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Novel device to measure multi-directional wicking of elastic knitted fabric for active sportswear

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Multi-directional liquid spreading behaviour of polyester/elastane knitted fabrics under various stretches has been studied. A novel device has been developed to measure the liquid spreading behaviour of elastic fabrics under various stretches using image processing techniques. An attempt has also been made to understand the trend of the stretch behaviour of elastic knitted fabrics under different loads and the relationship between extension percentage and the liquid spreading of fabrics. Polyester fabric shows high transverse wicking rate and longer saturating time than the other two samples. Also the result shows that the area of transverse wicking of polyester/elastane knitted fabric is directly proportional to the time and inversely proportional to the load and elastane content.

Keywords: Clothing comfort, Elastane fabric, Image processing, Knitted fabric, Polyester, Sportswear

1 Introduction

Tight fit compression garments made of elastane fabrics are widely used in competitive sports and fitness activities[1]. These are worn during the activities of sports such as cycling, athletics, triathlon, and gymnastics and also during exercises in the gym[2]. Elastic fabrics provide fit comfort by facilitating free body movement without any fabric resistance which is essential during sports activities and exercises[3]. Another reason for using this tight fit compression garment is to improve the performance and for a speedy recovery of an individual. These garments create pressure on the wearer. It decreases muscle oscillation, increases blood circulation and reduces muscle damage after exercises[4]. The ergonomic design of sports clothing is mainly based on the skin deformation and stretch property of fabric during the different sports activities[5]. The different parts of the skin expand differently.

The normal body movement and an effortless action make the skin to expand by about 10 - 45%[6-8]. The power stretch elastic fabrics elongate up to 10 - 60%, when worn during active sports[9, 10].

During intensive actions of active sports, the body generates sweat in order to cool the core temperature. The sweat in a garment increases damp and clingy sense and as a result, level of tiredness to the wearer increases. To avoid this, the garment should quickly absorb the sweat generated, transport it and keep the skin dry[11]. In the case of active wears, the sweat from the skin is transported to the fabric as multi-directional transverse wicking. The fabric with the faster rate of transverse wicking facilitates faster moisture transportation from the high wet area to dry area and it leads to quick evaporation[12]. But in the case of compression garments, the inner surface of the fabric is in full contact with the wearer's skin[13]. When the compression garment is used for an extended time, it fails to manage the sweat in terms of moisture transportation and evaporation. The development of such effective sweat management fabric is essential in the compression sportswear design. In order to address this issue, in this study a novel instrument has been developed to measure the sweat transfer characteristics of elastic fabric under various stretched states, assuming that the result from this instrument will be the most useful for developing suitable sportswear.

There are some standard test methods to measure the moisture wicking properties of fabric (AATCC 195, 197 & 198; ASTM 4772-97). These standard test methods measure the moisture transport capability of a fabric in static and relaxed state which is not similar in the case of compression garments. A mechanism was developed to investigate the performance of the

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yarn under cyclic testing to record its extension percentage at different loads[14]. Instron tensile tester was modified to evaluate the longitudinal wicking rate during the movement of yarn in the fabric under the cyclic loading. They found that the force applied on the fabric is one of the influencing factors of wicking[15]. The bending behaviour of fabric along the knee and elbow movements was duplicated by repeated loading with a fixed time. Researchers[16] also studied the wicking property of yarn and fabric when it was subjected to strains. Even though there are some standard methods and many innovations available to evaluate the moisture management properties of fabrics, it is inappropriate to consider the results of relaxed state and cyclic loading of fabric in product development of compression garment. The surface morphology of the fabric got modified when the garments stretch to the body shape[5].

An objective evaluation system is required to assess the transport of moisture in different stretched states. An instrument has been developed which is capable of creating various levels of extension of the sample by varying loads. It captures the image of the transverse liquid spread under different stretched state, stores in a computer and analyse with the help of image processing technique. The results from this instrument will give clear information about the trend of extension behaviour, the relation between extension and transverse spreading and its saturation point under various loads which helps in manufacturing effective moisture management fabrics for compression garments.

2 Materials and Methods

2.1 Design of Proposed Novel Device

A novel instrument was developed to investigate the influence of fabric extension on transverse wicking of the knitted fabric. The instrument (Fig. 1) is intended to produce required stretch percentage to knitted fabric by varying loads and to measure transverse wicking behaviour precisely for the different time duration in order to improve the comfort of the tight fit high active sportswear. This instrument consists of the extension unit with the load cell arrangement, liquid inlet unit and image processing unit.

Extension Unit with Load Cell Arrangement

The extension unit consists of two jaws, a fixed jaw and a movable jaw fixed to the base frame. The fabric sample is mounted between the jaws. The other end of the fixed jaw is connected to a load cell which is an electronic device used to measure the amount of the load applied to the fabric precisely. The other end of the movable jaw is connected to the pulley through a cord and bearing wheel to apply necessary loads to the test sample. The bearing wheel arrangement is provided for free and easy movement of movable jaw. A direct current motor is used to provide forward and reverse motion to the movable jaw through the pulley. The constant rates of the loads are applied to the sample by the DC motor. The required amount of load can be key in and the load applied can be measured through the load cell. The microcontroller will stop the action of DC motor after reaching predetermined load based on the value of the load cell. The forward and backward movement of the movable jaw, fabric stretch and its recovery can be controlled through microcontroller. The quantity of extension undergone by the sample because of the application of load is measured accurately with the help of measuring scale mounted on the side of the base frame. An U-slot sensor is fixed at the other end of the pulley to keep a record of the number of rotations made by the pulley for forward and backward movement.

This instrument is capable of measuring the extension of the fabric under the load and the liquid spreading behaviour of the high stretch fabric in static, relaxed and stretched condition. The transverse spreading behaviour of the fabric can be studied without providing drive to the movable jaw and this state can be considered as a static and relaxed state.

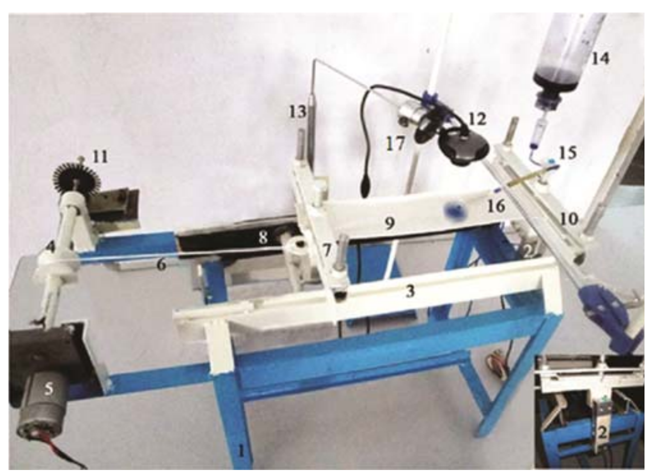

Fig. 1 — A novel device to measure the multi-directional liquid spreading area of stretched fabric [1–base frame, 2–load cell, 3–scale, 4–pulley, 5–dc motor, 6–cord, 7–movable jaw, 8–bearing wheel, 9–fabric sample, 10–fixed jaw, 11–u slot sensor, 12–camera, 13–support stand, 14–water reservoir, 15–drop flow rate controller, 16–syringe]

For the stretched state, the fabric samples are subjected to different load of the extension as determined by providing drive to the movable jaw.

Liquid Inlet Arrangement

The liquid inlet arrangement is set at the back in a separate stand fixed to the base frame. The artificial sweat is filled in the water reservoir and continuous, consistent and predetermined amount of the liquid can be fed to the sample through a narrow tube and syringe arrangement as drops and the amount of supply can be altered using the drop flow rate controller. The liquid inlet will be stopped once the fabric reaches its saturation level or when the liquid drops down from the fabric.

Image Processing Unit

A high-resolution Logitech HD Pro Webcam C920 is mounted on top of the instrument to capture the area of liquid spread of the sample. This camera is capable of the auto focusing and capturing precise images. The captured images of the liquid spread at different time intervals were stored in the computer. The stored image can be processed using Adobe Photoshop tool to analyse the contour of liquid spread, area of spreading and the rate of liquid spread.

2.2 Materials

Polyester yarn for three types of stretchable fabric samples was sourced from the local manufacturer from the same lot. The elastomeric yarn from a single lot was sourced from the local supplier. The samples were knitted on 24 gauge, 20 inch diameter Mayer and CIE circular knitting machine. The produced samples were single jersey, single jersey with elastane as half plated and full plated fabric structure. The selection of material is done mainly to get different stretch behaviours.

Plated structure is formed by the simultaneous feed of two threads for one loop. One set of the thread will lie on the face side and the other set of thread on the back side of the fabric[17]. The process of knitting spandex yarn with main yarn together in every course is called full plated fabric [Fig. 2(a)]. The process of knitting spandex yarn in alternate courses along with main yarn is half plated fabric [Fig. 2(b)]. These plated structures provide the opportunity to utilise the benefit of both yarns as one fabric. The particulars of fabrics produced are given in Table 1.

The cut samples of size 20 cm × 8 cm were prepared and conditioned at standard atmosphere of 27 ± 1 °C and 65 ± 2% relative humidity.

2.3 Experimental Methods

This instrument provides two possibilities of conducting the experiment, viz (i) different stretch percentage by constant load and (ii) constant stretch percentage by varying load. In this investigation, the stretch of the tight fit garment under static pressure was simulated by applying a constant load to the sample and evaluated the transverse wicking behaviour of the samples of various extensions.

The prepared and conditioned samples were clamped between the jaws. The DC motor drives the movable jaw for stretching the fabric and the length of fabric extension in course direction at different loads (10, 50, 100, 150, 200 g) was recorded with the help of scale[18]. Power stretch fabrics used for compressional garment show stretching in the range of 10 - 60% and the maximum load (200 g) is fixed in this work to achieve 60% extension[9, 10]. Similarly, the extension of fabric in wale direction was carried out and the percentage of extension was compared to assess the direction of maximum stretchability. The percentage of fabric extension was calculated by the ratio of the difference between initial and final lengths to its original length of fabric.

The fluid reservoir was loaded with artificial sweat prepared as the composition given by AATCC test method 15-2009, colour fastness to perspiration. The fabric was coloured by dissolving 2% of the blue reactive dye of cold brand in 100 ml of artificial sweat. This was used for getting an exact

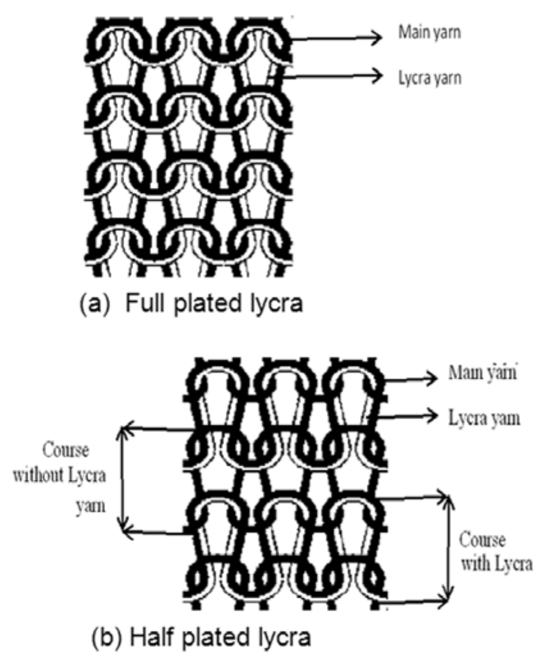

Fig. 2 — Structural images of plated lycra fabric

measurement of liquid spread area using the camera. The liquid was supplied continuously as one drop per second (weight of a drop = 0.10 g) from the height of 6mm to the test sample[19, 20]. The transverse wicking of the test sample at different stretched states was measured by means of web camera mounted above the sample. In this study, it captures images at different time intervals, such as 5 s, 10 s, 30 s, 1 min, 2 min, 4 min, 6 min and 8 min[21]. Liquid spread at relaxed condition without the load (0 g) was recorded and the procedure was repeated for the extension of 10, 50, 100, 150 and 200 g of load. The images were captured and stored. The trial was terminated, once the fabric attains its saturation level.

The area of liquid spread in a given time gives the degree of wick ability of the sample which is calculated from the captured image using the Photoshop tool. To calculate exact area of liquid spread, the resolution of the captured image size was changed into 10 pixels / cm. The option called 'anti-aliased', 'contiguous' was enabled. Anti-aliasing is to smoothen the serrated outline of the images and the contiguous option is to select the pixels of the similar colour in the picture. The stored image was cropped and selected using magic wand tool, which chooses the pixels of the same colour range. Furthermore, precise selection of the liquid spread area can be carried out by selecting 'grow' option of the select menu which further expands its selection. The number of selected pixels can be viewed from the histogram and recorded. The porosity percentage of the stretched fabric is evaluated by optical method using this instrument to further strengthen the findings of transverse wicking[22].

The consistency of this instrument was evaluated by conducting tests with a single sample and multiple samples[6]. The area of the liquid spread of single sample was evaluated by repeating the test procedure ten times with the same sample. The areas of the liquid spread of multiple samples were studied by repeating the test with ten different samples cut from the same variety of a fabric. The results of the area of liquid spread by single sample and multiple samples tests were compared for the consistency through its standard deviation values. The reliability of the instrument was confirmed by comparing the results obtained by the manual test method[2] and results obtained by this instrument. The test results from these two methods are statistically analysed with t-test at 95% confidence level.

3 Results and Discussion

Before the start of the study, consistency and reliability of the novel instrument are confirmed as mentioned in the methodology. The amount of extension of single jersey, half plated and full plated fabrics for different loads are recorded; it is repeated

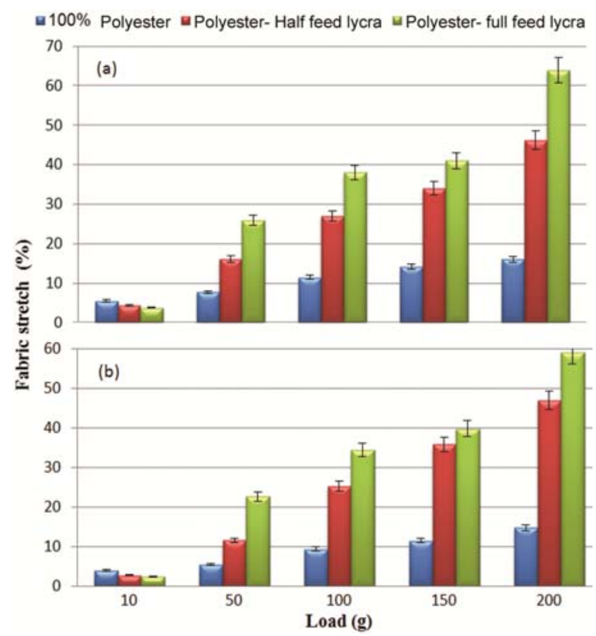

Fig. 3 — Fabric stretch behaviour in (a) course direction and (b) wale direction

Table 1 — Fabric particulars and standard deviation of single and multiple sample tests

Fabric	Structure	Count, den (polyester, lycra)	Construction particulars		Thickness mm	Areal density g/m^2	Standard deviation	
			WPC	CPC			Single sample	Multiple sample
100% Polyester	Single jersey	150	20.11	24.57	0.40	136.51	6.84	5.19
100% Polyester - half feed lycra	Single jersey – half plated	150 22	20.72	26.14	0.48	184.39	8.19	6.94
100% Polyester - full feed lycra	Single jersey – full plated	150 22	21.87	28.08	0.51	201.28	14.62	11.08

WPC–Wales per centimetre, CPC–Course per centimetre.

for ten trials. The percentage of fabric stretch at different loads in the course and wale directions is given in Figs 3(a) and (b). Later the rate of transverse wicking of the fabric with the influence of elastane content and the amount of load for different time durations is investigated using this instrument for the better understanding of transportation of moisture under the stretched, simulating the conditions during the active sports. Five trials are repeated for studying the liquid spreading and the average values are taken for discussion.

3.1 Validation of Novel Instrumental Method

The consistency of the results obtained from this instrument is evaluated by the standard deviations from the values of area of liquid spread of single and multiple samples of 100% polyester fabric, half plated lycra fabric and full plated lycra fabric. The results of standard deviation from the test are given in Table 1.

The calculated value of t-test for conforming the reliability of instrument for 100% polyester fabric is 2.001, half plated lycra fabric is 1.807 and full plated lycra fabric is 1.719, which is less than tabulated value of 2.262. The results of the instrumental method are found similar to the manual method.

3.2 Fabric Stretch under Application of Various Loads

In the real case of active sports, the maximum stretches of muscles in different parts of the body are around 10 - 45% (ref. 13). The power stretch fabrics provide 10-50% extension in order to avoid discomfort and obstacles to the players. The mean values of the stretch percentage of the samples of different loads in course direction are given in Fig. 3 (a). The fabric gets extended while applying load and it continues as the load increases. This is because of the tapering of the loop structure of the fabric along the direction of load. In the case of elastic knitted fabrics, a greater extension is achieved because of elastane feed along with the polyester yarn. The full plated fabrics with elastane content show greater stretchiness.

The stretchability of the fabric is calculated from the results of stretch percentage of both course and wale directions. During the stretch process, the length of the sample increases, while the width and the thickness of the fabric sample reduce. The increase in the length is due to straightening of the loop and further slimming down of the loop structure. The reduction in width of the fabric is due to the fact that the threads in the loop structure are tightly packed and jammed. The elongation percentage of the 100% polyester fabric is larger (5.5%) at initial 10 g of the load than lycra plated fabrics (half plated 4.35% and full plated 3.8%) in course direction at this load. This is because of the increased course density and tighter lycra fabric[23]. Tighter fabric requires an additional load to elongate in the beginning. In other words, it can be mentioned as lycra fabric show lesser elongation at the initial stage. But as the load increases, the role of elastane starts. The extension percentage started increasing from the load of 50 g onwards and it is 64 % for full plated lycra, 46.2% for half plated lycra and 16% for 100% polyester fabric at 200 g of load. This trend of stretch behaviour is found similar in all the cases of loads. The standard deviations of the results of the extensions of the course and wale direction are shown in Table 2. The stretch percentages of the fabric in course direction under various loads of 100% polyester sample are in the range of 5.5 - 16%, and it is because of more influence of the knitted fabric structure. The stretch percentages are ranging from 4.35% to 46.2% for half plated, and 3.8% to 64.05% for the full plated structure.

The percentage of fabric stretch in the wale direction is measured using this instrument similar to the procedure followed in the course direction and the results are shown in Fig. 3 (b). This is done to identify the direction of maximum stretch of the samples. The extension of 10 g of the load is higher for 100% polyester fabric than the other samples[24]. The stretch

Table 2 — Standard deviation of area of liquid spread - Stretch of fabrics under various loads

Fabric	Standard deviation									
	10 g load		50 g load		100 g load		150 g load		200 g load	
	C	W	C	W	C	W	C	W	C	W
100% Cotton	0.592	0.795	0.705	0.429	0.841	0.962	0.713	0.603	0.643	0.629
100% Cotton- half feed lycra	0.488	1.051	0.893	1.005	0.682	0.835	1.043	0.862	0.696	1.318
100% Cotton- full feed lycra	0.130	0.867	1.030	0.893	1.459	0.874	0.593	0.723	0.588	1.185

C–Stretch in course direction; and W–Stretch in wale direction percentage of the 100% polyester sample in wale direction is lower by 1.25 - 2.75% than in course direction. The results are also similar in the other two cases. When the load is applied in wale direction, the elongation would be usually lesser and which is because of the fabric structure. To continue the further study, the direction of maximum stretch-ability was considered for the application.

3.3 Area of Multi-directional Wicking under Various Loads

The developed instrument is used to measure the transverse liquid spread of fabrics with various elastane contents of different stretches. Five trials have been carried out and an average of the spreading area of the samples at different extension loads for different time intervals (Fig. 4). The rate of spread increases gradually with time and this is because of continuous supply of liquid to the samples which replaces air in the yarn interspaces with liquid, and later the transportation of liquid happens in the samples[25].

It is a well-known fact that the transverse wicking trend of all three samples will vary and the main goal of this study is to confirm the credibility of the instrument and to distinguish the values obtained from this instrument. From the results of the study, when comparing the three samples, the 100% polyester samples shows a high transverse wicking rate for a shorter time than the other two samples. The saturating time of the 100% polyester sample is longer than the other samples. The half plated and full plated samples display lower rate of liquid spread and it reaches its saturation point in 4 min and 2 min respectively at 10 g of load. The reason for this behaviour is the elastane content. The researchers confirm that the faster moisture transportation and quick evaporation of fabric are influenced by the availability of elastane fibre in the fabric[26]. Elastane cannot absorb the moisture since it is a hydrophobic fibre.

Based on the findings from this instrument for all the samples under relaxed state (0 g), the results show a faster rate of transverse spread of the liquid. This is because of the tight packing of threads and the capillary force of the fibres[27]. As the load applied to the sample increases, the extension of the fabric is increased along the direction of load and it plays a vital role in the rate of liquid spread. It is clearly observed from the result that as the load increases, the extensions of the samples influence the rate of liquid spread. The stretch in length direction creates long and elongated loops. It also forms larger void spaces between the loops (Table 3). The larger voids are filled with sufficient amount of droplets by replacing the air gaps. Also, as the contact angle of liquid in the voids of the larger pores increases, the rate of liquid spread decreases [28-30]. While the small pores are easily filled at lower saturation levels, it leads in faster

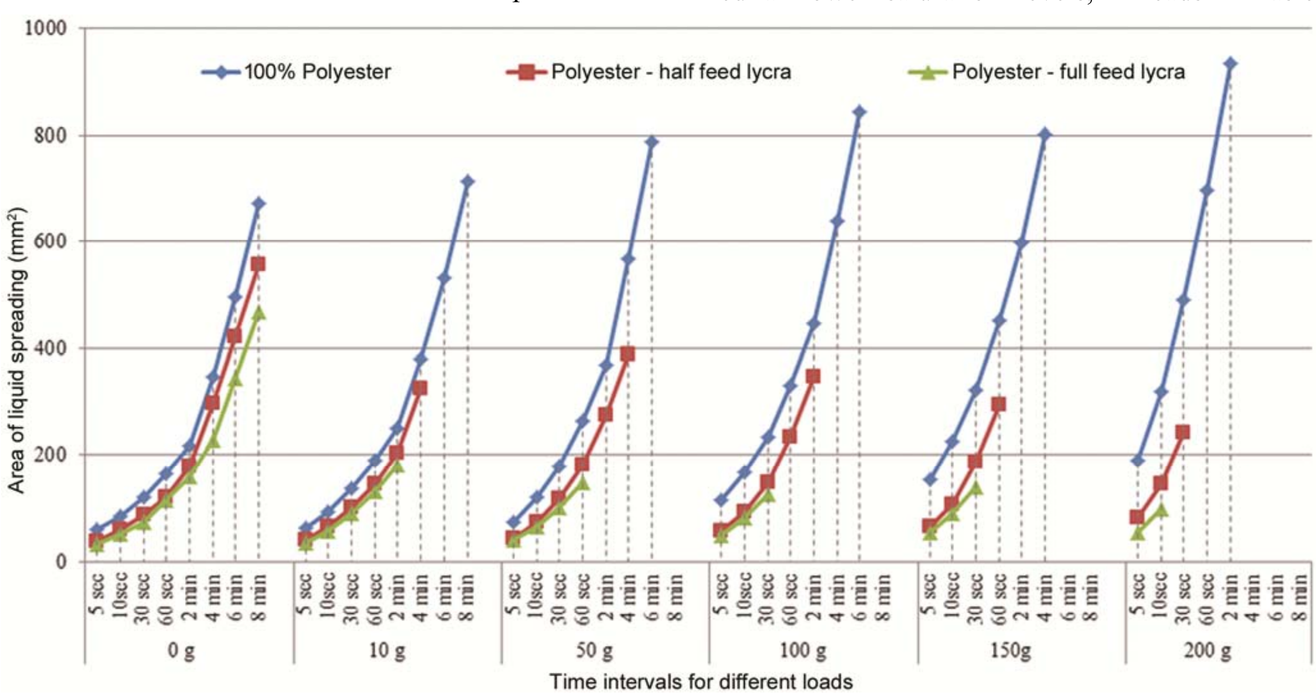

Fig. 4 — Area of multi-direction wicking under various loads

Table 3 — Porosity percentage of fabric under various stretches

Fabric	Porosity percentage				
	10 g	50 g	100 g	150 g	200 g
100% Polyester	58.37	62.03	64.61	67.52	69.62
100% Polyester - half feed lycra	52.12	63.17	67.18	71.83	76.89
100% Polyester - full feed lycra	44.09	64.81	69.08	75.23	79.49

transverse wicking. The saturation time differs with different loads for the same type of fabric. When the static loads of various ranges are applied to these samples, the percentage of elongation differs from one sample to another. There is a difference in pore size of the samples, which is the main reason for the reduction in saturation time. The water droplet slips through the large opening before spreading and hence lesser saturation time.

The average values of trials show increased rate of multi-directional wicking, but it reduces with load and elastane content. These findings show that the increase in elastane content of fabric rises the stretch of the fabric, but shows low wicking rate and shorter saturation time. As the elongation of the knitted fabric increases, it reduces the transportation of the liquid. This lower wicking rate influences the evaporation of the fabric and also the comfort level of an individual.

The p-values are calculated for three different fabrics to find the influence of different loads and time interval for its significance in the test. The p value of all the three samples is less than 0.05 and it proves its significance.

4 Conclusion

A novel instrument to measure the rate of transverse wicking at different stretched state of compression garment has been designed and developed. Three different samples of different stretch behaviour are tested and it is found that stretch behaviour of elastane fabric is less at initial stage than that of the non elastane fabric. The transverse liquid spread of the polyester knitted fabric is superior to the fabric with elastane content. The saturation time of elastane fabric is shorter than the elastane fabric.

References

1 Duffield R & Portus M, *Brit J Sport Med*, 41(7) (2007) 409.
2 Troynikov O, Ashayeri E & Fuss F K, *Proceedings, Inst Mech Eng J–J Eng Tribology , 226*(7) (2012) 588.
3 Senthilkumar M, Kumar L A & Anbuman N, *Fibres Text East Eur*, 20(1) (2012) 90.
4 Venckūnas T, Trinkūnas E, Kamandulis S, Poderys J, Grūnovas A & Brazaitis M, *Sci World J,* (2014). http://dx.doi.org/10.1155/2014/353040.
5 Luo S, Wang J, Yao X & Zhang L, *J Text Inst*, 108(9) (2017)1600.
6 Voyce J, Dafniotis P & Towlson S, *Textiles in Sport* (Wood Head Publications, England (2005) 205.
7 Yu Z C, Zhang J F, Lou C W, He H L, Chen A P & Lin J H, *Text Res J*, 85(14) (2015) 1486.
8 Kirk W (Jr) & Ibrahim S M, *Text Res J*, 36(1) (1966) 37.
9 Bera M, Chattopadhay R & Gupta D, *J Inst Engg (India): Series E*, 95 (1)(2014) 41.
10 Lyle D S, *Performance of Textiles* (John Wiley & Sons, New York), 1977.
11 Manshahia M & Das A, *Indian J Fibre Text Res,* 39 (2014) 441.
12 Sampath M B, Mani S & Nalankilli G, *J Ind Text*, 41(2) (2011) 160.
13 Troynikov O, Ashayeri E, Burton M, Subic A, Alam F & Marteau S, *Procedia Eng*, 2(2) (2010) 2823.
14 Frank F & Singleton R W, *Text Res J*, *34*(1) (1964) 11.
15 Nyoni A B & Brook D, *Text Res J*, 80(8) (2010) 720.
16 Kisilak D, *Text Res J,* 69(12) (1999) 908.
17 Abdessalem S B, Abdelkader Y B, Mokhtar S & Elmarzougui S, *J Eng Fiber Fabric*, 4(3034) (2009) 18.
18 Kawasaki K & Ono T, *J Text Mach Soc Jpn*, 14(3-4) (1968) 122.
19 Raja D, Ramakrishnan G, Ramesh Babu V, Senthilkumar M & Sampath M B, *J Ind Text*, 43 (2014) 366.
20 Onofrei E, Rocha A M & Catarino A, *J Eng Fiber Fabric*, *6*(4) (2011).
21 Raja D, Koushik C V, Ramakrishnan G, Babu V R & Subramaniam V, *Indian J Fibre Text Res*, 37 (2012) 381.
22 Imrith M K, Unmar R & Rosunee S, *Adv Mat Sci Eng,* 2016 (2016).
23 Eltahan E, *J Comp*, (2016). DOI: 10.1155/2016/3846936.
24 Sadek R, El-Hossini A M, Eldeeb A S & Yassen A A, *J Eng Fiber Fabric, 7*(2) (2012) 11.
25 Patnaik A, Rengasamy R S, Kothari V K & Ghosh A, *Text Prog,* 38(1) (2006) 1.
26 Umbach K H, *Melliand Testilber*, 74(2) (1993) E78.
27 Hollies N R, Kaessinger M M, Watson B S & Bogaty H, *Text Res J*, 27(1) (1957) 8.
28 Simile C B, *Critical Evaluation of Wicking in Performance Fabrics*, Ph.D. thesis, Georgia Institute of Technology, Atlanta, USA, 2004.
29 Yanılmaz M, Kalaoğlu F & Kalaog F, *Text Res J*, 82(8) (2012) 820.
30 Amico S & Lekakou C, *Compos Sci Technol*, 61(13) (2001) 1945.