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Effect of Spandex Input Tension, Spandex Linear Density and Cotton Yarn Loop Length on Dynamic Elastic Behavior of Cotton/Spandex Knitted Fabrics

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ABSTRACT

Analysis of dynamic elastic behavior is an objective evaluation of the stretch and recovery behavior of the elastic fabrics or tight fit garments. The analysis of this dynamics will help to reengineer new products for improving the stamina, speed and power of the sportsmen, as one particular type of garment doesn't serve the purpose of all kinds of sports events. The study is to analyze the effect of spandex input tension, spandex linear density and cotton yarn loop length on dynamic work recovery of cotton / spandex single jersey knitted fabric. The effect of different processing stages such as relaxation, heat setting, bleaching and compacting on dynamic work recovery of cotton / spandex single jersey knitted fabric has also been analyzed in this study. Effect of different stages of processing on DWR of the fabric has significant influence. The effect of spandex input tension and cotton yarn loop length on DWR of the fabric have been significant in any one direction. The effect of spandex linear density on DWR of the fabric has been significant at both wale and course directions.

Keywords: cotton yarn loop length, dynamic work recovery, plated fabric, spandex input tension, spandex linear density and tight fit sportswear

1. Introduction

Elastic knitted fabrics are normally produced by plating of spandex with companion yarn in a circular knitting machine. Elastic fabrics and their garments have immediate response and return to their original size and shape due to physical exertion by any organ of the human body. These garments are mainly used in sports activities such as cycling, swimming and athletics. They improve the sportsmen performance by offering least resistance during garment stretch and by enhancing the power by quick recovery of the fabric dimensions, because of the usage of the elastane in these garments. The recovery power of single jersey fabrics are generally sufficient for normal garment fit and it doesn't enough for stretch activities. Spandex yarn is capable of giving large stretch and dimensional recovery than can be achieved by cotton yarn alone [1].

1.1 Processing of Elastic Fabrics

In general, elastic knitted fabrics produced from knitting machine are relaxed and subjected to different processing treatments such as heat setting, bleaching, dyeing and compacting. But, for normal knitted fabric, heat setting is not recommended. Heat setting is the key step to control the desired fabric properties like width, weight, stretch and recovery. Heat setting is preferably done early in the wet processing rather than at the end in order to reduce yellowing on drying. During heat setting, spandex inter molecules are broken and reformed, and the polymer chains can rearranged. Under-setting of fabric results in eventual loss of dimensions, while over heat-setting lowers residual energy and can discolor the spandex and companion fibers. Relaxation treatment is used to reduce potential distortion or deformation of the fabric from residual uneven tension. It develops the power by improving dimensional recovery of the fabric [2].

Hydrogen peroxide can be used as a bleaching agent for elastic fabrics. Chlorine containing bleaches has to be avoided because it may cause yellowing in spandex fibres. Disperse dyes and acid dyes have good affinity to spandex and they have no affinity with direct dyes [3]. Compacting is a process which is used to physically rearrange the yarn geometry in the fabric. In woven fabrics, weft yarns can be forced closer together, thus preshrinking the fabrics. In the knit fabrics, the loops can be rearranged to overcome distortion in the length to width caused by stretching tensions [4].

1.2 Dimensional and Physical Properties of Elastic Fabrics

Bayazit[5] investigated dimensional properties of spandex plated cotton single jersey fabrics and compared the results with fabrics knitted from cotton yarn alone. The loop length and amount of spandex are used to determine the dimensional properties of the knitted fabrics. It is claimed that the power of dimensional recovery in single jersey fabrics that have been stretched is generally inadequate; therefore, spandex is increasingly used to impart a greater level of stretch and more dimensional recovery can be achieved with cotton yarn. Chathura and Bok also reported the same trend by analyzing the core - spun cotton / spandex single jersey [6] and rib structures [7].

Serkan and Yasemin [8] studied the dimensional and physical properties of cotton/spandex single jersey fabrics produced by plating technique. The effects of spandex brand and the tightness factor on dimensional and physical properties of cotton/spandex single jersey fabrics were investigated. The fabrics knitted with spandex yarns with the higher tension values under a constant draw ratio gave higher weight and thickness, and lower air permeability and bursting strength.

1.3 Elastic Characteristics of Elastic Fabrics

In ancient days, mercerization and texturizing processes were used to improve the elasticity of normal woven fabrics. Donald [9] claimed improvement in stretch properties of normal cotton fabrics by slack mercerization with sodium hydroxide. Mukhopadhyay et al. [10] developed the air-jet textured yarn to acquire stretch properties of woven fabric by analysing fabric extension and recovery characteristics by measuring immediate recovery, delayed recovery, resiliency and permanent set. Kentaro and Takayuki [11] studied the relationship between stretch properties of weft knit fabrics made from spun yarn by false texurizing and their geometrical characteristics. Stretch properties of these fabrics were affected by cover factor only. It is known that stress-strain behavior depends on raw material and knit construction, irrespective of the density of knitted fabrics.

Few attempts were reported on elastic properties of elastic fabrics produced with spandex [12]. Mukhopadhyay et al. [13] studied the effect of Lycra filament on the extension-at-peak load, immediate recovery, delayed recovery, permanent set and resiliency of cotton–Lycra blended knitted fabric. It was observed that the immediate recovery, extension and resiliency are higher for Lycra blended fabric, but its delayed recovery and permanent set was lower than 100 % cotton fabric. Dunja and Vili [14] investigated the behavior of woven fabric with elastomeric yarn during stretching. The study reported the viscoelastic part of the load extension curve and behavior of fabrics with elastomeric yarn after one hour stretching above the yield point.

1.4 Comfort Aspects of Elastic Fabrics

Elastic garments for sports and outer wear play an important role in optimizing an athletic performance by providing freedom movement, minimizing the risk of injury or muscle fatigue and reducing friction between body and garment. In the absence of body motion, many garments provide apparent comfort. But the moment the physical movement is made, the comfort performance level changes and that change could be significant. Therefore, the work or force needs to be measured over the line of the body movements. During the movement, the different parts of the body stretch vary differently and the amount of stretch will vary varying different in each direction [1].

Kirk and Ibrahim [15] reported that the fabric stretch is an important factor in analyzing pressure comfort, which largely depends on fabric elastic characteristics and elastic recovery properties. Whether a garment slips or stretches depends on the balance of the tensile forces in the fabric and the frictional forces between skin and fabric. If a fabric has high friction resistance and high stretch resistance, high clothing pressure is likely to be exerted on the body, which will result in discomfort sensations. The pressure P is calculated using Eq (1).

$$P = (T_H \; / \; Y_H) + (Tv \; / \; Yv) \qquad \ldots \quad (1)$$

where T is the tensile stress measured on the Instron at the same level of strain and Y is the radius of curvature of the relevant body parts. Subscripts H and V indicates horizontal and vertical direction, respectively.

Consumer preference on stretch level was studied in terms of comfort. It was found that higher stretch with lower power was always preferred, and that wearer's stretch preferences were in the range of 25% to 45%, depending on the end-use. Also, the direction of stretch relative to the body had significant impact on comfort [1].

In general, woven fabrics cannot attain the 10 – 50 % level of extensibility and recovery from extension. Hence, initially texturized weft knitted fabric was used in sportswear. The next development was plating an elastomeric component in the garment. This improved considerably stretch and recovery from stretch characteristics of the sportswear. Evaluation of elastic behavior of these garments is essential in order to develop a new products for tight fit sports wear[16].

1.5 Dynamic Elastic Behavior of Fabrics

Analysis of dynamic elastic behavior is an objective evaluation of the stretch and recovery behavior of the elastic fabrics or tight fit garments. The analysis of this dynamics will help to reengineer new products for improving the stamina, speed and power of the sportsmen, as one particular type of garment doesn't serve the purpose of all kinds of sports events [16].

Stress strain behavior of identical elastic fabric is shown in Figure.1. Loading and unloading behavior of the fabric is almost curvilinear, which is normally called as elastic deformation. This fabric is perfectly suitable for elastic sportswear where it requires stamina and power. But, most of the textile fabrics are non-linear in nature (viscoelastic deformation), which will produce hysteresis loop [17]. Higher the hysteresis area, the higher will be the energy loss, i.e. lower the fabric stress and strain recovery. The elastic fabrics should have higher elastic recovery with lower energy loss so that the wearer will get the additional benefit such as improved stamina and power to perform sports activity [16].

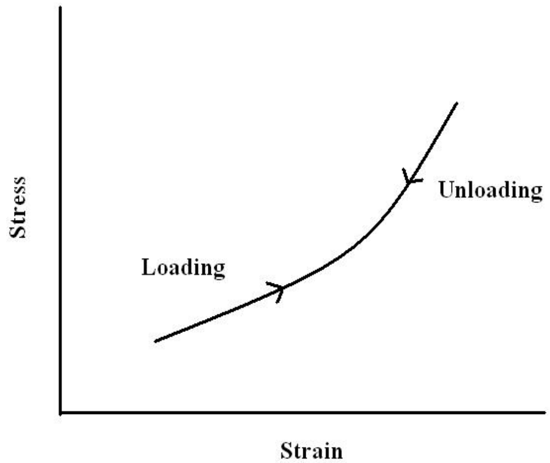


Fig. 1. Stress strain behavior of identical elastic fabric

Assessment of dynamic work recovery for applied extension is necessary to study the energy loss or power gain by the sports person wearing the elastic garment. Work recovery is not the same as elastic recovery. Work recovery is defined as the ratio between recovered elastic energy and the total tensile energy applied for the specific strain expressed in percentage (In other words, 100 – loss of energy) whereas elastic recovery [18] is the ratio of recoverable strain to total strain at any given stress [16].

The recovery behavior of the fabric or garment is important to enhance the power of the sports person involved in strenuous sports activity. In general, elastic textile material will give minimum work energy loss which can be calculated by assessing dynamic work recovery [16].

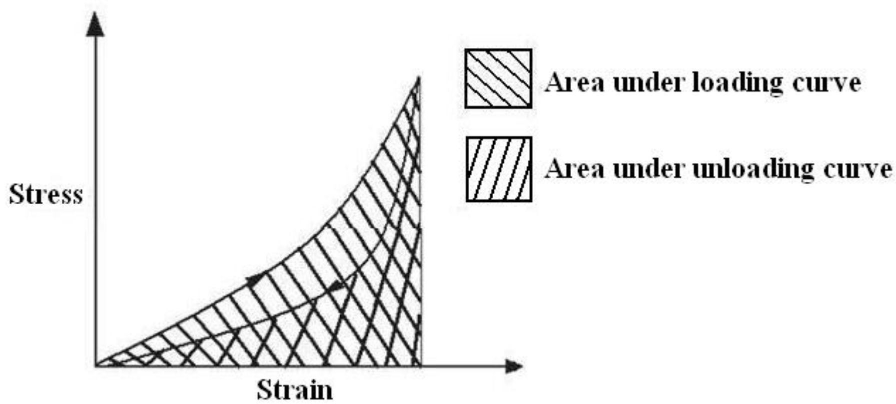


Fig.2 - Dynamic work recovery

Dynamic Work Recovery (DWR) of the fabric is calculated by the Eq. (2).

$$\text{Dynamic work recovery \%} = \frac{\text{Area under the unloading curve}}{\text{Area under the loading curve}} \times 100 \qquad \ldots (2)$$

Assessment of dynamic work recovery of the fabrics is a newly developed method based on the Kawabata [19] evaluation system for fabric total handle measurement. The evaluation method is based upon tensile resilience (RT %) measurement of Kawabata Evaluation System. The RT measurement will produce stress strain hysteresis for applied force of 500 gf / cm (constant rate of loading). For this applied force, the fabric extension is in the range of 5 – 15 %. But, a simple and ordinary body movement expands the skin by about 10 to 50% [1]. It is necessary to analyses the range of extension level for studying tight fit sportswear. The dynamic work recovery of the fabric is evaluated by constant rate of elongation principle using Instron.

$$\text{Tensile energy (loading)} = \int_{0}^{\mathbf{e}\,20\text{-}50\%} \vec{F}\; d\,e$$

$$\text{Tensile energy (unloading)} = \int_{0}^{\mathbf{e}\,20\text{-}50\%} \overleftarrow{F}\; d\,e$$

$$\text{Dynamic work recovery} = \frac{\text{Tensile energy (unloading)}}{\text{Tensile energy (loading)}} \times 100$$

That is,

Dynamic work recovery

$$= \int_{0}^{\mathbf{e}\,20\text{-}50\%} \overleftarrow{F}\; d\,e \quad \div \quad \int_{0}^{\mathbf{e}\,20\text{-}50\%} \vec{F}\; d\,e \quad \mathbf{X}\; 100$$

Where, F = Stress value during loading ($\vec{F}$) and unloading ($\overleftarrow{F}$), **e** = strain (%), de = extension with respect to time.

The simplified form (as mentioned in the figure 2),

$$\text{Dynamic work recovery} = \frac{\text{Area under unloading curve}}{\text{Area under loading curve}} \times 100 \qquad \ldots \quad (3)$$

The spandex input tension, spandex linear density and cotton yarn loop length are the major variables which control the dimensional stability of the elastic knitted fabrics as mentioned in the earlier literature. The effect of these variables on dynamic elastic behavior of the fabric could be further explored. This study could be more useful for the tight fit garment making industry to control the cost of manufacture without affecting the fabric properties.

The present study is to analyze the effect of spandex input tension, spandex linear density and cotton yarn loop length on dynamic work recovery of cotton / spandex single jersey knitted fabric. The effect of different processing stages such as relaxation, heat setting, bleaching and compacting on dynamic work recovery of cotton / spandex single jersey knitted fabric has also been analyzed in this study.

In order to study the effect of spandex input tension on dynamic work recovery of the fabrics, three levels of spandex input tension such as 2.5 - 3.0 cN/tex, 2.0 - 2.5 cN/tex and 1.5 - 2.0 cN/tex were kept constant to maintain spandex loop lengths such as 0.85 mm, 0.97 mm and 1.1 mm respectively. Thirty-denier spandex was used and cotton yarn loop length was kept as 2.9 mm.

In order to study the effect of spandex linear density on dynamic work recovery of the fabrics, three different linear densities of spandex yarn such as 20 denier, 30 denier and 40 denier were used. Spandex loop length and cotton yarn loop length were kept as 0.97 mm and 2.9 mm respectively.

In order to study the effect of cotton yarn loop length on dynamic work recovery of the fabrics, three levels of cotton yarn loop lengths such as 2.5 mm, 2.9 mm and 3.4 mm were used. Spandex input yarn tension and spandex linear density were kept as 2.0-2.5 cN/tex and 30 denier, respectively.

Table 1 - Cotton yarn properties

Count , *tex*	20.72
Count Variation , *CV%*	1.50
CSP	2514
Single Yarn Twist, cm^{-1}	8.02
Twist , *CV %*	4.18
U%	9.95
CV, *m%*	12.61
Thin (- 50%) , km^{-1}	22
Thick (+50%) , km^{-1}	34
Neps (+200%) , km^{-1}	94
Hairiness Index	6.97
Breaking Force , *gf*	335.40
Breaking force , *CV%*	7.59
Elongation , *%*	4.48
Elongation, *CV%*	6.93
RKM	17.00

Table 2. Spandex yarn properties

Specifications	20 D	30 D	40 D
Type, (Luster)	Clear	Clear	Clear
Linear density , (denier)	20 ± 0.5	30 ± 0.5	40 ± 0.5
Tenacity , (g / denier)	1.3 ± 0.1	1.4 ± 0.1	1.45 ± 0.1
Elongation , (%)	650 ± 30	650 ± 30	650 ± 30

Table 3. Knitting machine specifications

Model	MV -4. 2003
Machine diameter , (inches)	18
Machine gauge (needles per inch)	24
Number of feeders used	56
Machine speed , (rpm)	28

2. Materials and Methods

2.1 Cotton Yarn Properties

In order to study the dynamic work recovery of cotton / spandex fabrics, 20.72 tex combed cotton yarn was used and the properties of the yarn are given in Table 1.

2.2 Spandex Yarn Properties

The spandex yarn properties are given in Table 2.

2.3 Fabric Production

The cotton and spandex yarns were knitted in circular knitting machine. The knitting machine specifications are given in Table 3.

The knitted fabrics were dry-relaxed for 48 hours. Then the samples were subjected to subsequent processes under industrial conditions. The fabrics were heat set with the machine specification given in Table 4.

Table 4. Heat setting specifications

Make and Model		ASKME -TS-2430G5
Temperature	(^{o}C)	200
Dwelling time	(seconds)	30
Chamber length	(inches)	90
Fabric width stretch	(inches)	22.5 (25% of machine diameter)

Table 5. Compacting specifications

Make		Albert (tubular)
Temperature	(^{o}C)	110
Speed	(m/min)	4
Chamber length		one meter
Type of feed		26% over feed
Fabric width stretch	(inches)	20 (11% of machine diameter)

The heat-set fabrics were bleached. Bleaching was carried out with 2 g/l of hydrogen peroxide, 0.4 g/l of wetting oil, 0.5 g/l of dispersing agent, 1.0 g/l of lubricant, 0.25 g/l of stabilizer and 2.0 g/l of caustic soda for 110^{0}C at 30 minutes. Then the samples were hot washed for 10 minutes at 80^{o}C. Further, the fabrics were rinsed with 1.0 g/l of acetic acid for 15 minutes. The bleached fabrics were padded and dried at room temperature.

The bleached fabrics were subjected to compacting process with the specifications given in Table 5. After that, they were relaxed for 48 hours.

2.4 Test Methods

The fabrics were tested for their geometrical characteristics such as courses per centimeter, wales per centimeter and areal density and dynamic work recovery at 20%, 30%, 40% and 50% extension. The average number of wales per centimeter and courses per centimeter were measured with the help of counting glass. The average loop length was measured with the aid of the HATRA course length tester (method described in B.S. Handbook no. 11, 1974, pp 4/102-4/106). The fabric areal density was measured using an electronic scale according to method ISO 3801:1977. Fabric geometrical characteristics were measured at ten different places in the fabric in each case.

The fabrics were tested for their dynamic elastic behavior such as dynamic work recovery based on ASTM D 4964 – 96 method (CRE principle) at different extension levels such as 20%, 30%, 40% and 50% extension using Instron tester. Since, human body movement expands the skin by 10 to 50% at different parts [1], the applied load was 5 KN at a speed of 500 millimeters per minute for 10 cycles, 10 sample size and gauge length of 100 mm.

3. Results and Discussion

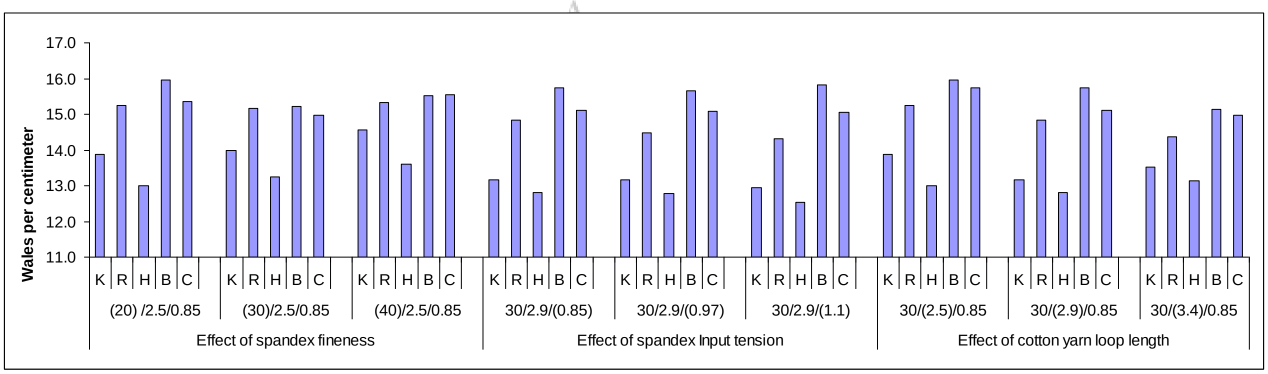
3.1 Effect of Different Processing Stages

3.1.1 Geometrical characteristics

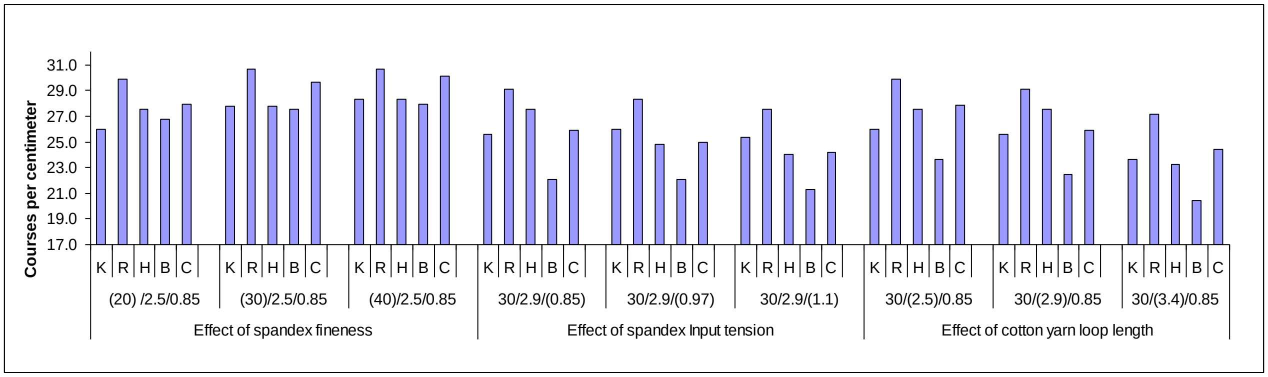
The effect of spandex input tension, spandex linear density and cotton yarn loop length on geometrical characteristics of the knitted fabrics were analyzed at every stage of processing and are represented in Figure 3.

From all the three cases, wale and course densities of the fabrics increase after dry relaxation for 48 hours. This relaxation shrinkage helps the fabric became dimensionally stable. When the fabric was heat set in width wise direction under stretched condition, spandex in the fabric remain elongated and it lost its residual energy considerably. Therefore, it results in lower loop density in both wale wise and course wise directions after the heat setting process. At bleaching stage, the wale density of the fabrics increases. This is mainly due to the fact that in the bleaching process, the water acts as a lubricating agent which reduces the yarn friction at intermeshing points. This reduction in friction leads to the recovery of the loops moving closer to each other. The decrease in course density after bleaching may be due to increase in loop density at wale direction. During compacting process, the fabric was over fed to the machine in length wise direction, which increase the course density of the fabrics and the wale density of the fabrics marginally decreases. This is due to the fabric fed to the machine in stretched form in the widthwise direction. These trends have been observed in all the cases.

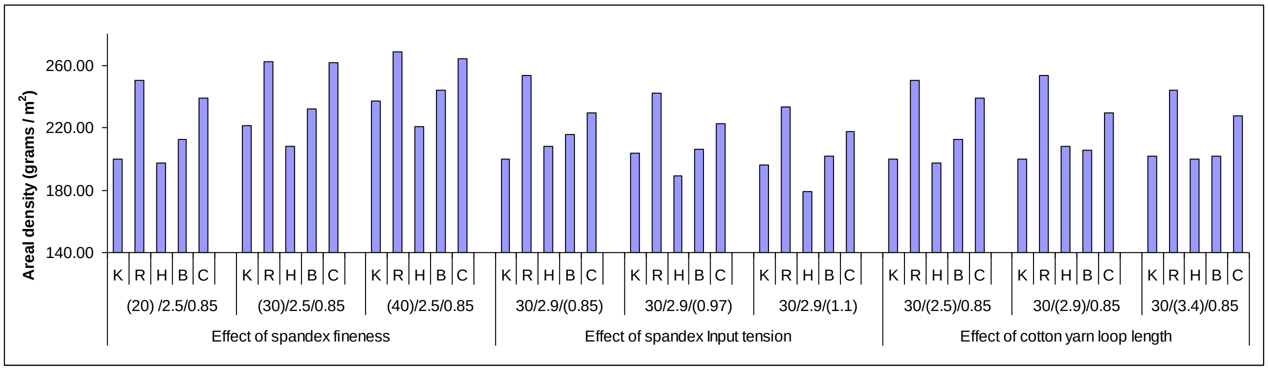
The fabric areal density increases after fabric is subjected to relaxation. Relaxation process stabilizes the fabric dimensions. After heat setting, the fabric areal density was reduced. This is due to fact that the spandex was under stretch condition during heat setting and it becomes finer. Further, the areal density was increased after bleaching. Bleaching process reduces the yarn friction and helps to bring the yarn loops closer to each other. Compacting is the pre-shrunk treatment on knitted fabric. So, Areal density of the fabric further increases with compacting. When the knitted fabric was processed, it was observed that the processes became unstable in terms of areal density.



a) Effect of spandex input tension, spandex linear density and cotton yarn loop length on wale density of the fabrics



b) Effect of spandex input tension, spandex linear density and cotton yarn loop length on course density of the fabrics



c) Effect of spandex input tension, spandex linear density and cotton yarn loop length on areal density of the fabrics

Fig. 3. Effect of spandex input tension, spandex linear density and cotton yarn loop length on geometrical characteristics of the fabrics

3.1.2 DWR of Cotton / Spandex Fabrics at Different Processing Stages

The effect of different processing stages on the dynamic work recovery of cotton / spandex fabrics was analyzed in both wale wise and course wise directions and are given in Figure 4.

The dynamic work recovery of the fabrics at grey stage is higher than that of the fabric treated at relaxation, heat set, bleaching and compacting. DWR of the fabric decreases after heat setting and further decreases for bleaching. After that, the DWR of the fabric increases for compacting process at wale direction and the DWR of the fabric decreases for heat-setting, bleaching and compacting at course direction. The DWR of heat set fabric is lower than that of the DWR of the fabric at grey stage in both wale and course directions. This is due to the reduction of residual energy of the spandex during heat setting. Bleaching process further reduces the DWR of the fabric. Compacting (pre-shrunk) process increases the DWR of the fabric in wale direction due to fabric over feed in the same direction. At the same time, DWR of the fabrics decreases in course direction during compacting process. This is due to fabric stretch in widthwise direction.

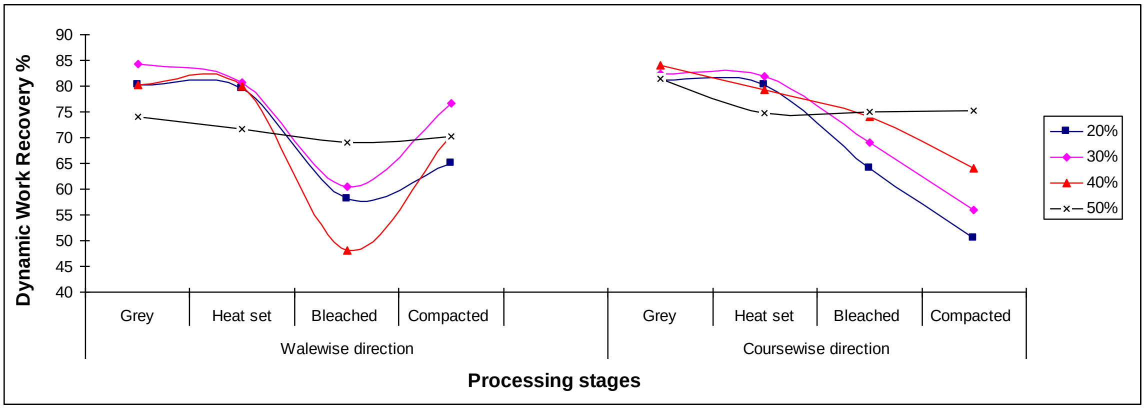


Fig. 4. Effects of different processing stages on DWR of the fabrics

No trend is found between different extension levels and processing treatments. But, the fabric DWR at extension levels 20 %, 30% and 40% follow the same trend at different processing stages. It is observed that fabric DWR at 50% extension has not much change in different processing stages at both wale and course directions. When the extension levels increase, DWR of the fabric at bleaching and compacting treatment also increase from 20 % to 40 % extensions.

Different stages of processing has significant effect on dynamic work recovery of the fabrics at both wale direction [F observed > F critical at F (3, 9) = 10.16, P <0.05] and at course direction [F observed > F critical at F (3, 9) = 7.65, P <0.05].

3.2 Effects of Spandex Input Tension, Linear Density and Loop Length on Geometrical Characteristics of the Fabrics

3.2.1. Spandex Input Tension

In order to analyze the effect of spandex input tension on geometrical characteristics of the knitted fabrics, the spandex loop length was selected as 0.85 mm, 0.97 mm and 1.1 mm for cotton / spandex fabric production. No significant difference is observed in the wale density when the spandex loop length increases in the fabric. But, course density decreases when the spandex loop length increases from 0.85 mm to 1.1 mm. The areal density of the fabric decreases with the increasing spandex loop length at various stages of treatments. When the spandex input tension decreases (i.e., increasing the spandex loop length from 0.85 mm to 1.1 mm), the yarn loop compression decreases. So that, wale and course densities of the fabrics decrease with increasing spandex loop length. The areal density of the fabrics decreases due to decrease in loop density.

3.2.2 Spandex Linear Density

In order to analyze the effect of spandex linear density on geometrical characteristics of the knitted fabrics, three different spandex deniers such as 20 denier, 30 denier and 40 denier were used for the cotton / spandex fabric production. When the spandex denier increases the wale density also increases for immediate after machine, relaxation and heat setting. After that the fabric dimensions become distorted and it doesn't influence the spandex fineness during bleaching and compacting processes.

When the spandex denier increases from 20 denier to 40 denier, the course density of the fabrics was also found to increase at various stages. This trend is reflected as there is increase in the fabric areal density. Areal density of the fabrics increases with increasing spandex denier from 20 denier to 40 denier. This is due to the increase in wale and course densities of the fabrics. Yarn weight also increases with the increasing spandex denier.

When spandex denier increases from 20 denier to 40 denier, the wale and course densities of the fabrics increase due to increase in yarn loop lateral compression.

This results in the increasing of areal density of the fabrics in all the cases.

3.2.3 Cotton Yarn Loop Length

The effects of cotton yarn loop length on geometrical characteristics of the knitted fabrics were analyzed by varying the cotton yarn loop length as 2.5 mm, 2.9 mm and 3.4 mm. No influence of the cotton yarn loop length on wale density was found immediately after knitting, fabric relaxation, heat setting. Cotton yarn loop length increases with decreasing wale density for bleaching processes were observed. At the same time, with increase in the cotton yarn loop length, the course density of the fabric was found to decrease at each of the processing stages. The areal density of the fabric decreases with increasing cotton yarn loop length in all cases. This is due to decreasing in course density.

The change in the wale density of the fabrics with increasing cotton yarn loop length from 2.5 mm to 3.4 mm is insignificant. But, the course density of the fabrics decreases with increasing cotton yarn loop length. The areal density of the fabrics decreases when the cotton yarn loop length increases in most of the cases.

3.3 Dynamic Work Recovery of the Fabrics

Effect of spandex input tension, cotton loop length and spandex linear density on dynamic work recovery of the compacted fabrics have been discussed.

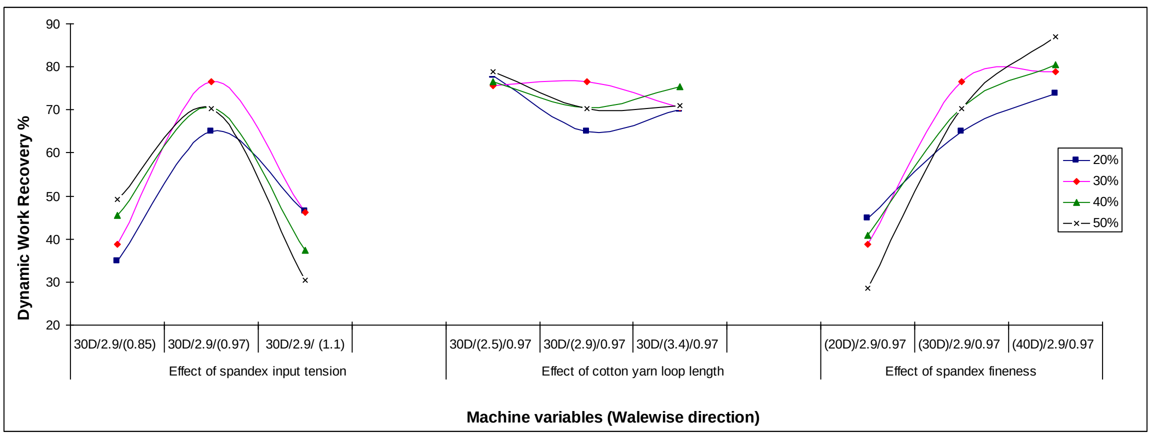


Figure 5 (a). Effects of spandex input tension, spandex linear density and cotton yarn loop length on DWR of fabrics - wale direction

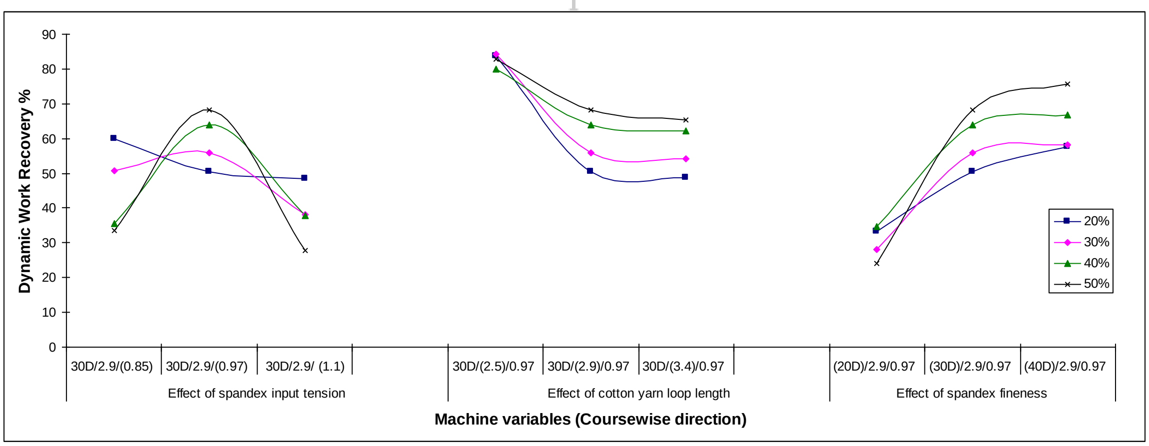


Figure 5 (b). Effects of spandex input tension, spandex linear density and cotton yarn loop length on DWR of fabrics - course direction

3.3.1 Effect of Spandex Input Tension

The spandex loop length was varied by varying the spandex input yarn tension as given in Table 6. The spandex loop length was set by adjusting the spandex yarn positive feeding pulley to find the maximum spandex yarn loop length. The maximum spandex yarn loop length was determined by increasing the spandex yarn feed amount until the machine stopped because of low tension of the spandex yarn. Similarly, the spandex yarn positive feeding pulley was adjusted to find the minimum spandex yarn loop length. The minimum spandex yarn loop length value was determined by decreasing the spandex yarn feed amount until the machine stopped because of breaking of spandex yarn due to high tension. The medium yarn loop lengths were determined by calculating the average of the maximum and minimum spandex yarn loop lengths [8].

The adjustments of loop lengths are made in variable diameter pulley fitted in the knitting machine. There are 4 to 6 pulleys which are used to adjust loop lengths according to the designs. The individual variable diameter pulleys are used for cotton yarn feed and for spandex feed. By altering the diameter of the pulleys, the feed of the yarns can be varied. The predetermined spandex loop length was achieved by varying the surface driven roller speeds. The roller speeds and corresponding spandex loop lengths are given in Table 6.

Table 6. Spandex loop length specifications

Predetermined Spandex loop length (mm)	Speed of the surface driven rollers (rpm)	Spandex input tension cN/tex
0.85	23.5	2.5 - 3.0
0.97	27.0	2.0 - 2.5
1.10	31.0	1.5 - 2.0

Effect of spandex input tension on dynamic work recovery of cotton / spandex knitted fabrics were analyzed and are given in Figure 5. When the spandex loop length increases from 0.85 mm to 0.97 mm, DWR of the fabric (30 denier spandex and 2.9 mm cotton loop length) first increases, then it decreases when the spandex loop length increases. This trend is observed in most of the cases at both wale and course directions.

It is observed that the 30D/2.9/0.97 fabric (30 denier spandex, 2.9 mm cotton loop length and 0.97 mm spandex loop length) shows higher DWR than that of the fabric having 0.85 mm and 1.1 mm spandex loop length. That is, 30D/2.9/0.97 has nearly 44 % higher DWR in wale direction and nearly 32% higher DWR in course direction. No trend is observed between DWR and the geometrical characteristics of the fabrics.

When the fabric extension levels increases from 20 % to 50 %, the DWR of 30D/2.9/0.85 fabric increases and the DWR of 30D/2.9/ 1.1 fabric decreases for wale direction. No trend was found between spandex input tension and extension levels in the course direction.

In order to find out the reason for the trends observed in Figure 5 (spandex input tension), the spandex in the fabrics was unraveled and its loop length was measured with a pretension weight of 0.001g/denier. The spandex loop length was calculated using the Eq (4).

$$\text{Loop Length of spandex yarn in } mm = \{\text{Weight of spandex for one full course } (g) \times 1000\} \div \{\text{Weight } (g) \text{ of spandex yarn for one meter} \times \text{Total number of needles in the machine}\} \quad \ldots \; (4)$$

The calculated spandex loop length was 1.39 mm, 1.41 mm and 1.52 mm for preset spandex loop of 0.85 mm, 0.97 mm and 1.1 mm respectively. The spandex loop length has no correlation with the DWR trends in both wale and course directions.

Normally, the spandex feed increases with increasing spandex loop length. Though the spandex feed was higher in case of 1.1 mm loop length fabric, the DWR of the fabric was lower. No reason was found for the lower DWR of the (30D/ 2.9/ 1.1) fabric.

Effect of spandex input tension on dynamic work recovery of the fabric has significant at wale direction (F observed > F critical at $F (2, 6) = 21.13$, $P < 0.05$) and insignificant effect at course direction. (F observed < F critical at $F (2, 6) = 3.71$, $P > 0.05$)

3.3.2 Effect of Cotton Yarn Loop Length

In order to vary cotton yarn loop length, the centralized system of cylinder bed height was kept to medium level by measuring the maximum bed height and minimum bed height. Then, the variable pulley was adjusted to feed the minimum cotton yarn loop length. The spandex yarn loop length was kept normal. The minimum cotton yarn loop length (2.5 mm) was determined by until the machine stops due to cotton yarn and spandex yarn jump. Similarly, the centralized system of cylinder bed height was kept to medium level. Then, the variable pulley was adjusted to feed the maximum cotton yarn loop length values. The spandex yarn loop length was kept normal. The maximum cotton yarn loop length (3.4 mm) was determined by until the machine stops due to slackness of cotton yarn. The medium yarn loop lengths were determined by calculating the average of the maximum and minimum yarn loop lengths [8]. The cotton yarn loop length was calculated using the Eq.(5) and tabulated in Table 7.

$$\text{Cotton yarn loop length } (mm) = \frac{\{\pi \times \text{VP diameter}\} \times \{\text{VP speed} \times \text{Positive storage pulley diameter}\}}{\{\text{Positive feeder belt drive pulley diameter}\} \times \{\text{Number of needles}\} \times 10} \quad \ldots \; (5)$$

Where VP = Variable Pulley

Table 7 - Cotton yarn loop length specifications

Cotton loop Length (mm)	Cotton yarn tension (cN/tex)	Spandex input yarn tension (cN/tex)
2.5	5.5	2.0 - 2.5
2.9	4.0	2.0 - 2.5
3.4	3.5	2.0 - 2.5

Effect of cotton yarn loop length on DWR of cotton / spandex knitted fabrics were analyzed and are given in Figure 5 (Cotton yarn loop length). The 30D/2.5/0.97 fabric has shown nearly 7 % higher DWR in wale direction and nearly 28 % higher DWR in course direction than that of 30D/2.9/0.97 and 30D/3.4/0.97 fabrics.

When the cotton yarn loop length increases from 2.5 mm to 2.9 mm, DWR of the fabric first decreases and then increases for 3.4 mm loop length in most cases. The effect of cotton yarn loop length has insignificant influence on the DWR of the fabric. But, no reason can be attributed for the decrease in the DWR of the fabric with increasing cotton yarn loop length from 2.5 mm to 3.4 mm.

Obviously, as the cotton yarn loop length increases, geometrical characteristics of the fabric such as wale density, course density and areal density decrease. The decrease in loop density and areal density reduces the recovery of stretched loops in the fabric. This results in lower DWR of the fabric at course direction.

When the extension levels increases from 20% to 50%, no trend was observed on fabrics produced with different cotton yarn loop lengths in wale direction. In the case of course direction, the DWR of 30D/2.9/0.97 and 30D/3.4/0.97 fabrics increases with increasing extension levels.

Effect of cotton yarn loop length on dynamic work recovery of the fabric has been insignificant at wale direction (F observed < F critical at $F(2, 6) = 4.23$, $P > 0.05$) and significant effect at course direction (F observed > F critical at $F(2, 6) = 29.23$, $P < 0.05$).

3.3.3 Effect of Spandex Linear Density

In order to study the effect of spandex linear density on dynamic work recovery of the compacted fabric, three levels of spandex linear density such as 20 denier, 30 denier and 40 denier were used for the study. Spandex input yarn tension was kept as 1.0 – 1.5 cN/tex for 20 denier spandex, 2.0 - 2.5 cN/tex for 30 denier spandex and 3.0 - 3.5 cN/tex for 40 denier spandex to set 0.97 mm spandex loop length and the cotton yarn loop length was kept as 2.9 mm.

Effect of spandex linear density on dynamic work recovery of cotton / spandex knitted fabrics was analyzed and is given in Figure 5 (spandex linear density). When the spandex denier increases from 20 denier to 40 denier, the DWR of the fabric increases in both wale and course directions.

The 40D/2.9/0.97 fabric has shown nearly 32 % higher DWR in wale direction and nearly 30 % higher DWR in course direction than that of other two fabrics. As the spandex denier increases, all the geometrical characteristics of the fabric such as wale density, course density and areal density increases. The increase in loop density helps to recover the stretched loops in the fabrics quickly. The increase in areal density due to higher loop density and higher spandex weight helps to give higher residual energy to the spandex fabric. Spandex linear density directly influences the DWR of the fabric.

No trend is found between spandex linear density and extension levels in wale direction. In the case of course direction, the extension levels increase with the increasing DWR of the 30D/2.9/0.97 and 40D/2.9/0.97 fabrics.

Effect of spandex linear density on dynamic work recovery of the fabric has been significant at both wale direction (F observed > F critical at $F(2, 6) = 41.49$, $P < 0.05$) and at course direction (F observed > F critical at $F(2, 6) = 30.85$, $P < 0.05$).

4. Conclusions

The study analyzed the effects of spandex input tension, spandex linear density and cotton yarn loop length on dynamic work recovery of the cotton/ spandex fabric.

4.1 The dynamic work recovery of the fabric at different processing stages such as relaxation, heat setting, bleaching and compacting treatments was analyzed. The fabric at grey stage showed higher DWR. After heat setting, DWR of the fabric was found to reduce. Bleaching process further reduces the DWR of the fabric. This trend was observed in both wale and course directions. Compacting process increases the DWR of the fabric in wale direction. At the same time, DWR of the fabrics decreases in course direction. Effect of different stages of processing on DWR of the fabric has significant influence.

4.2 In the case of spandex input yarn tension analysis, fabric produced from 0.97mm spandex loop length (30D / 29 / 0.97) shows nearly 44 % higher DWR in wale direction and nearly 32 % higher DWR in course direction, than that of the other two fabrics. The effect of spandex input tension on DWR of the fabric has been significant in wale direction and it has no influence on course direction.

4.3 In the case of cotton yarn loop length study, the fabric produced from 2.5 mm cotton yarn loop length (30 D/ 2.5 /9.7) shows nearly 7 % higher DWR in wale direction and nearly 28 % higher DWR in course direction, than that of other two fabrics. The effect of cotton yarn loop length on DWR of the fabric is significant at course direction and it has no influence at wale direction.

4.4 In the case of spandex linear density study, the fabric produced from 40 denier spandex (40D /2.9/ 0.97) shows nearly 32 % higher DWR in wale direction and nearly 30 % higher DWR in course direction, than that of other two fabrics produced from 20 and 30 denier. The effect of spandex linear density on DWR of the fabric has been significant at both wale and course directions.

4.5 The influence of extension levels on DWR of the cotton / spandex fabrics are insignificant at all the three cases such as spandex input tension, spandex linear density and cotton yarn loop length.

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