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Optimization of flexographic print properties on ecologically favorable paper substrates

ABSTRACT

Nowadays, the attention in many industries is shifting towards the problem of waste overproduction and production of the waste in general. This study aimed to find an alternative approach to the production of packaging which will be environmentally friendly and at the same time optimal in terms of the print quality. This was accomplished by using the minimal needed amount of material for the production of packaging and adjusting the parameters of the flexographic printing process to achieve the desired visual impression of the print. The designed motive for the packaging was printed on five different recycled papers, following the guidelines of sustainable design. Printing was performed on each recycled paper with different printing pressures (50N, 150N, and 400N). Smoothness was measured on each paper; and for every printed sample, colorimetric measurements and thickness of the lines in positive and negative were measured. Print contrast for each print was calculated, and microscopy of fine printed elements was performed. All chosen papers except one had average smoothnes of up to 3.2 s (the smoothest paper had the average smootheness value of 54.72 s). Smoothness results influenced the printed line widths. Specifically, when increasing the printing pressure, a significant deformation of the line width has occured on all papers except the smoothest one (deformations of the lines printed in positive were up to 400 µm for rough papers compared to maximum of 60 µm for lines printed on the smoother paper). Similar results were obtained for the lines printed in negative. Furthermore, legibility of the printed typographic elements of 4pt size was significantly influenced by the smoothness of the paper. Elements printed on the smoothest paper have displayed the negligible deformations when changing the printing pressure. For other papers, elements in positive were optimally printed by 50 N pressure, and elements in negative by the pressure of 400 N. The results of this research have enabled the optimization of the flexographic printing process when using each of the five types of recycled papers. Furthermore, the presented qualitative and colorimetric parameters of the prints enabled the assessment of the applicability of used papers as printing substrates for ecologically favorable packaging.

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Introduction

The packaging is nowadays a fast-growing and fast-developing area in graphic technology. Special attention when designing the packaging product and choosing the materials for the packaging is being given to the ecological aspect of the final product. The principle of sustainable packaging is emphasizing the need for the usage of ecologically favorable materials (Dahlbo et al., 2018; Kaiser, Schmid & Schlummer, 2017). This includes biodegradable and recycled materials (Moustafa et al., 2019; Marrez, Abdelhamid & Darwesh, 2019). Furthermore, the printing process should require a minimal amount of toxic chemicals. For example, printing plates used in the reproduction should be produced without using harmful compounds such as developing agents, and the usage of ecologically harmful printing inks should be avoided whenever possible (Tomašegović et al., 2020; Izdebska, Żołek-Tryznowska. & Świętoński, 2015). Printing substrates for packaging that are eco-friendly are made of recycled and/or biodegradable materials such as recycled (and uncoated) papers, cellophane, PLA, PCL, and other polymeric materials (Ivanković et al., 2017; Mohamed & Yusoh, 2015; Mraović et al., 2014; Pivnenko, Eriksson and Astrup, 2014). The potential issues which occur when printing on eco-friendly substrates, especially recycled papers are printability and the quality of the print (El-Sherif et al., 2019; Aydemir, 2016). Since recycled papers are usually not coated, the absorptivity and roughness of the substrate can cause problems with the ink spreading, absorption, and consequently the inability to print fine elements such as thin lines and small font sizes (Bates et al., 2020; Miljković, Valdec & Matijević, 2018). Furthermore, many recycled papers have their specific shade which influences the colorimetric properties of the printed ink. Therefore, color deviations from the original ink color can be noticeable and even decrease the contrast between the substrate and printing ink, causing illegibility.

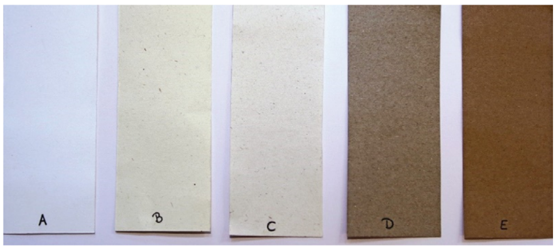
This research aimed to optimize the flexographic printing process used for printing on different recycled papers. Flexography was chosen as a printing technique because the elastomeric printing plate can adjust to rough printing substrates (Tomašegović et al., 2016). The process of the printing plate production can be aligned with ecological guidelines by using the laser-engraved EPDM printing plate and eliminating the need for harmful solvents. Modification of the printing pressure and analysis of the qualitative properties of the print on each recycled paper resulted in the recommendations for the application of used paper for specific types of motives on the packaging.

Experimental

Materials and methodology

To respect the sustainable design and ecological favourability of the packaging production, five different recycled paper was used as a printing substrate for packaging (Figure 1). The properties of each paper are listed in Table 1.

Papers were cut to samples of 5 x 70 cm and conditioned 24 hours before printing. The printing process was carried out using IGT Printability Tester F1 (IGT Testing Systems, 2016) in the laboratory, at a relative humidity of 55% and 23 ˚C.Anilox roller of 140 l/cm and 7.5 ml/m^2 was used. Anilox pressure was set to 300 N, and printing speed was set to 0.3 m/s. UV-curable ink, Pantone 363 U was used. Printing pressure was varied in the printing process – it was set to 50 N, 150 N, and 400 N. In that way, 3 sets of printed samples were obtained for each paper. In the reproduction process, the ethylene propylene diene monomer (EPDM) printing plate was used. The production of the EPDM printing plate does not include any solvents, since the image is transferred to the printing plate utilizing laser engraving, without any developing processes (Wienke et al., 2020).



» **Figure 1:** *Recycled papers used as a printing substrate*

Table 1
Grammage of the recycled papers used in the research

	A	B	C	D	E
Brand	MOHAWK	FLORA	FLORA	SCHOELLERS	SCHOELLERS
Grammage (g/m^2)	220	130	100	140	140

The smoothness of the paper was measured ten times on each sample according to Bekk method on a PTI-Line Bekk device. The smoothness test was carried out according to TAPPI standard T 479. Samples were placed on the glass plate, above which the measuring head is located. The measuring head pressed the sample with a weight of 10 kg. The vacuum pump adjusted the air tank to a target pressure of 50.7 kPa. Depending on the smoothness of the test sample, the air remaining between the paper surface and the glass plate was transferred to the tank, until the pressure dropped to 48.0 kPa. The time it takes for the air volume of 10 mL to achieve a pressure of 48.0 kPa provided the smoothness value expressed in seconds. A longer time indicates a smoother surface (Cigula, Tomašegović & Hudika, 2019).

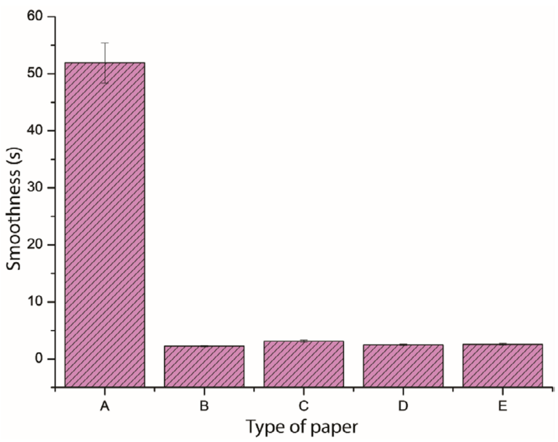
Colorimetric measurements were performed employing an X-rite eXact spectrophotometer (X-Rite, 2018). Measurements were performed 10 times on different parts of each printed sample, with the measurement conditions set to illuminant D50, a standard observer of 2° and filter M1. CIE L*, a*, and b* coordinates were measured on full-tone patches on each printed sample obtained by different printing pressures. L*a*b* values were also converted to the HEX system (Nazar et al., 2017).

Microscopy of printed elements and measurements of the line width was performed through an Olympus BX51 microscope. Obtained images were used for in-software measurements of the width of printed lines, both in positive and in negative. Line measurements were performed at a magnification of 200×, and images of the chosen typographic elements were taken at a magnification of 100×. Five measurements were performed on each print. The 200 µm and 80 µm lines in positive and negative were measured.

Results and discussion

Bekk smoothness of papers

The results of the smoothness measurements are presented in Figure 2. All papers except paper A displayed the smoothness under 3.2 s, which is typical for uncoated papers. Paper A displayed average smoothness of 54.72 s. Standard deviation of smoothness measurement for paper A was 7.01, and papers B-E displayed minimal standard deviations of measurements (<0.18).



» **Figure 2:** *Bekk smoothness of different recycled paper surfaces*

Higher smoothness of paper A compared to other papers means that the printing plate will have to deform less during the engagement in the printing process, and the deformation of the printed elements should therefore be less pronounced than on other papers. Furthermore, the adjustment of the printing pressure on rough papers would be crucial for the optimization of the print's qualitative properties.

Colorimetric measurements

The colorimetric properties of the prints (CIE L*a*b* values) are presented in Table 2. L*, a*, and b* coordinates of the Pantone 363 U ink are 50.91,-24.88, and 24.05, respectively. Letters A-E present the used papers, and numbers 1, 2, and 3 present the varied printing pressures – 50 N, 150 N, and 400 N, respectively.

Table 2

Colorimetric properties of prints obtained by PANTONE 363 U on different recycled papers and by different printing pressure

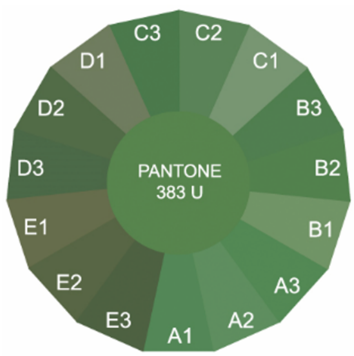
		1	2	3
A	L*	54.81 ± 0.18	51.62 ± 0.24	52.16 ± 0.41
	a*	-24.18 ± 0.22	-25.57 ± 0.23	-26.76 ± 0.17
	b*	19.53 ± 0.13	20.82 ± 0.15	22.19 ± 0.16
B	L*	57.43 ± 0.44	49.65 ± 0.35	48.45 ± 0.37
	a*	-18.89 ± 0.19	-23.96 ± 0.17	-23.68 ± 0.14
	b*	19.96 ± 0.17	22.43 ± 0.19	21.08 ± 0.18
C	L*	59.05 ± 0.32	50.85 ± 0.44	46.55 ± 0.45
	a*	-15.61 ± 0.16	-21.32 ± 0.13	-23.03 ± 0.22
	b*	15.51 ± 0.12	19.28 ± 0.17	19.36 ± 0.21
D	L*	50.31 ± 0.48	42.38 ± 0.41	40.89 ± 0.37
	a*	-8.21 ± 0.11	-15.31 ± 0.22	-16.06 ± 0.23
	b*	15.14 ± 0.16	17.11 ± 0.20	15.72 ± 0.19
E	L*	44.21 ± 0.33	40.95 ± 0.34	38.68 ± 0.28
	a*	-7.12 ± 0.09	-10.72 ± 0.10	-12.72 ± 0.14
	b*	17.56 ± 0.10	16.99 ± 0.14	15.63 ± 0.11

The values in Table 2 indicate that the prints on paper A have the most similar values to Pantone 363 U. All prints on paper A, together with B1 and C1 samples have an increased L* value compared to the original, which means that the colors are lighter. D1 and E1 samples have the lowest value of a*, which means that these colors are shifting away from green color. In general, papers D and E present with the highest deviations from the original color. Deviations of each individually printed color from Pantone 363 U are displayed in Figure 3, presented in the HEX system. HEX value for Pantone 363 U is 57844D. LAB color values converted to HEX color system are listed in Table 3.

Table 3

L*a*b* values of printed ink on each recycled paper in HEX color system

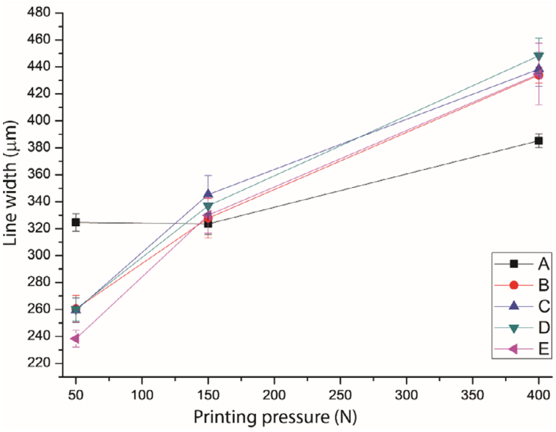
	A	B	C	D	E
1	5F8E60	719366	799672	707C5D	656C4B
2	548756	54814E	5B8357	526B47	576544
3	548854	517E4E	4D794C	4C6846	4D6141



» **Figure 3:** *LAB values of printed ink on each paper in HEX color system*

Width of the printed lines

The width of the lines of 200 µm was measured as a representative of the thickest printed line, and 80 µm as a representative of the thinnest printed line. The results of the 200 µm line's width obtained by the varied printing pressure in positive are presented in Figure 4.

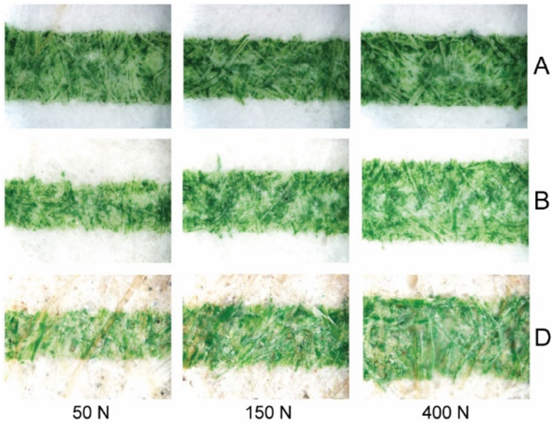


» **Figure 4:** *Width of the printed 200 µm line on each paper - positive*

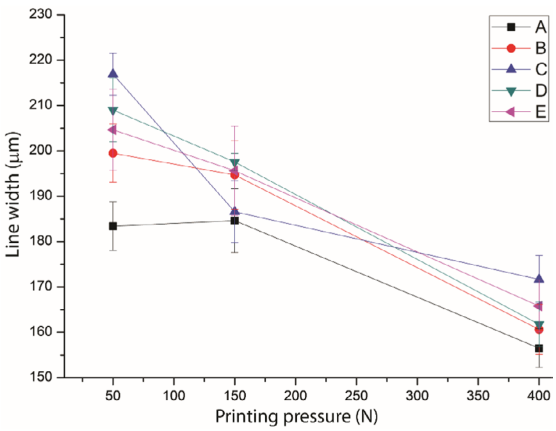
Observing Figure 4, one can conclude that paper A is the most constant in comparison to the others in terms of the changes in line width when different printing pressure is applied. This stability can be related to the smoothness of the paper. Since paper A is the smoothest paper among the five used types, the printed ink retains on the surface. Due to the lower smoothness of other papers, printing ink more easily penetrates the pores of the paper (Varepo et al., 2017). Therefore, when the printing pressure is increased, significant changes in the width of the printed lines will occur. At the lowest pressure, the flexible printing plate deforms the least. As the printing pressure increases, the printing plate deforms more, which increases the contact area with the printing substrate, i.e. the printed line becomes thicker. On all papers, the 200 µm line at a minimal pressure of 50 N has a width higher than 200 µm. Although at low pressure there is almost no printing plate deformation, the values for the line width on all papers are higher than they should be because papers are not coated and printed ink is absorbed into and spread on the paper. Therefore, special compensation curves (Tomašegović et al., 2014) should be applied when producing the printing plate intended for print on uncoated recycled papers. A visual comparison of 200 µm lines printed on papers A, B, and D can be seen in Figure 5.

Results presenting the measured width of 200 µm line in negative on each recycled paper after varying the printing pressure can be seen in Figure 6.

For lines in negative, increased printing pressure will result in the thinner line. Only on paper B, a 200 µm line in the negative can be printed at the lowest pressure of 50 N. At the lowest pressure, the line on paper A presents a value lower than 200 µm, while other papers display higher line widths. Increasing the pressure on papers reduces the width of the line, but paper A is stable in terms of line width decrease at 150 N pressure. 200 µm line can also be achieved on the print on papers B, D, and E when choosing the printing pressure of 150 N. Significant decrease of the line width at 400 N happens due to the expressed deformation of the elastomeric printing plate during the engagement. The deformation increases the contact area between the printing plate and the substrate. In general, when increasing the printing pressure from 50 N to 400 N on chosen substrates, the line width in negative falls by about a quarter of the original value. A visual comparison of 200 µm printed lines in negative can be seen in Figure 7.



» **Figure 5:** *Microscopic images of 200 µm line (positive) on papers A, B, and D, magnification of 200x*

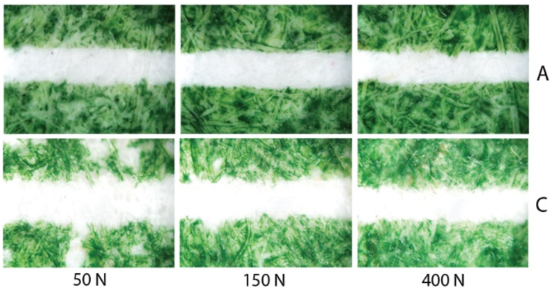


» **Figure 6:** *Width of the printed 200 µm line on each paper - negative*

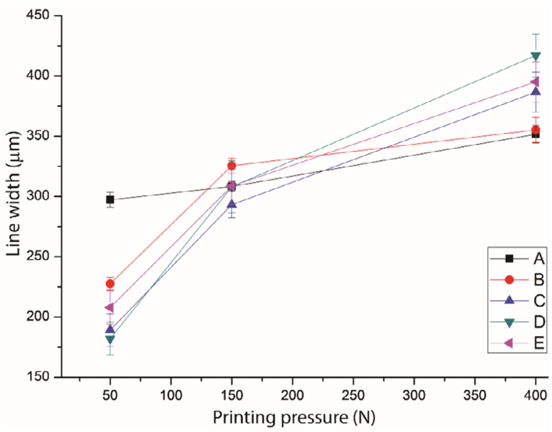
Results presenting the measured width of 80 µm line printed in positive on each recycled paper after varying the printing pressure can be seen in Figure 8.

On all papers, printed lines are wider than 80 µm. Paper D presents with the thinnest line at the lowest pressure

(50 N), but it is twice as wide as it should be. The line on paper A is significantly thicker than on other papers but has the most constant line width when increasing the printing pressure compared to other papers. On paper B, the line presents the smallest change in width when increasing the pressure from 150 N to 400 N, while on paper D, the increase of line width is most expressed. Presented results indicate that a specific compensation curve, different than one intended for printing on paper A, should be applied in the printing plate production process when choosing papers B-E as printing substrates. After the application of the specific compensation curves, printing pressure should be minimized to achieve a fine printed line of the desired width.



» **Figure 7:** *Microscopic images of 200 μm line (negative) on papers A, B, and D, magnification of 200x*

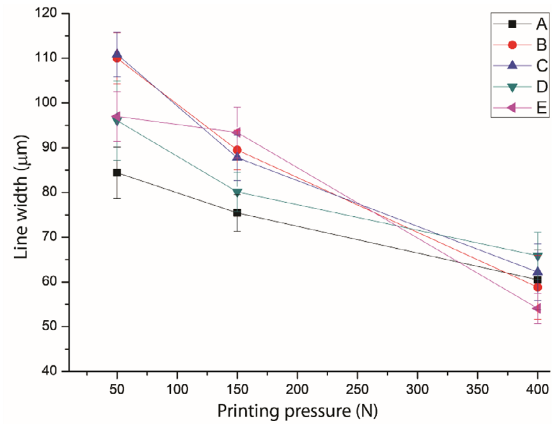


» **Figure 8:** *Width of the printed 80 μm line on each paper - positive*

Changes in the width of 80 μm line printed in negative on each recycled paper after varying the printing pressure can be seen in Figure 9.

On paper A, at a pressure of 50 N, the lines of 80 μm in negative are slightly wider than they should be but are the thinnest compared to the lines on other papers. As the line pressure increases up to 400 N, the lines become expressively thinner, as expected.

When observing the diagrams presenting the lines in positive (Figures 4 and 8), it can be noticed that paper A initially (when applying the pressure of 50 N) presents with wider lines compared to other papers. Similarly, lines printed on paper A in negative at 50 N are thinner than on other papers (Figures 6 and 9). This happens because paper A is much smoother than the others. On paper A, printing ink spreads mostly on the surface, even when using the minimal printing pressure, since the pores on the paper are not as large as on other papers. Deviations of line width on all papers are expressed because the papers are uncoated. In the negative, the deviations in the width of each specific line are generally higher than for the lines in positive. The lines in positive are thin, i.e. their surface is small, so the deformation is numerically lower than for the lines in negative, where the printing surfaces are much larger and the "closing" of the line due to the deformation of the printing plate is more pronounced and visible (Mahović Poljaček et al., 2014). Nevertheless, the 80 μm lines in the positive have a significantly higher value than 80 μm. They are similar in value to 200 μm lines. This indicates that most of the tested papers are not suitable for printing very fine elements in positive. However, 80 μm line in negative can be achieved on all papers when choosing the adequate printing pressure.

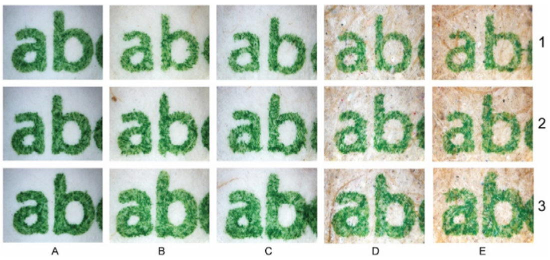


» **Figure 9:** *Width of the printed 80 μm line on each paper - negative*

Microscopy of typographic printed elements and determination of color contrast

Microscopic images of typographic elements (18 pt) in positive and negative are presented in Figures 10 and 11, respectively.

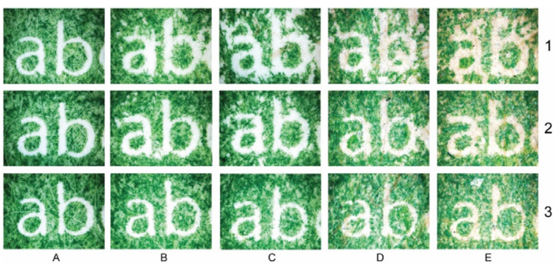
In Figure 10, it is visible that paper A presents with the sharpest edges of printed elements at all pressures, and printed elements on this paper have the smallest change in width when the printing pressure changes. The center of the printed letters is the palest – the element edges are outlined- which is usual for the flexographic print due to the printing plate deformation. This happens because of the different pressure distribution on the finer printing elements on the printing plate during the engagement. Printed elements on all papers are the widest and most filled when applying a printing pressure of 400 N, which reduces the kerning, and some letters could overlap. This is specifically visible on the prints on papers C and E.



» **Figure 10:** *Microscopic images of fine printed elements in positive, magnification of 100x*

Printing pressure of 50 N on papers C, D, and E results with partially illegible text in the negative (Figure 11). Because of the low printing pressure, the printing plate is not able to deform enough to adjust to the rough printing substrate and the full-tone printed area does not have enough coverage. By increasing the pressure to 150 N the text becomes more legible on all papers, but it is also thinner. Under the pressure of 400 N, due to the deformation of the printing plate, parts of the letters that are already very thin begin to disappear. It is visible that paper A presents with the "cleanest" lines.

It can be concluded that recycled papers D and E are not suitable for the typographic printed elements in negative of higher quality. For papers, A-C, printing pressure should be increased from the standard value of 150 N to achieve the optimal line edge definition and legibility of the typographic elements.



» **Figure 11:** *Microscopic images of fine printed elements in positive, magnification of 100x*

To determine whether the prints meet the recommendations on the applicability of images and text for the visually impaired (Chung & Bernard, 2018), the color contrasts of the typographic elements on all papers were measured against the background color (Table 4). Various accessibility standards and guidelines prescribe specific difference in luminance between two adjacent colours or overlaid colours, but commonly indorsed minimal contrast ratio for 18 px texts is 4:1 (Vischeck, 2002).

Table 4

Color contrast values concerning the background color (paper) for typographic elements:

	A	B	C	D	E
1	4.41	3.65	3.63	3.12	3.93
2	4.41	3.85	3.89	3.44	4.06
3	3.75	3.89	4.11	3.47	4.10

Minimal color contrast (for a font size of 18pt) was met on all prints except for prints on paper D. For this reason, paper D would not be suitable as a substrate for commercial use for the Pantone 363 U ink used in this experiment. The highest contrast values were achieved on paper A.

Conclusion

In this research, the optimization of the print quality on different recycled papers was performed. The choice of biodegradable materials as printing substrates for packaging in this experimental work is an optimal solution for the environment. However, there is a difference between recycled papers in terms of their properties, that influence the printability and print quality. For example, their natural shade and rough, porous surface influence the colorimetric properties of the print and ink absorption and spreading.

The results of this research have shown that specific shade of the papers can influence the colorimetric properties of the print to a significant extent, regardless of the increased printing pressure which enables the transfer of more printing ink to the printing substrate. Moreover, the smoothness of the paper is directly related to ink spreading on the surface of the print. Smoothest paper A is most constant in terms of the printed line width when the printing pressure is increased. Fine lines in positive (80 μm) were printed significantly too wide on all papers, even when the lowest pressure of 50 N was chosen. This means that special compensation curves should be applied in the printing plate production process to achieve the adequate width of such fine elements. When printing fine elements in positive, printing pressure should be minimized. Fine lines in negative can be correctly printed on all selected papers by carefully adjusting the printing pressure and achieving the optimal elastic deformation of the printing plate. Furthermore, increased printing pressure can result in the illegibility of the typographic elements in positive, and inadequate pressure in negative could result in unclear edges or disappearing of the printed typographic elements. All recycled papers except paper

D met the minimal color contrast required for the applicability of images and text for the visually impaired.

It can be concluded that most recycled papers used in this experimental work are not suitable for printing very fine elements in positive when choosing flexography as a printing technique. Fine elements in negative can be achieved by carefully adjusting the printing pressure. Since the principles of the sustainable design recommend the minimal needed amount of materials used for the (packaging) product, the consumption of the printing ink should be decreased as much as possible. Therefore, if the maximal possible quality of the print on a recycled paper is crucial, only important fine elements should be designed and printed in negative. Printing pressure should be carefully adjusted to each paper to transfer enough printing ink to achieve legibility, but at the same time to not cause extensive deformation of other printed elements.

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