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Assessment of Durability of Inkjet Prints on Laboratory Paper Substrates with Wheat Pulp Based on Rub Resistance

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Abstract

Paper recycling is becoming increasingly important as the production of packaging and various printed products grows. As alternative to wood fiber that is the most common raw material in paper production this research examines the quality of paper which is made with addition of non-wood fibers derived from wheat straw. For this purpose, laboratory paper substrates were made by blending recycled newspaper pulp and wheat straw pulp in different proportions. In this study we analyse rub resistance of laboratory paper substrates with variable content of wheat pulp printed in full tone with black and yellow inks by digital ink jet printing technique. The main objective of this research is to determine whether this kind of print has necessary durability for carrying stable illustrations. One of the main characteristics of print quality is resistance to rubbing which is very important for packaging during transport, storage and the end use. Rub resistance test was executed according to BS 3110 standard. The print durability was assessed through the Euclidean color difference and the individual CIE L*a*b* differences before and after the rub tests. The analysis showed that the increase of wheat pulp content in paper substrates has affected the increase of color difference. Greater rub resistance was observed on substrates with lower share of wheat pulp. Samples printed with yellow ink showed overall greater durability than samples printed with black ink. In further analysis we observed that for the black prints the difference in lightness (ΔL') of the CIE L*a*b* color space was most affected as the prints became lighter with the number of rubbing cycles. In samples printed with yellow ink most affected was the color difference on yellow-blue axis (Δb') meaning that the yellowness of the prints was degrading with the number of rubbing cycles.

Key words

durability, inkjet printing, paper substrate, rub resistance, wheat pulp

1. INTRODUCTION

Rapid rise in the production of paper products leads the paper industry to the search for alternative fiber sources that would reduce or replace wood as a main source of virgin fiber in papermaking processes. So far, the alternative sources of the virgin fibers can be categorized as: agricultural crop residues such as cereal or straw residues, natural growing plants such as miscanthus, reeds or other grasses and non-wood crops that include textile crops such as cotton or flax [1]. Agricultural crops residues are interesting for their abundance and low cost but also for the shorter growing cycle than wood [2]. As the most available crop that is grown in Croatia is

wheat [3], this research was focused on examining the quality and durability of laboratory paper substrates produced with different ratios of wheat straw fibers. The wheat straw was collected after harvesting, cut and converted to wheat pulp according to soda method where fibers are separated from plant tissue [4]. Wheat pulp was blended with wood pulp from recycled newsprint paper in different ratios to improve the characteristics of shortened recycled wood fibers [5]. The previous research has led to the conclusion that the addition of wheat pulp up to 30% provide good quality of the prints on such laboratory paper substrates [6-8].

Rub resistance is defined as the ability to resist damage during the friction of two surfaces in contact [9]. It is very important feature of the printed material, especially packaging, because it must endure the process of shipment, storage, and handling from production phase to the end use. It can be evaluated visually or by calculating Euclidean color differences (ΔE_{00}) of printed materials in the CIE L*a*b* color space [10].

2. MATERIALS AND METHODS

The research was divided into four phases: production of laboratory paper substrates, printing, rub resistance testing and spectrophotometric measurements of colorimetric values before and after the rub resistance testing to determine the changes in print coloration.

2.1. Production of Laboratory Paper Substrates

Four types of paper substrates were produced with different weight ratios of recycled newsprint pulp and wheat pulp:

- N – reference paper substrate – with 100% recycled newsprint pulp,
- 1NW – with 90% recycled newsprint pulp and 10% wheat straw pulp,
- 2NW – with 80% recycled newsprint pulp and 20% wheat straw pulp,
- 3NW – with 70% recycled newsprint pulp and 30% wheat straw pulp.

2.2. Printing

In the second phase laboratory paper substrates were printed using inkjet printing technique on EFI Rastek H652 digital printer. UV curable black and yellow inks were printed in full tone over the paper substrates. Settings of the printer were adjusted to "high quality" printing mode, with 8 passes in 600 dpi resolution and the printing speed of 12.1 m^2/h.

2.3. Rub resistance testing

Printed paper substrates were cut to smaller round samples with the diameter of 5 cm. The rub resistance test was performed on a tribometer Hanatek T4 Rub and Abrasion Tester according to the BS 3110:1959 standard under the constant pressure of 0.23 kg (0.5 lb) with rotational motions of 20, 40 and 60 cycles at the speed of 1 revolutions per second.

2.4. Spectrophotometric measurement of colorimetric values

Before the paper substrates were subjected to rub resistance tests the spectrophotometric measurements were made to determine the CIE L*a*b* colorimetric values of each printed sample. After the rub resistance tests had been made, the measurements were repeated and the Euclidean color difference ΔE_{00} was calculated according to CIEDE2000 formula (1). Device used for the spectrophotometric measurements was SpectroEye with illuminant D50 and 2° observer angle.

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_C S_H}\right)} \quad (1)$$

where: $\Delta L'$ is representing the difference in lightness between printed samples before and after the rub resistance test, $\Delta C'$ is the chroma difference between printed samples before and after the rub resistance test and $\Delta H'$ is the hue difference between printed samples before and after the rub resistance test. R_T is the rotation function, while k_L, k_C, k_H are the parametric factors for variation in the experimental conditions and S_L, S_C, S_H are the weighting functions [11].

In addition to the ΔE_{00} calculations, the difference of individual components of the CIE L*a*b* color space $\Delta L'$, $\Delta a'$ and $\Delta b'$ was calculated according to the formulas (2), (3) and (4) where the value marked with index 1

represents the value measured before the rub resistance test and the value marked with index 2 represents the value measured after the test.

$$\Delta L' = L_1^* - L_2^* \quad (2)$$

$$\Delta a' = a_1^* - b_2^* \quad (3)$$

$$\Delta b' = b_1^* - b_2^* \quad (4)$$

Durability is considered acceptable or print quality is good if the value of the Euclidean color difference is less than 1 and can be tolerated up to 2. The untrained eye of the observer does not notice a difference in color change for those values of ΔE_{00} [12].

3. RESULTS AND DISCUSSION

Euclidean color difference (ΔE_{00}) was measured before and after the rub resistance test on 30 samples, and average value was calculated. Table 1. shows values of ΔE_{00} for four types of paper substrates (N, 1NW, 2NW and 3NW) printed in full tone black and yellow after the rub resistance test with 20, 40 and 60 rubbing cycles. Prints on paper substrates with added wheat pulp showed slightly increased color difference compared to the prints on the reference paper substrates without added wheat pulp.

For the black prints, calculated color difference on samples marked N was 0.55 for 20 cycles, and 0.75 for 40 and 60 cycles, meaning that the color difference can't be perceived with the untrained eye and that the black prints are stable to rubbing. Black prints on papers with added wheat pulp show lesser durability and more fluctuation in rub resistance tests, regardless of the number of cycles and wheat content, with increased value of Euclidean color difference ranging from 0.77 to 1.2.

The Euclidean color difference for the yellow prints is less pronounced as indicated by the low ΔE_{00} values ranging from 0.39 to 0.51 on reference substrates marked N. Substrates with added wheat pulp showed a slight increase in Euclidean color difference values from 0.43 to 0.86 that predictably rise with the number of rub test cycles.

Table 1. Average ΔE_{00} values of black and yellow prints made on four paper substrates N, 1NW, 2NW and 3NW after the rub resistance test with 20, 40 and 60 rubbing cycles

Paper substrate type	N			1NW			2NW			3NW		
No. of rubbing cycles	20	40	60	20	40	60	20	40	60	20	40	60
	Average ΔE_{00}											
Black prints	0.55	0.75	0.75	0.98	0.83	0.91	0.8	0.82	1.2	0.77	0.79	0.98
Yellow prints	0.42	0.39	0.51	0.43	0.62	0.69	0.55	0.72	0.66	0.62	0.62	0.86

Further calculations have examined the difference of individual components of the CIE L*a*b* color space ($\Delta L'$, $\Delta a'$ and $\Delta b'$) with purpose to determine which of them were most affected by rub tests in respect of 20, 40 and 60 rubbing cycles. As predicted, the paper substrates printed with black ink had most significant change in L^* component which suggests that the rubbing test had most impact on lightness. Figure 1. shows the charts with the difference of $\Delta L'$, $\Delta a'$ and $\Delta b'$ for each type of the tested paper substrates. The reference substrate marked N showed gradual increase in $\Delta L'$ values with the increased number of rubbing cycles (Figure 1.a). The negative values indicating that the black color tone becomes lighter. Change on a^* (green/red) and b^* (blue/yellow) axis was slightly rising in the positive direction (< 0.2), although the changes cannot be perceived with the human eye. With the addition of wheat pulp, color durability showed greater fluctuations compared to reference paper substrate, with unpredictable results of $\Delta L'$ in relation to the number of rubbing cycles. However, Figure 1. b), c) and d) shows that all calculated $\Delta L'$ values were measured in the acceptable range < 1.2. In the paper substrates with added wheat pulp, the $\Delta a'$ values did not change significantly and the $\Delta b'$ values had slight increase with the number of rubbing cycles, although the difference was insignificant (< 0.4). The amount of wheat pulp in the paper substrate had no significant impact on the measured values.

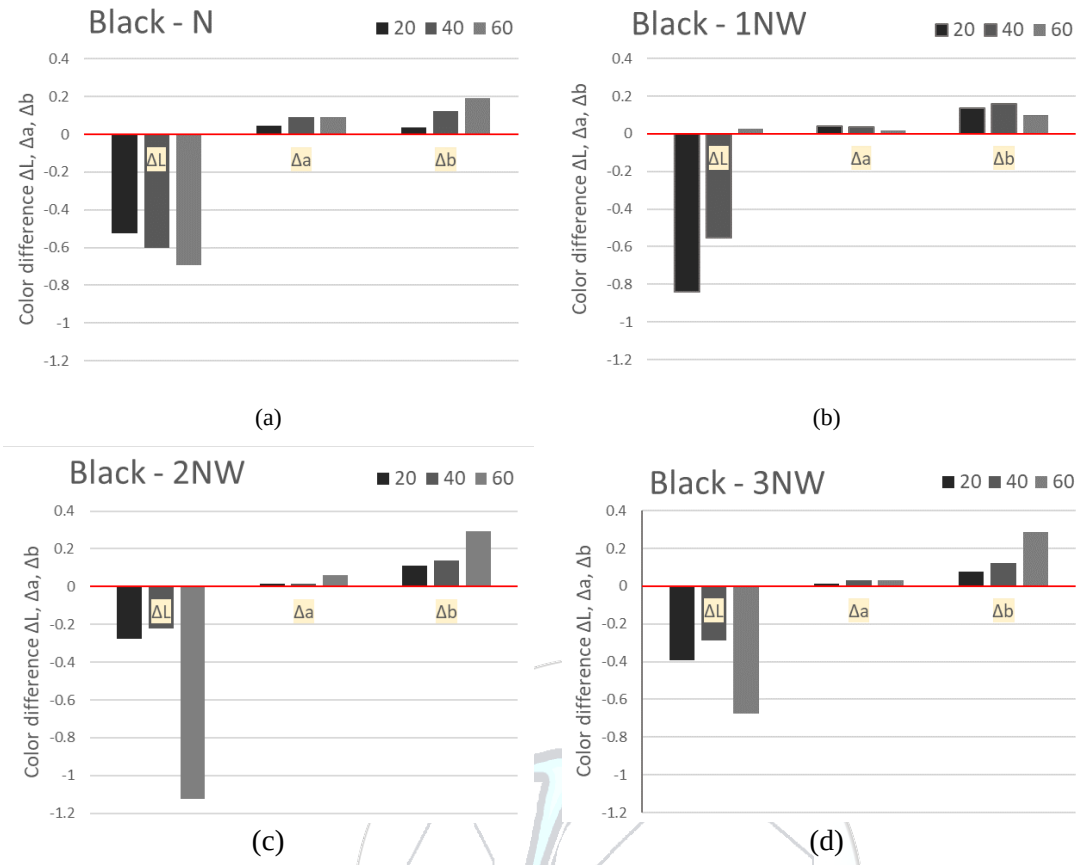

Figure 1. Color difference of ΔL', Δa' and Δb' for black prints on four paper substrates N, 1NW, 2NW and 3NW calculated from measurements before and after the rub resistance test with 20, 40 and 60 cycles

The greatest differences in *b** component of the CIE L*a*b* color space – the blue/yellow axis, was observed on prints with yellow ink. The reference sample (Figure 2.a) shows increase in $\Delta L'$ values in the acceptable range < 0.5 and shows good durability throughout 20, 40 and 60 rubbing cycles. The color difference in the component *a** – the red/green axis – had shown insignificant increase < 0.2, after the rub resistance testing. As expected, the greatest difference was observed for the $\Delta b'$ with the increased values in the positive range < 1.5, indicating that the yellow color after the rubbing test has slightly decreased yellowness. Figure 2. b), c) and d) show calculated values of $\Delta L'$, $\Delta a'$ and $\Delta b'$ for yellow prints on paper substrates with added wheat pulp. The change in lightness indicated with $\Delta L'$ has insignificantly increased compared to the reference substrate, measuring < 0.73 given the highest number of rubbing cycles. Differences $\Delta a'$ have not changed significantly in respect to the rubbing cycles and increase of wheat amount in the paper substrate (< 0.5). In the *b** axis changes were more pronounced after 40 and 60 rubbing cycles compared to the reference paper substrate, resulting with $\Delta b'$ of ~1 with 20 rubbing cycles regardless of wheat content, from 1.3 to 1.5 for 40 rubbing cycles and from 1.8 to 2 for 60 rubbing cycles. These results can still be categorized as acceptable with the very small color difference.

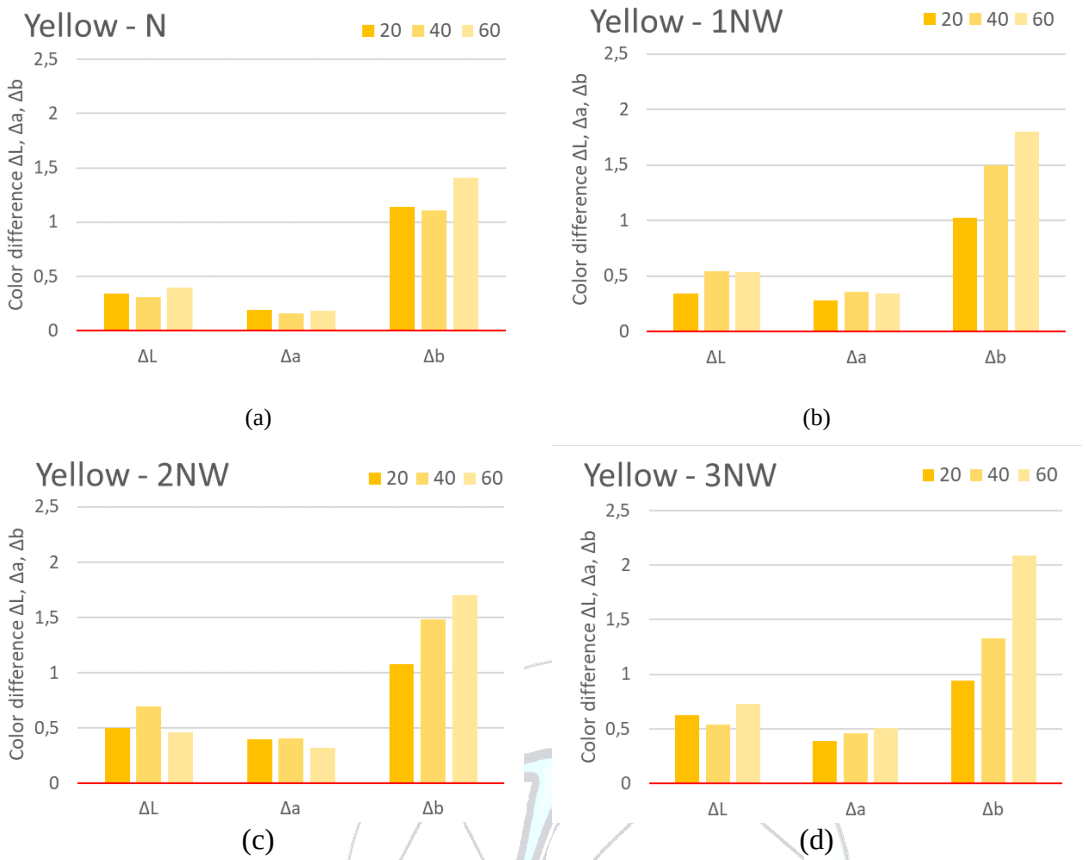

Figure 2. Color difference of ΔL', Δa' and Δb' for yellow prints on four paper substrates N, 1NW, 2NW and 3NW calculated from measurements before and after rub resistance test with 20, 40 and 60 cycles

4. CONCLUSION

In this paper the durability of black and yellow prints made on the paper substrates with added wheat pulp was assessed based on the rub resistance testing. The calculated Euclidean color difference and the color difference of separate components of the CIE L*a*b* color space values showed the satisfactory level of print durability for the black and yellow prints. Lesser rub durability of prints was determined on the paper substrates with added wheat pulp than on the reference substrate without wheat pulp, but the results were still in the acceptable ranges. The prints in full tone black ink showed overall the greater Euclidean color difference than the prints made with full tone yellow ink which indicated that the yellow prints were more durable in comparison with black ones. Black samples on paper substrates with added wheat pulp showed slightly unpredictable results in the Δ*L'* calculations regardless of the percentage of added wheat pulp or the number of rubbing cycles in the resistance testing. All results were within acceptable ranges. Yellow prints on paper substrates with added wheat pulp showed the greatest increase in Δ*b'* component with respect of the rubbing cycles increase, meaning there was a slight loss of yellowness in the color, but also in the acceptable range. The amount of wheat pulp in the substrate had not significantly affected results. It can be concluded that laboratory paper substrates with added wheat pulp up to 30% has provided satisfactory durability of digital inkjet prints in the rub resistance tests and can be recommended for further development in creating paper for packaging and other purposes.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest.

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