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Consumed sewing thread behaviour for knitted fabrics using factorial design method

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This study investigates experimentally the influence of key parameters on sewing thread consumption. Eight knitted fabrics with different plain structures and thicknesses are tested by sewing two layers using a chain stitch type 401. The effects of sewing machine foot pressure, needle thread tension and fabric thickness on the consumed sewing thread have been investigated. It is concluded that an increase in the foot pressure height increases sewing thread consumption, as well as the fabric thickness. However, increasing the needle thread tension decreases the sewing thread amount. Using the multi-linear regression method, good relationships (regression coefficient close to 1) between thread consumption behaviours and the investigated parameters are observed.

Keywords: Compressibility, Knitted textiles, Sewing thread, Thread consumption

1 Introduction

In today's competitive marketplace, there is a need for stringent cost control. For manufacturers, accurately estimating the required amount of sewing thread for a garment is crucial[1]. This comes back to the sewing thread price, which continues to increase due to the inflation of manufacturing costs and finishing touches[2]. A recent investigation across various garment types highlighted the practical difficulties of estimating sewing thread consumption across different sewing operations[3]. To date, several studies have been conducted to determine an exact method for calculating sewing thread consumption[4]. According to the literature, these studies are based on industrial methods or more scientific models such as geometrical, statistical and mathematical[5]. Even software solutions were developed in this direction to facilitate their use by manufacturers. Nevertheless, the field of sewing thread consumption remains only partially explored due to the large number of parameters involved and the difficulty of controlling all influencing factors simultaneously. In fact, several parameters determine the extent of thread consumption in any sewn product, including stitch type, seam type, material thickness, number of layers, and stitch density[4-7]. However, these factors are not consistent with the different style preferences. Hence, thread consumption is never standard for any sewn product categories, such as jeans, shirts, jackets, lingerie, and footwear. Generally, 10% to 15% wastage of thread is added to the consumption derived. This wastage occurs due to shop-floor conditions, like machine running, thread breakage, repairs, etc.[8]. Previous studies have shown that sewing processes can lead to a reduction in thread strength, depending on the fabric structure, highlighting the importance of fabric mechanics in sewing performance[9]. Nguyen & Nguyen confirmed strong correlations between stitch density, needle size and thread size in determining seam properties, supporting the combined influence of structural and machine parameters[10]. Lubrication and friction management of sewing threads have also been reported to influence thread damage during sewing, thereby affecting total thread consumption[11]. Some studies explain the uncertainty in calculating thread consumption by the complexity of seam structures, the difficulty in the geometry of stitches, variability in thread tension, and especially the compressibility of fabrics, sewing threads, and their compressive modulus[1,12,13]. Compressibility, which reflects the mechanical 'springiness' of a material, is an important fabric property alongside friction, bending, tension, and shear. Many researchers gave importance to this crucial parameter in the garment process[14-19]. Although fabric compressibility has been recognised as a critical factor in garment manufacturing, it has rarely been emphasised in studies on thread consumption. Apart from the work of

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Jaouachi and Khedher, who examined the relationship between thread consumption and fabric compressibility using a lockstitch seam301, limited research has addressed this parameter[20]. Furthermore, most existing studies have focused on woven textiles, leaving knitted fabrics relatively underexplored[6-8,21-26]. Researchers sought to identify the most influential parameters and to understand the thread consumption behaviour for woven supports. The knitted garments are often overlooked, and few studies have drawn attention to this gap. In this context, Brahem *et al.*[27] predicted the sewing thread consumption for underwear clothes using different stitch structures via regression models. Gazzeh *et al*. predicted the sewing thread consumption for cover-stitch 602 on T-shirts using geometrical models[8].

The present paper extends this line of research by investigating the knitted garment in terms of the sewing thread consumption using chain stitch type 401, a sewing class widely used in making knitwear and known for its high thread usage[28]. The study examines the effect of fabric, represented by variations in presser foot pressure, on thread consumption. According to the literature, this is only the second study to address this influential parameter on the sewing thread consumption, and the first to do so using knitted fabrics. Additionally, eight different textiles are used to assess the influence of fabric thickness on thread usage, while needle thread tension is considered as a third key parameter. This study aims to predict the swing thread length needed for producing knitted garments using chain stitch type 401. Moreover, a multi-linear regression model is developed to measure the consumed thread based on the input parameters.

2 Materials and Methods

Eight knitted textiles with different thicknesses were tested to investigate the influence of two additional parameters, compressibility and needle thread tension, on sewing thread consumption. Each test was performed times for each knitted fabric, according to the French standards. Table 1 presents the primary characteristics of the knitted fabrics studied in this work.

Two layers of each knitted fabric were sewn using a chain stitch machine (401 type SIRUBA F007k) (Fig. 1). The threads used for both needle and looper were 100% polyester, Z-twisted with Ne=50/3 (English number). The stitch density was fixed at 4 stitches/cm for all samples.

Fig. 1 — Chain stitch machine 401 used

Table 1 — Characteristics of Knitted fabrics used

	1	2	3	4	5	6	7	8
Plain structure	Stocking stitch (stst)	Interlock	Pique	Interlock	1/1 Ribs	1/1 Ribs	2/2 Ribs	Molleton
Image								
Blend ratio	100% cotton	100% cotton	50% cotton/50% polyester	50% cotton/50% polyester	50% cotton/50% polyester	48% cotton/48% polyester/ 4% elastane	48% cotton/48% polyester/ 4%elastane	50% cotton/50% polyester
GSM, g/m^2	113	200	175	180	230	277	390	200
Thickness, mm	0.88	1.16	1.21	1.31	1.48	1.50	1.57	1.76

The variation in height of foot pressure transduces the pressure rate (value) expressed by the knitted fabric resistance. A pressure sensor device (type Flexi force® A 301) and a digital multimeter were used to measure the fabric's electrical resistance in kilo-Ohms (KOhms). All tests were conducted under standard conditions for textile testing.

Before the experiments, all instruments were calibrated to ensure measurement accuracy. During testing, the pressure sensor was positioned between the foot pressure and the feed dog to record the resistance values corresponding to different presser foot heights. The presser foot height was adjusted using the machine's screw mechanism, and the corresponding resistance was measured at each setting. A step interval of 0.3 cm was selected to represent the variation across the experimental range, covering presser foot heights from 2.9 cm to 4.1 cm. Once the required pressure levels were established, the knitted fabrics were introduced, and the sewing experiments were carried out under the selected conditions.

The foot pressure was calibrated before testing to minimise errors during the test. The corresponding foot pressure height (FPH) values were converted into compression values. The relationship between resistance and foot pressure height for all samples is illustrated in Fig. 2. The shape of the curve is logical and expected. Indeed, resistance increased with increasing presser foot height, indicating a reduction in applied pressure on the fabric.

For each of the eight fabrics, the average sewing thread consumption value, expressed in centimetres, represented the total thread length used to sew two layers over a 10 cm length. After sewing all the samples, the amount of thread consumed was calculated. The mean length of the unstitched lengths corresponds to the total consumed thread values relative to the sum of both needle and looper threads. The stitch type (401, chainstitch) and seam configuration (two-layer seam) were identified according to ISO 4915 and ISO 4916 classifications[29,30].

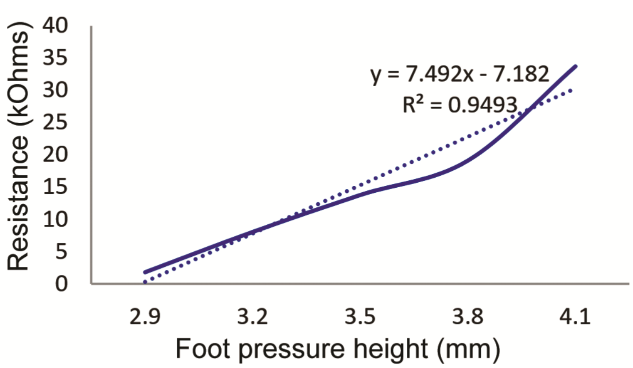

Fig. 2 — Correlation curve between resistance values and foot pressure height

The above experiments were conducted for two levels of needle thread tension and five levels of presser foot height, expressed as equivalent pressure values. Each combination of input parameters was tested five times and only results with a coefficient of variation (CV%) less than 5% were considered.

Data were statistically analysed using Minitab 14 software to examine the individual and interactive effects of foot pressure height (FPH), fabric thickness (FT) and needle thread tension (NTT). A full factorial experimental design was employed to ensure an objective analysis of all parameter combinations. Table 2 presents the input parameters studied and their respective levels.

3 Results and Discussion

In this study, eighteen sewing combinations are designed to evaluate the impact of compressibility, fabric thickness (FT) and needle thread tension (NTT) on the consumption behaviour. Each combination is tested five times to ensure reliability. The mean values of the sewing thread consumption for the eight tested knitted fabrics are given in Table 3.

The main effect plot, presenting the influence of each input parameter on the sewing thread consumption behaviour of knitted fabrics, is illustrated in Fig. 3.

To highlight the impact of changes in input parameters, the variation in sewing thread consumption "V_{STC}" is calculated using Eq. 1:

$$V_{STC} = \frac{\text{new STC} - \text{old STC}}{\text{old STC}} \times 100 \quad \ldots (1)$$

where STC is the sewing thread consumption (cm).

From Fig. 3, it can be concluded that the change in each input parameter influences the sewing thread consumption. An increase in FPH leads to a notable rise in sewing thread consumption, from 67.7 cm to

Table 2 — Experimental design of input parameter levels

Parameter	FPH, cm					FT, mm								NTT, N	
Level	1	2	3	4	5	1	2	3	4	5	6	7	8	1	2
Values	2.9	3.2	3.5	3.8	4.1	0.88	1.16	1.21	1.31	1.48	1.5	1.57	1.76	0.45	0.75

Table 3 —Mean sewing thread consumption values

FPH, cm	FT, mm	NTT, N	Mean consumption values, cm	CV
2.9	0.88	0.45	63.00	2.44%
2.9	0.88	0.75	64.33	1.19%
2.9	1.16	0.45	60.80	0.28%
2.9	1.16	0.75	59.23	0.42%
2.9	1.21	0.45	64.00	0.72%
2.9	1.21	0.75	60.93	0.19%
2.9	1.31	0.45	61.97	1.78%
2.9	1.31	0.75	60.07	1.78%
2.9	1.48	0.45	68.43	1.97%
2.9	1.48	0.75	68.47	2.43%
2.9	1.5	0.45	80.43	2.80%
2.9	1.5	0.75	74.13	1.35%
2.9	1.57	0.45	75.93	1.42%
2.9	1.57	0.75	72.90	1.62%
2.9	1.76	0.45	74.93	3.57%
2.9	1.76	0.75	73.77	0.78%
3.2	0.88	0.45	62.60	2.39%
3.2	0.88	0.75	59.17	1.15%
3.2	1.16	0.45	64.57	1.56%
3.2	1.16	0.75	62.63	1.78%
3.2	1.21	0.45	68.07	1.92%
3.2	1.21	0.75	67.50	0.15%
3.2	1.31	0.45	64.50	1.21%
3.2	1.31	0.75	66.67	0.43%
3.2	1.48	0.45	73.93	0.79%
3.2	1.48	0.75	70.47	1.92%
3.2	1.5	0.45	91.97	0.62%
3.2	1.5	0.75	81.00	2.38%
3.2	1.57	0.45	83.37	3.81%
3.2	1.57	0.75	78.30	1.17%
3.2	1.76	0.45	83.23	0.73%
3.2	1.76	0.75	78.53	0.94%
3.5	0.88	0.45	64.53	2.37%
3.5	0.88	0.75	60.93	0.78%
3.5	1.16	0.45	65.27	1.34%
3.5	1.16	0.75	64.03	0.36%
3.5	1.21	0.45	68.20	1.44%
3.5	1.21	0.75	65.60	3.97%
3.5	1.31	0.45	69.53	1.93%
3.5	1.31	0.75	67.37	2.41%
3.5	1.48	0.45	75.93	0.53%
3.5	1.48	0.75	73.37	0.52%
3.5	1.5	0.45	87.00	2.35%
3.5	1.5	0.75	75.33	0.38%
3.5	1.57	0.45	80.63	1.62%
3.5	1.57	0.75	81.60	1.28%
3.5	1.76	0.45	93.73	1.76%
3.5	1.76	0.75	87.93	0.47%
3.8	0.88	0.45	65.67	0.38%
3.8	0.88	0.75	62.80	1.43%
3.8	1.16	0.45	64.03	1.19%
3.8	1.16	0.75	65.17	0.69%
3.8	1.21	0.45	69.53	0.98%
3.8	1.21	0.75	68.40	1.41%
3.8	1.31	0.45	79.10	2.68%
3.8	1.31	0.75	75.33	0.65%

(*Contd.*)

Table 3 —Mean sewing thread consumption values — (*Contd.*)

FPH, cm	FT, mm	NTT, N	Mean consumption values, cm	CV
3.8	1.48	0.45	76.83	1.28%
3.8	1.48	0.75	77.83	1.95%
3.8	1.5	0.45	76.20	1.97%
3.8	1.5	0.75	75.23	1.81%
3.8	1.57	0.45	85.97	0.59%
3.8	1.57	0.75	92.97	1.65%
3.8	1.76	0.45	94.53	3.23%
3.8	1.76	0.75	94.83	1.51%
4.1	0.88	0.45	71.37	2.65%
4.1	0.88	0.75	70.43	2.06%
4.1	1.16	0.45	72.07	1.04%
4.1	1.16	0.75	74.50	1.23%
4.1	1.21	0.45	80.57	0.76%
4.1	1.21	0.75	71.20	2.53%
4.1	1.31	0.45	76.37	2.67%
4.1	1.31	0.75	72.83	2.21%
4.1	1.48	0.45	78.60	2.10%
4.1	1.48	0.75	79.63	2.73%
4.1	1.5	0.45	78.30	0.92%
4.1	1.5	0.75	76.53	2.72%
4.1	1.57	0.45	89.37	1.73%
4.1	1.57	0.75	90.20	1.25%
4.1	1.76	0.45	92.27	1.13%
4.1	1.76	0.75	87.73	1.03%

78.9 cm (V_{STC} = 16.54%). A variation of 1.2 cm in FPH thus causes a considerable increase in sewing thread usage for knitted fabrics when using chain stitch type 401. As the compression applied by the foot device decreases, the fabric becomes more relaxed, causing an increase in the sewing stitch height and subsequently higher sewing thread consumption. This result aligns with the findings of Jaouachi and Khedher[20], who reported that the compression applied by foot pressure during the seam process is a significantly influential input parameter on the variation in sewing thread consumption using lock stitch type 301 for denim fabrics.

Similarly, FT exerts a pronounced effect on sewing thread consumption. When the FT increases from 0.88mm to 1.76 mm, the consumed sewing thread rises from 64.5cm to 86.15cm (V_{STC}=33.56%).This trend confirms that thicker fabrics require greater thread length due to their lower compressional resilience. Despite structural variations among the knitted fabrics, thickness remains the dominant factor. Comparable findings by Akthar and Subramanian (1994) corroborate this result, highlighting the consumption superiority of sewing thread with thicker fabrics[31]. The results are evident as thicker fabrics display lower compressional resilience and vice versa, which, in turn, causes a high amount of consumed sewing thread.

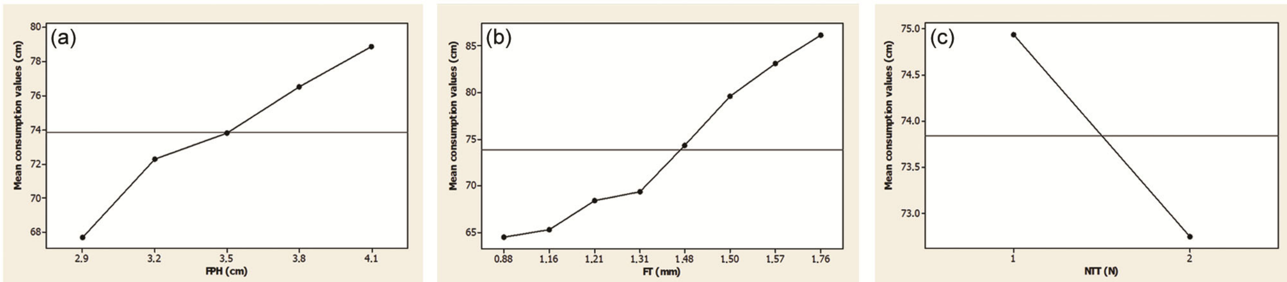

Fig. 3 — Effect of input parameters on sewing thread consumption

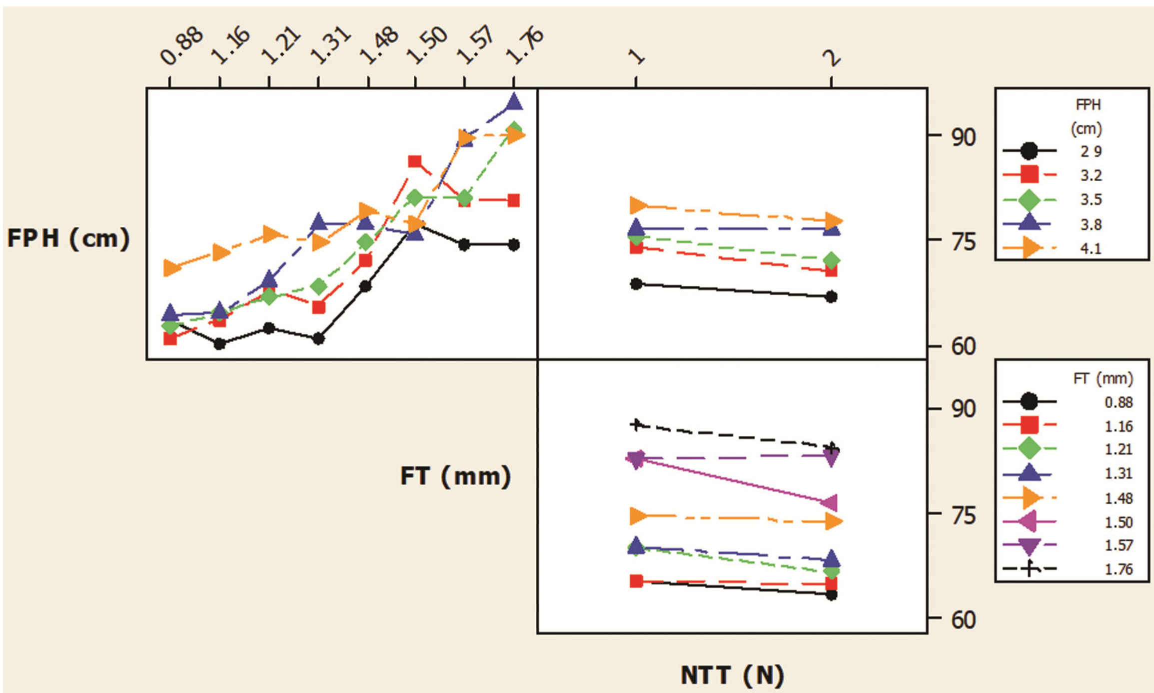

Fig. 4 — Interaction plots of the input parameters

In contrast, NTT exerts a comparatively minor effect on sewing thread consumption. Increasing NTT from 0.45 N to 0.75 N slightly decreases overall thread consumption from 74.9 cm to 72.7 cm ($V_{STC}$is -2.94%).Specifically, the needle thread length decreases from 23.7cm to 20.3cm, whereas the looper thread length increases slightly from 51.2cm to 52.4cm. Thus, the looper tried to compensate for the quantity lost by the needle due to the drop in flow. This affirmation aligns with previous studies that explain the inaccuracy of determining suitable sewing thread consumption values due to the neglect of influential parameters, such as thread tension value[5,32,33].

The present finding is also in accordance with numerous research studies that show a fruitful relationship between increased thread tension and consumption behaviors[23,34-36]. Linear regression equations are derived to predict, with a reasonable degree of accuracy, the consumption values as a function of the tensions generated under the specified sewing conditions. Similar relationships have also been reported by Brahem *et al*. (2019), who found high correlation coefficients (R values between 0.892 and 0.988)[27]. These values are close to 1, which reduces the effectiveness of the regression analysis in explaining the relationship between thread tension and consumption values.

The interaction plots shown in Fig. 4 illustrate the combined influence of input parameters. A strong interaction is observed between FPH and FT. The variation of the two factors together influences the mean consumption value, as in many thickness values, the variation in FPH is significant (an overlap). The knitted fabrics are compressible in terms of thickness, which explains the effect of these two parameters together on sewing thread consumption.

No significant interactions are detected between NTT and either FPH or FT, as indicated by the nearly parallel trend lines. This confirms that variations in thread tension do not substantially influence the relationship between foot pressure or thickness and total thread consumption.

3.1 Modelling of Sewing Thread Consumption

To study the effect of FPH, FT and NTT on sewing thread consumption, a general full factorial design (8 × 5 × 2) is implemented. The three experimental factors were FT (8 levels), FPH (5 levels), and NTT (2 levels), resulting in 80 treatment combinations. The response variable, STC, is defined as the total length of needle and looper threads required to sew a 10 cm seam. Each test condition is repeated five times, and the mean value is used for statistical analysis. Amultiple regression method incorporating all main effects and interactions is established as follows:

$$\begin{aligned} \mathrm{STC} = {} & 73.802 + (-6.147 - 1.520 + 0.009 + 2.599 + 5.059)[\mathrm{FPH}] \\ & + (-9.319 - 8.572 - 5.572 - 3.788 - 0.207 + 5.810 + 9.322 + 12.326)[\mathrm{FT}] \\ & + (0.987 - 0.987)[\mathrm{NTT}] \\ & + \begin{bmatrix} 5.33 & 0.93 & -0.47 & 1.35 & -2.77 & 3.82 & -2.56 & -5.63 \\ -2.08 & -0.11 & 1.08 & -2.91 & 0.13 & 8.39 & -0.77 & -3.73 \\ -1.76 & -0.59 & -1.34 & -1.57 & 1.05 & 1.54 & -2.02 & 4.69 \\ -2.85 & -3.23 & -1.86 & 3.60 & 1.14 & -6.50 & 3.75 & 5.95 \\ 1.36 & 3.00 & 2.60 & -0.47 & 0.46 & -7.26 & 1.60 & -1.29 \end{bmatrix}[\mathrm{FPH} * \mathrm{FT}] \\ & + \begin{bmatrix} -0.677 & 0.677 \\ 0.761 & -0.761 \\ 0.804 & -0.804 \\ -0.906 & 0.906 \\ 0.017 & -0.017 \end{bmatrix}[\mathrm{FPH} * \mathrm{NTT}] + \begin{bmatrix} -0.036 & 0.036 \\ -0.869 & 0.869 \\ -0.097 & 0.097 \\ 0.593 & -0.593 \\ -1.338 & 1.338 \\ 2.181 & -2.181 \\ -1.057 & 1.057 \\ 0.623 & -0.623 \end{bmatrix}[\mathrm{FT} * \mathrm{NTT}] \end{aligned} \quad \ldots (2)$$

Table 4 —ANOVA results for the multi-linear model

Source	DF	Adj SS	Adj MS	*F*-value	*p*-value
FPH, cm	4	1159.05	289.763	41.63	0.000
FT, mm	7	4783.50	683.358	98.18	0.000
NTT, N	1	77.93	77.930	11.20	0.002
FPH, cm*FT, mm	28	861.63	30.773	4.42	0.000
FPH, cm*NTT, N	4	40.09	10.021	1.44	0.247
FT, mm*NTT, N	7	91.69	13.099	1.88	0.111
Error	28	194.89	6.961		
Total	79	7208.79			

The coefficient of determination (R^2 = 97.30%) confirms that the model provides an excellent fit, explaining nearly all the variability in experimental data. The high R^2 value validates the robustness of the multi-linear regression for predicting sewing thread consumption.

Analysis of variance (ANOVA, Table 4) is conducted to assess the statistical significance of the model terms. The F- and p-values indicate that FPH, FT, and NTT are all significant factors ($p< 0.05$). Table 4 presents the *p*-value given directly by the Minitab software.

Moreover, the interaction between FPH and FT is highly significant. In contrast, the interactions FPH × NTT and FT × NTT are not statistically significant ($p > 0.05$), confirming the earlier graphical observations (Fig. 4). This confirms that foot pressure height and fabric thickness are the primary contributors influencing sewing thread consumption, whereas needle thread tension exerts a secondary effect.

3.2 Validation of Multi-Linear Model

To verify the predictive accuracy of the regression model, an experimental method is employed using an additional knitted fabric with different physical properties (Table 5).

The practical validation is done by calculating errors between the theoretical values given by the multi-linear model ($\widetilde{STC}_{Th}$) and the experimental values extracted after testing the new fabric (STC_{Exp}). The relative percentage error is calculated using Eq.3.This value serves as a practical comparison indicator to assess whether the forecast model is effective[37,38].

$$\mathrm{Error}(\%) = \frac{STC_{Exp} - \widetilde{STC}_{Th}}{STC_{Exp}} \times 100 \quad \ldots (3)$$

where STC_{Exp} is the sewing thread consumption experimentally measured; and $\widetilde{STC}_{Th}$, sewing thread consumption predicted by the multi-linear model.

Table 5 — Characteristics of knitted fabric used for validation

Plain structure	Ribs Richelieu
Image	
Blend	47 % cotton: 48 % polyester:5 % elastane
GSM, g/m^2	200
Thickness, mm	1.48

Table 6 — Validation test results

FT, mm	NTT, N	FPH, cm	$\widetilde{STC}_{Th}$, cm	STC_{Exp}, cm	Error, %
1.48	0.45	2.9	79.78	81.00	1.51
		3.2	90.41	88.00	-2.74
		3.5	85.13	85.00	-0.16
		3.8	77.97	80.00	2.53
		4.1	80.60	81.50	1.11
	0,75	2.9	74.80	75.50	0.93
		3.2	82.55	84.00	1.72
		3.5	77.19	76.50	-0.90
		3.8	73.41	75.50	2.77
		4.1	74.23	76.00	2.33

Similarly, to the knitted fabrics used in the database, the validation fabric is tested at two levels of NTT and for five levels of FPH (Table 6).

This table summarises the results estimated by the models (predicted consumption) for each production output, as well as the measured consumption after production. Additionally, it displays the error values calculated for all validation tests. The errors range from -2.74% to 2.77% of the consumption rate. The application of the model yielded very good measurement accuracy, with errors not exceeding ±2.77% of the consumption rate. In practice, this error is negligible, as it does not exceed 3 mm for a 10 cm seam. The statistical data confirmed that theoretical and experimental values are in close agreement. The results of testing and predicting the amount of sewing thread required for other knitted fabrics using our model are well-verified. Thus, the multi-linear regression model is well justified, and the findings show the high significance of this study's effectiveness, which provides industrialists with practical confirmation of the established models. Taking the example of a bra, which is a women's underwear (knitted clothing), requires 1050 cm to be sewn, as mentioned by Brahem *et al.*[27].According to our model, 29 cm is the error of the thread consumption, which is negligible value and not enough even to thread a sewing machine.

Considering the high regression coefficient (R^2 = 97.3%) and low prediction error, the developed model is statistically validated and practically reliable. Therefore, the sewing thread consumption for knitted fabrics can be expressed as:

$$STC_{Exp} = \widetilde{STC}_{Th} \pm 2.77\% \quad \dots (4)$$

This finding confirms that the proposed model is a reliable tool for predicting sewing thread requirements in chain stitch type 401 operations.

4 Conclusion

In this study, the influence of foot pressure height, fabric thickness, and needle thread tension on sewing thread consumption behaviour using chain stitch type 401 is investigated and discussed. The fabrics considered are knitted textiles of eight different thicknesses representing various plain structures. Five levels of foot pressure and two levels of needle thread tension are employed in the experiments. The results show that the sewing thread consumption behaviour in double-layered knitted fabrics exhibits a strong relationship with the input parameters. The amount of consumed thread increases with rising foot pressure height and fabric thickness, whereas it decreases with higher needle thread tension. The developed multi-linear regression model, correlating the input parameters with thread consumption, is highly significant with an R^2value of 97.30%. The variance analysis validated the significance of all input parameters, as well as one interaction, which is foot pressure height with fabric thickness, and ruled out the interaction between needle thread tension and either foot pressure height or fabric thickness for further studies. The model is validated using a new knitted fabric, and the computed prediction error of ≤ 2.77% is considered very low for the knitwear clothing industry. This error is due to industrial working conditions and other influential parameters not addressed in this work, but are the objectives of future investigation.

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