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An elliptical model for lockstitch 301 seam to estimate thread consumption

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ABSTRACT

A geometrical model for lockstitch seam 301 has been proposed based on elliptical profile to estimate the thread consumption. The realistic elliptical shape of a lockstitch 301 seam has been confirmed by observing cut section along seam line. In order to validate a model across the different fabric types, varieties of fabrics from woven shirting, woven jeans, knitted single jersey to nonwoven interlining fabric have been considered. The different number of plies (2, 3 and 4) of given fabrics have been stitched at different levels of stitch densities (3, 4 and 5 stitches per cm) to observe effects in prediction of these parameters. It is found that the error % is increasing with increase in stitch density and number of ply. The proposed elliptical model have been compared with other recent rectangular profile based models, it is found that the propose model is more accurate and generalised with less error %, as compared to other models across the different fabric types. Also there is a strong correlation obtained between practical (actual) thread consumption and predicted from model.

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KEYWORDS
Word; lock stitch 301; geometrical model; thread consumption

Introduction

For a garment industry, the selection of sewing thread type and the estimation of thread consumption is important from inventory management (COATS, 2018) point of view. The estimation of thread consumption is also important for cost estimation especially with the introduction of high performance and costly sewing threads (Efird, 2010).

For estimating sewing thread consumption various methods are available, industrial method, geometrical models and regression models. Sometime rough estimation can be done based on the empirical available data (AMANN, 2010) with range of variation. The industry method is considering a thread ratio of each seam type (AMANN, 2013; COATS, 2014) which is 2.5 cm per cm of seam for lock stitch seam in thread consumption calculation irrespective of fabric type and sewing parameters. But in actual the thread consumption is changes with change in fabric type (Dogan & Pamuk, 2014) and stitch density, therefore the thread ratio cannot be justified in general.

The regression models are more accurate in predicting thread consumption as reported by various studies but for a specific type of fabric and sewing conditions. The regression equations are available in terms of basic parameters; fabric thickness and stitch densities (Boubaker, Sana, & Faouzi, 2017; Dogan & Pamuk, 2014; Jaouadi, Msahli, Babay, & Zitouni, 2006) for lock stitch and chain stitch seams. The regression model proposed by Abeysooriya and Wickramasinghe (2014) for 100% cotton fabric considered thread tension in addition and by in another study (Amirbayat & Alagha, 1993) in terms of dimensionless equation by considering fabric elastic modules other than basic parameters. Based on Taguchi design analysis (Jaouachi, Khedher, & Mili, 2012) and fuzzy logic (Jaouachi & Khedher, 2013) Jaouachi proposed an equations for thread consumption at jeans pants by considering stitch types also. A regression equations for predicting thread consumption also proposed for cotton and polyester type of sewing for lockstitch (Midha, Sharma, & Gupta, 2016) and chain stitch (Sharma, Gupta, & Midha, 2017).

As far as geometrical modelsare concerned for thread consumption estimation, the models generally overestimating the thread consumption with a significant error percentage. The rectangular model was proposed initially by Davis (1933) for lock stitch seam where thread consumption is calculated just by addition of seam length and thickness. Afterword based on rectangular profile the geometrical models for the prediction of thread consumption for lock stitch seam have been proposed by Jaouadi et al. (2006), followed by Ghosh and Chavhan (2014) for lock stitch 301 seam in terms of fabric thickness, seam length and thread diameter and by Rasheed, Ahmad, Mohsin, Ahmad, and Afzal (2014) where fabric thickness is in terms of thread diameter.

In actual the more realistic stitch profile is elliptical for lockstitch seam for compressible material like textile fabrics, the only model based on an elliptical profile is by O'Dwyer (O'Dwyer & Munden, 1975). In order to get more accuracy in prediction of thread consumption and to study lock stitch

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Table 1. Details of fabric samples.

Fabric type-code	Woven (shirting)- WS	Woven (Jeans) -WJ	Knitted (Single jersey) -KS	Nonwoven (Interlining) -NI
Composition	100% cotton	100% cotton	100% cotton	100% polyester
Design/Type	Plain weave	2/1 twill weave	Plain	Needle punched
Thread density	150 × 84 (ends/inch × picks/inch)	61 × 42 (ends/inch × picks/inch)	40 × 60 (wales/inch × course/inch)	–
Yarn count	50^{s}Ne × 50^{s}Ne	6^{s}Ne × 6^{s}Ne	30^{s}Ne	–
Fabric weight (gsm)	116	472	189	223
Fabric thickness (mm)	0.219	1.001	0.515	1.108

Table 2. Practical and estimated thread consumption for fabric samples.

Sample number	Fabric type	Number of ply	Stitch density (stitches/cm)	Seam balance ratio	Practical thread consumption/ 20 cm (cm)	Estimated thread consumption/ 20 cm (cm)	% Error
1	WS	2	3	1.0	42.93	41.64	−3.02
2	WS	2	4	1.0	43.47	42.71	−1.75
3	WS	2	5	1.0	44.40	43.96	−1.00
4	WS	3	3	0.9	43.07	42.81	−0.59
5	WS	3	4	0.9	44.80	44.53	−0.59
6	WS	3	5	0.9	45.73	46.51	1.70
7	WS	4	3	0.9	45	44.15	−1.89
8	WS	4	4	0.9	46.4	46.59	0.41
9	WS	4	5	0.9	48.4	49.35	1.96
10	WJ	2	3	1.0	51.07	52.74	3.28
11	WJ	2	4	1.1	54.67	59.37	8.60
12	WJ	2	5	1.1	58.67	66.54	13.42
13	WJ	3	3	1.2	57.73	61.82	7.07
14	WJ	3	4	1.2	62.67	72.45	15.61
15	WJ	3	5	1.4	70.93	83.72	18.03
16	WJ	4	3	1.2	63.20	71.64	13.36
17	WJ	4	4	1.2	74.20	86.36	16.39
18	WJ	4	5	1.4	81.60	101.77	24.72
19	KS	2	3	1.0	46.40	45.17	−2.64
20	KS	2	4	1.0	48.27	48.14	−0.25
21	KS	2	5	1.2	51.73	51.48	−0.50
22	KS	3	3	1.1	49.87	48.98	−1.77
23	KS	3	4	1.2	52.53	53.84	2.49
24	KS	3	5	1.3	55.80	59.18	6.05
25	KS	4	3	0.9	51.73	53.24	2.91
26	KS	4	4	0.9	54.93	60.09	9.40
27	KS	4	5	0.9	57.73	67.50	16.92
28	NI	2	3	0.9	50.13	54.60	8.91
29	NI	2	4	1.0	54.13	62.07	14.66
30	NI	2	5	1.0	56.00	70.11	25.20
31	NI	3	3	0.9	56.80	64.90	14.26
32	NI	3	4	0.9	63.20	76.84	21.58
33	NI	3	5	0.8	69.07	89.44	29.50
34	NI	4	3	1.1	62.00	76.00	22.58
35	NI	4	4	1.2	70.13	92.48	31.86
36	NI	4	5	1.1	75.53	109.66	45.18

seam, it is required to propose a model for lock stitch seam based on realistic profile. In present study the elliptical profile of lockstitch seam is confirmed for different fabrics by taking cross-section of seam profile along the seam line. Based on actual elliptical seam profile, the new models is proposed by defining elliptical geometry of seam with interlacement point and the final equation is obtained in terms of fabric assembly thickness, stitch density and thread diameter.

Materials and methods

The different type of fabric have been considered for the study as shown in Table 1 of different fabric specifications including fabric thickness as per standards (ASTM D 1777, ISO 3616/9073). The different and diverse varieties of fabrics have been considered for study from low aerial density comparatively thin woven fabric to high weight thick denim fabric, knitted single jersey and of high aerial density nonwoven felt interlining fabric.

As the contribution of thread diameter is very less (Rasheed et al., 2014) and almost there is no effect of thread diameter (Jaouadi et al., 2006) on thread consumption, therefore only one type of sewing thread, a two ply poly-poly (polyester) core spun with resultant count of 25.19 Tex has been used for both needle and bobbin thread.

The stitching is done on JUKI DDL-8100B-7 lockstitch machine using a needle of 16 count (100 Nm). The stitching of three different number of layers for each fabric is done at different stitch density that is stitches per centimetre (SPC) as shown in Table 2. The needle thread tension is adjusted (Ferreira, Harlock, & Grosbera, 1994) for each type of fabric and for each ply number to achieve seam balancing at constant bobbin tension of 50 g. Where seam balance is the

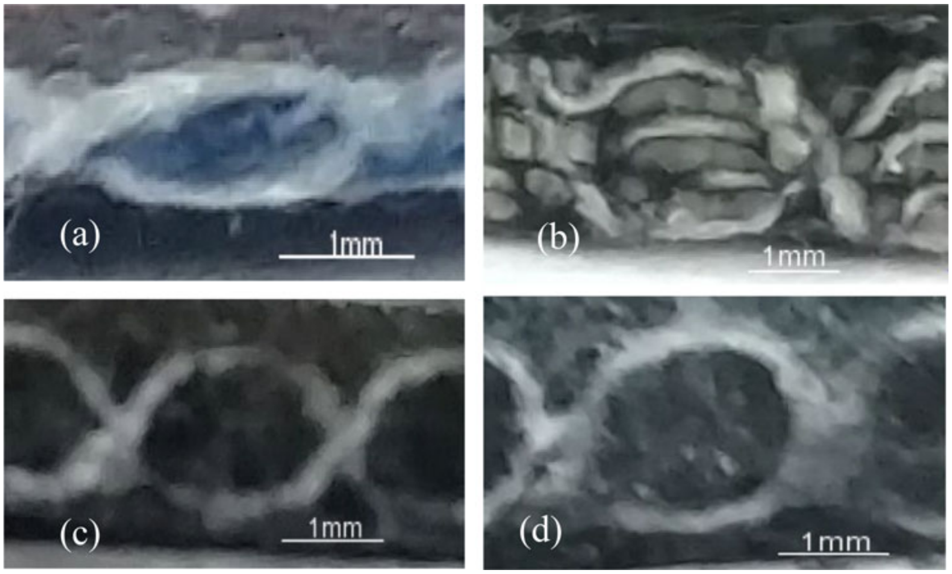

Figure 1. Actual stitch profile of lock stitch 301 seam at 4 spc and 3 number of ply (a) for woven shirting fabric (b) for woven jeans fabric (c) for knitted single jersey fabric (d) for nonwoven interlining fabric.

ratio of thread consumed at needle thread to bobbin thread for a given stitching length (Amirbayat & Alagha, 1993). The needle thread tension and bobbin thread is measure using digital yarn tension metre with an accuracy of 0.1 g. Finally after stitching, the actual length of needle thread and bobbin thread are measured practically by unravelling thread from a seam length of 20 cm. Seam by seam at each position both the needle and bobbin threads were unravelled one after another carefully in order to unravel thread without affected by tension. The lengths of unravelled thread have been straightened until crimp removed and then measured as per the ASTM standard D 3883-99 by applying a force (g) equals to the 0.25 times of the yarn number in tex. The seam profile is observe by freezing the seam using wax and afterward cutting along seam line for getting sectional view.

The proposed model

The seam profiles of lockstitch seam have been observed for different fabrics, it has been found that the profile of lockstitch seam is more like an elliptical shape than that of rectangular shape irrespective of fabric type. It is clearly seen in the Figure 1 that the shape of lockstitch seams is more or less an elliptical in nature irrespective of fabric type. Also from Figure 1 it can be said that the contact angle at the interlacement between the needle and bobbin thread would be less than 180° further which is depends on the fabric thickness. Therefore for the lockstitch seam 301 the model is proposed based on actual elliptical profile.

Geometry of proposed model

It is assumed that the sewing threads are circular in diameters and of incompressible nature and the diameter of needle thread is equal to the diameter of bobbin thread. The geometry of proposed elliptical profile base model for lock stitch seam is as shown in Figure 2. The centre axis of needle thread in a unit seam indicated by line (ABDEG) and for bobbin thread line (ACDFG). Where segment ABD of needle thread and segment ACD of bobbin thread forms an elliptical profile with major axis AD and minor axis BC. The total fabric assembly thickness (T) is represented by line JK whereas the seam length (p) by line A'O'. The geometry at interlacement formed by needle thread arc DFG and bobbin thread arc DEG.

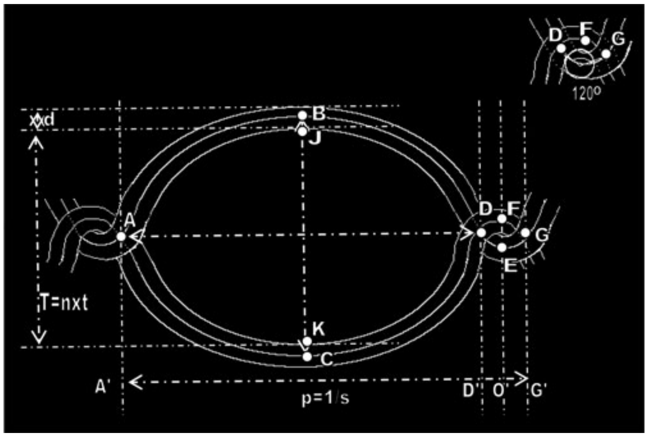

Figure 2. Elliptical geometry of lockstitch 301 seam.

Therefore,

$$\begin{aligned}\text{The total thread length per stitch } (T_{301}) &= \text{perimeter of ellipse } (ABDC) \\ &+ \text{Thread length at interlacement}(\text{arc } DFG + \text{arc } DEG)\end{aligned} \quad (1)$$

The perimeter of ellipse can be found out by different methods (Bourke & Cantrell, 2013), here the Ramanujan approximation I (Ramanujan, 1914) is considered which is one of the more accurate method. As per Ramanujan approximation I the perimeter of ellipse C is given by the

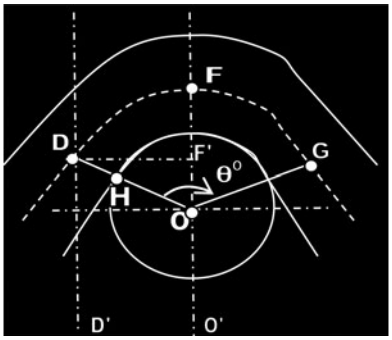

Figure 3. Geometry of interlacement point for elliptical model.

following formula

$$C = \pi\left[3(a+b) - \sqrt{10ab + 3(a^2+b^2)}\right] \qquad (2)$$

where,C - perimeter of ellipse as per Ramanujan approximation (cm)a - radius of major axis (cm)b - radius of minor axis (cm)

Solving for radius of major axis (a):

$$\text{We know that, diameter of major axis (AD)} = 2a \qquad (3)$$

$$\text{From figure, diameter of major axis (AD)} = \text{A'G'} - \text{D'G'} \qquad (4)$$

As, A'G' = length of a seam (p)

It can be written in terms of a stitch density's' which is stitches per centimeter as

$$\text{A'G'} = 1/s \qquad (5)$$

D'O' distance is equal to the DF' which can obtained by drawing perpendicular on to the line F as shown in Figure 3 and D'G'= 2D'O

From ΔDF'O,

$$\text{DF'} = \text{sine ofDOF' x OD}$$

As ∠ DOG is θ°, ∠ DOF' is 0.5 θ °and OD = DH + HO = d/2 + d/2 = d, Where d = diameter of sewing thread d(cm)

$$\text{Therefore DF'} = \text{d sine}(\theta/2) \qquad (6)$$

and DG =2 d sine(θ/2), also the distance DG = D'G', therefore

$$\text{D'G'} = 2\ \text{d sine}(\theta/2) \qquad (7)$$

From Equations (4), (5) and (7), diameter of major axis (AD) = $\left[{}^{1}/_{s} - 2\ \text{d sine}\left(\frac{\theta}{2}\right)\right]$Therefore,

$$\text{a} = 0.5\left[{}^{1}/_{s} - 2\ \text{d sine}\left(\frac{\theta}{2}\right)\right] \qquad (8)$$

Solving for radius of minor axis (b):

$$\text{We know that, diameter of minor axis(BC)} = 2\text{b} \qquad (9)$$

$$\text{From figure2, diameter of minor axis(AD)} = \text{BJ} + \text{JK} + \text{KC} \qquad (10)$$

and BJ = KC = d/2,

Where JK is thickness of fabric assembly 'T'(cm) further if 'n' are the number of ply and 't' is the fabric

$$\text{thickness(cm) thenT} = \text{nxt} \qquad (11)$$

Therefore, from Equations (9)–(11)

$$2\text{b} = \text{T} + \text{d}$$

$$\text{Thereforeb} = \frac{T+d}{2} \qquad (12)$$

Now solving for Thread length at interlacement:

Thread length at interlacement = arc length DFG + arc length DEG

$$\text{As arc length DFG} = \text{arc length DEG, thread}$$

$$\text{length at interlacement} = 2\ \text{(arch length DFG)} \qquad (13)$$

From Figure 3, as the angle subtended by arch DFG is θ ° and arc radius is equal to d.

$$\text{Therefore, arc lengthDFG} = \text{d}\ \theta \qquad (14)$$

$$\text{And from Equations (13) and (14), Thread length}$$

$$\text{at interlacement (I)} = 2\ \text{d}\ \theta \qquad (15)$$

And from Equations (1), (2) and (15)

$$\text{Total thread consumption } \text{T}_{301} = \pi[3(a+b)$$

$$-\sqrt{10ab + 3(a^2+b^2)}] + 2\ \text{d}\ \theta \qquad (16)$$

Generally for sewing thread the linear density is expressed in terms of tex, the following formula has been used to find out diameter of yarn from the yarn tex (Jaouadi, Msahli, & Sakli, 2009; Seyam & el-Shiekh, 1993) as follows

$$\text{d(cm)} = 0.00398\sqrt{\text{Nt}} \qquad (17)$$

where Nt is the thread linear density in Tex Nt.

By image analysis of seam profile of cut section, the minimum contact angle of 60° were obtained for thick nonwoven interlining fabric with four plies and maximum angle of 100° is obtained for the thin shirting fabric with two plies. As the angle is changing from 60° to 100°, the optimum contact angle (θ) 80° is assumed in the proposed model, where the error percentage with respective change in angle is in the range of ± 2% (As 1.7% error for WS sample number 1 at θmax and −1.1% for NI sample number 36 at θmin).

Therefore now from Equation (8) and (17), a = 0.5$\left[{}^{1}/_{s} - 2\ \text{d sine}(40°)\right]$

$$\text{a} = 0.5\left[{}^{1}/_{s} - 0.00512\ \sqrt{\text{Nt}}\right] \qquad (18)$$

from Equation (12) and (17)

$$\text{b} = \frac{nt + 0.00398\sqrt{\text{Nt}}}{2} \qquad (19)$$

And from Equation (15) and (17),

Thread length at interlacement = 2 $\left(\frac{80}{180}\right)\pi\ 0.00398\sqrt{\text{Nt}}$

$$\text{Thread length at interlacement} = 0.0111\sqrt{\text{Nt}} \qquad (20)$$

Now from Equation (16) and (20),

Table 3. Comparison of proposed elliptical model with other models.

Sample numbers	Fabric type	% Error range - elliptical model	% Error range - Rectangular model- Ghosh et al	% Error range - Rectangular model - Jaoudi et al.	%Error range - Rectangular model - Raheed et al.
1–9	WS	−3.02*, 1.96	16.4, 35.1	15.7, 34.1	5.2, 15
10–18	WJ	3.28, 24.72	34.6, 56.8	34.1, 56.2	−23.7*, −3.5*
19–27	KS	−2.64*, 16.92	23.0, 54.3	22.4, 53.4	−9.0*, 3.6
28–36	NI	8.91, 45.18	42.3, 80.7	41.7, 80.1	39.3, 78.1
Overall % error range		−3.02*, 45.18	16.4.08, 80.7	15.7, 80.1	−23.7*,78.1

*−ve mark indicates the under estimation.

Total thread consumption,

$$\mathrm{T301} = \pi\left[3(a+b) - \sqrt{10ab + 3(a^2+b^2)}\right] + 0.0111\sqrt{\mathrm{Nt}} \tag{21}$$

Where the values of a and b as obtained from above Equations (18) and (19), which are in terms of fabric thickness 't' (cm), number of plies 'n', Stitch density 's' (spc) and thread linear density 'Nt' (Tex). The final equation in terms of these parameters can be written as

$$\begin{aligned}\mathrm{T301} = \pi\Big\{1.5\left[\left({}^{1}/_{s} - 0.00512\sqrt{\mathrm{Nt}}\right) + \left(nt + 0.00398\sqrt{\mathrm{Nt}}\right)\right]\\ -\sqrt{\left[2.5\left({}^{1}/_{s} - 0.00512\sqrt{\mathrm{Nt}}\right)\left(nt + 0.00398\sqrt{\mathrm{Nt}}\right)\right] + 0.1875\left[\left({}^{1}/_{s} - 0.00512\sqrt{\mathrm{Nt}}\right)^2 + \left(nt + 0.00398\sqrt{\mathrm{Nt}}\right)^2\right]}\ \Big\}\\ + 0.0111\sqrt{\mathrm{Nt}}\end{aligned} \tag{22}$$

Similarly error percentage (with overestimation) is increasing with increasing in number of plies from 5.2% for two plies, 9.9% for three plies to 15.1% for four plies, may be due to the comparatively more initial compression (Maisudaira & Qin, 1995) of fabric and partially due to the change in contact angle. As it is observed practically by measuring the contact angle from the cut section of seam profile that the contact angle is changing with change in thickness of fabric assembly.

Result and discussion

The various types of fabric have been selected as shown in Table 2 to validate the model. The fabrics were stitched by changing the stitch density (spc) at different number of ply by maintaining seam balance in order to verify the predictability of the model for thread consumption. The % error is calculated by considering the predicted thread consumption calculated from the model with respect to the actual thread consumption obtained by practical measurement.

The accuracy in prediction is varying with respect to the fabrics type, spc and number of plies. For woven fabrics type, there is a more accuracy in prediction for comparatively thin shirting fabric than jeans fabric. Amongst the all given fabrics, the minimum % error obtained about 0.4% for a woven shirting fabric (sample number 8) and maximum of 45% for nonwoven interlining fabric (sample number 36) based on the proposed elliptical model for given range of fabrics. For knitted fabric also comparatively there is a less error % with minimum of −0.25% (sample number 20).

It has been found that the error percentage (with overestimation) is increasing with increasing in stitch density from 5.4% for 3 spc, 9.4% for 4 spc to 15.3% for 5 spc. This increase in error percentage may be due to the fabric compression effect as addressed by miller (Amirbayat, 1991; Miller, Amirbayat, & Miller, 1991) the compressive stress acting on a stitch is inversely proportion to the stitch length.

Comparative study

The comparative study of proposed elliptical model have been done with rectangular profile based geometrical models (Ghosh & Chavhan, 2014; Jaouadi et al., 2006; Rasheed et al., 2014) as shown in Table 3.

It has been found that the there is good accuracy in prediction for a proposed elliptical model as compared to rectangular models. The rectangular models by Ghosh and Chavhan and Jaoudi et al. almost giving the same results with overall error of around 40% (over estimation) while little deviation in results for recent model by Raheed et al., where the fabric thickness expressed as the sum of thread diameters but for different structures a proper approach has to be followed.

Regression analysis

To find out the correlation between the actual thread consumption (which is found out practically) with predicted thread consumptions, the regression analysis is carried out for each type of fabric and overall. There is a strong correlation with r-square value more 0.94 have been found out irrespective of fabric type. As shown in Figure 4, even though error percentage for the jeans and nonwoven interlining fabrics is comparatively more, the strong correlation with r-square vale of 0.99 and 0.97 obtained, respectively. Overall there is a good co relation with r-square vale 0.95 obtained.

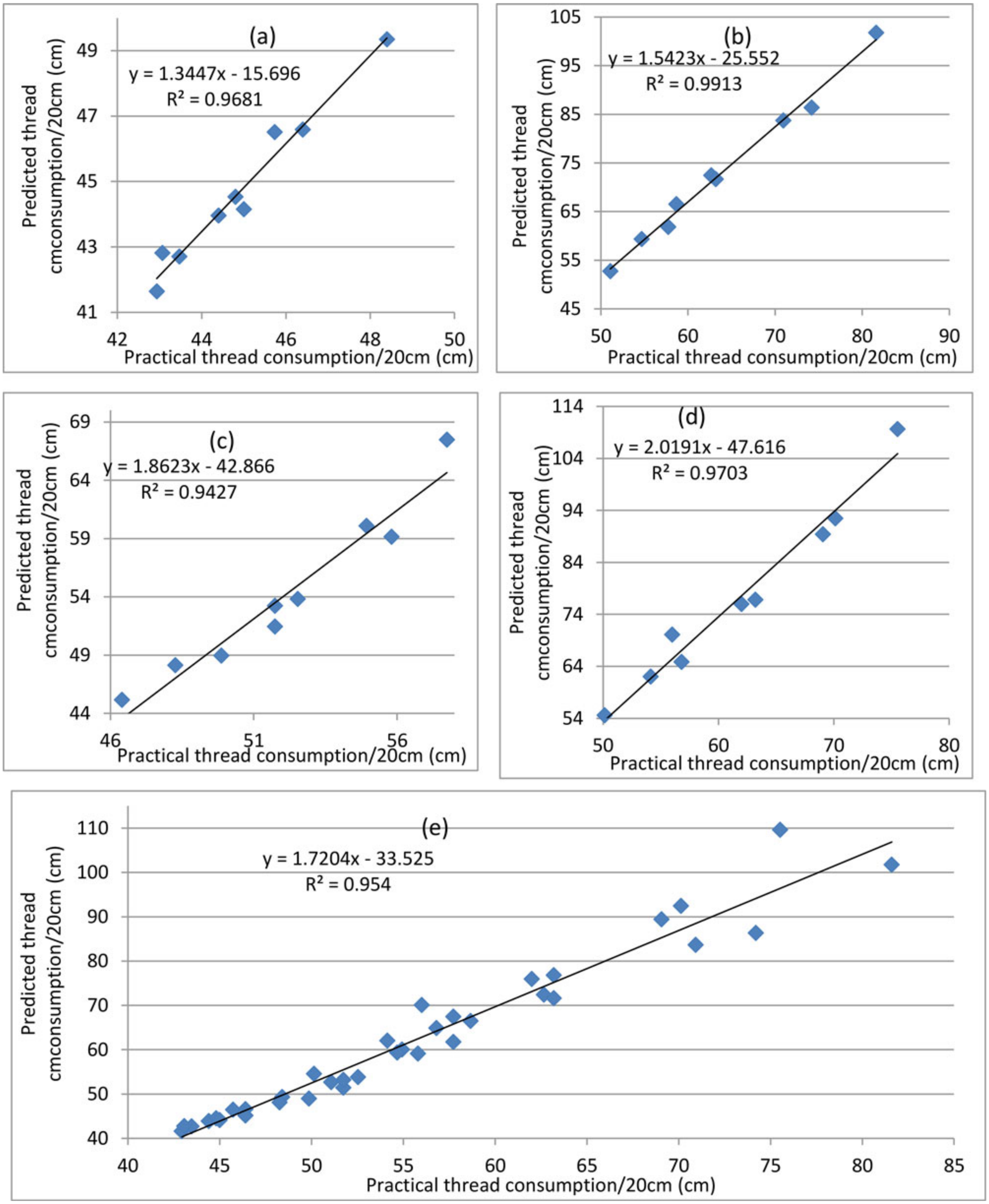

Figure 4. Relation between practical and predicted thread length for (a) woven shirting (WS) (b) Woven jeans (WJ) (c) knitted single jersey (KS) (d) nonwoven interlining (NI) (e) overall fabrics.

Conclusion

The proposed elliptical model based on realistic stitch profile is able to predict the thread consumption with more accuracy than other geometrical models which are based on rectangular profile, for lockstitch seam irrespective of fabric types. The accuracy in prediction is varying with fabric type, stitch density and number of plies. There is increase in error percentage (with over prediction) with increase in stitching density and number of ply, which may be reduce by proposing mechanistic model by considering a compressive forces acting at seam due to the thread tension. Also instead of assumed fixed value of contact angle an approach is required to predict contact angle value in terms of fabric assembly thickness.

Disclosure statement

No potential conflict of interest was reported by the authors.

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References

Abeysooriya, R. P., & Wickramasinghe, G. L. D. (2014). Regression model to predict thread consumption incorporating thread-tension constraint: Study on lock-stitch 301 and chain-stitch 401. *Fashion and Textiles*, *1*(1), 1–8. https://doi.org/10.1186/s40691-014-0014-5

AMANN. (2010). Determining your sewing thread requirements thread demand. Retrieved from http://www.amann.com/fileadmin/download/naehfaden/b_naehfadenbedarf_EN.pdf

AMANN. (2013). Thread consumption industry method. Retrieved from https://doi.org/10.1016/B978-0-08-087780-8.00056-5

Amirbayat, J. (1991). Profile of lockstitch seams: A theoretical study. *Textile Research Journal*, *61*(2), 119–122. doi:10.1177/004051759106100211

Amirbayat, J., & Alagha, M. J. (1993). Further studies on balance and thread consumptions of lockstitch seams. *International Journal of Clothing Science and Technology*, *5*(2), 26–31. doi:10.1108/eb003014

Boubaker, J., Sana, A., & Faouzi, K. (2017). Consumed sewing thread behaviour based on lockstitch and chainstitch. *Indian Journal of Fibre & Textile Research*, *42*(September), 325–334.

Bourke, P., & Cantrell, D. (2013). Circumference of an ellipse. Retrieved from http://paulbourke.net/geometry/ellipsecirc/

COATS. (2014). Introduction, contents thread, sewing classification, thread terminology, thread requirements, quality threads, coats sewing. Retrieved from https://www.coats.com/en/Guidance/The-Guide-to-Thread-Consumption https://www.coats.com/en/Guidance/The-Guide-to-Thread-Consumptionhttp://www.coatsindustrial.com/en/information-hub/apparel-expertise/thread-consumption

COATS. (2018). Thread storage - Guidance - Coats. Retrieved from https://www.coats.com/Guidance/Thread-Storage

Davis, W. (1933). 34—investigations on fabric seams. *Journal of the Textile Institute*, *24*(11), 361–382. https://doi.org/10.1080/19447023308661603

Dogan, S., & Pamuk, O. (2014). Calculating the amount of sewing thread consumption for different types of fabrics and stitch types. *Tekstil ve Konfeksiyon*, *24*(3), 317–323.

Efird, A. (2010). Thread price versus thread cost. Retrieved from http://www.amefird.com/wp-content/uploads/2010/01/Thread-Price-vs-Thread-Cost-2-6-10.pdf

Ferreira, F. B. N., Harlock, S. C., & Grosberg, P. (1994). A study of thread tensions on a lockstitch sewing machine (part iii) further stitch formation analysis. *International Journal of Clothing Science and Technology*, *6*(5), 39–42. doi:10.1108/09556229410074592

Ghosh, S., & Chavhan, M. V. (2014). A geometrical model of stitch length for lockstitch seam. *Indian Journal of Fibre and Textile Research*, *39*(June), 153–156.

Jaouachi, B., & Khedher, F. (2013). Evaluating sewing thread consumption of jean pants using fuzzy and regression methods. *Journal of the Textile Institute*, *104*(10), 1065–1070. doi:10.1080/00405000.2013.773627

Jaouachi, B., Khedher, F., & Mili, F. (2012). Consumption of the sewing thread of jean pant using Taguchi design analysis. *Autex Research Journal*, *12*(4), 81–86. doi:10.2478/v10304-012-0015-7

Jaouadi, M., Msahli, S., Babay, A., & Zitouni, B. (2006). Analysis of the modeling methodologies for predicting the sewing thread consumption. *International Journal of Clothing Science and Technology*, *18*(1), 7–18. doi:10.1108/09556220610637477

Jaouadi, M., Msahli, S., & Sakli, F. (2009). Contribution to measurement of real yarn diameter. *Journal of the Textile Institute*, *100*(2), 158–164. doi:10.1080/00405000701757487

Maisudaira, M., & Qin, H. (1995). Features and mechanical parameters of a fabric's compressional property. *Journal of the Textile Institute*, *86*(3), 476–486. doi:10.1080/00405009508658774

Midha, V. K., Sharma, S., & Gupta, V. (2016). Predicting sewing thread consumption for lockstitch using regression model. *Research Journal of Textile and Apparel*, *20*(3), 155–163. doi:10.1108/RJTA-08-2016-0019

Miller, J. A. J. M., Amirbayat, J., & Miller, J. M. (1991). Order of magnitude of compressive energy of seams and its effect on. *International Journal of Clothing Science and Technology*, *3*(2), 12–17.

O'Dwyer, U., & Munden, D. (1975). A study of the factors affecting the dimensions and thread consumption in 301 seams-part 1. *Clothing Research Journal*, *3*, 3–32.

Ramanujan, S. (1914). Modular equations and approximations to Pi. *Quarterly Journal of Mathematics*, *XLV*, 350–372. Retrieved from http://ramanujan.sirinudi.org/Volumes/published/ram06.pdf

Rasheed, A., Ahmad, S., Mohsin, M., Ahmad, F., & Afzal, A. (2014). Geometrical model to calculate the consumption of sewing thread for 301 lockstitch. *Journal of the Textile Institute*, *105*(12), 1259–1264. doi:10.1080/00405000.2014.886366

Seyam, A., & el-Shiekh, A. (1993). Mechanics of woven fabrics: Part III: Critical review of weavability limit studies. *Textile Research Journal*, *63*(7), 371–378. doi:10.1177/004051759306300701

Sharma, S., Gupta, V., & Midha V. K. (2017). Predicting sewing thread consumption for chainstitch using regression model. *Journal of Textile Science & Engineering*, *7*(2), 1–3. https://doi.org/10.4172/2165-8064.1000295