Indian Journal of Fibre & Textile Research
Vol. 41, December 2016, pp. 426-431

Impact of washing and sterilization on properties of fabrics used for medical applications

B Rogina-Car, T Pušić[a] & T Dekanić

Faculty of Textile Technology, University of Zagreb, 10000 Zagreb, Croatia

Received 19 August 2014; revised received and accepted 12 May 2015

This paper reports a study on the characterization of cellulosic, polyester/cotton (PES/cotton) and Tencel® fabrics as well as PES/PU/PES laminate used for medical applications, before and after frequent washing and sterilization. The impact of washing and sterilization is analysed by tensile properties, spectral changes and surface characterization. The results indicate that, during washing and sterilization, cellulosic fabrics show prominent changes of all studied properties when compared to PES/PU/PES laminate.

Keywords: Barrier textiles, Cellulosic fabric, Medical fabric, PES/cotton fabric, Tencel fabric

1 Introduction

Sterile barrier can be defined as a material located between sterile and contaminated areas, with the purpose of preventing microorganisms to penetrate through the material. To obtain a satisfactory microbial barrier system, there are three criteria, viz enable sterilization, provide a barrier for microorganisms and maintain sterility[1,2]. Sterile material, to be used later should be stored immediately after the sterilization process, while the period of storage depends on the type of packaging, transportation, storage and handling conditions. Each sterilized material has its own lifetime, as defined by the time its sterility is maintained. Packaging protects sterilized material against contamination from microorganisms, particles and solutions after sterilization, at the same time allowing permeability of air and sterilization medium. The microbial barrier system should provide protection against the penetration of microorganisms and maintain sterility of the products. Textile materials can also be efficient barriers applied in packing of material for sterilization, surgical gowns, cover and masks. Previous testing of microbial barriers was conducted with the goal of determining whether the applied medical textiles (one layer) can provide safe protection against contamination after sterilization, regardless of the fact that they did not meet the standard EN 868-02:2009 and EN ISO 11607-1:2009. It was proved that repeatedly used cellulosic medical textiles could provide a safe microbial barrier against contamination for packaging in sterilization, coincidence the validity term of minimum 3 months, 50 washing and 50 sterilization cycles[3]. Complete research findings of permeability in microbial barrier have been published earlier[3]. Contaminated medical textiles are a potential source of microbes and contribute to the transfer of hospital pathogens by endogenous and indirect contacts[4,5].

It is known that washing causes some changes in fabric characteristics, which can also effect on barrier properties[6]. The aim of this research was to identify a degree of modification of cellulosic medical textiles, proved to be an efficient barrier system[3], after multiple washing and sterilization cycles. Therefore, in the current study the characterization of two cellulosic medical textiles and three-layer textile laminate PES/PU/PES used for packaging, surgical material in sterilization and in operation theatres have been performed employing surface characterization, change in spectral characteristics and tensile properties. Surface characterization is based on SEM micrographs and zeta potential, which provides an insight of the charge and adsorption characteristics of solid surfaces. Due to possible contamination by cotton dust and due to microbiological cleanness 100% cotton fabric was not used in the test.

2 Materials and Methods

2.1 Materials

Two cellulosic medical fabrics and a three-layer textile laminate PES/PU/PES, used for packaging of

[a]Corresponding author.
E-mail: tpusic@ttf.hr

Table 1—Properties of fabrics used

Sample code	Fabrics	Composition, %	Weave	Surface area g/m^2	Yarn count, tex		Density, threads/cm		Color
					Warp	Weft	Warp	Weft	
Sample I	PES/cotton	50/50	Linen	178.6	28.60	42.28	34	25	Green
Sample II	Tencel®	100	Bluette 2/1	193.7	22.83	31.30	50	27	White
Sample III	PES/PU/PES	Three-layer textile laminate		216.0	-	-	-	-	Green

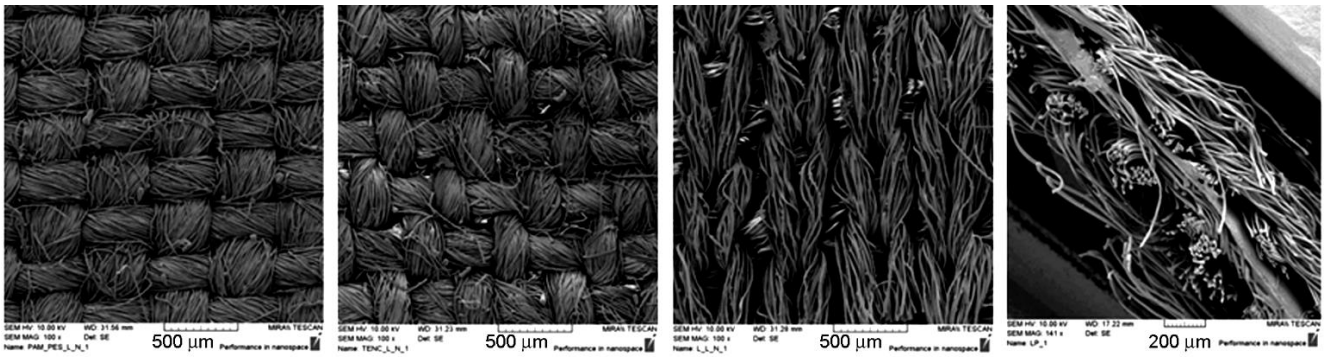

Fig. 1—Overview of fabric surface using a scanning electronic microscope Sample I - PES/cotton; Sample II - Tencel® and Sample III - three-layer textile laminate: (A) longitudinal, (B) cross-sectional view

surgical materials in sterilization and in the operation theatres, were tested. The properties of the textile materials used are shown in Table 1, and their surfaces can be seen in Fig. 1.

Barrier properties as well as their durability were tested before and after 1, 10, 20, 30 and 50 washing and sterilization cycles, under real hospital conditions at the University Hospital Centre, Zagreb. Washing and sterilization were performed in a hospital laundry under strict and controlled conditions (Table 2).

2.2 Methods

Tensile strength tester (Tensolab Mesdan S.P.A., Brescia, Italy) was used to evaluate mechanical properties through breaking strength and breaking elongation of the initial, washed and sterilized samples after 10, 20, 30, 40 and 50 cycles, according to the standard EN ISO 13934-1.

Spectral characteristics were determined by remission spectrophotometer (Datacolor Spectraflash SF 300, Swiss) under the conditions: aperture size 20 mm and standard illuminate D_{65}. The changes in coloration of PES/Cotton and laminate samples were characterized by the difference in lightness (dL*), hue (dH*), chroma (dC*) and total difference in color (dE*). Whiteness quality of Tencel® samples were evaluated by whiteness degree (W_{CIE}), tint value (TV), tint deviation (TD) and basic whiteness (Y).

Field emission scanning electron microscope (FE SEM, Mira II LMU, Tescan, Brno, Czech Republic) was used for sample analysis. The samples were coated with a conductive Ag/Pt layer and scanned under the conditions of high voltage (HV 10.00kV). Zeta potential, an experimentally-accessible parameter, was determined by streaming potential/streaming current as the most convenient for the surface characterization of textile materials. Measurements were performed by the electrokinetic analyzer (EKA) provided by Anton Paar GmbH, Austria. The zeta potential of the samples placed in the cylindrical cell was measured in the *p*H variation of 1 mmol/L KCl[7,8]. An aqueous electrolyte solution passed through the measuring cell containing the solid sample. The flow resistance of the gap created between the flat solid surfaces was adjusted to generate a pressure difference between the inlet and the outlet of the measuring cell. The electrolyte flow was generated by a dual syringe pump system and caused an electrical charge separation in the flow direction along the measuring cell. The resulting parameters were detected by measuring heads connected at the electrolyte inlet and outlet of the measuring cell. The measuring head was a combination of an Ag/AgCl or platinum electrode for measuring streaming potential, streaming current, electrical resistance, and an absolute pressure sensor. The measured values of Δp (pressure difference across the measuring cell) and ΔU (streaming potential) or ΔI (streaming current) were used to

Table 2—Washing parameters Sterilization was performed after each washing cycle at 134 °C for 5 min

Sample code*	Pre-washing solution	Washing solution	Time, min	Disinfecting agent	Neutralization	Temperature, °C	Bath ratio
I	5g/kg C[a] 1.5 g/kg C[b] 1 g/kg C[c]	2.1 g/kg C[a] 0.5 g/kg C[c]	12	6 g/kg C[d]	1.5 g/kg C[e]	70	1:5
II	3 g/kg C[a] 5g/kg C[b] 0.5 g/kg C[c]	4 g/kg C[a] 0.5 g/kg C[c]	6	6 g/kg C[f]	1.0 g/kg C[e]	85	1:3
III		4 g/kg C[c] 2.5 g/kg C[a]			0.7 g/kg C[e]	60	1:5

*Commercial names of all products are not given due to the secrecy of the participant laundry and impartiality of the research.

C[a]—Polycarboxylate (<5%), sodium hydroxide (10-20%).
C[b]—Sodium carbonate (30-50%), sodium silicate (10-20%), etoxylated fat alcohol >5EO (2-5%), phosphonate (1-2%), citric acid (0.5-1%).
C[c]—Etoxylated fat alcohol < C15 &<5EO (25-30%), solvent, 2-propanol, methanol (0.1-0.25%), amphoteric surfactants (1-2%), additives (0.1-0.25%).
C[d]—Hydrogen peroxide (20-25%), acetic acid (10-20%), peracetic acid (5-10%).
C[e]—Formic acid (50-100%).
C[f]—Hydrogen peroxide (30-50%), acetic acid (2-5%), peracetic acid (2-5%).

Table 3—Breaking strength (Fb) and elongation (ε) of the Samples I, II and III before and after different wash and sterilization cycles

Parameter	Sample I		Sample II		Sample III	
	Fb, N	ε, %	Fb, N	ε, %	Fb, N	ε, %
0 w+s	800	17.04	909	16.66	576.73	83.04
10 w+s	833	20.60	887	19.20	604.10	84.98
20 w+s	755	23.28	855	21.10	609.21	84.61
30 w+s	755	21.00	728	19.49	568.16	81.19
40 w+s	658	21.50	697	19.38	560.81	82.77
50 w+s	425	17.70	511	15.60	495.64	78.87

w+s – Washing and sterilization.

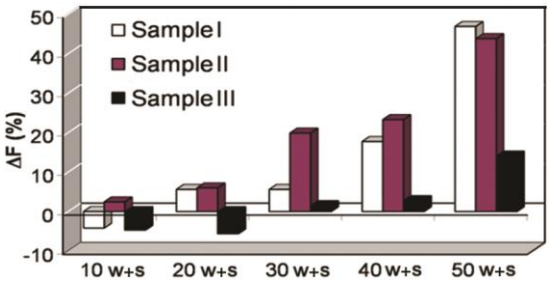

Fig. 2—Decrease in breaking strength (ΔF) of the Samples I, II and III influenced by washing and sterilization

calculate zeta potential. During the measurements, the pressure was continuously increased, and alternatively in both flow directions, Δp and ΔU or ΔI were recorded. Temperature, conductance, and *p*H measurements provided precise definitions of the electrolyte solution characteristics[9]. Zeta potential was defined according to the following equations:

$$\zeta = \frac{dI}{dp} \cdot \frac{\eta}{\varepsilon_r \cdot \varepsilon_0} \cdot \frac{L}{A} \quad \ldots (1)$$

$$\zeta = \frac{dU}{dp} \cdot \frac{\eta}{\varepsilon_r \cdot \varepsilon_0} \cdot \frac{L}{A \cdot R} \quad \ldots (2)$$

where ζ is the zeta potential (V); dU/dp ,the slope of streaming potential versus pressure (V Pa^{-1}); dI/dp, the slope of streaming current versus pressure (A Pa^{-1}); η, the electrolyte viscosity (Pa s); ε_r, the relative liquid permittivity; ε_0, the vacuum permittivity (8.854 10^{-12} F m^{-1}); L, the length of the streaming channel (m); A, the cross-section of the streaming channel (m^2) and R, the resistance inside the measuring cell (Ω).

3 Results and Discussion

Fabrics, subjected to highly aggressive chemicals, mechanical agitation superimposed by high temperature and duration during washing, are prone to damage after frequent washing. The change in tensile properties of washed and sterilized textile materials is monitored through breaking strength and decrease in breakg strength of washed and sterilized samples, as compared to the unwashed samples (Table 3 and Fig. 2).

Tensile properties of PES/cotton material have been preserved during 30 washes and sterilization (w+s) cycles. The most prominent change in breaking strength is obtained after 50 w+s cycles. It may be due to the chemical and mechanical impact on the cotton component in the blend with polyester. Cellulose based materials (natural and regenerated) tend to fibrillate under the action of mechanical stress. It is well known that PES exhibits no proneness to fibrillation. Minor changes in tensile properties of Tencel® are evident after 20 washing and sterilization cycles. Fibrillation of Tencel® is assumed to be due to high orientation of the amorphous regions[10], which affects progressive decrease in breaking strength of Tencel® after 30 w+s cycles. The Sample III is found resistant to chemical and mechanical actions. Decrease in breaking strength of the laminate after 50 w+s is found beyond 15%. This indicates optimal mechanical agitation in washings of the laminate PES/PU/PES. Tensile properties are harmonized with the results of testing, microbial barrier permeability of medical fabrics after extreme contamination with bacterial spores (*G. stearothermophilus* and *B. atrophaeus*). Tencel® provides better microbe barrier than PES/cotton, while the three-layered textile laminate provides full protection against the penetration of microorganisms, that is, an efficient microbial barrier, as not a single bacterial colony was able to penetrate. This is expected, as it meets all the standards mentioned above[3].

The change in the colour of PES/cotton material is characterized by grade scale (ISO A05) and total colour difference (dE), containing the differences of w+s materials in lightness (dL*), chromaticity (dC*), and hue (dH*) as compared to unwashed PES/cotton material (Table 4).

PES/cotton material exhibits color fastness during 20 cycles of washing and sterilization (Table 5). After 20 cycles, the change in color is found gradual. Hence, finally 50 w+s cycles result in the grade 1-2. The change in coloration of the cotton component is affected by the presence of optical brightener in the detergent. PES coloration in the blend is found to be more sensitive to sterilization conditions at 134 °C.

Laminate structure of PES/PU/PES was washed with a color detergent with no bleach active component and a mild change in color is observed through 20 w+s cycles. Further, washing and sterilization cycles show an impact on cumulative effect of detergent components regarding color appearance, with the final grading of 3. Washing and sterilization also show an impact on whiteness quality of Tencel® fabric characterized by whiteness degree tint value and tint deviation Table 6.

Initial whiteness degree of Tencel® fabric indicates the presence of optical brightener (WCIE = 134.80). Washing and sterilization causes continuous decrease in whiteness quality. Reduction in whiteness degree (WCIE) measured with UV stimulation is affected by washing with detergent without optical brightener. The main purpose of fluorescent additives in detergent is to keep or enhance high whiteness degree of the material.

Basic whiteness (Y) measured without UV stimulation is also lowered by repetition of washing cycles. This indicates an impact of temperature (85ºC) in main wash that is higher than recommended for Tencel® materials.

Surface changes can be characterised in a number of ways, one of them is by measuring surface charge, characterized by zeta potential. Distribution and the amount of functional groups in polymers are of particular importance, since they determine fibres structure and behaviour, as well as the changes that occur in various processes. The data on the distribution and amount of functional groups in fibre polymers are of particular importance, since they determine the fibre structure and behaviour, as well as the changes occurred

Table 4—Change in color of Sample I (PES/cotton) influenced by washing and sterilization

Sample I	dL*	dC*	dH*	dE	ISO A05
10 w+s	0.079	0.165	0.881	0.963	4-5
20 w+s	2.052	-3.867	1.584	4.658	3
30 w+s	3.504	-5.578	2.299	6.904	2-3
40 w+s	4.116	-7.078	2.829	8.664	2
50 w+s	4.849	-8.265	3.259	10.122	1-2

Table 5—Change in color of the Sample III influenced by washing and sterilization

Sample III	dL*	dC*	dH*	dE*	ISO A05
10 w/s	-0.114	0.031	0.397	0.449	5
20 w/s	-0.085	-0.620	1.341	1.482	4-5
30 w/s	0.264	-2.199	3.547	4.183	3
40 w/s	-0.082	-2.059	2.482	3.232	3-4
50 w/s	0.242	-3.023	3.841	4.905	3

Table 6—Change in whiteness of Sample II influenced by washing and sterilization

Sample II	W_{CIE}	TV	TD	Y
0 w+s	134.80	0.10	-	86.60
10 w+s	131.10	-0.10	-	86.40
20 w+s	124.10	-0.80	R1	86.20
30 w+s	112.30	-1.80	R2	81.30
40 w+s	115.40	-1.20	R1	81.90
50 w+s	109.70	-0.90	R1	80.50

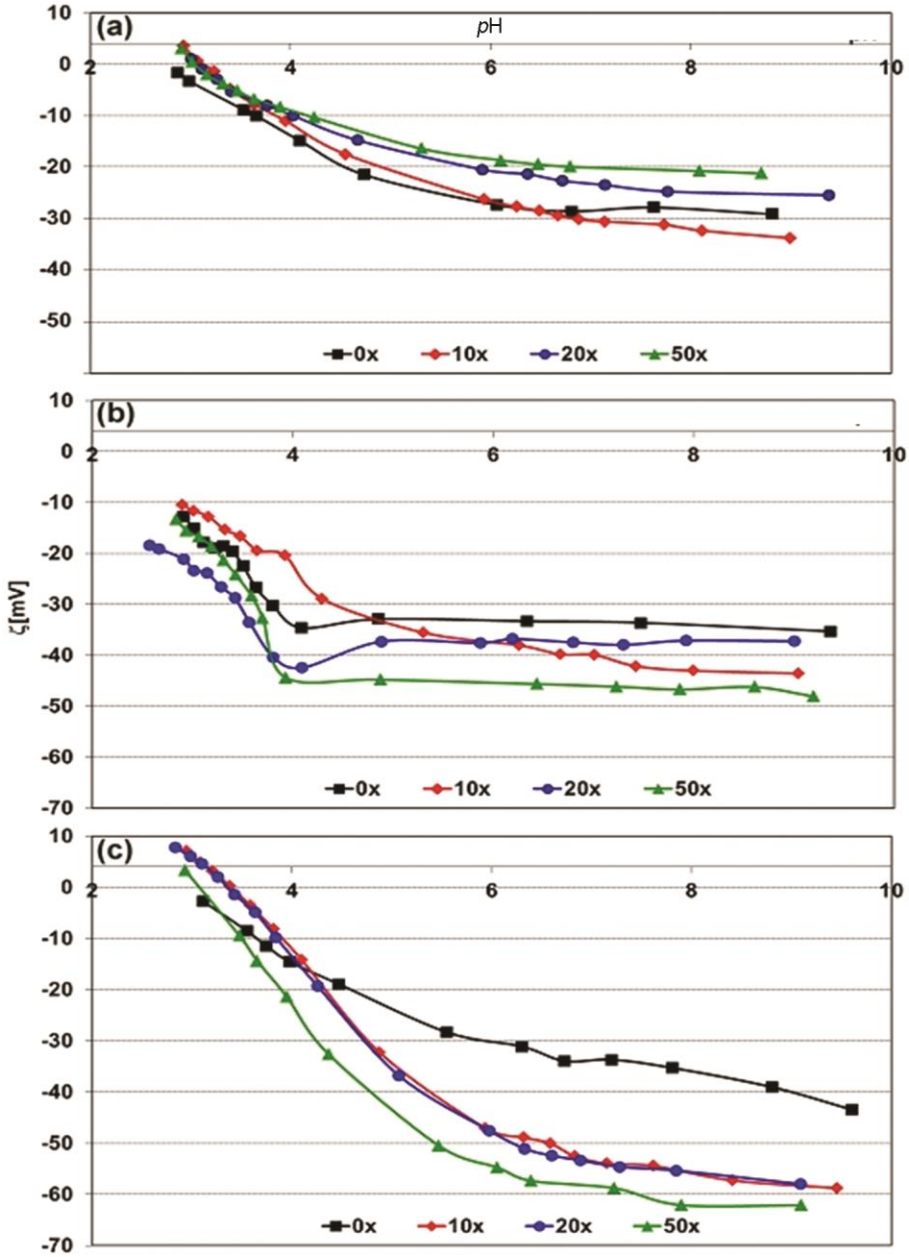

Fig. 3—Zeta potential of (a) PES/cotton, (b) Tencel®, and (c) PES/PU/PES laminate fabrics before and after 10, 20 and 50 washing and sterilization cycles under varied *p*H

in washing process. The intensity of fabric surface changes in washing depends upon a number of parameters. Sensitivity of fabrics is due to their high swelling capacity in alkali and the effect of bleaching agents, which is further increased by mechanical agitation in washing. The electrokinetic properties of the PES/cotton, Tencel® and laminate before and after 10, 20 and 50 w+s process are characterized in this investigation by zeta potential measured in the variation of *p*H (0.001 mol/L KCl) of the electrolyte solution (Fig. 3).

Zeta potential of PES/cotton fabric before washing is specified by characteristic ZP curve under varied *p*H. Washing and sterilization performed through 50 cycles cause surface changes in the PES/cotton fabric [(Fig. 3 (a)]. The reduction of negative zeta potential is affected by fibrillation of cellulosic component in the blend with PES.

Zeta potential depends upon construction properties and the degree of hydrophilicity. Fibres characterised by high hydrophilicity exhibit lower surface charge than

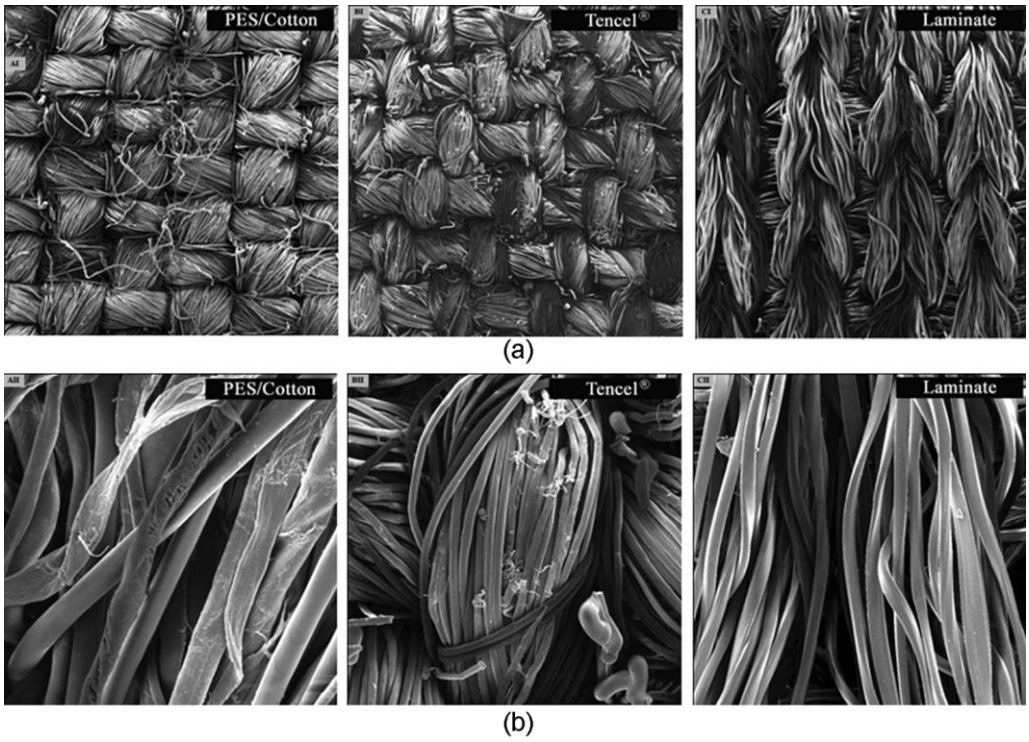

Fig. 4—SEM images of samples after 50 washing and sterilization process: (a) magnification ×100 and (b) magnification ×500

hydrophobic ones. Figure 3(b) shows that multiple washing and sterilization have an impact on the increase in negative zeta potential of Tencel®. This increase in negative zeta potential might indicate increased hydrophobicity on the surface, due to the build-up of negative ions on the surface. This correlates with the tendency of Tencel® fabrics to greying, noticed after 30 washing and sterilization cycles.

Laminate PES/PU/PES exhibits specific ZP curve for synthetic material and hydrophobic surface of lower magnitude [(Fig. 3(c)]. It indicates the presence of special finish on the surface of the laminate face side. Multiple washing and sterilization cycles has an impact on the increase in negative zeta potential due to the poor polymer durability. After washing and sterilization, the surface of PES/PU/PES becomes more hydrophobic.

The morphology of fabrics after washing can be analysed by microscopic methods. Micrographs, under two magnifications (×100 and ×500) of the tested fabrics after 50 washings and sterilization cycles can be seen in Fig.4.

The micrographs of the tested fabrics before washing indicate an integrated structure, and recognisable appearance (Fig. 1). SEM micrographs prove the fibrillation of cellulosic component in the blend PES/cotton, as well as the tendency to fibrillation of Tencel® after 50 w+s cycles (Fig. 4). Morphology of laminate after multiple w+s cycles proves that PES/PU/PES endure minor changes.

4 Conclusion

It is observed that washing and sterilization performed through 50 cycles have an impact on tensile, spectral and surface characteristics. Optical properties of Tencel® are found to be deteriorated due to unadapted washing conditions. Cellulosic fabrics show most prominent changes in all the relevant properties, when compared to laminate.

References

1 Enko M T, *Sterile Supply Packaging* (WFHSS-ÖGSV Basic Script), 2009.
2 Bojic-Turcic V, *Sterilizacija i dezinfekcija u medicini* (Medicinska naklada and Medicom, Zagreb) 1994.
3 Rogina-Car B, Budimir A, Turčić V & Katović D, *Cellulose*, 21 (2014) 2101.
4 Borkow G & Gabbay J, *Med Hypotheses*, 70 (2008) 990.
5 Fijan S & Šoštar-Turk S, *Int J Environ Res Public Health,* 9 (2012) 3330.
6 Leonas K K, *Am J Infect Control*, 26 (1998) 495.
7 Jacobasch H-J, Bauböck G & Schurz J, *Colloid Polym Sci*, 263 (1985) 3.
8 Grancarić A M, Tarbuk A & Pušić T, *Coloration Technol*, 121 (2005) 221.
9 Luxbacher T, Bukšek H, Petrinić I & Pušić T, *Tekstil*, 58 (2009) 393.
10 Chaudemanche C & Navard P, *Cellulose*, 18 (2011) 1.