TEKSTİL VE KONFEKSİYON

VOL: 32, NO. 3
DOI: 10.32710/tekstilvekonfeksiyon.1137635

Maximization of Sewing Strength and Minimization of Seam Pucker for Denim Fabrics Using Taguchi Method

Gulsah Pamuk 0000-0002-9358-2331

Ege University / Emel Akin Vocation School / Izmir / Türkiye

Corresponding Author: Gulsah Pamuk, gulsah.pamuk@ege.edu.tr

ABSTRACT

Seams provide the shape of the garments and support the fabric pieces together. The seam quality is important for the serviceability of any garment. In general, the seam quality depends on various factors such as fabric weight, sewing thread type, and stitches per unit area. In this research, three different levels of fabric types with the same construction and different weights, which are mostly used in the production of denim products, were examined. For this purpose, each fabric was sewn in the warp direction with three different levels of sewing threads and three different levels of stitch densities. Then, the values of seam strength, and the seam pucker values were obtained with three replications for each combination of levels. In this study, it is aimed to obtain the optimum levels of fabric weight, sewing thread type, and stitch density of denim fabrics by using the Taguchi method. Custom Taguchi Design is employed to observe the efficiency of factor levels on seam strength and seam pucker, and existence of interactions among fabric weight, sewing thread type, and stitch density.

ARTICLE HISTORY

Received: 29.05.2022
Accepted: 13.09.2022

KEYWORDS

Seam quality, seam strength, seam efficiency, denim fabric, Taguchi method

1. INTRODUCTION

Denim is considered indispensable for clothing industry worldwide because, regardless of their area, age, sex and status, most of the population owns a pair of jeans [1]. Among woven fabrics, the denim usage, as a main part of garment fashion, greatly increases year on year [2]. Denim fabrics are mostly produced using cotton fiber in twill weave with colored warp and white weft yarns that are mainly used for the production of jeans, work clothes and casual wear [3].

Fabric quality alone does not fulfil all the criteria for production of high quality garments. The conversion of a two-dimensional fabric into a three-dimensional garment involves many other interactions such as selection of a suitable sewing thread, optimization of sewing parameters, ease of conversion of fabric to garment and actual performance of a sewn fabric during wear of the garment [4]. The specifications of fabrics for apparel manufacturing can be considered in terms of primary and secondary quality characteristics. The primary quality characteristics are static physical dimensions and the secondary characteristics are the reactions of the fabric to an applied dynamic force. The apparel manufacturer is usually interested in the secondary characteristics of the fabric and focuses on the seam quality during the fabrication and production of apparel [5].

Seam quality is determined by the correlation between types of fabric, structures of fabric, sewing threads and selection of stitches and seams. The performance of seam also depends on the sewing conditions like size of needle, sewing thread tension, stitches per inch and lastly on the proper working and maintenance of the stitching machine [6]. Seam quality problems such as skipped stitches, thread breakage, fabric damage, faulty seam appearance, needle damage and etc., can be time-consuming and frustrating. They may spoil the appearance of a garment and be the cause of ultimate failure and rejection reduce productivity and seam quality [7, 8]. Good overall seam quality is essential for the longevity of the apparel product, which together with consumer satisfaction affects its saleability [9]. Seam quality is also an important factor to determine

To cite this article: Pamuk G. 2022. Maximization of sewing strength and minimization of seam pucker for denim fabrics using taguchi method. *Tekstil ve Konfeksiyon*, 32(3), 288-295.

the garment quality which is a big deal in today's competitive world market as quality can be seen as the synonym of excellence and as a means to make differentiation of different products having perceived value [10]. Since numerous factors such as seam type, sewing thread, fabric and sewing parameters, technological adjustments have influence on seam's quality, making research on about this subject may be difficult [11, 12].

It is necessary to determine the most appropriate seam for each type of fabric structure to achieve a desired product quality. The quality reflects the performance of the apparel product. Certain stitches are suitable for particular fabrics because each fabric has its own unique properties [13]. All the factors required for the production of high quality ready-made garments in standard sizes and specifications must be determined in advance and adjusted for each model to be the same for all machines in the assembly line. Today, in the apparel industry, while the number of models has increased, production amounts have decreased. Since each different model, fabric and thread feature require different sewing types, the settings of all machines in the assembly line need to be changed. It is very important to optimize the sewing performance, that is, to adjust all these variables that will give the best sewing performance during the sewing process [14].

Seam quality affects two factors; appearance and strength [15]. The sewing performance and sewing strength properties of denim fabrics have been considered by many researchers. Tiber and Yilmaz studied the comparison of seam performance properties of elastic and regular polyester sewing threads on stretch denim fabrics [16]. Ates et al. analyzed the seam performance of the chain stitch and lockstitch used in denim trouser. They examined fabric strength, seam strength and seam efficiency of cotton denim woven fabrics with elastane and without elastane [17]. Sarkar et al. aimed to predict and develop a model for forecasting the seam strength of denim garments with respect to the thread linear density (tex) and stitches per inch by using a Fuzzy Logic Expert System. That model showed good performance in prediction of the seam strength of denim garments [18]. Tuteja and Sen investigated the impact of commercial sewing thread counts and stitch densities on seam strength, seam elongation and seam efficiency on medium-heavy and heavy weight cotton denim fabrics. The effects of different sewing thread sizes and different levels of stitch densities were assessed on the selected seam parameters. It was found that statistically there was a significant interaction between stitch density, sewing thread count and fabric weight on strength, elongation and efficiency of lapped seam [13]. Nayak and Padhye, analyzed the sewability of denim fabrics stitched with air-jet textured sewing thread. The authors found that the fabric formability is dependent on the fabric weight [19]. Seam appearance which is the second side of seam quality concerns the situation known as seam pucker. Seam pucker is an unacceptable waviness in appearance along the seam length [15]. Also the seam performance by means of durability is based on the strength and efficiency of seam as well as seam appearance along the seam line attributed by the seam puckering [20]. Sular et al., compared the seam performance of 12 woven fabrics by means of seam pucker and other seam properties. They observed that twill fabrics which are also used in denim garments showed lower seam pucker values for all types of the test fabrics [21]. Mak and Li emphasized the importance of seam pucker evaluation in quality control of garments manufacturing [22]. The authors presented an objective method which using image analysis and pattern recognition technologies in their paper.

Process variability causes quality problems in product. Therefore, methods used to reduce variability increase product quality and reduce product cost [23]. The origins of the idea of reducing variability were revealed in 1920 by Dr. Walter Shewhart. This idea, later, has been expanded by the work of W. Edwards Deming, J. A. Juran, Armand Feigenbaum, and Genichi Taguchi [23]. Taguchi method is an experimental design method that tries to minimize the variability in the product and process by choosing the most appropriate combination of the levels of the controllable factors against the uncontrollable factors which create the variability in the product and the process [24]. This method, besides being effective in product quality improvement, gives better results with much less experimentation. In addition, as a philosophy, it envisages ensuring quality in design and process [25].

Taguchi methods have extensive applications in manufacturing enterprises and are applied in various manufacturing fields such as plastics, automotive, metal fabrication, process, electronics, and in service [26]. This methodology has been also employed in textile engineering [27]. Onal et al. evaluated the effect of factors such as fabric width, folding length of joint, seam design and seam type on seam strength. They studied using both Taguchi's design of experiment and artificial neural network [28]. Almetwally analyzed multi-response optimization based on Taguchi-grey relational analysis to maximize tensile strength, breaking extension and air permeability of cotton woven fabrics. Cotton woven fabric parameters such as weft yarn count, weave structure, weft yarn density with three levels, and twist factor of the weft yarn with two levels were used as control factors [29]. Ustuntag and Turksoy aimed to optimize the various coating process parameters for the air permeability properties of denim fabrics by using Taguchi method. They found that weft density and viscosity have significant influence on the air permeability properties of coated denim fabrics [27]. Hossain et al. found the optimal dyeing conditions and predicted the colour strength of viscose/lycra blended knitted fabrics using Taguchi method. The controllable factors such as dye concentration, temperature, time, alkali concentration, salt concentration and liquor ratio have been used as input variables and colour strength of the fabric as response variable. The authors pointed out that Taguchi method is efficient on the optimisation and prediction of fabric colour strength in non-linear complex dyeing [30].

Ghosh et al. investigated the effect of yarn count, loop length, knitting speed, and yarn input tension in the presence of two uncontrollable noise factors on selected comfort properties of single jersey and 1×1 rib knitted fabrics using the Taguchi experimental design. It is observed that yarn count and loop length have significant influence on the thermo-physiological comfort properties of knitted fabrics [31].

The main purpose of this study was to observe the sewing performance properties of denim fabrics by using Taguchi's Custom Design technique and obtain the optimum levels of fabric weight, sewing thread type, and stitch density of denim fabrics by using the Taguchi method.

2. MATERIALS AND METHOD

2.1. Materials

Twill woven denim fabrics, commercially used for the manufacture of men's and women's wear, were used for this study. Three types of commonly used denim fabric weights were chosen. All fabrics had 1% elastane content in the weft direction. The properties of the denim fabrics used in this study is shown in Table 1.

Three different compositions of sewing threads commonly used for stitching denim fabrics were selected for this research. The details of the selected threads with their codes are given in Table 2. The ticket number indicates the thickness of the thread; the higher the value, the finer the thread. In order to observe the effect of the sewing thread type, same ticket number were used.

An industrial Juki DDL 9000A locksticth machine was used for sewing the denim samples. The sewing was performed with Type-301 (Figure 1) stitch in three different stitch densities (3/4/5 stitches/cm). 90 size needle with rounded end was selected, and machine speed was kept constant during sewing as 3000 cycle/minute.

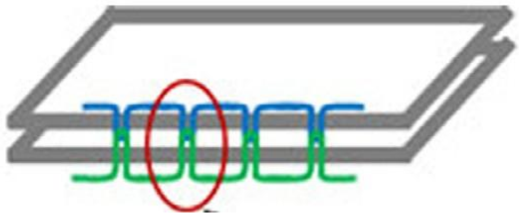

Figure 1. Locksticth type 301 [5]

2.2. Method

The produced samples were conditioned on a flat surface for 24 hours under standard atmospheric conditions at relative humidity before testing. The seam strength test was carried out using a Zwick Roell ZO10 tensile tester, in accordance with the standard TS EN ISO 13935-1. Specimens with a length of 350 mm and a width of 100 mm were prepared for the test. The device setting was kept constant for all tests. The set distance between the jaws was 200 mm, and the gauge speed was 50 mm/min. In order to prepare samples for seam strength test, the fabrics were sewn in the warp direction because the warp density is usually greater than weft density. Hence the effect of inserting a thread during sewing in the warp direction should a more pronounced effect on the seam performance. Furthermore, in apparel manufacturing, the fabrics are usually cut and sewn in the warp direction due to the texture and design of the fabric [15].

Seam pucker was determined by measuring the difference in fabric and seam thickness under a constant compressive load. Therefore, fabric thickness values of unsewn and sewn fabric samples were utilized. The seam thickness strain (%) as an indicative of seam pucker of the sewn fabrics is calculated by using the following formula *(1)* where seam thickness and fabric thickness are in mm [21, 32]. The seam area of about 30 cm was examined and measurements were taken from ten different locations on the sample using a Wira digital thickness gauge.

Table 1. The properties of denim fabrics

Fabric code	Fiber composition	Weight (gr/m^2)	Fabric thickness (mm)	Warp yarn density (ends/cm)	Weft yarn density (picks/cm)
1	99% Cotton - 1% Elastane	342	0,78	30	22
2	99% Cotton - 1% Elastane	424	0,92	28	20
3	99% Cotton - 1% Elastane	298	0,70	23	19

Table 2. Properties of sewing threads

Sewing thread code	Composition	Number of plies	Ticket number
1	Polyester-Polyester Corespun	2	50
2	Polyester-Cotton Corespun	2	50
3	Staple Polyester	2	50

$$Seam\ pucker\ (\%) = \frac{Seam\ thickness - 2\ x\ Fabric\ thickness}{2\ x\ Fabric\ thickness}\ x\ 100 \quad (1)$$

2.3. The Taguchi Approach to Analysis of Test Data

In this study, the Taguchi Method is used to analyze test data obtained by the method described in Section 2.2. This method emphasises on variance reduction. The variables under consideration may be quantitative or qualitative, and the performance criterion is the signal-to-noise ratio (SNR). There are four types of SNRs suggested by Taguchi [33]. Depending on the goal of the experiment, different signal-to-noise ratio can be chosen. There are three specific goals and therefore signal to noise ratios:

In this work two goals are considered i)to maximize the mean seam strength(the larger the better) ii) to minimize the mean seam pucker(the smaller the better). Therefore, the larger the better and the smaller the better are the goals aimed to achieve.

In *the larger the better case*, the SNR is given by Myers et al., as follows [33]:

$$SNR_l = -10 \log \sum_{i=1}^{n} \left[\frac{1}{y_i^2}\right] / n \quad (2)$$

where y_i $i=1,2,..,n$ are observed values of the response, seam strength. In this study factors; fabric weight, sewing thread type, and stitch density, that maximize SNR_l are sought.

In *the smaller the better case*, the SNR is given by Myers and Montgomery as follows [33]:

$$SNR_s = -10 \log \sum_{i=1}^{n} \left[\frac{y_i^2}{n}\right] \quad (3)$$

where y_i $i=1,2,..,n$ are observed values of the response, seam pucker, and values of the variables, fabric weight, type of sewing thread, and stitch density, that minimize SNR_s are sought.

Table 4 shows the factors; fabric weight, sewing thread type and stitch density, and their levels. Each factor has three levels and Taguchi analysis was carried out using Minitab Statistical Software version 16.0, in order to find the factor levels giving the maximum seam strength and minimum seam pucker. During the usage of software, “Define Custom Taguchi Design” was selected, so that the factor-interactions could be investigated.

For collecting data on factors and responses, three replicates were performed at each combination of factors’ levels. Thus totally 81 measurements were made. For the sake of simplicity, average value of three replicates are computed and given in Table 5.

3. RESULTS AND DISCUSSION

3.1. Maximizing the Mean Seam Strength

In this part of the study the aim was to determine the conditions, optimum factor levels, which give the highest mean seam strength. Calculated S/N ratios (larger-the-better) for seam strength were given in Table 6. Delta statistics were given in Table 6 compare the relative magnitude of effects. This statistic value is calculated by subtracting the highest value from the lowest value among the values in each column. Rank 1 is assigned to the highest Delta value where Rank 2 is assigned to the highest Delta value. The delta values in Table 6 indicates that among three factors (fabric weight/sewing thread type/stitch density) stitch density has the greatest influence on SNR where fabric weight has the lowest influence on SNR.

Table 3. Types of SNRs

Signal to noise ratio (SNR)	Goal of the experiment
Larger is better	Maximize the response
Nominal is best	Target the response and the signal-to-noise ratio is based on standard deviations only
Smaller is best	Minimize the response

Table 4. Factors and their levels

Levels	Factors		
	Fabric weight (gr/m^2) (A)	Sewing thread type (B)	Stitch density (stitch/cm) (C)
1	342	Polyester/Polyester Corespun	3
2	424	Polyester/Cotton Corespun	4
3	298	Staple Polyester	5

Table 5. Design matrix and mean response values

FACTORS			RESPONSES	
Fabric weight (gr) (A)	Sewing thread type (B)	Stitch density (stitch/cm) (C)	Seam strength (N)	Seam pucker (%)
1	1	1	531,19	21,87
1	1	2	540,22	8,49
1	1	3	563,41	7,48
2	1	1	484,43	16,72
2	1	2	842,03	15,19
2	1	3	892,27	14,97
3	1	1	773,04	14,58
3	1	2	802,79	8,47
3	1	3	829,69	4,31
1	2	1	629,17	15,97
1	2	2	765,98	7,05
1	2	3	782,43	3,31
2	2	1	567,56	15,74
2	2	2	732,60	14,75
2	2	3	990,98	14,75
3	2	1	782,65	11,81
3	2	2	892,30	7,50
3	2	3	931,02	4,03
1	3	1	667,64	25,18
1	3	2	649,34	11,94
1	3	3	669,50	10,94
2	3	1	629,17	21,75
2	3	2	801,56	18,69
2	3	3	839,98	18,58
3	3	1	679,26	18,33
3	3	2	781,95	12,78
3	3	3	878,11	10,14

Table 6. Response table for signal to noise ratio for seam strength

Level	**Fabric weight (A)**	**Sewing thread type (B)**	**Stitch density (C)**
1	56,04	55,58	55,32
2	56,92*	56,96*	56,46
3	56,12	56,54	57,30*
Delta	0,88	1,38	1,98
Rank	3	2	1

As a result, the following can be suggested as the optimal levels of A_2, B_2, and C_3 if factor interactions are not considered. In other words 424 gr/m^2 fabric weight, Polyester/Cotton Corespun sewing thread and 5 stitch/cm gave the maximum seam strength value.

In Table 7, Analysis of Variance results for seam strength are displayed. It includes components of the total variability in the response variable, seam strength. From the analysis of Table 7, it is concluded that factors A(fabric weight), B (sewing thread type), and C (stitch density), and interactions A-B, A-C, B-C and A-B-C have significant effects on seam strength at an α level of 0,10 since their p-values are less than 0,10. The value of coefficient of multiple determination, R-Sq, is 0,7438. That is, the factors and their interactions explain about 74,38% of the variability observed in seam strength.

Table 7. Analysis of variance results for seam strength

Source	**DF**	**SS**	**MS**	**F**	***p*-value**
A	2	89349	44674	8,83	0,000
B	2	138606	69303	13,70	0,000
C	2	297270	148635	29,38	0,000
A*B	4	46802	11701	2,31	0,069
A*C	4	72721	18180	3,59	0,011
B*C	4	63914	15979	3,16	0,021
A*B*C	8	84362	10545	2,08	0,053
Error	54	273145	5058		
Total	80	1066169			

S = 71,1213   R-Sq = 74,38%   R-Sq(adj) = 62,05%

In addition to the ANOVA results in Table 7, the two factor interaction plots are depicted in Figure 2 which also explores that the effect of each factor is influenced by the level of another factor [34]. It is clear that the second levels of fabric weight and sewing thread are more effected by the third level of stitch density. As can be seen, the highest mean seam strength is produced with stitch density (5 stitch/cm) when fabric weight is second level. This result is consistent with the optimal levels of factor levels mentioned above.

3.2. Minimizing the Mean Seam Pucker

Seam pucker is a distortion in the surface of a sewn fabric and appears as a swollen effect along the line of the seam. It is determined by measuring the percentage increase in the thickness of the seamed fabric over the original fabric under a constant load [4]. Therefore, main aim is minimizing the mean seam pucker. For each experimental run, design matrix and response values were given in Table 5.

In the smaller the better case, the factor levels that maximize SNRs, as in the larger the better case, but minimize the mean seam pucker are sought. Means for SNRs and response against levels of factors were given in Table 8.

As a result, the following can be suggested as the optimal levels of A_3, B_2, and C_3 if factor interactions are not considered. In other words 298 gr/m^2 fabric weight, Polyester/Cotton Corespun sewing thread and 5 stitch/cm gave the minimum seam pucker value. Seam pucker takes place mainly due to the contractive forces introduced in the seam during sewing. When the contractive force exceeds the buckling resistance of fabric inside a stitch, the fabric starts puckering along the seam line. If the sewing thread penetrates into a heavy weight fabric, it introduces very high contractive force and so high puckering has been seen in heavy weight fabrics [4]. The result given in Table 8 also supports this situation.

From Table 9, it can be concluded that A (fabric weight), B (sewing thread type), C (stitch density), two factor interactions; A – C, and three factor interaction; A – B – C have significant effects on mean seam pucker at an α level of 0,10 since their p-values are less than 0,10. It must be noted that although A-B, and B-C interactions appear as insignificant, the A–C and three-factor interactions are significant. The value of coefficient of multiple determination, R-Sq, is 0,8948. That is, the factors and their interactions explain about 84,41% of the variability observed in seam pucker.

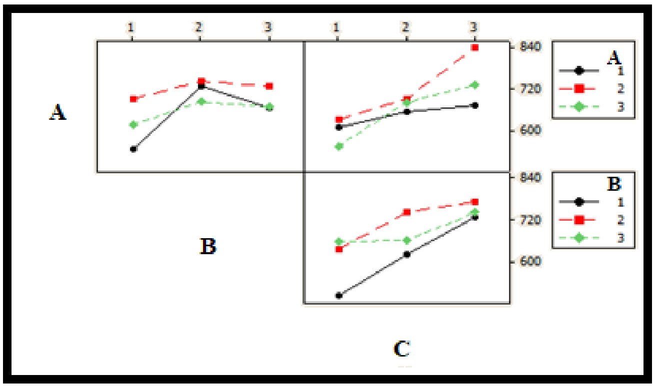

Figure 2. Interaction plot (data means) for seam strength

Table 8. Response table for signal to noise ratio for seam pucker

Level	Fabric weight (A)	Sewing thread type (B)	Stitch density (C)
1	-20,46	-21,04	-25,01
2	-24,42	-19,27*	-20,87
3	-19,51*	-24,08	-18,50*
Delta	4,91	4,80	6,51
Rank	2	3	1

Table 9. Analysis of variance results for seam pucker

Source	DF	SS	MS	F	*p*-value
A	2	564,67	282,33	47,34	0,000
B	2	530,15	265,08	44,45	0,000
C	2	1091,24	545,62	91,49	0,000
A*B	4	35,25	8,81	1,48	0,222
A*C	4	388,88	97,22	16,30	0,000
B*C	4	31,26	7,82	1,31	0,278
A*B*C	8	97,69	12,21	2,05	0,058
Error	54	322,05	5,96		
Total	80	3061,20			

S =2,44211 R-Sq = 89,48% R-Sq(adj) = 84,41%

When the plots displaying the factor interactions in Figure 3 are considered, third levels of A (fabric weight) and C (stitch density), produce smaller response with the second level of B (sewing thread type). A*C interaction plot implies that the smallest seam pucker is produced with the third level of stitch density (5 stitch/cm) when the second level of sewing thread type is used. This result is consistent with the suggested operating conditions mentioned in Table 8.

4. CONCLUSION

In experimental design, Taguchi Method has great importance in optimization of input factors. In the current study, according to the results obtained by Taguchi Custom Design *i)* maximum seam strength was obtained by 5 stitch/cm, Polyester/Cotton Corespun thread and 424 gr/m^2 fabric weight, and *ii)* the seam pucker was minimized when process is settled to 5 stitch/cm, 298 gr/ m^2 fabric weight and Polyester/Cotton Corespun thread. Furthermore, three-way ANOVA results showed that *i)* fabric weight, sewing thread type, stitch density, and their two-way, and also three-way interactions have significant effects on the seam strength, *ii)* for seam pucker; effects of three factors, and fabric weight-stitch density interaction are significant. Since three-way interaction is also significant, it can be concluded that fabric weight-stitch density interaction may differ for one level of sewing thread type compared to another level of sewing thread type.

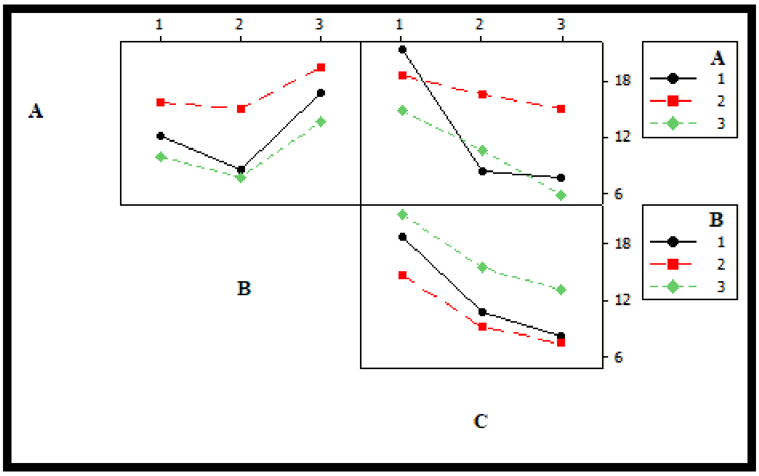

Figure 3. Interaction plot (data means) for seam pucker

REFERENCES

1. Annapoorani, SG., 2017. Introduction to Denim, In S.S. Muthu (Ed.), Sustainability *in Denim,* Woodhead Publishing, 1-26.
2. Haghighat, E., Etrati, S.M., Najar, S.S., 2014. Evaluation of Woven Denim Fabric Sewability based on Needle Penetration Force. *Journal of Engineered Fibers and Fabrics*, 9(2), 47-60.
3. Eryuruk, H. S. 2019. The effects of elastane and finishing processes on the performance properties of denim fabrics,*International Journal of Clothing Science and Technology*, 31(2), 243-258.
4. Behera, B.K., Chand, S., Singh, T.G. and Rathee, P. 1997. Sewability of denim", *International Journal of Clothing Science and Technology*, 9 (2), 128-140.
5. Malek, S., Jaouachi, B., Khedher, F., Said, S.B. and Cheikhrouhou, M. 2017. Influence of some sewing parameters upon the sewing efficiency of denim fabrics, *The Journal of the Textile Institute*, 108 (12), 2073-2085.
6. Rajpu, B. et. al., 2018. Effect of sewing parameters on seam strength and seam efficiency", Trends in Textile Engineering & Fashion Technology, 4 (1), 1-5.
7. Hayes, S. and Mcloughlin, J. 2013. The sewing of textiles", in Jones, I. and Stylios, G.K. (Eds), Joining Textiles Principles and Applications, Woodhead Publishing Series in Textiles, No. 110.
8. Mandal, S. and Abraham, N. 2010. An overview of sewing threads mechanical properties on seam quality, *Pakistan Textile Journal*, Vol. 59(1), 40-43.
9. Bharani, M. and Mahendra Gowda, R.V. 2012. Characterization of seam strength and seam slippage on pc blend fabric with plain woven structure and finish", *Research Journal of Recent Sciences*, 1(12), 7-14.
10. Hossain, A. et. al, 2020., Effect of Different Sewing Parameters on Lockstitch Seam Strength for Denim Fabric, *Journal of Engineering Advancements*, 1 (4), 139-143.
11. Germanova-Krasteva, D. and Petrov H. 2008. Investigation on the seam's quality by sewing of light fabrics. *International Journal of Clothing Science and Technology*, 20 (1), 57-64.
12. Malek, S., Khedher, F., Jaouachi, B. and Cheikhrouhou, M. 2019. Influence of denim fabric properties and sewing parameters upon the seam slippage and seam quality prediction, *Journal of Textile and Apparel, Technology and Management*, 11(1), 1-17.
13. Tuteja, S. and Sen, P. 2019. Influence of stitch density and sewing thread count on the seam performance of denim fabric, *Journal of The Textile Association*, 9 (2), 442-448.
14. Yildiz, E.Z. 2018. Modeling of Seam Quality by Using Different Seam Parameters, Ege University, Turkey, PhD Thesis.
15. Ghani, S.A. and Gong, H. 2010. "Seam quality: experimental and modelling works using the structural equation methodology", *Scientific Research Journal*, 7(1), 13-36.
16. Tiber, B. and Yilmaz, N.2022, Investigation of the effects of elastic sewing thread on seam performance properties of stretch denim fabrics. *Tekstil ve Konfeksiyon*, 32 (1), 47-56.

17. Ateş, M., Gurarda, A. and Ceven, K. 2019. Investigation of seam performance of chain stitch and lockstitch used in denim trousers, *Tekstil ve Mühendis*, 26 (115), 263-270.

18. Sarkar, J., Al Faruque, A. and Mondal, M.S.. 2021. Modeling the seam strength of denim garments by using fuzzy expert system. *Journal of Engineered Fibers and Fabrics*, 16, 1-10.

19. Nayak, R. and Padhye, R. 2013. Sewability of Air-Textured Sewing Threads in Denim. *Journal of Textile and Apparel, Technology and Management*, 8(1), 1-11.

20. Kakde, M.V. and Gulhane, S.S. 2018. Effect of sewing parameters on seam strength and seam efficiency, *Trends in Textile Engineering and Fashion Technology*, 4(1), 1-5.

21. Sülar V., et al., 2015. A Comparative Study on Seam Performance of Cotton and Polyester Woven Fabrics, *The Journal of Textile Institute*, 106 (1), 19-30.

22. Mak, K.L. and Li, W. 2008. Objective Evaluation of Seam Pucker on Textiles by Using Self-Organizing Map, *International Journal of Computer Science*, 35 (1), 1-8.

23. Ross, J. E. 1999. Total Quality Management (3rd edition). ABD: St. Lucie Press

24. Canyılmaz, E. ve Kutay, F. 2003. Taguchi Metodunda Varyans Alnalizine Alternatif Bir Yaklaşım, *Gazi Üniversitesi Mühendislik Mimarlık Dergisi*, 18 (3), 51-63

25. Taguchi, G. ve Clausing, D. 1990. Robust Quality, Hardward Business Review, pp. 65-76.

26. Rowlands, H., Antony, J. ve Knoles, G. 2000. An Application of Experimental Design for Process Optimization. *The TQM Magazine*, 12 (2), 78-83.

27. Ustuntag, S. and Turksoy, H.G., 2019. Optimization of coating parameters for air permeability of denim fabrics through Taguchi method", *Industria Textila*, 70 (3), 259-264.

28. Onal, L., Zeydan, M., Korkmaz, M. and Meeran, S. 2009. Predicting the seam strength of notched webbings for parachute assemblies using the Taguchi's design of experiment and artificial neural networks, *Textile Research Journal*, 79 (5), 468–478.

29. Almetwally, A.A. 2020, Multi-objective Optimization of Woven Fabric Parameters Using Taguchi–Grey Relational Analysis, *Journal of Natural Fibers*, 17 (10), 1468-1478.

30. Hossain, I., Hossain A., and Choudhury, I.A., 2016. Dyeing process parameters optimisation and colour strength prediction for viscose/lycra blended knitted fabrics using Taguchi method, *The Journal of The Textile Institute*, 107 (2). 154–164.

31. Ghosh, A., Mal, P., Majumdar, A. and Banerjee, D. 2017. An investigation on air and thermal transmission through knitted fabric structures using the Taguchi method, *AUTEX Research Journal*, 17 (2). 152-163.

32. Hati, S. and Das, B.R. 2011. Seam Pucker in Apparels: A Critical Review of Evaluation Methods, *Asian Journal of Textile,* 1, 60-73.

33. Myers, R.H., Montgomery, D.C., Anderson, C.M., (2009), Response Surface Methodology: Process and Product Optimization Using Designed Experiments, John Wiley&Sons, Inc., New Jersey.

34. Hines W.W. and Montgomery, D.C., 1990. Probability and Statistics in Engineering and Management Science, third edition, John Wiley and Sons, New York.