Dynamic Elastic Behavior of Cotton and Cotton / Spandex Knitted Fabrics

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ABSTRACT

The dynamic elastic behavior such as dynamic work recovery and stress at specific extension of the fabrics helps to analyze the instant garment response to body movements. It is an objective evaluation of the performance of the elastic fabrics for tight fit sportswear. The aim of the study was to compare the dynamic elastic behavior of cotton/ spandex fabrics with 100% cotton fabrics, since it is mandatory to know the level of performance of the cotton/spandex fabrics as compared with normal cotton fabrics with respect to energy gain or work recovery by the fabric which is necessary in evaluating the performance of the garment for specific sports application. It was found that the cotton/spandex fabrics have higher dynamic work recovery and lower stress value than those of cotton fabrics for both walewise and coursewise directions. The predictions of dynamic work recovery and stress values for different extension levels were made using a regression model.

INTRODUCTION

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 movement, different parts of the body stretch very differently, and the amount of stretch will vary differently in each direction [1].

Kirk and Ibrahim [2] reported that three essential components such as garment fit, garment slip, and fabric stretch were involved in the garment during the skin (body parts) movement. Garment fit provides the space allowance for skin strain, which is affected by the ratio of garment size to body size and the nature of garment design. Secondly, Garment slip, which is determined mainly by the coefficient of friction between skin and fabric and between layers of garments, is another mechanism for a garment to accommodate skin strain. Both components are difficult to quantify since the variables are sensitive to measure.

Thirdly, 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 a low resistance to stretch and high friction against the skin or fabric, it tends to stretch rather than slip. The opposite is true if the fabric has lower friction and high tensile resistance. 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 [3]. The pressure P is calculated using Eq. (1).

$$P = (T_H \; / \; Y_H) + (Tv \; / \; Yv) \tag{1}$$

where T is the tensile stress measured on the dynamometer (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. Denton stated that the pressure threshold of discomfort was found to be around 70 g / cm^2 which were close to the average capillary blood pressure of 80 g / cm^2 near the skin surface [3]. The pressure comfort zone for the normal condition is less than 60 g / cm^2.

In general, woven fabrics cannot reach the 10 – 50 % level of extensibility and recovery from extension. Hence, initially texturised 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 [4].

Elastane (Spandex ®) is readily compatible with other common fibers including cotton, nylon, polyester, acetate, polypropylene, acrylic, wool and rayon [5]. In general, breaking strength of spandex fiber is 0.7 g / den and elongation before break ranges from 520% to 610%. Spandex fiber is white and dyeable with disperse and acid dyes. It has good resistance to chemicals and withstands the action of perspiration. It may degrade and turn yellow when it is treated with chlorine. It can be washed at 60^0C and tumble dried at 80^0C. The fiber has moisture regain of about 0.3 % with melting point of 250^0C, but starts sticking at 175^0C [6].

Elastane is used in all areas where a high degree of permanent elasticity is required; for example, in tights, sportswear, swimwear, corsetry, and in woven and knitted fabrics. Elastane is a prerequisite for fashionable or functional apparel, intended to cling to the body making it remain comfortable. Worldwide spandex consumption and growth is 30 - 40% per year and is expected to grow high. Asian countries have a share of nearly 60% of world consumption and contribute 25% of world wide spandex growth per year [7].

Analysis of dynamic elastic behavior is an objective evaluation of the stretch and recovery performance of the elastic fabrics or tight fit garments [8]. The analysis of this dynamics will help to engineer 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.

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 nonlinear in nature (viscoelastic deformation), which will produce hysteresis loop [9]. 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.

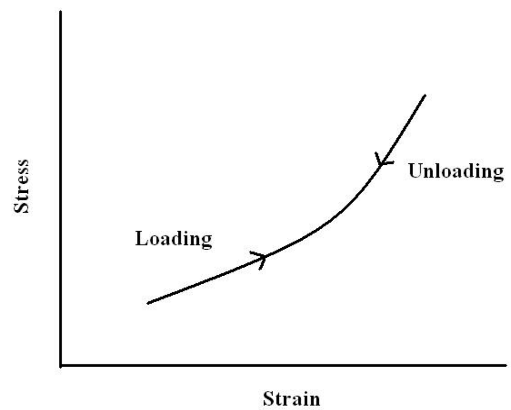


FIGURE 1. Stress strain behavior of identical elastic fabrics.

Assessment of dynamic work recovery (as shown in the *Figure 2*) 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 elastic energy for the specific strain expressed in percentage (In other words, 100 – loss of energy) whereas elastic recovery [10] is the ratio of recoverable strain to total strain at any given stress.

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.

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

Dynamic work recovery %

$$= \frac{\text{Area under the unloading curve}}{\text{Area under the loading curve}} \times 100 \quad (2)$$

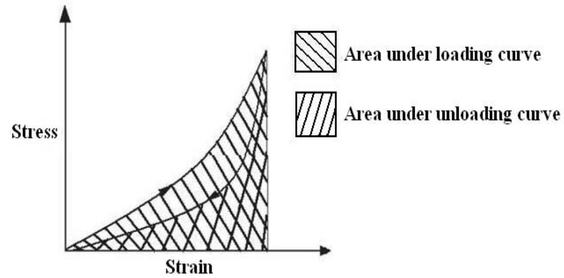


FIGURE 2. Dynamic work recovery of fabric.

Assessment of dynamic work recovery of the fabrics is a newly developed method based on the Kawabata [11] 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%. The dynamic work recovery of the fabric is evaluated by constant rate of elongation principle using dynamometer (Instron ®).

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

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

Dynamic work recovery

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

That is,

Dynamic work recovery

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

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

The simplified form,

Dynamic work recovery

$$= \frac{\text{Area under unloading curve}}{\text{Area under loading curve}} \times 100$$

Peter Popper [12] reported on dimensional properties of the elastic knitted fabrics. Since, the mechanical properties of the elastic material purely depend on fabric geometry, the comparison study was made between carded and combed yarn knitted fabrics with respect to elastic properties under static condition [12]. But so far no attempt has been initiated on assessment of energy loss during any activity by analyzing the elastic hysteresis for right selection of elastic garments for specific sportswear.

The aim of the study is to compare the dynamic elastic behavior of cotton/spandex fabrics with 100% cotton fabrics, since it is mandatory to know the level of performance of the cotton/spandex fabrics as compared with normal cotton fabric with respect to energy gain or work recovery by the fabric which is necessary in evaluating the performance of the garment for specific sports application.

MATERIALS AND METHODS

<u>Yarns</u>

In order to study the dynamic elastic behavior of the cotton and cotton/spandex fabrics, the selected cotton yarns were used to produce 100% cotton knitted fabrics. Similarly, the selected cotton yarns with different denier spandex (at 3% spandex feed) were used to produce cotton/spandex fabrics by plating method. The circular weft knitting machine was used to produce these fabrics. The specifications of the machine are tabulated in *Table I.*

TABLE I. Knitting machine specifications.

Model	MV 4 - Mayer & Cie (2001)
Machine diameter (inches)	24
Machine gauge (Needles per inch)	24
Number of feeders used	72
Machine speed	20 - 30

<u>Processing Treatments</u>

<u>*Heat Setting*</u>

The cotton/spandex single jersey knitted fabrics were heat set at 200^0C using heating chamber (ASKME Make, chamber length of 228.6 cm and fabric stretch at width wise direction is 25% of machine diameter). Cotton fabric wasn't heat set. Then, both the fabrics were dyed, compacted and tested for their geometrical characterisitcs.

Dyeing

Spandex fibers are less fast to dyes than most companion fibers, and this must be taken into account during dyeing and subsequent wet processing. Dyeing temperature above 104°C will lower the spandex fineness. Spandex will start melting losing its fiber shape, and will result in lower power. When dyeing temperature goes above 120°C, it will result in spandex degradation [13].

The knitted fabrics were first bleached using hydrogen peroxide bleaching for two hours. Then peroxide nutrition treatment was given for one hour. Wetting oil was added to dye bath. The fabric samples were dyed with 2% shade hot brand reactive dyes. The fabric was soaked in the dye bath for four hours. Again the samples were treated with salt & soda and steamed at 65^0C temperature. Then, the sample was treated with soap solution and acetic nutrition treatment for one hour.

Compacting

These fabrics were compacted using tubular compacting machine (Albert make, Speed of 4 meters per minute, Chamber length of 1 meter, 26 % over feed, Fabric stretch in width wise direction was kept at 11% of machine diameter and at the temperature of 94^0C). Then, the fabrics were relaxed for 48 hours.

Testing Methods

Geometrical Characteristics

The average 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. The fabric thickness was measured with the aid of thickness gauge (under the applied load of 50 grams per square centimeter) according to method ISO 5084:1996. Fabric geometrical characteristics were measured at ten different places in the fabric in each case [14].

Dynamic Elastic Behavior

The fabrics were tested for their dynamic elastic behavior such as dynamic work recovery and stress at specific extension 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.

RESULTS AND DISCUSSION

In order to study the level of performance of the cotton/spandex fabrics for tight fit sportswear, a comparative study was made between cotton/spandex knitted fabrics and 100% cotton knitted fabrics with respect to dynamic elastic properties.

Geometrical Characteristics

Though the two sets of fabrics were made on same machine, the geometrical characteristics of the fabrics showed significant difference as stated by the author Bayazit [15].

Geometrical characteristics such as wales per centimeter, courses per centimeter, loop length, thickness and areal density of the 100% cotton and cotton/spandex fabrics were tabulated in *Table II.* The courses and wales per centimeter of cotton/spandex fabrics are higher than that of cotton fabrics. The same trend was found by Bayazit [15]. This is due to the contribution of spandex in the cotton/spandex fabrics. The spandex compress the yarn loops within its structure and causes the yarn loop jamming. Cotton/spandex fabrics loop lengths are apparently higher than that of cotton fabrics. This may be due to minimum robbing back during knitting.

TABLE II. Geometrical characteristics of cotton and cotton/spandex fabrics.

Sample No	Yarn Count (tex)	Loop length (mm)	Wales per centimeter	Courses per centimeter	Thickness (mm)	Areal density (g / m^2)
Sample 1a	**14.05**	**2.43**	**18.05**	**25.10**	**0.495**	**197.45**
Sample 1b	14.05	2.51	16.66	18.79	0.386	134.27
Sample 2a	**14.05**	**2.82**	**17.87**	**25.0**	**0.492**	**194.12**
Sample 2b	14.05	2.92	16.41	18.52	0.384	133.34
Sample 3a	**14.05**	**3.17**	**17.54**	**24.42**	**0.488**	**191.56**
Sample 3b	14.05	3.20	16.24	18.29	0.372	129.45
Sample 4a	**14.76**	**2.42**	**18.21**	**27.54**	**0.525**	**198.50**
Sample 4b	14.76	2.53	16.72	19.26	0.410	136.46
Sample 5a	**14.76**	**2.85**	**17.72**	**25.20**	**0.520**	**196.50**
Sample 5b	14.76	2.94	16.54	18.90	0.405	134.25
Sample 6a	**14.76**	**3.09**	**17.51**	**24.86**	**0.515**	**194.78**
Sample 6b	14.76	3.24	16.35	18.72	0.395	132.85
Sample 7a	**16.40**	**2.42**	**18.53**	**27.43**	**0.531**	**208.98**
Sample 7b	16.40	2.51	16.85	20.45	0.425	142.40
Sample 8a	**16.40**	**2.82**	**17.84**	**27.12**	**0.528**	**201.15**
Sample 8b	16.40	2.94	16.63	19.40	0.420	136.47
Sample 9a	**16.40**	**3.08**	**17.64**	**26.84**	**0.516**	**198.05**
Sample 9b	16.40	3.24	16.52	19.21	0.415	132.25
Sample 10a	**17.36**	**2.42**	**19.23**	**27.23**	**0.530**	**212.18**
Sample 10b	17.36	2.53	17.01	19.52	0.424	147.28
Sample 11a	**17.36**	**2.79**	**18.74**	**26.82**	**0.526**	**206.41**
Sample 11b	17.36	2.94	16.88	19.25	0.418	142.57
Sample 12a	**17.36**	**3.11**	**17.92**	**25.71**	**0.508**	**202.54**
Sample 12b	17.36	3.22	16.74	18.72	0.407	138.27
a = Cotton / Spandex fabrics, b = Cotton fabrics						

Fabric thickness is higher in the case of cotton/spandex fabrics than that of cotton fabrics. This is due to lateral compression of the cotton/spandex fabrics (Lateral compression is the compression parallel to the plane). The cotton/spandex fabrics have higher loop density due to higher yarn loop lateral compression which resists the fabric compression (perpendicular to the plane). Higher loop density and spandex presence in the cotton/spandex fabrics increases the fabric areal density.

Elastic Hysteresis

In order to study the dynamic elastic behavior of the fabrics such as dynamic work recovery and stress at specific extension, the elastic hysteresis of the cotton and cotton/spandex fabrics were analyzed. The hysteresis of these fabrics at different extension levels such as 20%, 30%, 40% and 50% in walewise and coursewise direction were observed. The stress strain behavior of the fabrics was studied by dynamic loading under CRE principle. That is the applied extension cause the fabric loading. When the load (or energy) is applied to a fabric (or garment), a part of energy will deform the yarn loop and part of energy will stretch the yarn.

It is understand that, when the fabric extension increases from 20% to 50%, the slope of the hysteresis also increases in both wale wise and course wise direction of both the fabrics. It was predominantly visible in the case of 100% cotton fabrics. Cotton/spandex fabrics have lower stress values for the given extension levels in walewise and coursewise directions.

In the case of cotton fabrics, zero stress was observed up to 10 % of the applied extension. This may be due to loop deformation. After that, the yarn may have stretched out of its structural cell. In the case of cotton/spandex fabrics, the fabrics were in jammed state due to the yarn loop lateral compression. Since, stress initiated from initial extension and gave the minimum hysteresis slope; this causes minimum stress level (less than 0.05 N / mm^2) for all level of applied extensions from 20 to 50% in both walewise and coursewise directions. This will help the wearer to feel more comfortable because of minimum friction or skin irritation.

Dynamic Work Recovery

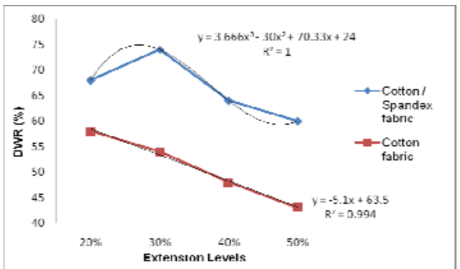
Based on the elastic hysteresis of these fabrics, the dynamic work recovery and stress at applied extension was measured. The DWR value of the cotton fabrics and cotton/spandex fabrics at different extension levels such as 20%, 30%, 40% and 50% in both wale wise and course wise directions were shown in *Figure 3*. It is known that the walewise extension means it's against course density. Similarly, the coursewise extension means it's against wale density.

The geometrical characteristics of the fabrics greatly influence the dynamic elastic behavior of the fabric. The change in the geometry of the cotton/spandex fabrics was mainly due to the yarn loop lateral compression because of plating of spandex. The yarn loop compression is calculated by equations 3 and 4.

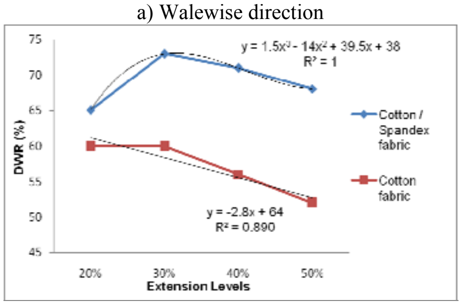
$$\text{Yarn loop compression in walewise direction (\%)} = \frac{[\text{Course density of cotton/spandex fabric} - \text{Course density of cotton fabric}] \times 100}{\text{Course density of cotton/spandex fabric}} \quad (3)$$

$$\text{Yarn loop compression in coursewise direction (\%)} = \frac{[\text{Wale density of cotton/spandex fabric} - \text{Wale density of cotton fabric}] \times 100}{\text{Wale density of cotton/spandex fabric}} \quad (4)$$

Yarn loop compression of the cotton/spandex fabric in walewise direction is 25.0% and coursewise direction is 6.65%. The DWR values of the cotton/spandex fabrics are higher than that of cotton fabrics in both the walewise and coursewise direction at four levels of extension. The cotton/spandex fabrics have nearly 20% higher DWR in walewise direction and nearly 15% higher DWR in coursewise direction, than that of cotton fabric. This is mainly due to the yarn loop compression of the fabric in both the directions.



a) Walewise direction



b) Coursewise direction

FIGURE.3. DWR of cotton and cotton/spandex fabrics.

The DWR of cotton fabrics are decreasing with increasing fabric extension from 20% to 50%, that is, the average values of DWR of cotton fabrics starts from 58.2% for 20% extension to 43.5% for 50% extension in walewise direction. Similarly, the average values of DWR value of the fabrics starts from 60.8% for 20% extension to 52.4% for 50% extension in coursewise direction.

In the case of cotton/spandex fabrics, the average DWR values of the fabrics increases from 20% to 30% extension and then it gets decreasing for 40% and 50% in both walewise and coursewise directions.

In order to analysis the reason for the behavior, these fabrics were examined under microscope (attached with CCD camera) at different extension levels. Fabric extension from 20% to 30% may cause only loop deformation which may not affect the residual energy of the spandex. So, the fabrics have higher DWR for both walewise and coursewise directions. But, the fabrics at extensions from 30 % to 50% cause yarn stretch from its loop structure and at this extension level, the spandex in the fabrics reduce its residual energy.

The DWR of cotton fabrics have good correlation with the different extensions level and the predicted linear equations 5 and 6 are given.

$$\text{DWR Cotton} = -5.1 \text{ extension } \% + 63.5 \quad (R^2 = 0.994) \text{ for walewise direction} \tag{5}$$

$$\text{DWR Cotton} = -2.8 \text{ extension } \% + 64 \quad (R^2 = 0.89) \text{ for coursewise direction} \tag{6}$$

The DWR of cotton/spandex fabrics have good correlation with the different extensions level and the predicted third order polynomial equations are Eq. (7) and Eq. (8).

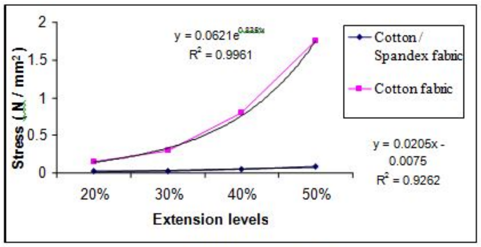
$$\text{DWR of Cotton/Spandex fabrics} = 3.66 \text{ extension}^3 - 30 \text{ extension}^2 + 70.33 \text{ extension} + 24 \text{ for walewise direction} \tag{7}$$

$$\text{DWR of Cotton/Spandex fabrics} = 1.5 \text{ extension}^3 - 14 \text{ extension}^2 + 39.5 \text{ extension} + 38 \text{ for coursewise direction} \tag{8}$$

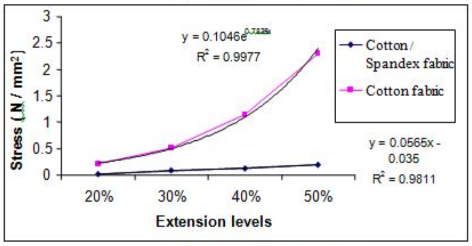
Eq. (5) through Eq. (8) will help to predict the DWR of the fabrics at different extension levels.

Stress at Specific Extension

Analysis of stress imposed for the applied extension is important to study the pressure between body and garment. The higher the stress value the higher the skin strain. The stress values of the fabrics for applied extension levels are given in *Figure 4.*



a) Walewise Direction



b) Coursewise Direction

FIGURE 4. Stress values of cotton and cotton/spandex fabrics.

In general, the fabric stress values for applied extensions in coursewise direction are always been higher than that of stress values in walewise direction. This is also influenced by the yarn loop lateral compression of the fabrics. The higher the lateral compression the lower the stress value of the fabrics. Stress values of cotton fabrics are higher than that of cotton/spandex fabrics in both walewise and coursewise direction for all the levels of extension. When the applied extension increases from 20 % to 50%, the stress values of the cotton fabrics increase exponentially in both walewise and coursewise directions. It has stress value of 1.75 N /mm^2 in wale wise direction and 2.3 N /mm^2 in coursewise direction at 50 % of the extension. Normally, the stress value of the garment should be in the range of 0.05 – 0.25 N / mm^2 (Li 2010). But, here the cotton fabrics exceed its pressure comfort limits.

The stress values of the cotton fabrics have good correlation with different extension levels. The predicted stress values of cotton fabrics are given in Eq. (9) and Eq. (10).

Stress value of cotton fabrics
$$= 0.0621\, e^{0.8351\, \text{extension}}\ (R^2 = 0.9961) \quad (9)$$
for walewise direction

Stress value of cotton fabrics
$$= 0.1046\, e^{0.7835\, \text{extension}}\ (R^2 = 0.9977) \quad (10)$$
for coursewise direction.

The cotton/spandex fabrics stress value is less than 0.2 N / mm^2 in all the cases. The increase in stress values of the cotton/spandex fabrics are linear relationship with different extensions in both walewise and coursewise directions.

The stress values of the cotton/spandex fabrics have good correlation with different extensions level. The predicted stress values of cotton/spandex fabrics are given in Eq. (11) and Eq. 12.

Stress value of Cotton/Spandex fabrics
$$= 0.0205\ \text{extension} - 0.0075 \quad (11)$$
(R^2 = 0.9262) for walewise direction

Stress value of Cotton/Spandex fabrics
$$= 0.0565\ \text{extension} - 0.035 \quad (12)$$
(R^2 = 0.9811) for coursewise direction.

CONCLUSION

The instantaneous garment response due to body movement can be assessed by calculating the dynamic work recovery and stress value at different extension levels. The comparative analysis on dynamic elastic behavior of cotton and cotton/spandex fabrics was made. It is found that the cotton/spandex fabrics have higher DWR and lower stress value than that of cotton fabrics for both walewise and coursewise directions. The prediction of DWR and stress value for different extension levels are made using regression model. The cotton/spandex fabrics are preferable than cotton fabrics with respect to dynamic elastic characteristics due to its quick work recovery which enhances the power of the performance of the sports person. This objective analysis of garment response is to help engineer a garment for sports activity.

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REFERENCE

[1] Voyce, J. Dafniotis, P. and Towlson, S. "Elastic Textiles, Textiles in Sport", *Wood Head Publications, Cambridge, UK*, 2005.

[2] Kirk Jr. and Ibrahim, S.M. "Fundamental Relationship of Fabric Extensibility to Anthropometric Requirements and Garment Performance", *Textile Research Journal*, Vol.36, No.1, 1966, pp.37 - 47.

[3] Li, Yi. and Anthony, S.W. and Wong. Clothing Biosensory Engineering, Chapter 7; Tactile Sensations, *Wood Head Publications, Cambridge, UK*, 2010.

[4] Bardhan, M.K. and Sule, A.D. “Anatomy of Sportswear and Leisurewear: Scope for Spandex Fibres”, *Man Made Textiles in India*, Vol.3, 2001, pp.81-86.

[5] Rozelle Walter, N. “Spandex: Miracle Fiber Now Coming into its Own”, *Textile World*, Vol.147, No.1, 1997, pp. 80- 82.

[6] Moncrieff, R.W. Man-Made Fibres, Wiley-Interscience Publication, Edition 5, USA, 1970.

[7] John, E.L. Stretch Challenge, *Textile World*, Vol.152, No.1, 2002, pp. 46 - 49.

[8] Senthilkumar, M., Anbumani, N. and Mario de Araujo, “Elastic Properties of Spandex Plated Cotton Knitted Fabric”, *The Institution of Engineers (India)*, Vol. 92, No.8, 2011, pp 9 - 13.

[9] Donna Sajn Gorjanc. Vili Bukosek. “The Behaviour of Fabric with Elastane Yarn during Stretching”, *Fibres and Textiles in Eastern Europe*, Vol.16, No. 3, 2008, pp. 63 - 68.

[10] Arnold M.Hansen and Hazel M.Fletcher. “Elastic Recovery in Cotton Knitted Fabrics”, *Textile Research Journal*, Vol.16, No.1, 1946, pp.571 – 575.

[11] Kawabata, S., Postle, R. and Masako, N. “Objective Specification of Fabric Quality, Mechanical Properties and Performance”, Proceedings of the Japan - Australia Joint Symposium, Kyoto, Japan, May 10 -12, 1982, pp.1 -29.

[12] Peter Popper. “The Theoretical Behavior of a Knitted Fabric Subjected to Biaxial Stresses”, *Textile Research Journal*, No.2, 1966, pp.148 – 157.

[13] http://www.elaspan.com/about3.html, Accessed date, 22.08.2009.

[14] Senthilkumar, M. and Anbumani, N. “Dynamics of Elastic Knitted Fabrics for Sportswear”, *Journal of Industrial Textiles*, Vol. 41, No.1, 2011, pp. 13 -24.

[15] Bayazit Marmarali, A. “Dimensional and Physical Properties of Cotton/Spandex Single Jersey Fabrics”, *Textile Research Journal*, Vol.73, No.1, 2003, pp.11 - 14.

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