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INFLUENCE OF DENIM FABRIC PROPERTIES AND SEWING PARAMETERS UPON THE SEAM PUCKERING

MALEK S.*, JAOUACHI B., KHEDHER F., BEN SAID S. AND CHEIKROUHOU M.

TEXTILE ENGINEERING LABORATORY, UNIVERSITY OF MONASTIR, TUNISIA

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ABSTRACT

This paper reports an experimental investigation into the effect of fabric and sewing parameters on the seam slippage. In this work, different parameters such as sewing thread, stitch density and fabric parameters, which are mass and composition, are studied to determine their performance according to the seam's appearance after sewing.

The seam puckering has been calculated by measuring the thickness of both, the fabric and the seam, under a load of 2kPa. It has been observed that the seam puckering decreases with the increase of stitch density and it increases with the decrease of the fabric mass. It was also concluded that, for the high linear density, the polyester sewing thread increases the seam pucker rather than the cotton sewing thread for both warp and weft direction. The result is reversed for the low linear density. Various other factors influencing the seam puckering are also discussed and investigated.

KEYWORDS

Seam pucker; fabric properties; sewing thread; stitch density; multi-linear model.

1. INTRODUCTION

To maintain a garment quality, seam performance is one of the most important parameters that should be taken into account (Bharani et al. 2012). Some researches, using different seam performance characteristics such as the experimental comparison of seam performance properties made by Vildan's study; the effects of fabric structural parameters and the effect of sewing thread on sewability performance were examined by means of seam strength; seam efficiency, seam slippage, and seam pucker (Vildan et al., 2014). According to seam pucker, some researches were ignoring this quality performance parameter, such as Belkis's study. A statistical approach was carried out to determine the effects of the selected sewing parameters in denim fabric on seam strength. Seam puckering however was not investigated (Belkıs, 2012). Other researchers said that the performance and appearance of garments and sewing techniques especially seam pucker problems have become important (Anon, 1977). In fact, seam pucker appears along the seam line of garment when sewing parameters and material properties are not properly selected, then that deteriorates the aesthetic appearance of garments (Chang et al., 1999). In the Oxford English Dictionary, the seam pucker is defined as "a ridge, wrinkle or corrugation of the material or a number of small wrinkles running across and into one another, which appear in sewing together two pieces of cloth" (Oxford Univ. Press, 1967). Five primary causes of puckered seams were identified and the

*: Corresponding author. Email : maleksarah88@gmail.com

seam pucker was classified into four groups: Inherent pucker, feeding pucker, tension pucker, and thread shrinkage pucker (Chang K. et al., 2009).

For several decades, many different ways to define and control seam pucker have been introduced. These are the international standard method, laser scanner method, seam length method and thickness strain method (Thanaa, 2013). Many researchers have also been working on the relationships between fabric properties and seam pucker in apparel manufacturing in order to predict seam pucker on the basis of fabric properties, especially its structure and mechanical properties under low stress. Several charts and equations have also been developed for the determination of seam pucker grade, but they can only provide guidelines and cannot offer specific predictions of how the seam pucker might perform in garment manufacturing (Gong, 1999; Stylios et al., 1990). Further, Choudhary and Amit investigated the effect of fabrics and sewing conditions (Blend composition of fabric, needle thread tension, needle size and sewing thread linear density) on apparel seam characteristics. The ANOVA technique is conducted to see the effect of individual factors on the seam quality dimensions (chaoudhary et al., 2013).

Referring to different researchers, it is noted that very little researches have been focusing on investigating the aspect of seam puckering behavior of the seams for heavy fabrics. For example, Vaida and Milda was evaluated the influence of mechanical properties of yarn such as tensile strength on seam pucker of lightweight fabric after washing and drying with comparison (Vaida et al., 2006). Furthermore, seam puckering had unattractive appeal to textiles and represented be a severe problem in lightweight fabrics especially with low bending rigidity (Sandunet al., 2014).

As it is mentioned above, many researchers studied the effects of different sewing and fabric parameters in different papers. Limited studies have discussed the effects of these parameters together in the same study. Therefore, this study presents and compares the effect of different parameters on sewing pucker, namely the fabric mass parameters which include the medium and heavy mass. In this work we chose to study the medium and heavier denim fabrics. Undoubtedly, the denim garments remained largely used and consumed. Hence, this particularity proves the necessity to study it in order to optimize the puckering phenomenon, which occurs as function of number of fabric input parameters. Although it is fashionable to have a garment without puckering, the denim fabric remains, in contrast with the worsted ones, the most popular fabric to produce garments (Gazzah et al., 2014).

The object of this study is to evaluate the seam pucker. Indeed, the effects of sewing threads such as the linear density and the composition will be studied. Also the stitch density and the fabric properties, especially the mass and the blend composition on seam puckering in the warp and weft directions are investigated.

2. MATERIALS

2.1. Fabric properties

The fabrics have been chosen according to two parameters; compositions and mass. Five fabrics are considered to study the impact of these parameters on the seam pucker. All the denim fabrics are prepared on weaving Loom projectile SULZER P7300 with 3/1 twill structure, having a little difference in warp and weft density. The fabric specifications are given in Table 1.

We chose five samples of denim fabric. The choice was based on two characteristics; the first one is the fabric mass, so we have three different levels of mass 243 g/m², 328 g/m² and 430 g/m². The second property is the composition; we have three different compositions which are 71% cotton +24% polyester + 5% elastane, 100% cotton and 95% Cotton +5% elastane.

Table 1: Specifications of denim fabrics

N° of fabric			1	2	3	4	5
Composition			71% Cotton +24% Polyester + 5% Elastane			100% Cotton	95% Cotton + 5% Elastane
Warp yarn density (ends/cm)			36	28	31	27	30
Weft yarn density(picks/cm)			20	22	20	20	20
Mass (g/m²)			243	328	430	394	416
Thickness (mm)			0.76	0,75	0.9	0.87	0.78
Breaking strength (N)			459.34	528,13	526.64	853,81	453,88
Elongation at break (%)			28.12	25.12	25.19	14,74	27,65
Rigidity (N/m)			37345	37304	40168	56249	37613
Yarn fabric properties	Linear density (tex)	warp	60	70	80	80	88
		Weft	36	36	80	60	42
	Twist (T/m)	warp	674	621	413	413	526
		Weft	314	314	547	524	626
	Breaking strength (N)	warp	9.47	9.06	9.78	9.78	7,86
		Weft	4.44	4.44	9.54	8.08	6,68
	Elongation at break (%)	warp	6.31	5.17	8.04	8.04	6,45
		Weft	5.81	5,81	11.36	5.49	6,31
	Tenacity (cN/tex)	warp	15.78	12.94	12.23	12.23	8,93
		Weft	12.43	12.43	11.93	13.47	16,03
	Rigidity (N/m)	warp	432	652	521	521	517
		Weft	623	623	761	1683	643

2.2. Seam thread properties

A literature review (Gersak, 2002; Pavlinic et al., 2006; Zavec et al., 2004) indicates that the degree of seam puckering depends on the structure, construction and fineness of the fabric, its mechanical properties, sewing needle gauge and stitch density.

The choice of the sewing thread was essentially based on the composition and the linear density because it affects directly the seam quality of apparels. Four types of commercial sewing threads commonly used for sewing denim fabric are selected. The sewing threads proprieties are given in Table 2.

Table 2: Properties of sewing threads

N° of thread	Linear density (tex)	Composition	Breaking strenght (N)	Breaking elongation (%)	Rigidity (N/m)	Twists(T/m)	Tenacity (cN/tex)
1	31	100% Polyester	10.7	17.06	289.6	477	34.52
2	34	100% Cotton	8.83	5.85	383.62	572	25.97
3	63.5	100% Polyester	24.23	21.12	389,12	353	38.16
4	55.5	100% Cotton	11.41	5.52	481,88	381	20.56

2.3. Sewability properties

In this work, sewability is investigated by measurement of seam puckering. A high-speed industrial lockstitch machine (JUKI) was selected for sewing the samples with the following specifications:

-Type of stitch: lockstitch type 301
-Machine speed: 2000 stitches per minutes
-Needle size: 90
- Stitch density (three levels): which are 3 stitches per cm, 4 stitches per cm and 5 stitches per cm.

3. METHODS

3.1. Testing of sewing yarns properties

The composition was determined according to their burning behavior. The yarn size was determined according to BS EN ISO 20601(995) by using a winder and electronic balance. The linear density (T) was determined by applying the following equation 1.

$$T(\text{tex}) = 1000 * \frac{\text{M (g)}}{\text{L (m)}} \quad (1)$$

To determine the twist of a textile yarn, the untwisting-retaliation method was applied (ISO 2061:2015).It is to untwist the thread until maximum elongation. Finally, to determine the tensile proprieties, the ISO 2062 (2009) was applied, the specimen is subjected to tension until break, using a suitable tester (dynamometer type "LLOYD Instruments") that indicates the applied tensile force and elongation of the specimen. The device must be set, so that the average rupture test durations of a series of samples are equal to the prescribed time (20s) with a tolerance of ±3s; then the tenacity was calculated following equation 2.

$$\text{Tenacity (cN/tex)} = \frac{\text{F}}{\text{T}} \quad (2)$$

Where M: mass, L: length and F: Breaking strength

3.2. Testing of fabric samples

The fabric weave was determined according to ISO 7211-1(1984), the number of warp and weft yarn density was measured according to ISO 7211-2(1984). The mass per square meter in normal atmosphere was based on EN 12127 (1997). The linear densities of the warp and weft fabric yarns were calculated according to ISO 7211-5 (1984) and the determination of the thickness of each sample was based on ISO 5084 (1996). The tensile behavior of the fabric was applied according to ISO 13934-1:2013 that allows us to determine the breaking strength, the elongation at break and the tensile stiffness.

3.3. Evaluation of fabric sewability

The MINITAB software is conducted to see the individual and interactive effects of seam thread (four levels), stitch density (three levels) and fabric (three levels). Full experimental design type factorial was used to analyze objectively all experiment combinations of inputs. Table 3 presents the input parameters and their different levels.

Table 1 : The input parameters and their different levels

Parameter	Fabric	Seam density	Seam thread
Level	3	3	4

Therefore, there are two experimental designs applied in our work. Indeed, this choice was based on the variation of the fabric input which for the first design, this parameter was presented its mass. However, for the second one, the fabric parameter was tested using its composition input variable.

Seam puckering in a garment is the uneven appearance of a seam in a smooth fabric. Seam puckering appears along the seam line of garment when the sewing parameters and sewn materials properties are not properly selected.

In this work, seam puckering is calculated by measuring the difference between fabric and seam thickness under constant compressive load equal to 2kPa, according to NF EN ISO 9073-2 (1997). Five tests for each combination are carried out. Seam puckering (S_p) is calculated by using the following equation 3.

$$S_p(\%) = \frac{ts - 2t}{2t} * 100 \quad (3)$$

Where, ts= seam thickness and t= fabric thickness.

This method is widely used for evaluating seam puckering because it is well referred and can give more accurate results than other methods. Indeed, it is also easy to be calculated during a few time compared to other methods.

4. RESULTS AND DISCUSSIONS

The seam pucker has been evaluated for the different studied parameters in warp and weft directions. These results are dependant on the fabric mass and its blend composition, stitch density and seam thread. The overall results are presented in Table 4 and 5, respectively.

Table 2 : Seam puckering response of five fabrics in warp direction (%)

Tests	3stitches /cm				4 stitches /cm				5 stitches /cm			
Thread	1	2	3	4	1	2	3	4	1	2	3	4
Fabric 1	1,04	4,167	10,42	0,05	-1,04	1,04	10,07	0,035	-1,042	1.00	5,21	0,02
Fabric 2	-0,82	0,984	6,56	1,91	-0,27	0,98	3,83	0,27	-0,820	0,98	2,19	-1,09
Fabric 3	-0,13	2,02	0,17	2,75	-0,99	1,37	-2,62	-0,26	-1,20	0,52	-4,12	-0,69
Fabric 4	0,48	0,91	3,08	-0,61	-0,39	-0,17	1,56	1,35	-1,26	-0,82	-0,39	-1,04
Fabric 5	0,10	1,909	7,93	0,46	-0,93	0,103	7,42	1,75	-2,22	-0,41	3,56	-0,31

Table 3 : Seam puckering response of five fabrics in weft direction (%)

Tests	3 stitches /cm				4 stitches /cm				5 stitches /cm			
Thread	1	2	3	4	1	2	3	4	1	2	3	4
Fabric 1	5,21	15,28	19,44	0,156	4,51	8,68	17,36	0,135	2,43	6,25	16,32	0,125
Fabric 2	0,546	2,46	9,84	3,83	0,27	2,19	8,20	1,91	-1,09	-0,27	5,19	0,27
Fabric 3	-0,26	2,88	-0,26	0,39	-1,85	0,30	-1,97	-2,19	-1,63	-0,13	-3,48	-0,47
Fabric 4	0,694	1,13	3,30	1,56	-1,04	0,17	1,56	-0,39	-1,259	-1,91	-1,26	-0,61
Fabric 5	0,62	2,425	9,74	5,10	-1,19	1,39	7,42	4,84	-0,67	0,62	5,62	2,01

According to Table 4 and 5, it can be concluded that with the change of each input parameter the value of puckering is clearly affected, in both warp and weft directions. We also can note that seam pucker values are high, medium, null and negative. According to Rajkishore et al (2010) seam pucker is the distortion in the surface of sewn fabric which appears as swollen effect along the line of seam**.** So we have puckering only when the percentage of seam puckering is greater than 0%. In fact, negative values mean that the stitching is tight and the surface is flattened. If we have no inflatable structure, then there is no puckering effect.

4.1. Effect of seam thread on seam puckering

To study the effect of the sewing thread, namely the impact of the linear density and the composition, four different threads are investigated. A factorial experimental design (Plan A) is applied to analyse the contributions and the effects of seam thread on the seam puckering of all fabric samples. The input parameters and their levels will be investigated in Table 6.

Table 4 : Input parameters and their levels (Plan A)

Parameters	Fabric	Stitch density	Seam thread
Level 1	Fabric 1: 243 g/m^2	3stitches /cm	1:polyester (31 tex)
Level 2	Fabric 2: 328 g/m^2	4 stitches /cm	2:cotton (34 tex)
Level 3	Fabric 3: 430 g/m^2	5 stitches /cm	3:polyester (63.5 tex)
Level 4			4: cotton (55.5 tex)

The plot of the main effects presents the influence of each seam thread on the seam puckering.

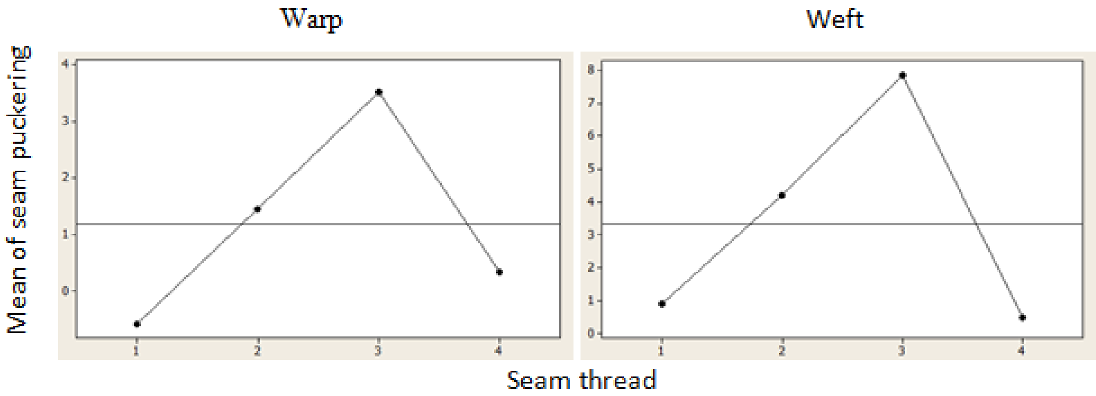

Figure 1: Effect of seam thread on seam puckering

4.1.1. Effect of linear density

Regarding the polyester threads, as it is observed from figure 1, seam puckering is highly dependent on the sewing count and compositions. Level 1 and 2 present respectively the polyester and cotton thread having the lowest density. Level 3 and 4 present the polyester and cotton thread with 63.5tex and 55.5tex respectively. As mentioned by Sundaresan et al (1998) the sewing thread size is one of the most influencing factors for the seam puckering. For the polyester thread composition, the mean of seam puckering in the warp and weft directions increases when the linear density increases too. In the warp direction, the mean of seam puckering increases from negative value to more than 3. In the weft direction, it increases from 1 to 8. The increase of density means the increase of yarn diameter so it causes more mechanical restraint and deformation of the yarns in the fabric, when inserted by the needle. This result is in accordance with Choudhary and Amit (2013) which says that seam puckering increases with the increase in sewing thread linear density.

About the cotton thread, it is remarked that when the linear density increases, the mean of seam pucker decreases. In the warp and weft direction, the mean of pucker decreases successively from 1.5 to 0.5 and from 4 to 0.5.That can be caused by the fact that when the linear density increases, breaking elongation and tenacity decrease; generating fabric stability after sewing.

The increase of the sewing thread count of both cotton and polyester sewing thread has a significant impact on the seam pucker.

4.1.2. Effect of blend composition

For the low linear density, it is observed that the mean of seam puckering is important for the cotton (level 2) yarn in both warp and weft direction more than the polyester composition (level 1).

For the high linear density, the mean of seam puckering is more important for the polyester thread (level 3) than for the cotton seam thread (level 4) in both directions. Thus, it can be explained by the smooth surface of polyester thread. Indeed, the sliding of polyester thread can generate pucker. The elasticity of yarn fabric is also more important than the elasticity of the cotton sewing thread so it generates stability, while the polyester sewing thread has a greater elasticity than the fabric so generating pucker.

This result was confirmed by Fathy's study (2012) when some time passes after sewing the greatest crease to seams is made by polyester sewing threads. This result can be explained by the fact that the cotton thread can generate the blocking of fabric structure.

4.2. Effect of stitch density

The level 1, 2 and 3 correspond to 3 stitches /cm, 4stitches /cm and 5stitches /cm respectively. Figure 2 shows that the seam puckering decreases with the increases of stitch density in both warp and weft directions. This is in accordance with Najwa's study (2013) as the stitch density increases from 3 to 5stitches/cm; the seam thickness strain decrease; so the seam pucker decreases. Also, when the stitch density is low, the space between the two layers of fabric remains. This space generates slippage between the two parts of fabric to be assembled, so that generating pucker. Also, at low stitch density, the space between the two layers of fabric remains which generates slippage between the two stitched yoke, so that generates puckering.

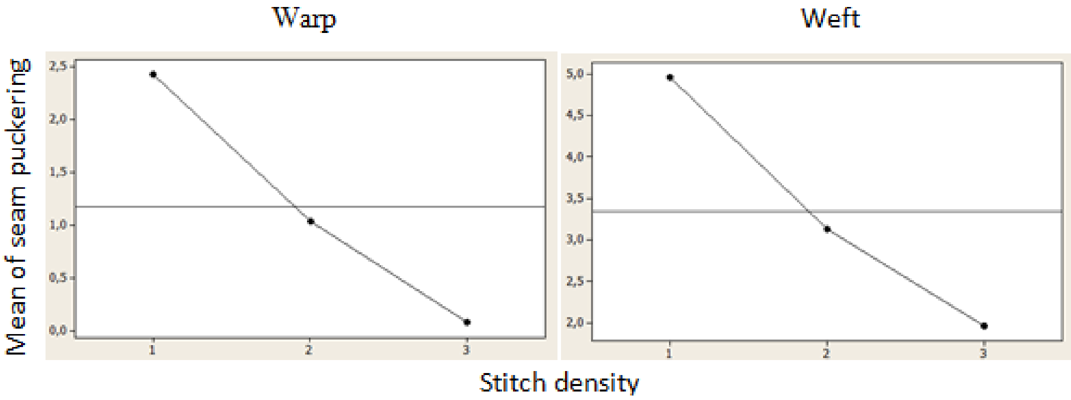

Figure 2: Effect of stitch density on seam pucker

This result is in accordance with Zahra's study (Zahra, Saeed, 2015), the longer the length of the stitch, the more puckered it will get.

4.3. Effect of fabric properties on seam puckering

To analyse the effect of fabric properties on seam puckering, the impact of fabric mass and blend composition were studied in this part. To determine the effect of fabric mass, we used the same factorial design as previously studied (Plan A). However, to investigate the effect of blend composition on the seam puckering property, another experimental design (plan B) was elaborated. Table 7 shows the different input parameters and their levels.

Table 5 : Input parameters and their levels (Plan B)

Parameters	Fabric	Stitch density	Seam thread
Level 1	Fabric 4: 100% cotton	3stitches /cm	3: polyester (63.5 tex)
Level 2	Fabric 5: 95% cotton + 5% elastane	4 stitches /cm	4: cotton (55.5 tex)
Level 3	Fabric 3: 71% cotton + 24% polyester +5% elastane	5 stitches /cm	

4.3.1. Effect of fabric mass on seam puckering

Level 1, 2 and 3 present respectively 243 g/m^2, 328 g/m^2 and 430 g/m^2. All the fabrics having the same blend composition which is 71% Cotton, 24% Polyester and 5% Elastane.
According to figure 3, the seam pucker decreases with the increase of the fabric mass parameter in both warp and weft directions. Indeed, when the fabric mass increase, the fabric rigidity and resistance increase, which improves fabric training during sewing.

Furthermore, when the fabric mass increase, the linear density of fabric yarn in both warp and weft direction increase; their values are superior then the linear density of seam threads used to sew the denim samples. Then, the penetration of seam thread into fabric yarns becomes easier and it does not cause any blockage of seam thread during sewing which decreases puckering appearance.

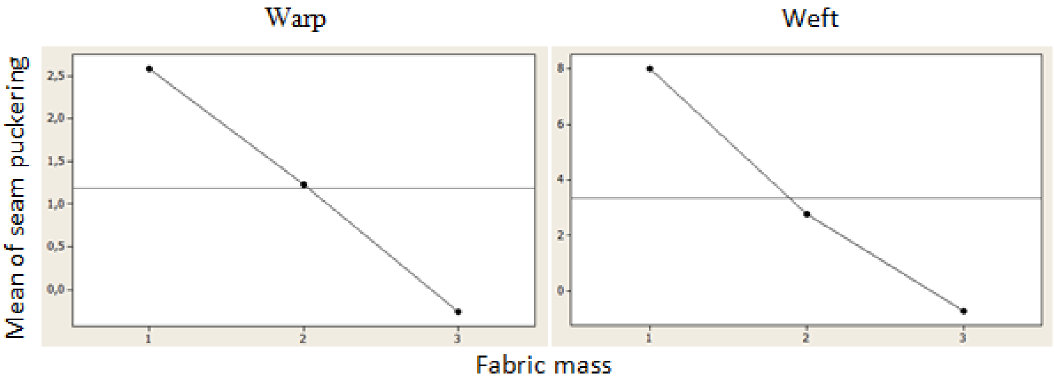

Figure 3: Effect of fabric mass on seam puckering

This result seems in good agreement with Thanaa's study (2013) mentioning that the light weight fabrics displays less stability in the course of garment manufacturing and reduces the aesthetic performance of the seam in terms of seam puckering.

4.3.2. Effect of blend composition of the fabric on seam puckering

The second part of this study attempts to evaluate the blend composition impact on the seam pucker. So, this part evaluates the impact of three fabrics with different blend compositions; having the same weight range. The evaluation focuses on the fabric composition parameter. Figure 4 shows the obtained findings about blend composition effect on the seam puckering.

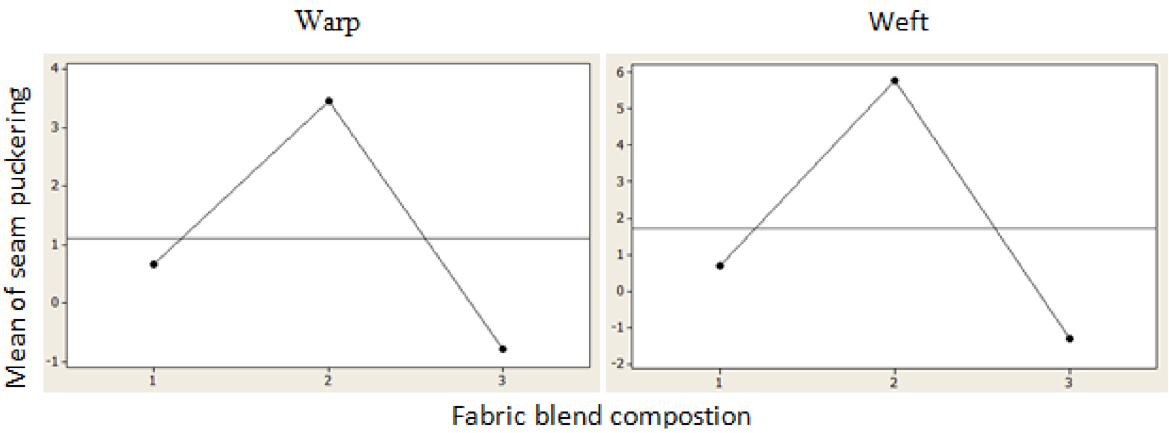

Figure 4: Effect of fabric blend composition on seam puckering

The mean seam pucker value, in both warp and weft directions, seems more important for the 95%coton and 5%elastane fabric (level 2). It is almost null for the 100% cotton fabric (level 1) and it is lower with negative values for the 71%cotton, 24% polyester and 5%elastane fabric (level 3).
Therefore, the 100% cotton fabric composition is more stable than the 95% cotton and 5% elastane fabric.
Besides, the elastane loses the stability of the fabric and creates shrinking after sewing which creates puckering. This is in accordance with Choudhary and Amit study's (2013); when the cotton dominates sewing fabrics, the fabric stiffness increases which increases the in-plane compression resistance. So, it creates less seam puckering, as it is proved in this case.
However, the polyester decreases puckering because it is more elastic than the cotton fabric. In fact, the elongation at break of the fabric 3 is greater than the fabric 1. Indeed, the sliding of the polyester thread causes the fabric clamping and generates the slightly negative value.
It is notable that the seam puckering is more important in the weft direction than in the warp direction. This result is in a good agreement with Cheng and Poon's result (2002) where it has been proved that the seam puckering grades in the weft direction are higher than those in the warp direction.

4.4. Statistical study

4.4.1. Studying of the interaction plot

In the previous study, the effect of each input parameter on the sewing puckering was analysed. In this part the interactions between input parameters will be studied to predict whether there is an interaction that affects the appearance of puckering while sewing.

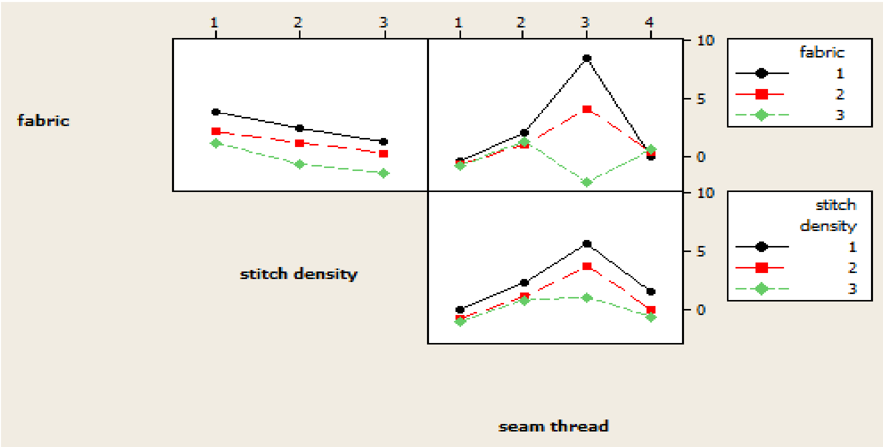

Figure 5: Interaction plot in the warp direction

Based on the interactions plots given by Minitab in both warp and weft directions (respectively figure 5 and 6), it is clear that there is a parallelism between the fabric and stitch density parameters on one hand and density and sewing thread on the other hand; thus there is no interaction between these input parameters. While there is an interaction between the fabric and sewing thread parameters.

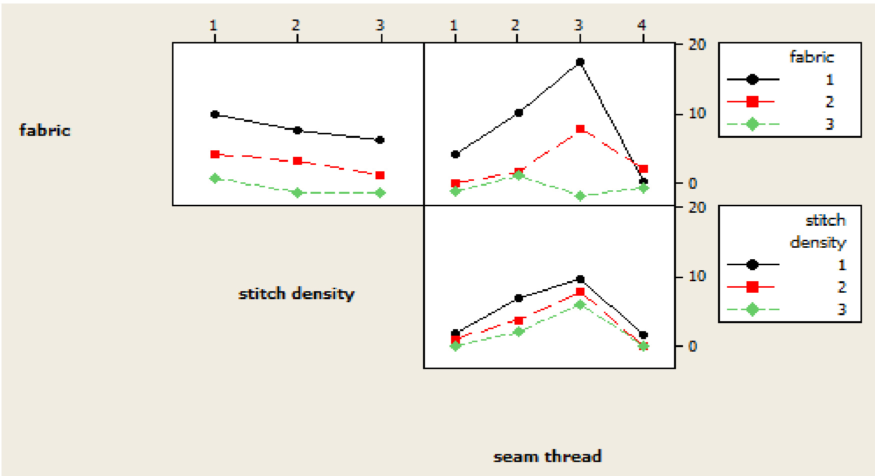

Figure 6: Interaction plot in the weft direction

4.4.2. The regression equation of seam puckering

To study the effect of fabric type, sewing thread count and composition and stitch density on seam quality, a full factorial design was implemented. According to the studied parameters listed in table 3, a 3×3×4 mixed factorial design was implemented. Also, the multiple regression method was selected in this study. To compare the performance of these models, the coefficient of determination (R^2) is discussed.

The regression models correlate fabric properties, stitch density and sewing thread to each seam properties (seam puckering). The multi-linear models can be written as follow (see equation 3).

$$P = a + X + Y + Z + X*Y + X*Y + Y*Z \quad (3)$$

Where,

- A: constant
- P: seam puckering value
- X: fabric mass coefficient
- Y: stitch density coefficient
- Z: seam thread coefficient

The linear model relating the main factors and their interactions with the response, which is the seam puckering, are established in warp and weft directions.It was found that these models fit the data very well with a high R^2 value in the warp and weft directions equal to 88.8% and 95.6% respectively.

It is important to analyse the statistical variance. In fact, this allows us to evaluate the importance of different factors and their interactions on the study of all parameters based on the probability coefficient p. (p) are evaluated as follows:

- p = 0: highly significant factor
- 0 <p<= 0.05: significant factor
- p> 0.05: negligible factor

The following Table 8 shows that the sources of variation are statistically significant. The factor within the p value is less than 0.05 are significant from statistical point of view.

Table 6 : The p value of each input parameter

Source	Fabric	Stitch density	Seam thread	Fabric* Stitch density	Fabric* Seam thread	Stitch density *Seam thread
Warp	0.000	0.000	0.000	0.881	0.000	0.149
Weft	0.000	0.000	0.000	0.432	0.000	0.293

Based on the p values, the warp and weft directions, four highly significant parameters (p= 0.00) are saved. Moreover, regarding these obtained findings shown in table 8, it can be remarked that fabric, sewing thread and stitch density parameters can affect widely the studied output property. In addition, the results show the effectiveness of the interaction between fabric and sewing thread parameters. Indeed, there is a strong and significant interaction between those inputs explaining that changing fabric characteristics affects the sewing thread choice and behaviour. It is notable that their changes present important variations of the output. However statistically speaking, interactions between factors “fabric * stitch density” and “stitch density * sewing thread” are less significant because their correlation coefficients are greater than 0.05.These results confirm the findings made from the diagram of the main effects and the interactions. Their variations cannot affect the studied output. Furthermore, the variations of the density of stitches and fabric or sewing thread parameters cannot affect the pucker phenomena during sewing or seeming process. Individually, these inputs cause notable variations of the fabric puckering behaviour. Thus, these are no interactions between the stitch density and fabric or sewing thread.
According to these findings, Table 9shows the coefficients of the different predicted parameters.

Table 7 : Different coefficient of the multi-linear models

Coefficient	Warp	Weft
a	1.18	3.35
[X]	[1.40, 0.04, -1.44]	[4.64, -0.57, -4.07]
[Y]	[1.25, -0.14, -1.10]	[1.61, -0.22, -1.39]
[Z]	[-1.77, 0.27, 2.34, -0.85]	[-2.44, 0.83, 4.50, -2.89]
[X*Z]	$\begin{pmatrix} -1.16 & -0.78 & 3.64 & -1.70 \\ -0.10 & -0.51 & 0.62 & -0.01 \\ 1.26 & 1.30 & -4.27 & 1.71 \end{pmatrix}$	$\begin{pmatrix} -1.50 & 1.25 & 5.21 & -4.96 \\ -0.42 & -2.15 & 0.46 & 2.11 \\ 1.92 & 0.91 & -5.68 & 2.85 \end{pmatrix}$

Determination of the estimation

To determine the estimation percentage, formula 4 will be applied and the result will be presented in the Table 9 and 10 respectively in the warp and weft directions.

$$\text{Estimation } (\%) = 100 * \frac{Pestimated - Pmesured}{Pestimated} \quad (4)$$

Some tests are considered and established in Table 10. According to this result, it is proved that our model is significant because the estimated percentages are optimal; their values are low and ranges between -10% and 5%. A change in the conditions of the experiment may reveal elementary errors. Indeed, these factors may be due to environmental variations also called "influents" such as temperature, humidity, vibration...

Table 8 : Estimation tests

	Fabric	Stitch density	Seam thread	$P_{calculated}$	$P_{estimated}$	Estimation (%)
Warp	1	1	3	10.42	9.81	-6%
	2	2	3	3.83	4.05	5%
	3	2	1	-0.99	-0.92	-8%
Weft	1	1	3	19.44	19.37	-0.6%
	2	2	4	1.91	1.82	-5%
	3	1	2	2.88	2.63	-10%

Considering this value, we can determine a belonging interval of puckering values of such fabrics. This interval will be equal to [p Estimated ± 10%].

To validate the result, this model was applied on two fabrics having important masses which are fabric 4 and fabric 5 (table 1). The result of the evaluation of some tests is presented in Table 11.

Table 9 : Validation tests

Fabric	Direction	Stitch density	Seam thread	$P_{calculated}$	$P_{estimated}$	Estimation (%)	belonging interval
4	warp	1	1	0.48	0.47	-1.52%	[0.42 0.52]
5	warp	2	1	-0,93	-0.92	-1.24%	[-0.83 -1.01]
5	weft	1	2	2.425	2.63	8%	[2.36 2.89]

Based on the table 11, we conclude that the calculated puckering of the selected samples belong, obviously, to the estimation intervals. So the result is validated.

5. CONCLUSION

In the current study, the effect of three parameters which are fabric structural properties, namely the blend composition and fabric mass, sewing thread properties and the stitch density on the seam pucker has been investigated. The results showed that they statistically have significant effect on seam performance characteristic, especially the weft direction.

In the first part of study, the effect of each parameter has been studied. In fact, seam threads parameters, which are the composition and the linear density, have shown significant effects on seam pucker. In fact, comparing threads having a same composition; the increase of the linear density of polyester thread increases the seam pucker. However, the increase of cotton thread linear density decreases the puckering phenomena. At a low level of linear density, the mean seam pucker is more important for the cotton yarn, in both warp and weft directions than for the polyester thread. At a high linear density, the mean seam puckering is more important for the polyester thread than the cotton seam thread in both warp and weft directions. According to the stitch density effect, we can conclude that the increase of stitch density increases the sewing stability, and then decreases seam pucker on seamed fabrics. As for the effect of fabric characteristics, we have noticed that the seam pucker decreases with the increase of fabric mass in the warp and weft directions. Moreover, the fabric having a composition of 100% cotton is more stable than the fabric produced with 95% cotton and 5% elastane. Therefore, the elastane percentage loses the stability of the fabric and creates the slippage, while the polyester generates seam puckering with a negative value. In the second part, parameters interactions have been studied. The results prove that there is a significant interaction between the fabric and the seam thread. Finally a regression equation has been determined to estimate the coefficient of puckering in such circumstances.

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