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Comparison of Softened Polylactic Acid and Polyethylene Terephthalate Fabrics Using KES-FB

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Abstract
We examined and compared low-stress mechanical properties, such as tensile, shear, bending, compression, and surface properties, measured by the Kawabata Evaluation System for Fabrics (KES-FB), of polyethylene terephthalate (PET) and poly(lactic acid) (PLA) fabrics before and after softening with commercial softeners. The bending and shear properties of both fabrics were influenced by the chemical nature of the softening agents and the emulsion type used in the softener. In contrast, the ionicity and hydrophobicity of the softener appeared to have little or no effect on bending and shear properties of both fabrics. There is no clear trend showing that the LT, RT, MMD, MIU, LC, and RC values of both fabrics were influenced by any of the following properties of the softeners: the chemical nature, emulsion type, ionicity, or hydrophobicity. The best performing softener for both fabrics was a slightly cationic hydrophobic aminofunctional polydimethylsiloxane micro-emulsion softener. Overall, all softened PLA fabrics exhibited lower bending rigidity, tensile linearity, and tensile resilience as well as higher tensile energy, extensibility, geometrical roughness, mean deviation of friction, and compression energy values than all softened PET fabrics, leading to a softer, fuller, and fluffier but rougher fabric handle.

Key words: *KES-FB, mechanical properties, surface properties, PLA fabric, PET fabric, softener, softening.*

Introduction

The feel or handle of a textile product is very important in determining its quality and acceptability for its intended end-use from customers' and users' points of view. Wet processing and softening treatments can generally modify the handle significantly. Improving the handle of a garment at the 'point of sale' is very effective as a marketing tool [1], therefore softeners have an important place in textile finishing, and almost no piece of textile substrate leaves the production facilities without being treated with a softener to impart a soft hand, smoothness, increased flexibility, and better drape to the textile substrates [2 – 4].

Commercial softeners are available in a wide range of formulations: while some act to enhance the hydrophilic nature of the substrate, others do not, and some can even render the hydrophobic properties. The type and effect of the softener polymer film on the surface of the substrate, and the orientation, attraction, distribution, and uniformity of distribution of the softener on the substrate are usually the main factors leading to observed alterations in the low-stress mechanical and surface properties of treated fabrics [5].

Fabric objective measurement (FOM), such as the Kawabata Evaluation System for Fabric (KES-FB), through measuring the low-stress mechanical and surface properties of fabrics [6], is an efficient and reliable way of defining the handle, tailorability, and quality of fabric which avoids the inconsistencies and subjectivity of evaluators. Fabric properties measured with instruments are necessary for quantifying changes in fabric tailorability, quality, and garment performance [7]. FOM also provides scientific data to control the fabric performance and quality and to define the performance features of different finishing auxiliaries on fabrics.

Polyester fibres, mainly polyethylene terephthalate (PET), are a very widely used fossil fuel resource dependent synthetic fibre and account for the biggest share of world textile fibre consumption. However, poly(lactic acid) (PLA), the first melt-processable natural-based synthetic fibre produced from annually renewable resources, combines ecological advantages with excellent performance in textiles. It is an aliphatic polyester which can be derived from 100% renewable resources such as corn [8 – 10]. Poly(lactic acid) is a relatively stiff polymer at room temperature [11, 12], with a surface cohesion that gives the fibres a property known as scroop [9]. The scroop of fibres causes a sound or feeling of 'crunchiness' when the fibres are rubbed against one another, most likely caused by a stick-slip action as fibres slide past each other. This feature of PLA fabrics may influence the resilience and thus cause problems in some applications by resisting recovery after deformation. Scroopiness might be overcome by applying a suitable fabric finish [9, 13]. Avinc *et al.* [14] studied the effects of softeners and repeated laundering on the handle and scroopiness of knitted fabrics constructed from PLA. They found a moderate correlation between the subjective scroopiness and softness evaluations and objective measurements of bending stiffness (B), bending hysteresis (2HB), shear stiffness (G), shear hysteresis at 0.3° (2HG), and geometrical roughness (SMD). They reported that both objective and subjective evaluations suggest that the distinction between the effects of the various softening agents diminishes during repeated laundering, presumably due to the progressive removal of or damage to the softener. However, the handle of all the softened fabrics continued to surpass that of the untreated fabrics even after 15 washes [14].

However, no study has been reported in literature about a comparison of the handle and low stress mechanical properties of softened PLA and PET fabrics. In the current paper, we examined and compared the low stress mechanical properties such as tensile, shear, bending, compression and surface properties, measured by the KES-FB system, of identically constructed PET and PLA fabrics before and after softening with commercial softeners which differed in their ionicity, emulsion type, hydrophobicity, and formulation chemistry.

Experimental

Materials and methods

This study employed two sets of identically constructed 'piqué' type knitted fabrics provided by NatureWorks LLC, USA. These piqué type knitted fabrics were derived from 100% PLA (Ingeo™ fibre, 247 g/m^2) and 100% PET (209 g/m^2) filament yarns, respectively, having the same yarn count (150/144 dtex/filament). These kinds of fabrics are generally used for sport, active, and fashion wear. "Ingeo™ fibre" is the trademark of NatureWorks LLC's poly(lactic acid) polymer produced from corn starch.

PLA and PET knitting mill fabric (greige) fabrics were pre-scoured in a bath containing 1 g/l of "Kieralon Jet B" (a non-ionic surfactant produced by BASF) and 1 g/l of sodium carbonate at 60 °C for 15 minutes. After scouring, the fabrics were rinsed with cold water for 10 minutes and dried at room temperature. PLA and PET fabrics were dyed using a laboratory-scale Mathis Labomat infrared dyeing machine (Werner Mathis, Zurich, Switzerland) with a liquor ratio of 10:1 and at temperatures of 110 °C and 130 °C, respectively [15]. Then the PLA and PET fabrics were treated with 2 g/l of sodium carbonate and 2 g/l of sodium dithionite for 15 minutes at 60 °C [16]. Both fabrics were then rinsed in warm and then cold water until neutral and air-dried at room temperature.

Nine commercially available softeners (***Table 1***) were selected for the study, differing with respect to their ionicity, emulsion type, formulation chemistry, and hydrophobicity. They were provided, respectively by Rudolf, Ciba, BASF, and LJ Specialities.

All softeners (***Table 1***) were applied by padding to the air-dried fabrics at a concentration of 30 g/l and pH 5.0 – 5.5 (adjusted where necessary using acetic acid) with a pick-up of 90%. The softened fabrics were dried on a Werner Mathis AG DHE-18874 stenter at 110 °C for 30 seconds and then heat-set under typical industrial conditions: 30 seconds at 130 °C for PLA, and 30 seconds at 180 °C for PET. The heat-set temperature for PLA fibre is relatively low in comparison with that generally used for conventional polyesters, which was necessary because PLA melts at approximately 170 °C.

Samples were coded to make the presentation easier. Sample codes DSH1 – DSH9 represent the fabrics which were padded with Softeners 1 – 9, respectively, and then dried and heat-set under the aforementioned conditions. Two control fabrics were added to the study. The first control fabric was a knitting mill (greige) fabric, coded as D. DDH, which represents the second control fabric, was dyed and padded with water only at pH = 5.0 – 5.5, followed by the same drying and heat-treatment as the softened fabrics.

After finishing, the basic mechanical properties such as the tensile, bending, shearing, compression, and surface properties of the fabric samples were measured by KES-FB using the standard sensitivity of knits set-up [6]. A list of measured parameters provided by KES-FB is presented in ***Table 2***. For each sample, each measurement was made twice on three separate samples cut from the centre of the knitted fabric, and the six resulting values were averaged. Standard size samples of 20 cm × 20 cm were tested in the wale and course directions. Because anisotropy is a consideration in knitted fabrics, the mechanical and surface properties (tensile, bending, shear and surface properties) were measured in both the course and wale directions, and averages calculated for further analysis. Specimen preparation, pre-conditioning and testing were carried out under standard atmospheric conditions of 20 ± 2 °C temperature and 65 ± 2% relative humidity.

Table 1. *Details of softeners used.*

Softener	Softener chemistry (PDMS = polydimethylsiloxane)	Ionicity + = cationic – = anionic 0 = nonionic	Hydrophobicity	Emulsion type
Softener 1	OH-functional PDMS with hydrophilic polyester resin	0	Hydrophilic	macro
Softener 2	Reactive fatty acid amide	+	Hydrophobic	micro
Softener 3	Quarternary-functional PDMS micro-emulsion			
Softener 4	Aminofunctional PDMS micro-emulsion	0/+		
Softener 5	Fatty acid condensation product	0	Hydrophilic	macro
Softener 6	Fatty ester	–		
Softener 7	Aminofunctional PDMS micro-emulsion	+ (slight)	Hydrophobic	micro
Softener 8	Aminofunctional PDMS micro-emulsion	0	Hydrophilic	
Softener 9	Fatty acid amide and polyethylene wax	+ (slight)		macro

Table 2. *KES-FB parameters.*

Property	Description
EM	Extension at the load of 500 gf/cm, %
WT	Energy to extend fabric to 500 gf/cm, gf.cm/cm^2
RT	Recovery from tensile deformation, %
LT	Linearity of load-extension curve
G	Shear rigidity, gf/cm.deg
2HG	Shear hysteresis at 0.3° of shear angle, gf/cm
2HG3	Shear hysteresis at 3° of shear angle, gf/cm
B	Bending rigidity, gf.cm^2/cm
2HB	Hysteresis in bending, gf.cm/cm
SMD	Surface geometry variation, μm
MIU	Coefficient of friction
MMD	Mean deviation in the frictional force
WC	Energy to compress fabric under 50 gf/cm^2, gf.cm/cm^2
RC	Recovery from compression deformation, %
LC	Linearity of compression curve

Results and discussion

Bending properties

The results of the bending properties, bending stiffness (B) and bending hysteresis (2HB) of PLA and PET fabrics before and after finishing with different softeners are shown in ***Figures 1.a*** and ***1.b***. The bending properties of a fabric are influenced mainly by inter-fibre and inter-yarn forces. High values of bending rigidity indicate greater resistance/stiffness to bending. Bending hysteresis (2HB) is a measurement of energy loss occurring during bending deformation. Higher 2HB values indicate greater fabric inelasticity and lower elastic recovery.

Knitting mill (greige) PLA fabric exhibited higher bending rigidity (B) and bending hysteresis (2HB) than knitting mill PET fabric. There is a remarkable increase in bending values after the dyeing and heat setting of PLA and PET fabrics (DDH) in comparison with knitting mill fabrics (D), which can be due to fabric shrinkage and, consequently, the limitation of fibre and yarn movement within the fabric structure after these processes. After dyeing, drying, and heat-setting,

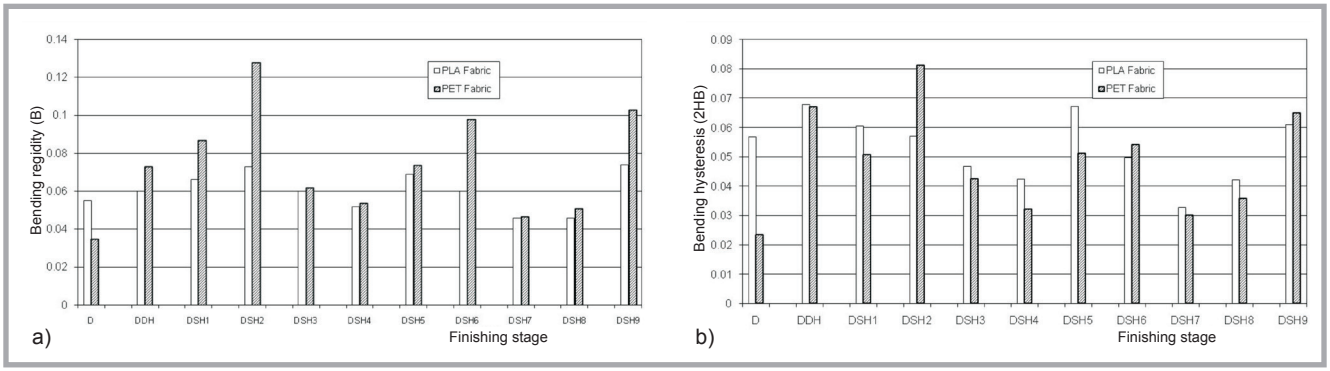


Figure 1. *Changes in bending: a) rigidity (B) and b) hysteresis (2HB) of PLA and PET fabrics before and after finishing.*

the bending values of PET fabric catch up with those of PLA fabrics, and the bending rigidity of PET was even slightly higher than that of PLA fabrics after these processes, which could be due to the more aggressive applied conditions of dyeing (130 °C versus 110 °C) and heat-setting (180 °C versus 130 °C) for PET fibre in comparison to PLA fibre.

A reduction in bending hysteresis is observed for both PLA and PET fabrics after softening compared with dyed and heat set fabrics (DDH), which shows increased yarn and fibre mobility within the structure. Generally softened PLA fabrics exhibited lower bending rigidity than softened PET fabrics. The results reveal that the application of Softener 2, a 'reactive fatty acid amide', resulted in a remarkable increase in the bending properties of PLA and PET fabrics (DSH2) in comparison to DDH. In contrast, with the exception of Softener 1 (DSH1), the fabrics treated with silicone softeners (DSH3, DSH4, DSH7 & DSH8) exhibited lower B and 2HB values than all other softened fabrics (DSH2, DSH5, DSH6 & DSH9) and controls (D & DDH). Softener 1 is based on OH-functional PDMS with a hydrophilic polyester resin. DSH1, treated with Softener 1, exhibited higher bending properties than the other fabrics treated with silicone softeners (***Figures 1.a*** and ***1.b***), which could be due to the OH groups, since the introduction of OH groups into silicone softening agents usually results in improved hydrophilicity but reduced softness. Pure aminofunctional (DSH4, DSH7, DSH8) and quaternary functional (DSH3) silicones exhibited the best performance with the lowest bending rigidity (B) and bending hysteresis (2HB). It is known [1, 17] that aminofunctional PDMS type softeners typically give the softest handle and also produce good lubricity, hence reducing inter-fibre friction. Frictional resistance (due to inter-fibre and inter-yarn movements at the cross-over points) is reduced by good softeners, leading to better fabric recovery from deformation and finally a decrease in hysteresis.

The remaining softeners studied, which were based on fatty acid products alone as well as with mixtures and fatty ester, led to higher values of B and 2HB than the pure amino and quaternary functional PDMS types. For example, DSH9, softened with Softener 9, which is based on a cationic fatty acid amide with polythene wax, resulted in very high bending values which were similar to or higher than those of DDH. Avinc *et al.* [14] also reported a reduction in bending stiffness and hysteresis with silicone softened fabrics, while Kut *et al.* [19] found that softeners with polysiloxane micro-emulsions imparted better bending and drape than those employing fatty acids. The results of our study are in line with these observations.

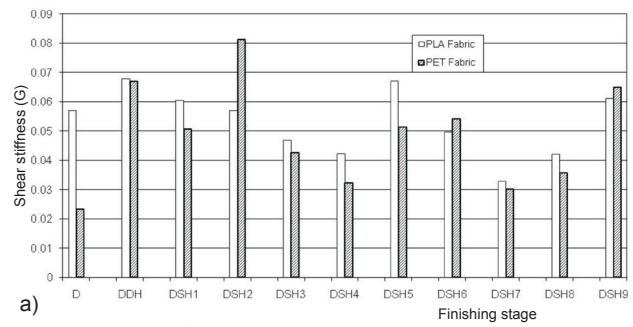
Some cationic softeners (DSH3, DSH7) improved the bending properties and some (DSH2, DSH9) did not. Similarly nonionic softeners behaved differently with respect to bending properties. It appears that the effect of the ionicity of the softener on bending properties is insignificant.

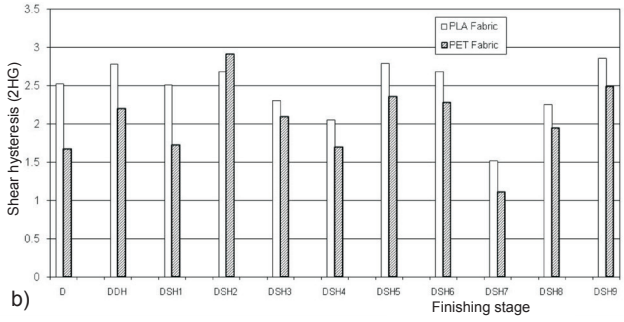
The four best-performing softeners with the lowest bending rigidity (B) and bending hysteresis (2HB) are micro-emulsion softeners. It is claimed that normal (macro) emulsion softeners impart a 'soft to greasy' handle, while micro-emulsion ones give a very soft, non-greasy handle [2]. Micro-emulsions impart internal lubrication, excellent softness, and surface smoothness without greasiness because of their very small average particle size of below 40 nm. The particle size of the active softening agent affects the distribution of the silicone on the fabric. Micro-emulsion silicone softener products with very small drops penetrate the closely packed yarn structure and the space between single fibres, while macro-emulsified softeners deposit the silicone on the surface of the yarns in larger drops of around 150 – 300 nm [1, 20, 22]. It has been stated that micro-emulsions of amino-modified silicone impart a very soft handle [23,14], which is in line with the results of the current study.

On the one hand, three of the four hydrophobic softeners (DSH3, DSH4, DSH7) exhibited very low bending properties. Only one hydrophobic softener, Softener 2 (DSH2), resulted in very high bending properties. On the other hand, hydrophilic softeners (DSH1, DSH5, DSH6, DSH9) resulted in higher bending properties, with the exception of Softener 8 (DSH8), compared to the hydrophobic softeners. However, hydrophilic Softener 8 (DSH8) showed very low bending properties which were similar to the performance of hydrophobic Softeners 3, 4 & 7 (DSH3, DSH4, DSH7). As observed for the ionicity of the softener, the effect of the softener's hydrophilicity on bending properties appears to be insignificant.

The bending properties of the fabrics were influenced by the chemical nature of the softening agents and the emulsion type used in the softener. In contrast, the actual ionicity of the softener and the level of hydrophobicity of the treated fabric appeared to have little or no effect. This finding is in agreement with that of Kut *et al*. [19], who reported that the influence of softeners on the bending rigidity of PET fabric depended more on their chemical structure than on their ionicity.

Overall, Softener 7 (DSH7), a hydrophobic, slightly cationic aminofunctional PDMS micro-emulsion, resulted in the





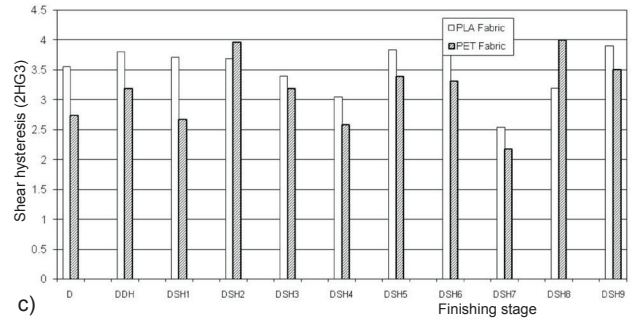


Figure 2. *Changes in shear: a) stiffness (G), b) hysteresis (2HG) and c) hysteresis (2HG3) of PLA and PET fabrics before and after finishing.*

highest improvement in both fabrics' bending properties, giving the lowest bending rigidity and bending hysteresis values compared to the other softeners.

Shear properties

The results of shear properties, shear stiffness (G), shear hysteresis at 0.3° (2HG), and shear hysteresis at 3° (2HG3) of PLA and PET fabrics before and after finishing with different softeners are shown in ***Figures 2.a - 2.c***. Lower values of shear rigidity and shear hysteresis indicate less resistance to the shearing movement, corresponding to a softer material of better drape. The more easily the yarns glide over each other, the smaller the fabric hysteresis [20].

Knitting mill (greige) PLA fabric exhibited higher shear stiffness (G) and shear hysteresis (2HG, 2HG3) than knitting mill PET fabric. As observed for the bending properties, there is an important increase in shear values after dyeing and heat setting (DDH), which could be due to the limitation of fibre and yarn movement in the fabric as a result of fabric shrinkage during such processes. Although the differences in shear values between PLA and PET fabrics diminish after dyeing, drying and heat-setting, most probably due to the more aggressive application conditions, the shear properties of PLA fabrics were still slightly higher than those of PET fabrics. This trend generally continues, with PLA fabrics having slightly higher G, 2HG, and 2HG3 values than PET fabrics after softener finishing, with few exceptions.

Almost all softeners improved the shear properties of both fabrics compared to DDH, which is due to the fact that the softener finishing substantially reduces inter-fibre and inter-yarn friction, leading to increased yarn and fibre mobility within the structure. As observed for the bending properties, micro-emulsion aminofunctional (DSH4, DSH7, DSH8) and quaternary functional (DSH3) silicones exhibited the best performance, having the lowest shear stiffness (G) and shear hysteresis (2HG) values. As mentioned earlier, it is known [1, 14, 17] that aminofunctional PDMS type softeners typically give the softest handle and also produce good lubricity, hence reducing inter-fibre friction. The remaining softeners studied, which were based on fatty acid products alone and with mixtures and fatty ester, led to higher values of G, 2HG and 2HG3 than the amino and quaternary functional PDMS types.

As observed for the bending properties, Softener 7 (DSH7), a hydrophobic slightly cationic aminofunctional PDMS micro-emulsion, resulted in the highest improvement in shear properties of both fabrics, giving the lowest shear stiffness (G) and shear hysteresis (2HG, 2HG3) values of all the softeners.

The organisation and orientation of softener molecules on the surface of synthetic fibres have been the focus of attention of many researchers. They would appear to depend on the electronic charge interaction between the fibre and softener molecules, the hydrophobicity of the softener, and the relative hydrophobicity of the fibre surface [2, 3]. Wahle and Falkowski [3] stated that the deposition of softener onto the fibre surface is due to hydrophobic ejection from water. Textile softeners have a hydrophilic group attached to a hydrophobic tail. The hydrophobic parts of the silicone softener chains cooperate robustly with the hydrophobic and rela-

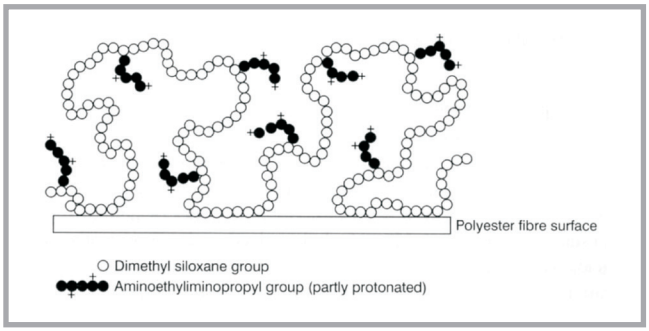


Figure 3. *Possible orientation of an aminofunctional silicone on the surface of polyester fibre [22].*

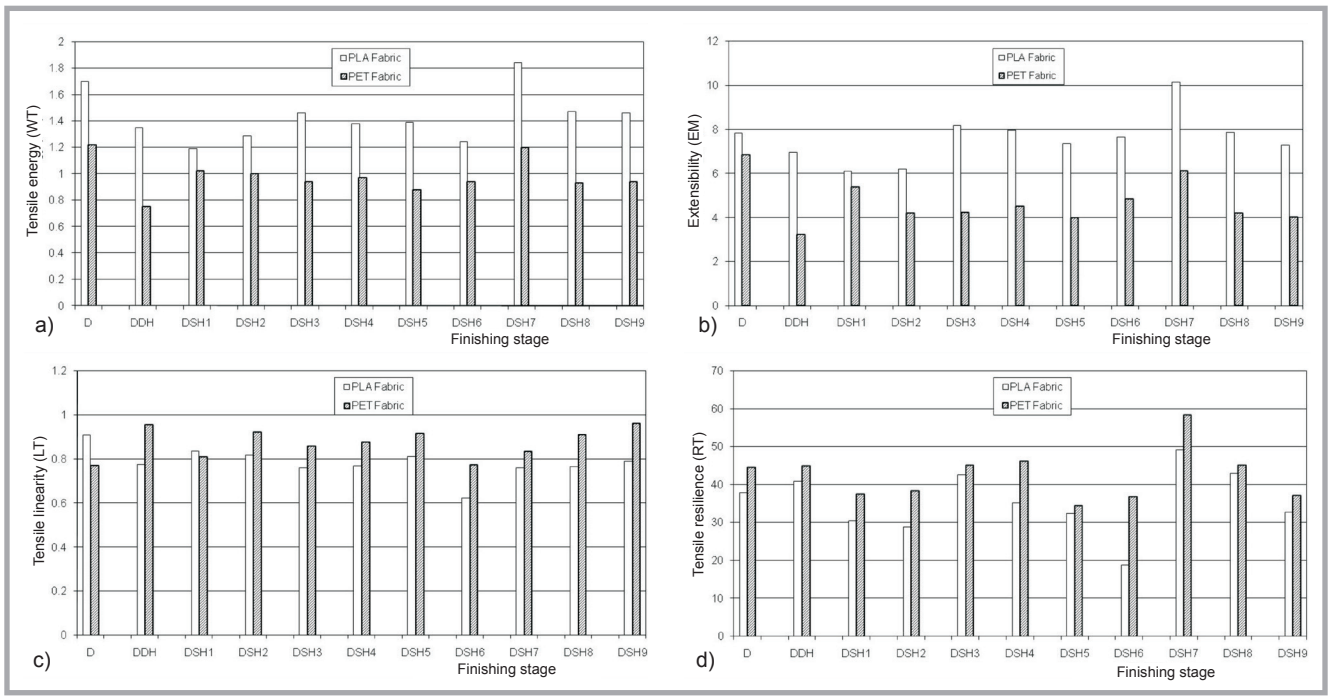


Figure 4. *Changes in: a) tensile energy (WT), b) extensibility (EM), c) tensile linearity (LT) and d) tensile resilience (RT) of PLA and PET fabrics before and after finishing.*

tively non-polar fibre surface (in the case of PET) [2]. For example, a theoretical softening mechanism for a positively charged amino-side hydrophilic group attached to polydimethylsiloxane (PDMS) hydrophobic group softeners was considered by Habereder *et al.* [21] (***Figure 3***).

The PDMS hydrophobic backbone imparts substantivity to hydrophobic fibres such as polyester or aliphatic polyester PLA. It is suggested that amino side-chains in the polymer on the polyester surface exhibit random distribution [21]. The distribution and orientation of the silicone softeners on the PET fibre surface are directed by hydrophobic fibre-PDMS polymer interaction, leading to an increase in the mobility of the silicone chain segments and enhanced flexibility of the silicone chain loops because of electrostatic repulsion between adjacent cationic amino side groups which are partly protonated [17, 21]. This is the reason for the super-soft handle of relatively non-polar hydrophobic fibre softened with aminofunctional silicone [2, 17, 21], which could be the explanation for the superior performance of aminofunctional PDMS micro-emulsion softener on both PLA and PET fabrics.

As observed for bending properties, the shear properties of the fabrics were influenced by the chemical nature of the softening agents and the emulsion type used in the softener. In contrast, the actual ionicity of the softener and the level of hydrophobicity of the treated fabric appeared to have little or no effect.

Tensile properties

The results for the tensile properties, tensile linearity (LT), tensile energy (WT), tensile resilience (RT) and elongation (EMT) of PLA and PET fabrics before and after finishing with different softeners are shown in ***Figures 4.a – 4.d***. Tensile linearity reflects the elasticity of the fabric: the higher the LT value, the stiffer the material. Tensile energy is the work done during the extension of the fabric, and a greater WT value corresponds to a higher tensile strength of the fabric. Tensile resilience reflects the recovery ability of a fabric after being extended [20].

Knitting mill (greige) PLA fabric exhibited higher extensibility (EM) and tensile energy (WT) than knitting mill PET fabric. There are substantial decreases in EM and WT after dyeing, drying and heat setting for both fabrics (DDH), which again could be due to the limitation of fibre and yarn movement in the fabric as a result of fabric shrinkage during such processes. This decrease observed was greater for PET fabric, most probably because of the higher dyeing and heat-setting temperature conditions. Similarly PET exhibits higher RT and LT values than PLA after dyeing, drying and heat-setting, leading to a stiffer handle.

Higher tensile energy (WT), higher extensibility (EM), lower tensile linearity (LT), and lower tensile resilience (RT) were generally observed after softening for both fabrics, with few exceptions. These changes show that the friction between fibres was reduced during the softening process. It seems that the softening agent facilities the movement of fibre and yarn in the fabric structure by reducing inter-fibre and inter-yarn friction. As a result of this, both fabrics became more extensible and less stiff with better elastic recovery and higher tensile strength.

Although there is no clear trend indicating that the tensile properties of both fabrics were influenced by any of the following softener properties: their chemical nature, emulsion type, ionicity and hydrophobicity, as observed for the bending and shear properties, the micro-emulsion aminofunctional (DSH4, DSH7, DSH8) and quaternary functional (DSH3) silicones exhibited high tensile energy (WT) and high extension (EM) values. As observed for the bending and shear properties, Softener 7 (DSH7), a hydrophobic, slightly cationic aminofunctional PDMS micro-emulsion, caused more improvement in tensile properties, giving the highest tensile energy (WT) and exten-

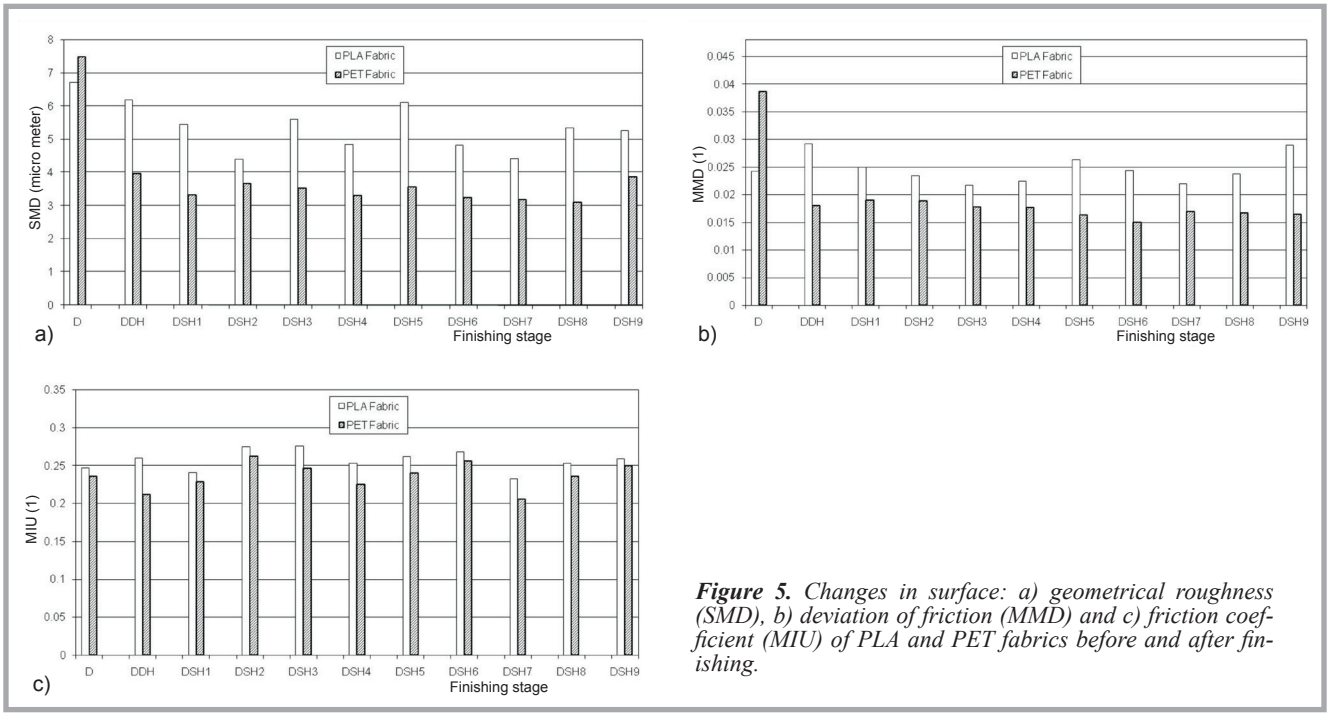


Figure 5. *Changes in surface: a) geometrical roughness (SMD), b) deviation of friction (MMD) and c) friction coefficient (MIU) of PLA and PET fabrics before and after finishing.*

sion (EM) of both fabrics among all the softeners studied.

Surface properties

The results for the surface properties, geometrical roughness (SMD), mean deviation of friction (MMD), and friction coefficient (MIU) of PLA and PET fabrics before and after finishing with different softeners are shown in ***Figures 5.a – 5.c***. SMD is a measure of a fabric's surface 'profile'. The surface roughness depends on the yarn spacing irregularity and fabric geometrical factors. Higher SMD values indicate a geometrically rougher surface.

Knitting mill (greige) PLA fabric exhibited lower geometrical roughness (SMD) and mean deviation of friction (MMD) than knitting mill PET fabric. The results show a remarkable change during the wet processing which is applied to PLA and PET fabrics in comparison to knitting mill fabrics. There is a substantial decrease in SMD and MMD after dyeing, drying, heat setting, and softening for both fabrics, leading to smoother fabric surfaces. Relaxation shrinkage during wet processing decreases the roughness (SMD) and mean deviation of friction (MMD) of both fabrics, which may be due to the tighter and more compact structure of the fabrics after shrinkage, making gaps in the fabrics and the surface variation smaller.

The softened specimens had lower SMD and MMD values than the controls, leading to smoother fabrics because the yarns became softer with fewer spaces left between them after softening. In addition, softeners mask the irregularity of the knitted fabrics. In this way, the smoother surface of the fabric has more contact with the probe tip and this gives a very slight rise in the friction coefficient (*MIU)*. Fabrics softened with silicone softeners (DSH1, DSH3, DSH4, DSH7, DSH8) exhibited the lowest SMD values and were thus the smoothest fabrics among the softened specimens in the assessment. As observed for the bending, shear and tensile properties, Softener 7 (DSH7), a hydrophobic, slightly cationic aminofunctional PDMS micro-emulsion, caused more improvement in the surface roughness (SMD) of both fabrics than the other softeners studied. There is no clear trend showing that the MMD and MIU properties of either fabric were influenced by any of the following softener properties: their chemical nature, emulsion type, ionicity, or hydrophobicity.

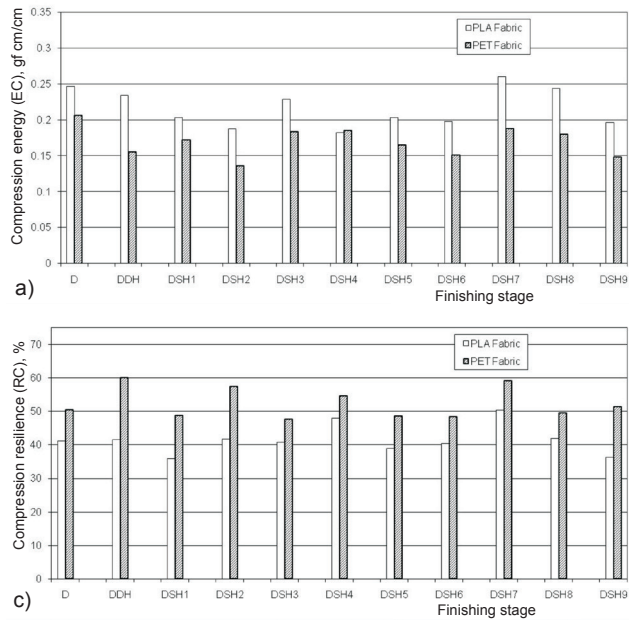
All PET fabrics treated exhibited lower SMD, lower MMD and lower MIU values than treated PLA fabrics, leading to smoother fabric surfaces.

Compression properties

The results for the compression properties, compression energy (WC), compression resilience (RC) and compression linearity (LC) of PLA and PET fabrics before and after finishing with different softeners are shown in ***Figures 6.a – 6.c***. The compression energy (WC) reflects the fluffy feeling of the fabric. The larger the RC values, the better the retention ability of the fullness of the fabric after compression. Compression linearity reflects the elasticity of fabric after the removal of the compression load [20].

Knitting mill (greige) PLA fabric exhibited higher compression energy (WC) than knitting mill PET fabric, leading to a fuller hand. After dyeing, drying and heat-setting, both fabrics exhibited lower compression energy (WC), lower compression linearity (LC) and higher compression resilience (RC), leading to a fabric hand which was less fluffy but smoother, which is in line with the surface properties.

Higher WC values were generally observed after softening. Although there is no clear trend showing that all of the compression properties of the two fabrics were influenced by any of the following softener properties: the chemical nature, emulsion type, ionicity and hydrophobicity of the softeners, as observed for the bending, shear, tensile and surface properties, the micro-emulsion aminofunctional (DSH4, DSH7, DSH8) and quaternary functional (DSH3) silicones exhibited the highest change in compression energy (WC). Fabrics softened with these silicone softeners exhibited the highest WC values, leading to fuller



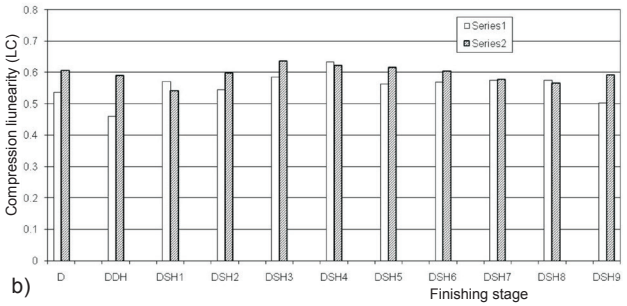


Figure 6. *Changes in compression: a) energy (WC), b) linearity (LC) and c) resilience (RC) of PLA and PET fabrics before and after finishing.*

and fluffier fabrics among the softened specimens in the assessment. Moreover the application of Softener 7, the hydrophobic, slightly cationic aminofunctional PDMS micro-emulsion, on both PLA and PET fabrics (DSH7) gave the highest compression energy (WC) and compression resilience (RC) values, leading to a fuller, fluffier and smoother fabric hand. This observation is also in line with the bending, shear, tensile and shear properties. There is no clear trend showing that the LC property of either fabric was influenced by any of the following softener properties: their chemical nature, emulsion type, ionicity, or hydrophobicity.

Overall, all PLA fabrics exhibited higher WC and lower RC values than PET fabrics, leading to a fluffier, fuller, and less smooth fabric hand, which is also in line with the surface properties.

Conclusions

Knitting mill (greige) PLA fabric exhibited higher bending rigidity (B), bending hysteresis (2HB), shear stiffness (G), shear hysteresis (2HG, 2HG3), extensibility (EM), tensile energy (WT) and compression energy (WC) as well as lower geometrical roughness (SMD) and mean deviation of friction (MMD) values than knitting mill PET fabric.

After dyeing, drying and heat-setting, both PLA and PET fabrics showed higher bending rigidity (B), bending hysteresis (2HB), shear stiffness (G), shear hysteresis (2HG, 2HG3), tensile resilience (RT) and compression resilience (RC) as well as lower tensile energy (WT), extensibility (EM), compression energy (WC), compression linearity (LC) and geometrical roughness (SMD) values, leading to a stiffer and less fluffy but smoother fabric handle.

Softened PLA and PET fabrics generally exhibited lower bending rigidity (B), bending hysteresis (2HB), shear stiffness (G), shear hysteresis (2HG), tensile resilience (RT), geometrical roughness (SMD) and mean deviation of friction (MMD) as well as higher tensile energy (WT), extensibility (EM) and compression energy (WC) values than dyed, dried and heat-set fabrics, leading to a softer, smoother, fluffier and fuller fabric hand.

The bending (B, 2HB) and shear (G, 2HG) properties of both fabrics were influenced by the chemical nature of the softening agents and the type of emulsion used in the softener. In contrast, the ionicity and hydrophobicity of the softener appeared to have little or no effect on the bending and shear properties of either fabric. There is no clear trend showing that the LT, RT, MMD, MIU, LC and RC values of either fabric were influenced by any of the following softener properties: their chemical nature, emulsion type, ionicity, or hydrophobicity.

Aminofunctional and quaternary-functional silicone micro-emulsions exhibited the best performance, giving the lowest bending rigidity (B), bending hysteresis (2HB), shear stiffness (G), shear hysteresis (2HG) and geometrical roughness (SMD)as well as the highest compression energy (WC), high tensile energy (WT) and extension (EM) values by reducing inter-fibre friction, leading to the softest, fluffiest, and smoothest fabrics among the softened specimens in the assessment. Fatty ester softener and fatty acid based softeners were less effective than aminofunctional and quaternary-functional silicone micro-emulsions.

Overall, the best softener for both fabrics was a hydrophobic, slightly cationic, aminofunctional polydimethylsiloxane micro-emulsion softener, which gave the lowest bending rigidity (B), bending hysteresis (2HB), shear stiffness (G),and shear hysteresis (2HG, 2HG3), the highest tensile energy (WT), extension (EM), compression energy (WC) and compression resilience (RC), as well as very low geometrical roughness (SMD) values, leading to the softest, fullest, fluffiest, and smoothest fabric handle in this study.

Overall, all the softened PLA fabrics exhibited lower bending rigidity (B), tensile linearity (LT), and tensile resilience (RT) as well as higher tensile energy (WT), extensibility (EM), geometrical roughness (SMD), mean deviation of friction (MMD) and compression energy (WC) values than all softened PET fabrics, leading to a softer, fuller and fluffier but rougher fabric handle.

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