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RESEARCH ARTICLE

Colour fastness to washing of multi-layered digital prints on textile materials

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Abstract: This paper considers the influence of multiple ink jet printed layers and woven fabric thread count on the colour fastness to washing of printed polyester textile products. The goal was to investigate the possibility for optimisation of the number of ink layers and thread count in order to increase print quality and colour fastness to washing. Materials with the same composition and different thread counts were printed ranging from one to five ink layers. The samples were subjected to washing process after which colour fastness was examined according to appropriate standards. The colour fastness was judged subjectively by trained professionals using the standard grey scale, and objectively using spectrophotometric measurements, with calculation of colour differences caused by the washing. Surface changes were observed using SEM analysis. Results indicate that multiple layer printing gives more saturated colour due to better ink coverage, but on the other hand it enhances the ink wash-out effect. The research suggests the possibility of optimising the number of ink layers in relation to thread count number when print quality and colour fastness to washing is the objective.

Keywords: Colour fastness, digital printing, ink layers, polyester, textiles, washing.

INTRODUCTION

Printing on textile substrates can be achieved using a variety of different techniques and machines (Stančić *et al.*, 2014). Digital printing technologies for textiles have become ubiquitous on today's market, where ink jet technology has become the most common one (Jurič *et al.*, 2015). Although ink jet printing machines for textiles differ in construction and characteristics, printing principles are the same regardless of the machine type. The main advantages of digital textile printing compared to traditional methods are time reduction and repeatable results in high-quality reproductions (Chen *et al.*, 2004). The advantage of digital ink jet textile printing is the possibility of printing onto a vast number of different materials (Kašiković *et al.*, 2015b). The most commonly used artificial material is polyester, which became widespread due to its mechanical properties and resistance to environmental influences (Zhang & Fang, 2009). The other advantages of ink jet technologies are: inclusion of new production possibilities like diversification and personalisation of textile products (Fralix, 2001; Park *et al.*, 2006), its environmentally friendlier process due to less ink consumption (Ujiie, 2006; Changa *et al.*, 2009) and the possibility of multicolour printing (various quantities of cyan, magenta, yellow and black ink) resulting in higher contrast and greater edge sharpness of the prints. The print quality manipulation can be performed directly by the software while printing (Kim, 2009).

One of the shortcomings of digital printing systems is their relatively low printing speed. The fastest digital machines can print 230 m^2h^{-1} at 600 dpi resolution while the rotary screen printing machines can print over 3000 m^2h^{-1} (Clark *et al.*, 2009). The limiting factor concerning printing speed in the case of ink jet printing is construction and operation principle of the ink jet

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printers. It can be assumed that significant advances in printing speed will not be possible unless changes are made in mechanical principles of ink distribution and transfer. The printing equipment and inks are more expensive in comparison to those used for screen printing for example, but innovations brought by this printing method have been well accepted by both manufacturers of textile products and consumers (Fang *et al*., 2011).

During exploitation, printed textile materials are exposed to various influences such as washing, heating, rubbing, sunlight, etc. (Stančić *et al*., 2016; Kašiković *et al*., 2017). The washing process in a laundry machine combines complex effects and involves many factors, such as mechanical action, chemical action, temperature and time, where the chemical action has the most significant effect on soil loosening besides fabric moving, water flow rate and washing time. The washing process can be divided into three consecutive steps, that are: induction period, a rapid soil removal period and a final period, while according to other authors it consists of only two steps: loosening of soil from the textile by the combined action of detergent solution and mechanical agitation, and rinsing of the loosened soil from the textile into the bath (Kissa, 1971; Ganguli & van Eendenburg, 1980; Lee *et al*., 2008). The mechanical action can be classified into four types: soaking, hydrodynamic flow action, flexing and abrasion action, which is the most effective for soil removal (Lee *et al*., 2008). Repeated laundry process leads to dimensional instability and textiles distortion, which results in changes in mechanical properties (e.g. an increase in surface roughness) and causes specific changes in fabric structure (Tomsic *et al*., 2008; Vilcnik *et al*., 2009; Agarwal *et al*., 2011; Lam *et al*., 2011). The period of life cycle of a garment during usage can be represented by the number of laundry cycles which a garment can withstand before showing the first signs of damage, because washing processes generally contribute more to fabric damage than use or wear (Agarwal *et al*., 2011).

A considerable number of authors have investigated the influence of washing process on printed textile materials using the standard recommendation, ISO105–C01 (Xiang & Cai, 2008; Nakpathom *et al*., 2009; Chairat *et al*., 2010; Kalantzi *et al*., 2010; Ferrero & Periolatto, 2011). Most of them have investigated the potential influence of prepress treatments of fabrics. Plasma treatment of polyester textile material before ink jet printing did not give any improvement to material washing fastness (Fang & Zhang, 2009); the same treatment of 100 % propylene material gave better results for washing fastness according to grey scale (Nasadil & Benešovsky, 2008). Cationic treatment of polyester material provided the improvement of washing fastness in the case of cyan ink prints, at the same time causing reduction of the lightness (Chen *et al*., 2004). Considerable improvement of black ink prints washing fastness was achieved by gamma radiation (Bhatti *et al*., 2012). However, the majority of printing houses cannot afford the equipment for preprint treatments of textile substrates.

Making prints with numerous ink layers can influence the print resistance. Several researches showed that applying more ink layers improve light fastness (Kašiković *et al*., 2012a; 2015a), but at the same time reduce the rubbing fastness (Kašiković *et al*., 2012b). Numerous formulas were developed for the purpose of colour differences estimation such as basic ΔE_{76}, more advanced CMC (l: c) (Clarke *et al*., 1984), BFD (l: c) (Luo & Rigg, 1987), CIE 94 (CIE, 1995) and the most recent one CIE ΔE_{2000} (Kim & Nobbs, 1997). All colour difference formulas use the Euclidean distance in a device independent colour space (ΔL, Δa, Δb) (Luo *et al*., 2001). Newer colour difference formulas are extended to address perceptual non-uniformities while retaining the Lab colour space. There is an ongoing debate on which of the formulas gives the best results, but majority of the researchers are claiming the CIE ΔE_{2000} to be the best one (Xu *et al*., 2001; Kočevar, 2006; Gabrijelčić & Dimitrovski, 2007; 2009).

Printed textile fabrics are usually exposed to the influence of various factors during exploitation. Besides ironing, one of the most influential factors is washing treatment since it influences both the printed inks and fibres of the printed substrate, which highlights the importance of this research regarding influence of washing treatment on colour fastness.

The aim of this research was to analyse the influences of the number of printed ink layers, different fabric weights and thread counts on ink washing resistance. For the purpose of this experiment, colour fastness in regard to the washing treatment was judged, both subjectively by trained professionals using the standard grey scale, and objectively, by calculating colour differences between samples before and after washing treatment.

METHODOLOGY

In this research, three types of polyester fabrics were used; the composition of polyester (100 %) and yarn count of 75D were constant. The varying parameters, fabric weight and thread count were determined according to

Table 1: Characteristics of materials used in testing

Tests	Material composition (%)	Fabric weight (g/m^2)	Thread count p/10 cm	
			Warp	Weft
Material 1	Polyester 100 %	101,5	160	100
Material 2	Polyester 100 %	110,6	170	120
Material 3	Polyester 100 %	141,3	260	120
Methods	ISO 1833	ISO 3801	ISO 7211-2	

the standards: ISO 3801 and ISO 7211–2, respectively. The characteristics of the samples are shown in Table 1.

Digital ink jet printing and after-treatment

A digital piezoelectric drop on demand ink jet printer, able to print up to five ink layers (Mimaki JV 22 - 160, Mimaki Engineering Co., Ltd.) was used for printing the samples. Four commercial process inks (CMYK), J-Eco Subly Nano, were used without further purification. A test target dimensioned 150 cm × 10 cm was prepared to assess the effects of washing treatment on the colour of the printed inks. The test target consisted of four colour patches with same size (35 cm × 10 cm) printed using different process inks: the first patch - 100 % cyan, the second patch - 100 % magenta, the third patch - 100 % yellow and the fourth patch - 100 % black. The test target was printed varying the number of ink layers from one to maximum possible, five ink layers. Alongside advantages of multi-layer printing, the economic aspects of increasing the number of ink layers must be taken into consideration. The ink consumption depends on the device profile used by Mimaki's RasterLink series RIP software. According to Mimaki, rough consumption can be estimated to about 12 cm^3 of ink used in total of four colours on 833 mm × 1041 mm print (Mimaki, n.d.). Operation of printing machines that supply ink from the cartrage can be significantly influenced by multi-layer printing, which demands cartrage replacement more often, considering the usual capacity of 220 cm^3 per cartrage. Although affordable, the ink price of 50 to 70 $ per liter also must be taken into consideration.

After ink jet printing process, printed samples were air-dried for 180 s and then passed through a drying chamber at 130 °C for ink fixating.

Spectrophotometric measurements

Spherical spectrophotometer Datacolour Spectraflash SF 600® PLUS-CT was used to measure colourimetric and reflective changes of printed textile samples. This instrument utilises the d/8 geometry, D65 illuminant and 10° standard observer. CIE L, a and b colour coordinates were determined for each sample. Colour difference values were calculated using CIE ΔE_{76} and CIE ΔE_{2000} formula, between samples printed with 1 to 4 ink layers and samples printed with 5 ink layers ($\Delta E_{a,b}$). In order to estimate the influence of the number of ink layers printed on surface reflectivity, spectral curves were generated for each sample using Techkon SpectroDens measuring device, under the standard D50 illuminant and 2° standard observer (0°/45° geometry).

Determination of colour fastness of printed fabric

After measurements of the printed samples, the samples were exposed to washing treatment according to standard ISO 105-C01 (40 °C, 30 min) using Launder-Ometer® device (SDLAtlas, Great Britain) after which they were compared with untreated samples visually using grey scale, according to SISTEN 20105-A02:1996 and SISTEN 20105-A03:1996 standards.

SEM analysis

SEM analysis was performed to determine the behaviour of every process ink (CMYK) and to analyse the influence of the number of ink layers on washing treatment effects. The SEM microscopic analysis was conducted using electronic microscope JEOL 646O LV. The samples were classified, labelled, and prepared according to the laboratory procedures. To achieve electric conductivity and avoid blurred and unacceptable images, the samples were exposed to gold steaming process (in device Baltec SCD 005).

RESULTS AND DISCUSSION

The changes of ink jet printed textile material characteristics caused by washing treatments were established and quantified *via* previously described experimental procedures, and it will be presented in this section of the paper.

Spectrophotometric measurements after printing

Table 2 presents colour coordinates for all the samples determined by spectrophotometer Datacolour Spectra flash SF 600® PLUS- CT (CIE L, a, b, C, H). Analysis of results shown in Table 2 leads to the conclusion that the number of ink layers affects colour coordinates in the following manner:

Table 2: Characteristics of samples made by spectrophotometric surveying

Sample	Material 1				Material 2				Material 3			
	L	a	b	$\Delta E_{a,b}$	L	a	b	$\Delta E_{a,b}$	L	a	b	$\Delta E_{a,b}$
Cyan 1	48.29	- 7.29	-31.13	16.74	44.21	- 4.32	-31.74	18.99	52.3	-0.53	- 32.08	17.98
Cyan 2	43.78	- 6.09	- 27.7	11.1	37.11	- 2.44	-27.27	10.4	42.67	-0.31	- 31.27	8.67
Cyan 3	39.94	- 5.82	-25.95	6.9	34.42	- 0.02	-24.02	6.3	38.89	0.73	- 30.16	4.65
Cyan 4	36.15	- 5.29	-24.75	2.89	30.73	- 1.23	-23.17	2.74	36.69	2.45	- 28.95	2.14
Cyan 5	33.5	- 4.72	-23.74	/	28.62	- 0.46	- 21.6	/	34.95	1.75	- 27.91	/
Magenta 1	46.74	48.71	0.88	16.38	43.07	49.59	1.55	18.78	51.34	38.48	- 8.58	21.12
Magenta 2	41.34	44.94	2.95	9.56	36.49	42.8	3.12	9.29	39.15	41.25	- 3.06	11.65
Magenta 3	39.24	41.96	2.59	6.2	32.81	38.87	5.51	4.55	36.62	33.33	- 4.57	5.09
Magenta 4	36.54	40.27	3.45	2.91	32.79	38.66	5.12	4.21	34.49	31.06	- 4.06	2.91
Magenta 5	34.37	38.54	4.33	/	29	32.36	5.28	/	32.28	31.87	- 2.35	/
Yellow 1	78.28	- 2.73	65.72	16.57	77.17	4.82	75.02	20.86	79.74	-3.25	68.35	16.53
Yellow 2	74.64	1.78	68.71	10.12	71.77	4.82	75.02	15.02	75.14	2.06	68.87	10.02
Yellow 3	72.02	4.39	70.92	6.03	67.91	6.93	72.02	10.03	72.56	3.81	68.68	7.13
Yellow 4	69.81	6.78	71.71	2.73	64.85	8.49	68.91	5.77	69.69	6.53	66.88	2.88
Yellow 5	68.03	8.84	71.67	/	62.31	8.95	65.05	/	67.68	7.59	65.12	/
Black 1	36.04	- 0.33	- 1.18	13.89	27.28	- 0.3	- 0.14	6.4	35.17	3.42	0.85	12.86
Black 2	30.01	- 0.65	- 0.91	7.85	23.81	- 0.43	- 0.14	2.96	26.84	1.64	- 0.3	4.33
Black 3	25.68	- 0.4	- 1.02	3.52	22.23	- 0.18	- 0.19	1.36	26.03	1.58	- 0.27	3.53
Black 4	23.35	- 0.58	- 0.95	1.19	21.52	- 0.1	- 0.09	0.66	24.15	1.53	- 0.17	1.67
Black 5	22.16	- 0.51	- 0.88	/	20.97	0.07	- 0.18	/	22.52	1.55	- 0.51	/

Increase in the number of printed ink layers resulted in lower CIE L values for each group of samples. Furthermore, if every sample is compared to the corresponding sample printed with five ink layers, the largest colour difference is noticed between the one-layer and five-layer samples, while the smallest colour difference is present between the four-layer and five-layer samples.

After printing, spectral curves were generated for each sample using the spectrophotometer Techkon SpectroDens. The spectral curves of the samples printed on material 3 were selected as representative and will only be shown (due to the limited space) (Figure 1).

Although all spectral curves have a similar and consistent shape, it is evident from Figure 1 that the increased number of ink layers causes lower reflectivity of the printed fabric surface. This is characteristic to all the materials and therefore, can be concluded that further increase in the number of ink layers would cause decline of fabric surface reflectivity. Prints made with four and five layers show equalisation of the spectral curves, which can be expected to continue with futher increase of the number of ink layers. This experimental setup did not allow for further increase of the number of ink layers due to printing machine limitation.

Colour fastness to washing

Once the spectrophotometric measurements of the printed samples were completed, all the samples were exposed to washing treatment according to standard ISO 105 – C01 (40 °C, 30 min), followed by visual evaluation of the samples using grey scale. The results of the visual evaluation (GS) are listed in Table 3. Based on these findings it is noticeable that all three evaluated parameters (colour change, the staining of polyester and cotton adjacent fabric) are decreasing with the increase of the number of printed ink layers for all the materials. It suggests that thread count and fabric weight are not influencing the colour differences after washing treatment, as much as the ink volume is increased by the number of ink layers printed, possibly due to washing treatment breaking bounds between the ink layers rather than the links between inks and fabric surfaces. This explains the greater colour difference in case of samples with higher number of ink layers before and after washing treatment.

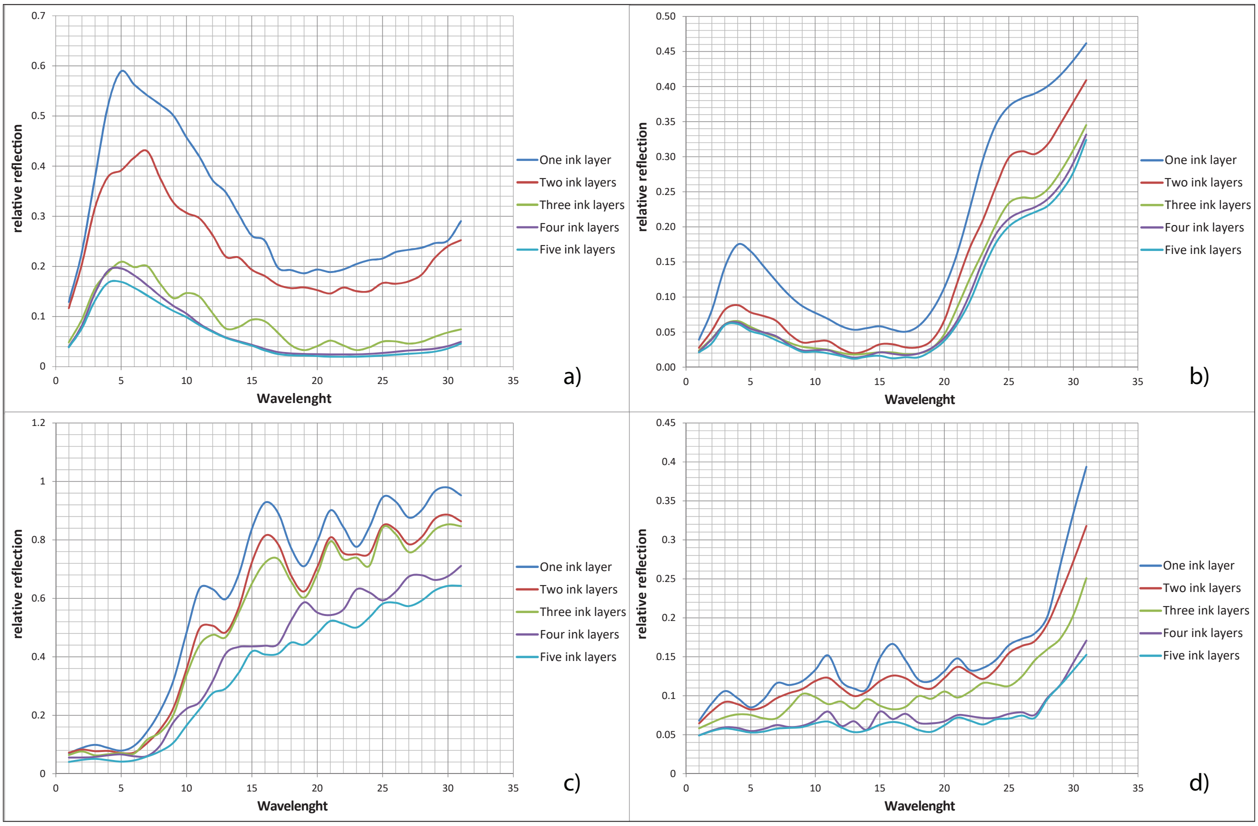

Figure 1: Spectral curves of samples after printing (material 3): cyan (a); magenta (b); yellow (c); black (d)

Visual evaluation and spectrophotometric measurements after washing treatment

Visual evaluation showed insignificant differences between samples through all the materials and number of ink layer variations, although differences between colours are observed even with the grey scale visual evaluation method.

Spectrophotometric measurements are far superior to visual evaluation. The samples were analysed using Datacolour Spectraflash SF 600® PLUS-CT spectrophotometar. The spectrophotometric measurements yielded clear indication of colour differences between samples prior to and after washing (ΔE_{76} and ΔE_{2000}) as shown in Table 3.

These measurements confirmed that the increase in the number of printed ink layers causes larger colour differences before and after washing treatment, as it was assumed after visual evaluation. The values of colour difference after washing treatments between samples printed with five layers and all the other samples did not significantly change. Visual evaluation was the method used for the assessment of staining of the polyester and cotton adjacent fabric as it was not possible to conduct measurements by the spectrophotometric device due to large aperture of 8 mm, which would measure the colour of the cotton adjacent fabric and would not detect small specks of transferred ink.

Statistical analysis

In order to determine how the ink layers and material characteristics (thread count and surface weight) influence both objectively measured colour differences (ΔE) and subjectively judged colour fastness, two-way ANOVA was conducted with material characteristics and number of ink layers as independent factors. In the case of statistically significant ANOVA results, the posthoc Tukey test was used for comparing each pair of sample groups. All statistical tests were conducted using the software IBM SPSS with a 0.01 significance level. Besides statistical significance, the effect size (the practical significance) is also calculated for each test using partial *eta* squared. Table 4 summarises the analysis results while mean values of sample groups are graphically presented in Figure 2.

Table 3: Colour difference values between untreated samples and samples subjected to washing process printed using the same number of ink layers (colour fastness to washing according to ISO 105-C01; 40 °C, 30 min)

Samples	Material 1			Material 2			Material 3		
	ΔE_{76}	ΔE_{2000}	GS*	ΔE_{76}	ΔE_{2000}	GS*	ΔE_{76}	ΔE_{2000}	GS*
C1	5.24	4.61	3 – 4	9.72	6.01	3	14.07	11.78	1
C2	5.56	3.78	3 – 4	10.72	8.45	3	16.20	16.06	1
C3	6.55	4.71	3 – 4	11.10	7.55	2 – 3	17.94	17.14	1
C4	8.27	6.03	3 – 4	13.56	9.26	2 – 3	18.56	17.76	1
C5	10.72	7.65	3 – 4	14.10	9.07	2	20.12	18.84	1
M1	3.22	1.76	4 – 5	7.45	4.19	4	10.45	7.08	4
M2	4.02	2.98	4 – 5	11.54	6.36	4	15.07	13.29	4
M3	4.79	2.01	4 – 5	11.78	5.77	4	17.45	8.31	3 – 4
M4	6.95	3.93	4	13.37	6.23	4	18.40	8.33	3 – 4
M5	8.38	4.09	4	13.61	6.57	4	20.75	10.07	3 – 4
Y1	4.87	2.80	4 – 5	7.23	3.45	3 – 4	9.02	5.65	4
Y2	7.61	3.86	4	11.00	6.23	3 – 4	12.45	7.87	4
Y3	8.78	5.04	4	12.75	8.98	3	15.03	10.03	3
Y4	12.88	6.56	3 – 4	15.91	9.11	3	16.02	10.35	3
Y5	16.38	8.98	3	16.50	11.42	3	18.73	5.32	3
B1	1.36	1.16	5	2.02	1.69	4 – 5	7.10	6.56	2
B2	1.39	1.37	4 – 5	2.09	1.72	4 – 5	12.46	10.52	2
B3	1.78	1.59	4 – 5	3.03	2.34	4 – 5	12.85	10.66	2
B4	2.26	2.00	4 – 5	3.31	2.39	4 – 5	12.93	10.15	1 – 2
B5	3.16	2.82	4 – 5	4.95	3.60	4 – 5	13.02	10.63	1 – 2

Table 4: Results of two-way ANOVA with material characteristics and number of ink layers as independent factors

Dependent value	Effect	F	p	Partial *eta* squared**
ΔE_{2000}	Material	26.158	< 0.01*	0.538
	Ink layers	2.231	0.081	0.166
	Material*ink layers	0.305	0.960	0.051
ΔE_{76}	Material	27.072	< 0.01*	0.546
	Ink layers	5.345	< 0.01*	0.322
	Material*ink layers	0.170	0.994	0.029
Assessment of colour change-grey scale	Material	14.198	< 0.01*	0.387
	Ink layers	0.594	0.669	0.050
	Material*ink layers	0.036	0.990	0.006

* significant at a 0.01 significance level

** less than 0.01 is a small effect; between 0.01 and 0.06 is a medium effect; greater than 0.14 is a large effect

The two-way ANOVA with material characteristics and number of ink layers between subject factors showed the main effect of only material characteristics, and no main effect of number of ink layers or interactive effect in the case of ΔE_{2000} and the subjective assessment of specimen colour change according to grey scale.

The posthoc tests also showed the same results in both cases, that a statistically significant difference existed between material 3 and the other two: material 1 and material 2, while material 1 and 2 did not differ significantly from each other.

The ANOVA analysis of ΔE_{76} values showed the main effect of both factors, where posthoc tests showed that statistically significant difference existed between each of the materials and significant difference between samples with one ink layer and samples with four and five ink layers, while the group of samples with two and three ink layers did not differ significantly from each other and did not differ from other specimens.

Spectral curves were also generated using the spectrophotometer SpectroDens after the washing treatment. Samples printed with five ink layers on

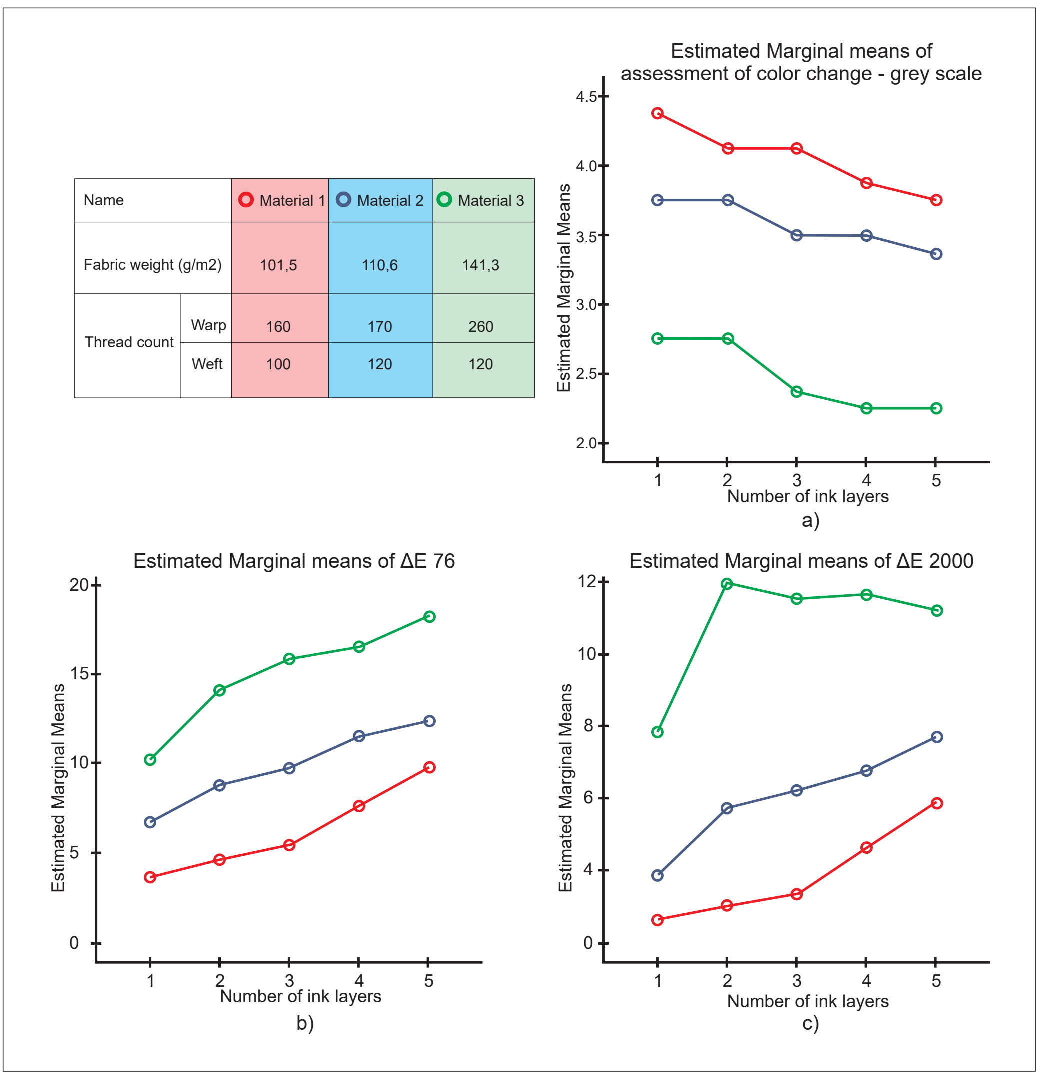

Figure 2: The mean values of sample groups for the subjective assessment of specimen colour change according to grey scale (a); ΔE_{76} (b) and ΔE_{2000} (c)

material 3 were selected as representative samples, and they show a typical influence of washing treatment on the reflectance of printed material surface, which can be seen in Figure 3. In case of all four process inks it is noticeable that the washing treatment caused an increase in relative spectral reflectance. This could be explained by the ink washing off from the material surface, that resulted in increasing surface reflectance.

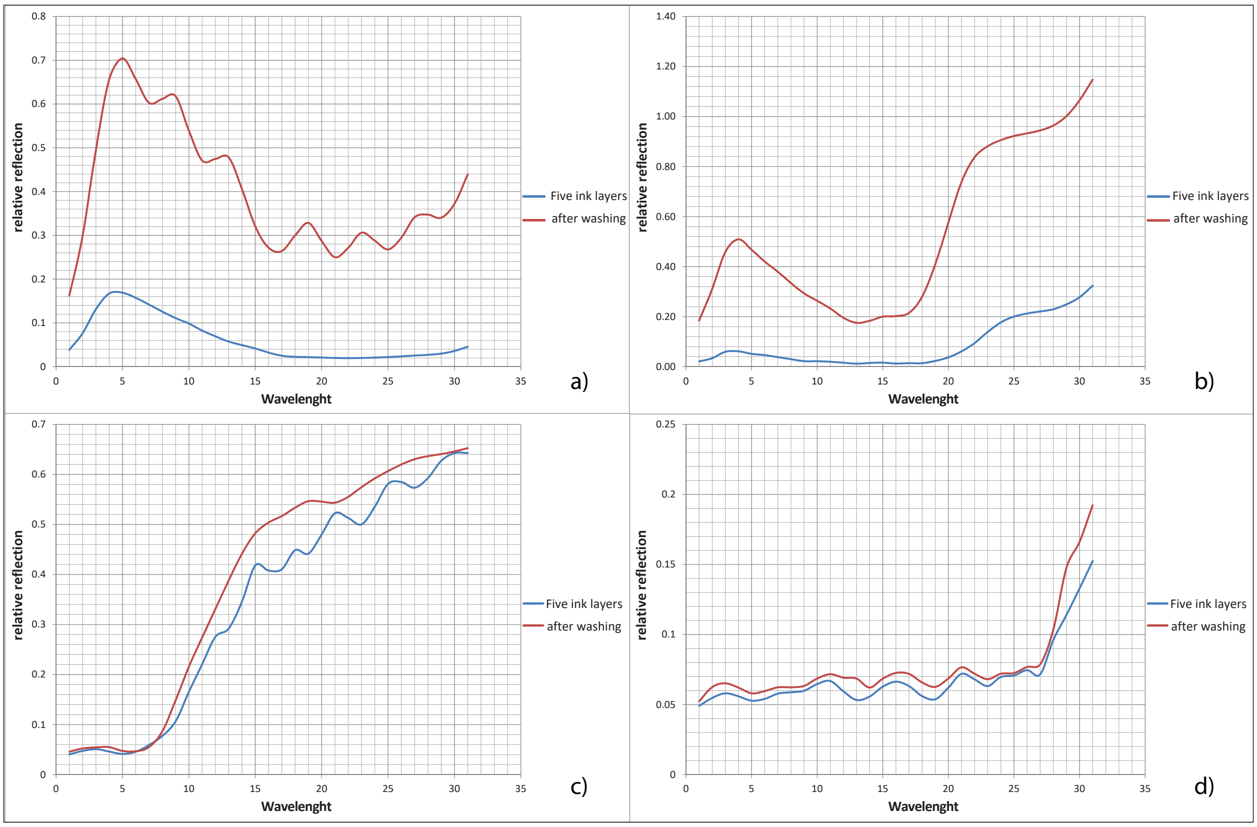

Figure 3: Spectral curves of the samples printed with five ink layers, before and after washing treatment (material 3): cyan (a); magenta (b); yellow (c); black (d)

SEM analysis

Using the SEM, all the samples were analysed before and after the printing process, as well as after the washing treatment. Samples printed with five cyan ink layers on fabric 3 were selected as representative samples (due to limited space). Figure 4 shows clean textile material fabrics before printing, fibres printed with five ink layers and fibres after washing treatment magnified 5,000 times.

It can be noticed that the morphology of the surface exhibits changes after printing. Figure 4a shows the smooth fabric surface before printing, while Figure 4b shows some ink particles (pigment) on the fibre surface. The amount of these particles increases with the rise of printed ink layers as confirmed by spectrophotometric measurements, which was also noticed in previous researches (Kasikovic *et al*., 2012a; 2015b).

Fabric surface observations after washing treatment, using SEM analysis show that particles were partially removed as shown in Figure 4c. This removal of ink particles resulted in the smoother and more reflective surface, which was also confirmed by spectrophotometric measurements using SpectroDens device.

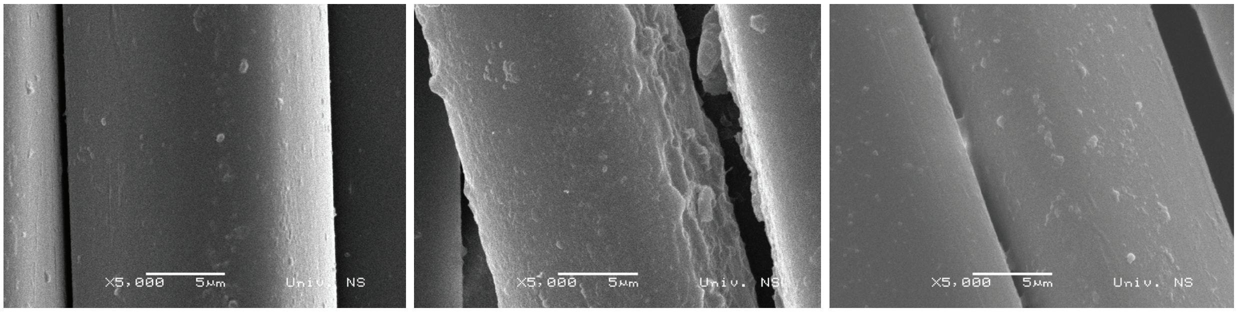

Figure 4: SEM images of material 3 C5 samples, before printing (a); after printing (b); after washing (c)

CONCLUSION

The aim of this research was to determine the behaviour of textile materials printed using different number of ink layers exposed to a washing treatment. The analysed samples differed in their material properties, colours of printed ink and number of printed ink layers.

The results of the research show that increased number of printed ink layers always results in lower luminance coordinates of Lab colour space, while the trend continues with each new printed ink layer. On the other hand, increasing the number of printed ink layers reduces surface reflectivity, which is caused by the larger amount of ink (thicker ink deposit) on the material surface that absorbs light and also by the fibres merging together by ink. However, increased number of printed layers reduces resistance to washing, diminishing the fastness of colour and increasing the staining of adjacent fabric, as it was confirmed by spectrophotometric measurement and visual evaluation. Samples exposed to washing treatment had higher surface reflectance due to partial removal of ink particles from the surface as shown by SEM analysis.

This experiment showed that higher number of printed ink layers does not improve resistance to washing treatments. It is necessary to take into consideration the influencing factors examined in this research in order to correctly predict the behaviour of the product during exploitation. There are numerous other influencing factors whose impact should be examined in relation to increased number of layers in order to obtain complete insight into printed material behaviour during exploitation period.

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REFERENCES

Agarwal G., Koehl L., Perwueltz A. & Lee K.S. (2011). Interaction of textile parameters, wash - ageing and fabric softener with mechanical properties of knitted fabrics and correlation with textile- hand. I. Interaction of textile parameters with laundry process. *Fibres and Polymers* **12**(5): 670 – 678.
DOI: https://doi.org/10.1007/s12221-011-0670-7

Bhatti I.A., Adeel S., Nadeem R. & Asghar T. (2012). Improvement of colour strength and colourfastness properties of gamma irradiated cotton using reactive black–5. *Radiation Physics and Chemistry* **81**(3): 264 – 266.
DOI: https://doi.org/10.1016/j.radphyschem.2011.10.019

Chairat M., Darumas U., Bremnerc J.B. & Bangrakb P. (2010). Dyeing of cotton yarn with the aqueous extract of the leaves of *Eupatorium odoratum* L. in Thailand and associated extract toxicity studies. *Colouration Technology* **127**(5): 346 – 353.
DOI: https://doi.org/10.1111/j.1478-4408.2011.00321.x

Changa I.S., Leea S.S. & Choeb E.K. (2009). Digital textile printing (DTP) wastewater treatment using ozone and membrane filtration. *Desalination* **235**(1 – 3): 110 – 121.

Chen W., Zhao S. & Wang X. (2004). Improving the colour yield of ink-jet printing on cationized cotton. *Textile Research Journal* **74**(1): 68 – 71.
DOI: https://doi.org/10.1177/004051750407400112

Clark M., Yang K. & Lewis D.M. (2009). Modified 2,4-difluoro-5-chloro-pyrimidine dyes and their application in ink-jet

printing on wool fabrics. *Colouration Technology* **125**(3): 184 – 190.
DOI: https://doi.org/10.1111/j.1478-4408.2009.00195.x

Clarke F.J.J., McDonald R. & Rigg B. (1984). Modification to the JPC79 colour-difference formula. *Journal of the Society of Dyers and Colourists* **100**(4): 128 – 132.
DOI: https://doi.org/10.1111/j.1478-4408.1984.tb00969.x

Fang H., Hou Y., Liang T. & Fan Q. (2011). Study status and development trends of digital inkjet printing of textiles. *Textile Auxiliaries* **9**: 5 – 9.

Fang K. & Zhang C. (2009). Surface physical-morphological and chemical changes leading to performance enhancement of atmospheric pressure plasma treated polyester fabrics for inkjet printing. *Applied Surface Science* **255**(17): 7561 – 7567.
DOI: https://doi.org/10.1016/j.apsusc.2009.04.028

Ferrero F. & Periolatto M. (2011). Ultrasound for low temperature dyeing of wool with acid dye. *Ultrasonics Sonochemistry* **19**(3): 601 – 606.
DOI: https://doi.org/10.1016/j.ultsonch.2011.10.006

Fralix M.T. (2001). From mass production to mass customization. *Journal of Textile and Apparel, Technology and Management* **1**(2): 1 – 7.

Gabrijelčić H. & Dimitrovski K. (2007). Numerički i grafički prikaz i usporedba dvobojnih tkanina s različitim modelima boja. *Tekstil* **56**(4): 209 – 220.

Gabrijelčić H. & Dimitrovski K. (2009). Use of regression methods for determining the relation between theoretical-linear and spectrophotometrical colour values of bicolour woven structures. *Colouration Technology* **125**(2): 74 – 85.
DOI: https://doi.org/10.1111/j.1478-4408.2009.00178.x

Ganguli K.L. & van Eendenburg J. (1980). Mass transfer in a laboratory washing machine. *Textile Research Journal* **50**(7): 428 – 432.
DOI: https://doi.org/10.1177/004051758005000707

International Commission on Illumination (CIE) (1995). *Industrial Colour-difference Evaluation. CIE Publication 116, 1995*. International Commission on Illumination Central Bureau, Vienna, Austria.

Jurič I., Kašiković N., Stančić M., Novaković D., Vladić G. & Majnarić I. (2015). The influence of heat treatment on print mottle of screen printed textile knitted fabrics. *Applied Thermal Engineering* **90**: 215 – 220.
DOI: https://doi.org/10.1016/j.applthermaleng.2015.07.013

Kalantzi S., Mamma D., Kalogeris E. & Kekos D. (2010). Improved properties of cotton fabrics treated with lipase and its combination with pectinase. *Fibres and Textiles in Eastern Europe* **18**(5): 86 – 92.

Kašiković N., Novaković D., Karlović I. & Vladić G. (2012a). Influence of ink layers on the quality of ink jet printed textile materials. *Tekstil ve Konfeksiyon* **22**(2): 115 – 124.

Kašiković N., Novaković D., Vladić G. & Avramović D. (2012b). Influence of ink layers on the colourfastness to rubbing of printed textile materials. *Tekstilna Industrija* **60**(1): 28 – 32.

Kašiković N., Novaković D., Karlović I., Vladić G. & Milić N. (2015a). Colourfastness of multilayer printed textile materials to artificial light exposure. *Acta Polytechnica Hungarica* **12**(1): 161 – 173.

Kašiković N., Novaković D., Milić N., Vladić G., Zeljković Ž. & Stančić M. (2015b). Thermovision and spectrophotometric analysis of ink volume and material characteristics influence on colour changes of heat treated printed substrates. *Technical Gazette* **22**(1): 33 – 41.
DOI: https://doi.org/10.17559/TV-20130928115500

Kašiković N., Stančić M., Vladić G., Grujić D., Novaković D., Milošević R. & Pinćjer I. (2017). The influence of heat treatment on the quality of screen printed textile substrates. *Revista Materia* **22**(1): e11791.
DOI: https://doi.org/10.1590/s1517-707620170001.0123

Kim D.H. & Nobbs J.H. (1997). New weighting functions for the weighted CIELAB colour difference formula. In: AIC Colour 97. *Proceedings of the 8th AIC Colour Congress*, The Colour Association of Japan, 25 – 30 May, Kyoto, Japan, pp. 446 – 449.

Kim S.H. (2009). Developing textile design having watercolour effect and woven texture using photoshop for transfer digital textile printing (DTP). *Journal of Fashion Business* **13**(6): 89 – 98.

Kissa E. (1971). Kinetics of oily soil release. *Textile Research Journal* **41**(9): 760 – 767.
DOI: https://doi.org/10.1177/004051757104100907

Kočevar N.T. (2006). Kolorimetrijska analiza i vizuelna ocjena boja na dvobojnoj tkanini. *Tekstil* **55**(3): 127 – 134.

Lam Y.L., Kan C.W. & Yuen C.W.M. (2011). Physical and chemical analysis of plasma-treated cotton fabric subjected to wrinkle-resistant finishing. *Cellulose* **18**(2): 493 – 503.
DOI: https://doi.org/10.1007/s10570-011-9498-y

Lee A., Seo M.H., Yang S., Koh J. & Kim H. (2008). The effects of mechanical actions on washing efficiency. *Fibres and Polymers* **9**(1): 101 – 106.
DOI: https://doi.org/10.1007/s12221-008-0017-1

Luo M.R., Cui G. & Rigg B. (2001). The development of the CIE2000 colour difference formula: CIEDE2000. *Colour Research and Application* **26**(5): 340 – 350.
DOI: https://doi.org/10.1002/col.1049

Luo M.R. & Rigg B. (1987). BFD (l: c) colour-difference formula. Part I: development of the formula. *Journal of the Society of Dyers and Colourists* **103**(2): 86 – 94.
DOI: https://doi.org/10.1111/j.1478-4408.1987.tb01099.x

Mimaki (n.d.) How much ink is consumed in a image? Available at *http://www.mimakieurope.com/faq/how-much-ink-is-consumed-in-a-Image/*, Accessed 28 August 2017.

Nakpathom M., Somboon B. & Narumol N. (2009). Papain enzymatic degumming of Thai Bombyx mori silk fibres. *Journal of Microscopy Society of Thailand* **23**(1): 142 – 146.

Nasadil P. & Benešovsky P. (2008). Plasma in textile treatment. *Chemicke Listy* **102**: 1486 – 1489.

Park H., Wallace W.C., Hyunyoung O. & Soomin P. (2006). Image quality of inkjet printing on polyester fabrics. *Textile Research Journal* **76**(9): 720 – 728.
DOI: https://doi.org/10.1177/0040517507074368

Stančić M., Grujić D., Novaković D., Kašiković N., Ružičić B. & Geršak J. (2014). Dependence of warm or cold feeling and heat retention ability of knitwear from digital print parameters. *Journal of Graphic Engineering and Design* **5**(1): 25 – 32.

Stančić M., Ružičić B., Kašiković N., Grujić D., Novaković D. & Milošević R. (2016). Washing treatment impact on print quality of screen printed knitted fabrics. *Revista Materia* **21**(3): 817 – 826.
DOI: https://doi.org/10.1590/S1517-707620160003.0076

Tomsic B., Simoncic B., Orel B., Cerne L., Forte Tavcer P., Zorko M. & Kovac J. (2008). Sol-gel coating of cellulose fibres with antimicrobial and repellent properties. *Journal of Sol-Gel Science and Technology* **47**(1): 44 – 57.
DOI: https://doi.org/10.1007/s10971-008-1732-1

Ujiie H. (2006). *Digital Printing of Textiles*, 1st edition, pp. 29 – 52. Woodhead Publishing Limited, Cambridge, England.

Vilcnik A., Jerman I., Surca Vuk A., Kozelj M., Orel B., Tomsic B. & Kovac J. (2009). Structural properties and antibacterial effects of hydrophobic and oleophobic sol-gel coatings for cotton fabrics. *Langmuir* **25**(10): 5869 – 5880.
DOI: https://doi.org/10.1021/la803742c

Xiang W. & Cai Z.S. (2008). Dye behaviour of cationically treated silk. *Journal of Applied Polymer Science* **108**(2): 1005 – 1012.
DOI: https://doi.org/10.1002/app.26990

Xu H., Yaguchi H. & Shiori S. (2001). Testing CIELAB-based colour-difference formulae using large colour differences. *Optical Review* **8**(6): 487 – 494.
DOI: https://doi.org/10.1007/BF02931740

Zhang C. & Fang K. (2009). Surface modification of polyester fabrics for inkjet printing with atmospheric-pressure air/ Ar plasma. *Surface and Coatings Technology* **203**(14): 2058 – 2063.
DOI: https://doi.org/10.1016/j.surfcoat.2009.02.006