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Textile Sublimation Printing: Impact of Total Ink Limiting Level and Sublimation Transfer Paper on Black Print Quality

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ABSTRACT

The sublimation transfer paper with different weights and transfer rates was printed in black color with total ink limiting levels of dye sublimation ink, from 100 % to 400 %, using an ink jet printing system with the CMYK color system. Then, the test image was transferred to fabric using the sublimation printing process. The ink jet printer was installed with dye sublimation ink. Color strength, *CIELab* color coordinate, color difference ΔE^* and GLCM (grey level co-occurrence matrix) image processing method were used to analyze the print quality. The significant change in print quality was caused by the sublimation transfer paper, resulting in a medium color difference noticeable to the human eye, while the significant change in print quality was not caused by the total ink limiting level of dye sublimation ink for printing sublimation transfer paper. The print with the maximum color strength was obtained with the 270 % total ink limiting level of dye sublimation ink. The color difference between prints obtained with lighter sublimation transfer paper with a higher transfer rate printed with 100 % and 270 % total ink limiting levels of dye sublimation ink was less than 1, suggesting a color difference undetectable to the human eye. Considering the importance of ink in terms of costs in businesses, the optimal total ink limiting level of dye sublimation ink for printing sublimation transfer paper and achieving good print quality was 100 %. The total ink limiting level of dye sublimation ink for printing sublimation transfer paper is useful for saving money on ink, so good print quality will be reached at a lower total ink limiting level.

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KEYWORDS

Sublimation printing, polyester fabric, grey level co-occurrence matrix (GLCM), total ink limiting level, print quality

1. INTRODUCTION

Textile printing allows an intriguing combination of art, craft, and technology. The development of the textile printing industry is daily focused on improving and creating new technologies and products [1-7]. Printing also demands the technologist to develop appropriate processes to ensure that the final quality of the print matches the often rigorous specification of the customer [8-10]. Sublimation printing is suitable for printing on textiles, especially where it is difficult to achieve a high-fidelity image on the textile by printing techniques, such as ink-jet printing, rotary screen printing, and roller printing. In a typical case, the print substrate may be a substrate with a shape or texture challenging to feed to a printer or a substrate that does not readily receive high-fidelity images by some printing techniques. Sublimation printing is a process where the desired image is reverse printed on sublimation transfer paper by ink jet printing to provide a reverse printed sublimation transfer paper. The reverse printed sublimation transfer paper and textile to receive the desired image are combined with a heat press under temperature and pressure, where the sublimation dye is transferred from the sublimation transfer paper to the textile [11,12]. In ink jet printing, the CMYK color model is commonly used. The basic primaries in ink jet printing are cyan, magenta, yellow and black. Yellow is usually added to control the hue and lightness of the produced colors. Black ink is added to increase the contrast and details in dark shades and reduce the general ink consumption. In most cases, a four primary (CMYK) system can produce reasonably good color outputs to satisfy the customer [13]. Ink limit also relates to gamut mapping. However, to enlarge the color gamut, yield better details and contrast, and produce smoother color

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transitions, additional color ink channels may be added. The sublimation printing process involves printer machinery, ink chemistry, sublimation transfer paper, textile material, printing parameters, color management software, etc. [14]. Each component is essential in production speed, print quality, and procedure cost. The desired print image includes a characterization of the clarity, color fidelity, and fastness. In general, print quality refers to the ability to provide a color match that is as close as desired. Therefore, it is desirable to provide a sublimation transfer paper that can provide comparable or improved image quality on a print textile as a result of sublimation printing while receiving less sublimation ink. Sublimation transfer paper comprises at least one receiving layer, base paper, and a back coating layer; from top to bottom, the receiving layer, base paper, and the back coating layer together form the transfer paper sequence. The base paper is made of 100 % wood pulp, and the receiving layer consists of 30 to 70 weight percent of white pigment and 30 to 70 weight percent adhesive. The solid content of the receiving layer is 10-50 %, and the coating weight of the receiving layer is 1 g/m^2 to 20 g/m^2. The back coating is composed of natural glue or synthetic glue. The solid content of the back coating is 2-10 %, and the coating weight is 0.5-2 g/m^2 [15]. The receiving layer is the ink holding layer capable of holding ink, reffered to also as a blocking layer on the base paper. On the other hand, this layer can absorb ink, and it can block the dye dispersed from seeping into the paper fiber and affecting escaping while heating. Ink limiting level refers to the maximum amount of ink that can be jetted during the printing of sublimation transfer paper. It is an essential parameter for color CMYK channels of ink jet printers for printing sublimation transfer paper. For each channel, the ink limiting level varies from 0 % to 100 %. In a particular CMYK four-color printing system, the default total ink limiting level is 400 % which indicates that the maximum amount of ink to be used in the printing should not exceed 400 % [13]. The amount of dye sublimation ink printed on sublimation transfer paper may affect printing color and print quality. Therefore, it is necessary to have good control of the total ink limiting level of dye sublimation ink for printing sublimation transfer paper. Regarding the usage of ink, manufacturers prefer a reduction of the ink together with a minimum loss of print quality. The total ink limiting level of dye sublimation ink for printing sublimation transfer paper is useful for reducing the consumption of printing ink, and thereby ink costs, without reducing print quality.

Exploring the challenge of adjusting the total ink limiting level of dye sublimation ink was to look at the total ink limiting levels of dye sublimation ink related to the current industrial problems associated with the textile sublimation printing process to find the optimal total ink limiting level of dye sublimation ink for printing sublimation transfer paper in combination with sublimation transfer paper and obtain a good print quality. Through a literature review, it was noted that the optimization of the sublimation printing process and the dynamics of sublimation printing are problems in the sublimation printing of textiles that have been worked on [14,16]. Research was conducted to create a process for optimizing sublimation printing conditions using Taguchi design to minimize the water vapour resistance of knitted fabrics. From Taguchi's analysis using the response of means and response of S/N ratios, the predominant factor influencing the quality of sublimation printed single jersey knitted fabrics was the number of strokes of printing on the sublimation transfer paper. The minimum water vapour resistance of printed fabrics was achieved with a number of strokes equal to 2, 74 g/m^2 weight sublimation paper, at the temperature of 205 °C and 50 s pressing time [15]. Another research emphasizes the necessity to consider changes in fabric properties after the sublimation printing process [17]. There is interest in studies related to changes in fabric properties after the printing process, and some have been performed. The impact of the sublimation process on air permeability, compression properties, and the structural and physical properties of knitted fabrics have been discussed in papers by research groups [10,17,18]. Sublimation printing has been reported to influence the alteration of the structural and physical properties of polyester, cotton, and cotton/polyester knitted fabrics [10]. For the sublimation of cotton/polyester and cotton knitted fabric, a coating powder was used to bond the ink to cotton-rich fabrics. Further, the structural changes of the fabrics (thickness and density) during heat pressing, both without application of dyes (without transfer printing on material) and with the application of dyes were also studied to analyze the extent of the effect of printing conditions (pressure and temperature) on the total wear comfort printed fabrics. The results showed that smaller changes in structural and physical properties were noticed for polyester knitted fabrics, while major changes in structure were observed in cotton knitted fabrics (where weight was gained and geometrical roughness value was reduced). A significant change in density was recorded for polyester printed knitted fabrics. Tests were conducted to investigate the effect of sublimation printing on the mechanical properties (breaking force and elongation and abrasion resistance), physiological properties (water vapour permeability, air permeability), and color fastness (resistance to rubbing, domestic and commercial laundering, to perspiration) of the polyester knitted fabrics [17]. Tested samples showed good color fastness to rubbing, domestic and commercial laundering (grade 5). In terms of abrasion resistance, the material also showed high resistance. The air permeability decreased by about 40 % compared to the value obtained before printing, and the mechanical properties slightly increased (about 8 %). This change was due to an increase in the stitch density, and a decrease in the thickness, therefore reducing the porosity of the material for printing conditions, mainly due to the influence of pressure and temperature within the heat press machine. A study of the sublimation printing influence on the change in compression properties of polyester, cotton, and cotton/polyester knitted fabrics using KES-FB3A compression tester has been conducted [18]. For cotton-rich knitted fabrics, sublimation coating powder was used for sublimation transfer paper to bond disperse dyes to natural fibers. The printing process had a smaller influence on the change of compression parameters of polyester in relation to cotton and cotton/polyester knitted fabrics. The printing process affected on thickness reduction for all knitted fabrics to varying degrees. The printing process contributed to a small decrease in compressibility and special volume values for polyester knitted fabrics compared to cotton and cotton/polyester. However, no research has been found on whether lighter weight sublimation transfer paper is of a lower or a higher transfer rate. There are almost no papers covering the total ink limiting level of dye sublimation ink impact on print quality in the sublimation printing industry. The effect of the total ink limiting level of dye sublimation ink on the print quality of sublimation printed fabric is an important area to study because sublimation printing is more widely accepted. A balance must be struck between cost and quality. However, most of the color management ink limiting level related subjects were studied in paper printing [13], and they lack significant guidance in textile printing. The results from research that was done in paper printing relating to ink optimization technology showed that ink optimization works; the systems were able to process files in real-time, new optimized files had lower CMY values, reduced ink consumption on the press, were more stable on the press, yet files still retained colorimetric accuracy to the original and did not introduce imaging artifacts [13]. In this research, a primary objective of ink optimization processing was that cyan, magenta, and yellow (CMY) inks could be replaced by a given amount of black (K) ink, appropriately chosen to create the same visual color as the original but with less total ink coverage. Ink optimization systems were used to process images to create color separations of RGB to CMYK or color reseparations from CMYK to CMYK. The ink optimization technology incorporates aspects of under color removal (UCR) and gray color replacement (GCR) technologies in black channel generation but extends these concepts to include ink saving, press stability, and workflow integration. This technology is currently used in web and sheet-fed offset lithographic printing, where high-quality images and long press runs offer the opportunity for maximum ink saving. It should be noted that for good sublimation print quality in textile sublimation printing, a properly selected total ink limiting level of dye sublimation ink is desirable. There is a need to obtain an optimal total ink limiting level of dye sublimation ink that will match good print quality at lower total ink limiting level.

Sublimation printing is increasingly considered necessary in the printing technology in the textile sector. This research was conducted to investigate the print quality of sublimation printed fabric depending on the total ink limiting level of dye sublimation ink for printing sublimation transfer paper and sublimation transfer paper. The print quality was evaluated by examining color strength, *CIELab* color coordinates, color difference (ΔE^*), and GLCM (grey level co-occurrence matrix) image processing method. This research provided information on the impact of the total ink limiting level of dye sublimation ink for printing sublimation transfer paper and sublimation transfer paper on print quality, which manufacturers can use to improve and optimize the sublimation printing process while saving money on ink and sublimation transfer paper, and in turn achieve good print quality.

2. MATERIAL AND METHODS

2.1 Material

White fabric, 97 % polyester, and 3 % elastane, with 160 g/m^2 weight, 0.36 mm thickness, and 43 cm^{-1} and 22 cm^{-1} warp and weft densities, respectively, with twill structure, was used.

2.2 Methods

2.2.1 Printing procedure

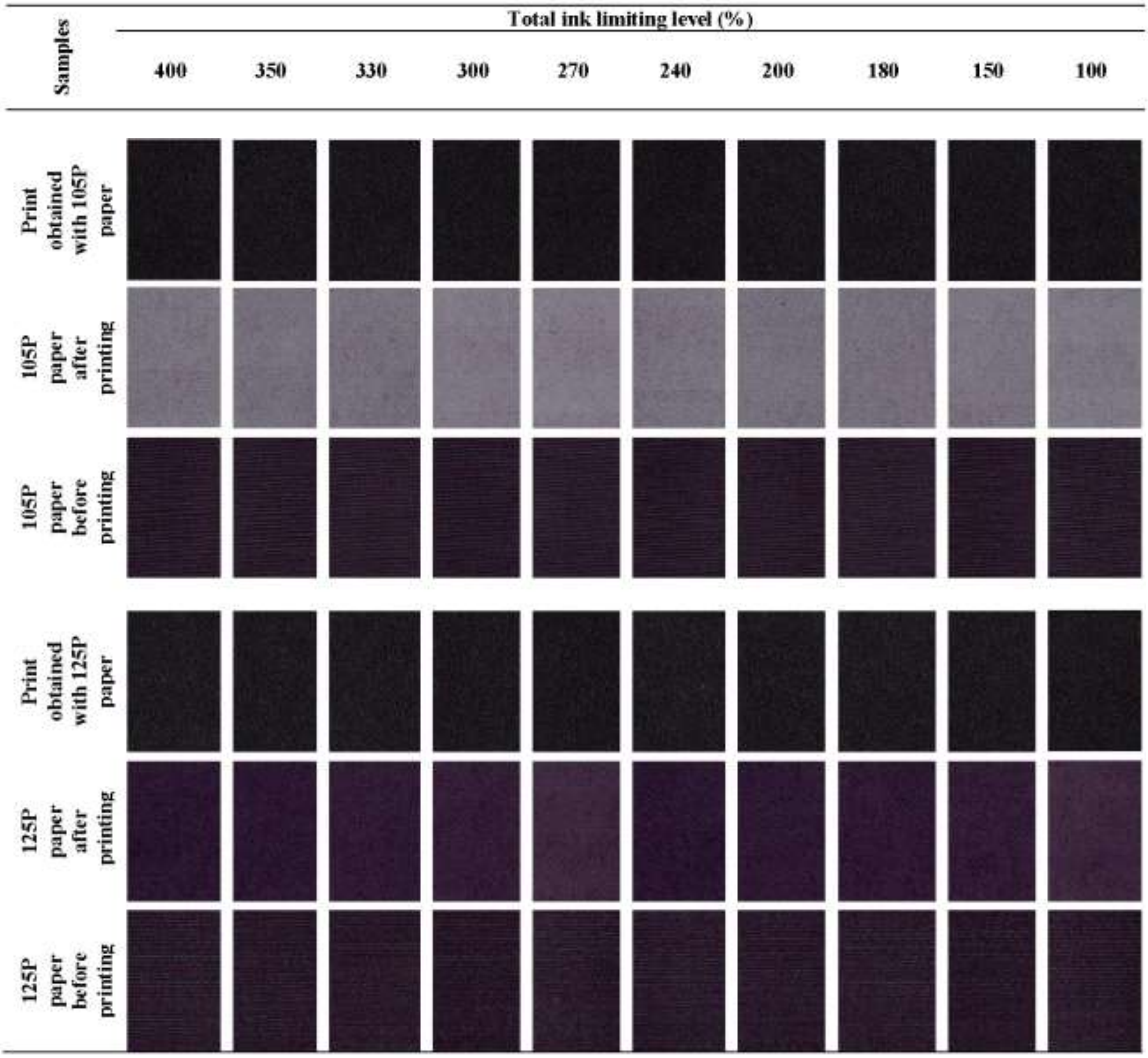
The image for printing was created in Adobe Illustrator software in the CMYK color system and consisted of 10 rectangles in full-tone black color obtained by different combinations of CMYK values, and thus different total ink limiting levels of dye sublimation ink, from 100 % to 400 %. The dimensions of the rectangle were 3.5cmx3.5cm. Combinations of CMYK values and total ink limiting levels of dye sublimation ink for the CMYK color system of rectangles are shown in Table 1.

The test image was printed on commercially available A4 format sublimation transfer paper weighting 105 g/m^2 (105P marкed) and 125 g/m^2 (125P marкed) respectively with an A4 format EPSON ink jet printer for sublimation with four CMYK ink jet channels. Ink jet printer was with the printing method: Micro Piezo^{TM} print head and nozzle configuration: 180 nozzles for black and 50 nozzles for color, model L3151. The printer was installed and dye sublimation ink SUBLYFUN by Print Equipment Gmbh&Co. was used. Pre-pressing and sublimation printing processes were performed by the press model BESTSUB SB3A (38 cm x 38 cm) and medium pressure (2.3-3.5 bar). Pre-pressing of fabric was conducted at print temperature for 6 seconds, and then sublimation printing was performed at the temperature of 190 °C for 60 s. Afterward, the fabric thus processed was cooled down to room temperature, and the baking paper was removed. The sublimation printed fabrics were conditioned and tested in a standard atmosphere (temperature 20 °C and 65 % relative humidity) for 24 hours. Scanned images of the sublimation printed fabrics and the sublimation transfer papers before and after the sublimation printing process are given in Table 2.

Table 1. Combinations of CMYK values and total ink limiting levels of dye sublimation ink for the black color of the test image for printing sublimation transfer paper

Code	C	M	Y	K	Total ink limiting level (%)
1	100	100	100	100	400
2	90	80	80	100	350
3	90	70	70	100	330
4	80	60	60	100	300
5	70	50	50	100	270
6	60	40	40	100	240
7	40	30	30	100	200
8	30	20	20	100	180
9	30	10	10	100	150
10	0	0	0	100	100

Table 2. Scanned images of sublimation printed fabrics and sublimation transfer papers before and after the sublimation printing process



2.2.2 Color strength

The color strength (K/S) of the printed fabric was determined by measuring the corresponding reflectance value using the X-Rate Color i7 reflectance spectrophotometer and calculating the K/S value using Kubelka-Munk Equation (1).

$$K/S = \frac{(1-R_{\lambda max})^2}{(2R_{\lambda max})} \quad (1)$$

where: K is the absorption coefficient, S is the scattering coefficient, and R is the reflectance value of the print at the wavelength at maximum absorption.

2.2.3 *CIELab* color coordinates

The *CIELab* color coordinates and chroma C^* measurements of the printed fabrics were performed according to ISO 105-J01:1997 standard on an X-Rate Color i7 reflectance spectrophotometer under illuminant D65 and using the 10° standard observer and measuring port 16 mm. The L^* value represents lightness and varies from 0 (black) to 100 (white) along the white-black axis. The a^* and b^* values refer to redness (+)-greenness (-) and yellowness (+)-blueness (-), respectively. The chroma C^* measures color saturation and refers to vivid (+)-matte (-).

2.2.4 Color difference

Color difference, ΔE^* was measured by L^*, a^*, and b^* using an X-Rate Color i7 reflectance spectrophotometer. ΔE^* value is calculated by using the $CIEL^*$, a^* and b^* values where ΔL^*, Δa^* and Δb^* values were the difference between L^*, a^*, and b^* values of a pair of a color standard and sample according to Equation (2).

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (2)$$

where: ΔE^* is the color difference, $\Delta L^* = L^*_{sample} - L^*_{standard}$, $\Delta a^* = a^*_{sample} - a^*_{standard}$ and $\Delta b^* = b^*_{sample} - b^*_{standard}$.

It is expressed as a numerical value (ΔE^*) and represents the visual difference between color standard and the sample. Each sample was categorized according to the magnitude of its ΔE^* value into fifth groups of visual difference: $\Delta E^*<0.2$ as "Not visible", ΔE^* between 0.2 and 1 as "Very small", ΔE^* between 1 and 3 as "Small", ΔE^* between 3 and 6 as "Medium", $\Delta E^*>6$ as "Large". ΔE^* was also expressed by grades (from 1 to 5) according to ISO-105-A01:2010.

2.2.5 The transfer rate of sublimation transfer paper

The transfer rate is determined by specifying the ink patch to transfer under transfer conditions and measuring the color strength on the sublimation transfer paper before and after transfer conditions using Equation (3).

$$TR(\%) = \frac{K/S_B - K/S_A}{K/S_B} \cdot 100 \quad (3)$$

where: TR is the transfer rate of sublimation transfer paper, K/S_B is the color strength of sublimation transfer paper before transfer conditions, and K/S_A is the color strength of sublimation transfer paper after transfer conditions.

2.2.6 GLCM (grey level co-occurrence matrix) image processing method

Non-uniformity of print density called print mottle was assessed by the image analysis method using a grey level co-occurrence matrix (GLCM). After sublimation printing, the printed fabrics were scanned and digitalized by flatbed scanner EPSON L3151 at 600 dpi scanning resolution without auto-correction. The actual rotation angle determined by the orientation of the sample set in the sample input was 90°. Scanned images in the TIFF files were scaled at 500 x 500 pixels using Photoshop software and saved as separate TIFF files for easier processing in MATLAB. Then, the samples were subjected to GLCM analysis to obtain quantitative print uniformity results. GLCM analysis was done in MATLAB software with the code according to Uppuluri [19] using the following parameters: the number of grey levels was set to 8 (L^* channel), the distance between two pixels (d) was set to 1, and four angles of orientation were used (horizontal 0°, right-diagonal 45°, vertical 90°, and left-diagonal 135°). Print mottle using MATLAB code was assessed through contrast, correlation, entropy, energy, and homogeneity parameters. GLCM parameters were calculated for all total ink limiting levels and sublimation transfer papers.

3. RESULTS AND DISCUSSION

The effect of different total ink limiting levels of dye sublimation ink for printing sublimation transfer paper in the sublimation printing process on the print color strength is shown in Table 3. The prints obtained with all total ink limiting levels of dye sublimation ink showed maximum intensity at 560 nm. This led to the conclusion that sublimation printing with different total ink limiting levels of dye sublimation ink resulted in the same tone of black color. Print obtained with sublimation transfer paper printed with 270 % total ink limiting level of dye sublimation ink showed more intensive color strength than those obtained with sublimation transfer paper printed with other total ink limiting levels of dye sublimation ink. When comparing K/S values for prints obtained with sublimation transfer paper printed with 100 % and 270 % total ink limiting levels of dye sublimation ink, it can be seen that they were similar. Amorphous areas of polyester fibers exist when the temperature rises to about 200 °C, the amorphous zone moves vigorously, allowing the gaseous sublimation dye to enter the fiber. At this temperature, the dye sublimation is gaseous; because of the attraction of dye sublimation power, the dye in such a gaseous state has the potential to move towards the polyester fiber, then diffuses and gets into the amorphous area and along with the reduction of temperature, the dye molecule desublimates and is wrapped in amorphous area, reaches the printing effect [20]. This effect was better reached during sublimation printing with 105P sublimation transfer paper compared to 125P sublimation transfer paper (Table 3). The maximum K/S value, 13.96, which was obtained for the print made with 105P sublimation transfer paper, was higher than the maximum K/S value, 9.87, which was obtained for the print made with 125P sublimation transfer paper, while both were printed with the 270 % total ink limiting level. Fabrics printed with lighter sublimation transfer paper had a higher increase in K/S values than the fabrics printed with heavier sublimation transfer paper. The color strength of the prints was influenced by the transfer rate of sublimation transfer paper as represented by a darker color shade for the prints obtained with the sublimation transfer paper with a higher transfer rate. The transfer rate of sublimation transfer paper used for sublimation printing was different (Table 3). The lighter 105P sublimation transfer paper had a higher transfer rate than the heavier 125P sublimation transfer paper. After the transfer process, the transfer rate reflected the sublimation of the dye sublimation ink. The higher the print color strength of the fabric after the transfer process, the less the amount of ink remaining on the sublimation transfer paper, and the higher the transfer rate of the sublimation transfer paper. When the transfer rate was high, most of the dye sublimation ink on the sublimation transfer paper was sublimated. This was a result of the receiving layer, i.e., the holding layer from sublimation transfer paper, which was capable of absorbing and holding dye sublimation ink. The receiving layer absorbs the ink and enables a better sublimation process [16]. Sublimation transfer paper comprises base paper, the least one receiving layer, and a back coating layer [20].

The variation in L^*, a^*, and b^* color coordinates relative to the total ink limiting level of dye sublimation ink for printing sublimation transfer paper and the transfer rate of sublimation transfer paper is presented in Table 4. Print obtained with sublimation transfer paper printed with 270 % total ink limiting level of dye sublimation ink showed a darker color (lower L^* value) compared to prints obtained with sublimation transfer paper printed with other total ink limiting levels. Fabrics printed with sublimation transfer paper with a higher transfer rate showed darker color (lower L^* value) than fabrics printed with sublimation transfer paper with a lower transfer rate. The change of a^* and b^* values was more intensive to prints obtained with sublimation transfer paper with a higher transfer rate. In terms of transfer rate, it can be seen that the prints obtained with sublimation transfer paper with a higher transfer rate showed more redness and blueness compared to sublimation transfer paper with a lower transfer rate. In visual color perception, chroma expresses the vibrancy, i.e., vividness or opacity properties of a color. A positive chroma value shows that the color has a higher saturation [11]. When the chroma values were examined according to Table 4, it was determined that the prints obtained with sublimation transfer paper with a higher transfer rate had a higher saturation (higher C^* value) than the prints obtained with sublimation transfer paper with a lower transfer rate, hence more vivid colors.

Table 3. Color strength of sublimation printed fabrics and transfer rate of sublimation transfer paper used for sublimation printing

Code	Total ink limiting level (%)	K/S		TR (%)	
		105P Sublimation transfer paper	125P Sublimation transfer paper	105P Sublimation transfer paper	125P Sublimation transfer paper
1	400	13.42	10.68	67.69	12.38
2	350	13.27	11.03	67.52	14.95
3	330	13.18	10.93	65.51	16.38
4	300	13.67	11.65	69.97	20.56
5	270	13.96	12.11	70.60	27.93
6	240	13.62	10.60	65.98	11.37
7	200	13.25	10.89	68.15	15.20
8	180	13.17	10.78	66.13	16.79
9	150	13.78	11.44	70.79	19.97
10	100	13.95	11.89	71.82	26.91

Table 4. *CIELab* color coordinate of sublimation printed fabrics in respect of the total ink limiting level used for printing of sublimation transfer paper and sublimation transfer paper

Code	Total ink limiting level (%)	105P Sublimation transfer paper				125P Sublimation transfer paper			
		L^*	a^*	b^*	C^*	L^*	a^*	b^*	C^*
1	400	23.91	1.38	-2.01	2.44	27.38	0.20	-1.68	1.69
2	350	24.49	1.35	-2.11	2.50	27.03	0.32	-1.69	1.72
3	330	24.16	1.32	-2.11	2.50	27.06	0.35	-1.68	1.72
4	300	23.68	1.50	-2.02	2.52	26.15	0.66	-1.31	1.77
5	270	23.42	1.58	-1.87	2.55	25.63	0.89	-1.54	1.79
6	240	23.99	1.39	-2.05	2.48	27.60	0.10	-1.70	1.71
7	200	24.13	1.30	-2.07	2.45	27.10	0.32	-1.68	1.72
8	180	24.18	1.33	-2.10	2.49	27.67	0.20	-1.64	1.66
9	150	23.56	1.52	-1.96	2.48	26.39	0.58	-1.61	1.72
10	100	23.41	1.61	-1.93	2.51	25.78	0.80	-1.25	1.78

Print mottle presented through GLCM parameters is a suitable indicator of non-uniformity of print density [21-23]. The results of GLCM parameters (energy, entropy, contrast, homogeneity, and correlation) of sublimation printed fabric depending on total ink limiting level of dye sublimation ink and sublimation transfer paper are shown in Figures 1-5. It can be noticed that prints obtained by sublimation transfer paper printed with 270 % ink limiting level of dye sublimation ink showed significantly lower values for the entropy, contrast, and correlation parameters and higher values for the energy and homogeneity parameters compared to the prints obtained by sublimation transfer paper printed with other total ink limiting levels of dye sublimation ink. This indicated the lowest print mottle presence on the print was obtained with sublimation transfer paper printed with the 270 % total ink limiting level of dye sublimation ink. Low contrast, low entropy, low correlation, high energy, and high homogeneity correspond to uniform grey level distribution, i.e., indicate a uniform surface [24,25]. When comparing values of print mottle for prints obtained with sublimation transfer paper printed with 100 % and 270 % ink limiting levels of dye sublimation ink, it can be seen that they were similar. Comparing the prints obtained between sublimation transfer papers, certain differences can be observed for all five GLCM parameters, indicating that the higher transfer rate of sublimation transfer paper had a more intensive impact on the print mottle of sublimation printed fabrics. Based on the results shown in Figures 1-5, it can be concluded that the prints obtained with sublimation transfer paper with a higher transfer rate had a uniform surface and that prints obtained with sublimation transfer paper with a lower transfer rate had a larger non-uniformity print mottle. The print obtained with sublimation transfer paper with a higher transfer rate had the lowest entropy, contrast, and correlation and the highest energy and homogeneity; therefore, it can be regarded as the sample with the highest print quality. The reason why print mottle was lower when printing on fabric with sublimation transfer paper with a higher transfer rate than printing on fabric with sublimation transfer paper with a lower transfer rate was connected with transferred dye sublimation ink on the fabric surface, and hence with the color strength of prints. Fabric printed with sublimation transfer paper with a higher transfer rate had higher K/S values, so the amount of dye sublimation ink was higher and evenly distributed over the fabric, than fabric printed with sublimation transfer paper with a lower transfer rate, which resulted in uneven print over the fabric. The unequal transfer of sublimation dye on the surface of the fabric led to a higher value of print mottle.

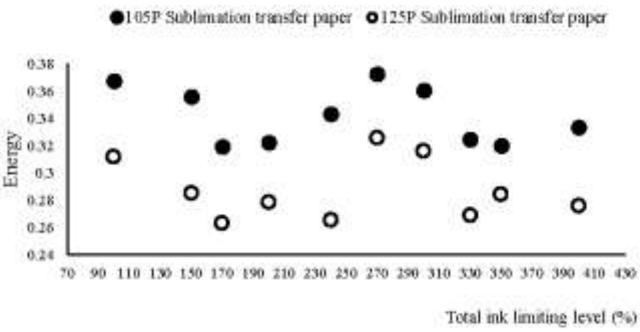


Figure 1. Energy GLCM parameter of sublimation printed fabrics depending on total ink limiting level of dye sublimation ink and sublimation transfer

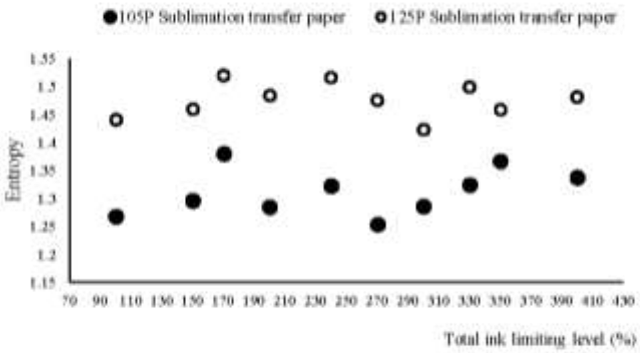


Figure 2. Entropy GLCM parameter of sublimation printed fabrics depending on total ink limiting level of dye sublimation ink and sublimation transfer paper

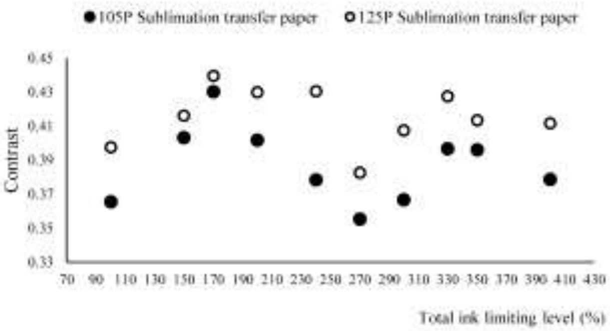


Figure 3. Contrast GLCM parameter of sublimation printed fabrics depending on total ink limiting level of dye sublimation ink and sublimation transfer paper

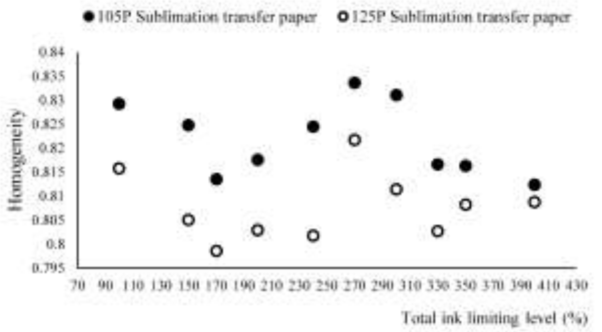


Figure 4. Homogeneity GLCM parameter of sublimation printed fabrics depending on total ink limiting level of dye sublimation ink and sublimation transfer paper

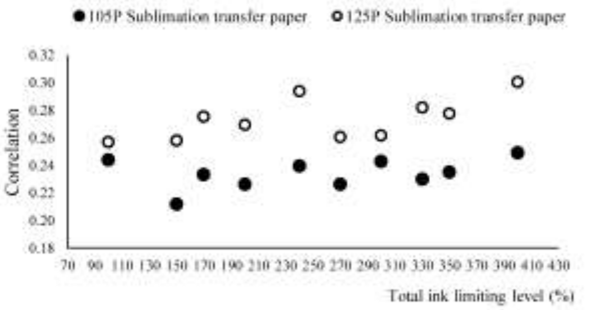


Figure 5. Correlation GLCM parameter of sublimation printed fabrics depending on total ink limiting level of dye sublimation ink and sublimation transfer paper

The overall color changes of the printed fabric are assessed by ΔE^* values [26]. The color difference between prints obtained for each sublimation transfer paper was done to determine the difference. The color difference between the print obtained with sublimation transfer paper printed with each total ink limiting level of dye sublimation ink (used as sample) and the print obtained with sublimation transfer paper printed with the 270 % total ink limiting level of dye sublimation ink (used as standard) within each sublimation transfer paper is shown in Table 5. When Table 5 is examined, it is seen that the ΔE^* calculated according to the total ink limiting level of dye sublimation ink used for printing sublimation transfer papers belonged to the first (ΔE^* <0.2), second (ΔE^* 0.2-1) and third (ΔE^* 1-3) groups, indicating from not visible to the small color difference between print colors. The prints obtained with the 105P lighter sublimation transfer paper with a higher transfer rate showed a color difference lower than 1 compared to the prints obtained with the 125P heavier sublimation transfer paper with a lower transfer rate. This color difference lower than 1 indicated a color difference undetectable to the human eye. Higher ΔE^* values indicate intensive color change [26,27]. It can be concluded that increasing the total ink limiting level of dye sublimation ink for printing sublimation transfer paper had not significantly affected the color of the sublimation print. Considering the importance of the total ink limiting level of dye sublimation ink for printing sublimation transfer paper in terms of cost in businesses, the 100 % total ink limiting level of dye sublimation ink for printing sublimation transfer paper will save time and reduce unnecessary costs.

Further, the color difference between prints obtained with the differently used sublimation transfer papers was done. In Table 6 is shown the color difference between print obtained with the 125P sublimation transfer paper (used as sample) and print obtained with the 105P sublimation transfer paper (used as standard) for each total ink limiting level of dye sublimation ink. The color difference that appeared between the prints obtained with both sublimation transfer papers mostly belonged to the fourth (ΔE^* 3-6) group, indicating medium color differences. This color difference was noticeable to the human eye. It was noticed that the transfer rate of sublimation transfer paper had a significant effect on the color difference.

Table 5. The color difference between prints obtained for each sublimation transfer paper

Sample=Standard	105P Sublimation transfer paper			125P Sublimation transfer paper		
	ΔE^*	Gray scale	Visual difference	ΔE^*	Gray scale	Visual difference
1=10	0.55	4-5	very small	1.89	4	small
2=10	1.10	4-5	small	1.52	4	small
3=10	0.82	4-5	very small	1.53	4	small
4=10	0.31	4-5	very small	0.61	4-5	very small
5=10	0.63	4-5	very small	2.13	4-3	small
6=10	0.79	4-5	very small	1.58	4	small
7=10	0.83	4-5	very small	2.16	4-3	small
8=10	0.18	5	not visible	0.82	4-5	very small
9=10	0.07	5	not visible	0.34	4-5	very small

Table 6. The color difference between prints obtained with the differently used sublimation transfer papers

Sample=Standard	ΔE^*	Gray scale	Visual difference
125P-1=105P-1	3.68	3	medium
125P-2=105P-2	2.77	4-3	small
125P-3=105P-3	3.09	3	medium
125P-4=105P-4	2.70	4-3	small
125P-5=105P-5	2.34	4-3	small
125P-6=105P-6	3.85	3	medium
125P-7=105P-7	3.15	3	medium
125P-8=105P-8	3.70	3	medium
125P-9=105P-9	3.00	3	medium
125P-10=105P-10	2.60	4-3	small

3. CONCLUSION

The sublimation transfer paper with different weights and transfer rates was printed with different total ink limiting levels of dye sublimation ink in black color, and then was used for sublimation printing on fabric at 190 °C for 60 s. The prints obtained with lighter sublimation transfer paper were darker and more vivid with more intensive color strength than the prints obtained with heavier sublimation transfer paper; their redness and blueness were more pronounced. The lighter sublimation paper had a lower transfer rate than the heavier sublimation transfer paper. It can be said that the sublimation transfer rate affected print quality, since the majority of print color differences belonged to the fourth (ΔE^* 3-6) group, indicating a medium color difference that was noticeable to the human eye. The prints obtained with sublimation transfer paper printed with the 270 % total ink limiting level of dye sublimation ink were darker and more vivid with more intensive color strength and lower value of print mottle than the prints obtained with sublimation transfer paper printed with other total ink limiting levels of dye sublimation ink; their redness and yellowness were also more pronounced. The increase of the total ink limiting level of dye sublimation ink for printing sublimation transfer paper had no significant effect on the black color of the sublimation print. The color difference between prints obtained with lighter sublimation transfer paper with a higher transfer rate printed with 270 % and 100 % total ink limiting levels of dye sublimation ink was less than 1, suggesting a color difference undetectable to the human eye. Considering the importance of the total ink limiting level of dye sublimation ink for printing sublimation transfer paper in terms of cost in businesses, the 100 % total ink limiting level of dye sublimation ink will save time and reduce unnecessary costs for the sublimation printing process.

REFERENCES

1. Kašiković N, Novaković D, Karlovic I, Vladić G. 2012. Influence of Ink Layers on the Quality of Ink Jet Printed Textile Materials. *Tekstil ve Konfeksiyon* 22(2), 115-124.
2. Golja B, Forte Tavčer P. 2016. Textile Functionalisation by Printing Fragrant, Antimicrobial, and Flame-Retardant Microcapsules. *Tekstilec* 59(4), 278-288.
3. Ružičić B, Stepanić M, Kasiković N, Majnarić I. 2015. The Influence of Thermal Load on the Print Quality of Screen Printed Knitted Fabric. *Advanced technologies* 4(1), 78-83.
4. Boh Podgornik B, Šandić S, Kert M. 2021. Microencapsulation for Functional Textile Coatings with Emphasis on Biodegradability-A Systematic Review. *Coatings* 11(11), 1371.
5. El-Halwagy AA, El-Sayad SH, El-Molla MM. 2001. Sublimation Transfer Printing of Cotton and Wool Fabrics. *Macromolecular Materials and Engineering* 286(10), 618-623.
6. Özgüney TA, Seçim P, Demir A, Gülümser, Özdogan E. 2015. Ecological Printing of Madder Over Various Natural Fibres. *Tekstil ve Konfeksiyon* 25(2), 166-171.
7. Tavčer Forte P, Štular D, Ahtik J. 2013. Digital Printing of Anaglyph Onto Textile. *Tekstil ve Konfeksiyon* 23(4), 381-386.
8. Stančić M, Grujić D, Kašiković N, Novaković D, Ružičić B, Milošević R. 2015. Influence of Washing Process and the Perspiration Effects on the Qualities of Printed Textile Substrates. *Tekstilec* 58(2), 135-142.
9. Kalendraite B, Krisciunaite J, Mikucioniene D. 2021. Influence of Sublimation Process on Air Permeability and Water Absorption Dynamics. *International Journal of Clothing Science and Technology* 33(6), 863-872.
10. Stojanović S, Grešak J, Trajović D, Ćirković N. 2020. Influence of Sublimation Transfer Printing on Alterations in the Structural and Physical Properties of Knitted Fabrics. *Coloration Technology* 137(2), 108-122.
11. Özomay M, Özomay Z. 2021. The Effect of Temperature and Time Variables on Printing Quality in Sublimation Transfer Printing on Nylon and Polyester Fabric. *European Journal of Science and Technology* 23, 882-891.
12. Cie C. 2015. *Ink Jet Textile Printing*. Oxford: Woodhead Publishing.
13. Sharma A. 2010. Evaluation of Ink Optimization Technology in Offset Color Printing. *Journal of Imaging Science and Technology* 54(6), 0605041-06050413.
14. Kumar AJ, Kumar SM. 2021. Optimisation of the Sublimation Textile Printing Process Using the Taguchi Method. *FIBRES & TEXTILES in Eastern Europe* 29(1/145), 75-79.
15. Xiumei L, Zhiqiang C, Rongfeng L, Fushou L, Jiyou H. 2017. CN107435275B. Beijing, China.
16. Kumar R. 2021. Dynamic of Sublimation Printing. *International Journal of Trend in Scientific Research and Development* 5(6), 397-401.
17. Glombikova V, Komarkova P. 2014. Study on the Impact of Dye-Sublimation Printing on the Effectiveness of Underwear, *Tekstilec* 57(2), 133-138.
18. Stojanović S, Grešak J, Trajković D. 2021. Compression Properties of Knitted Fabrics Printed by Sublimation Transfer Printing Technique. *Advanced Technologies* 10(1), 46-53.
19. Uppuluri A. 2022, May 25. GLCM Texture Feature. https://ww2.mathworks.cn/matlabcentral/fileexchange/22187 -glcm-texture- features?s_tid=FX_rc1_behav.
20. Shedd WM, Jose DB, Dizier JG. 2008. US2008/0229962A1. Alexandria, Virginia.
21. Stančić M, Kasiković N, Novaković D, Milošević R, Grujić D. 2013. Thermal Load Effect on Print Quality of Ink-Jet Printed Textile Materials. *Journal of Graphic Engineering and Design* 4(2), 27-33.
22. Vojčić Đ, Ružičić B. 2017. The Influence of Washing Treatment and Macro Non-Uniformity on Color Reproduction of Screen Printed Cotton Knitted Fabrics. *Journal of Chemical Technology and Metallurgy* 52(5), 825-835.
23. Zubar RA, Alo AO. 2019. Grey Level Co-occurrence Matrix (GLCM) Based Second-Order Statistics for Image Texture Analysis. *Internaltional Journal of Science and Engineering Investigations* 8(93), 64-73.
24. Hladnik A, Lazar M. 2011. Paper and Board Surface Roughness Characterization Using Laser Profilometry and Grey Level Co-occurrence Matrix. *Nordic Pulp and Paper Research Journal* 26(1), 99-105.
25. Milošević R, Kašiković N, Novaković D, Jurić I, Stančić M. 2014. GLCM Print Mottle Assessment of Ink Printed Billboard. *Journal of Printing Science and Technology* 5(5), 339-346.
26. Toshikj E, Jordanov I, Demboski G, Mangovska B. 2016. Influence of Multiple Laundering on Cotton Shirts Properties. *Tekstil ve Konfeksiyon* 26(4), 393-399.
27. Toshikj E, Mangovska B. 2012. Analyses of Some Undesirable Effects in Industrial Exhaust Dyeing of Knitted Fabrics of Different Grades of Cotton with Reactive Dyes. *Tekstil* 61(1-6), 41-47.