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EVALUATION OF SEAM QUALITY RESISTANCE USING THE FUZZY THEORY

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ABSTRACT

This study deals with prediction of seam quality resistance. Twelve denim fabrics, having different compositions and masses are sewn with three commercial sewing threads having different linear densities. The statistical analysis steps are implemented using Fuzzy modelling method, thanks to MATLAB-17 software. Based on obtained results, Fuzzy-modelling method can widely predict both seam efficiency and seam slippage of sewing denim fabrics. By comparing four models, findings obtained revealed that Fuzzy model is verified widely based on tested database and particularly when a triangular membership function was applied. In addition, the evaluation of the impacts of overall studied input parameters such as fabric properties, sewing thread linear densities and sewing conditions on seam quality of denim fabrics are investigated and discussed deeply. According to results, it may be concluded that increasing sewing thread linear density and decreasing stitch length are recommended enormously to industrials to improve their sewing quality performance of sewed fabrics.

KEYWORDS

Fuzzy logic analysis; Seam slippage; Seam efficiency; Fabric properties; seam thread linear density; stitch length.

1. INTRODUCTION

The global quality of seamed garments depends on their strength, elasticity, durability, stability, and appearance. The seam characteristics parameters are seam strength, seam pucker, seam stiffness, seam appearance, and seam efficiency (Dobilaite, Juciene, 2006). According to many researchers, there are various factors affecting the seam quality. These include sewing thread, sewing condition, and others (Tarafder et al., 2007).

In fact, prediction of seam performance based on fabric properties and sewing parameters have been considered by many researchers. The fabric quality influences not only the quality of the garment but also the ease with which a shell structure can be produced out with flat fabric. The specifications of fabrics for apparel manufacturing can be considered in terms of primary and secondary quality characteristics. The primary quality characteristics are the static physical dimensions and secondary characteristics are the reactions of the fabric to an applied dynamic force. The apparel manufacturer is usually interested in the quality characteristics of the fabric and focuses on the seam quality during the production of apparel (Carr, Latham, 1995; Behera et al., 2000).
Mukhopadhyay et al. studies showed that seam appearance and performance depend on the interrelationship of fabrics, threads, the stitch and seam selection, and sewing conditions (Mukhopadhyay et al., 2004). Other previous studies showed that seam appearance and performance depend on the interrelationship of fabrics, threads, stitch and seam selection, and sewing conditions, which include the needle size, stitch density, the appropriate operation and maintenance of the sewing machines etc. (Behera et al., 2000; Mukhopadhyay et al., 2004; Malek et al., 2016 and JEBALI et al., 2016). Selection of sewing thread and sewing condition for a particular type of material is an integral part of producing a good seam quality (Thanaa, 2013). According to Choudhary and Amit, the size of the sewing thread is the most crucial for the stability of apparel seam, thus the improper

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use of sewing thread size affects directly the apparel seam quality (Choudhary, Amit, 2013). Rengasamy et al. established that sewing thread type has a great influence on seam efficiency (Rengasamy et al., 2003).
In this context, many researchers have considered the seam performance prediction of fabric, based on fabric properties and sewing parameters. Besides, other studies have been conducted to predict seam performance (Germanova & Petrov, 2008; Fan & Leeuwner, 1998; Chi & Sau, 2009; Thanaa, 2013). John and Steven (John and Steven, 2010) have developed a system to give advanced warnings about the sewability of tissues based on their Kawabata characteristics. Furthermore, Rostam et al (Rostam, Saeed, Sayed & Albert., 2014) suggest that the slippage of the seam and the strength of the elastic fabrics can be well interpreted from the point of view of the tensile properties of the fabric. All studies focus on the fabric mechanical characteristics. However, in the industrial level, it's preferable to focus on the sewing parameter and the most common fabric properties for the manufacturer. In this context, the study of Jebali (Jebali, Babay & Ben Hassen, 2016) attempts to evaluate the effect of the input factors (stitch type, stitch density and sewing thread) based on statistical model. A multiple linear regressions have been developed, in this context, using the experimental results of Taguchi design to predict the overall seam quality. Nevertheless, this work was limited only for two cotton weaves. Moreover, our earlier works dealt with prediction of seam quality based on multiple linear regression models (Malek et al, 2016; Malek et al, 2017).
Undoubtedly, several studies are conducted using another method that is Fuzzy approach. This method is investigated to evaluate and predict textile structure properties. In fact, several advantages make Fuzzy logic theory among the tools of forecast which are most used by researchers (Altinoz, Winchester, 2001; Jaouachi et al., 2010). Indeed, Altinoz suggested that Fuzzy logic is an enabling technology that can be used to capture expertise and compute using linguistic rules for supplier selection (Altinoz, Winchester, 2001). Notwithstanding, this approach is not conducted to evaluate sewing performance.

The present work tackles the prediction of seam quality by studying the input parameters which are fabric mass, sewing threads and stitch length in both warp and weft directions. Moreover, their effects on denim fabrics seam performance are considered. The seam quality is judged as the seam efficiency and the seam slippage. Thanks to MATLAB-17 software, Fuzzy modelling method is well applied, and the prediction of seam performance is investigated, discussed and evaluated.

2. MATERIALS AND METHODS

2.1. Seam thread

Three kinds of commercial sewing threads commonly used for sewing denim fabric are selected. The choice of the sewing thread is based on their linear density that can probably affects the seam quality of clothing. Table 1 presents the sewing threads properties.

Table 1: Seam threads properties

Thread	N° 1	N° 2	N° 3
Linear density (tex)	50.20	63.50	95.00
Number of twisted thread	3	3	3
Blend composition	100% PES	100% PES	100% PES
Direction of twist	S	S	S
Breaking strength (N)	14.26	24.23	26.43
Breaking elongation (%)	16.16	21.12	16.90
Rigidity (N/m)	301.4	389.12	536.59
Twist/m	411	353	294
Tenacity (cN/tex)	22.82	38.16	27.82

2.2. Fabrics

The fabrics were chosen according to two criteria: composition and mass. In fact, tested fabrics have two blend compositions. Thus, fabrics are classified in two groups;

-Group 1: fabrics having 71%coton, 24% polyester and 5% elastane weft yarns composition and 100% coton yarn composition in the warp direction

-Group 2: fabrics having 95% coton and 5% coton yarn composition in the weft yarns and 100% coton yarn composition in the warp direction

A large range of fabric masses are selected (from 243 g/m² to 430 g/m²). All tested samples were prepared on weaving loom projectile type SULZER P7300 with 3/1 twill structure, having a little difference in warp and weft yarn densities. Table 2 shows the fabric properties.

Table 2: Fabric properties

Composition		Group	N° Fabric	Warp yarn density (ends/cm)	Weft yarn density (picks/cm)	Mass (g/m²)	Thickness (mm)	Breaking Strength (N)	Elongation at break (%)
Warp	Weft								
100% Ct	71% Ct, 24% PES and 5% Ct	1	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
	95% Ct and 5% El	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

Where Ct: Cotton; El: Elastane; PES: Polyester

2.3. Evaluation of the fabric sewability

In this work, sewability of specimens was investigated by measuring seam efficiency and seam slippage. A high-speed industrial lockstitch machine type Brother (Brother, 2002) was used for sewing the samples with the following properties:

- Type of stitch: lockstitch type 301;
- Machine speed: 2000 rounds/minute;
- Needle size: 90 (It is chosen according to NFG 07-117 (NFG 07-117, 1981); if the fabric mass ≥ 200g/m^2, then the needle size will be equal to 90 -110);
- Needle shape : normal rounded;
- Stitch density: three levels are considered, which are 3 stitches/cm, 4 stitches/cm and 5 stitches/cm.

2.3.1. Seam efficiency

This test was performed on a dynamometer. The standard NF EN ISO 13935-1 is used to evaluate the seam efficiency property of the tested denim samples (ISO 13935-1, 2014).The seam efficiency refers to the strength when seam finally ruptures. For each test, elongation at constant speed and distance between grips (equals to 100 mm/min and 200mm +/- 1mm respectively) are adjusted. Figure 1 presents the sample dimensions. The maximum force before the seam breakage is determined. In fact, the rupture may be reached for different causes. For appropriate results, only the seam break that occurs by breaking seam thread was considered

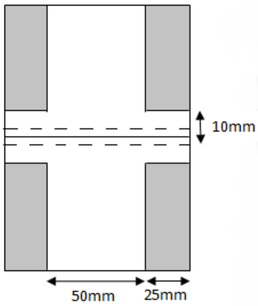


Figure 1: The specimen form

Seam efficiency is calculated as the ratio between seam strength by fabric strength using the following Equation 1.

$$\text{Seam efficiency } (\%) = \frac{\text{seam tensile dtrength}}{\text{fabric tensile strength}} * 100 \quad (1)$$

2.3.2. Seam slippage

The applied standard is NF EN ISO 13936-1 (NF EN ISO 13936-1, 2004). A tensile tester, type LLYOD instrument, is used. Once the test is completed, we immediately measure the unstitching of seam at the widest point (seam opening), as shown in Figure 2.


Figure 2: Seam opening

According to Rajkishore, the force at which the load-elongation curves of the fabric with the seam is a predetermined distance greater than the load elongation of the fabric without a seam. The distances difference is reported as yarn slippage strength (Rajkishore et al., 2010). Consequently, the method applied by Rajkishore is considered in this study and the seam slippage is calculated based on Equation 2.

Seam slippage = elongation at break of the seam – elongation at break of the fabric (mm) (2)

2.4. Fuzzy logic memberships and rules

Fuzzy logic method is conducted to determine the best membership function fitting the seam performance behavior. Indeed, Triangular, Trapezoidal, Gaussian and Gaussian combination membership functions are used and investigated to evaluate and predict the seam quality. The possible Fuzzy rules of seam behavior are obtained according to our experimental database and expert's judgments. Indeed, the implemented rules are trained for developed Fuzzy model using each Fuzzy membership previously involved. Figure 3 shows the basic structure of the Fuzzy logic model, which includes fuzzification, Fuzzy inference, Fuzzy rule base and defuzzification (Jaouachi et al., 2010). Usually, the Fuzzy logic method is based on four essential steps:

- Fuzzification consists to convert the feature values of input and output parameters.
- Design of the Fuzzy rules to implement the model for prediction
- Deduction of Fuzzified values to provide decisions by the inference engine with the support of the Fuzzy rule base.
- Selection by defuzzification converts Fuzzy sets into a crisp value.

There are five built-in methods supported: centroid (used on our study), bisector, medium-maximum (the average of the maximum value of the output set), high-maximum and low-maximum (Jaouachi et al., 2010).

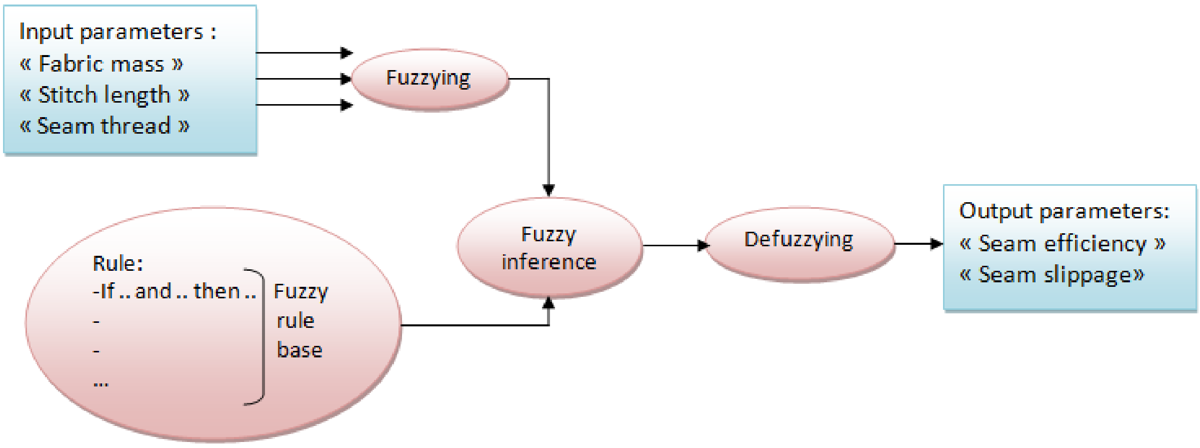


Figure 3: Basic structure of developed Fuzzy model

In our work, Triangular, Trapezoidal, Gaussian and Gaussian combination membership functions are used to evaluate and predict seam quality quantitatively. Figure 4 shows an example of tested membership functions of "fabric mass" input parameter.

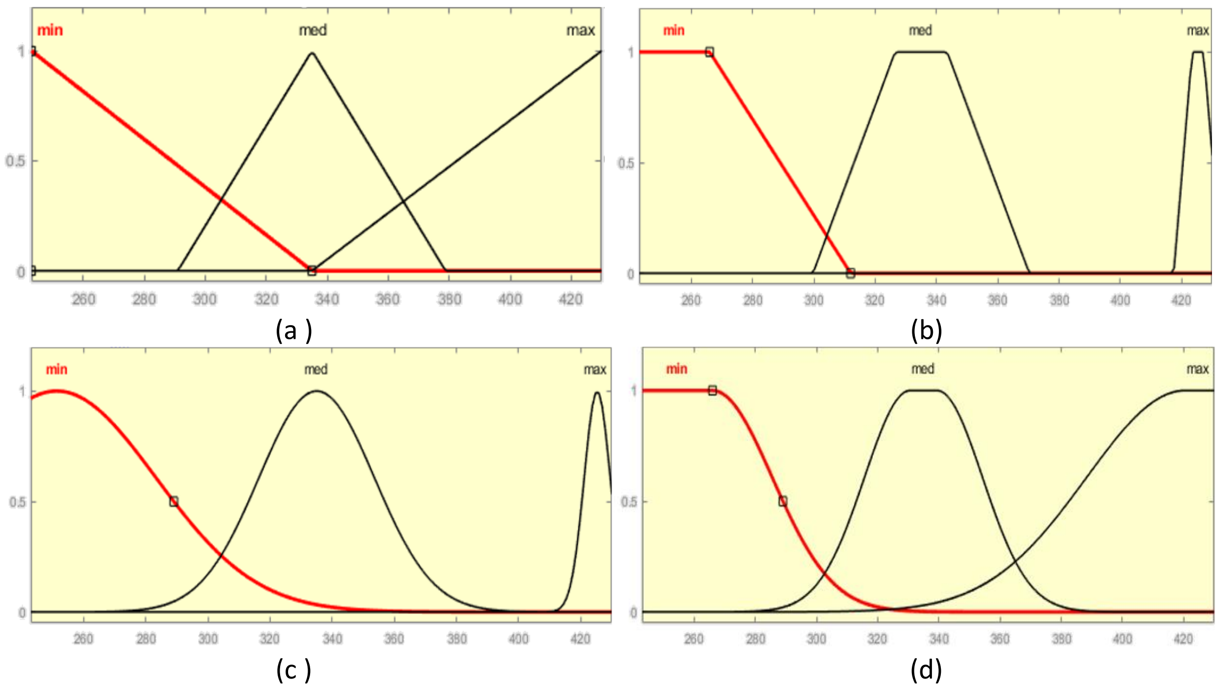


Figure 4: Example of Fuzzy memberships, (a) Triangular, (b) Trapezoidal, (c) Gaussian and (d) Gaussian combination as function of "fabric mass" input parameter (Group1 of fabrics)

The ranges (low, medium and high level values) relative to each studied parameter are considered according to expert's judgments and they are summarized in Table 3.

Table 3: Different levels of parameters using Triangular membership functions

Order	Studied parameters		Minimum level	Medium level	Maximum level
Input 1	Fabric mass	Group 1	[243 243 335]	[290 335 380]	[335 440 440]
		Group 2	[328 328 390]	[375 390 445]	[390 445 445]
Input 2	Stitch length		[2 2 2.5]	[2 2.5 3.33]	[2.5 3.33 3.33]

Input 3	Seam thread	[50 50 63]	[50 63 76]	[63 95 95]
Output 1	Seam slippage	[0 0 4.5]	[2 4.5 7]	[4.5 9 9]
Output 2	Seam efficiency	[10 10 63]	[45 63 81]	[63 100 100]

3. RESULTS AND DISCUSSIONS

Fuzzy modeling is applied and the seam quality of tested fabric is investigated using Fuzzy theory system to evaluate the obtained results, the average absolute relative error, $Error$ (Equation 3) between the theoretical (Th_v) and the experimental values (Exp_v). The high value of the mean absolute error values used in the modeling is estimated to be 6% (Gazzah, 2015). It was considered in this work to qualify the effectiveness and the efficiency of findings.

$$Error = \frac{|Th_v - Exp_v|}{Exp_v} * 100 \quad (3)$$

Tables 4 and 5 compare the results of theoretical properties of the seam efficiency and the experimental ones using the Triangular, Trapezoidal, Gaussian and Gaussian combination functions in the warp and weft directions for the group 1 and 2 of fabrics respectively. Moreover, the average errors are presented for studied functions.

Table 4: Compared experimental results of the seam efficiency within theoretical ones using Triangular, Trapezoidal, Gaussian and Gaussian combination functions in the warp and weft directions (Group 1 of fabrics)

S.E* Test			Ex. val*	Th.val*				$Error$			
FM*	SL*	ST*		Tr*	Trp*	Gss*	Gss2*	Tr*	Trp*	Gss*	Gss2*
Warp											
243	2	63	65	63.1	63.1	63	63	2.9	2.9	3.1	3.1
328	3.33	63	30	27.8	26.1	31.7	27.1	7.3	13.0	5.7	9.7
328	2	95	75	76	76.5	55.8	59.5	1.3	2.0	25.6	20.7
328	2.5	95	50	43.1	40.6	43.9	41.7	13.8	18.8	12.2	16.6
410	2	95	63	63.1	63.1	44.9	44.4	0.2	0.2	28.7	29.5
410	3.33	63	27	28.1	26.4	32	29.5	4.1	2.2	18.5	9.3
430	3.33	63	26	27.4	25.8	29.6	26.9	5.4	0.8	13.8	3.5
243	3.33	50.2	52	55	55	44.6	41.6	5.8	5.8	14.2	20.0
243	2	50.2	60	63.1	55	63	63	5.2	8.3	5.0	5.0
328	2	50.2	44	45.1	55	46.6	45.8	2.5	25.0	5.9	4.1
Weft											
243	2.5	63	66	63	63	63	63	4.5	4.5	4.5	4.5
243	3.33	95	81	88	87	85	94.8	8.6	7.4	4.9	17.0
243	2.5	95	67	63	63	63	63	6.0	6.0	6.0	6.0
243	2	95	65	63	63	63	63	3.1	3.1	3.1	3.1
334	3.33	95	74	76	76.5	71	71.4	2.7	3.4	4.1	3.5
334	2.5	95	71	76	76.5	71	71.5	7.0	7.7	0.0	0.7
410	3.33	63	62	63	63	63	63	1.6	1.6	1.6	1.6
410	2	63	67	63	63	63	63	6.0	6.0	6.0	6.0
410	3.33	95	65	63	63	63	63	3.1	3.1	3.1	3.1
410	2	95	65	63	63	63	63	3.1	3.1	3.1	3.1
430	2.5	63	65	63	63	63	63	3.1	3.1	3.1	3.1
430	2	95	64	63	63	63	63	1.6	1.6	1.6	1.6
328	2.5	50.2	76	72.8	55	69.8	70.1	4.2	27.6	8.2	7.8
328	2	50.2	78	72.8	55	69.8	70.1	6.7	29.5	10.5	10.1
243	2.5	63	66	63	63	63	63	4.5	4.5	4.5	4.5
Average $Error$ (%)					Warp			4.8	7.9	13.3	12.1
					Weft			4.4	7.5	4.3	5.0

*: Th.val= theoretical value; Ex.val= Experimental value, S.S= seam slippage, S.E= seam efficiency, FM=fabric mass, SL=seam length and ST=seam thread, Tr= Triangular, Trp= Trapezoidal, Gss= Gaussian, Gss2= Gaussian combination function

Table 5: Compared experimental results of the seam efficiency within theoretical ones using Triangular, Trapezoidal, Gaussian and Gaussian combination functions in the warp and weft directions (Group 2 of fabrics)

S.E* Test			Ex.	Th.val*				$Error$			
FM*	SL*	ST*	val*	Tr*	Trp*	Gss*	Gss2*	Tr*	Trp*	Gss*	Gss2*
Warp											
328	2.5	50.2	32	36.1	55	42.3	38	12.8	71.9	32.2	18.8
342	2.5	63	30	29.3	27.6	28.8	25.1	2.3	8.0	4.0	16.3
342	2.5	95	42	42.2	41.6	42.8	41.6	0.5	1.0	1.9	1.0
359	2.5	95	52	54	58.1	56.8	61.5	3.8	11.7	9.2	18.3
359	2	95	64	63	63	56.8	61.5	1.6	1.6	11.3	3.9
416	2.5	50.2	50	45.1	55	37.8	35.4	9.8	10.0	24.4	29.2
445	2	50.2	50	54.9	55	52.9	52.3	9.8	10.0	5.8	4.6
445	2.5	63	42	41.1	40.4	43.5	41.6	2.1	3.8	3.6	1.0
445	2	63	51	52.4	51.9	47.3	44.4	2.7	1.8	7.3	12.9
445	3.33	95	43	41.1	40.4	43.8	41.7	4.4	6.0	1.9	3.0
416	3.33	50.2	35	36.1	55	37.5	35.4	3.1	57.1	7.1	1.1
Weft											
328	2	50.2	76	81.9	55	94.1	95	7.8	27.6	23.8	25.0
342	2.5	95	85	87.5	88.7	95.9	96.3	2.9	4.4	12.8	13.3
359	2.5	50.2	79	81.9	55	73.8	80.8	3.7	30.4	6.6	2.3
359	2.5	63	81	86.3	87.4	88.5	95.8	6.5	7.9	9.3	18.3
372	2.5	63	89	85	86	84.7	94.6	4.5	3.4	4.8	6.3
372	2	95	85	85	86	95.6	96	0.0	1.2	12.5	12.9
416	2	63	68	63	63	64.2	65.7	7.4	74	5.6	3.4
445	2.5	63	67	63	63	64.2	63.1	6.0	6.0	4.2	5.8
445	2	63	60	63	63	64.2	63.1	5.0	5.0	7.0	5.2
445	2	95	83	88	89	74	78.2	6.0	7.2	10.8	5.8
Average $Error$ (%)					Warp			4.8	16.6	9.9	10.0
					Weft			5.0	10.0	9.7	9.8

Therefore, Tables 6 and 7 present the results of theoretical output values of the seam slippage and the experimental ones using the four choosing functions in the warp and weft directions for the group 1 and 2 of fabrics respectively. In addition, the average errors are presented for studied functions.

Table 6: Results of theoretical output values of the seam slippage and the experimental ones using Triangular, Trapezoidal, Gaussian and Gaussian combination functions in the warp and weft direction (Group 1 of fabrics)

S.E* Test			Ex.	Th.val*				$Error$			
FM*	SL*	ST*	val*	Tr*	Trp*	Gss*	Gss2*	Tr*	Trp*	Gss*	Gss2*
Warp											
243	2.5	63	4	4.51	4.51	4.5	4.5	12.8	12.8	12.5	12.5
328	2	63	3.1	3.06	2.99	3.03	2.93	1.3	3.5	2.3	5.5
328	2	95	1.49	1.51	1.36	2.84	2.35	1.3	8.7	90.6	57.7
328	3.33	95	3	3.06	2.99	3.2	3.07	2.0	0.3	6.7	2.3
410	3.33	95	1.63	1.53	1.38	1.86	1.65	6.1	15.3	14.1	1.2
410	2.5	95	1.61	1.53	1.38	1.86	1.65	5.0	14.3	15.5	2.5
410	2	63	1.63	1.53	2.64	1.86	1.65	6.1	62.0	14.1	1.2
410	2.5	63	1.5	1.53	1.38	1.86	1.65	2.0	8.0	24.0	10.0
243	3.33	50.2	4.8	4.5	4.5	4.5	4.5	6.3	6.3	6.3	6.3
328	2	50.2	3.5	3.47	4.5	3.66	3.55	0.9	28.6	4.6	1.4
328	3.33	50.2	3.5	3.47	4.5	3.66	3.55	0.9	28.6	4.6	1.4
Weft											
243	2	63	1.5	1.47	1.59	1.66	1.42	2.0	6.0	10.7	5.3
328	2	63	1.69	1.51	1.36	1.4	1.22	10.7	19.5	17.2	27.8
328	2.5	95	1.5	1.51	1.36	1.66	1.43	0.7	9.3	10.7	4.7

430	3.33	63	1.45	1.47	1.34	1.66	1.43	1.4	7.6	14.5	1.4
430	2.5	63	1.43	1.47	1.34	1.66	1.43	2.8	6.3	16.1	0.0
328	2.5	63	2	1.51	1.36	1.4	1.22	24.5	32.0	30.0	39.0
341	2	95	1.56	1.5	1.35	1.66	1.43	3.8	13.5	6.4	8.3
328	3.33	50.2	2.3	2.21	4.5	2.32	2.15	3.9	95.7	0.9	6.5
243	2.5	50.2	2.25	2.21	4.5	2.34	2.15	1.8	100.0	4.0	4.4
Average $Error$ (%)				Warp				4.1	17.1	17.7	9.3
				Wetf				5.7	32.2	12.3	10.8

Table 7: Results of theoretical output values of the seam slippage and the experimental ones using Triangular, Trapezoidal, Gaussian and Gaussian combination functions in the warp and weft direction (Group 2 of fabrics)

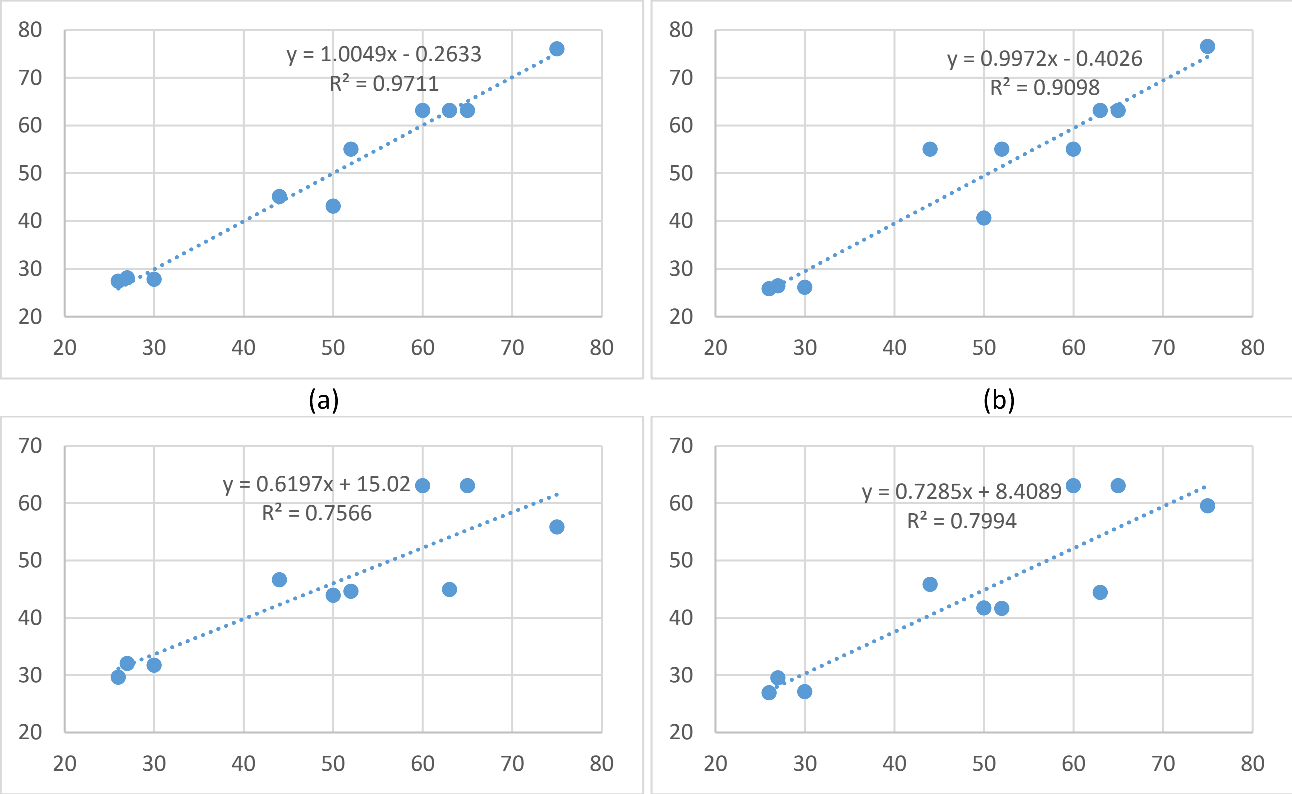
S.E* Test			Ex.	Th.val*				$Error$			
FM*	SL*	ST*	val*	Tr*	Trp*	Gss*	Gss2*	Tr*	Trp*	Gss*	Gss2*
Warp											
328	2.5	63	1.57	1.47	1.34	1.41	1.22	6.4	14.6	10.2	22.3
328	2	63	1.49	1.47	1.34	1.41	1.22	1.3	10.1	5.4	18.1
328	2.5	95	1.59	1.47	1.34	1.66	1.43	7.5	15.7	4.4	10.1
359	2.5	50.2	2.4	2.21	4.5	2.32	2.15	7.9	87.5	3.3	10.4
372	2	50.2	2.2	2.21	4.5	2.32	2.15	0.5	104.5	5.5	2.3
445	2	95	1.4	1.47	1.34	1.66	1.43	5.0	4.3	18.6	2.1
372	3.33	95	1.36	1.48	1.34	1.66	1.43	8.8	1.5	22.1	5.1
416	3.33	95	1.67	1.62	1.48	1.84	1.63	3.0	11.4	10.2	2.4
445	2	63	1.5	1.47	1.34	1.66	1.43	2.0	10.7	10.7	4.7
445	2.5	63	1.5	1.47	1.34	1.66	1.43	2.0	10.7	10.7	4.7
372	2.5	50.2	2.3	2.21	4.5	2.32	2.15	3.9	95.7	0.9	6.5
Weft											
328	2	95	1.42	1.47	1.34	1.66	1.43	3.5	5.6	16.9	-0.11
342	2.5	50.2	2	2.21	4.5	2.32	2.15	10.5	125.0	16.0	-0.15
359	2.5	63	1.67	1.68	1.54	1.58	1.34	0.6	7.8	5.4	0.33
359	2	50.2	2	2.21	4.5	2.32	2.15	10.5	125.0	16.0	-0.15
359	2	63	1.63	1.68	1.54	1.58	1.34	3.1	5.5	3.1	0.09
359	2.5	95	1.61	1.68	1.54	1.66	1.43	4.3	4.3	3.1	-0.12
372	2.5	50.2	2.2	2.21	4.5	2.32	2.15	0.5	104.5	5.5	-0.35
372	2	63	1.73	1.84	1.71	1.84	1.62	6.4	1.2	6.4	0.11
445	2.5	63	1.59	1.47	1.34	1.67	1.43	7.5	15.7	5.0	0.16
445	2	95	1.46	1.47	1.34	1.67	1.43	0.7	8.2	14.4	-0.16
Average $Error$ (%)				Warp				4.4	33.3	9.3	8.1
				Weft				4.8	40.3	9.2	8.5

3.3. Seam efficiency

3.3.1. Seam efficiency modeling

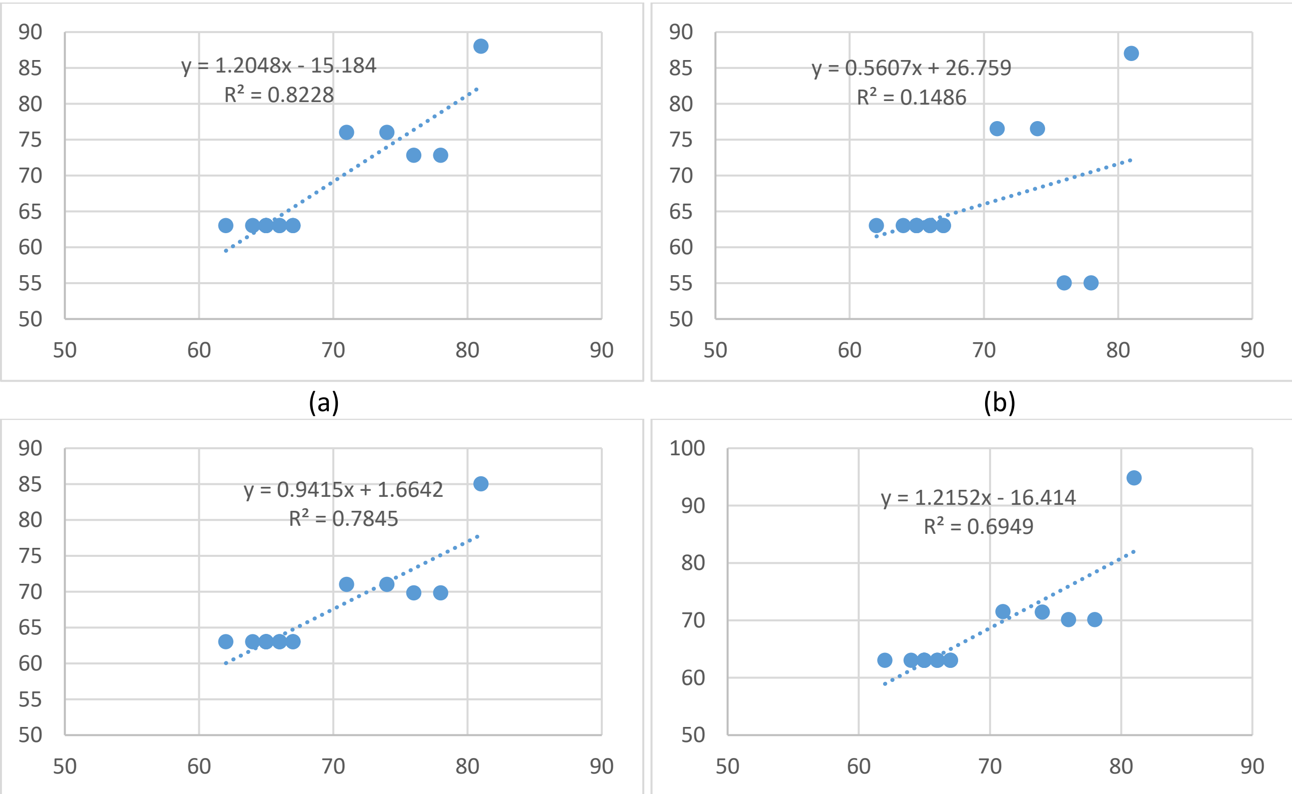
Tables 4 and 5 present the results of theoretical and experimental values for four functions as well as the average error for each function, in the warp and weft directions respectively for two groups of fabrics. Based on the average error values, we found that the obtained Fuzzy models gave theoretical values of the seam efficiency close correlated with the experimental values (average error < 6%) for:

-Triangular function in the warp direction and the Trapezoidal, Gaussian and Gaussian combination functions in the weft direction for the group 1 of fabrics;
-Triangular function in the warp direction and weft directions for the group 2 of fabrics;
Figures 5 and 6 show the regression model evolutions of the seam efficiency behaviors using the Fuzzy logic method as function of the experimental results, in the warp and weft direction, using Triangular, Trapezoidal, Gaussian and Gaussian combination functions for group 1 and 2 of fabrics respectively. Nevertheless, Figures 7 and 8 depict the regression model evolutions of the seam efficiency behaviors of group 2 of fabrics in the warp and weft directions respectively.



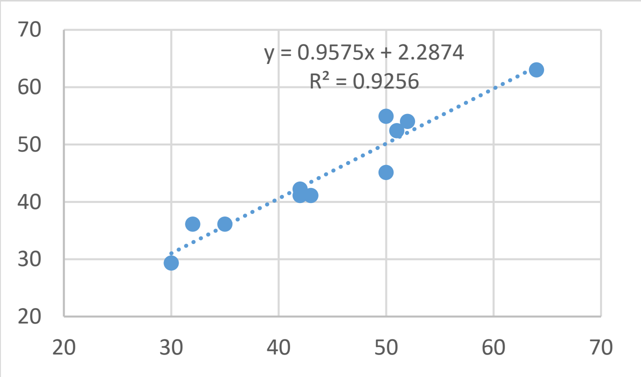
(c) (d)

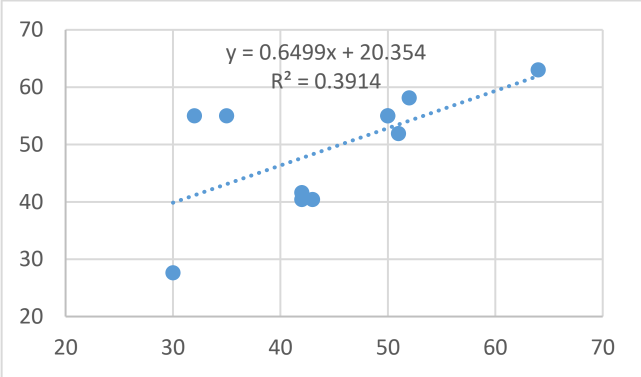
Figure 5: Relationship between actual values and Fuzzy predicted ones of seam efficiency evolution using Triangular (a), Trapezoidal (b), Gaussian (c) and Gaussian combination (d) membership functions (Group 1 of fabrics) in the warp direction



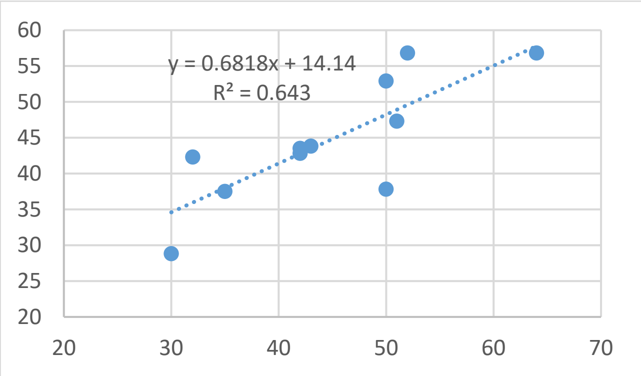
(c) (d)

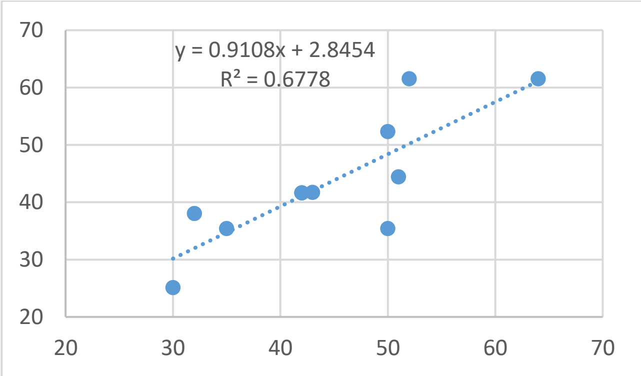
Figure 6: Relationship between actual values and Fuzzy predicted ones of seam efficiency evolution using Triangular (a), Trapezoidal (b), Gaussian (c) and Gaussian combination (d) membership functions (Group 1 of fabrics) in the weft direction





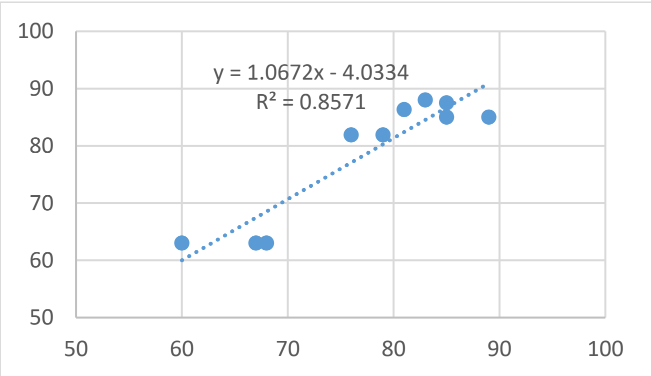
(a) (b)

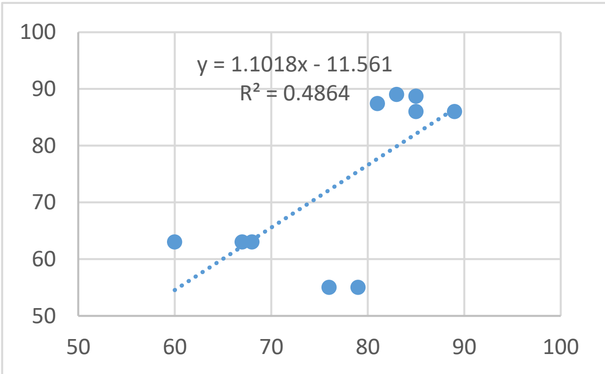




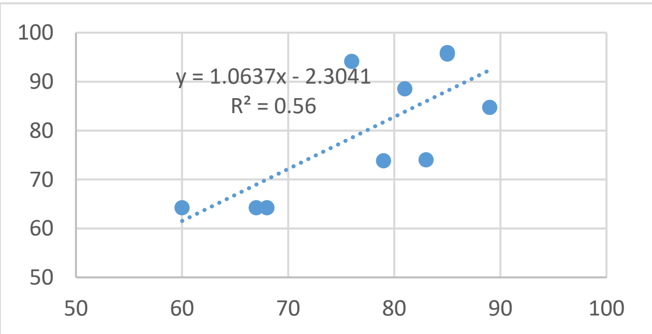
(c) (d)

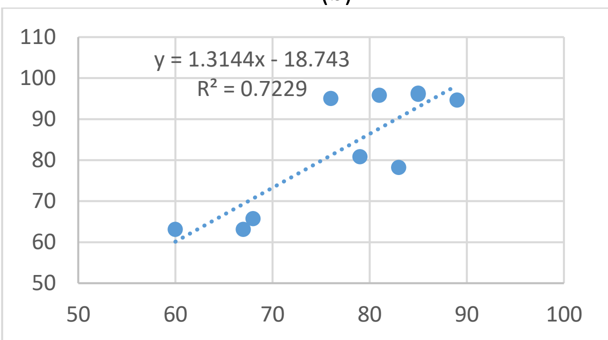
Figure 7: Relationship between actual values and Fuzzy predicted ones of seam efficiency evolution using Triangular (a), Trapezoidal (b), Gaussian (c) and Gaussian combination (d) membership functions (Group 2 of fabrics) in the warp direction





(a) (b)





(c) (d)

Figure 8: Relationship between actual values and Fuzzy predicted ones of seam efficiency evolution using Triangular (a), Trapezoidal (b), Gaussian (c) and Gaussian combination (d) membership functions (Group 2 of fabrics) in the weft direction

According to the following figures, we note that:
- For the group 1: the obtained Fuzzy models gave theoretical values of the seam efficiency arrow close correlated with the experimental values, ranging from 76% to 97% in the warp direction (see Figure 5). The triangular and trapezoidal functions have the highest value, equals to 97% and 91% respectively. In the weft direction, Fuzzy models obtained have not given theoretical values of seam efficiency near arrow correlated with those for the experimental Trapezoidal and Gaussian combination functions, while the values of regression coefficients (R^2) are important (78% and 82% respectively) for the triangular and Gaussian functions respectively (Figure 6).
- For the group 2: In the warp direction, Fuzzy models obtained have not given theoretical values of seam efficiency near arrow correlated with those experimental, while the value of regression coefficient (R^2) is significant (93%) for the triangular function (see Figure 7). In the weft direction, Fuzzy models obtained have not given theoretical values of seam efficiency near arrow correlated with those for the experimental ones, while the values of regression coefficients (R^2) are considerable (72% and 86%) for triangular and Gaussian combination functions respectively (see Figure 8).
By comparing the four obtained models, we find that the membership function of the triangular shape provides the most efficient and significance results in the most cases. Hence, the Fuzzy model for this function is recorded in the study of the sewing efficiency in the warp and weft direction, for the two groups of fabrics. Thus, Fuzzy modelling technique is relatively improved based on tested database using a triangular membership function, particularly in our experimental design of interest. This finding seems in a good agreement with Majumdar's results (Majumdar et al., 2005). It found that the triangular function gives the best prediction and evaluation accuracy. The simplest function is the triangular one because it is formed with straight lines.

4.2.2. Effect of input parameter on seam efficiency

This study was verified by simulation test using MATLAB-17. A 3D surface appears which varies according to the 36 mentioned rules. An evolution states that the system is fair and works properly. This model predicts the required quality parameters in functions of two different input parameters taken in pairs.

Figures 9, 10 show the sewing efficiency evolutions in function of input parameters in the warp and weft directions for group 1. Besides, Figures 11 and 12 present the sewing efficiency evolution for group 2 of fabrics in the warp and weft directions respectively.

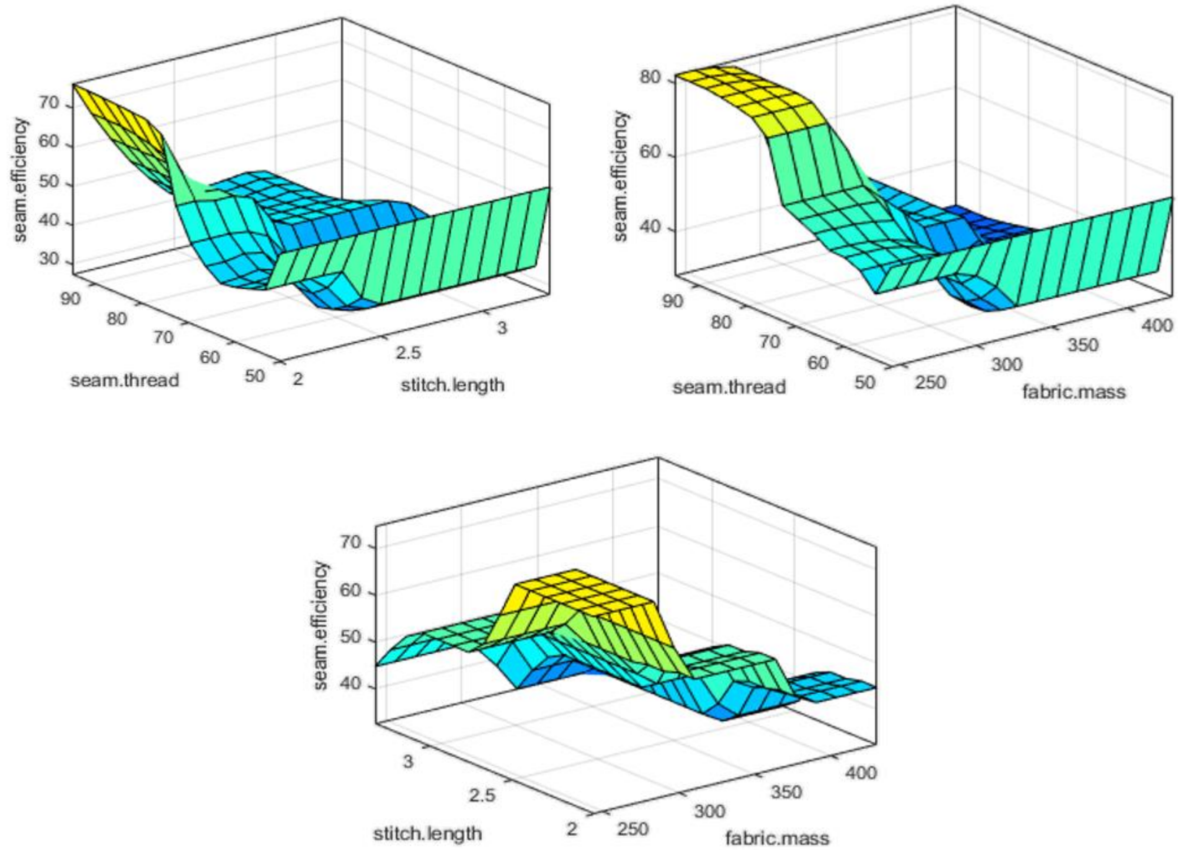


Figure 9: Seam efficiency evolutions as a function of input parameters in the warp direction for group 1 of fabrics

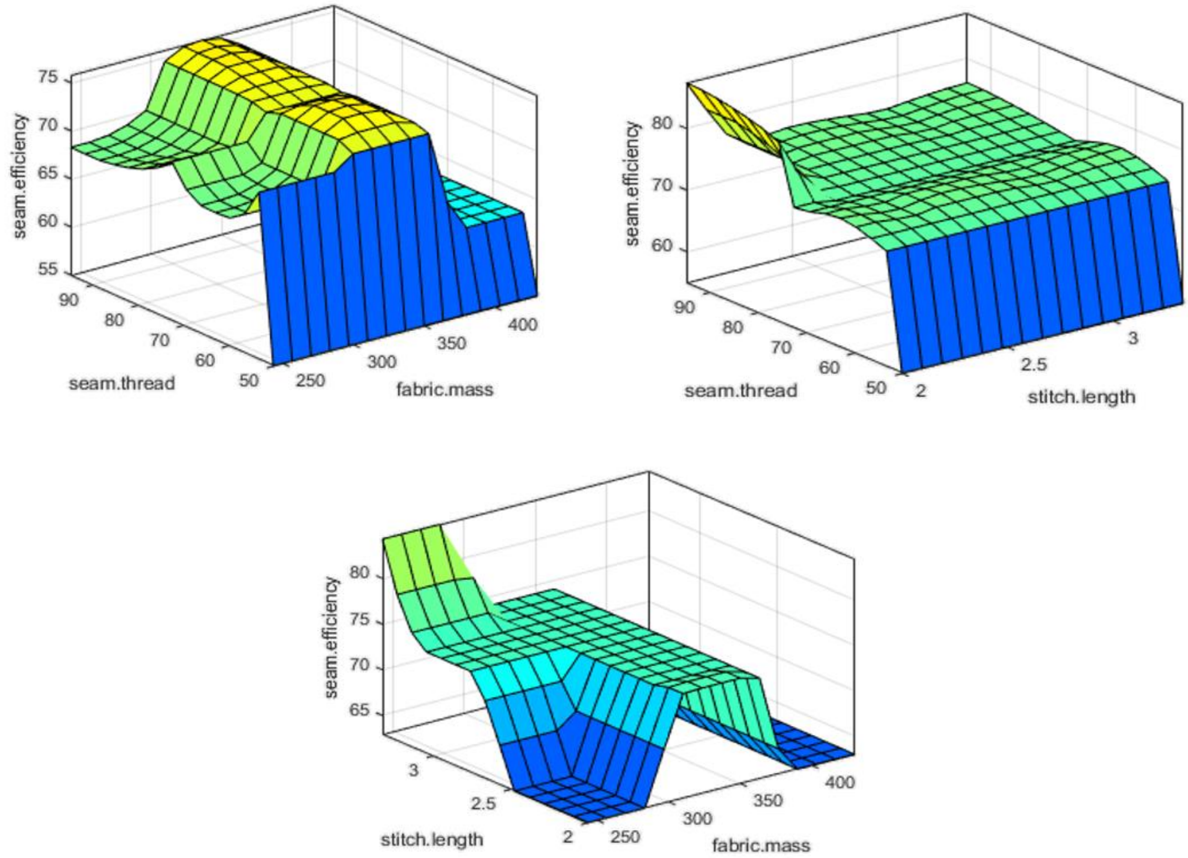


Figure 10: Seam efficiency evolutions as a function of parameters in the weft direction for group 1 of fabrics

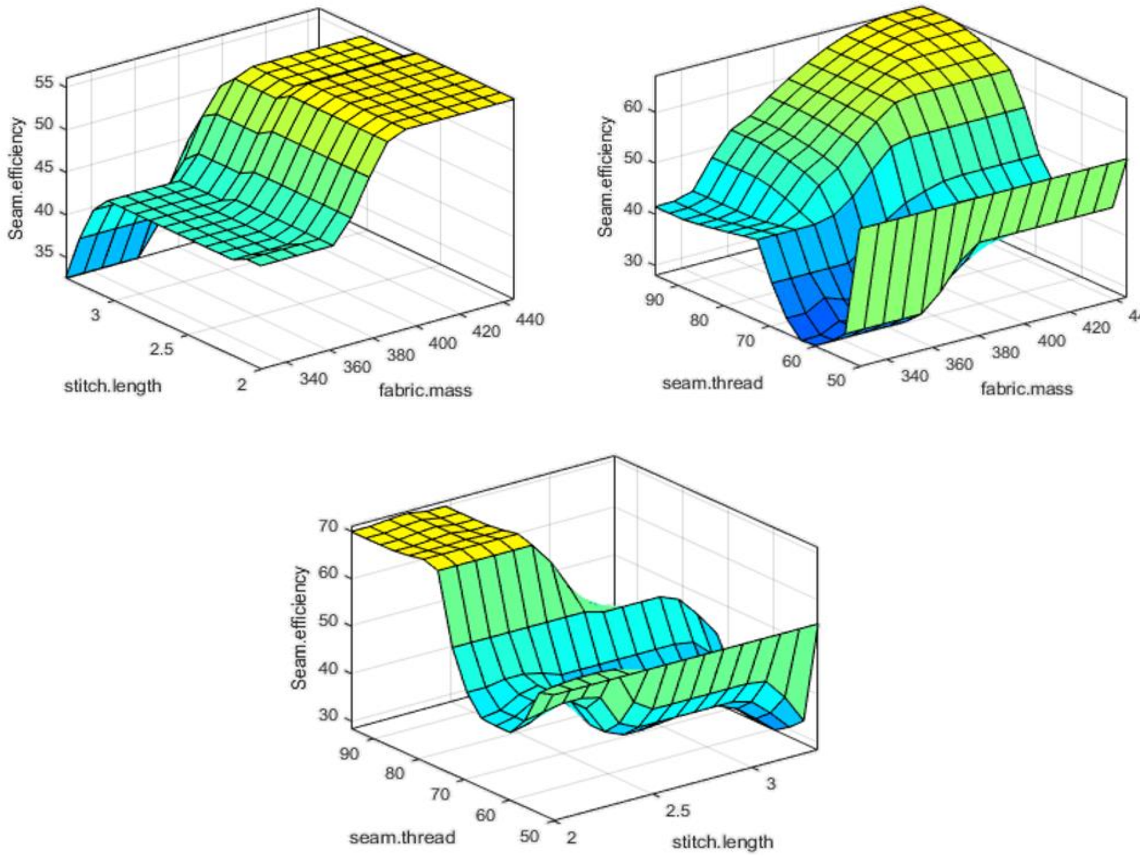


Figure 11: Seam efficiency evolutions as a function of parameters in the warp direction for group 2 of fabrics

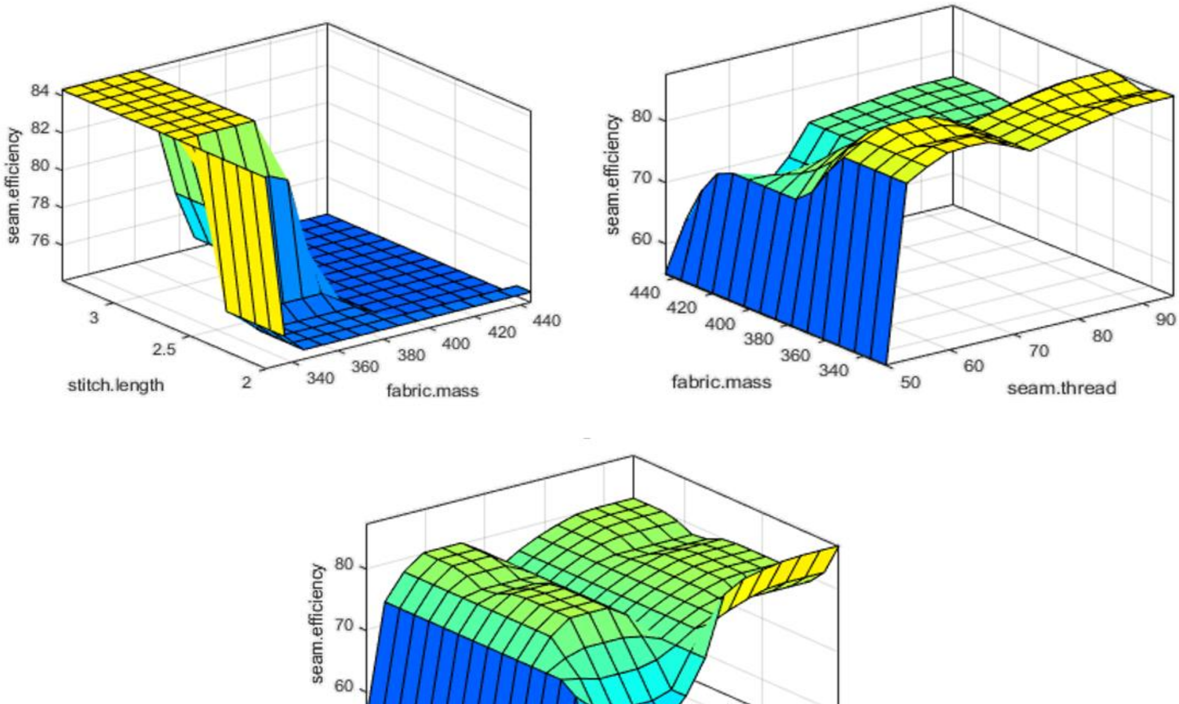


Figure 12: Seam efficiency evolutions as a function of studied parameters in the weft direction for group 2 of fabrics

The size of the sewing thread is the most crucial for the seam stability of clothing. In addition, Rengasamy has shown that high thread seam strength is a basic requirement for good sewability (Rengasamy et al. 2003). In our case, previous figures show that in the warp and weft directions, seam efficiency increases with the increase of sewing thread linear density. In fact, the higher the sewing thread linear density, the higher the thread breaking strength and rigidity. Hence, the seam efficiency is correlated to the sewing thread resistance accurately.
The increase of stitch length encourages the decrease of seam efficiency. Indeed, the decrease of stitch length increases the sewing threads consumption, as a consequence the seam resistance increases enormously. This seems in a good agreement with Lauriol's results, who suggested that the increase of stitch density from 4 to 5 stitches/cm (decrease of stitch length), increases the thread demand by average 10% (Laurial, 1999). Moreover, according to our earlier work, the decrease of stitch length increases considerably the number of contact points between sewing thread and fabric yarns, so a tighter surface is obtained (Malek, Jaouachi and Khedher, 2017). Hence, the tensile force is distributed over a larger number of points and the resistance will be higher. According to Rostam, the increase of stitch density leads to a higher amount of seam strength (Rostam et al, 2014). He investigated that sewn structure resistance can be divided into two regions named; "Pure fabric area" and "Sewing area ". Thus, decrease of stitch length, for a given fabric, result an increase of “sewing area” resistance, which presents the most resistant area of a sewn structure during a tensile test (Rostam et al, 2014).
Otherwise, the fabric property affects directly the seam property. In this context, Choudhary and Amit proved that the fabric properties, which affect the seam quality of apparel, are cover factor, weight, thickness, strength, shrinkage, functional finishing, extensibility, bending rigidity, and shear rigidity, some of which form an integral part of low stress mechanical properties (Choudhary, Amit, 2013). In this study, the fabric mass has a random effect on seam efficiency. This result is in accordance with our earlier study (Malek et al, 2017). Therefore, by increasing of the fabric mass, the seam efficiency decreases in case (group 2 of fabrics in the weft direction, for example) and increases in other cases (group 2 of fabrics in the warp direction, for example). This result is confirmed by Choudhary and Amit who proved that the increase of fabric strength decreases the seam strength efficiency (Choudhary, Amit, 2013) and it seems in a perfect agreement with Cheng study; the heavier and thicker the fabric, the higher the seam strength (Cheng and Poon, 2002).

4.3. Seam slippage

4.3.2. Seam slippage modeling:

Tables 6 and 7 present the compared results between theoretical and experimental values when four fuzzy membership functions are implemented as well as the average error for each of them, in warp and weft directions respectively for two groups of fabrics. In fact, based on the average error values, it can be remarked easily if the theoretical values, obtained using Fuzzy models, are very close with the experimental values. Table 6 and 7 show that, for both studied groups of fabrics, the Triangular function presents the most significant fuzzy membership (average error< 6%), in the warp and weft directions. Thus, Triangular function can traduce sufficiently the behavior of seam slippage.

Furthermore, Figures 13 and 14 show the behavior evolutions of the seam slippage, obtained from the Fuzzy model, as function of the experimental results using the studied fuzzy functions in the warp and weft directions for the group 1 of fabrics. However, Figures 15 and 16 present the evolutions of the seam quality behavior as function of the experimental ones in both warp and weft directions regarding the group 2 of fabrics.

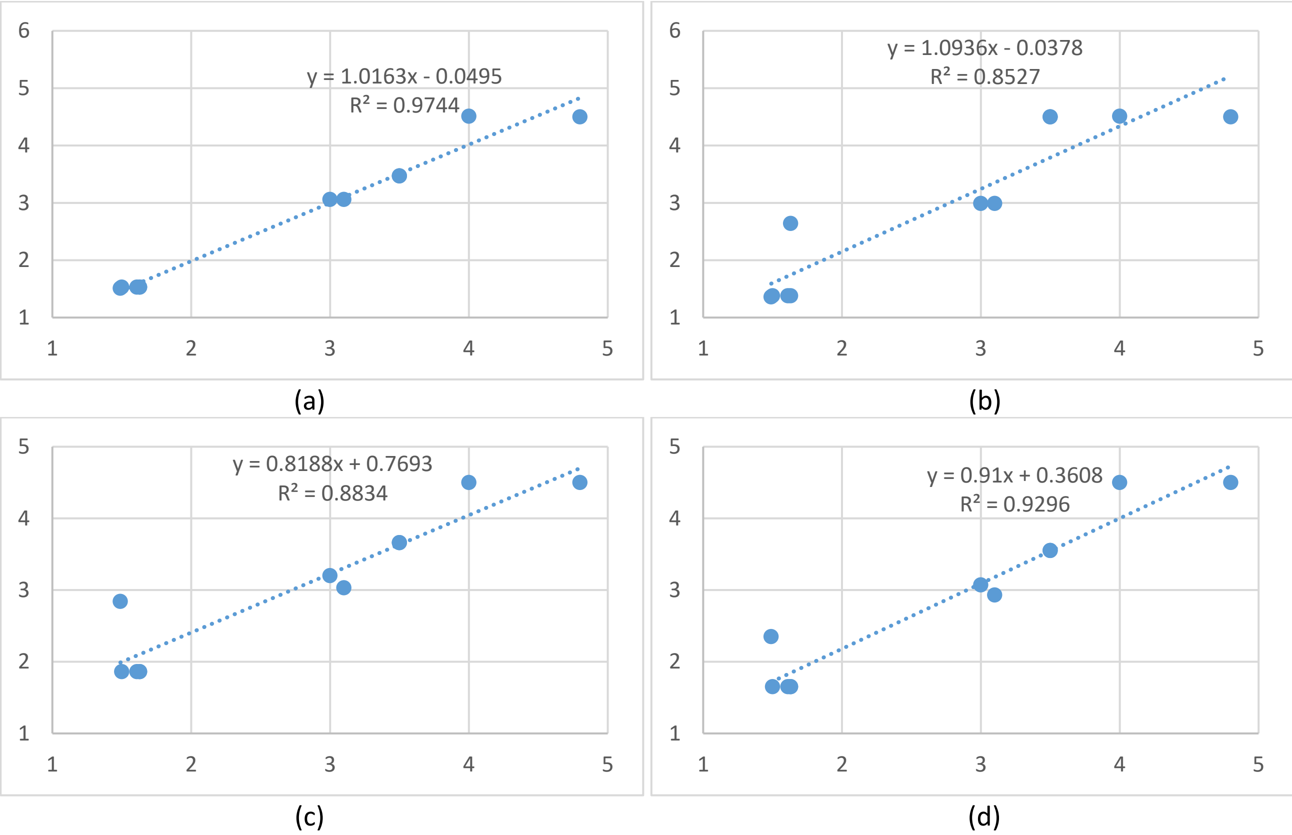


Figure 13: Relationship between actual values and Fuzzy predicted ones of seam slippage (b) evolution using Triangular (a), trapezoidal (b), Gaussian (c) and Gaussian combination (d) membership function (Group 1 of fabrics) in the warp direction

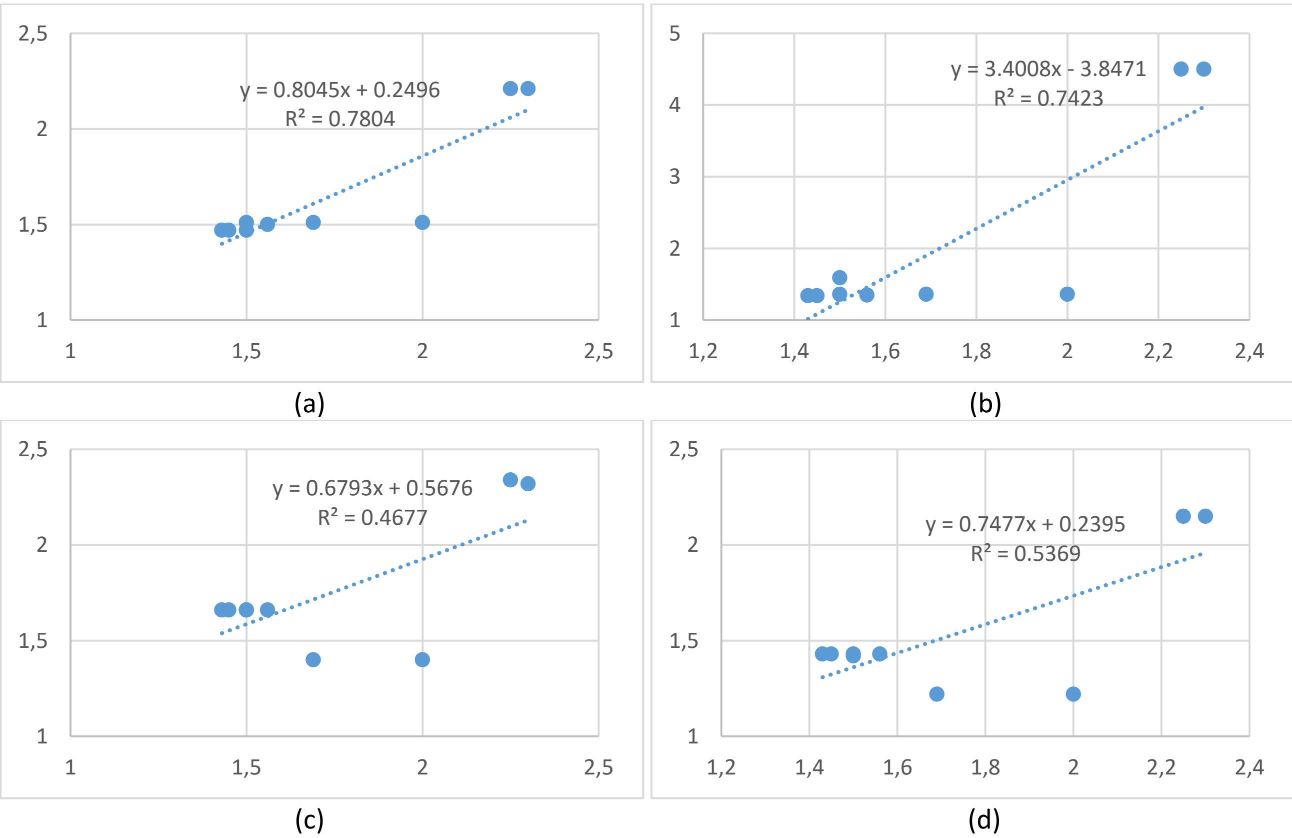


Figure 14: Relationship between actual values and Fuzzy predicted ones of seam slippage (b) evolution using Triangular (a), trapezoidal (b), Gaussian (c) and Gaussian combination (d) membership function (Group 1 of fabrics) in the weft direction

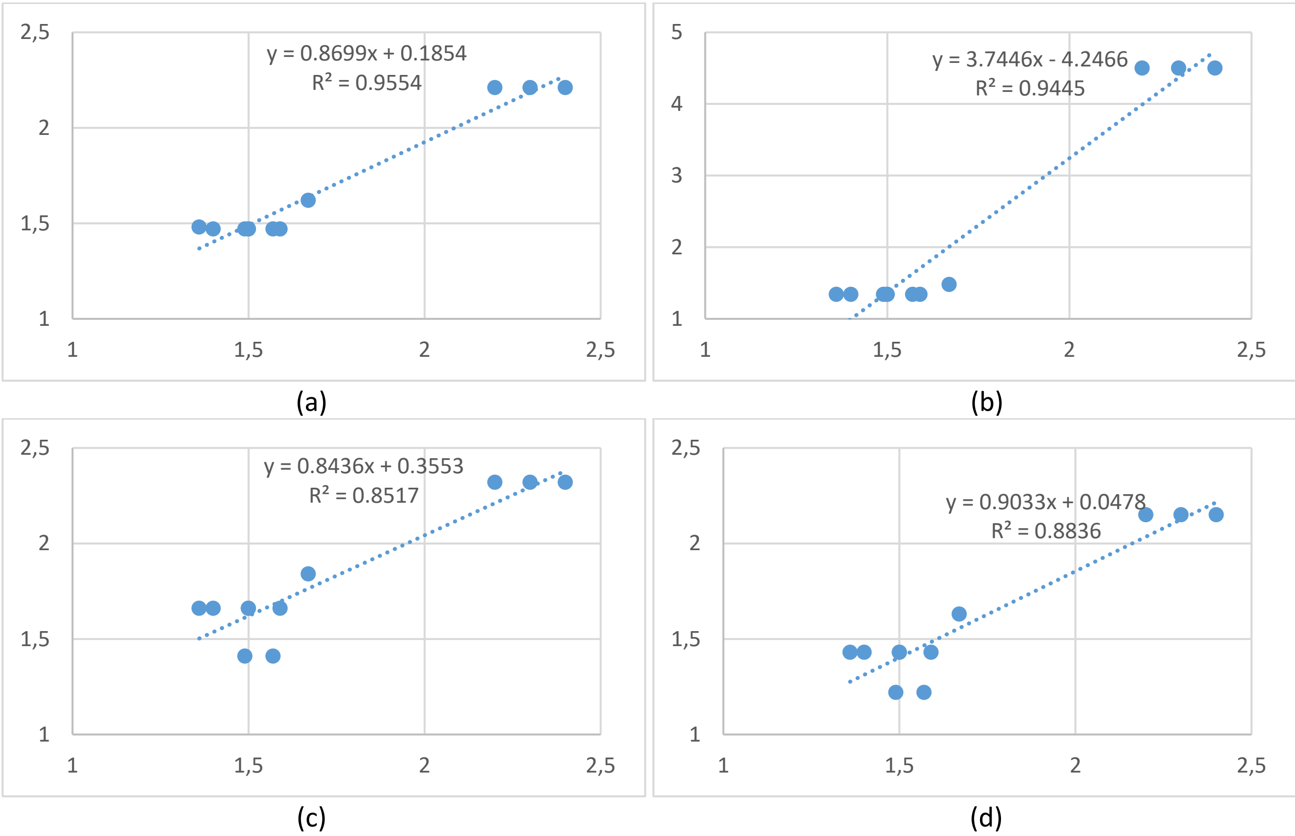


Figure 15: Relationship between actual values and Fuzzy predicted ones of seam slippage (b) evolution using Triangular (a), trapezoidal (b), Gaussian (c) and Gaussian combination (d) membership function (Group 2 of fabrics) in the warp direction

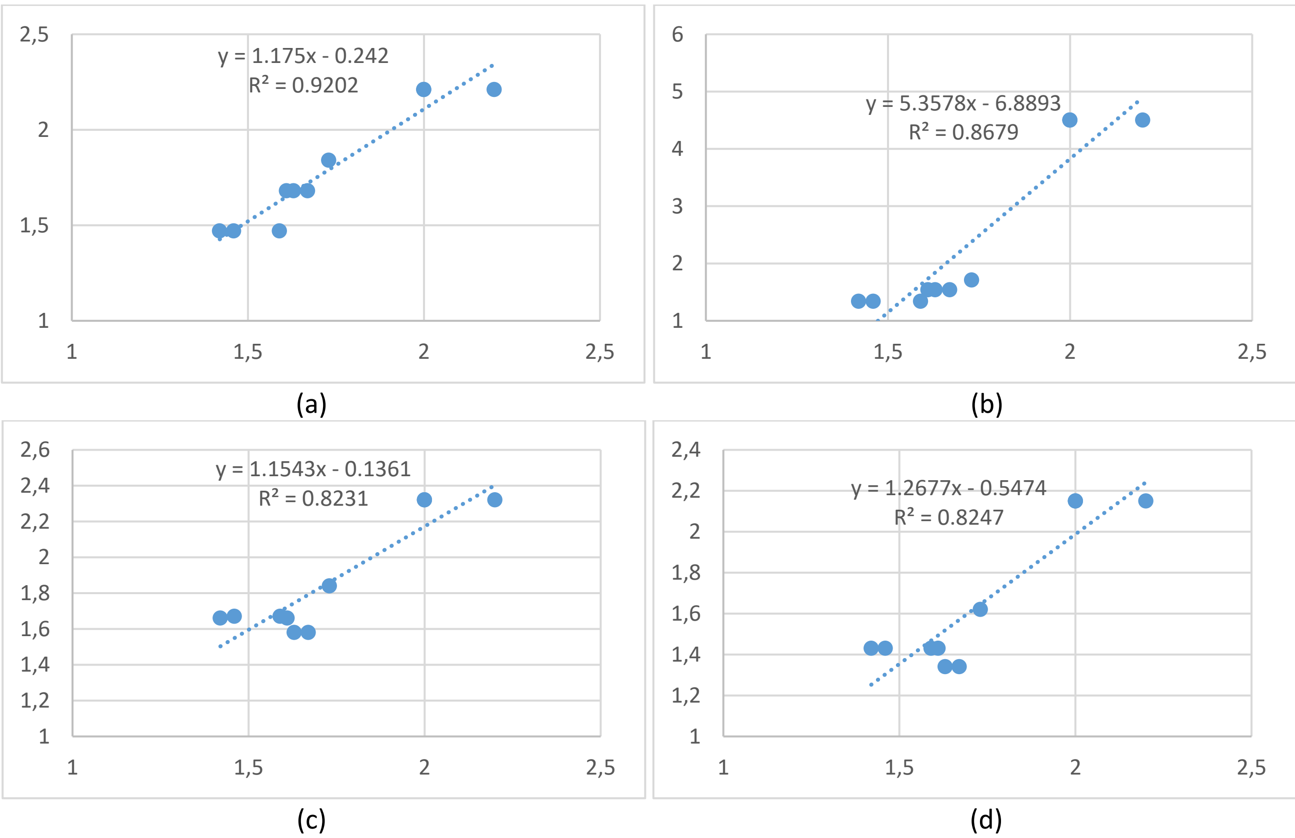


Figure 16: Relationship between actual values and Fuzzy predicted ones of seam slippage (b) evolution using Triangular (a), trapezoidal (b), Gaussian (c) and Gaussian combination (d) membership function (Group 2 of fabrics) in the weft direction

According to these previous figures, we note that:
- For Group 1: the obtained Fuzzy models present theoretical values of the seam slippage correlated with the experimental values ranging from 85% to 97% in the warp direction for all fuzzy membership functions. The triangular function has the most important R^2 value. However, in the weft direction, the obtained Fuzzy models does not present accurate predictions of seam slippage for the Gaussian and the Gaussian combination fuzzy membership functions. While, R^2 regression coefficients values are relatively more significant for the triangular (R^2 equals to 78%) and trapezoidal (R^2 equals to 74%) functions, respectively.
- For Group 2: the obtained Fuzzy models present a good correlation between theoretical and experimental values expressed by the high values of R^2 (ranged from 85% to 95% in the warp direction) for overall studied fuzzy membership functions. Nonetheless, in the weft direction, the developed Fuzzy models proved also their accuracy (R^2 ranged from 82% to 92%) to explain the seam slippage behavior in the experimental field of interest. Among all investigated fuzzy membership functions, the triangular one helps successfully industrials to predict seam slippage behavior. Indeed, triangular shape provides the most efficient and effective results in most studied properties as those in seam efficiency evaluation case. Hence, Triangular function can traduce sufficiently the behavior of seam slippage for the two groups of fabrics, in both warp and weft directions.

4.3.3. Effect of input parameters on seam slippage

To improve results, we studied the evolution of seam slippage based on tested input parameters. Figures 17-20 show the stitch length, fabric weight and the sewing thread density effects on the seam slippage in the warp and weft directions for group 1 and 2 of fabrics.

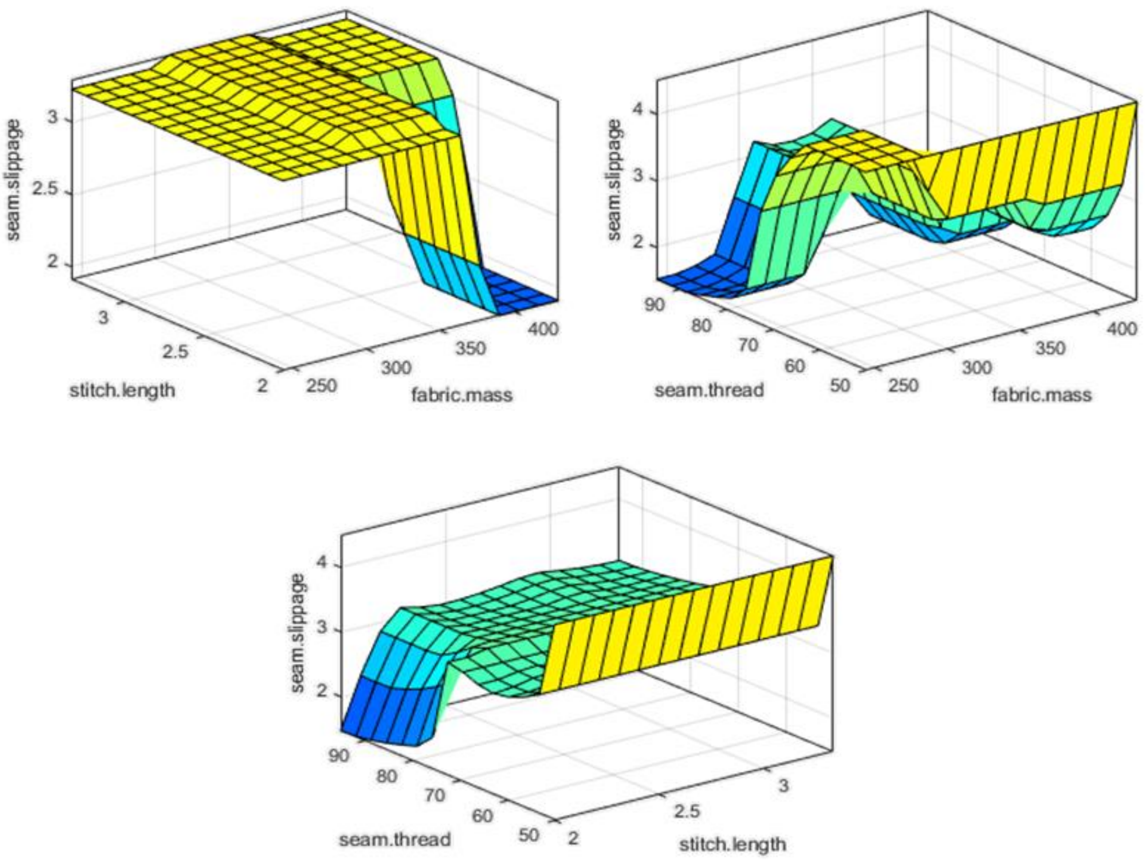


Figure 17: Seam slippage evolution as a function of parameters in the warp directions for group 1 of fabrics

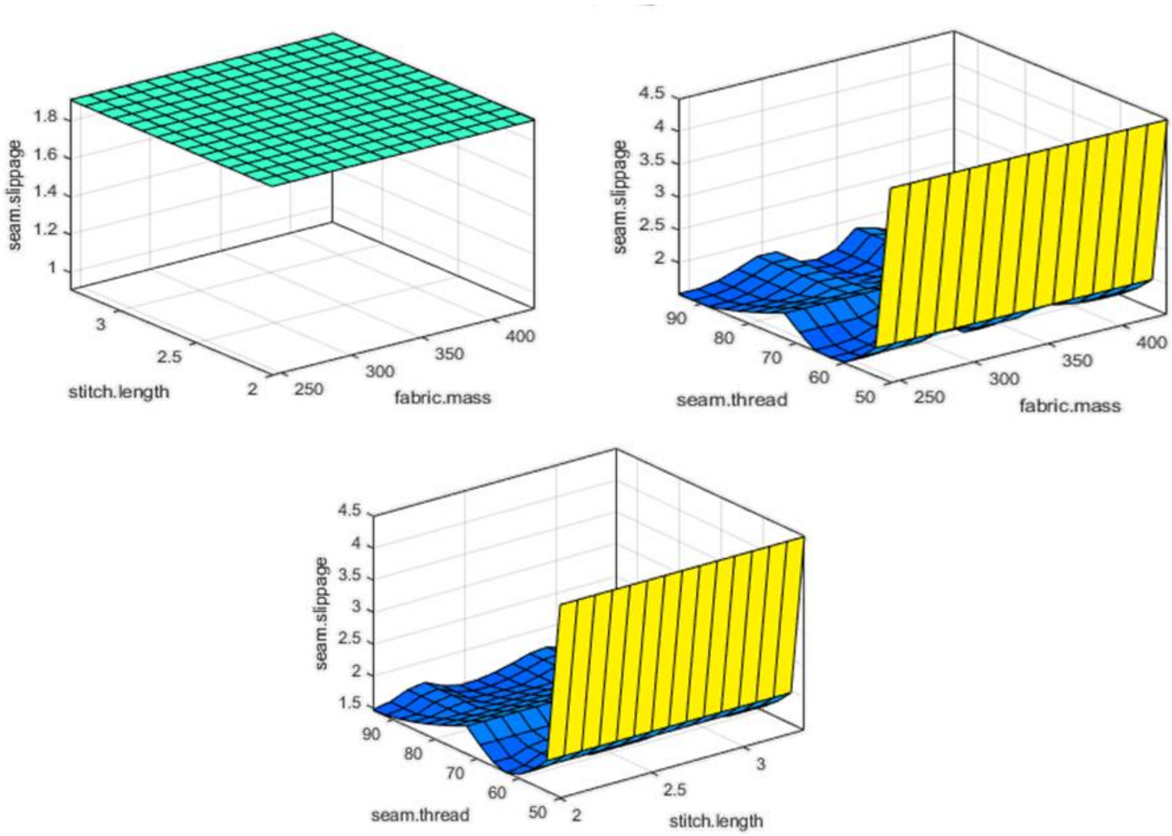


Figure 18: Seam slippage evolution as a function of parameters in the weft direction for group 1 of fabrics

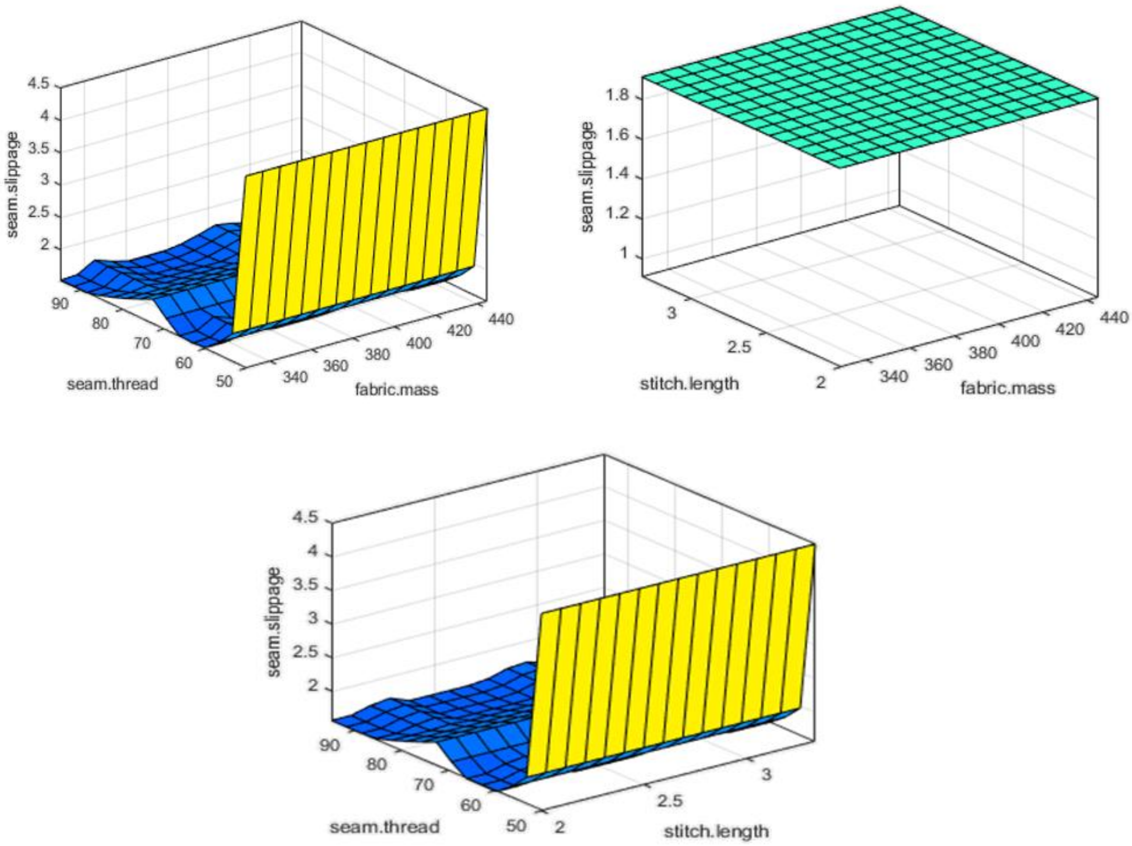


Figure 19: Seam slippage evolution as a function of parameters in the warp direction for group 2 of fabrics

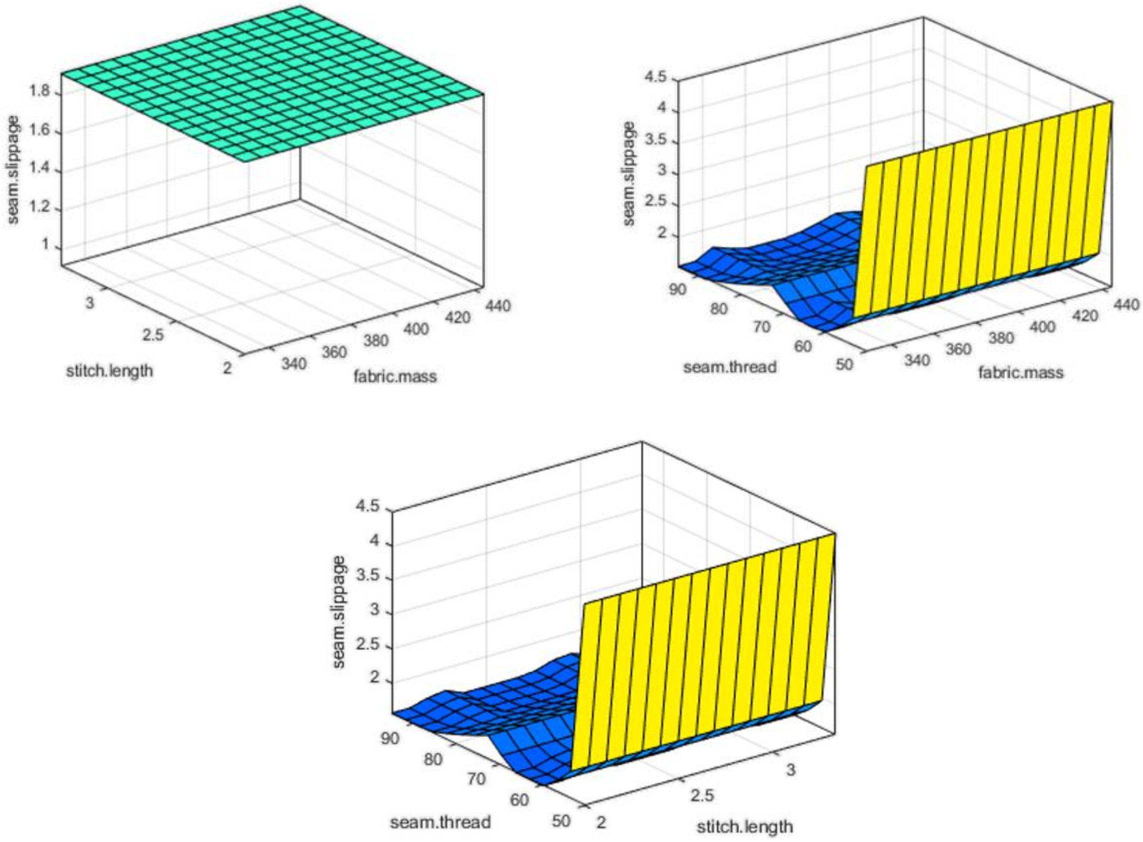


Figure 20: Seam slippage evolution as a function of parameters in the weft direction for group 2 of fabrics

According to these figures, fabric mass has no significant effect in most of cases. Nevertheless, in such cases (for group 1 in the warp direction), the seam slippage decreases with increasing of fabric mass. This finding is a good agreement with Choudhary and Amit study. In fact, it is proved that the increase of fabric strength decreases the seam strength (Choudhary, Amit, 2013). This result can be explained by the relationship between the fabric strength and the mass of fabric.

Furthermore, seam slippage decreases with the increase of sewing thread linear density. Indeed, the increase of the sewing thread linear density increases the thread rigidity. Thus, the seam the seam slippage decreases with the increase of sewing thread linear density. Therefore, it may be concluded that seam slippage is inversely proportional to sewing thread resistance. This result seems in a good agreement with Rengasamy and confirms our finding that high thread seam strength is a basic requirement for good sewability namely, the seam strength (Rengasamy et al. 2003). According to stitch length, it has no significant effect on the seam slippage.

5. CONCLUSION

The obtained results revealed that Fuzzy theory method is well verified to predict seam quality in term of seam efficiency and seam slippage. The impact of fabric mass, seam thread and seam length are considered in both warp and weft directions. The average error as well as the regression models (theoretical values as a function of experimental ones) show very interested results and prove that Fuzzy-modeling method can be successfully used for evaluation and prediction of seam slippage and seam efficiency. According to our results, the average error and the R^2 values proved that among the overall membership functions, the triangular function predicts accurately the seam quality in the experimental design of interest. Moreover, to optimize stitching quality, it is important to increase the seam efficiency and decrease the seam slippage. However, based to our finding, it is suitable to increase the sewing thread linear density and decrease stitch length to improve sewing quality performance. Moreover, for the manufacturers and industrials it is important to predict seam quality before production, aim of this work. Indeed, obtained results encourages industrials to anticipate quality of their sewed fabrics before starting production using fuzzy theory method. Compared with experimental results, theoretical method presents its accuracy and low error values proved that this technique is fruitful for prediction of seam efficiency and seam slippage.

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