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Investigating the Performance of Various Relaxation Processes on the Surface Regularity and Dimensional Properties of Plain Knitted Fabrics Using the Image Processing Technique

Abstract
The main objective of this paper was to develop a more advanced finishing treatment for the stitch shape regularity and dimensional properties of knitted fabrics. In our previous work, we presented a novel definition of knitted fabric regularity. In the present study we utilised our pervious approach based on Radon transformation analysis to study the effect of different relaxation regimes on the above properties of plain fabrics. We applied various relaxation methods to plain fabrics to make the stitch shape closer to the ideal. The rhythm of stitch shape improvement was evaluated by measuring the deviation of the direction angle of the stitches against the ideal state. The results show that the average fabric irregularity index after ultrasonic-chemical relaxation treatment is better than other relaxation method indices. Moreover the average fabric constant dimensional parameter (Ks) after the above treatment is higher than values reported by pervious workers. Therefore we propose this relaxation treatment as a new relaxation method that is more effective with respect to plain fabric regularity and stability during usage.

Key words: *dimensional properties, fabric regularity, relaxation treatment, knitted fabric, ultrasonic-chemical relaxation, image processing technique.*

Introduction

Both the surface regularity and dimensional stability of weft-knitted fabrics play a great role in knitted fabric quality. Previous studies have shown that in fully relaxed knitted fabric, the loop takes a fixed geometrical shape [1]. Last century many researchers studied the dimensional properties of weft-knitted fabrics, in which they used various relaxation processes to obtain the minimum fabric internal energy and maximum fabric shrinkage. In general, two kinds of relaxation processes exist: mechanical and chemical treatment. Munden [1] defined two fabric relaxation methods: dry and wet processes. In the first method knitted fabrics were exposed to air for some days, and in the second method knitted fabrics were immersed in warm water. Knapton et.al. [2] applied both mechanical (laundering and tumble drying cycles) and chemical (fabric mercerisation without tension) relaxation treatments to knitted fabrics. They declared that both treatments cause large linear-dimensional changes leading to the same final stable condition of the fabric. They also expressed that these treatments lead to the stabilisation of the dimensions by allowing the yarn to bulk, which causes three-dimensional changes in the loop shape and consequent relaxation shrinkage. An ideal loop shape and consequent dimensional stability of the fabric appear to be obtained when yarn-bulking is restricted by yarn jamming. Semnani et.al. [3] proposed an ideal model for plain weft-knitted fabric using classical mathematical curves based on the elastic rod model of leaf's theory [4]. According to this model, in a fully relax state, the loop takes a specific shape whose factor is about 1.4. Moreover, in this theoretical model, the fabric constant dimensional parameter value (K_S = 25.98) was higher than the experimental one for fully relaxed plain knitted fabrics, as reported by pervious researchers, who concluded that a more advanced relaxation method should be used in finishing treatment for weft-knitted fabrics to make the stitch shape closer to the ideal and to raise the practical K_S-value. In the next attempt, Jeddi et.al. [5] employed ultrasonic waves as a new mechanical relaxation method to achieve maximum fabric shrinkage. Ultrasonic waves with frequencies of above 20 KHz, which are beyond the capability of human hearing, are longitudinal pressure waves. By using the ultrasonic relaxation process on cotton plain knitted fabrics, they could reach a K_S-value equal to 24.87, which is higher than with other relaxation methods, but still smaller than the theoretical K_S-value. Moreover, the average loop shape factor after the ultrasound relaxation process still differs from the ideal value. In another work Jeddi and Otaghsara [6] investigated correct relaxation treatment for 100% cotton, cotton/polyester blended and 100% polyester knitted fabrics. In an experimental analysis they concluded that the correct relaxation state for cotton fabrics to achieve maximum shrinkage is full mechanical relaxation, and for cotton–polyester blended and 100% polyester fabrics chemical relaxation treatment should be used. Their empirical results showed that the effect of mechanical relaxation decreases as the percentage of polyester increases. Anand et.al.[7] studied the dimensional properties of three popular 100% cotton weft-knitted fabrics (plain, 1×1 rib and interlock) subjected to five cycles of four different washing and drying regimes. This study had two stages: In the first stage, they investigated the effect of laundering with detergent as opposed to water, and tumble drying against line drying. In this stage they demonstrated that changes occurring after laundering were largely due to alterations in the loop shape rather than yarn or loop length shrinkage. They also stated that the effect of tumble drying on the dimensional stability of knitted fabrics is more evident than for line drying . In the second stage they investigated the effect of each part of the relaxation process (wash, rinse, spin & agitation during drying and heat during drying) on fabric dimensional change and demonstrated that changes occurring after laundering were largely caused by agitation during tumble drying (34%) and the spin cycle during washing (24%).

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Computer vision is an accurate tool to evaluate fabric features. It is clear that human inspection is time consuming and tiresome and also depends on human measuring precision. In recent decades many researchers have applied computer imaging to improve human inspection methods for textile products. Some workers have attempted to utilise the image analysis technique as a real-time inspection tool for the evaluation of fabric quality. Kim et.al.[8] utilised the image analysis technique for quantifying marquisette damage in home laundering. In this method, images of washed marquisette samples were processed with Gabor filters to extract distorted yarns from a regular weave. In another work, Furferi [9] et.al. presented a machine vision tool for the on-line detection of defects on textile raw fabrics. This tool worked in four stages: (1) the image acquisition of the raw fabric, (2) the extraction of some critical parameters from the images acquired, (3) the detection and classification of the most frequent defects using an artificial neural network (ANN) as a classifier, and (4) applying the image processing technique to measure the geometric properties of the defects detected. They stated that the accuracy of this tool is about 90%, which is close to the performance of a human expert. Ghazi Saeidi et.al. [10] developed an on-line computer vision system for knitted fabric inspection on a circular knitting machine. They considered the performance of this tool in two states: on a laboratorial and industrial scale. They also used three different spectral transforms (discrete Fourier, wavelet and Gabor transforms) and concluded that the Gabor transform method has the highest efficiency value from among the three methods.

In all the works mentioned above , both the number of faults and their area were used to define the knitted fabric quality. The defects that were probable in the knitting process were broken needle, hole, soil strip or thin and thick-yarn defects etc. But one of the most important faults in weft-knitted fabric is irregularity of stitch direction during the knitting process. On the other hand the quality of non-defective fabric depends on the regularity of the fabric surface, which is related to the direction of stitches in ideal , almost fully relaxed fabric. In our previous work [11] we developed a grading method for weft-knitted fabrics based on stitch deformation in weft-knitted fabric. In another study we presented a novel definition of knitted fabric quality and defined a fabric irregularity index that determined the deviation of the angle of the stitch direction from an ideal state [3] for different weft-knitted fabric structures of various yarns using the image processing technique. In this study, we used the image analysis method to study the effect of various relaxation processes on fabric regularity and stitch shape. In addition we defined new and more effective relaxation processes to obtain a stable form of knitted fabric, where the angle of stitch direction is close to the ideal, and therefore the stitch shape is also close to being ideal.

Methods and experiment

Sample preparation

In this research various weft-knitted fabric samples were prepared from ring spun yarns of plain knitted structure and equal loop length to consider the effect of various raw materials and relaxation treatments on the dimensional properties and surface regularity of distorted stitches. Samples were produced without knitting faults, such as holes, drop stitches and stripes.

Six samples of various yarn types were prepared including cotton ring spun yarn of 20 and 30 tex, polyester/cotton ring spun yarn (65%/35%) of 20 and 30 tex and polyester/viscose ring spun yarn (65%/35%) of 20 and 30 tex. All the samples were produced on a circular knitting machine with a positive feed; they were of a plain structure and similar knitting stiffness with an equal stitch length (0.345 cm). The machine had a 16-in diameter cylinder, 24 gauge, four cam tracks, and 24 feeders. The machine's yarn input tension was set at 5 g. Four specimens were taken from knitted fabrics produced from the different yarn types. Then each of the samples was subjected to seven different kinds of relaxation regimes (dry, wet, washing, ultrasonic, chemical, detergent-washing, and ultrasonic-chemical).

Relaxation process

To consider the effectiveness of the various relaxation regimes on knitted fabric regularity and dimensional properties and to obtain a more suitable relaxation treatment, the seven different relaxation processes were defined in three categories. In general, the relaxation treatments were divided into two main categories: mechanical and chemical . In the mechanical relaxation process, the knitted fabrics were subjected to mechanical forces to decrease the potential energy of the fabric. Dry, wet, washing and ultrasonic relaxation regimes are common mechanical relaxation processes in the knitting industry. However, the ultrasound relaxation regime is a more advanced mechanical relaxation method than the usual ones. As regards chemical methods, by using such chemical processes as immersing the fabric in aqueous solutions e.g. ionic detergent bath, attempts have been made to decrease the friction between yarns and, hence, obtain a stable knitted structure.

In this study, we defined two complex (mechanical-chemical) relaxation processes of the third category to consider the overall effect of the above treatments on fabric regularity and dimensional properties and thereby obtain a more advanced finishing treatment for weft-knitted fabrics. Therefore each sample was subjected to the following relaxation treatments, respectively:

Mechanical relaxation methods:

- *Dry relaxation*: The samples were relaxed on a flat surface at room conditions (temperature, 25 ± 2 °C and RH, 65 ± 2%) for 24 h to release knitted stresses.
- *Wet relaxation*: the samples were immersed in a water bath containing 0.01% wetting agent at 38 °C for 12 hours, then removed, gently hydroextracted, and finally dried on a flat surface for 24 h at room conditions.
- *Washing*: the samples were washed in a domestic washing machine with water containing 0.1 % of neutral detergent at 50 °C for 35 min, and then the water was drained off. Afterwards the fabric samples were removed from the washer, hydroextracted and then dried in a tumble drier for 10 min. Finally the sample was placed on a flat surface for 24 h at room conditions.
- *Ultrasonic waves*: fabric samples were placed in an ultrasonic cleaning bath, made by the Walter Company, with a frequency of 35 kHz, an intensity wave of 9 W/cm^2, and a water temperature of 70 °C for 10 min relaxation time. Afterwards the samples were dried for 24 h on a flat surface at room conditions.

__Table 1.__ Values of the dimensional parameter (K_s) of plain knitted fabrics for each relaxed state.

Yarn type	Yarn count, tex	K_s													
		Dry	CV%	Wet	CV%	Washing	CV%	Ultrasonic	CV%	Chemical	CV%	Detergent /Washing	CV%	Ultrasonic /Chemical	CV%
Cotton	30	19.45	2.1	21.36	1.1	23.51	1.7	24.45	1.3	22.62	5.6	24.40	3.1	25.26	0.8
	20	19.30	0.9	20.97	2.2	23.75	3.6	24.28	2.1	22.88	4.7	24.73	3.3	25.83	1.1
Polyester /cotton (65/35)	30	19.26	1.4	20.91	5.1	23.46	4.1	24.46	1.8	23.16	1.2	24.49	1.2	25.18	1.3
	20	19.10	1.8	20.71	0.6	23.08	1.0	24.03	3.3	23.96	0.5	24.15	1.8	25.27	2.1
Polyester / viscose (65%/35)	30	18.53	2.0	21.55	2.4	23.46	3.1	24.03	1.5	24.13	2.2	24.84	2.0	25.38	2.7
	20	19.25	1.6	21.26	3.1	23.50	1.6	24.35	0.6	23.92	2.1	24.12	2.3	25.54	0.9

__Table 2.__ Values of the Loop Shape Factor (Kr) of plain knitted fabrics for each relaxed state.

Yarn type	Yarn count, tex	K_r													
		Dry	CV%	Wet	CV%	Washing	CV%	Ultrasonic	CV%	Chemical	CV%	Detergent /Washing	CV%	Ultrasonic /Chemical	CV%
Cotton	30	1.12	1.7	1.15	2.3	1.23	3.6	1.38	0.7	1.31	4.1	1.37	5.1	1.4	4.4
	20	1.10	2.1	1.12	3.7	1.18	4.5	1.33	2.3	1.30	3.8	1.36	6.0	1.39	3.6
Polyester /cotton (65/35)	30	1.17	1.0	1.23	1.4	1.26	4.4	1.36	1.4	1.34	2.6	1.37	1.2	1.39	2.2
	20	1.13	3.2	1.16	4.2	1.22	1.5	1.34	5.0	1.31	1.3	1.36	1.3	1.37	3.4
Polyester / viscose (65%/35)	30	1.20	2.5	1.25	3.3	1.33	1.7	1.38	2.2	1.37	3.6	1.39	0.5	1.41	3.1
	20	1.14	4.1	1.18	3.1	1.24	4.0	1.34	2.9	1.33	4.0	1.34	1.1	1.38	3.0

Chemical relaxation method:

- *Chemical relaxation*: fabric samples were immersed in a water bath containing 2 g/l of cationic detergent at 50 °C for 20 min, then removed, gently hydroextracted , and finally dried on a flat surface for 24 h at room conditions.

Complex relaxation methods:

- *Detergent-Washing*: the samples were washed in a domestic washing machine with water containing 2 gr/lit of cationic detergents at 50 °C, conditions as in a washing relaxed state.
- *Ultrasonic-Chemical*: fabric samples were placed in an ultrasonic cleaning bath, made by Walter Company, containing 2 g/l of cationic detergent, conditions as in the ultrasonic wave process.

After each relaxation treatment, the fabric dimensional parameters i.e. courses/cm (cpc), wales/cm (wpc) and stitch/cm^2 (SD) of all the fabric samples were measured. Moreover fabric constant parameters were calculated according to Munden's equations [1]. The averages of four measurements of K_s and K_r values are shown in ***Tables 1*** and ***2***.

Measuring methods for stitch direction

In the next stage, in order to evaluate the stitch formation rhythm during the various relaxation processes, we utilised our pervious approach as a new intelligent method for evaluating knitted fabric regularity based on the image processing technique and Radon transformation analysis. Moreover, we compared the results of this method with those obtained by the conventional method with respect to the angle of stitch direction after each relaxation process. The fabric samples were scanned in BMP format of gray scale at a resolution of 1200 dpi. The images scanned were 200 × 200 mm in size. To detect the stitch direction, the gray scale image of the yarn was converted to an edge-detected form using a differential mask. There are different methods of edge detection in the image processing technique. In one edge-detection method an intensity image is processed and returned as a binary image of the same size, with 1's where the function finds edges and 0's elsewhere. In accordance with our pervious study, we used the Canny method, being the most powerful edge-detection method, to convert the gray scale image of knitted fabric to an edge-detected form. The Canny method [12] differs from other edge-detection methods in that it uses two different thresholds (to detect strong and weak edges) and includes weak edges in the output only if they are connected to strong edges. This method is therefore more likely to detect true weak edges. A sample of an edge-detected image in a dry relaxed state is shown in ***Figure 1***. After converting the original image to an edge-detected form, the Radon transformation was used to find the stitch directions. Applying the Radon transform to an image $f(x,y)$ for a given set of angles can be thought of as computing the projection of the image along the given angles. The resulting projection is the sum of the intensities of the pixels in each direction, i.e. a line integral. The result is a new image $R(\rho, \theta)$, which can be written mathematically by defining

$$\rho = x \cos \theta + y \sin \theta \quad (1)$$

After which the Radon transform can be written as

$$R(\rho,\theta) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(\rho - x\cos\theta + - y\sin\theta)dxdy \quad (2)$$

Where $\delta(\cdot)$ is the Dirac delta function [13]. In accordance with our pervious approach, we applied the Radon transformation to fabric images of each relaxed state 180 times for one degree increment. The result will be a matrix, R, of n by 180, where n is the length of each column, the number of columns being 180. An R matrix is an intensity matrix which can be presented as a colour map histogram. A plot of the high intensity raw of the Radon transformation matrix is shown in ***Figure 2***. In this plot the maximum value refers to the column number or angle of direction of stitches [13]. Because of the Radon transpose of the edge image, where the direction of stitches is evaluated in the x and y axes, the maximum value is repeated after 90 degrees at the mirror point of the first repeat, which is located before 90 degrees. To detect the true direction of stitches, the value of the spirality angle must be added to the maximum value of ***Figure 2***. Spirality is a problem in single jersey knitted-fabrics that occurs when the wales are not perpendicular to the courses. In these fabrics the direction of wales skews to the left or right. You can see this phenomenon in ***Figure 1.*** In ***Figure 2*** the second pick that occurred near 180 degrees was referred to as the spirality angle. Moreover, another pick occurred at a 90 degree angle, indicating the course direction. For all the fabric image preparation and image analysis to detect stitch direction, the image processing toolbox of MATLAB 7 was applied.

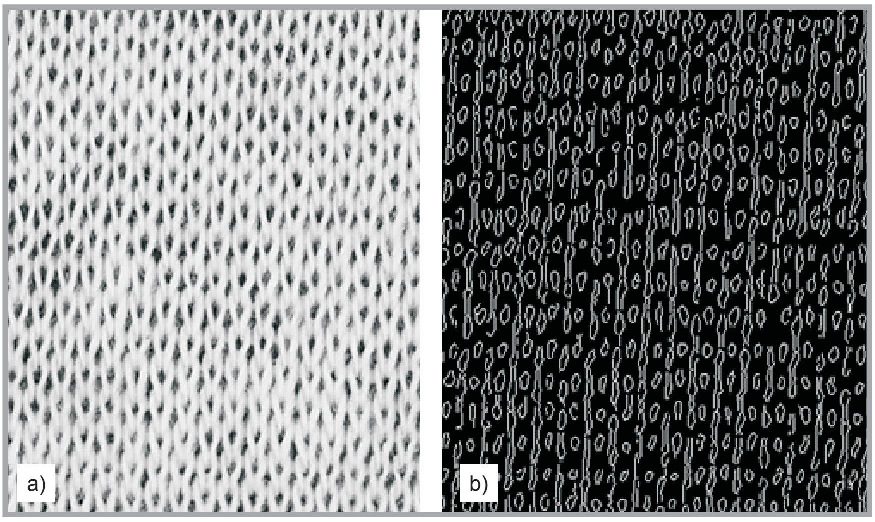

Figure 1. *Cotton 20 Ne plain knitted fabric in a dry relaxed state: (a) original image of fabric and, (b) enhanced image of fabric as an edge-prepared image.*

According to Munden's equations, the stitch shape factor is defined as below:

$$\text{tg}\ \alpha_k = K_r = \frac{cpc}{wpc} = \frac{K_c}{K_w} = \frac{D}{d} \quad (3)$$

where α_k is the angle between the stitches of consecutive courses in a plain knitted structure. Model of stitches in an ideal knit structure [3] is shown in ***Figure 3***. α_k is located between two stitches in successive order in which one of them is located in the first course and the other in the second course. D and d are the height and width of a stitch, respectively. As we demonstrated in our pervious paper, we assumed values of $K_c = 6.12$ and $K_w = 4.37$ for a fully relaxed state, obtained from a three-dimensional model [3], thus:

$$\text{tg}\ \alpha_k = \frac{K_c}{K_w} = 1.4 \quad (4)$$

Then, $\alpha_k = 54.5$.

To consider the effect of each relaxation process on plain knitted fabric regularity, we calculated the index of irregularity as in our previous work [11] i.e. after each relaxation treatment. Moreover, to compare the results of human vision and computer vision, we defined two fabric irregularity indexes as below:

$$I_a = \frac{|54.5 - \alpha_a|}{54.5} \times 100 \quad (5)$$

and

$$I_r = \frac{|54.5 - \alpha_r|}{54.5} \times 100 \quad (6)$$

Where α_a and α_r are the angles of stitch direction calculated manually and by Radon transformation analysis, respectively. The results of the above calculations are shown in ***Tables 3*** and ***4*** (see page 40) for all the knitted samples in each relaxed state.

Result and discussion

In the first part, we attempted to consider the efficacy of each relaxation process and yarn type on knitted fabric regularity based on our pervious approach. Images of all the knitted fabrics in each relaxed state were analysed by appropriate software to detect the angle between the stitches of consecutive courses (α_r). In previous work it was shown that this analysis software can calculate stitch direction irregularities with an error of less than 9%. In the present study, to retest the accuracy of this method, we compared the results of the irregularity index calculated manually from Equation 5 with those of the software calculated from

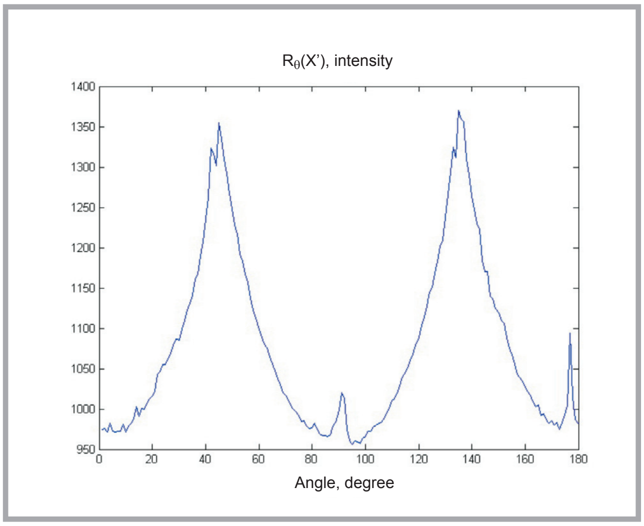

Figure 2. *Plot of the high intensity raw of the Radon transformation matrix of the hot histogram.*

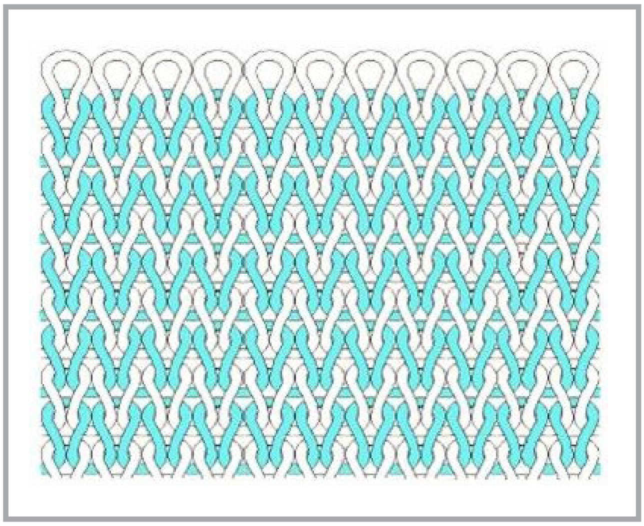

Figure 3. *Model of stitches in an ideal knit structure.*

Table 3. Results of the actual irregularity index (Ia) for plain knitted fabrics in each relaxed state.

Yarn type	Yarn count, tex	I_a													
		Dry	CV%	Wet	CV%	Washing	CV%	Ultrasonic	CV%	Chemical	CV%	Detergent /Washing	CV%	Ultrasonic /Chemical	CV%
Cotton	30	11.47	2.4	10.08	1.2	6.58	0.7	0.77	3.6	3.38	4.2	1.13	3.4	0.05	1.7
	20	12.40	3.1	11.46	1.1	8.73	2.4	2.61	3.3	3.78	5.0	1.51	2.9	0.40	0.9
Polyester /cotton (65/35)	30	9.20	3.6	6.62	3.0	5.35	3.1	1.50	1.7	2.25	1.4	1.12	3.3	0.39	2.3
	20	11.01	5.1	9.26	2.6	6.91	3.4	2.23	4.0	3.37	2.3	1.22	1.5	0.86	1.9
Polyester / viscose (65%/35)	30	7.81	0.9	5.44	4.4	2.62	1.6	0.91	2.3	0.87	3.7	0.38	2.0	0.62	1.4
	20	9.83	0.4	8.74	1.4	6.20	4.1	2.22	1.9	2.62	2.2	2.22	2.2	0.78	2.7

Table 4. Results of the Radon irregularity index (Ir) for plain knitted fabrics in each relaxed state.

Yarn type	Yarn count, tex	I_r													
		Dry	CV%	Wet	CV%	Washing	CV%	Ultrasonic	CV%	Chemical	CV%	Detergent /Washing	CV%	Ultrasonic /Chemical	CV%
Cotton	30	10.09	4.2	9.17	3.4	5.50	2.2	0.91	0.8	5.13	5.1	1.20	2.4	0.73	1.7
	20	15.59	2.3	11.92	6.0	6.78	4.3	5.50	1.1	6.60	5.6	2.75	2.0	1.10	3.1
Polyester /cotton (65/35)	30	8.25	3.0	8.25	4.1	4.58	2.6	0.91	1.6	3.11	3.3	2.01	3.5	0.73	2.2
	20	9.17	3.4	8.99	3.5	6.42	2.8	4.58	2.4	6.42	2.7	3.30	1.8	0.91	0.7
Polyester / viscose (65%/35)	30	7.33	1.5	4.58	2.7	3.11	1.9	0.73	1.7	0.91	2.8	0.73	1.9	0.55	4.1
	20	8.62	1.8	8.25	1.4	8.07	4.5	3.66	2.6	4.58	4.2	2.56	2.4	0.91	3.2

Equation 6. The results again showed good agreement between the image analysis method and the manual method (The result of the correlation test showed that the correlation is significant at a level of 0.01). Therefore, because of its simplicity and accuracy, the computer vision method is acceptable for inspecting the stitch shape irregularity of weft-knitted fabrics.

Statistical analysis using the ANOVA test showed that the type of yarn and relaxation regime, together and alone, affected fabric regularity and fabric dimensional parameters. To compare the mean of the I_r-value of the different yarn types and relaxation treatments, Duncan's multiple range tests were performed. The results for the fabric irregularity index in ***Table 4*** confirmed that yarn type has a major effect on fabric regularity, which must be due to the reaction of the yarn to the internal stresses of the fabric and to the different frictional behaviour of the different yarn. According to the results in this table, the weft-knitted fabric samples of cotton showed a greater irregularity index in comparison to the samples of knitted fabrics from polyester blended yarn. Moreover the knitted fabric samples of polyester/viscose yarn have a better regularity than the knitted fabric samples of polyester/cotton yarn, which must be due to the more uniform structure of yarns produced from synthetic fibres than that of natural ones.

Furthermore the results in ***Table 4*** show that by improving the performance of the relaxation treatment, the fabric irregularity index decreases. The forces imposed on the yarn during the knitting process and stitch formation cause some non-uniformity in the stitch shape. By releasing the stitches from theses extra forces, the relaxation treatment makes the stitch shape closer to a fixed geometrical and uniform one. Stitch shape uniformity can be increased by improving the relaxation treatment with respect to overcoming the extra forces on the stitch. The results obtained confirm that in a fully relaxed state, the stitch takes a shape closer to the ideal [3]. The results shown in ***Tables 3*** and ***4*** show the minimum values of the irregularity index of the weft-knitted fabric samples subjected to ultrasonic-chemical relaxation treatment.

In general, ultrasonic cleaning consists of immersing a part in a suitable liquid medium, agitating or sonicating that medium with high-frequency (18 to 120 kHz) sound for a brief interval of time (usually a few minutes), rinsing with clean solvent or water, and drying. The mechanism underlying this process is one in which microscopic bubbles in the liquid medium implode or collapse under the pressure of agitation to produce shock waves, which impinge on the surface of the part and, through a scrubbing action, displace or loosen particulate matter from that surface. The process by which these bubbles collapse or implode is known as cavitations. The intensity with which cavitations take place in a liquid medium varies greatly with the colligate properties of that medium, which include vapour pressure, surface tension, viscosity and density, as well as any other property that is related to the number of atoms, ions, or molecules in the medium. In ultrasonic cleaning applications, the surface tension and vapour pressure characteristics of the cleaning fluid play the most significant roles in determining cavitation intensity and, hence, cleaning effectiveness. The energy required to form a cavitation bubble in a liquid is proportional to both the surface tension and vapour pressure; thus, the higher the surface tension of a liquid, the greater the energy required to produce a cavitation bubble, and, consequently, the greater the shock-wave energy produced when the bubble collapses, which is produced with facility when a surface-active agent is added to the liquid. In the same manner, when the vapour pressure of a liquid is low, as is the case with cold water, cavitations are difficult to produce, becoming less and less so as the temperature is increased. In the ultrasonic-chemical relaxation method, the role of three factors: bubble formation and collapse (cavitation), heat and detergent allow knitted samples to release more extra forces than other relaxation regimes. In fact, the effect of the heat increase and detergent on the colligative properties of the water and cavitation intensity, therefore, lead to a more stable stitch shape and knitted structure after ultrasonic-chemical relaxation treatment than after the conventional ultrasonic method. Therefore, we can state that by using ultrasonic-chemical relaxation treatment, a more uniform plain knitted structure will be obtained.

In the next stage, the effectiveness of various relaxation processes for the dimensional properties of plain knitted fabrics produced from different yarn types was considered. In this stage too, the statistical analysis using the ANOVA test showed that the type of yarn and relaxation regime, together and alone, affected fabric dimensional parameters. To compare the mean of the K_S-value of different yarn types and relaxation treatments, Duncan's multiple range tests were performed again.

The results in ***Table 1*** show that the means of the K_S-values of knitted fabrics subjected to wet relaxation treatment are greater than dry ones. It is clear that knitted fabrics will be more free from tensions after wet relaxation than after dry relaxation. In particular, in hydrophilic yarns like cotton and viscose, molecules of water lead to decreasing intermolecular forces in these chains by destroying hydrogen bonds between cellulose molecular chains; moreover, these chains can easily decrease tensions in the knitting and fabrication of textiles; however, it makes the fabric relax, and the K_S-value, increases. The result in ***Table 1*** confirms that washing relaxation treatment leads to a higher increase in K_S-values than for tow prior regimes. In washing relaxation treatment, tumble drying causes a higher shrinkage than in a wet relaxed state. It would appear that this method of fabric drying tends to cause more dimensional changes in the fabric due to a combination of constant slow agitation and temperature. This mixture forces the structures to take up their minimum energy state, which causes the most dimensional changes in the loop shape [7]. However, the mean of K_S-values after these finishing treatments is still less than 24.00. The results for K_S-values in ***Table 1*** indicate that ultrasonic relaxation treatment is more effective for the shrinkage of all the knitted fabric samples than pervious relaxation methods. In this relaxed state, the average K_S-values are higher than 24.00. As mentioned above, the nature of the cavitation phenomenon in ultrasonic relaxation treatment causes more shrinkage in knitted fabrics than other mechanical stabilisation regimes. Therefore, we can declare that ultrasonic relaxation treatment is more effective for fabric stabilisation in comparison to common mechanical relaxation methods; however, the average K_S-values after this treatment is still smaller than the theoretical value derived from the ideal stitch shape [3]. It can be concluded that a more effective relaxation method should be found for weft-knitted fabrics to raise the practical K_S-value.

However, the performance of the chemical relaxation process varies with different yarn types. Chemical treatment caused higher shrinkage in weft-knitted fabric samples of polyester blended yarns than in 100% cotton ones. In chemical relaxation treatment, detergent helps water molecules to enter the textile easily because of the reduction in surface tension. The surface tension of a liquid is defined as the energy required to break through the surface. Liquids in which there are strong molecular interactions, such as water, typically have high surface tension. Surface tension accounts for the spherical shape of liquid drops. The surface molecules of a liquid are pulled sideways, but attractions from underneath also pull them down into the liquid. This pulling of surface molecules into the liquid causes the surface to contract and become as small as possible. The surface tension of water is dramatically reduced by the addition of detergent. Detergent molecules tend to aggregate at the surface of the water, where their non-polar tails stick out away from the water. At the surface, these molecules interfere with the dipole-dipole interactions among water molecules, thereby reducing surface tension. Moreover, it is clear that textile humidity depends on the easy entering of water molecules into the textile and on preparing the textile for accepting water molecules. The second factor can be achieved by increasing the temperature up to 50 °C. Increasing the temperature provides larger pores for water molecules, and hence the breakage of internal bonds could be easier; moreover, at a higher temperature the absorbance of water molecules could be faster. However, in the knitted fabric samples produced from 100% cotton yarns, detergent caused more yarn bulking and also damage to the fibres; therefore, the K_S-value decreased. According to the results shown in ***Table 1***, for polyester blended knitted fabrics, chemical treatment was more effective with respect to fabric shrinkage than the washing relaxation process, leading to a greater K_S-value than washing treatment. However, there is no significance difference between ultrasonic and chemical relaxation treatment for these knitted fabric samples.

In the next attempt, to combine the efficacy of laundering and chemical treatment, all the knitted fabric samples were subjected to the detergent-washing relaxation process. The results in ***Table 1*** show that detergent-washing treatment leads to further shrinkage for all samples compared to that after the common washing method; however, there is not any significance change in the K_S-value for cotton knitted fabrics compared to that in a ultrasound relaxed state. Moreover, polyester blended knitted fabrics, after detergent-washing treatment are the same as after the ultrasonic or chemical relaxation processes. Therefore detergent-washing relaxation treatment cannot be a more advanced relaxation method than other conventional relaxation methods. The results in ***Table 1*** indicate that ultrasonic-chemical relaxation treatment gives the highest value of the constant dimensional parameter (K_S) for the all fabrics. As mentioned above, in this state the influence of three factors: the cavitation, heat and detergent tend to produce the most shrinkage in all the knitted fabrics in comparison to the methods above. The average K_S-value after ultrasonic-chemical relaxation treatment is higher than those reported by pervious workers and closer to the ideal K_S-value [3]. Therefore, we can conclude that the ultrasonic-chemical relaxation method is more effective relaxation treatment with respect to the stitch shape regularity and dimensional stability of weft-knitted fabrics than common relaxation treatments or the ultrasound relaxation method.

Conclusion

In the present research we determined a more suitable relaxation method of determining the stitch shape uniformity and dimensional properties of plain weft-knitted fabrics. For this aim, different plain knitted fabrics were subjected to common and novel relaxation treatments. Moreover, to consider the rhythm of stitch shape enhancment during each relaxation process, the image processing technique was applied. The results show that significance changes occur in the dimensions of all the fabrics during each mechanical relaxation process; however, the chemical finishing process has more effect on the dimensional stabilisation of plain knitted fabrics produced from synthetic fibers. According to the results obtained , by using the ultrasonic-chemical relaxation process as a novel relaxation treatment, the K_S-value of all the knitted fabric samples was closer to the ideal K_S-value of the theoretical model [3]. The results also show that the most regular knitted structure is obtained after ultrasonic-chemical relaxation treatment. This process is not only a more effective finishing treatment with respect to the dimensional properties of plain knitted fabrics, but it also leads to stitch shape enhancment and knitted fabric surface regularity. Thus we propose ultrasonic-chemical relaxation treatment as a new relaxation method that is more effective with respect to knitted-fabric regularity and dimensional stability.

References

1. Munden D. L.; J. Tex. Inst., Vol. 50 (1959) pp. 448-471.
2. Knapton J. J. F., Truter E. V., Aziz A. K. M. A.; J. Text. Inst., Vol. 66, No. 12, (1975) pp. 413 - 419.
3. Semnani D., Latifi M., Hamzeh S., Jeddi A. A. A.; J. Text. Inst., Vol. 94 (2003), pp. 202–211.
4. Leaf G. A. V.; J. Appl. Phys., Vol. 9 (1958), pp. 71–72.
5. Jeddi A. A. A., Mohammadi, V., Rahimzadeh H., Honarvar F.; Fibres and Polymers., Vol. 8 (2007) pp. 408-413.
6. Jeddi A. A. A., Otaghsara M. R. T.; J. Text. Inst., Vol. 90 (1999) pp. 541-554.
7. Anand S. C., Brown K. S. M., Higgins L. G., Holmes D. A., Hall M. E. Conrad D.; AUTEX Res. J., Vol. 2 (2002) pp. 85–100.
8. Kim Soo Chang., Kang Tae Jin., Hong Kyung Hwa., Xu Bugao.; Textile Res. J., Vol. 75 (2005) pp. 474-479.
9. Furferi Rocco, Governi Lapo; J. Text. Inst., Vol. 99 (2007) pp. 57-66.
10. Ghazi Saeidi R., Latifi M., Shaikhzadeh Najar S., Ghazi Saeidi A.; Textile Res. J., Vol. 75 (2005) pp. 492-497.
11. Semnani D., Sheikhzadeh.; Textile Res. J., Vol. 79 (2009), pp. 1578-1587.
12. Canny J.; IEEE Transactions on Pattern Analysis and Machine Intelligence, Vol. 8(6) (1986) pp. 679–698.
13. Robinson E. A.; Proc. IEEE Inst. Electr. Electron Eng., Vol. 70, (1982) pp. 1039–1053.

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