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THE IMPACT OF FABRIC STRUCTURE AND WASHING/DRYING ON SEAM QUALITY OF WOVEN COTTON APPAREL

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ABSTRACT: The goal of the present work is to study the effect of fabric structure and washing/drying on the seam quality of two woven cotton fabrics. The effects of weave type, seam direction and washing/drying on the seam quality were investigated and predicted using the analysis of variance technique ANOVA and multiple regression models. The seam quality and performance of the woven cotton fabrics was characterized by the seam strength, the seam efficiency, the seam slippage and the seam pucker.
The results of this study showed that fabric structure and washing/drying have a profound influence on the seam quality of the cotton woven fabrics and accepted adjusted R^2 were obtained.
Keywords: Washing, woven cotton fabric, multiple regression, seam quality, seam direction, seam strength, seam efficiency, seam slippage, seam pucker.

INTRODUCTION

Producers, retailers, and customers, all of them demand quality. And in the apparel industry, product quality always means seam quality. In fact, the overall seam quality is defined through various functional and aesthetic performances desired for the apparel product during their end use. 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 [1], [3]. Seam also comes under abrasion with body parts at wear or at the time of washing or dry cleaning. It is expected that the seam should have a good abrasion and/or washing and/or dry cleaning resistance.
For manufacturers to be able to select appropriate thread types and stitch densities to achieve quality in seams, garments during use must also be examined. In fact, garments do not only go through wear in the course of use, but also care, which include laundry and storage among others. As indicated by Mukhopadhyay et al. (2004) [4], in the lifetime of a garment, both cloth and seam undergo repeated laundering, which may result in a change in the quality and the performance of the sewn product. Seam performance after laundering is important in adjudging the suitability of a sewn product since seam quality is an important parameter deciding the performance of garments. The quality and performance of a sewn garment depends on various factors such as seam strength, slippage, puckering, appearance and yarn severance [1], [5].
Generally, all the fabric properties such as weight, cover factor, thickness, strength, extensibility, bending rigidity, bending hysteresis, shear rigidity, shear hysteresis and coefficient of friction have considerable effect on seam quality of apparel products.
Few researchers were investigated in the effect of washing and/or drying on the seam quality. Studies have been done to determine its impact on the performance properties of textile fabrics, but not much have been done on the seam appearance and performance characteristics [4], [6], [8].
Moris and Prata (1977) [9] stated that as much as half of the wear on fabrics during use may occur in laundering. They indicated that, for example, abrasion may occur both in washing and in drying, and studies have shown that water quality, detergent type, and drying conditions are important variables affecting the amount of damage. The resistance of the product against washing and dry cleaning is a basic factor for evaluation of the exploitation properties of the seam in apparels [8].
The purpose of this study was to investigate and to predict the effect of washing/drying cycles, weave fabric and seam direction on the seam quality such as: the seam strength, the seam efficiency, the seam slippage and the seam pucker.

MATERIALS AND METHODS

Fabric properties

Fabric dimensional properties: 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. 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. End and pick density were measured using the fabric dissection according to the NF G07-155 test method. Linear density (tex) of warp and weft yarns was measured according to the NF G07-077. Crimp value in warp and weft yarns was measured according to NF G07-156. Yarn count was measured using Beesley's balance. The cover factor of fabrics is determined by Peirce method [10] which is conceived for cotton fabrics. It consists in applying the equation 1:

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

With: Ne is the English count.
The dimensional parameters of the fabrics are given in Table I.

Table I: Fabrics dimensional properties

Ref.	**Weave**	**Linear density (tex)**		**End/Pick density**		**Weight (g/m²)**	**Thickness (mm)**	**Crimp (%)**		**Cover factor**		
		Warp	Weft	Warp	Weft			Warp	Weft	Warp	Weft	Fabric
F1	Twill 3	20/1	34/1	46	26	179.1	0.31	9	6	79	59	138
F2	Plain	19/1	34/1	31	21	137.7	0.26	4	8	53	49	102

Fabric mechanical properties: the tensile test for measurement of breaking load and elongation was conducted according to the NF G07-001 test method on the dynamometer LLOYD LRSK 5 KN. Bending and shear rigidity of the fabrics was measured and calculated by FAST instrument under standard conditions [11]. The results of all the tests were presented in Table II.

Table II: Fabrics mechanical properties

Ref.	**Breaking strength (N)**		**Breaking extension (%)**		**Work of rupture (J)**		**Bending rigidity (□.N.m)**		**Shear rigidity (N/m)**
	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft	
F1	759.48	647.92	11.09	10.98	5.70	4.56	25.56	27.71	223
F2	517.25	551.79	7.18	14.11	2.67	4.57	29.55	19	263.38

Sewing properties

Sewing was done on the PFAFF industrial sewing machine 1183 with a needle type Groz-Beckert 134 R, size Nm 75/11. Each fabric sample was sewn with a plain lockstitch seam with a stitch density of six stitches/cm using sewing thread of polyester (PES) of 30 tex. Samples consisted of five specimens test sewn in the warp direction and other five sewn in the weft direction. The sewing thread characteristics are indicated in Table III.
The systematic pursuit of the process consisted in testing the specimens after each of the cycles indicated as follows: 0-1-2-3-4-5-10-15-20 [7].

Table III: Sewing threads properties

Twist (tours/m)			493.5
Twist distance (cm)			4.78
Single strand	Breaking load (N)	x	11.33
		CV	8.02%
	Breaking elongation (%)	x	16.68
		CV	6.29%
	Breaking work (J)	x	0.41
		CV	13.61%
In loop	Breaking load (N)	x	19.74
		CV	10.24%
	Breaking elongation (%)	x	15.66
		CV	5.87%
	Breaking work (J)	x	0.67
		CV	14.01%

Dimensional stability of fabrics and sewn samples

Dimensional stability of woven fabric samples was characterized as fabric shrinkage. In this study, dimensional stability of washed and dried woven fabric samples was taken in warp and weft direction. The shrinkage in longitudinal and transverse directions of laundered samples was calculated after each cycle of washing and drying. The shrinkage value was defined by the equation 2:

$$\lambda = \frac{(L - Lo)}{Lo} \times 100 \qquad (2)$$

Where λ is the fabric shrinkage percent, Lo is the dimension of the sample before washing and drying; L is the dimension of the sample after washing and drying.

The fabrics and the sewn samples were laundered according to the LSEMA test method 1 which is based on the wash tests in AATCC test method 135, adapted to suit European washing/drying equipment. Laundering was carried out with the following specifications:

- ✓ Washer: home washing machine Miele WS5425;
- ✓ Cycle: normally “colored” cycle;
- ✓ Temperature: 60°C;
- ✓ Detergent: “Dixan” is a non-phosphated washing detergent (Henkel);
- ✓ Drying: in Miele T5206 electronic tumble dryer with humidity control during 15 min at 70°C approximately.

Seam quality analysis

Seam strength was measured according to the international standard ISO 13935-1 (seam rupture using the strip method) on the dynamometer LOYD LRSK 5 KN. The seam efficiency was determined by equation 3:

$$S.eff\,(\%) = \frac{\text{Seam tensile strength}}{\text{Fabric tensile strength}} \times 100 \qquad (3)$$

The seam slippage test was carried out according to the international standard ISO 13936-2. The seam slippage was obtained by measuring the opening of the seam after a wrenching test.

Seam pucker was determined by measuring the difference in fabric and seam thickness under a constant compressive load (2 gf/cm²) [6], [12], with the compression meter of FAST system. The seam thickness strain was calculated using the equation 4:

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

Where: - ts is the seam thickness;
- t is the fabric thickness.

Statistical analysis

In the investigation of the effect of weave type (factor A: F1: twil 3 and F2: plain), seam direction (factor B: warp and weft) and washing/drying cycles (factor C: 0, 1, 2, 3, 4, 5, 10, 15 and 20) on the seam quality, the Analysis of Variance (ANOVA) technique has been used. The significant effect of each factor and interaction is evaluated by the P-value. The P-value is typically compared against an alpha value of 0.001 and 0.05. If the p-value is lower than 0.001, then the factor has a high significant effect and if it is lower than 0.05, the factor has a weak significant effect.

The analysis of variance was carried out for each considered parameter: seam strength, seam efficiency, seam pucker and seam slippage.

In order to predict the seam quality parameters at different levels of factors analysis, a multiple linear regression analysis were conducted. Representing the seam quality parameter “y”, the regression model can be expressed as:

$$y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n-1} \left(\sum_{j=i+1}^{n} \beta_{ij} x_i x_j \right) + \varepsilon \tag{5}$$

Where xi and xj are variables representing factors, βi and βij are regression coefficients that depend on main effects and two-way interaction effects respectively, ε represents error associated with the model.

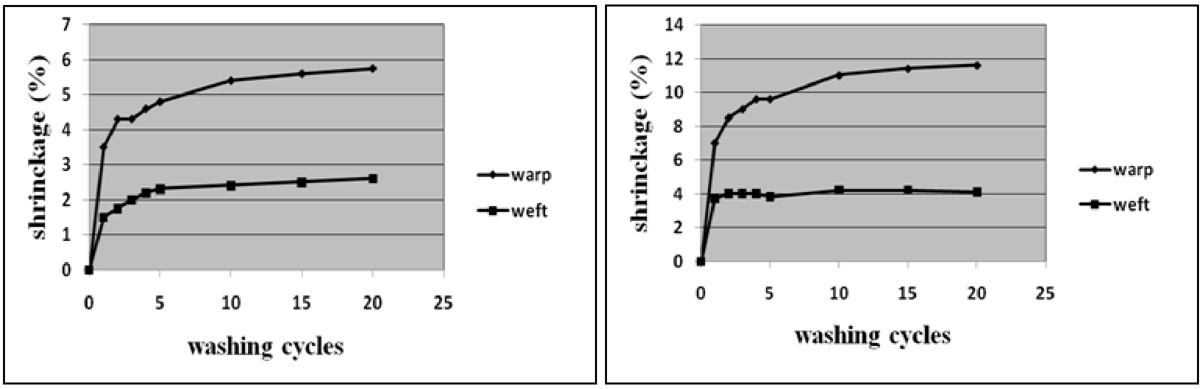
The regression models were validated by the adjusted coefficient of determination, i.e. R^2 value, which ranges between 0 and 1.

RESULTS AND DISCUSSION

Fabric dimensional stability

Dimensional stability refers to a fabric's ability to resist a change in its dimensions. A fabric or garment may exhibit shrinkage, i.e. decrease in one or more dimensions or growth, i.e. increase in dimensions under conditions of refurbishing [11].

Figure 1 (a and b) shows the results of the dimensional stability test of two fabrics during the various washing cycles. According to these graphs, the shrinkage increases from one cycle to another for two fabrics. It is very significant in the first five washing cycles and it tends to be stabilized in the last cycles. The high shrinkage in the warp direction is explained by the stress applied on the warp threads during the sewing and the finishing process of the fabric. Moreover, the cover factor in the weft direction is low, what supports a high slip of the weft yarns after washing and consequently, a stronger gripping of the warp yarns and thus a high shrinkage of warp yarns. The shrinkage is more important for fabric 2 in both directions because it has a lower cover factor.

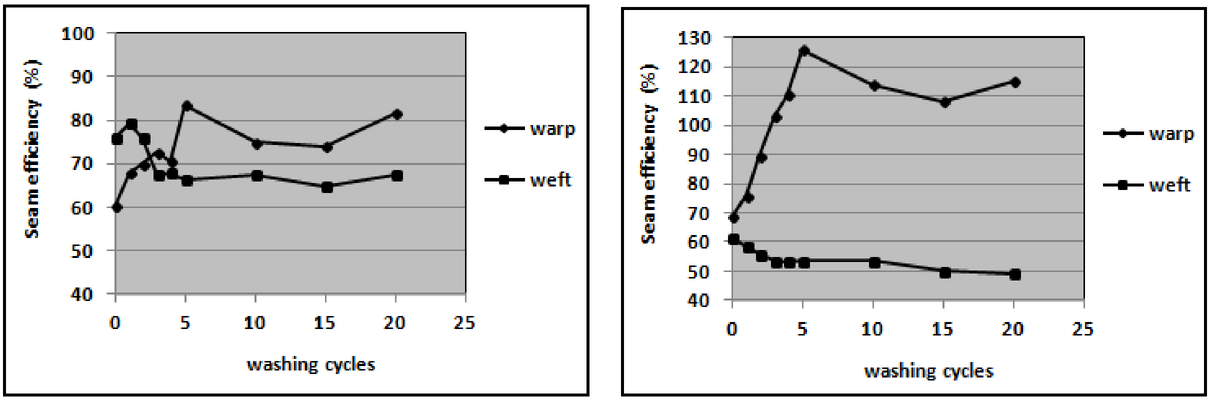


(a) (b)

Figure 1: The dimensional variations of F1 and F2

Seam efficiency

The influence of the washing cycles on the seam efficiency of fabric 1 and fabric 2 in both directions (warp and weft) is presented in figure 2 (a, b). According to these graphs, the seam efficiency is generally improved in the weft direction contrarily in the warp direction for both fabrics. It has a tendency to increase in weft direction and to decrease in the warp direction in the first five washing/drying, but its evolution is more significant for the fabric 2. Thus the seam efficiency has a tendency to be stabilized from the fifth washing cycle. The explanation for this evolution is involved in the parameter definition and, thus, determined by both the seam and fabric strengths.

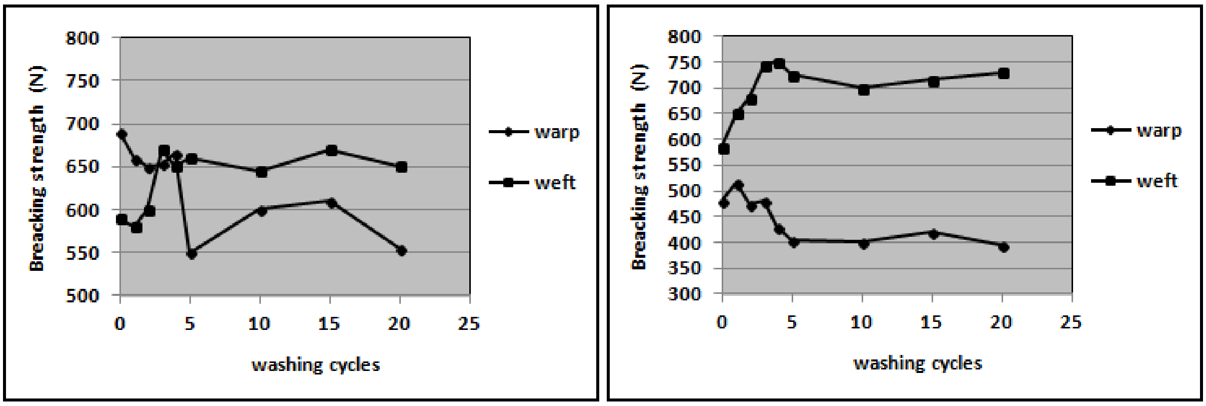


(a) (b)

Figure 2: Influence of the washing cycles on the seam efficiency of F1 and F2

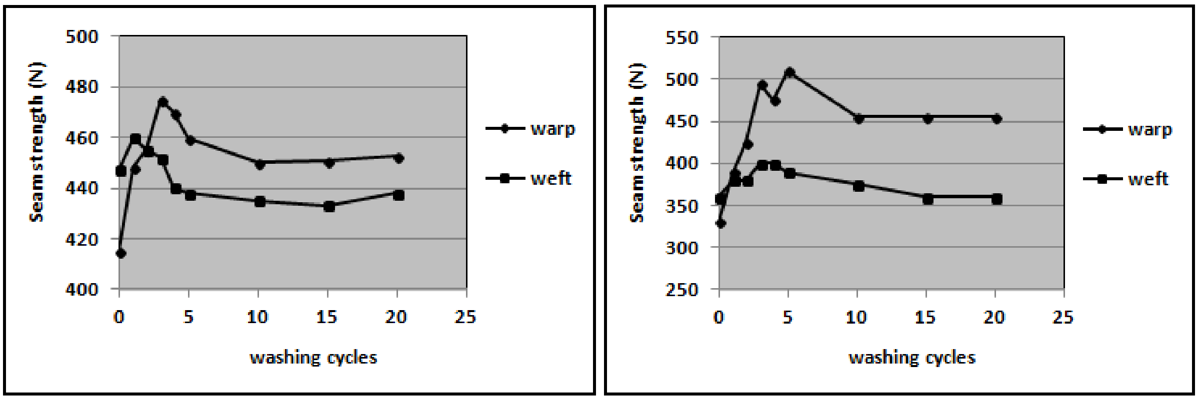
It can be observed on figures 3 (a, b), that the fabric strength has a tendency to increase in the weft direction and to decrease in the warp direction before to be stabilized from the fifth washing cycle. The great shrinkage of fabrics in the warp direction causes the gripping of fabrics in the weft direction and therefore the increase of the fabric strength in this direction. Thus, the washing and drying process create an abrasion phenomenon inter-yarns and generates the progressive elimination of the adhesive residues of the warp yarns, which causes a certain degradation of their properties and thus the decrease of the fabric strength in the warp direction. The great variations of the fabric strength are distinguished in the first five washing cycles because the dimensional variations are accentuated in these cycles. After the fifth washing cycle, the fabric strength tends to be stabilized.

It can be seen from figure 4 (a, b) that the seam strength has a tendency to increase in the first washing cycles and to be stabilized from the third or the fifth washing cycle. The great dimensional variations in the first washing cycles cause an increase of the stitch density and consequently an increase in seam strength.
The stabilization of the dimensional variations in the last washing cycles causes the stabilization of the fabric structure and thus the seam strength. The seam strength in the warp direction is more important that in the weft direction, this is explained by the great fabric strength in the weft direction which is perpendicular to the seam and the stress direction.



(a) (b)

Figure 3: Influence of the washing cycles on the breaking strength of F1 and F2

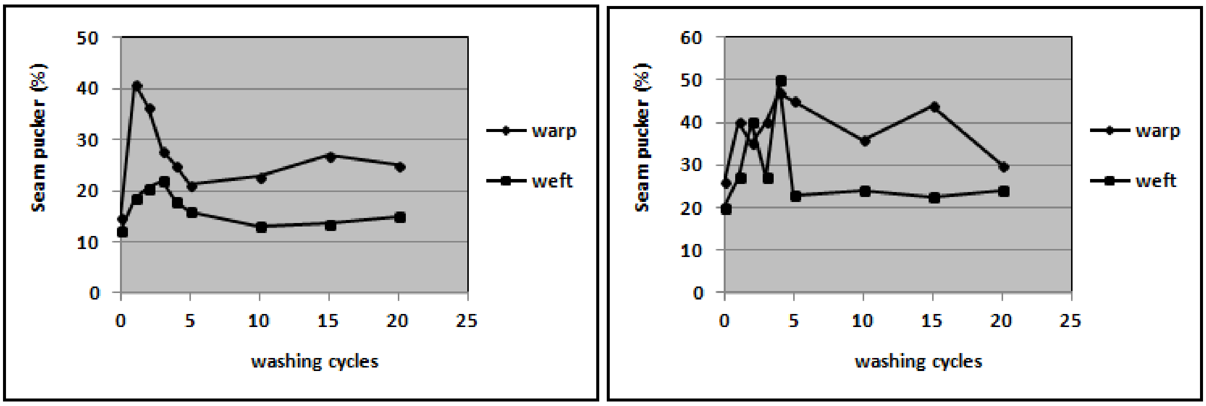


(a) (b)

Figure 4: Influence of the washing cycles on the seam strength of F1 and F2

Seam pucker

The results of investigation the seam pucker show on figure 5 (a, b). Generally, the seam pucker increase after washing/drying cycles. It has a tendency to increase in the first (after 1 or 4) washing cycles and to decrease until becomes stable itself after the fifth washing cycle. This is valid for the two fabrics in both directions. The seam pucker is accentuated by the fabric shrinkage in both directions. After washing the fabric contracting causes a jamming of the yarns fabric and increases the disruption along the seam line, which generates an increase in the seam thickness and thus the seam pucker.
The seam pucker can be explained by the differential shrinkage between the fabric and the thread. The tendency of stabilization of pucker can be justified by the stabilization of the fabrics dimensional variations in the last washing cycles. Also, for both fabrics the seam pucker is more important in the warp direction than in the weft one, this is can be explained by the important shrinkage in the warp direction.

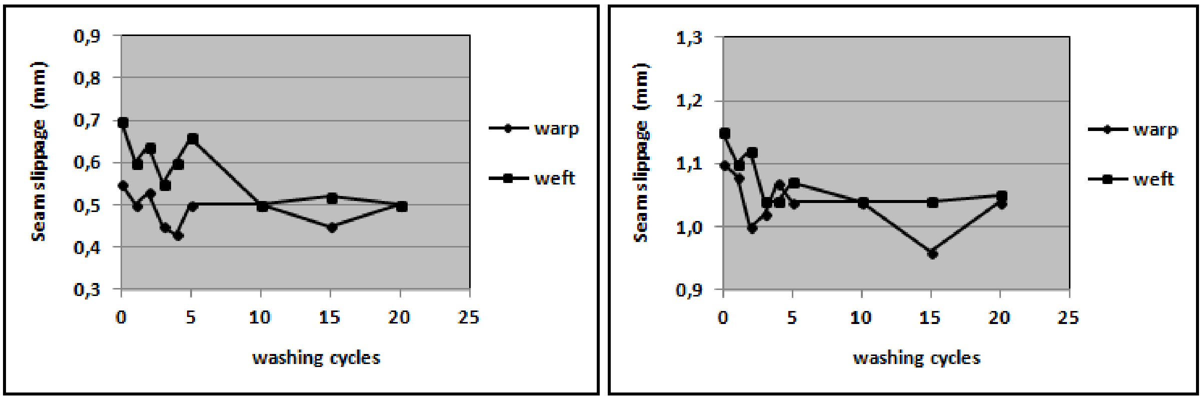


(a) (b)

Figure 5: Influence of the washing cycles on the seam pucker of F1 and F2

Seam slippage

Figures 6 (a, b) shows the observed trends during 20 washing/drying cycles. According to these figures, the seam slippage decreases in both directions for the two fabrics. This variation is noted in the first washing cycles, after the fifth washing cycle the seam slippage has a tendency to be stabilized. This is due to the relaxation shrinkage taking place during washing, which results in a stronger gripping of fabric yarns providing high frictional resistance during the tensile loading of the seam and hence less slippage. Also, the dimensional variations cause an increase of the stitch density and this result in a less seam slippage.



(a) (b)

Figure 6: Influence of the washing cycles on the seam slippage of F1 and F2

ANOVA analysis

According to ANOVA table, the weave type and the seam direction produce the highly significant effect on seam strength, seam slippage and seam pucker but the most significant factor on seam efficiency is the seam direction. The washing/drying has a weak significant effect ($p<0.05$) on the all seam quality parameters. The weave type has also a weak significant effect on seam efficiency.

The interactions between factors have a non significant effect on the seam quality parameters, except interaction between weave type and seam direction. The effect of weave type on seam efficiency varied in function of seam direction. Indeed, their interaction has a weak significant effect on seam strength and seam slippage. The interaction between washing/drying and seam direction has a weak significant effect on seam slippage.

Multiple Regression Models

A series of regression models combining different parameters were analyzed. In the first step, the models with square and interactions have been selected. After examining the highest adjusted R^2, the models are reduced by elimination terms with no significant on the responses. The final multiple regression models of seam quality parameters were listed in Table IV. Both model in this table exhibited higher adjusted R^2 (between 0.605 and 0.979), meaning that a higher correlation existing between the experimental and predicted values and these regression equations could best predict the seam quality parameters.

Table IV: Regression equations obtained by Analyze Response Surface Design

Dependent variable	Independent variable	Coefficient	P-value	Adjusted R^2	R
Seam strength	(constant)	305.298	0.000	0.605	0.827
	A	36.352	0.001		
	B	37.579	0.247		
	C	95.958	0.005		
	A^2	-2.395	0.003		
	A*B	2.592	0.442		
	A*C	-10.192	0.005		
	B*C	-53.778	0.004		
Seam efficiency	(constant)	115.158	0.000	0.851	0.938
	A	-0.820	0.592		
	B	-36.938	0.000		
	C	-31.035	0.000		
	A^2	-0.279	0.015		
	A*B	1.221	0.018		
	A*C	1.762	0.001		
	B*C	22.500	0.000		
Seam slippage	(constant)	-0.168	0.060	0.979	0.991
	A	-0.021	0.172		
	B	0.596	0.000		
	C	0.202	0.000		
	A^2	0.002	0.098		
	A*B	0.003	0.549		
	A*C	-0.009	0.085		
	B*C	-0.062	0.022		
Seam pucker	(constant)	15.738	0.008	0.608	0.807
	A	5.419	0.008		
	B	11.677	0.000		
	C	-9.933	0.000		
	A^2	-0.566	0.005		

CONCLUSIONS

The results which have been presented clearly show that the influence of washing/drying cycles on the seam quality parameters is very complex. Based on the results, it can be conclusion that all the parameters analyses are more influenced by weave type and seam direction than washing/drying. Interactions are not significant in this case, except the interaction between weave type and seam direction. The seam quality parameters are relatively varied in the first washing/drying cycle and have a tendency to be stabilized after the fifth washing/drying cycle. Generally, the seam efficiency is improved after washing/drying in weft direction while it is becomes lower in warp direction. In addition, the seam slippage tends to improved in both direction and fabric and the seam pucker is accentuated after washing mainly during the first cycles.

In addition, the ANOVA table has proved that the elaborated mathematical models allow predicting seam quality parameters values with a high adjusted R^2.

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