DIMENSIONAL STABILITY OF COTTON/ACRYLIC PLAIN KNITTED STRUCTURE PRODUCED WITH FLAT-BED KNITTING

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Abstract

The project focused on the dimensional stability of plain knitted structures from soft cotton/acrylic spun yarn which were produced using flat-bed knitting machine. The test samples were knitted with four different cam settings, while the machine gauge and the number of needles used were kept constant. The test samples were then delivered to different stage of relaxations; 24 hours of dry relaxation, steaming, and washing and tumble drying. It was found that the fabric shrunk in length and width direction, whilst the stitch length was more or less constant after the relaxations. Since there was no significant variation in the stitch length, hence the dimensional change of a knitted structure during relaxation was actually influenced by the distortion of the stitch rather than changes in the stitch size.

Keywords: Knitted structure, dimensional stability, flat-bed knitting, stitch length, shrinkage.

1. Introduction

1.1 Overview of knitting industry

Today, knitting industry has shown a competitive growth with over 17 million tons of production of knitted textiles and apparel, which representing one third of the global textile market. By 2013, it is predicted that the output of knitting industry grows by 25%, reaching more than 21 million tons per year (CIRFS, 2003). The situation is much less influenced by the low capital cost and technology’s quick respond to the requirements in apparel and non-apparel market. This is due to the industry’s capability to manufacture 3D textile products as well as flat fabrics and also because of the properties of knitted structure itself, which is able to be engineered to fulfil those demanding requirements (Spencer, 2001).

1.2 Properties of knitted structure

Knitted structure has its own uniqueness that makes it suitable for certain end uses especially hosiery, underwear and knitwear, which cannot be found in other form of 2-dimensional textile material. In general, knitted fabric is more elastic than woven or nonwoven, and it has the ability to recover when being stretched. This is due to the knitted loops configuration in the structure that allows yarn to move or bend better. Such characteristic fulfils Doyle’s suggestion (1953) that the most important mechanical requirements in shape fitting garments is high extensibility in all directions, particularly in width.

Apart from that, knitted fabric generally has comfort properties as it offers easy body movement to the wearer. This is due to the behaviour of knitted structure which has a fairly low average modulus especially along the courses (usually the width direction in actual garments), and also because of its high load-extension properties. Such characteristics according to Doyle (1953), make the fabric in a garment can be stretched slightly to make a neat fit and is then extended by changes in body dimensions, which is associated with muscular action.

Despite having such properties which are advantageous, weft knitted structure has characteristic that is undesirable. From the past until today, it is known that most of knitted structures' problem is regarding dimensional stability. It is a serious problem that 20% of all textile complaints made by customers were regarding shrinkage of knitted fabrics (Munden, 1960). So, it becomes a struggle for knitters and finishers nowadays to produce fabrics and garments which have low level of potential shrinkage in order to capture consumer's preference.

From the consumer's point of view, subsequent shrinkage allowance by practicing oversizing is unacceptable for outerwear garments because they should look right and fit from the first time of wearing (Burkitt, 1986). Hence, there are many works done in order to find out the cause and nature of knitted structures' dimensional stability. Those researches are important so that the problem can be worked out during knitting or finishing process rather than solution during garment make-up which is not go well with customer's want.

1.3 Dimensional stability of knitted structure

It is said that weft knitted structures (especially plain knitted) expand easily in lengthwise or widthwise direction even when subjected to little force. This extension involves changes in loop shape, which eventually may recover from its distorted state due to potential energy in the stretched fabric (Smirfitt, 1975). The force that is always imparted into knitted structure might occur during production, wearing and washing. In any one of the condition stated, the structures have the tendency to shrink and vary in size even produced with same knitting condition and parameters.

After such forces been applied and then released, the deformed structure changes to a state in which the fabric holds a minimum of potential energy, which is called 'relaxed state' (Doyle, 1953). This phenomenon explains why knitted textiles or apparel dimensions vary after being produced. Other than that, the dimensional stability of a knitted structure is said to be due to the amount of yarn knitted into the loop, which is called stitch length (Munden, 1960). Therefore, this study was carried out in order to discover the dimensions of plain knitted structures made from different stitch length after being subjected to different kinds of relaxations.

1.4 Objectives of the study

The objective of this study was mainly to observe the influence of stitch length and stitch shape on the dimensional properties of knitted structure after series of relaxations. Stitch length would determine how tight or how loose a knitted structure for a given machine gauge and yarn count. So, it was expected that knitted fabric compactness would influence the dimensional properties of the structure and the stitch length was the main element which related to this factor.

This study was also carried out in order to investigate the effect of stitch shape on the dimensional changes of plain knitted structure after relaxations. It was to prove that the shrinkage characteristic of a knitted structure after production process is mainly influenced by the changes in stitch shape rather than changes in stitch length.

Finally, the research is significant for future studies with the purpose of exactly determine the fabric's dimensional properties before and after knitting, and eventually to convey this information to the knitter in the hope that it will be used for the ultimate advantage of the consumer.

2. Methods

2.2 Samples preparation

Cotton/acrylic 50/50 spun yarn was used and every piece of test sample was produced on Shima Seiki flat-bed knitting machine, model SES122-S. Cotton/acrylic 50/50 was used in this study because of the soft characteristic of a spun yarn. Hence, the effect of stitch shape on the shrinkage of this kind of yarn could be observed because spun yarn could be easily distorted into loops and retained the stitch shape.

Machine setting to knit cotton/acrylic test samples is indicated in Table 1. The number of needles, machine gauge, and structure for all panels were kept constant. The number of courses for the panels was also kept constant, which were 100 courses. Only the cam setting was varied in order to investigate the behaviour of the fabrics' dimensions under different stage of relaxations.

Table 1. Machine settings for cotton/acrylic samples production

Number of samples	Cam setting	Yarn size (tex)	Number of needles	Machine gauge (G)	Knitted structure
40	20	75	100	7	Plain
40	24	75	100	7	Plain
40	28	75	100	7	Plain
40	32	75	100	7	Plain

Due to the inherent edge curling of plain knitted structures, the test samples were knitted with a border as shown in Figure 1 below. As stated earlier, the actual test area of the sample consisted of 100 wales and 100 courses; however the sample border was created with a few additional wales and courses, sufficient to prevent the edge curling.

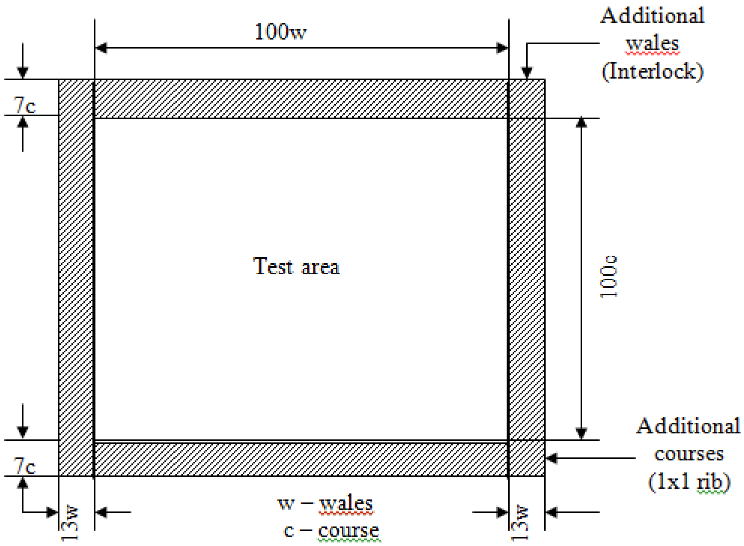

Figure 1. Sample panel

On either side of the test area, 13 wales were knitted with interlock structure because of its stability that would prevent the fabric from curling at the edges. As for the additional structures on the top and bottom, they were knitted with 1x1 rib structure. The above technique enabled the author to differentiate between the test area from the additional border area in the test sample easily, so that the dimensions and their variations could be measured with a minimum error.

2.3 Relaxations route

All the test samples were delivered to a series of relaxation (Figure 2). After every relaxation, the dimension of each test sample was measured to observe the shrinkage or expansion that might occur on the fabric. Apart from that, the stitch length was also determined. A variation in stitch length or stitch shape would influence the dimensional changes of a knitted structure. Thus, the stitch length determination on the relaxed test sample was essential to examine whether there was a variation in the stitch size or not.

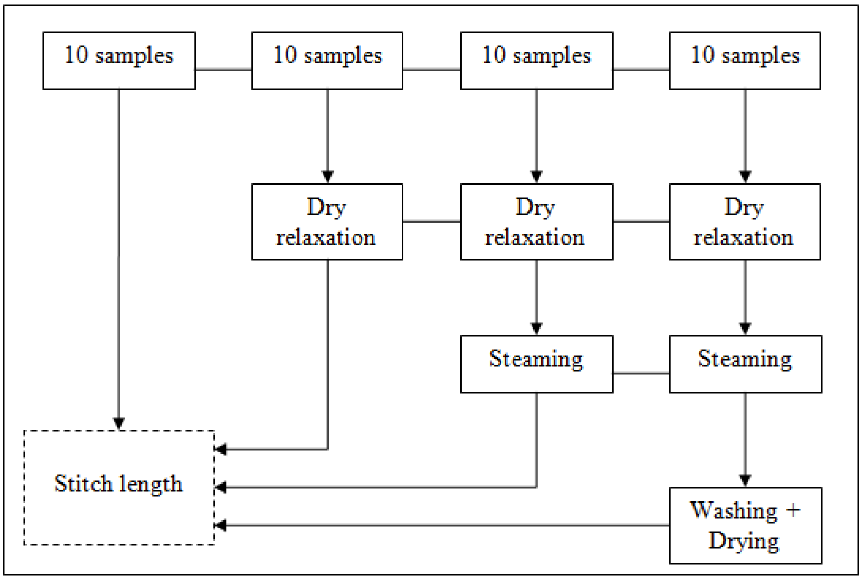

Figure 2. Route of relaxations treatments for cotton/acrylic samples

2.2.1 Soon after knitting (SAK)

The length and width of all 40 samples were measured just after they had been produced. During this stage, time was a critical thing where all the test samples must be measured quickly after knitting process. A delay in measuring the test samples would cause a variation in the results. This was caused due to the behaviour of a knitted structure that would shrink when being released from a tension during knitting. Hence, quick measurement was essential in order to produce a reliable result because the dimensions soon after knitting would be set as the original dimensions of the test samples. Yarns from 10 test samples were then unravelled to measure the stitch length.

2.2.2 Dry relaxation

The 30 samples left were then laid free from constraints on a table for 24 hours under standard atmosphere (20ºC±2ºC and relative humidity of 65%±2%). The samples were conditioned to facilitate recovery from the stress imposed during knitting without applying any physical action like agitation, heat or moisture. After 24 hours, the dimensions of all 30 samples were measured, and 10 test samples were utilised to determine the stitch length.

2.2.3 Steaming

The samples were laid on BM steam bed with 4 bar of pressure and no tension applied on them to be treated under heat and moisture. They were steamed for about 10 seconds and vacuumed for another 10 seconds. The samples were then turned to the other side and were subjected with another 10 seconds of steaming and 10 seconds of vacuuming. The dimensions of all 20 samples were measured, and 10 test samples were utilised to determine the stitch length. The 10 test samples remaining were then delivered to washing and tumble drying.

2.2.4 Washing and tumble drying

The test samples were washed using a domestic washing machine according to British Standard (EN ISO 6330:2000), washing procedure number 5A. The samples were delivered to washing with normal agitation, 2.0 kg total load at 40^{o}C and 500 revolution/min of spin rotational frequency.

Drying of the specimens were carried out using tumble dryer according to British Standard (EN ISO 6330:2000), Procedure E. The tumble dryer was set for heavy press or about 70ºC, and the fabrics were dried until completely dry. The dimensions of the samples are then measured.

The washing and drying cycle were repeated twice with the dimensions being measured after every washing and drying cycles. After the third cycle, the stitch lengths of the samples were measured. In this study, only three cycles of washing and drying were carried out because they were sufficient to stabilise the fabric because the dimensions of the test samples were more or less constant after the third cycle, which means there were no dimensional changes after three cycles of washing and drying.

2.4 Fabric dimensional stability

2.4.1 Stitch length and stitch shape

The course length was measured according to British Standard (BS ISO 7211-3:1984), by using a Shirley yarn crimp tester and the readings were divided by the number of wales in the test area which was hundred. Six test courses (odd and even) were selected and the selection was distributed along the panel from each test sample. The sampling was kept in similar way for all samples by setting the position number of the yarn.

Apart from stitch length, the unravelled yarn was observed to see the trend of the knitting crimp formed on it. This observation was important in order to examine the effect of relaxation on the configuration of the loop, and hence on the dimension of the test sample.

2.4.2 Fabric dimensions

The dimension of the panel was directly measured from the first course to hundredth course in the test area for length, and from the first wale to hundredth wale for the width. Hence, the length and width measured would consist of 100 courses and 100 wales respectively. The distance was marked so that the dimension could be measured at the same place after different stage of relaxations. The samples were also numbered, as the same test samples will be measured again later to observe how they changed in dimension after relaxations.

2.4.3 Dimensional change

Previous dimension based

This change of dimension was based on the previous measurement. It represented the behaviour of the fabric whether it shrunk or expanded after each of relaxation based on the previous length and width. The change was worked out by subtracting current dimension from the previous one.

$$\%\ Length\ changes\ (PDB) = \frac{Current\ length - Previous\ length}{Previous\ length} \times 100$$

$$\%\ Width\ changes\ (PDB) = \frac{Current\ width - Previous\ width}{Previous\ width} \times 100$$

Initial dimension based

This total change of dimension was based on the initial or original dimension (soon after knitting dimension). It represented the behaviour of the fabric whether it shrunk or expanded after each relaxation based on the original dimension. The change was worked out by subtracting current dimension with the original dimension.

$$\%\ Length\ changes\ (IDB) = \frac{Current\ length - Original\ length}{Original\ length} \times 100$$

$$\%\ Width\ changes\ (IDB) = \frac{Current\ width - Original\ width}{Original\ width} \times 100$$

For both previous and initial based dimension change, negative value would represent shrinkage, while positive value would indicate expansion in the fabric sample.

3. Results and Discussions

3.1 Stitch length and stitch shape

3.1.1 Stitch length

Table 2 illustrates the average of stitch length for odd and even course for every set of test samples. It was found that, the higher the number of cam setting, the longer the stitch length, and the smaller the difference between the long and short stitch length. The difference between the two courses was due to the pulling of unequal lengths of yarn from the yarn package, which caused variation in yarn tension during knitting the alternate courses (Choy, Atkinson and Dias, 1995). However, there was no significant variation in the stitch length from the same odd and even position course after different relaxation process.

Table 2. Average stitch length

Cam setting	Course	Stitch length (cm)	Std. dev	% CV	Difference (cm)	Average (cm)	Std. dev	% CV
20	Odd	0.770	0.01	0.77	0.067	0.736	0.03	4.67
	Even	0.704	0.01	1.45				
24	Odd	0.851	0.02	1.98	0.063	0.819	0.03	4.17
	Even	0.788	0.01	0.99				
28	Odd	0.920	0.02	2.05	0.055	0.893	0.03	3.70
	Even	0.865	0.02	2.04				
32	Odd	0.981	0.03	2.91	0.042	0.960	0.03	3.15
	Even	0.938	0.01	1.17				

3.1.2 Stitch shape

Figure 3 shows an unravelled yarn from a test sample soon after knitting and Figure 4 is the yarn from the same quality that was subjected to 24 hours of dry relaxation. It can be seen that the yarn unravelled soon after knitting was basically a straight yarn, with no significant crimp by knitting action. As for the 24 hours of dry relaxation, the knitting crimp was quite noticeable.

Figure 3. Yarn shape (soon after knitting)

Figure 4 Yarn shape (24 hours of dry relaxation)

Cotton/acrylic spun yarn is soft in nature and it has the ability to be bent and retains the stitch shape. After 24 hours of dry relaxation, the knitting crimp was noticeable as compared to the soon after knitting. This was because, the longer the time that the loop configuration was in, the longer it took to return to its straight original shape.

There was full knitting crimp noticed in unravelled yarn from steamed and washed sample (Figure 5 and Figure 6 respectively), with the latter showed a more even wave of crimp. This was due to the degree of wetting, since steaming only applied moisture with the presence of heat, while washing involved full immersion and agitation in the water. The agitation in washing and rotational motion in tumble drying have caused the yarn to exploit the space around it and the yarn loops attained a state of minimum energy and fully dimensionally stable (Sharma, Ghosh and Gupta, 1985). Hence, the effect on the fabric was more significant and permanent.

Figure 5. Yarn shape (steaming)

Figure 6. Yarn shape (washing and drying)

Stitch shape variations

Stitch length remained more or less constant after the fabrics were subjected to 24 hours of dry relaxation, steaming, and washing and drying. As for the stitch shape, it varied from one relaxation to other relaxation. This confirms Munden's theory that the changes in fabric's dimensions and properties are mainly due to changes in loop shape rather than loop length (Anand et al., 2002).

Unlike stitch length which could only be modified during knitting process, the shape of stitch could change both during and after production (relaxation process like steaming, wetting, washing and drying). In flat bed knitting machine, the fabric was strained and distorted when being subjected to tension from the fabric take-down rollers or holding-down sinkers during the stitch formation process (Choy, Atkinson and Dias, 1995). So, the stitch would elongate in length direction (change in shape), but the stitch length remain unchanged.

After production or during relaxation process, the stitch changed in shape depending on what kind of relaxations were carried out, how the relaxations were done, and what type of fibre the yarn was made. Different kind of relaxations would give different results on the stitch shape, as in this study, yarn from washing and drying retained more even wave of crimp as compared to steaming or 24 hours of dry relaxation. The way how the relaxation was done also influenced the stitch shape, such as temperature, number of washing cycles, and type of drying (Anand et al., 2002). So is with the type of fibre, where the effect of washing on stitch shape of natural or hydrophilic spun yarn was so obvious. This was due to soft characteristic of spun yarn which is could easily be bent and distorted, and eventually retains the new configuration of loop.

3.2 Fabric dimensions

Table 3.2 indicates the dimensions of cotton/acrylic samples after the series of relaxations. It was found that the longer the stitch length, the slacker was the fabric. The relationship between stitch length with the dimensions will be discussed based on the next graphs.

Table 3. Average dimensions

Cam setting		20	24	28	32
Stitch length (cm)		0.736	0.819	0.893	0.960
Tightness factor (tex$^{1/2}$cm^{-1})		11.77	10.57	9.70	9.03
Length	**SAK (cm)**	**14.0**	**16.5**	**18.5**	**20.4**
	Std dev.	0.13	0.18	0.36	0.28
	% CV	0.89	1.11	1.96	1.36
	24 hrs (cm)	**13.8**	**16.0**	**17.8**	**20.3**
	Std dev.	0.16	0.11	0.12	0.23
	% CV	1.17	0.68	0.70	1.15
	Steaming (cm)	**12.9**	**14.7**	**16.3**	**18.0**
	Std dev.	0.07	0.30	0.23	0.16
	% CV	0.53	2.02	1.40	0.89
	Washing (cm)	**11.7**	**12.8**	**14.0**	**14.8**
	Std dev.	0.11	0.09	0.27	0.13
	% CV	0.97	0.74	1.96	0.89
Width	**SAK (cm)**	**21.0**	**23.2**	**24.9**	**27.0**
	Std dev.	0.23	0.22	0.23	0.27
	% CV	1.11	0.95	0.92	0.99
	24 hrs (cm)	**20.8**	**22.9**	**24.6**	**26.6**
	Std dev.	0.30	0.19	0.58	0.25
	% CV	1.43	0.84	2.35	0.92
	Steaming (cm)	**19.9**	**21.2**	**23.1**	**24.6**
	Std dev.	0.26	0.20	0.26	0.28
	% CV	1.30	0.94	1.11	1.14
	Washing (cm)	**19.0**	**21.8**	**23.6**	**25.2**
	Std dev.	0.14	0.20	0.23	0.16
	% CV	0.76	0.90	0.98	0.63

Figure 7 represents the relationship between the stitch length and length of the test sample. From the graph, it is shown that the greater the stitch length, the bigger the dimension of the fabric in length direction. This was due to the amount of yarn introduced in the fabric which was longer than the fabric with shorter stitch. Hence, the fabric was capable to spread more in length direction. The same trend also occurred on the fabric width (Figure 8).

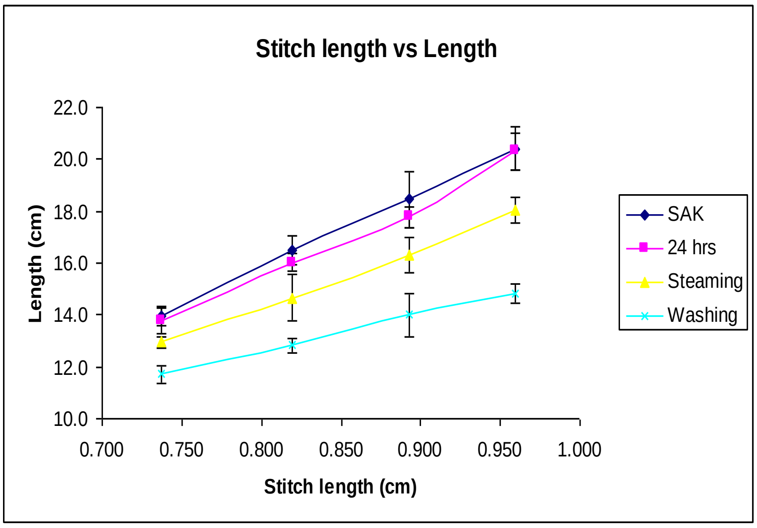

Figure 7. Relationship between stitch length and fabric length

With the same number of knitting needles or wales, it was found that the width of cotton/acrylic samples increased with the stitch length. Longer stitch length has made the fabric spread in width direction because the spacing between two wales increased (Heap and Stevens, 1996). For stitch length of 0.736 cm, the length and the width soon after knitting of the samples were 14.0 cm and 21.0 cm respectively. While for the slackest fabric (stitch length of 0.960 cm), the length and the width were 20.4 cm and 27.0 cm. It was also shown that after steaming and washing, the samples have same width (about 20.5 cm) when the stitch length was about 0.777 cm.

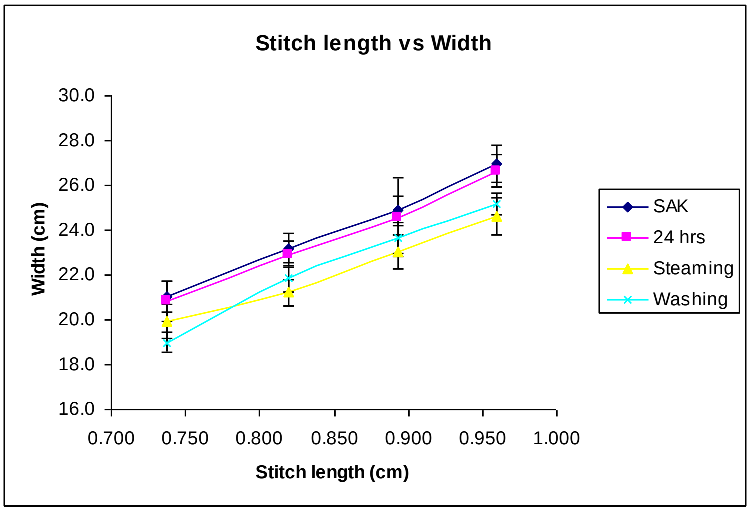

Figure 8. Relationship between stitch length and fabric width

3.3 Dimensional change

3.3.1 Previous dimension based

Table 4 illustrates the dimensional changes of cotton/acrylic samples based on the previous dimensions. Negative values represent shrinkage, while positive values for expansion. The trend of the changes will be discussed in the following graphs.

Table 4. Dimensional changes (PDB)

Cam setting		20	24	28	32
Stitch length (cm)		0.736	0.819	0.893	0.960
Tightness factor ($tex^{1/2}cm^{-1}$)		11.77	10.57	9.70	9.03
Length changes (%)	**SAK**	0.0	0.0	0.0	0.0
	24 hrs	-1.6	-2.9	-3.8	-0.5
	Steaming	-5.9	-8.5	-8.2	-11.2
	Washing	-9.4	-12.5	-14.1	-17.8
Width changes (%)	**SAK**	0.0	0.0	0.0	0.0
	24 hrs	-1.0	-1.1	-1.1	-1.2
	Steaming	-4.2	-7.5	-6.2	-7.5
	Washing	-4.8	3.0	2.5	2.3

The changes of the length from one relaxation to the next relaxation showed a considerable transformation. As the stitch length increased, it was found that the changes of the dimension in length direction became more significant (Figure 9). This was due to more spaces available in a slacker structure for the loops to turn to its original loop shape, and hence more changes could take place in the fabric. The fabric was imparted with tension during production process and therefore, when it came to relaxation, the strain was dissipated whilst the loops went back to its original shape.

For stitch length 0.960 cm, the biggest change occurred during washing with shrinkage of 17.8%, while the least change was 0.5% of shrinkage which occurred during 24 hours of dry relaxation. This condition was caused by a very late recovery of slack structure after the removal of fabric from the machine, and also after the dry relaxation (Sharma, Ghosh and Gupta, 1985).

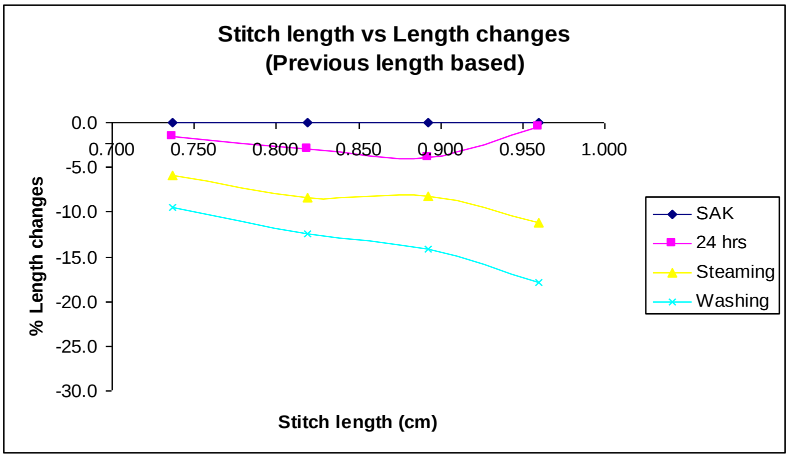

Figure 9. Relationship between stitch length and length changes (PDB)

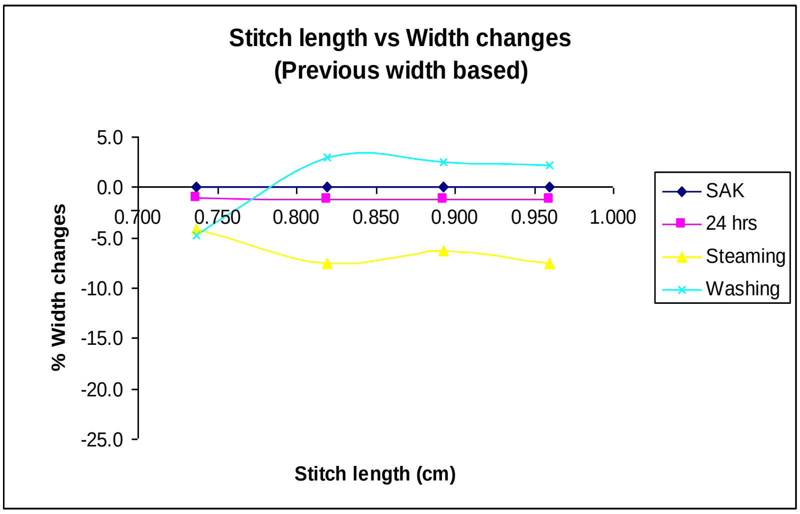

Figure 10. Relationship between stitch length and width changes (PDB)

A different trend occurred on the width changes (Figure 10). It was found that the width expanded by 2.3%-3.0% during washing and drying, while the other relaxations caused the structure to shrink. The structures expanded after washing and tumble drying because of the severity of the process which caused them to stretch in width direction, and this occurred on to loose structure. For the other relaxations, the fabrics were laid free either on the table or steam bed which did not give strains to the fabric. Therefore, the changes of the width for the first two relaxations were caused mainly due to the stitch distortion, whilst during washing and tumble drying there was a tightening of structure, but the physical action applied had imparted strains and hence loosening the fabric.

It was also found that the width shrinkage is smaller than length shrinkage. This is because of the tension applied in length direction during knitting (take down tension) is greater, and therefore the changes are more significant. As for the width direction, the shrinkage is due to the distortion of the loops into a more compact structure, not because of the loops are freed from strains. Thus, the shrinkage effect is smaller.

3.3.2 Initial dimension based

Table 5 illustrates the total changes of the dimensions after every relaxation based on the original dimensions. The changes are used to find out how the dimensions respond from the original length and width until up to a particular relaxation.

Table 5. Dimensional changes (IDB)

Cam setting		20	24	28	32
Stitch length (cm)		0.736	0.819	0.893	0.960
Tightness factor ($tex^{1/2}cm^{-1}$)		11.77	10.57	9.70	9.03
Length changes (%)	**SAK**	0.0	0.0	0.0	0.0
	24 hrs	-1.6	-2.9	-3.8	-0.5
	Steaming	-7.4	-11.1	-11.7	-11.6
	Washing	-16.2	-22.3	-24.2	-27.4
Width changes (%)	**SAK**	0.0	0.0	0.0	0.0
	24 hrs	-1.0	-1.1	-1.1	-1.2
	Steaming	-5.1	-8.5	-7.3	-8.7
	Washing	-9.7	-5.8	-5.0	-6.6

There was more or less similar trend between previous and original based length shrinkage, except the shrinkage is far greater in original based (Figure 11). This was because the changes were calculated from the initial length (soon after knitting) as the benchmark, while the other one was worked out based on the length of particular previous relaxed sample. From the graph, the total highest shrinkage recorded is 27.4% which occurred during washing and drying.

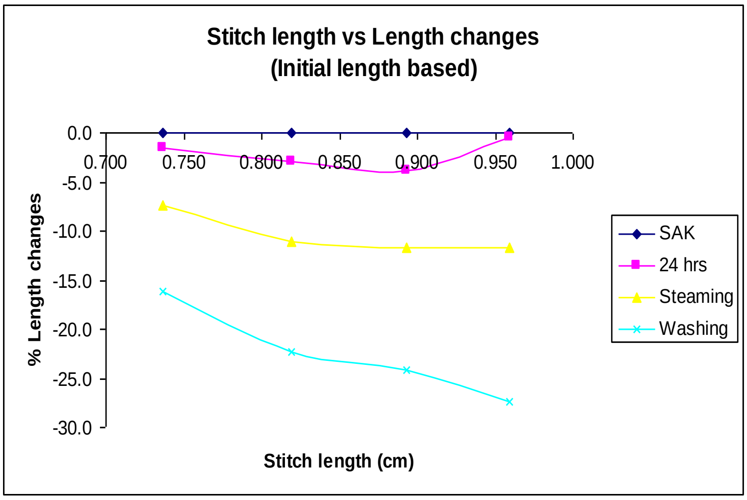

Figure 11. Relationship between stitch length and length changes (IDB)

There was a different trend of changes in width during washing for original (Figure 12) with previous dimension based. As a whole, there was no expansion of width after the fabric was produced. All the structures shrunk; with the highest shrinkage was 9.7% which occurred on the fabric with shortest stitch length, 0.736 cm. Fabric with longer stitch length expanded after washing, which has lowered the total shrinkage.

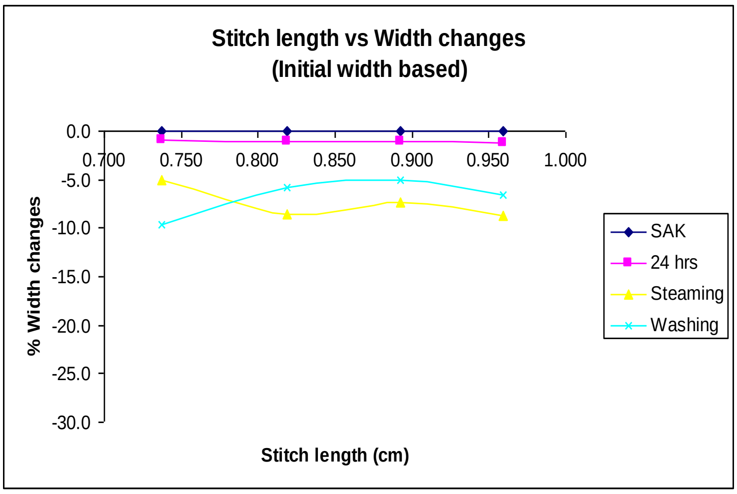

Figure 12. Relationship between stitch length and width changes (IDB)

4. Conclusion

As a conclusion, stitch length is a knitting variable that cannot be altered once the fabric has been produced. As such it is vital to control the stitch length during the stitch formation process. Accurate definition of the stitch length can be achieved with positive yarn delivery systems, which have become standard equipment of modern high production circular knitting machines. However, positive delivery systems are still not available for flat-bed knitting. Therefore it is very important that the most care is taken in the adjustment of the cams as other related parameters. For the stitch shape, it may be modified after production, depending upon the yarn used and the finishing that the fabric has received. Washing and tumble drying have given full knitting crimp on the yarn, whilst yarn from 24 hours of dry relaxation is basically a straight yarn with unnoticeable knitting crimp.

The second conclusion gained from this study is that stitch length as the main element that influences the dimensions of a knitted structure. It was found that the bigger the stitch length, the greater the dimension of the fabric, and the larger the shrinkage occurred on cotton/acrylic. Length of samples reduced, as well as the width with the greatest shrinkage occurred on the slackest structure during washing and drying. The fabrics shrunk due to the soft characteristic of spun yarn which could be distorted and retain the stitch shape. Thus, the changes in fabric dimension during finishing are due to the changes in stitch shape rather than changes in the yarn itself.

Finally, it can be concluded that a correct yarn selection and right machine setting are essential to produce a fabric with minimum variation in stitch size and stitch shape. A soft yarn produces a dimensionally unstable fabric with a slacker structure. Therefore, they must be delivered to an appropriate finishing process after the production in order to improve the serviceability of the fabrics.

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