



# Effect of different parameters on stitch shape and thread consumption

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The present work is aimed at studying the effect of fabric compressibility, feed rate and thread tension on the shape of lockstitch and the amount of thread consumed per stitch. Images of different possible stitch shapes have been captured by varying these parameters, and it is found that stitch shape may be rectangular, elliptical, elongated elliptical or circular, depending on the interaction between these parameters. Then, Box-Behnenken design of experiment is applied to study the effect of these parameters on the amount of thread consumed per stitch. The contribution% of all the parameters affecting thread consumption is calculated and it is found that the feed rate has highest contribution (92%) followed by thread tension (2.18%) and fabric compressibility (1.53%). From this study, it can be concluded that the prediction of thread consumption in lock-stitching process is only possible if the geometry of the stitch is correctly assumed which varies due to the variations in feed rate, fabric compressibility and thread tension.

**Keywords:** Fabric compressibility, Feed rate, Lockstitch, Sewing thread, Stitch shape, Thread tension, Thread consumption

## 1 Introduction

Sewing thread is one of the most important accessories in stitching process. Lockstitch is the most broadly used stitch among different stitch classes, thus making its thread consumption a vital consideration for valuing a reliable cost of sewing thread.

Sewing thread consumption has been a subject of interest for many researchers since many years and many of them have worked on studying the factors affecting thread consumption<sup>1-8</sup>. Few researchers have worked on developing mathematical models based on assumed stitch geometry, i.e. either rectangular or elliptical geometry to calculate thread consumption<sup>1,5,9-13</sup>. Some of the researchers used other techniques like fuzzy logic, regression analysis, artificial neural networks and Taguchi design<sup>1-4,14</sup>. In a recent study, it was reported that geometrical modeling method gives less error values (0.01-18.83%) than statistical methods (0.17-18.98%) and is considered better method to evaluate thread consumption<sup>15</sup>.

A review of the literature shows that feed rate, thread tension and fabric thickness are the most important parameters influencing thread consumption<sup>6,7,11,14,15</sup>, but the thickness of the fabric gets compressed on stitching<sup>10,13</sup>. So, it is the fabric compressibility which may decide the thread consumption other than feed rate and thread tension.

Although various researchers have studied the influence of various parameters on thread consumption of lockstitch seam, but no one has given any evidence on the parameters affecting lockstitch profile. ISO Standard definition<sup>16</sup> and most of the experimental research till date considered the shape of lockstitch as rectangular in nature<sup>1,5,11-12,17</sup> and few have suggested elliptical shape of the lockstitch<sup>9-10,13</sup>. So, rectangular stitch can be considered as an ideal geometry of lockstitch seam. But there is no evidence available in the literature on the condition for the occurrence of ideal rectangular stitch geometry and the condition of any deviation of stitch geometry from this ideal geometry. Any change in stitch shape will ultimately result in change in thread consumption. So, the objective of this study is to identify the factors responsible for variation in stitch shape and investigate the interactive effect of these parameters on thread consumption of lockstitch seam.

## 2 Materials and Methods

### 2.1 Change in Shape of Lockstitch Seam due to Thread Movement during Stitching Process

To identify the possible condition when the formation of an ideal geometry of lockstitch can be possible, an experiment was carried out by hanging a yarn of 40.8 tex in the form of a stitch from two piercings made in the sponge surface at a low value of load (2.3gf) and at a high load value (20gf) on the yarn. From the experiment, it was observed that the yarn holds almost a rectangular shape at lower load

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and the shape gets converted to ellipse when it is subjected to higher load. So, this experiment gives an idea that the ideal rectangular geometry of lockstitch may occur under low thread tension and the shape will be changed at higher thread tension, depending on the compressibility of material.

Furthermore, in order to confirm the above and understand the formation of different stitch shapes, thread movement during lock-stitching process was observed by running a lockstitch machine at a very slow speed. The images of stitches after stitching were captured before and after stitch tightening process as shown in Fig. 1.

Figure 1(a) shows that before stitch tightening, the current stitch in formation (stitch no. 1) holds almost a rectangular configuration and the stitch already formed (stitch no. 2) looks somewhat elliptical in shape. On the other hand, it can be seen from Fig. 1(b) that both the stitches (stitch no.1 and 2) become elliptical after stitch tightening. It may be possible that an increase in thread tension during stitch tightening tends to rob back some amount of thread, leading to change in stitch geometry from rectangular to elliptical shape. This backward flow of thread may be similar to the one observed in knitting known as Robbing back phenomenon<sup>18</sup>. This analysis is supported with the earlier observation of Ferreira *et. al*<sup>19</sup> who identified the mechanism of stitch formation based on robbing-back phenomenon. So, it can be said that rectangular geometry is occurring at low tension and gets converted to elliptical or other shape the moment stitch tightening takes place [Fig. 1(b)]. Any change in the stitch shape due to movement of thread will always play an important role in deciding the amount of thread consumed in a stitch.

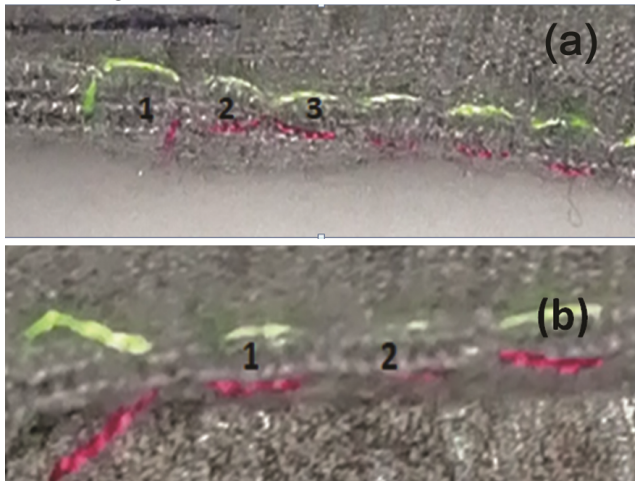


Fig. 1 — Thread configuration (a) before stitch tightening, and (b) after stitching tightening

**2.2 Measuring Techniques**

From the literature, it was found that compressive stress acting on the stitch is an important factor affecting thread consumption<sup>10, 13</sup>. So, fabrics of different compressibility were used for studying the stitch shape and thread consumption. Fabric compressibility was measured in Prolific thickness gauge at a pressure ranging between 2kPa and 200kPa, using the following equation:

$$\text{Compressibility \%} = \frac{t_i - t_f}{t_i} \times 100 \quad \dots (1)$$

Where  $t_i$  is the initial thickness at a pressure of 2 kPa; and  $t_f$ , the final thickness after the fabric, which is compressed at a pressure of 200 kPa<sup>20,21</sup>. The compressibility values of different fabrics are shown in Table 1.

Feed rate is defined as the amount of fabric fed to the machine per unit time. Feed rate can be quantified by following equation:

$$\text{Feed rate} = \frac{l}{t} \quad \dots (2)$$

where  $l$  (cm) is the length of the fabric stitched for a fixed unit of time  $t$  (s). Feed rate is controlled by knob position and was calculated at different positions as given in Table 2.

Needle thread input tension was measured at a position between takeup lever and thread length guide using a tension meter designed on the basis of strain gauge principle. To study the effect of needle thread input tension, fabric was stitched at three different input tensions, namely 30gf, 60gf and 100gf in balanced seam conditions.

**2.3 Experimental Set-up**

The study was carried out in two steps. In the first step, the effect of fabric compressibility, feed rate and

Table 1 — Compressibility values of different fabrics

Fabric	Initial thickness ( $t_i$ ), mm	Final thickness ( $t_f$ ), mm	Compressibility %
Woven jute (A)	0.69	0.58	15.94
Denim (B)	0.75	0.61	18.67
Leather (C)	1.75	1.31	25.14
Plain knit (D)	0.39	0.28	28.21
Rib knit (E)	0.86	0.59	31.39
Knitted fleece (F)	1.41	0.60	57.45
Spacer (G)	1.46	0.55	62.33
Non-woven (H)	1.65	0.41	75.15
Sponge (I)	2.5	0.31	87.60

Table 2 — Feed rate values at different knob positions

Knob position	1	2	3	4
Feed rate, cm/s	0.77	1.43	2.28	2.96

thread tension on stitch shape was studied. For this, fabrics having different compressibility (15.94-87.60%) were taken, irrespective of their structure and stitched at four feed rates (0.77, 1.43, 2.28 & 2.96 cm/s) and three needle thread input tensions (30, 60 & 100 gf). All the fabric samples were stitched in Brothers S-7000 DD-403 Lockstitch machine. A spun polyester sewing thread of 29 tex having 26.70 cN/tex breaking tenacity and 11.15% breaking elongation with sewing needle of the size 18 was used for stitching. After stitching, all the seamed fabrics were cut along the stitched line and placed between two glass plates to observe the seam configuration. The effect of these parameters on stitch profile of lockstitch seam was observed by taking images of all the stitched samples using a digital camera.

In the second step, the interaction effect of these parameters on thread consumption was analyzed by using Box-Behenken design of experiment at three factors of three levels giving 17 runs. The fabrics of different compressibility were taken, irrespective of their structure in such a manner that the initial thickness of all the fabric chosen is approximately same (1.4 mm). So, the fabrics chosen were jute woven fabric (2 layers), knitted fleece (1 layer) and a spacer fabric (1 layer). The levels were chosen based on our initial experimental data. The actual values of different parameters corresponding to coded levels are listed in Table 3.

All the samples were stitched as per the design and then the actual thread consumed per stitch was calculated for each run experimentally by unraveling method.

**3 Results and Discussion**

The effect of fabric compressibility, feed rate and thread input tension on stitch shape and thread consumption has been analyzed on the basis of stitched samples and are discussed hereunder.

**3.1 Effect of Fabric Compressibility, Feed Rate and Thread Input Tension on Stitch Shape**

**3.1.1 Effect of Fabric Compressibility on Stitch Shape**

Fabrics of different compressibility values are stitched at a feed rate of 1.96 cm/s and needle thread

input tension of 60gf in balanced seam condition. The images of stitch configurations obtained for all fabrics having different compressibility are shown in Fig. 2.

From Fig. 2, it can be seen that the shape of a lockstitch seam at a given feed rate and thread tension is different for different fabrics. It can be seen that a relatively rigid material like jute woven fabric (A), denim (B) and leather (C) exhibits almost a rectangular configuration. On the contrary, a fabric having medium compressibility like plain knit (D), rib knit (E), knitted fleece (F), spacer fabric (G) and non-woven (H) tends to give probably an elliptical or an elongated elliptical stitch shape, and a highly compressible material like sponge (I) may form a circular stitch shape. The reason for such variations in stitch shape for different fabrics may possibly be due to the different amount of fabric compression after stitch tightening.

For a compressible material, thickness of the fabric assembly gets reduced to a larger extent after stitch tightening due to the tension developed at thread interlacing point which causes the stitch to take elliptical shape<sup>9,13,22</sup>. On the other hand, a rigid material will not get compressed much and thickness of the material remains unchanged after stitching, thus stitch will maintain almost a rectangular configuration<sup>1,5,11</sup>. Further, a circular stitch shape in highly compressible material like sponge may be formed due to open structure of the sponge which facilitates higher amount of thread movement from previous stitch during stitch tightening process. Stitch tightening process may reduce the sponge thickness to a value equal to stitch spacing, resulting in the formation of circular stitch shape.

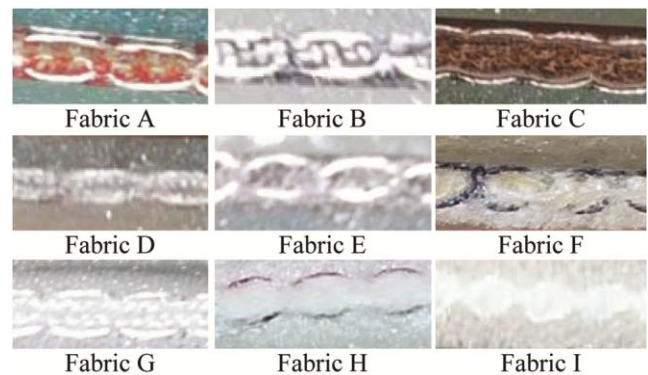


Fig. 2 — Stitch profile of fabrics with different compressibility stitched at a feed rate of 1.96 cm/s and needle thread input tension of 60gf

Table 3 — Design of experiment

Factors	Levels		
	-1	0	+1
Fabric compressibility, %	15.94	57.45	62.33
Feed rate, cm/s	0.77	1.96	2.96
Needle thread pre-tension, gf	30	60	100

### 3.1.2 Effect of Feed Rate on Stitch Shape

Rib knitted fabric (E) having compressibility of 31.39% was used and stitched at a needle thread input tension of 60gf in balanced seam condition to study the effect of feed rate on stitch shape.

From Fig. 3(a), it is observed that stitch profile is closer to circular geometry at slower feed rate and changes from circular to elliptical with increase in feed rate as shown in Figs 3(b) and (c). At maximum feed rate, it gets a shape closer to elongated ellipse, as shown in Fig. 3(d).

At higher feed rate, the stitch spacing will be longer and, so the amount of sewing thread supplied to the machine will be larger giving a larger stitch length<sup>6</sup>, thus forming elliptical stitch shape. On the other hand, slower feed rate means stitch spacing will be less<sup>5</sup>, giving a smaller stitch length, thus forming a stitch shape similar to circular profile. So, when the stitch spacing will be approaching closer to fabric thickness, the stitch shape approaches towards circular geometry as shown in Fig. 3(a). Thus, the stitch shape is also changing from circular to elongated ellipse with the increase of feed rate from 0.77 cm/s to 2.96 cm/s.

### 3.1.3 Effect of Thread Tension on Stitch Shape

The effect of needle thread input tension on stitch configuration of lockstitch seam has been studied on a rib knitted fabric stitched at a feed rate of 1.96 cm/s and at three different input tensions (Fig. 4).

It is observed from Fig. 4(a) that at low thread input tension (30 gf), stitch profile is much closer to rectangular shape and it changes to elliptical or elongated elliptical shape on increasing the thread tension, as shown in Figs 4(b) and (c).

At lower thread tension, the force at which thread is pulled from the stitch during stitch tightening will be lower. Hence, less amount of thread will be robbed off from previous stitch and fabric compression will also be less, resulting in a little change in stitch profile from its ideal geometry. So, a near rectangular shape will be formed at lower thread tension [Fig. 4(a)]. On the other hand, higher thread tension will develop higher pulling force on the sewing thread and pulls more amount of thread from previous stitch which will compress the fabric more and so the stitch will take the shape similar to an ellipse or elongated ellipse, as shown in Figs 4(b) and (c)<sup>13</sup>.

Also, it is observed that at a higher tension (100gf), the fabric gets highly compressed and the thickness of the fabric is reduced to a large extent, resulting in the formation of an elongated ellipse, as shown in

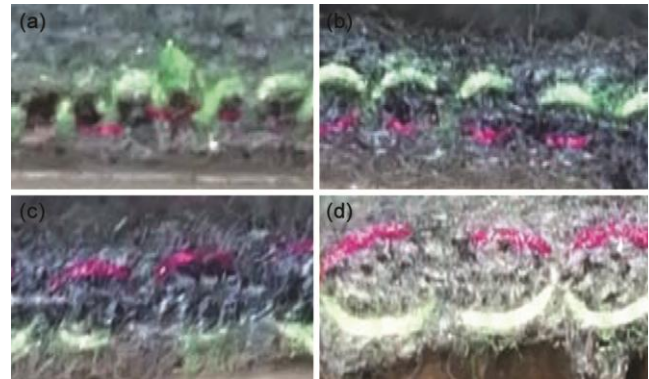


Fig. 3 — Stitch configuration at different feed rates (cm/s): (a) 0.77, (b) 1.43, (c) 2.28 and (d) 2.96 on rib knitted fabric at a needle thread input tension of 60gf

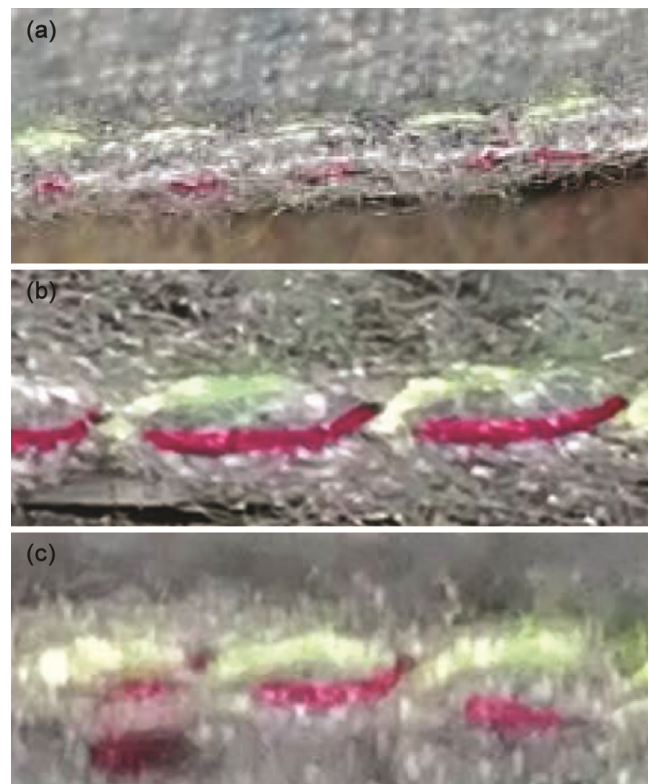


Fig. 4 — Stitch configuration at different thread tensions: (a) 30gf, (b) 60gf, and (c) 100gf on rib knitted fabric at a feed rate of 1.96 cm/s

Fig. 4(c). Therefore, the different stitch shapes which can be seen from Figs 4(a)–(c) at different tension values may be due to different compression levels on the same fabric at three different thread tension values. Hence, the stitch shape is affected by the thread tension level also.

So, it can be said that different types of stitch shape possibly depend on the compressibility of fabric, feed rate and thread tension. The stitch profile may be rectangular, elliptical, elongated elliptical or circular, depending on the interaction between these three

parameters. Hence, the thread consumption calculation by using single geometrical shape may not be the right approach to predict thread consumption in lockstitch. There is a need to identify the stitch shape in order to predict thread consumption accurately. So, a right kind of stitch shape is pre-requisite for the prediction of the theoretical thread consumption in lockstitch seam.

**3.2 Effect of Fabric Compressibility, Feed Rate and Thread Tension on Thread Consumption**

Based on our experiment and research literature<sup>1-8</sup>, it has been identified that thread consumption in a lockstitch seam is a function of feed rate, fabric compressibility and thread tension. An interaction among these parameters will decide the shape of the stitch and ultimately the amount of thread consumption in a lockstitch.

The effect of fabric compressibility on stitch consumption is directly related to the change in fabric thickness due to pressure. So, to know the nature of fabric compression, the pressure vs thickness curve of jute woven fabric (2 layers), knitted fleece and spacer fabric having approximately same initial thickness ( $\cong 1.4$  mm) were studied at a pressure range between 2 kPa and 200 kPa in Prolific thickness gauge as shown in Fig. 5.

Figure 5 shows the nature of compression curve of three different fabrics taken. It is found that knitted and spacer fabric tends to reduce the thickness rapidly with small increase in pressure, and then there is little change in the fabric thickness at higher pressure. On the other hand, there is a nominal change in thickness of the jute fabric other than the initial compression at low pressure.

The effect of fabric compressibility, feed rate and thread tension on the amount of thread consumed per

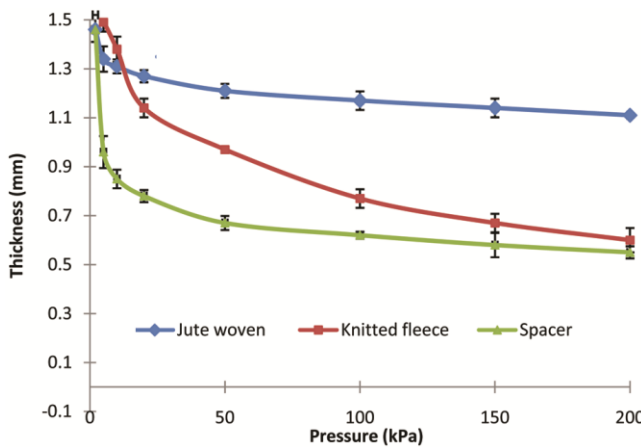


Fig. 5 — Pressure-thickness curve of fabrics

stitch and their individual contributions has also been investigated by employing Box-Behenken design and Response surface methodology. The experimental design with the response (actual thread consumed) is shown in Table 4.

All main effect and two-factor interaction effect and the quadratic effect obtained by ANOVA are shown in Table 5. The values of "Prob> F" less than 0.0500 indicates that the model terms are significant at 95% confidence interval. In this case, X, Y, Z, X<sup>2</sup>, Z<sup>2</sup> are significant model terms. The contribution % of all parameters affecting thread consumption is calculated to understand the influence of these parameters as shown in Table 5, and it is found that the feed rate has highest contribution (91.13%) followed by fabric compressibility (3.23%) and thread tension (2.39%).

The coefficient of determination is found to be 0.9606 implying a goodness of fit. The model equation in the coded unit is:

$$\text{Thread consumed per stitch} = 4.83 - 0.45X + 2.39Y - 0.39Z + 0.40 X^2 + 0.28Z^2$$

This equation can predict the amount of thread consumed for given fabric compressibility, feed rate and thread tension. The results showing the effect of fabric compressibility, feed rate and thread tension on the amount of thread consumed are given in Figs 6(a-c).

**3.2.1 Effect of Feed Rate and Fabric Compressibility**

The effect of feed rate and fabric compressibility on the amount of thread consumed at a constant

Run	Factor X Fabric compressibility %	Factor Y Feed rate cm/s	Factor Z Thread tension, gf	Thread consumed mm
1	-1	0	1	5.3
2	1	0	-1	5.4
3	1	-1	0	2.2
4	1	0	1	4.6
5	0	0	0	4.8
6	1	1	1	7.5
7	0	1	1	7.1
8	0	-1	-1	3.2
9	0	0	0	4.8
10	0	0	0	4.8
11	0	1	-1	7.6
12	0	0	0	4.8
13	-1	0	-1	6.6
14	0	-1	1	2.7
15	-1	1	0	8.2
16	-1	-1	0	3.2
17	0	0	0	4.8

Table 5 — ANOVA result for the amount of thread consumed per stitch

Source	Contribution, %	SS	Df	MS	F-value	p-value
Model		49.50	5	9.90	199.37	< 0.0001
Fabric compressibility ( $X$ )	3.23	1.62	1	1.62	32.63	0.0001
Feed rate ( $Y$ )	91.13	45.60	1	45.60	918.40	< 0.0001
Thread tension ( $Z$ )	2.39	1.20	1	1.20	24.19	0.005
$X^2$	1.38	0.69	1	0.69	13.88	0.0034
$Z^2$	0.66	0.33	1	0.33	6.62	0.0259
Residual	1.09	0.55	11	0.050		
Lack of Fit	1.09	0.55	7	0.078		
Pure Error	0	0.000	4	0.000		
Cor Total	100	50.04	16			

\*\*Significant

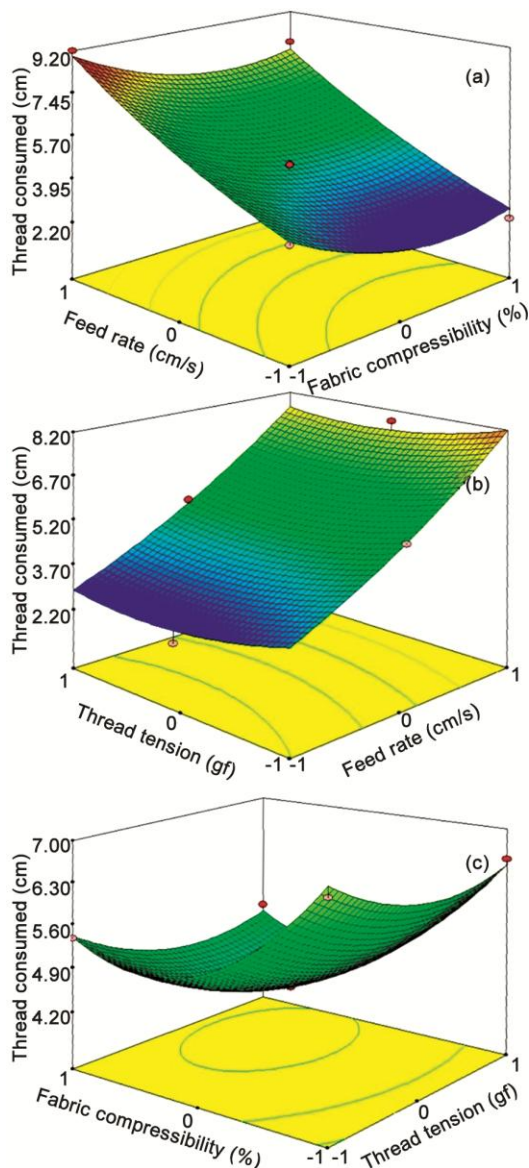


Fig. 6 — Interactive effect of different parameters on thread consumption: (a) effect of feed rate and fabric compressibility, (b) effect of feed rate and thread tension and (c) Effect of fabric compressibility and thread tension

thread tension is depicted in Fig. 6(a). It is observed that the amount of thread consumed increases with increase in feed rate which may be due to an increase in stitch spacing at higher feed rate<sup>5,6</sup>. Higher stitch spacing requires longer length of thread to form a stitch, thus increasing the amount of thread consumed<sup>4</sup>.

Also, it is found that thread consumption first decreases with increase in fabric compressibility and then there is not much change in thread consumption with further increase in fabric compressibility. This is probably because of the compressive behavior of fabric under high pressure. A highly compressible material tends to compress to a larger extent during the process of stitching, which results in reduction in fabric assembly thickness<sup>13</sup>. This forms elliptical or elongated elliptical stitch geometry as mentioned previously, thus reducing the amount of thread consumed per stitch. On the other hand, the non-compressible fabric will not get much compressed on stitching, and so stitch shape will be closer to rectangular geometry giving higher thread consumption.

Also, from pressure-thickness curve of fabrics (Fig. 5), it can be seen that the thickness of knitted fleece and spacer fabric is almost similar at high pressure (around 200 kPa). So, there is not much change in thread consumption of these fabrics when they are stitched under similar kind of thread pressure.

### 3.2.2 Effect of Thread Tension and Feed Rate on Thread Consumption

Figure 6(b) shows the effect of feed rate and thread tension on the amount of thread consumed at knitted fleece fabric having 57.45% compressibility. This graph shows that there is an increase in the amount of thread consumed with increase in feed rate. It is due to the fact that at higher feed rate, the fabric is moving faster and hence the length of thread supply is increased<sup>7</sup>. More thread supply will increase the

stitch spacing and stitch length. An increase in stitch length increases the amount of thread consumed<sup>5,6</sup>. So, increase in feed rate increases the amount of thread consumed per stitch.

Figure 6(b) shows that there is a slight decrease in the amount of thread consumed with increase in thread tension and then it becomes almost stable. The probable reason for this slight decrease may be that with increase in thread tension, the pressure exerted on the fabric due to yarn tension increases and the fabric gets compressed, which reduces the fabric thickness, thus reducing the amount of thread consumed. Another reason may be that at higher thread tension, more amount of thread is pulled from the stitch during stitch tightening process changing its shape from rectangular to elongated ellipse or ellipse. Hence, the thread consumption is lowered at higher tension<sup>7</sup>. With further increase in thread tension, there is no change in thread consumption. The pressure-thickness curve for a compressible fabric gives a dramatic decrease in thickness as the load increases initially followed by lower decrease in fabric thickness with further increase in load (Fig. 5). The final stage of the curve gives almost a straight line, indicating that the fabric is difficult to compress when the pressure is greater than a critical value<sup>21,23</sup>. So, if we will increase the pressure beyond a certain level, then there will not be much change in the fabric thickness. So, thread tension will affect the thread consumption only in the initial part of the in fabric thickness vs pressure curve.

### 3.2.3 Effect of Thread Tension and Fabric Compressibility on Thread Consumption

Figure 6(c) shows the response surface curves of the relationship between fabric compressibility and thread tension, while the feed rate is kept constant at 1.96 cm/s. It shows that the amount of thread consumed per stitch first decreases with increase in fabric compressibility and then it becomes stable. It is because of the same reason explained earlier that the reduction in amount of thread consumed with increase in fabric compressibility is due to the reduction in fabric thickness for a compressible material during stitching process. The amount of thread consumed depends on the thickness of the fabric and decreases with the decrease in thickness of the fabric<sup>1,5,6</sup>. Any further increase in fabric compressibility does not reduce thread consumption, because from thickness vs pressure curve, it can be seen that knitted fleece fabric and spacer fabric give almost same thickness at higher pressure (Fig. 5), resulting in similar thread consumption values.

Also, it can be seen that there is a slight decrease in the amount of thread consumed with increase in thread tension and then it becomes almost stable. The probable reason for this slight decrease is same as explained previously that the pressure exerted over the fabric in a stitch increases with increase in thread tension. So, the fabric gets compressed, thus reducing the amount of thread consumed<sup>7</sup>. Higher thread tension will also allow more sewing thread to get pulled from the previously formed stitch, resulting in lower amount of thread consumed. After that, any increase in thread tension will not decrease the thread consumption because the fabric may have attained its threshold value of thickness. So, there will be no change in thread consumption at higher thread tension.

From this study, it is found that the fabric compressibility and thread tension show a relatively lesser contribution (3.23% and 2.39% respectively) as compared to the feed rate (91.13%) on the amount of thread consumed per stitch (Table 5). The impact of feed rate on thread consumption is more due to increase in stitch spacing with increase in feed rate. It is obvious that any increase in stitch spacing will increase the amount of thread required (both needle and bobbin thread), thus increasing needle and bobbin thread lengths. The lesser impact of fabric compressibility and thread tension on the amount of thread consumed can be explained by the pressure-thickness curve of the fabric as explained previously.

## 4 Conclusion

In this study, the effect of feed rate, fabric compressibility and thread tension on stitch shape and thread consumption per stitch has been studied. It is observed from contribution% calculation that feed rate is the most influential factor affecting the amount of thread consumed followed by fabric compressibility and thread tension. It is also found that the length of thread consumed in a stitch depends on the stitch shape which changes with any change in feed rate, fabric compressibility and thread tension. This study also shows the possibilities of four different stitch geometries after stitching of fabric, i.e. rectangular, elliptical, elongated-elliptical and circular depending on the interaction between these parameters, i.e. feed rate, fabric compressibility and thread tension.

It is found that the thickness of a compressible fabric gets reduced due to fabric compression under pressure during stitching. This reduced thickness will act as the effective thickness in the stitch, which, in turn, reduces the amount of thread consumption. The stitch shape of

compressible fabric also changes due to change in fabric thickness, which will also reduce the thread consumption. Thus, the knowledge of stitch shape and the exact value of fabric thickness after fabric compression under pressure are the pre-requisite for predicting the thread consumption of lockstitch seam.

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