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MODELING THE OVERALL SEAM QUALITY OF WOVEN COTTON FABRIC

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ABSTRACT

The aim of this research is to select a suitable form of regression model and predict the seam quality of woven cotton fabric.

Firstly, the effects of seam parameters on the seam quality are investigated while using the principal effects graphs and analysis of variance (ANOVA). The results have shown that seam efficiency was mainly influenced by sewing thread and stitch density. Moreover, stitch density and stitch type have the most significant effect on seam slippage and pucker. In second stage, we were interested to identify the suitable sewing conditions in order to achieve a good seam quality using a new term called a total seam quality index (TSQI) which takes account of all the seam quality parameters analysis.

Finally, In order to evaluate the effect of the influencing factors, statistical models based on multiple linear regressions were developed using the experimental results of Taguchi design to predict the overall seam quality. Very good results were obtained with high correlation coefficient values.

KEYWORDS

Seam quality; seam efficiency; seam pucker; seam slippage; stitch type; total seam quality index.

1. INTRODUCTION

In case of clothing choice, the consumer satisfaction depends to many thinks, assembly quality is the more important parameter after the fabric quality. Quality seams in sewn garments contribute to the overall performance of the garment in use. Poor quality seam makes a garment unusable even though the fabric may be in good condition.

For common garments, the seam is an essential part of the garment (Lindberg et al., 1960). A seam is manufactured employing sewing methods, with the idea that the seam should satisfy all the requirements imposed by a number of end-users of garments (Rosenblad et al., 1973; Stylios et al., 1990). For any garment, it is necessary to clearly understand the seam parameters, as it is the basic element of a cloth.

Since textile materials have non-linear mechanical properties, one set of sewing parameters cannot be used for all types of fabric (Pavlinic et al., 2003). By changing the parameters, the fundamental rules of sewing can be understood and the selection of parameters can be optimized in order to achieve a good sewing quality (Gribaa et al., 2006).

In order to understand various seam performances, the knowledge of various factors affecting the seam quality is necessary. Seam quality is governed by a broad spectrum of factors including sewing thread type and size, fabric, sewing machine speed, needle kind and size, stitch type and density and operator skills (Salhotra et al., 1994; Gribaa et al., 2006; Krasteva et al., 2008) etc. In the apparel industry, overall seam quality is defined through various functional and aesthetic performances during end use of the product.

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The functional performance mainly refers to the strength, tenacity, efficiency, elasticity, elongation, flexibility, bending stiffness, abrasion resistance, washing resistance and dry cleaning resistance of the seam under conditions of mechanical stress for a reasonable period of time (Mehta, 1985; Solinger, 1989; Carr, Latham, 1995).

Most previous studies (Chmielowice, 1987; Tarafdar et al., 2005) investigated the functional performance of seam mainly in terms of the seam strength and/or seam efficiency.

The fabric quality is one of the fundamental requirements for the production of a good seam quality in clothing manufacture. However, the fabric quality alone does not fulfill all the criteria for production of high quality garments. The transformation 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 the sewn fabric during wear of the garment (Behera et al., 1997a). Similarly, the quality and the performance of a sewn garment depend on various factors such as seam strength, slippage, puckering, appearance and yarn severance (Mehta, 1985; Choudhry, 1987).

There are also numerous studies (Gupta et al., 1992; Gersak, 2002; Ananthakrishnan et al., 2005; Juciene et al., 2008) on the seam quality based on the aesthetic performance. However, these studies focus mainly on the seam defects such as the seam puckering and seam damage.

Up to now, very limited work has been done to study the seam quality on functional and aesthetic performance together (Krasteva et al., 2008; Bharani et al., 2012; AL Sarhan, 2013). Moreover, the authors did not study the relative importance of dimensional seam quality analyses on overall seam quality of the fabrics analyses. Thus, the most obvious limitation of the study lies in fact that it cannot provide any knowledge on the overall seam quality and they did not adopt any systematic approach for predicting the seam quality.

This study attempts to analyze the seam quality from the aspects of both functional and esthetic performance, and to study the effect of stitch type, stitch density and sewing thread type on the seam quality for two cotton weaves. It also attempts to define a total seam quality index (TSQI) of an assembly which takes account of all the quality parameters analyses. Linear regression models were developed for predicting the relationships between seam quality and sewing parameters. The success of this study could help apparel manufacturers to evaluate the seam quality more effectively by using a single expression. In turn, this would facilitate apparel engineers in the production planning and quality control.

2. MATERIALS AND METHODS

2.1. Fabric parameters

In the present work, the investigation was carried out upon two cotton fabrics of medium weight. The plain and 3 twill weaves represent a broad range of use in clothes industry.
Basic properties of experimental fabrics were as follow: warp density 31/46 Ends.cm^{-1}, weft density 21/26 Picks.cm^{-1}. Linear density (tex) of warp and weft yarns was measured according to the NF G07-077. Fabric weight was measured with an electronic weighting balance (NF G07-150). The fabric thickness was measured according to the NF G07-153 test method.
The tensile test was conducted according to the NF G07-001 test method on the dynamometer LLOYD LRSK 5 KN. The cover factor of fabrics is determined by Peirce method (Segan, El-Sheikh, 1994) which is conceived for cotton fabrics.
It consists in applying the following equation (1):

$$\text{Cover factor (Kc)} = \left[\frac{\text{Warp yarns in fabric (ends/cm)}}{\sqrt{\text{Ne}}\text{(warp)}} + \frac{\text{Weft yarns in fabric (picks/cm)}}{\sqrt{\text{Ne}}\text{(weft)}} \right] \times 9.65 \qquad (1)$$

With: Ne is the English count.

The shear rigidity and formability were tested by FAST instrument under standard conditions (CSIRO Division of Wool Technology, 1989). The term formability (CSIRO, 1993) was derived to describe the maximum in-plane compression that a fabric will accommodate before it buckles. In the FAST system, formability is calculated as follows:

$$\text{Formability}\ (\text{mm}^2) = \text{B.R.} \times \frac{\text{EXT (20)-EXT (5)}}{14.7} \quad (2)$$

Where:

B.R. = bending rigidity (uNm – from a cantilever bending test)
EXT (20) = extensibility (% - at 20 gf cm^{-1})
EXT (5) = extensibility (% - at 5 gf cm^{-1})

The fabric properties were described in Table 1.

Table 1: Fabrics properties

	Direction	Linear density (tex)	Cover factor		Weight (g. m^{-2})	Thick. (mm)	Breaking strength (N)	Breaking extension (%)	Work of rupture (J)	Formability (mm^2)	Shear rigidity ($N.m^{-1}$)
Fabric 1 (twill3)	Warp	20/1	79	138	179.14	0.31	759.48	11.09	5.70	0.99	223.63
	Weft	34/1	59				647.92	10.98	4.56	0.94	
Fabric 2 (plain)	Warp	19/1	53	102	137.7	0.26	517.25	7.18	2.67	0.40	263.38
	Weft	34/1	49				551.79	14.11	4.57	0.73	

2.2. Sewing threads properties

Commercial cotton and polyester spun sewing threads of 30 tex are used to sew the two fabrics. The twist of sewing threads is made in S direction. The details of sewing threads properties are given in table 2.

Table 2: Sewing threads properties

Sewing thread			Polyester	Cotton
Twist (turns m^{-1})			493.5	449.1
Twist distance (cm)			4.78	7
Single strand	Breaking load (N)	$\bar{x}$	11.33	6.11
		CV(%)	8.02	6.46
	Breaking elongation (%)	$\bar{x}$	16.68	7.04
		CV(%)	6.29	6.77
	Breaking work (J)	$\bar{x}$	0.41	0.11
		CV(%)	13.61	11.33
In loop	Breaking load (N)	$\bar{x}$	19.74	11.15
		CV(%)	10.24	5.09
	Breaking elongation (%)	$\bar{x}$	15.66	7.46
		CV(%)	5.87	3.95
	Breaking work (J)	$\bar{x}$	0.67	0.20
		CV(%)	14.01	9.03

2.3. Seam quality analysis

The three important dimensions for seam quality evaluation (seam efficiency, seam puckering and seam slippage) were inferred as critical dimensions for seam quality evaluation.

✓ *Seam strength:* it refers to the load required to break a seam. Two pieces of woven fabric are joined by a seam and if tangential force is applied the seam line, rupture ultimately occurs at or near the seam line. Every seam has two components, fabric and sewing thread.
Therefore, seam strength must result from the breakage of either fabric or thread or, in more cases, both simultaneously. It was measured according to the international standard ISO 13935-1 (seam rupture using the strip method) on the dynamometer LLOYD LRSK 5 KN (figure 1), which express the value of seam strength in terms of maximum force to cause a seam specimen to rupture.

Figure 1: Seam strength Test

✓ *Seam efficiency:* it measures the durability along the seam line (Pai et al., 1984; Sundaresan et al., 1997; Behera, 1997b). Durability is identified as necessary to satisfactory seam's functional performance, and efficient seams are assumed to be more durable than weak ones. Many studies (Mohanta, 2006; Cheng et al., 2002; Tarafdar et al., 2007; Gurarda, 2008) measured the seam efficiency from strength tester, based on the pendulum lever principle according to the ASTM 1683-04 standard method. In this method, seam efficiency was measured by using the following equation:

$$\text{Seam efficiency (\%)}= \frac{\text{Seam tensile strength}}{\text{Fabric tensile strength}} \times 100 \quad (3)$$

✓ *Seam slippage:* it is the pulling away or separation of the fabric at the seam, causing gaps or holes to develop without yarn breakage and it is also one of the most objectionable faults in case of woven garments. It is expressed as the transverse ratio of seam strength to fabric strength including the ratio of elongation of fabric to the ratio of elongation at the seam (Behera, 1997b; Kothari, 1999). Any movement of the warp and weft yarns away from a seam line under transverse stresses exacerbates the potential slippage. It was obtained by measuring the opening of the seam after a wrenching test (figure 2) according to the international standard ISO 13936-2.

Figure 2: Seam slippage test

✓ *Seam pucker:* it is the deformation or wrinkling of a fabric along a sewing line. It is identified as a sewability problem about seventy years ago and has been regarded as one of the most important parameter of quality control in garment manufacturing industries. It can appear when the sewing parameters and sewn materials properties are not properly selected. Puckering can occur due to excess fabric and not enough thread in the seam (Hennig, 2002; Lojen et al., 2003; Gersak, 2004; Hu et al., 2006). After analyzing the puckering behavior of various seamed fabrics, it has been found that seam puckering depends mainly on the thickness properties of the fabric (Behera, 1997b; Kothari, 1999). As a result, seam puckering calculated by measuring the difference in fabric and seam thickness under constant compressive load (2 $gf.cm^{-2}$) (Behera et al., 1997a), with the compression meter of FAST system. Seam puckering calculated by using the following equation (Kothari, 1999; Mohanta, 2006; Pavlinic et al., 2006):

$$\text{Thikness strain (\%)} = \frac{ts-2t}{2t} \times 100 \quad (4)$$

Where: ts and t are the seam thickness and the fabric thickness.

✓ *Sewing condition parameters:* for selected fabric, two sewing thread type size were used at various stitch density with different stitch type. The levels of each factor are illustrated in Table 3 and the parameters of sewing conditions maintained for the test sample were as follows:

- 301 Lockstitch (figure 3): sewing was done on PFAFF (industrial) sewing machine 1183 with a needle type Groz-Beckert 134 R, size Nm 75/11.
- 401 Double Chainstitch (figure 4): sewing was done on Brother (industrial) sewing machine DT4 – B261 with a needle type Groz-Beckert UY 128 GAS RG, size Nm 80/12.
- 504 overlock stitch (figure 5): sewing was done on Pegasus MFG. CO. sewing machine standard LTD. 516-4-26 spec 2×3 with a needle type Groz-Beckert B 27 RG, size Nm 80/12.
- 516 (401+504) Safety Stitch (figure 6): sewing was done on Pegasus MFG. CO. sewing machine standard LTD. 516-4-26 spec 2×3 with a needle type Groz-Beckert B 27 RG, size Nm 80/12.

The assemblies are carried out in both directions (warp and weft).

Table 3. Considered factors and their levels

		Stitch Type	Stitch density	Sewing Thread
Level	1	301	3 $stitches.cm^{-1}$	Cotton
	2	401	4 $stitches.cm^{-1}$	Polyester
	3	504	5 $stitches.cm^{-1}$	
	4	516	6 $stitches.cm^{-1}$	

Figure 3: 301 Lockstitch

Figure 4: 401 Double stitch

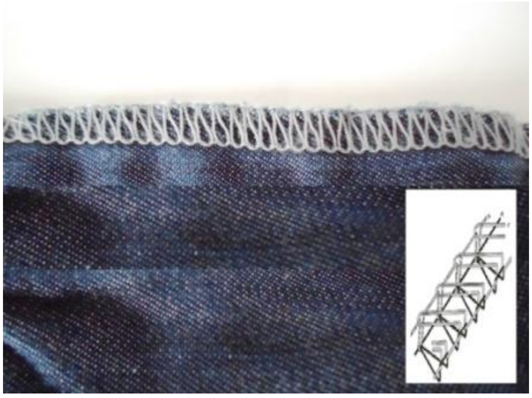

Figure 5: 504 Overlockstitch

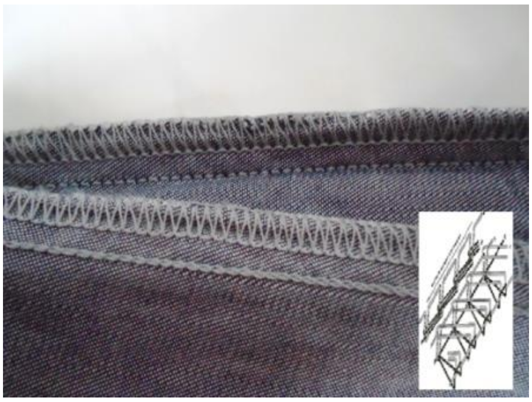

Figure 6: 516 Safety stitch

2.4. Statistical analysis

To explore the effects of stitch density, sewing thread, and stitch type on the different seam quality parameters and total seam quality index (TSQI); a Taguchi design was performed. All test results were assessed at significance level 0.05 ≤ α ≤ 0.01. To predict these effects, a multiple linear regression models were established with the following linear form equation:

$$Y=b_0+\sum_{i=1}^{n} b_i X_i \tag{5}$$

Where: b_0 is constant, b_i is coefficient and X_i is the value of the parameter objectively measured.
The validation of the regression models was performed using the coefficient of determination, R^2. R-square measures the reduction in the total variation of the dependent variable due to the independent variables.

3. RESULTS AND DISCUSSIONS

The characteristics of high-quality seam are strength, elasticity, durability, stability and appearance (Behera , 1997b). These qualities can be measured by seam parameters such as: seam efficiency, seam pucker and seam slippage. The seam efficiency and seam slippage are used to evaluate the functional performance of seam in terms of durability (Kothari, 1999; Mohanta, 2006; Tarafdar et al., 2007; Gurarda, 2008). Seam puckering is the dimension for the evaluation of seam aesthetic performance (Tarafdar et al., 2005; Krasteva et al., 2008). The seam quality parameters results are analyzed by the principal effects graphs, the interaction diagrams and the variance analysis are modeling by a multiple linear regression using the version 2013 of XLSTAT statistical software.

3.1. Seam efficiency

Figures 7, 8, 9 and 10 show the principal effects for the seam efficiency. It can be seen that stitch density has an important effect on seam efficiency. This is true for the two fabrics in both direction (warp and weft).

The seam efficiency and strength increase when the stitch density increase (Wang et al., 2001; Mukhopadhyay et al., 2004; Tarafdar et al., 2007; Gurarda, 2008; Midha et al., 2011). It can be explain by the increase of the number of contact points between the sewing thread and the fabric yarns, which results in a stronger gripping of seam line, thus the tensile stress will be distributed on several points.

The second factor which influences seam efficiency is the sewing thread. The seam efficiency increases when the values of twist and breaking strength (in single strand and in loop) increase. It was proven that the seam efficiency depends on the breaking strength and the twist of the used sewing thread (Gribaa et al, 2006). In fact, high strength of sewing thread always gives better seam functional performance, namely seam strength and seam efficiency (Bhatnagar, 1991; Sundersan et al.; 1998).

Also, the stitch type has a less effect on the seam efficiency. The stitch type 516 has a better seam efficiency than the stitch type 301 because it is formed simultaneously by one row of 401 stitch and another of 504 stitch.

On the other hand, for fabric 2, the seam efficiency is greater in the weft direction than in the warp direction seams, reversely for fabric 1. The seam efficiency increases when the shear rigidity of fabric increases (Mandal et al., 2007). Moreover, the seam efficiency was greatly reduced as the cover factor of fabric increases. Some studies revealed that fabrics with high cover factor (fabric 1 in this case) have an increased tendency to break the fabric yarns (warp and/or weft) at the time of sewing (Miguel et al., 2005), as a result the decrease of the seam functional performance such as seam strength and seam efficiency (Nergis, 1997/1998).

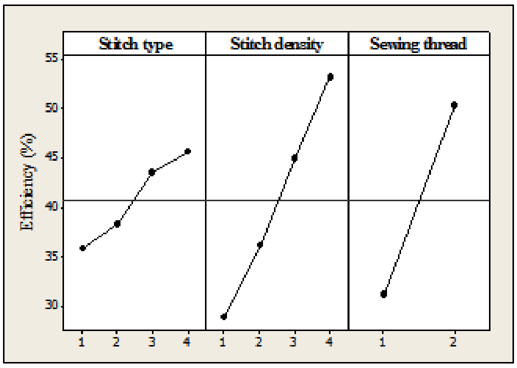

Figure 7: The principal effects for the seam efficiency of sewn fabric 1 in warp direction

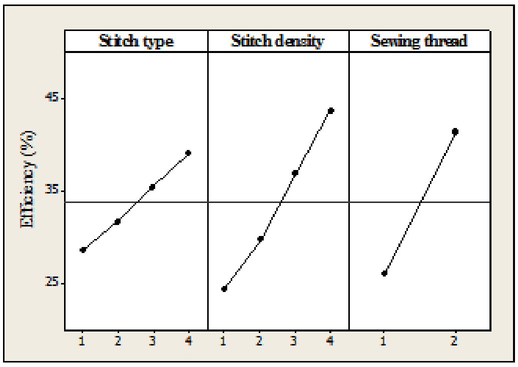

Figure 8: The principal effects for the seam efficiency of sewn fabric 1 in weft direction

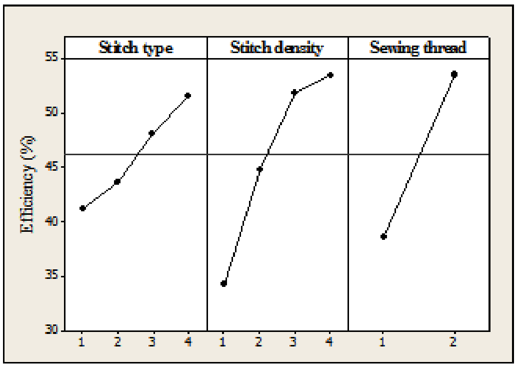

Figure 9: The principal effects for the seam efficiency of sewn fabric 2 in warp direction

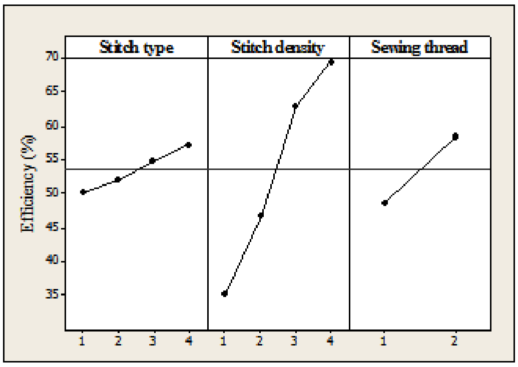

Figure 10: The principal effects for the seam efficiency of sewn fabric 2 in weft direction

3.2. Seam pucker

Seam pucker is the distortion in the surface of a sewn fabric and it appears as a swollen effect along the line of the seam (Taylor et al., 1967; Kawabata et al., 1989; Stylios et al., 1990).

The results of the experimental design show that for both fabrics, the stitch type has an important effect on the seam pucker as seen in figures 11, 12, 13 and 14. The seam pucker is very low for stitch type 301 (< 15 % for two fabrics) whereas it is very high for stitch type 516 (30 % for fabric 1 and 50 % for fabric 2). This result is due to the fact that stitch type 301 gives a flat and compact seam whereas the other stitch types are formed on the fabric surface and stitch type 516 gives a great thickness compared to the other seams since it consumes a lot of sewing thread.

The second factor which influences the seam pucker is the stitch density. The developed pucker is basically the deformation of fabric yarns caused by the penetration of the thread and the needle during the sewing operation (Behera et al., 1997a) and when the stitch density increases, the number of penetration of the sewing thread and needle during sewing increases, as a result a higher seam pucker.

In this study, the sewing thread properties have a less influence on the seam pucker, the two sewing threads gives respectively the same results of puckering, whereas the fabric properties have an important influence on the puckering of seams (Juciene et al., 2008). In fact, seam pucker is higher in warp direction than in weft direction and it more accentuates for fabric 2. Puckering was greatly reduced as the formability of fabric increases (De Boos et al., 1995).

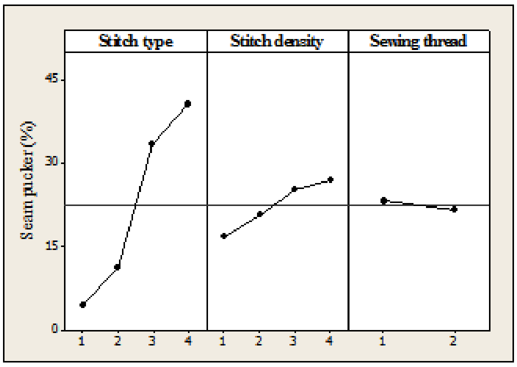

Figure 11: The principal effects for the seam pucker of sewn fabric 1 in warp direction

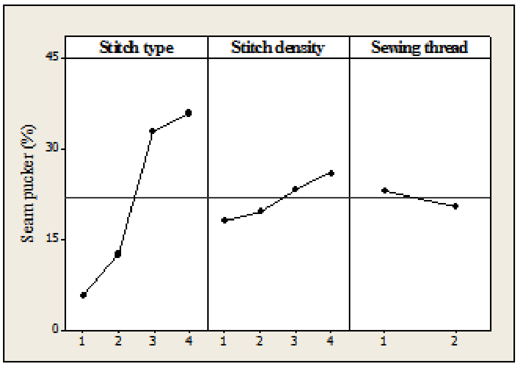

Figure 12: The principal effects for the seam pucker of sewn fabric 1 in weft direction

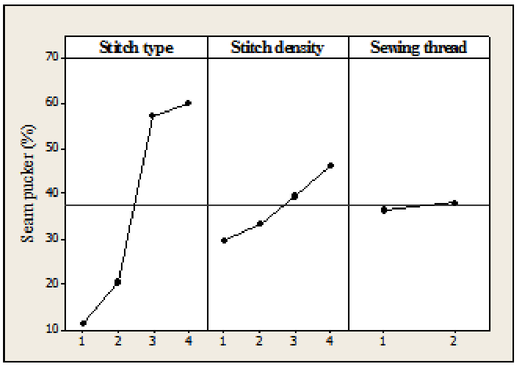

Figure 13: The principal effects for the seam pucker of sewn fabric 2 in warp direction

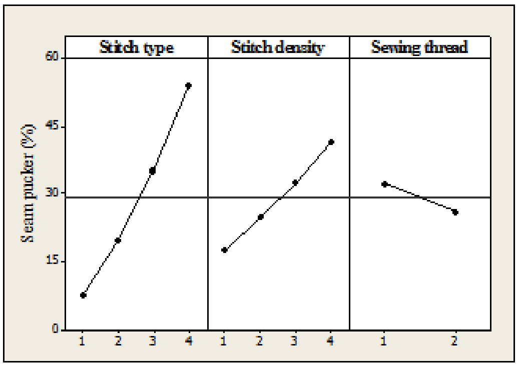

Figure 14: The principal effects for the seam pucker of sewn fabric 2 in weft direction

3.3. Seam slippage

A partial or complete loss of seam integrity manifested by yarn slippage parallel to the stitch line is considered as seam slippage. It is caused by pulling out of the yarns in the fabric from the seam under strain.

Considering figures 15, 16, 17 and 18, it is shown that the stitch type and the stitch density have an important effect on the seam slippage.

In this study, it was found that the seam slippage value is the highest for the 504 stitch and the lowest for the 301 stitch. The lockstitch is a very tight stitch for the reason that the loop is done between the two layers of fabric, but the 504 stitch is formed on the edge of the fabric by an important reserve of sewing thread than the other stitches, the thing that allows a great seam slippage. Besides, the 516 stitch is sewn by one row of the 504 stitch and one row of the 401 stitch having a specified distance from the edge of the fabric on which the tensile force is applied, this explains the decrease of the seam slippage value compared to the one of the 504 stitch.

On the other hand, the seam slippage tends to decrease when the stitch density increases because the number of contact points between fabric yarns and sewing thread increases, which results in stronger gripping of fabric yarns providing high frictional resistance during the tensile loading of the seam.

In addition, the sewing thread has a less influence on the seam slippage, the seam slippage decreases when the breaking load of sewing thread increases. This can be explained by the few levels of sewing thread analyzed and the measurement errors.

Also, the seam slippage in the warp direction is higher than in the weft direction for fabric and it is more significant for fabric 2 than fabric 1. That may be explained by the greater value of cover factor in warp direction, which is perpendicular direction to the tensile stress direction.

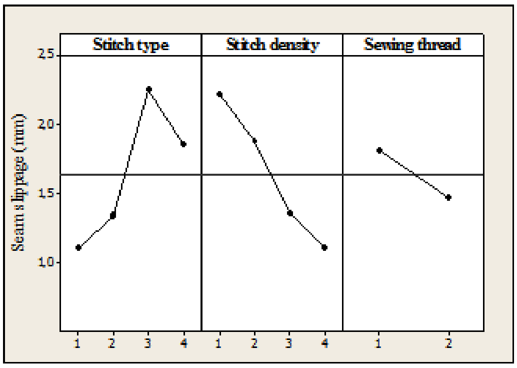

Figure 15: The principal effects for the seam slippage of sewn fabric 1 in warp direction

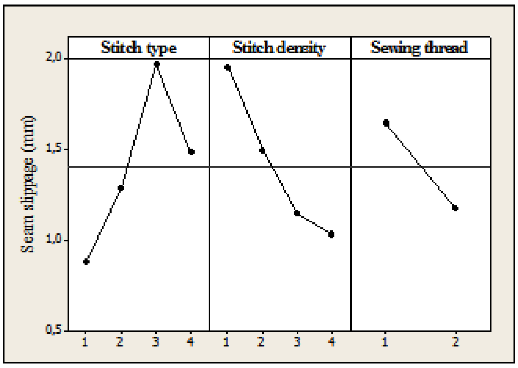

Figure 16: The principal effects for the seam slippage of sewn fabric 1 in weft direction

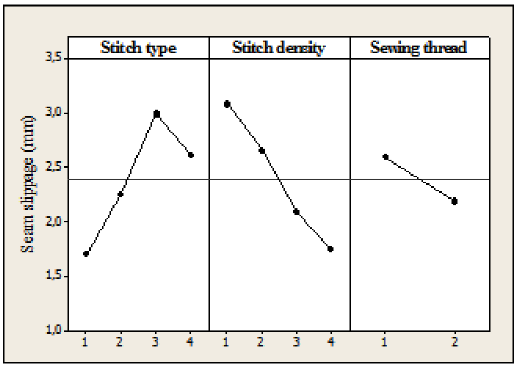

Figure 17: The principal effects for the seam slippage of sewn fabric 2 in warp direction

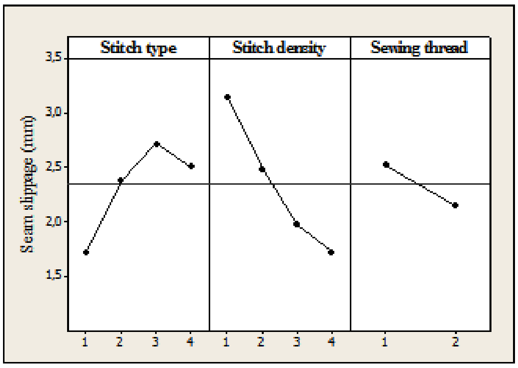

Figure 18: The principal effects for the seam slippage of sewn fabric 2 in weft direction

3.4. Modelling the seam quality parameters

For better seam quality, it is important to consider the complete harmony of the key fabric properties, sewing thread properties and sewing condition parameters used. The functional and aesthetic performance of the seam line is the result of all these factors. It is important to predict the effectiveness of assembly by a systematic approach defining the overall seam quality.

3.4.1. The Total Seam Quality Index "TSQI"

The TSQI is a global parameter characterizing the seam quality of an assembly and allowing determining the optimal sewing conditions for each fabric and it includes all the seam quality parameters (seam efficiency, pucker and slippage) by taking account their degrees of importance for the clothing manufacturer.
In order to calculate the weighing factor of seam efficiency, seam puckering and seam slippage, it was essential to calculate their relative importance on the overall seam quality of the garment. A subjective evaluation was carried out to understand the relative importance of each seam quality parameter. It was rated by a group of 20 experts of clothing quality control. They were asked to assign a number in percentage to each critical dimension on the overall seam quality. An average of the percentage of relative importance for each critical dimension assigned by all the experts was calculated. The investigation has led to the weighting coefficients average values as follows:

- Seam efficiency: 44 %;
- Seam pucker: 26 %;
- Seam slippage: 30 %.

The results obtained by experts show that seam efficiency has the important contribution in the overall seam quality with value of 44 % respectively, then the seam pucker and the seam slippage with percentage of 26 and 30 respectively.
The seam quality parameters don't have the same unit, this influences the answer space impact/effect compared to the others in the calculation of the total seam quality index. For that, the approach "Dynamic Method put in Scale (DMS)" (Chaouch et al., 2011) was used. DMS method can control any types of linear systems that are difficult or impossible to model mathematically and it can be decomposed in three steps: classification, inference and valorization.
The basic idea consists to increasing the fuzzy subsets permitting to achieve stages of classification and valorization. This increase permits a better precision of the output set evolution according to input sets. The using of level-headedness coefficient provides a simple way to arrive at a definite conclusion based on input information.
The TSQI was developed from the DMS method and the following equation represents this formula:

$$\mathrm{TSQI} = \mathrm{R}\ (\mathrm{Veff}) \times \mathrm{b}\ (\mathrm{Veff}) - \mathrm{R}\ (\mathrm{Vpck}) \times \mathrm{b}\ (\mathrm{Vpck}) - \mathrm{R}\ (\mathrm{Vsl}) \times \mathrm{b}\ (\mathrm{Vsl}) \quad (6)$$

Where:
b (Veff), b (Vpck), b (Vsl) : weighting coefficients for the seam efficiency, pucker and slippage in overall seam quality.
R (Veff), R (Vpck), R (Vsl): the input scaling values of the seam efficiency, pucker and slippage and calculated by the formula:

$$\mathrm{R(V)} = \mathrm{n} \times \frac{\mathrm{Vi - Min}}{\mathrm{Max - Min}} \quad (7)$$

With:
Min, Max: minimum or maximum value of input variable.
n: number of classes corresponds to the input variable (Vi).

A high percentage of seam efficiency always represents good seam quality and it has a positive impact on the overall seam quality. Therefore, it has a positive contribution in the equation 6. In contrast, a greater seam puckering and seam slippage always lead to poor seam quality. As a result, it always has a negative impact on the overall seam quality and has negative sign in the equation 6.
The total seam quality index (TSQI) allows identifying the optimum parameters giving the best seam quality. According to these results, the best seam parameters for assembling both fabrics in both directions are the lockstitch or the double stitch of 6 stitches per cm with the spun polyester thread.
After determination the TSQI for each fabric, we proved that the best seam parameters for assembling the fabrics analysis are the lockstitch or the double stitch of 6 stitches per cm with the spun polyester thread.

3.4.2. Multiple Regression Models

At this stage, the main purpose is to select a suitable form of regression model for predicting TSQI with a minimum number of parameters to make a practical approach. The regression models were determined based on the results obtained from ANOVA tables and after examining the highest adjusted R^2. Two staged prediction procedure is suggested. In the first stage, the regression equations to predict the seam efficiency, pucker, slippage and TSQI were established for each fabric and in both seam directions. The seam parameters such as: stitch type, stitch density and sewing thread were considered as independent variables in these equations. The ANOVA results and the coefficients of regression equations are given in Table 4. According to this table, it is shown that the adjusted R^2 is more than 80% for the models of seam efficiency and pucker, which shows a high correlation between the experimental and predicted values, except for the seam slippage models is. Also, all the seam parameters have a significant effect on the TSQI at the 99.9% confidence level and both regression equations were exhibited higher adjusted R^2 values (> 80%).

Table 4: ANOVA and the Multiple Regression Models results for seam quality for fabric 1 and 2

	Seam direction	Fabric	Seam efficiency		Seam pucker		Seam slippage		TSQI	
			b	p-value	b	p-value	b	p-value	b	p-value
Constant	Warp	1	-16,917	0.000	-16.772	0.000	2.329	0.000	-32.365	0.000
		2	-1.225	0.820	-24.924	0.003	3.283	0.000	-42.616	0.000
	Weft	1	-14.324	0.000	-8.959	0.030	2.276	0.000	-37.797	0.000
		2	3.252	0.580	-20.131	0.011	3.4	0.000	-33.656	0.000
Sewing thread	Warp	1	19,195	0.000	-1.614	0.355	-0.347	0.046	19.628	0.000
		2	14.907	0.000	1.641	0.641	-0.411	0.021	21.047	0.000
	Weft	1	15.371	0.000	-2.658	0.140	-0.474	0.004	21.247	0.000
		2	9.808	0.001	-6.193	0.070	-0.367	0.069	13.283	0.000
Stitch type	Warp	1	3,455	0.000	13.114	0.000	0.318	0.000	-6.852	0.000
		2	3.567	0.002	18.383	0.000	0.348	0.000	-5.475	0.000
	Weft	1	3.51	0.000	11.16	0.000	0.250	0.001	-5.582	0.000
		2	2.387	0.050	15.538	0.000	0.272	0.004	-4.121	0.001
Stitch density	Warp	1	8,140	0.000	3.546	0.000	-0.387	0.000	8.375	0.000
		2	6.441	0.000	5.537	0.001	-0.456	0.000	9.659	0.000
	Weft	1	6.474	0.000	2.718	0.002	-0.312	0.000	7.715	0.000
		2	11.886	0.000	7.88	0.000	-0.478	0.000	12.297	0.000
D.F.	Warp	1 & 2	3		3		3		3	
	Weft	1 & 2	3		3		3		3	
R^2	Warp	1	0.959		0.918		0.639		0.869	
		2	0.756		0.845		0.698		0.897	
	Weft	1	0.945		0.886		0.612		0.874	
		2	0.814		0.837		0.611		0.853	
Adj. R^2	Warp	1	0.955		0.909		0.601		0.855	
		2	0.730		0.828		0.665		0.886	
	Weft	1	0.939		0.874		0.571		0.860	
		2	0.795		0.819		0.569		0.837	
Error	Warp	1	257.165		660.44		6.2		1173.133 968.573	
		2	1273.978		2714.327		6.295			
	Weft	1	237.319		686.229 2425.579		5.191		1047.9	
		2	1514.687				8.4		1402.698	
Total	Warp	1	6332.451 5220.183		8063.43 17479.48		17.197		8939.014	
		2					20.819		9443.752	
	Weft	1	4296.962 8162.603		6020.44 14873.29		13.387		8286.285	
		2					21.582		9542.027	

In the second stage, in order to simplify the TSQI modeling, the fabric and seam direction were considered as independent variables and a general regression model is given below to predict TSQI. This regression equation is available for all the fabrics and in both seam directions. The ANOVA table and the parameters of regression equation are given in Table 5 which shows that all factors have a significant effect at the 95% confidence level and the obtained model has a good adjusted R^2 value (82.8%).

Table 5: Multiple regression results for TSQI

	Coefficient	p-value	R^2	Adjusted R^2	Error	Total
Constant	-45.342	0.000	0.834	0.828	6186.815	37369.143
Seam direction	2.905	0.023				
Fabric	2.917	0.022				
Sewing thread	18.801	0.000				
Stitch type	-5.508	0.000				
Stitch density	9.511	0.000				

4. CONCLUSION

The assembly of the garment is a very complex depending on several factors. Some of them are well analyzed in this work. In the first part of this study an experimental design was established to examine the effect of the sewing parameters such as the seam efficiency, the seam slippage and the seam pucker on the seam quality. It was been proved that the seam efficiency is practically influenced by the stitch density and the sewing thread. It grows with the increase of the stitch density and for the polyester sewing thread. Also, the seam slippage and pucker are influenced by the stitch type and the stitch density. The seam slippage decreases with the increase of the stitch density and the seam pucker is proportional to the stitch density. The fabric and sewing thread properties have an important influence on the seam efficiency and the seam slippage. The seam efficiency increases with the increase of shear rigidity of fabric and decreases with the increase of cover factor. The seam pucker was greatly reduced as the formability of fabric increases and the seam slippage decreases when the breaking load of sewing thread increases.

The analysis of the interactions diagrams of factors show that all the interactions of order 2 have no influence on all the seam quality parameters. It is also proved that the fabric properties, the sewing thread properties and the seam direction have an important influence on the seam quality. The relationships between the seam quality parameters and sewing parameters can be predicted by linear regression models with high coefficient of determination.

The study of the effect of sewing parameters shows that it is not possible to optimize all the seam quality parameters simultaneously. That's why a total seam quality index (TSQI) was defined. TSQI has proved that the best parameters of the sewing operation are the stitch type 301, the density value of 6stitches/cm and the polyester sewing thread. To model the total seam quality index (TSQI) a regression equation is determined for all woven fabrics in each seam direction. The ANOVA table have proved that the elaborated model allow predicting TSQI with a 99.9% confidence level and a high adjusted coefficient of determination (R^2 > 80%).

A study which considers both functional and aesthetic performance of seam together will definitely contribute to the knowledge of the overall seam quality for garments. Knowledge on the overall seam quality will help the apparel engineers to evaluate the quality of garments more precisely, when a particular sewing thread type, stitch type and stitch density are applied on a particular type of fabric. This will facilitate the apparel engineers for proper planning and control of quality during the course of apparel manufacturing.

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