Cost and Efficiency Analysis of Commercial Softeners in the Sewability Behavior of Cotton Fabrics

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ABSTRACT

This paper reports a comparative case study on the use of different softening products for bed linen fabrics, specifically regarding the sewability of the fabrics. The market offers a wide variety of commercial formulations of softeners for this purpose, but the composition and price varies considerably. This work was aimed to assess the relationship between the cost and effectiveness of different softener formulations in home textiles finishing. Objectively, the effect of different softeners and their concentrations on sewability of the fabrics was studied. Non-ionic polyethylene dispersions and a cationic silicone softener micro-emulsion in different concentrations and combinations were considered in this investigation.

It was found that a combination of silicone and polyethylene based softeners presents the most interesting cost/performance behavior.

Keywords: sewability, needle penetration forces, bed linen fabrics, textile finishing, softening, non-ionic polyethylene dispersions, cationic silicone softener micro-emulsion concentrations

INTRODUCTION

Motivation

Considering the variety of softening products commercially available, textile manufacturers often lack objective information to support the optimal choice and concentration of these products. Not only are these products based on different formulations, but also the concentration and application process is distinct, with consequences on the cost and efficiency of the processes and the quality of the finished product.

Most studies on the effect of softeners on textile properties have been focused on the appearance and maintenance properties of materials. Thus, whiteness, pilling formation, wrinkle recovery and dimensional stability were usually considered. Despite the importance of the softening products on the sewability parameters, studies concerning the influence of this parameter have generally been dedicated to theoretical aspects (regarding the measurement process, the physical phenomena during sewing or the development of new materials).

In a more practical approach, an extensive study of the influence of commercial softeners on several process and product-related properties has been conducted by Vidrago in a specific industrial case-study [1]. The aim was to use quantitative methods for evaluation of the effect of the softeners, with the purpose of providing tools for objective support on the choice and concentration of these products. This paper describes the results related to the influence on sewability, namely needle penetration forces, with the objective of optimising the relationship between the cost and effectiveness of the process in this context.

Objective

In this work, the effect of different types of softeners and their concentrations on the needle penetration forces, measured after the easy-care treatment, was studied. The objective was to observe the effect of varying concentrations of each softener on the resulting needle penetration values, to establish general trends of this property, and relate these values to the cost of the products and process.

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STATE-OF-THE-ART

Sewability and Measurement of Needle Penetration Forces

The instrumentation of sewing machines to measure process variables online during the process is a subject studied by several authors, amongst them researchers from the current group. Carvalho describes the development of techniques for measurement, processing and interpretation of sewing machine process variables, including needle penetration and withdrawal forces [2]. His work is based on a sewing test rig whose development was initiated by Rocha *et al.* [3,4]. A comprehensive state-of-the art of this subject is described by Carvalho *et al.* [2,5]. Measurement of needle penetration forces whilst stitching fabrics in several stages of finishing are presented in this work.

The specific topic of needle penetration force measurement has been investigated since the 1960's, regarding aspects such as fabric damage by needles, theoretical modelling of needle penetration forces, needle heating, and the measurement of these variables.

Hurt and Tyler established that the finishing processes applied to the fabrics modify their frictional properties and thus have an influence on needle penetration and sewing damage [6,7].

Leeming and Munden observed two very important facts regarding the current investigation. First, the needle penetration forces are critically affected by the use of lubricant or softener, second, and most important, fabrics exhibiting higher penetration forces were also the fabrics exhibiting sewing damage [8].

Recent work has provided some interesting investigations regarding the theoretical modelling and numerical simulation of needle penetration. Lomov presented a mathematical model for needle penetration force in woven fabrics [9]. . Mallet and Du used finite element modelling techniques to predict penetration forces into fabrics [10]. It is interesting to note that the predicted penetration force profile is functionally identical to the signals measured by Carvalho [2,5]. These can be separated in three different phases: first contact of the needle tip, penetration of the needle body, and withdrawal.

Regarding the influence of finishing and its relation to sewability/needle penetration forces, Grancaric *et al.* have more recently produced studies on the relation between the needle penetration forces and fabric finishing. The influence on sewability of pre-treatments of cotton fabrics [11] enzymatic scouring and the treatment with zeolite nanoparticles have been investigated [12]. In their work, measurement of needle penetration forces was achieved using a setup developed by ITV-Denkendorf on a PFAFF 1053 lockstitch machine. The setup uses a sensor applied to the machine's throat plate. When the fabric is pushed against the throat plate during needle penetration, the sensor is able to pick up a peak force value [11,12].

The measurement method used in the work herein presented is based on a Singer 882 three-thread overedge machine with a piezoelectric force sensor (Kistler 9001) inserted into the needle bar. The signals are divided in the three previously mentioned penetration phases. Force peaks are measured in phases one (first contact) and two (penetration of needle shaft), and the force valley is measured in phase three (withdrawal). The sensor picks up all forces on the needle bar, which include acceleration forces, thread forces and needle penetration/ withdrawal forces. Since only the latter is of interest, the other two have to be eliminated. Thread forces are eliminated by unthreading the machine and stitching the fabric without thread. This has an insignificant effect on results; according to Blackwood and Chamberlain (1970), the damage produced on a fabric does not change significantly with thread in the needle [13].

Acceleration forces are filtered using signal processing techniques [2, 14]. This process leads to a residual error dependent on speed. It affects mostly the measurement of the withdrawal force, whose values are low and thus more sensitive to this mechanical noise component. Measurement of peak forces in penetration phases one and two are minimally affected by noise up to medium sewing speeds. At sewing speeds around 2000 stitches per minute (spm), residual noise is in the order of a few tens of cN, whilst penetration forces are normally an order of magnitude higher.

Softeners

Softeners are essentially used to improve soft handle, wearability, and facilitate processability of textile fabrics. Numerous studies have been conducted to understand the influence of softeners on textile fabric properties [15]. Typically, these studies were carried out analyzing the durability and efficiency of a particular type of softener in one type of substrate.

The softeners differ in chemical structure and type of interaction with the substrate. They can be classified as anionic, non-ionic and cationic according to their charge in water. But they can also be grouped as siloxanes and non-siloxanes, with reactive or non-reactive characteristics [16]. Therefore, chemical composition, structure and amount of softener are critical in softener effect.

Polyethylene and amino functional silicon softeners are the most commonly used additives in cotton and cotton blend materials finishing processes. It is generally accepted that siloxanes, namely organo functional siloxanes with amino groups, provide the best relationship between softness/hydrophobicity properties due to their flexible backbone structure, high heat stability and reduced friction [17,18]. Since they are expensive, they are often used in conjunction with nonionic softeners, such as polyethylene derivatives. Moreover, benefits of polyethylene softeners include excellent sewability, durable abrasion resistance, good hand and non-yellowing. Thus, they are ideal for the finishing of optically-brightened textiles [19].

Softeners used in the textile industry are usually liquid dispersions, with typical solid levels between 10-50% and concentrations of 15-25% of active matter. In addition to active agents they contain emulsifiers, dispersants, defoamers, and pH adjusters, essential to meet the requirements of their technical applications [19]. Usually, the technical literature provided by manufacturers does not contain detailed information about softener composition and effect on fabric performance. It is expected that the results of this study will help the industrial finishers provide a better selection of suitable softeners for bed linen material from the available options nowadays on the market.

EXPERIMENTAL DETAILS

Softening

Seven, different commercial fabric softeners based on non-ionic polyethylene dispersions designated as (A, B, C, D), a cationic silicone softener micro-emulsion (E) and a combination F (C + E) were added in 5 different concentrations (5, 10, 20, 40 and 150 gL^{-1}) to the easy-care finishing bath (final pH 4.5-5.5), composed by a resin, a catalyst and a surfactant auxiliary product. All softeners used have similar concentration of active matter (%).

After impregnation using a pick-up of 60%, the fabrics were dried at 120 ºC during 1.5 minutes and thermo-fixed at 180ºC during 30 seconds.

A control sample X, finished with a bath composed by a resin, a catalyst and a surfactant auxiliary product (without any softener) was also studied.

Table I summarises the information about the softeners considered.

TABLE I. Identification of the sample, softener and price per kg.

Sample Softener	Softener Type	Price per kg [€]
A	non-ionic polyethylene dispersions	0.68
B	non-ionic polyethylene dispersions	0.80
C	non-ionic polyethylene dispersions	2.20
D	non-ionic polyethylene dispersions	2.45
E	cationic silicone softener micro-emulsion	1.20
F	Combination C+E at a 50/50 proportion	3.40
X	No softening	-

Fabrics

Tables Il to *IV* give a complete overview of the characteristics of the tested fabric and their properties.

TABLE II. Fabric Characteristics.

Structure	Satin
Composition	100 % cotton
Density - Warp	220 yarns/inch
Density - Weft	56 yarns/inch
Yarn Linear density	80 Ne
Previous process	Bleaching

TABLE III. Mass per unit area (g/m^2) NP EN 12127 (1999).

Concentr. (gL^{-1})	0	5	10	20	40	150
A	145.6	146.9	148.3	146.8	146.0	147.7
B	145.6	147.3	144.6	146.9	145.9	151.1
C	145.6	148.6	149.5	146.7	145.4	149.6
D	145.6	147.6	148.7	146.7	146.4	147.5
E	145.6	146.9	146.9	149.7	145.9	147.5
F	145.6	148.7	147.6	146.9	148.1	151.9

TABLE IV. Thickness (mm) measured with Alambeta according to manufacturer's instructions.

Concentr. (gL^{-1})	0	5	10	20	40	150
A	0.395	0.374	0.356	0.363	0.407	0.441
B	0.395	0.348	0.337	0.352	0.364	0.334
C	0.395	0.360	0.340	0.372	0.320	0.341
D	0.395	0.363	0.399	0.370	0.326	0.365
E	0.395	0.347	0.395	0.357	0.363	0.399
F	0.395	0.381	0.360	0.404	0.373	0.382

Sewability Testing

Measurement of needle penetration forces was performed according to the parameters listed in *Table V*.

TABLE V. Conditions for sewability testing.

Sewing speed	2000 stitches per minute
Number of fabric layers	2 and 3 layers
Number of stitches	3 samples, 22 stitches each,
Stitching direction	Warp
Parameters considered	Peak1: Force peak at first contact Peak2: Force peak during penetration

A new needle was inserted at every change to a differently softened fabric.

Measurement of Tear Resistance after Finishing

As described previously, Leeming and Munden stated that fabrics exhibiting higher penetration forces were the fabrics exhibiting sewing damage [8]. However, the inverse statement may not always apply, since a fabric exhibiting low penetration forces may not always present less sewing damage. Supposing that a fabric treatment – whatever it might be – is aggressive enough to reduce fabric mechanical resistance, it is also expected that this leads to lower penetration forces. In this case, probability of sewing damage would increase, although needle penetration forces are low. For this reason, the fabrics were tested for tear resistance according to ASTM D 1424:2009 – "Standard Test Method for Tearing Strength of Fabrics by Falling-Pendulum Type (Elmendorf) Apparatus". This allowed cross-validating that a reduction in needle penetration force that may possibly be observed is not due to a reduction of mechanical resistance of the fabric (which is actually very unlikely with the treatments considered).

RESULTS AND DISCUSSION

In terms of discussion, it is interesting to group the softening formulations in three sets according to the type of softener used: formulations consisting of polyethylene derivatives, micro emulsion of the siloxane, and the mixture of the siloxane and polyethylene C softener.

Tear Resistance

Softeners improve the tear strength of fabrics by lubricating the yarns making them more flexible[16]. Nevertheless, the intensity of this effect depends on the type, concentration of softener used and distribution on surface or inner fibers. On another hand, it is well know that polyethylene or silicone based softeners are able to confer tear resistance to the materials that usually increases with concentration [20].

Figure 1 shows the tear resistance measured.

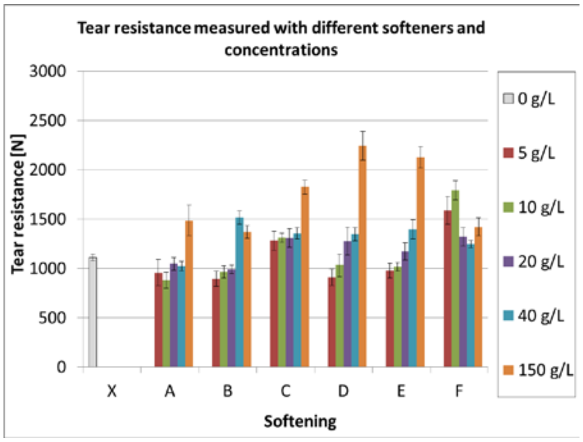

FIGURE 1. Average Tear resistance measured with different softeners and concentrations. (5% confidence intervals assuming normal distribution are given).

Using the formulations with a single type of softener, the resistance slightly increases in concentrations until $40gL^{-1}$, while a more significant increase is observed for high softener concentrations ($150gL^{-1}$).

It should be noted that the recommended concentration of the softener for all these products is between $5\text{-}40gL^{-1}$. For this range of concentrations, only the softener C yielded materials having higher resistance than the control sample. In this case, the effect was similar for all tested concentrations. Still higher resistance with softener C was achieved using $150gL^{-1}$ of softener application.

The slight decrease of strength observed for lower concentrations of some cases may be explained by decrease of elasticity of material by resin application.

Softener combination F shows different behavior. It is well known that polyethylene-based softeners provide their main effect by molecular deposition on the fabric surface, being molecular orientation dependent on the nature of the fiber. In cotton, the hydrophobic portion of softener is attracted to the hydrophilic surface. However, silicone-based softeners are able to form Si-O-polymer films on the material surface. Small softener molecules of micro emulsions, in addition, penetrate the fiber reducing its glass transition temperature, producing an internal plasticization [20]. Thus, the obtained results may be explained by the polymerization of silicone softener on cotton surface with inhibition of the polyethylene derivatives attachment. This justifies that strength does not change with increasing of polyethylene concentration, even for higher concentrations.

In conclusion, it can be stated that the application of softener does generally not decrease tear resistance of the fabrics. Although a small decrease is observed in some cases of lower concentration, it is not significant in the context of this work, unless it would cross-relate to a decrease of needle penetration force, which is not the case.

Average Penetration Forces- 2 layers of Fabric

Figures 2 and *3* present the needle penetration force values for 2 layers of fabric.

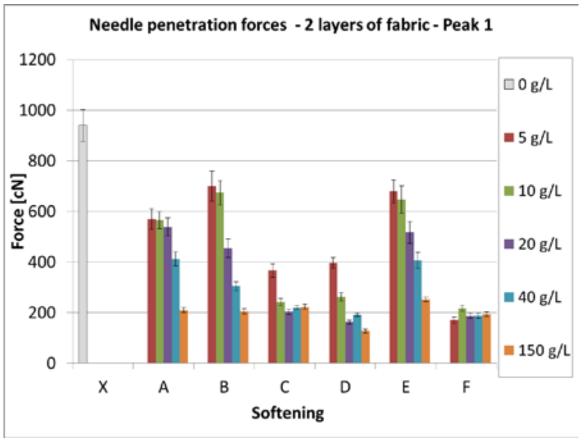

FIGURE 2. Average peak 1 of penetration forces for 2 layers of fabric measured with different softeners and concentrations (5% confidence intervals assuming normal distribution are given).

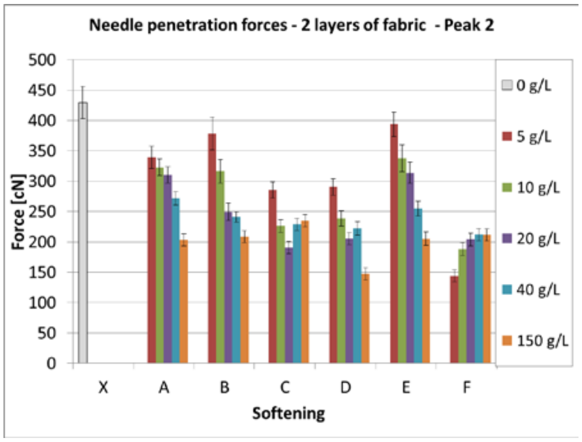

FIGURE 3. Average peak 2 of penetration forces for 2 layers of fabric measured with different softeners and concentrations. (5% confidence intervals assuming normal distribution are given).

The data show a general decrease of needle penetration force peaks 1 and 2, proportional to the concentrations used. Products C and D provide low penetration forces at low concentrations, but they are also considerably more expensive than the remaining ones.

Combination F is a very special case, providing a very low force for the lowest concentration of all. The “contact” penetration force peak 1 does not vary significantly for increasing concentration, but the “penetration” force peak actually increases with concentration. This may be explained by the physical effect resulting from the combination of the two, cluttering the fabric and thus making penetration more difficult. Additionally, as explained before, the micro softener molecules can penetrate in fiber producing an internal plasticization, which contributes to this effect. Even so, forces stay low when compared to the other softeners.

In all cases except in product B and E at their lowest concentrations, the needle penetration forces are lower than using the greige material, although the confidence intervals show a statistically non-significant difference.

Average Penetration Forces- 3 Layers of Fabric

Figures 4 and *5* show the data obtained for 3 layers of fabric. The measurements made on three layers of fabric provide very similar conclusions to those already drawn for two layers of fabrics, but with the force values 30% to 50% higher.

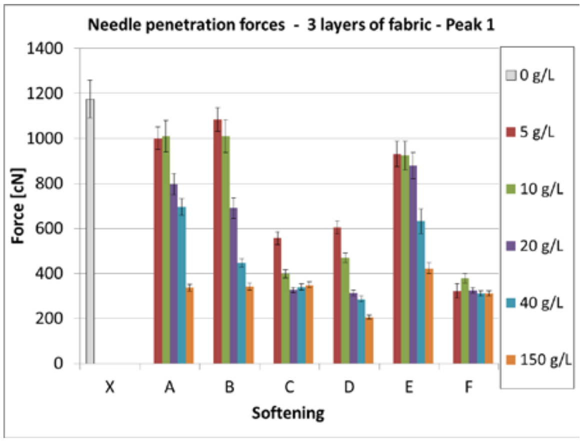

FIGURE 4. Average peak 1 of penetration forces for 3 layers of fabric measured with different softeners and concentrations. (5% confidence intervals assuming normal distribution are given).

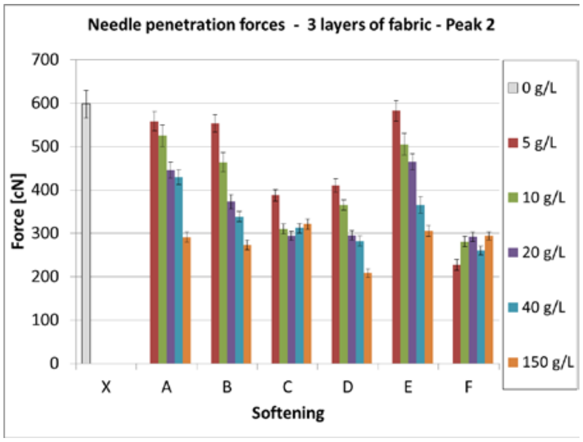

FIGURE 5. Average peak 2 of penetration forces for 3 layers of fabric measured with different softeners and concentrations. (5% confidence intervals assuming normal distribution are given)

Penetration Forces as a Function of Cost

To allow a graphical analysis of the cost / benefit of the different softeners and concentrations, a recipe price for each of the cases studied was computed based on the following expression:

$$R_p = c \cdot P \qquad (1)$$

where

Rp: Recipe price in Euro cents per liter
c: Concentration in g/L
P: Price per g of softening product

Figures 6 and *7* display the results of this analysis.

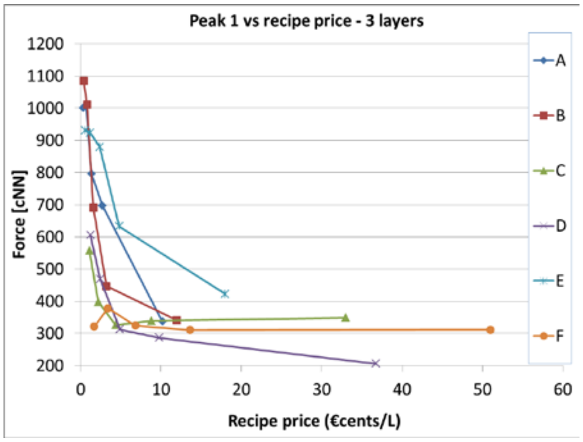

FIGURE 6. Recipe price vs average peak 1 of penetration forces for 3 layers of fabrics, different softeners and concentrations.

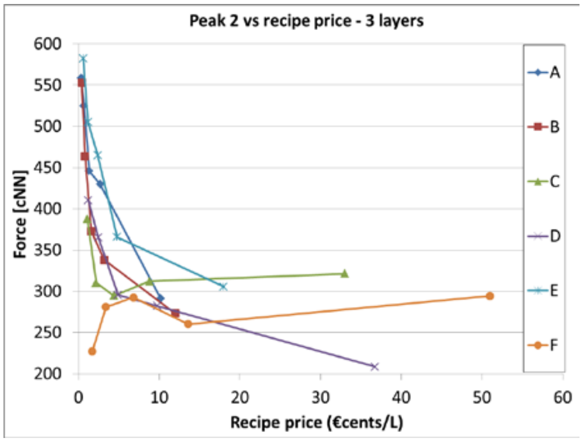

FIGURE 7. Recipe price vs average peak 2 of penetration forces for 3 layers of fabrics, different softeners and concentrations.

The lowest penetration forces at a very low price point are obtained by the combination product F.

Considering the remaining products, it can be observed that products C and D produce the best results at the lowest concentrations. These are also the two most expensive products of all. Between these two, one might prefer product C as it results in higher tear resistance for low concentrations.

Product B approaches the performance of C and D at higher concentrations, considering both sewability as well as tear resistance, and still at a low recipe price.

Nevertheless, it is advantageous to use the least possible amount of softener for many reasons in addition to the price so as to:

1. Avoid the interference with other material´s properties and prevent the softener deposition on the surface,
2. Reduce the environmental impact of the process, during the finishing process and care in their life cycle,
3. Prevent health risks described for softened materials [21].

Products E and A can be considered the worst performers in the specific evaluation that we carried out.

CONCLUSION

The main conclusion that can be drawn from cost/benefit of the different softener formulation analysis is that the combination of silicone and polyethylene based softeners used boasted the most interesting cost/performance behavior. In fact, it produced the lowest penetration forces of all products at a very low price point. None of the remaining cases produced such a good result. This is a most interesting result and the underlying reasons for it should be further studied.

Another important conclusion is that the effect of different softeners on sewability varies significantly, with high cost not necessarily reflecting more effectiveness. The use of specific instruments for quantitative assessment of the associated parameters is thus of high interest to fabric manufacturers.

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