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Experimental analysis of cotton-based textile surface modification influence on wear comfort

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Abstract Surface modification of the cotton textiles by sol-gel method in order to give antimicrobial, water and dirt repellent properties is widely discussed in the scientific literature. This study focuses on multifunctional surface nano-coatings of mixed cotton/polyamide and pure cotton knitwear, particularly on impact estimation of surface modification onto day-to-day wear comfort properties, such as air permeability, thermal and water vapour resistance, as well wearer perceptions and sensory evaluation of comfort. Experimental samples were treated with silica sol modified with the zinc acetate dihydrate and subjected to various final processing regimes, specifically optimized for mixed yarn knitwear. The effectiveness of the added attributes on modified textile surface is evaluated by testing water-repellent ability. Air and vapour permeability determination, as well as "in vivo" testing in experimental wearing process were carried out in order to evaluate wear comfort.

***Keywords*—cotton blends, sol-gel, textile surface functionalization, wear comfort evaluation.**

I. Introduction

This study is a part of continuing research aiming to adapt the previously developed sol-gel method to knitwear worn as a base layer or the first to the body cloth layer, therefore wear comfort is a matter of concern. The wearer comfort is influenced by textiles properties such as air, thermal and water vapour permeability, and exchange between human body and external environment [5]. Textile surface modification with sol-gel method must ensure that these comfort properties are not affected negatively. Sol-gel method can impart and secure more than one additional functional property for textile surface in one step processing while using low concentrations of the active chemicals, making it potentially favourable comparing to conventional textile finishing methods [6,7]. Two different types of sol-gel system can provide antimicrobial environment. One is photoactive titania nanosol coatings, and the other is sol synthesis with embedded metal compounds, like silver, copper, and zinc [7].

Both knitwear products used in this study can be greatly improved with sol-gel method, thus giving antimicrobial properties, increasing time between washing, wear durability, and dirt repellent properties. The high UV protection ability and antimicrobial activity of functionalized cotton fabric samples, as well improved wear resistance attained by the used sol-gel process is discussed in previous publications [1-4].

II. Materials and Methods

2.1 Experimental procedures and materials

Silica sol with TEOS precursor modified with the 5 wt% and 7.5 wt% zinc acetate dihydrate (ZAD) [1] was used to modify 45 organic cotton (81%) and polyamide (19%) blend yarn weft knitted socks and 85 pure cotton jersey and double jersey knitwear (T-shirts). Modification was carried out on white samples in order to observe any visual changes on surface that might indicate fibre destruction. Single and double jersey structure characteristics and observed changes after modification were discussed in previous publication [4]. The average vertical and horizontal density (determined in compliance with the corresponding EU standards) of used cotton/polyamide yarn sock samples before modification is 100 loops per 1cm^2. Modified and unmodified sock sample and jersey sample legends and treatment descriptions are listed in Table 1.

Sol was synthesized according to following method developed in previous research [1-4]. In the solution of tetraethyl orthosilicate (TEOS, $C_8H_20_4Si$) and ethanol, distilled water is added to provide alkoxide condensation

TABLE I
SAMPLE LEGENDS AND DESCRIPTIONS

Legend of sample	Treatment description
K	Control sample, socks;
100/8	Dipping time: 10 min, consolidation T: 100ºC, time: 8 min;
120/8	Dipping time: 10 min, consolidation T: 120ºC, time: 8 min;
W100/8	Dipping time: 10 min, consolidation T: 100ºC, time: 8 min, washed after modification;
W120/8	Dipping time: 10 min, consolidation T: 120ºC, time: 8 min, washed after modification;
120/5	Dipping time: 10 min, consolidation T: 120ºC, time: 5 min;
W120/5	Dipping time: 10 min, consolidation T: 120ºC, time: 5 min, washed after modification;
Single and double jersey samples	Dipping time: 15min, consolidation T:120 °C, time 5 min.

and hydrolysis. Hydrofluoric acid (HF) is added as catalyst. Solution is stirred for 30 minutes, and zinc acetate dihydrate ($Zn(CH_3COO)_2 \cdot 2H_2O$) is added, carefully monitoring the temperature of solution (temperature should not exceed 50 º C). In the first pilot experiment after sample dipping in, a large amount of excess sol solution was observed. In order to minimize usage of chemicals and components, experiment solution and textile sample weight ratio was changed from 1:10 to 1:8.

To ensure steady removal of excess fluid, the samples were pressed using a calender. In the final processing of cotton/polyamide samples, various consolidation regimes were tested in order to optimize the initial consolidation regime previously used only for pure cotton textile.

Sample washing was carried out in Electrolux-W 465H equipment according to EN ISO 105C10-A01: 2006 standard, using soap without brightening agents in defined concentration 5 mg/per l litre to water. Same hydrothermal treatment (t30º C, 20 min, and 700 min) with following drying at room temperature 22 +/- 2º C and relative air humidity 60% was used (before and after modification) for both - sock samples and cotton jersey T-shirts. For comparison 8 sock samples were pre-treated with acetone solution (50% acetone, 50% distilled water, dipping time 5 minutes, rinsed in distilled water) in order to remove any industrial oils and dirt.

2.2. Test methods and equipment

Surface wettability of socks and T-shirts is examined by water contact angle measurements using optic tensiometer Theta Attention (Finland). SDL Atlas Air Permeability tester (Canada) was used for surface permeability evaluation. Sock samples were tested at pressure of 30 Pa; the measurements were taken in sock top and foot. For water vapour and thermal permeability evaluation Permetest Skin sensora (Czech Republic) tester was used.

Wear comfort properties of modified and unmodified T-shirts were evaluated by volunteers participating in experimental testing (day- to-day wearing). All observations where documented in wearing protocols. Questionnaires consisted of brief annotation which includes: modified t-shirt description, brief explanation of this study and testing length and contact information. Wearing protocol form consist of 10 general information questions about respondent, a table, where wearing hours, dates, washing frequency and physical load assessment is noted, and 7 questions about observations and general conclusions.

All obtained data were statistically arranged and analysed. Data from air, thermal, water vapour permeability and surface water contact angle testing were inserted in first level - full factor experiment plan 2^{-3}, to observe interaction between consolidation time, temperature, and ZAD concentration.

III. RESULTS AND DISCUSSION

Selected sock control samples before modification show high air permeability - average 24,33 +/- 2 mm/s in sock stallion and 24 +/- 2 mm/s in foot. Water-vapour resistance for control sample is 6,60 Pa.m^2 W^{-1}. As the average knitwear density after modification decreased from 100 loops to 90 per 1cm^2, the air permeability decreased slightly, which is due to the fact that the nano-level coating isolates fibre pores.

3.1. Surface wettability

After modification hydrophilic cotton single and double jersey surface becomes hydrophobic. Water contact angle remains high (above 130 degrees) and material can be classified as water repellent [4]. Cotton/polyamide blend yarn sock samples modified with 7,5 %wt ZAD and consolidation regimes – 8 minutes at temperature 100 and 120ºC and hydrothermal treatment after modification has shown (Fig. 1) results with water drop contact angle remained above 119º, +/- 2 degrees after 60 seconds of measurement, therefore proving good surface

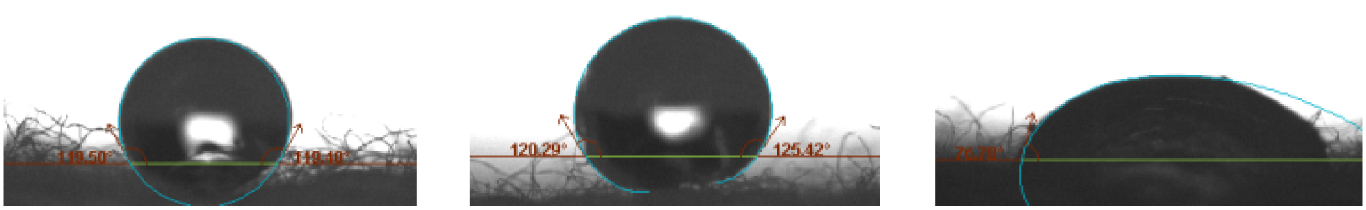

Fig. 1. Water contact angle measurements 60 s, from left to right: w100/8, w120/8, K.

hydrophobicity. The difference between control and modified sample is significant. During water contact angle measurement of unmodified sock samples (marked K in Fig.1), the angle decreased fast and water was absorbed into the fabric within 60 seconds. Comparing results of samples, with hydrothermal treatment after modification and without, shows better water repellence for the first ones (Fig. 2). The contact angle moderately increases and stabilizes regardless of consolidation regime, because in the wet environment, the fibre surface coating has self-healed the initial micro-defects. At the same time before first hydrothermal treatment water contact angles are much lower for all sample variants.

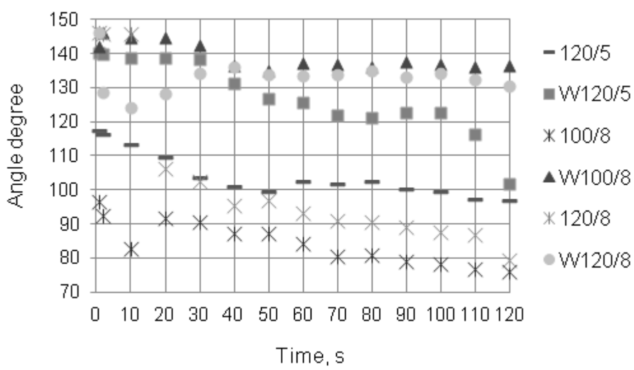

Fig. 2. Water contact angle of modified sock samples with and without following hydrothermal treatment.

3.2. Water vapour and air permeability

Air permeability test results of 7,5 wt% ZAD sol modified sock sample (measurements taken in stallion and foot) show drop down from 24% (W120/8) to 25% (W100/8) After hydrothermal treatment, optimal (18,8-19,1 Pa l/m^2) air permeability persists, if consolidation is carried out at a temperature of 100-112^{o}C for 7,5 - 8 minutes. It shows that longer consolidation time and lower temperature is more favourable. Similar tendencies are observed evaluating single and double jerseys after modification, where air permeability of single jersey samples decreased by 20 % and of double jerseys samples by 14 % [4].

Water vapour resistance Y_R of modified socks after first hydrothermal treatment describes the equation (1) and two-dimensional splits (Fig. 3).

$$Y_R = 6.60+0.03x_1-0.08x_2+0.13x_3+0.16x_1x_2+0.05x_2x_3-0.01x_1x_2x_3 \quad (1)$$

Where:
x_1 – ZAD wt%;
x_2 – consolidation temperature, ^{o}C;
x_3 – consolidation time, min.

The influence of consolidation time and temperature on modified with 7,5wt% ZAD socks water vapour resistance Y_{R2} is described by equation (2)

$$Y_{R2} = 6,63+0,08*x_2+0.13*x_3+0,03*x_2*x_3 \quad (2)$$

Where:
Y_{R2} – water vapour resistance;
X_2 – consolidation time;
X_3 –consolidation temperature.

More sensitive to the consolidation temperature and time where sock samples with the applied modifier ZAD 5wt% (Fig. 3, a) showing lower vapour resistance in a temperature range 100-107^{o}C and consolidation time 7.5-8 minutes. At the same time water contact angle curve W100/8 (Fig. 2) show high stable surface hydrophobicity in this area.

Samples water vapour resistance with modifier ZAD 7.5wt% vary in a range 6.46-6.87 Pa. M^2 W^{-1} (6 %) and are less sensitive to the consolidation parameters (Fig. 3, b). The graph and equation (2) show that vapour resistance slightly increase with the increase of temperature and consolidation time reaching the highest values when temperature vary in a range 115-120 ^{o}C and corresponding time 7.5-8 min. The water contact angle curve of variant W120/8 (Fig. 2) testifies of high hydrophobicity.

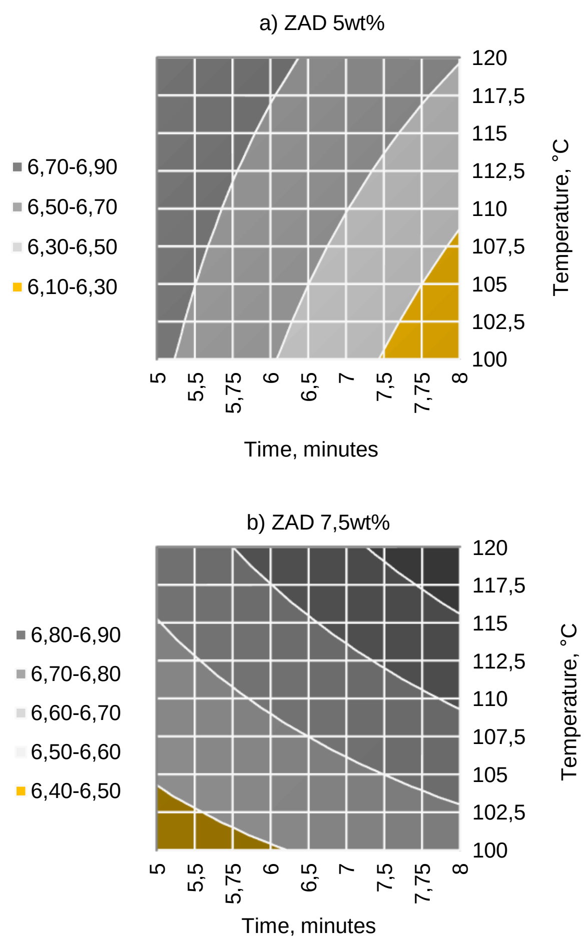

Fig. 3. Consolidation time and temperature influence on water vapour resistance Pa. M^2 W^{-1} of modified samples represented in surface section.

From the obtained results could be concluded that with 7,5wt% ZAD concentration to ensure water vapour resistance between 6,4 and 6,5 Pa M^2 W^{-1}, best results are at consolidation regime with temperature from 100 to 105ºC and time 5–6 minutes (Fig. 3). As observed during the sample comparison, when increasing ZAD concentration (from 5wt% to 7,5wt%), consolidation time needs to be increased to 7,5–8 minutes, thus proving lowest water vapour resistance and at the same time high surface hydrophobicity of loose structure cotton/polyamide socks.

T-shirt samples after modification and hydrothermal processing show higher water vapour permeability, indicating that knitwear has stretched out [4].

3.3. Wearer comfort evaluation

100 volunteers of different age and occupation (Fig. 4) were engaged in experimental wear. 85 volunteers wore modified cotton T-shirts and a control group of 15 volunteers wore unmodified T-shirts. 66 % of volunteers perceived differences between unmodified and by sol-gel method modified T-shirts. 26% noticed lack of sweat odour (Fig.6).

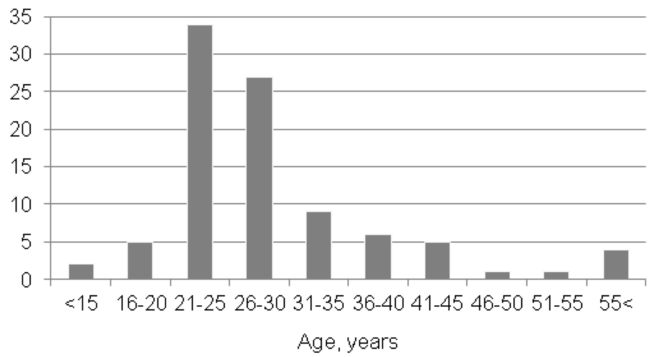

Fig. 4. Age distribution of volunteers

Increased resistance to dirt and need for less frequent washing, are the main advantages, named by T-shirt wearers (Fig. 5). However, wearers who admitted that they sweat more than average, observed that modified t-shirts surface absorbs humidity in slower rate, which causes discomfort although sweat odour is not observed.

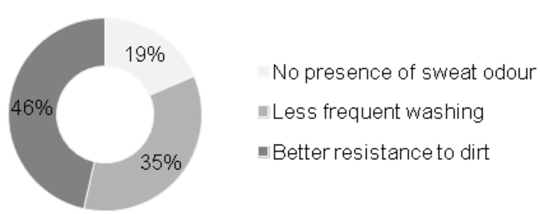

Fig. 5. User perceived benefits

53% of participants who wore unmodified cotton t-shirts responded that, in average t-shirts needed to be washed after 3 times of usage (average 1 wearing time 8,74 hour with low metabolic activity). With surface modification periods between washing was extended to 1 time per 7 days. But the following factors must be taken into account: t-shirts were tested for a short amount of time (30 days) and with the specific washing conditions (using distributed standard soap in a gentle washing regime).

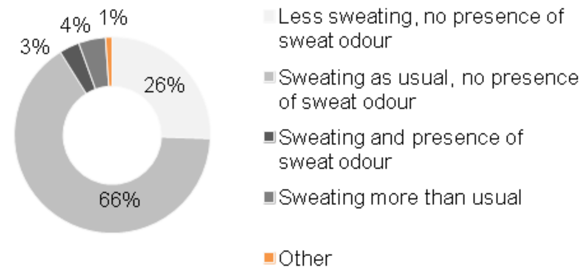

Fig. 6. User observations

Those, who are working ten and more hours, greatly appreciated all three mentioned benefits. Proposed applications ranged by experimental users shown in Fig. 7.

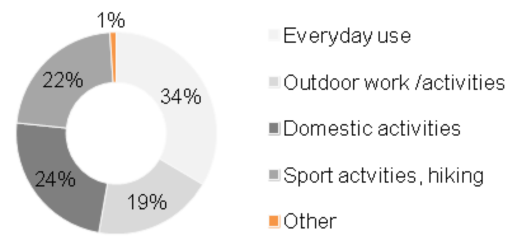

Fig. 7. Distribution of T-shirt usage

IV. CONCLUSIONS

Cotton/polyamide sock pre-treatment by dipping in acetone solution for surface cleaning was deemed unnecessary, because it worsened the targeted functional properties and increase chemical costs and treatment time, washing according to ISO 105:1989: C01-C05 is sufficient for sample preparation.

By changing the percentage of the sol solution active components and after treatment time and temperature, it is possible to give surface coating necessary qualities without significantly downgrading textile already possessed properties. By lowering the proportion of sol solution and sample weight to 1:8 accordingly, a cost reduction could be possible.

Mixed cotton/polyamide sock and pure cotton jersey T-shirt surfaces after modification are hydrophobic maintaining water contact angle above 100 degrees. Increased resistance to dirt and need for less frequent washing, are the main advantages, named by T-shirt wearers, as well as 26% of volunteers noticed lack of sweat odour during T-shirt wearing.

Modified surface abrasion durability should be tested, as it is important for sock wear, due to intensive loads and wearing condition.

V. Acknowledgment

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