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Investigation on Regenerated Cellulosic Knitted Fabric Performance by Using Silicone Softeners with Different Particle Sizes

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Abstract
Silicone softeners make fabric not only softer, brighterd slippery but also more elastic in order to produce desirable handle. In this paper, the affect of silicone softeners on some mechanical and functional properties of knitted regenerated (viscose, modal, Viloft®, micromodal, lyocell and bamboo) fabrics were assessed. For this purpose, commercially used silicone softeners with three different particle sizes (macro, semi-macro, micro) were applied on these fabrics by a continuous methodin identical conditions. The impact of using different softeners on the weight, thickness, pilling resistance, wet and dry rubbing fastness, total colour change and air permeability of these fabrics were investigated. Results revealed that the highest colour efficiency is obtained from lyocell fabrics. Silicone softener application increased the pilling performance of regenerated cellulose fabrics but had no affect on the wet and dry rubbing color fastness. It was found that the application of softeners has a significant affect on air permeability with respect to untreated fabrics.

Key words: *regenerated fibers, silicone softeners, pilling resistance, rubbing fastness, colour analysis.*

Introduction

Regenerated fibres are produced from natural cellulose based materials such as wood pulp or cotton linter. The natural raw materials are reformed to produce fibres or filaments suitable for making into yarns. Since cellulose has strong intermolecular bonds, it does not melt nor dissolve readily in ordinarily available solvents. Studies were performed for the derivation of cellulose to render it soluble and processable. Viscose fibre is the first commercial regenerated fibre that is made from modified cellulose/ wood pulp [1]. New regenerated cellulosic fibres, that is lyocell fibres, are produced with a more environmentally friendly procedure from a solution of non-derivative cellulose in a solvent spinning process where the cellulose is dissolved directly in organic solvent N-methylmorpholine-Noxide, without the formation of derivatives [2]. Tencel is the brand name of lyocell fibre, which is a new age fibre that absorbs excess liquid and quickly releases it again into the atmosphere; it is more absorbent than cotton, softer than silk and cooler than linen [3]. The attributes of lyocell include good drape, a diverse range of tactile properties, ease of blending with other fibres, a high wet modulus and good wash stability, resulting in low shrinkage and environmental friendliness [2].

Regenerated bamboo fibre is obtained from the bamboo plant, which is an abundant and cheap natural resource. Bamboo fibre is obtained from bamboo pulp, which is extracted from the bamboo stem and leaves by wet spinning, including a process of hydrolysis-alkalisation and multi-phase bleaching that is quite similar to that of viscose rayon fibre [4]. In addition, bamboo viscose fibre exhibits good dyeability, soft handle and proper moisture absorbility and permeability [5].

Modal fibre is produced from the wood of the beech-tree. The dry and wet strength of this fibre is high. Either woven or knitted modal fabrics have smooth handle with high resistance to wear and they transfer humidity well [6]. Micromodal fibre extra fine, making textiles even lighter, and are produced as alternatives to modal fibre [7]. Viloft® is a viscose fibre with a modified flat fibre cross-section, making it particularly well suited for warm textiles and giving it better thermal insulation properties. It is naturally soft, supple and breathable [8].

In different commercial types of softeners, applications are available with different concentrations and proportions of ingredients viz., amphoteric, anionic, cationic, non ionic and reactive silicone softeners. Silicone softeners have little affinity towards textile materials because they are compatible with other finishing agents and can be applied to both natural and man-made fibre fabrics. The application of silicone softener to easy care finished fabric decreased the fabric friction and a further increase in the crease recovery angle was observed. Easy care finishing marginally changed the bending length, which is reduced, to some extent, by the application of silicone softener [9], giving better inner and surface softness, lightness, elasticity, easy sewing as well ashigh tear and abrasion resistance to textiles [10]. The particle size of macro emulsion silicone softeners is 150 - 250 nm, while that of micro emulsion silicone softener is lower than 30 nm [11]. Silicone softeners are based on macro emulsions and micro emulsions. The choice of softeners is of paramount importance as the pilling performance of a fabric is one of the major requirements of customers along with fabric handle [12].

According to our survey, some researchers have studied the affects of silicone softeners on the mechanical and chemical properties of fabrics. Chattopadhyay and Vyas investigated the affect of silicone nano-emulsion softener against silicone conventional softener on the softness, feel, wrinkle recovery, absorbency, soiling and tensile properties of cotton fabrics. It was stated that softener

Table 1. Properties of yarn samples; * Tensel® is used as the trade name of this fibre.

Yarn samples	Yarn linear density, tex	Twist level, t.p.m	Tenacity, RKM	Elongation, %	Cvm, %	Imperfections			Hairiness, %
						Thin places, - 50 %/ km	Thick places, + 50 %/ km	Neps, +200%/km	
Viscose	19.7	802	15.03	14.23	13.24	2.5	18.8	43.8	6.94
Modal		768	24.80	9.17	10.65	0	1.3	25.0	7.03
Viloft®		773	11.77	9.89	16.13	75	142.5	326.3	10.60
Micromodal		763	20.52	9.52	10.45	0	16.3	102.5	5.76
Lyocell*	21.1	713	28.27	8.48	13.30	0	126.3	101.3	8.14
Bamboo	19.7	774	16.87	13.90	13.54	0	51.3	76.3	6.12

improves the feel, softness and crease recovery of cotton fabric [13]. Çelik at al. claimed that knitted fabrics applied with nano silicone softener had poor abrasion resistance but better pilling resistance [11]. Choudhury et al. evaluated the hydrophilicity and some pyhsical properties of plain-woven fabrics treated with macro, micro and nano silicone softeners with three different concentrations. They concluded that there were significant changes in the degree of hydrophilicity, crease recovery, stiffness, bending modulus, drape as well as tearing strength [14]. Zia et al. studied amino functional based softener with different emulsifiers (i.e., 30, 40 and 50 g/l) and its concentration on cotton and blends of cotton/polyester plain weave dyed and printed fabrics. It was indicated that fabrics applied with softeners have lower surface roughness and better strength [15]. Zuber et al. evaluated the pilling performance and colour fastness properties of cotton and blends of cotton/polyester plain weave dyed and printed fabrics treated with amino functional based softener. They observed that the colour fastness to rubbing of samples of dyed and printed fabric treated with the softeners prepared showed some poor ratings as compared to the untreated fabrics. They also concluded that the softeners applied contributed to the pilling performance [16]. Robati examined the mechanical properties of cotton fabric treated silicone softener of different viscosity by comparing with conventional softener. Positive static and kinetic friction index changes were observed by increasing the percentage of softener [17].

There are different types of softeners used commercially, and some researchers have studied the performance of fabric treated with different types of softeners such as anionic, nonionic, PE emulsion, amino silicone, micro amino silicone, reactive softener etc. Hussain et al. determined the softening and sanforising treatment affect on the pilling performance of polyester / viscose blended woven fabric. It was stated that nonionic organo-modified silicone microemulsions and amino functional polysiloxanes had a negative effect on the pilling performance of fabric samples, and sanforising treatment after softening also adversely affected the fabric [18]. Chinta et al. evaluated cotton, polyester/viscose, cotton/polyester fabric comfort properties by applying different types of softeners such as anionic, nonionic, reactive, reactive softener with glycerin, amino silicone, amino silicone with glycerin, micro amino silicone, micro silicone softener, hydrophilic silicone and PE emulsion softener [19]. Parvinzadeh et al. investigated polyester fabric properties treated with

macro and microemulsions of silicones with different concentrations [20]. Kang et al. Studied the dimensional properties of plain weave wool fabrics treated with a simple pad-dry-cure process in an aqueous bath with aminofunctional and epoxyfunctional silicone softeners [21].

In the literature survey, no study has been encountered about a comparison of the affect of silicone softeners of different particle size applied on 100% percent regenerated cellulose fibres. In this study, different, most commonly commercially used 100% percent regenerated cellulose fibres were selected in order to determine the affect of silicone softeners with different particle sizes, namely macro, semi-macro and micro on some selected properties, as well as the pilling performance, and wet and dry fastness. Colour tests of the knitted fabrics were also carried out. Related tests were performed and the results measured, evaluated and compared with untreated dyed fabrics.

Experimental

Materials

The regenerated cellulose fibres chosen were viscose, modal, Viloft®, micromodal, lyocell and bamboo, commercially used in apparel, including underwear products, t-shirts, home textiles, sport clothes etc. To evaluate the affect of softener with different particle sizes on fibres, 100% percentage ring-spun yarns of these fibres were supplied instead of blending of these fibres with any others. For this study, viscose fibre of 1.3 dtex fineness and 38 mm length, modal fibre of 1.3 dtex fineness and 39 mm length, Viloft® fibre of 1.9 dtex fineness and 39 mm length, micromodal fibre of 1 dtex fineness and 39 mm length, lyocell fibre of 1.3 dtex fineness and 38 mm length, and bamboo fibre of 1.5 dtex fineness and 38 mm were used. Since different yarn production conditions are required depending on the raw materials, the yarn production parameters are different but as close as possible. Yarn samples were produced by the Selçuk Textile Group, located in Gaziantep, Turkey. After conditioning in standard atmospheric conditions (20 ± 2 °C temperature and 65 ± 2% relative humidity) for 24 hours, An Uster Tester-4 (Switzerland) was used to determine the CVm%, total imperfections (thin places, thick places and neps) and hairiness at a speed of 400 m/min for 5 minutes according to ISO 16549:2004 - *Textiles - Unevenness of textile strands - Capacitance method test method*. Tenacity in RKM and elongation in % properties of the yarn samples were also obtained from the measurement. RKM is the short expression for Reisskilometer, which can be expressed by the breaking force of yarn per kilometer at which yarn will break under its own weight. Five yarn samples were tested for each type, the properties of which are given in ***Table 1***. Each type of yarn was knitted as single jersey fabric on a sock machine, model Faycon brand CKM-01-5, with 200 needles, at a capacity of 100 rev/min speed. In this study, the chemicals used for the bleaching and dyeing process of the fabric samples were provided by Eksoy Kimya and silicone softeners were obtained from CHT

Textile Chemicals Company, located in Turkey. Amino functional silicone softeners were selected according to those commonly used for knitted fabrics. In that respect, Arristan 444, Arristan 65 and Tubingal Micro softeners were used as macro, semi-macro and micro silicone softeners, respectively. These fabrics were bleached and dyed in the same conditions. Then macro, semi-macro and micro silicone softeners were applied to dyed fabrics by padding. Samples were conditioned in standard atmospheric conditions (20 ± 2 °C temperature and 65 ± 2% relative humidity) for 48 hours.

Fabric bleaching, dyeing and finishing

All grey knitted fabrics are processed in the same bath to eliminate the any variations during processes. Firstly fabrics were bleached in a hydrogen peroxide bath. The bleaching parameters are presented in ***Table 2***.

The wetting agent was added into the bath at 60 °C, and then the temperature was increased until 95 °C. Hydrogen peroxide and a stabiliser were added at this temperature and processed for 45 minutes. After rinsing to remove hydrogen peroxide residue, anti-peroxide enyzme with a catalase chemical structure which converts hydrogen peroxide in the bath into water and oxygen was used and applied with a 0.2 g/l concentration at 80 °C. And finally it was rinsed.

All fabric samples were dyed in the same conditions in a blue colour in a piece dyeing machine at 60 °C for 45 minutes on laboratory scale after the bleaching process. The dyeing recipe is illustrated in ***Table 3***.

Afterwards the cold rinsing process was conducted for 10 minutes. Then soap was applied at 70 °C and 100% acetic acid was used to neutralise the pH value. The silicone softeners presented below were applied on the fabrics with the same padding application. Each softener was applied at the same concentration i.e. 20 g/l with an 80% pick-up value. The pH of the softener solutions were adjusted between 5 and 5.5 with acetic acid. The fabrics were padded separately with each softener solution in a padding mangle with an average mangle pressure of 0.4 MPa and 2 m/s machine speed. After padding, the samples were dried at 130 °C for 2 minutes and then conditioned for 48 hours at room temperature.

Method

The fabric samples were conditioned for 48 hours in atmospheric conditions of 20 ± 2 °C temperature and 65 ± 2% relative humidity before the tests were performed. Thickness and fabric weight values were determined according to ISO 5084:1996- *"Textiles- Determination of thickness of textiles and textile products"* and BS EN 12127:1998- *"Textiles- Fabrics- Determination of mass per unit area using small samples"*, respectively. The pilling performance was studied according to ISO 12945-2:2000-*"Textiles- Determination of fabric propensity to surface fuzzing and to pilling -Part 2: Modified Martindale method"* standard, using a Martindale abrasion and pilling tester after a different number of rubs - 125, 500, 1000, 2000, 5000 and 7000. Three specimens were tested for each fabric sample. The appearances of the samples were assessed according to ASTM pill grade photographic views in a light cabinet under D65 daylight conditions. Samples were rated on a scale of 1 to 5 (1 for the worst, 5 for the best). Dry and wet rub fastness tests were carried out according to BS EN ISO 105-X12: 2002- *"Textiles- Tests for colour fastness- Colour fastness to rubbing"* test method on the samples which were with silicone and without silicone softeners. After the rubbing test, fabrics were evaluated according to the gray scale change in colour under D65 daylight conditions. Ten specimens for each fabric sample were tested. The air permeability of a fabric is a measure of how well it allows air passage through the fabric. The air permeability of the fabrics was determined on an SDL Atlas air permeability tester for ten repeats of each fabric type at 100 Pascals air pressure according to test method ISO 9237:1995- *"Textiles - Determination of the permeability of fabrics to air"* in order to identify air permeability characteristics of fabric samples treated with and without silicone softeners of different particle size. Ten measurements for each sample were performed at a constant pressure drop of 100 Pa and 20 cm^2 test area.

Colour measurement was carried out using a reflectance spectrophotometer (Hunterlab Colourquest II) coupled to a PC. Four readings were performed for each sample by rotating 90° CW after each reading. The measurement was applied to samples which were untreated and treated with macro, semi-macro and micro silicone softeners. CIELAB coordinates L* (lightness), a* (red-green axis) and b* (yellow-blue axis), the total colour difference (ΔE*) and K/S (colour strength) values were calculated as the reflectance values. Since all samples were dyed in blue colour, K/S values were measured at a wavelength of maximum absorption of 600 nm. To compare the test results easily, fabric samples were abbreviated, which is illustrated in ***Table 4***.

Table 2. *Bleaching recipe of samples.*

Bleaching parameters	
Liquor ratio	1 : 30
Wetting agent (Exowet), g/l	1
Hydrogen peroxide (H_2O_2) 50%, g/l	2
Levelling agent (Exolube NC), g/l	2
Temperature, °C	95

Table 3. *Dyeing recipe of samples.*

Dyeing recipe	
Bath ratio	1 : 15
Reactive dye (Synozol Brillant Blue BB), %	1
Sodium sulphate, g/l	50
Sodium carbonate, g/l	10
Sequestering agent (Antisil CONZ), g/l	0.5
Temperature, °C	60

Table 4. *Abbreviation of samples*

Samples	Without softener	Macro silicone softener	Semi-macro silicone softener	Micro silicone softener
Viscose	CV	CV1	CV2	CV3
Modal	M	M1	M2	M3
Viloft®	V	V1	V2	V3
Micromodal	MC	MC1	MC2	MC3
Tensel®	T	T1	T2	T3
Bamboo	B	B1	B2	B3

Results and discussion

Fabric weight and thickness

The change in fabric weight and thickness when treated by macro, semi-macro and micro silicone softeners with respect to control i.e. untreated dyed fabrics for each fibre is illustrated in ***Table 5***.

Table 5. Physical and construction properties of samples.

Sample	Coarse per inch, CPI	Wales per inch, WPI	Fabric weight, g/m^2	Fabric thickness, mm
CV	25.40	30.48	97.7	0.42
CV1	25.40	25.40	82.0	0.44
CV2	33.02	25.40	95.8	0.51
CV3	30.48	22.86	92.5	0.53
M	27.94	30.48	105.7	0.43
M1	30.48	27.94	99.5	0.47
M2	27.94	27.94	101.9	0.50
M3	30.48	25.40	99.6	0.50
MC	22.86	30.48	92.0	0.37
MC1	25.40	25.40	79.5	0.40
MC2	27.94	25.40	87.2	0.41
MC3	25.40	27.94	87.3	0.42
V	27.94	30.48	92.7	0.46
V1	30.48	22.86	81.6	0.48
V2	27.94	25.40	91.5	0.53
V3	30.48	25.40	86.0	0.50
T	25.40	27.94	92.0	0.42
T1	27.94	27.94	93.6	0.51
T2	33.02	30.48	111.0	0.56
T3	27.94	30.48	108.8	0.54
B	25.40	33.02	99.9	0.41
B1	30.48	27.94	94.0	0.46
B2	27.94	27.94	97.1	0.51
B3	30.48	25.40	96.9	0.49

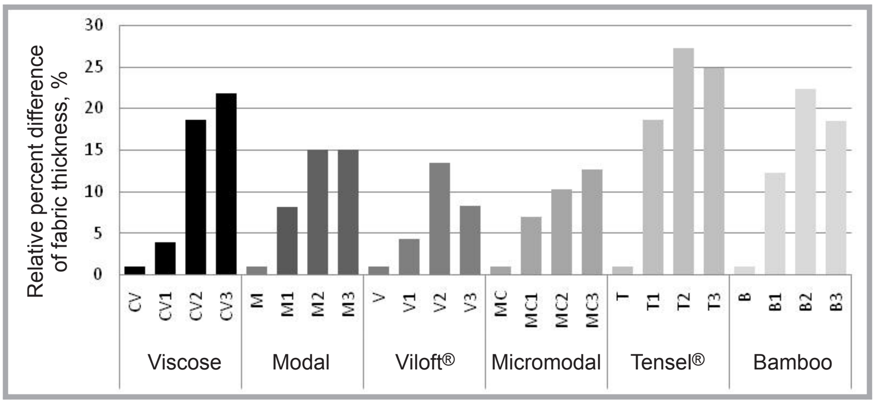

Figure 1.*Thickness changes of samples using RPD.*

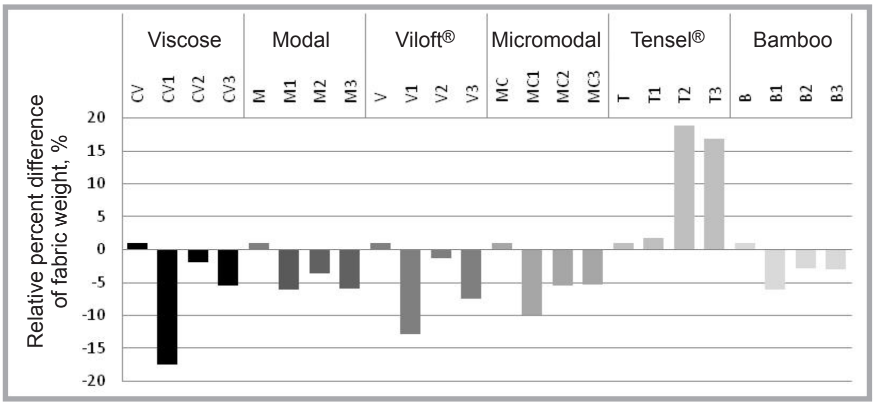

Figure 2.*Weight changes of samples using RPD.*

To compare the control fabrics with respect to silicone softener treated fabrics, we aimed to perform a precision analysis of differences so that the relative percent difference (RPD) change in both weight and thickness could be calculated. The relative percent difference expresses the precision of duplicates and is calculated as follows:

$$RPD = \frac{|x_1 - x_2|}{\acute{x}} \times 100$$

where, x_1, x_2 values observed, $\bar{x}$ mean of values observed [22].

To calculate the RPD values of the untreated or reference fabrics for each fibre were taken as x_1, x_2 value in the formula is the fabric treated with silicone softeners with differer $|x_1 - x_2|$ e size. RPD is a percent value of $\bar{x}$:lative changes in thickness and weight for each treated fabric versus to reference fabric for each type of fibre. The RPD of the fabric thickness for each fibre is illustrated in ***Figure 1***. As seen in ***Figure 1***, *CV*, *M* and *MC* show the same behavior. RPDs with respect to the reference fabric values increased from macro to micro silicone softener applications. On the other hand, maximum RPDs were obtained in semi-macro silicone softener application for the *V*, *T* and *B* fibres.

To evaluate the negative changes in the weight, we took only the difference in x_1 and x_2 instead of absolute values of the difference. As seen in ***Figure 2***, the RPD of the weight are similar and lower than for control fabrics, except the *T* fabric. The maximum weight increase was observed for the *T* fabric treated with semi-macro silicone softener. On the other hand, the highest weight differences were detected for *CV*, *M*, *V*, *MC* and *B* fabrics, which were treated with macro silicone softener, and the lowest weight differences were obtained with semi-macro silicone softener, except for the *T* sample.

Pilling behaviour

The pilling test results of *CV* fabrics are given in ***Figure 3***. It was observed that softeners applied to the *CV* fabric samples have a decreasing affect on the pilling grade, except for *CV* fabric treated with semi-macro silicone softener. There is no affect of silicone applications on the pilling grade until 500 cycles. In comparison with macro and micro silicone softeners, semi-macro silicone softener has a better performance. The pilling test results of *M* fabric samples are

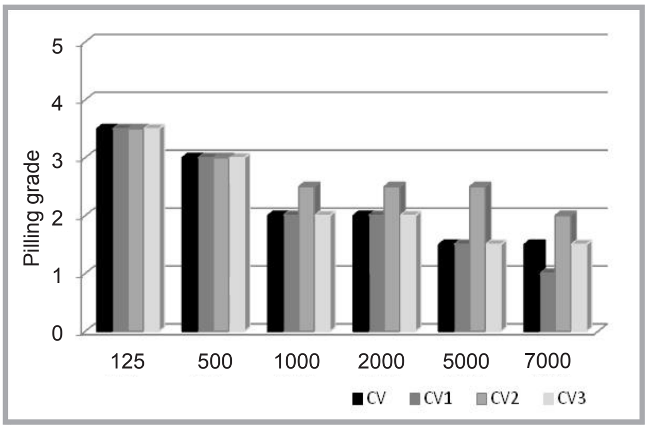

Figure 3. *Pilling grade versus rubbing cycles of viscose fabrics.*

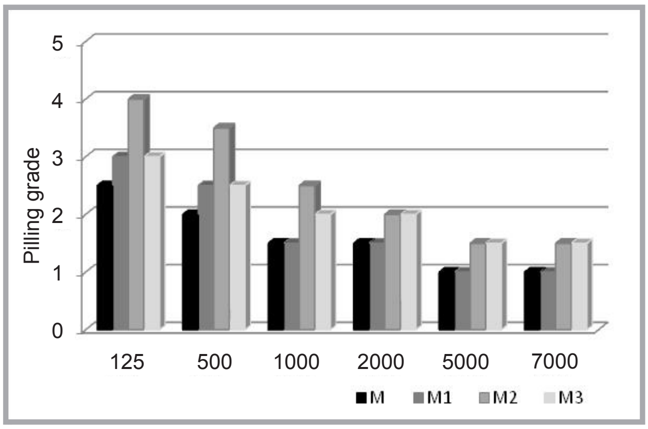

Figure 4. *Pilling grade versus rubbing cycles of of modal fabrics.*

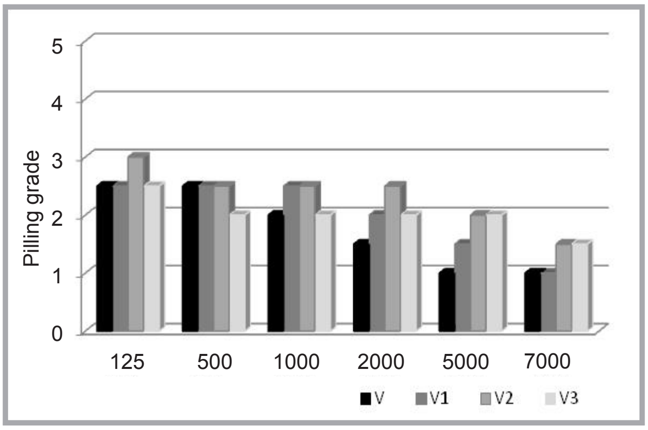

Figure 5. *Pilling grade versus rubbing cycles of Viloft® fabrics.*

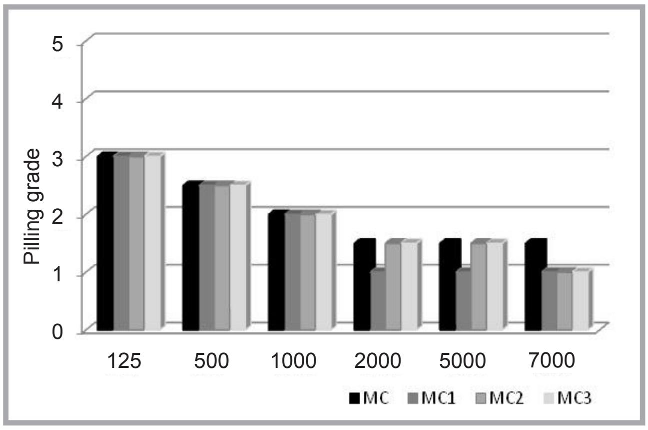

Figure 6. *Pilling grade versus rubbing cycles of micromodal fabrics.*

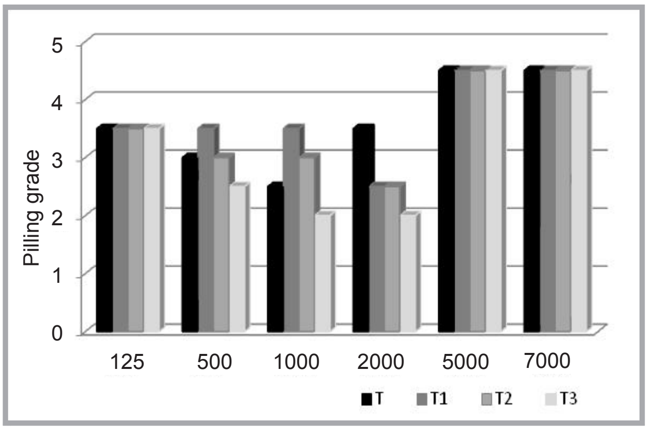

Figure 7. *Pilling grade versus rubbing cycles of Tensel® fabrics.*

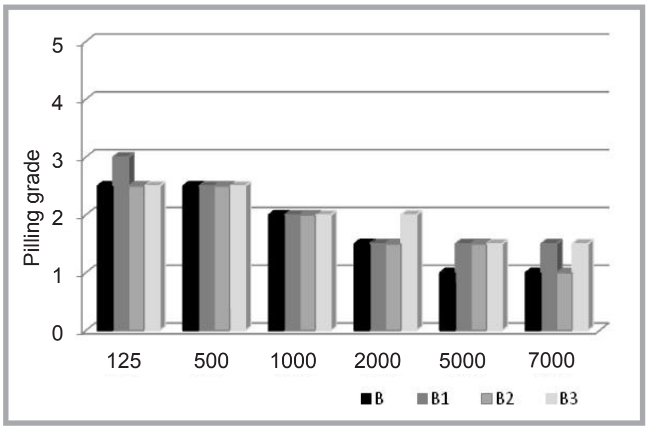

Figure 8. *Pilling grade versus rubbing cycles of bamboo fabrics.*

presented in ***Figure 4***, showing that the softeners have an upgrading affect on them. Between 2000 to 7000 cycles it is obvious that the pilling grade of untreated fabrics and those treated with macro silicone softener are equal and worse. The semi-macro silicone softener has better pilling performance than the other ones. Softener applications have a significant effect on the pilling performance of *V* fabric samples, as shown in ***Figure 5***. After 7000 cycles, samples applied with semi-macro and micro silicone softener have better piling performance. A lower particle size applied causes better pilling performance for *V* and *M* fabrics. All of the softener types applied have a decreasing affect on the pilling performance of *MC* fabric samples, which is illustrated in ***Figure 6***. It can be seen from ***Figure 6*** that three of the softeners have nearly the same grade of decreasing affect. The affect of the softeners on the pilling performance of *T* fabrics is variable according to the number of cycles, which is shown in ***Figure 7***. Macro and semi-macro softeners have an increasing affect up to 2000 cycles. The softeners have a decreasing affect on pilling performance between 2000 and 5000 cycles. As presented in ***Figure 7***, the softeners have no affect on the pilling behavior after 5000 cycles. As seen in ***Figure 8***, the pilling performance of *B* fabrics increased with softener application. For all types of regenerated fabric samples,

Table 6. Colour test results; ^{0}: reference fabrics.

Sample	L*	a*	b*	K/S	ΔE*
CV^0	48.04	-0.85	-40.37	5.15	-
CV1	52.05	-1.87	-39.87	3.88	4.17
CV2	52.76	-1.40	-38.40	3.44	5.15
CV3	49.36	-0.97	-40.88	4.75	1.43
M^0	51.93	-1.28	-38.60	3.66	-
M1	50.53	-0.86	-40.05	4.19	2.06
M2	51.06	-0.93	-39.09	3.90	1.04
M3	52.63	-1.22	-38.76	3.49	0.72
MC^0	50.78	-1.43	-38.49	4.01	-
MC1	52.34	-1.22	-39.66	3.65	1.96
MC2	51.46	-1.00	-39.39	3.84	1.21
MC3	51.42	-0.82	-40.02	3.90	1.76
V^0	48.61	-0.55	-39.58	4.70	-
V1	52.11	-1.00	-39.90	3.71	3.54
V2	48.92	-0.19	-40.33	4.64	0.88
V3	49.58	-0.66	-39.41	4.36	0.99
T^0	44.93	0.77	-41.17	6.31	-
T1	40.39	3.05	-44.35	9.64	5.99
T2	40.87	2.36	-42.71	8.86	4.63
T3	39.21	3.26	-43.75	10.37	6.75
B^0	49.46	-2.22	-38.38	4.56	-
B1	47.63	-1.52	-39.45	5.30	2.23
B2	47.94	-1.59	-38.80	5.07	1.70
B3	47.43	-1.61	-38.96	5.31	2.2

Table 7. Dry and wet rubbing colour fastness results of fabric samples.

Sample	Dry-staining	Wet-staining
CV	5	4/5
CV1	5	4/5
CV2	5	4/5
CV3	5	4/5
M	5	4/5
M1	5	4/5
M2	5	4/5
M3	5	4/5
MC	5	4
MC1	5	4/5
MC2	5	4/5
MC3	5	4/5
V	5	4
V1	5	4/5
V2	5	4/5
V3	5	4/5
T	5	4
T1	5	4/5
T2	5	4/5
T3	5	4/5
B	5	4/5
B1	5	4/5
B2	5	4/5
B3	5	4/5

except *T* samples, it is clearly seen that the pilling grade decreased by increasing the rubbing cycle, that is, the number of pills, which are masses of tangled fibres appearing on fabric surfaces, increase because of rubbing. The only reason for increasing the pilling grade of *T* fabrics after 2000 cycles is the breaking of pills away from the fabric surface.

Colour analysis

To compare the affect of the softeners on different regenerated knitted fabrics, the total colour difference (ΔE*) and the change in the colour shade of the fabrics (K/S) were analysed on a reflectance spectrophotometer. Fabrics without softener application were taken as references samples. The colour test results of reactive dyed is given in ***Table 6***. The lower ΔE* value is, the colour difference between silicone applied sample and reference sample is lower. When ΔE ≤ 1, it is assumed that there is approximately no colour difference. On the other hand, The larger the ΔE value, the greater will be the colour difference between pair of colour standard or reference fabric and sample. K/S is strength of colour shading. The higher K/S value, the stronger colour result in high dye uptake from the dye bath is obtained.

Micro silicone softener gives better result in ΔE* for *CV* fabric samples. The strongest colour result is obtained with micro silicone softener treated fabric with respect to reference fabric. *M* fabrics have lower ΔE* than *CV* fabrics and micro silicone softener gives the best result at colour difference (the lowest ΔE*) like observed in *CV* samples. The highest K/S value is obtained for macro silicone softener application. Although, the highest K/S value is obtained with micro silicone softener application among the *MC* fabrics, it is seen that ΔE* has the lowest value at semi-micro silicone softener. The lowest change in ΔE* are obtained by semi-micro and micro silicone softeners for *V* fabric samples. On the other hand, it is clearly seen that the macro silicone softener has the highest total colour difference.

Among the all regenerated cellulose fabric samples, the highest K/S value is achieved from *T* fabric and K/S increases after all silicone applications. The highest total colour difference is attained in micro silicone softener. Semi-macro silicone softener is the best application to have a little change in and K/S values for *B* fabric samples. The similar ΔE* values are provided noticeably by three of softener applications. Further, it can be observed that the softener application process affects the colour strength of dyed fabrics.

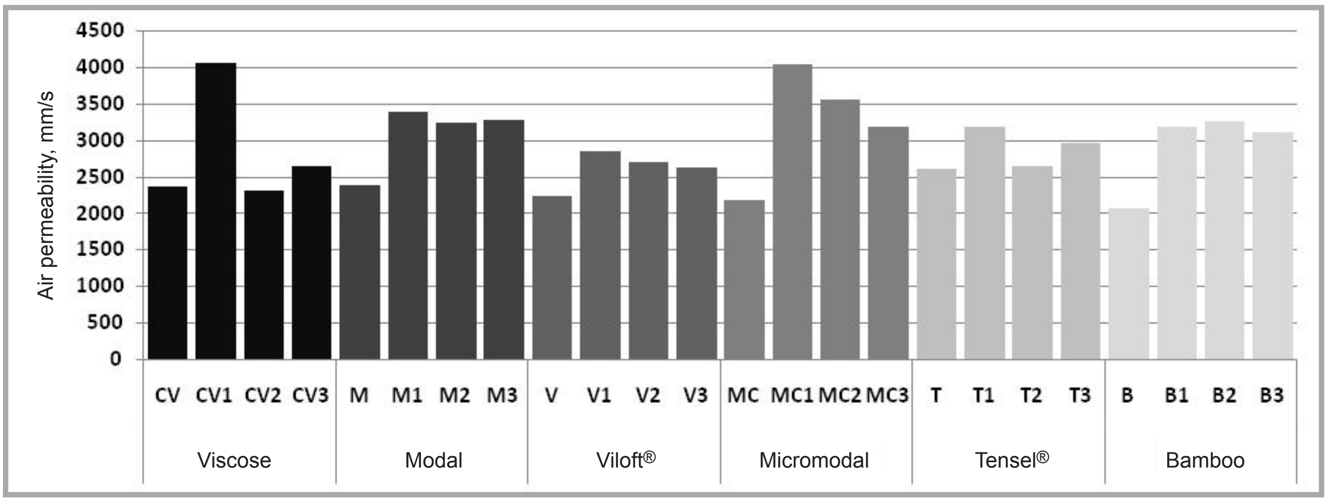

Figure 9. Air permeability values of samples.

Table 8. One-way ANOVA results for air permeability test.

Materials	F	Significance
Viscose	94.741	0.000
Modal	112.046	0.000
Viloft®	131.037	0.000
Micromodal	52.871	0.000
Tencel®	19.780	0.000
Bamboo	13.296	0.000

Colour fastness

Wet and dry rubbing colour fastness test results of the all fabric samples are presented in ***Table** 7*. All softeners have no significant affect on both dry and wet rubbing colour fastness of samples. It can be seen clearly that all the tested samples have high rubbing fastness values.

Air permeability

The air permeability of a fabric is defined as the amount of air passed over a surface under a certain pressure difference in a unit time. Air permeability of fabrics is shown in ***Figure 9***. ANOVA analysis was performed to understand statistical importance of particle size of silicone softener on air permeability property of knitted fabrics for each fibre type, separately. Statistical software package SPSS 18 was used to interpret the experimental data at significance levels of $\alpha \leq 0.05$ and $\alpha \leq 0.01$. ***Table 8*** exhibits one-way ANOVA results for air permeability for knitted fabric samples with and without silicone softeners. According to these results it can be concluded that particle size of silicone softener has a statistically significant affect on air permeability at significance level of $\alpha \leq 0.01$ for all types of fabric samples. The fabrics treated with macro-silicone softener have highest air permeability value for all regenerated cellulose fabrics except *B*.

Conclusion

Following observations can be concluded from the pilling resistance, colour analysis, rubbing colour fastness and air permeability test results.

- It can be generalized that applying the softeners have a significant effect on the pilling performance of all fabric samples. But, some different circumstance was observed in the semi-macro silicone softener applications. It can be said that semi-macro silicone softener have a little increasing affect on the pilling performance of *CV* and *M* fabrics samples. It can be stated that the pilling resistance of *T* fabrics is much better than other fibre types. So, *T* fibre can be preferred for apparel or under wear application for a better appearance.
- In general, macro-silicone softener gives the worst result for all fabric samples in terms of ΔE* except *CV* and *T* fabric. Micro and semi-macro silicones have not got a noticeable influence on the ΔE* values of *M* and *V* fabrics samples, because $\Delta E^* \leq 1$. When all the colour test results are compared, it is evaluated that the highest ΔE* value is obtained for *T*. It means that the softener applications have the highest effect in terms of ΔE* on *T* fabric samples. On the other hand, the best colour strength is obtained with *T* fabrics compared with other regenerated cellulose fabrics.
- In terms of wet and dry rubbing fastness, all softeners have no significant affect.
- It is concluded that air permeability values are significantly affected by the application of softeners with respect to different particle size.

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