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Influence of Denim Fabrics Properties and Sewing Parameters upon the Seam Slippage and Seam Quality Prediction

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ABSTRACT

This paper reports an experimental investigation of the effect of fabric properties and sewing conditions on the seam slippage. Moreover, basing on the input parameters, multi linear regression models were determined to predict seam slippage. Then, a program was investigated to predict seam quality. In this work, eighteen denim fabrics, having different compositions and masses, were sewn with two commercial sewing threads. Their performances, ranked according to the seam quality, were also determined in the first part.

The proposed study combines two programs, which are MINITAB-17 and Excel. At first, by used Minitab-17, an experimental investigation of the effect of the seam threads linear density, the stitch density and some fabric properties on the seam slippage behavior. Furthermore, six regression models were determined and discussed in order to predict the seam slippage. Then, an Excel application was realized. The principle consists in entering the input parameters and the slippage quality will be displayed automatically.

It was concluded that the increase of the seam thread linear density decreases the seam slippage, as well as the stitch density. However, the fabric mass has a random effect on seam slippage. It may also be concluded that the seam slippage is more important in the warp direction than in the weft one.

In the second part, on the basis of the seam quality parameters, regression models, for each blend composition and sewing direction, were determined in order to predict seam slippage thanks to statistical software. With respect to fabric yarn composition, elastane and polyester decrease the seam slippage.

Keywords: Seam slippage, fabric properties, sewing thread, stitch density, modeling, quality prediction

1. Introduction

For good appearance, seam should not contain any defects including skipped stitches, broken stitches, improper stitch balance, puckered seams, improper drapeability, irregular seam density, yarn damage, etc. Different parameters are currently adopted by the apparel industry to assess the seam quality and performance of commercial woven fabrics such as seam strength, slippage, elasticity, durability, stability and puckering which is used to assess durability and appearance of the seam [1, 2].

According to many researchers, different parameters affect seam quality, such as the sewing thread, the sewing condition, and others [3]. However, among all these influential input parameters, the sewing thread size is the most crucial one on the apparel seam stability. Moreover the improper use of seam thread size directly affects the seam quality of garments. Furthermore, previous studies showed that seam appearance and performance depend on the interrelationship of fabrics, threads, stitch type, seam type and sewing conditions [4]. Among the sewing conditions parameters affecting seam appearance and performance, we can cite needle size, stitch density, the appropriate operation and maintenance of the sewing machines etc. In fact, the selection of seam thread and sewing condition for a particular type of material is an integral part of producing a good seam quality [5]. The fabric parameters influence the garment quality and also the ease with which a structure can be manufactured.

Based on fabric properties and sewing parameters, the prediction of fabric seam performance has been considered by many researchers [5, 6, 7]. However, until now, there is no work dealing with modeling of seam slippage.

The aim of this study is to evaluate seam slippage. In fact, for different fabric compositions, the effect of stitch density, seam thread linear density and fabric mass are investigated. To prove the effectiveness of obtained results, a multi-linear regression equation is determined for each blend fabric composition and each seam direction to allow the manufacturer seam slippage prediction. A program is applied, using the Excel software, to calculate the slippage value and determine the slippage quality by entering input parameters.

2. Materials and methods

2.1 Fabric properties

Eighteen denim fabrics were chosen in this study. Since denim fabrics are generally made of cotton, cotton and elastane or a mixture of cotton, polyester and elastane, the three compositions are chosen in this study. Moreover, a wide range of masses is considered.

The studied fabrics were prepared on weaving loom projectile SULZER P7300 with 3/1 twill structure, having a little difference in warp and weft density. The impact of two fabric parameters (mass and blend composition) on the seam slippage was investigated. The fabric parameters are given in Table 1.

Table 1. Fabric properties

Parameter		Warp yarn density (ends/cm)	Weft yarn density (picks/cm)	Mass (g/m²)	Thickness (mm)	Breaking strength (N)	Elongation at break (%)
Fabric							
Composition	N°						
1	8	26	17	323	1.2	413.63	12.66
	14	32	19	341	0.93	985.62	15.03
	16	31	22	368	1.00	996.54	6.94
	19	30	22	387	1.04	1071.90	17.89
	17	27	20	390	0.97	779.42	19.14
	13	27	20	406	0.87	853.81	14.74
2	11	29	18	328	0.85	564.96	24.84
	29	29	22	342	0.90	624.21	30.45
	18	28	17	359	0.91	568.46	23.36
	15	29	18	372	0.97	810.30	24.34
	23	30	20	416	0.78	453.88	27.65
	22	32	17	445	0.96	894.26	17.40
3	27	36	20	243	0.76	459.34	28.12
	21	28	22	328	0.75	528.13	25.12

	25	31	21	334	0.85	557.24	33.64
	20	32	19,5	341	0.99	540.44	36.14
	12	30	20	410	1.04	757.45	33.16
	24	31	20	430	0.90	526.64	25.19

Where: 1: 100% cotton fabric composition, 2 : 95% cotton and 5% elastane fabric composition, 3 : 71% cotton, 24% polyester and 5% elastane fabric composition, Wp : Warp, Wt : Weft

The warp and weft yarn densities were determined based on ISO 7211-2:1984 [8]. The mass of studied fabrics, in standard atmosphere was measured according to EN 12127:1997 [9]. Similarly, the determination of the thickness of each sample was based on ISO 5084: 1996 [10]. The tensile behavior of the denim fabric was applied according to ISO 13934-1:2013 to determine the breaking strength and the elongation at break [11].

2.2 Sewing thread properties

In this work, two commercial seam threads (N°1 and N°2) commonly used for stitching denim fabric were selected. The choice of the sewing thread was based on the large difference in linear densities which are equal to 63.5 tex and 95 tex. This parameter can significantly affect the seam quality of garments. For the studied sewing threads, mercerizing and bleaching pre-treatments were applied. Moreover, these threads used have the same finish treatments. The linear density of the sewing thread was chosen according to NFG 07-117 [12]. Seam threads' characteristics are given in Table 2.

Table 2. Sewing threads properties

Parameter	Thread N°1	Thread N°2
Linear density (tex)	63.50	95.00
Number of strands	3	3
Composition	100% PES	100% PES
Twist direction	S	S
Breaking strength (N)	24.23	26.43
Breaking elongation (%)	21.12	16.90
Rigidity (N/m)	389.12	536.59
Twists/m	353.00	294.00
Tenacity (cN/tex)	38.16	27.82

The thread size was determined according to NF EN ISO 2060 [13]. The linear density (T) was determined by applying the following Equation (1).

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

Where: M: mass
L : sewing thread length

To determine the thread twist, the ISO 2061 was applied [14]. The tensile properties were determined according to ISO 2062; the specimen was subjected to tension until break using a suitable tester (dynamometer type "LLOYD Instruments" as shown in Figure 2) that indicates the applied tensile force and elongation [15]. Hence, the tenacity can be calculated following Equation (2).

$$\mathrm{Tenacity\ (cN/tex)} = \frac{\mathrm{Bs}}{\mathrm{T}} \quad (2)$$

Where : T : Linear density (tex) ; Bs : Breaking strength (cN)

2.3 Sewing properties

In this work, sewability is studied by measuring seam slippage. A high-speed industrial lockstitch machine type Brother was used for sewing the fabric samples [16]. The stitch type was a lockstitch type 301. The machine speed was around 2000 rounds/minute. The needle size is equal to 90. This choice was according to NFG 07-117; if the fabric mass ≥ 200g/m² , then the needle size should be equals to 90 -110 [12]. The normal rounded needle shape was chosen. Thus, the choice of both the needle size and the sewing thread linear density was based on the NFG 07-117 standard [12]. The threads range for experimentation was chosen basing on the demand of the manufacturer, in order to help solve seam slippage.

Three levels of stitch density were considered, which are 3 stitches/cm, 4 stitches/cm and 5 stitches/cm. In fact, to simulate the reality of industrial sewing conditions and to help clothing manufacturers to evaluate their seam slippage, it is suitable to focus on the useful range of densities. To obtain an efficient seam of denim fabrics and to avoid puckering during the seaming process, it is important to use from 3 stitches/cm to 5 stitches/cm [17].

To ensure a balanced seam, before starting seaming steps, overall conditions were regulated and adjusted according to the instructions of Brother's manufacturer [16] to obtain a satisfactory sewing quality appearance. Indeed, Brother Lockstitch machine type SL-755 parameters were adjusted to the manufacturer's recommended standard settings. Furthermore, the tension screw on the bobbin case was adjusted until the bobbin and its case just moved down the thread, i.e. the thread tension was nearly equal to the weight of the bobbin and its case [18].

To make the needle point compatible with the fabric type, the SPI needle type was used just in denim fabric [19, 20]. So, in this study, the SPI needle type has been chosen because of its normal rounded point that separates the fabric threads without damaging them. This is the most versatile of the tips.

2.4 Testing of seam slippage

The applied standard NF EN ISO 13936-2, was used to evaluate the seam slippage property of tested denim samples [21]. This test was performed on a dynamometer type "LLOYD Instruments". After the test is completed, we measured the unstitching of seam at the widest point (figure 1).

Figure 1. Seam opening

Referring to Rajkishore et al, [22] the elongation at break of the fabric with the seam (E_s) is a predetermined distance greater than the elongation of the fabric without a seam (E_f). The distances difference is reported as seam slippage. Then seam slippage ($S.S$) can be calculated basing on this formula 3.

$$S.S(mm) = E_s - E_f \quad (3)$$

2.5 Evaluation of fabric sewability

The statistical software (MINITAB-17) was applied to analyze the individual and interactive effects of fabric mass, stitch density and seam thread linear density. For rigorous information, full experimental factorial design was used to analyze objectively all experiment combinations of input parameters.

To evaluate the effect of input parameters on seam slippage, different experimental designs (plans) are considered. The input parameters and their levels are presented in Table 3.

Table 3. Experimental design of plan A, B and C

Parameter	Mass (g/m^2)						Stitch densities (stitches/cm)			Linear density (tex)	
Level	1	2	3	4	5	6	1	2	3	1	2
Plan A	323	341	368	387	390	406					
Plan B	328	342	359	372	416	445	3	4	5	63.5	95
Plan C	243	328	334	341	410	430					

Each plan concerns six fabrics having the same blend composition and different masses. Plans A, B and C correspond to the "100% cotton", "95% cotton and 5% elastane" and "71% cotton, 24% polyester and 5% elastane" fabrics, respectively. Each plan was studied in the warp and weft directions separately.

3. Results and discussion

In this study, different parameters were studied, which are fabric mass, stitch density and seam thread linear density. Eighteen fabrics (each six fabrics have the same blend composition and different masses), two seam threads and three stitch densities were considered. To determine the seam quality in the warp and weft directions, the sample was sewn in both directions. Five tests were repeated for each variation in order to ensure the reliability of the obtained results. 216 different sewing combinations were designed. The overall results of seam slippage tests are presented in Table 4.

Table 4. Overall results of seam slippage tests

Fabric mass (g/m²)			Stitches/cm	Seam Thread (tex)	Seam slippage (%)					
Plan A	Plan B	Plan C			Plan A		Plan B		Plan C	
					Warp	Weft	Warp	Weft	Warp	Weft
323	328	243	3	63.50	2,10	1,91	2,00	0,72	4,50	1,00
323	328	243	3	95.00	0,00	0,00	1,23	0,46	0,81	0,00
323	328	243	4	63.50	1,70	1,05	1,57	0,8	4,00	0,99
323	328	243	4	95.00	0,00	0.00	0,90	0,35	0,52	0,00
323	328	243	5	63.50	1,20	0,90	1,62	0,67	3,60	0,82
323	328	243	5	95.00	0.00	0.00	0,72	0,37	0,40	0,00
341	342	328	3	63.50	1,90	2,29	1,70	0,90	4,50	0,93
341	342	328	3	95.00	0.00	0,41	1,07	0,37	1,44	0,08
341	342	328	4	63.50	2,50	1,61	1,66	0,97	3,50	0,91
341	342	328	4	95.00	0,00	0,29	0,93	0,00	0,95	0,17
341	342	328	5	63.50	2,40	1,43	1,53	0,91	2,65	0,68
341	342	328	5	95.00	0,00	0,00	0,57	0,00	1,00	0,10
368	359	334	3	63.50	1,38	2,33	1,93	1,10	3,47	0,84
368	359	334	3	95.00	0,45	0,56	1,20	0,47	1,42	0,00
368	359	334	4	63.50	1,29	1,75	2,08	1,09	3,10	0,66
368	359	334	4	95.00	0,39	0,39	1,09	0,49	0,91	0,00
368	359	334	5	63.50	1,44	1,25	1,92	0,98	2,59	0,46
368	359	334	5	95.00	0,29	0,19	0,92	0,33	0,33	0,00
387	372	341	3	63.50	2,13	2,71	2,07	1,27	3,61	0,82
387	372	341	3	95.00	0,85	0,74	1,36	0,80	0,94	0,00
387	372	341	4	63.50	2,11	2,01	1,86	1,16	3,50	0,72
387	372	341	4	95.00	0,79	0,52	1,03	0,51	0,72	0,00
387	372	341	5	63.50	1,90	1,80	1,90	1,11	2,07	0,46

387	372	341	5	95.00	0,65	0,32	0,70	0,32	0,77	0,00
390	416	410	3	63.50	1,73	2,17	2,36	1,5	3,99	0,90
390	416	410	3	95.00	0,00	0,95	1,47	0,9	1,83	0,31
390	416	410	4	63.50	1,40	1,98	2,19	0,96	2,58	0,61
390	416	410	4	95.00	0,00	0,50	1,20	0,64	1,50	0,00
390	416	410	5	63.50	1,77	1,60	2,02	1,22	1,70	0,43
390	416	410	5	95.00	0,00	0,41	0,82	0,53	0,37	0,00
406	445	430	3	63.50	2,44	2,69	2,30	1,36	3,00	1,10
406	445	430	3	95.00	0,00	0,69	1,51	1,00	1,30	0,00
406	445	430	4	63.50	2,60	1,90	2,14	1,59	2,50	1,00
406	445	430	4	95.00	0,00	0,53	1,38	0,80	0,65	0,00
406	445	430	5	63.50	2,22	1,65	1,79	1,27	2,20	0,61
406	445	430	5	95.00	0,00	0,00	1,20	0,62	0,00	0,00

It can be concluded that the change of each input parameter affects clearly the seam slippage, in both warp and weft directions. The effects of different parameters on seam slippage and the statistical study were also evaluated to select the most important and influential input parameters on the seam slippage behavior of denim fabrics.

3.1 Effect of different input parameters on seam slippage for each blend composition

Based on plans A, B and C, the main effect plots presenting the influence of each parameter are presented hereafter.

Plan A (100% cotton fabric): Figure 2 shows the influence of the three studied parameters on the sewing slippage in the warp direction for the 100% cotton fabric.

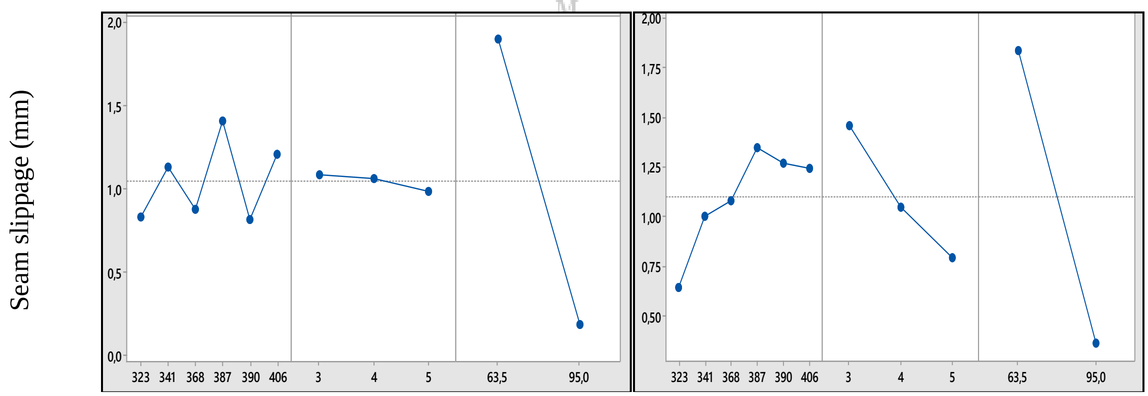


Figure 2. Parameters influence on seam slippage*; (a)warp direction and (b) weft direction* (for 100% cotton fabric)

As shown in this figure, it can be seen that, in the warp direction, the variation in the sewing slippage is low and random by increasing the fabric mass. It varies between 0.83 and 1.40mm, whereas, in the weft direction, the variation in the sewing slippage as a function of the mass per unit area increases from 0.64 to 1.35mm.

By increasing stitch density, the sewing slippage decreases slightly from 1.08 to 0.99mm in the warp direction and the decrease is more important in the weft direction, from 1.45 to 0.80mm. By increasing the sewing thread linear density, the sewing slippage in both directions decreases (from 1.90 to 0.19mm and from 1.83 to 0.36mm in the warp and weft directions respectively).

Plan B (95% cotton and 5% elastane fabric): Figure 3 shows that, by increasing the fabric mass, the sewing slippage increases, from 1.24 to 1.72mm in the warp direction and from 0.52 to 1.11 mm in the weft direction.

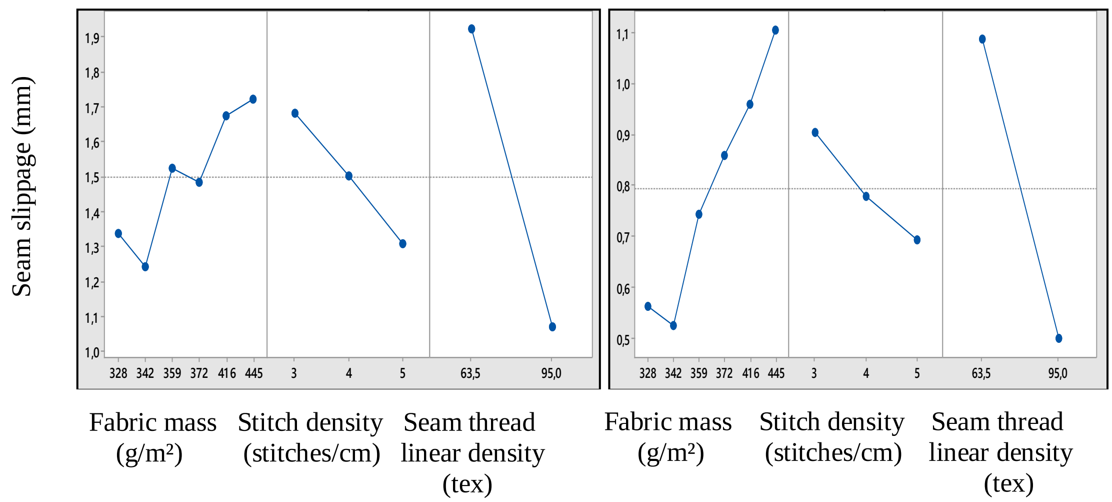


Figure 3. Parameters influence on seam slippage*; (a)warp direction and (b) weft direction* (for 95% cotton and 5% elastane fabric)

The increase of the stitch density decreases the sewing slippage, in both sewing directions; from 1.68 to 1.31 mm and from 0.90 to 0.70 mm in the warp and weft directions respectively. Also, increasing the sewing thread linear density decreases the sewing slippage from 1.92 to 1.07mm in the warp direction and from 1.09 to 0.49mm in the weft direction).

Plan C (71% cotton, 24% polyester and 5% elastane fabric): Based on Figure 4, it may be concluded that, in the warp direction, the sewing slippage decreases when the fabric mass increases (from 2.34 to 1.61mm). In the weft direction, by increasing the fabric mass, the seam slippage decrease seems not vary significantly (from 0.48 to 0.33mm).

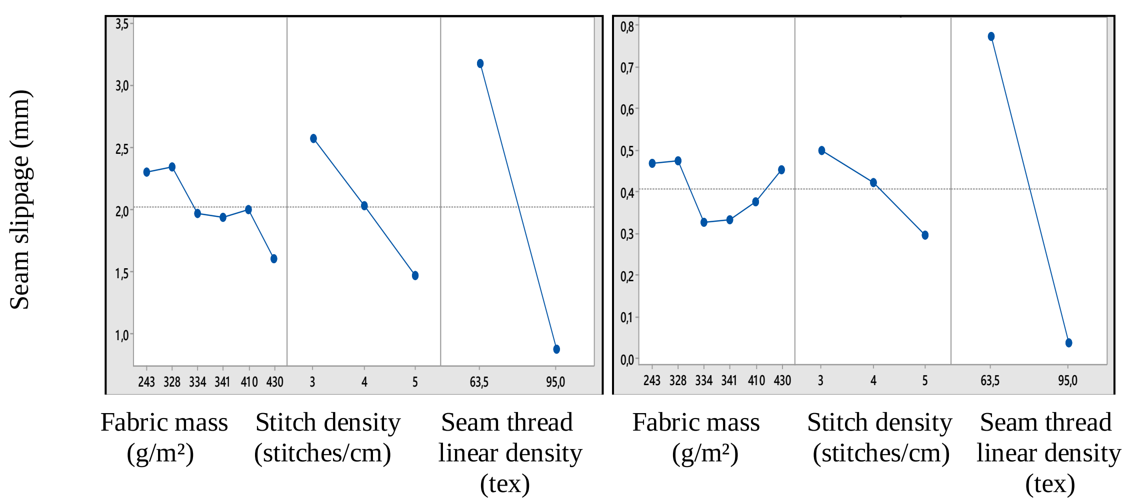


**Figure 4. Parameters influence on seam slippage*; (a)warp direction and (b) weft direction*
(for 71% cotton, 24% polyester and 5% elastane fabric)**

Increasing the stitch density in the warp and weft directions decreases the sewing efficiency from 2.57mm to 1.47mm in the warp direction, whereas in the weft direction, the variation in the seam efficiency value is low (from 0.50mm to 0.30mm). Increasing the sewing thread linear density decreases the seam slippage, especially in the warp direction (from 3.17mm to 0.89mm). In the weft direction, the variation is less important, compared to warp direction, ranging from 0.77mm to 0.04mm.

3.1.1 Effect of fabric properties on seam slippage

Fabric mass: Some researchers have studied the effect of fabric properties on seam quality such as Choudhary and Amit [23] who have shown that the increase of fabric strength decreases the seam strength efficiency. Indeed, they justified this result by seam strength efficiency is inversely proportional to the fabric strength for a given sewing thread. This finding seems in a good agreement with Bharani's study [24]. In fact, it was found that the greater the fabric strength, the greater is the fabric resistance. However, Cheng's study, demonstrated that the heavier and thicker the fabrics, the higher the seam strength become [1]. In addition, Bose and Mukhopadhyay have studied the correlation between fabric strength and seam strength [25]. They have found that the seam strength is highly dependent (the correlation coefficient equals 0.83) on the strength of the fabric.

In this work, the strength of the fabric does not increase necessarily with the increase of the fabric mass value. Consequently, the influence of the fabric mass is random. In fact, for 100% cotton fabrics (in both seam directions) and for 95% cotton and 5% elastane fabrics (in the warp direction), the increase of fabric mass increases seam slippage. However, in other cases, the increase of fabric mass decreases the sewing slippage. Thus, in our cases, there are positive and negative correlations between fabric mass and seam slippage.

Fabric blend composition: Table 5 shows the variation of seam slippage as a function of fabric blend composition regarding weft and warp directions.

Table 5. Average seam slippage according to the fabric composition

Direction		Warp			Weft		
Composition		1	2	3	1	2	3
Seam slippage (%)	M	1,12	1,48	1,97	1,00	0,82	0,40
	S	1,03	1,50	2,02	1,13	0,80	0,40
	T	1,05	1,50	2,03	1,10	0,79	0,41

Where: M: surface mass, S: stitch density; T: seam thread linear density

In warp direction, the seam slippage increases from blend composition 1, 2 and 3. Choudhary and Amit [23] found that the polyester dominated suiting fabrics give minimum seam stiffness because polyester component has a low flexural rigidity and a low bending stiffness. By comparing fabric composition 1 (100% cotton) and 3, this result was successfully confirmed. In fact, the seam slippage for the 100% cotton is less important than the 71% cotton, 24% polyester and 5% elastane. However, in the weft direction, seam slippage decreases from fabric composition 1 to fabric composition 3. Hence, the elastane and the polyester reduce the seam slippage. In the weft direction, from fabric composition 1 to fabric composition 2, seam slippage decreases; thus, seam slippage decreases with elastane. This result is in agreement with Gurada and Meric's study [26]. In fact, a higher percentage of elastane (type lycra) in the denim increases the fabric elasticity and seam performance.

3.1.2 *Effect of stitch density on seam slippage*

Seam slippage decreases with the increase of stitch density in both warp and weft directions. In fact, the increase of stitch density increases the sewing threads consumption, so the seam resistance becomes higher. This seems in a good agreement with Lauriol's results, who confirmed that the increase of stitch density from 4 to 5 stitches/cm, increases the thread demand by average 10% [27].

The increase of stitch density increases the number of contact points between sewing thread and fabric yarns, so a tighter surface will be obtained. Hence the tensile force will be distributed over a larger number of points and the resistance will be higher. This result is confirmed by Rostam [28] who found that the increase of stitch density leads to a higher amount of seam strength. Furthermore, the sewn structure resistance can be divided into two regions named; "Pure fabric area" and "Sewing area".

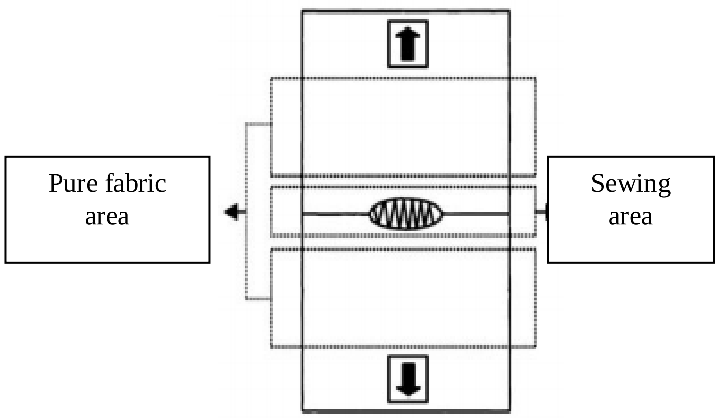


Figure 5. Presentation of a woven structure imposed on a tensile force

Thus, the increase of stitch density, relative to studied fabrics, the results increase the "sewing area" resistance, which presents the most resistant area of a sewn structure during a tensile test. Thus, the seam slippage decreases.

3.1.3 *Effect of seam threads linear density on seam slippage*

A number of studies have shown that the size of the sewing thread is the most important factor for the seam stability of clothing. Choudhary and Amit founded that the abuse of the sewing thread size affects the sewing garments quality significantly [23]. In addition, they have proved that the sewing thread has an important impact on the quality improvement, although it generally represents less than 1% of garment mass. The high resistance of the sewing thread gives the best functional performance of the seam, namely, the seam strength. Rengasamy has shown that high thread seam strength is a basic requirement for good sewability [29].

In this study, the sewing thread presents the most important parameter influencing sewing slippage. Indeed, the increase of the sewing thread linear density is followed by the increase of its rigidity, decreasing of the seam slippage. Thus, seam slippage is inversely proportional to sewing thread resistance.

3.1.4 *Effect of the seam direction on seam slippage*

Fabric direction presents an important parameter that causes changes in fabric properties. In our case, the fabric's yarn composition changes only in the weft direction; the warp yarns have a 100% cotton composition for all studied fabrics. Hence, fabric properties change from the warp to the weft direction. Indeed, researchers have noted that the role of fiber type and its percentage in fabrics are very important for sewing performance and characteristics because of its effect on the mechanical properties of sewing fabrics [23]. In our study, the elastane percentage exists in the weft direction. That is the reason that the elongation at break is greater in the weft direction, hence, increasing the seam strength. Even though, the decrease in seam slippage in the weft direction is greater than in the warp one.

Furthermore, the sewing slippage depends on the fabric cover factor. Indeed, the cover factor increases in the perpendicular direction of the seam, the seam slippage decreases accurately as the structure will be tighter in the traction direction. The cover factor is defined by Pierce method. It is in a good relationship within the ratio of the area covered by the warp and weft yarns fabrics, covered by the whole fabric [30]. In our case, the warp count (yarn density in the warp direction) is more important than the weft count (yarn density in the weft direction), practically for all tested fabrics. Hence the slippage is more important in the warp direction.

3.2 Statistical study

To study the effect of fabric mass, the sewing thread linear density and stitch density on seam quality, a full factorial design was implemented. The treatment design was a 6×3×2 factorial (according to the studied parameters listed in table 2). The multiple regression method is selected in this study. To compare the performance of these models, the regression coefficients (R^2) were compared.

The multi-linear regression models correlate fabric mass (M), stitch density (S) and sewing thread linear density (T) to seam slippage (SS). The generalized multi-linear model can be expressed as follows (Equation 4).

$$SS = \alpha + \alpha_1 . M + \alpha_2 . S + \alpha_3 T + \alpha_4 . M . S + \alpha_5 . M . T + \alpha_6 . S . T \quad (4)$$

Where α is a constant value

α_1, α_2 and α_3 represent the coefficients of fabric mass, stitch density and sewing thread respectively,

α_4 , α_5 and α_6 are the coefficients of fabric mass and stitch density interaction, fabric mass and sewing thread interaction and stitch density and sewing thread interaction respectively.

The multi-linear models involving the main input parameters and their interactions with the seam slippage were established in warp and weft directions. According to table 6, it has been found that these models are significant. Indeed, the lowest values of R^2 in the warp and weft directions are equal to 85.48% and 89.74% respectively. These values are very close to 1. Hence, these models fit the data very well and the obtained models are significant to predict the seam slippage behavior.

Table 6. Multi-linear regression models

Composition	Direction	Multi-linear regression model	R^2
1	Warp	$SS = 4{,}92 + 0{,}0026\,M - 0{,}36\,S - 0{,}0490\,T + 0{,}00062\,M \times S - 0{,}000026\,M \times T + 0{,}00104\,S \times T$	85.48%
	Weft	$SS = 1{,}55 + 0{,}01930M - 0{,}487\,S - 0{,}0476\,T - 0{,}00130\,M \times S - 0{,}000085\,M \times T + 0{,}00805\,S \times T$	96.20%
2	Warp	$SS = 0{,}97 + 0{,}00610\,M + 0{,}263\,S - 0{,}0105\,T - 0{,}000449\,M \times S - 0{,}000006\,M \times T - 0{,}00353 S \times T$	94.52%
	Weft	$SS = -1{,}44 + 0{,}00841\,M + 0{,}411\,S - 0{,}0036\,T - 0{,}000733\,M \times S - 0{,}000008\,M \times T - 0{,}00303\,S \times T$	89.74%
3	Warp	$SS = 18{,}92 - 0{,}01756\,M - 0{,}532\,S - 0{,}2084\,T - 0{,}00209\,M \times S + 0{,}000287\,M \times T + 0{,}00897\,S \times T$	95.03%
	Weft	$SS = 4{,}057 + 0{,}00045\,M - 0{,}261\,S - 0{,}05150\,T - 0{,}000651 M \times S + 0{,}000025\,M \times T + 0{,}00487\,S \times T$	93.37%

Nevertheless it is important to analyze the statistical variance. Based on the p-value of statistical coefficient, it is possible to evaluate the importance of different parameters and their relative interactions. In fact, three conditions are presented:

- When p-value is null, the parameter is very significant.
- When p-value ranges from 0 to 0.05, the parameter is significant
- When p-value is higher than 0.05, the relative parameter is negligible.

Table 7 summarizes the p-values for each considered experimental design.

Table 7. p value of each input parameter

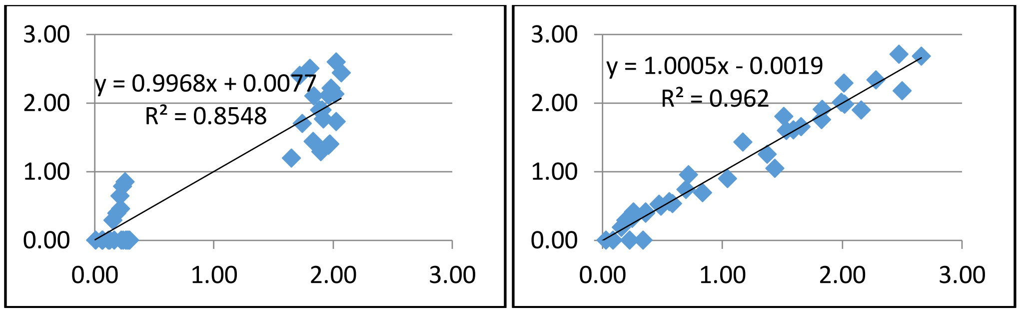
Plan	A (composition 1)		B (composition 2)		C (composition 3)	
Direction	Warp	Weft	Warp	Weft	Warp	Weft
Parameter	p-value	p-value	p-value	p-value	p-value	p-value
M	0,875	0,014	0,111	0.044	0.010	0.842
S	0,749	0,347	0,351	0.178	0.308	0.157
T	0,399	0,081	0,466	0.819	0.000	0.000
$M \times S$	0,825	0,318	0,490	0.297	0.067	0.101
$M \times T$	0,861	0,211	0,851	0.824	0.000	0.226
$S \times T$	0,840	0,002	0,043	0.103	0.043	0.003

Regarding the regression coefficient range and the statistical analysis results, the regression model is appropriate and well-predictive of seam slippage. Thus, considering the statistical analysis results, the multi-regression models, presented in Table 6, can be widely useful. Moreover, the developed multi-linear regression models reflect the accuracy of our findings.

To validate the regression equations, two methods will be followed; statistical and experimental ones.

Statistical method: The first method consists on a comparison between theoretical and experimental seam slippage values. By presenting the theoritical values as a function of the experimental ones in the warp and weft direction, we note that:

- For composition 1 (100% cotton): according to figure 6, the regression coefficient is equal to 85% in the warp direction and it is equal to 96% in the weft direction.

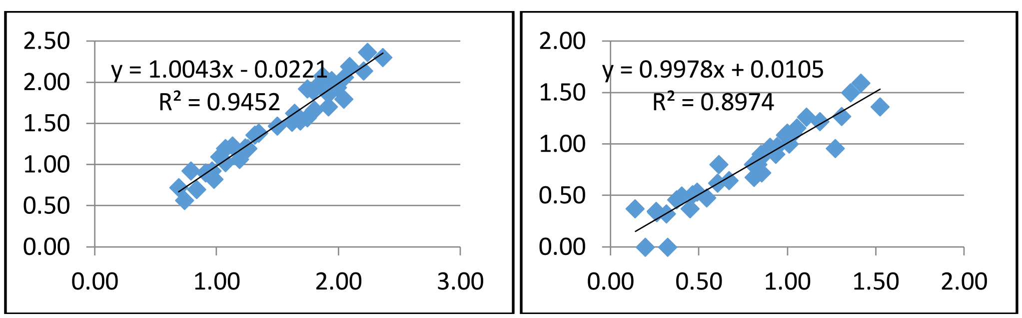


(a) (b)

Figure 6. Theoretical slippage values as a function of the experimental ones in the warp (a) et weft directions (b) for the composition 1

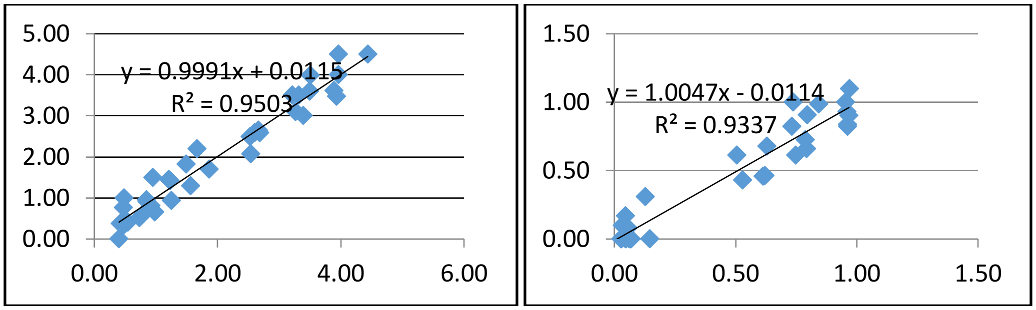
- For composition 2 (95% cotton and 5% elastane): regarding figure 7, it is concluded that the regression coefficient is equal to 94% in the warp direction and 90% in the weft and weft directions respectively.

- For composition 3 (71% cotton, 24% polyester and 5% elastane): from figure 8, it may be concluded that the regression coefficient is equal to 95% in the warp direction. It's equal to 93% in the weft direction.



(a) (b)

Figure 7. Theoretical slippage values as a function of the experimental ones in the warp (a) et weft directions (b) for the composition 2



(a) (b)

Figure 8. Theoretical slippage values as a function of the experimental ones in the warp (a) et weft directions (b) for the composition 3

The regression coefficients are greater than 85% for each fabrics group and each seam direction. Therefore, we conclude that the theoretical values are very close to those of the experimental ones. Regarding the obtained findings, the models for 1b), 2a) and 3a) are most robust, and that 1a), 2b) and 3b) have reasonable predictive value. To conclude, the developed models of seam slippage can be considered as efficient and accurate

Experimental method: The second method consists on experimental tests using a third polyester sewing thread having a different linear density than those used previously. In fact, the model developed above was validated experimentally by using a new sewing thread and comparing predicted slippage to the model prediction. Similarly, by comparing the experimental and theoretical values, we calculated the mean absolute relative error for seam slippage ($\boldsymbol{Error}$) (calculated according to Equation 5), in the warp and weft directions, as shown in Table 8.

$$\boldsymbol{Error} = \frac{|\mathbf{V_{th}} - \mathbf{V_{exp}}|}{\mathbf{V_{exp}}} * \mathbf{100} \qquad (5)$$

Where V_{th}: theoretical value of seam slippage;

V_{exp}: experimental value of seam slippage

Table 8. Regression models errors of seam slippage

	$Error$ (%)	
Composition	Warp	Weft
1	3	2
2	3	3
3	2	4

Regardless of the values in table 8, the average error, which not exceeding 3% in the warp direction and 4% in the weft direction was eventually found. Refering to El-Ghezal' study, the limit of the mean absolute error values used in the modeling is estimated to be 6% [31]. Though, our result is well justified.

Considering that the error is very low and the values of regression coefficients are very high, it has been deduced that the theoretical values are very close to the experimental ones. Therefore, the obtained regression models are well justified.

3.3 Seam slippage prediction

To determine the seam quality, seam slippage parameter is classified into quality intervals;

-"Refused quality" interval, which represents the most mediocre quality that will be rejected (> 6 mm).

-"Best quality" interval, which represents the optimum quality sought (0-3 mm)

-"Acceptable quality" interval, which represents the medium quality (3-6%).

A questionnaire was carried out for 20 quality agents, from different denim garment manufacturers, to validate this choice of quality intervals for sewing parameters. Table 9 presents the validation percentage of seam slippage interval. Thus, this classification is justified and validated by 80% of the quality agents at least.

Table 9. Validation percentage of seam slippage interval

Quality of slippage	Best quality	Medium quality	Mediocre quality
Slippage interval	[0 mm, 3 mm]	[3 mm, 6 mm]	>6 mm
Validation percentage	80 %	80 %	80 %

Excel application

Excel software provides a convenient procedure to determine the quality index. The principle consists in entering the input parameters into the worksheet "Predicted quality" (Figure 9).

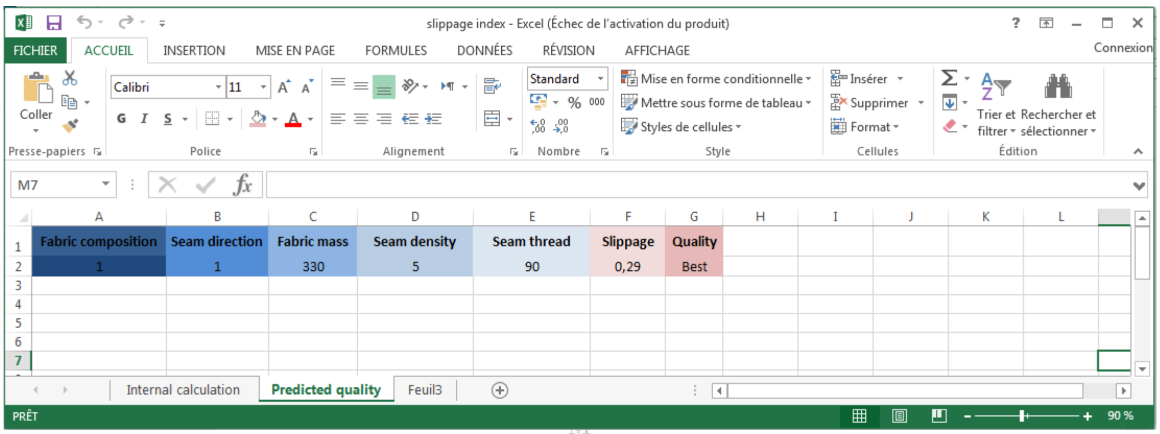


Figure 9: Predicted quality

This latter carries out calculations and displays the results. The input parameters are;

- Fabric composition that will be equal to:
  - -"1": if the fabric composition is 100% cotton
  - -"2": if the fabric composition is a mixture of cotton and elastane
  - -"3": if the fabric composition is a mixture of cotton, polyester and elastane
- Sewing direction will be equal to:
  - -"1": if the seam is made in the warp direction of the sewing fabric
  - -"2": if the seam is made in the weft direction of the sewing fabric
- Fabric mass : its value will be entered directly (g / m²)
- Stitch density : its value will be entered directly (stitches / cm)
- Sewing thread linear density : its value will be entered directly (tex) (for the 100% polyester threads).

The program recalls the "Internal calculation" worksheet (Figure 10) to calculate seam slippage by using the regression equations.

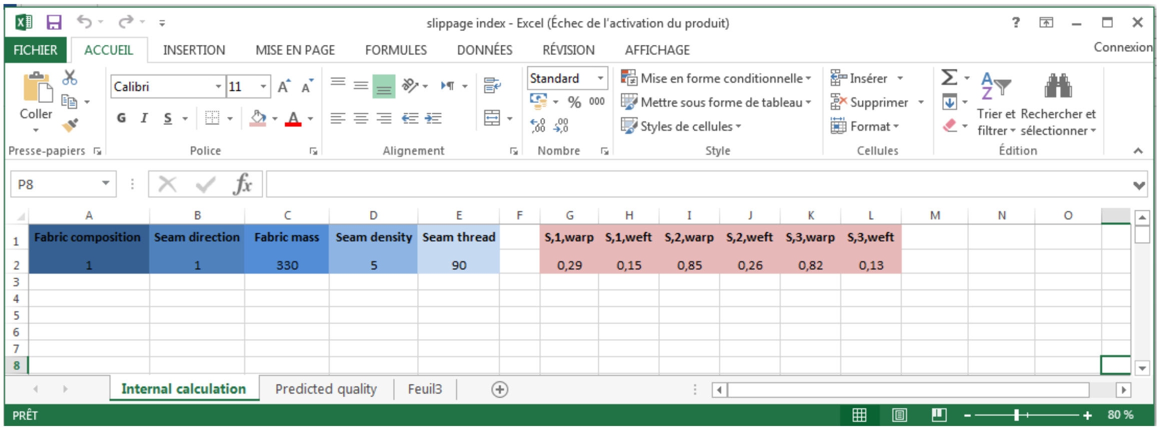


Figure 10: Internal calculation

Then, the slippage value calculation will be carried out and the seam quality will be displayed automatically in the "Predicted quality" worksheet (Figure 9).

4. Conclusion

In this study, the sewing performance has been evaluated by measuring the seam slippage of denim fabrics. Seam slippage should be eliminated from fabrics designed for clothing manufacture such as the ones included in this study. The findings obtained shows that, in both warp and weft directions, the increase of seam thread linear density decreases seam slippage, while the stitch density decreases enormously. However, the increase of the fabric mass has a notable effect on seam slippage. Seeing that elastane and elastane /polyester were only included for the fabric weft direction, regarding the fabric blend composition, elastane and polyester decrease seam slippage in the weft direction. According to seam direction, it was found that, in the warp direction, seam slippage values are still more important than those in the warp direction.

Regarding the importance of seam quality prediction for the manufacturers, it's interesting to found a way to forecast the seam quality before production. Indeed, significant regression models were determined based on input parameters. Then, a program was realized using the Excel software. By entering input parameters, the slippage value is determined based on the regression models already calculated, and the slippage quality can be predicted.

This study allows manufacturers to predict the seam slippage before production so as to avoid the loss of time and material and reduce the production cost.

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