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The Structure Characteristics and Air Permeability of PA and PES Plain and Plated Knits Influenced of Antimicrobial Treatment Conditions

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Textile materials are usually exposed to thermal, physical and mechanical effects during treatment processes. These influence the changes of material dimensions. Designing knitted products it is important to predict direction and rate of dimensions change, because this can affect physical properties such as air permeability of knits.

The objective of this research was to investigate the influence of antimicrobial treatment conditions on the structure characteristics, thickness and air permeability of plain and plaited knits. The investigations were carried out with two groups of plain and plated single jersey knits. The face yarns of these groups were cotton, bamboo viscose yarn and polyester (Dacron®) thread. 10 tex × 2 textured polyamide (PA) and 20 tex textured polyester (PES) threads were used as the base threads in plated knits. Knitted samples were treated with antimicrobial material Isys AG and organic-inorganic binder Isys MTX (CHT, Germany).

It was established that blank and antimicrobial treated knits changed structure parameters, thickness and air permeability. The changes of structure parameters, thickness and air permeability were more associated with conditions of treatment (temperature, treatment in solution, mechanical action) rather than with antimicrobial and sol-gel substances used in treatment.

Keywords: air permeability, antimicrobial treatment, plain and plated knit, knitted structure, thickness.

1. INTRODUCTION

The clothing and textiles are an integral part of our lives. We can't imagine a single day without it. However, clothing and textile materials carry microorganisms such as pathogenic bacteria, odour generating bacteria and mould fungi, which also provide a good space for the growth of the microorganisms [1]. Microorganism growth on textiles can result in a loss of functional properties, an unpleasant odour, unsightly patches, and even posing a potential risk for users [2]. To prevent growth of microorganisms and to prevent the impact microorganisms of fabrics and their users, many manufacturers apply antimicrobial finishing. Antimicrobial finish is significant not only in medicine clothing, but also in home, technical wear, sports and leisure clothing [3].

The most important antimicrobial substances used in textile finishing are organic (biguanide, izotiazoline, ammonium compounds with organosilicone etc.), inorganic (metal ions (Cu, Ag, Zn), zeolites, ceramic substrates with metal ions etc.) chemicals and chemicals of natural origin (chitosan, polysaccharides from clam, sea, some dumb, plant extracts, etc.). Silver nano particles (AgNPs), silver nitrate ($AgNO_3$), silver chloride AgCl compounds are the best known and most commonly used inorganic antimicrobial finishes agents/materials [4]. Unfortunately, many of these agents have possible harmful or toxic effect. Silver, on the other hand, is a relatively non-toxic disinfectant that can significantly reduce many strains of bacteria and fungi [2]. However, silver ions must be sufficiently anchored on the textiles in order to provide durability of antimicrobial properties [5].

The antimicrobial agents can be applied to the textile substrates by exhaust, pad-dry-cure, coating, spray and foam techniques [6]. A well-known technique for textile modification is the sol-gel method. The sol-gel process allows the production of inorganic polymer coatings with embedded inorganic (e. g. Ag, Cu) or organic biocides [7]. Sol-gel technology can enable coating of textiles with almost unlimited functionality by incorporating functional agents into the sol-gel nanoparticles [8]. The organic-inorganic binder used together with metal ions nanoparticles forms a sol-gel layer on the fiber. In the literature [9] it is reported that non the metallic silver itself acts antimicrobial but a release of silver ions from surface of silver particles can be responsible for the antimicrobial effect of elementary silver particles embedded in sol-gel coatings.

Many scientists researched the antimicrobial [7, 10–12], physical [7, 12, 13] and mechanical [7, 14] properties of the textile materials treated with variety of antimicrobial treatments. There were not found papers, which would present the influence of antimicrobial treatment on the structure of plain and plated knits. However, it was found a few articles, which were investigating an air permeability of knits after different antimicrobial agents. Mustafa E. Ureyen et. al. investigated that antimicrobial finishing with silver-doped calcium phosphate powders had influence on the air permeability of cotton (100 %) and polyester (100 %) knits. It was found that after antimicrobial treatment the air permeability of cotton and polyester fabrics decreased compared with that the untreated fabrics [15]. R. Bagherzadeh and other, investigated the effect of antimicrobial finishing on the comfort properties of 3D knitted polyester fabrics and found that there is not significant differences between the air permeability of untreated and treated fabrics [16]. Air

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permeability allows to transport moisture from the skin to the outside atmosphere [10] and this ensures better hygiene properties of human.

Therefore the aim of research work was to investigate the influence of antimicrobial treatment conditions on the structure characteristics, thickness and air permeability of plain and plated knits.

2. EXPERIMENTAL DETAILS

Materials. The investigations were carried out with two groups of plain and plated single jersey knits. The knits were knitted on the 14 E weft knitting machine D3VC (f. Unilplet, Germany). The samples were grouped: I group – the basic yarn was 10 tex × 2 textured polyamide (PA) thread and the face yarns were cotton 29.4 tex (C1); 14.8 tex × 2 (C2); 25 tex (C3), bamboo viscose yarn 29.4 tex (B1); 14.8 tex × 2 (B2), 25 tex PES (Dacron®) (P3) thread. II group – the basic yarn was 20 tex textured polyester (PES) thread and the face yarns were the same as in the I group. The samples of I and II groups before treatment were named as knitted. The indications of initial knitted samples are presented in Table 1.

Methods. A part of every group knits was treated in an antimicrobial solution of iSys AG (CHT, Germany) and organic-inorganic binder iSys MTX (CHT, Germany). The main conditions of antimicrobial treatment were: aqueous solution of 25 °C, 2 g/l iSys AG and 10 g/l of iSys MTX, pH 5.5, 10 min. All samples were centrifuged for 12 min at 1200 rpm and tumble dried for 50 min at 120 °C, permanently treated for 1 min at 160 °C. The finishing conditions were performed according to the producer recommendations. The samples treated according these conditions were named as antimicrobial treated.

A part of initial samples were treated at the same conditions as the ones treated with antimicrobial solution, however, antimicrobial material and binder were not used (distilled water was used instead of antimicrobial material). Samples treated according these conditions were named as blank treated.

Knitted, blank and antimicrobial treated samples were relaxed in a flat state for three days at 20 °C ±2 °C temperature and 65 % ±2 % relative humidity conditions.

The wale (P_h) and course (P_v) densities of knitted samples were measured (according to standard EN 14971:2006 [17]) in longitudinal and transverse direction in 10 cm distance and evaluated per cm.

The following parameters of knitted structures were calculated according to standard [17]: wale spacing (A, mm) of knitted (A_k), blank (A_b) and antimicrobial treated (A_a) knits; course spacing (B, mm) of knitted (B_k), blank (B_b) and antimicrobial treated (B_a) knits; stitch length (l, mm), area density (M, g/m^2) and tightness factor (TF, %) of knitted, blank and antimicrobial treated knits.

The major properties of knits depend on a stitch length and yarn linear density [18]. The tightness of knitted samples is characterized by the tightness factor (TF). It is known that TF is expressed as a ratio of the area covered by the yarns in one stitch to the area occupied by that stitch. Thereby it is an indication of the relative looseness or tightness of the plain knitted weft structure [19]. For determination of TF the formula was used:

$$TF = \frac{\sqrt{T}}{l}, \quad (1)$$

where: T is the linear density of the yarn (tex); l is the stitch length, (mm).

The thickness of samples was measured with an automatic micrometer Louis Schopper Leipzig Automatic Micrometer (f. Germany) according to European Standard EN ISO 5084:1996 [20].

Air permeability of samples investigated according to EN ISO 9237:1997. The air permeability was measured using an L14DR air permeability tester "Karl Schroder KG" (Germany) with a head area of 5 cm^2. The airflow rate determines the air permeability of test specimens, hence after test, the values of air permeability were calculated using equation [21]:

$$R = \frac{q_v}{A} \cdot 167, \quad (2)$$

where: R is the air permeability in mm/s; q_v is the mean of airflow yield in dm^3/min; A is the sampling area in cm^2; 167 – is coefficient to convert from dm^3/cm^2 × min or l/cm^2 × min to mm/s.

The relative error of all measurements did not exceed 3 %.

3. RESULTS AND DISCUSSION

Usually the composition of the fiber, linear density of the yarn and treatment conditions influence the wale and course spacing, stitch length, area density and etc. There were no articles found analysing the impact of antimicrobial

Table 1. The initial plain and plated knitted samples

Group	Indication of the knitted sample		Fiber composition, %	Nominal linear density, tex
I	C1PA	Cotton 29.4 tex + Polyamide 10 tex × 2	60 / 40	49.4
	C2PA	Cotton 14.8 tex × 2 + Polyamide 10 tex × 2	60 / 40	49.6
	C3PA	Cotton 25 tex + Polyamide 10 tex × 2	56 / 44	45.0
	B1PA	Bamboo 29.4 tex + Polyamide 10 tex × 2	60 / 40	49.4
	B2PA	Bamboo 14.8 tex × 2 + Polyamide 10 tex × 2	60 / 40	49.6
	P3PA	Polyester 25 tex + Polyamide 10 tex × 2	56 / 44	45.0
II	C1PES	Cotton 29.4 tex + Polyester 20 tex	60 / 40	49.4
	C2PES	Cotton 14.8 tex × 2 + Polyester 20 tex	60 / 40	49.6
	C3PES	Cotton 25 tex + Polyester 20 tex	56 / 44	45.0
	B1PES	Bamboo 29.4 tex + Polyester 20 tex	60 / 40	49.4
	B2PES	Bamboo 14.8 tex × 2 + Polyester 20 tex	60 / 40	49.6
	P3PES	Polyester 25 tex + Polyester 20 tex	100	45.0

treatment conditions on the structure of knits. This fact determines investigations on structure parameters of antimicrobial treated where the sol-gel layer was formed on the fiber of plain and plated knits. The structure parameters of investigated knits are presented in Table 2.

The results show that conditions of the blank and antimicrobial treatment had an effect on the wale and course spacing of knits. The wale spacing of knits was varying. The A_b and A_a of *C1PA*, *B1PA* and *B1PES* were higher than of the same knitted A_k samples. A_b and A_a of *P3PA* and *B2PA* remained unchanged while of another knits mentioned characteristics decreased.

The changes of wale spacing of blank and antimicrobial treated knits are almost the same in their sizes. The differences of A_b and A_a changes of I group knits vary from 0 % up to 0.8 %, of II group they vary from 0 % to up 1.8 %. The course spacing after both treatments decreased in all tested knits. The differences of course spacing changes of I group knits vary up to 1 %, of II group knits vary up to 3 %.

The data presented in Table 2 show that after both treatments the area density M_b and M_a of knits increased compared with to knitted knits M_k. It was estimated that antimicrobial treated knits (except *B1PES*, *P3PES*) had higher area density compared with the same blank treated knits. The differences of area density changes after antimicrobial treatment of I group knits were higher up to 2 %, of II group knits (except *B1PES*, *P3PES*) were higher up to 4 % comparing with that blank treated.

The stitch length is another important characteristic of knit structure. According to the literature [18, 22] stitch length is the main element of knit structure, which depends directly on the fiber composition, the number of yarns per stitch, linear density and knitting structure.

The data of stitch length of knitted, blank and antimicrobial treated knits are presented in Figure 1.

The comparative analysis of stitch length results showed that stitch length of all treated knits was smaller compared to that knitted. The both treatments influenced the stitch length of all knits almost in the same size. The differences of stitch length changes of I group antimicrobial treated knits were higher up to 0.5 %, of II group knits were higher up to 2 % compared with that blank treated knits. The changes of stitch length were influenced more by the fiber composition of the knits, treatment conditions like sol-gel components. The results show and the literature [18] says that the changes of stitch length express the shrinkage of knitted fabric. One of the reasons for the shrinkage is loss of elastic deformation then knitted fabric is exposed to heat and moisture during treatment. On the other hand, there may be a fibre volume alteration in transverse direction due to treatment conditions. Stitch length changes may also be influenced by the yarn twist, rigidity and surface smoothness [23].

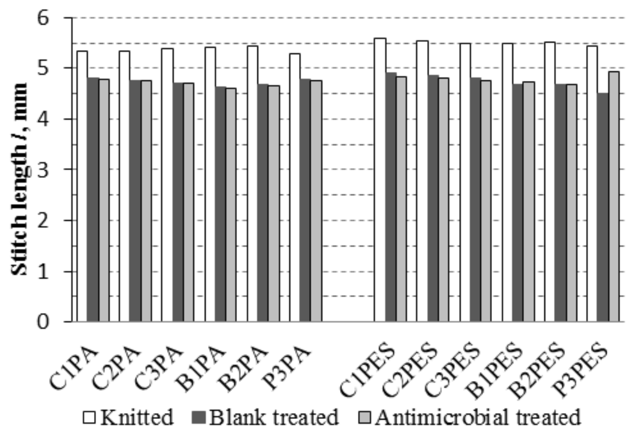

Fig. 1. The influence of treatment on the stitch length of knit

The data of tightness factor of knitted, blank and antimicrobial treated knits are presented in Figure 2.

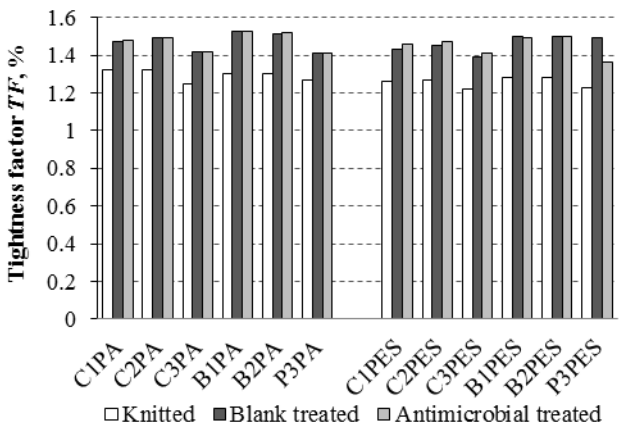

Fig. 2. The influence of treatment on the tightness factor of knit

Table 2. The structure characteristics of knitted, blank and antimicrobial treated knits

Group	Variant of knit	Wale spacing *A*, mm			Course spacing *B*, mm			Area density *M*, g/m^2		
		A_k	A_b	A_a	B_k	B_b	B_a	M_k	M_b	M_a
I	C1PA	1.19	1.20	1.20	1.30	1.02	1.01	169	196	198
	C2PA	1.25	1.20	1.19	1.25	1.00	1.00	171	201	202
	C3PA	1.17	1.16	1.16	1.35	1.02	1.02	153	179	180
	B1PA	1.14	1.16	1.16	1.36	0.95	0.94	174	210	211
	B2PA	1.20	1.17	1.16	1.33	0.96	0.96	170	208	209
	P3PA	1.20	1.20	1.20	1.28	1.02	1.01	154	175	177
II	C1PES	1.26	1.23	1.22	1.38	1.05	1.02	161	191	195
	C2PES	1.24	1.23	1.21	1.36	1.02	1.01	164	195	196
	C3PES	1.21	1.18	1.19	1.37	1.06	1.02	149	172	177
	B1PES	1.12	1.18	1.16	1.40	0.96	1.00	174	207	205
	B2PES	1.18	1.18	1.18	1.38	0.96	0.96	169	206	207
	P3PES	1.27	0.98	1.21	1.30	1.06	1.09	148	195	168

The results showed that knits after both treatments had higher tightness factor. The *TF* values of knitted samples ranged from 1.22 % to 1.32 % while of blank and antimicrobial treated they were from 1.36 % up to 1.53 %. This means that the treatments influenced the area filling and density comparing with knitted samples. The differences of tightness factor between blank and antimicrobial treated knits were insignificant. The tightness factor of antimicrobial treated knits *C1PA*, *B2PA*, *C1PES*, *C2PES*, *B1PES* was higher up to 0.03 % compared to the blank treated knits. While *TF* differences between antimicrobial and blank treated *C2PA*, *C3PA*, *B1PA*, *P3PA* and *B2PES* knits were not noted.

The fiber composition of the knits, linear density of yarns/threads, knit pattern, filling and treatment have influence on thickness of knits [18].

To determine the influence of antimicrobial treatment on the thickness of knitted samples, the comparative analysis was performed of untreated (knitted) and treated plain and plated knits. The data presented in Figure 3 show the influence of treatment conditions on the thickness of plain and plated with PA and PES threads knits.

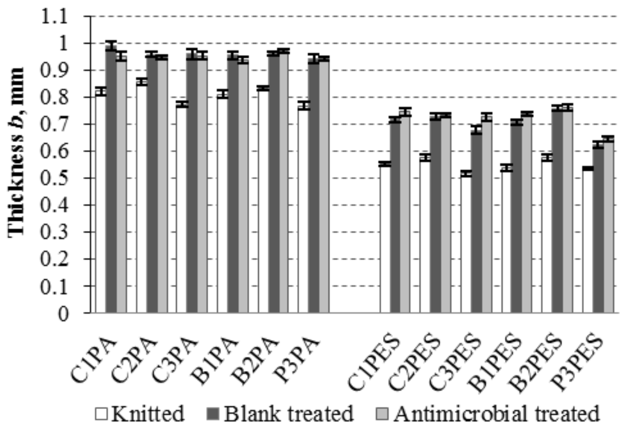

Fig. 3. The influence of treatment on the thickness of knit

The results showed that the values of thickness of *C2PA*, *B2PA*, *C2PES* and *B2PES* knitted (untreated) knits were higher than of other knits of appropriate group. This may be associated with the higher nominal linear density and the number of yarns in the stitch (Table 1). The knits after blank and antimicrobial treatment became thicker comparing with that untreated (Fig. 3). The finishing processes remove the emergent internal stresses from the knits, which occur during knitting process. Then the knits acquire a fixed equilibrium state and they become more stable, thicker and heavier [24]. The higher thickness increase was stated for knits of the II group and the values of thickness changes varied from 21 % up to 41 %, while of I group knits they were from 11 % up to 23 %. The higher thickness changes of knits plated with PES were influenced of the very base thread, which was the textured polyester thread. The polyester fiber is more shrinkable, compared with polyamide fiber [25].

Analysis of thickness of PA plated knits after blank and antimicrobial treatments shows that slightly higher thicknesses were of blank treated knits (except *B2PA*, *P3PA* knits). It was noticed that the values of thickness changes of both treatments differed only in few percent (of cotton knits ~5 %; bamboo knits ~2 %; while of *P3PA* after both treatments they were very similar). The PES plated and antimicrobial treated knits had higher values of thickness than that blank treated. The results obtained in contrast to PA plated knits. The differences of thickness changes of II group blank and antimicrobial treated knits were: of cotton knits ~10 %, bamboo knits ~6 %; *P3PES* knit ~4 %. It can be concluded that both treatments have almost the same influence on the change of thickness.

There are several factors, which influence the air permeability, among which are type of fabric, construction, bulk density, thickness, air porosity in the yarn, etc. [26].

Investigation of air permeability of plain and plated knits showed that knitted samples after blank and antimicrobial treatments have significantly lower air permeability comparing with that untreated (Fig. 4). The untreated knits were more air permeable for their higher porosity and looser structure comparing with that treated.

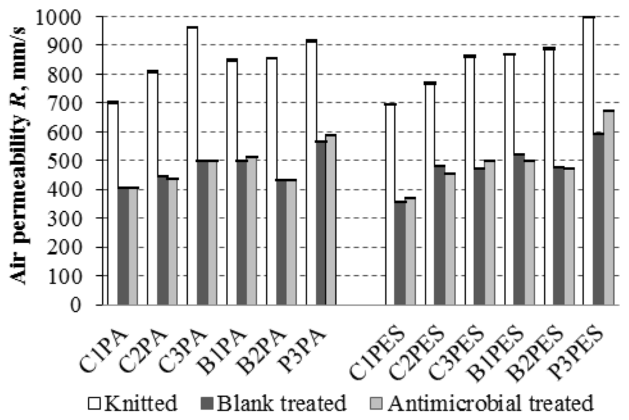

Fig. 4. The influence of treatment on the air permeability of knit

The range of air permeability difference of untreated and treated knits was significant. The untreated knits of both groups were more air permeable (of I group knits (701 – 961) mm/s, II group knits (694 – 999) mm/s), whereas blank and antimicrobial treated knits showed rather lesser air permeability. The highest changes of air permeability due to blank and antimicrobial treatments were determined for *C2PA*, *B2PA* and *B2PES* knits, where the air permeability decreased from 42 % up to 49 %. The smallest changes of air permeability were of *P3PA* and *P3PES* knits. This result may be attributed to the behavior of spun polyester yarn (*P3*), which was used as a face yarn in the knit. The polyester fibers resist moisture and certain temperature influence during treatment processes [27]. The differences of air permeability changes comparing blank and antimicrobialy treated knits of I group were up to 2 % and of II group knits were from 1 % to 3 % (except *P3PES* knit, where differences of changes amounted to 8 %). The air permeability changes of investigated knits depended on fiber composition, linear density and structure of yarns, finishing conditions.

Mustafa E. Ureyen and others established influence of antimicrobial finishing with agent based on silver-doped calcium phosphate powders of cotton and polyester knitted fabrics. They found that air permeability of antimicrobial treated knits was decreased by 19.50 % for the cotton and 8.50 % for the PES fabrics comparing with untreated knits. The results were attributed to the deposition of the polymer binder and polymer network formation on the yarns surfaces [15].

4. CONCLUSIONS

In this research it was estimated that treatment conditions impacted changes of knits structure, thickness and air permeability, however the differences of these changes were insignificant between the blank and antimicrobial treated knits. The changes of knits structure characteristics, thickness and air permeability during antimicrobial treatment were more related to treatment conditions (temperature, treatment in solution, mechanical action) then with sol-gel formation on the fiber surface.

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