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Optimising L&M Sewability Testing Procedure on Woven Structures

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Abstract: ***The current study is the second part of the previous research focused on the dependency of the needle penetration force through the fabric to its inherent properties, in conjunction with the necessity to develop a concrete and objective testing method of interpretation for the sewability testing results on woven structures obtained by the L&MSewability tester. The literature presents investigations on mathematical model analysis of sewing knitted and light woven fabrics using Instron tester, automation of sewing intelligent systems using modified sewing machines while the use of L&Msewability tester was solely on knitted fabrics. The current study focuses on the more rigid structures such as woven cellulosic fabrics at distinctive softener treatment levels. The actual process performance in the stitching room was evaluated, matched by L.M Sewability test prediction findings, and the input testing parameters of the laboratory procedure for the given result were deduced. The statistical relationship between the input testing parameters and the inherent fabric properties is analysed and an equation model is generated through Multiple Regression. The determined equation can be used to improve the testing procedure as well as for the interpretation of the results. The ease of use and performance of the model is further discussed.***

Keywords: Stitching Performance, Needle Penetration Force, Sewability

1. Introduction

The sewing process is the action where two or more plies of fabric are connected using an auxiliary thread with the help of a penetrating needle through the fabrics to form variable types of stitches ASTM D5646-13(2018). During this process, several faults may appear and correct machine settings are critical to avoid most of them. However, faults other than that of the operator's mishandling can still appear as a result of the fabric construction and state.

Sewability is the ability of a fabric to be sewn without faults and is attributed to precise inherent fabric properties, pretreatment, finishing, sewing conditions and handling[2, 6]. Additionally, finishing treatments have been shown to affect those properties as well as the sewing quality of the resulting garments[2]. Handle is an important criterion for customer selection and it has been well demonstrated that softeners can significantly help meet customer demands [7, 8, 9].

Sewability is a complex concept of fabric which comprises two basic aspects; namely tailorability and sewing damage. Several studies have focused on the aspect of the sewing damage as seam puckering of the garment's fabric (ASTM D1683 and ISO 7770), while fewer are on the tailorability aspect. Tailorability intends to represent the ease of fabric processing at a satisfactory level and hence, it can help predict problems which may occur during stitching resulting in poor performance of the sewing room, as presented by Stylios [3]. Several studies aimed to quantify sewability and tailorability as an expression of needle penetration force through the fabric. This was conducted using sewing or overlock machines equipped with sensors or cameras aiming to build knowledge and understanding, mainly for research purposes as presented by Chmielowiec [10]. Leeming &Munden [11] have devised the L&MSewability Tester for the same scope. The used apparatus and its prediction process were widely used mainly for knitted fabrics [5], although knitted garments are mainly stitched with an overlock machine and the structure of the L&MSewability tester resembles more to the ordinary stitching machine where the thread moves perpendicularly to the plane of the fabric in absence of loop and chain formation.

To perform the L&MSewability test and predict the ease of the stitching process, a specific variable must be input into the system, in the form of a constant. For knitted structures, this derives from the measurement of the mass per unit area of the fabric ($g*m^{-2}$) expressed in g and rounded up to the nearest 25g increment for double jersey and down for single jersey [11]. This constant expresses the limit of the maximum needle penetration force over which problems may occur and it is named as sewability threshold. When less than 10% of the stitches exert a needle penetration force exceeding this limit, named as high values, the process is predicted to be non-problematic. whereas 10% to 20% indicate a harder-to-process fabric. When high-counties are more than 20% then a very problematic fabric is to be stitched and a very poor sewing performance is expected. While all previous measurements and predictions involve knitted fabrics, woven fabrics must use the "sewability averager function" of the equipment which calculates and presents the average value of the penetration force [11]. However, in defining the problem, there is no clear indication of how to determine the sewability threshold or a concrete interpretation of the value obtained by the average function in the form of sewing performance expected or ease of stitching process expected [11]. For woven fabrics, other researchers have used the Instron tester with some modifications [3, 4, 12, 20]. Similarly, Ghada [13] has also used the L&MSewability Tester and method to investigate the effect of the yarn spinning method on the needle penetration force. Previous work by Karypidis G. and Savvidis G. has shown that the mass per unit area is an important criterion associated with sewability, however, this was not the sole inherent property which affected sewability. Frederick [14], tried to model test methods for predicting the sewability of cotton fabrics by establishing a ratio between the strength of the original and the strength of the seamed fabric, as a more reproducible and sensitive test.

1.1 Scope

The scope of the current study is to optimise the prediction procedure of the L&MSewablity test procedure by proposing a statistical model that objectively calculates the necessary input value of the sewability threshold to set up and conduct the LM. sewability test for woven structures. Additionally, it proposes a preset interpretation scale for the findings, named high-counts, which translates to the sewing performance expected known as the sewability of the fabric.

1.2 Analysed Properties

Studies have explained that the penetrating needle into fabrics causes the yarns to move away from it but friction against it is unavoidable [11, 15]. In the case of woven fabrics with a rigid structure where yarn mobility is restricted strength, bending and mass per unit area have shown to follow a very close relationship [1, 2] with needle penetration force developed. As friction depends on the vertical force and the coefficient of friction, the level of lubrication remains an influencing factor. Therefore, the inherent fabric properties of strength, bending as an expression of flexibility and mass per unit area will be examined in three distinctive levels of lubrication [2, 13].

2. Materials and Methods

As the current study is an extension of previous work [1, 2] the same materials as in previous work had to be used on similar and new methods, however for a completely different scope.

2.1 Materials

2.1.1 Samples

Fabric samples of several weave constructions have been used since fabric construction plays an important role in needle penetration as reported by Khan et. al. [16] using a modified Instron machine. To ensure that the weave design factor has been taken into consideration a variety of fabric weave designs have been used varied from the most common plain and twill weave to more complicated weaves such as Panama, dobby and double face. All fabrics studied were cellulosic, made of 100% cotton except for the lining which was rayon. The fabric samples used are presented with the same sequence throughout this study which can be seen in Table 1.

Table 1: Fabrics used in the study

No	*Name*	*Weave*
1	Twill 2/1	2/1
2	Panama	Basket 2/1 (rib)
3	Double Face	2/1 (rib) and 2/1
4	Basket	2/2
5	Lining (rayon)	1/1
6	Muslin	1/1
7	Denim (twill)	2/1
8	Poplin	1/1
9	Taffeta	1/1
10	Canvas	1/1
11	Dobby	Honeycomb
12	Twill 3/1	3/1

2.1.2 Specimens and Sample Treatment

All fabrics in Table 1, were used in their normal finished state, named as control fabrics. Additionally, samples have undergone a washing treatment to make the fabrics unlubricated by removing all fatty components from their surfaces and so to increase the coefficient of friction. Samples resulting from washed fabrics were named as washed. Finally, fabrics were treated with the imidazoline cationic softener which has shown to alter the lubrication state of the fabric [2]. The samples resulting from softener-treated fabrics were named as softened.

2.1.3 ECE Detergent

The detergent used to wash the samples was the ECE-1 Standard Detergent whose formulation does not contain any sodium perborate, bleach activator, or enzymes and conforms with the ISO105-C06:2010.

2.1.4 Softeners

The structure of quaternised imidazoline softener in Figure 1 was used to soften the samples.

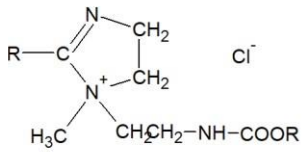

Figure 1: Chemical formula of imidazioline softener

2.2 Procedure (Method)

2.2.1 Fabric washing

Fabrics samples were undergone a washing cycle at 90°C with ECE Detergent under the 5A program (BS EN ISO 26330) using Wascator.

2.2.2 Softeners application

Fabrics were treated with 10 g/l of the imidazoline cationic softener applied by mechanical deposition with the use of a Benz padder set at the wet pick-up of 75%. The samples were consequently gently dried using the Mathis Steam Drier without pretension, using the air flap at position 1 (even airflow distribution) at the temperature of 85°C, till totally dry. The period of treatment was between 2 to 5 minutes depending on the fabric thickness and the samples were re-assured to be sufficiently dried by cross-checking their dry pick-up [1, 2].

2.2.3 Properties Testing Procedure

Sewability expresses the performance of the sewing action during stitching and can represent the ease of fabric stitching in the absence of faults. The L&MSewability tester can predict problematic sewing performance and the appearance of these faults. This is achieved by measuring the needle penetration force of a needle penetrating through the fabric and counting the proportion of penetrations, named as high-count, which has exceeded a specific value which represents the maximum limit of penetration force with trouble-free processing, named sewabilitythreshold[11]. This threshold is obtained empirically when it concerns the knitted structures [11] whereas there is no clear indication of how to be determined in the case of the woven structures. Similarly, there is no clear indication of how to interpret the high count in the woven structures, as mentioned in the introduction. A priori, the L&M testing laboratory apparatus has the intention of simulating the stitching operation of a professional user and that sewability interpretation should match the evaluating report for stitching by the operator concerning the ease of and performance of the stitching processes. Therefore, the laboratory-simulating procedure should be directly related to and reflect the real stitching procedure. Consequently, the samples from all the fabrics in the study, processed in the three treatments, control, washed and softened, were stitched at full speed by a professional operator using a Singer model 212G141 sewing machine. The operator's evaluation report about the stitching performance and ease of the process was objectively recorded with a preset questionnaire. The questionnaire in Tables 3 and 4 records all the main faults that can occur during stitching operation which are attributed to the fabric characteristics and express the ease of processing during stitching or else sewability in real conditions. Namely, faults such as N.B.= Needle Breakage, N.O.= Needle Overheating, F.D..=Damage of fabric yarns, T.B.= Thread Breakage, T.M.= Thread Melting, S.M.= Seam Deformation, S.M.= Missing of Stich, S.P.= Seam Puckering, were taken into account and the score of 0, expresses excellent conditions, up to score of 4, expressing a very problematic fabric and very poor performance, were given by the operator to evaluate the ease of the process of every sample processed. The most frequent value was taken as a representation of the fabric.

The sewability threshold could be easily deduced working backwards, as the operator's evaluation report on the ease of process was known and it was used as a reference point to set experimental sewability value in the form of high counts. This was made possible using the proposed correlation scale of high count to the ease of process evaluation, as shown in Table 2, for the recorded measurements of needle penetration force from the L&MSewability laboratory apparatus for all fabric samples. This scale follows the stated scale of the L&MSewability manual [11] but divides the fabrics into two divisions, based on the fabric hand and mass per unit area, namely scale A used for lighter structures of lower mass per unit area fabrics, as the muslin, lining, taffeta and twill 3/1, and scale B for stiffer and more rigid construction of medium-high mass density of more than170 g*m^{-2}, as the rest of the fabrics in the study. Previous study confirms the distinct behaviour of the more rigid woven structure fabrics where the relationship of the needle penetration force through them exerts a stronger dependency on the fabric's inherent properties than for less rigid ones [1].

Table 2: Scale correlating operator's evaluation with L&MSewabiltiy high-count

Seam Quality	*Operator's process evaluation (Score 0-4)*	*L&MSewability high-count Scale A*	*L&MSewability high-count Scale B*
Excellent Seam	0	0 - 5	0 - 12,5
Good Seam	1	5 - 10	12,5 - 25
Mediocre Seam	2	10 - 15	25 - 50
Problematic Seam	3	15 - 20	50 - 75
Very Problematic Seam	4	20 - Over	75 - 100

The following inherent fabric properties of the samples were selected to be measured as a previous study has demonstrated the existence of a strong relationship between them and the needle penetration force through the fabric [2]. The properties were measured in both warp and weft direction and their averages were taken into account. Fabric mass per unit area, bending length, strength and needle penetration force were obtained in the same principle as the previous study [1, 2] while the ease of stitching process representing the sewability was determined by the following method.

Fabric mass per unit area as a representation of the mass density of the fabric. Fabric with higher mass density would normally impose more impedance on the moving needle. Additionally, higher mass density could make the structure more rigid affecting fabric deformation and flexibility during needle penetration. Yildiz et. al. [17] claimed that needle force penetration increases exponentially with increasing mass density. The readings of the fabric mass per unit area are expressed in (g*m^{-2}) while measurements conformed to ISO 3801:1977 procedure and 5 samples were used.

Fabric bending length represents its ability to deform perpendicularly to its plane before needle penetration. Deformation takes place at the moment of the needle contact with the warp and weft yarns found on its path. Fabric bending length is directly related to seam puckering formation as reported by Stylios [19]. Additionally, flexural rigidity which is derived from bending length is the factor on which Stylios [15] based his mathematical model for the prognosis of sewing damage. The readings of the bending length (for warp, weft and 45°) are expressed in (cm) while measurements conformed to BS 3356:1990 procedure and 5 samples for each direction were used.

Fabric strength represents the force that the fabric yarns can withstand when needle force penetration displacement in two planes [18], namely within the plane of the fabric (x,y displacement) and perpendicular to the plane of the fabric(z-displacement). Previous work has shown that the plane of interest is z-displacement [1, 2] which occurs when several yarns come in contact with the penetrating needle. The yarns are tensioned until they slide aside from the point of the needle or stay on top with the pressure building until fail. The readings of the strength (for warp and weft) are expressed in (kg) while measurements conformed to ISO 13934-1 procedure and 5 samples for each direction were used.

Needle penetration force was measured in (g) and it is referred to as sewability force. Measurements were conducted using the L&M sewability tester apparatus. The instrument enables consecutive readings of force built during the penetration of fabric by the selected needle (90s title) to be measured on a small sample of fabric at a rate of 100 penetrations/min [11]. The average force of 100 perforations is measured over a specimen length of about 350 mm wide. **Sewability (ease of processing) in real conditions is evaluated by the operator**. Stitching was performed at the top speed of the stitching machine with the nominative motor speed being 3.000rpm, over strips of fabric, repeated five times, over two plies of previously treated fabric in 1m in length and 20cm in width, which was adequate for the stitches not to overlap when repeating the operation. A white fresh good quality common cotton sewing thread of
N.E. 36/2 and a 90s title needle. To account for the psychological factor, the ambient environment was well organized and clean, of the low nose and free from any disturbance, with abundant lighting while the operator performing the test, was experienced, in good health, working in the absence of any pressure in the means of volunteering participation and hence having no intentions of misleading the results. Finally, the sewing machine was well serviced, and appropriately set up in thread tensions to perform correct stitches.
The number of observations for the operator that the study must meet was calculated using the formula in Figure2and it showed that the sample size of 17 measurements of 100 penetrations sufficed, when the level of confidence was set at 90% and so the value of $Z_{1-a/2}$ from the statistic Z score table equals 1.65, while the error of measurement e=0.2 which is accurate enough since the value of the threshold that was to be determined follows increments of 25g as an input parameter for the L&M, Sewabilityapparatus.The value for the probability of fault occurrence p was set to 0.5 as the highest possible value. As a result, sufficient fabric length of fabric sample was provided to the operator to perform 5 repetitions of stitches of 1m in length with the stitch density of 4.5 stitches per cm equal to 2250 stitches approximately. The same fabric samples used by the operator, in the non-tested areas, were also examined using the L&M Sewability tester in the laboratory and their needle penetration forces were recorded.

$$N \geq \left(\frac{Z_{1-\alpha/2}}{e} \right)^2 * p * (1-p)$$

Figure 2: Formula determining sample size for the operator’s evaluation

3. Results and Discussion

All samples were processed in the three treatments and were tested to determine their inherent properties, strength, mass per unit area and bending, followed by the L&MSewability test to find their average needle penetration force, as well as to evaluate their ease of process by the operator, in the manner stated in the 2.2.3Properties and Testing procedure. Tables 3 and 4presents the results of the evaluation of ease of process by the operator as well as the average values obtained by the L&MSewability tester. The data were divided into two tables solely for publishing convenience.

Table 3: Operator’s evaluation questionnaire and average needle penetration force (g), fabrics 1 to 5

		Type of problem during Stitching									
Sample Fabric Type	*Sample Treatment*	*N.D.*	*N.O*	*F.D.*	*T.B.*	*T.M.*	*S.D.*	*S.M.*	*S.P.*	*Operator’s evaluations (Score 0-4)*	*Average needle penetration Force (g)*
Twill 2/1	*Control*	-	X	-	X	-	-	-	-	4	224
	Washed	-	-	-	-	-	-	-	-	0	185
	Softened	-	-	-	X	-	-	-	-	3	268
Panama	*Control*	-	-	-	X	-	-	-	-	4	459
	Washed	-	-	-	X	-	-	-	-	3	453
	Softened	-	-	-	-	-	-	-	-	0	458
Double Face	*Control*	-	X	-	X	-	-	-	-	4	542
	Washed	-	-	-	X	-	-	-	X	3	543
	Softened	-	-	-	X	-	-	-	-	4	544
Basket	*Control*	X	X	-	X	-	-	-	-	4	528
	Washed	-	-	-	-	-	-	-	-	0	504
	Softened	-	-	-	X	-	-	-	-	1	289
Lining (rayon)	*Control*	-	-	-	-	-	-	-	X	2	22,5
	Washed	-	-	-	-	-	-	-	X	4	17,5
	Softened	-	-	-	-	-	-	-	X	2	53,5
Muslin	*Control*	-	-	-	-	-	-	-	X	2	29,5
	Washed	-	-	-	-	-	-	-	-	0	27,5
	Softened	-	-	-	-	-	-	-	X	4	22

Table 4: Operator's evaluation questionnaire and average needle penetration force (g), fabrics 5 to 10

		Type of problem during Stitching									
Sample Fabric Type	*Sample Treatment*	*N.D.*	*N.O*	*F.D.*	*T.B.*	*T.M.*	*S.D.*	*S.M.*	*S.P.*	*Operator's evaluations (Score 0-4)*	*Average needle penetration Force (g)*
Denim (twill)	Control	-	X	-	X	-	-	-	-	4	252
	Washed	-	-	-	-	-	-	-	-	0	278
	Softened	-	-	-	X	-	-	-	-	1	313
Poplin	Control	-	-	-	X	-	-	-	-	2	154
	Washed	-	-	-	-	-	-	-	-	0	175
	Softened	-	-	-	-	-	-	-	-	0	118
Taffeta	Control	-	-	-	-	-	X	-	X	2	124
	Washed	-	-	-	-	-	-	-	-	0	358
	Softened	-	-	-	X	-	-	-	-	1	145
Canvas	Control	-	-	-	X	-	-	-	-	4	348
	Washed	-	-	-	-	-	-	-	-	0	289
	Softened	-	-	-	X	-	-	-	-	2	422
Dobby	Control	-	-	-	X	-	-	-	-	4	251
	Washed	-	-	-	X	-	-	-	-	3	265
	Softened	-	-	-	-	-	-	-	X	3	235
Twill 3/1	Control	-	-	-	-	-	-	-	X	3	43
	Washed	-	-	-	-	-	-	-	X	2	51
	Softened	-	-	-	-	-	-	-	X	4	37

According to the proposed scale in Table 2 which correlates the ease of sewing process performance with sewability assessment in the form of high-count values, the corresponding sewability threshold values were deduced according to the findings of the individual measurements from by L&M Sewability apparatus during laboratory testing. The average sewability threshold values for warp and weft are presented in Table 5.

Table 5: Sewability threshold averages from warp and weft in (g) for all fabric samples found in the three treatments

Fabric Sample	*Sample Treatment*		
	Control (g)	*Washed (g)*	*Softened (g)*
Twill 2/1	150	350	212,5
Panama	337,5	400	370
Double Face	500	500	500
Basket	462,5	500	412,5
Lining (rayon)	25	50	25
Muslin	50	37,5	25
Denim (twill)	100	500	462,5
Poplin	162,5	325	300
Taffeta	137,5	487,5	175
Canvas	250	475	450
Dobby	87,5	175	137,5
Twill 3/1	50	75	50

Results were statistically analysed using the SPSS software (ver13.0) with a level of confidence a=0.05. Previous work has shown a close relationship between the needle penetration force as the dependent variable, against the arithmetic mean of the readings for the warp and weft direction of the fabric's inherent properties of strength, mass per unit area and bending, for every fabric found in all three states of treatment, namely control, washed and softened [2]. The sewability threshold is also an expression of the needle penetration force, however, following increments of 25g. Therefore, it must also follow a similar dependency to the inherent fabric properties. To examine the existence of this relationship the same 180 cases were statistically analysed using Pearson R correlations values and the results were tabulated in Table 6.

Table 6: Correlation between fabric properties and sewability threshold

		Independent Variables		
Dependent Variables		Mass per unit area (g*m^{-2})	Strength (g)	Bending (cm)
Sewability Threshold Force (g)	Pearson Correlation	0.595	0,719	0,633
	Sig.(2-tailed)	0	0	0
	N	180	180	180

The strong relationship observed in previous work [2] continues to exist between the sewability threshold, and the inherent fabric properties strength, bending length and mass per unit area of the fabric, although the values of Pearson R values are slightly lower as 0.595, 0.719 and 0.633, respectively, and this is merely due to previously mentioned non-continuous data of incremental steps of 25g. The significance values of below 0.05 in the 2-tailed test also emphasise the strong relation between needle penetration force and the three previously mentioned fabric properties. Bending length and mass per unit area are measurements which compose the flexural rigidity of the fabric, a property which exerted a similar behaviour to the model of Stylios [15] with similar accuracy, about 85%, confirming the above results.

As the scope indicates a statistical model was created based on the previous findings. The dependent variable sewability threshold has been input into the statistical program to form a linear regression model with the correlated properties of strength, mass per unit area and bending in the equation form of $f(x)=aX+bY+cZ+Constant$. The average data derived from the property of mass per unit area were used as X values, the average data from strength as Y values and for Z the average data from bending. Accordingly, the variable coefficients a, b and c along and the Constant were calculated by the SPSS statistical program. The R-value represents the correlation between the predicted and observed values, and the fit R^2 goodness representing the accuracy of the model, reveals an acceptable threshold prediction level at R= 0.753 and R^2=0.567, bearing in mind that the L&M Sewability apparatus accepts input setting value in incremental steps of 25g and taking into account that the Sig. values of the a, b, c and constant were below the value α=0.05. An attempt to shorten the time to calculate the sewability threshold rose the necessity to develop an additional linear model using the same statistical regression with only two of the three fabric properties as independent variables. Table 7 shows the coefficients of the equations as well as their constants, followed by R and the goodness of fit of each model.

Table 7: Linear regression models (coefficients for equations 1, 2 and 3)

Equation	Independent Variables	Coefficient		Sig.	*R*	*R²*
1	Mass per unit area (g*m-2)	a	-0,302	0,014	0,753	0,567
	Strength (Kg)	b	2,289	0,000		
	Bending (cm)	c	95,609	0,000		
	-	Const.	-112,210	0,012		
2	Strength (Kg)	a	2,048	0,000	0,743	0,552
	Bending (cm)	b	45,550	0,000		
	-	Const.	-28,725	0,328		
3	Mass per unit area (g*m-2)	a	0,122	0,062	0,725	0,526
	Strength (Kg)	b	2,331	0,000		
	-	Const.	54,670	0,020		
4	Mass per unit area (g*m-2)	a	0,043	0,747	0,633	0,401
	Bending (cm)	b	102,473	0,000		
	-	Const.	-65,750	0,203		

Equations 4 and 2 were rejected due to the low R^2 observed as well as that the Sig values of the coefficients are above the limit of α=0.05. Equation 3 shows a small drop in R and the goodness of fit R^2 while both a and b coefficients have Sig. values close below the acceptance limit of 0.05.

4. Conclusions

The suggested method to optimise the L&Msewability protocol is a step forward to the unclear instructions for woven structures. When accuracy is of concern equation 1, bearing three variables is recommended to be used. The equation takes into account a wide range of different types of weaves as well as different levels of lubrication. In cases that fast decision needs to be taken, equation 3 can be considered instead to save time but sacrificing accuracy.

Future work can consider parameters such as different fabric compositions for synthetic fibres of smooth surface, and different finishes commonly found on woven fabrics, following the same course of methodology.

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