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Study of 504-overlock Three Stitch Consumption using Statistical and Geometrical Methods

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Abstract:

This study highlights an evaluation of the consumption values of 504-overlock three-stitch of using statistical and geometrical calculation methods. Based on mixed Taguchi analysis and linear regression method, the consumed lengths using 504-overlock three-stitch are widely evaluated as function of studied influential factors. In fact, a database is used and basic geometry parameters of the 504-overlock three-stitch are conducted to evaluate and discuss the contributions of all input parameters on the sewing thread consumption of woven fabric samples. In this study, to calculate geometrically the consumed amount, some influential input factors are considered. However, some assumptions are taken in account to enormously facilitate the derived consumption. Findings show that, the increase of the seamed thickness of fabric enormously encourages the consumption value of the sewed 504-overlock three stitch. Thanks to both statistical and geometrical analysis, good relationships between the tested factors and the thread consumption value have been proposed and proved. Furthermore, accurate correlations are obtained between consumption of sewing thread and the thickness (R^2 ranged from 0.84 to 0.91) and mass of fabric (R^2 ranged from 0.933 to 0.9612) respectively. In addition, compared to experimental consumption values, the proposed geometrical model predicts the thread consumption with 98.26% accuracy against 90.4% only for the linear regression method. The proposed model can predict the thread consumption sufficiently for 504-overlock three stitch and helping industrials to provide their suitable thread amounts before sewing.

Keywords: *Geometrical consumption; Unstitching length; 504-overlock three stitch; Looper thread; Statistical method.*

1. Introduction

Undoubtedly, the suitable sewing thread consumption value to sew garment helps enormously industrials to predict exactly the suitable number of sewing thread bobbin before starting the sewing steps. In fact, due to the increase of the cost of sewing thread, its breakage numbers and strength loss in threads during high-speed industrial sewing [1-2] it seems reasonable to minimize the consumed thread needed to sew garment. Moreover, knowing the consumption rates could help to avoid stock in the company, to anticipate a probable risk of stock-out of the sewing thread during manufacturing [3].

Although the majority of garments contain different parts, which are seamed using the overegged stitch types, there are few studies that have dealt with the consumptions based on these stitches. Regarding the literature survey, different works related to consumption behaviour were conducted except from those based on the overegged stitches [4]. studied the possibility of an innovative device for bobbin thread consumption measurement on industrial lockstitch sewing machines. Hence, in their study they depict an overview of the used technique given within particular interests to the quantification of bobbin thread consumption in lockstitch machines. Abeysooriya and Wickramasinghe, Rasheed et al., Mukhopadhyay and Jaouadi et al.

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[3, 5, 6-7] while studying the consumption of sewing thread for lockstitch (301), they used a geometrical modelling and a regression analysis. They also studied the effect of two different types of stitches viz, lockstitch (301) and chain stitch (401) at the seam of trousers for the military armed forces. In fact, the investigated performances of both chain and lockstitch types are reported and compared.

Recently, the consumption have been studied using different methods as function of some sewing parameters and their impacts on the consumed thread [6, 8-15]. However, until today, there are no statistical and geometrical models giving exactly the consumption of sewing thread in the garment factories except for the compared regression and theoretical calculation of the consumption using the fuzzy theory or neural networks [4, 16, 17]. In fact, all previous researchers have studied problems in already existing thread consumption calculation methods; i.e. limitations in existing formulae, which cause inaccurate predictions of consumed sewing thread lengths needed for sewing steps [4].

In this present study, we made a comparison between statistical and geometrical consumptions of sewed thread using the 504-overlock three-stitch as function of influential input parameters: fabric thickness, number of fabric layers, seam length, sewing thread's diameter, sewing width and number of stitch per centimetre. Therefore, due to the stitch structure complexity and the high number of influential inputs, some assumptions are considered to objectively depict the consumed stitch length. It enables thus to accurately facilitate to industrialize the consumption calculation using the most efficient derived and computed model.

2. Material and Methods

Six different woven fabrics within their characteristics were selected and tested to investigate their correspondent sewing thread consumption values ($CST_{(504)}$) based on 504-overlock three-stitch. Actually, four denim fabrics within different properties and two other woven ones (flat and lining) were tested in order to objectively evaluate the consumptions.

Table 1. Studied denim fabric layer characteristics.

Woven fabric characteristics	Woven fabrics					
	Fabric #1	Fabric #2	Fabric #3	Fabric #4	Fabric #5	Fabric #6
Type	lining	Flat	denim	denim	denim	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
F_{th} (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

Table 1 shows these fabrics and their physical characteristics used in our experimentation. In fact, to evaluate statistically the consumption of sewed three-thread 504-overlock three-stitch ($CST_{(504)}$), two input parameters were tested as well as their contribution values. Hence, the number of fabric layers (N_L) and the thickness of woven fabric sample (F_{th}) represented our tested inputs in this work. Their levels and adjustments were tackled on Table 2.

Table 2. Studied inputs and their levels.

Levels	Inputs	
	F_{th} (mm)	$N_L(Layers)$
I	0.33	1
II	0.42	2
III	0.53	3
IV	0.68	-
V	0.81	-
VI	0.88	-

To investigate and analyse each input contribution when level is changed, a mixed Taguchi design was elaborated using Minitab software. As a matter of fact, when the level value equals to I, it means the minimum value of the relative parameter. However, the maximum level value is represented by II if the relative parameter has, for example, two different levels only. Otherwise, the highest value of level represents the maximum parameter value used to regulate it in the experimentation (see Table 3). In our case, the level VI indicates the maximum number of the tested fabric thicknesses are used in the present work. Therefore, the level III represents the highest level relative to the number of layers parameter, because in practice it represented the maximum number of the assembled fabric thicknesses using the 504-overlock three-stitch. The overlock stitches important classes for functional clothing [15], are classified as one of the most extensible stitch type due to used number of threads during the stitching step. Regarding this number, industrial overlock machines can be called using 1, 2, 3, 4, or 5 thread formations.

Table 3. Taguchi design used for experimentation.

Input parameters	
F_{th}	N_L
0.33	1
0.33	2
0.33	3
0.42	1
0.42	2
0.42	3
0.53	1
0.53	2
0.53	3
0.68	1
0.68	2
0.68	3
0.81	1
0.81	2
0.81	3
0.88	1
0.88	2
0.88	3

By comparing the stitch operation, each of these formations has unique uses and benefits as well. For example, 1-thread formations are used for end-to-end seaming, or ‘butt-seaming’. However, two- and three-thread formations, also known as ‘merrowing’, are the most common, used for edging and seaming, especially on knitted and woven fabrics. Therefore, four-thread formations are called mock safety stitches and create extra strength while retaining flexibility. Finally, 5-thread formations, where 2 needles are used, are called safety stitches, creating a very strong seam used, especially, for device manufacturing. The 504-overlock three-stitch is widely used in the manufacture of jeans pants and other articles, as well as the lockstitch and chain stitch. Because the geometry of the overlock stitch implies more sewing yarn contact with the cloth (the yarn penetrates and surrounds the edge of the fabric), the effect of the raw material will be clearer sewn and facilitates the analysis of the relationship between consumption of sewing thread and characteristics of the fabric sewn. Hence, the characteristics of sewing threads for both needle and loopers (upper and lower looper) used to produce garment samples are given by Table 4.

Table 4. Characteristics of sewing threads used for overegged three-thread (504).

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

Before and after stitching the specimens, all experimental conditions are regulated and adjusted as recommended by Brother FB-N110-3020-05-S3F industrial 3 thread overlock sewing machine manufacturer instructions to obtain good sewing quality appearance. This sewing machine was performed to seam both thin (heavy) and thick woven fabrics. Its maximum speed of stitching is 1300 stitch per minute. In addition, each stitch length can be adjusted from 2mm to 4mm within a width ranging from 2.3mm to 7mm. Our stitch to sew fabric samples is type SCHEMETZ 130/705H.

It is notable that, the sewing thread to sew woven fabric samples within length equals to 100mm as well as the sewing machine adjustments are kept constant to guarantee the same experimental conditions for overall tested specimens [4, 17, 18]. Overall combinations were performed, adjusted to the manufacturer’s recommended standard settings and repeated 10 times to have significant results within a low coefficient of variation (under 5%). In contrast with the choice of Webster’s study [19], the number of seamed layers is varied from 1 to 3. All consumption values determined in this work are relative to this length (100mm) using the same seaming machine conditions. Experimentally, the consumption of sewing thread ($CST_{(504)}$) value is measured after unstitching carefully all assembled layers of fabric specimen lengthening 100mm and then the sewed thread lengths are evaluated. In fact, knowing the consumption value relative to length 100mm, allows us enormously to know the amount of sewing thread per garment as have been studied in others works [14-18].

Figure 1 shows the 504-overlock three-stitch geometry structure. Figures 2a, 2b and 2c show the different stitching situations relative to 1, 2 and 3 layers respectively of seamed fabric samples along the length previously mentioned using stitch length equals 3 stitches per centimetre with a seam width of 5mm.

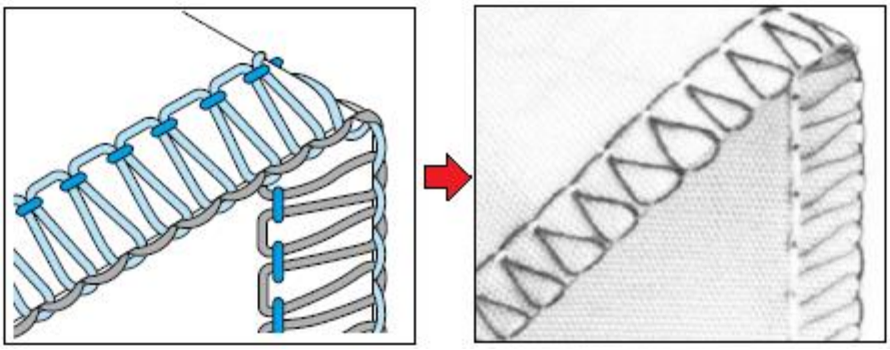

Figure 1. Stitch geometry type: in three-thread overegged stitch structure (504).

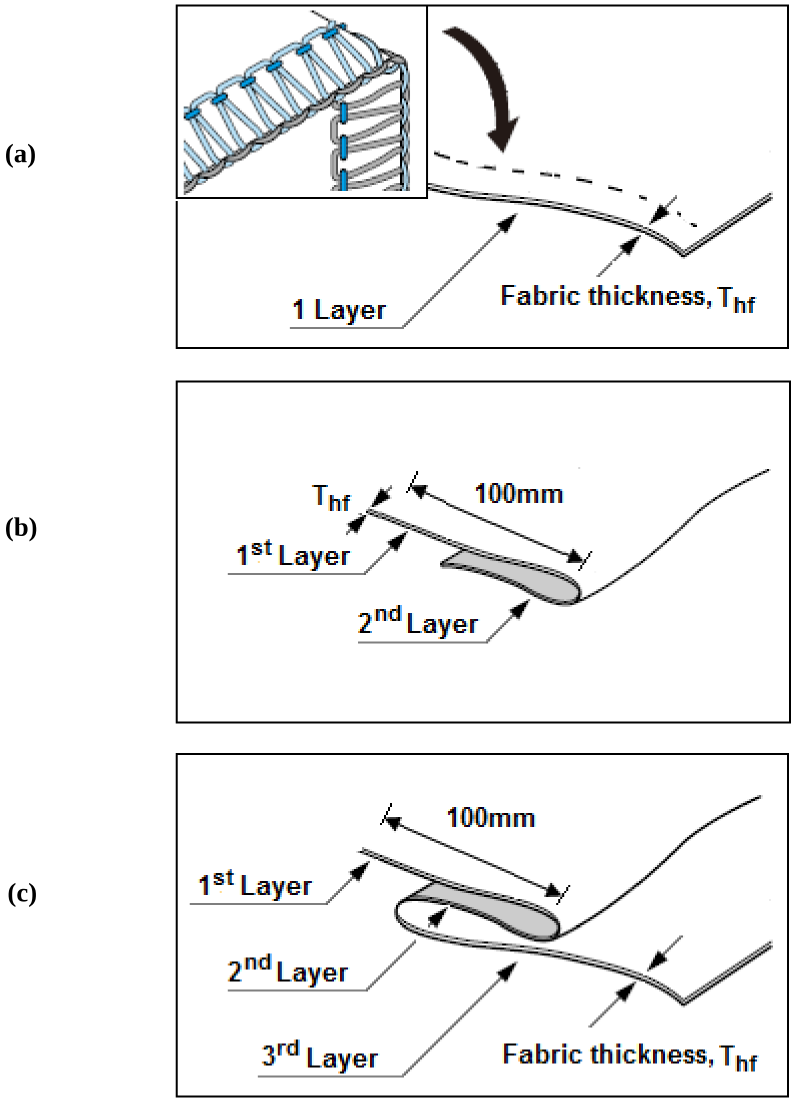

Figure 2. Different stitching situations relative three-thread overegged stitch type 504; (a) Using one layer; (b) Using two layers and (c) Using three layers.

The contributions of the thickness of fabric samples, the number of layers stitched and the mass of fabrics were investigated and analysed. These contributions help to understand the relationships between the consumptions and the studied inputs to select them based on their woven fabrics influences. A linear regression method was applied to improve the effectiveness of the obtained correlations. Furthermore, for the geometrical calculation work, not all the input factors that may influence the stitch length were considered and some assumptions were taken in stitch length calculation of the study. For example, in the case of the geometrical model of lockstitch type 301, Rasheed et al. [5] are assumed that the yarns are perfectly circular and incompressible. Besides, some other studies considered different of proposed models are elliptical stitch model [13], 3D rectangular stitch model, rectangular stitch model [21] and lock stitch model [8] to make the stitch length calculation easier. In fact, for the geometrical calculation work, the database used of input parameters is the fabric thickness(F_{th}), the stitch density expressed by stitch number/cm(N), the yarn linear density(Y_{ld}), the sewing length(S_L), the sewing width(S_w) and the thread diameter($d = D_N = D_U = D_L$). According to me recent studies [6, 21-22], sometimes, threads having same count are used, while in some cases, threads having different counts are also used. Besides, during our experimental analysis of consumed thread, the consumption values were measured by unstitching the seam accordingly to the French Standard NFG07101. We used this abbreviation during this study.

$CST_{(504)}$: Consumption of Sewing 504-overlock three-stitch,

$CST_{(N_{th})}$: Consumption of Needle thread,

$CST_{(U_{lt})}$: Consumption of Upper looper threads,

$CST_{L_{lt}}$: Consumption of Lower looper threads,

3. Results and Discussion

3.1. Taguchi Analysis and Linear Regression Results

To investigate the effect of the sewn thickness variations of the unstitched fabric and seamed layers of the same fabric samples on the consumption of sewing thread, the experimental Taguchi design was applied. The obtained findings using Minitab software show that there is a good relationship between the consumption value and the studied input parameters for the all woven fabric samples. Nevertheless, to improve the obtained findings, the regression analysis yielded coefficients of each parameter as well as the constant term, from which we obtained the Taguchi design analysis as shown in both Equations 1 and 2 within the coded and coded forms respectively.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ ... + \beta_k x_k + e \tag{1}$$

where

y is the response (in our case it is the consumption of sewing thread,$CST_{(504)}$, value) or studied output, x_i is the predictor or input parameter (in our case it is the $F_{th}$and N_L).

β_i represents the population regression coefficients where i is ranged from 0 to k is the maximum number of inputs studied.

e is the error term.

$$CST_{(504)} = 86.55 + 3.41F_{th} + 7.98N_L \tag{2}$$

We calculated the values of overall correlation coefficients (see Equation 3) by dividing the sum of squares error values due to regression (SS_{error}, see Equation 4) by the total sum of squares (SS_{tot}, see Equations 5-7) as shown in Table 4.

An R^2value of $CST_{(504)}$ of 0.904 indicates that this model can explain widely the total variation in the sewing thread consumption.

$$R^2 = 1 - (SS_{error}/SS_{tot}) = 1 - (SS_{regr}/SS_{tot}) \tag{3}$$

where

SS_{error}: The portion of the variation, which not explained by the model and is attributed to error. It calculated according to Equation 4:

$$SS_{error} = \sum(CST_{(504)} - \widehat{CST_{(504)}})^2 \quad (4)$$

SS_{regr}: The portion explained by the linear regression model. To calculate it, we used this formula given by Equation 5.

$$SS_{regr} = \sum(\widehat{CST_{(504)}} - \overline{CST_{(504)}})^2 \quad (5)$$

SS_{tot}: The sum of squared distances represents the total variation in the experimental data according to these relationships (see Equations 6 and 7 respectively).

$$SS_{tot} = SS_{reg} + SS_{error} \quad (6)$$

$$SS_{tot} = \sum\left(\widehat{CST_{(504)}} - \overline{CST_{(504)}}\right)^2 + \sum\left(CST_{(504)} - \widehat{CST_{(504)}}\right)^2 = \sum\left(CST_{(504)} - \overline{CST_{(504)}}\right)^2 \quad (7)$$

Hence, in the selected experimental design of interest, the consumption of sewing thread can be predicted following the high coefficient of regression (close to 1) obtained. Moreover, the probability of obtaining a statistic test that is at least as extreme as the actual calculated value, if the null hypothesis is true. In addition, it is used in hypothesis tests to help decision whether to reject or fail to reject a null hypothesis. A commonly used cut-off value for the P-value is 0.05. Regarding the high values of R^2(close to 1), it may be concluded that good correlations between experimental results and those using elaborated models proved the effectiveness of the established relationship mentioned above. Therefore, and based on these results, it may be possible to predict the behaviour of the consumed thread during stitching step. Besides, the predictive values of inputs on the consumed sewing thread ones are significant in the experimental design of interest and can be considered widely to minimise the quantity of sewing thread to sew garments. Based on the high coefficient of regression value, which reflects the good relationship between $CST_{(504)}$and the tested inputs; the evolution consumption is explained sufficiently. Indeed, these input parameters seem influential to the value of the consumed thread. In addition, by analysing the overall combinations proposed by statistical analysis, it may be concluded that the contributions of the studied parameters are accurately significant.

Consequently, the concerned variables change from lower to higher levels as shown in Figures 2 and 3. The amount, by which the response changes, is given by the amount of change in the controlled variable multiplied by the value of the coefficient. Referring to Equation 2 (previously mentioned), the findings show that the present main effects make negative contributions and the increase of consumption values of sewed thread in case of woven fabric samples was probably occurred. The obtained results objectively proved that optimizing the consumed thread to sew garments, remained function of the choice of low level of inputs. Therefore, the results obtained using the experimental Taguchi design showed that the average consumption values increased widely when the tested inputs levels increased. The raise of the input parameter levels increases the consumed thread which does not encourage minimising the consumption based on the 504-overlock three-stitch and in the selected experimental design of interest. This finding seems in a good agreement with Rengasamy and Wesley [21, 22]. They proved that, in lockstitch type 301 case, heavier threads develop lower tightening tension, which may affect the seam balance and the consumed length values. This result helps to optimize (minimize) sewing thread consumption value when only the lowest level values should be adjusted for the tested woven fabric samples.

However, Figure 3 shows the variation of the consumption values as function of fabric thicknesses corresponding to the investigated layers. Based on the regression analysis, the consumption evolutions as function of the different layers of fabric thickness were also discussed. All evolutions have widely presented high coefficients of regression that proved that prediction of the consumed thread can be realised accurately. In fact, the increase of fabric's thickness is correlated with the consumed thread and the coefficient of regression seems to improve this relationship. Besides, compared to one layer seamed using the 504-overlock three-stitch, the coefficient of regression highly elevates as mentioned in Figure 3. Thus, the consumed yarn changes from one layer (CST_{1L})to two layers (CST_{2L}) and three layers (CST_{3L}) as function of fabric thickness. The linear regression given by the Equation 8 shows that a good relationship was founded between the thickness and the consumption value[4]. To improve results, the coefficient of regression (equals 0.847) calculated using equation 3 (mentioned above) is close to 1, which reflects the pertinence of the obtained correlation.

$$CST_{(504)} = 14F_{th} + 97.9 \quad (8)$$

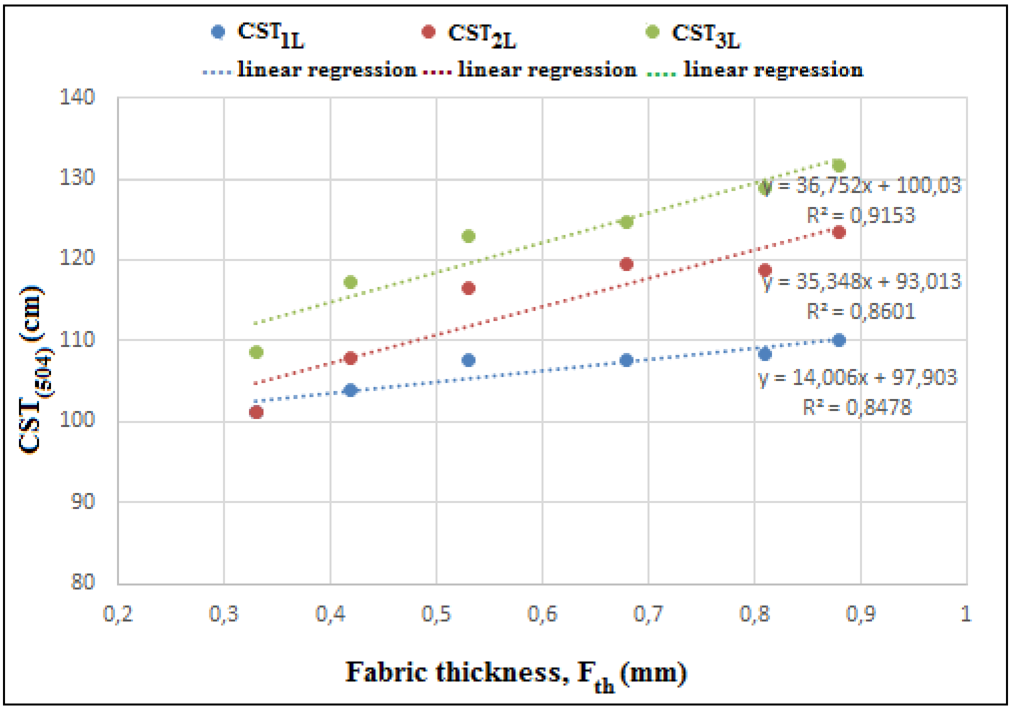

Figure 3. Relationship between studied fabric thicknesses and the sewing thread consumption using different layers.

As reported by the Equation 9, the evolution of the consumption of sewing thread using two assembled fabric layers within the same thickness proves that the increase of the number of layers helps to highten the consumed yarns. Indeed, our results show that the interdependence between the thickness and the consumed sewing thread was encouraged enormously and as a result the regression coefficient grow clearly ($R^2(CST_{2L}) = 0.86$) compared to one layer used only ($R^2(CST_{1L}) = 0.847$). The relationship between the consumption values and the thicknesses relative to two and 3 layers is given by Equations 9 and 10 respectively.

$$CST_{2L} = 35.34F_{th} + 93.01 \quad (9)$$

$$CST_{3L} = 36.75F_{th} + 100 \quad (10)$$

However, when the assembled layers numberincreases, using the same experimental conditions to seam fabrics within different thicknesses values, the consumption valuesincreased consequently. Using the overgged thread type 504, to stitch three layers of the same fabric ameliorate ($R^2(CST_{3L}) = 0.915$) widely the used sewing thread. Regarding their variations as function of the number of layers assembled, the evaluated consumption values upgrade when this number level up too. In spite of the thickness of woven fabric samples, the consumed thread using the 504-overlock three-stitch to sew article zones remained in good tie up with the layers sewed. According to Rengassamy and Wesley [21], the thickness of fabric plies does not affect the needle thread tension as well as the consumed thread must to sew garment in lockstitch cases. In accordance with findings obtained, it may be concluded that the data presented high contributions, which differ accordingly to the seamed fabric kinds. Based on these outcomes, the contributions were ranged from 6.94% (for lining fabric) to 17.17% (for denim fabric) which seem important on the consumption of sewing thread using 504-overlock three-stitch. During our work the overall participations relative to the tested fabrics were calculated. It is obvious that the increased effects for the lining, the flat and the four denim fabrics are 6.94%, 11.81% and 12.87%, 14.25%, 16.57%, 17.17% respectively. Thus, it is apparent that the thickness of the woven fabrics significantly influences the consumption values as proved in the literature survey by Rasheed et al. [5], SaiKrishnan and Ashok Kumar [10] and Ghosh and Vaseem Chavhan [24]. The consumption behaviour has high correlation values with thickness of the woven fabrics reflecting tremendous influence of the woven fabric construction on the consumed thread. Consequently, the consumption value of thread during overegged three-thread stitch step remained influenced accurately by both the variation of studied inputs, number of layers and the thickness of the stitched fabric because their variations are highly significant and influential. As it happens, this result seems to see eye to eye with Abeysooriya, and Wickramasinghe [3] when they studied the lockstitch 301 and chainstitch 401 consumptions incorporating thread-tension constraint. Referring to their results, there are combined effects of fabric thickness together with parameters such as stitch density and thread tensions that determine accurate consumption rates considering the characteristics of the stitch. By comparing all data details, the lining and flat fabrics give the lower participation than those obtained using denim fabric samples. Compared to the denim fabric, the contributions of the sewing thread consumption values having the highest thicknesses increase the sewed amount of thread. In addition, the thickness of fabric remained an influential parameter on the consumed thread of woven fabrics [24]. As for Abeysooriya and Wickramasinghe [3], there are combined effects of fabric thickness together with parameters such as thread tensions and stitch density, which determine accurate consumption values considering the properties of the stitch. To improve the findings three added fabrics, which presented thicknesses values inside the experimental design of interest, were tested and compared using the statistical and experimental methods. The difference between the theoretical results, $CST_{(504)stat.}$(using the linear regression technique) and the experimental consumptions, $CST_{(504)exp}$ based on stitching and unstitching sewed thread were investigated. We call the difference between theoretical and experimental consumption values as the error value carried out as function of the number of the seamed layers. Hence, in case of one seamed layer thickness of fabric, for example the expression of the error value, $\overline{Err_{1L}}$is calculated conforming to Equation 11 as follows.

$$\overline{Err_{1L}}(\%) = 100 \times \frac{CST_{(504)stat.} - CST_{(504)\,exp}}{CST_{(504)stat.}} \tag{11}$$

Using the same expression of error, it can be identified the difference between statistical and experimental consumption when two ($\overline{Err_{2L}}$) or three ($\overline{Err_{3L}}$) layers are seamed (see Table 5). Besides, Table 5 gives the overall errors calculated using the relationships (Equations 8-10) developed using the regression method and the experimental method mentioned previously. Experimental tests are repeated many times (10 tests) to obtain an objective mean value of the sewing thread. Consequently, the coefficient of variation, CV% of the experimental values of the consumptions are lower than 5%which consolidate, according to French standards, that the saved mean consumption values are widely an objective ones.

Table 5. Errors between experimental and theoretical consumptions relative to others fabric thicknesses.

Layers/ Thickness (mm)	Denim fabric (100% Cotton) ♦$CST_{(504)\,exp}$ (cm) $F_{th}=0.71$ (CV%)	$F_{th}=0.73$ (CV%)	$F_{th}=0.86$ (CV%)	°$CST_{(504)\,stat.}$ (cm) ($F_{th}=$ 0.71)	($F_{th}=$ 0.73)	($F_{th}=$ 0.86	Error (%) ▲$\overline{Err}_{1L}$	♠$\overline{Err}_{2L}$	♥$\overline{Err}_{3L}$
1	103.50 (2.7%)	105.50 (2.6%)	111.20 (2.47%)	107.84	108.12	109.94	4.02%	2.42%	1.14%
2	112.20 (2.8%)	114.7 (2.05%)	125.50 (1.82)	118.10	118.80	123.40	4.99%	3.45%	1.70%
3	121 (2.22%)	120.9 (2.42%)	134.90 (3.55%)	126.09	126.82	131.60	4.03%	4.66%	2.50%

▲$\overline{Err}_{1L}$, ♠$\overline{Err}_{2L}$ *and* ♥$\overline{Err}_{3L}$ *: Error values which determined between the theoretical and experimental consumptions relatives to different thicknesses using 1, 2 and 3 layers.*

♦$CST_{(504)exp}$*and* °$CST_{(504)stat.}$*: Experimental and statistical consumptions of sewing thread.*

Therefore, regarding the compared values given by Table 5, it may be founded that for woven fabrics, the statistical consumptions using 504-overlock three-stitch were evaluated widely as function of both fabric thickness and number of layers parameters. To validate these results, the error values saved show the effectiveness of the regression method and industrials can hence use the developed relationships to predict their consumed thread accurately. This available prediction in the studied experimental design of interest may be optimized as in lockstitch 301 and chainstitch 401 cases. Indeed, the proposed formulae by Abeysooriya and Wickramasinghe [3] are expected to be a better approach to calculate and predict thread consumption including the thread tension variable depicts reduction in error percentages.When the number of layers is changed, the relationship between thickness and the consumption modified too. Thus, it can be explained by several reasons such as the compressibility of assembled layers due to the overegged zones [24], the structural changes in the threads (their mechanical and thermo-mechanical properties) after the sewing process (due to tensile forces), frictions of needle thread at critical guides and loadings during the sewing process [1, 2, 6-21]. The increase of the layers increased the consumption values but not by multiplying on the number of layers, because no relationship which correlates the consumption for one layer within two or three layers. Other parameters should be considered such as the pre-tension on the bobbin thread, the compressibility of the fabric, the deformation of the loop during stitching, and the strength of fabric layers when they are assembled together. For example, referring to Rengasamy and Wesley studies [21-22], the pre-tension on the bobbin thread affects the amount of sewed thread when affects only the needle thread tension during the take up lever pulls up the needle thread loop to release it from the rotary shuttle hook gib. In the other hand, the obtained findings confirmed that there are accurate relationships between the mass of fabric samples and the consumed thread.

Indeed, Figure 4 shows the effect of the tested layers of woven fabrics and their consumption values simulating different thicknesses. Besides regarding the regressions obtained and shown in the figures 3 and 4, it is undoubtedly remarkable that high correlations tie the mass within the woven fabric consumptions. Indeed, the coefficients of regression values are 0.933 (for 1 layer of fabric) 0.936 (for 2 layers) to 0.961 (for 3 layers), which widely explain the possible prediction in the specific design of interest. Otherwise, the consumption behavior has high correlation values with mass of the woven fabrics based on its big influence on the consumed thread. Knowing the range of the CV % of the consumption values (from 1.92% to 5.62%), it may be concluded that there are efficient results. Nevertheless, based on the different variations of consumption values as function of the mass relative to each case of seamed layer numbers, our results has proved that, as it has been founded for the thickness effects, the findings seem in good agreement with each other [2].

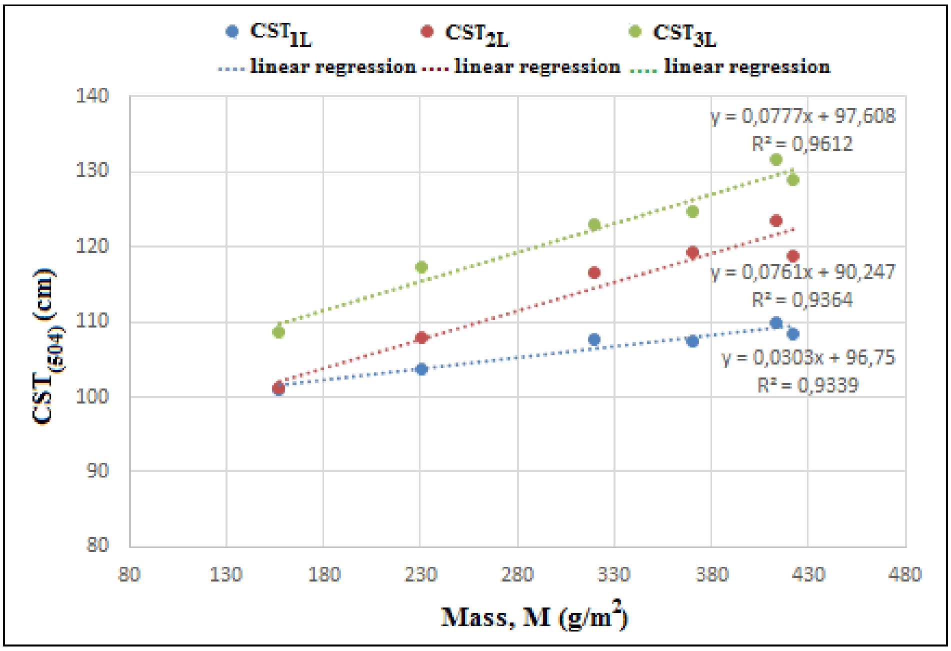

Figure 4. Relationship between consumption of sewing thread and the mass relative to different stitched layers of woven fabric specimens.

In the experimental design of interest, thickness seems in a good agreement with the thickness except for the two last fabric samples where we saved the contrast. This contrast can be, then explained due to these fabrics presenting thicknesses value, which are not corresponding to their mass.

3.2. Geometrical Calculation of the Consumption of 504-overlock three-stitch

Figure 5 shows the basic geometry of the shape 504-overlock three-stitch. Indeed, geometrical analysis is based on earlier works in literature survey [6, 20, 21].According to Abeysooriya and Wickramasinghe [3], the existing methods of consumption calculations exhibit significant error percentages and does not high lighten sufficiently the suitable amount of sewed thread due to the ignorance of important parameters (which have been studied in literature) that affect the thread consumption [3, 14-20].

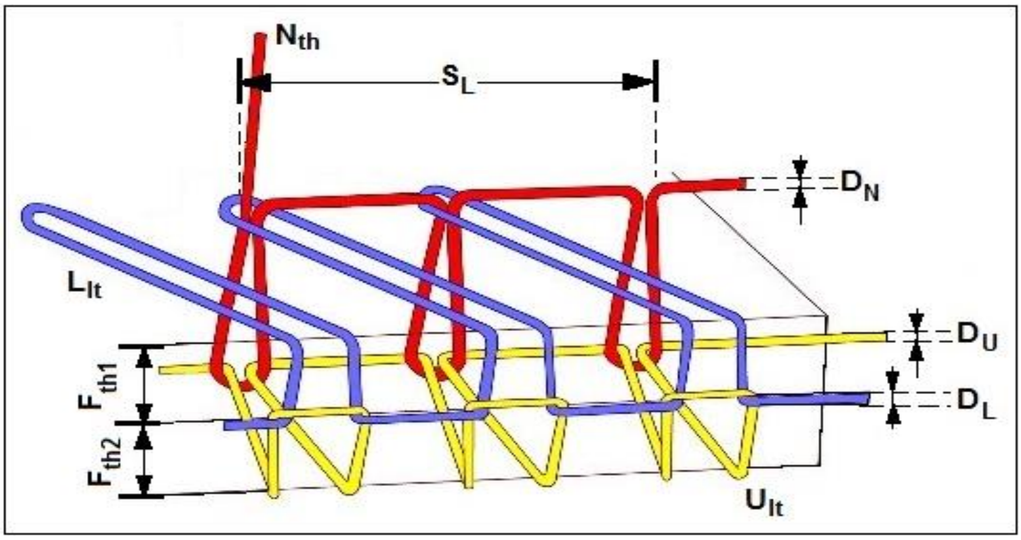

Figure 5. Geometric shape of overegged three-thread type 504 stitch.

It is notable, that the stitch structure in Figure 5 is studied based on some assumptions such as the thread tension which kept invariable for all tests, the formability of seamed fabrics [25], the compressibility of assembled layers due to the overegged zones are not considered as well as the flexibility of different interloping threads. Besides, before calculating the consumed amount of sewing thread based on 504-overlock three-stitch, other hypothesis were taken in account to facilitate the analysis such as the compressibility of the fabric, the deformation of the loop during the stitching and the tension applied to threads [21]. The ultimate configuration of yarn in the stitch structure shown in ideal stitch structure is considered to minimize as possible the number of studied parameters and to decrease the complexity of the stitch length calculation. The 504 stitch is formed with one needle thread and two looper threads, the looper threads form a purl on the edge of the seam. Equations 12-18 show the tie-ups between the consumption of the sewing threads $\left(CST_{(504)}\right)$ needed for this stitch and the geometrical parameters (see Figure 5).

$$CST_{(504)} = \left(CST_{(N_{th})} + CST_{(U_{lt})} + CST_{(L_{lt})}\right) \times N \times S_L \quad (12)$$

$$CST_{(N_{th})} = \frac{1}{N} + 2 \times (F_{th1} + F_{th2}) \times D_N(\pi + 1) \quad (13)$$

In case of $F_{th1} = F_{th2}$, then the consumption for needle ($CST_{(N_{th})}$), upper looper ($CST_{(U_{lt})}$) and lower looper ($CST_{(L_{lt})}$) threads expressions become, respectively, as follows

$$CST_{(N_{th})} = \frac{1}{N} + 4F_{th} \times d(\pi + 1) \quad (14)$$

$$CST_{(U_{lt})} = \frac{1}{2N} + 2F_{th} + 2S_w + 2D_N(\pi - 2) \quad (15)$$

$$CST_{(U_{lt})} = \frac{1}{2N} + 2F_{th} + 2S_w + 2d(\pi - 2) \quad (16)$$

$$CST_{L_{lt}} = 2\sqrt{{S_w}^2 + \frac{1}{N^2}} + \frac{3}{2N} + 2F_{th} + 2d(\pi - 3) \quad (17)$$

Hence, Equation 18 gives the total consumption expression of the three threads:

$$CST_{(504)} = 2S_L\left(\frac{3}{2} + N \times \left[4F_{th} + S_w + \sqrt{{S_w}^2 + \frac{1}{N^2}} + 3d(\pi - 2)\right]\right) \quad (18)$$

To calculate a yarn thicknesses or diameters(d), we use the general equation suggested in literature survey by Seyam and El-Sheikh [24], Jaouadi et al. [7] as well as Khedher and Jaouachi [18]. This proposed (see Equation 19) equation is transformed to obtain the (d)value in centimeter.

$$d(cm) = \frac{1}{251{,}37} \times \sqrt{Y_{ld}} \quad (19)$$

With Y_{ld} is the thread linear density expressed in tex unit.

All the theoretical models explained above have been used to predict the consumption of the sewing thread for woven fabrics. The thickness of the fabric varies from one assembly to another. Similarly, consumed amount varied as function of the number of woven fabric thicknesses assembled. To improve our findings, we calculated the difference values and errors between experimental consumption ratio and those obtained geometrically. Referring to the experimental analysis of 45 different kinds of woven fabrics seamed, Figure 6 shows the obtained findings in the global error values as function of geometrical results.

By applying the obtained geometrical consumed thread, the unstitched sewing thread value can be widely predicted as function of the studied geometrical variables. An accurate relationship between the two consumptions is expressed by the coefficient of regression, which is equal to 0.9826 (which means that its accuracy equals 98.26%). This value is close to 1 (accuracy equals 100%) means a good predicted amount of sewed thread based on basic geometry of 504 stitch. This correlation is fruitful, and can be optimized, because it largely explains the experimental consumptions for different combinations of the input values. In fact, this geometrical model fits the behaviour of the consumed thread. Knowing the high value of the coefficient of regression between geometrical and statistical consumptions, our compared findings imply that the theoretical method gives results that are more accurate to provide and predict than the consumption of sewed thread. Nevertheless, the experimental method gives an approximate consumption of thread because this method considers or neglects the exceed thread after sewing as well as the earlier theoretical models found in literature [3]. Moreover, it may be concluded that these error values recently found could be related to some assumptions considered in the beginning of calculation as the yarn flexibility, the fabrics compressibility, the ultimate configuration of yarn in the stitch structure, not shown in ideal stitch structure. Otherwise, in order to facilitate the geometrical calculation, these considered assumptions are neglected and can undeniably affect stitch length calculation. In contrast with experimental results, the coefficient of variation relative to geometrical calculation method is ranged from 1.28% to 1.39%, justifying the effectiveness of this technique. Besides, compared to statistical method, the geometric proposed model proves results that are more accurate. This finding helps industrials to evaluate and predict their consumptions based on 504-overlock three-stitch.

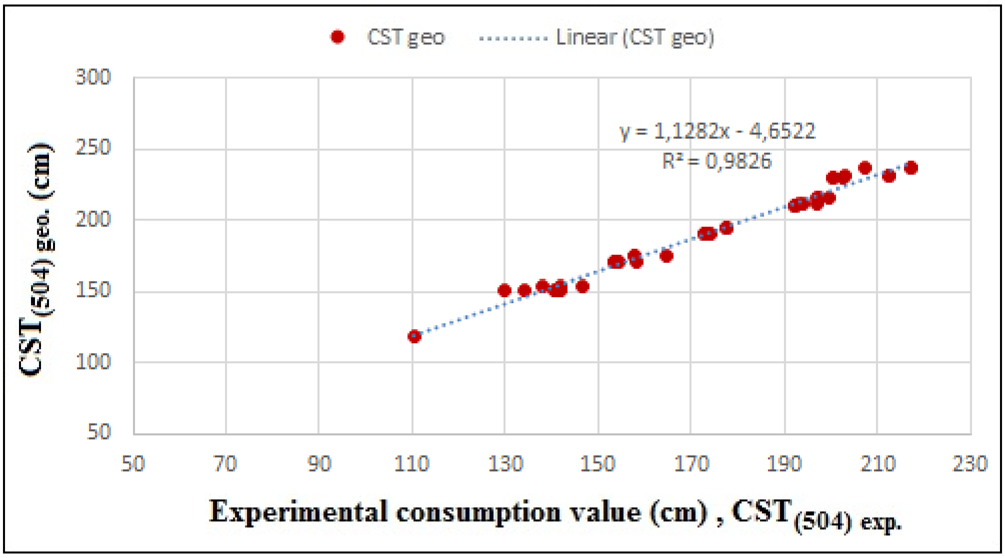

Figure 6. Relationship between geometrical and actual consumptions.

4. Conclusion

A comparison between experimental technique (stitching and unstitching) and two theoretical methods (statistical and geometrical techniques), have been applied and discussed using different input parameters. Indeed, compared to unstitching method, the findings show that the geometrical model proposed gives accurate results and can be applied by industry apparel to prevent the excessive waste rate of threads probably occurred during sewing step due to tenacity loss of thread. Practically, although it is always wasted at the beginning and end of any sewing operation, using the developed model, industrials can rapidly anticipate the suitable length of consumed threads and widely decrease the wasted threads. According to our results, both inputs are studied, have been investigated and discussed based on their significant influences on the sewing thread consumption behavior of 504-overlock three-stitch. The applications of the statistical method using Taguchi analysis and linear regression techniques have proved the effectiveness of the studied parameters and the prediction possibility of the consumed amount. Based on findings obtained, possible correlations seem significant and can be more effective and fruitful when other influential parameters are taken in account. Furthermore, consumption of sewing thread is correlated accurately to the thickness (R^2 ranged from 0.84 from 0.91) and mass of fabric (R^2 ranged from 0.93 to 0.96). However, the proposed geometrical model presents an accuracy (R^2=0.98) higher than the statistical (R^2=0.90) one, reflecting that geometrical calculation can be widely applied to predict consumed amount of 504-overlock three-stitch.

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