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Prediction Modeling of Compression Properties of a Knitted Sportswear Fabric Using Response Surface Method

Jawairia Umar, Tanveer Hussain, Zulfiqar Ali, Muhammad Maqsood

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***Abstract*—**Different knitted structures and knitted parameters play a vital role in the stretch and recovery management of compression sportswear in addition to the materials use to generate this stretch and recovery behavior of the fabric. The present work was planned to predict the different performance indicators of a compression sportswear fabric with some ground parameters i.e. base yarn stitch length (polyester as base yarn and spandex as plating yarn involve to make a compression fabric) and linear density of the spandex which is a key material of any sportswear fabric. The prediction models were generated by response surface method for performance indicators such as stretch & recovery percentage, compression generated by the garment on body, total elongation on application of high power force and load generated on certain percentage extension in fabric. Certain physical properties of the fabric were also modeled using these two parameters.

***Keywords*—**Compression, sportswear, stretch and recovery, statistical model, kikuhime.

I. INTRODUCTION

THE body comfort and fit is associated with the stretchable knitted structures not only for professional sportsmen but also for normal daily use. The knitted structures allow the wearer to move freely with least resistance due to their stretch-ability and elasticity [1]. Among other fields of technical textiles, sport-tech is also an emerging branch. It has been the area of researcher's interest in recent years and keeps on developing from fibre to garment with the interest to boost the energy of athletes. Comfort is an important factor for the selection of a sportswear fabric for the well-being and efficiency of athlete [2]. The change of market trend from natural to synthetic fabric in sports textiles is due to its requirement of being light, strong and stretchable. The courser to fine counts movement of market is also for the same reason of light weight so that it could maintain the comfort level of the sportsmen [3]. Compression garments are the fabric devices made of natural or synthetic yarns in combination with the elastomeric yarn which help to apply certain pressure on the surface of body to compress and stabilize the body tissues [4]. Compression garments can affectedly improve the performance of the sportsman by blood circulation which help not only improving recovery process but also prevent injuries. When an elastomeric fabric is stretched, it stores the kinetic energy equal to the work done during this displacement. The substantial pressure exerted by the compression garment releases the stored kinetic energy which is then gain by the sportsman, hence increase his power stamina and speed [5]. Compression garments for sportsmen helps maintain power production during repetitive jumps. Since it enhances force production by increasing blood circulation on the areas where these compression garments are worn [6]. The lower knee compression stockings with constant pressure at the calf muscle significantly increase the running speed of athletes both at aerobic and anaerobic metabolic thresholds and delays process of fatigue both during and after run [7]. The pressure produced by the compression garments is due to stretch and recovery of the fabric [8]. Even though knitted fabrics have their generic stretchability but this stretch and recovery is not to that extend to exert the substantial pressure required for compression sportswear. Therefore, an elastomeric yarn like spandex is used in knitting fabrics in addition to main yarn to accomplish the need of elasticity and stretchability in compression fabrics [8].

Haji studied the physical and mechanical properties of cotton/spandex weft knitted fabrics. He concluded that stitch length and spandex percentage of any knitted fabric has significant effect on the weight of the fabric. Spandex percentage has direct relation whereas stitch length has inverse relation with weight of knitted fabrics [9]. Abramaviciute et al. investigated the physical and structural properties of knitted fabrics made of different nature of natural yarns in combination with spandex and textured polyamide. They concluded that plating of fabric with spandex increased the CPI and WPI of the fabric as compare to the fabric plated with polyamide [10]. Senthilkumar et al. studied the mechanical properties of the cotton/spandex knitted fabrics with the spandex denier, spandex yarn tension during knitting and stitch length of the cotton yarn. In this study they concluded that linear density of the spandex increased the dynamic work recovery of the fabric in both course and wale wise direction [11]. Abdessalem et al. related the physical and dimensional properties of fabric with spandex consumption. They concluded that consumption of Lycra and the width of the fabric can be reduced by increasing the tension on Lycra yarn [12]. Maklewska et al. designed a model for producing the

J. Umar is with the University of Agriculture Faisalabad, Pakistan (corresponding author; phone: +92 3228665457; e-mail: jiaumar@gmail.com).

T. Hussain, is with the National Textile University, Faisalabad, Pakistan. (e-mail: hussain.tanveer@gmail.com).

Z. Ali is with the Yarn Manufacturing Department, National Textile University Faisalabad Pakistan, (e-mail: zakwan7o@yahoo.com).

M. Maqsood is with the Fabric Manufacturing Department, National Textile University Faisalabad, (e-mail: engr.maqsood@hotmail.com).

compression garments used in medical textiles to generate a pre-set pressure on the application area using Laplace law [13]. Yildiz investigated the thermo-physiological properties and compression behavior of a pressure fabric for the curing of hypertrophic burn scars [14]. Dias et al. in their research on medical textiles modelled the interface pressure of a compression garment [5].

Although a lot of research work has been reported in the literature on compression sportswear, but only a few worked on its prediction modeling and stretch, recovery properties of knitted fabrics from knitting characteristics. Therefore, in this background, this present research was planned to study the effect of linear mass density of spandex (plating yarn) and stitch length of the polyester (base yarn) on the stretch, recovery and compression properties of the special sportswear fabric made from polyester and spandex. Prediction models were developed to accurately predict the compression properties of knitted stretchable fabrics for sportswear. These prediction models would help the manufacturer to estimate an amount of pressure generated by the compression garment at the time of fabric manufacturing. Hence it would help the design and development team of compression garment industry to customize the required pressure according to the requirement of the sports and respective sportsmen. In due course, it will minimize the hit and trial experimentations by the research and development persons.

II. MATERIAL AND METHODS

Combination of two kinds of yarns as 100% polyester with 48 filaments and 100% spandex with mono filament were used in the planned study. Spandex yarn was further categorized by four different linear densities each used in combination with same linear density of polyester. Properties of the yarns used in this study are given in Table I.

TABLE I
PROPERTIES OF PLANNED YARNS

No.	Parameters	Units	PES	SPX 1	SPX 2	SPX 3	SPX 4
1	Linear Density	dtex	83	22	33	44	78
3	Tenacity	cN/dtex	4.65	1.16	1.28	1.09	0.9
4	Elongation	%	20.74	500	493	481	527

PES= Polyester, SPX= Spandex

Plating technique was used to knit the twelve fabric samples according to Table II from (PES/SPX) on the Mayer and Cie knitting machine in Masood Textile Mills Faisalabad (Fig. 1). Full feeding technique of spandex feeding was used to feed the spandex on every course along with polyester yarn on keeping the spandex feed tension constant. Detailed specifications of the knitting parameters are given in Table III.

Three different levels of stitch length of PES were taken, as 2.7 mm, 2.9 mm and 3.1 mm.

Fig. 1 Mayer and Cie weft knitting machine

TABLE II
DESIGN OF EXPERIMENTS

No.	Base yarn	Base yarn, dtex	Spandex, dtex	Base yarn stitch length, cm
1	Polyester	83	22	0.27
2	Polyester	83	22	0.29
3	Polyester	83	22	0.31
4	Polyester	83	33	0.27
5	Polyester	83	33	0.29
6	Polyester	83	33	0.31
7	Polyester	83	44	0.27
8	Polyester	83	44	0.29
9	Polyester	83	44	0.31
10	Polyester	83	78	0.27
11	Polyester	83	78	0.29
12	Polyester	83	78	0.31

TABLE III
KNITTING SPECIFICATIONS

No.	Parameters	Polyester/Spandex
1	Machine Diameter	86.36 (34) cm/inch
2	Gauge	9.45 (24) N/cm N/inch
3	Stitch length	2.7, 2.9, 3.1mm
4	Spandex feeding Mechanism	Full
5	No. of Feeders	108
6	Machine speed	22~24rpm

After knitting heat setting of the samples was done on eight chamber Monfort's stenter machine of chamber length 3m each in order to stabilize the synthetic yarns. Temperature, speed, stay time, stretch %age and overfeed of the heat-set were 190°C, 14 m/min, 1.9 minutes, 5% and 50% respectively. Heat setting was done without any chemical in finishing. Polyester/spandex samples were semi bleached using hydrogen peroxide and caustic soda with a multifunctional scouring agent at 98°C for 15 minutes followed by neutralization of pH with acetic acid and catalase enzyme. After semi bleach PES/SPX samples were dyed using disperse dyeing process at liquor ratio 1:10 in a pressurized winch at 130°C for 30 minutes. After that washing of the samples was done to remove residual unfix dye, which are then hydro extracted to remove extra liquor from the fabric. All the samples were then stretch and dried on Monfort's stenter and compacted on Ferraro compaction machine.

For dimensional stability experimental samples were dip-tumbled according to AATCC135. Before testing standard

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conditioning of the samples was done at 20 ± 1°C and 65 ± 2% relative humidity. ASTM D 3887 standard test method was used to measure the fabric course and wale density. Dimensional stability and areal density of the fabric were measured according to AATCC135 and ASTM D 3776-96 respectively. ASTM D 2594-99 standard test method for low tension force was used to measure the stretch and recovery of the experimental samples as shown in Fig. 2.

Fig. 2 Stretch and recovery setup

Equation (1) was used to calculate the course and wale wise stretch percentage of the PES/SPX knitted samples.

$$\text{Stretch percentage} = (C-A)/A \times 100 \quad (1)$$

where, A is distance in mm between the marked points before the application of force and C is the distance in mm between the marked points under tensional force.

The recovery percentage was calculated separately using (2) and (3) after 60 seconds and 60 mins.

$$\text{Recovery percentage after 60 sec} = (B-D)/(B-A) \times 100 \quad (2)$$

$$\text{Recovery percentage after 60 mins} = (B-E)/(B-A) \times 100 \quad (3)$$

where, B is the distance between the marked points under extension of 35% and 60% in wale and course wise direction respectively. D and E are the distance between the original marked points after 60 secs and 60 mins respectively, measured after the release of extension.

Similarly, elongation and tension in fabric was calculated according to ASTM D 4964-96 using Llyod tensile tester. In this method a constant load of 100N was used to extend the knitted samples and total elongation was calculated. Recovery percentage was measured after the immediate removal of the high tension force. Another important factor i.e. force required to produce 50% extension in the fabric was also calculated which is an important indicator of ease of movement of abody during routine exercise.

Kikuhime pressure sensor was used to measure the sub-garment pressure generated by the PES/SPX looped fabric on the cylindrical body as shown in Fig. 3.

Four different readings were taken at different positions of the body for each test specimen. After testing, Minitab 17 (a statistical software was used for the data analysis by using response surface method.

Fig. 3 Pressure sensing device

III. RESULTS AND DISCUSSION

A. Physical Characteristics

Three different stitch lengths of polyester as base yarn (2.7 mm, 2.9 mm and 3.1mm) and four different linear densities of spandex yarn (22 dtex, 33 dtex, 44 dtex and 78 dtex) were taken as input variables whereas wale density, course density and areal density were taken as response variables. Three replicates were taken for each test.

The testing results of the samples produced from polyester/spandex blend were analyzed by regression analysis in Minitab 17 statistical software. The P-values and regression coefficients of physical properties of PES/SPX fabric are given in Table IV.

B. Fabric Course Density

It can be noticed in Table IV that the effect of spandex linear density (d) is not significant on the course density of the fabric but the effect of square of spandex linear density (d × d) on PES/SPX fabric course density is significant with P-value 0.00 as shown in Table IV. It is indicating that the change in fabric course density is not linear with the change in spandex linear density showing curvature in the trend. The polyester yarn stitch length both alone and in square is not affecting the course density significantly with P-value 0.9 and 0.92 respectively. Whereas interaction of polyester yarn stitch length with spandex linear density (d × l) is statistically significant with p value 0.01, which means the effect of change in stitch length of base yarn is affecting the effect of spandex linear density on the course density of the fabric. From the R2 of the regression model in Table V, it can be concluded that 94.45% change in fabric course density of PES/SPX fabrics can be explained by the terms included in the model.

It can be seen from Fig. 4, the course density of the fabric increased with the increase of spandex linear density and decreased with the increase of base yarn stitch length in PES/SPX fabric. This effect is due to the fact that with the increase of spandex linear density, percentage of spandex in the fabric increases which increases the yarn lateral loop contraction. The course density of polyester yarn decreases with the increase of yarn stitch length and this is due to decrease in number of loops per unit area with the increase of stitch length. There is also some interaction effect of spandex linear density and base yarn stitch length, which is evident from the Fig. 4. At both low and high spandex denier the increase in base yarn stitch length tends to decrease the fabric course density but the range of decrease is not very steep due to small span of base yarn stitch length and by increasing the span the effect may be steeper.

C. Fabric Wale Density

It can be seen from the P values in Table IV that both factors do not have any significant effect on the wale density of the PES/SPX fabric. This null effect may be due to setting of spandex yarn in the width direction on stenter during heat setting which reduced the lateral contraction of spandex in width direction by thermosetting of soft segments in spandex yarn. This setting of chains reduced the effect of change in wale density with the change in spandex linear density which should be increased with the increase of spandex linear density. But the heat setting of all samples on the same width reduced the ability of highly elastic yarns to revert the loops to their original position after the removal of tension. From Table V, the R square of the regression equation of PES/SPX is 28.24%, which indicates that the change in wales per centimeter of the PES/SPX fabric cannot be adequately explained by the terms given in the equation and there may be other factors affecting the wale density of the fabric. It can be seen in Fig. 4 (b) that the number of wales per cm remained 18 to 19 when the base yarn stitch length changed from 2.7 mm to 3.1 mm. Similarly, there is not a significant change in wale density of PES/SPX fabric when linear density of spandex changed from 22 dtex to 78 dtex and this may be due to heat setting of spandex yarns in width direction.

TABLE IV
REGRESSION COEFFICIENTS OF PHYSICAL PROPERTIES OF PES/SPX FABRICS

Terms	Course density, cm^{-1}		Wale density, cm^{-1}		Areal density, gm^{-2}	
	Coef	P-Value	Coef	P-Value	Coef	P-Value
d	-0.06	0.70	-0.01	0.92	-0.03	0.98
l	-5.90	0.90	18.10	0.32	-194.00	0.64
d × d	0.00	0.00	0.00	0.18	-0.01	0.01
l × l	-0.82	0.92	-3.28	0.29	28.10	0.69
d × l	0.13	0.01	0.01	0.68	0.99	0.02

Legend: P=Probability of null hypothesis, P is significant if P<0.05, Coef= Regression coefficient, d=SPX yarn linear mass density, l = stitch length

TABLE V
REGRESSION EQUATIONS OF PHYSICAL CHARACTERISTICS OF PES/SPX

Fabric Properties	Regression Equation	R^2, %
c, cm^{-1}	= 52.00 - 0.055 d - 10.68 l - 0.001680 d × d + 0.1339 dxl	94.45
w, cm^{-1}	= 19.153 - 0.01034 d	28.24
m, gm^{-2}	= 169.5 - 0.03 d - 30.7 l - 0.01195 d×d + 0.990 d×l	95.74

c=courses per unit length, w= number of wales per unit length, m = mass per unit area

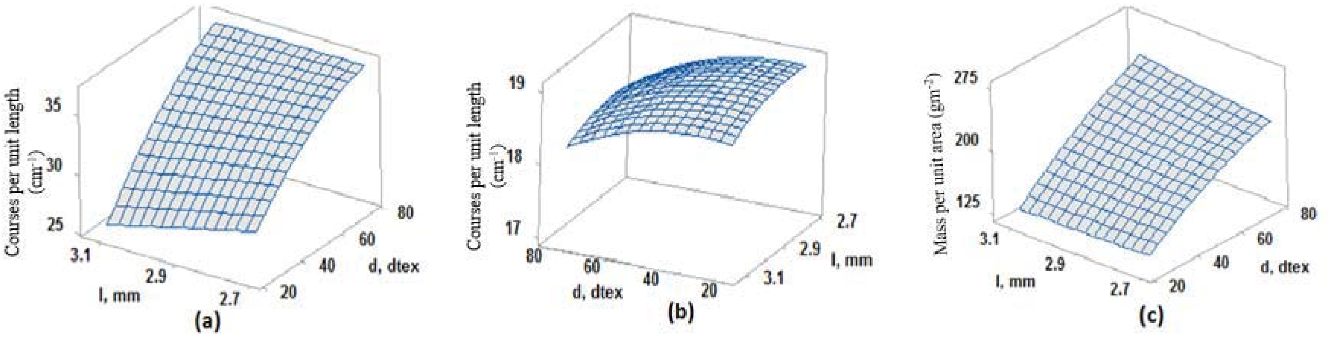

Fig. 4 Influence of spandex linear mass density and stitch length on fabric course density (a), wale density (b) and areal density (c)

D. Fabric Areal Density

The influence of spandex linear mass density and base yarn stitch length is not substantial individually on the areal density of the PES/SPX samples but the interaction of both factors with respect of their effect on the areal density of the fabric is significant as indicated with the P values in Table IV. The R2 of the regression model of PES/SPX fabric areal density is 95.74% indicating fabric areal density can be predicted quite accurately by the terms in the equation given in Table V. It can be seen from the surface plot in Fig. 4 (c), the areal density of the fabric increases with the increase of spandex linear density. The areal density of PES/SPX samples increased with the increase of spandex linear mass density due to increase in course density of the fabric. The higher weight of courser spandex yarn from 22 dtex to 78 dtex contributes to increase in overall weight of the fabric as shown in Fig. 4 (c). The areal density of PES/SPX fabric does not change significantly with the increase of yarn stitch length and this is due to less effect of stitch length from 2.7 mm to 3.1 mm on course and wale density of the PES/SPX fabric.

E. Mechanical Properties

For the evaluation of mechanical properties, fabric stretch percentage in both course and wale direction of the fabric and recovery percentage after the removal of tension in stretched fabric both immediately after 60sec and delayed recovery (%) after 60min were measured at four different linear densities of spandex and at different loop lengths of polyester yarn on knitting machine.

F. Influence of 44N Force on Fabric Stretch and Recovery

From the P-values in Table VI, it can be seen that the influence of spandex linear mass density (d) on the stretch percentage in course (St_c, %) and wale (St_w, %) direction of fabrics is not significant as their P-values are greater than

0.05. But, the effect of stitch length on the stretch percentage in course direction is significant with P value 0.01. However, the effect of interaction of both parameters significantly affect the stretch percentage in the fabric in both course and wale direction. The regression models of stretch % in both course and wale direction of the fabric are presented in Table VII with R^2 96.96% and 82.84% respectively. So 96.96% and 82.84% change in course and wale wise stretch percentage of the fabric can be explained by the terms in the given regression models in Table VII.

From the surface plot in Fig. 5 (a) it can be noticed that, the course wise stretch (Stc, %) of the PES/SPX fabric decreases with the increase of spandex linear mass density and increases with the increase of base yarn stitch length. This may be attributed to the fact that the spandex is plaited straight in the form of straight rod in the horizontal (course) direction of the fabric. So on increasing the thickness or linear mass density of the straight rod (spandex) laying in between the loops made by the base yarn, the resistance to longitudinal extension of yarn increases. Similarly increased linear mass density of the spandex increases the stitch density of the fabric by compressing the loops together which also makes the fabric denser and more resistant to stretch. The similar sort of trend was observed in the wale direction of the fabric but the effect is less intense due to the indirect influence of spandex in the vertical direction of fabric which is evident from the Fig. 5 (b).

TABLE VI
LOW TENSION STRETCH AND RECOVERY

Terms	St_c, %	RLa_c,%	RLb_c, %	St_w,%	RLa_w, %	RLb_w, %
	P	P	P	P	P	P
d	0.63	0.17	0.15	0.31	0.66	0.78
l	0.01	0.05	0.00	0.35	0.01	0.04
d×d	0.62	0.00	0.00	0.00	0.00	0.00
l×l	0.00	0.04	0.00	0.38	0.02	0.05
d×l	0.07	0.65	0.66	0.00	0.00	0.05

Legend: Stc= Course wise stretch, Stw= Wale wise stretch, RLac=Course wise recovery after 60sec, RLbc= Course wise recovery after 1hr, RLaw= Wale wise recovery after 60sec, RLbw= Wale wise recovery after 1hr

TABLE VII
REGRESSION MODELS AT LOW TENSION FORCE

Stretch and Recovery	Regression Models	R^2, %
St_c, %	= 1453 + 0.321 d - 1004 l + 195.6 lxl - 0.608 dxl	96.96
RLa_c, %	= 72.71 + 0.4736 d - 0.00311 dxd	81.91
RLb_c, %	= 533 + 0.4074xd - 313.1x l- 0.002557 dxd+ 53.6 lxl	86.73
St_w, %	= 92.1 - 1.25 d - 20.2 l - 0.03190 dxd + 1.687 dxl	82.84
RLa_w, %	= 995 - 0.321 d - 637 l - 0.01653 dxd + 105.4 lxl + 0.775 dxl	76.94
RLb_w, %	= 861 + 0.250 d - 549 l - 0.01458 dxd + 92.3 lxl + 0.497 dxl	67.33

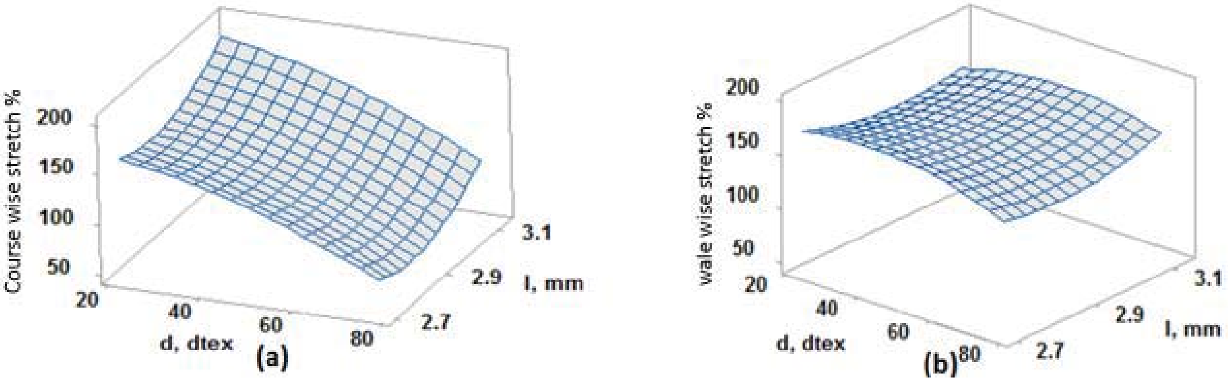

Fig. 5 Influence of spandex linear mass density and stitch length on stretchability in course (a) and wale direction (b)

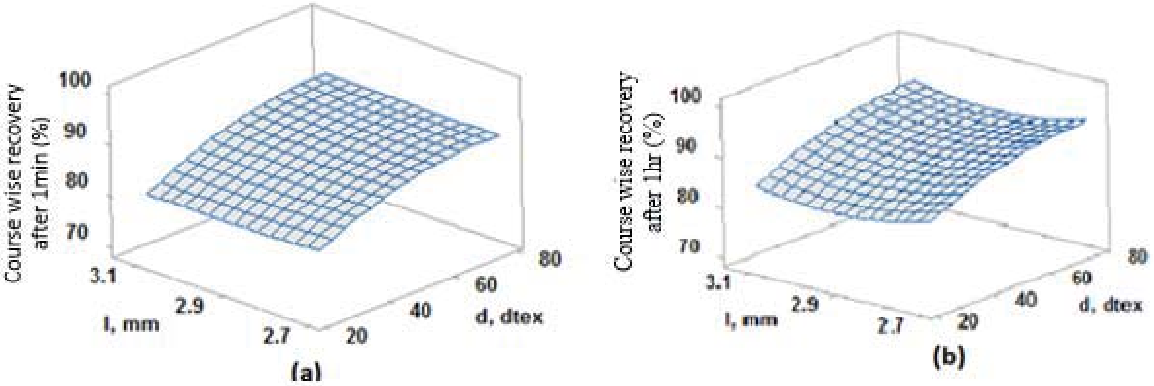

Fig. 6 Influence of spandex linear mass density and stitch length on recovery (%) after 60 seconds (a) and 1 hour (b) in course direction

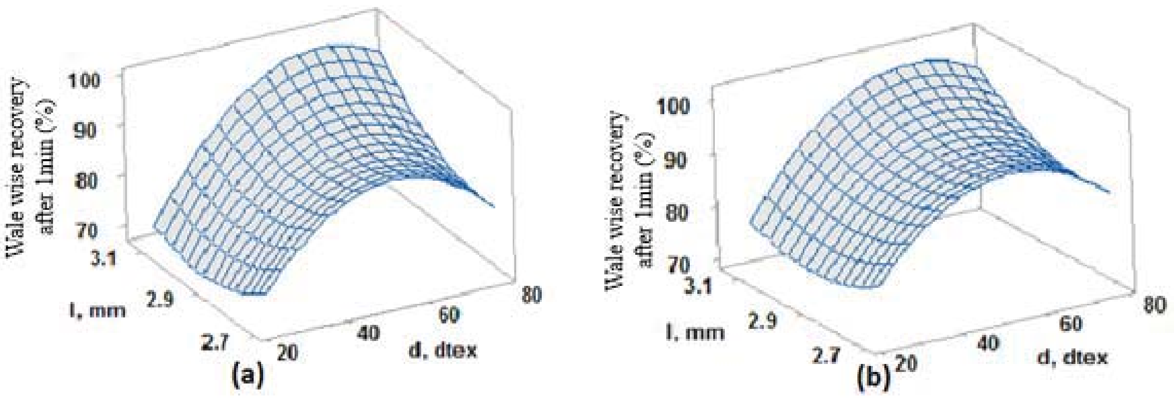

Fig. 7 Influence of spandex linear mass density and stitch length on recovery (%) after 60 seconds (b) and 1 hour (b) in wale direction

The influence of spandex linear mass density and base yarn stitch length on the recovery behavior of the experimental fabric was also determined. In this case all the samples were relaxed for 60sec and 1hr after the removal of extension and ability of fabric to recover to its original position was measured. It can be seen from the P-values given in Table VI that the influence of spandex linear mass density is statistically significant with P values of d^2 is 0.00 but the relation is not linear as the significance of d^2 indicates presence of curve in the system. Similarly, the influence of base yarn stitch length is also significant on both immediate and delayed recovery percentage of the PES/SPX fabric in both directions. A contrasting behavior to stretch percentage in the fabric can be observed in case of recovery phenomenon as shown in Figs. 6 and 7. Due to higher retarding capacity of higher denier spandex recovery percentage shown to increase in both course and wale direction. Increasing behavior of recovery in fabric with the increase of spandex linear mass density can also be explained as less frictional contact offered by the presence of highly elastic yarn between the interlocking points of the loops which tend to revert to their original shape and position as soon as the mechanical stresses are removed from the fabric. Similarly, the influence of stitch length of the base yarn is also shown an inverse relation as do in stretch percentage in the fabric. But it did not play a crucial role by indication proper increasing or decreasing trend and this may be due to short span of change in stitch length to influence the recovery percentage in the fabric.

G. Influence of High Tension Force on Stretch and Recovery

The mechanical properties of the PES/SPX fabric were also calculated under high tension force of 100N in a CRE type tensile testing machine in order to calculate the percentage maximum elongation of the samples under the fixed load of 100N. The experimental values of the elongation percentage and load at 50% extension of fabric were calculated automatically by the system after the third cycle loading and unloading of the sample.

It can be noticed from the P-values in Tables VIII that the influence of both parameters as spandex linear mass density and base yarn stitch length is statistically significant on the maximum elongation in the course direction of the fabric. The interaction of both parameters is also observed significant. The regression equations of elongation percentage both in course and wale direction of fabric are given in Table IX indicating that above 90% change in elongation percentage can be explained by the terms in the equations.

TABLE VIII
P-VALUES OF ELONGATION AND RECOVERY AT HIGH TENSION FORCE

Terms	Ec, %	RHc, %	Lc, N	Ew, %	RHw, %	Lw, N
	P	P	P	P	P	P
d	0.03	0.357	0.07	0.39	0.033	0.78
l	0.00	0.583	0.00	0.45	0.026	0.01
dxd	0.00	0.999	0.00	0.00	0.002	0.00
lxl	0.00	0.510	0.00	0.48	0.049	0.01
dxl	0.01	0.255	0.01	0.35	0.001	0.60

Ec=Course wise total elongation, RHc= Course wise recovery at zero load, Lc= Course wise load at 50% extension, Ew= Wale wise total elongation at maximum force, RHw= Wale wise recovery at zero load, Lw= Course wise load at 50% extension.

TABLE IX
REGRESSION EQUATIONS AT HIGH TENSION FORCE

Elongation, Recovery & Load	Regression Models	R^2, %
Ec, %	= 2508 + 0.007 d - 1706 l - 0.01156 dxd + 315.4 lxl	92.88
RHc, %	= -409 + 0.7002 d + 324.8 l - 0.004255 dxd - 56.0 lxl	95.34
Lc, N	= -156.9 + 0.0985 d + 112.9 l + 0.001151 dxd - 20.11 lxl	99.33
Ew, %	= 235.9 - 4.16 d - 62.0 l - 0.02787 dxd + 2.785 dxl	90.46
RHw, %	= 103.73 - 0.365 d - 6.44 l + 0.1365 dxl	38.46
Lw, N	= 6.301 + 0.0480 d - 1.221 l + 0.000429 dxd	97.79

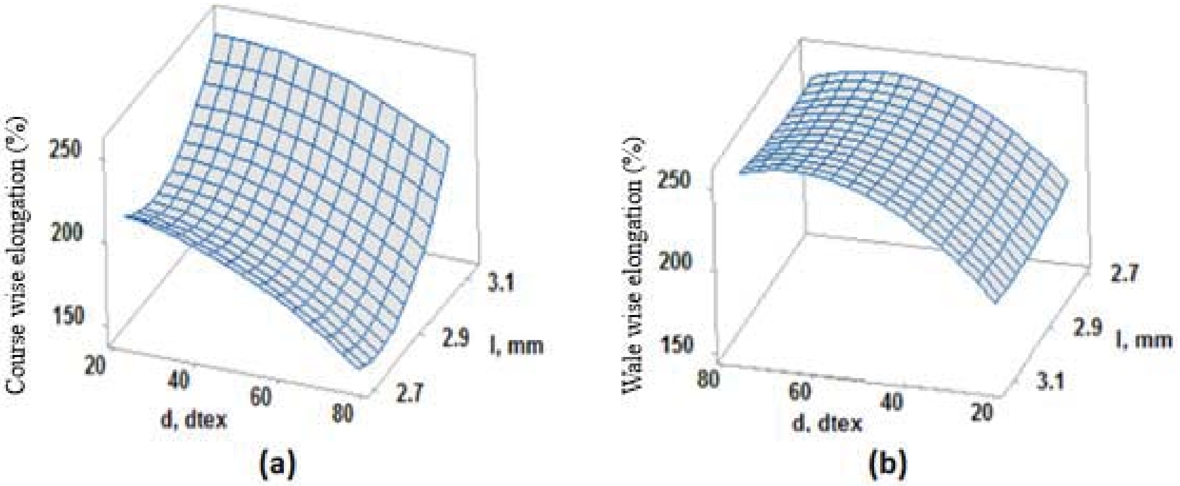

Fig. 8 Influence of spandex linear mass density and stitch length on elongation in course (a) and wale (b) direction

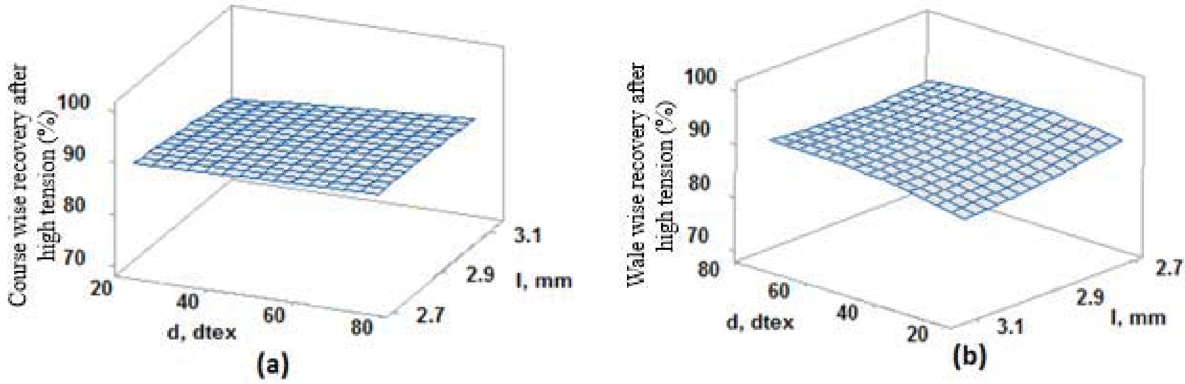

Fig. 9 Influence of spandex linear mass density and stitch length on recovery in course (a) and wale (b) direction after high tension force

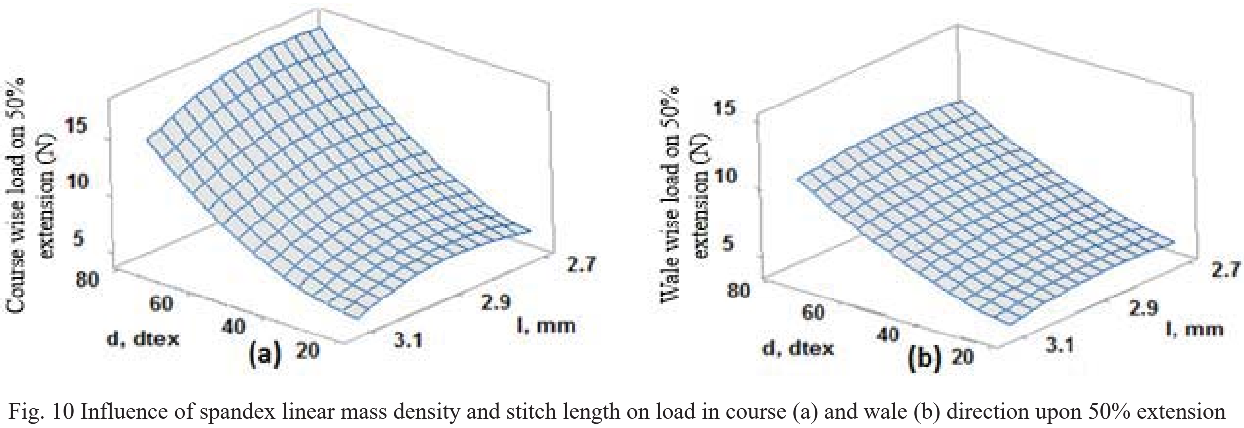

Fig. 10 Influence of spandex linear mass density and stitch length on load in course (a) and wale (b) direction upon 50% extension

From the surface plots in Fig. 8 (a) the maximum elongation percentage of the fabric in the course direction decreases with the increase of spandex linear density due to higher resistance to stretch of higher strength spandex. It is also evident that the elongation at break of spandex decreases with the increase of its linear density. The elongation % in course direction increased with the increase of base yarn stitch length due to lower course density and loose structure. In the wale direction the % total elongation increased with the increase of spandex linear density to certain extent and then start showing decreasing trend with the further increase of spandex linear density as shown in Fig. 8 (b).

From the P-values in Table VIII, it is indicated that the spandex linear density and base yarn stitch length do not affect much on the recovery % in course direction of the polyester/spandex fabric after the removal of high tension load on tensile testing machine. But the effect is significant in wale direction. Similarly, from the R^2 values in Table IX only 35.7% change in course wise recovery % can be explained by the terms included in the equations and 74% change in wale direction can be explained by the given model.

From Fig. 9 it can be noticed that recovery % of the fabric after the removal of high tension force increases with the increase in spandex linear density due to higher retracting force because of higher course density and higher elasticity of the spandex yarn. Recovery % of the fabric after the removal of high tension force decreases with increase in base yarn stitch length in both course (left) and wale (right) direction, however the effect is not much significant, because the difference in recovery% is not much noticeable at 2.7 mm and 3.1 mm stitch length.

H. Load Required to Produce Extension in Fabric

A normal human body may expand the garment up to 10% - 50% by ordinary body movements. Therefore, force required for 50% extension of the fabric was also determined on the tensile tester machine in order to study the behavior of change of elastane linear mass density and stitch length on the ease of movement of the wearer. So the load at 50% extension of the fabric can be a vital performance indicator of a compression sportswear.

From the regression Table VIII it can be seen that effect of elastane linear mass density and base yarn stitch length is significant on load at 50% extension in both course and wale direction of the fabric but the effect is showing nonlinear relation. The R^2 of the regression equation of load at 50% extension of PES/SPX fabric in course and wale direction are 99.33 and 97.79% respectively as given in Table IX, indicating above 95% change in load at 50% extension can be explain by the terms in the equation.

It can be observed from Figs. 10 (a) and (b) that with the increase in spandex linear mass density load at 50% extension of the fabric increases in both course and wale direction of the fabric due to increase in strength of the yarn as shown in Table I. Therefore, more force will be required for the longitudinal stretching and deformation of the yarn. It may also be due to higher cover factor of the fabric with the increase of spandex linear mass density. There is not much change in the load at extension of the fabric with the change in base yarn stitch length because the span of 0.2mm in stitch length is not significant to affect the amount of force required to deform a fabric. Fabric

I. Sub Garment Substantial Pressure

Ultimate pressure generated by the looped garment made of PES/SPX stretchable fabrics on the surface of a cylindrical body was also calculated with the help of Kikuhime pressure sensing device.

From the P-values in the Table X, it can be observed that the effect of spandex linear mass density and base yarn stitch length is statistically significant on the pressure generated by PES/SPX stretchable fabrics. Both of these two parameters not only individually affect the compression properties of PES/SPX garments but also their interaction is statistically significant with P-values less than 0.05. The regression equations for the prediction of compression generated by PES/SPX fabric is given in Table XI with R^2 96.48%. This high value of R^2 is an indication of the authenticity of the model.

TABLE X
P-VALUES OF COMPRESSION BY PES/SPX FABRIC

Terms	Pressure, mmHg	
	Coef	P
d	-0.436	0.006
l	-81.7	0.02
d×d	0.002578	0.00
l×l	12.5	0.066
d×l	0.1523	0.003

TABLE XI
REGRESSION EQUATION OF PRESSURE BY PES/SPX FABRIC COMPRESSION

Pressure	Regression Equation	R^2, %
Pressure (mmHg)	=32.56 - 9.24 l - 0.436 d 0.002578 dxd+ 0.1523 lxd	96.48

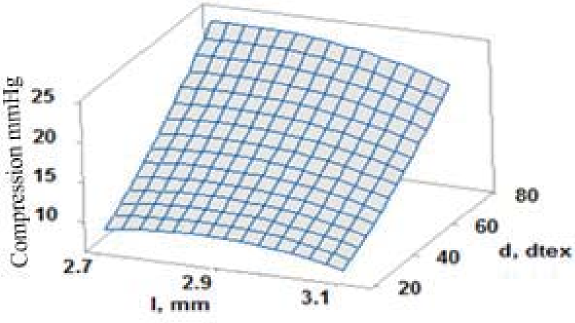

Fig. 11 Compression behavior w.r.t spandex dtex & stitch length

It can be observed from the surface plot in Fig. 11 that, with the increase in spandex linear mass density compression generated by the looped garments made by PES/SPX fabric increases. This is due to higher contraction offered by the higher denier spandex which increased the stitch density of the fabric, hence higher pressure generated on the application area. But there were recorded a decreasing trend on increasing the stitch length of the base yarn but the change is not very steep. However, a strong influence of the interaction of spandex linear mass density and base yarn stitch length is observed as shown in Fig. 11.

IV. CONCLUSION

Linear mass density of the elastomeric yarn used in plaited knitted structures and base yarn stitch length can vary the physical and mechanical properties of the technical knitted fabrics and garments generated from these fabrics for special applications. These two parameters differently alter the fabric characteristics in course and wale direction. In course direction both stretch properties and high force elongation in fabric decease with the increase of linear mass density of spandex but increase with the increase of polyester yarn stitch length. Whereas, in the wale direction stretch and elongation both first increases up to certain limit then start decreasing on further increase with the increase of spandex linear density.

However elastic recovery in the stretched fabric showed some inverse relation as do in case of stretch percentage. After both high and low tensional forces recovery percentage in the fabric increases with the increase of spandex linear mass density and decreases with the increase of base yarn stitch length. Similarly, when spandex linear mass density increases more load is required to produce 50% extension in the fabric, but on increasing stitch length of base yarn, this load can be decreased. So elastane yarn denier and stitch length of the fabric can be adjusted to make a compression garment with sound ease of body movement. Likewise garment loop pressure (mmHg) rises with the increase of spandex denier and reduces with the increase of stitch length of the base yarn. So it can be observed that by using above statistical models stretch recovery and compression of the fabric can be predicted at that early stage during the fabric manufacturing. Since the R^2 of the models are very high which is an indication of satisfactory prediction ability of the models. So higher pressure generated garments can be generated by engineering the knitted fabric parameters taking higher denier elastane yarns with smaller loop length structures.

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