><td colspan="2">Fabric drape coefficient (%)</td><td colspan="2">55.3</td><td colspan="2">17.41</td></tr>
<tr><td rowspan="3">Comfort</td><td colspan="2">Moisture transport (wicking)</td><td colspan="2">Water proof</td><td colspan="2">Water repellent fabric (see fabric finger print)</td></tr>
<tr><td colspan="2">Stretch and recovery
Mean extension
Mean residual extension</td><td colspan="2">Not applicable</td><td>Wale
79%
2.66%</td><td>Courses
146%
6.75%</td></tr>
<tr><td colspan="2">Water vapour resistance (Pa m^2/W)</td><td colspan="2">11.7</td><td colspan="2">4.3</td></tr>
</table>

	Absolute water vapour permeability (%)	45.5	65.3
	Thermal resistance (m^2 K/W)	Not applicable due to fabric thickness < 0.2 mm	53.0

by warp yarns exceed weft yarns. In the case of the knitted fabric, the tightness factor indicates the extent to which area of the knitted fabric is covered by the yarn. Generally, yarn count affects the tightness factor of a knitted fabric. The tightness factor of 11.0 indicates the fabric has an optimum level of closeness. In the case of woven fabric, warp yarns are finer (5 tex) than the weft yarn (12 tex). In the case of knitted fabric, yarn count is of medium quality (20 tex). The fabric count for woven fabric 100 x 72, indicates the fabric is an unbalanced weave, where warp yarns (100) exceed the weft yarns (72). In the case of knitted fabric, 24 courses per cm x 15 wales per cm indicates that the fabric has moderate closeness or compactness. This factor affects the ability of the fabric to transmit moisture between the skin and the environment.

Fabric pilling grade 5 reveals that the fabric performed well, with little or no surface fuzz, in the case of knitted, there were minor surface fuzz (pilling grade 4). Fabric abrasion resistance reveals that at 10,000 rubs there were minor colour change with no change in the mass and thread bare. The abrasion resistance for knitted fabrics were good, with little change in mass and no thread bare and slight increase in shade. Fabric durability depends on fibre type as well as on fabric structure and yarn fineness. The drape coefficient of 55% indicates that the woven fabric possess medium drape, such that it is neither stiff nor a flexible fabric. However, in the case of knitted fabric, the drape coefficient of 17.4% indicate that the fabric is pliable. In the case of fabric stiffness, bending length is observed from which flexural rigidity is calculated. The flexural rigidity is a measure of stiffness that depends on fabric thickness, yarn count, fabric structure and finishes applied on to the fabric which makes the fabric compact. Flexural rigidity of 12.0 µNm in warp direction and 4.3 µNm in weft direction indicate that fabric possess stiffness in the lengthwise direction compared to width wise direction. In the case of knitted fabric, the flexural rigidity of 2.8 µNm indicates that the fabric possess little stiffness, in other words the fabric is pliable. The moisture assessment using MMT fabric print indicated that woven fabric is a water proof fabric (as there were no wicking) and knitted fabric was water repellent due to its specific finish. Knitted fabric possess good stretch in width wise direction (146%) than the lengthwise direction (7%) which is an important parameter especially in designing base layer garments worn next to the skin that requires stretch and recovery, for instance, in seat area, knee flex, back arm flex. It is also important to note that fabric growth after extension is 2.6% in wale direction and 7% in course direction. This should be considered in designing products as close fit garments such as tops for women may become baggy after repeated usage that involves intense body stretch (yoga practice or aerobics). In the case of comfort assessment – water vapour permeability, compact nature of the woven fabric resulted in average permeability (45%) compared to knitted fabric which had a better permeability (65%). The water vapour resistance for woven fabric was 11.7 (Pa m2/W) and 4.3 (Pa m2/W) for knitted fabric. This meant that knitted fabric is comfortable to wear as the moisture permeability is marginally better than the woven fabric. Thermal resistance of woven fabric could not be assessed as the fabric thickness was less than 0.20 mm.

Based on the above findings, it could be inferred that the knitted fabric is durable and it is suitable for active wear applications as it offers good resistance to pilling and abrasion. In addition, the fabric is flexible, offers stretch in width wise direction and water repellent which can be used for outdoor wear. Fabric possess good moisture permeability characteristics which enables the wearer to remain comfortable during an activity. In the case of the woven fabric, the fabric is suitable for soft shell jackets which offers resistance to wear and tear and has average moisture permeability. Both the fabrics can be recommended for performance applications which is targeted on low to medium market where the garment usage is less frequent.

Summary

Sportswear and functional clothing sector drives innovation, particularly in the area of fabric and accessories. Textile testing had been instrumental in determining the performance of these innovative high performance materials. In addition, different type of sporting activity requires different performance and the choice of fabrics vary. For example, an outdoor cycling kit requires a fabric that is light weight, possess stretch, and offers thermal balance next to the skin. However, a ski wear requires good thermal insulation to protect the wearer from severe cold condition. The chapter highlighted the importance of fabric evaluation in determining the fit for purpose using various textile parameters including physical characteristics, durability, aesthetics and comfort. Each test parameter was referred to British standards and a brief description of the test method was presented along with the visual illustration of the test equipment. In addition, example results were also presented to enable the reader to understand the outcomes and its relevance in fabric assessment (grade). The chapter also emphasized the importance of physical characteristics of fabric on its performance. In the case of performance assessment various test equipment including Taber abrasion tester, pilling box, stiffness tester, drape meter, moisture management tester, Fryma extensiometer and Permetest was discussed. The final section which outlined the fabric specification with example results between woven and knitted fabrics will enable the reader to interpret test results and comprehend how performance is assessed using the outcomes. The test methods discussed in the chapter were presented in the context of evaluating fabrics used in performance clothing and will serve as an invaluable resource to professionals and novice alike.

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