THERMOVISION AND SPECTROPHOTOMETRIC ANALYSIS OF INK VOLUME AND MATERIAL CHARACTERISTICS INFLUENCE ON COLOUR CHANGES OF HEAT TREATED PRINTED SUBSTRATES

Nemanja Kašiković, Dragoljub Novaković, Neda Milić, Gojko Vladić, Željko Zeljković, Mladen Stančić

Original scientific paper

This paper presents experimental usage of updated control methods such as thermovision and spectrophotometric analysis in graphic industry. These methods were applied to research the influence of ink volume and material characteristics on colour and heat treated printed substrates. Samples used in these experiments were printed by digital ink jet printing technique using Mimaki JV22 printing machine and J-Eco Subly Nano inks. As printing substrates, three different types of materials were used. Materials were different in respect of fabric weight and thread count, while material composition was the same for all three materials. The appropriate test card consisting of fields of CMYK colours was printed, varying the number of ink layers applied. Samples were exposed to heat treatment after printing. The heat applied was measured by thermovision camera. Spectrophotometric measurements were conducted before and after heat treatment. Based on data gathered by spectrophotometric measurements colour difference ΔE_{76} was calculated. Results showed that increasing number of layers, as well as right choice of substrates, can improve behaviour of printed product during exploitation.

Keywords: digital textile printing; heat treatment; ink layers; material characteristics

Termovizijska i spektrofotometrijska analiza diferenciranog nanosa boja na specifične podloge izložene toplinskim opterećenjima

Izvorni znanstveni članak

U radu su predstavljene primjene suvremenih metoda kontrole, kao što su termovizijska i spektrofotometrijska analiza, u grafičkoj industriji. Suvremene metode kontrole primijenjene su pri istraživanju parametara diferenciranog nanosa boje na specifične podloge izložene toplotnim opterećenjima. Uzorci koji su rabljeni za istraživanje odštampani su Ink jet postupkom na digitalnom tiskarskom stroju Mimaki JV 22 koja koristi J-Eco Subly nano boje. U procesu tiska, rabljene su tri vrste podloga, pri čemu je za sve njih sastav materijala bio isti, ali su se razlikovale prema parametrima površinske mase i gustoće pletenja. Odgovarajuća test karta koja se sastojala od polja CMYK otiskana je s pet različitih nanosa boje. Ti uzorci su izloženi toplinskom djelovanju, pri čemu je polje toplinskog djelovanja mjereno termovizijskom kamerom. Uzorci su analizirani spektrofotometrijskim mjerenjima prije i poslije toplinskog djelovanja te je na osnovu tih podataka određena vrijednost razlike boje (ΔE_{76}). Dobiveni rezultati su pokazali da povećanje broja nanosa boje, kao i odabir odgovarajuće podloge za štampu, može povećati eksploatacijske karakteristike otisaka.

Ključne riječi: digitalni tisak tekstila; karakteristike podloge; nanosi boje; toplotno djelovanje

1 Introduction

In order to achieve the best possible quality of final product, manufacturers have to use measurements and control techniques up to date, regardless of the industry type. Besides spectrophotometric print measurements and analysis which are widely spread in graphic industry, measurement methods such as thermovision are more often used today. Thermovision measurements enable control of process parameters that have influence on quality of final products especially textile products that are usually exposed to heat treatment.

When special attention is given to the part of graphical industry that deals with textile printing it can be observed that nowadays a wide range of textile materials and different printing techniques are used. Among techniques used for textile printing, digital printing is taking significant market share due to its advantages [1]. The quality of colour reproduction on textile materials is influenced by wide variety of factors, such as graphic system used for printing, ink volume, ink characteristics, substrate characteristics, etc.

During exploration printed products are exposed to variety of environmental factors such as light, heat, chemical agents, etc. [2]. Heat treatment of printed textile products is usually used during manufacturing process in order to achieve better visual effects. Heat can be applied by any heating element such as a hand held or an industrial iron. In these processes heat applied influences

ink as well as textile fibres of printed material. As a consequence characteristics of printed colour are changed.

In order to achieve desired quality, changes in colour should be as small as possible. Besides standard criteria for evaluation of colour fastness such as gray-scale, instrumental spectrophotometric measurements are used to quantify changes in colour. When the top quality is a goal, manufacturers cannot rely on visual judgment as used in gray-scale method. Much more reliable is determination of colour characteristics and colour differences by means of instrumental measurements which provide numerical values for describing colour. Graphic industry has predetermined colour management standards which include such objective methods of describing colour and colour differences.

Spectrophotometer and colorimeter are instruments most often used for colour determination. Although spectrophotometers give more precise measurements of colour characteristics, colorimeters are also often used because they are more affordable. As a result of spectrophotometric measurement spectrophotometric curve is created due to emission, reflection and transmission factors. Today's spectrophotometers provide CIE standard observer settings as well as standard light sources. Information retrieved from the instrument can be translated to any stimulus colour model. Colour difference can be calculated based on colour characteristics measured by instrument, thus provide objective information of colour reproduction and any changes in

colour during production or exploitation.

Heat can be transferred from heating element to textile material by means of conduction, convection and radiation [3, 4, 5]. In order to examine influence of heat treatment on print it is of crucial importance to gather accurate values of temperature transmitted by heating element. Measurement of temperatures is possible by usage of thermovision cameras. Although heating element gives constant temperatures, these temperatures are different across the heating surface. Thermovision cameras give precise information related to temperatures in certain areas of heating element surface.

This is possible by capturing image of infra-red radiation. Measurements gathered by thermovision camera are more accurate than other measurement methods since its non-intrusive measurement method (does not disturb the measured field of temperature) and it gives very accurate and precise measurements [6, 7].

Principle of measurement is based on:
- Temperature is measured from heating field [8];
- Appropriate software can calculate temperatures according to image captured by thermal imaging camera and it can be further analysed [9];
- Temperature value can be expressed as function of five parameters [10]:

$$T_{ob} = f(\varepsilon_{ob}, T_{atm}, T_0, \omega, d\,),\, \mathrm{K} \qquad (1)$$

where: ε_{ob} – band emissivity of investigated surface, T_{atm} – temperature of atmosphere, T_0 – ambient temperature, ω – relative humidity, d – camera to object distance.

Having in mind that all mentioned parameters are taken into consideration during temperature measurement, precision gets very high. Additional advantage of thermo visual camera is safety of the operator because it is not in direct contact with the hot object. Procedure of taking thermo vision measurements is described in literature [11].

The right choice of printing technique is crucial for production of high quality prints. In order to make the right choice one must take into consideration all the parameters from characteristics substrates, characteristics of orienting process, quality expectations and volume of print runs. Digital ink jet printing is taking considerable market share of printed textile products due to its ability to print on wide variety of materials.

One of the possibilities provided by digital ink jet printing is printing in multiple ink layers. This possibility is utilized in this experiment. As substrate for this experiment artificial polyester textile material is chosen. This material is commonly used in production of graphic products that are exposed to environmental influences and demand long exploitation periods (for example flags, billboards, sport wear etc.).

The purpose of this conducted experiment is to determine how characteristics of material and number of ink layers of printed product which are exposed to standard heating treatment will influence print quality.

2 Materials and methods

This research is dealing with examination of thermal treatment conducted on three specific types of textiles printed using digital ink jet printer. Spectrophotometric measurements were conducted before and after heat treatment. For all samples, colour coordinates were determined by spectrophotometer, as well as value of colour difference of treated and untreated samples.

Following the strict scientific research methodology relevant data was measured and quantified in order to describe precise influence of heat treatment on printed samples. Samples were printed on Mimaki JV22 – 160 digital ink jet printing machine using J-Eco Subly nano inks. Three different types of textile material were selected as printing substrates, chosen because of its specific characteristics such as superior straight and durability to atmospheric influences [12]. For each of the samples the following characteristics were determined: fabric weight using standard ISO 3801, thread count (ISO 7211-1) and material composition (ISO 1833). Material characteristics are shown in Tab. 1.

Table 1 Characteristics of textile materials used in the experiment

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

For purpose of researching heat influence treatment custom test chart was developed sized 150 × 10 cm. Chart consisted of four fields sized 35 × 10 cm; first field – 100 % cyan, second field – 100 % magenta, third filed – 100 % yellow and fourth filed – 100 % black.

Digital ink jet printing machine Mimaki JV22 – 160 provides possibility to print multiple ink layers, used in order to print test charts in five different number of ink layers. Therefore measurement and analysis included these variations in combination with thermal treatment in order to examine influence of ink volume on colour changes related to heat treatment.

One could assume that increasing ink volume will also increase durability over long period of use and exposure to heat treatment. For colorimetric measurements and reflection measuring spectrophoto-meter Datacolor Spectraflash SF 600® PLUS - CT was used with D65 light source, standard observer 10° and aperture 16 mm.

60 samples were analysed altogether, 20 samples of each material varying colours and number of ink layers. Exposing samples to heat treatment was conducted according to standard ISO 105-X11. Recommended temperature for this material composition is 110 °C.

In order to apply heat load on printed samples Quick Tech 45 was used. Heating element was preheated on desired temperature in order to achieve constant temperature during experiment. To achieve precise and constant thermal treatment thermovision IR camera FLIR P65 was utilized. This camera provided thermal imaging and temperature measurements of heating surface.

After thermal treatment of samples spectrophoto-metric measurement was conducted in order to determine influence of thermal treatment on printed samples and their colour. In order to determine statistically how

material characteristic and number of ink layer influence the colour differences (CIE LCH colour space) caused by ironing ANOVA, tests were used.

3 Results

In this chapter results gathered by instrumental measurements are reported. Results are divided according to the type of measurement conducted.

3.1 Spectrophotometric measurements after printing process

After samples were printed, coordinates CIE L (lightness), a (green-red coordinate), b (blue-yellow coordinate), C (chroma) and H (hue) colour coordinates (CIE Lab and LCH colour spaces) were determined for all printed samples. The CIE LCH colour space is similar to CIELAB, with polar coordinates of chroma (C) and hue (H) derived directly from the rectangular ones – a and b

value, while lightness coordinate L is the same in both spaces. The reason for calculating C and H values lies in their intuitive connection with human perception of colour. Results are presented in Tab. 2, 3 and 4. In the same table colour difference between samples and sample printed with five ink layers was given. All the samples were compared to one printed with five layers because earlier research shows that five layer prints showed best light fastness [13]. Colour difference was calculated using ΔE_{76} formula. The colour difference ΔE_{76} is generally calculated as the square root of the combined squares of the chromaticity differences, Δa and Δb, and the Lightness difference, ΔL. Colour difference ΔE_{76} was chosen as recommended by [14].

Besides values of colour coordinates and colour difference, the Pearson correlation coefficient (r) and the corresponding coefficient of determination (r^2) between lightness and ink layer number and between chroma and ink layer number are shown.

Table 2 Spectrophotometer measurement results for material 1

Sample	L	a	b	C	h	ΔE	$r(r^2)$ (L and ink layer number)	$r(r^2)$ (C and ink layer number)
1-1C	48,29	−7,29	−31,13	31,97	256,82	16,74		
1-2C	43,78	−6,09	−27,7	28,36	257,6	11,1		
1-3C	39,94	−5,82	−25,95	26,6	257,36	6,9		
1-4C	36,15	−5,29	−24,75	25,31	257,94	2,89	−0,99	−0,97
1-5C	33,5	−4,72	−23,74	24,2	258,77	/	(0,98)	(0,94)
1-1M	46,74	48,71	0,88	48,72	1,03	16,38		
1-2M	41,34	44,94	2,95	45,03	3,76	9,56		
1-3M	39,24	41,96	2,59	42,04	3,53	6,2		
1-4M	36,54	40,27	3,45	40,42	4,9	2,91	−0,98	−0,98
1-5M	34,37	38,54	4,33	38,78	6,41	/	(0,96)	(0,96)
1-1Y	78,28	−2,73	65,72	65,77	92,38	16,57		
1-2Y	74,64	1,78	68,71	68,73	88,52	10,12		
1-3Y	72,02	4,39	70,92	71,05	86,46	6,03		
1-4Y	69,81	6,78	71,71	72,03	84,6	2,73	−0,99	0,94
1-5Y	68,03	8,84	71,67	72,22	82,97	/	(0,98)	(0,88)
1-1K	36,04	−0,33	−1,18	1,23	254,56	13,89		
1-2K	30,01	−0,65	−0,91	1,12	234,55	7,85		
1-3K	25,68	−0,4	−1,02	1,1	248,63	3,52		
1-4K	23,35	−0,58	−0,95	1,11	238,68	1,19	−0,96	−0,91
1-5K	22,16	−0,51	−0,88	1,02	239,54	/	(0,92)	(0,83)

Note: Labels in the Sample column are structured so that the first number represents textile material; the second number represents number of ink layers while the letter represents colour that the sample was printed in.

Table 3 Spectrophotometer measurement results for material 2

Sample	L	a	b	C	h	ΔE	$r(r^2)$ (L and ink layer number)	$r(r^2)$ (C and ink layer number)
2-1C	44,21	−4,32	−31,74	32,03	262,25	18,99		
2-2C	37,11	−2,44	−27,27	27,38	264,88	10,4		
2-3C	34,42	−0,02	−24,02	24,02	269,95	6,3		
2-4C	30,73	−1,23	−23,17	23,2	266,96	2,74	−0,97	−0,95
2-5C	28,62	−0,46	−21,6	21,6	268,79	/	(0,94)	(0,90)
2-1M	43,07	49,59	1,55	49,62	1,79	18,78		
2-2M	36,49	42,8	3,12	42,92	4,17	9,29		
2-3M	32,81	38,87	5,51	39,26	8,06	4,55		
2-4M	32,79	38,66	5,12	39	7,55	4,21	−0,95	−0,96
2-5M	29	32,36	5,28	32,79	9,26	/	(0,90)	(0,92)
2-1Y	77,17	4,82	75,02	75,18	86,32	20,86		
2-2Y	71,77	4,82	75,02	75,18	86,32	15,02		
2-3Y	67,91	6,93	72,02	72,36	84,5	10,03		
2-4Y	64,85	8,49	68,91	69,43	82,98	5,77	−0,99	−0,96
2-5Y	62,31	8,95	65,05	65,66	82,17	/	(0,98)	(0,92)
2-1K	27,28	−0,3	−0,14	0,33	205,02	6,4		
2-2K	23,81	−0,43	−0,14	0,45	198,29	2,96		
2-3K	22,23	−0,18	−0,19	0,26	227	1,36		
2-4K	21,52	−0,1	−0,09	0,14	222,64	0,66	−0,93	−0,77
2-5K	20,97	0,07	−0,18	0,19	293,04	/	(0,86)	(0,59)

Note: Labels in the Sample column are structured so that the first number represents textile material; the second number represents number of ink layers while the letter represents colour that the sample was printed in.

Table 4 Spectrophotometer measurement results for material 3

Sample	L	a	b	C	h	ΔE	r(r^2) (L and ink layer number)	$r(r^2)$ (C and ink layer number)
3-1C	52,3	−0,53	−32,08	32,09	269,06	17,98		
3-2C	42,67	−0,31	−31,27	31,27	269,43	8,67		
3-3C	38,89	0,73	−30,16	30,17	271,38	4,65	−0,93	−0,99
3-4C	36,69	2,45	−28,95	29,05	274,84	2,14	(0,86)	(0,98)
3-5C	34,95	1,75	−27,91	27,97	273,59	/		
3-1M	51,34	38,48	−8,58	39,43	352,19	21,12		
3-2M	39,15	41,25	−3,06	41,36	355,75	11,65		
3-3M	36,62	33,33	−4,57	33,64	352,19	5,09	−0,90	−0,87
3-4M	34,49	31,06	−4,06	31,33	352,56	2,91	(0,81)	(0,76)
3-5M	32,28	31,87	−2,35	31,96	355,78	/		
3-1Y	79,74	−3,25	68,35	68,42	92,72	16,53		
3-2Y	75,14	2,06	68,87	68,9	88,29	10,02		
3-3Y	72,56	3,81	68,68	68,78	86,83	7,13	−0,99	−0,83
3-4Y	69,69	6,53	66,88	67,2	84,42	2,88	(0,98)	(0,69)
3-5Y	67,68	7,59	65,12	65,56	83,35	/		
3-1K	35,17	3,42	0,85	3,52	13,89	12,86		
3-2K	26,84	1,64	−0,3	1,67	349,55	4,33		
3-3K	26,03	1,58	−0,27	1,6	350,32	3,53	−0,90	−0,72
3-4K	24,15	1,53	−0,17	1,54	353,8	1,67	(0,81)	(0,52)
3-5K	22,52	1,55	−0,51	1,63	341,99	/		

Note: Labels in the Sample column are structured so that the first number represents textile material; the second number represents number of ink layers while the letter represents colour that the sample was printed in.

3.2 Thermovision measurements

Thermovision camera was used for measurement of heating element temperature. According to standard ISO 105-X11 temperature of 110 °C is recommended for material composition used in this experiment. Surface of heating element was cleaned and prepared for measurement. The whole process of heat treatment was filmed with a thermovision camera. Special attention was given in order to minimize or completely eliminate temperature variations. Fig. 1 represents characteristic values of temperatures used in this experiment.

As it can be seen from Fig. 1 there are some differences in temperature of the heating element surface. In order to eliminate possibility of variation in thermal load applied, all the samples were positioned in the same spot so they can be in contact in the centre of the heating element where temperature was constant.
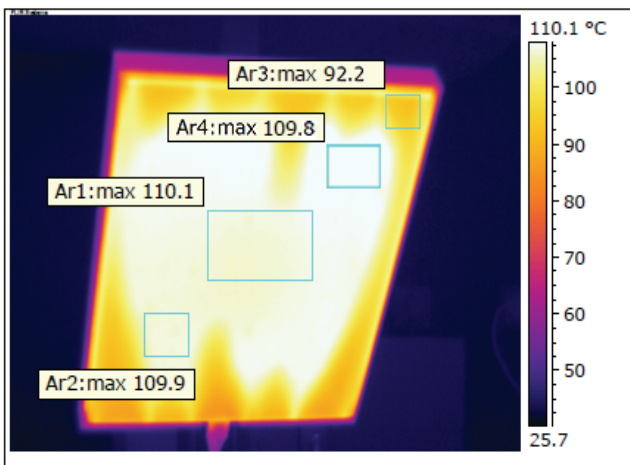

Figure 1 Thermovision image of heating element

3.3 Spectrophotometric measurements after thermal load

After thermal treatment of printed samples spectrophotometric measurements were done in order to determine influence of thermal treatment on the printed

samples. Earlier research with similar topic [15] showed that the number of ink layers does not influence amount of changes caused by thermal treatment. These researches based their conclusion on visual judgment, grayscale method while this research presented instrumental measurements. Results of these measurements, values of ΔL, Δa, Δb, ΔC and Δh are shown in Tabs. 5, 6 and 7.

Measured values of colour coordinates before and after heat treatment for all variations of ink layers are presented in 3-dimensional colour space, Figs. 2, 3 and 4. Summary of colour differences grouped by colour is shown in Fig. 5.

Table 5 Differences of colour coordinates before and after thermal load for material 1

Sample	ΔL	Δa	Δb	ΔC	Δh
1-1C	2,39	−0,33	−1,09	1,13	−0,36
1-2C	0,23	−0,25	−2,26	2,27	0,37
1-3C	−1,53	0,84	−0,99	0,79	2,45
1-4C	−1,24	0,58	0,42	−0,53	5,71
1-5C	−0,1	−0,58	−0,24	0,37	−1,07
1-1M	1,27	3,88	−0,56	3,82	−1,1
1-2M	1,44	2,75	−0,09	2,74	−0,27
1-3M	−1,47	−0,67	−0,16	−0,69	−0,15
1-4M	0,9	0,78	−0,21	0,77	−0,28
1-5M	0,73	−0,42	−0,28	−0,43	−0,27
1-1Y	1,08	−1,12	−0,13	−0,26	1,09
1-2Y	0,03	−1,13	−0,94	−1,03	1,12
1-3Y	0,92	−0,63	−0,49	−0,57	0,54
1-4Y	1,03	0,25	−0,3	−0,28	−0,3
1-5Y	0,28	−0,41	0,65	0,59	0,48
1-1K	0,95	0,48	−0,58	0,71	-
1-2K	1,16	0,24	−0,2	0,31	-
1-3K	0,39	0,75	−0,37	0,83	-
1-4K	−0,63	−0,27	−0,08	−0,18	-
1-5K	−0,27	0,07	0,58	−0,28	-

Note: Labels in the Sample column are structured so that the first number represents textile material; the second number represents number of ink layers while the letter represents colour that the sample was printed in. The value of hue change Δh was not calculated for black colour because of its achromacy.

Table 6 Differences of colour coordinates before and after thermal load for material 2

Sample	ΔL	Δa	Δb	ΔC	Δh
2-1C	−0,7	−1,28	−2,52	2,64	−3,13
2-2C	0,87	−0,92	−0,93	1,06	−2,03
2-3C	0,92	−0,45	−1,19	1,22	−1,19
2-4C	0,65	0,79	1,15	−1,26	1,39
2-5C	1	0,12	0,71	−0,72	0,1
2-1M	0,46	2,8	1,36	2,93	1,24
2-2M	1,15	1,98	0,67	2,04	0,63
2-3M	1,51	1,67	0,19	1,68	0,02
2-4M	0,1	1,29	0,47	1,33	0,38
2-5M	0,18	−1,15	−0,63	−1,21	−0,65
2-1Y	−0,19	0,25	−1,63	−1,6	−0,36
2-2Y	−0,36	0,24	0,97	0,98	−0,18
2-3Y	0,15	−0,11	0,91	0,89	0,26
2-4Y	0,64	−0,61	−0,15	−0,23	0,57
2-5Y	0,12	−0,26	0,06	0,03	0,25
2-1K	−1,36	−1,32	0,49	−1,41	-
2-2K	0,07	−1,08	0,26	−1,1	-
2-3K	−0,03	−0,66	0,35	−0,72	-
2-4K	−0,33	−0,5	0,27	−0,56	-
2-5K	−0,41	0,15	0,42	0	-

Note: Labels in the Sample column are structured so that the first number represents textile material; the second number represents number of ink layers while the letter represents colour that the sample was printed in. The value of hue change Δh was not calculated for black colour because of its achromacy.

Table 7 Differences of colour coordinates before and after thermal load for material 3

Sample	ΔL	Δa	Δb	ΔC	Δh
3-1C	−0,3	−4,28	−7,52	7,98	−7,32
3-2C	1,5	−1,72	−7,46	7,6	−2,27
3-3C	−1,03	−3,83	−5,36	5,97	−6,14
3-4C	−1,09	−4,06	−3,71	4,45	−7,26
3-5C	−0,42	−2,85	−3,47	3,81	−5,97
3-1M	2,06	13,26	0,73	13,26	0,78
3-2M	−0,18	11,16	3,18	11,37	3,27
3-3M	−0,08	10,17	2,51	10,32	2,56
3-4M	−3,65	7,66	3,23	7,8	4
3-5M	−0,93	4,58	2,34	4,68	2,98
3-1Y	−1,97	−1,93	2,24	2,12	2,1
3-2Y	−0,36	−0,79	3,29	3,18	1,14
3-3Y	0,68	−0,2	2,14	2,11	0,38
3-4Y	−0,24	0,87	1,93	1,96	−0,86
3-5Y	−0,18	0,44	0,89	0,93	−0,33
3-1K	−4,43	0,44	−2,89	0,3	-
3-2K	−3,88	−1,02	−1,93	−1,16	-
3-3K	−3,9	−0,33	−1,86	−0,54	-
3-4K	−2,88	−1,63	−0,93	−1,79	-
3-5K	2,52	0,42	−0,35	0,3	-

Note: Labels in the Sample column are structured so that the first number represents textile material; the second number represents number of ink layers while the letter represents colour that the sample was printed in. The value of hue change Δh was not calculated for black colour because of its achromacy.
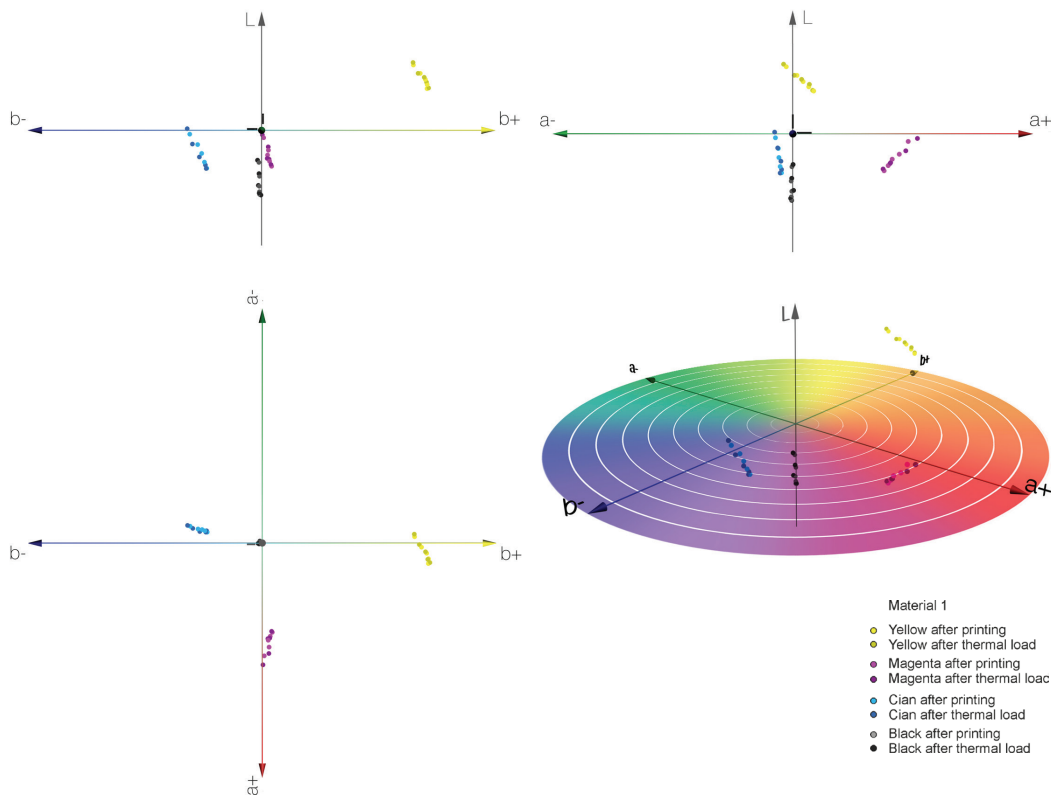

Figure 2 Coordinates of sample colours before and after thermal treatment of all colour printed on material 1
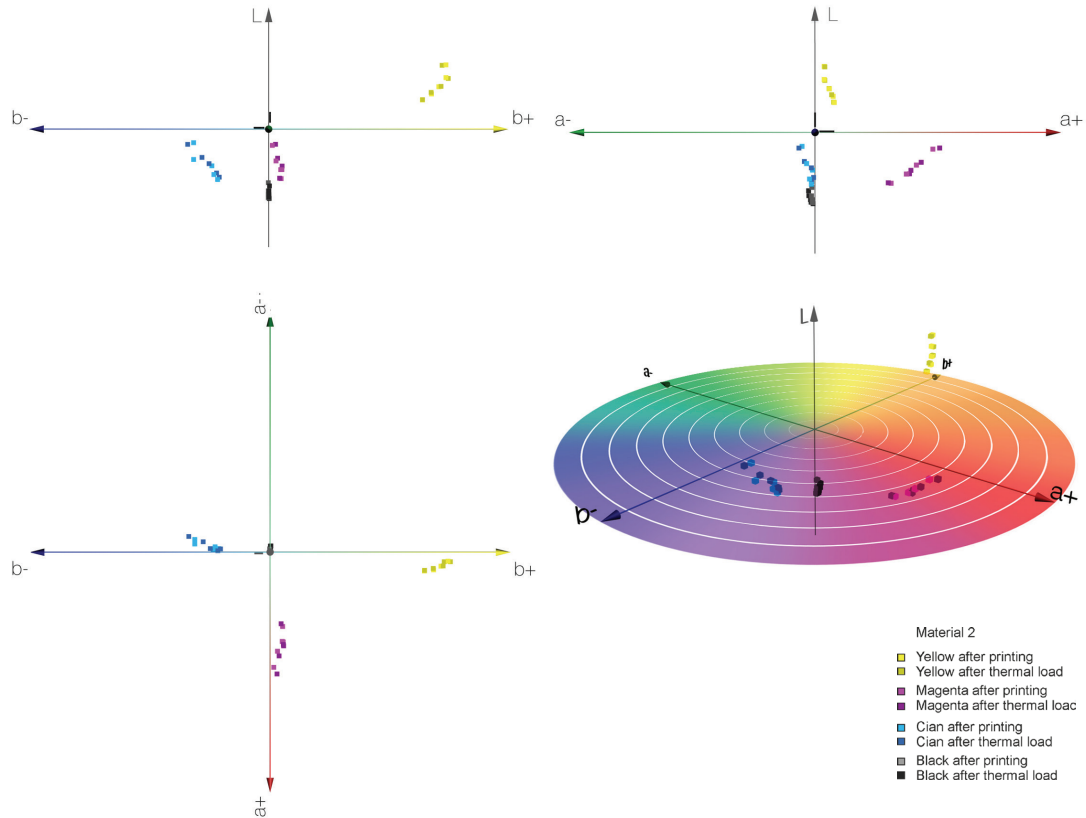
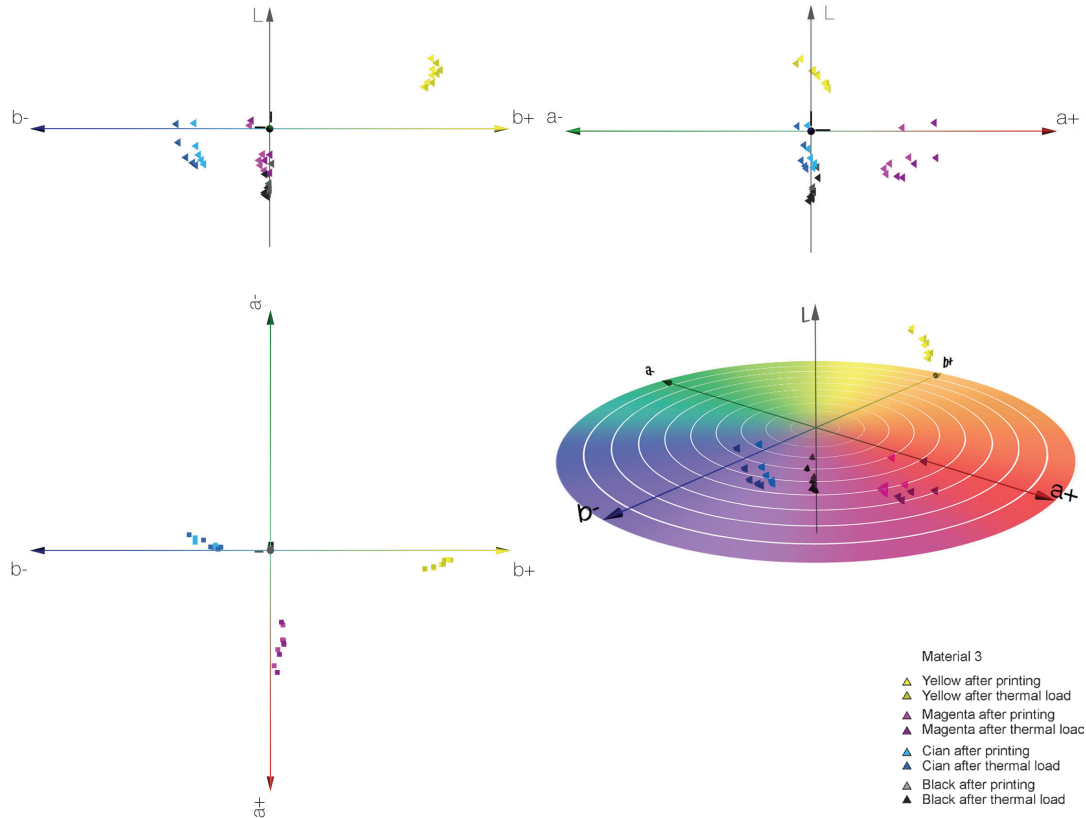**Figure 3** Coordinates of sample colours before and after thermal treatment of all colour printed on material 2

Figure 4 Coordinates of sample colours before and after thermal treatment of all colour printed on material 3
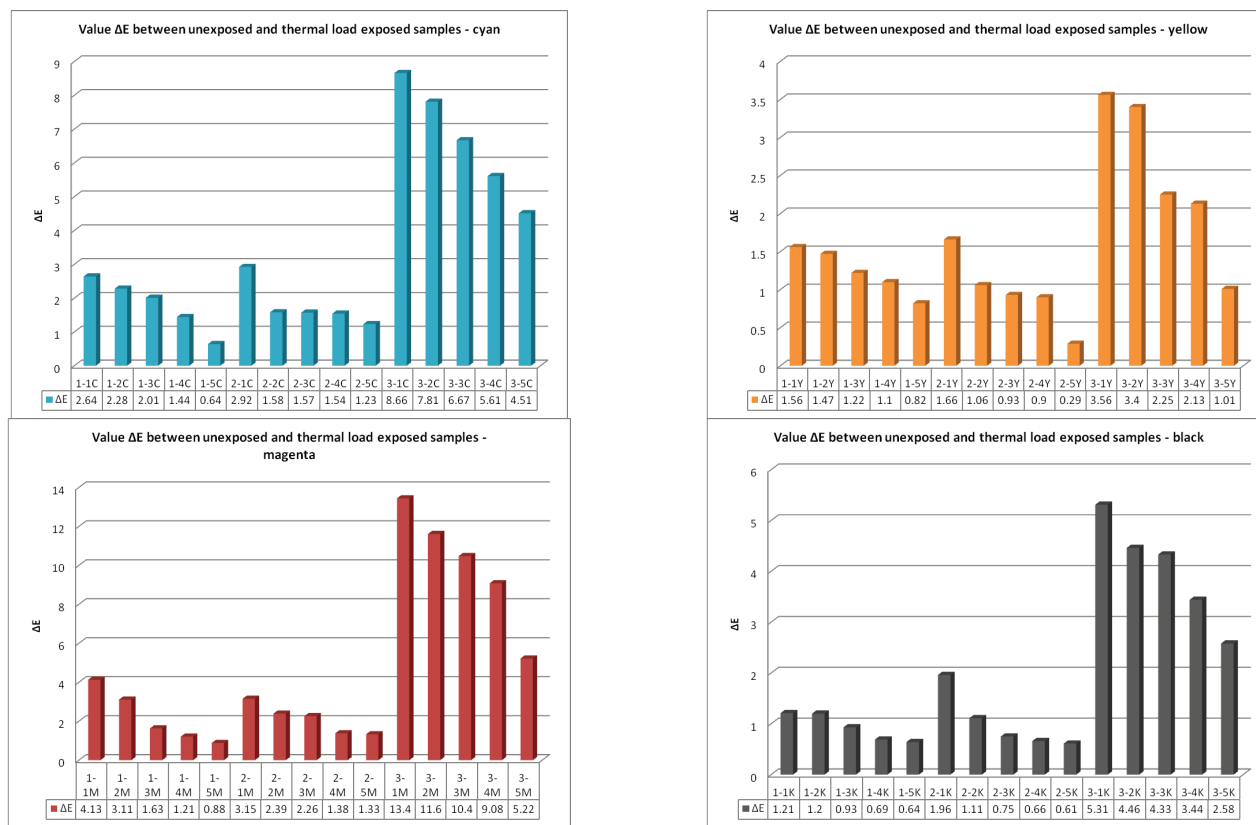
Figure 5 Value ΔE between unexposed and thermal load exposed samples – all textiles printed by: a) cyan, b) magenta, c) yellow, d) black colour

As Fig. 2 shows colour coordinates of colour measured before and after thermal treatment are not far apart from each other which indicates that there is no significant changes caused.

Changes of material 2 colour are similar to those seen on material 1. Fig. 3 shows that colour differences are similar in value but in different direction of colour space.

Material 3 shows greatest colour differences caused by thermal treatment amongst all materials. For magenta colour changes are noticeable along the *a* axis, while magenta colour suffered changes along the *b* axis. Value of colour differences for samples pre and post thermal treatment are shown in Fig. 5.

In order to determine how ink layers, material characteristics (fabric weight and thread count) and type of ink influenced colour difference (ΔE), ANOVA analysis was conducted followed by Tukey tests. Although ANOVA test, as all parameter tests, has assumption about normal distribution of sample group, it is very robust and in case of bigger samples it does not cause any significant problems [16].

The two-way ANOVA with material characteristics and ink layer number as between subject factors showed the main effect of both factors and no interactive effect.

F is the result of statistical test in which the test statistic has an *F*-distribution under the null hypothesis. The null hypothesis for the overall *F*-test for this experiment would be that all levels of the factors (ink layer and material type) produce the same colour difference, on average.

After discovering main effect of the material type on colour change, $F(2;57) = 29,256$, $p=0,000$ with partial eta squared of 0,565 (large effect size), post-hoc tests showed that statistical difference existed between material 3

(M=5,78, SD=3,40) and other two - material 1 (M=1,54, SD=0,90) and material 2 (M=1,46, SD=0,76), while material 1 and 2 did not differ significantly from each other.

After discovering the main effect of the number of ink layers on colour change, $F(4;55) = 2,691$, $p=0,043$ with partial eta squared of 0,193 (large effect size), post-hoc tests showed that there was significant difference between samples with one (M=4,18, SD=3,56) and with five ink layers (M=1,65, SD=1,62), while the group of samples with two (M=3,45, SD=3,2), three (M=2,92, SD=2,92) and four layers (M=2,43, SD=2,52) did not differ one from another and did not differ from samples with one and with five ink layers.

Tab. 8 presents colour difference grouped by influence factors: textile and number of ink layers, and Fig. 6 represents graphs of grouped colour difference.

Table 8 Differences of colour coordinates before and after thermal load (grouped by influence factor)

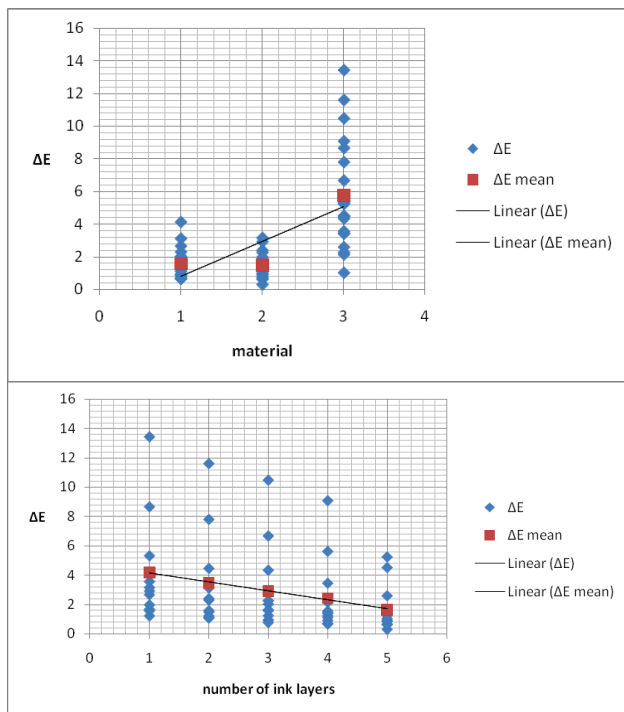| Factor		Number	Mean value	Standard deviation
material	1st	20	1,5396	0,90130
	2nd	20	1,4619	0,75974
	3rd	20	5,7764	3,39947
Ink layer	1	12	4,1813	3,56022
	2	12	3,4547	3,20130
	3	12	2,9173	2,92195
	4	12	2,4297	2,52412
	5	12	1,6469	1,61735

Figure 6 Colour difference graphs grouped by factors: a) material, b) number of ink layers

4 Discussion

Results presented in Tab. 2 show that increasing number of ink layers during print leads to decreasing of lightness and saturation at all four process colours, while hue changes are not so noticeable. Changes of lightness and saturation have linear tendency with a high value of correlation coefficient. Therefore, colour difference value will rise with change of ink layer number.

The lowest values of ΔE were calculated for black colour for all materials, while samples printed by cyan, magenta and yellow showed higher values of ΔE, similar across all materials. This can be explained with the achromatic nature of black colour where change of ink layer number influences only the lightness value, while chromatic coordinates of colour (chroma and hue or a and b value) remain the same. Lightness change of black samples caused by adding ink layers is in the range of changes of other three colours.

Colour difference values where mostly greater than 5, $\Delta E > 5$, except in comparison to samples printed with four and five ink layers. Based on linear tendency of lightness and saturation changes it can be assumed that further increase in number of ink layer number will increase value ΔE also.

Using thermovision temperature measurements constant level of heating element surface was insured, which is shown in Fig. 1. Constant temperatures have great significance in assuring the same experimental conditions for all samples.

Results obtained by spectrophotometric measurement showed that increasing number of ink layers has significant influence on heat treatment fastness. Increasing number of ink layers thus increases ink volume results in prints and gets more resistant to heat treatment. This was observed for all colour and all materials used in this experiment.

Material 3 which has the greatest thread count and fabric weight showed greatest changes after heat treatment while material 2 that has the lowest thread count and fabric weight showed lowest values of colour difference. Increase of materials thread count results in increasing colour differences. These results can be explained by the fact that during printing, ink penetrates materials with lower thread count. Smaller amount of ink is left on the surface of the material where it is directly exposed to temperature of the heating element.

5 Conclusion

This research showed that changes of printed textile materials are caused by thermal treatment. This was confirmed by spectrophotometric measurement which was used to quantify colour differences before and after heat treatment. By increasing number of ink layers, value of colour difference was smaller therefore the fact of increased number of ink layers could be characterized as positive. The choice of materials that are used as printing substrates is also influential factor on quality of prints and exploitation characteristics of products. Samples made of material 3 showed the worst exploitation characteristics. Material 3 had the greatest thread count and fabric weight. Values for colour differences before and after heat treatment for material 1 and 2 are similar, which can be explained by similarities in thread count and fabric weight of these materials.

6 Acknowledgements

7 References

[1] Kašiković, N.; Novaković, D.; Vladić, G.; Avramović D. Influence of ink layers on the colour fastness to rubbing of printed textile materials. // Tekstilna industrija. 60, 2(2012), pp. 28-32.

[2] Kašiković, N.; Novaković, D.; Vladić, G.; Klančnik, M. Influence of heat treatment on characteristics of Inkjet print on textile material. // Journal of Graphic Engineering and Design. 2, 1(2011), pp. 24-30.

[3] Mao, N.; Russell, S. J. The Thermal Insulation Properties of Spacer Fabrics with a Mechanically Integrated Wool Fibre Surface. // Textile Research Journal. 77, 12(2007), pp. 914-922.

[4] Bankvall, C. Heat Transfer in Fibrous Material. // Journal of Testing and Evaluation. 1, 3(1973), pp. 235-243.

[5] Bomberg, M.; Klarsfeld, S. Semi-Empirical Model of Heat Transfer in Dry Mineral Fibre Insulations. // Journal of Thermal Insulation. 6, 1(1983), pp. 157-173.

[6] Dudzik, S. A simple method for defect area detection using active thermography. // Opto-Electronics Review. 17, 4(2009), pp. 338-344.

[7] Novaković, D.; Kašiković, N.; Zeljković, Ž.; Agić, D.; Gojo, M. Thermo graphic analysis of thermal effects on the change of colour differences on the digitally printed textile materials. // Tekstil. 59, 7(2010), pp. 297-306.

[8] Rogalski, A. Infrared Detectors, Gordon and Breach Science Publishers, Amsterdam, 2000.

[9] Dudzik, S. Termolab – a digital measurement system for the thermal image processing, uses a universal matrix interface. // Proc. 35th Inter. University Conf. of Metrologists MKM'03, Cracow, 2003, pp. 95-98 (in Polish).

[10] Yang, Y.; Naaranib, V. Effect of steaming conditions on colour and consistency of ink-jet printed cotton using reactive dyes. // Coloration Technology. 120, 3(2004), pp. 127-131.

[11] Minkina, W.; Dudzik, S. Simulation analysis of uncertainty of infrared camera measurement and processing path. // Measurement. 39(2006), pp. 758-763.

[12] Zhang, C.; Fang, K. Surface modification of polyester fabrics for inkjet printing with atmospheric-pressure air/Ar plasma. // Surface and Coatings Technology. 203, 14(2009), pp. 2058-2063.

[13] Kašiković, N. Razvoj modela praćenja procesnih parametara štampe tekstilnih materijala, PhD Thesis, Faculty of technical sciences, Novi Sad, Serbia, 2012.

[14] Gulrajani, M. L. et al. Colour measurement principles, advances and industrial applications, Woodhead Publishing Limited in association with The Textile Institute Abington Hall, Granta Park, Great Abington Cambridge CB21 6AH, UK, 2010.

[15] Kašiković, N.; Novaković, D.; Karlović, I.; Vladić, G. Influence of ink layers on the quality of ink jet printed textile materials. // Tekstil ve konfeksiyon. 22, 2(2012), pp. 115-124.

[16] Pallant, J. SPSS Survival Manual, Allen & Unwin, Crows Nest NSW 2065, Australia, 2011.

Authors' addresses

Nemanja Kašiković, PhD
University of Novi Sad
Faculty of technical sciences
Trg Dositeja Obradovića 6
21000 Novi Sad, Serbia
Phone: +381 21 485 2622
E-maile: knemanja@uns.ac.rs

Dragoljub Novaković, PhD
University of Novi Sad
Faculty of technical sciences
Trg Dositeja Obradovića 6
21000 Novi Sad, Serbia
Phone: +381 21 485 2620
E-maile: novakd@uns.ac.rs

Neda Milić, MSc
University of Novi Sad
Faculty of technical sciences
Trg Dositeja Obradovića 6
21000 Novi Sad, Serbia
Phone: +381 21 485 2625
E-maile: milicn@uns.ac.rs

Gojko Vladić, MSc
University of Novi Sad
Faculty of technical sciences
Trg Dositeja Obradovića 6
21000 Novi Sad, Serbia
Phone: +381 21 485 2622
E-maile: vladicg@uns.ac.rs

Željko Zeljković, Mr
University of Novi Sad
Faculty of technical sciences
Trg Dositeja Obradovića 6
21000 Novi Sad, Serbia
Phone: +381 21 485 2627
E-maile: zeljkoz@uns.ac.rs

Mladen Stančić, MSc
University of Banja Luka
Faculty of technology
Vojvode Stepe Stepanovića 73
78000 Banja Luka, Bosnia and Herzegovina
Phone: +387 51 434 357
E-maile: mladen.stancic@tfbl.org