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Effect of test conditions and structural parameters on surface roughness of weft knitted fabrics

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An objective evaluation method of knitted fabric roughness by using the textile surface tester has been reported. The study has been aimed at investigating the effect of test conditions and structural parameters of knitted fabrics using a full factorial design of experiments and then establishing the relationship among the sample characteristics (fabric structure and yarn count), the test conditions (force applied by the sensor feeler and fabric extension) and the surface roughness parameters (average roughness, absolute roughness, total roughness and standard deviation) using the analysis of variance (ANOVA). Finally, the results are compared with those predicted using a multiple regression models. The experimental results demonstrate that the yarn count, fabric structure, extension, applied force of the sensor and their interactions influence fabric roughness. Finally, some multiple regression models are obtained to predict the surface roughness parameters with good values of adjusted R^2.

Keywords: Cotton, Fabric objective measurement, Fabric surface roughness, Knitted fabric, Regression model, Textile surface tester, Weft knitted fabric

1 Introduction

Fabric hand has been recognized as one of the most important performance attributes of textiles intended for use in apparel. This fabric property is critical to manufacturers, garment designers, and merchandisers in developing and selecting textile materials[1,2]. Many studies have reported that the fabric hand depends on structural properties. Several researchers[3,4] asserted that fabric hand is affected by fibre type. Other investigations affirmed that fabric hand is influenced by yarns properties such as type, production process, count and twist[4,6-9]. It changes also with the weave and knit structure[7,10-12], fabric density[6,10,13-15] and fabric or knitting production process[15,16]. Most of the studies relating to fabric hand with structural properties involved woven fabrics. A few researches investigated the effect of knitting conditions on the hand fabric of knits[10, 12-14, 16-18].

Thus, the more important parameters to objectively evaluate the hand of knitted fabrics are surface properties[17,19,20], such as surface roughness and surface friction coefficient[18]. Standard methods of surface roughness measurement are based on the surface profile evaluation. This profile indicates height variation in selected direction which is used to compute a number of roughness parameters. Objective methods are divided into two groups namely contact or mechanical methods and non-contact methods.

The surface roughness has been traditionally measured by the stylus profiling method, creating a surface profile called the surface height variation trace (SHV)[21,22]. Modern methods are based on the image processing of surface images of fabric[23] or images of properly bend fabric. The surface irregularity of plain textiles has been identified by friction, a contact blade, lateral air flow, a step thickness meter or subjective assessment[21,22,24-29]. Standardized parameters describing roughness of technical surfaces are given in the ISO 4287-1997.

For the objective measurement of the surface roughness of knitted fabrics, a new apparatus called the textile surface tester (TST) was designed and used by Maâtoug *et al*[30]. Maâtoug *et al* .[14] have investigated the effect of construction parameters (yarn count and loop length) and the test conditions (force applied by the sensor, linear slipping speed of the feeler on the fabric and sampling time) on the surface roughness parameters of knitted fabrics. They concluded that the stitch length is the most important parameter influencing sample surface roughness, and the signal

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emitted by the sensor becomes more important by applying more pressure on the sample. This study is limited for jersey knitted structure produced by using a 7 gauge knitting machine and the pretension applied on the sample for fixing it to the plate is not investigated.

The present study is aimed at investigating the effect of variations in knitted fabrics construction (yarn count and fabric structure) and the testing conditions (force applied and extension) on the surface roughness parameters measured by the textile surface tester.

2 Materials and Methods

2.1 Samples

Evaluation of surface roughness attributes is important for all knitted fabric types and it also has a greater importance for clothing fabrics. In this study, two double knits were produced on 24 gauge circular knitting machine to be representative of winter outerwear knits. A series of cotton fabrics was obtained, where the yarn count and the fabric structure were systematically varied. All fabrics were produced with a course length compatible with a commercially acceptable tightness factor of 14.7 (ref. 18). The fabrics were dyed and finished according to a process that is traditionally used by the textile industrialists.

The basic structural parameters of the test knitted fabrics are summarized in Table 1. Before testing, all samples were conditioned for a minimum of a 24 h under standard atmospheric conditions (20° ± 2°C temperature, 65 ± 2 % relative humidity).

2.2 Principle of Measurement

The surface profile of the knitted fabric was evaluated using the textile surface tester[30]. The sample rotates under an inductive sensor of displacement and the fabric relieves animating the sensor feeler in vertical vibrations. These vibrations are transformed to an electric stream which is measured in real time during the test. The sensor feeler has a hemispherical shape with a radius of 1.5 mm to enable it to penetrate partially into the sample cavities. The spring integrated in the sensor core makes it possible to apply force on the fabric to help the feeler to penetrate through the fabric sites.

Table 1—Basic structural parameters of knitted fabrics

Fabric property	Interlock fabric		1×1 rib fabric	
	I1	I2	R1	R2
Yarn count, tex	16.7	14.7	16.7	14.7
Courses / cm	15.7	16	14	13.2
Wales / cm	15	14	17	16.3
Fabric weight, gsm	218	187	177	152
Density, stitch / cm²	235	224	238	215
Thickness, mm	0.847	0.762	0.719	0.662

I1, I2, R1 and R2 are the sample codes.

The signal produced by the sensor is digitized and stored online onto the computer hard disk by using a data acquisition box. This permits the adjustment of sampling time (*T*s) and the number of samples or the run-time of the measurement. To extract the part of the signal which represents the sample's surface roughness, we applied a decomposition process by the Fourier and the wavelet transforms. This decomposition was applied by using specially-developed scripts and functions for the wavelet transform and the Fast Fourier Transform (FFT)[31]. The Matlab statistical toolbox was applied to the data measured in order to determine the surface roughness parameters.

2.3 Experimental Design

Interlock (I1 and I2) and rib (R1 and R2) knitted fabrics were evaluated using the surface textile tester (TST). For each test, four specimens were cut off on the centre of the knitted fabrics, and the average of each measurement was calculated.

Circular samples having a radius of 15 cm were used for all measurements. The measurement of fabric surface roughness by the textile surface tester has to go through three fundamental stages viz the preparation of the sample, measurement on the test bench and signal treatment to extract useful information. After cutting the sample, we traced a circle in its centre having a diameter (24, 23.5, 23 and 22.5cm) which corresponds to the desired extension. Four levels of extension were applied in order to give a pretension in the sample during their fixing to the plate.

Before beginning the test, the sampling time (Ts = 20 ms), the applied force on the fabric and the radius of the feeler trajectory (r = 11 cm) on the fabric must be fixed. The force (F) applied by the sensor on the samples takes 4 levels by fixing the turns of the crank at the corresponding number. It was calculated by the following equation:

$$F = 0.394n + 0.449 \quad \ldots (1)$$
$$R^2 = 0.995$$

where n is the number of crank turn.

In this study, the combination of the four factors [fabric structure (S), yarn count (C), extension (E) and applied force (F)] was arranged according to general full factorial set and thus gives 64 tests[32]. The data results were experimentally analyzed in order to quantify the effects of the above described factors. The factors and their levels are illustrated in Table 2.

2.4 Roughness Parameters Analysis

The test bench generates a profile containing peaks and valleys from which we extract parameters by using a statistical calculation according to the standard ISO 4287-1997. Surface roughness can be evaluated using various parameters but in this study the most used ones have been selected. Four surface roughness parameters were determined using the following formulas:

(i) The average roughness (*Rp*) represents the average of the amplitude

$$Rp\ (\text{mm}) = \frac{1}{L}\int_0^L y\, dx^2 \quad \dots (2)$$

(ii) The absolute roughness (*Ra*) represents the deviation of the profile compared to the average (*R*p)

$$Ra\ (\text{mm}) = \frac{1}{L}\int_0^L |y - Rp|\, dx \quad \dots (3)$$

(iii) The total roughness (*Rt*) represents the difference between the maximum and the minimum of the profile

$$Rt\ (\text{mm}) = y_{max} - y_{min} \quad \dots (4)$$

(iv) The standard deviation (*σ*) evaluates the difference between the maximum or minimum peak and the average of the roughness (*R*p)

$$\sigma = \left[\frac{1}{L}\int_0^L |y - Rp|^2\, dx\right]^2 \quad \dots (5)$$

2.5 Statistical Analysis

The data obtained from tests were evaluated by the software for statistical data analysis MiniTab16. First, the analysis of variance (ANOVA) was applied to evaluate the significance of each factor and interaction. The effect of each parameter or interaction and their significance were determined by the p-value and the percentage of contribution (PC %). When p-value is less than 0.05 (or 95 % confidence level), the parameter is statistically significant. The percentage of contribution was calculated by dividing each sequential sum of squares (SeqSS) by the total sequential sum of squares and multiplying by 100. To investigate the influence of each factor and interaction on the surface roughness parameters, plots of main effects and interactions were constructed. After this step, regression analyses were performed by multiple linear models to predict the surface roughness parameters. The functional relationship between dependent output parameters and the independent variables under investigation are postulated by using the following equation[33]:

$$y = \beta_0 + \sum_{i=1}^{n} \beta_i x_i + \sum_{i=1}^{n-1}\left(\sum_{j=i+1}^{n} \beta_{ij} x_i x_j\right) + \varepsilon \quad \dots (6)$$

where x_i and x_j are the variables representing factors; β_i and β_{ij}, the regression coefficients that depend on main effects and two-way interaction effects respectively; and ε, the error associated with the model. To select the best models, the adjusted coefficient of multiple correlations R^2_{adj} was studied.

3 Results and Discussion

3.1 Analysis of Variance

Tables 3-6 show the experimental results and the analysis of variance of the surface roughness parameters (*R*p, *R*a, *R*t and *σ*). The analyses of the main effects and interactions show that the most significant factor on *R*p is applied force with contribution of 90.3 % and the interaction between yarn count and fabric structure has a significant effect

Table 2—Factors and levels used in full factorial set

Factor level	Fabric structure (*S*)	Yarn count (*C*) tex	Extension (*E*), %	Applied force (*F*), N
1	Interlock	14.17	4	0.64
2	1×1 Rib	16.66	6	0.74
3	-	-	8	0.84
4	-	-	10	0.94

Table 3—Analysis of variance (ANOVA) for average roughness (*R*p)

Source	DF	SeqSS	*F*	*P*	PC %
Main effects					
Extension (*E*)	3	0.013	0.56	0.642	0.03
Yarn count (*C*)	1	3.97	529	0.000	8.26
Fabric structure (*S*)	1	0.109	14.5	0.001	0.23
Applied force (*F*)	3	43.9	1929	0.000	90.3
Two-way interactions					
E × *C*	3	0.031	1.37	0.269	0.06
E × *S*	3	0.094	4.19	0.013	0.20
E × *F*	9	0.076	1.13	0.367	0.16
C × *S*	1	0.104	13.8	0.001	0.22
C × *F*	3	0.0006	0.03	0.994	0.00
S × *F*	3	0.0307	1.36	0.271	0.06
Error	33	0.247	-	-	0.52
Total	63	48.1	-	-	100

Table 4—Analysis of variance (ANOVA) for absolute roughness (*R*a)

Source	DF	SeqSS	*F*	*P*	PC %
Main effects					
Extension (*E*)	3	1E-07	0.14	0.937	0.29
Yarn count (*C*)	1	2E-07	1.16	0.289	0.58
Fabric structure (*S*)	1	26E-07	7.46	0.010	7.64
Applied force (*F*)	3	4E-07	0.57	0.638	1.16
Two-way interactions					
E × *C*	3	12E-07	1.91	0.147	3.48
E × *S*	3	48E-07	6.38	0.002	13.9
E × *F*	9	16E-07	0.84	0.585	4.64
C × *S*	1	212E-07	84.2	0.000	61.6
C × *F*	3	4E-07	0.67	0.579	1.16
S × *F*	3	1E-07	0.17	0.915	0.29
Error	33	18E-07	-	-	5.29
Total	63	345E-07	-	-	100

Table 5—Analysis of variance (ANOVA) for total roughness (*R*t)

Source	DF	SeqSS	*F*	*P*	PC %
Main effects					
Extension (*E*)	3	1.54E-5	0.31	0.819	0.93
Yarn count (*C*)	1	0.31E-5	0.19	0.663	0.19
Fabric structure (*S*)	1	15.2E-5	7.17	0.011	9.22
Applied force (*F*)	3	2.8E-5	0.56	0.647	1.69
Two-way interactions					
E × *C*	3	2.55E-5	0.51	0.677	1.55
E × *S*	3	42.8E-5	5.61	0.003	25.9
E × *F*	9	17E-5	1.14	0.367	10.3
C × *S*	1	59.4E-5	23.82	0.000	36
C × *F*	3	3.47E-5	0.70	0.561	2.11
S × *F*	3	2.93E-5	0.59	0.628	1.78
Error	33	16.9E-5	-	-	10.3
Total	63	165E-5	-	-	100

Table 6—Analysis of variance (ANOVA) for standard deviation (σ)

Source	DF	SeqSS	*F*	*P*	PC %
Main effects					
Extension (*E*)	3	0.3E-6	0.27	0.834	0.58
Yarn count (*C*)	1	0.4E-6	1.34	0.255	0.78
Fabric structure (*S*)	1	2.7E-6	8.7	0.006	5.25
Applied force (*F*)	3	0.45E-6	0.58	0.630	0.87
Two-way interactions					
E × *C*	3	1.29E-6	1.39	0.263	2.51
E × *S*	3	7.85E-6	6.28	0.002	15.3
E × *F*	9	2.7E-6	0.95	0.496	5.25
C × *S*	1	31E-6	85.3	0.000	60.3
C × *F*	3	0.8E-6	0.86	0.470	1.56
S × *F*	3	0.3E-6	0.32	0.814	0.58
Error	33	3.61E-6	-	-	7.04
Total	63	514E-07	-	-	100

on the absolute roughness (*R*a), total roughness (*R*t) and standard deviation (σ), with respective contribution of 61.6, 36 and 60.3 %. Likewise, yarn count, fabric structure and its interaction with yarn count or extension have significant effects on *R*p (significant at $\alpha = 0.01$ level) with a few percentage of contribution (PC=8.26, 0.23, 0.22 and 0.2 %). The next largest contribution on *R*a, *R*t and σ (significant at $\alpha = 0.05$ level) comes from the fabric structure (PC = 7.64, 9.22, and 5.25 %) and the interaction *E* × *S* with contribution of 13.9, 25.9 and 15.28 % respectively. Based on these results, extension has no significant effect on the surface roughness parameters but its effect is dependent of surface structure. There is a non-significant interaction among all the factors.

3.2 Analysis of Main Effects and Interactions

The main effects of various levels of factors when they change from the lower to higher value can be visualized in the Figs 1 (a), (b), (c) and (d). Figure 1 (a) shows that the applied force (*F*) by the sensor feeler on the sample has an important and increasing effect on *R*p. Indeed, when the force applied increases, the sensor feeler penetrates more in the cavities of surface sample. In contrast, it has a non significant effect on *R*a, *R*t and σ. They increase when the applied force increases to 0.74 N and tend to decrease in the two other factors. This result is in contradiction with that obtained by Maâtoug *et al*[14]. They reported that the applied force by the sensor feeler has an important and increasing effect on surface roughness parameters (*R*a, *R*t and σ) of single jersey.

Extension does not also produce consistent effect on all the surface roughness parameters but its effect depends on the fabric structure. The surface roughness tends to increase in the first three extension values and then decrease in 10 % of extension, except for the average roughness. The yarn count has a weak effect on surface roughness parameters. They decrease when the yarn count increases. This result is found similar to the one obtained by Maâtoug *et al*[14].

On the other hand, fabric structure has an important effect on *R*a, *R*t and σ; 1×1 rib is more rougher than interlock. Rib knits have a very high degree of elasticity in the crosswise direction than the other knit structure because of the relief intensities of its surface. On the other side, Interlock is a balanced, smooth, stable structure that lies flat without curling.

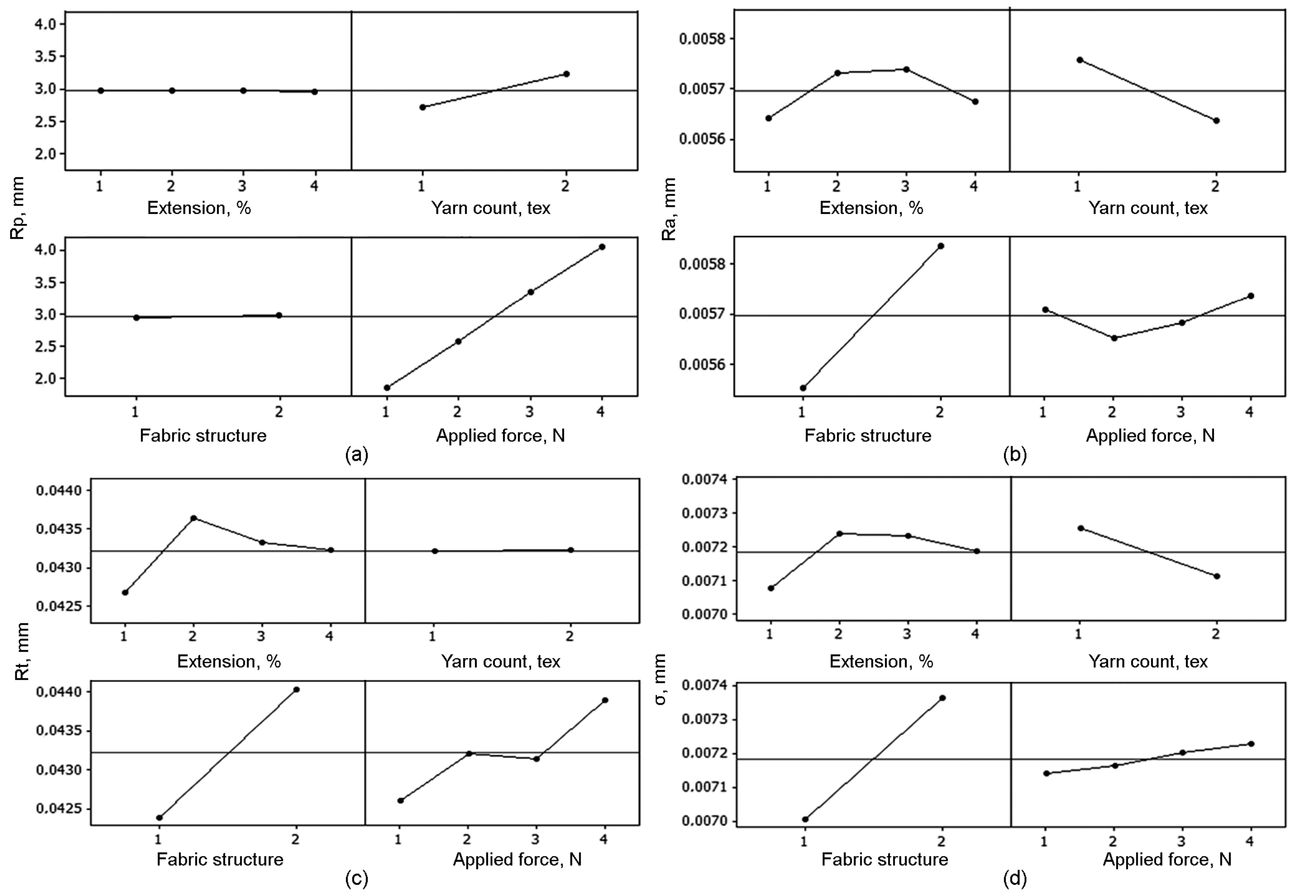

Fig. 1—Main effects plot (a) average roughness *R*p, (b) absolute roughness *R*a, (c) total roughness and (d) standard deviation σ

Based on the ANOVA model, the surface roughness parameters are significantly influenced by the interaction between fabric structure and extension or yarn count. Figures 2 (a), (b), (c) and (d) and Figures 3 (a), (b), (c) and (d) illustrate the evolution of surface roughness parameters as a function of the variation in yarn count and fabric structure. Figure 2 (a) shows that the effect of interaction between fabric structure and yarn count has a weak effect on average roughness (*R*p). The value of *R*p increases when the yarn count increases for both fabric structures. This result is not suitable for the other surface roughness parameters. The effect of yarn count is varying according to the fabric structure. In case of interlock, the absolute roughness (*R*p), total roughness (*R*t) and standard deviation (σ) tend to increase when the yarn count increases. In contrast, they decrease when the yarn count, used to produce the 1×1 rib, increases.

The extension carried on the knitted fabrics has an important effect on the surface roughness parameters when the type of knit is varied. Figures 3 (a), (b), (c) and (d) show the increase in surface roughness parameters with increasing of extension applied on the 1×1 rib fabric. On the other side, the interlock fabric becomes smoother when the extension increases.

3.3 Regression Analysis

The main objective is to select a suitable form of regression models and predict surface roughness parameters with a minimum number of parameters to make a practical approach. The regression models are determined based on the results obtained from ANOVA tables and after examining the highest adjusted R^2. In the first step, the models with all interactions have been selected. In the case of insignificant interaction, the reduced models have been applied. The final linear models of responses equations are presented below:

$$Rp\ (\mathrm{mm}) = 0.242 + 0.0017 \times E + 0.498 \times C + 0.0824 \times S + 0.736 \times F \quad \ldots (7)$$

$R^2 = 98.7\ \%$, $R^2_{adj} = 98.6\ \%$

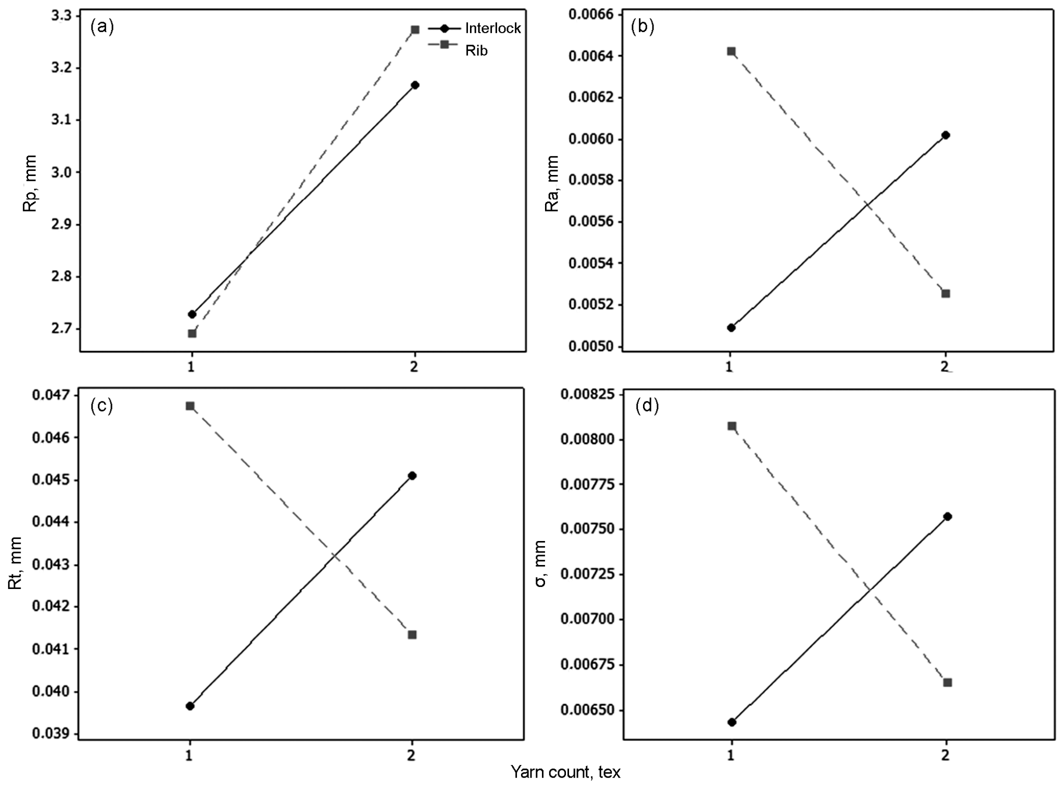

Fig. 2—Surface roughness parameters as a function of fabric structure and yarn count

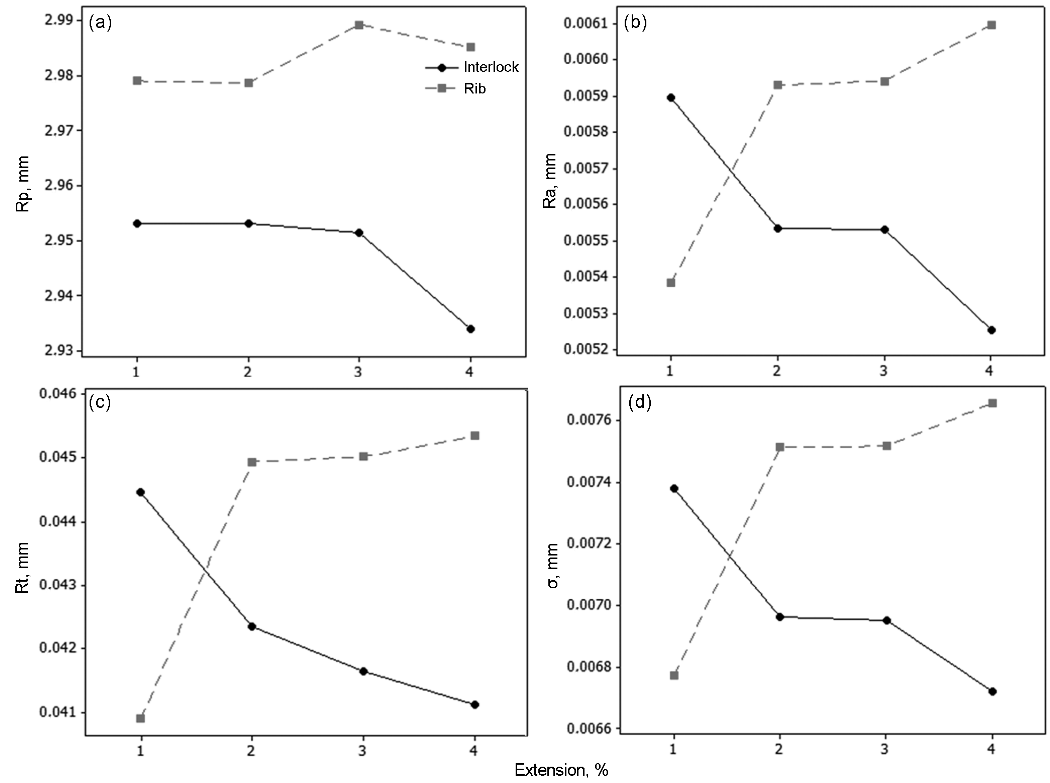

Fig. 3—Surface roughness parameters as a function of fabric structure and extension

$$Ra\ (\mathrm{mm}) = 2.23\text{E-}03 + 5.83\text{E-}04 \times E + 3.04\text{E-}03 \times C + 2.49\text{E-}03 \times S + 4.61\text{E-}05 \times F + 3.97\text{E-}04 \times E * S + 2.11\text{E-}03 \times C * S \quad \ldots (8)$$

$R^2 = 85.65\ \%$, $R^2_{adj} = 83.14\ \%$

$$Rt\ (\mathrm{mm}) = 0.023 + 1.57\text{E-}03 \times E + 0.015 \times C + 0.015 \times S - 3.21\text{E-}04 \times F + 1.26\text{E-}03 \times E * S - 9.95\text{E-}03 \times C * S \quad \ldots (9)$$

$R^2 = 74.36\ \%$, $R^2_{adj} = 72.45\ \%$

$$\sigma\ (\mathrm{mm}) = 2.77\text{E-}03 - 6.34\text{E-}04 \times E + 3.69\text{E-}03 \times C + 3.15\text{E-}03 \times S - 6.20\text{E-}05 \times F + 4.45\text{E-}04 \times E * S - 2.57\text{E-}03 \times C * S \quad \ldots (10)$$

$R^2 = 85.92\ \%$, $R^2_{adj} = 82.33\ \%$

The regression equation of average roughness is very interesting, and shows a high correlation (98.6 %) between the experimental and the predicted values. On the other hand, the other multiple regression models obtained can estimate better the absolute roughness, the total roughness and the standard deviation with adjusted R^2 between 72 % and 83 %.

4 Conclusion

It has been observed that yarn count, fabric structure, extension, applied force of the sensor and their interactions influence fabric roughness. The applied force of the sensor significantly influence the average roughness but the absolute roughness, the total roughness and standard deviation are clearly affected by the fabric structure and their interaction with the fabric extension or the yarn count used. The experimental results show that the absolute roughness (*R*p), total roughness (*R*t) and standard deviation (σ) have generally the same variation. *R*p, *R*t and σ of interlock fabric tend to increase when the yarn count is increased. In contrast, they decrease when the yarn count increases for the product 1×1 rib. The extension carried on the knitted fabrics has an important effect on the surface roughness parameters when the type of knit is varied. The surface roughness parameters become greater when the extension applied on the 1×1 rib fabric increases. On the other side, the interlock fabric becomes smooth when the extension increases.

Multiple regression analysis has also been applied to find out suitable equations which could best describe or predict the surface roughness parameters. In this study, only the significant factors or interactions are considered. The obtained values of adjusted R^2 show that the mathematical model could well estimate the surface roughness parameters.

References

1 Pan N & Yen K C, *Text Res J*, 62 (1992) 279.
2 Pan N, Zeronian S H & Ryu H S, *Text Res J*, 63 (1993) 33.
3 Winakor G & Kim C J, *Text Res J*, 50 (1980) 601.
4 Mackay C, Anand S C & Bishop D P, *Text Res J*, 69(4) (1999) 252.
5 Chattopadhyay R & Banerjee S, *J Text Inst*, 87(1) (1996) 59.
6 Sahnoun M, *Caractérisation et modélisation de l'influence des paramètres de structure des étoffes sur l'évaluation mécanique et sensorielle de leur toucher*, Ph.D. thesis, Université de Mulhouse, France, 2002
7 Behery M H, *Effect of Mechanical and Physical Properties on Fabric Hand* (Woodhead Publishing in Textiles), 2005.
8 Ben Said S, Schacher L & Adolphe D C, *Proceedings, 2nd International Conference on Applied Research to Textiles*, (CIRAT, Monastir), 2006.
9 Behera B K, *Autex Res J*, 7(1) (2007).
10 Choi M S & Ashdown S P, *Text Res J*, 70(12) (2000) 1033.
11 Ben Said S, *Contribution à l'Evaluation par Analyse Sensorielle du Toucher des Etoffes, Influence des Paramètres de Structure, Interaction Vue/Toucher*, Ph.D. thesis, Université de Mulhouse, France, 2007.
12 El-Ghezal Jeguirim S, Babay Dhouib A, Sahnoun M, Cheikhrouhou M, Schacher L & Adolphe D, *J Tekstil*, 59 (4) (2010) 122.
13 Maâtoug N, Sahnoun M & Sakli F, *J Appl Sci Res*, 7(3) (2011) 260.
14 Maâtoug N, Sahnoun M & Sakli F, *J Eng Fibers Fabrics*, 7(4) (2012).
15 Romdhani Z, Hamdaoui M, Baffoun A, Maâtoug N & Roudesli S, *Res J Text Apparel*, 17(2)(2013).
16 El-Ghezal Jeguirim S, Sahnoun M, Babay Dhouib A, Cheikhrouhou M, Njeugna N, Schacher L & Adolphe D, *J Sensory Studies*, 25(2) (2009) 201.
17 Finnimore E, *Proceedings, 3rd Japan-Australia Symposium on Objective Measurement: Applications to Product Design and Process Control* (The Textile Machinery Society of Japan, Osaka), 1985, 45.
18 Chen P L, Barker R L, Smith G W & Scruggs B, *Text Res J*, 8(4) (1992) 200.
19 Kawabata S, *Proceedings, The first-Japan Australia Symposium on Objective Specification of Fabric Quality : Mechanical Properties and Performance*, Kyoto, Japan, 1982, 3.
20 Bishop D P, *Text Prog*, 26(3) (1996) 1.
21 Kawabata S, *Hand Evaluation and Standardization Committee* (Text Mach Soc, Osaka), 1980.
22 Greenwood J A, *Proc Royol Soc London*, A393 (1984) 33.
23 Zhang C & Gopalakrishnan S, *Int J Mach*, 36 (1996) 1137.
24 Stockbridge H C W, Kenchington K W L, Conkindale K G & Greenland J, *J Text Inst*, 48 (1957) 26.
25 Ajayi J O, *Text Res J*, 64 (1994) 475.
26 Militký J & Mazal M, *Int J Clothing Sci Technol*, 19 (2007)186.
27 Bueno M A, Lamy B & Renner M, *Wear*, 253 (2002) 448.

28 Bueno M A, Durand B & Renner M, *Experimental Techniques*, 24(2) (2000) 23.

29 Fontaine S, Marsiquet C, Nicoletti N, Renner M & Bueno M A, *Sensors Actuators A*, 120 (2005) 507.

30 Maâtoug N, Sahnoun M & Sakli F, *Proceedings, 3rd International Conference of Applied Research in Textile,* (CIRAT, Sousse, Tunisia), 2008.

31 Maâtoug,N, Sahnoun M & Sakli F, *Res J Text Apparel*, 15(4) (2011)44.

32 Fisher R, *The Design of Experiments*, 1st edn (Oliver and Boyd, London), 1935.

33 Rawlings J O, Pantula S G & Dickey D A, *Appl Regression Analysis: A Research Tool* (Springer, New York), 1988.