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Research Article

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An Investigation into the Effect of Fabric Structure and Yarn Twist Direction on the Curling Behavior of Single Jersey Weft Knitted Fabrics

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Abstract

In this work, the curling behavior of single jersey weft-knitted fabrics produced from different structures and yarn twist directions is studied. Curling behavior was characterized in terms of curling surface in both course and wale directions. It is concluded that the curling surface value of weft-knitted fabric samples produced from the Z-twist ring-spun yarn is higher than that of the samples produced from the S-twist cotton ring-spun yarn. The comparison between different fabric structures reveals that the presence of tuck stitches in fabric structure results in a (or leads to a) lower curling surface. During the tuck loop formation, the higher yarn tension on the held loop causes them to rob yarn from adjacent knitted loops. This in turn exposes more moment though the loop and the higher curling would be expected. But the results show that the friction between the yarns in contact points has a significant effect on curling reduction. It has been figured out that the structures comprised of tuck and knit loops present lower curling phenomenon. In this study, double cross tuck and triple cross miss structures show the lower and higher curling surface values. Totally it could be stated that the structures possess miss loops have the lower curling surface in the wale direction while it is the opposite in the course direction. For structures including tuck loops, the results are quite in contrary.

Keywords

Single jersey weft-knitted fabric; Curling surface; Yarn twist direction, Fabric structure

Introduction

A wide variety of knitted fabrics are commonly comprised of the single jersey-knit construction, ranging from sheer, lightweight hosiery to thick, bulky sweaters. These fabrics are of unbalanced structures which have a tendency to curl at the edges. This condition can frequently be corrected during the fabric finishing process. If not corrected, this problem can be quite troublesome in cutting and sewing processes [1].

In general, knitted fabrics have a three-dimensional structure. At the point where the new needle loop is drawn through the old loop, the structure is composed of two yarn thicknesses. During the loop formation, the needle loop is held down through both its head and feet, by the other loops in the same wale, but its side-limbs tend to curve upwards. When the fabric is cut, the loops are no longer held in this configuration; so that the fabric curling along the wale and course direction respectively occurs towards the fabrics technical face and technical back.

Doyle [2] described the curling behavior of plain-knitted fabrics and studied the effect of yarn elasticity, flexural rigidity and torsion rigidity on this phenomenon. Hamilton and Postel [3] analyzed the curling behavior of un-relaxed weft-knitted fabrics in terms of curling couple about the course and wale directions using a pure bending tester. Bühler et al. [4] developed a test method to measure the selvedge curling of plain-knitted fabric. Besides, they studied the effects of fiber type, yarn dying process, tightness factor, relaxation process, and condition and time of stocking on curling behavior of weft-knitted fabrics. Phukan and Subramaniam [5,6] investigated the effect of treatment on curling and proposed some methods to reduce it.

Ucar [7,8] used a multiple regression analysis to predict the curling distance of dry-relaxed cotton plain-knitted fabric based on mechanical parameters such as bending moment and flexural rigidity. Kurbak and Ekmen [9] also presented a new geometrical model for widthwise curling of plain-knitted fabrics. Basiri et al. [1] investigated the curling behavior of cotton dry-relaxed single jersey weft-knitted fabric using a new non-destructive test method in which the curling behavior could be characterized in terms of de-curling force at the peak point, and total de-curling energy.

Minapoor et al. [10] investigated the effect of fiber, yarn, and fabric parameters on curling phenomenon of single jersey weft-knitted fabrics which is interpreted to have curling surface in both course and wale directions. Through their researches, the curling behavior of fabric samples was predicted using artificial neural network in which the scale of conjugate gradient learning algorithm based on the selected process parameters was determined.

In this paper, the effects of the tuck and miss stitches and also yarn twist direction on the curling of single jersey knitted fabrics in terms of curling surface about the course and wale directions have been investigated.

Experimental

Samples preparation

In this research, two groups of fabric samples were produced in order to investigate the effects of yarn twist direction and the fabric structures individually on the curling phenomenon of single jersey knitted fabrics.

In this work, plain weft-knitted samples produced from cotton/polyester blended yarns have been employed for investigating the curling behavior affected by varying the yarn twist direction. The 70/30 blending ratio of cotton/polyester slivers (Ne_{sliver}=0.91) was utilized and the 27Ne spun yarns with two different twist directions (Z and S) were spun using a conventional ring spinning machine

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Table 1: Specifications of fibers.

Fiber type	Mean length (mm)	Fiber fineness (dtex)
Polyester	38(CV%= 4.5)	1.70(CV% ~ 0)
Cotton	28(CV%= 35.4)	1.38(CV%= 5.5)

Table 2: Characteristics of cotton/polyester yarns.

Yarn type	T.P.M *	Elongation Force (cN)	α_{Tex}
S-Type	568 (CV%= 4.1)	262.6 (CV%= 19.7)	~ 2658.2
Z-Type	609 (CV%= 3.2)	242.8 (CV%= 13.9)	~ 2850.1

* *Twist per Meter*

Table 3: Characteristics of plain weft knitted samples of blended yarns with different twist directions.

Fabric samples	Weight (g/m^2)	Thickness (mm)	CPC (course per cm)	WPC (wale per cm)	SD (stitch density)
Solely S-twist yarn	140	0.44	18.9	11.8	223.2
Solely Z-twist yarn	124	0.39	16.5	11.8	195.3
S-and-Z twist yarn (per courses alternatively)	134	0.39	16.5	11.8	195.3

Table 4: Characteristics of the produced knitted fabrics with different structures.

Fabric structures	Weight (g/m^2)	Thickness (mm)	CPC (course per cm)	WPC (wale per cm)	SD (stitch density)
Plain knit	55	0.29	18.9	11.8	223.0
Cross miss	113	0.41	24.4	14.9	363.5
Double cross miss	116	0.41	26.8	14.2	380.5
Triple cross miss	121	0.43	21.3	15.7	334.4
Cross tuck	78	0.39	12.6	9.4	118.4
Double cross tuck	80	0.42	7.9	9.8	77.4
Triple cross tuck	72	0.43	10.2	8.7	88.7

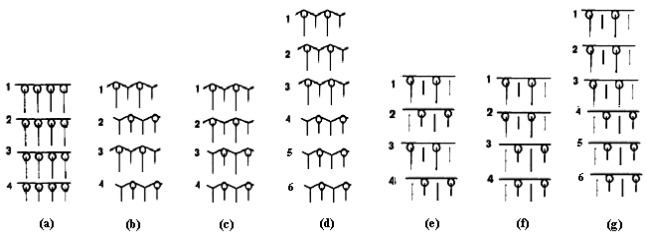

Figure 1: Knitted fabric structures; (a) plain knit, (b) cross tuck, (c) double cross tuck, (d) triple cross tuck, (e) cross miss, (f) double cross miss, (g) triple cross miss.

(Howa U32606, Japan). Table 1 shows the specifications of cotton and polyester fibers. In Table 2, the characteristics of two different-twisted yarns are available.

Three kinds of plain single jersey weft knitted fabrics were produced with different twist-direction spun yarns using a single jersey circular-knitting machine (Falmac, FSB3XSK, E 24, 16" diameter, 48 feeders, and 100 r.p.m).During the fabrics production, stitch densities of fabric samples remained constant. Fifteen samples were prepared among which one third of them solely comprised of the S-twist yarn, another third produced from the Z-twist yarn and the remaining were of S and Z twisted yarns per courses alternatively. The specifications of produced plain weft knitted samples after dry relaxation are given in Table 3.

As Minapoor et al. [10] reported that the fabric structure is the most important factor which affects the curling phenomenon of single jersey knitted fabrics. For this reason, the second group of single jersey knitted fabrics comprised of different loop type combination was produced. The required samples for investigating the effects of successive tuck and miss loops,were classified in three categories: (1) a plain single jersey fabric produced from knit stitches; (2) single jersey structures combined from tuck and knit stitches i.e. cross tuck, double cross tuck and triple cross tuck; (3) single jersey structures combined from miss and knit stitches i.e. cross miss, double cross miss and triple cross miss. The fabric samples were produced on the same single jersey circular-knitting machine using the textured 100Den polyester filament yarns. The knitted structures notation of the produced fabrics are shown schematically in Figure 1. Table 4 presents the specifications of the second group of samples after dry relaxation.

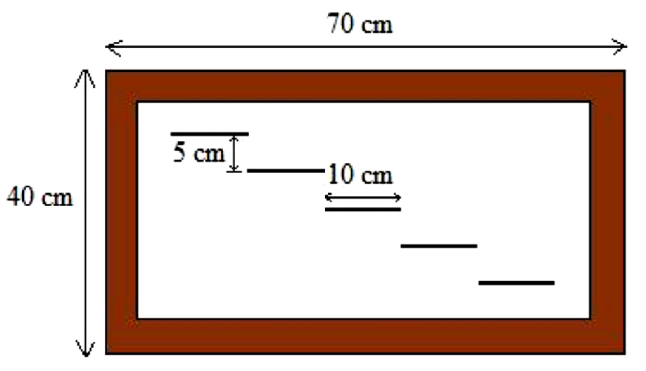

Figure 2: Plexiglas frame and its slots.

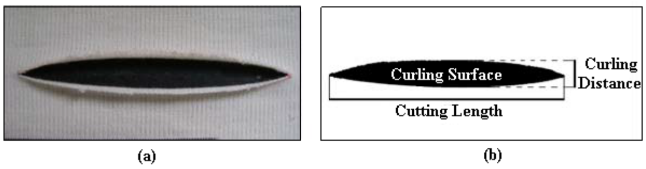

Figure 3: A typical image of curling shape (a) digital image and (b) binary converted image and the curling features.

Curling test

For investigating the curling phenomenon of produced fabrics, 75×45 cm^2 samples were cut immediately after taking off the fabrics from the knitting machine. Before testing, the fabric samples were conditioned and fully dry-relaxed at the room temperature and humidity conditions of 20 ± 2°C and 65 ± 2% R.H. for 24 hours.

According to the proposed method by Bühler et al. [4], each sample was laid on a flat surface without any crease or applied tension. To prevent any unevenness and measurement failure, samples were clamped on each edge using a Plexiglas frame. Five slots were created in different positions on the Plexiglas frame as shown in Figure 2. A line of 10 cm length should be drawn on the sample by a cutter in wale or course direction to measure the fabric curling. After cutting, the edges of fabric will curl as shown in Figure 3(a).

The images of curling shapes for each sample were taken using a digital camera. Applying the image processing of MATLAB software, the camera lens' errors were improved and a clear image was obtained

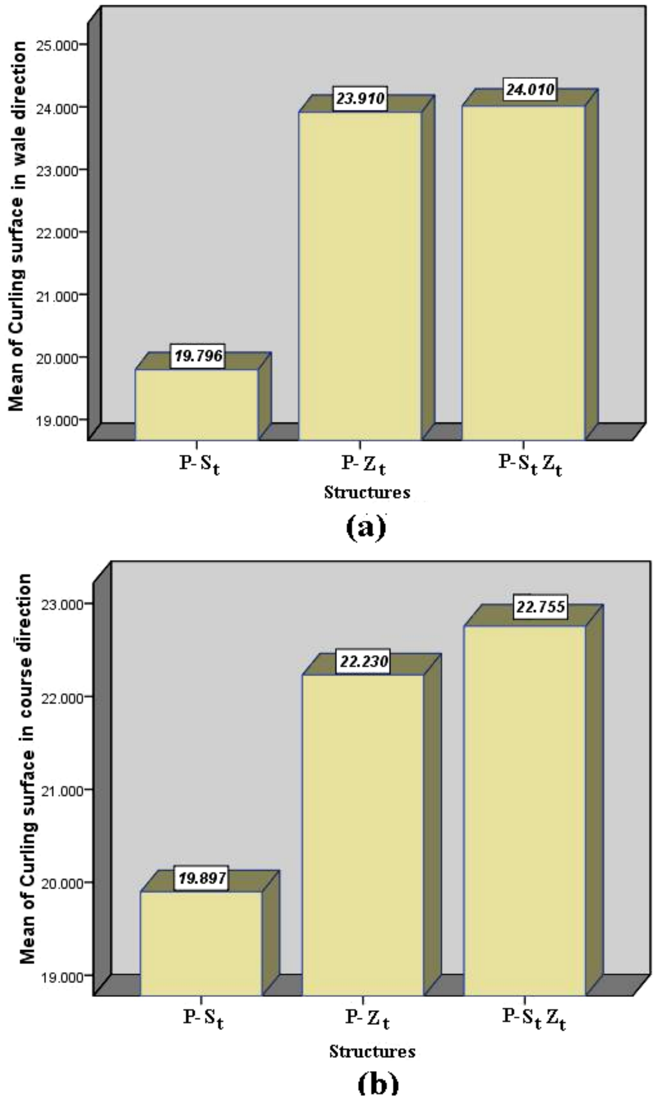

Figure 4: Comparison between the curling surface of structures; (a) in wale direction, (b) in course direction.

for analyzing the curling behavior. Also a line gauge was used to correct the image scales. Test was repeated five times for each knitted structure to achieve an acceptable coefficient of variation. A black layer was placed under the fabric samples as a background of the images. The high resolution captured images were constrained to a size of 70×40 cm² cm and saved as JPEG format. The RGB images were transferred into binary images which are typically shown in Figure 3(b). Using MATLAB software, three different features were extracted from the converted binary images of the curled samples in both wale and course directions individually as follows: (1) curling distance calculated in course (CD_C) and wale (CD_W) directions; (2) curling surface which can be defined as area of dark zone for cutting in course (CS_C) and wale (CS_W) directions; and (3) the ratio *CD/L* in course and wale directions where *L* is the cutting length.

Results and discussions

Results of the curling test for all samples in both course and wale directions are given in Tables 5 and 6. Values given in Table 5 refer

Table 5: Curling results of plain knitted structures comprised of different twisted-yarns.

Fabric code	CD_c*(cm)*	CD_c / L	CD_w*(cm)*	CD_W / L	CS_c *(cm²)*	CS_W *(cm²)*
P-S_t	1.59	0.16	1.57	0.16	19.90	19.80
P-Z_t	1.68	0.17	1.76	0.18	22.23	23.91
P- S_tZ_t	1.59	0.16	1.95	0.20	22.76	24.01

P-S_t : Plain knitted structure of S-twist yarn
P-Z_t : Plain knitted structure of Z-twist yarn
P-S_tZ_t : Plain knitted structure of S-twist and Z-twist yarns alternatively per course

Table 6: Curling results of different knitted structures.

Fabric code	CD_c*(cm)*	CD_c / L	CD_w*(cm)*	CD_W / L	CS_c *(cm²)*	CS_W *(cm²)*
P	2.16	0.22	2.55	0.26	29.81	33.70
C-T	2.20	0.22	2.44	0.24	30.45	36.91
D-C-T	1.54	0.15	1.96	0.20	22.50	25.08
T-C-T	1.92	0.19	1.77	0.18	26.93	23.34
C-M	1.35	0.14	2.28	0.23	18.08	32.33
D-C-M	0.99	0.10	2.87	0.29	11.10	38.39
T-C-M	1.88	0.19	2.34	0.23	16.35	32.84

P: plain C-T: Cross Tuck D-C-T: Double Cross Tuck
T-C-T: Triple Cross Tuck
C-M: Cross Miss D-C-M: Double Cross Miss T-C-M: Triple Cross Miss

Table 7: ANOVA results of the curling surface (Cotton/polyester plain knitted fabrics).

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Wale Direction	**Between Groups**	57.821	2	28.911	1.156E7	.000
	Within Groups	.000	12	.000		
	Total	57.821	14			
Course direction	**Between Groups**	23.144	2	11.572	4628892.667	.000
	Within Groups	.000	12	.000		
	Total	23.144	14			

to the curling features of plain knitted fabrics produced from blended yarns with different twist directions while the values in Table 5, are the curling features related to the polyester knitted fabrics of different knitted structures. The values of CD_C and CD_W in Tables 5 and 6 are the average amounts between five measurements for each sample. The statistical analyses of the curling results were also held using SPSS-software.

During the loop formation, forces of bending and torsion would be applied on the feeding yarn. Work done by these external forces is stored aspotential energy. During the curling phenomenon, the stored energy is going to release and the fabric reaches the lowest energy level.

Minapoor et al. [10] pointed out that higher required bending moments and loop energy could be a reason for increasing the curling phenomenon. On the other hand, more friction between yarns in the fabric structure makes it hard to release the stored energy and this can be a reason for lower curling values. They concluded that there are high correlation coefficients between three curling features. Thus, one of these curling features named curling surface was considered for further analyses.

Effect of Yarn Twist Direction on The Curling Surface

A one-way ANOVA test using Tukey method was applied for statistical analysis. Table 7 presents the ANOVA results of the curling

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surface in the wale and course directions for cotton/polyester plain knitted fabrics comprised of different twisted yarns. It's concluded that the effect of yarn twist direction on the curling behavior is statistically significant. The comparison of curling behavior between these three different fabric samples (P-S_t, P-Z_t, P-S_tZ_t) either in the wale or the course direction are given in Figures 4(a) and 4(b) respectively.

Generally, the legs of the formed loops in a knitted structure possess different yarn directions. In the case of using the S-twisted yarns, one of the loops' legs possesses S-twist direction while the other one has Z-twist direction. These loops are held tightly between other adjacent loops in the wale and course direction by their feet; so a torsional force applies to the loops' legs and made the loops' head to show in-plane bending. Since the direction of this torsional force remains the same as the force caused due to the twisted yarn, the resulted moment would be totally increased which in turn leads to more curling. On the other hand, if the torsional moment applies in the opposite direction to the curling force, the less curling phenomenon would be resulted. The same analysis is available for structures comprised of Z-twisted yarns. The only difference here is the position of twist directions on the loops' legs. In structures with Z-twisted yarns, the moment of torsional force have the same direction with the curling force which results in more curling phenomenon. The twist moment performance and its components are depicted in Figure 5.

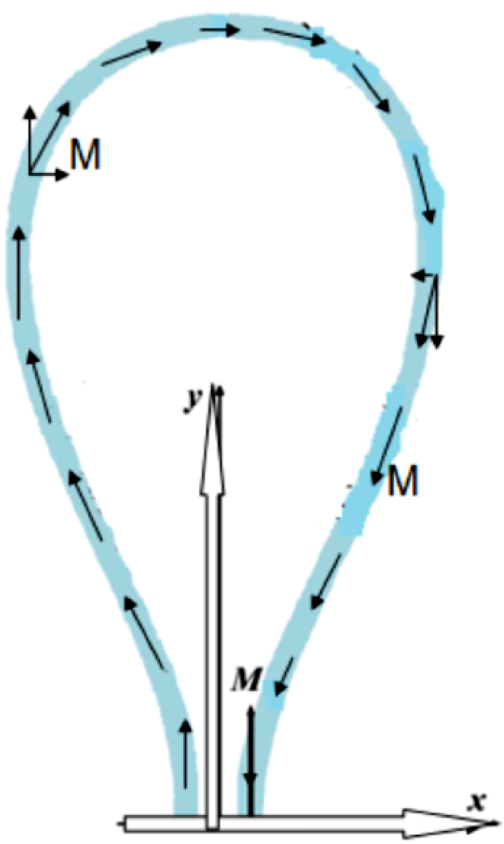

Figure 5: The twist moment and its components.

As the results show, the plain knitted fabrics with S-twisted yarns have the lower curling surface values in both wale and course directions. The fabric samples produced of Z-twist yarns presents the high curling surface than S-twist yarns. In fabrics comprised of two different twisted yarns, the force of Z-twist direction would be amplified and the much more torsional moment which has a direct effect on the curling would be increased. Totally it can be stated that

Table 8: ANOVA results of the curling surface (different polyester knitted structures).

		Sum of Squares	df	Mean Square	F	Sig.
Wale Direction	Between Groups	956.213	6	159.369	4209744.654	.000
	Within Groups	.001	28	.000		
	Total	956.214	34			
Course direction	Between Groups	1614.293	6	269.049	7242228.033	.000
	Within Groups	.001	28	.000		
	Total	1614.294	34			

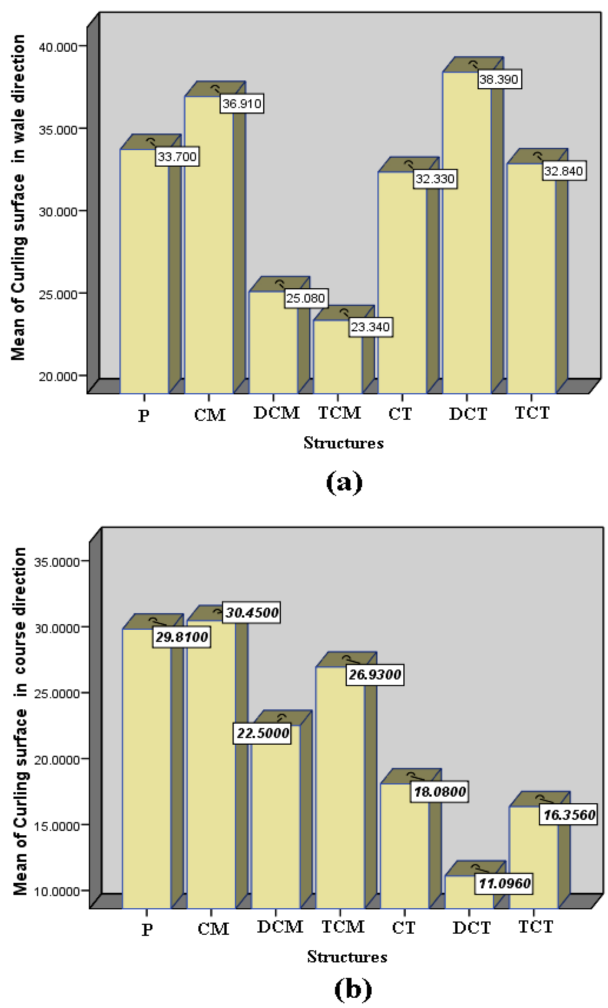

Figure 6: Comparison between the curling of structures; (a) in wale direction, (b) in course direction.

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the curling phenomenon is more happened in the wale direction of knitted fabrics.

Effect of fabric structure on the curling

The statistical analysis of curling surface results for different knitted structure fabrics produced form polyester filament yarns is given in Table 8. The comparison between the different structures is depicted through the diagram in Figure 6. The ANOVA table reveals that the fabric structure has a significant effect on fabric curling.

Knitted structures depend on their pattern are incorporated of three different loop shapes named as knit loop, tuck loop and miss loop. During the miss or tuck loops formation, the float yarn extends from the base of one knitted or tucked loop to the next. In the case of tuck loop, the held loop extends into the courses above until a knitted loop is formed in that wale. In analysis, a tuck stitch is identified by the fact that its head is released as a hump shape immediately the needle loop above it is withdrawn. A knitted loop would be required to be separately withdrawn and a miss stitch would always be floated freely on the technical back.

Different radius of curvature in knit, tuck, and miss loops, as shown in Figure 7, causes different applied bending moments and bending strain energy [10]. The strain energy in bending phenomenon (U_b) can be defined by Equation 1.

$$U_b = \frac{1}{2}\int \frac{M_b^2}{EI}\, ds \qquad (1)$$

where E is elastic modulus, I is the moment of inertia, and M_b is the bending moment which can be derived using equation 2:

$$M_b = B\frac{d\varphi}{ds} \qquad (2)$$

where B=EI is the flexural rigidity [11]. According to Equation 2, if the radius of curvature increases, applied bending moment decreases. Figure 7 shows that tuck and miss loops have bigger radius of curvature than knit loop. They need therefore low bending moment during loop formation process and subsequently low residual stress. This could be the reason for lower values of curling surface of the structures composed from tuck and miss stitches compared with plain knitted structures [10].

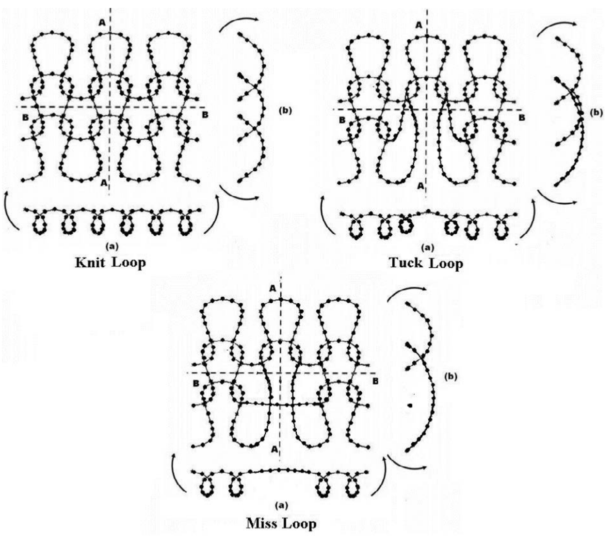

Figure 7: Schematic of three different loops; (a) and (b) are the view of A-A and B-B cross-sections of fabrics respectively. The arrows show the curling behavior in both wale and course directions.

In overall, in the wale direction, the difference between the curling surface of plain fabric and the fabrics containing tuck stitches is not very much. According to Figures 7(a) and 7(b), the bending and torsional moments are responsible for the curling in wale direction. Generally, the bending and torsional moments applied to tuck stitches is lightly less than knit stitches. In opposite, in the course direction, due to bigger radius of curvature, lower bending moment is needed to form the tuck loops. Therefore, the energy saved in structures comprised of tuck stitches will be lower than that of the other structures and they represent lower curling surface in course direction.

Cross miss structure represents the higher curling surface than plain fabric in both course and wale directions. The miss loop shows the yarn floating freely on the reverse side of the held loop. Miss loops reduce fabric width and width-wise elasticity because the higher yarn tension on the held loops causes them to rob yarn from adjacent knitted loops, making them smaller and providing more stored energy. It has been found that increasing the stitch density resulted in higher bending rigidity and hence a higher curling couple for plain-knitted fabric [10]. As a result, it is deduced that fabric samples with a lower loop length exhibit a higher curling tendency. The presence of two successive miss loops on the same needle leads to higher yarn tension on the held loops, more the yarn robbing from adjacent knitted loops , and increasing the fabric density. Due to higher fabric stitch density, it is expected to greatly reduce the curling tendency. However, the opposite trend is observed. In double cross miss structure, the number of miss loops is multiplied. This can reduce greatly the applied bending moment on the yarn as well as stored energy during loop formation. It seems that this factor has more dominant effect compared with the effect of fabric stitch density. Three successive misses on the same needle which create triple cross miss structure leads to increase the gaps on the fabric surface. This can reduce the stitch density as is shown in Table 4, and subsequently reduce more greatly the applied bending moment on the yarn as well as stored energy during loop formation. It seems that yarn robbing has more dominant effect compared with the effect of applied bending moment.

The findings reveal that the number of successive tuck and miss loops on the same needle plays an important role on the curling of knitted fabrics. The least values of fabric curling surface in course direction were observed for the structures composed from tuck stitches. The structures contain knit and miss loop represent lower values of the curling surface in wale direction in comparison with the course direction. When a needle holds its old loop and also receives the new loop, a tucked loop would be produced. Due to the presence of held loops in would be increased, friction between yarns in contact points would be increased. As it is shown in Table 4, the stitch density of the weft knitted fabrics containing tuck stitches has been remarkably reduced. Therefore, curling of this structure will be lower than plain structure in the same condition.

Also, it could be concluded that the cross tuck structure represents lower value of curling surface than cross miss structure, either in course or wale directions. This can be due to lower stitch density of structures containing tuck stitches compared with those comprised from miss stitch. Oppositely, the double cross tuck gives the structure higher curling surface in wale direction compared with those comprised from tuck stitch. In double cross tuck structure, tuck

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loops are placed in back of held loops which lead to more friction than plain structure. Increasing the number of tuck loops results in more friction in contact point and consequently the curling behavior in such structures would be decreased. The structures comprised of three successive tucks on the same needle, i.e. triple cross tuck structure can intensify the yarn robbing back from the adjacent knitted loops and also simultaneously reduce more greatly the applied bending moment on the yarn as well as stored energy during loop formation. It seems that yarn robbing which leads to higher stitch density, has more dominant effect compared with the effect of yarn friction.

Conclusion

The curling phenomenon always occurred in single jersey knitted fabrics due to the stored residual stress through the loop formation as well as the torsional forces applied to the twisted yarns. In this study, the effects of fabric structure and yarn twist direction on the curling behavior have been investigated. The results showed that Z-twisted yarns in fabric structures, increase the curling surface in both wale and course directions. The torsional forces of the formed loops and the twist moment have the same direction to the curling force; consequently, using Z-twisted yarns results in more fabric curling.

The comparison between different knitted fabric structures revealed that the presence of tuck loops in fabrics results in fabric curling decrement. During the tuck loop formation, the higher yarn tension on the held loop causes them to rob yarn from adjacent knitted loops. This in turn causes more moment to the loop and the higher curling would be expected. But the results showed that the friction between the yarns in contact points has a significant effect on the curling reduction. It has been figured out that the structures comprised of tuck and knit loops present lower curling phenomenon. In this study, double cross tuck and triple cross miss structures showed the lower and higher curling, respectively. Totally it could be stated that the structures possess miss loops have the lower curling surface in the wale direction while it is opposite in the course direction. For structures including tuck loops, the results are quite in contrary.

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