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Effect of compressional behaviour and sewing machine foot pressure on sewing thread consumption

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Effect of compressibility and foot pressure on the consumption behaviour of sewing threads in case of single and double-layered denim fabrics has been investigated. Experiments involve fabric thickness of three different denim samples (cotton, and 90/8.5/1.5% & 92/6.5/1.5% cotton/polyester/elastane) and their compression properties measurement using Kawabata device. A relationship between compressional energy and consumed sewing thread values using lock stitch type 301 has been investigated. Based on this, accuracy of the coefficient of regression (close to 1) has been observed, indicating the positive relationship between compressibility property and sewing thread consumption behaviour. Implementation of software can help the industries to minimize their consumption errors and approximations. Nevertheless, under the same pressure value applied by the foot pressure, the thickness values of sewed layers can decrease differently as a function of their compressional resilience. Thus, it is obvious that thicker fabrics display lower compressional resilience and vice versa, which encourages more consumption of sewing thread.

Keywords: Cotton, Denim fabric, Elastane, Fabric compressibility, Polyester, Sewing thread, Thread consumption

1 Introduction

Sewing thread is one of the integral materials required for garment manufacturing, and a suitable estimation of its consumption is important for the apparel cost estimation especially with the introduction of high performance and costly sewing threads [1,2]. Moreover, Buzov *et al.*[3] demonstrated that poor sewing thread can greatly increase production costs, as they cause frequent stoppages of sewing machines[3]. Apart from that and from industrial's point of view, there are no efficient techniques, which can help industrials to count the needed number of sewing bobbins per garment. Based on the literature, various methods are available, such as industrial method, geometrical models and regression models, in order to estimate accurately sewing thread consumption. However, due to the complexity of stitch structure, high number of the influential parameters and difficulty to control simultaneously overall input factors, some approximations and hypothesis are usually used. Indeed, rough estimation can be done based on the empirical available data with range of variation. Some explanations have been given in different studies [1, 4, 5]. In fact, they are related to the complexity of studied seam structures, difficulty in the geometry of stitch, variability in thread tension and especially compressibility of fabrics, sewing threads and their compressive modulus [1, 6-9]. Although the study of the compressibility property of woven fabrics was initiated with Peirce, Kemp & Hamilton's approach on circular yarns and flattened yarns of a fabric under pressure, its contribution on the consumption of sewing thread remained unexploited and unknown yet to explain some behaviors[10]. Compressibility is one of the important properties of fabric, in addition to friction, bending, tension and shear. In garment automation, for instance, compressibility can be a crucial property for successfully separating plies from a stack. With the growing need for better material modeling for simulation purposes, objective measurements of fabric compression will become increasingly important, since static compression gives an indication of the mechanical 'springiness' of the material. Referring to Gurumurthy[10], the fit of the pressure-thickness relationship is being improved using the exponential interpolation and extrapolation methods, as well as iterative methods, such as the Marquardt algorithm for fitting the curves. Midha *et al.*[11] reported that the compression, friction and bending during the sewing process cause damage/pullout of surface resulting in a loss in mechanical properties. Abher *et al.*[5, 12]

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considered that stitching is also used on some incompressible or relatively less compressible materials (e.g. leather). Ghosh *et al.* [4] reported that the needle thread forms the top surface and bobbin thread forms the bottom surface of lock stitch seam. The length of stitch depends on the feed rate, whereas height of seam depends on the thickness and compression of fabric, and the position of cross over point is decides by the flow of yarn due to tension development in the threads [5]. Due to the relaxation process, the sewing thread tends to contract to its initial length according to its elastic strain. Hence, an inner compressive force is generated in the sewing thread, which, in turn, exerts an in-plane compressive force on the fabric in each stitch length. This difference on geometric shape of the seamed layered thicknesses causes the difference in the consumed thread values using theoretical model [13, 14]. Furthermore, to develop their models and explain the effectiveness of their findings, all researchers, industrials and manufacturers consider the shape of seam line as non-deformable shape, the deformability of the fabric and sewing thread structures, the compressibility of investigated materials and their shapes during and after seaming, etc.[7, 8]. In addition, to decrease the error values between theoretical consumptions, using for example the geometric stitch shapes and the experimental or regressive ones, the tensile properties of fabrics and threads are considered along with the compressive stresses and the deformability of seamed fabrics. Even though it was mentioned as an influential parameter on the consumption of sewing thread, the compressibility of denim fabrics was not highlighted. The purpose of this study is to describe an evaluation of the thread consumption behavior as a function of fabric compressibility using lockstitch seam 301. In addition, the paper reports an established model for measuring the consumed thread based on compressed thickness under a known pressure which can be increased gradually and continuously. The change in thickness with either increasing or decreasing pressure can also affect sewing thread consumption values widely.

2 Materials and Methods

Three most commercialized denim fabrics within their following characteristics were selected and used in the present study (Table 1).

These samples are chosen to explore experimental designs of variation based on their uses as denim garments. Besides, these denim fabrics are considered to be adequate as are ranged inside a wide spectrum of denim fabrics. To determine pressure values applied by foot pressure device, two layers of denim fabrics are sewed using a sewing machine type DURKOPP ADLER and a pressure sensor device type Flexi force® A 301was used (Figs 1 and 2).

The choice of machine and stitch type were selected garment making process which uses machine 301 in the denim garment assembly line. The average sewing thread consumption value, expressed in centimeters, is the quantity of thread sewn onto the garment at the assembly folds. After sewing all the samples, the length of thread consumed by experimentally unstitching them measured. Each combination tested in our experimental design was repeated 5 times in order to objectively obtain an average representative experimental sewing thread consumption value objectively. The above work was carried out for 6 different heights and the results are translated directly into pressure. Due to the importance in the clothing field, the 301-lock stitch was used to assemble the layers of fabrics. The variation in height of foot pressure (HFP) transduces the pressure rate (value) expressed by resistance of denim fabric (Fig. 2). Tests were carried out on the standard conditions for textile testing.

Figure 3 presents the pressure evolutions of compressed denim samples as a function of the height

Table 1 — Different characteristics of denim fabrics

Samples	Blend raw materials	Mass g/m²	Weft density cm^{-1}	Warp Nm	Weft Nm	Thickness mm
#1	100% CO	386	21	12.5	20.4	0.8
#2	90/8.5/1.5% CO/PES/EL	377	21	15	26	0.79
#3	92/6.5/1.5% CO/PES/EL	359	22	14	26	0.72

EL-Elastane, CO- Cotton, PES- Polyester.

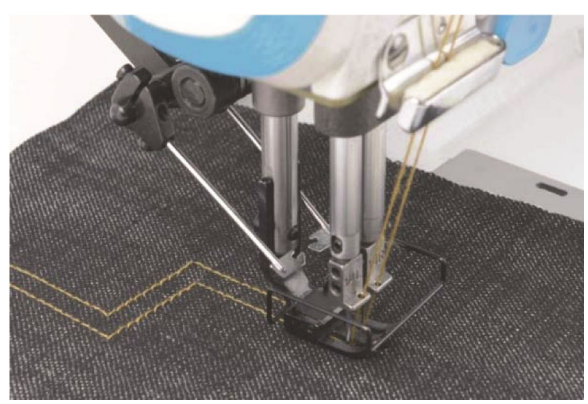

Fig. 1 — Denim fabric under foot pressure during seam process

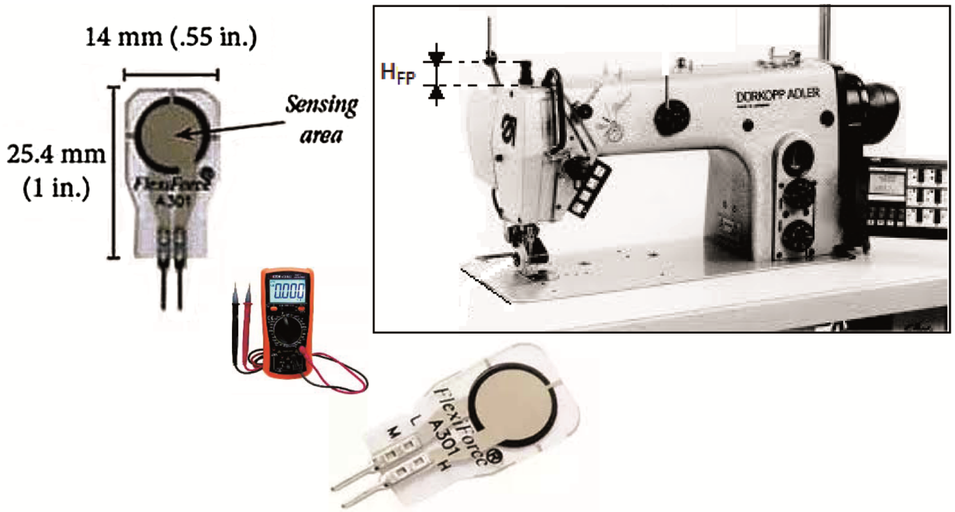

Fig. 2 — Variation in H_{FP} to measure the pressure applied during the use of DURKOPP machine

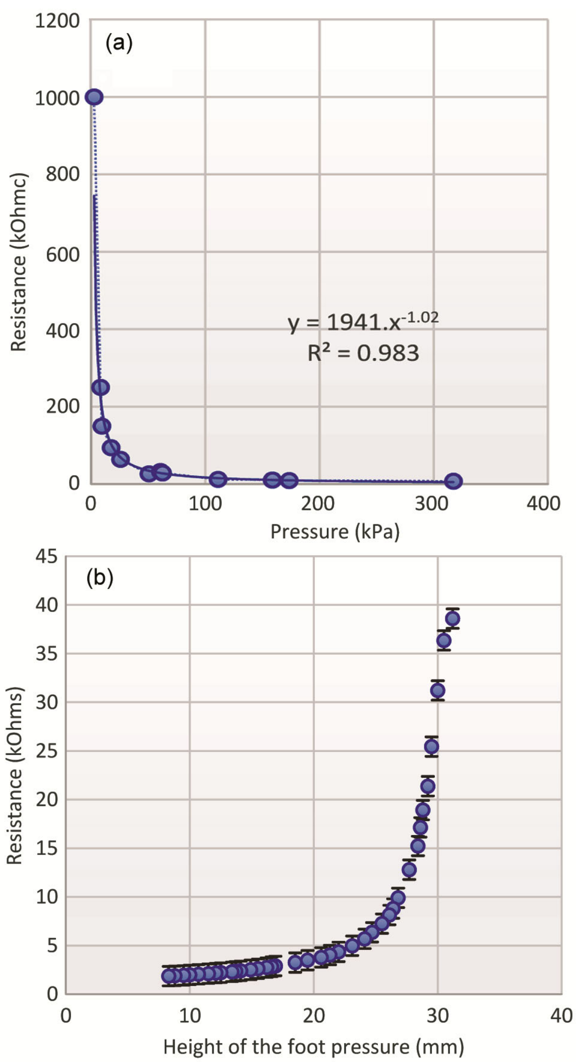

Fig. 3 — Evolution of resistance values of studied samples as function of (a) pressure and (b) height of foot pressure

values of foot pressure of the sewing machine. Each test is repeated 5 times for each denim sample according to the French standards.

The foot pressure was calibrated before using it to minimize the errors during test. The foot pressure height values are obtained by conversion applied to obtain the compression values. For each pressure value expressed by the height of foot pressure on sewing machine, denim layers are sewed along 150mm repeated five times. The mean length of the unstitched lengths corresponds to the total consumed thread values relative to the sum of both stitch and bobbin threads.

This experiment was repeated for each height of the foot pressure to evaluate the impact of compressibility of denim fabrics on the consumption behavior. The investigated compressibility values using experimental method are compared with those obtained using KES device.

2.1 Kawabata Evaluation System for Fabrics Device

As mentioned previously, Kawabata introduced four parameters as part of the KES-F (the Kawabata evaluation system for fabrics) to determine the compressibility values and to compare them with those obtained by foot pressure of sewing machine. Hence, one layer of denim fabric was investigated. Based on Fig. 4, the four parameters in the KES-FB3 test express the work of compression WC (WC' is the area under the release curve). The first parameter is resilience of the fabric (RC), that represents the hysteresis in the compression graph, it is calculated using the following equation:

$$RC = 100 \times \frac{WC'}{WC} \quad \ldots (1)$$

where the expressions relative to WC and WC' are given by the following equations:

$$WC = \int_{T_0}^{T_m} \vec{P} dt \quad \ldots (2)$$

$$WC' = \int_{T_m}^{T_0} \overleftarrow{P} dt \quad \ldots (3)$$

Normally, the curves relating to pressure-thickness relationships are plotted considering pressure on the Y-axis. The relationship between pressure and thickness is defined by an exponential curve. The compressional work per unit area, (WC (cN/cm)) varies depending on the type of fabric. A more compressible material gives larger values; for example, wool gives a larger value of WC as compared to other fabrics. Hence, the higher the WC values, the more will be the fullness and the compressibility of the fabrics. The difference in the values may be attributed to the surface layer of the fabric, which makes a large contribution to the compressibility (springiness) of the material.

2.2 Compressional Parameters of Fabrics using KES Device

Notwithstanding, the applied pressure is expressed by 'P' and the thickness by 'T', with 'T_0' and 'T_m' being the thickness at a minimum pressure of 0.5 gf/cm^2 and a maximum pressure of 50 gf/cm^2

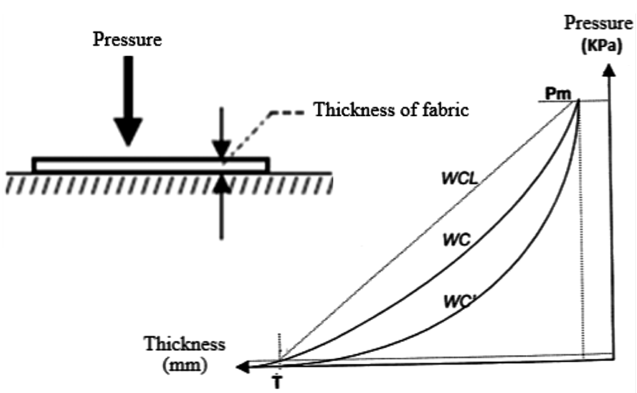

Fig. 4 — Evolution of pressure as a function of thickness using KES-FB3

respectively. The second distinctive parameter for compression is the linearity of the compression (LC). If the thickness of the fabric decreases linearly with increasing pressure, the LC value would be 1 according to Fig. 4 and Eq. (4). However, all fabrics compress non-linearly, and have an LC value ranging between 0.14 and 0.47. The harder fabrics have a lower value of LC, which would result in a steeper rising compression. Equation (4) is given below:

$$LC = \frac{WC}{WCL} = \frac{WC}{[0.5 \times (P_m \times (T_0 - T_m))]} \quad \ldots (4)$$

Finally, the dimensionless EMC parameter expresses the compressibility of a fabric. The smaller the EMC value, the more incompressible will be the fabric. Its expression is given by the following equation:

$$EMC = 1 - \left(\frac{T_m}{T_0}\right) \quad \ldots (5)$$

The study on the compressibility of woven fabrics is initiated coupled with Peirce, Kemp & Hamilton's approach for circular and flattened yarns of a fabric under pressure. The fit of pressure thickness relationship is being improved using exponential interpolation and extrapolation methods, as well as iterative methods, like the Marquardt algorithm for fitting the curves to overcome the limitations of existing models. Although there is a recent trend towards the automation of studying the structure/property relationship of textile fabrics, an objective and efficient method for predicting properties with a rapid prototype that outputs to sophisticated instruments like the KES-FB3 is essential. To build the relationship between the compression applied by the foot pressure and consumed thread, this study aims to investigate three denim fabrics. To study the compressive behavior of woven fabrics, the obtained findings are compared with those using the KES-FB3 device.

3 Results and Discussion

Table 2 shows the mean values of the sewing thread consumptions of three tested denim fabrics.

Table 2 — Sewing thread consumption of fabrics as a function of foot pressure height (mm)

Fabric	Mean consumption values, mm (CV%)					
	30 mm	27.50 mm	25 mm	20 mm	15 mm	10 mm
#1	44.32 (1.27)	43.60 (0.71)	43.54 (1.21)	42.24 (1.28)	41.66 (2.06)	41.30 (1.86)
#2	43.38 (0.34)	42.38 (0.51)	42.40 (0.80)	42.10 (0.96)	41.46 (0.50)	40.56 (1.00)
#3	46.42 (1.31)	45.24 (1.30)	44.12 (1.56)	43.06 (0.78)	42.38 (1.40)	41.54 (0.37)

30, 27.50, 25, 20, 15 and 10 mm are heights of foot pressure.

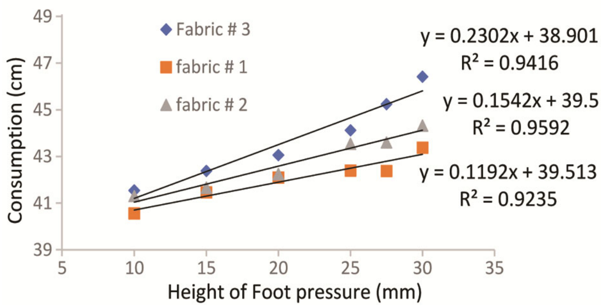

Fig. 5 — Effect of height of the foot pressure on sewing thread consumption of studied denim fabrics

Figure 5 shows the effect of foot pressure height of the sewing machine on the behavior of the sewing thread consumption relative to the studied denim fabrics. These evolutions are found using a lock stitch type 301.

It can be observed that fabric thickness has a significant effect on the compressional and consumed amount of sewing thread (Fig. 5). Moreover, a considerable amount of compression of polyester blended fabrics (Fabrics #2 and #3) occurs at very low pressures. Based on the results shown in Fig 5, it may be remarked that, during seam process on denim samples, the same behavior of the consumption as a function of foot pressure of the sewing machine increases. The increase in height value of the foot pressure decreases the pressure applied on double-layered fabrics. By comparing overall behaviors of the consumed thread with the foot pressure, it is clearly remarkable that Fabric #3 presents the highest consumption values. Despite of their compositions, the results obtained using the KES-FB3 (Table 2) demonstrate that Fabric #3 shows a higher value of the dimensionless EMC parameter than those relative to Fabric #2 and Fabric #1 respectively. The result reflects the incompressibility property of the fabric that have the lowest EMC, which is in agreement with the values reported by Gurumurthy [10]. Under the same pressure value applied by the foot pressure, thickness value of assembled layers is decreased differently as a function of their compressional resilience. Table 2 shows that a lower value of thickness loss (Fabric #1) is associated with a higher value of compressional resilience. As proved by Akthar & Subramanian [15], this result seems understandable and highlights the consumption superiority of sewing thread using Fabric #1. The results are obvious as thicker fabrics display lower compressional resilience and vice versa, which, in turn, causes high consumed amount of sewing thread. Nevertheless, for compressional properties, it is reported that the fabric's bending rigidity basically depends on the bending rigidity of constituent fibre/yarns from which the fabric is manufactured, fabric construction and, most importantly, the nature of the chemical treatment given to the fabric[16], Besides, the compressibility of a fabric mainly depends on the yarn packing density and yarn spacing in the fabric. In fact, compressibility property provides a feeling of bulkiness and sponginess in the fabric. Compressibility has some correlation with the thickness of the fabric; the higher the thickness, the higher will be the compressibility. The low-stress compressional parameters such as linearity of compression (LC), compressional energy (WC), compressional resilence (RC), and thickness curve (Th) are related to the primary hand value (Fukurami or bulkiness) of the fabric. Physically these properties are analogous to the tensile parameters such as LC, WC and RC; RC gives the compressional resilience, WC is compressed energy and LC is the linearity of compression and fabric thickness, whereas Th is the thickness of the fabric. However, it may be observed that generally compressional resilience has a direct bearing on the fabric areal density. The compressional energy at low-stress deformation for linen/viscose-blended fabrics is found to be less compared to linen-cotton, 100% linen and 100% cotton fabrics[16]. Otherwise, many other parameters affect the mass and the thickness of samples, such as warp density, and count of warp and weft yarns. For example, in some published works, the studied denim fabrics are produced within same weft density but they show different mass and thickness values. Although the studied denim fabrics, within the same weft density value (20 cm^{-1}) and having 3/1 twill weave, are produced from 100% cotton (weight 349.0g/m^2 and warp density 25cm^{-1}) and 98.5-1.5% cotton-elastane (weight 328.1g/m^2 and warp density 27 cm^{-1}), their weights are different [17]. In addition, in the Kos *et al.*' study [17], the warp density of studied samples is varied (ranged from 16 threads/cm to 24 threads/cm), while weft density for all the samples is found the same (11 threads/cm). Their results demonstrate that the changes in warp density provide significant correlation coefficients between the warp density and physical and mechanical properties of fabrics and multi-component materials [18, 19]. On another hand, a higher number of picks and ends and higher linear density of threads give a bigger mass per

Table 3 — Properties of fabrics measured using KES-FB3

Property	KES-FB3 results		
	Fabric #1	Fabric #2	Fabric #3
$Th_{p=0.5}$, mm	0.947	1.106	1.204
$Th_{p=50}$, mm	0.618	0.684	0.708
WC, cN/cm	0.367	0.367	0.299
RC, %	34.330	34.33	41.140
LC^{*}	0.296	0.336	0.283
EMC, %	34.741	38.155	41.196

*Without unit.

square meter [20]. Moreover, a formula, developed by Milašius [20,21] explains widely the relationship among all these parameters and the variation of one parameter [21, 22], as shown below:

$$T_{av} = \frac{T_1 \times S_1 + T_2 \times S_2}{S_1 + S_2} \quad \ldots (6)$$

where T_{av} is the average linear density of yarn in tex; S_1 , the warp density in cm^{-1}; S_2 , the weft density in cm^{-1}; T_1 , the linear density of warp yarn in tex; T_2 , the linear density of weft yarn in tex; and T_{av} , the average of linear density of thread.

Table 3 shows the thickness values relative to tested denim fabrics using the Kawabata device (KES-FB3). According to the obtained findings, it is remarkable that the increase of pressure from 0.5gf/cm^2 to 50gf/cm^2, decreases the thickness of fabric clearly. This result that seems in a good agreement with Schiefer [23], traduces the effect of pressure applied on compressive fabrics. According to his study, the thickness of textiles and many other similar materials depends greatly upon the pressure applied to the surfaces of the specimen. It decreases as the pressure is increased. Comparing Fabrics #2 and #3, having the same blend components, the results show that the highest resilience (RC) value is relative to Fabric #3. Indeed, the higher the RC values, the more springy the fabric and the better hand. Thinner fabrics have higher RC values. This obviously results in soft feel and better comfort and consumption properties. According to Behera [24], on comparing the fabric thickness of similar fabric weights, it may be observed that the 100% linen fabrics are usually thicker than cotton and blended fabrics, which is indeed true.

Based on the results reported by Behera [24], it is shown that a high areal density is obtained either by using high thread density or coarse warp and weft yarns. The increase in fabric weight generally shows a comparable increase in fabric thickness[16, 20-22]. On overall examination of the construction parameters of various fabrics, it may be observed that 100% linen fabrics could be manufactured with comparatively low thread density, as compared to 100% cotton and blended fabrics of similar areal density [16]. This is in good agreement with the results obtained by Matusiak and Milašius[20-22]. Following equation helps to understand the effect of blends, warp and weft density and warp and weft count on thickness and areal density (GSM); it reports the relationship among all these structural parameters:

$$\varphi = \sqrt{\frac{12}{\pi}}\frac{1}{P}\sqrt{\frac{T_{av}}{\rho}}\,S_2^{\frac{1}{1+\frac{2}{3}\sqrt{\frac{T_1}{T_2}}}}\,S_1^{\frac{\frac{2}{3}\sqrt{\frac{T_1}{T_2}}}{1+\frac{2}{3}\sqrt{\frac{T_1}{T_2}}}} \quad \ldots (7)$$

where φ is the integrated structure factor defined by Milašius[20, 21]; ρ , the overall density of raw materials of threads; and P, the weave factor (the weave–firmness factor) proposed by Milašius[20, 21].

However, during seam process, the consumed thread made using one layer is not the same when many layers are assembled and the same applied pressure is used. The main difference is the ability degree of the compared layers of denim fabrics to compression property. According to some published studies, the compressibility depends mainly upon the structure of the specimen, whereas the compressional resilience depends upon the kind of material and the structure of the specimen[1, 4, 23]. This result seems in a good agreement with those obtained in present study. Indeed, among all fabrics, it is observed that Fabric #3 is characterized by a higher value of RC; this is due to the effect of samples, containing some percentage of polyester components and removal of cellulosic component. Otherwise, compression resilience is influenced by the type of fibre used. In this context, it has been found that the compression resilience increases with a decrease in polyester content. Besides, the compressibility of a fabric mainly depends on yarn packing density and yarn spacing in the fabric. In fact, compressibility property provides a feeling of bulkiness and spongy property in the fabric. Compressibility has some correlation with the thickness of the fabric; the higher the thickness, the higher is the compressibility. According to Behera's study[24], physically these properties are analogous to the tensile parameters, such as linearity (LT), tensile energy (WT) and tensile resilience (RT); RC gives the compressional resilience, WC is compressed energy and LC is the linearity of compression and fabric thickness, whereas Th is the thickness of the fabric[16]. However, it may be observed that generally compressional resilience has a direct bearing on the fabric areal density. To understand the effects of blends, it is demonstrated that the compressional energy at low stress deformation, for example, for linen/viscose-blended fabrics is found to be less as compared to linen-cotton, 100% linen and 100% cotton fabrics [16].

In fact, as fabric is compressive, more is its ability to return to its initial geometry form. Hence, the consumption value could undoubtedly vary due to the intrinsic change in thickness. This seems in a good agreement with the findings of other researchers [1, 25, 26]. For example, according to Gurumurthy [10], the lateral compression of a fabric is defined as the intrinsic change in thickness with an appropriate increase in pressure when the fabric is subjected to a barely perceptible pressure, which is generally about 1% of the maximum pressure. Nevertheless, Sharma[27] reported that the difference of thickness variation due to pressure applied on the surface contributes enormously on the consumption behavior. Indeed, fabric assembly thickness (1.64 - 6.65mm) has 77.11% contribution on the prediction of sewing thread consumption [28]. Similarly, other researchers demonstrate in their developed geometrical models for lock stitch 301 seam that, in terms of fabric thickness, it has a significant effect on the sewing consumption behavior [3, 5, 23, 25, 29]. Despite all models tackled in the literature, giving only an approximate fit, considering the complexity of volume and pressure, some of the constants used in these models are not defined, and there are significant differences between the model values. The assembled thickness parameter significantly affects the behavior of the consumed thread. Recently, a geometrical model for lockstitch seam 301 has been proposed by Chavan *et al.* [1], a based on elliptical profile to estimate the thread consumption in different fabric types with selected properties thicknesses, varieties of fabrics from woven shirting, woven jeans, knitted single jersey to nonwoven interlining fabric. Therefore, it has been reported that the error (expressed in %) is increasing with increase in number of ply (indirectly the thickness and compressibility of the assembled fabrics). Despite of fabrics stitched at different levels of stitch densities (3, 4 and 5 stitches/ cm), the existence of that error explains the compressibility contribution of seamed layers.

Indeed, to measure consumed thread, most of the researchers[21, 26, 30] considered some assumptions and hypothesis to facilitate their calculations. Therefore, some reasons are reported in the literature, explaining this inaccuracy to determine the suitable sewing thread consumption values, such as the insignificance of some influential parameters, the compressibility of seamed materials, the thread tension value and the thread extensibility [21, 26, 30].

Class 301 is lockstitch which is the simplest type of stitch when geometry of the stitches is under consideration. This type of stitch is very commonly used in garment manufacturing. There has been an extensive research on the sewing thread properties during and after stitching[20]. It has been reported that seam strength depends on the sewing thread properties. Ivanov *et al*[31]. explained that draping deformations affect the fabric properties and result in non-uniform thickness. This situation is particularly pronounced for thick components of complex shapes as in the seamed layers during assembly step. In addition, findings highlight the consumption behavior as a function of thickness, where it has been found that an increase in fabric thickness is quite substantial – up to 100% and higher prior to wrinkling [32].

4 Conclusion

According to obtained results, the consumption behavior in single and double-layered denim fabrics, when foot pressure is changed, shows a good relationship. Indeed, the relationship between compressional energy and consumed sewing thread values using lock stitch type 301 is investigated. A comparison between the experimental pressure-displacement of the foot pressure device during seam process and those obtained using KES device explains widely the accuracy of the coefficient of regression ranged from 96.09 % to 97.93%. Based on this accuracy, the compression applied by the foot pressure during seam process is a significant influential input parameter on the variation of the sewing thread consumption. By comparing the energy of compression relative to the investigated fabrics, it may be concluded that industry can objectively quantify the compression contribution to calculate the consumption of sewing thread using denim fabrics.

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