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Optimization of parameters for needle cut index using TOPSIS method

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The influence of loop length, stitches per inch, and sewing needle type on needle cut index in 100% cotton single jersey fabric has been studied considering factorial design. Further optimization of factors using Design Expert Tool has been done followed by ranking the optimized solution through TOPSIS method along with the confirmatory test. The results show that sewing needle type has the highest contribution with 29.83% followed by the 23.08% for stitches per inch and 11.95% in the case of loop length as far as needle cut index in the course direction is concerned. In the wale direction, sewing needle type has the highest contribution with 50.45% followed by the 13.30% for loop length and 10.77% for stitches per inch. It has also been observed that SES needle type is generating more needle cut as compared to SUK and SAN type needles. It is confirmed that the error percentage has been the lowest for highest rank solutions and subsequently the error increases with decreasing rank in terms of closeness coefficient. The present study is expected to be helpful for garment industrialists in minimising the needle cut defect among knitted garments and improve the quality of producing seam.

Keywords: Cotton, Loop length, Needle cut index, Sewing needle type, Single jersey fabric, Stitch density, TOPSIS method

1 Introduction

Knitted garments are more popular in the modern fashion scenario as compared to woven garments. The higher demand for knitwear is due to its ease of production, excellent elasticity, ability to resist wrinkling, closer fit to the body, fewer seams, and openings than a woven garment. When the knitted fabric is converted into three dimension garment using seam and stitches, sewing damage is one of the majorly occurring sewability problems[1,2]. Needle cut is another very significant frequently occurring sewing damages during garment construction. It is mechanical damage that takes place during seam preparation in the sewing process, when sewing needle penetrates in the fabric and cut the yarn or fibre. These are a recurring problem in many apparel industries during knitted garment construction. The quantitative value of the needle cut index is used to determine the intensity of the needle cut damages in fabric. The needle cutting or yarn severance is due to the stiffness of yarn in fabric and a lack of mobility of yarn in fabric structure when sewing needle sews the fabric[3-5].

A study on sewability of denim fabric was conducted and assessed for seam efficiency, seam pucker, seam slippage, needle cutting index, and seam appearance[6]. From the study it was clear that for light weight fabrics, seam efficiency increased with the decrease in linear density of thread; for heavy weight denim, seam efficiency decreased with the increase in thread linear density. Sewing of light weight denim with coarse threads increased seam slippage. Needle cutting index decreased with the decrease in linear density of sewing threads for all the fabrics and the damage increased with the increase in fabric weights for a given ticket number. Core-spun threads give maximum yarn damage compared to cotton and polyester threads. Needle cutting index was affected by fabric cover factor and weave too. Further, modeling of impact damage of sewing machine needle on woven fabric by finite element method was studied[7]. In this model (ABAQUS 6.8), the orthotropic properties of the fabric, the elastic nature of the yarn, the sliding contact between yarns and the yarn breakage were included while employing solid elements. Experimental works were also performed to compare with the simulation results. In order to quantify the damage of woven fabrics punched by sewing needles in experimental and simulation work, a damage index was introduced. It can be concluded that both manual and simulation procedures indicated that the needles with larger diameter increased the fabric damages. The model developed in this study

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was able to simulate the impact damage of sewing machine needles on the woven fabric. The damage indexes derived from the model can be applied to compare the effect of different needle sizes on the fabric. In another study, the influence of fabric finishes (pigment, enzyme, and stone wash) on the seam quality of cotton/lycra denim fabric was investigated[8]. Three different needle sizes (14, 16 and 18 Nm) were used to study the needle penetration force, needle cutting index, and seam mechanical properties of different finished cotton/Lycra denim fabric. The number of fabric layers from 1 to 4 was used for three different needle sizes. The result concludes that better sewability was noticed for unfinished and finished cotton/lycra denim fabric sewn by needle size 14 and 16 Nm respectively in comparison to other needle sizes.

It is observed that limited work is available about needle cut in knitted fabric as compared to that in woven fabrics. Hence, optimization of parameters through selection of their suitable combination is required for reduction of needle cut in knitted fabrics. The present study focuses on the effect of loop length, stitches per inch and sewing needle type on needle cut index in 100% cotton single jersey fabrics. Once the garment is in the consumer's hands the needle cuts can take an even more destructive route turning into long runs. Therefore, minimization of needle cut has emerged as one of the foremost priorities for the manufacturer. So, understanding of parameters affecting the needle cut index will be helpful for garment manufacturers/researchers to improve the seam quality in the garment.

2 Materials and Methods

The 100% cotton fabric of 24 Ne yarn count and 2.6 mm loop length having 182 GSM has been selected for the current study. The needle cut index is measured according to ASTM-D 1908 test method. Needle cut is one of the significant sewing damages, which occur during garment construction as the needle enters the seam. Needle cuts are randomly appearing and are responsible for small or big holes of the same or different size along with the seam line in the knitted fabrics. Needle cut index (NCI %) is the ratio of number of loops cut per inch to the number of loops in fabric per inch. According to ASTM 1908, test specimens were prepared from each fabric sample in the course and wale direction. Then all fabric samples were sewn with 24 tex spun polyester sewing thread on an over-lock sewing machine (3000 rpm). The sewn fabric surface was analyzed for needle cut index using an image analyzer system (Leica). The quantitative value of the needle cut index is used to determine the intensity of the needle cut damages in fabric. The average of five readings for each sample in the course and wale direction was used for the analysis of the results.

2.1 Experimental Plan

A three-level factorial experimental design has been applied, generating a total of 30 combinations. The responses are analyzed and the impact of various factors has been studied through regression equations and analysis of variance (ANOVA). The investigated operating factors are: loop length (2.6mm, 3.0mm, 3.4mm), stitches per inch (9,12,14), and sewing needle type (SES, SUK SAN). The factors have been investigated as per three-level factorial experimental design.

The results are analyzed by carrying out ANOVA through Design Expert Software. Further, the outcome is optimized by means of the software. Through optimization, the most optimum solution is obtained by executing the TOPSIS method. Further confirmation test is carried out to validate the TOPSIS method, which ensures that the method is realistic and is an acceptable ranking system.

2.2 Technique for Order Preferences by Similarity to Ideal Solution (TOPSIS)

TOPSIS method has been established based on the phenomenon of negative ideal and positive ideal solution. This technique offers a solution nearest to the most optimized outcome as well as to the farthest from the minimum (worst) outcome. The basis of this technique has been to attain a solution in accordance with the nearness coefficient between feasible and the ideal solution by means of the steps as follows[9-14].

Following steps have been followed:

Step I—In the first step of this method, a normalized matrix is determined as given below:

$$T_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}^2} \quad \ldots (1)$$

where i refers to 1, 2, and so on up to mth time; j can be 1, 2, 3…..n; x_{ij} depicts the real value of the i^{th} experimental outcome for j^{th} response; and T_{ij} shows the subsequent normalized value.

Step II—Further the weightage of every outcome is to be determined.

Step III—The third step deals with the calculation of the weighted normalized decision matrix through the multiplication of the normalized matrix with its associated weights as presented through following equation:

$$V_{ij} = W_j \times T_{ij} \quad \text{... (2)}$$

where i and j are the same as in Eq. (1), while W_j depicts the mass of j^{th} attribute.

Step IV—The negative ideal solution termed as V^- refers to the worst possible value while positive ideal solution symbolized as V^+ refers to the best value of each trait of beneficial criteria and reverse for non-beneficial criteria, by weighted decision matrix and can be determined as:

$$V^+ = (V_1^+, V_2^+, V_3^+ \ldots\ldots\ldots V_n^+) \quad \text{... (3)}$$

$$V^- = (V_1^-, V_2^-, V_3^- \ldots\ldots\ldots V_n^-) \quad \text{... (4)}$$

Step V—Further, the separation distance of each solution is calculated using the following equations:

$$S_i^+ = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^+)^2} \quad \text{... (5)}$$

$$S_i^- = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^-)^2} \quad \text{... (6)}$$

where i refers to 1, 2, 3 so on up to n^{th} time.

Step VI—The co-efficient of closeness (CC_O) can be determined through following equation:

$$CC_O = \frac{S_i^-}{S_i^- + S_i^+} \quad \text{... (7)}$$

Step VII—The outcome of CC_o is finally ranked in ascending order as per the nearness-coefficient values.

2.3 Confirmation Test

To get the confirmation, the top three ranked solutions are further tested from the optimized solutions. The confirmation results are calculated using the following equation:

$$\text{Error (\%)} = \frac{\text{Experimental Value} - \text{Predicted Value}}{\text{Predicted Value}} \quad \text{... (8)}$$

3 Results and Discussion

3.1 Influence of Loop Length, Stitches Per Inch, and Sewing Needle Type on Needle Cut Index

It is observed from Figs 1(a) & (b), that cotton fabrics have needle cut index percentages ranging between 1% and 4% for the course and between 1% and 6% for wale direction. The needle cut index is found to be more in wale direction as each stitch in this structure is inter-looping vertically with the previous stitch, hence the chances of the loop to rupture becomes more prominent due to the consecutive loops in a single row.

The needle cut index decreases with loop length for each sewing needle type under investigation. The reason for the reduction in needle cut index can be attributed to less compactness as the tightness factor decreases with loop length. Thus, low frictional characteristics are generated between the sewing needle and the adjacent loops of yarn.

A surge in needle cut index is noticed at a higher value of stitches per inch for each sewing needle type. This is because as stitches per inch rise, the chance of needle penetration into the fabric structure becomes more vulnerable, leading to increased chances of loop rupture.

Also, it is concluded that the needle cut index measured with SUK needle and SAN 10 needles is less than that with SES needle type. This is because the tension exerted by ball point sewing needle on the yarn surface is less and also when the size of ball point increases that is from SES to SUK, the amount of tension of yarn reduces as it pushes the yarn aside to create space for them. So SUK type sewing needle generates a lesser needle cut index as compared to SES type of sewing needle. Further, the slim shape of SAN 10 sewing needle geometry reduces the needle cut index. Its slim design results in a decrease cross-section in the eye area, reducing the stress on the fabric structure during the needle penetrates. Also, the SAN 10 needle generates a small stitch hole and optimizes fabric displacement. In the case of SES and SAN 10 sewing needle types, medium loop length with lowest SPI is observed to exhibit a minimum

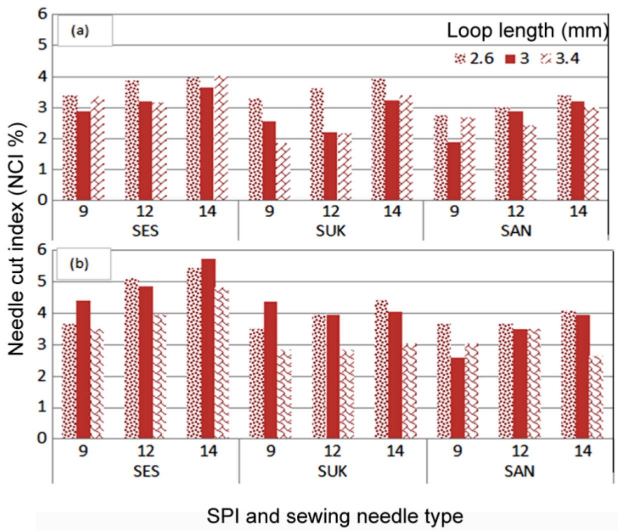

Fig. 1 — Influence of loop length, stitches per inch (SPI), and sewing needle type on needle cut index in (a) course direction and (b) wale direction

Table 1 — ANOVA results for needle cut index % (NCI)

Responses	Effect	Contribution, %	F-ratio	p- value	R^2
NCI (%) in course direction	Model	-	19.6	0.0001	
	Loop length, mm	11.95	20.2	0.0001	
	SPI	23.08	39.0	0.0001	0.816
	Sewing needle type	29.83	25.2	0.0001	
	Loop length, mm× loop length, mm	10.40	17.6	0.000213	
	Loop length, mm × sewing needle type	6.07	5.13	0.0119	
NCI (%) in wale direction	Model	-	29.4	0.0001	
	Loop length, mm	13.30	31.4	0.0001	
	SPI	10.77	25.4	0.0001	0.869
	Sewing needle type	50.45	59.8	0.0001	
	Loop length, mm ×loop length, mm	6.46	15.3	0.000461	
	SPI× sewing needle type	5.82	6.88	0.00337	

needle cut index as a result of better cumulative behavior of fabric structure and sewing needle type. Similarly, in the case of SUK needle type, the higher loop length with 12 SPI reveals relatively less value for needle cut index.

3.2 Analysis of Variance (ANOVA)

The analysis of variance of needle cut index response data depicts the significance of the model through F-value and p-value. For course direction, A, B, C, and AC are found to be significant terms with a p-value less than 0.05 while for wale direction A, B, C, AC, and BC have been significant. While model F-value in course direction is obtained as 19.63 and R^2 is 0.816 defines the model to be significant. The adjusted R^2 is found to be 0.774, indicating the 77% accuracy of the model. The precision value for the model has been 17.9, which defines its goodness. Similarly, in wale direction, the model F-value is 29.37, and R^2 is obtained to be 0.869. In this case, adjusted R^2 is 0.839, which shows 83% chance of accuracy for the model predicted response. The adequacy precision value of the model is found to be 21.0, which signify the goodness of the model. The analysis of variance reveals that factor C (sewing needle type) has the highest contribution 29.83% and other individual/interactive effects such as factor A (Contribution 11.95%), B (Contribution 23.08%), and AC (Contribution 6.07%) have relatively less contribution percentage for needle cut index in course direction. For wale direction, it is observed that factor C (sewing needle type) has the highest contribution (50.45%) for needle cut index. The other factors, viz. A (Contribution 13.30%), B (Contribution 10.77%) and BC (Contribution 5.82%) reveal comparatively lower contribution.

Referring to Table 1, the sewing needle type (Factor C) has the highest contribution among all the

Table 2 — Optimized conditions for various responses with desirability value

Loop length mm	Stitches per inch (SPI)	Sewing needle type	NCI, %		Desirability
			Course	Wale	
3	9	SES	1.98	3.05	0.846
3.33	9	SES	2.08	3.03	0.846
3.4	9	SUK	1.92	3.98	0.846
3.34	12.2	SUK	2.98	4.05	0.846
3.4	9	SAN 10	2.45	2.7	0.846
3.37	9	SAN 10	2.41	2.93	0.846
2.7	11.9	SAN 10	3.05	3.71	0.846

factors. Hence, this factor has been selected for further investigation. The coefficient of determination is generated in both course and wale directions using the backward elimination regression method at 95% confidence interval.

3.3 Optimization of Sewing Needle Type with Loop Length and Stitches Per Inch

The Design Expert Software delivers the most optimized solution from a number of factors under all set of conditions. The usual process for optimization has been to place the responses into the range of desirability function usually from 0 to 1. In view of that, an optimized criterion has been implemented on each response as per requirement. The ranges defined for needle cut index in course direction and wale directions have been 1.8 - 4% and 2- 6% respectively. Seven varieties of optimum outcomes are achieved comprising a desirability of 0.846, depending upon the criteria. The optimized value for each input variable and response is represented in Table 2. However, it is generally a tough task to achieve the most appropriate combination as every combination meets the same value of desirability. Hence, TOPSIS can be applicable for finding the most optimized solution allied to the ranking technique. A numerical value is generated through TOPSIS by determining the two responses, for example needle cut index in both course and wale directions. Initially normalized matrix has been generated from Eq. (1) as presented in Table 3. Thereafter, the relative weights for NCI % in course and wale directions have been considered as 0.40 and 0.60 respectively. Further, the normalized weight matrix has been achieved through Eq. (2), as shown in Table 3.

Needle cut index comes under the category of non-beneficial criteria, therefore minimum value has been considered as positive ideal solution (V^+) and maximum value as negative ideal solutions (V^-) for the responses of NCI % in course (0.296521, 0.471036) and wale direction (0.301182, 0.451773) respectively.

Table 4 depicts the separation matrix (Si^+, Si^-) and closeness coefficients (CC_o) determined using Eqs (5), (6), and (7). It reveals the TOPSIS score and the rank for the optimal set for parametric combinations. Optimized solutions have been ranked based on the TOPSIS score; the highest score being the first ranked solution, and so on.

In Table 5, all the alternative optimized outcomes have been set as per the rank. Solution coded A1 is known to secure the first rank having optimized values of loop length (mm) as 3.4, stitches per inch 12 with sewing needle type being SUK. This is happening as the ball point of the sewing needle SUK type is larger than that of SES, and when the needle penetrates the open fabric structure (loop length 3.4mm), the frictional and tension forces decrease.

3.4 Confirmation Test

To achieve confirmation of the test, top three rank solutions have been further tested using optimized solutions. The predicted values are obtained by the process parameters of CCo results in rank order 1, 2, and 3, i.e. optimized solutions 4, 6, and 7. The confirmation results have been determined using Eq. 8 and results are given in Table 6.

It is observed that the error percentage in terms of needle cut index has been -27.65%, -1.63%, and 10.37% for first, second, and third rank respectively for course direction. Error percentage for needle cut index in wale direction is known to increase with the increase in rank order. Therefore, the confirmation test validates that, TOPSIS increases the accuracy of the results by reducing the chances of errors. From the table, it can also be emphasized that TOPSIS provides a realistic and acceptable ranking system.

Table 3 — Normalized matrix and normalized weighted matrix

Normalized matrix		Normalized weighted matrix	
Course	Wale	Course	Wale
0.305788	0.340224	0.122315	0.204135
0.321231	0.337993	0.128493	0.202796
0.296521	0.443965	0.118609	0.266379
0.460226	0.451773	0.18409	0.271064
0.378374	0.301182	0.151349	0.180709
0.372196	0.326839	0.148878	0.196103
0.471036	0.413847	0.188415	0.248308

Table 4 — Ranking of solutions in terms of closeness coefficient

Si^+	Si^-	Closeness coefficient (CCo)	Rank
0.199414	0.430455	0.683403831	7
0.194714	0.423469	0.685022208	6
0.181285	0.398217	0.687170975	5
0.116395	0.339108	0.744468799	1
0.188649	0.419137	0.68961214	4
0.181218	0.411282	0.694146683	3
0.120344	0.348243	0.743176445	2

Table 5 — Ranking of optimized parameters

Alternative optimized solutions	Loop length mm	Stitches per inch (SPI)	Sewing needle type	Rank
A7	3	9	SES	7
A6	3.33	9	SES	6
A5	3.4	9	SUK	5
A1	3.34	12.2	SUK	1
A4	3.4	9	SAN 10	4
A3	3.37	9	SAN 10	3
A2	2.7	11.9	SAN 10	2

Table 6 — Confirmation results

Loop length, mm	Stitches per inch (SPI)	Sewing needle type	Confirmation results for Needle cut index , %					
			Course			Wale		
			Predicted results	Experimental results	Error %	Predicted results	Experimental results	Error %
3.34	12.2	SUK	2.98	2.156	-27.65	4.05	2.81	-30.61
2.7	11.9	SAN 10	3.05	3.00	-1.63	3.71	3.63	-2.15
3.37	9	SAN 10	2.41	2.66	10.37	2.93	3.04	3.75

4 Conclusion

In the present study, a three-level factorial method is employed for analyzing the effect of three parameters viz. loop length, stitches per inch, and sewing needle type needle cut index in the course and wale directions respectively. Analysis of variance reveals that all three factors have a significant effect on the needle cut index. The findings of this study can be summarized as follows:

4.1 The needle cut index increases with the increase in stitches per inch and reducing loop length.

4.2 The SES needle type generates more needle cut as compared to SUK and SAN 10 needle types.

4.3 The sewing needle type has the highest contribution with 29.83% followed by 23.08% of stitches per inch and 11.95% of loop length for needle cut index in course direction.

4.4 In the TOPSIS method, the first ranked solution referring to the most optimized conditions in terms of loop length, stitches per inch, and sewing needle type have been 3.34, 12.2 (consider 3.4, 12), and SUK respectively. Under these optimal conditions, the values for needle cut index in the course and wale directions have been 2.98 and 4.05 respectively.

4.5 The confirmatory test shows that the error percentage is lowest for the highest rank solutions and soon the error increases with decreasing rank in terms of closeness coefficient.

4.6 The method can also be applied to other fibres and knitted structures used at commercial levels for predicting the needle cut index before going for the actual manufacturing of the product.

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