THE HEAT TREATMENT EFFECT ON THE PRINT QUALITY OF INKJET PRINTED TEXTILE MATERIALS

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ABSTRACT

This paper presents the research of the heat treatment effect on printed textile substrates. The samples used in the experiment are printed employing Epson Stylus Pro 4880 inkjet printing machine and Epson Ultrachrome inks. Two different types of textile materials are used as printing substrates. The composition of the materials is identical, but they differ in respect to their fabric weight and thread count. The samples are exposed to two heat treatments after printing. The results obtained provide the conclusion that the heat treatment affects the color change, while the print uniformity remains unchanged to some extent.

Keywords: *heat treatment, inkjet printing, textile material, color difference, GLCM method.*

INTRODUCTION

Nowadays, the most important textiles printing technique refers to screen printing whose advantages are determined by its low cost and a higher productivity for large print runs [1 - 3]. Besides, the usage of an inkjet printing technique for printing textile materials is gaining popularity primarily because of its flexibility. The inkjet printing process can achieve better visual effects in comparison to those of the screen-printing method and is not limited by the format size. Furthermore, the process provides better results in respect to the print repeatability [4 - 6]. One of the most important characteristics of the textile inkjet printing process is that it can be used for a wide range of materials. The most commonly used textile materials are made of cotton [7]. Those materials are frequently used in textile industry because of their excellent properties, such as air permeability, diffusion of moisture and heat, softness, hypoallergenic and antistatic properties [8], as well as exceptional thermal properties [9 - 11].

In the exploitation process, the textile materials can be exposed to the effect of various treatments such as ironing, washing, ageing, etc. The heat treatment during the ironing process is a very important factor, which affects both the ink applied to the surface of the material and the textile material itself. The change of the printed color gamut as well as the structural changes of the textile material and the ink [12 - 14] are the consequences of these processes.

Heat can be transferred to the textile material by conduction, convection and an electromagnetic radiation [15 - 17]. Several standards can be used to examine the effect of the heat treatment on the changes of the printed material. One of those standards, ISO 105-X11:1994, deals with the effect of the ironing treatment of the printed materials using temperatures of 110°C, 150°C and 200°C. According to this standard, the grey scale (from one to five) is used for quality judgment (one being the worst, while five is the best).

The color changes should be as small as possible to achieve the desired quality. Instrumental spectro-

photometric/colorimetric measurements can be used to quantify color changes of printed ink in addition to standard criteria for evaluation of color fastness such as gray-scale or blue wool. The manufacturers cannot rely on visual judgment as used in the grayscale or blue wool method in case the high quality is the main goal. Much more reliable is the determination of the color characteristics and the color differences obtained on the ground of instrumental measurements that provide numerical quantification of the measured color. The graphic industry has predetermined color management standards that include objective methods describing the color of the printed ink and the color differences.

The print quality analysis, besides the color, includes other print quality attributes including a line quality, blurriness, raggedness, a line width, darkness, micro (graininess) and macro (print mottle) uniformity [18]. A number of different methods can be used to assess the print uniformity, but GLCM (Gray Level Co-occurrence Matrix) method has proved to be the best regarding the correlation with the human visual system [19].

The aim of this paper is to determine the effect of the heat treatment on the color of the printed ink and the print uniformity (print mottle) of cotton materials printed with an inkjet technique.

EXPERIMENTAL

Two textile knitted fabrics of a single weave type were used in the study carried out. The material characterization was done according to the following standards: a material composition (ISO 1833), a fabric weight (ISO 3801) and a thread count (ISO 7211-2). These properties are presented in Table 1.

The test chart used for the experiment consisted of four CMYK solid tone patches, 5 cm x 5 cm each, for obtaining the color differences, as well as one black square, 2,5 cm x 2,5 cm rotated by 5 degrees for examining the print uniformity (ISO 12233:2000).

The samples were printed with Epson Stylus Pro 4880 digital inkjet printing machine using Epson Ultrachrome inks. They were subjected twice to a heat treatment according to the standard ISO 105-X11:1994 using the hot press Hix HT600P for 15 s at contact pressure of 850 daN and a temperature of 110 ^{0}C. These conditions were constant during the experiment.

A colorimetric characterization

The colorimetric measurements were done prior to and after each heat treatment. The color coordinates of all samples were determined by a spectrophotometer, while the colour (ΔE^*_{ab}), chrome (ΔC^*_{ab}) and hue difference (ΔE^*_{ab}) between the treated and the untreated samples was calculated.

The sphere spectrophotometer HP200 was used for measuring the colorimetric properties of the samples. It used CIE D65 standard illuminant and a standard 10° observer and provided a measuring aperture of 8 mm. Each sample was measured ten times and the average L*a*b* values were calculated accordingly. The spectrophotometer's accuracy was tested according to standard ASTM E2214-08 (2008) prior to starting the measurement procedure.

After the printing process, L*a*b*coordinates were measured for all printed samples. Then, after each heat treatment, the measurement was repeated to determine the effect of the thermal treatment on the printed samples.

The color differences were calculated using ΔE^*_{ab} formula (1) as a square root of the summed squares of the chromaticity differences, Δa^* and Δb^*, and the lightness difference, ΔL. This formulation for colour difference calculation was adopted as a recommendation made in ref. [20]:

$$\Delta E^*_{ab} = [\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}]^{1/2} \quad (1)$$

where:

$\Delta L^* = L^*_1 - L^*_2$, $\Delta a^* = a^*_1 - a^*_2$, $\Delta b^* = b^*_1 - b^*_2$

L_1 a_1, b_1 were the lightness and chromaticity coor-

Table 1. Characteristics of the materials used in the experiment.

	Type of wave	Material composition (%)	Fabric weight (g/m^2)	Thread count (cm^{-1})	
				Warp	Weft
Material A	single	Cotton	110,2	12	16
Material B	single	Cotton	207,2	15	18

dinates of sample 1 (printed, heat untreated), while L_2, a_2, b_2 were the lightness and chromaticity coordinates of sample 2 (printed, heat treated).

The Mean Color Difference from the Mean (MCDM) was computed using Eq. (2) for each material and each process color in order to give a better insight in respect to the color variability caused by the heat treatments [21]:

$$MCDM = \sum_{i=1}^{n} E^*_{abi} \quad (2)$$

where:

$\Delta E^*_{ab} = [(L_i^*-L^*_{mean})^2 + (a_i^*-a^*_{mean})^2 + (b_i^*-b^*_{mean})^2]^{1/2}$

$L^*_{mean} = \sum_{i=1}^{n} L_i^*/n;$

$a^*_{mean} = \sum_{i=1}^{n} a_i^*/n;$

$b^*_{mean} = \sum_{i=1}^{n} b_i^*/n;$

where n was the number of the samples; it was equal to 3 in this study (L*a*b* values referred to the untreated and the heat-treated samples (two treatments)).

The chroma (C*) and the hue angle (h*) values, which are easier to correlate with the visual appearance of a color than the chromaticity coordinates, were calculated according to ref. [22]:

$$C_{ab}^* = [(a^*)^2 + (b^*)^2]^{1/2} \quad (3)$$

$$h_{ab}^* = \tan^{-1}(b^*/a^*) \quad (4)$$

where a*, b* were the chromaticity coordinates of the sample.

The chroma (ΔC^*_{ab}) and the hue (ΔH^*_{ab}) differences were calculated using the relations advanced in ref. [22]:

$$\Delta C^*_{ab} = C^*_{ab,1} - C^*_{ab,2} \quad (5)$$

$$\Delta H^*_{ab} = 2(C^*_{ab,1}\ C^*_{ab,2})^{1/2}\sin(\Delta h_{ab}/2) \quad (6)$$

$$\Delta h^*_{ab} = h^*_{ab,1} - h^*_{ab,2} \quad (7)$$

where $C^*_{ab,1}$ was the chroma of sample 1 (printed, heat untreated), $C^*_{ab,2}$ was the chroma of sample 2 (printed, heat treated), $h^*_{ab,1}$ was the hue angle of sample 1 (printed, heat untreated), while $h^*_{ab,2}$ was the hue angle of sample 2 (printed, heat treated).

A print uniformity characterization

The print uniformity was characterised according to Gray Level Co-occurrence Matrix (GLCM) [19]. The printed samples had to be captured as digital images in case of assessing the print mottle by the image analysis method. Therefore, after printing and every heat treatment, the samples were scanned by Canon CanoScan5600F scanner at 600 spi.

The quantification of the print uniformity by GLCM method was done in MATLAB using a code proposed in ref. [23]. It was found [24] that five parameters could be used for analysing the energy, the homogeneity, the entropy, the correlation and the contrast [3, 25]:

$$Energy = \sum_{i,j} p(i,j)^2 \quad (8)$$

$$Homogeneity = \sum_{i,j} \frac{1}{1-(i-j)^2} p(i,j) \quad (9)$$

$$Entropy = \sum_{i,j} p(i,j)\log(p(i,j)) \quad (10)$$

$$Correlation = \frac{\sum_i \sum_j (ij)p(i,j) - \mu_x \mu_y}{\sigma_x \sigma_y} \quad (11)$$

$$Contrast = \sum_{i,j} |i-j|^2 p(i,j) \quad (12)$$

where p(i, j) stood for (i, j)th entry or the value in a normalized GLCM.

Parameters such as the number of the grey levels, the distance between two pixels of GLCM (d) and the orientation (q) should be taken into account in building GLCM. A 256 grey level image was used in this experiment. The distance (d) between two pixels whose repetition was examined was set to 1 pixel (there were no other specifications related to the distance, so 1 pixel was used). The average of the possible four (0^0, 90^0, -45^0 and 45^0) was taken into account in determining the orientation (q).

RESULTS AND DISCUSSION

The L*a*b* color coordinates, prior to and after the heat treatments, for all printed inks are depicted in the Figs. 1 - 4 where A and B marks denote the material type, C, M, Y and K denote the printed ink, while marks

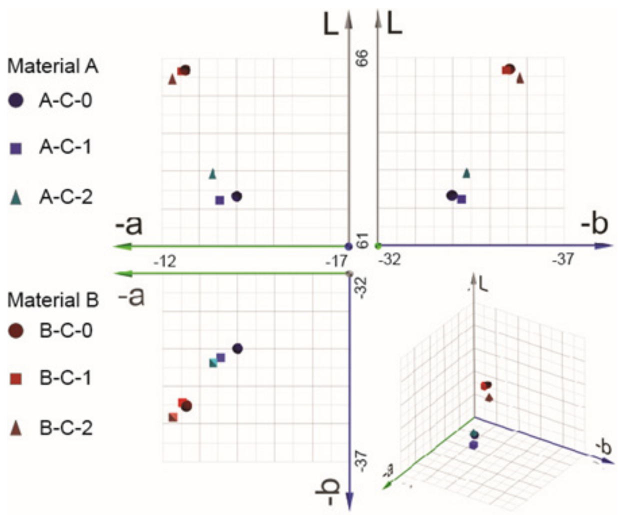

Fig. 1. L*a*b* values of a cyan ink prior to and after the thermal treatments applied.

Table 2. Chroma and hue angle values in case of using a cyan process ink.

Material	Heat untreated		Heat treated (first treatment)		Heat treated (second treatment)	
	C	h	C	h	C	h
Material **A**	37,10	246,17	37,66	245,80	37,76	245,53
Material **B**	39,11	245,26	39,18	245,14	39,53	244,99

Table 3. Chroma and hue angle values in case of using a magenta process ink.

Material	Heat untreated		Heat treated (first treatment)		Heat treated (second treatment)	
	C	h	C	h	C	h
Material **A**	36,66	348,19	36,51	348,61	35,53	349,21
Material **B**	40,23	347,25	40,02	347,50	39,76	347,70

Table 4. Chroma and hue angle values: yellow process ink.

Material	Heat untreated		Heat treated (first treatment)		Heat treated (second treatment)	
	C	h	C	h	C	h
Material **A**	51,58	96,20	51,63	96,32	51,08	96,37
Material **B**	63,26	96,54	63,34	96,42	63,39	96,41

Table 5. Chroma and hue angle values: black process ink.

Material	Heat untreated		Heat treated (first treatment)		Heat treated (second treatment)	
	C	h	C	h	C	h
Material **A**	3,23	179,47	2,97	180,39	3,26	184,92
Material **B**	2,90	202,68	3,14	202,65	3,18	205,76

0, 1 and 2 express the number of the thermal treatments. The chroma and hue angle values of the process inks prior to and after each heat treatment are presented in Tables 2 - 5.

Figs. 1 - 4 provide to conclude that the thermal treatment leads generally to lighter prints in case of both substrate materials for all four printed process inks. A similar trend of the chromatic coordinates values (a* and b*) is obtained for both materials in case of using a cyan ink where the increase of the thermal treatments number leads to a decrease of b* value and an increase of a* coordinate value (Fig. 1). According to the results presented in Table 2, the heat treatment causes a chroma shift towards higher values indicating a slightly higher color saturation. The hue shift (Table 2) towards lower values (cyan/green) caused by the heat treatment indicates that the exposition of the cyan printed materials to heat will cause some color fading.

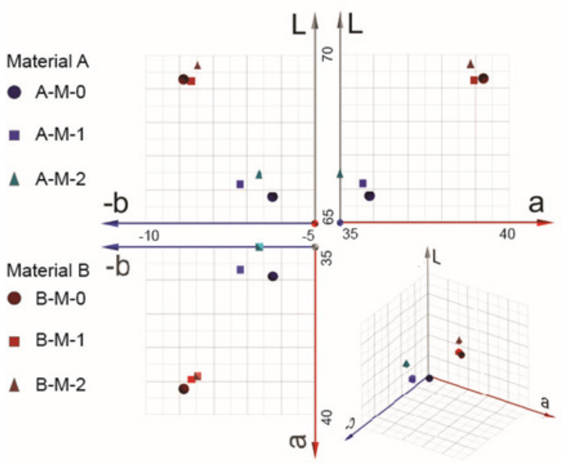

Fig. 2. L*a*b* values obtained prior to and after thermal treatments in case of using a magenta ink.

A decrease of both chromatic coordinates values (a*, b*) is observed for material A, while an increase of b* and a decrease of a* values are recorded for material B (Fig. 2) when the samples are printed with a magenta ink. The chroma and the hue changes caused by the heat treatment (Table 3) of both tested materials indicate a slightly lower saturation and a mild color tone shift towards red.

A decrease of a* and b* values occurs for material A in case of using a yellow process ink (Fig. 3), while an increase of both chromatic coordinates is noticed for material B. The results presented in Table 4 show a slight increase of the chroma value in case of both materials. The hue shift of material A is slightly towards yellow-

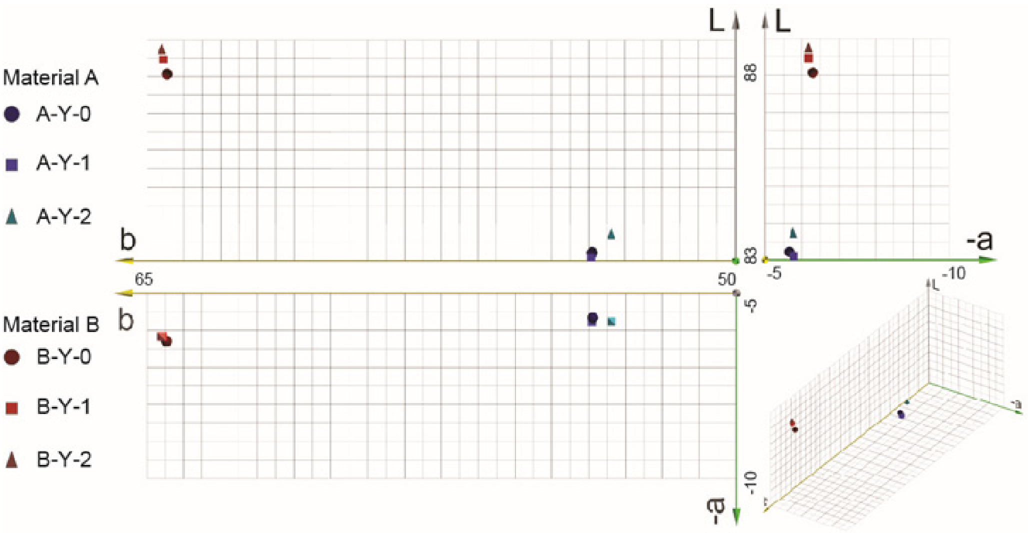

Fig. 3. L*a*b* values prior to and after thermal treatments in case of using a yellow ink.

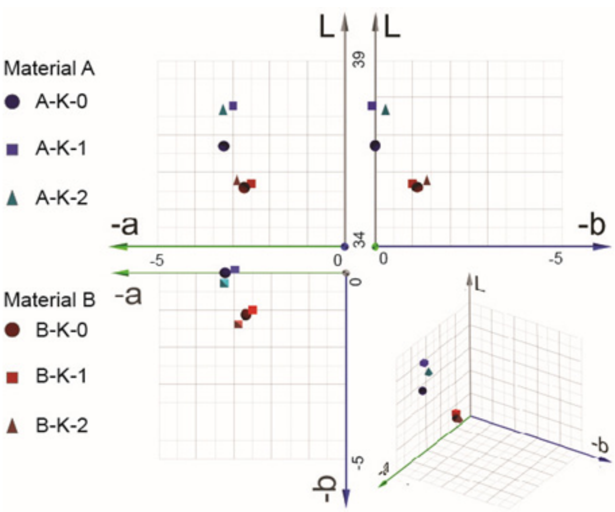

Fig. 4. L*a*b* values prior to and after thermal treatments in case of using a black ink.

green, while that of material B is towards warm yellow.

A decrease of b* and an increase of a* is recorded for material A when the corresponding samples are printed with a black process ink (Fig. 4), while a decrease of the chromatic coordinates occurs in case of material B. The chroma and the hue are shifting towards higher values with the increase of the thermal treatments (Tab.5) indicating a slight color shift from the so called black with a warm cyan undertone to black with a cool cyan undertone.

Figs. 1 - 4 and Tables 2 - 5 show that all color coordinates (L*, a*, b*, C* and h*) of the measured printed process inks prior to and after thermal treatments are quite close to each other indicating that there are color changes regarding both substrate materials. It is expected that a better insight in respect to the color change caused by heat treatment will be given through overall color (ΔE^*_{ab}), hue (ΔH^*_{ab}) and chroma (ΔC^*_{ab}) difference analysis.

Fig. 5 illustrates the color differences (E^*_{ab}) between the heat untreated and the heat-treated samples. The results show that the increase of the number of the heat treatments leads to a color differences increase.

The calculated MCDM values (Fig. 6) show that in general the color differences of material A caused by heat treatments are greater. The highest values of ΔE^*_{ab} for material A as well as for material B are calculated for samples printed using a magenta ink. The recorded color difference values are below 1, except for magenta where ΔE^*_{ab} between the heat untreated and the heat-treated samples is up to 1,5 (Fig. 5). A color difference below 1 can be declared small in textile industry, but it is still visually noticeable by the human eye [20]. In

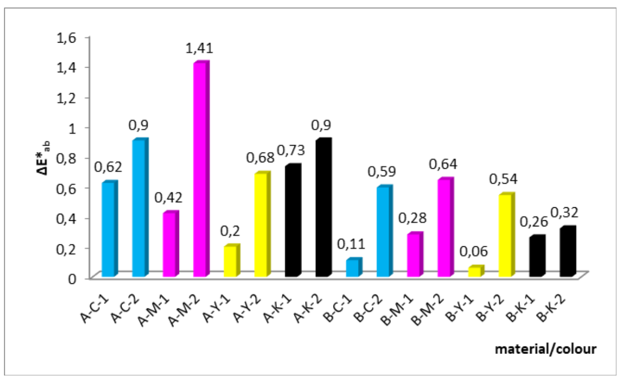

Fig. 5. Color differences (ΔE^*_{ab}) between heat untreated and heat treated samples.

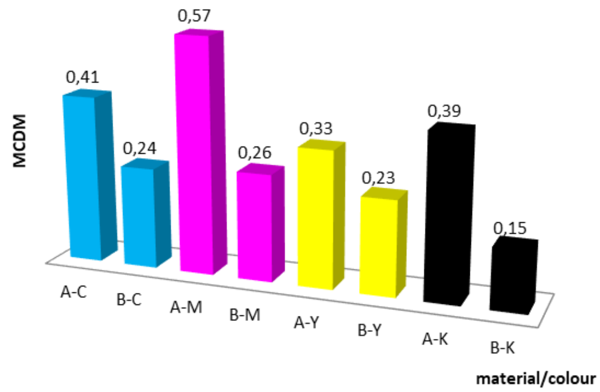

Fig. 6. MCDM values for each material and process color

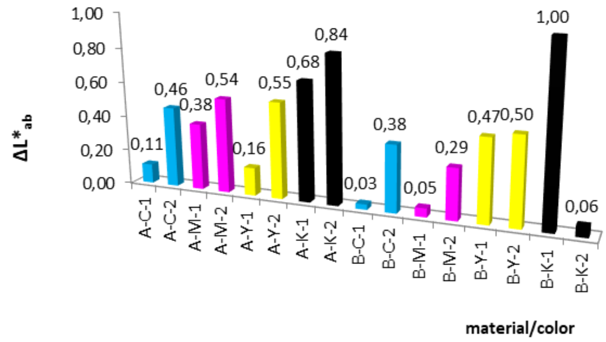

Fig. 7. Lightness differences (absolute values) (ΔL^*_{ab}) between heat untreated and heat-treated samples.

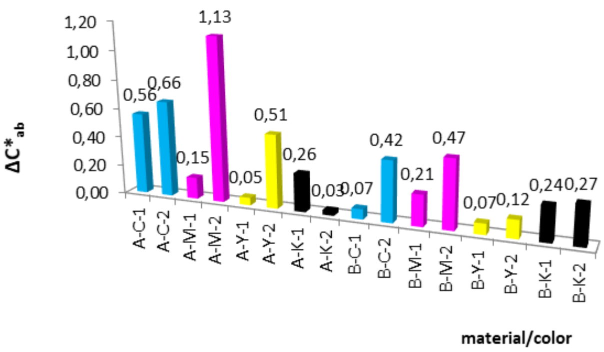

Fig. 8. Chroma differences (absolute values) (ΔC^*_{ab}) between heat untreated and heat-treated samples.

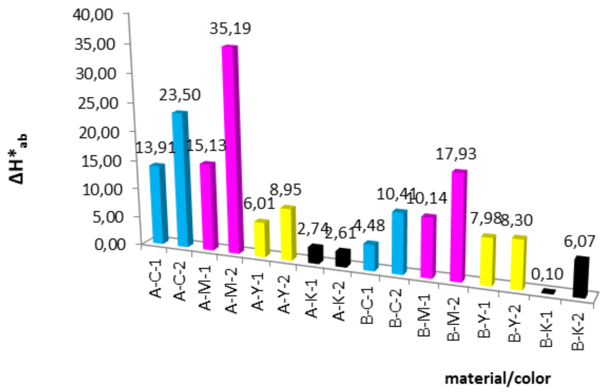

Fig. 9. Hue differences (absolute values) (ΔH^*_{ab}) between heat untreated and heat-treated samples.

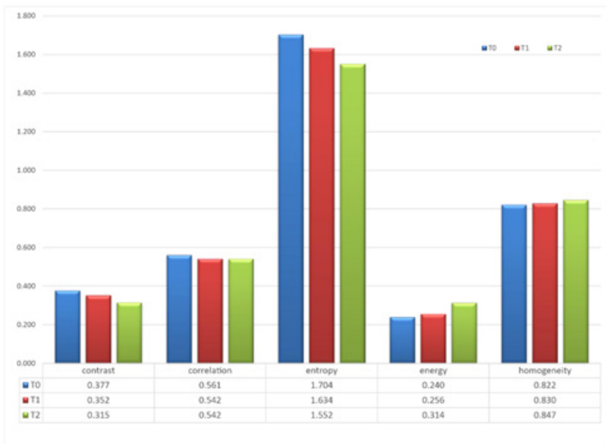

Fig. 10. Results of material A print uniformity (print mottle) measured by GLCM.

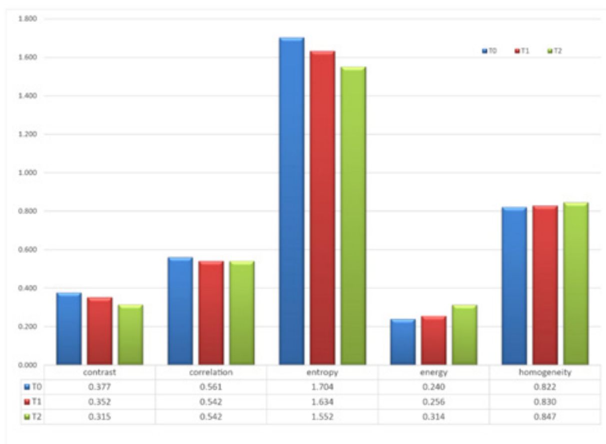

Fig. 11. Results of material B print uniformity (print mottle) measured by GLCM.

view of the fact that the latter is more sensitive to bright, unsaturated colors, especially pastel ones, whereas the same difference would be barely noticeable in case of dark color tones, and also more sensitive in the orange and yellow color areas, it can be assumed that the color differences determined will be the most visually noticeable in case of a yellow process ink and even in case of cyan and magenta one [20].

The results presented in Figs. 7 - 9 show that the heat treatment has the largest impact on the hue changes, especially in case of magenta, cyan and yellow process inks. Knowing that the observer will see the hue differences first, then the chroma differences and at last the lightness differences [20], it can be assumed that the

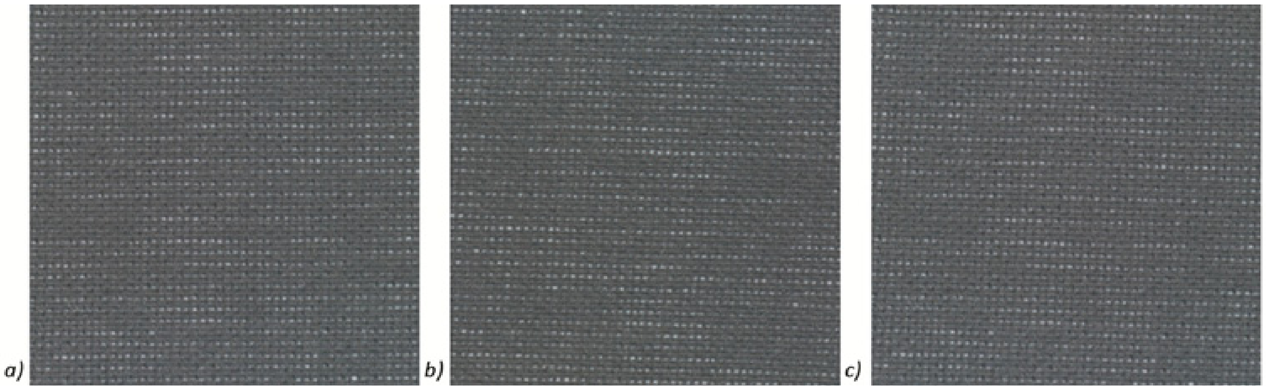

Fig. 12. Patches used for print mottle quantification by GLCM in case of material A; a) after printing, b) after the first heat treatment and c) after the second heat treatment.

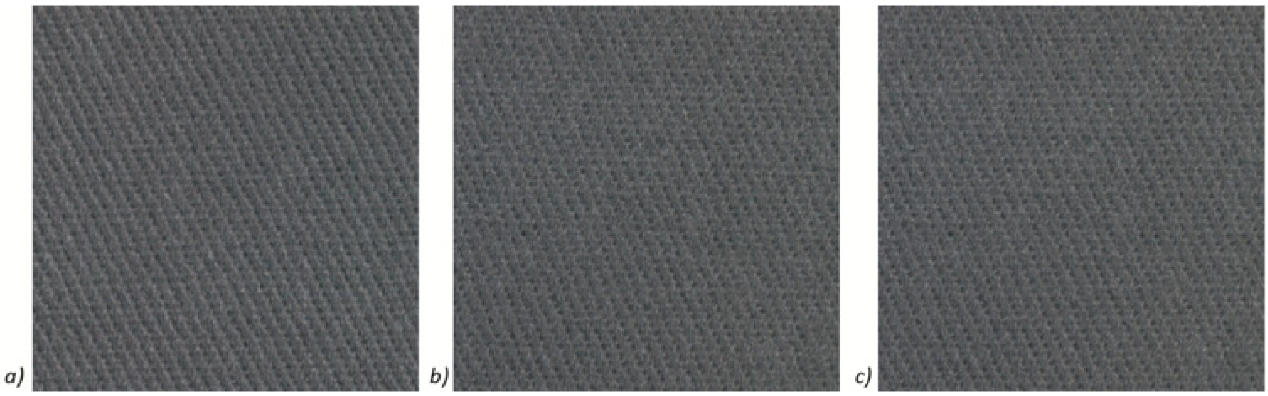

Fig. 13. Patches used for print mottle quantification by GLCM in case of material B; a) after printing, b) after the first heat treatment and c) after the second heat treatment.

color shift will be visually detected.

The print uniformity of the samples prior to and after two heat treatments is presented in Fig. 6 for material A and in the Fig. 7 for the material B.

The smaller values of the contrast, the correlation and the entropy, but the higher values of the energy and the homogeneity refer to the better uniformity of the prints [3, 23]. The results presented in Fig. 10 and Fig. 11 indicate that in general the print uniformity is better in case of material B. The same conlusion can be drawn on the ground of the scanned patches shown in Fig. 12 and Fig. 13. It is evident that material A has many areas not covered by the ink, and which is why the non-uniformity of these patches is clearly visible. Better uniformity is achieved on a material of a higher fabric weight and a higher thread count (material B) in case of using identical printing machines and inks.

The heat treatment has approximately the same effect on both materials which verifies the identical trend of the print mottle parameters' values. When the samples are exposed to heat, the print uniformity increases although the differences are minimal. The CVs values (a coefficient of a variation calculated for three values - T0, T1 and T3) are quite similar. They are low and less than 2 % with minor exceptions in case of the entropy (4.6 %), the contrast (8.9 %) and the energy (14.4 %) of material A. It can be stated that the print uniformity is mostly constant showing minimal changes.

CONCLUSIONS

This research shows that the heat treatment causes colour changes of the printed inks. This is confirmed by a colorimetric measurement used to quantify the color differences of the printed samples prior to and after the heat treatment. The increase of the number of the heat treatments leads to an increase of the value of the colour difference for all samples studied. Therefore, the color difference values will increase with every additional heat treatment. The heat treatment will have a higher impact on the hue differences, rather than on those of the chroma and the lightness. According to the given differences value range and previous findings on

visually perceivable differences of color [20], the color shifts affected by the heat treatment are assumed to be visually noticeable, especially in case of a magenta, a cyan and even a yellow process color.

The choice of the materials used as printing substrates is also a factor affecting the quality of the prints as well as the exploitation characteristics of the final product. The study findings confirm the conclusions from a previous research in which similar materials have been submitted to testing [26]: samples made of material B show better exploitation characteristics than those of material A. The latter has a lower fabric weight, a lower thread count, while the colour differences in case of all samples are higher than those of material B.

The recorded non-uniformity which is higher for material A is due to gaps left without an ink coverage on the material surface. This leads to a lower print quality compared to that of material B. The heat treatment does not significantly change the overall print uniformity of both materials.

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