Indian Journal of Fibre & Textile Research
Vol 46, March 2021, pp. 22-28

Seam performance of knitted fabrics based on seam strength and seam efficiency

Payal Bansal[a], Monica Sikka & AK Choudhary

Department of Textile Technology, Dr B.R. Ambedkar National Institute of Technology, Jalandhar 144 011, India

Received 16 March 2020; revised received and accepted 22 June 2020

The current study has been conducted on 100% cotton, polyester/cotton and cotton/lycra single jersey fabrics for investigation of seam performance in term of seam strength and seam efficiency. The influence of various parameters, viz. sewing needle size, sewing needle type and seam angle, on seam performance of these fabrics have been studied and analyzed. The response surface methodology is employed to investigate their effect on seam strength and seam efficiency by analysis of variance and regression equations. The test results reveal that cotton and cotton/lycra fabrics have lower seam strength as compared to polyester/cotton fabric. Also, with increase in seam angle and needle size, seam strength decreases. However, with sewing needle type, an increase in seam strength is observed for all the three fabrics. The cotton/lycra half plated fabric shows higher seam efficiency among all the three fabrics. It is noted that seam efficiency increases with seam angle and sewing needle type. It has been found that SES needle type (Small ball point) exhibits poor seam efficiency but an improvement in efficiency has been observed with SUK (Medium ball point) and SAN needle type (Conical point) for all three knitted fabrics.

Keywords: Cotton, Lycra, Polyester, Seam angle, Seam efficiency, Sewing needle type, Sewing needle size, Seam strength

1 Introduction

The physical and mechanical stability of single jersey knitted fabric has been one of the most widely investigated areas for many years[1,2]. The apparel shape for wearing purpose is generally given by joining different components of fabrics together using stitches and seams during the sewing process[3,4]. Sewing is a complex technique in garment industry that aims to achieve superior quality product. The total concept of product quality can be divided into two parts, viz. intrinsic and extrinsic[5,6]. Intrinsic refers to the enduring property of the apparel product, like fabric, fit and style of the garment and seam quality, while cost of the product, brand names, visual display and promotional strategies come under the category of extrinsic. The industries have been striving to produce high quality garments by improving the quality of the seam so that any kind of rejection from its buyers can be avoided[7,8]. Seam strength, seam efficiency, seam slippage and seam puckering are the parameters, on the basis of which, seam performance can be analyzed. Among all these parameters, seam strength and seam efficiency play a significant role as far as the quality aspect is concerned[9]. Alongside, there are other parameters which also influence the seam strength and seam efficiency of garment, such as fabric characteristics, direction of fabric, stress location on the seam line, sewing thread, sewing machine, sewing needle type, stitch and seam types[10-12]. The sewing needle size and type is one of the basic elements that directly contributes to seam formation. During sewing process, the approach of sewing needle at the time of penetration into the fabric structure generates different impact on seam strength and seam efficiency[13-15]. Optimtized parameter selection not only facilitates manufacturing process of garment but also helps to reduce their defects and enhances durability.

Investigation on the effect of different bias angles of stitching on seam strength and seam breaking extension of wool suits has been studied and the outcome revealed higher seam strength with 0°, 45° and 90° bias angles[16]. In the identification of seam performance of natural wool textile fabrics, seam quality was measured by seam strength, seam elongation, seam efficiency and seam stiffness. The result showed highest value of seam strength, seam elongation, seam performance and seam stiffness for seam type SSw followed by the lapped seam type LSq and the superimposed seam SSa-1[17]. During another related research, the results of seam performance based on seam strength, seam efficiency, seam pucker, seam slippage of woven fabrics concluded that the cotton fabrics sewn with any

---

[a] Corresponding author.
E-mail: payal888y@gmail.com

kind of sewing thread had similar seam efficiency values. For polyester fabrics stitched with core-spun polyester sewing thread, low seam efficiency values were obtained[18]. Investigation on the seam strength and seam performance with different stitches per inch on different fabrics showed that with an increase in stitches per inch, the seam strength is known to increase[19]. Study on the impact of stitch density on seam strength, seam elongation, and seam efficiency was done for 100% cotton muslin fabric. The results depicted that stitch density influences both the strength and elongation of the seams[20]. In another study, the effect of seam strength on different types of fabrics and sewing threads was accomplished using 100% cotton with three different weaves, viz. plain, twill and satin. Twill fabric has the maximum seam strength while plain fabric has maximum seam efficiency[21]. The polyester/cotton woven and knitted fabrics were considered to investigate the effect of sewing needle count, thread count, stitch density and stitch type on seam resistance using factorial study. These factors were found to have a significant effect on seam resistance[22]. Another study on garment seam strength based on needle size and stitch length was conducted using three different fabrics, sewing needle types and feed material. An optimized value of needle size, breaking force and material feed was reported, which was responsible in reducing the sewing damages[23]. During a comparative study on the effect of sewing thread count for different types of seam strength, an increased seam strength was noticed with rise in thread count[24]. For a study on dimensional stability and sewing performance of cotton single jersey fabrics by considering loop length, washing cycles and yarn twist factor, an improved seam elongation was observed[25]. The investigation on the effect of sewing machine parameters on seam quality and seam performance for cotton woven fabrics revealed a significant effect of sewing machine parameters on seam quality of the cotton woven fabrics[26]. The analysis of lockstitch seam strength and its efficiency was done using four types of polyester/wool fabric with varying sewing thread and stitch densities. The outcome noticed an increased seam strength and seam efficiency values with rise in stitch density and their impact was laso found to be significant[27].

There have been plenty of studies on seam performance properties of woven fabrics. However, limited research is available on seam performance of the knitted fabric. The general focus of researchers comprises testing of seam strength and seam efficiency with more prominence for fibre, yarns, fabric characteristics, sewing thread, seam types, stitch density and visual inspection of apparel products. A comprehensive analysis is required to understand the effect of sewing needle size, needle type and seam direction on the seam performance of the knitted fabric. Therefore, in the present study, the quantitative influence of these parameters on seam strength and seam efficiency of cotton, cotton/lycra and polyester/cotton single jersey fabrics have been investigated.

2 Materials and Methods

2.1 Materials

Single jersey fabrics have been used for the investigation. The details of fabric samples are given in Table 1. Before starting the sewing process, all the fabric samples are conditioned for 24 h at standard temperature (27±2˚C) and relative humidity (65±2%).

2.2 Measurement of Seam Strength and Seam Efficiency

ASTM D1683-04 method has been followed for analyzing seam strength and seam efficiency of different knitted fabrics. The fabric samples are sewn with 24 tex spun polyester sewing thread by preparing ISO-514 stitch type using 12 stitches per inch on an over-lock sewing machine (3000 rpm). All the materials have been tested for seam performance in terms of seam strength and seam efficiency using three different sewing needle types and sizes. For each test specimen, five test samples, each for course, wale and bias directions were cut. The test was performed on the Instron tensile testing machine for the measurement of seam strength and seam efficiency.

2.3 Experimental Design and Data Analysis

The experimental runs are designed in accordance with 3-level factorial response surface design using Design Expert 6 software. The effect of independent factors, viz. sewing needle size (Numeric factor), seam angle (Numeric factor) and sewing needle type (Categorical factor), on seam strength and seam

Table 1 — Fabric sample specifications

Properties	Fabric 1	Fabric 2	Fabric 3
Fibre composition	100% Cotton	Polyester/cotton (70/30)	Cotton/lycra (half plating)
Yarn count , Ne	24	30	30/40
Loop length, mm	2.6	3.4	3.0
Wales per inch	34	35	47
Courses per inch	54	58	69
GSM	182	155	238

Table 2 — Regression equations for seam strength (N)

Fabric	Sewing needle type	Regression equations	R^2
100 % cotton	SES	$283.95 - 1.2634A - 0.7841B + 4.67917B^2$	0.7861
	SUK	$299.307 - 1.26344A - 0.78415B + 4.67917B^2$	
	SAN	$293.122 - 1.26344A - 0.78415B + 4.67917B^2$	
Cotton/lycra	SES	$282.93609 - 1.25950A - 1.97143B + 0.021344\,AB$	0.9369
	SUK	$277.24788 - 1.25950\,A - 1.77706B + 0.021344AB$	
	SAN	$314.87506 - 1.25950A - 2.05357B + 0.021344AB$	
Polyester/cotton (70/30)	SES	$691.58671 - 10.35463A - 4.44182B + 0.057559A^2$ $+0.020518B2 + 0.035278AB$	0.9958
	SUK	$729.77171 - 11.25463A - 4.45171B + 0.057559A^2$ $+0.020518B2 + 0.035278AB$	
	SAN	$710.01953 - 10.79263A - 4.38597B + 0.057559 * A^2$ $+0.020518B2 + 0.035278AB$	

* A- Sewing needle size, B-Seam angle and C- sewing needle type

Table 3 — ANOVA results for seam strength (N)

Responses	Effect	Contribution,%	F-ratio	p- value
100% cotton	Model		24.26	0.0001
	A	7.11	10.97	0.0023
	B	47.54	73.34	0.0001
	C	15.35	11.84	0.0001
	B^2	8.61	13.29	0.0009
	Residual	21.39	-	-
	Lack of fit	11.06	0.61	0.8427
	Pure error	10.32	-	
	Cor total	100	-	
Cotton/lycra	Model		65.72	0.0001
	A	0.33	1.67	0.2061
	B	34.15	167.74	0.0001
	C	52.71	129.44	0.0001
	AB	2.33	11.47	0.0019
	BC	4.13	10.16	0.0004
	Residual	6.31	-	-
	Lack of fit	2.37	0.38	0.9709
	Pure error	3.93	-	-
	Cor total	100	-	-
Polyester/ cotton	Model		576.29	0.0001
	A	0.62	39.59	0.0001
	B	0.65	41.56	0.0001
	C	24.01	764.56	0.0001
	A^2	0.07	4.50	0.0433
	B^2	58.89	3749.37	0.00001
	AB	3.11	198.18	0.0001
	AC	0.25	7.96	0.0019
	BC	0.12	4.00	0.0301
	Residual	0.42	-	-
	Lack of fit	0.31	2.22	0.0854
	Pure error	0.11		
	Cor total	100		

* A- Sewing needle size, B-Seam angle and C- sewing needle type.

efficiency has been investigated. Further, the experimental data are analyzed by appling analysis of variance (ANOVA) technique using all materials. In order to study individual and interactive effects of each parameter on seam strength and seam efficiency, the linear and polynomial equations are tried under a 95 % confidence level. The coefficient of determination (R^2) shows the quality of the model fit quadratically with its statistical significance evaluated by the F-test.

3 Results and Discussion

3.1 Regression Analysis for Seam Strength

By applying the backward elimination method, the regression equations (Table 2) and ANOVA results (Table 3) for all three knitted fabrics are generated. The regression equations can well predict the relationship between the responses and three independent factors with the help of the coefficient of determination (R^2). The proposed model for the seam strength responses adjust very well to the experimental data and there was a logical agreement between R^2 and adjusted R^2. It is observed that the seam strength of all three knitted fabrics is significantly influenced by three factors (sewing needle size, seam angle and sewing needle type) with some interaction between these factors as shown in regression equations.

3.2 Effect of Sewing Needle Size, Seam Angle and Sewing Needle Type on Seam Strength

Figure 1 shows that cotton and cotton/lycra fabrics have less seam strength as compared to polyester/cotton fabric. This can be attributed to the lower strength of cotton yarn against polyester. Also, stretch recovery of polyester/cotton (70/30) yarn is better than those of cotton and cotton/lycra fabrics. This may happen as polyester/cotton is used as a blended yarn and cotton/lycra as half plated structure in knitted fabric, due to which the recovery behavior of cotton and lycra are different, causing breakage of cotton yarn prior the lycra filament. It is observed that

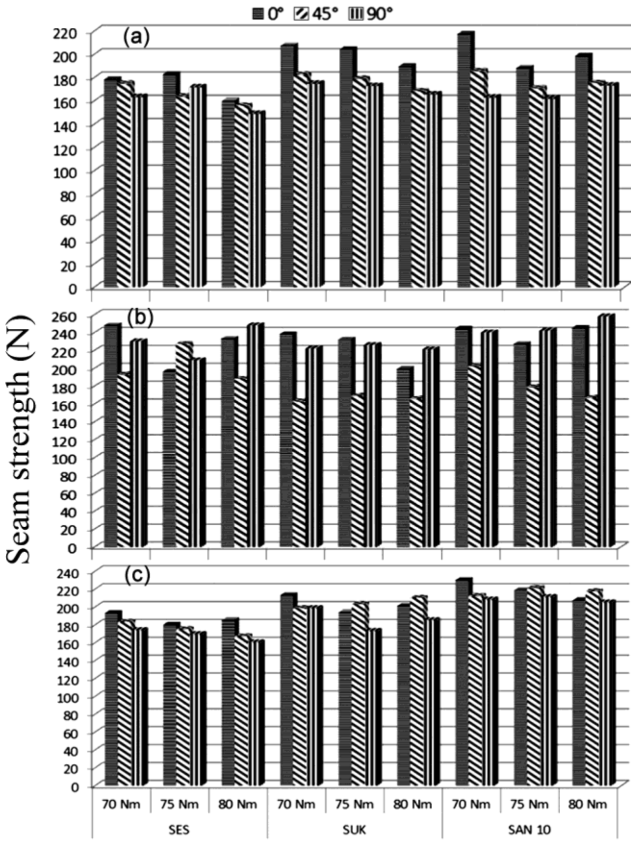

Fig. 1 — Influence of seam angle, sewing needle size and sewing needle type on seam strength of (a) 100% cotton, (b) polyester/cotton and (c) cotton/lycra fabrics

with an increase in seam angle and needle size, seam strength decreases while with sewing needle type there is an increase in seam strength for all three fabrics. When the load is applied on the seam, the force causes the seam elongation before breakage of seam, due to which the force is shared by every knit loop and stitch in fabric structure along the seam line which contributes to seam strength. It is also noted that seam strength has positive effect when seam is prepared in course-wise direction (0°), as seam elongation is higher than in wale-wise (90°) and bias (45°) directions due to straightening of loops. The seam strength reduces with sewing needle size because the frictional and tension force increases as needle size increase, beacuase the diameter of the needle is large which weakens the yarn in the fabric during penetration. It is observed that by using SES needle-type, seam strength decreases and it is maximum with SAN needle-type because of the shape of the needle point which penetrates more into the fabric structure. The special conical shape of SAN needle generates a lower penetration force during the sewing process.

3.3 Effect of Individual and Interactive Effect of Each Factor on Seam Strength

Analysis of variance (ANOVA) is carried out to find out the significance of every single factor and their contribution towards the seam strength. The p values in Table 3 indicate that the models are significant, due to only 0.05% chances of noise relation. P value of less than 0.05 indicates that an individual factor has a significant influence on the response. It can be seen from the ANOVA (Table 3) that sewing needle size (A), seam angle (B) and sewing needle type (C) significantly affect the seam strength for all three fabrics. Among the interaction effects, factor AB and AC for cotton/lycra, AB, AC, and BC for polyester/cotton(70/30) interactions are found to be significant. In 100% cotton fabric, analysis of variance shows that factor B has the highest contribution of 47.54 % and another individual/interactive effects like factor A (Contribution 7.11 %) and C (Contribution 15.35 %) have small contribution percentage for seam strength. In the cotton/lycra fabric, it is observed that factor C has the highest contribution of 52.71 % and after that factor B has 34.15 % contribution for seam strength. The other factors, A (Contribution 0.33%), AB (Contribution 2.33%) and BC (Contribution 4.13%) also show a very small interaction effect. The factor A (Contribution 0.621%), B (Contribution 0.65%), C (Contribution 24.01%), AB(Contribution 3.11 %), AC(Contribution 0.25 %) and BC (Contribution 0.12 %) show a very small individual and interactive effect for polyester/cotton fabric. The polyester/cotton fabric sample is known to exhibit relatively large F ratio (572.29). This represents more variation among group means which is an indicator of the measure of dispersion from the mean value. This large dispersion could occur due to noise. The lack of Fit F-value of 2.22 indicates that there is 8.54% chances that a lack of Fit F-value could occur due to noise. Further, it can also be observed that lack of fit for the quadratic model is non-significant in terms of seam strength (p= 0.8427, p=0.9709, p=0.0854). The pure error noted to be occurring for the repeated values of dependent variables are 3.44, 1.31, 0.03 for seam strength. This corresponds well with the very small vertical displacement of treatment means from the fitted quadratic regression model. Thus, from the pure error and lack of fit behavior, the model is confirmed to be fit.

3.4 Regression Analysis for Seam Efficiency

The seam efficiency data is analyzed by applying the backward elimination method to obtain the

Table 4 — Regression equations for seam efficiency (%)

Responses	Sewing needle type	Regression equations	R^2
100 % cotton	SES	$182.57256 - 1.09356A - 1.23840B + 7.46208B^2 + 8.62963AB$	0.9567
	SUK	$167.42333 - 1.09356A - 1.23840B + 7.46208B^2 + 8.62963AB$	
	SAN	$172.54410 - 1.09356A - 1.23840B + 7.46208B^2 + 8.62963AB$	
Cotton/lycra	SES/SUK/SAN	$701.95778 - 16.25986A + 0.34175B + 0.10833A^2 - 4.14074E-003AB$	0.7006
Polyester/cotton (70/30)	SES	$-272.49955 + 10.53674A - 0.72113B - 0.075390A^2 + 0.010448AB$	0.8717
	SUK	$-233.58519 + 10.00874A - 0.73306B - 0.075390A^2 + 0.010448AB$	
	SAN	$-333.93942 + 11.38774A - 0.78106B - 0.075390A^2 + 0.010448AB$	

* A- Sewing needle size, B-Seam angle and C- sewing needle type.

Table 5 — ANOVA results for seam efficiency (%)

Responses	Effect	Contribution,%	F-ratio	p- value
100% cotton	Model		117.73	0.0001
	A	5.02	37.10	0.0001
	B	5.29	39.06	0.0001
	C	34.65	127.95	0.0001
	B^2	49.67	366.82	0.0001
	AB	1.01	7.50	0.0100
	Residual	4.33	-	-
	Lack of fit	2.18	0.61	0.8414
	Pure error	2.14	-	-
	Cor total	100	-	-
Cotton/lycra	Model		19.89	0.0001
	A	9.07	10.31	0.0029
	B	18.49	21.00	0.0001
	A^2	37.06	42.09	0.0001
	AB	5.43	6.17	0.0181
	Residual	29.93	-	-
	Lack of fit	24.08	2.24	0.0747
	Pure error	5.85	-	
	Cor total	100	-	
Polyester/ cotton (70/30)	Model		19.02	0.0001
	A	4.19	9.15	0.0053
	B	13.40	29.25	0.0001
	C	2.59	2.83	0.0757
	A^2	8.52	18.61	0.0002
	AB	16.42	35.84	0.0001
	AC	35.96	39.25	0.0001
	BC	6.05	6.61	0.0045
	Residual	12.82	-	-
	Lack of fit	4.72	0.44	0.9382
	Pure error	8.10	-	-
	Cor total	100	-	-

* A- Sewing needle size, B-Seam angle and C- sewing needle type

regression equations (Table 4) and ANOVA (Table 5) for all three knitted fabrics. These equations can well predict the seam efficiency for 100% cotton, cotton/lycra, and polyester/cotton fabrics with the factors due to the high coefficient of determination. It is observed that sewing needle type does not have any influence on seam efficiency of cotton/lycra fabric sample. The seam efficiency of 100% cotton and polyester/cotton (70/30) knitted fabrics are significantly affected by all three individual factors.

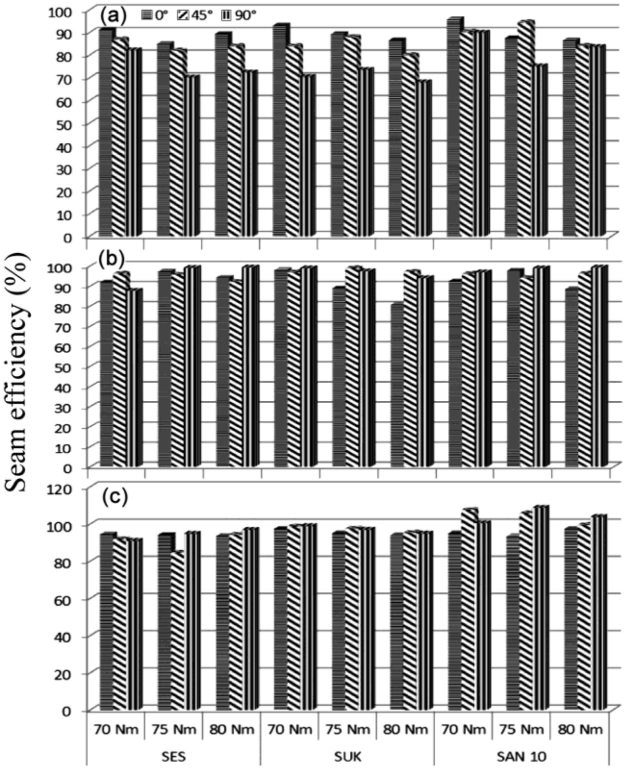

Fig. 2 — Influence of seam angle, sewing needle size and sewing needle type on seam efficiency of (a) 100% cotton, (b) polyester/cotton and (c) cotton/lycra fabrics

3.5 Effect of Sewing Needle Size, Seam Angle and Sewing Needle Type on Seam Efficiency

Generally, the seam efficiency for good quality seam ranges between 85% and 95%. If the seam efficiency falls below 65%, there will be chances of excessive seam damages. In Fig. 2, the experimental results reveal that 100% cotton has seam efficiency between 65% to 95%. The cotton fabric is compact in structure with coarser yarn count and smaller loop length. The coarser yarn count shares more load due to a higher number of fibres in the yarn structure which gives the seam efficiency in-demand range. In the case of 100% cotton fabrics as the seam angle increases from

0° (Course direction) to 90° (Wale direction), the seam efficiency decreases. This could be related to the elongation of fabric which is more in course direction than in wale and bias direction. During load distribution on the seamed fabric, straightening of loops in fabric and stitched seam occurs hence load is distributed equally in loops which as a result increase the seam efficiency in course direction. The extension in wale (90°) and bias (45°) directions is lower than in course direction; hence fabric structure does not support equal distribution of load and load is concentrated on certain loops which reduces the seam efficiency.

The seam efficiency decreases with increase in sewing needle size. When needle size increases, the frictional and penetration force also increase as larger diameter of needle weakens the fabric yarn. SES needle type has poor seam efficiency and further it improves with SUK and SAN needle type due to its geometrical shape. It is observed that seam efficiency ranges between 80 % and 100 % for both cotton/lycra and polyester/cotton fabrics. In cotton/lycra fabric, lycra is incorporated in half plated form in fabric structure, thus extensibility and strength of fabric influence the seam efficiency. Since polyester/cotton is a blended fabric which gives property of both polyester and cotton fibre, the extensibility and strength of polyester/cotton fabric become better than other two fabrics, which helps seam efficiency to maintain its range. It can be observed that with increase in seam angle the seam efficiency increases for cotton/lycra fabrics. In cotton/lycra fabric samples, cotton yarn and lycra filament have different extensibility. Lycra filament is presented in half plated form in fabric structure, due to which load bearing component does not support uniform load distribution, hence seam efficiency decreases. In wale direction, consecutive loops share the load equally, but in bias direction locked loop structure contributes to an increase in the seam efficiency. It is found that in polyester/cotton (70/30) fabric seam efficiency decreases with a seam angle. For both cotton/lycra and polyester/cotton fabrics, the effect of sewing needle size and needle type on seam efficiency follow a similar trend, as explained above for cotton fabric.

3.6 Investigation of Individual and Interactive Effect of Each Factor on Seam Efficiency

The statistical data indicate that all three factors have a significant effect on seam efficiency for 100% cotton, cotton/lycra and polyester/cotton knitted fabrics. The ANOVA results are summarized in Table 5, in which p values of less than 0.05 indicates that the models are significant. It is observed that for cotton/lycra fabric sample, the sewing needle type (C) is not a significant factor for the seam efficiency. This is because in cotton/lycra fabric, lycra filament is incorporated as half plated in fabric structure and as a result fabric strength is weakened which further lowers the seam efficiency relatively. Among other two knitted fabrics, sewing needle size(A), seam angle (B) and sewing needle type (C) all three individual factors significantly effect the seam efficiency. The interaction effects, AB for 100% cotton, AB for cotton/lycra, AB, AC and BC for polyester/cotton interactions are found to be significant. In 100% cotton fabric, analysis of variance shows that factor C has second highest contribution (34.65%) for seam efficiency. Other individual/interactive effect, like factor A (Contribution 5.02 %), B (Contribution 5.29 %) and AB (Contribution 1.01 %) have very small contribution percentage. For cotton/lycra fabric, it has been observed that factors A (Contribution 9.07 %), B (Contribution 18.49 %) and AB (Contribution 5.43 %) have small interaction effect on seam efficiency. The polyester/cotton(70/30) fabric has highest contribution of 35.96 % for interactive effect of factor AC. Also other factors, A (Contribution 4.19 %), B (Contribution 13.40 %), C (Contribution 2.59 %), AB (Contribution 16.42 %) and BC (Contribution 6.05%) reveal small individual and interactive effect for seam efficiency. The cotton fabric sample is known to exhibit relatively large F ratio (117.73). This represents more variation among group means which is an indicator of the measure of dispersion from the mean value. This large dispersion could occur due to noise. The lack of Fit F-value is 0.61, which implies that there is 8.41% chance that a lack of Fit F-value is exhibited as a result of noise. It can also be observed that lack of fit for the quadratic model is non-significant in terms of seam efficiency (p= 0.8414, p=0.0747, p=0.9382). The pure error noted to be occurring for the repeated values of dependent variables are 0.71, 1.95, 2.70 for seam efficiency. This corresponds well with the very small vertical displacement of treatment means from the fitted quadratic regression model. Thus, from the pure error and lack of fit behavior, the model is confirmed to be fit.

4 Conclusion

For a comprehensive analysis to understand the effect of sewing needle size, needle type and seam angle on seam performance, the influence of these parameters on different knitted fabrics have been investigated. It has been observed that all three parameters have a significant impact on seam strength and seam efficiency. It is also observed that 100% cotton and cotton/lycra fabrics have lower seam strength as compared to polyester/cotton fabric. With an increase in seam angle and needle size, seam strength is known to decrease. The experimental result shows that for 100% cotton the seam efficiency ranges between 60% and 85%, while for cotton/lycra and polyester/cotton fabrics the seam efficiency is varying between 80% and 100%. The seam efficiency of 100% cotton fabric decreases with a rise in seam angle but for both cotton/lycra and polyester/cotton fabrics a reverse trend is observed. Also, a decrease in the seam efficiency is observed with increase in sewing needle size. It has been found that SES needle type (small ball point) exhibits poor seam efficiency, but an improvement has been observed using SUK (medium ball point) and SAN needle type (conical point).

References

1 Ozgen B, *Tekstilve Konfeksiyon* , 3 (2014) 24.

2 Larsson J**,** *Autex Res J*, 13(3) (2011) 1.

3 Larsson J, Peterson J, Mattila H, *Autex Res J*, 12 (2012) 1.

4 Kumar V & Sampath V R, *Fibers Text East Eur*, 21(3) (2013) 73.

5 Glock R E & Kunz G I, *Apparel Manufacturing: Sewn Product Analysis* (Englewood Cliffs, New Jersey, Prentice Hall), 1995, 345.

6 Hossain Md E, Quaddus M & Shanka T, *J Quality Assurance Hospitality Tourism*, 16 (2015) 119. DOI: 10.1080/1528008X.2015.1013405.

7 Pavlinic D Z, Gersak J, Demsar J and Bratko I, *Text Res J*, 76(3) (2006) 235. DOI: 10.1177/0040517506061533.

8 Bansal P, Sikka M & Choudhary AK, *Indian J Fibre Text Res*, 45 (2020) 388.

9 Gurarda A, *Text Res J*, 78(1) (2008) 21. DOI: 10.1177/0040517507082636.

10 Gurarda A, *Intech Open*, (2019) 1. DOI: http://dx.doi.org/10.5772/intechopen.86436.

11 Gurarda A & Meric B, *Fibres Text Eastern Eur*, 15(4) (2007) 73.

12 Nurunnabi, Shibly MAH, Tammana T A & Rahman Md M, *Int J Text Sci*, 6(5) (2017) 119. DOI: 10.5923/j.textile.20170605.01.

13 Stjepanovic Z & Strah H, *Int J Clothing Sci Technol*, 10(3) (1998) 209.

14 Malek S, Kheder F, Jaouachi B & Cheikhrouhou M, *J Text Apparel, Technol Management*, 11(1) (2019) 1.

15 Choudhary AK, Sikka MP & Bansal P, *Res J Text Apparel*, 22(2) (2018) 109.

16 Oztas H & Gurarda A, *Autex Res J,* (2018) 1. DOI: 10.1515/aut-2018-0060.

17 Seif M A, Int Design J, 6(4) (2016) 389.

18 Sulara V, Mesegulb C, Kefsizc H & Sekia Y, *J Text Inst*, 106(1) (2015) 19. http://dx.doi.org/10.1080/00405000.2014.899079.

19 Jaber M & Islam Md M, *IOSR J Polym Text Eng* , 6(2) (2019) 32.

20 Chowdhary U & Poynor D, *Int J Consumer Studies*, 30(6) (2006) 561. doi: 10.1111/j.1470-6431.2005.00479.x.

21 Islam T, Mia Md R, Ahmed Khan S, Hossen Md R & Rahman Md A, *Res J Eng Sci*, 7(2) (2018) 1.

22 Sauri R M, Manich A M, Barella A, Lloria J, Etayo J M & Rosanas J, *Indian J Text Res*, 12 (1987) 188.

23 Rogale S, Bobovcan Marcelic M, Rogale D, Dragcevic Z & Nikolic G, *Annals Proceedings DAAAM Int*, 23(1) (2012) 1.

24 Hasan Md Z, *Eur J Adv Eng Technol*, 3(10) (2016) 1.

25 Nassif G A A, *Life Sci J*, 10(1) (2013a) 1181.

26 Nassif NAA, *Life Sci J*, 10(2) (2013b) 1427.

27 Frydrych I & Greszta A, *Int J Clothing Sci Technol*, 28(4) (2016) 480.