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Consumed sewing thread behaviour based on lockstitch and chainstitch

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The effect of stitches/cm, number of assembly layers and fabric thickness on the sewing thread consumption values has been studied using the lockstitch type 301 and chainstitch type 401. Experimental, regressive and geometrical consumption values are compared and discussed to select the best predictive modelling technique to objectively estimate the thread amount required to seam garments. Compared to lockstitch, the thread consumption using chainstitch includes higher lengths of sewing threads. Moreover, in chainstitch type 401, the results depict that fabric sample thickness does not have the same influence rate as in the lockstitch case. Therefore, among all tested inputs, the stitch type remains the most important parameter in the case of chainstitch. Regarding regressive and geometrical methods, the regressive technique is found more effective than the geometrical method and fitted the experimental results widely. This difference can be explained by the hypothesis used to simplify the determination of an approximate consumption value. The developed multi-linear models allow a fruitful prediction of the consumed thread amount for the experimental design of interest.

Keywords: Chainstitch, Denim, Lockstitch, Multi-linear regression, Sewing thread, Woven fabrics

1 Introduction

According to literature survey, many studies have dealt with analysing some woven and knitted garment problems to find an accurate method able to objectively evaluate the amount of sewing thread required to prepare garments[1-2]. However, the exact determination of the consumption value is still a difficult clothing problem. In fact, the industrial consumptions of sewing thread depend on different input parameters, such as controllable (yarn count, mass, etc.) and uncontrollable (wastage, rate of breaks during sewing, etc.) parameters, thus making it difficult to identify the suitable consumed threads[3, 4]. Lauriol[5] estimated waste percentage value of sewing thread (10-15%), which should be added to the approximate values of consumed sewing thread. This waste, as evaluated recently by Khedher and Jaouachi[6], occurs due to shop-floor conditions, like machine running, thread breakage, repairs, ends of the seam, etc[7-10]. Furthermore, the estimated thread consumptions using such techniques were evaluated considering some input parameters, such as the stitch length, thread tension and its compressive modulus[11-19]. However, due to the complexity of consumption length, other influential factors have not been yet studied, which can enormously affect the thread consumption during sewing steps. Indeed, little investigation has been done to determine the relationship among the sewing machine parameters, the thread insertion inputs, the clothing morphology factors simultaneously and the consumed thread[20-21]. It is highly complicated to optimize all effective parameters during sewing steps, the predictive thread consumption still relates to the stitched fabric plies or layers. That is why, the consumed thread was generally estimated using approximations and presumptions especially when stitch density, seam type and material thickness were the main studied input parameters[22-24]. In fact, these variables change according to the presumed garment's style or type. So, the thread consumption value cannot be considered, in any case, as standard for sewn garment such as jean pants, shirts, and jackets.

Until now, to evaluate the sewing thread's amount required to stitch a garment and to predict it as a function of the most influential input parameters has been very difficult. The purpose of this study is to accurately determine the amount of sewing thread required to stitch a specific length of woven fabric using two different types of stitch, namely lockstitch (301) and chainstitch (401).

2 Materials and Methods

The characteristics of sewing thread as well as fabric samples used are given in Table 1. In fact, three different stitches/cm (N_S), three different assembly layers (N_L) and two types of stitches are considered for investigation. Besides, six different woven fabrics having different thickness (T_{hf}) and mass (M) were

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Table 1 — Denim fabric layer characteristics

Woven fabric characteristics	Woven fabrics					
	Fabric #1 Lining	Fabric #2 Flat	Fabric#3 Denim	Fabric #4 Denim	Fabric #5 Denim	Fabric #6 Denim
Weave pattern	Juxtaposed 3-thread twill and plain	3-thread twill	3-thread twill	3-thread twill	3-thread twill	3-thread twill
Composition	65%PES+ 35%CO	100% CO	100% Hemp	100% CO	100% CO	100% CO
M, g/m²	157	231	320	370	422	413
T_{hf}, mm	0.33	0.42	0 .53	0.68	0.81	0.88
Ends/cm	31	35	39	32	27	26
Picks/cm	42	33	22	22	19	18

M– Mass or weight of tested fabric, T_{hf}– Thickness of tested fabric.

selected and used to analyse their corresponding sewing thread consumption values. To discuss their contributions on the consumption behaviour, different woven fabric (light jeans, heavy jeans, lining and flat) thicknesses were stitched together and then unstitched. The needles (type *SHEMTZ* Nm 90 and Nm120), were used as a function of the varied thread thickness values to sew the overall assembled layers of woven fabrics for both lockstitch type 301 and chainstitch type 401. For quality reasons and appearance of stitching, the linear density of the needle thread was kept greater than that of the looper thread. Needle threads (Polyester) having 110tex and bobbin thread having 60tex yarn count were frequently used for woven fabrics, especially for denim ones. Hence, for both threads and fabrics, different inputs (N_S, N_L and T_{hf}) within their corresponding levels (non-equal) were varied according to experimental design (a mixture design type Taguchi) to widely analyse the overall contributions. It was elaborated using Minitab 14 software to determine the significant parameters and to classify their effects on the sewing thread consumption behaviour. This experimental design is called mixture, because it contains different inputs at different levels. Table 2 shows that all tested input parameters and their corresponding levels which are considered for both lockstitch type 301 and chainstitch type 401. The lowest input level is mentioned as level I and the highest as II or III, if the parameters have two or three different adjustments respectively. For example, in case of more than three levels for any input parameter, the highest value of this level is presented by the greatest number as in case of the T_{hf} parameter (Table 2).

To analyse the consumed thread and to obtain a good seam appearance, the same experimental adjustments, sewing machine conditions and relaxation are fixed and regulated, according to technical manufacture instructions[25-27]. Some researchers [28] suggested that to obtain good sewing quality appearance and to avoid seam puckering and deformation of a multi-layer seam surface, considering the thread tension puckering and the fabrics compression properties, different factors should be considered. For good stitch appearances and comparative tested values, sewing machines type *JUKI* lockstitch (*DLN-5410N*) and *JUKI* chainstitch type *MH-380*, within suitable adjustments were used. In fact, they are regulated and kept unchangeable for all experiment. In addition, the basic sewed length of all investigated woven fabric samples is kept constant (100mm) during all sewing steps. Therefore, the consumed thread values are relative to this length sample (X); which can be used further as basic and representative consumptions to determine the consumption value (C_X) for each part length of garment (l) by a simple conversion. This conversion, to determine the relative consumed lengths, is given by the following equation :

Table 2 — Studied inputs and their levels

Levels	Inputs		
	T_{hf}, mm	N_L (Layers)	Ns, stitches/cm
I	0.33	2	3
II	0.42	3	4
III	0.53	4	5
IV	0.68	-	-
V	0.81	-	-
VI	0.88	-	-

(-)–No level was considered.

$$C_X(\text{mm}) = \frac{X*l}{100} \quad \ldots (1)$$

where C_X is the converted consumption value regarding the presumed length of garment part; X, the basic consumption value relative to seamed length (100mm); and l, the seamed length of garment part.

Table 3 shows the characteristics of sewing needle and looper threads used to sew garment samples for both stitch types. The overall woven fabrics are sewn using fine and coarse polyester threads. In this regard, it suggested that the sewing polyester threads are required to seam both heavy and light denim fabrics[27]. Among the types of stitches, fabric assemblies in the different sewed parts of the garments (especially jean) were made in majority of cases using lockstitch (301) and thread's chainstitch (401). Indeed, around 57% of stitching range of jean pants is performed by both stitch types. In fact, lockstitch type 301 is formed by two threads viz a needle thread and an under-thread which are interlaced between the layers of fabric being sewn [Fig (1a)].

Figure 1 shows the geometry of the main stitch types and their appearance as sewn in denim fabric samples. Fabrics layers were seamed with different stitch densities such as 2, 3, 4 and 5 stitches/cm. To measure objectively the thickness values of different woven fabric samples, a tester type *Sodemat* TROYES (Standard: EN ISO 5084, NF G07-153, ASTM D 1777, ISO 3616/9073, BS 2544/3424/29073, ERT 30-4) was used. Each test was repeated 5 times; their CV% values were ranged from 0.80% to 2.54% and can be considered significant. The thickness parameter of the seamed layers is considered to be the most important and influential factor which affect the consumption value enormously. The experiment to stitch woven fabric specimens is repeated 10 times in order to obtain objective mean consumption values. Experimentally, the consumption of sewing thread (C_{st}) is also measured after unstitching carefully all assembled plies of fabric samples and then the sewed thread lengths are evaluated. The overall input contributions are investigated, compared and analysed. These contributions help to accurately understand the relationships between the consumed amount of sewing thread and the studied parameters based on their woven fabric effects. A multi-linear regression method and analysis of variance statistical tests were applied to discuss the effectiveness of the obtained correlations and findings. Comparative results with those using geometrical model, were analysed to select the best technique reflecting the reality of seamed garments.

Table 3 — Characteristics of sewing threads used for lockstitch (301) and chainstitch (401)

Sewing thread characteristics	Needle thread	Bobbin/looper thread
Twisted ends	2	3
Composition	PES (100%)	PES (100%)
Linear density, tex	110	60
Twist type	Z	Z

3 Results and Discussion

To analyse the effect of input parameter levels on the sewing thread consumption, a mixture factorial Taguchi design was applied for each stitch type. Based on each stitch type used, all tested parameters within their relative consumption values in the different combinations of the experimental design were discussed (Table 4). Figure 2 shows the evolutions of sewing thread consumption ($C_{st(301)}$) as a function of studied input parameters, in case of lockstitch type 301.

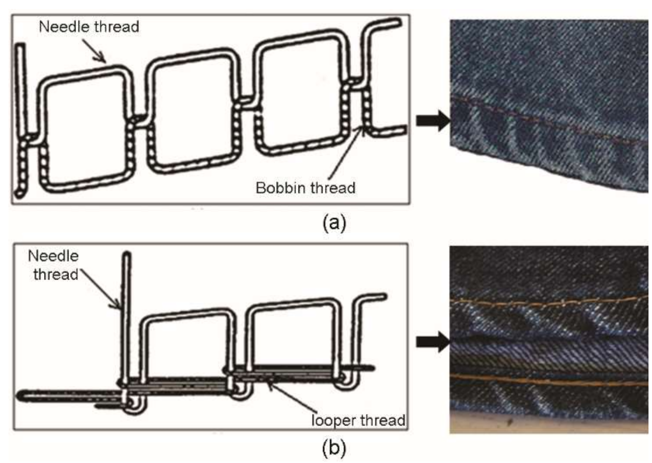

Fig. 1 — Examples of stitch geometry types within their structures from left to right on jean pant parts (a) Lockstitch type 301; and (b) Chainstitch type 401.

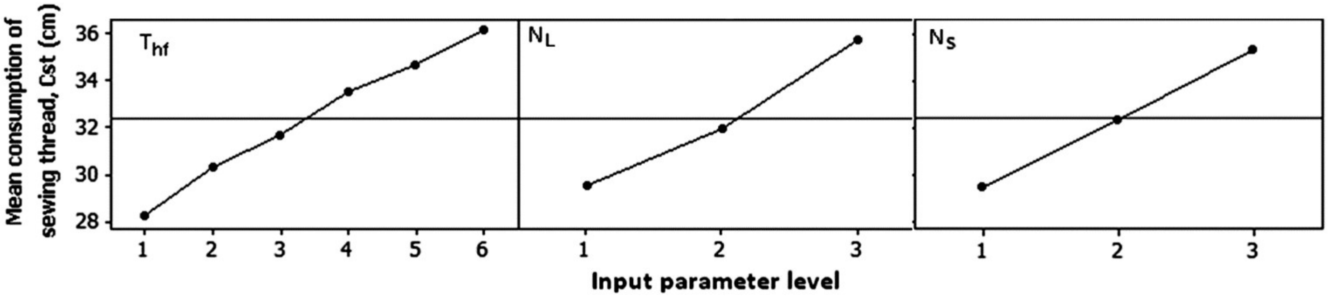

Fig. 2 — Main effects of studied inputs on consumption value as function of the input's level value variations in case of lockstitch type

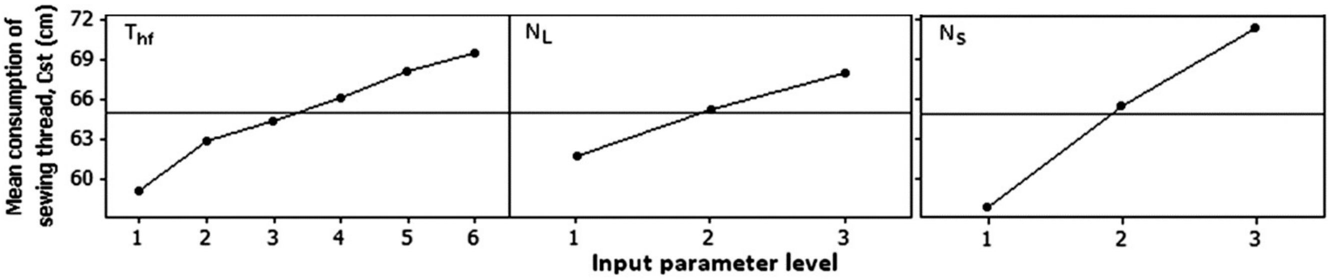

Fig. 3 — Main effects of studied inputs on consumption value as function of the input's level value variations in case of chainstitch type

Besides, it is observed that each input parameter affects the behaviour of consumed thread enormously. Indeed, the increase in each of the input level leads to a rise in amount of sewed thread (Table 4). The number of layers and the stitch increase the consumption values in denim fabrics. Hence, there is a much increase in consumption values with the increase in level of thickness parameter. It means that the thickness of fabric samples affects widely the consumed thread. This finding is in good agreement with the findings of other researchers[12-16]. However, regarding the number of layered thicknesses of all woven fabrics, the findings present a clear variation in consumption values, specially using chainstitch type 401 ($C_{st(401)}$). Figure 3 shows the overall evolutions of studied input parameters at different levels with respect to their corresponding thread consumption. Regarding the findings shown in Fig. 3, when the type of stitch is modified (increased or decreased), the consumption values are same for the same corresponding input parameters. Indeed, when all levels of inputs increase, the amount of sewing thread increases considerably using the chainstitch type 401. However, in 401, the contribution of overall inputs is low as compared to those obtained using lockstitch type 301. In spite of the contributions, which are different using these stitch types, the consumed thread is remained high for chainstitch type 401. Indeed, an increase in the value of consumed thread from 14.92% to 21.95% is observed when the level of T_{hf} parameter is varied from the lowest to the highest in case of lockstitch. In this regard, the change in levels of N_S and N_L causes an increase in the corresponding consumptions from 9.3% to 17.43% and from 16.41% to 18.8% respectively.

3.1 Statistical Analysis (Regressive Consumption Model)

Keeping in mind the statistical analysis results using Minitab software 14, good correlations are found between the sewn thread consumption and the studied inputs. Following equations are used to present the relationships between the consumed threads and the

Table 4 — Taguchi experimental design used for 301 and 401 stitch types

N° Test	T_{hf} mm	N_L Layers	Ns stitches/cm	$C_{st(301)}$ cm	$C_{st(401)}$ cm
1	0.33	2	2	22.75	49.30
2	0.42	2	2	23.60	51.11
3	0.53	2	2	24.10	52.00
4	0.68	2	2	24.65	52.65
5	0.81	2	2	24.85	55.03
6	0.88	2	2	25.30	54.90
7	0.33	2	3	24.60	50.46
8	0.42	2	3	24.96	53.84
9	0.53	2	3	26.64	53.77
10	0.68	2	3	28.50	55.50
11	0.81	2	3	28.96	58.29
12	0.88	2	3	30.54	57.65
13	0.33	2	4	25.20	55.00
14	0.42	2	4	25.55	58.68
15	0.53	2	4	27.35	63.11
16	0.68	2	4	29.35	62.40
17	0.88	2	4	32.25	66.30
18	0.81	2	4	30.25	64.10
19	0.33	2	5	27.86	60.10
20	0.42	2	5	27.50	63.20
21	0.53	2	5	29.80	65.50
22	0.68	2	5	32.50	69.35
23	0.88	2	5	35.50	72.60
24	0.81	2	5	32.50	69.25
25	0.33	3	2	23.70	50.68
26	0.42	3	2	24.20	52.77
27	0.53	3	2	25.50	54.75
28	0.68	3	2	26.50	56.71
29	0.88	3	2	28.00	58.37
30	0.81	3	2	27.20	57.73
31	0.33	3	3	25.00	52.84
32	0.42	3	3	26.60	55.78
33	0.53	3	3	28.50	56.98
34	0.68	3	3	30.10	59.57
35	0.88	3	3	31.30	62.53
36	0.81	3	3	30.00	61.04
37	0.33	3	4	27.50	57.20
38	0.42	3	4	28.80	62.83
39	0.53	3	4	30.70	64.45
40	0.68	3	4	34.20	67.93
41	0.88	3	4	36.00	72.22
42	0.81	3	4	35.50	71.23
43	0.33	3	5	29.50	64.10

(*Contd.*)

Table 4 — Taguchi experimental design used for 301 and 401 stitch types — *Contd*

N° Test	T_{hf} mm	N_L Layers	Ns stitches/cm	$C_{st(301)}$ cm	$C_{st(401)}$ cm
44	0.42	3	5	31.20	70.50
45	0.53	3	5	34.60	70.63
46	0.68	3	5	35.20	75.43
47	0.88	3	5	39.00	80.15
48	0.81	3	5	38.10	78.05
49	0.33	4	2	24.40	51.50
50	0.42	4	2	24.80	55.33
51	0.53	4	2	27.30	57.00
52	0.68	4	2	28.50	58.90
53	0.88	4	2	31.30	62.17
54	0.81	4	2	29.00	61.65
55	0.33	4	3	26.70	54.45
56	0.42	4	3	27.40	58.05
57	0.53	4	3	31.20	60.53
58	0.68	4	3	33.00	61.93
59	0.88	4	3	35.60	65.93
60	0.81	4	3	34.50	66.55
61	0.33	4	4	29.10	60.65
62	0.42	4	4	29.90	65.98
63	0.53	4	4	33.50	68.65
64	0.68	4	4	39.00	72.00
65	0.88	4	4	43.90	77.17
66	0.81	4	4	37.90	76.10
67	0.33	4	5	33.30	67.20
68	0.42	4	5	35.10	74.13
69	0.53	4	5	41.20	76.05
70	0.68	4	5	44.00	81.73
71	0.88	4	5	51.50	84.63
72	0.81	4	5	45.40	83.05

input parameters in case of both lockstitch and chainstitch types:

$$C_{st(301)} = 14{,}9 + 1{,}56\ T_{hf} + 3{,}12\ N_L + 2{,}90\ N_S \quad \dots (2)$$

$$C_{st(401)} = 38{,}2 + 1{,}98\ T_{hf} + 3{,}17\ N_L + 6{,}73\ N_S \quad \dots (3)$$

These equations can be used and applied for any sewing thread and fabrics when all tested inputs are especially ranged inside their limits of the experimental design of variation. In addition, a multi-linear regression method (RM) is clearly followed to objectively investigate these findings. Moreover, regarding high coefficient values, the prediction of consumed amount of thread seems reasonable. Indeed, the obtained R^2 coefficients of regression values explain the pertinence of fitting experimental results when they are close to 1. In fact, the good regression (R^2) values mentioned by statistical analysis for lockstitch and chainstitch thread consumptions are found 0.936 and 0.959 respectively. This indicates that the obtained model encourages prediction of the consumed thread, considering the total variation in sewing thread amount for the studied design of interest.

The contributions of the sewn thickness, the seamed layers of the unstitched fabric sample and the stitch length as function of stitch type have also been analysed. All these parameters reflect the significance of their corresponding inputs on the consumption behaviour. Thus, our findings can be useful as predictive models, helping industries to quantify their suitable amount of thread to seam their garments, based on the tested fabric specimens. In fact, this determination is still based on a simple conversion between the consumed thread relative to 100 mm (as a basic tested length of seam) and the desired lengths relative to garment part lengths [Eqs (2) and (3)]. For economic reasons, in terms of amount of thread, it is recommended to choose a low number of stitches/cm, ensuring a low quantity of sewn thread length for any seamed fabric. When the stitch length is increased from 4 stitches/cm to 5 stitches/cm, the consumption increases about 10%, which is in good agreement with findings of Lauriol[5]. Therefore, the increase in stitch length causes, in our present work, an increased value equals to 8.5% on the whole consumption value using 100 mm. Thus, it is logical that seaming fabrics using 5 stitches/cm consumes more thread length than using 3 stitches/cm only. By analysing Figs 2 and 3 along with the regression coefficient values, it may be concluded that the consumed sewing thread seems strongly correlated (R^2 value is ranged from 0.959 for lockstitch type 301 to 0.977 for chainstitch type 401) with the number of assembled fabric layers, thus prediction possibilities are significant and fruitful in the specific experimental interval. So, the variation in thread consumption, depending on the seamed layer numbers, is increasing, especially when the thickness increases. Hence, the greater the layer number the more is the consumption. At the industrial point of view, to measure accurately and estimate objectively the suitable consumption value, these findings are fruitful without hypotheses and approximations. Nevertheless, based on the all inputs effect values on the consumption, the most significant studied parameter is selected by classification of all the tested input parameters (Table 5).

The above findings show clearly that among all the tested inputs, the T_{hf} remains the most influential parameter in case of lockstitch consumption. However, it is the second one regarding the chainstitch type. In these cases, this parameter is a relevant factor which needs to be considered the most. This classification, reflects the relevance and the significance of this parameter compared to the others. The parameters N_L and N_S are classified as second and third influential inputs respectively in case of lockstitch type. In case of chainstitch type 401, T_{hf} and N_L are however, ranked as second and third influential parameters respectively. In contrast, with the results of classification given by Minitab software 14 in case of lockstitch type, N_S remains the most influential input in case of chainstitch type.

3.2 Influences of Different Inputs on Consumed Thread Behaviour

There is an average increase of 50% in thread consumption when the seamed fabrics are based on chainstitch type compared to those using a lockstitch one. This increase appears logical and reasonable due to the high chain or loops number, which exists and requires a large amount of thread in this kind of seam. This gives more extensibility rate for the seamed parts of garments. To analyse the variation in most important parameters, we have calculated their contributions ($Cont_p$), expressed by centimetre and converted in percentage ($Cont_p$ %) on the sewing thread consumptions (Table 6). High differences are observed as a function of studied parameters levels between lockstitch and chainstitch (Table 6). Besides, the Eq. (4) presents the calculated contributions relative to the tested fabrics according to their high ($C_{st_{HL}}$) and low level ($C_{st_{LL}}$) values. Eq. (4) is shown below:

$$Cont_p = \left(C_{st_{HL}} - C_{st_{LL}}\right) * 100/C_{st_{HL}} \quad \ldots (4)$$

Referring to the results shown in Table 6, it may be concluded that all inputs show high contributions as a function of stitch type. By comparing the contributions of input parameters, the lining and flat fabrics give the lower contributions as compared to denim fabric samples. In addition, the comparative denim fabric contributions on C_{st} values shows that the fabrics having high thicknesses (heavy fabrics) give the high thread consumption values. The T_{hf} parameter remained the most influential factor on the consumed thread of woven fabrics.

Table 5 — Classified input contributions on the sewing thread consumptions as a function of studied stitch types

Levels	T_{hf}		N_L		N_S	
	301	401	301	401	301	401
I	28.20	59.07	29.52	61.67	29.53	57.97
III	30.30	62.83	31.97	65.22	32.37	65.50
III	31.67	64.30	35.75	68.00	35.33	71.42
IV	33.53	66.03	-	-	-	-
V	34.63	68.10	-	-	-	-
VI	36.13	69.43	-	-	-	-
Delta	7.93	10.37	6.23	6.33	5.80	13.45
Rank	1	2	2	3	3	1

Delta– The difference between the consumption of the highest level and that corresponding to the lowest level.
Rank– A classification made by Minitab software to put in order all the study prioritized influence on consumption of sewing thread factors.
(-)– No value mentioned.

Table 6 — Contributions relative to the influential inputs on the consumed sewing thread values for lockstitch (301) and chainstitch (401)

Contributions $Cont_{N_L}/Cont_{N_S}$	N_S	N_L	Stitch type	$T_{hf1} = 0.33$	$T_{hf2} = 0.42$	$T_{hf3} = 0.53$	$T_{hf4} = 0.68$	$T_{hf5} = 0.81$	$T_{hf6} = 0.88$
$Cont_{N_{L1}}(Cont_{N_{L1}}\%)$	2	-	301	1.65 (6.76)	1.2 (4.84)	3.2 (11.72)	3.85 (13.5)	4.15 (14.3)	6 (19.1)
			401	2.2 (4.72)	4.22 (7.63)	5 (8.77)	6.25 (10.6)	6.62 (10.74)	7.27 (11.69)
$Cont_{N_{L2}}(Cont_{N_{L2}}\%)$	3	-	301	2.1 (7.87)	3.4 (11.97)	4.2 (13.46)	4.6 (13.94)	5 (14.71)	5.3 (14.89)
			401	2.5 (4.66)	4.6 (7.93)	5.1 (8.56)	6.9 (11.06)	7.3 (11.59)	10.2 (15.4)
$Cont_{N_{L3}}(Cont_{N_{L3}}\%)$	4	-	301	3.9 (13.40)	5.4 (16.93)	6.2 (17.71)	7.4 (19.53)	8.5 (21.52)	9 (21.95)
			401	4.9 (7.95)	5.6 (8.72)	6.3 (9.36)	7.2 (10.16)	8.3 (11.4)	9 (12)
$Cont_{N_{L4}}(Cont_{N_{L4}}\%)$	5	-	301	5.6 (16.82)	8.7 (23.45)	10.5 (25.5)	12.6 (27.9)	13.5 (28.7)	14.4 (22)
			401	6 (8.96)	8.2 (11.31)	8.7 (11.63)	11.8 (14.8)	12.5 (15.3)	14.3 (16.6)
$Cont_{N_{S1}}(Cont_{N_{S1}}\%)$	-	2	301	5.11 (18.34)	3.9 (14.8)	5.7 (19.12)	7.85 (24.2)	7.65 (23.54)	10.2 (28.73)
			401	10.8 (17.9)	12.1 (19.13)	13.5 (20.6)	16.7 (24.1)	14.22 (20.5)	17.7 (24.4)
$Cont_{N_{S2}}(Cont_{N_{S2}}\%)$	-	3	301	5.8 (19.66)	7 (22.44)	9.1 (26.3)	8.5 (24.15)	10.9 (28.6)	11 (28.2)
			401	13.4 (20.94)	17.73 (25.2)	15.88 (22.5)	18.7 (24.8)	21 (26.9)	21.8 (27.2)
$Cont_{N_{S3}}(Cont_{N_{S3}}\%)$	-	4	301	8.9 (26.7)	10.3 (29.35)	13.9 (33.74)	15.5 (35.2)	16.4 (36.12)	20.2 (39.22)
			401	15.7 (23.4)	18.83 (25.4)	19 (25)	22.83 (28)	21.4 (25.8)	22.46 (26.5)

Woven fabric thickness (T_{hf}), mm

$Cont_{N_{L1}}(Cont_{N_{L1}}\%)$, $Cont_{N_{L2}}(Cont_{N_{L2}}\%)$, $Cont_{N_{L3}}(Cont_{N_{L3}}\%)$, $Cont_{N_{L4}}(Cont_{N_{L4}}\%)$ — Contributions relative to the difference between four and two seamed fabric layers of sewn thread consumptions.

$Cont_{N_{S1}}(Cont_{N_{S1}}\%)$, $Cont_{N_{S2}}(Cont_{N_{S2}}\%)$, $Cont_{N_{S3}}(Cont_{N_{S3}}\%)$ — Contributions relative to the difference between five and three stitches per centimetre of sewn thread consumptions for two, three and four seamed fabric layers.

This finding is true for all the studied fabric thicknesses. Moreover, our findings show that the contribution of number of seamed fabric layers on the C_{st} is ranged from 6.76% (for lining fabric) to 19.1% (for denim fabric) under the same sewing conditions (lockstitch type 301 settle on 2 stitches/cm). In addition, it range from 4.72% (for lining fabric) to 11.62% (for denim fabric) when the chainstitch type 401 is applied using 2 stitches/cm. However, the contributions relating to the stitch density input range from 18.34% (for lining fabric) to 28.73% (for denim fabric) for lockstitch type 301 in case of two seamed fabric layers; and from 17.9% (for lining fabric) to 24.4% (for denim fabric) using the chainstitch type 401 within two seamed fabric layers. These non-negligible increased values reflect that the number of assembly layers affects widely the mean consumed thread during seaming process. By analysing the $Cont_{N_S}$ and regression coefficients, we find that the consumption of sewing thread is strongly correlated with N_S for any number of assembled fabric layers. Furthermore, the finding of $Cont_{N_L}$ shows that the C_{st} is much affected by the N_L parameter using any stitch density. Thus, these contributions remain important for the consumption of sewing thread and confirm the significance of all studied inputs. As a consequence, the consumption value of thread during lockstitch and chainstitch type remains influenced accurately by the variation of tested inputs with their highly significant effects. In addition, based on the results summarized in Table 6, following two main and essential remarks should be mentioned and discussed:

(i) According to the overall results, the increase in seamed layer numbers or fabric thickness increases, undoubtedly, the C_{st} value using any type of stitch and independently of the N_S; and

(ii) Our results show that there is no constant value of $Cont_{N_L}$, when N_L's levels is changed using the same T_{hf} and for any N_S level value. However, the contribution of N_L should be kept the same, in spite of the variation in level value of N_S parameter. To explain this paradox, the layered fabrics and the extension of sewed thread after seaming step have been studied for their participation enormously on the consumption values.

Machine and process factors such as the compressibility of fabric and thread, and the combination of fabric and thread, the dimensional and the surface characteristics of sewing thread parameters affect the value of consumed thread. Moreover, the deformation and internal stresses should be controlled and kept constant to objectively study all fabric weights and thread types in order to ensure an accurate value of consumed sewing thread. Since the fabric undergoes deformation due to the applications of stress in the making up process, mechanical properties of the fabric play an important role in the study of sewability[29]. In most studies, this kind of factors is usually neglected or supposed geometrically due to some presumptions used, to facilitate quantification of the suitable amount of sewing thread.

3.3 Comparative Results using Geometrical Model (GM)

To improve our results obtained using the Taguchi analysis method, three added denim fabrics are investigated. The experimental findings of consumption (C_{stexp}) are compared with the theoretical ones (C_{sttheo}) using the regression equations and the mathematical formula determined geometrically. The amount of sewing thread C_{st301} needed for the 301 lockstitch, whose geometry is represented previously in Fig. 1(a), is estimated by the following formula:

$$C_{st301} = C_{sta} + C_{stb} \quad \text{... (5)}$$

where C_{sta} is the consumption of needle thread; and C_{stb}, the consumption of bobbin thread,

$$C_{sta} = L(1 + 2ne + nd(\pi - 1) \quad \text{... (6)}$$

$$C_{stb} = L(1 + 2ne + nd(\pi - 1) \quad \text{... (7)}$$

where L is the sewing length; n, the stitch density (stitch number per centimetre); e, the fabric thickness; and d, the presumed diameter of thread.

The amount of sewing thread C_{st401} needed for the 401 chainstitch, whose geometry is represented previously in Fig. 1(b), is estimated by the following formula:

$$C_{st401} = (C_{sta} + C_{stl})nL \quad \text{... (8)}$$

where C_{stl} is the consumption of looper thread

$$C_{sta} = \frac{1}{n} + 4e + d(\pi + 1) \quad \text{... (9)}$$

$$C_{stl} = \frac{3}{n} + 2d(\pi - 1) \quad \text{... (10)}$$

According to Seyam[30], to obtain the d value in centimetre, the following expression of the yarn diameter is used:

$$d(cm) = \frac{1}{251.37}\sqrt{T_{Tex}} \quad \text{... (11)}$$

The differences, relative to each studied parameter (Err_p), between these consumption values for each tested fabric have been calculated and discussed. The expression of the calculated difference for thickness (Err_{th}) parameter is given below:

$$Err_{th}(\%) = 100 \times \frac{C_{sttheo}-C_{stexp}}{C_{stthe}} \quad \dots (12)$$

Using the same error expression, it is observed that the difference between theoretical, C_{sttheo} [(using regressive or statistical model ($C_{st\,RM}$) and geometrical model ($C_{st\,GM}$)] and experimental (C_{stexp}) consumption values relative to fabric layer using the regression models is considered low (Table 7). Experimental tests are repeated 10 times to obtain objective mean values (their CV%< 5%) of the measured C_{st}. By comparing our regressive method (based on statistical analysis) results and those obtained using the geometrical model, it may be concluded that non negligible difference values are obtained. This finding is explained by the deformation caused by many factors, as mentioned in literature survey[31]. Mousazadegan *et al.*[31] proved that during a sewing process, thread is fed to the sewing machine under a controlled tension, which leads to sewing thread extension. Because of the relaxation process, the sewing thread tends to contract to its initial length according to its elastic strain. Hence, an inner compressive force is generated in the sewing thread, which, in turn, exerts an in-plane compressive force on the fabric in each stitch length. This difference on geometric shape of the seamed layered thicknesses causes the difference in the value of consumed thread using theoretical model. To develop the geometrical models, they considered the shape of seam line as non-deformable shape. However, the fabric structures are deformable, and compressive materials and their shapes during and after seaming should be taken into account, normally to calculate adequately the suitable

Table 7 — Contributions relative to the influential inputs on the consumed sewing thread values for lockstitch (301) and chainstitch (401)

N_L	N_S/T_{hf} (mm)	Stitch type	Denim fabric (100% Cotton)						Errortheo, %					
			C_{stexp}, cm			C_{sttheo}, cm			$T_{hf}=0.71$		$T_{hf}=0.73$		$T_{hf}=0.86$	
			$T_{hf}=$ 0.71 (CV%)	$T_{hf}=$ 0.73 (CV%)	$T_{hf}=$ 0.86 (CV%)	T_{hf} = 0.71	T_{hf} = 0.73	T_{hf} = 0.86	RM	GM	RM	GM	RM	GM
2	2	301	27.4 (3.12)	27.2 (2.76)	27.5 (1.7)	28.04	28.1	28.3	2.28	20.26	3.20	21.55	2.83	25.19
		401	57.7 (4.5)	57.2 (2.9)	58.3 (4.83)	59.4	59.44	59.7	2.86	3.7	3.77	2.22	2.35	0.45
	3	301	30 (4.46)	30.5 (2.01)	32 (3.39)	30.95	30.98	31.18	3.06	28.05	1.55	27.68	2.62	29.35
		401	64.6 (1.96)	65 (2.41)	65.5 (1.17)	66.14	66.18	66.43	2.33	2.38	1.78	2.48	1.40	6.12
	4	301	33 (2.75)	33.4 (3.0)	34.5 (3.35)	33.85	33.88	34.08	2.50	32.55	1.41	32.61	1.23	35.78
		401	70.5 (1.26)	71 (1.47)	73.8 (0.86)	72.87	72.91	73.16	3.25	5.87	2.61	6.00	0.87	7.40
	5	301	35 (2.81)	36 (2.52)	36.2 (1.66)	36.75	36.78	36.98	4.76	37.67	2.12	36.79	2.11	41.76
		401	76.5 (1.7)	77.3 (1.46)	78 (1.51)	79.60	79.64	79.89	3.89	8.51	2.93	8.43	2.37	12.97
3	2	301	29.7 (3.26)	30.5 (2.81)	29.1 (2.3)	31.17	31.2	31.4	4.72	25.81	2.24	24.73	7.32	33.32
		401	60.5 (3.5)	61.6 (1.75)	62.15 (3.1)	62.57	62.61	62.87	3.31	1.34	1.61	0.32	1.15	4.27
	3	301	32.8 (2.03)	33.2 (2.39)	35 (1.82)	34.07	34.10	34.30	3.72	34.68	2.64	34.82	2.04	37.07
		401	67.7 (1.05)	68.3 (1.04)	70.2 (1.43)	69.31	69.35	69.60	2.32	9.36	1.51	9.43	0.86	12.35
	4	301	35.4 (3.06)	36.5 (2.54)	38 (2.79)	36.97	37.00	37.20	4.24	41.28	1.35	40.40	2.15	43.69
		401	75.5 (1.16)	76 (0.89)	78.5 (0.77)	76.04	76.08	76.33	0.70	12.47	0.10	12.86	2.84	16.00
	5	301	38.9 (2.12)	39.7 (2.68)	41.4 (2.08)	39.87	39.90	40.10	2.43	44.71	0.50	44.52	3.24	47.83
		401	81.5 (2.17)	82.9 (1.25)	84 (1.06)	82.77	82.81	83.06	1.53	16.68	0.11	16.28	1.13	21.36
4	2	301	32,6 (2.12)	33 (3.71)	33.5 (2.5)	34.28	34.31	34.52	4.9	28.7	3.82	28.82	2.95	33.68
		401	63,6 (4.3)	63 (2.89)	64.1 (1.77)	65.75	65.79	66.04	3.27	5.07	4.24	6.86	2.94	10.72
	3	301	37 (1.51)	37.5 (2.6)	39 (1.86)	37.19	37.22	37.42	0.50	37.00	0.76	37.18	4.22	40.85
		401	70 (1.35)	70.5 (1.32)	74 (1.28)	72.48	72.52	72.77	3.42	15.88	2.78	16.24	1.69	18.15
	4	301	40.2 (3.75)	40.8 (2.79)	42 (3.14)	40.09	40.12	40.32	0.28	43.89	1.70	44.05	4.16	48.30
		401	77.5 (1.04)	78.3 (0.93)	81.6 (2.47)	79.21	79.25	79.50	2.16	20.61	1.20	20.83	2.64	23.89
	5	301	43.7 (0.92)	44.3 (2.44)	45.2 (1.43)	42.99	43.02	43.22	1.66	48.32	2.98	48.58	4.58	53.19
		401	85.8 (0.83)	86.2 (0.7)	87.5 (0.98)	85.94	85.98	86.23	0.16	23.41	0.26	24.13	1.47	29.45

$\mathrm{Error_{theo}}$ — Error values which determined between the regression or geometrical and experimental consumptions relatives to different thicknesses using 2, 3 and 4 layers.

$\mathrm{C_{stexp}}$ and $\mathrm{C_{sttheo\ RM}}$ — Experimental and theoretical RM (regression model) consumptions of sewing thread.

consumption value. According to our results, non-negligible differences are ranged from 20.26% to 53.19% between theoretical and experimental consumptions. In contrast with the developed models, experimental evaluation and statistical models present more effectiveness measure of the consumed thread to seam garment. This effectiveness superiority is explained by some factors such as seam elasticity and flexibility which should be considered during the evaluation of consumed amount thread without any presumptions to be considered in these kinds of geometrical modelling methods. Moreover, thread tension and fabric compression modulus determine seam profile, affecting compressive energy (stored in fabric) during sewing process. Although sewing thread takes a slight space in a seamed fabric, as it has been demonstrated that the physical and mechanical properties of sewing threads affect the seam appearance of fabrics. Sewing thread tensile behaviour under low load applied on the thread during sewing process, affect its contraction after sewing and accordingly seam pucker formation and their amplitudes.

Therefore, considering the sewn thread consumption values given in Table 7, it may be concluded that for tested woven fabrics, the theoretical consumptions using both lockstitch type 301 and chainstitch type 401 have been evaluated widely as a function of T_{hf}, N_L and number of N_s parameters using different techniques. Assimilations among statistical, geometrical and experimental results (Table 7) are important to be mentioned in order to understand the lack of efficiency and accuracy of theoretical results to those practical, because they do not consider several parameters that can affect the result. Nevertheless, the predicted values of consumption of sewing thread using the developed regression models appear more acceptable. Otherwise, their error values prove their effectiveness to objectively estimate the amount of sewing thread as a function of all studied inputs in the specific area of interest.

Some added fabrics are tested to measure the length of consumed thread. Hence, findings improve our results mentioned above and reflecting that these developed relationships can be used by industrials to predict and help accurately their suitable amounts of sewing thread. Moreover, to decrease the error values between theoretical consumptions, using the geometric stitch shapes, and the experimental or regressive ones, the tensile properties of fabrics and threads should be considered along with the compressive stresses and the deformability of seamed fabrics. This appears in good agreement with the earlier results, indicating that these parameters are the most important factors for denim fabrics sewability especially.

4 Conclusion

Three influential input parameters have been investigated to evaluate their contributions on the mean sewed thread consumption of woven fabrics using two different stitch types (301 and 401). The application of the statistical method helps to determine the amount of thread consumed using regression method by statistical analysis. According to Taguchi design results, the effectiveness of studied parameters and the regression technique are improved and discussed. Based on the obtained results, high significant correlations between input parameters and the consumed sewing thread values are obtained. Due to the coefficients of regression values, which are high and close to 1, the consumption value in each stitch type is predictable accurately for the specific design of interest. The findings show that among these tested input parameters, the stitch type remains the most important one in the case of chainstitch. In case of lockstitch type, the fabric sample thickness is found the most influential input parameter. However, the variation in stitch type input level encourages considerably the behaviour of the mean thread consumptions, which can be minimized if these influential factors are adjusted in their lowest levels. By comparing all theoretical and statistical consumption values as a function of input parameters, it may be concluded that the regressive method gives more accurate results. Using the established geometrical models, both compressibility and deformability of sewing thread and fabrics are not considered widely. Besides, some internal stresses and extensions of fabrics and sewed thread explain the difference between experimental and theoretical values. This allows us to understand the high error values, found in the sewing thread of garments, especially jean pants.

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