# COMPARISON OF THE RUB STABILITY OF GRAVURE AND OFFSET UVINKS PRINTED ON SUBSTRATES WITH NON-WOOD FIBERS

# USPOREDBA STABILNOSTI NA OTIRANJE BAKROTISKARSKIH I OFSETNIH UV BOJA OTISNUTIH NA PODLOZI S NEDRVNIM VLAKANCIMA

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**Abstract**

The final quality of a graphic product largely depends on the source of raw materials for pulp and paper, the type of printing ink, the technology of printing the product and the conditions under which the printing was performed. Each analog printing technology is suitable for a particular type of printing substrate depending on the transfer of printing ink from the printing plate to the printing substrate. In the last few years, due to the over-exploitation of forests as a natural resource on a global scale, there is a growing tendency to replace wood as a traditional raw material for the production of paper with fibres from non-wood sources. The use of other cellulose sources for paper production is a cost-effective and environmentally friendly solution that reduces the consumption of virgin wood pulp. In this paper, the rub stability was analyzed on a printing substrate with non - wood fibers obtained from triticale straw printed with gravure and offset UV inks. By comparing the mechanical stability of prints made by these two analog technologies, direct and indirect, the usability of innovative printing substrates with non-wood fibers was assessed.



***Keywords:*** *gravure, offset printing, paper, triticale, rub stability*

**Sažetak**

Krajnja kvaliteta grafičkog proizvoda uveliko ovisi o izvoru sirovina za celulozu i papir, vrsti tiskarske boje, tehnologiji otiskivanja proizvoda te uvjetima pri kojima je vršeno otiskivanje. Svaka analogna tehnologija otiskivanja prikladna je za određenu vrstu tiskovne podloge ovisno o prijenosu tiskarske boje s tiskovne forme na tiskovnu podlogu. Zadnjih nekoliko godina radi prekomjerne eksploatacije šuma kao prirodnog resursa, na globalnoj razini raste tendencija za zamjenom drva kao tradicionalne sirovine za proizvodnju papira s nedrvnim izvorima. Korištenje drugih celuloznih izvora za proizvodnju papira je isplativo i ekološko rješenje s kojim se smanjuje potrošnja primarne drvne celuloze zamjenjujući je drugom biljnom biomasom. U ovom radu analizirana je stabilnost na otiranje na tiskovnoj podlozi s nedrvnim vlakancima dobivenoj iz slame pšenoraži otisnutoj s bakrotiskarskom i ofsetnom UV bojom. Usporedbom mehaničke stabilnosti otisaka načinjenih dvjema analognim tehnologijama, direktnom i indirektnom, procijenjena je uporabljivost inovativnih tiskovnih podloga s nedrvnim vlakancima.

***Ključne riječi:*** *bakrotisak, ofsetni tisak, papir, pšenoraž, stabilnost na otiranj*

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## 1. INTRODUCTION

The printing press is the basic unit of the entire printing process. This precise instrument has come a long way from Gutenberg's types and presses and is evolving daily to improve the quality and speed of delivery. Over the centuries, many different printing technologies have been developed, which today can be divided into four main technologies: offset printing, gravure printing, flexographic printing and digital printing. Each printing process is limited by the characteristics of the plate or image carrier, the ink and the way the ink is transferred to the substrate. Regardless of which printing technique is used, there are some important characteristics that must be met and followed in order to achieve a quality print.

Offset printing is the most common printing technique used for publications. This technique is also one of the most important techniques for printing packaging on absorbent substrates. Offset printing is a printing process in which the printing and non-printing elements are at the same level on the printing plate. The special feature of the printing areas is that they accept ink, while the non-printing areas reject the ink. In this way, a very thin ink layer is achieved on substrates of 0.5 μm to 1.5 μm [1]. Offset printing inks are very viscous, ranging from 40 Pa·s to 100 Pa·s, with a surface tension of about 35 mN/m and low polarity [2].

Gravure printing is the printing technique in which the engraved cylinder, under very high pressure, transfers the liquid ink held by its cells to the substrate. This printing technique is suitable for publications in very large runs (over 500,000 impressions), due to its excellent consistency. This printing technique is also dominant in the printing of luxury products and in decorative printing, as it is the only seamless conventional printing process. Gravure printing is also widespread in the printing of packaging (paper and polymeric materials). The engraved steel-based cylinder is covered with a thin layer of nickel and then covered with a thick layer of copper. After the electromechanical procedure, the resulting cells are engraved, which vary in width and depth. After engraving, the cylinder is covered with a thin layer of chrome, which provides hardness and longevity. The viscosity of the printing ink varies from 0.05 Pa·s to 0.02 Pa·s and the possible thickness of the ink on the printing substrate is ranging from 8 μm to 12 μm [1], [2].



These two techniques are most widely used in the printing of packaging and labels and were therefore used in this study. The packaging and label printing sector is continuously and rapidly evolving, where environmental protection, energy efficiency and sustainability are now the main focus.

Since paper substrates have been mostly made from wood-derived cellulose since the 18th century, deforestation has increased significantly in recent years, leading to global awareness of the potential depletion of forests and the importance of reusing waste paper as a source of recycled cellulose fibers.

Europe is also currently experiencing a paper shortages due to the war in Ukraine, as a result of restrictions leading to the elimination of paper and board from Russia [3].

In the last decade, the use of recycled paper in the paper and board industry has increased worldwide, with recycled paper accounting for about 50% of the total paper fiber production used worldwide [4].

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Paper production cannot be based solely on recycled fibers from recovered paper, as these cannot be used for all paper grades, nor can they serve as a raw material forever. Indeed, cellulose fibers become shorter with each recycling process, so they can be recycled up to seven times [5]. For this reason, recycled fiber pulp is usually enriched with a certain amount of virgin fiber to increase the strength and quality of the paper produced [6].

Aware of this environmental problem - the lack of forest land - researchers are constantly working on the introduction of alternative sources of cellulose fibers. Alternative sources of cellulose fibers have been analyzed and used worldwide depending on their availability [4]. Alternative fiber sources can also be divided into two major groups: agricultural residues and primary crops [7]. The following are some of the alternative sources of cellulose fibers that have been analysed in numerous studies: straw, sugarcane, bamboo, kenaf, hemp, sisal, abaca, cotton linter, reed, aquatic plants, tea waste, palm leaves and banana stems[8]–[12]. Since the properties of the paper substrate are one of the factors that undoubtedly affect the overall quality of printing on packaging, this study focuses on the printing laboratory paper substrates with pulp obtained from triticale straw [13].

The aim of this study was to determine and compare the stability of the printed substrate with the addition of 30% triticale pulp into the pulp of recycled fibres, printed using the two most common printing techniques (offset printing and gravure). The assessment of the stability of the prints was observed by determining the change in colour of the prints after performing the rub resistance test. The print stability or colour degradation was evaluated by the Euclidean colour difference ($\Delta E_{00}$*) calculated from the measured colourimetric values (L*, a*, b*) of the prints.



## 2. EXPERIMENTAL PART

The experimental part of this study was performed in five steps: 1. obtaining pulp from triticale straw; 2. forming laboratory paper substrates; 3. printing of paper substrates with offset printing and gravure printing; 4. assessment of the rub resistance of prints and 5. comparison of offset and gravure prints stability.

### 2.1. Obtaining pulp from triticale straw

Agricultural residues were collected after triticale crop has been harvested in the continental part of Croatia. Triticale straw was converted into cellulose pulp by decomposition of lignin and hemicellulose without depolymerization of cellulose fibers. The process conditions of obtaining pulp from triticale straw are summarized in Table 1. [13].

**Tab. 1: The process of converting triticale straw into pulp**

| Soda pulping – cooking in autoclave | | Decantation and rinsing | | Defibration in Holländer Valley mill | |
|---|---|---|---|---|---|
| Chemical $NaOH_{(aq)}$ | 16% | Tap water | 2 × 10 l | Tap water | 23 l |
| Bath ratio straw:$NaOH_{(aq)}$ | 1:10 | | | At 24 °C | 40 min |
| At 120 °C and 170 kPa | 60 min | | | pH | 8.5 – 9.0 |

### 2.2. Forming laboratory paper substrates

Laboratory paper substrates of approx. 42.5 g/m$^2$ were formed by Rapid-Kothen sheet former (FRANK-PTI) according to standard EN ISO 5269-2:2004[14]. The obtained unbleached triticale pulp was mixed with recycled wood pulp in a 3:7 ratio. The procedure for forming laboratory paper substrates under laboratory conditions is shown in Table 2. As a reference sample, under the same conditions, a laboratory paper substrate from recycled wood pulp is produced.

**Tab. 2: Procedure for forming laboratory paper substrates**

| **Disintegration** | | **Homogenisation** | | **Handsheet /paper substrate** | |
|---|---|---|---|---|---|
| m (pulp) | 80 g | V ($H_2O$) | 10 l | weight | 42.5 g/m$^2$ |
| V ($H_2O$) | 1.6 l | pH | 7.5 | | |
| pH | 8 | T | 45 °C | diameter | 20 cm |
| T | 45 °C | t | 5 min | | |

## 2.3. Printing paper substrates with offset printing and gravure printing

The paper substrates were printed by simulating the process of offset and gravure printing. Offset printing was done in full tone on a Prüfbau multi-purpose testing machine with SunCure Starluxe (manufactured by Sun Chemicals) at a temperature of 23 °C and a relative humidity of 50%. All samples were printed at a speed of 0.5 m/s and a pressure of 600 N, after which the prints were dried in a continuous dryer Technigraf Aktiprint L 10-1 (output power of the UV lamp max. 120 W/cm). On the other hand, printing by gravure printing technique was performed with a laboratory device KPP Gravure System using a printing cylinder of mechanical hardness (HS) 65 Shore and an engraved printing plate at an angle of 37 ° with a diamond needle at an angle of 130 ° with a screen of 100 lines/inch, or 40 lines/cm. The prints were done in full tone with Solarflex UV inks from Sun Chemical at a temperature of 23 °C and a relative humidity of 52%.



Rub resistance was tested on monocolour and multi-colour prints. Printing is made with one layer of cyan (C), magenta (M), yellow (Y) or black (K) ink - monocolour, two layers with cyan and yellow (C+Y), magenta and yellow (M+Y), cyan and magenta (C+M) and three layers with cyan, magenta and yellow (C+M+Y) - multi-colour prints. Some basic characteristics of the analysed paper printed for this study are shown in the table below (Table 3), where the paper labeled as K - commercial paper was made from recycled pulp and ind this study used as control sample, N - laboratory paper made from recycled pulp used as reference sample, and 3NT - laboratory paper made from 30% triticale pulp and 70% recycled pulp.

**Tab. 3: Characteristics of paper substrates** [13]

| **Paper substrates** | **Thickness (μm)** | **Ash (%)** | **$R_a$ (μm)** |
|---|---|---|---|
| K | 63.20 ± 2.90 | 10.00 ± 0.04 | 2.57 ± 0.32 |
| N | 94.00 ± 2.79 | 4.73 ± 0.22 | 4.15 ± 0.34 |
| 3NT | 99.40 ± 6.20 | 3.99 ± 0.15 | 4.40 ± 0.39 |

## 2.4. Assessment of the rub resistance of prints

In order to achieve high quality print on consumer products, the rub stability of prints is one of the most important parameters that must be met, and in order to achieve it, it is necessary to know the properties of the paper substrate and the possibilities of each printing technique. Durability or rub stability is the resistance of prints to colour fading during transportation, storage and handling or during end-user use, with large-format packaging and reusable products requiring a high level of rub stability.

In this paper, the rub resistance of samples printed in one, two or three layers on paper substrates made with addition of triticale pulp and from recycled wood pulp (laboratory N or commercial K) was investigated.

The evaluation of the rub resistance of the prints was carried out according to the standard BS 3110: 1959 [15] using a rub and abrasion tester (manufactured by Hanatek) at a constant speed of 60 rpm. The tests were performed by rub the entire contact area of a printed substrate with a diameter of 50 mm uniformly according to the principle of circular motion (20, 40 and 60 rotations) with an unprinted substrate with a diameter of 115 mm under constant pressure of 3.45 kPa and a block weight of 0.5 psi (0.23 kg).

Optical colour changes or fading were monitored using the Euclidean colour difference ($\Delta E_{00}^*$) calculated from the colourimetric values measured before and after the performed test. Measurements of colourimetric values on printed laboratory paper substrates were performed using SpectroEye (manufacturer X-Rite) under measurement conditions of status E, standard illumination D50 and 2° observer. The Euclidean colour difference ($\Delta E_{00}^*$) of all analyzed prints produced by offset and gravure printing was calculated according to the following equation 1 [16], [17].



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

Where:

$\Delta E_{00}^*$– the total colour difference, the Euclidean colour difference

$\Delta L'$ – the lightness difference between print before and after rub resistance test

$\Delta C'$ – the chroma difference between print before and after rub resistance test

$\Delta H'$ – the hue difference between print before and after rub resistance test

$R_T$ – the rotation function

$K_L$, $K_C$, $K_H$ – the parametric factors for variation in the experimental conditions

$S_L$, $S_C$, $S_H$ – the weighting functions

## 2.5. Comparison of offset and gravure prints stability

For a better insight into the possibility of using papers with the addition of triticale pulp as printing substrates, a comparison of achieved rub stability of offset and gravure prints was done. The comparison was performed in such a way that the obtained values of

Euclidean colour difference ($\Delta E_{00}^{*}$) after the rub resistance test for gravure and offset prints were subtracted from each other according to the following equation 2:

$$\Delta = \Delta E_{00}{}^{*}{}_{gravure} - \Delta E_{00}{}^{*}{}_{offset} \quad (2)$$

The rub resistance results of offset prints from our previous research [18] were used in this study for comparison of offset and gravure prints stability.

## 3. RESULTS AND DISCUSSION

To define and compare the durability of prints on paper substrates with triticale pulp intended for usage in packaging and publications, the two most common printing techniques were used for printing and the results were compared. The analysis of the durability of prints produced by offset and gravure printing techniques was based on the colour change due to rub stability on monocolour and multi-colour prints.

Figure 1 shows the colour degradation on monocolour prints made with the gravure printing process depending on the number of rotations during rub resistance test performed on all printed substrates. Paper substrates with the addition of triticale pulp printed with cyan and magenta ink show lower stability after the rub resistance test than commercial paper (K) and reference laboratory paper (N), while the ones printed with yellow and black ink show very similar stability to reference laboratory paper (N). Colour degradation calculated as $\Delta E_{00}^{*}$, for cyan prints on paper with 30% triticale pulp (3NT) ranges from 2.56 to 2.78, while for magenta prints on the same substrate $\Delta E_{00}^{*}$ values are ranging from 2.22 to 2.98, which is a moderate difference perceived by the average human eye. Yellow prints are the most stable considering that the largest observed Euclidean difference after 60 rotations is 0.91.

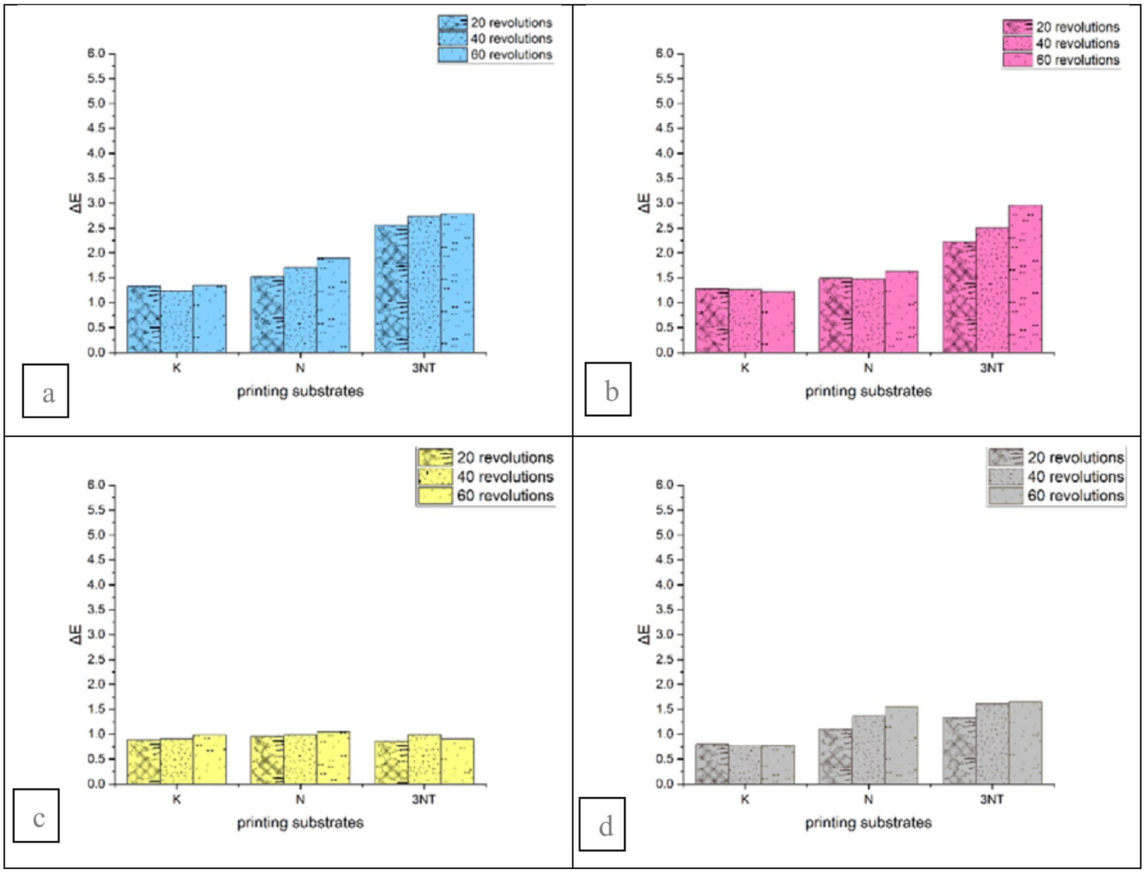


**Fig. 1: Colour difference ($\Delta E_{00}^*$) of the monocolour gravure prints made with cyan (a), magenta (b), yellow (c) and black (d) ink, after rub resistance testing with 20, 40 and 60 rotations**



Figure 2 shows that the values of the Euclidean colour difference do not increase significantly with a higher number of rotations on all multi-colour gravure prints. Printed substrates with two layers of ink show a colour difference, $\Delta E_{00}^*$, of up to 3.30, which is a moderate difference.

For magenta and yellow ink prints (M+Y) the largest colour difference reached 2.19, for cyan and yellow ink prints (C+Y) the largest difference, after 60 rotations, reached 3.30, while for prints with cyan ink and magenta ink (C+M) the maximum difference was achieved on commercial paper up to 2.50. Laboratory paper with 30% triticale pulp printed in three layers of ink with cyan, magenta and yellow ink (C+M+Y) shows the weakest rub resistance where the colour difference values reach 5.91 after 60 rotations.

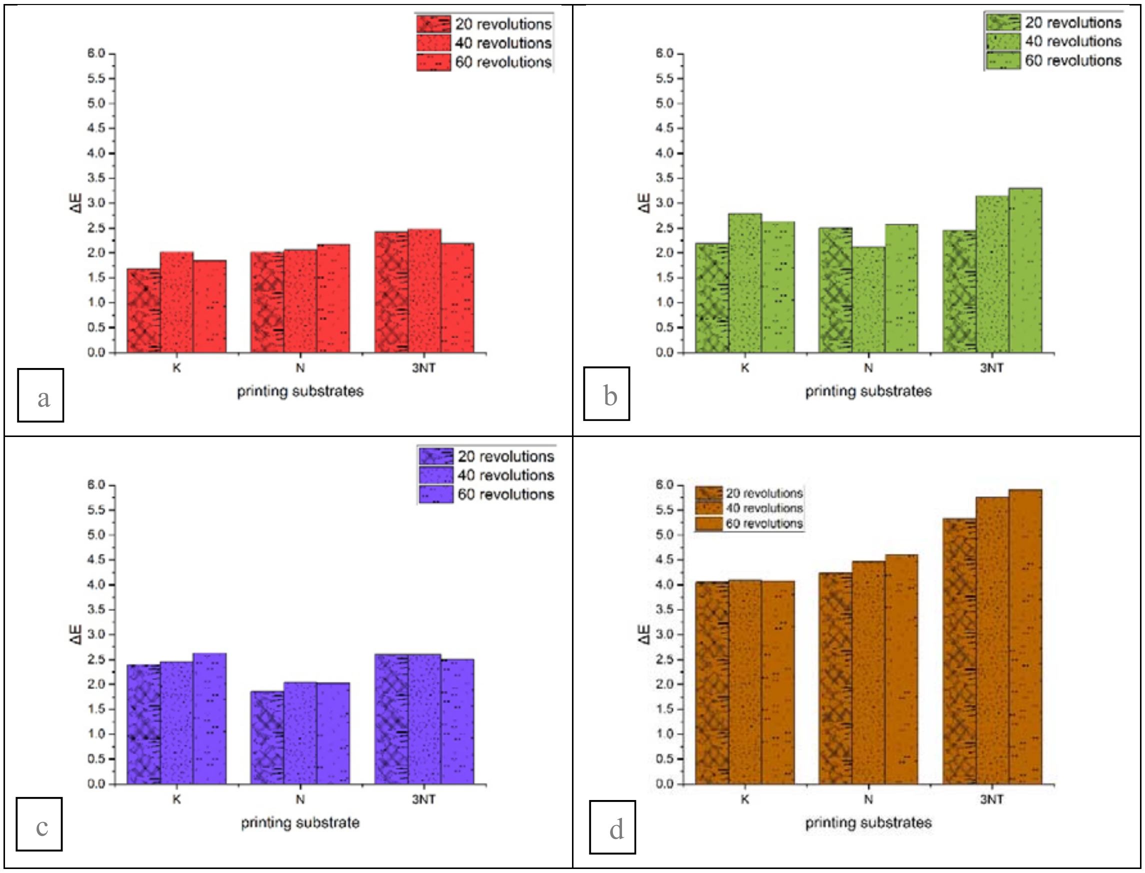


**Fig. 2: Colour difference ($\Delta E_{00}^*$) of the multi-colour prints made with magenta and yellow (M+Y) (a), cyan and yellow (C+Y) (b), cyan and magenta (C+M) (c) and cyan, magenta, and yellow ink (C+M+Y) (d), after rub resistance testing with 20, 40 and 60 rotations**



Considering the results of rub stability of prints produced by offset [18] and gravure printing processes in relation to the properties of the substrate and the technique of printing, very similar rub resistance was found for monocolour prints as calculated differences are very small (Table 4), where black prints produced by gravure printing technique have better mechanical stability than offset prints.

The differences between the achieved rub resistance of prints with two printing techniques are much greater for prints with two and three layers of ink (Table 5), and it can be found that multi-colour offset prints are more stable to rub than gravure prints.

Comparing all the results of rub stability, it can be concluded that the rub stability of the paper with 30% triticale pulp is the same or similar to papers made only from recycled pulp.

**Tab. 4: Comparison of Euclidean colour differences on monocolour prints obtained by gravure and offset printing after analysis of rub resistance**

| | $\Delta = \Delta E_{00}{}^{*}{}_{gravure} - \Delta E_{00}{}^{*}{}_{offset}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | | | M | | | Y | | | K | | |
| K | 0.47 | 0.38 | 0.75 | 0.44 | 0.35 | 0.44 | 0.64 | 0.32 | 0.43 | -0.55 | -0.64 | -0.63 |
| N | 0.30 | 0.96 | 0.77 | -0.10 | 0.35 | 0.33 | 0.56 | 0.44 | 0.14 | -0.01 | 0.05 | 0.17 |
| 3NT | 0.86 | 0.98 | 0.88 | 1.09 | 1.30 | 1.37 | 0.00 | 0.29 | 0.25 | -0.05 | -0.35 | -1.44 |

**Tab. 5: Comparison of Euclidean colour differences on multi-colour prints obtained by gravure and offset printing after analysis of rub resistance**

| | $\Delta = \Delta E_{00}{}^{*}{}_{gravure} - \Delta E_{00}{}^{*}{}_{offset}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Y+M | | | Y+ C | | | M+ C | | | Y+M+C | | |
| K | 1.68 | 2.02 | 1.85 | 2.52 | 2.79 | 2.63 | 2.40 | 2.46 | 2.63 | 4.05 | 4.09 | 4.08 |
| N | 2.02 | 2.06 | 2.17 | 2.50 | 2.13 | 2.57 | 1.86 | 2.04 | 2.03 | 4.24 | 4.47 | 4.60 |
| 3NT | 2.42 | 2.48 | 2.19 | 2.45 | 3.14 | 3.30 | 2.61 | 2.61 | 2.50 | 5.33 | 5.76 | 5.91 |

## 4. CONCLUSION



Based on the results obtained for evaluating the rub resistance of printed laboratory papers with triticale pulp, printed by offset and gravure printing techniques, the following conclusions can be drawn:

- All examined monocolour prints have good rub resistance regardless of the type of pulp for papermaking, with the exception of prints with cyan and magenta ink on paper with 30% triticale pulp, where moderate colour differences were observed after the test ($\Delta E_{00}{}^{*}$ max = 2.98).
- Multi-colour prints made with two layers of ink show the same stability, with a maximum colour variation of up to 3.30 for laboratory prints with and without added triticale pulp into the printing substrate.
- Multi-colour prints made with three layers of ink showed lower rub stability and were found to be the most unstable regardless of the composition and production of the printing substrate.
- Monocolour prints produced by offset and gravure printing have shown the same rub resistance, while black gravure prints have better stability than offset. Multi-colour offset prints, on the other hand, are much more resistant to rub than gravure prints.
- Analysis of rub resistance of laboratory and commercial papers confirms that paper with the addition of triticale pulp has no significant colour deterioration and can be used in the printing industry for printing packaging to reduce the use of virgin wood fiber resources.

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