Indian Journal of Fibre & Textile Research
Vol. 39, September 2014, pp. 230-237

Dimensional parameters of 1×1 rib fabric produced on a circular bed double jersey knitting machine using ultrasonic technique

Sandip Mukherjee[1,a], Sadhan Chandra Ray[2] & S K Punj[3]

[1]Department of Fashion Design, National Institute of Fashion Technology, Kolkata 700 098, India
[2]Department of Fabric Manufacture, Institute of Jute Technology, Kolkata 700 019, India
[3]Department of Textile Technology, The Technological Institute of Textile & Sciences, Bhiwani 127 021, India

Received 9 July 2013; revised received and accepted 13 November 2013

An attempt has been made to investigate as well as to gain an insight on the non-dimensional parameters such as course constant (Uc), wale constant (Uw), stitch density constant (Us) and loop shape factor (Ur) of the knitted fabrics produced on a double jersey circular bed machine equipped with 1×1 rib gaiting using cotton, polyester/viscose, acrylic and polyester multifilament yarns. Fabric samples are prepared by varying the stitch cam setting, input tension, yarn count, etc. on a 16 gauge circular knitting machine and are subjected to relaxation treatment by using conventional technique as well as mechanical energy of ultrasonic waves for maximum shrinkage. It is observed that this new relaxation technique produces similar dimensional and non-dimensional parameters of the fabric as obtained with the conventional relaxation treatments. It is also found that the values of the four non-dimensional parameters such as Uc, Uw, Us and Ur follow a specific trend and are found comparable with the experimental values obtained by previous workers for cotton fabrics knitted in circular knitting machine. Regression analyses have been made and regression equations are generated to study the effect of loop length on courses and wales (ribs) per cm at different stages of relaxation.

Keywords: 1×1 rib fabric, Circular knitting machine, Dimensional parameters, Regression analyses, Ultrasonic waves

1 Introduction

In the early days knitting was an art, since all knitted fabrics were fashioned by hand and the end-product used to depend entirely on the skill, dexterity and artistic ability of the knitter. Recently, the knitting industry has witnessed a number of rewarding technological advances that have transformed knitting from an art, to a more efficient industrial technique. Many attempts have been made in recent years to rationalize the knitting process. In accordance to Munden[1] the dimensions of the relaxed fabrics in the weft knitted structure are solely determined by the length of the yarn in the knitted loop. Nutting[2] has shown that the wet relaxation process is irreversible, but the fabric dimensions depend upon water temperature used for relaxation and the regain of the fabrics when they are measured.

Nutting and Leaf[3] opined that in a relaxed state, a relation between courses per unit length and loop length, for structures other than plain–knitted ones, would not be in the simple form. Smirfitt[4(a)] concentrated his attention on 1×1 rib structure and performed experimental work on wool fabrics. He concluded that these fabrics in a tumble-relaxed state are described by 'K' factors analogous to those proposed by Munden[1] for single jersey fabrics. Smirfitt studied the fabrics in both these states and after being tumble dried. Smirfitt [4(b)] also investigated the effects of changes in loop length and yarn diameter on the physical properties of fabrics in wet relaxed state. Doyle[5] described the phenomenon of high extensibility of 1×1 rib fabric which arises from the rotation of the links that join the face and back loops. Nutting[6] suggested that this being so, initially most of the work done in extension will be again the torsional resistance of the yarn. A series of three non dimensional parameters was introduced by Knapton *et al*.[7(a)] to specify the dimensional properties of plain wool knitted structure. Knapton *et al*.[7(b)] also studied the dimensional properties of 1×1 rib and half-cardigan structures of knitted wool fabric and found similar behaviour to the plain structure. The effect of loop length on courses and ribs spacing was studied and several regression equations were derived at different stages of relaxation. Woolfardt and Knapton[8] statistically analysed the results revealed from their studies on dimensional behavior of tumble-relaxed wool 1×1 rib structures and found that it is similar to plain knitted structure. Jeddi and Zarien[9] introduced a

[a]Corresponding author.
E-mail: sandip_m1995@ rediffmail.com

series of non dimensional parameters Uc, Uw and Us to specify the dimensional properties of the structure. They introduced the new technique of ultrasonic waves to obtain full relaxation of the circular bed knitted fabrics using cotton yarn. By using this technique, it is observed that the U-values achieved in this method are higher than reported experimentally by previous workers. It is also reported that yarns with elastomeric components[10] increase tightness factors which have a significant effect on dimensional behavior, giving better dimensional stability to knitted fabrics. The study on the effect of resin finish[11] on the dimensional stability of cotton knitted fabrics showed that resin finishing can effectively stabilize the change in dimensional stability. Mukherjee *et al*.[14] studied the dimensional parameters of 1×1 rib fabrics produced on a flat bed double jersey knitted fabric using ultrasonic technique and acrylic yarn. It is observed that this new relaxation technique produces similar dimensional and non-dimensional parameters of the fabric as obtained with the conventional relaxation treatments. The values of the four non-dimensional parameters such as Uc, Uw, Us and Ur follow a specific trend and these values are found to be comparable with the experimental values obtained for fabrics knitted in circular knitting machine.

As the determination of loop length and dimensional parameters are of prime importance in defining the end use of the knitted fabrics, the present study is the continuation of the earlier studies in this field. So the objectives of the present research work is to establish the dimensional constants of 1×1 rib knitted fabric on a circular bed knitting machine, to investigate the relationship amongst the different knitted fabric parameters. For the purpose, principle of ultrasonic wave, the latest technology for knitted fabric relaxation, has been incorporated to obtain fully relaxed fabric. The study has been extended not only for cotton rib knitted fabric but also for fabrics made of acrylic, polyester/viscose and polyester multifilament by varying different input parameters and to study the effect of loop length on courses and wales spacing at different stages of relaxation which is not reported earlier.

2 Materials and Methods

In order to study the dimensional properties of double jersey fabrics, thirty 1×1 rib fabric samples were made on a circular bed double jersey knitting machine having 1×1 rib gaiting. Cotton (20, 24 and 30 tex), polyester/viscose or P/V (20tex), acrylic (20 tex) and polyester or PET multifilament yarns (18 tex) were used to prepare the fabric samples. The fabric samples were subjected to dry relaxation, wet relaxation and ultrasonic treatment for full relaxation. The fabric samples under different states of relaxation were analysed.

2.1 Testing of Yarn Parameters

Yarn count, tensile properties and unevenness of the test samples were measured as per the specifications described in our earlier paper[14] . The test results are shown in Table 1.

2.2 Preparation of Fabric Samples

The fabrics were knitted on the circular interlock knitting machine [Make: Knitting & Textile Machinery Works, Tirupur, India] using the gauge 16, diameter 30cm and positive feed. One set of needles (short needles) was removed from both the beds in order to get 1×1 rib gaiting and as a result, the gauge of the machine was converted to 8. Thirty (30) samples were prepared on the circular bed machine.

2.3 Total Combination of Input Parameters

Total thirty fabric samples were produced on a circular bed machine by varying the input parameters like stitch cam setting, input tension and yarn. The yarn input tension was kept at three different levels. In each case, the tension was measured by a Digital Tensiometer. The cylinder stitch cam settings were also kept at three different levels, keeping the dial stitch cam setting constant. The combinations of these

Table 1—Yarn testing results

Yarn	Count, tex	Breaking load, N	% Strain	Tenacity, cN/tex	U %	CV%	Hairiness index
Cotton	24	3.19	4.30	13.52	10.47	13.32	5.88
Cotton	20	4.68	9.34	23.83	11.12	14.09	5.07
Cotton	20	2.24	4.12	10.69	11.16	14.17	6.84
P/V	30	3.59	4.77	11.92	11.65	14.78	4.59
Acrylic	20	2.91	17.03	14.65	11.92	15.26	7.39
PET multifilament	18	6.35	21.08	36.22	1.86	2.25	7.35

parameters for all the fabric samples are shown in Table 2.

2.4 Relaxation Treatments

Knitted fabrics are similar to woven fabrics in that they are subject to relaxation shrinkage. However, it has been found difficult experimentally to determine when a fabric has reached a totally relaxed state in which it is in a stable state with the minimum energy. The fabric samples were subjected to the following relaxation treatments:

(i) Dry relaxation treatment—This is the condition reached by the fabric after a sufficient period of time subsequent to being removed from the knitting machine. Fabric samples were placed on a flat surface at room conditions for 24 h.

(ii) Wet relaxation treatment—This is achieved by a static soak in water and flat drying of fabric. Fabric samples were immersed in water for 24 h followed by gentle rinsing and drying at room conditions on a flat surface for 24 h.

(iii) Ultrasonic treatment—Fabric samples were subjected to ultrasonic treatment for full relaxation. The specifications of the ultrasonic cleaner used and the conditions maintained for the present experiment are: brand –PCI, model –3.5 L100H, capacity –3 L, frequency –33 kHz, water temperature –50°C, and relaxation time period –15 min. Fabric samples were placed in the ultrasonic cleaning bath containing 3 L of water and then 0.5g/L of non-ionic detergent was added in the bath before placing the fabric. Relaxation treatment was carried out for 15 min at 50°C. The fabric samples were then taken out, rinsed and dried at room conditions for 24 h. The relaxation treatment was repeated three times for every fabric sample. The first, second and third relaxation treatments are termed as Ultrasonic 1 (US-1), Ultrasonic 2 (US-2) and Ultrasonic 3 (US-3) states respectively.

Table 2—Input parameters for knitting of fabric samples

Fabric code	Yarn count tex	Yarn type	Cylinder cam setting mm	Dial cam setting mm	Input tension g
A1	24	Cotton	2.46	0.89	8
B1	20	P/V	2.46	0.89	8
C1	20	Cotton	2.46	0.89	8
D1	30	Cotton	2.46	0.89	8
E1	20	Acrylic	2.46	0.89	8
F1	18	PET filament	2.46	0.89	8
A2	24	Cotton	2.46	0.89	5
B2	20	P/V	2.46	0.89	5
C2	20	Cotton	2.46	0.89	5
D2	30	Cotton	2.46	0.89	5
E2	20	Acrylic	2.46	0.89	5
F2	18	PET filament	2.46	0.89	5
A3	24	Cotton	2.46	0.89	12
B3	20	P/V	2.46	0.89	12
C3	20	Cotton	2.46	0.89	12
D3	30	Cotton	2.46	0.89	12
E3	20	Acrylic	2.46	0.89	12
F3	18	PET filament	2.46	0.89	12
A4	24	Cotton	1.60	0.89	8
B4	20	P/V	1.60	0.89	8
C4	20	Cotton	1.60	0.89	8
D4	30	Cotton	1.60	0.89	8
E4	20	Acrylic	1.60	0.89	8
F4	18	PET filament	1.60	0.89	8
A5	24	Cotton	2.06	0.89	8
B5	20	P/V	2.06	0.89	8
C5	20	Cotton	2.06	0.89	8
D5	30	Cotton	2.06	0.89	8
E5	20	Acrylic	2.06	0.89	8
F5	18	PET filament	2.06	0.89	8

2.5 Method of Fabric Analyses

In the present study, the dimensional parameters like courses per cm (c), wales or ribs per cm (w), loop length (L) in mm, length and width of the fabric samples were measured in the standard atmospheric conditions. The experimental details for these fabric properties are given below:

(i) Courses and wales (ribs) per cm —Ten readings were randomly taken from the fabric samples at different stages of relaxation to calculate courses and wales (ribs) per cm.

(ii) Stitch density —Stitch density was calculated from the product of courses and wales (ribs) per cm for all the samples at all different relaxation stages.

(iii) Loop length —Eighty needles were selected to prepare the samples. To measure the loop length the full course comprising 80 loops was unraveled from the fabric sample. One end of the yarn was fixed on a support by means of a cello tape and a load of 0.5 g/tex was applied at the other end to remove the crimp of the yarn or in other words to straighten the same. The length of the yarn was measured thereafter by means of a measuring tape. Twenty such observations were performed and the average value of the reading was calculated. The loop length was calculated using the following formula:

Loop length (L) = Uncrimped length of the yarn making 80 loops / 80.

3 Results and Discussion

3.1 Knitting Constants

It is established that courses per cm (c), wales per cm (w) and loop length (L) are related to each other by dimensionless constants (U-values). Four non-dimensional parameters, namely Uc, Uw, Us and Ur are used to specify the dimensional properties of double jersey knitted structures. Uc and Uw are dimensionless parameters called course constant and wale constant, whose values are fairly constant for each state of relaxation. Ur is the ratio Uc/Uw, a direct measure of the loop shape called the loop shape factor. Us is termed as stitch density constant which is the product of Uc and Uw.

In the present research work, the values of these dimensionless knitting constants (U-values) were obtained for 1×1 rib fabrics produced on circular bed knitting machine at different stages of relaxation treatments such as dry, wet and ultrasonic and then subjected to statistical analyses for getting insight of the dimensional properties of the fabrics. The average numerical values of these parameters were calculated and compared with the values obtained by previous workers in this field.

The mean values of Uc, Uw, Us and Ur of 30 different fabric samples produced with different combination of input parameters at different stages of relaxation are shown in the Table 3.

The mean U values in the fully relaxed state obtained in the present research work have been compared with the earlier findings as shown in the Table 4. It is found that the values obtained in the present research are very much similar to that of the study reported earlier[9,14]. The range of average values of the constants for confidence interval at 95% level are also calculated and it is observed that almost all the values are within the range, suggesting that the U-values for different fabrics irrespective of relaxation stages are constant, supporting the work of previous researchers[9,14]. It is observed that the Uc and Us values gradually increase from dry relaxed state and reaches the maximum when the fabric samples are subjected to ultrasonic treatment. This signifies that the shrinkage of the fabric is higher when it is subjected to ultrasonic treatment as compared to wet relaxation.

It is observed that the value of Uc gradually increases from 8.55 in the dry relaxed condition to 9.28 in wet relaxed condition and ultimately to 10.13 at fully relaxed state where it is subjected to three consecutive ultrasonic treatments. This signifies that on subsequent relaxation process the fabric undergoes progressive length-wise shrinkage, resulting in gradual decrease in the course spacing. It is established that the loop length remains almost constant irrespective of the relaxation treatments, thus the value of Uc gradually increases with subsequent stages of relaxation. The variation in Uw values is not very significant when the fabrics are subjected to different relaxation stages. It is also observed that the value of Us changes from 65.84 in the dry relaxed condition to 69.23 in wet relaxed condition. After the first ultrasonic treatment it increases to 70.55 and ultimately stabilizes to 69.33 at fully relaxed state due to three consecutive ultrasonic treatments. It is observed that the value of Ur marginally increases from 1.12 in the dry relaxed condition to 1.25 in wet relaxed condition. Thereafter, it increases to 1.50 at fully relaxed state due to three consecutive ultrasonic treatments. The change in the Ur value suggests that there is a significant effect on the shape of the loop which changes as the fabrics are subjected to various relaxation treatments. Due to the ultrasonic treatment the increase in shrinkage of the fabric is owing to the fact that the energy in fabric reaches its lowest degree. It can be said that the use of vibrations of the ultrasonic waves obviously results in permitting more inter-yarn and inter-fibre slippage and thus facilitates

Table 3—Mean values of dimensional constants of knitted fabric samples at different stages of relaxation

Parameter	Dry	Wet	US-1	US-2	US-3
Uc	8.55	9.28	9.80	10.03	10.13
Uw	7.72	7.46	7.21	6.87	6.85
Us	65.84	69.23	70.55	68.77	69.33
Ur	1.12	1.25	1.37	1.47	1.50

Table 4—Comparison of U values for 1×1 rib structures in fully relaxed state

Sample	Us	Uc	Uw	Ref.
100% Wool	66.00	10.60	6.28	4
100% Wool	67.60	10.70	6.32	12
100% Wool	63.70	10.60	6.03	7
100% Wool	62.70	10.70	5.85	8
100% Wool	63.80	11.10	5.76	7
100% Cotton	61.20	10.20	6.00	13
100% Cotton – ultrasonic waves treatment	67.22	10.34	6.53	9
100% Acrylic – ultrasonic treatment	69.40	10.40	6.67	14
100% Cotton, P/V, acrylic & PET multifilament (average value) – ultrasonic waves	69.33	10.13	6.85	Present work

the attainment of minimum energy state. It removes the internal forces exerted during knitting operations and decreases the potential energy of the fabrics. Therefore, this treatment is not only a new and advanced technique in the relaxation process of knitted fabric, but it requires less energy, time, water and detergents. This is more useful with a view to environmental protection as compared with traditional relaxation methods which has also been reported in earlier work for 1×1 knitted fabric produced in flat bed machines[14].

The U-values of the knitted fabric samples for five different stages of relaxation treatments are subjected to ANOVA analyses (Table 5).

From the analyses, p-values and F-critical values are obtained. The p- values in case of Uc, Uw and Ur are less than 0.05, indicating that there are significant differences at different stages of relaxation. The p-value is the probability level at which the null hypothesis, means equality of averages, is just rejected. If the p-value is less than 0.05 there is sufficient scope of difference of the average values, therefore the significant difference exists among the average or the mean values at 5% level or it is accepted at 95% confidence limit. To identify the significant differences, the least significant difference (lsd) or critical difference (cd) value at 5% level of significance is also calculated.

3.2 Effect of Loop Length on Courses and Wales (Ribs) Spacings

In order to find the best regression between courses per cm (c) and loop length (L) in mm, at different stages of relaxation, the values of 1/courses per cm is plotted against loop length using MINITAB software. The regression equations between courses per cm (c) and loop length (L) at different stages of relaxation are shown in the Table 6.

The relationships between c and 1/L as well as between 1/c and L or the numerical regression equations with and without intercept at different stages of relaxation are obtained and shown in Table 6. In accordance to Woolfardt and Knapton[8] the regression analyses between courses per cm and

Table 5—ANOVA (single factor analyses) for dimensional constants values at different stages of relaxation

Source of variation	SS	df	MS	F	P-value	F critical
			Uc Value			
Between groups	37.33829867	2	18.66915	72.0930695	3.44E-19	3.101296
Within groups	22.52943317	87	0.258959			
Total	59.86773184	89				
			Uw Value			
Between groups	11.9188531	2	5.959427	12.5777069	1.59E-05	3.101296
Within groups	41.221354	87	0.473809			
Total	53.1402071	89				
			Us Value			
Between groups	236.8332665	2	118.4166	2.91255638	0.059654	3.101296
Within groups	3537.18375	87	40.65728			
Total	3774.017017	89				
			Ur Value			
Between groups	2.197886149	2	1.098943	42.967783	1.05E-13	3.101296
Within groups	2.225110089	87	0.025576			
Total	4.422996239	89				

Table 6—Regression equations between courses per cm (c) and loop length (L) in mm at different stages of relaxation

Relaxation stages	c and 1/L		1/c and L	
	With intercept	Without intercept	With intercept	Without intercept
DR	c= -3.96+119/L	c= 85.8/L	1/c= -0.0528+0.0180*L	1/c= 0.0117*L
WR	c=-3.05+119/L	c= 93.0/L	1/c= -0.0187+0.0130*	1/c= 0.0180*L
US-3	c=-2.95+126/L	c= 102.0 /L	1/c= -0.0328+0.0138*L	1/c= 0.0099*L

1/loop length was also explored. Although this relation is very much similar with the relation given by Knapton in his research findings, in the present case the relation between 1/c and L is more significant due to low value of standard error obtained as compared to the relation between c and 1/L.

The observed (O) and expected (E) values of 1/c against the loop length at three different stages of relaxation i.e. dry, wet, and ultrasonic, are plotted and the nature of the curves is shown in Fig. 1 for dry and ultrasonic state. The observed values of 1/c (O) are the actual values obtained from the experiment and the expected values of 1/c (E) are the theoretical values obtained from the regression equation. The trend is similar for wet relaxation also. From the above figures, it is clearly visible that both the curves are very near to each other which justifies that the relationship between 1/c and L under different stages of relaxation has been derived very accurately and hence can predict the desired value which is not covered under the experiment.

The regression analyses for the relationship between c and 1/L as well as 1/c and L at different stages of relaxations are made and the values of correlation coefficient R, R^2 and adjusted R^2 with significant intercepts are obtained. For significance test the p-values are also calculated. In all the cases it is observed from the value of correlation coefficient R, R^2 and adjusted R^2 that the relationship is highly significant by plotting c against 1/L. But in the present research work the most significant regression equations obtained at different stages of relaxation by plotting 1/c against L with similar values of correlation coefficient R ranging from 0.9973-0.9978, R^2 ranging from 0.9947-0.9957 and adjusted R^2 ranging from 0.9620- 0.9630, have a very small value of standard error of 0.0056- 0.0073 which is much less than the previous relations.

Similarly in order to find the best regression between wales per cm (w) and loop length (L) in mm at different stages of relaxation, the values of 1/wales per cm is plotted against loop length using MINITAB software. The regression equations between wales per cm (w) and loop length (L) at different stages of relaxation are shown in the Table 7.

The relation between w and 1/L as well as that between 1/w and L or the numerical regression equations with and without intercept at different stages of relaxation are obtained. In accordance to Woolfardt and Knapton[8], the regression analyses between wales per cm and 1/loop length are also explored. Although this relation is very much similar with that given by Knapton in his research findings, but in the present case the relation between 1/w and L is more significant due to low value of standard error obtained as compared to the relation between w and 1/L.

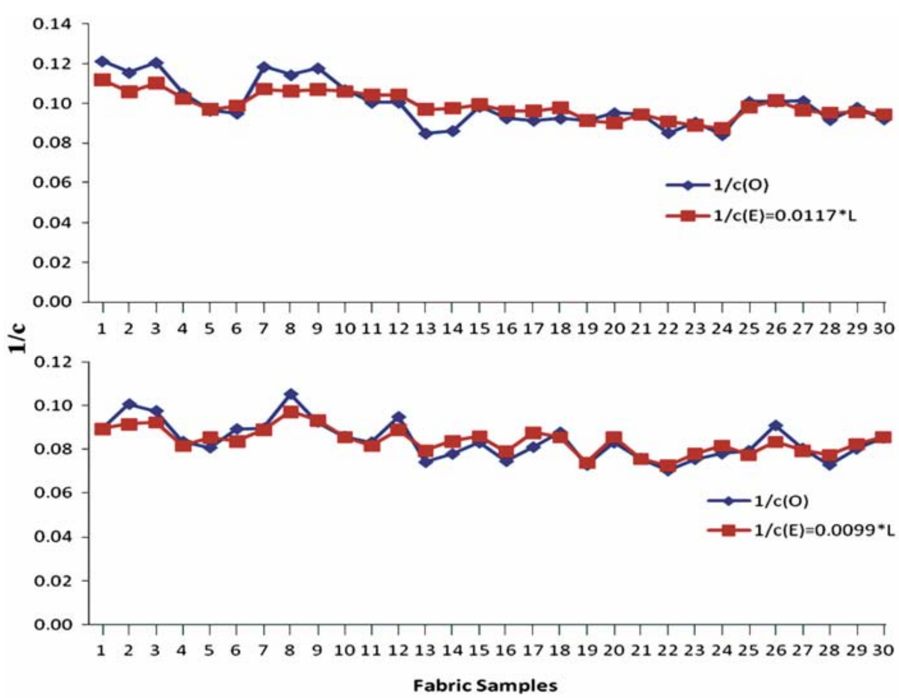

Fig. 1—Trends showing observed & expected values of 1/c of fabric samples in dry and ultrasonic state

Table 7—Regression equations between wales per cm (w) and loop length (L) in mm at different stages of relaxation

Relaxation stages	w and 1/L		1/w and L	
	With intercept	Without intercept	With intercept	Without intercept
DR	w= 7.85+10.8/L	w= 76.7/L	1/w= 0.0889+0.0025*L	1/w= 0.0132*L
WR	w= 6.28+21.7/L	w= 74.2/L	1/w= 0.0775+0.0042*L	1/w= 0.0133*L
US-3	w= 7.10+8.5/L	w= 68.0/L	1/w= 0.1070+0.0020*L	1/w= 0.0146*L

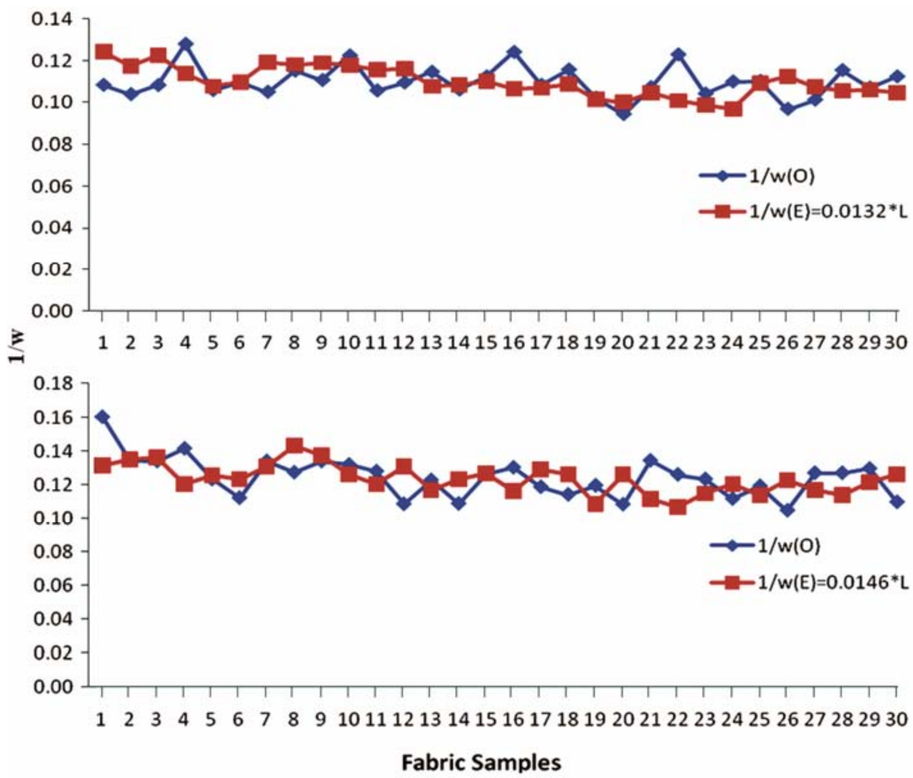

Fig. 2—Trends showing observed & expected values of 1/w of fabric samples in dry and ultrasonic state

The observed (O) and expected (E) values of 1/w against the loop length at three different stages of relaxation (dry, wet and ultrasonic) are plotted and the nature of the curves are shown in Fig. 2 for dry and ultrasonic state. The trend is also similar for wet relaxation state. From the above figures, it is clearly visible that both the curves are very near to each other which justifies that the relationship between 1/w and L under different stages of relaxation has been derived very accurately and hence the derived relationship can predict the desired value which is not covered under the experiment.

The regression analyses for the relationship between w and 1/L as well that between as 1/w and L at different stages of relaxations are made and the values of correlation coefficient R, R^2 and adjusted R^2 with significant intercepts are obtained. For significance test the p-values are also calculated. In all the cases it is observed from the value of correlation coefficient R, R^2 and adjusted R^2 that the relationship is highly significant by plotting w against 1/L. But in the present research work, the most significant regression equations obtained at different stages of relaxation by plotting 1/w against L with similar values of correlation coefficient R ranging from 0.9938 to 0.9960, R^2 ranging from 0.9877 to 0.9920 and adjusted R^2 ranging from 0.9530 to 0.9590, have a very small value of standard error ranging from 0.0076 to 0.0139 which is much less than the previous relations.

4 Conclusion

The values of dimensionless knitting constants such as course constant (Uc), wale constant (Uw), stitch density constant (Us) and loop shape factor (Ur), obtained in 30 fabric samples made from cotton, P/V, acrylic and PET multifilament yarn on circular bed double jersey machine by varying different input parameters, do not show much variations and there is no significant difference between the values at 95% confidence limit. These values obtained in the study are also in line with the findings of the previous works in this field. The values of Uc, Us and Ur increase progressively from dry relaxed state to wet relaxed state and ultimately reach to a stable maximum value at fully relaxed state due to three consecutive ultrasonic treatments. This signifies that on subsequent relaxation process the fabric undergoes progressive length-wise shrinkage, resulting in gradual decrease in the course spacing. There is a decreasing trend in the value of Uw signifying a nominal width wise extension, resulting in a minor increase in wale spacing. It is also observed that the loop length remains almost constant irrespective of the relaxation treatments as already reported in the literature. Thus, from the experimental results it can be concluded that the ultrasonic wave treatment is a suitable and advanced technique for better dimensional stability of 1×1 rib knitted fabrics. The effect of loop length (L) on courses and wales (ribs) per cm at different stages of relaxation has also been studied. The best fitted linear regression equations between 1/c or 1/w and L have been derived in the case of circular knitted fabrics. The results of these equations have very small standard error as compared to the regression equations derived in earlier studies between c or w and 1/L. The intercepts of the regression equations in the dry relaxed state are visible and are of negative sign and their magnitudes are considerably larger, following a decreasing trend and the values are least when the fabric samples are subjected to ultrasonic treatments. It can only be explained that the intercepts are the results of changes in processing variables during knitting such as take down load, knitting tensions and yarn frictional characteristics governing the magnitude and sign of the intercepts and not due to the effects of yarn diameter.

References

1 Munden D L, *J Text Inst*, 50 (1959) T448.
2 Nutting T S, *J Text Inst*, 52 (1961) T-407.
3 Nutting T & Leaf G A V, *J Text Inst*, 55 (1964) T45.
4 Smirfitt J A, *J Text Inst*, 56 (1965) T248 (a) and T298 (b).
5 Doyle P J, *J Text Inst*, 44 (1953) P561.
6 Nutting T S, *J Text Inst*, 49 (1958) P-490.
7 Knapton J J F, Ahrens F J, Ingenthron W W & Frong, *Text Res J*, 38 (1968) 999(a) and 1013(b).
8 Woolfardt C & Knapton, J J F, *J Text Inst*, 62 (1971)561.
9 Jeddi A A A & Zareian A, *J Text Inst*, 97(6) (2006)P475.
10 Chathura N Herath, *Text Res J*, 78 (3) (2008)P-209.
11 Waisza L, *J Text Inst*, 100 (6) (2009)P-530.
12 Natkanski K B, *The Geometry and Dimensional Properties of 1×1 Rib structures*, Ph.D. Thesis, University of Leeds, 1967.
13 Poole Hardy B & Brown Peter, *Text Res J*, 48 (1978)P-371.
14 Mukherjee S, Ray S C & Punj S K, *Indian J Fibre Text Res*, 37 (2012) P-60-67.