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Seam elongation behavior of knitted fabrics due to donning-doffing.

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Seam elongation behavior of knitted fabrics has been studied along with the effect of various parameters like stitch type, sewing thread, fabric direction and fabric layers on the strain encountered by seams in knitted garments. Seam strain is assessed both in longitudinal and transverse directions under tensile loading. The experimental results show that these parameters affect seam elongation differently when stressed in longitudinal and transverse directions. Occurrence of seam cracking is observed in lockstitch when elongated in longitudinal direction. A phenomenon known as seam grinning is observed in all transverse direction loads. This paper also reports the effect of above parameters on the grinning behavior of seams at different elongation percentage (30% and 40%) of seams. It is found that over-lock stitch gives the maximum amount of seam grin. Fabric stitched in wales direction and fabric layers formed by joining two plain knitted fabrics give higher amount of seam grinning.

Keywords: Donning-doffing, Longitudinal direction, Plain knit fabric, Rib knit fabric, Seam elongation, Seam cracking, Seam grinning, Transverse direction

1 Introduction

Stitches and seams are prerequisite in garment industry for apparel construction and seam quality. A good seam quality means, a seam should bear quality such as good seam strength, elasticity, durability, balanced sewing thread tension and higher seam efficiency[1]. Seams are subjected to repeated stress during daily use, such as walking, sitting, squatting down, etc. depending on the application of garment and position of the seam in the garment[2]. Donning and doffing also cause considerable stress in the clothing and thus leads to the extension of fabric and seam as well. During garment wear process, certain parts of fabric are stretched in various directions by forces of different intensity. Body movements, garment design and seam characteristics decide the forces acting on the seams in clothing[3].

Knitted fabrics are known from years for their excellent elasticity over other fabrics, and hence knitted garments are designed to utilize their characteristic elongation and to accommodate body movements, which are responsible for imparting seam stress in different directions[3]. Seam and fabric extensibility should match with each other, otherwise seam extension may lead to sewing thread breakage and seam cracking. Weft knitted structures extend by 80-100%, thus knitted fabric is more extensible than the seam substrate. So, the seams in such stretchable garments should also provide sufficient elongation to avoid garment distortion, wearer discomfort and seam failure[4]. It is reported that 25-30% and 40-60% extension is needed for normal comfortable clothing and sportswear respectively to accommodate body movements. Extensibility greater than about 60% is not normally required, except in fabrics designed for special applications like pantyhose[5].

Due to repeated loading, several seam defects like seam slippage and seam grinning occur[6]. Seam grin is the separation of sewn seam as a result of transverse stress that allows the stitches and threads to reveal a gap between the seam line joining two fabrics. This seam opening is a kind of seam failure which enables the movement of sewing thread at either side of the seam and is known as seam grinning[7].

Studies were conducted to determine the effect of some properties on seam strength, elongation and seam grinning. Seam elongation is positively affected by initial modulus of thread, loop length and yarn twist factor of knitted fabric[8]. Seam strain increases with increase in thread linear density and is higher for chainstitch seams as compared to lockstitch seams[8]. Researchers studied the effect of fabric thickness on seam elongation and found that seam elongation increases with increase in fabric thickness for straight

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Table 1 — Fabric specifications

Fabric	Fabric weight GSM	Courses per inch (CPI)	Wales per inch (WPI)	Loop length mm	Linear density tex	Tightness factor	Tensile strength N			Elongation %		
							Wale-wise	Course-wise	Bias	Wale-wise	Course-wise	Bias
Plain knit	129.5	30	52	2.74	21.3	0.1684	558.6	500.5	612.1	103.82	142.38	99.36
Rib knit	318.7	50	32	2.76	27	0.1883	1167.8	506.2	728.4	153.34	461.62	182.42

lockstitch seams at any value of stitch density[9]. An increase in number of fabric plies increases seam elongation by increasing the amount of sewing thread per unit seam[10]. Studies have shown that seam elongation increases as sewing thread elongation increases[10]. Researchers, however, have shown that for industrial lockstitch machines, maximum seam elongation was obtained when needle thread was slightly longer than the bobbin thread per stitch[11,12].

Researchers have found that the seam slippage and grinning of the sewn fabrics increase with decreasing weft density and increasing fabric extensibility[13,14]. Ucar[15] investigated the effect of mechanical properties of knitted fabric on seam grinning, and reveals that an increase in fabric rigidity and sewing thread extensibility as well as a decrease in stitch density result in an increased amount of seam grinning[15].

Although there are several studies related to seam defects in the form of seam slippage and seam failure occurring in knitted fabrics, there are a limited number of studies relating to seam grinning behavior of knitted fabrics. Most of the work reported has been done on woven fabrics. In this study, the influence of various stitch parameters on seam extensibility in longitudinal and transverse direction and the grinning behavior of seam in knitted fabrics have been studied.

2 Materials and Methods

2.1 Materials

In this work, commercially available plain and rib knitted fabrics were used. The selection of the fabrics was based on their suitability as per the daily physical activities of human being for the upper body garments. The impact of different stitch type, sewing thread, fabric direction and fabric layer on seam elongation and seam grinning was studied. Two types of sewing thread (100% spun polyester and polyester/cotton core spun), which are most commonly used in sewing knitted fabric, were selected. All the fabrics were stitched using ball point needle of size 12 with three different types of stitches, viz lockstitch, overlock stitch and chainstitch. A ball point needle of size 12 was used for stitching all the samples and needle was replaced after every 20 specimens. Stitching is done using Juki Single Needle Lockstitch Machine DDL 8300N, Juki 3Overlock stitch Machine MO-6700S and Chainstitch Machine. The specifications of fabric and sewing thread are given in Tables 1 and 2 respectively.

Table 2 — Sewing thread particulars

Particulars	Thread 1	Thread 2
Type	100% spun polyester	P/C core spun
Ticket no	120	120
Linear density, tex	27	27
Ply	2-ply	2-ply
Breaking strength, N	9.34	12.01
Elongation, %	16.3	20.5

2.2 Sample Preparation

Three sets of fabric samples, viz wale-wise, course-wise and bias direction of size 100 mm ×200 mm were cut from both fabrics as shown in Fig. 1. Then these samples were paired with each other to give two different types of fabric layers. In one type, the both the superimposing layers were of plain knitted fabric (denoted as P+P) and in the other type, one layer of plain knitted fabric was superimposed with one layer of rib knitted fabric (denoted as P+R).

2.3 Methods

2.3.1 Measuring Seam Elongation

An Aimil tensile testing machine was used with the following machine setting adjustments: gauge length 75 mm and speed 220 mm/min. The test method was set up according to ASTM D 6193[16]. All the samples were stitched using three different stitch types. Seamed specimens were mounted in tensile testing machine with the seam centrally positioned in the jaws in both directions (longitudinal and transverse) till the first stitch or sewing thread breaks as shown in Fig. 2. This break was accurately located on the load

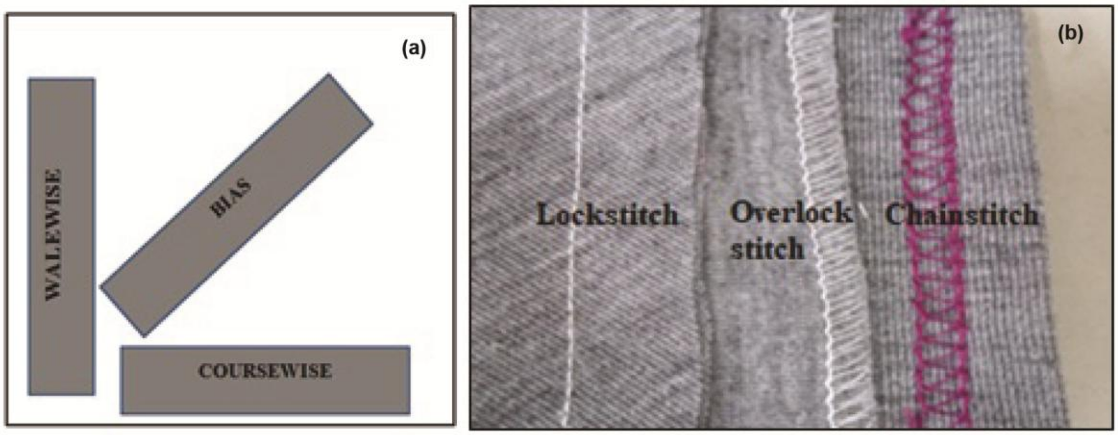

Fig. 1 — (a) Sample preparation in three directions and (b) lockstitch, overlock stitch and chainstitch

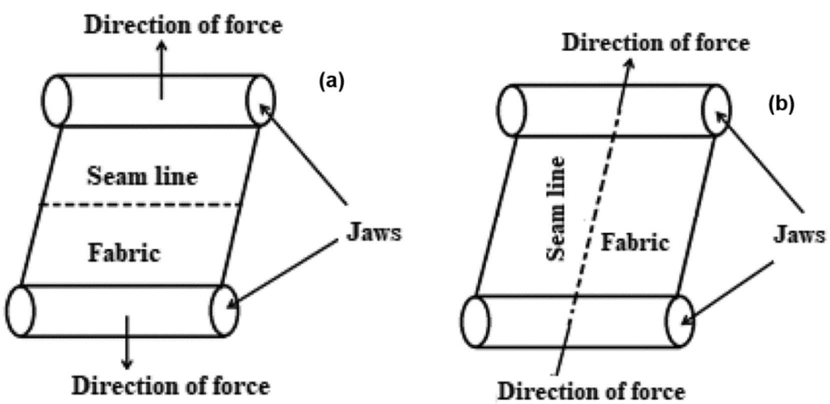

Fig. 2 — Seamed specimen in (a) transverse direction and (b) longitudinal direction

elongation curve, where it is shown as a small but definite discontinuity on the graph. The apparent seam elongation% was calculated at this point using the following formula:

$$\text{Apparent seam elongation} = \frac{\text{Seam elongation at first stitch break (mm)}}{\text{Gauge length (75 mm)}} \times 100 \quad \ldots (1)$$

2.3.2 Measuring Seam Grinning

The test to measure seam grinning was set up according to ASTM D 5034 (Grab method)[17]. Specimen dimensions were 200×100 (±1) mm and gauge length was set as 75 mm. The strain encountered in the garment was represented by 30 % and 40 % extension, since an elongation of 25-40 % is required for normal comfortable clothing. The length of seam grinning was measured immediately in the stretched condition with an accurate linear compass to avoid any recovery at 30% and 40% extension after 10 cycles.

3 Results and Discussion

3.1 Effect of Different Parameters on Seam Elongation of Knitted Fabrics

Table 3 shows the results showing the influence of stitch type, sewing thread, fabric direction and fabric layers on seam elongation% in both longitudinal and transverse directions.

The effect of these parameters on seam elongation has been discussed in detail by considering the average values of a particular parameter in all conditions for both longitudinal and transverse directions.

3.1.1 Influence of Stitch Type on Seam Elongation

The influence of stitch type on seam elongation is depicted in Fig. 3(a). It is observed that when seam is elongated under longitudinal stress, lockstitch gives lowest seam elongation followed by overlock and chainstitch. Figure 3(a) shows that lockstitch gives around 23% elongation in longitudinal stress which is lower than the minimum amount of seam elongation required for comfortable clothing (30%). Such lower elongation of lockstitch leads to seam cracking in knitted

Table 3 — Apparent seam elongation at-break

Stitch type	Seam Layer	Seam elongation, %											
		Spun polyester sewing thread						Core spun sewing thread					
		Wale-wise		Course-wise		Bias		Wale-wise		Course-wise		Bias	
		L	T	L	T	L	T	L	T	L	T	L	T
Lock stitch	P+P	17.73	81.2	18.67	150.5	20.53	79.6	24.67	91.3	22.13	163.3	25.33	87.3
	P+R	19.07	103.6	21.20	257.3	21.60	83.2	26.67	115.2	32.67	307.7	33.33	93.6
Overlock stitch	P+P	47.8	73.3	52.3	101.5	46.77	60.3	59.7	70.1	57.6	132.9	49.07	63.3
	P+R	52.4	82	56.4	238.1	51.1	86.5	63.7	90.5	60.9	266.7	52.5	88
Chain stitch	P+P	51.63	70.8	54.4	98.1	56	69.5	66.1	73.6	66.1	104.6	58.4	72.4
	P+R	57.7	87.1	61.1	172	62.3	92.3	69.6	98.4	72.3	200	69.5	97.1

P+P- Plain-plain layer, P+R- Plain- rib Layer, L-Longitudinal direction and T-Transverse direction.

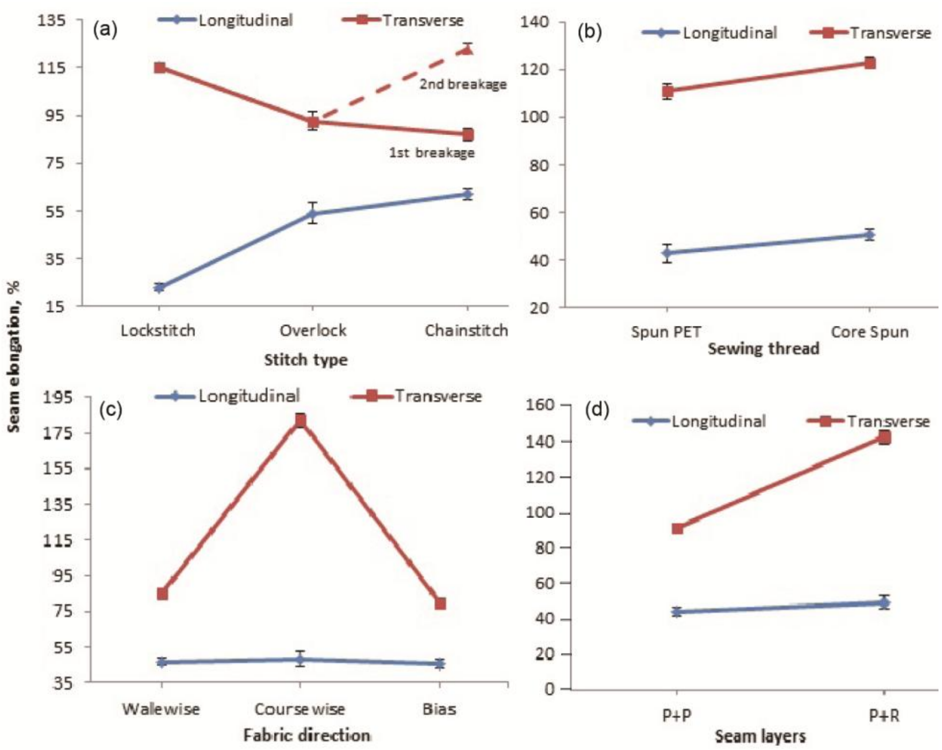

Fig. 3 — Effect of different parameters on seam elongation (a) stitch type, (b) sewing thread, (c) fabric direction and (d) seam layers

fabrics. It is also observed that lockstitch has a tendency to run back on breakage when elongated along the seam line. Higher seam elongation of overlock and chainstitch is due to increased amount of sewing thread per unit stitch length and angular placement of stitches, which allows them to straighten out under stress.

On the other hand, lockstitch gives highest seam elongation when elongated in transverse direction. It can be seen from Fig. 3(a) that the transverse load behavior of chainstitch is giving two breakages. It is due to the configuration of chainstitch which consist of two stitches in parallel line connected by angular threads superimposed on one another, which provides extra support for each single stitch within one chainstitch. Therefore, a lower load is carried by a single stitch in chainstitch. In this work, seam failure at 1st stitch break was considered which give lesser elongation value in chainstitch in transverse direction. From Fig. 3(a), it can also be seen that if 2nd stitch break will be considered, then chainstitch will give highest seam elongation.

3.1.2 Influence of Sewing Thread on Seam Elongation

The effect of sewing thread on seam elongation is illustrated in Fig. 3(b). It can be seen that seam elongation in both longitudinal and transverse directions is greater for seams sewn with core spun sewing thread. Table 2 shows that the per cent elongation-at-break of core spun sewing thread is higher than the spun polyester thread due to the presence of core filament in the core-spun sewing thread[18]. Higher breaking strength of core-spun sewing thread as compared to spun polyester sewing thread results in higher seam elongation in core spun sewing thread in both the directions.

3.1.3 Influence of Fabric Direction on Seam Elongation

Figure 3(c) shows the effect of fabric direction on seam elongation. It is observed from Fig. 3(c) that the seam elongation in all three fabric directions in the longitudinal direction is nearly same, whereas seam elongation changes drastically in transverse direction and is found higher in course direction. This may be due to the fact that in longitudinal direction, the seam is elongated along the seam line and only the seam shares the total load exerted. On the other hand, in transverse direction, seam is elongated in a direction perpendicular to the seam line and so, the fabric also shares the load and gets elongated until the force is exerted over the sewing thread.

Also, it can be seen that course direction is giving highest seam elongation when elongated under transverse load. It may possibly be due to the opening of loops giving higher elongation of fabric itself in course direction[18,19]. On the other hand, lower seam elongation in wale and bias direction is because its loop structure does not support extension of loops.

3.1.4 Influence of Fabric Layers on Seam Elongation

The effect of different fabric layers on seam elongation is illustrated in Fig. 3(d). It is observed that the changes in seam elongations obtained by changing the seam layer from Plain-Plain layer to Plain-Rib layer are smaller in longitudinal elongation than in transverse elongation. It is again due to the same reason as explained previously that load is shared by the seam alone in longitudinal direction. The higher value of seam elongation in transverse direction with highest value in P+R layer is due to the incorporation of rib fabric in the seam layer. It can be seen from Table 1 that rib fabric is more extensible (153.34%) than plain knitted fabric (103.82%) and, so the rib component of the fabric layer extends to a larger amount, thus giving higher seam elongation.

3.1.5 ANOVA Results for Seam Elongation

Table 4 shows the ANOVA results for seam elongation values in longitudinal and transverse directions. The contribution % of each factor on seam elongation was calculated for both cases.

From Table 4, it is clear that stitch type is the most influencing parameter in affecting seam elongation (90%) in longitudinal direction followed by sewing thread (5%) and fabric layer (2.2%), whereas fabric direction has no significant effect

Table 4 — ANOVA of seam elongation in both longitudinal and transverse directions

Effect	Longitudinal direction					Transverse direction				
	SS	D.f.	MS	F	%C	SS	D.f.	MS	F	%C
Fabric layer	220.57	1	220.57	120.28	2.2	23291.8	1	23291.8	545.96	17
Sewing thread	556.72	1	556.72	303.60	5	1458.0	1	1458.0	34.17	1
Fabric direction	36.91	2	18.45	10.06	0.3	78525.9	2	39262.9	920.33	57
Stitch type	9901.08	2	4950.54	2699.66	90	6235.6	2	3117.8	73.08	4.5
Fabric layer*sewing thread	6.28	1	6.28	3.42	0	182.7	1	182.7	4.28	0.1
Fabric layer*fabric direction	8.42	2	4.21	2.30	0.1	18595.1	2	9297.6	217.94	13.5
Sewing thread*fabric direction	48.99	2	24.49	13.36	0.5	831.7	2	415.9	9.75	0.6
Fabric layer*stitch type	13.04	2	6.52	3.56	0.1	357.1	2	178.5	4.19	0.3
Sewing thread*stitch type	20.66	2	10.33	5.63	0.2	96.3	2	48.1	1.13	0.1
Fabric direction*stitch type	108.65	4	27.16	14.81	1	6432.1	4	1608.0	37.69	4.7
Fabric layer*sewing thread*fabric direction	7.78	2	3.89	2.12	0	121.5	2	60.7	1.42	0.1
Fabric layer*sewing thread*stitch type	14.70	2	7.35	4.01	0.1	52.3	2	26.1	0.61	0
Fabric layer*fabric direction*stitch type	11.45	4	2.86	1.56	0.1	1382.1	4	345.5	8.10	1
Sewing thread*fabric direction*stitch type	40.50	4	10.13	5.52	0.4	86.4	4	21.6	0.51	0
Error	7.34	4	1.83		0	170.6	4	42.7		0.1

(0.3%). On the other hand, fabric direction is the most influential factor (57%) followed by fabric layer (17%), stitch type (4.5%) and sewing thread (1%) in transverse direction.

3.2 Effect of Different Parameters on Seam Grinning of Knitted Fabrics

It is observed that all the seams result in some amount of seam grin when stressed in transverse load (Fig. 4). So, the effect of different parameters on seam grinning is studied at 30% and 40% elongation. Table 5 shows the seam grinning values of different samples at 30% and 40% elongation. The individual effect of different parameters on the amount of seam grinning is discussed hereunder.

3.2.1 Influence of Stitch Type on Seam Grinning

Figure 5(a) shows the effect of different stitch types at 30% and 40% elongation on seam grinning.

It is clearly visible from Fig. 5(a) that chainstitch gives highest seam grinning at 30% elongation and overlock stitch gives highest seam grinning at 40% elongation, and lockstitch gives lowest value of seam grinning for both elongation%.

Fig. 4 — Seam grinning

Lower seam grinning of lockstitch may be due to its compact structure which resists it to extend and reveal sewing thread. On the other hand, overlock and chainstitch consist of larger amount of thread and show comparatively loose arrangement of threads which make it easier for these stitches to stretch and reveal sewing thread when under transverse load. With increase in elongation percentage from 30 to 40, seam grinning for lockstitch and chainstitch increases from 0.2 mm to 0.5 mm, whereas for overlock stitch the increase is above 1 mm. Such exceptionally higher seam grinning of overlock stitch at 40% elongation may be attributed to the angular placement of stitches and lower stitch tension in overlock stitch, which allows them to straighten out. So, the garment stitched with overlock stitch has the maximum tendency to show seam grinning[7].

3.2.2 Influence of Fabric Direction on Seam Grinning

Figure 5(b) shows the effect of fabric direction on seam grinning. It is analyzed that seam grinning is highest in wales and lowest in course direction for both elongation percentages. Also, it is observed that seam grinning is more at 40% elongation than at 30% elongation. It is known that when transverse load is applied on the seam, it first causes deformation and then seam grinning.

The reason behind higher seam grinning in wale and bias directions than in course direction may be the lower elongation of fabric in wale and bias directions as compared to that in course direction. It happens because when the fabric elongation is higher, then the load applied will be shared by the fabric to a larger extent as compared to seam and does not allow seam line to reveal the sewing thread, thus reduces seam grinning. Therefore, high elongation of knitted fabric in course direction can be the reason for its lower seam grinning.

Table 5 — Seam grinning

Sample	Stitch type	Seam grinning, mm											
		Spun PET sewing thread						Core spun sewing thread					
		Walewise		Coursewise		Bias		Walewise		Coursewise		Bias	
		30%	40%	30%	40%	30%	40%	30%	40%	30%	40%	30%	40%
P+P	Lockstitch	1	1.5	0.5	0.8	0.7	1	1.5	2	0.8	1	0.6	1
	Overlock	2.8	3.5	2.5	3	3	3.2	3	3	2	2.5	2.7	3
	Chainstitch	2.5	3	2	2.5	2.2	3	3	3.5	2.5	3	2.8	3
P+R	Lockstitch	0.8	1	0.3	0.5	0.5	0.8	1.2	1.5	1	1	1	1.2
	Overlock	2.5	3	2	2.5	2.3	2.8	2.8	3.2	2	3	2.5	3
	Chainstitch	1.7	2	0.8	1	1.5	2	2	3	1.5	2.5	2.5	2.8

P+P- Plain-plain seam layer; P+R- Plain-rib seam layer. 30% & 40%- elongation.

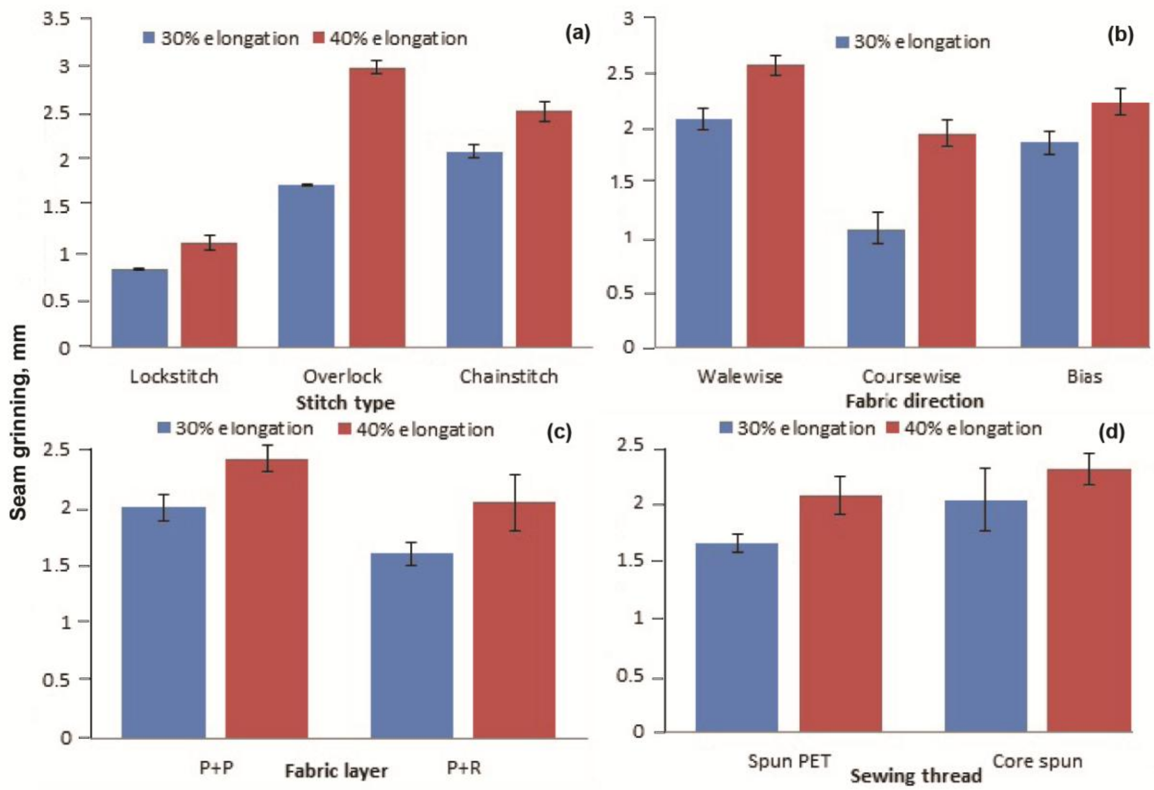

Fig. 5 — Effect of different parameters on seam grinning (a) stitch type, (b) fabric direction, (c) fabric layer and (d) sewing thread

Table 6 — ANOVA of Seam grinning

Effect	SS		D.f.		MS		F		%C	
	30%	40%	30%	40%	30%	40%	30%	40%	30%	40%
Stitch type	18.3906	23.4756	2	2	9.1953	11.7378	5517.17	1006.10	72.06	75.68
Fabric direction	2.0339	1.9839	2	2	1.0169	0.9919	610.17	85.02	7.97	6.39
Fabric layer	1.4400	1.2469	1	1	1.4400	1.2469	864.00	106.88	5.64	4.02
Sewing thread	0.9344	1.0336	1	1	0.9344	1.0336	560.67	88.60	3.66	3.33

3.2.3 Influence of Fabric Seam Layer on Seam Grinning

It is observed from Fig. 5(c) that seam layer formed by joining plain and rib fabric together gives lower seam grinning as compared to plain and plain layer. Seam grinning occurs when fabric is elongated in transverse direction, and it can be seen from Table 1 that rib fabric gives much higher elongation than plain knitted fabric. So, (P+R) layer gives higher extensibility than (P+P) layer. If the fabric extensibility is more, then the load will be experienced by both fabric and seam. Thus, (P+R) layer offers much high extensibility than (P+P) layer and, so it will give less grinning.

3.2.4 Influence of Sewing Thread on Seam Grinning

Figure 5(d) shows the effect of sewing thread on seam grinning. It is observed that seam grinning is more in case of fabrics sewn with core-spun sewing thread as compared to those sewn with spun polyester thread. This difference may be due to higher extensibility of core-spun sewing thread than spun polyester sewing thread. Higher extensibility of sewing thread will cause the sewing thread to extend more on the application of load[14]. Due to this, seam line will make the sewing thread visible to a larger extent, thus leading to increase in seam grinning. So, seam grinning is more with core-spun sewing thread for both the elongation percentages.

3.2.5 ANOVA Results for Seam Grinning

ANOVA results of grinning behavior by varying different parameters are summarized in Table 6. The contribution percentage of each parameter has been evaluated using ANOVA.

From Table 6, it can be seen that stitch type contributes to the maximum (~ 75%) in seam grinning among all the factors. Thus, stitch type is the most significant factor affecting seam elongation. So, it can be said that seam grinning can be reduced by using chainstitch.

4 Conclusion

Stitch type is the leading parameter affecting seam elongation in longitudinal direction. Overlock and chainstitch gives high seam elongation in longitudinal directions. A phenomenon known as seam cracking occurs in lockstitch when knitted garment is elongated in longitudinal direction. Course direction gives higher seam elongation as compared to wale and bias directions. Seam layer formed by stitching plain and rib fabric together gives higher seam elongation than seam layer formed by stitching plain and plain fabric. Sewing thread influences seam elongation considerably but to a lesser extent. Core-spun sewing thread gives higher seam elongation as compared to spun polyester.

As the knitted fabric is elongated in transverse direction, seam grinning occurs in all the fabrics to a varying amount. The decreasing order of parameters influencing seam grinning is:

Stitch type > fabric direction > fabric layer > sewing thread.

Stitch type is the most influencing factor affecting seam grinning and maximum seam grinning is observed in overlock stitch. Seam grinning is more in garments stitched with core-spun sewing thread than in spun polyester sewing thread due to higher extensibility of core-spun sewing thread. Seam grinning decreases with increase in extensibility of knitted fabric and is, therefore, more in wales and bias directions. Seam grinning is more in plain-plain seam layer.

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