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# The effect of washing temperature and number of washing cycles on the quality of screen printed textiles materials

N. Kašiković[1], M. Stančić[2], I. Spiridonov[3*], D. Novaković[1], R. Milošević[1], D. Grujić[4], B. Ružičić[2]

[1] *University of Novi Sad, Faculty of Technical Sciences, Department of Graphic Engineering and Design, Trg Dositeja Obradovića 6, 21 000 Novi Sad, Serbia*

[2] *University of Banja Luka, Faculty of Technology, Department of Graphic Engineering, Bulevar Vojvode Stepe Stepanovića 73, 78 000 Banja Luka, Bosnia and Herzegovina*

[3] *University of Chemical Technology and Metallurgy, Department of Printing Arts, Pulp and Paper, bulevard "Sveti Kliment Ohridski" 8, Sofia, Bulgaria*

[4] *University of Banja Luka, Faculty of Technology, Department of Textile Engineering, Bulevar Vojvode Stepe Stepanovića 73, 78 000 Banja Luka, Bosnia and Herzegovina*

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The life standards growth has led to the fact that buyers of textile materials, beside functionality, expect aesthetic value as well. The aesthetic characteristics of the textile materials are often promoted by the printing process of these materials. Printed textile materials, as well as printed surfaces itself, are exposed to various influences during exploitation. One of the most common impacts that these materials are exposed to is the washing process. Washing process causes the change of textile fibers as well as the change of the colour reproduction on these materials, where, as a result, the overall print quality changes. The aim of this research is to determine the effects of the washing process on the colour change in the CIE L*a*b* colour space, as well as the effects of the washing process on water retention value change of screen printed cotton textile materials using black ink. The study included an analysis of two different parameters connected to the washing process: temperature and number of washings. The research results indicate that the washing temperature increase leads to major colour reproduction changes, where beside that, the number of washing cycles has certain influence on the colour reproduction of printed textile materials exposed to washing tests as well. The investigation revealed that the washing process caused washing-out of ink particles which increases the water retention value of the tested printed materials. The research results indicate that the quality of printed textiles, besides the washing process parameters, affects its material characteristics.

**Keywords:** cotton, washing, screen printing, colour reproduction, water retention value

## 1. INTRODUCTION

On the global market are nowadays present garments manufactured by processing of a wide range of textile raw materials. The most frequently used textile material is cotton. The reason of great market share of this material is its excellent properties, such as air permeability, ability to conduct moisture and heat, softness, low-allergen and anti-static properties [1]. Furthermore, cotton materials do not require special care, possess the ability to be washed well and have a relatively long life, which is another reason for their prevalence in the clothing industry. The life standard increase of society, in general, and of individuals, has caused a great turn in the textile and clothing industry because the customer requirements became higher ever before. For today's average buyer it is not enough that the garment meets only basic functions, such as protection of the body and functionality, but the selected garment is expected to meet the fashion and visual requirements (shape, colour, and material) [2]. The increase of the aesthetic values of textile materials, and therefore of the clothes as a whole, is often carried out with the printing process. Printing of textile materials can be described as the art and science of decorating fabric with a colourful pattern or design [3]. Certain reports indicate that more than 27 billion m2 of textile material substrates are printed every year [4]. Also, it is considered that printing of textile materials has annual growth of 2% [5]. The most important printing technique of textiles is screen printing technology [6, 7, 4] that is characterized by considerably lower costs for high circulations, and high productivity [8, 9].

The clothes are usually exposed to external influences such as washing, heat, abrasion, UV light, etc. [10]. One of the most influential factors these materials are exposed to is the washing process. It is proved that the washing process causes certain changes in physical and chemical characteristics [11], as well as changes in micro-mechanical properties (permeability, resistance to

*Corresponding author.
E-mail address: i_spiridonov@abv.bg

cracking, stiffness) [12]. Also, it was noticed that the washing process causes a colours change [13]. The degree of textile fibers change, as well as the colour change, depends on the washing method, washing temperature, water hardness and washing time. Further, modern detergents consist of bleaching substances and their enzymatic activators as well as inhibitors of the dyes transfer. All of these substances can cause colours change of the printed inks [14].

To achieve the highest possible quality of the prints, there is an increasing trend of using instrumental measuring methods, i.e. spectrophotometric measurements. The instrumental colour measurement methods allow quantification of colour by numerical values. The basis of this process is the determination of the colour difference between the two prints. Determination of the colour differences is based on the calculation of the colour coordinates differences of the CIELab colour space (ΔL*, Δa*, Δb*) [15, 16]. It is expressed as a ΔE value and corresponds to the visual difference between the two colours. To determine the value of colour differences, it can be used a larger number of formulas, such as CMC (l: c) [17], BFD (l: c) [18], CIE 94 [19] and the newest one CIE $\Delta E_{2000}$ [20]. Ranges of possible colour differences values are presented in Table 1 [21].

Wearing comfort of a garment, besides other things, is conditioned by the sorption properties of the material [22]. The most important sorption characteristics are water retention value, air permeability, and relative humidity. Water retention value of textile materials largely depends on the type of fiber or the creation of chemical bonds between water molecules and fibers.

**Table 1.** Ranges of colour differences

| ΔE | Effect |
|---|---|
| < 3 | Hardly perceptible |
| 3 < 6 | Perceptible, but acceptable |
| > 6 | Not acceptable |

This study aims to determine how the parameters of washing, before all temperatures and number of cycles, affect the quality of the prints on the printed textile materials. To obtain more accurate results, a large number of printed samples (three types of textile material surfaces), subjected to a number of washing processes using different temperatures are analyzed.

## 2. METODS AND MATERIALS

The investigation was conducted on the textile materials of different surface structures, thereby three types of cotton knitwear were used: single, pike and interlock. Material characterization was carried out through the following parameters: material composition (ISO 1833), surface mass (ISO 3801) and the knitting density (ISO 7211-2). The materials characteristics are presented in Table 2.

**Table 2.**Properties of the used textile materials

| Tests | Type of weaves | Material composition (%) | Fabric weight (g/m$^2$) | Thread count (cm$^{-1}$) | |
|---|---|---|---|---|---|
| | | | | Vertical | Horizontal |
| Material A | Single | Cotton 100 % | 138 | 14 | 19 |
| Material B | Pike | Cotton 100 % | 185 | 15 | 16 |
| Material C | Interlock | Cotton 100 % | 207 | 12 | 18 |
| Method | | ISO 1833 | ISO 3801 | ISO 7211-2 | |

For the study, a special test chart using Adobe Illustrator CS5 software package was developed. The size of test chart is 297 x 420 mm, and it contains different elements for analysis of print quality. In the study were examined solid fields (100% tone value) with the size of 30 x 120 mm, printed using process black ink.

Printing of the samples was carried out using screen printing technique, with six colour printing system M & R Sportsman E Series. Pan et al. have found that the quality of screen printing process is largely influenced by four parameters [23], which is why these parameters were kept constant during the printing process of all the samples. Printing speed was 15 cm/sec, the hardness of the squeegee 80° Shore Type A, the printing pressure 275.8 x $10^3$ Pa and the snap-off distance 4 mm. Printing is done by Sericol Texopaque Classic OP Plastisol ink. Fixing of printed ink was carried out at the temperature of 160° C for 150 seconds.

For the preparation of the printing carrier (printing plate), the mesh with the mesh count of 120 threads/cm was selected. Aluminium screen printing frames with the size of 58 x 84 cm were used as the holders of the printing mesh. The size of the printing plate, without a frame, was 50 x 76 cm. Printing plates have been developed using conventional linearized positive films. The optical density of the transparent and opaque (black) parts of the film was 0.03 and 4.1 respectively. The resolution of the film was five times lower than the mesh count. As a photosensitive layer was used

Sericol Dirasol 915 emulsion. Exposition of the printing plate was done using metal halide UV lamp (1000 W); at a distance of 1 m from the printing mesh. The exposure time was 2.6 minutes that was determined using an Autotype Exposure Calculator (Sericol) control strip.

The printed samples were subjected to ten washing cycles. The washing process is carried out at the two different temperatures according to ISO 105- C10:2006 standard [24]. Washing bath contained 5 g/l of soap for textiles while the solution to cotton material ratio was 50:1. The samples were washed for 30 minutes at the temperatures of 30°C and 60°C. After the washing process, the samples were rinsed twice with distilled water, after which they were rinsed for 10 minutes using cold water. The rinsed samples were drained and dried in the spread-out state at a temperature of 60°C.

Analysis of print quality included an analysis of colour reproduction. The colour reproduction was characterized by the means of 1) CIE L*a*b* colour coordinates measurements of solid patches (100% coverage) printed with black ink, which enabled the calculation of the colour differences (ΔE) between the materials of the same material composition but different characteristics in terms of surface mass and knitting density; 2) relative spectral reflection measurements of the printed samples. All the measurements were done after the printing process as well as repeated after subjecting the samples to a multiple of washing cycles under different temperatures. The CIE L*a*b* colour coordinates were determined using a spectrophotometer HP200 (D65 illumination, 10° standard observer, measuring geometry d/8, aperture 8 mm), while the relative spectral reflectance characteristics were measured using spectro-densitometer Techkon SpectroDens (D50 illumination, the standard observer 2º, measuring geometry 0°/45°, aperture 3mm).

SEM microscopic analysis provides high-quality microscopic images of the fibers [25], thus provides further analysis of the reasons for the textile materials colour change. The analysis was performed using a JEOL electron microscope LV 6460, with the focus on observing the changes on the textile materials surfaces, which are generated by the printed ink and the effects of the washing processes. The samples were classified, labeled and prepared according to the specifications for laboratory measurements. To make the samples become electro conductive and prepared for SEM analysis, they are vaporized using gold.

The sorption properties of textile materials affect both the printing process, and the washing process. Changing the sorption properties of knitwear due to printing and washing processes were determined by measuring the water retention value of the knitwear. Determination of the water retention value in knitwear Wrv was performed according to standard DIN 53814 [26]. Acclimatized fabric sample (approximately 1.6 g) was cut into small pieces. Each sample was examined four times in parallel sessions, where each previously weighed cuvette, contained 0.4 g of a sample. Cuvettes with the samples were placed in a glass and transfused with a previously prepared solution (1g non-ionic agent in 1L of distilled water). Bubbles were expelled from the cuvette by using a needle after which prepared samples were left to rest for 2 hours. Afterwards, the cuvettes were subjected to centrifugal forces for 20 min at 3000 rev/min, using a CENTRIC 150A (Tehtnica) device. After the centrifugation process was done, cuvettes with the samples were weighed and from the mass differences values of cuvettes with the samples after the centrifugation process and empty cuvettes, the mass values of processed samples are generated [26].

The ability to retain water in fabrics $W_{rv}$ (%) is calculated according to the formula:

$$W_{rv} = \frac{m_c - m_{kl}}{m_{kl}} \cdot 100 \tag{1}$$

where:

$m_c$ - mass of the centrifuged sample [g],

$m_{ki}$ mass of the acclimatized sample [g].

## 3. RESULTS AND DISCUSSION

Results of the spectrophotometric analysis of the samples printed in the experiment are presented in Table 3. For each sample, are determined by CIE L*a*b* colour coordinates, and are calculated the colour difference values. On the basis of these results, it was found out in what extent the colour reproduction of the original had changed after washing cycles with different washing temperatures.

When calculating colour differences (ΔE), as the reference CIE L*a*b* values were taken the CIE L*a*b* values of solely printed samples, and in regard to these values, colour difference values were calculated after a number of washing cycles at different temperatures for each material.

After washing process, in case of all knitted samples it was noticed that the increase of washing temperature causes major changes of the analyzed samples, i.e. colour difference values are greater between the samples before and after washing under the temperature of 60°C comparing to the colour difference values between the samples that were washed at a temperature of 30°C. Also, it was noticed that with the increase in the number of washing processes major changes of the analyzed samples occur, thus the colour difference values increase with increasing number of washing cycles

.**Table 3.**Values of CIE L*a*b* colour coordinates and colour differences after printing process and washing cycles under different temperatures

| Sample | L* | a* | b* | ΔE |
|---|---|---|---|---|
| A- P | 22,390 | 0,180 | -0,238 | - |
| A- 30- W1 | 24,702 | 0,116 | -0,366 | 2,316 |
| A- 30- W5 | 28,130 | -0,216 | -0,448 | 5,758 |
| A- 30- W10 | 30,148 | -0,258 | -0,744 | 7,787 |
| A- 60- W1 | 25,522 | 0,126 | -0,366 | 3,135 |
| A- 60- W5 | 29,508 | -0,170 | -0,416 | 7,129 |
| A- 60- W10 | 32,438 | 0,054 | -1,154 | 10,091 |
| B- P | 21,506 | -0,114 | -0,796 | - |
| B- 30- W1 | 24,628 | -0,176 | -0,200 | 3,179 |
| B- 30- W5 | 27,518 | -0,160 | -0,492 | 6,020 |
| B- 30- W10 | 28,392 | -0,296 | -0,488 | 6,895 |
| B- 60- W1 | 25,662 | -0,092 | -0,362 | 4,179 |
| B- 60- W5 | 29,718 | -0,066 | -0,500 | 8,218 |
| B- 60- W10 | 30,860 | -0,236 | -0,456 | 9,361 |
| C- P | 26,570 | 0,158 | -0,340 | - |
| C- 30- W1 | 27,074 | -0,090 | -0,244 | 0,570 |
| C- 30- W5 | 28,284 | -0,194 | -0,592 | 1,768 |
| C- 30- W10 | 28,680 | -0,242 | -0,308 | 2,148 |
| C- 60- W1 | 25,966 | 0,122 | -0,436 | 0,613 |
| C- 60- W5 | 29,558 | -0,022 | -0,508 | 2,998 |
| C- 60- W10 | 31,376 | -0,270 | -0,488 | 4,827 |

Analyzing the results of the material A, it can be noticed that the colour difference after the first washing process at a temperature of 30°C is barely noticeable. By increasing the number of washings, colour difference values rise. After the fifth washing process, the colour difference is noticeable, but still acceptable, while, after the tenth washing process, the values of colour differences are too large, thus unacceptable. The washing temperature of 60°C causes major changes of the prints, where after the first washing process at this temperature, the resulting colour difference value is noticeable, but acceptable. By increasing the number of washing processes, produced colour differences can be characterized as significant or unacceptable.

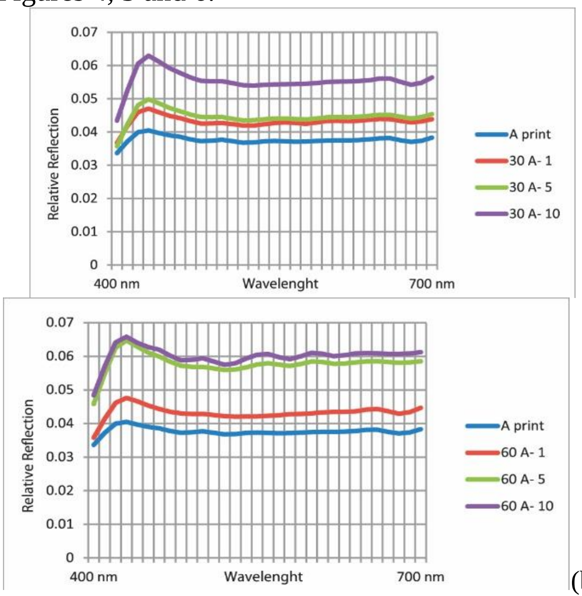
In case of the material B, a similar behaviour of the colour differences values is present, at all washing temperatures. Thus, after the first washing process, a noticeable but acceptable colour difference occurs, while, after the fifth and tenth washing processes, a large and unacceptable colour differences are generated. Although the colour differences behaves in the same manner with the increase of the temperature and the number of washing processes, it can be noticed that the increase of washing temperature generates the greater colour difference change as well.

By reviewing the colour differences results of material C (material with the greatest surface mass and the most pronounced relief surface structure),lower colour difference values were observed, comparing to the other two materials. The influence of washing process at a temperature of 30°C resulted in a barely perceptible colour differences after ten washing processes. Colour difference, under the washing temperature of 60°C, after the first and the fifth washing, is barely noticeable, while after the tenth wash cycle it is noticeable but acceptable.

In addition to CIE L*a*b* colour coordinates and colour differences determination, the relative spectral reflection for all samples were obtained, both after the printing process and after the washing processes. The effect of washing temperature and the number of washing processes on the relative spectral reflectance of the samples surface was monitored. In Figures 1, 2 and 3 are presented the relative spectral reflection curves of samples after printing and washing processes.

Washing process affects the change of the relative spectral reflection curves of the samples, so the relative spectral reflection curves after the washing process exhibit higher degree of reflectivity comparing to the relative spectral reflection curves of the solely printed samples. From the Figures 1, 2 and 3, it can be noticed that the increase in washing temperature, as well as in the number of washing cycles leads to the higher reflectivity of the sample surface. This can be explained by the fact that during the exposure of the printed samples to washing process, a part of the ink particles is being washed away, which causes a decrease of light absorption and on the other side the increase of light reflection. Thus, it can be concluded that the increase of the washing cycles and the washing temperature leads to washing out of larger quantities of printed ink, and hence to a higher reflectivity of the surface.

Analysis of SEM micrographs (x500 magnification) was conducted on the unprinted samples, samples after printing process, and after the first washing cycle under the tested washing temperatures, Figures 4, 5 and 6.



(b)

**Fig. 1.** Relative spectral reflection curves obtained after printing and washing cycles for material A at washing temperature of 30°C (a) and 60°C (b)

Remark: Letter A is a material A mark, numbers 30 and 60 represent washing temperature in °C; 1 is sample mark after the first washing, 5 is sample mark after the fifth washing, and 10 is sample mark after the tenth washing.

Figures 4, 5 and 6 indicate that the analyzed samples underwent a change of the surface morphology after the printing process. Figures 4a, 5a and 6a clearly show a smooth fiber structure, whereas in Figure 4b, 5b and 6b can be noticed ink particles on the surface of the fibers which is a result of the printing process. It can be said that the fibers are almost entirely covered in ink due to the high ink deposit. By exposing the printed samples to the washing process, a part of the ink quantity is washed off the fibers surface, which can be seen in Figures 4c, 4d, 5c, 5d, 6c and 6d. Thereby, it can be seen that the effect of washing process at higher temperatures leads to the removal of larger quantities of printed ink. The consequence of the partially ink removal is that it reduces the amount of ink that absorb a part of the light spectrum, so the surface becomes smoother, and, therefore, more reflective. These conclusions are directly related to the changes in spectral and colour difference values.

Water retention value was measured on the samples before printing, after printing, and after the first, the fifth and the tenth washing processes at all washing temperatures. The results are presented in Table 4.

The water retention value test results indicate that the printing process reduces water retention value, which is valid for all three materials. This phenomenon can be explained by the fact that during the printing process, the ink layer is transferred both onto the material surface and in the material structure. The ink deposition on the material surface covers the hydrophilic cotton fibers, reducing that way the amount of space where the water molecules come in contact with the cotton fibers, which lowers the absorption ability of the fibers and thus the ability to retain water.

After subjecting the samples to the first washing process, no matter the washing temperature is, water retention value is increased.

This is caused by the fact that washing process causes washing out of the printed ink particles. After washing out the ink particles, the hydrophilic surface of cotton fibers is released, this in turn allows greater fiber absorption characteristics and greater water retention value.

By further observation of the water retention values, in case of washing temperature of 30°C, it was noticed that in the case of materials A and B, after the fifth washing cycle there is a decrease in the water retention value in comparison to the same samples, after the first washing cycle.

This phenomenon can be explained by the fact that during the printing process, an uneven clustering of ink particles occurred on the surface of the substrate material, which led to the appearance of mottle or macro nonuniformity on the prints. After the first washing cycle, a complete ink washout from the fibers occurred on the surfaces with a lower concentration of ink, which released the material surface enabling contact of the fibers with water.

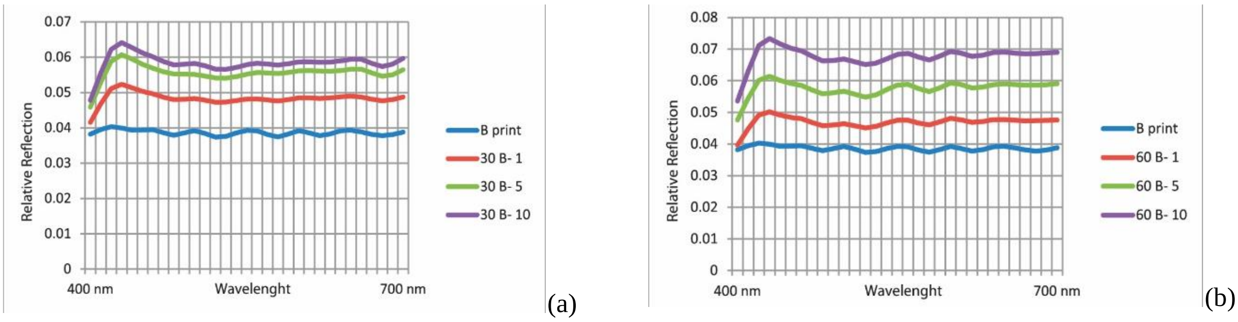



**Fig. 2.**Relative spectral reflection curves obtained after printing and washing cycles for material B at washing temperature of 30°C (a) and 60°C (b).Remark: Letter B is a material B mark, numbers 30 and 60 represent washing temperature in °C; 1 is sample mark after the first washing, 5 is sample mark after the fifth washing and 10 is sample mark after the tenth washing.

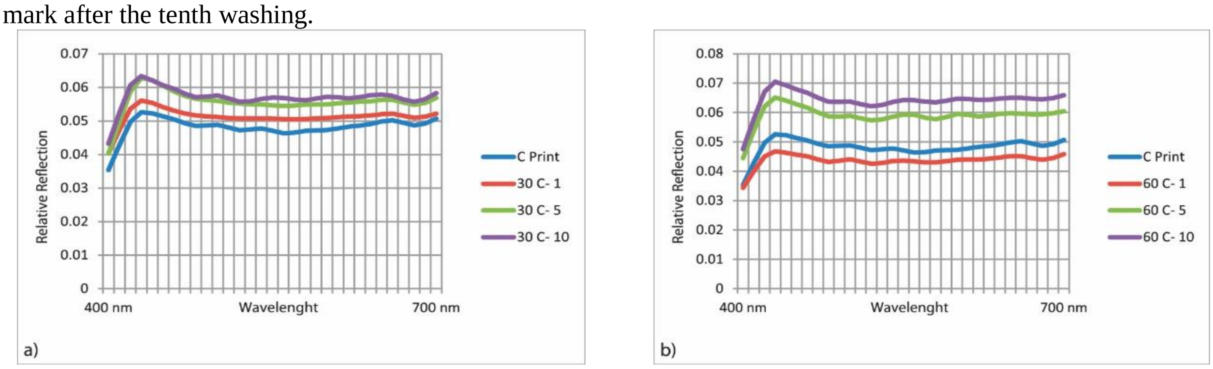



**Fig. 3.**Relative spectral reflection curves obtained after printing and washing cycles for material C at washing temperature of 30°C (a) and 60°C (b). Remark: Letter C is a material C mark, numbers 30 and 60 represent washing temperature in °C; 1 is sample mark after the first washing, 5 is sample mark after the fifth washing, and 10 is sample mark after the tenth washing.

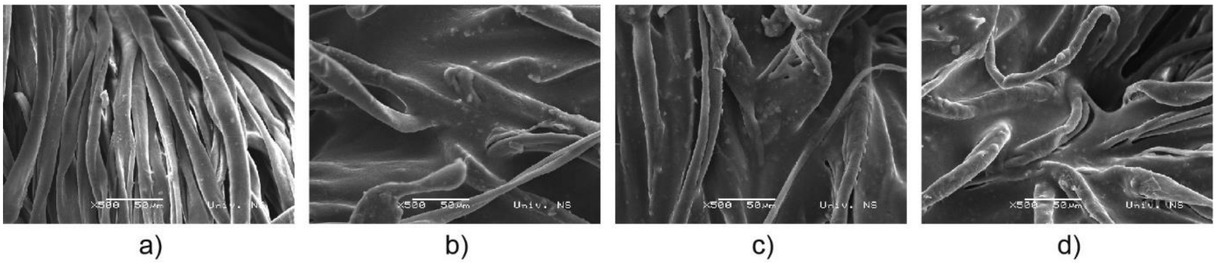



**Fig. 4**. SEM micrographs for material A: a) before printing process, b) after printing process, c) after washing process (30°C), d) after washing process (60°C).

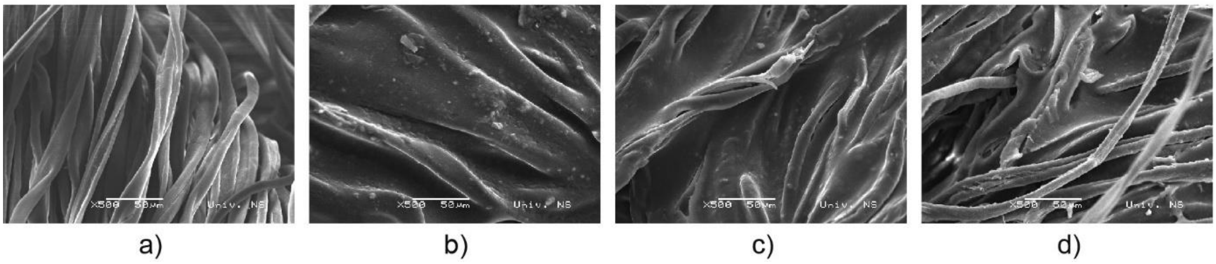



**Fig. 5.** SEM micrographs for material B: a) before printing process, b) after printing process, c) after washing process (30°C), d) after washing process (60°C).

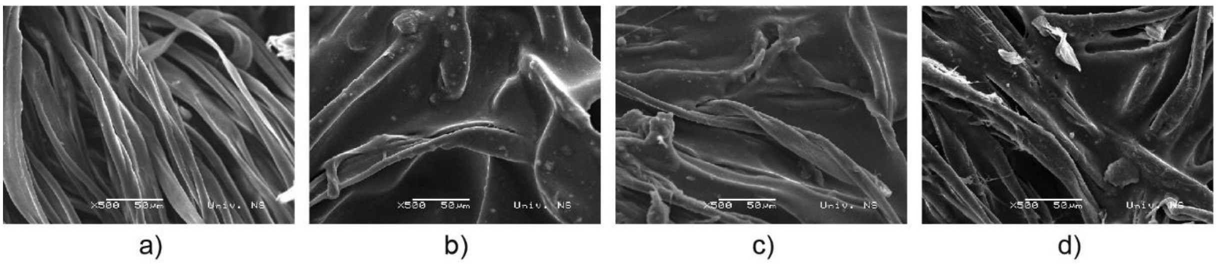



**Fig. 6.** SEM micrographs for material C: a) before printing process, b) after printing process, c) after washing process (30°C), d) after washing process (60°C)

**Table 4.**Water retention value of tested materials

| Sample | $W_{rv}$ (%) | Sample | $W_{rv}$ (%) | Sample | $W_{rv}$ (%) |
|---|---|---|---|---|---|
| A | 33.04 | B | 33.04 | C | 28.48 |
| A- P | 22.92 | B - P | 24.42 | C – P | 22.60 |
| A- 30- W1 | 23.78 | B - 30- W1 | 28.48 | C - 30- W1 | 23.29 |
| A- 30- W5 | 22.62 | B - 30- W5 | 27.96 | C - 30- W5 | 24.88 |
| A- 30- W10 | 24.78 | B - 30- W10 | 28.36 | C - 30- W10 | 22.89 |
| A- 60- W1 | 24.38 | B - 60- W1 | 26.44 | C - 60- W1 | 23.48 |
| A- 60- W5 | 25.61 | B - 60- W5 | 26.82 | C - 60- W5 | 23.70 |
| A- 60- W10 | 27.04 | B - 60- W10 | 27.13 | C - 60- W10 | 23.50 |

The increasing number of washing cycles affects printed ink particles to remove or regroup from the regions with higher ink concentrations to the regions with lower ink concentration. Free surfaces of the fibers are then recovered with the ink particles that consequently lead to the reduction of water retention value. However, a further increase of washing cycles even further affects ink particles to remove, and thus the water retention value rise. In the case of the material C (material with the greatest surface mass and the most pronounced relief surface structure) the ability to retain water was higher after the first wash than after the fifth wash. However, a further increase of the number of washing cycles brings to the decline of the material ability to retain ink. The initial trend of the water retention value behaviour can be explained by washing out of ink particles, similarly as in the case of two previously analysed materials. However, exceptionally strong relief surface structure of this material leads to the fact that the phenomenon of ink particles regrouping from regions with higher ink concentrations to the regions with lower ink concentrations occurs by exposing samples to higher number of washing cycles, hence this is the reason for water retention value decrease after the tenth washing cycle, comparing to the same value after the fifth washing cycle.

In the case of washed samples at the washing temperature of 60°C it can be noticed that with the increase of washing cycles number, water retention value rise. It can be assumed that the higher the washing temperature, the better the washing out of ink particles, which will be further rinsed with every following washing cycle without retention. At the same time, as an exception, material C possesses the water retention values that are slightly lower after the tenth washing comparing to the recorded value after the fifth washing. This phenomenon is due to the rougher surface relief structures of this material.

Obtained colour reproduction results were processed using multiple linear regression analysis, where statistically reliable relation of colour differences on the number of washing cycles and washing temperatures was obtained. The resulting statistical models are presented in Tables 5, 6, 7.sing multiple linear regression analysis, mathematical dependence models of the water retention value relative to the number of washing cycles and washing temperature were created, for materials A and B (Tables 8 and 9).

The resulting statistical dependence model of the water retention value on the washing cycles and washing temperature for material C is not statistically significant, because the coefficient of the multiple linear regression is 0.041, for the given mathematical model.

**Table 5.** Multiple linear regression coefficients for the obtained mathematical model that determine dependence of colour difference value ΔE on water temperature T and series of washing WS for all material A

| $\Delta E = 0.149 + 0.682 * WS + 0.05 * T$ | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Multiple reg. coef. | Std. Error of the Estimate | $b_0 = 0.149$ | | | $b_1 = 0.682$ | | | $b_2 = 0.05$ | | |
| | | Std. Error | t | p | Std. Error | t | p | Std. Error | t | p |
| $R^2$ | s | 1.093 | 0.136 | 0.900 | 0.085 | 7.997 | 0.004 | 0.021 | 2.384 | 0.097 |
| 0.959 | 0.770 | | | | | | | | | |

**Table 6.** Multiple linear regression coefficients for the obtained mathematical model that determine dependence of colour difference value ΔE on water temperature T and series of washing WS for all material B

| ΔE = 0.904 + 0.482 * WS + 0.063 * T | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Multiple reg. coef. | Std. Error of the Estimate | $b_0$ = 0.904 | | | $b_1$ = 0.482 | | | $b_2$ = 0.063 | | |
| | | Std. Error | t | p | Std. Error | t | p | Std. Error | t | p |
| $R^2$ | s | 1.523 | 0.594 | 0.594 | 0.119 | 4.056 | 0.027 | 0.029 | 2.156 | 0.120 |
| 0.876 | 1.072 | | | | | | | | | |

**Table 7.** Multiple linear regression coefficients for the obtained mathematical model that determine dependence of colour difference value ΔE on water temperature T and series of washing WS for all material C

| ΔE = - 1.516 + 0.318 * WS + 0.044 * T | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Multiple reg. coef. | Std. Error of the Estimate | $b_0$ = - 1.516 | | | $b_1$ = 0.318 | | | $b_2$ = 0.044 | | |
| | | Std. Error | t | p | Std. Error | t | p | Std. Error | t | p |
| $R^2$ | s | 1.183 | - 1.282 | 0.290 | 0.092 | 3.440 | 0.041 | 0.023 | 1.937 | 0.148 |
| 0.839 | 0.833 | | | | | | | | | |

**Table 8.** Multiple linear regression coefficients for the obtained mathematical model that determine dependence of water retention value $W_{rv}$ on water temperature T and series of washing WS for material A

| $W_{rv}$ = 20.658 + 0.210 * WS + 0.065 * T | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Multiple reg. coef. | Std. Error of the Estimate | $b_0$ = 20.658 | | | $b_1$ = 0.210 | | | $b_2$ = 0.065 | | |
| | | Std. Error | t | p | Std. Error | t | p | Std. Error | t | p |
| $R^2$ | s | 1.245 | 16.599 | 0.000 | 0.097 | 2.158 | 0.120 | 0.024 | 2.725 | 0.072 |
| 0.801 | 0.877 | | | | | | | | | |

**Table 9.** Multiple linear regression coefficients for the obtained mathematical model that determine dependence of water retention value $W_{rv}$ on water temperature T and series of washing WS for material B

| $W_{rv}$ = 29.559 + 0.033 * WS - 0.049 * T | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Multiple reg. coef. | Std. Error of the Estimate | $b_0$ = 29.559 | | | $b_1$ = 0.033 | | | $b_2$ = - 0.049 | | |
| | | Std. Error | t | p | Std. Error | t | p | Std. Error | t | p |
| $R^2$ | s | 0.447 | 66.152 | 0.000 | 0.035 | 0.954 | 0.411 | 0.009 | - 5.721 | 0.011 |
| 0.918 | 0.315 | | | | | | | | | |

## 4. CONCLUSIONS

Textile products made of cotton fibers are exposed to different environmental influences, out of which the washing process is one of the most frequent. This paper examined the effect of washing cycles at different washing temperatures on the quality of screen printed cotton textile materials. To determine print quality, following measurements were conducted: spectrophotometric analysis of colour reproduction, SEM microscopic analysis of the samples and water retention value of the samples before and after washing processes.

Investigation revealed that washing process affected the quality of the screen printed textile materials, which was confirmed by spectrophotometric analysis, consisted of CIE L*a*b* coordinates determination (after which ΔE values were calculated) and the determination of relative spectral reflection values.

The increase in a number of washing cycles leads to a bigger colour reproduction change in comparison to the samples that were not subjected to the washing process. Also, a rise of the washing temperature contributes to even bigger colour differences between the samples. This can be explained by the fact that the washing process leads to peeling, i.e. washing out of the printed inks. Rinsing process is supported with the certain amount of heat. Thus bigger deviation of reproduced colours was recorded after washing processes conducted at higher temperatures. Effects of the washing processes are the change of the relative spectral reflectance values of the samples, which is confirmed by generated spectral curves.

It was also proved that the surface mass, knitting density and type of weave, affect the behaviour of printed materials in the process of exploitation. Knitted sample C, that possesses the greatest surface mass, lowest knitting density and relatively rougher surface structure comparing to knitted materials A and B, showed the best service properties with regard to the quality of the printed impression after washing process.

SEM microscopic analysis of samples was monitoring the behaviour of the material before, after printing and after washing process at different temperatures. The analysis showed that after the printing process, the highest amount of ink is present on the sample surface. However, subjecting the samples to washing process leads to washing out of printed ink. SEM analysis also indicates that washing temperature increase leads washing out of larger amounts of printed ink. Due to the reduction of ink amount on the surface of the samples, a greater amount of light is being reflected from the surface, thus perceived differences of colour reproduction on the prints before and after the washing process.

Obtained results indicate that the printing and washing processes, as well as washing temperatures, have an impact on the water retention value of the tested materials. Printing process leads to a reduction of water retention value, while exposure to a larger number of washing cycles leads to increase of water retention value. Washing processes at higher temperatures lead to the improvement of the water retention value as well.

By summarizing all the results, it can be concluded that the effect of washing has an impact on the quality of impressions printed by screen printing technique on textiles. The effect of washing process on the print quality may be reduced by selecting the appropriate materials with respect to the type of applied weaves or its surface structure, as well as selecting the appropriate washing temperature.

By processing the results of the investigation using multiple linear regression analysis, statistically reliable dependence of the water retention value $W_{rv}$ on the number of washing cycles and washing temperature was obtained, with a very high multiple regression coefficient value for materials A and B, while for the material C statistically reliable model of interdependence of tested parameters was not obtained. Further examination of the results using multiple linear regression analysis led to a statistically reliable dependence model of colour differences $\Delta E$ on the number of washing cycles and washing temperature, with a very high multiple regression coefficient value for all materials.

In order to broaden current knowledge in this scientific area, it is planned to test how printing parameters, primarily screen mesh count in combination with external factors affect print quality on the textiles. When printing textile materials besides the quality of the image reproduction an important aspect is the comfort that person perceives while wearing a garment made by treating these materials. For this reason, in the future investigations it is planned to examine the impact of printing on thermal and physiological properties of the textile materials.

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# ИЗСЛЕДВАНЕ НА ВЛИЯНИЕТО НА ТЕМПЕРАТУРАТА И БРОЯ ЦИКЛИ НА ИЗПИРАНЕ ВЪРХУ КАЧЕСТВОТО НА ТЕКСТИЛНИ МАТЕРИАЛИ СЪС НАНЕСЕНИ СИТО-ПЕЧАТНИ ИЗОБРАЖЕНИЯ


Н. Кашикович[1,] М. Станчич[2], И. Спиридонов[3*], Д. Новакович[1], Р. Милошевич[1], Д. Груджич[4], Б. Ружичич[2]

*Университет на Нови Сад, Технически факултет, Катедра по графично инженерство и дизайн, Сърбия*
[2] *Университет на Баня Лука, Технически факултет, Катедра по графично инженерство, Босна и Херцеговина*
[3] *Химикотехнологичен и металургичен Университет, Катедра „Целулоза, хартия и Полиграфия“, България*
[4]*Университет на Баня Лука, Технически факултет, Катедра по текстилно инженерство, Босна и Херцеговина*


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(Резюме)

В съвременното общество се наблюдават все по-високи изисквания към текстилните материали и платове - освен удобно облеклото е необходимо да отговаря и на редица естетични критерии. Външния вид и естетиката на текстилните материали често се определят от качеството на печата върху тях.

Печата и самия текстилен материал са подложени на редица различни въздействия по време на експлоатацията. Едно от най-срещаните и влияещи въздействия е процеса на изпиране, който влияе върху текстилните влакна и цветната репродукция изразена чрез промяна в качеството на отпечатъка.

Целта на настоящото изследване е установяване на влиянието на перилния процес върху изменението на цветовите характеристики в цветово пространство CIE L*a*b* на памучни текстилни материали отпечатани по ситопечатния метод. В изследването е направен анализ на влиянието на два различни параметъра свързани с процеса на изпиране – температурата и брой цикли на изпиране. Получените резултати показват, че увеличаването на температурата на изпиране води до сериозна промяна в цветовите характеристики на ситопечатните изображения и текстила. Броя цикли на изпиране също оказва, макар и по-малко влияние върху цветовите промени. Изследванията показаха, че в процеса на изпиране се отделят частици от мастилата, което води до промяна не само на цветовите характеристики, но и на другите изследвани свойства на текстилния материал.