Mladen Stančić[1], Dragana Grujić[2], Nemanja Kašiković[3], Dragoljub Novaković[3], Branka Ružičić[1] and Rastko Milošević[3]
[1]University of Banja Luka, Faculty of Technology, Department of Graphic Engineering
[2]University of Banja Luka, Faculty of Technology, Department of Textile Engineering
[3]University of Novi Sad, Faculty of Technical Science, Department of Graphic Engineering and Design

Influence of the Washing Process and the Perspiration Effects on the Qualities of Printed Textile Substrates

Vpliv pranja in znojenja na kakovost potiskanih tekstilnih substratov

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Abstract
Clothes are exposed to different impacts during usages and maintenance. The more frequent impacts on textile materials are the washing processes and the perspiration effects. These mentioned effects are the causes of specific changes of the textile fibres and on colour reproduction on printed materials. This paper presents research into the impacts of a series of washing and perspiration effects on the colour reproduction studied with a spectrophotometric analysis and the water retention capacities of the prints using the screen-printing technique. The research results indicate that with the increase in the number of washes, major changes occurred in the reproduced colours compared to the colours of the samples that did not undergo the process of washing. It was determined that, besides the series of washings, the perspiration effects also had an impact on the reproduced colour changes. The impacts were also affirmed of printing and a series of washings on water retention on textile materials.
Keywords: screen-printing, washing process, perspiration effects, print quality, colour reproduction, water retention capacity

Izvleček
Oblačila so med uporabo in vzdrževanjem izpostavljena različnim vplivom, med katerimi sta najpogostejša pranje in izpostavljenost telesnemu znoju. Omenjena učinka povzročata določene spremembe na vlaknih in barvnih odtisih tekstilnih materialov. V članku je predstavljena raziskava vpliva znojenja in zaporednih pranj barvnih odtisov na tekstilnih materialih, izdelanih v tehniki sitotiska. Proučevani sta bili reprodukcija barv s spektrofotometrično analizo in sposobnost zadrževanja vode. Izsledki raziskave kažejo, da s povečanjem števila pranj prihaja do večjih sprememb barvnih odtisov. Ugotovljeno je bilo tudi, da poleg več zaporednih pranj na barvo odtisov vpliva tudi znojenje. Potrjen je bil vpliv tiskanja in pranja na sposobnost zadrževanja vode v tekstilnih materialih.
Ključne besede: sitotisk, pranje, vpliv znojenja, kakovost tiska, barvna reprodukcija, sposobnost zadrževanja vode

1 Introduction

The main task for the clothing is to protect the body from various environmental impacts and to mitigate the effects of various climatic and mechanical influences (such as pressure, friction, stretching, etc.). The rises in the living standards of individuals have conditioned the major shift in textile and clothing manufacturing because the demands of customers today are higher than they used to be.

Corresponding author/*Korespondenčni avtor:*
MSc Mladen Stančić
E-mail: mladen.stancic@unibl.rs

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For today's customers it is insufficient for clothes just to meet only basic functions such as protecting the body and functionality, selective clothing is also expected to meet the aesthetic and fashion requirements so that it can better depict the personal characters and lifestyles of individuals [1].

Increases in the aesthetic values of clothes are often achieved by printing on these materials. Printing on textile materials can more appropriately be described as an art and a science of desired design transfer onto textile materials' surfaces [2]. Some estimates indicate that more than 27 billion m2 of textile material substrates are printed every year [3]. Also, it is considered that printing on textile materials has an annual growth of 2% [4]. The most important printing technique in textile printing is screen printing [3, 5, 6] that is characterised by the fact that the print of a larger circulation has significantly lower costs and higher productivity [7, 8].

Factors affecting the quality of screen printing are closely related to each other [9]. Halftone value reproduction depends on the thread counts and thicknesses of the threads [10], whilst printing form, ink and substrates' characteristics affect the reproductions of lines and dots [11]. Print quality also depends on process parameters such as the printing speed, squeegee hardness, squeegee pressure and distance of mesh from the substrate. Pan and others have found that the squeegee hardness and printing speed have decisive influences on print quality [12]. In order to obtain high quality print, it is necessary to choose the appropriate ink [13]. The more common inks applied on textile materials in screen printing are plastisol inks that contain PVC resin dispersed in plasticiser [11]. During the printing they penetrate into textile material and after drying they create a strong connection with textile material, which makes this product very resistant when exposed to different influences. It is significant that they are characterised by very good coverage [14].

After printing, textile materials are often exposed to external influences such as washing heat, abrasion, UV light etc. One of the more influential factors that textile materials are exposed to is the washing process. It has been proven that the washing process causes certain changes in the physicochemical features [15], as well as changes in the micromechanical properties (air permeability, resistance to cracking, stiffness) [16].In addition it has been noted that the washing process causes a change in colour [17]. The degree of change in the properties of textile materials and the colour depends on: ways of washing, washing temperature, water hardness, washing time. In addition, modern detergents consist of whitening substances and their enzyme activators and also inhibitors of the dye transfer. All of these substances can son

In the printing textile industry, achieving the highest colour reproduction quality and also the maintaining of the same after production, requires standardisation and the introduction of objective methods of quantifying colour. A common way of controlling the print quality consists of the spectrophotometric analysis of colour. The basis of this process is to determine the colour differences between two prints. Determination of colour differences is based on the determination of the differences in the colour space coordinates (ΔL^*, Δa^*, Δb^*) [19, 20]. That difference is expressed as a number (ΔE) and corresponds to the visual difference between two colours. The gained values can be classified into several groups: ΔE between 0 and 1 (generally, difference cannot be noticed), ΔE between 1 and 2 (small colour difference, visible to the "trained" eye), ΔE between 2 and 3.5 (medium colour difference, visible to "untrained" eye), ΔE between 3.5 and 5 (obvious colour difference), and ΔE above 5 (massive colour difference). [21].

In addition to the esthetic demands, clothing should fulfill the ergonomic and physiological requirements [22]. Clothing must allow a certain thermal insulation, a high degree of moisture permeability and good ventilation for maintaining optimal thermal regulation of the human body. The result of balanced interaction the system „ person – air – clothing" is expressed as human comfort when wearing clothes. More than 90% of the body surface is directly in contact with the clothing that is worn practically 24 hours a day, at work and leisure time, and partly in bed. This means that most of the surface of the human body is exposed to "microclimate" that is created between the skin and the clothes [23].

Based on all the above-mentioned parameters, the goal of the research was set and that was to determine how the washing process affects colour reproduction, and how much resistance reproduced colour has on perspiration as well. In addition to this, the aim was to determine what are the impacts of the material type, printing and washing on changes of material sorption properties, i.e. the water retention capacity of the textile material. In order to obtain more accurate results, there were analyses of a large number of samples that were printed by the screen-printing technique on two types of textile substrates, and subjected to a series of five washes.

2 Materials and methods

Research into the effects of washing and perspiration on colour reproduction and the influence of the printing and number of washings on the change of water retention capacity was performed on two types of textile materials of approximately the same surface masses but different surface structures. Material characterisation was done according to the following parameters: material composition (ISO 1833), mass per unit area (ISO 3801), and number of threads per unit length (ISO 7211-2). The characteristics of the materials are presented in Table 1.

A special test image was created for this study using Adobe Illustrator CS 5 software. This test image contained two 150 1 pt 150mm patches with 100% tone values of the processed black colour.

Samples were printed by the screen-printing technique, using the 6-colour graphic M&R Sportsman E Series system. Printing speed was 10cm/sec, squeegee hardness – 70 Shore Type A, printing pressure 275.8 × 10^3Pa, and 4mm snap-off distance. It was printed with Sericol Texopaque Classic OP (OP001) Plastisol black ink. Ink fixation was done at a temperature of 160°C, exposure time 150 seconds. Whilst preparing a printing form a screen was used with mesh count of 90 threads per cm. A printing form was made conventionally using positive films. The optimal densities of the transparent areas of the film were 0.04 and 3.9 on opaque areas. Photosensitive Sericol Dirasol 915 emulsion was used. Light exposure was done using a metal-halogen UV lamp (1000W) at a 1m distance from the mesh. The exposure time was calculated using a control tape Autotype Exposure Calculator by the Sericol Company and it lasted 3.5 minutes.

The printed samples were subjected to a series of washings that consisted of five washes. The washing bath contained 5g/l of textile soaps, and the ratio of solution to the textile substrate was 50:1. Soaps, containing not more than 5% moisture and complying with the following requirements based upon dry mass: free alkali, calculated as Na_2CO_3: 0.3% maximum; free alkali, calculated as NaOH, 0.1% maximum; total fatty matter: 850g/kg minimum; titer of mixed fatty acids, prepared from soap: 30°C maximum; iodine value: 50 maximum. The samples were washed for 30 minutes at 40°C. After washing, the samples were rinsed twice with distilled water and then rinsed for 10 minutes in cold water. The washed samples were drained and in spread-out state dried at a temperature of 60°C. The persistence of each reproduced colour after each wash and after the effect of perspiration was tested according to ISO 105-C10: 2006 [24].

The persistence of reproduced colour was analysed by measuring the CIE L* a* b* coordinates of the solid tones of black, determining the differences between the reproduced colours (ΔE) after the printing process and exposing the printed samples to a series of washes. CIE L* a* b* coordinates were determined using a Konica Minolta CM-2600d diffuse spectrophotometer (Illumination types D65, standard observer angle 10°, measurement geometry d/8°, measurement aperture 8mm). Measuring was repeated five times for each sample, and as the results used values corresponding to the arithmetic mean of a series of measurements.

A test of resistance to perspiration staining was performed according to standard EN ISO 105-E04: 2012,

Table 1: Characteristics of the materials used during the testing

Materials	Fabric type	Raw material composition (%)	Mass per unit area (gm^{-2})	Density of fabric (cm^{-1})
1	knitted	cotton/elastane 93.2/6.8	180.0	Vertical: 22.0 Horizontal: 17.0
2	woven	cotton 100%	184.4	Vertical: 21.3 Horizontal: 19.0

with treatment in alkaline and acidic solutions without L-histidine *monochlor – hydrate*. A combined sample for testing, size 100 x 40mm, is wetted with alkaline solution (pH 9.5) previously heated to 45°C. The cuvettes were treated for 30 minutes under these conditions, and after that acetic acid was added to the solution diluted to pH 4.7 and the treatment prolonged for a further 30 minutes. Thus the processed samples were drained, split on three sides and dried without rinsing. Rating of discolouration was performed with spectrophotometric colour measuring and determination of colour differences (ΔE).

Determination of the water retention capacities in the textile materials W_{ZV} was carried out according to DIN 53 814. Acclimatised fabric samples (approximately 1.6g) were cut up into small pieces. Four parallel tests were made for each sample then into each pre-weighted cuvette was placed 0.4g of the sample. Cuvettes with samples were placed in a glass and topped with a previously prepared solution (1g of anionic agents – Leonil FW (Hoechst AG) in 1 litre of distilled water). Air bubbles were expelled from the cuvette with a needle and thus the prepared samples were left to stand for two hours. Thereafter the cuvettes were centrifuged for 20 min at 3000rpm; the centrifuge device was a CENTRIC 150A from the Tehtnica manufacturer. After centrifugation the cuvettes with the samples were weighed and the differences in weights between the cuvettes with samples after centrifugation and those cuvettes with 0.4g of dry samples before centrifugation produced a mass of treated samples. Retention water capacity in the fabrics W_{ZV} (%) was calculated according to Equation 1:

$$W_{ZV} = \frac{(m_c - m_{kl})}{m_{kl}} \cdot 100 \qquad (1)$$

where:
m_c – centrifugated sample mass [g],
m_{kl} – acclimatised sample mass [g].

3 Results and discussion

3.1 Spectrophotometric analysis of a sample before and after the washing process

Spectrophotometric measurements were used to determine CIE L* a* b* coordinates of colours after printing and washing treatments. The measured values are shown in Table 2.

When calculating the colour difference (ΔE), values taken as reference were the values of the printed samples and by comparing with them the colour difference values were obtained after a series of washings for each material.

Table 2: CIE Lab coordinates of colours and colour differences after printing and washing treatments

Materials	L*	a*	b*	ΔE
1 P	22.81	0.19	–0.59	/
1 W1	23.32	0.10	–0.51	0.52
1 W2	23.93	0.31	–0.78	1.14
1 W3	24.75	0.31	–1.00	1.99
1 W4	25.13	0.27	–0.73	2.33
1 W5	25.35	0.28	–0.88	2.56
2 P	23.31	0.06	0.76	/
2 W1	23.84	0.17	–0.69	1.55
2 W2	24.32	0.37	–0.99	2.04
2 W3	24.49	0.32	–0.88	2.04
2 W4	24.84	0.31	–0.95	2.31
2 W5	26.09	0.30	–1.09	3.35

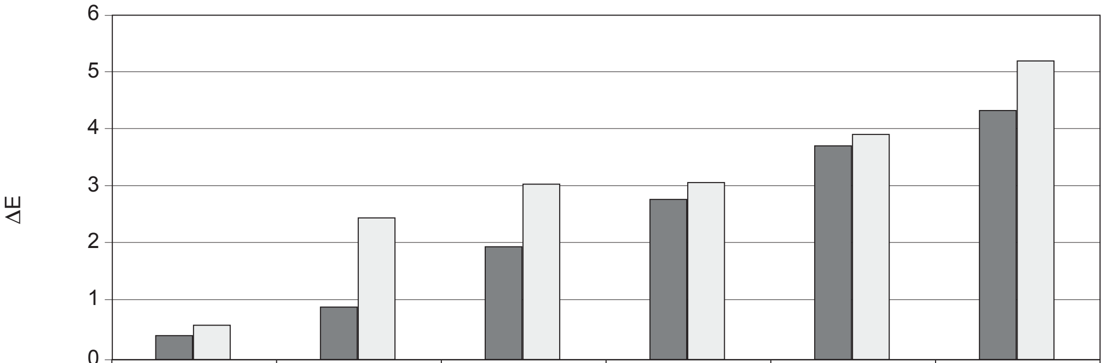
Note: Letter P represent printed sample; W1 is the mark of the sample after the first washing treatment, W2 – after the second washing treatment, W3 – the third washing treatment, W4 – the fourth washing treatment, W5 – the fifth washing treatment.

Taking into account the results in Table 2, it can be concluded that in both materials, with the increasing number of washings came major changes of reproduced colour compared to the colours of the samples which had not undergone the process of washing. It also notes that the differences in reproduced colour were greater on material 2 in relation to the colour differences arising on the material 1. When analysing the results of the measurements of colour differences for material 1, it could be observed that the colour difference after the first washing treatment couldn't be noticed by the human eye. The colour difference after the second and third washing treatments was very small and culd only be noticed by "trained eye". After the fourth and fifth washing treatments of material 1, the result was a medium colour difference and could be noticed by an "untrained eye". At the same time, the colour difference after the first washing treatment of material 2 belonged to a group of very small colour differences (may be noticed by the "trained eye"). The medium difference of reproduced colour, i.e. the difference noticed by the "untrained eye" on material 2 was already there after the second washing treatment and was held until the fifth treatment. In the reproduction on material 1 these colour differences did not occur until the fourth washing treatment. The resulting changes of reproduced colours can be explained by the fact that in the process of washing it happens that some of the paint particles wash away thus reducing the possibility of light absorption and reflection increases, which affects the experience of colour. Larger deviations of reproduced colour on material 2 can be interpreted by different surface structures, and due to less surface roughness of fabric and ink layer during the process of printing was lower than in material 1 (knitwear).

3.2 Colour fastness to perspiration

Determination of colour fastness to perspiration was done by measuring the CIE L* a* b* coordinates of reproduced colours and specifying the colour differences (ΔE). The tested samples after printing and each of the washing treatment were exposed to the effects of perspiration and the colour difference calculated. When calculating the colour differences the (ΔE) values taken as reference were those values of the printed samples not subjected to the washing and perspiration effects, and the colour differences compared to them. The obtained values are presented in Figure 1.

When considering the obtained values in Figure 1, they show the effect of perspiration causes a change in reproduced colour. It can also be noted that increasing the number of washings with the perspiration effect formed greater changes of the reproduced colours. Also, analysing the value of the colour differences of the printed samples when exposed to a series of washings (Table 2) and the values of the colour differences of the printed samples exposed to a washing effect with perspiration (Figure 1) confirmed that the effect of perspiration causes additional changes in reproduced colours. Looking at the results for material 1 it was noted that the colour difference between the printed sample and the printed sample exposed to the effect of perspiration (P-S) was 0.45, which represents a colour difference that cannot be noticed. The colour difference after the first washing treatment and the effects of perspiration (W1-S) also belong to this group of colour differences. After the second washing treatment of the samples with the effect of perspiration (W2-S) the resulting colour difference was very small, noticeable only to the "trained eye". The series of three washing treatments with the effect of perspiration (W3-S) resulted in medium colour difference that can be noticed by the "untrained eye". By increasing the number of washes with the effect of perspiration the



	P-S	W1-S	W2-S	W3-S	W4-S	W5-S
Material 1	0.45	0.94	1.98	2.8	3.73	4.35
Material 2	0.62	2.48	3.06	3.09	3.93	5.2

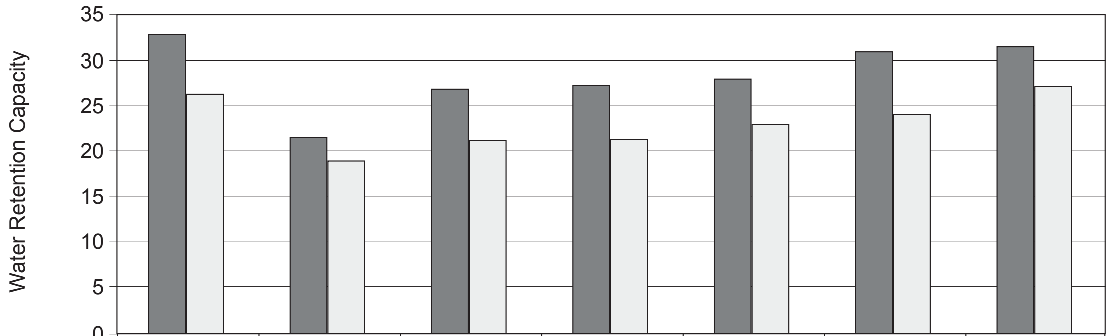
Figure 1: Colour difference (ΔE) after effects of washing and perspiraton (Note: Letter P represent printed sample; W1 is the mark of the sample after the first washing treatment, W2 – after the second washing treatment, W3 – the third washing treatment, W4 – the fourth washing treatment, W5 – the fifth washing treatment and S stands for perspiration)

differences became obvious colour differences. At the same time, on the material 2 colour difference between the printed sample and the printed sample exposed to the effect of perspiration (P-S) represented a colour difference that cannot be noticed. Differences of colour after the first, second and third washing treatments with the effects of perspiration (W1-S, W2-S, and W3-S) were significantly greater and belong to the group of medium colour differences that can be can notice by the "untrained eye". The colour difference after the fourth washing treatment and the effects of perspiration was the obvious colour difference, and after the fifth washing treatment the perspiration effect caused massive colour difference. These results indicate that the effect of perspiration causes a change of reproduced colours. This is explained by the fact that sweat "breaks" paint particles, and that is why there is the colour difference between printed colour and printed colour exposed to the effects of perspiration. Furthermore, with the "digestion" of paint particles, the effect of perspiration enhances the wash-out of colour during the washing process, and brings greater colour differences with the combination of the above actions.

3.3 Water retention capacities of printed samples before and after the washing process

Determinations of the water retention capacities in textile materials W_{ZV} were carried out by measuring the differences between the masses of the centrifugated samples and masses of the acclimatised samples. The study analysed the water retention capacities of unprinted materials, printed materials and printed materials exposed to a series of washes. The obtained values are presented in Figure 2.

The results of the water retention capacities of the analysed materials indicated that the printing reduces the value of this parameter, i.e. the sorption capability of the material. By exposing the samples to washing processes increased their water retention capabilities. It was also noted that the measured value of this parameter was greater for material 1 than for material 2, which can be explained by the influence of the surface structure and the various constructional characteristics of the materials. The results of the water retention capacity can be explained by the fact that during the process of printing, ink penetrates into the fibrous materials, and closes the pores between the fibres in the yarn and between the threads of yarn in textile materials. In this way it reduces the diffusion of water in the material and the possibility of its absorption, which directly reflects the reduction of water retention capacity. During the washings of the samples parts of the printing inks were washed, which increased the absorption of water in the textile materials and that's how there were greater values of the water retention capacities after a series of washings.



	Material	Printed Material	W1	W2	W3	W4	W5
Material 1	32.91	21.53	26.95	27.33	27.98	30.98	31.55
Material 2	26.37	18.95	21.18	21.29	22.98	24.1	27.18

Figure 2: Water retention capacities of textile materials before printing, after printing and after the washing processes of the printed materials (Note: W1 is the mark of the sample after the first washing treatment, W2 – after the second washing treatment, W3 – the third washing treatment, W4 – the fourth washing treatment, W5 – the fifth washing treatment.)

4 Conclusion

Textile products are exposed to a variety of impacts during usages and maintenance. Amongst the more common operations that these materials are exposed to are the washing process and the effects of perspiration. This paper showed the effects of a series of washings and the perspiration effects on print quality and the water retention capacities of screen printed textile materials. In order to determine the print quality, spectrophotometric analysis of reproduced colours before and after a series of washings and the effects of perspiration were made, and also the water retention capacities of unprinted and printed materials before and after a series of washings.

Spectrophotometric analysis of the printed samples before and after a series of washings showed that with the increasing number of washes major changes of reproduced colour occurred compared to the colours of those samples which had not undergone the process of washing. The cause of this phenomenon was that during the process of washing part of the ink was washed away, thus leading to different light reflection from the surface of the material and different experiences of printed colour. It was observed that the surface structure or structural characteristics of the textile materials significantly affected the colour change.

The performed spectrophotometric analysis of the samples confirmed that the effect of perspiration also caused changes in the reproduced colours. Perspiration affects the printed material in such a way that it "breaks" ink particles, which cause differences in reproduced colours before and after exposure. It was also revealed that perspiration had enhanced the wash-outs of printed ink during the washing processes.

Analysis of the water retention capacities of the unprinted materials, printed materials and printed materials exposed to the washing process indicates that the penetrating of printing inks to the fibres, reduces the water absorption capacities of the textile materials. The washing of the samples and washing out of the ink particles causes an increase in the number of hydroxyl groups capable of binding with water molecules. This leads to an increase in the water retention capacity, which is a parameter of the sorption characteristics of textile materials.

Summarising the results we can conclude that the washing process and its frequency, as well as the effect of perspiration have a significant impact on the print quality of a textile material and the water retention capacity as one of the important parameters for defining the thermal comfort of textile materials. In addition to these impacts, the materials with their raw material compositions and structural characteristics partially affect the print quality and the water retention capacities. In order to gain further knowledge testing is planned on how other external influences affect the print quality, and examining the influence of the print on the thermal properties of textile materials as well. Completed research would be related to the prints made by the screen printing technique, so the same research should be obtained and with prints occurred by digital printing technology.

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