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Seam Strength Prediction for Different Stitch Types Considering Stitch Density of Cotton Woven Fabrics

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Article

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ABSTRACT

Seam strength is critical in achieving the proper and adequate quality seam, which eventually determines the overall quality of any garment. The target of this research was to investigate exactly how different stitch density affected seam strength for different stitch types. Commercially available, 100% cotton plain weave structured woven fabric with mass per unit area of 270 g/m^2 was used in this analysis. Two different stitch types, such as lock stitch (ISO#301) and chain stitch (ISO#401), along with four stitch densities like 8, 10, 12 and 14 per inch were utilized. The seam strength of the prepared samples was determined using a tensile strength tester followed by the ASTM D1683 standard procedure. The impact of independent variables on superimposed seam strength was statistically analyzed using a regression correlation with the help of SPSS software to construct a regression equation to predict seam strength before the manufacturing process. The study found a non-linear relationship between seam strength and stitch density. When the stitch density is too low, the seam strength is shown low as well, because the cloth cannot be held under tensile load. In a very compact woven fabric, structural jamming or intrinsic puckering occurs if it is too high. As a result, the best stitch density should be chosen to achieve the best seam strength. This study will help the manufacturers choose a suitable SPI for lock and chain stitches from polynomial regression equations before the sewing production of cotton woven fabric, which was not predicted by any researcher before. Therefore, the optimum stitch density can be chosen using regression equations to get the best result for seam strength.

KEYWORDS

stitch type, stitch density, seam strength, seam efficiency, sewing thread

INTRODUCTION

The garment business is entering an era in which production quality, cost, and compliance are given top priority. Current trends indicate that order volumes are shrinking, and that customers are placing increased emphasis on faster delivery times and higher quality. The most basic factors for the success of this firm, regardless of where it is done, are better quality and reduced costs [1]. However, today's world is a golden era of fashion, and fashionable apparels are part and parcel of daily life. To be fashionable apparel, a garment product must have aesthetic beauty, like texture, color, unique design, patterns, etc. But technical properties are as important as aesthetic properties. Technical properties include performance features like durability, comfort, drapability, strength, elasticity, tenacity, etc. Technical properties can be classified into two groups. One is the selection of proper raw materials like fabric, sewing thread, interlining, etc. For instance, cotton fabric cannot be used as cold-weather apparel. The selection of the right raw materials not only comforts the wearer, but also leads to defect-free clothing as it smooths out the manufacturing process [2–5]. The other factor is maintaining the right parameters during the processing, like stitch density, sewing speed, stitch types, seam types, etc. These parameters have to be maintained in order to maximize the product durability by ensuring a proper interaction between the fabrics and the seam [6–8]. Yassen studied the effect of sewing thread count, sewing needle size, stitch density, and fabric properties on seam strength and showed that both sewing and fabric parameters had a substantial impact on seam strength [9]. As sewing thread keeps the fabric together and converts two-dimensional (2D) fabric into three-dimensional (3D) garments, and selecting the perfect stitch type, seam type, sewing thread, stitch density, sewing speed etc. is significant. The impact of sewing thread on seam performance is undeniable even though it weighs 1% of the total weight in comparison to the sewn fabric [10]. All of these parameters influence the seam strength.

Seam efficiency is also another important factor, one that determines whether the calculated seam strength is sufficient for that fabric or not. It can be defined as the ratio of seam strength to the unseam fabric tensile strength expressed as a percentage [11–14]. The seam efficiency generally lies between 85-90% depending on the stitch density, the seam type, the type of sewing thread, the needle type, and the size [15]. The seam strength of the US military cotton fabric should be 80% of the fabric strength. So, the seam efficiency should be maintained properly. If the seam strength is higher than the fabric strength, it deteriorates the fabric by pulling warp or weft threads and eventually creates seam slippage and it is irreversible [16]. Even though the material strength is excellent, the garment is inappropriate due to poor seam performance. As a result, determining the seam strength in terms of the clothing performance during use is vital [17].

Hence, it leads to a shorter life cycle of the end-product due to the distortion of the sewing surface [18, 19]. If the condition is reversed, then the sewing thread can be broken easily and can create seam openings and hence cannot hold the fabric together. As a result, the quality and performance of a sewn garment are both determined by the seam strength and efficiency. Even if the fabric is still intact, a seam failure might render the garment unfit for regular wear [20].

Indeed, many studies have been carried out to determine seam strength based on various parameters [21–27]. However, some studies showed a linear relationship between seam strength and stitch density, as all used a very low stitch density of 7 to 13 stitches per inch [28–30]. However, beyond that, what will happen is not studied yet. According to the data found, if the SPI (stitches per inch) increases, the seam strength will also increase. But it should not be true for all cases, because when the SPI increases, a greater number of needles gets inserted in a given area, thus a greater number of threads takes place between warp or weft yarns. If there is not enough gap between the adjacent yarns for the sewing thread to be placed, it will produce structural jamming or inherent puckering. When the SPI is more than adequate, it will not increase the seam strength. Again, chain stitches and lock stitches do not have the same amount of thread consumption, thus a different amount of thread needs to be inserted between the gap of warp or weft yarns, hence the seam strength is different.

The aim of this research was to investigate the seam strength for different stitch types depending on the stitch density. Commercially available, 100% cotton plain weave structured woven fabric was used in this analysis and four stitch densities, 8, 10, 12 and 14 stitches per inch, were utilized. The impact of independent variables on the seam strength was statistically analyzed using a regression correlation with the help of the SPSS software in order to construct a regression equation to predict the seam strength before the manufacturing process.

MATERIALS AND METHODS

A 100% cotton plain weave structured woven fabric having mass per unit area of 270 g/m^2 was collected from the local market in Dhaka, Bangladesh. The fabric specifications are mentioned in Table 1.

Table 1. Woven fabric specifications

Fabric structure	Fabric density (cm^{-1})		Yarn count (tex)		Mass per unit area (g m^{-2})
	Warp	Weft	Warp	Weft	
Plain weave (1/1)	41	21	37	49	270

Two stitch types, lock stitch (ISO 301) and chain stitch (ISO 401), were employed, as well as four stitch densities (stitches per inch) of 8, 10, 12, and 14. The 100% cotton sewing threads were selected to produce superimposed seam, where thread linear density was 60 tex. The seam strength of the samples was evaluated using a tensile strength tester (Testometric, 5kN, England) according to the ASTM D1683 standard method.

$$\text{Efficiency of seam (\%)} = \frac{\text{Seam strength}}{\text{Fabric strength}} \times 100 \quad (1)$$

Figure 1 shows the experimental setup of the specimen. Five samples were prepared for each type.

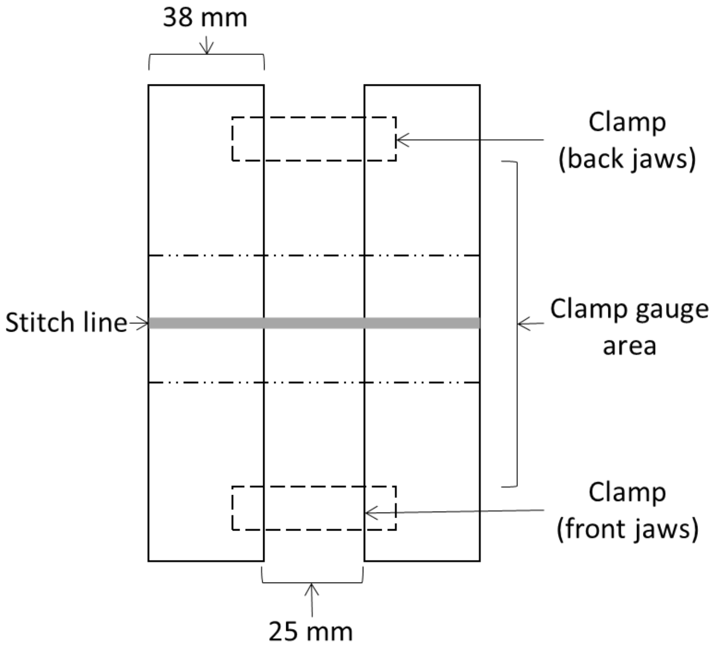

Figure 1. Experimental setup for the superimposed seamed specimen placed in clamps

The tensile strength of woven fabric in warp and weft direction is indicated in Table 2.

Table 2. Tensile strength of the woven fabric in warp and weft directions

Observations	Tensile strength (N)		Mean tensile strength (N)	
	Warp	Weft	Warp	Weft
1	515.83	316.75		
2	590.36	333.43		
3	584.48	333.43	558.00±14.08	326.56±4.01
4	537.40	316.75		
5	561.92	332.45		

The efficiency of the seam was measured according to the ASTM standard D1683/D1683M-17(2018). The samples are identified as mentioned in Table 3.

The seam strength and seam efficiency based on stitch type and stitch density are mentioned in Table 4. The samples were conditioned for 24 hours at a standard testing atmosphere before testing.

Table 3. Sample identification

Seam type	Stitch type	Stitch density, stitch per inch	Sample code
Warp	301	8	FS_3E1
		10	FS_3E2
		12	FS_3E3
		14	FS_3E4
Weft		8	FS_3P1
		10	FS_3P2
		12	FS_3P3
		14	FS_3P4
Warp	401	8	FS_4E1
		10	FS_4E2
		12	FS_4E3
		14	FS_4E4
Weft		8	FS_4P1
		10	FS_4P2
		12	FS_4P3
		14	FS_4P4

Table 4. Tensile strength and the efficiency of the seam of the designed samples

Sample code	Observations	Seam strength, N	Mean seam strength, N	Seam efficiency, %	Mean seam efficiency, %
FS_3E1	1	284.22	275.35±9.11	55.09	49.59±2.68
	2	252.82		42.82	
	3	253.98		43.45	
	4	292.00		54.34	
	5	293.74		52.27	
FS_3P1	1	222.63	253.39±9.69	70.29	77.59±2.80
	2	267.68		80.28	
	3	270.14		81.02	
	4	268.19		84.67	
	5	238.35		71.69	
FS_4E1	1	297.95	293.25±7.19	57.76	52.63±1.42
	2	316.65		53.64	
	3	294.68		50.42	
	4	274.72		51.12	
	5	282.26		50.23	

Sample code	Observations	Seam strength, N	Mean seam strength, N	Seam efficiency, %	Mean seam efficiency, %
FS_4P1	1	306.41	275.90±8.08	96.74	84.62±3.29
	2	275.73		82.69	
	3	266.60		79.96	
	4	271.15		85.60	
	5	259.61		78.09	
FS_3E2	1	436.33	454.53±10.68	84.59	81.53±1.45
	2	480.55		81.39	
	3	478.14		81.81	
	4	449.36		83.62	
	5	428.27		76.22	
FS_3P2	1	269.17	273.99±4.19	84.98	83.96±1.67
	2	280.23		84.04	
	3	259.73		77.89	
	4	279.11		88.12	
	5	281.74		84.75	
FS_4E2	1	398.28	389.18±8.96	77.21	69.91±2.34
	2	383.15		64.90	
	3	391.63		67.01	
	4	359.36		66.87	
	5	413.47		73.58	
FS_4P2	1	281.89	285.59±3.59	88.99	87.48±1.14
	2	282.93		84.85	
	3	282.26		84.65	
	4	280.98		88.71	
	5	299.90		90.21	
FS_3E3	1	401.41	389.10±7.96	77.82	69.91±2.30
	2	375.22		63.56	
	3	412.83		70.63	
	4	370.45		68.93	
	5	385.61		68.62	
FS_3P3	1	284.16	271.40±3.68	89.71	83.19±1.99
	2	273.39		81.99	
	3	264.25		79.25	
	4	271.06		85.58	
	5	264.14		79.45	

Sample code	Observations	Seam strength, N	Mean seam strength, N	Seam efficiency, %	Mean seam efficiency, %
	1	362.01		70.18	
	2	393.33		66.63	
FS_4E3	3	389.78	388.84±10.72	66.69	69.83±2.43
	4	425.32		79.14	
	5	373.77		66.52	
	1	291.61		92.06	
	2	233.44		70.01	
FS_4P3	3	283.60	272.29±11.29	85.06	83.46±3.73
	4	260.50		82.24	
	5	292.34		87.93	
	1	354.98		68.82	
	2	284.72		48.23	
FS_3E4	3	321.65	317.97±13.59	55.03	57.33±3.77
	4	338.46		62.98	
	5	290.04		51.62	
	1	282.62		89.22	
	2	279.13		83.71	
FS_3P4	3	239.74	261.09±8.40	71.90	80.04±3.03
	4	252.64		79.76	
	5	251.32		75.59	
	1	377.03		73.09	
	2	351.57		59.55	
FS_4E4	3	330.92	365.04±10.37	56.62	65.73±3.29
	4	386.47		71.91	
	5	379.23		67.49	
	1	262.38		82.84	
	2	222.60		66.76	
FS_4P4	3	269.93	251.83±8.22	80.96	77.18±2.79
	4	246.77		77.91	
	5	257.49		77.45	

RESULTS AND DISCUSSION

Seam strength and efficiency analysis

In order to ensure the influence of stitch density on the seam strength, two different stitch types, a lock stitch (ISO#301) and a chain stitch (ISO#401), were employed. The changes of the seam strength of all selected samples during different stitch density are shown in Figure 2 and seam efficiency is shown in Figure 3.

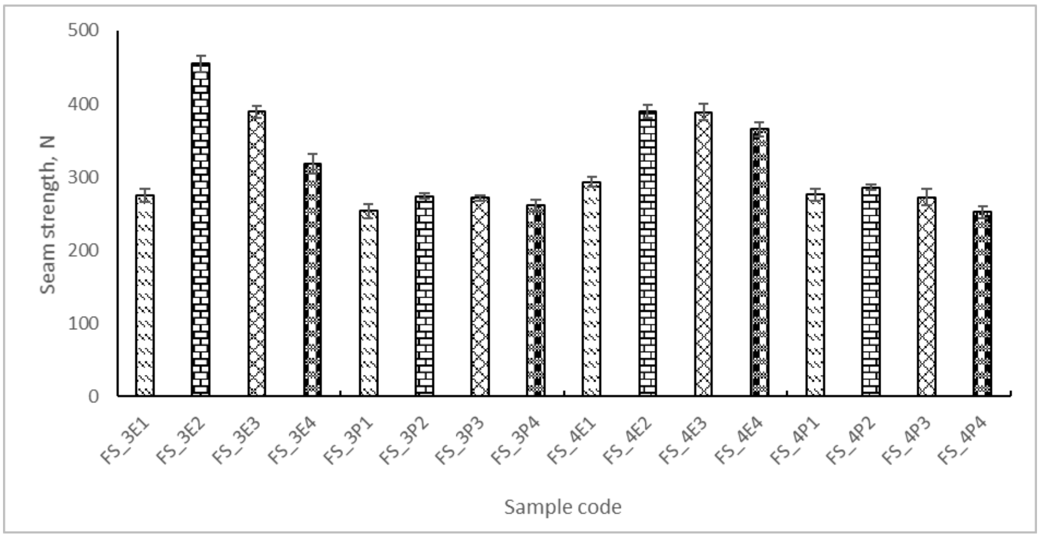

Figure 2. Dependency of the seam strength and stitch density of different stitch types

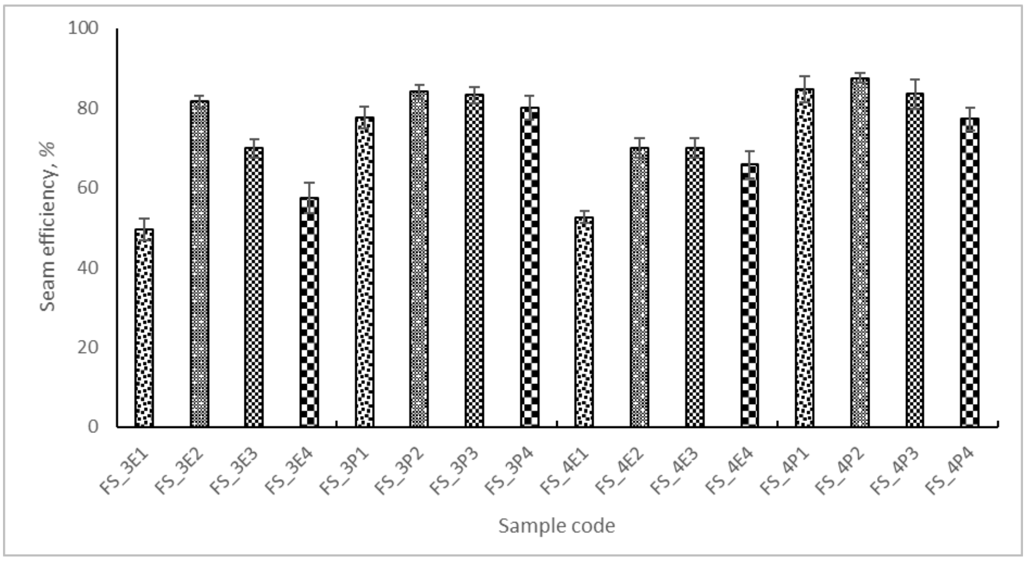

Figure 3. Dependency of the seam efficiency and stitch density of different stitch types

The obtained results demonstrate the changing aspects of the seam strength of different stitch types depending on stitch density. The seam strength required to reach the targeted strength strongly depends on stich density and the direction of the seam (warp and weft) in the woven structure. For the single needle lock stitch, the average seam strength in the warp direction was found to be 275.35 N, 454.53 N, 389.10 N and 317.97 N for FS_3E1, FS_3E2, FS_3E3 and FS_3E4, respectively. On the other hand, the average seam strength in the weft direction was found to be 253.40 N, 273.99 N, 271.40 N and 261.09 N for FS_3P1, FS_3P2, FS_3P3 and FS_3P4, respectively.

For chain stitch, the seam strength was observed as 293.25 N, 389.18 N, 388.85 N and 365.04 N for FS_4E1, FS_4E2, FS_4E3 and FS_4E4, correspondingly in the warp direction. On the other hand, the seam strength was noticed as 275.90 N, 285.59 N, 272.30 N and 251.83 N for FS_4P1, FS_4P2, FS_4P3 and FS_4P4 likewise in the weft direction.

Overall, the stitch density of 10 SPI was found to be the best in the case of both lock and chain stitch seam for both the warp and weft way seam. It has also been found out that the seam strength of warp way seam is constantly higher than weft way seam but in the case of seam efficiency, this relationship was observed in reverse scenario.

For seam efficiency, Figure 3 shows a similar pattern as the seam strength in the case of both lock and chain stitch for both the warp and weft way seam. The seam efficiency was found to be the maximum for stitch density of 12 SPI.

It is clearly evident that the stitch density has a significant impact on the seam strength. The seam strength exhibits at a lower level while the stitch density is low. The excessive stitch density in the compact fabric reduces the seam strength due to the creating of inherent puckering or structural jamming problems. Therefore, the optimum stitch density is recommended to get the most excellent seam strength.

Statistical analysis

The correlations among the factors such as the stitch type, the stitch density, the fabric direction, and the seam strength were computed and the obtained results are presented in Table 5.

Table 5. Correlation analysis of different parameters

Correlations					
		Fabric direction	Stitch type	Stitch density	Seam strength
Fabric direction	Pearson correlation	1	0.000	0.000	-0.719**
	Sig. (2-tailed)		1.000	1.000	0.000
	N	80	80	80	80
Stitch type	Pearson correlation	0.000	1	0.000	0.025
	Sig. (2-tailed)	1.000		1.000	0.827
	N	80	80	80	80
Stitch density	Pearson correlation	0.000	0.000	1	0.094
	Sig. (2-tailed)	1.000	1.000		0.407
	N	80	80	80	80
Seam strength	Pearson correlation	-0.719**	0.025	0.094	1
	Sig. (2-tailed)	0.000	0.827	0.407	
	N	80	80	80	80

** Correlation is significant at the 0.01 level (2-tailed).

The Table 5 shows that the seam strength has strong and negative correlation with the fabric direction. In contrast, the seam strength has weak and positive correlation with the stitch type and the stitch density.

Table 6 shows the multiple linear regression model summary for the stated factors.

Table 6. Multiple linear regression model summary

Model summary				
Model	R	R^2	Adjusted R^2	Standard Error of Estimate
1	0.726[a]	0.527	0.508	44.64897
a. Predictors: (Constant), SPI stitch type, fabric direction				

The model summary in Table 5 reports the strength of the relationship between the model and the dependent variable. In multiple linear regression, the R2 represents the correlation coefficient between the observed values of the outcome variable and the predicted values. The R2 value was found to be 0.527 (Table 6). The R2 value denotes that 52.7% of the changes in the seam strength (dependent variables) can be explained by independent variables in the model which indicates the lesser efficiency of the model. Also, it can be suggested (depending on the R2 value) that the relationship among the factors may be non-linear. The present assumptions are supported by another study [31]. From multiple linear regression model, by a different researcher, if the SPI increases, the seam strength will also increase [28, 29]. Stated could not be true in all cases because when the SPI is increased, a higher number of needles is inserted per unit area, thus a higher number of threads will take place between warp or weft yarns. If there is not enough of a gap between the adjacent yarns for the sewing thread to be placed, it would produce inherent puckering or structural jamming. So, when the SPI is more than adequate, it would not increase the seam strength. To overcome the limitation of linear regression, a higher degree polynomial regression has also been computed. For the quadratic polynomial regression model, it was found that the curve does not fit perfectly. Due to space consumption, the analysis for quadratic polynomial models have not been presented here. After that, the cubic polynomial regression model was computed, namely, cubic polynomial regression of the warp seam strength for the stitch type 301, cubic polynomial regression of the weft seam strength for the stitch type 301, cubic polynomial regression of the warp seam strength for the stitch type 401, and cubic polynomial regression of the weft seam strength for the stitch type 401. The obtained results are presented in Figures 4-7. For every model, cubic polynomial regression equations were obtained, which are presented in Equations 2-5.

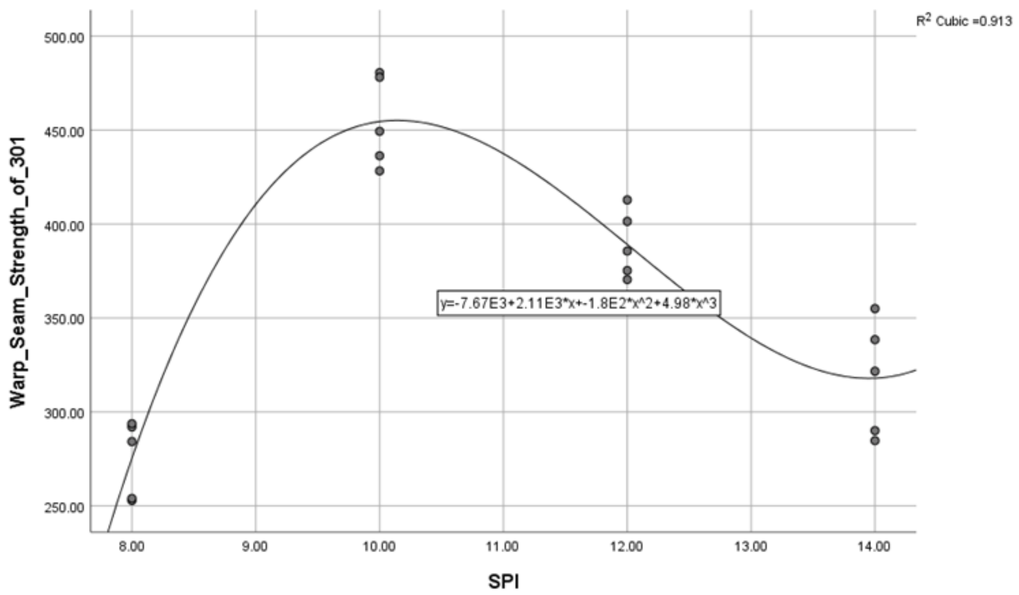

Figure 4. The cubic polynomial regression curve of the warp seam strength for the stitch type 301

The prediction of the warp seam strength of the 301 according to the (cubic) polynomial regression:

$$\text{Seam strength} = -7670+2110*\text{SPI}-180*\text{SPI}^2+4.98*\text{SPI}^3 \quad (2)$$

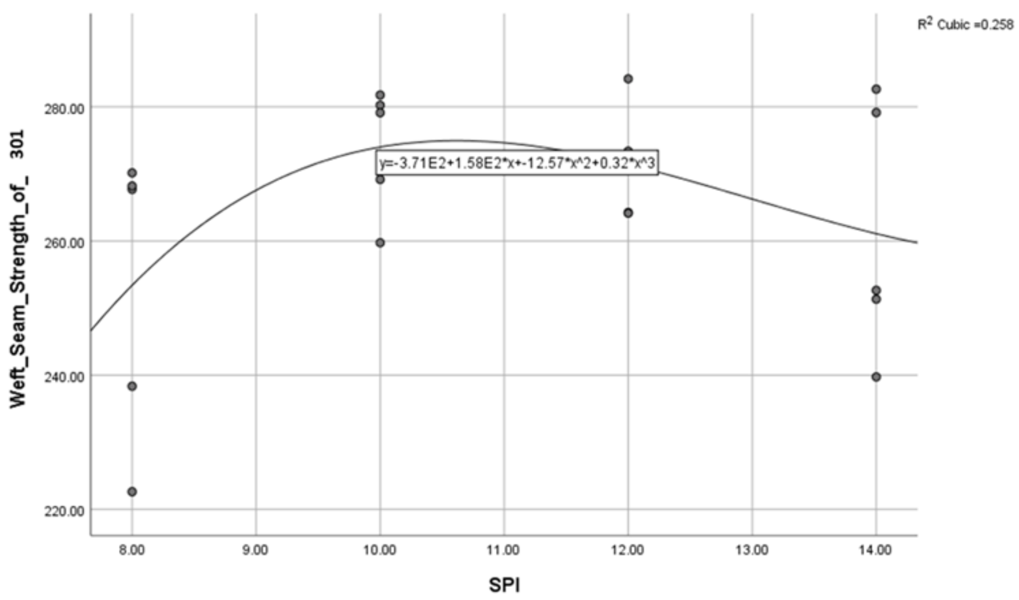

Figure 5. The cubic polynomial regression curve of the weft seam strength for the stitch type 301

The prediction of the weft seam strength of the 301 according to the (cubic) polynomial regression:

$$\text{Seam strength} = -371+158*\text{SPI}-12.57*\text{SPI}^2+0.32*\text{SPI}^3 \quad (3)$$

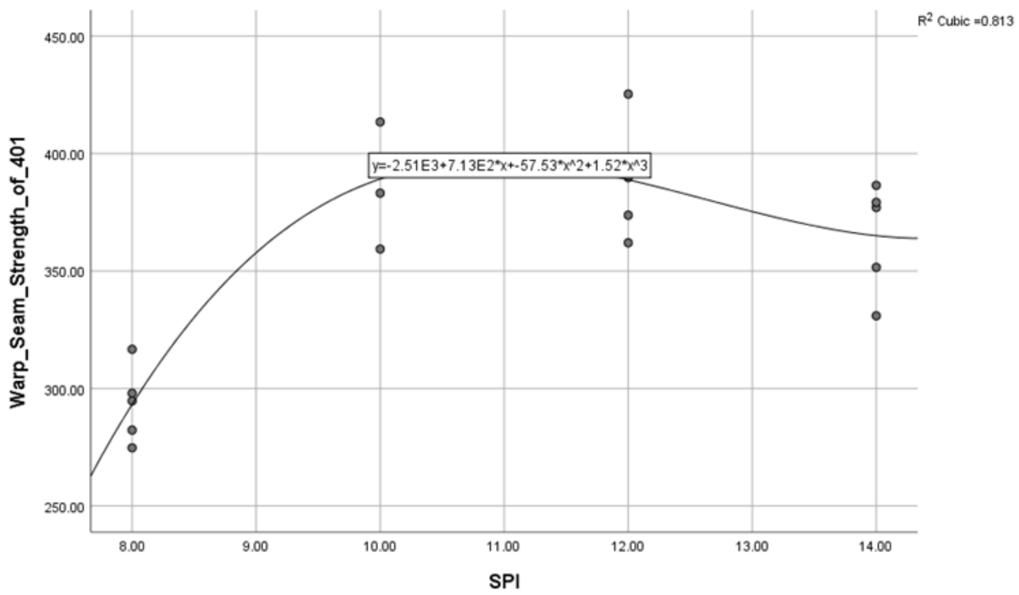

Figure 6. The cubic polynomial regression curve of the warp seam strength for the stitch type 401

The prediction of the warp seam strength of the 401 according to the (cubic) polynomial regression:

$$\text{Seam strength} = -2510+713*\text{SPI}-57.53*\text{SPI}^2+1.52*\text{SPI}^3 \quad (4)$$

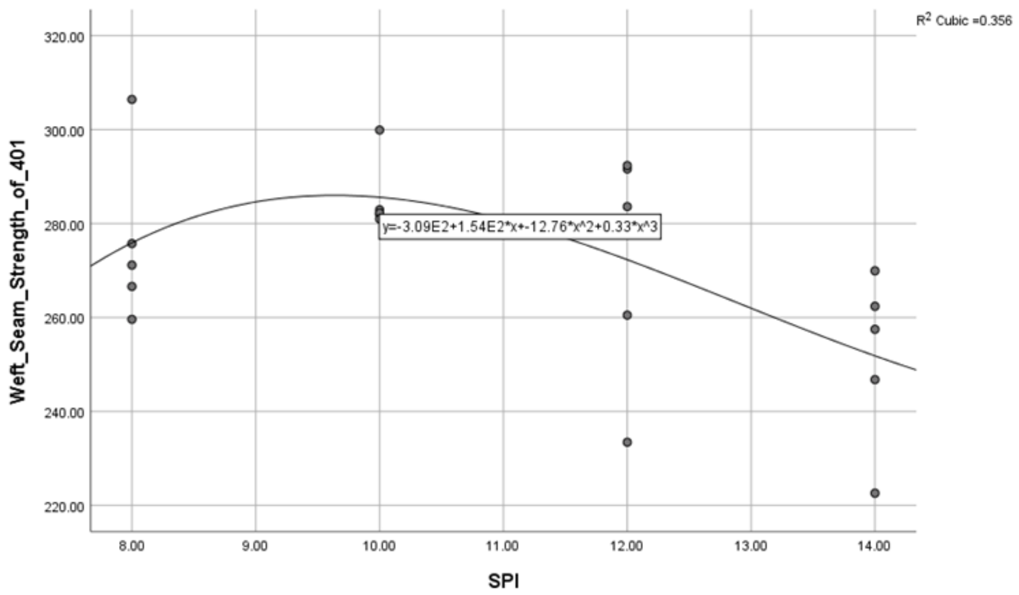

Figure 7. The cubic polynomial regression curve of the weft seam strength for thestitch type 401

The prediction of the weft seam strength of the 401 according to the (cubic) polynomial regression:

$$\text{Seam strength} = -309+154*SPI-12.76*SPI^2+0.33*SPI^3 \quad (5)$$

The polynomial regression has been analyzed in order to get a more accurate relationship. From the regression analysis, it can be concluded that the seam strength has a non-linear relationship with the stitch density. Although polynomial regression is technically a special case of a multiple linear regression, the interpretation of the polynomial regression model in this study is more suitable. Using these predicted equations, a suitable SPI can be selected for both the lock and the chain stitch when sewing the cotton woven fabric, which will help the production unit to get the best possible seam strength result.

CONCLUSION

The experimental results disclosed the non-linear dependency of the seam strength on the stitch density which was not predicted before. Furthermore, it was also found that different stitches differ in their impact on the strength under different SPI for the cotton woven fabric. The seam quality is subjected to the seam strength, strength efficiency, puckering and appearance. Consumers evaluate the seam quality mainly based on the seam appearance and its durability after the wear and care procedures. So, this study will help garment manufacturers predict the optimum SPI for both the lock and chain stitches before the sewing operations, which will ensure they get the best end-use performance from the garment.

It is clearly realized from the outcomes that the stitch density has a significant impact on the seam strength and a suitable stitch density is very important to enhance the strength of the produced seam which ultimately affects the end-product quality.

It is also important to minimize the loss in seam strength during sewing for a better seam strength realization. The main limitation of this study is that only the 100% cotton woven fabric having plain structure was used for the investigation. In the next research phase, the authors will investigate the possibilities of the seam strength prediction for different fabric structures of various fabrics made with different natural and synthetic fibers by varying EPI, PPI and SPI.

Author Contributions

Conceptualization – Islam MM and Hossain MT; methodology – Islam MM and Hossain MT; formal analysis – Islam MM, Repon MR and Islam T; investigation – Islam MM and Repon MR; resources – Islam MM and Jalil MA; writing-original draft preparation – Islam MM, Repon MR, Islam T and Kibria

G; writing-review and editing – Islam MM, Repon MR and Jalil MA; visualization – Islam T and Repon MR; supervision – Repon MR and Jalil MA. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest

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