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Analysis of Natural and Artificial Aging Influence on UV Inkjet Prints on Printing Substrates with Straw Pulp

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Abstract

Paper substrate, as the most common used substrate for printing labels or packaging, is traditional produced from cellulose fibres derived from wood. The growth of a large number of industries has led to a significant increase in the use of such resource, which consequently led to a global awareness of the possibility of forest exploitation and the importance of reusing waste paper as a source of fibres. Hence, paper fibres can be recycled up to seven times and it is important to enrich paper pulp with virgin fibres during paper production. In such a way, the characteristics of the paper and the quality of the printed elements are improved. In this paper, cereal straw as an alternative resource of virgin fibres was turned into pulp and mixed with recycled wood pulp to conduct printing substrates using laboratory equipment. Since aging is an inevitable process of any printing substrates and prints, and the degradation of print quality due to aging largely depends on the properties of the printing substrate, ink and type of printing. This research was focused on analysing optical stability of prints made on printing substrates with straw pulp by UV inkjet technique after natural and artificial aging. From a comparison of the aging processes based on the Euclidean difference results, it was observed that natural aging of UV inkjet prints yields less colour changes compared to artificial aging. Greater or equal optical stability after aging was perceived for prints on printing substrates with wheat, barley and triticale pulp compared to prints on substrates made with recycled wood pulp.

Key words

aging, optical stability, printing substrate, straw pulp, UV inkjet printing

1. INTRODUCTION

Aging can be defined as irreversible changes that occur slowly over time [1], and in the case of paper and print this process may result in deterioration of useful properties, resulting in an unsuitable final graphic product. Although cellulose due to accidental hydrolysis of glycosidic bonds between glucose residues into cellulose macromolecules, oxidation and crosslinking affects the natural aging of paper, it is shown that the energy radiation, temperature and relative humidity (RH) are crucial to the longevity of paper substrate. The degree of polymerization (DP) of cellulose is also been reduced by aging process which causes deterioration of the optical properties of the cellulose and thus paper as a sheet made from randomly deposited cellulose fibres in network. The deterioration in print quality due to aging is largely dependent not only on the properties of the paper as a printing substrate, but also on the ink and type of printing process [2].

Since paper substrates have been traditionally produced from wood-derived cellulose fibres, the consumption of wood raw materials has increased significantly in recent years, which led to a global awareness of the possibility of forest exploitation and the importance of reusing waste paper as a source of cellulose fibres.

Over the past decade, the use of recovered paper in the paper and cardboard industry has grown all over the world. Recycled paper makes up about 50% of the total production of paper fibres used worldwide. The utilization rates of recycled paper substrates are very different, depending on the desired quality and final purpose. In the year 2010, the main purpose of recycled paper in Europe was for packaging production with 63.7%, for publications with 26.0% (18.6% for newsprint and 7.4% for other graphic products), for household and sanitary with 6.9%, and only 3.4% for other paper grades [3]. Substitition virgin wood fibers with recycled ones fiber also reduces greenhouse gas emissions by about 37% [4]. Paper production cannot be supplied only with recycled fibres derived from waste paper, because they cannot be used effectively in all paper grades, nor can be used indefinitely as raw material. Therefore, recycled pulp needs to be enriched with a certain amount of virgin fibres in order to increase the strength (wood cellulose fibres decay with each recycling process) and the quality of the paper [3].

Many countries around the world are struggling with the forest shortages, and this problem would become even greater in the coming years. Aware of this environmental problem, researchers are constantly introducing alternative sources of cellulose fibres. Alternative resources of non-wood virgin fibres are divided into this groups: purpose dedicated crops, agricultural residues, industrial residues and uncultivated crops that occur naturally [5]. The most widely used are cane bagasse, bamboo, kenaf, hemp, sisal, abaca, cotton linter and reeds, as well as some exotic raw materials like aquatic plants, tea waste, palm leaf and banana stem. Most of these plants are annual plants that develop the full potential of fibre in one growing season [6].

Printed paper substrates are frequently used in a variety of everyday applications, from newspapers to packaging material and labels. Since the colour durability and permanence of a graphic product plays an important role in ensuring accuracy, prints should not be degraded in quality before the product is sold or during usage [7]. Therefore, this research is focused on the analysis of optical stability of prints made on printing substrates without and with straw pulp by UV curable inkjet digital technique after natural aging and artificial aging. Laboratory printing substrates made with cereal straw were compared to laboratory printing substrates made only from recycled fibers which are used as reference paper (N), while commercial printing substrates were used as control substrate (K).

2. MATERIALS AND METHODS

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2.1. Papers with straw pulp

The straw of the most common crop species in Croatia: wheat (Triticum spp.), barley (Hordeum vulgare L.) or triticale (Triticale sp.) straw were collected after the harvest and manually cut using scissors into 3 cm long pieces. Purified straw was conducted into semichemical pulp according soda pulping method [8]. Laboratory papers of approx. 42.5 g/m2 were formed by Rapid-Köthen sheet former (FRANK-PTI) according to standard EN ISO 5269-2:2004 [9] whereby straw pulp (wheat, barley or triticale) was added in proportions of 10%, 20% or 30% into reference pulp of recycled paper (Table 1).

According to their composition, 10 different laboratory papers were formed and compared to each other and observed in relation to commercial paper made from recycled wood pulp.

Table 1. Commercial paper and laboratory papers composition

MARK OF SUBSTRATE	COMMERCIAL PRINTING SUBSTRATES - COMPOSITION
K	Commercial paper - 100% recycled wood pulp
MARK OF SUBSTRATE	**Laboratory printing substrates - Composition**
N	100% recycled wood pulp - reference paper
1NW	10% wheat pulp + 90% recycled wood pulp
2NW	20% wheat pulp + 80% recycled wood pulp
3NW	30% wheat pulp + 70% recycled wood pulp
1NB	10% barley pulp + 90% recycled wood pulp
2NB	20% barley pulp + 80% recycled wood pulp
3NB	30% barley pulp + 70% recycled wood pulp
1NT	10% triticale pulp + 90% recycled wood pulp
2NT	20% triticale pulp + 80% recycled wood pulp
3NT	30% triticale pulp + 70% recycled wood pulp

2.2. UV curable inkjet printing

In order to analyze changes in optical properties of printed commercial and laboratory substrates, both sample types were printed by digital EFI Rastek H652 UV inkjet digital machine at ambient conditions of 55% RH and temperature of 23°C. Cyan, magenta, yellow and black UV curable inks were printed in fulltone on each laboratory paper and commercial paper with the resolution of 600 × 600 dots per inch (dpi) (respectively with high quality mode 8 pass) and printing speed of 12.10 m2/ h. EFI Rastek digatal machine uses the Toshiba Tec CA-5 printhead for each color. These printheads offer the ability to print grayscale, which means it can produce droplets of different sizes from 6 pl to 42 pl, which creates prints of the higher quality.

Figure 1. Printed commercial and laboratory substrates

2.3. The process of prints aging

The experimental part of this research was divided into two parts to conduct the two types of aging processes: artificial aging and natural aging.

2.3.1. Artificial aging process of prints

Printed commercial and laboratory paper substrates without and with straw pulp were shaped into 60 mm x 90 mm strips and placed side by side on a white background in the Suntest XLS + test chamber. The imitation of natural aging treatment was performed by xenon lamp with a daylight filter, emitting visibly and close to ultraviolet electromagnetic radiation with the wavelength in a range from 290 nm to 800 nm.

The artificial aging procedure was performed in two cycles of 48 hours according to ASTM D 6789-02 [10], during which the light intensity level was 765 ± 50 W/m^2.

Table 2. Conditions during artificial aging treatment

Cycle of aging	Duration of the aging process (h)	Heat flow rate intensity (J/s·m^2)	Ambient condition	
			Temperature (°C)	Relative humidity (%)
I	48	765	24.8	54.7
II	96	765	23.5	47.4

2.3.2. Natural aging process of prints

The printed samples were stored during period of 365 days side by side in a black bookcase in a dark and dry place to analyse the influences of the natural aging process.

Spectrophotometric analysis

Spectrophotometric measurements in the visible part of electromagnetic spectrum were performed before and after aging processes on all printed substrates by SpectroEye device, X-rite (D50, 2°). Spectrophotometric measurements provided data on the optical properties of analysed prints that were observed using colorimetric characteristics by CIE L*a*b* values. The colorimetric values L*a*b* were used to define the optical degradation of printed substrates, before and after aging processes, which were ultimately presented on the basis of Euclidean differences (ΔE_{00}*). Colour difference or Euclidean difference (ΔE_{00}*) is the numerical value for describing difference between two colours. Analysing of optical stability of cyan, magenta, yellow and black UV inkjet prints without and with straw pulp was determined based on Euclidean color difference which was calculated according equation (1).

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

Values $\Delta L'$ (lightness), $\Delta C'$ (chroma) and $\Delta H'$ (hue) are calculated based on the colorimetric values of the analysed prints after the aging process L^{*1}, a^{*1}, b^{*1} and the colorimetric values of prints before aging process L^{*2}, a^{*2}, b^{*2}, where $\Delta L'$, Δa^*, Δb^* are differences between colorimetric values of the print after aging and colorimetric values before aging process, R_T is the rotation function S_L, S_C, S_H are weighting functions for lightness, chroma and hue, factors k_L, k_C, k_H are defined with respect to observation conditions. In the CIE L*a*b* colour space the value L' represents the lightness of the colour and the value +a* represents redness or the value –a* represents greenness, and the +b* value represents yellowness or the value –b* represents blueness [11,12]

According to Euclidean differences definition $\Delta E_{00}^* \leq 2$ is classified as very small noticeable difference for standard observer, while $\Delta E_{00}^*=5$ is defined like a big noticeable difference in the colour whose standard observer can recognized [13].

Figure 2. Spectrophotometric measurements

3. RESULTS AND DISCUSSION

Comparison of optical stability of prints performed on papers without and with straw pulp after first artificial aging cycle of 48 hours and natural aging process observed on the basis of the Euclidean difference is presented in Figure 3.

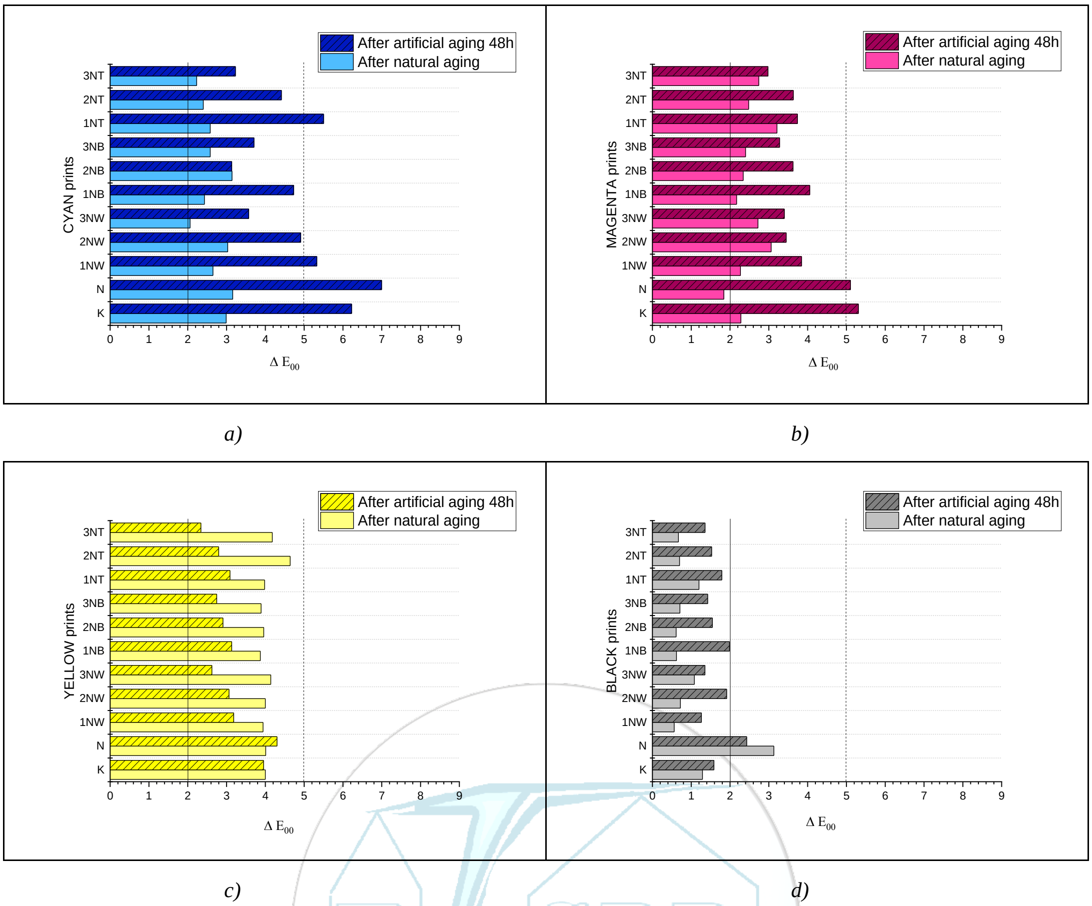
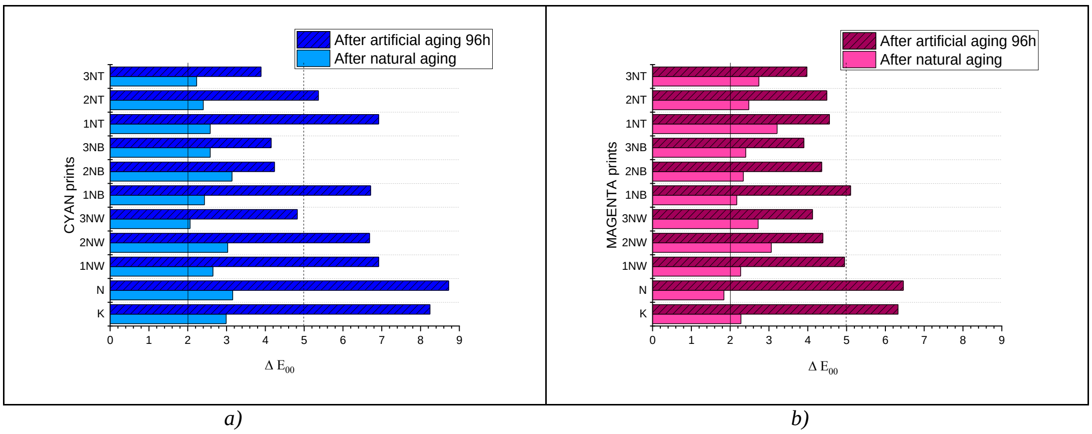


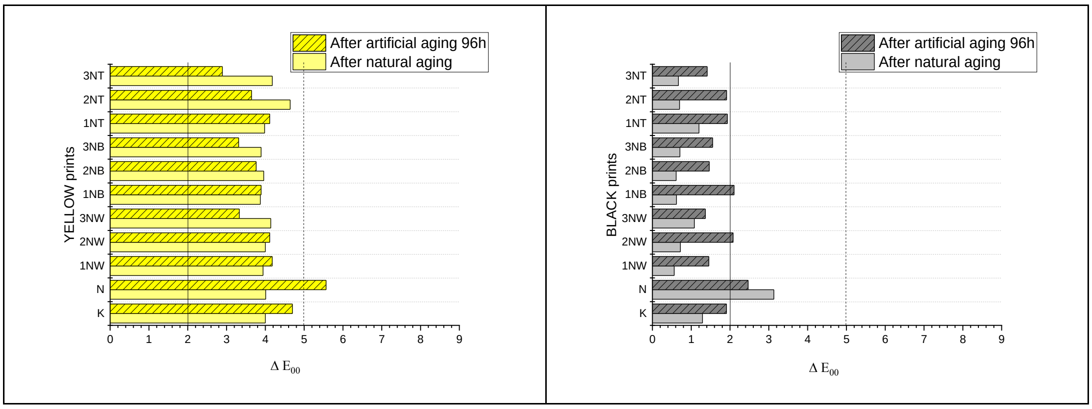
Figure 3. The comparison of the first cycle of artificial aging and natural aging processes based on the Euclidean colour difference of cyan (a), magenta (b), yellow (c) and black (d) UV inkjet prints

According to spectrophotometric measurements the addition of wheat, barley and triticale pulp into laboratory substrates provide equal or slightly greater optical stability during aging process. Observing all results it could be assumed that magenta and cyan prints made on the reference paper (N) and commercial paper (K) show the most pronounced changes in the coloration after the artificial treatment of 48 hours while the less visible changes are observed on printed substrates with the addition of straw pulp. From obtained results of all yellow prints it is evident that printed substrates with the addition of straw pulp have slightly larger colour changes during natural aging than after first cycle of artificial aging treatment.

Given treatments of aging, black prints have similar behaviour as cyan and magenta prints. After both of observed aging treatments, a slight reduction in the colour of the black print was obtained, which is defined according to tolerance definition as a small noticeable difference in the tone that standard observer can recognize. Generally, the most stable prints, regardless of the substrate composition, are those obtained with black UV inkjet ink, where the largest Euclidean colour difference after natural aging is $\Delta E_{00(N)} = 3.2$, while the Euclidean colour difference after artificial aging is up to $\Delta E_{00(N)} = 2.43$.

The comparison of optical properties of prints performed on papers without and with straw pulp after second artificial aging cycle (in total 96 hours) and natural aging process observed on the basis of the Euclidean difference is presented in Figure 4.





c) *d)*

Figure 4. The comparison of the second cycle of artificial aging and natural aging processes based on the Euclidean colour difference of cyan (a), magenta (b), yellow (c) and black (d) UV inkjet prints

From the Figure 4 it is visible that greater colour deviations were obtained on all printed substrates without and with wheat, barley or triticale pulp after artificial aging period for 96 hours, which are defined as significant noticeable difference in the print tone that standard observer can recognize.

From the value of Euclidean colour difference, it is noticeable that the colour degradation of the UV inkjet prints decreases with the gradual addition of straw pulp in laboratory substrates.

When comparing colour difference after second artificial aging treatment and after natural aging process it is possible to define that 96-hour artificial aging treatment yielded the same colorimetric differences as the natural aging on yellow printed substrates, regardless of the substrate composition.

The black UV inkjet ink on the prints after a longer period of artificial aging treatment provides the most stable prints on all observed printed substrates, where the highest colorimetric difference goes up to a value of $\Delta E_{00(N)} = 3.3$.

4. CONCLUSION

Based on obtained data from the comparison of the aging processes, the following conclusions can be drawn:

- Prints on laboratory substrates which containing wheat, barley or triticale straw pulp have the greater optical stability after artificial aging treatments compared to printing substrates made from recycled wood pulp.
- The greatest optical instability after natural aging was noticed for yellow prints on all printing substrates, while only after artificial aging of 96 hours the same colorimetric differences were obtained as after natural aging.
- Cyan, magenta and black prints obtained on printing substrates with and without straw pulp after natural aging for a period of one year have shown greater stability compared to prints after artificial aging treatment.
- The greatest ability to remain chemically and physically stable over long periods of time was noticed for black prints on all observed substrates.
- Experimental observation of optical stability confirmed that laboratory papers with addition of straw pulp could be used for certain categories of printing papers, such as for packaging, labels or some publications.

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