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Study on Geometric and Dimensional Properties of Double Pique Knitted Fabrics Using Cotton Sheath Elastomeric Core Spun Yarn

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ABSTRACT

The present study was done on the influence of various loop length variables and subsequent tightness factors on geometric and dimensional properties of knitted fabrics produced from cotton sheath elastomeric core spun yarn. Cotton sheath elastomeric core spun yarn was knitted into one of the single jersey derivative structures called double pique or thick pique with three different loop length variables to obtain equal number of variables in tightness factor. The results show that the changes in loop length and corresponding tightness factor have significant impact on knit fabric geometric properties except wale density measured in terms of wales per inch at all the relaxation states. The changes in the wale density values among the samples with different tightness factors at same or different relaxation states may be the effect of widthwise shrinkage and growth of the samples. The results have clearly depicted that the changes in loop length do not play any role in the wale density of the samples knitted. All the double pique fabric samples have attained their dimensionally stable state perfectly after the fourth washing and drying cycle and the same trend is noticed after the fifth wash also. The sample knitted with the smallest loop length and highest tightness factor has reached its width wise dimensionally equilibrium state in the first wash itself. In all the samples, the contraction in length and growth in width was noticed uniformly after every washing and drying cycle.

Keywords: Cotton sheath elastomeric core spun yarn, Loop length, Double Pique, Geometric and Dimensional properties

1. Introduction

Dimensional instability of circular weft knitted fabrics which is a major concern in view of knit fabric quality assurance and it is very much influenced by loop length and its allied geometric properties mainly and also due to progressive relaxation states. Doyle[1] (1953) suggested that the knitted loop and the length of yarn knitted into the stitch in particular, is an important parameter for the measurement of knitted fabric quality. The most convenient means of assessing the knitting performance of a spun yarn is by the use of “tightness factor” concept. Munden[2] (1962) first suggested the use of a constant factor to indicate the relative tightness or looseness of a plain knit structure. Nutting and Leaf[3] (1964) has proposed a generalized geometry of weft-knitted fabrics which introduced a term involving the yam diameter. Smirfitt[4] (1965) defined the geometry of the 1X1 rib structure and established that the tightness factor formula is identical to that of the plain knit structure. Criteria for suitable combinations of machine gauge and yarn tex could be the extent and evenness of the dispersion of possible tightness factor values around 14.5. Moon Won Suh[5] (1967) studied the shrinkage of plain knitted cotton fabric, based on the structural changes of the loop geometry due to yarn swelling and deswelling and reported that the structural change of the jersey loop upon yarn swelling is related to the amount of expected laundering shrinkage in cotton jersey fabric by introducing a three-dimensional loop model. The lengthwise shrinking is explained by the geometry of loop migration and curvature changes upon wetting and drying of the fabric. Also, width wise shrinking is explained by the relationship between wale spacing and yarn diameter. The proposed jersey model explains shrinkage phenomena and also provides a means of estimating loop length of jersey fabric on the basis of courses per inch, wales per inch, and yarn diameter. Knapton[6] et al (1968) suggested that most spun yarn single knit fabric is commercially knitted between the tightness factor range of 9 and 19. It is essentially impossible on any machine gauge or with any yarn count to knit fabric over a wider tightness factor range. A more usual knitting tightness factor range, from tight to loose fabric is 12 to 18 with a mean value of 15. They also found that approximately at the tightness factor 15, the dynamic forces required to pull a wide range of yarn counts into a knitting loop are at a low and equivalent value. Knapton[7](1979) again showed that dimensional stability in cotton plain-jersey fabrics can be attained by either mechanical relaxation techniques or chemical treatments, and that k-values are not entirely independent of the fabric tightness factor. Schulze[8] (1993) investigated the dimensional properties of single jersey, lacoste and fleecy fabrics knitted with cotton - spandex yarns and reported that the weight and loop densities of cotton/spandex fabrics were higher than cotton fabrics; also the extension, both widthwise and lengthwise, increased as the relaxation progressed. Tasmaci[9] (1996) found that variations are higher both in width wise and in weight for the spandex containing fabrics. Bayazit Marmarali[10] (2003) investigated the dimensional and physical properties of cotton/spandex single jersey fabrics and the results compared with fabrics knitted from cotton alone. They found that the loop length and amount of spandex are used to determine the dimensions and properties of the knits. Prakash and Thangamani[11] (2010) observed that the dimension of fabric showed considerable change during wet relaxation. Sadek et al[12] (2012) studied the effect of extension increase percent of bare lycra yarns during loop formation on the geometrical, physical and mechanical properties of plain jersey fabrics. Results showed a sharp increase in the courses density rather than the wales density. Kumar and Sampath[13] (2013) investigated the suitability of cotton sheath elastomeric core spun yarn for circular knitting as an alternative for bare spandex feeding and the effect of loop length variables on single jersey knitted fabric's geometric quality attributes such as wale density, course density, stitch density and areal density under different states of relaxation. They indicated that the change in loop length values do not have any significant impact on wale density values. At the same time, the remaining geometric properties of the samples were found to be inversely proportional to the loop length values uniformly at all the states of relaxation. They also investigated the ability of the samples to reach their dimensional equilibrium state after repeated cycles of washing and drying and reported that the fabric samples attained a perfect state of dimensional stability before five cycles of washing and drying, and also the sample knitted with the smallest loop length value reached its equilibrium state in a quick time.

In this research paper, studies have been done on the geometric properties of knitted fabrics produced from cotton sheath elastomeric core spun yarn. Cotton sheath elastomeric core spun yarn was knitted into a single jersey derivative structure double pique with three different tightness factor variables and their geometric and dimensional properties have been studied and compared.

2. Experimental materials and methodology

Single jersey derivative structures double pique with three different loop length variables [1] such as 0.27 cm, 0.30 cm and 0.33 cm were knitted by using 19.28 Tex cotton sheath elastomeric core spun yarn to obtain fabric samples with three different tightness factors [2,6] for the comparative study of geometric and dimensional properties [8,10,13]. The samples were produced with the help of single jersey multi track circular weft knitting machine having diameter 18 inches and machine gauge 24. Subsequently, the samples were subjected to various states of relaxation such as DRS, WRS and FRS [7,11]. After every relaxation state, the influence of stitch length on geometric properties [1,12] was observed, recorded and compared. The geometric properties studied were wale density, course density, stitch density and areal density. The dimensional stability of the samples and their potential to reach dimensionally equilibrium state were observed through five repeated cycle of washing and tumble drying [5,7,13] and the changes occurred in the fabric specifications at fully relaxed state were studied.

2.1. Production of cotton sheath elastomeric core spun yarn and its techno particulars

The yarn with spandex at the core and cotton at sheath with following technical particulars given in Table 2.1 was produced for knitting from Amsler core spun system at M/s. Peninsula Spinning Mills, Coimbatore, Tamil Nadu, India.

Table 2.1. Yarn parameters

Properties	Result
Cotton type / Yarn linear density	MCU5 / 19.28 tex
Spandex type / Linear density	Elaspan / 40 Denier
Cotton %	90
Spandex %	10
Strength	65.16 lbs.
CSP	1920
Count CV%	1.1
Strength CV %	4.47
TPI	20.52
U %	9.04
Thin (-50%)	0
Thick (+50%)	14
Neps (+200%)	40
Total imperfections per km	54

2.2. Development of grey fabric samples and first dry relaxation

The double pique samples [8] were knitted by varying the loop length [1,13] with the help of the knitting machine with specifications mentioned in Table 2.2 to obtain three corresponding fabric tightness factor values [2,6] for comparison. The knitted fabric samples were developed as per the fabric sample plan given in Table 2.3.

Table 2.2. Knitting Machine Specifications

S. No.	Machine specifications	
1.	Type of knitting machine	Circular Knitting
2.	Make	Unitech, Singapore
3.	Machine Diameter (inch)	18
4.	Gauge	24
5.	No of Feeders	54
6.	Feeder Type	Positive Storage
7.	No. of Needles	1356
8.	No. of Cam tracks	4

Table 2.3. Fabric Sample Plan

Sample code	Type of yarn	Fabric Structure	Loop length in cm	Tightness Factor (K)
DP 1	Cotton sheath elastomeric core spun yarn	Double Pique	0.27	16.4
DP 2			0.30	14.8
DP 3			0.33	13.5

Fabric tightness factor [2] was estimated by using the following formula.

$$\text{Tightness factor (K)} = \frac{(\text{Tex})^{1/2}}{\text{Loop length in cm}} \qquad (1)$$

After knitting, the grey samples were subjected to DRS I at standard atmospheric condition (25º ± 2ºC and RH 65%) for 24 hours [7]. Then the geometric properties such as wale density, course density, stitch density, areal density were measured and their respective constants such as Kw, Kc, Ks, Kc/Kw were derived for all the samples [2,12].

2.3. Heat setting and second dry relaxation

The dry relaxed fabric samples were subjected to heat setting before coloration for stabilizing the elastomeric part present in the yarn core of the fabrics [8,9,12] and the machine used for this purpose and other necessary techno particulars are given in Table 2.4.

Table 2.4. Heat setting machine specifications

Heat setting machine specifications	
Make	Ask Me, Taiwan
Machine width	3 meters
No of Chambers	1
Machine Speed	3 mpm
Temperature	180ºC to 200ºC

After heat setting, the grey samples were subjected to one more dry relaxation called DRS II at standard atmospheric condition (25º ± 2ºC and RH 65%) for 24 hours to understand the impact of heat setting process. Then the geometric properties such as wale density, course density, stitch density, areal density were measured and their respective constants such as Kw, Kc, Ks, Kc/Kw were derived for all the samples [2,12].

2.4. Wet processing and wet relaxation

The heat set knitted fabric samples were scoured and dyed in a laboratory model soft flow machine of 10 kg capacity.

The following recipe was adopted to wet and scour the samples.

(a) M: L Ratio : 1: 10
(b) Wetting agent : 0.7 %
(c) Lubricant : 0.5 %
(d) Stabilizer : 0.5 %
(e) Caustic soda : 3 %
(f) Hydrogen peroxide : 2.5 %
(g) Temperature : 95°C
(h) Time : 60 min
(i) Peroxide killer : 0.7%
(j) Acetic acid : 1.0%
(k) pH : 6.5
(l) Temperature : 80°C
(m) Time : 30 min.

The following recipe was followed for dyeing by using Reactive Hot brand dyes.

(a) M: L Ratio : 1:10
(b) Salt : 35 gpl
(c) Black B : 1.7%
(d) Blue EDG : 0.90 %
(e) Red MEABL : 0.45 %
(f) Soda ash : 20 gpl
(g) Temperature : 70°C - 80°C

The dyed knitted fabric samples were given a hot wash at 60°C for 15 minutes followed by a cold wash for 10 minutes to remove the excess colour from the surface. The washed fabric samples were hydro extracted and applied with softener to improve the surface feel.

The softened samples were laid flat for drying and at the same time subjected to wet relaxation at standard atmospheric condition (25º ± 2ºC and RH 65%) for 72 hours. Then the changes in geometric properties such as wale density, course density, stitch density, areal density were recorded once again and their respective constants such as Kw, Kc, Ks, Kc/Kw were derived for all the samples [2,11,12].

2.5. Repeated cycles of washing and tumble drying and fully relaxation:

From the each tightness of wet relaxed samples three 70 cm X 70 cm size pieces were cut. Every cut fabric sample was marked 50 cm apart lengthwise by using the shrinkage template in three adjacent positions with uniform spacing with the help of tex marker to obtain three readings for lengthwise dimensional change after a cycle of washing and drying. Similarly, they were marked widthwise also to obtain three readings for widthwise dimensional change after a cycle of washing and drying. They were subjected to repeated cycles of washing and tumble drying in a standard front loading washing machine and in a tumble drier respectively in order to bring the cotton part of the loops to their minimum energy level and into the state of equilibrium [5,7,13]. The specifications of washing machine and tumble drier used are given below in Table 2.5.

Table 2.5. Washing and tumble drying specifications

Washing and drying specifications	
Washing machine make / Load	IFB / Front
Tumble dryer make / Load	IFB maxi dry / Front
Washing time in minutes	60
Washing temperature ^{o}C	50
Washing soap	5 gpl neutral soap
Drying temperature ^{o}C	40 - 50
Drying time in minutes	10 - 20

The length wise and width wise changes in dimensions were measured in percentage with the help of a specially designed percentage scale after every washing and drying and mean value of the alike samples were estimated and noted down to understand the potential of the developed samples with different tightness factor to reach their dimensionally equilibrium state. This state is known as FRS. In this state the knitted fabric samples were brought to a dimensionally equilibrium condition [5,7].

Fabrics were once again kept on flat surface for 24 hours at standard atmosphere of 25±2^{0}C and the RH 65% to reach their FRS. After that, the changes in the geometric properties such as wale density, course density, stitch density, areal density were examined and duly recorded and their respective constants such as Kw, Kc, Ks, Kc/Kw were derived [2,7,12,13].

3. Results and Discussion

For all the developed samples, geometric properties such as loop length , course density, wale density, stitch density, areal density and tightness factor were studied after every relaxation state as per the procedure given in STARFISH technical manual [14] and the changes were noted down and tabulated for comparison.

Table 3.1. Effect of loop length on geometric properties at DRS I

Structure	Code	‘l’ in cm	WPI	CPI	Kw	Kc	S	Ks	K	Kc/Kw	GSM
Double Pique	DP 1	0.27	32	70	3.39	7.42	2240	25.15	16.4	2.19	195
	DP 2	0.30	30	60	3.54	7.06	1800	25.06	14.8	2.0	180
	DP 3	0.33	28	50	3.61	6.45	1400	23.28	13.5	1.79	160

3.1. Effect of loop length on geometric properties at DRS I

From Table 3.1, it is evident that the changes in loop length and fabric tightness have significant impact on knit fabric geometric properties after dry relaxation apart from WPI. There is a slight decrease has been found in the WPI among the samples due to the increase in loop length. But, it may because of varying relaxation behavior in width direction of the fabrics rather than the loop length. From the results, it is clear that the property wale density is not governed by variations in loop length and fabric K values. Changes in this geometric property are normally influenced to a greater extent by the machine gauge and least extent by relaxation pattern of the structure [1,2,13]. There is a prominent decrease in CPI of the samples due to the increase in loop length and vice-versa. The decrease in CPI inversely reflects in the values of stitch density, tightness factor and areal density [1,2,3,7]. It means the increase in loop length has caused considerable decrease in the values of the above said three parameters.

Table 3.2. Effect of loop length on geometric properties at DRS II

Structure	Code	‘l’ in cm	WPI	CPI	Kw	Kc	S	Ks	K	Kc/Kw	GSM
Double Pique	DP 1	0.27	34	72	3.6	7.63	2448	27.46	16.4	2.11	205
	DP 2	0.30	32	64	3.77	7.55	2048	28.46	14.8	2.0	190
	DP 3	0.33	30	53	3.87	6.83	1590	26.43	13.5	1.76	165

3.2. Effect of loop length on geometric properties at DRS II

From Table 3.2, it is visible that the changes in loop length have significant impact on other knit fabric geometric properties except WPI after heat setting. Like previous state, here also there is a slight decrease in WPI due to the increase in loop length and vice-versa. It may be because of the relaxation pattern of the fabrics in width direction during heat setting and not due to varied loop length among the samples. The double pique fabric samples knitted with smallest loop length has exhibited more number of WPI and vice- versa. It may be the result of more width wise contraction in the sample of smallest loop length than the others [9,10,12]. The CPI of all the knitted fabric samples has shown considerable reduction in their numeric while increase in loop length and vice-versa. It is clear that the decrease in CPI is inversely proportional to stitch density, tightness factor and areal density. It means the increase in loop length has caused corresponding decrease in the values of geometric properties such as course per inch, stitch density, tightness factor and areal density and vice-versa [1,2,3,7].

Table 3.3. Effect of loop length on geometric properties at WRS

Structure	Code	'l' in cm	WPI	CPI	Kw	Kc	S	Ks	K	Kc/Kw	GSM
Double Pique	DP 1	0.27	36	76	3.81	8.05	2736	30.63	16.4	2.11	230
	DP 2	0.30	34	68	4.01	8.02	2312	32.16	14.8	2.0	215
	DP 3	0.33	32	59	4.12	7.61	1888	31.41	13.5	1.84	195

3.3. Effect of loop length on geometric properties at WRS

From Table 3.3, it is evident that the changes in loop length have significant impact on knit fabric geometric properties after wet relaxation also. In this case, there is negligible decrease in WPI due to the increase in loop length and vice-versa. It shows loop length does not have any influence in the change of WPI among the fabrics knitted with different loop length values. In most of the cases, it is a parameter governed by gauge of the machine and width wise contraction or growth of the fabric [1,2,13]. In this case also like the previous one, the increase in loop length has caused considerable decrease in the properties such as CPI, stitch density, tightness factor and areal density and vice-versa [1,2,3,7].

Table 3.4. Effect of loop length on geometric properties at FRS

Structure	Code	'l' in cm	WPI	CPI	Kw	Kc	S	Ks	K	Kc/Kw	GSM
Double pique	DP 1	0.27	38	80	4.03	8.48	3040	34.17	16.4	2.1	255
	DP 2	0.30	36	72	4.25	8.50	2592	36.13	14.8	2.0	240
	DP 3	0.33	35	65	4.52	8.38	2275	37.88	13.5	1.85	223

3.4. Effect of loop length on geometric properties at FRS

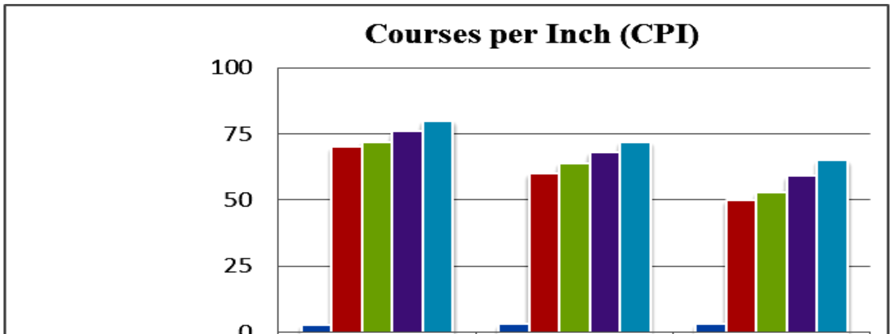
From Table 3.4, it is visible that the changes in loop length have caused significant effect over knit fabric geometric properties after repeated cycle of washing and drying. During washing, a negligible decrease in WPI is observed because of the increase in loop length and vice-versa as in the previous. It is once again proved that loop length does not have any prominent impact over WPI of the fabrics because of its variations [1,2,13]. In FRS also the increase in loop length has caused considerable decrease in the properties such as course per inch, stitch density, tightness factor, areal density and vice-versa [1,2,3,7].

A constant but, trivial increase in WPI has been observed for the similar loop length double pique samples during progressive relaxation states. There is a prominent state after state increment has been found between DRS and FRS in the case of CPI, stitch density and areal density of the samples knitted with different loop length variables and corresponding K values [2,4,7,12]. All these geometric parameters are found attaining their maxima at FRS

[2,7,8]. From the observed test results, it is clear that there is a continuous lateral and longitudinal contraction between one relaxation state and another [5,13]. But, latter may be larger than the former during every relaxation state because of the huge increase observed in CPI and other related geometric values [11,12].

Among the double pique samples knitted, both DP 1knitted with smallest loop length and DP 2 knitted with medium loop length have exhibited remarkable loop shape stability. It is evident from more or less similar values and unchanged values of loop shape factors respectively for DP 1 and DP 2 in all their relaxation states. It may due to the ideal degree of tightness between the loops of these samples and also the presence of elastomer in the core.

Figure 3.1. Effect of loop length on CPI

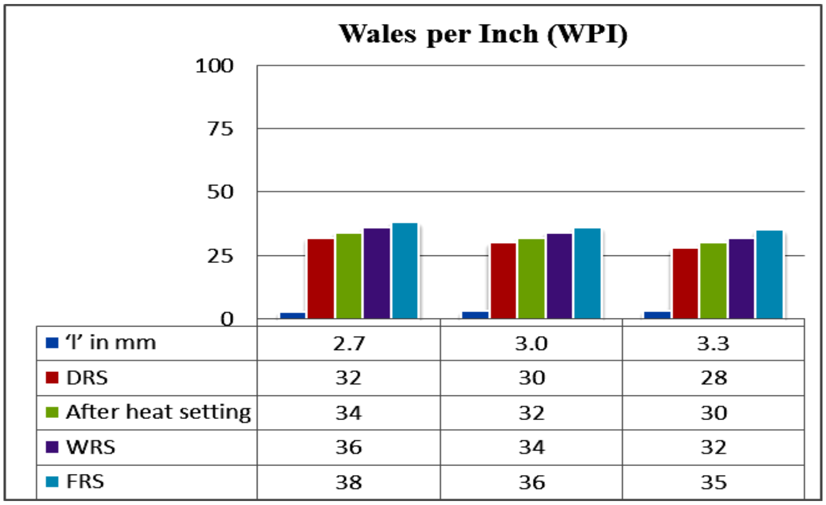


'l' in mm	2.7	3.0	3.3
DRS	70	60	50
After heat setting	72	64	53
WRS	76	68	59
FRS	80	72	65

3.5. Effect of loop length on CPI

From Figure 3.1, it has been observed that the values of CPI have gradually and prominently increased for all the samples after every relaxation state. It is in higher order for the fabric sample knitted with smallest loop length in all the relaxation states and vice-versa [10,12].

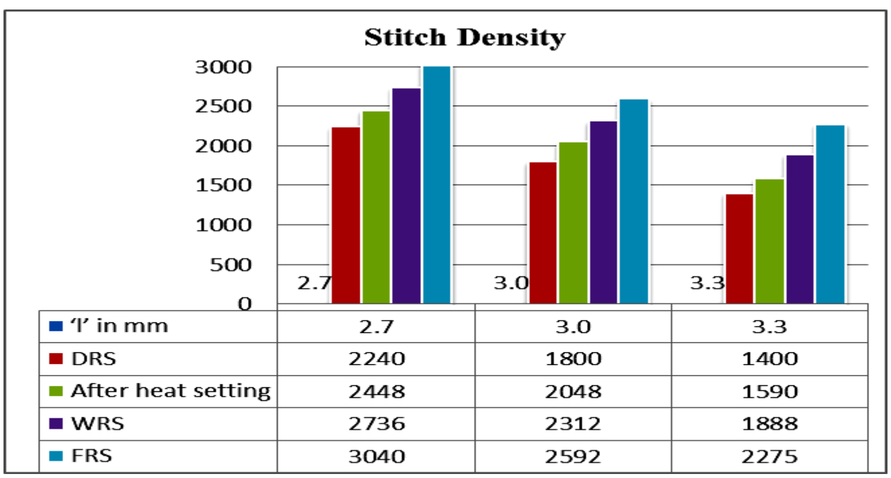
Figure 3.2. Effect of Loop length on WPI



3.6. Effect of loop length on CPI

From Figure3.2, it can be easily observed that the WPI are more or less similar for all the developed samples. The results have clearly depicted that the changes in loop length do not play any major role in the wale density of knitted fabrics [12,13].

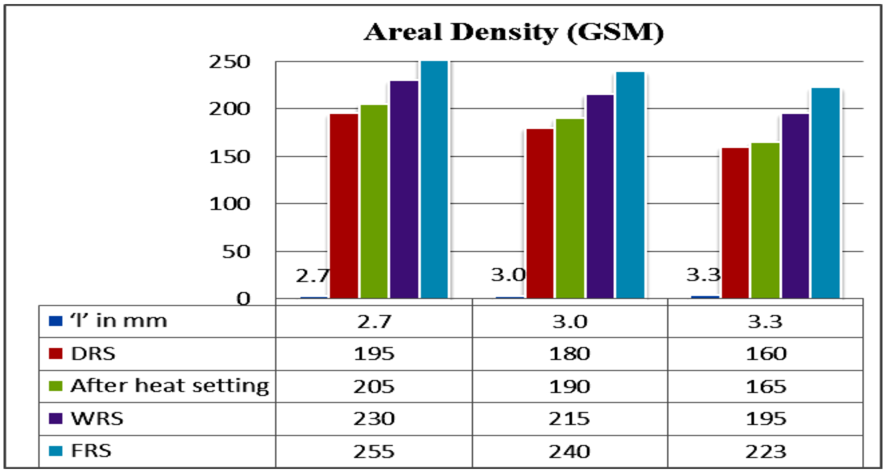
Figure 3.3. Effect of loop length on stitch density



3.7. Effect of loop length on stitch density

From Figure 3.3, it has been shown that the change in loop length has considerable impact on stitch density values. It has been noted that the increase in loop length has caused considerable decrease in the stitch density values or vice-versa. It is due to the resultant reduction in CPI because of increase in loop length values. It has also been evident that the stitch density values have increased considerably after every relaxation state for all the samples. It may be due to the relaxation pattern towards continual contraction of the samples and also it is interesting to note that the relaxation pattern is uni-directional during progressive relaxation states [8,12].

Figure 3.4. Effect of loop length on GSM



	2.7	3.0	3.3
'l' in mm	2.7	3.0	3.3
DRS	195	180	160
After heat setting	205	190	165
WRS	230	215	195
FRS	255	240	223

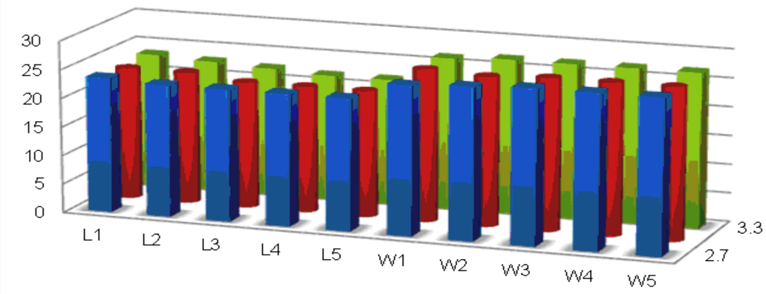
3.8. Effect of loop length on GSM

From Figure 3.4, it has been observed that the GSM values have increased remarkably for all the samples to a prominent level for the descending order of loop length values and also after every relaxation state. It is because of the uni-directional relaxation pattern of all the samples and as a result of the increase in course density values [5,12,13]. From the GSM values, it is once again proved that the loop length is inversely proportional to areal density of knitted fabrics.

3.9. Effect of loop length on dimensional stability

The consolidated results of repeated washing and drying cycles and subsequent dimensional changes are shown in Figure 3.5 for the developed core spun spandex double pique samples with three different loop length values. From the test results, it is evident that all the samples were not able to reach their minimum energy level both in length and width direction after the first wash. Immediately after that the samples have gradually moved towards the minimum energy level in their length and width direction after the second wash. All the knitted fabric samples have attained their dimensional stable state perfectly after the fourth wash and dry cycle and the same trend is noticed after the fifth wash also. Anyhow, the sample knitted with the smallest loop length has reached its width wise dimensionally equilibrium state in the first wash itself. Moreover, the contraction in length and growth in width was noticed uniformly for all the samples after each wash and dry cycle [5,8,13].

Figure 3.5. Effect of loop length on dimensional stability



	L1	L2	L3	L4	L5	W1	W2	W3	W4	W5
2.7	23.5	23	23	23	23	26	26.5	27	27	27
3	23	23	22	22	22	26.5	26	26.5	26.5	26.5
3.3	23.5	23	22.5	22	22	26.5	27	27	27	27

4. Conclusions

- Cotton sheath – spandex core combed hosiery yarn has been found more suitable for knitting the double pique, one of the popular derivative structures of single jersey widely used in designing the casual wear and sportswear T-shirts.
- It is evident that the changes in loop length have significant impact on other knit fabric geometric properties except WPI at all the relaxation states.
- The values of WPI have increased for all the samples at a trivial level for descending order of loop length values and also after every relaxation state. From the test values, it can be easily observed that the WPI values are more or less similar for all the developed knitted fabric samples. The results have clearly depicted that the change in loop length does not play any major role in the wale density of knitted fabrics. So, it is obvious that it is a parameter governed by gauge of the machine and width wise contraction or growth of the fabric during the relaxation.
- It is interesting to note that the values of CPI have increased for all the samples after every relaxation state. It is higher in number for the fabric sample knitted with smallest loop length in all the relaxation states and vice-versa.
- It has been found that the change in loop length has considerable impact on stitch density values. It has been noted that the increase in loop length has caused considerable decrease in the course density and further more in stitch density values. It has also been evident that the stitch density values have increased considerably after every relaxation state for all the samples. It may be due to the relaxation pattern of the samples and from the results it is clear that the relaxation is unidirectional.
- The knitted fabric areal density (GSM) values have increased remarkably after every state of relaxation. It is because of the unidirectional relaxation pattern of all the samples. From the GSM value, it has become visible fact that the loop length and tightness factor of knitted sample is inversely and directly proportional respectively to its areal density.
- All the three double pique samples are able to move towards their dimensionally equilibrium state after the second wash and they become perfectly stable after the fourth wash both length as well as width.

Abbreviations: *l – Loop length , WPI – Wales per Inch, CPI – Courses per Inch, Kw – Wales constant, Kc – Course constant, S –*

Stitch density, Ks – Stitch density constant, Kc/Kw – Loop shape factor, K-Tightness Factor and GSM – Areal Density.

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