Influence of substrate roughness on print quality parameters of digitally printed paper substrates

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In addition to printing techniques, there are various characteristics that affect the quality of printed products. Most frequently questioned features are line, dot, and text reproduction. In this paper it is investigated how different substrates, printed by the same printing technique, affect the quality parameters of printed samples. Print quality includes the process of obtaining the desired reproductions of color and image elements, important parameters of print quality are the quality of lines and dots, and the feature of the substrate that is significant for this work is the roughness of the substrate. This paper presents the testing of three different materials on to which the test form was printed by electrophotography, as a digital printing technique. The tests are based on analysis of line, dot and text reproduction, as well as analysis of the roughness of the substrate on samples printed in black. Based on the obtained results it can be concluded that the substrate affects the quality of printed products.

INTRODUCTION

When we talk about the printing industry, it can be said that the digital printing is one of the most contemporary printing techniques. The reason for this is the large number of advantages of this printing technique, such as the lack of a printing form, and thus the reduction cost and printing time. Another advantage of digital printing that can be mentioned is the wide range of printing substrate, but also a large number of different printing techniques (Milošević et al., 2019). Most commonly used NIP (Non Impact Printing) technique of digital printing with variable printing form, beside the InkJet technology, is electrophotography (Radić at al., 2020). During this research, the samples used for testing are printed by digital printing technique - electrophotography. The color, sharpness and uniformity of the print are the most important parameters of perception of the printed product and they depend on the printing technique. For these reasons, an examination of lines, dots and text reproduction on substrates printed by the electrophotography technique was performed through this paper. There is a close connection between surface structure, deformable behavior of different paper substrates and print quality. By increasing the roughness core of the substrate there is an exponential development of the missing points and that influence of the surface structure can be compensated, if the printing of monochrome tones is done with enough color (Tomić et al., 2020). Considering that during this research printing was performed on three different materials, it was the roughness of the substrate that was measured, in order to determine how it affects the process of printing monochrome tones, and thus the quality of printing.

The latest achievements in printing technologies relate to production printing through the application of low cost methods, high frequency jetting and high resolution methods. Among the newer technologies, which today are also most often used for printing various graphics, there is digital printing. Digital printing technologies use bitmaps or computer-generated images for applying paint to a target substrate (Kwon et al., 2020). The most important factors which contribute to the maintenance of long-lasting digital prints are the use of printing processes and materials that are necessary for obtaining good quality prints, having adequate storage space and ensuring compatibility between digital printing and storage conditions. There are four main printing processes used in digital technology: digitally exposed chromogens, InkJet, electrophotography and thermal color transfer with diffusion (Knoll & Carver-Kubik, 2019).

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In this paper, printing was performed on different types of cardboard, where printing was performed by electrophotography. In the process of electrophotography, a unique virtual printing form is created on the surface of the photoconductor and at each print cycle, the print image is transferred to the print form (Devai et al., 2019). Process of electrophotographic printing can be divided into five phases: charging, imaging, transfer of toner (print), fixing toner and cleaning (conditioning). An important component of this printing technique is the structure of the image carrier, which can be consisted of a cylinder or flexible strip with a suitable photoconductive layer (Novaković & Kašiković, 2013). Color range in electrophotographic digital printing depends on various parameters, which include a printing machine and toner, but especially it depends on the properties of the substrate (whiteness, roughness and gloss), which affect the final printed color gamut and reproduction quality (Ataeefard & Sadati Tilebon, 2021). Toners are the coloring agents used in electrophotographic systems. Nowadays, they are often used conventional pulverized toner and polymerized toner. Polymerized toner is a high-performance toner produced by chemically combining a resin with color pigment particles. Unlike conventional pulverized toner, which is made by crushing lumps of plastic into small particles, the polymerized method enables precise control of the structure of each toner particle. This, in turn, makes it possible to tailor the size and shape of each particle and impart various properties to it. The polymerized achieves a print product that exhibits a high-quality image while reducing environmental impact. Polymerized toner features a core-shell configuration comprised of a thin outer layer of hard resin wrapped around a soft core of inner resin, to enable fusing at a lower temperature while also offering the thermostability required for high-speed printing. This kind of toner contains wax dispersed evenly during manufacturing, thereby realizing oil-free fixing when printing. By using plant-based materials for the wax component in all colors of toner it reduces the use of materials derived from petroleum, a finite resource. Producing polymerized toner entail a relatively simple manufacturing process using chemical synthesis to make the toner particles. This reduces energy consumption and also ensures uniform particle size, which minimizes the sorting needed. Compared to pulverization methods, these advantages help to reduce generation of CO_2 and the acid-rain causes SO_x (sulfur oxide) and NO_x (nitrogen oxide), thereby significantly reducing environmental impact (Konica Minolta, 2021). In their research, Karlovits and associates highlighted toner adhesion as one of important parameters of the quality of electrophotographic printing technique, because it is a parameter that shows the resistance of prints to different mechanical loads. In the research, they came to the conclusion that this is also a parameter that depends on the substrate on which printing was performed, and the results showed that substrates with low surface roughness result in low adhesion toner (Karlovits et al., 2021).

The interaction between the substrate and the color depends on various factors (Eshbaev et al., 2021). The aim of this research is to determine how the substrate affects the various quality parameters that can be measured during printing. Quality parameters measured in this paper are: line reproduction in positive and negative, dot reproduction, text reproduction and substrate roughness.

One of the methods of assessing the quality of line reproduction is the measurement of the line stiffness. Line stiffness shows that there was a certain deviation in the printed lines in relation to the line of ideal geometric shape. If the line stiffness is too pronounced, it is an undesirable feature of the line that can appear when printing, and which leads to a decrease in the quality and sharpness of the print (Stančić et al., 2013).

The reproduction quality of a dot can be determined by measuring its surface, i.e. the roundness of the dot. The basis of the differences between the dots is the difference in their size. During file processing in RIP systems, different types of raster dots are used, so a comparison of their size is made. The easiest way to compare the size of a dot is to compare the dimensions of the imaginary circles that are the same surface as a dot, i.e. a comparison of their diameters (Petrović, 2020). When measuring roundness of the dot as a quality parameter, the size of the dot is compared to the ideal circle, whose value is 1.

Substrate roughness can be taken as a substrate feature that affects print quality. The roughness is microgeometric surface irregularity, which occurs during the processing or some other impact. Paper roughness can be assessed by several test methods to various international standards. These test methods include lateral air leakage measurement (Bendtsen roughness, Bekk roughness, Parker print-surf roughness) and surface profilometry (contact profilometry and non-contact profilometry) (Smithers, 2021). Air-leak methods of characterizing the surface roughness of paper and paperboard has a common practice of determination of the coefficient of variation. However, this practice runs the risk of drawing wrong conclusions since two different surfaces having the same average roughness and the coefficient of variation can exhibit totally different properties. To avoid such mistake, a contact profilometry has been developed to determine surface roughness of paper and paperboard. Contact profilometry generates surface roughness profile to determine its variability which has been defined as the mean deviation from the roughness average. In determining the mean deviation from the roughness average, it is noted that thickness measurement is not required. In this method, stylus shape and size, contact force of the stylus to the surface, scan speed and resolution have been identified as the key parameters of generating stable surface roughness profiles. In research by Jeong, Ko and Kim it has been further identified that the optimal conditions on these parameters should depend on paper grade. They suggest that a stylus-type contact method should be used to determine surface roughness of paper and paperboard to help determine their practical applications such as printing, coating and embossing (Jeong et al., 2019). The size of the substrate roughness is measured in relation to the reference line of the roughness profile and it divides the profile in such a way that the size of all squares of the profile deviation within the measured length of the reference line is the smallest. The size used to measure roughness is Ra, i.e. medium arithmetic deviation of the profile that is equal to the arithmetic value of the absolute values of the profile height at measured length and which can be expressed by a mathematical formula (Kuzmić, 2016):

$$SRF = 2\frac{PA^2b}{\mu c} \quad (1)$$

In their research, Dedijer and her associates came to the conclusion that the longer the interaction between the printed circuit board, the ink and the printing plate of the substrate, accompanied by the applied pressure and printing speed, the higher the roughness of the substrate, i.e. there is an increase wear of profile peaks and lowering of valley depths (Dedijer et al., 2020)

MATERIALS AND METHODS

During the research, three types of substrates were used in this paper: Sample 1 – Mayr Melnhof cardboard, Sample 2 - Garda Gloss Art paper and Pattern 3 – Fedrigoni offset paper. Table 1. shows the characteristics of the used substrates.

The test form printed on the mentioned substrates was created in the application software Adobe Illustrator CC 2019. It was made on A3 format, size 297 x 420 mm. The test form contains various elements, such as fields of solid tone (25.4 x 25.4 mm) in all four process colors (black, cyan, magenta and yellow), fields with 60% and 30% tone values, lines with different thicknesses (from 1/8 pt to 2 pt) in positive and negative, dots with different diameters (1 mm, 1.5 mm and 2 mm) and text sizes from 4 pt to 12 pt.

The test form was printed on three different substrates, which were previously mentioned, by digital printing technique - electrophotography. The printing machine used in this printing process is Konica Minolta - Bizhub Pro C6000L. Printing is performed at a resolution of 1200 x 1200 dpi x 8 bits with speed of 34 ppm and with polymerized toner for low temperatures for achieving high image quality - Simitri HD toner.

The test image is printed with all four process colors (CMYK). However, the tests are performed only on black color and they are presented in this paper. The printed samples were then digitalized using a scanner Brother ADS1700WTC1 at 600 dpi resolution and saved as TIFF format.

The research in this paper refers to the comparison of the elements of digitalized samples with the same elements of rasterized test map. The application software used for the comparison is ImageJ. In application software, calibration was performed using created test form, shown in Figure 1., the resolution is set to 600 dpi, with a step length of 25.4 mm. Selecting tool is set to select a contiguous area under the condition that all pixel values in that area must be in the range initial value ± 100.

Measurements performed using the ImageJ application software refer only to black tones, and the measurements are as follows: area and perimeter of lines of thickness 1 pt and 2 pt in positive and negative, roundness of a dot of size 1 mm, 1.5 mm and 2 mm, area and perimeter of the letter S of size 8 pt. In addition to the above measurements, the research in this paper also includes the measurement of substrate

Table 1. Characteristics od the substrates used in research

Material designation	Material	Paper format (mm)	Surface mass (g/m^2)	Material volumen (cm^3/g)	Material whiteness (%)	Roughness of the substrate Ra (µm)	
						Cross direction	Grain direction
Sample 1	Mayr Melnhof cardboard	297x420	250	1.32	80	0.788	0.711
Sample 2	Garda Gloss Art paper	297x420	135	0.76	118	0.293	0.248
Sample 3	Fedrigoni offset paper	297x420	100	1.70	102	1.205	1.159

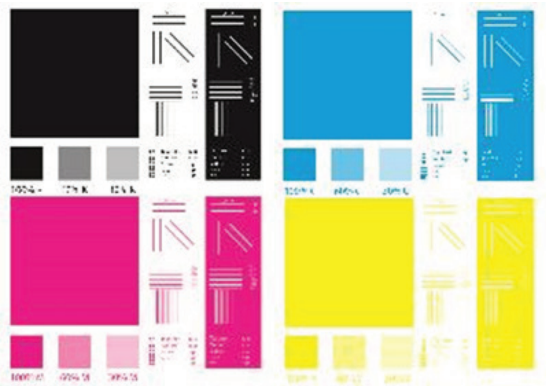


Figure 1. The test form used in research

Figure 2. Device used to measure the roughness Mitutoyo SJ-210

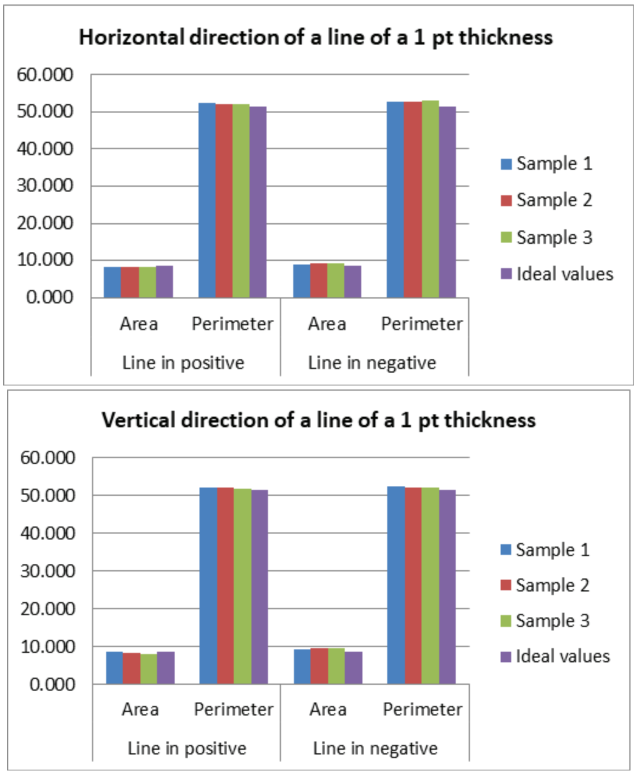


Figure 3. Comparative representation of the area and perimeter of a line of a 1 pt thickness which extend vertically and horizontally

roughness on which the test form was printed. The device used to measure the roughness is Mitutoyo SJ-210 (Figure 2.)

RESULTS AND DISCUSSION

Line reproduction analysis

In this study, the values of line reproduction in positive and negative for black color were measured. There were measured line values with 1 pt and 2 pt thickness, whose length is 25.4 mm. The measured values are the area and perimeter of the line using application software ImageJ for measurments. The ideal line area expected for a 1 pt thick line is 8.616 mm^2, while the ideal perimeter of the same line is 51.463 mm. For a 2 pt thick line, an ideal area of 17.919 mm^2 is expected, and an ideal perimeter of 52.225 mm. Table 2. shows the obtained measurement values for a line of 1 pt thickness.

In Figure 3. it can be seen that in the case of a line of 1 pt thickness which extends in the horizontal direction and which is printed in positive, there is a decrease in area relative to the ideal area and an increase in perimeter relative to the ideal perimeter.

Table 2. Area and perimeter of a line of a 1 pt thickness in horizontal and vertical direction

Sample	Measurements	Line in positive		Line in negative		Ideal values
		Horizontal direction	Vertical direction	Horizontal direction	Vertical direction	
Sample 1	Area	8.120 mm^2	8.747 mm^2	8.975 mm^2	9.326 mm^2	8.616 mm^2
	Perimeter	52.432 mm	52.216 mm	52.822 mm	52.416 mm	51.463 mm
Sample 2	Area	8.179 mm^2	8.466 mm^2	9.185 mm^2	9.615 mm^2	8.616 mm^2
	Perimeter	52.036 mm	52.145 mm	52.651 mm	52.106 mm	51.463 mm
Sample 3	Area	8.287 mm^2	8.023 mm^2	9.179 mm^2	9.570 mm^2	8.616 mm^2
	Perimeter	52.032 mm	51.991 mm	53.092 mm	52.300 mm	51.463 mm

With the same line printed in the negative, it can be noticed that there is an increase in both area and perimeter compared to ideal values. Also, the largest deviation is noticeable for the Sample 1, i.e. for the sample with the largest paper weight.

With a line of a 1 pt thickness extending in the vertical direction and printed in positive, an area increase is noticeable in sample 1 in relation to the ideal area, while in the other two samples there is a reduced area in relation to the ideal value, while the perimeter in all three samples increases relative to the ideal value of the perimeter. At the same line printed in negative, there is a noticeable increase in both area and perimeter relative to ideal values.

It is noticeable that the largest deviation from the ideal value is for Sample 1. Irrespective of the direction of the line, the largest deviations from the ideal line are noticeable for the sample with the largest grammage, i.e. cardboard with weight 250 g/m^2, so it can be concluded that there are deviations from the ideal value of area and perimeter that are larger for substrates with a larger grammage.

Table 3. shows the obtained measurement values for a line of 2 pt thickness.

Figure 4. shows the decrease in area and increase in perimeter at a line of 2 pt thickness extending in the horizontal direction and printed in positive. With the same line printed in the negative, a decrease in area and an increase in perimeter are also noticeable relative to ideal values. The largest deviation from the ideal values is noticeable in Sample 3 for lines in the positive, while for lines in the negative the largest deviation is noticeable in Sample 1 for area and Sample 2 for perimeter.

In the case of a line of a 2 pt thickness extending in the vertical direction and printed in the positive, it is noticeable that it comes to a reduction of an area and increase of the perimeter. The same goes for lines printed in negative. The largest deviation is noticeable in Sample 1 for lines in the positive. For lines in the negative, the largest deviation of the area

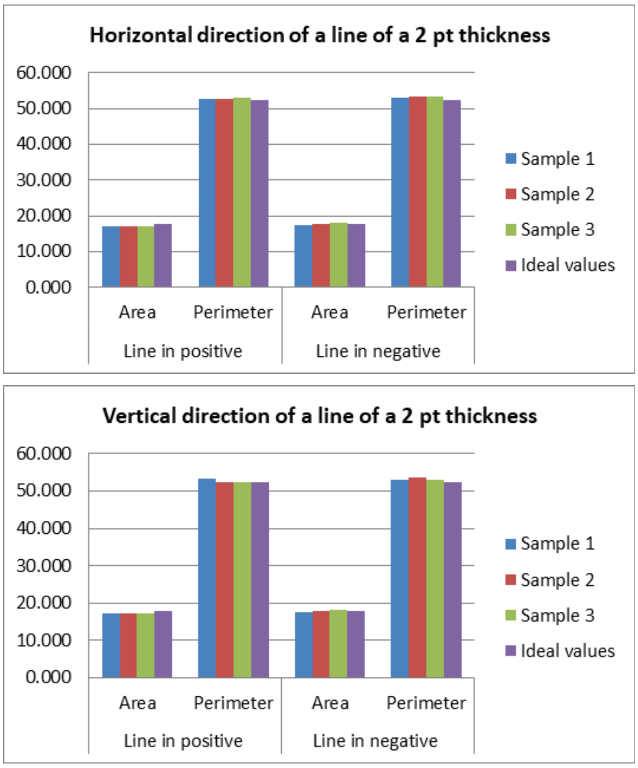


Figure 4. Comparative representation of the area and perimeter of a line of a 2 pt thickness which extend vertically and horizontally

from the ideal value is noticeable in Sample 1, and for the perimeter, the largest deviation is noticeable in Sample 2.

From these data it can be concluded that the perimeter of the line of a 2 pt thickness is most deviated in Sample 2, i.e. coating paper, and that there is a deviation of the perimeter of the line in relation to the ideal value of the perimeter, and that this deviation stands out more in coated paper compared to uncoated ones.

Dot reproduction analysis

On digitalized samples, the roundness of a dot was measured using the application software ImageJ. This

Table 3. Area and perimeter of a line of a 2 pt thickness in horizontal and vertical direction

Sample	Measurements	Line in positive		Line in negative		Ideal values
		Horizontal direction	Vertical direction	Horizontal direction	Vertical direction	
Sample 1	Area	17.235 mm^2	17.061 mm^2	17.536 mm^2	17.563 mm^2	17.919 mm^2
	Perimeter	52.748 mm	53.409 mm	53.194 mm	53.023 mm	52.225 mm
Sample 2	Area	17.226 mm^2	17.151 mm^2	17.627 mm^2	17.943 mm^2	17.919 mm^2
	Perimeter	52.693 mm	52.227 mm	53.493 mm	53.741 mm	52.225 mm
Sample 3	Area	17.066 mm^2	17.056 mm^2	17.928 mm^2	18.036 mm^2	17.919 mm^2
	Perimeter	53.014 mm	52.402 mm	53.419 mm	53.103 mm	52.225 mm

value was measured only on the black dots on the digitalized test form. Values were measured for three dots with different diameters on all three sample. The expected ideal value is a dot with diameter of 1 mm. Table 4. shows the measured values.

Based on the results from the table, it can be concluded that the reproduction of the dot on Sample 2 is closest to the ideal values for the roundness of a dot, while the largest deviations from the ideal value of the roundness of a dot are noticeable in Sample 1, i.e. cardboard, although even these deviations are not drastic. Also, it can be noticed that the roundness of a dot depends on the size itself that is reproduced, so based on these results it can be concluded that dots with a diameter of 1.5 mm are the closest to the ideal values, while at dots with a diameter of 1 mm the largest deviations can be noticed.

Text reproduction analysis

In this study, the reproduction values of the letter S of size 8 pt in positive and negative were measured, on all three sample. The ideal value of the area that is expected is 0.740 mm^2 and the perimeter is expected in value of 6.122 mm. Measurement results of the letters S reproduction is shown in Table 5.

Figure 5. shows the measured values of the area and perimeter of the letter S that is printed on three different samples. From the displayed image, it is seen that there are significant deviations both in the area and in the perimeter of the letter S. Deviations are present in all three samples and in text printed in both positive and negative. When it comes to area, it can be noticed that the biggest deviation from the ideal surface is present in Sample 3, and the smallest

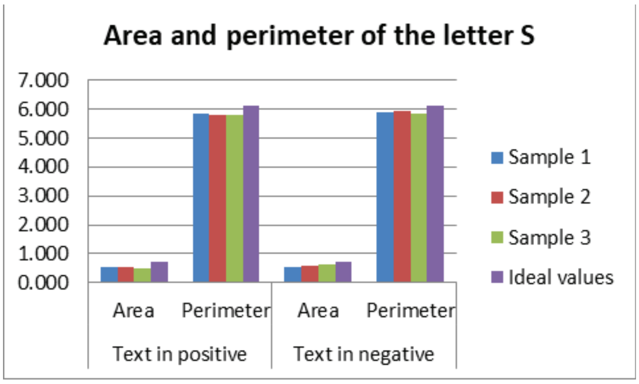


Figure 5. Measured area and perimeter of letter S in positive and negative compared to the ideal values

deviation is present in Sample 1, when it comes to the text in the positive. But when it comes to the text in the negative, the largest deviation from the ideal values of area is noticeable in Sample 1, and the smallest deviation in Sample 3. It can be concluded that the text printed in positive with an increase in paper weight decreases the deviation from the ideal values of area, while the text printed in negative with an increase in paper weight increases the deviation from ideal values of perimeter. When analyzing the perimeter of the letter S, it can be seen from the graph that there are significant deviations of the perimeter of the printed letter S related to the ideal perimeter of the letter. The smallest deviation in the text printed in the positive is present on Sample 1, while on the other two samples the deviation is equal. The least deviation from the ideal values of perimeter of printed text in the negative is present in Sample 2, and the largest deviation in Sample 1. It can be concluded that Sample 1 has the least deviation in the text printed in the positive, and the largest deviation in the text

Table 4. Measured roundness of a point with different diameters

Sample	Diameter = 1 mm	Diameter = 1,5 mm	Diameter = 2 mm
Sample 1	0.996 mm	0.993 mm	0.989 mm
Sample 2	0.996 mm	0.999 mm	0.995 mm
Sample 3	0.991 mm	0.996 mm	0.994 mm

Table 5. Measured area and perimeter of the letter S in positive and negative

Sample	Measurments	Text in positive	Text in negative	Ideal values
Sample 1	Area	0.550 mm^2	0.552 mm^2	0.740 mm^2
	Perimeter	5.872 mm	5.833 mm	6.122 mm
Sample 2	Area	0.536 mm^2	0.566 mm^2	0.740 mm^2
	Perimeter	5.787 mm	5.932 mm	6.122 mm
Sample 3	Area	0.502 mm^2	0.622 mm^2	0.740 mm^2
	Perimeter	5.787 mm	5.872 mm	6.122 mm

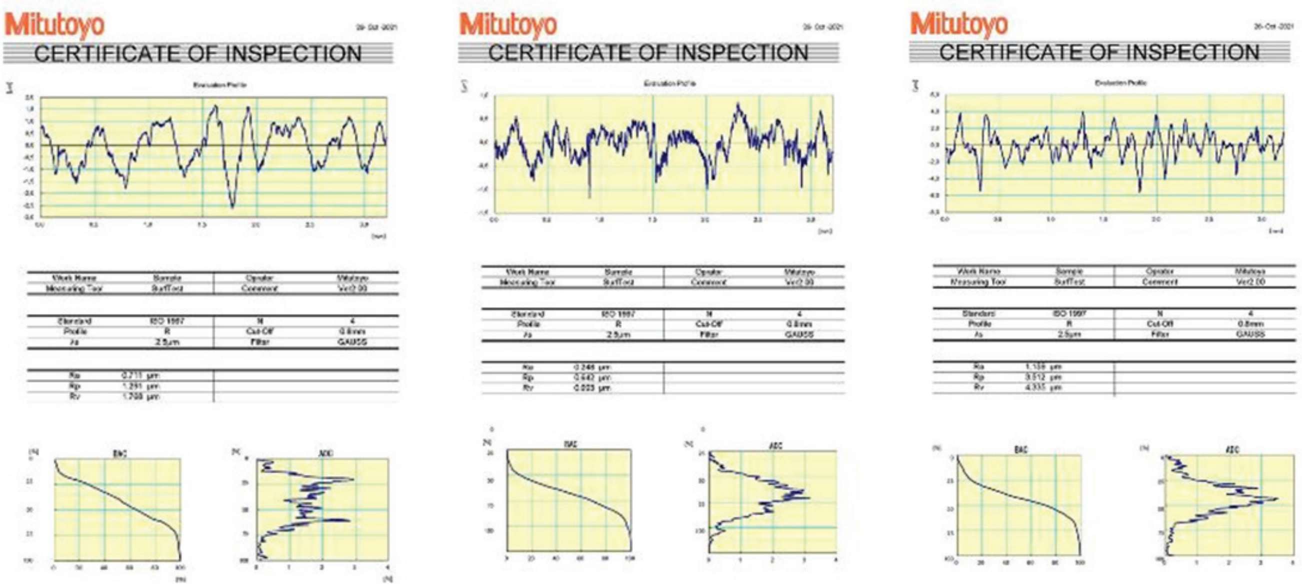
printed in the negative. Also, smaller deviations value of perimeter from the ideal values are present in coated paper.

Substrate roughness analysis

Substrate roughness was measured via the value of Ra, which refers to the arithmetic mean deviation of the profile, over the value of Rp, which refers to the maximum height of the peak of the profile and over the value of Rv, which refers to the maximum depth valley of the profile. The values were measured on three different cardboard samples, in fields where there are no test form elements.

Figure 6a-c. show the measured values of Ra, Rp and Rv for all three samples. The roughness of different substrates is measured in two directions, due to the intertwining of the paper fibers. The first direction of measurement is the grain direction and the second direction the measurement is the cross direction. The measured values of all three samples in both directions are presented in Table 6.

The measured values indicate that the differences in the grain and cross directions in the same type of sample are not significantly large, which indicates that the roughness in both directions is approximately equal. The highest values of substrate roughness were obtained in the Sample 3. While the lowest roughness values were obtained in the Sample 2. It can be concluded that the roughness values decrease at coated papers compared to uncoated papers.



a b c

Figure 6. Substrate roughness of (a) Sample 1; (b) Sample 2; (c) Sample 3

Table 6. Substrate roughness on different samples

Sample	Measured value	Grain direction	Cross direction
Sample 1	Ra	0.711 µm	0.788 µm
	Rp	1.291 µm	1.680 µm
	Rv	1.768 µm	2.595 µm
Sample 2	Ra	0.248 µm	0.293 µm
	Rp	0.642 µm	0.799 µm
	Rv	0.993 µm	0.977 µm
Sample 3	Ra	1.159 µm	1.205 µm
	Rp	3.512 µm	3.027 µm
	Rv	4.335 µm	3.731µm

CONCLUSIONS

As part of this research, the influence of the substrate on the print quality parameters was examined. For examination purposes, test form was printed on three different substrates, cardboard, coated paper and offset paper. The printed test form contained elements for measuring certain quality parameters. Quality parameters that were measured in this study are line, dot, and text reproduction and substrate roughness. These quality parameters are tested for black color only.

Based on the results obtained by measuring the reproduced lines, it can be concluded that the substrate affects the reproduction of the lines and that significant deviations of the area and perimeter of the line from ideal values are noticeable. At a line thickness of 1 pt, independent of the direction of the line and if the print of the line is in positive or negative, the largest deviation of the area and perimeter of the line from the ideal values is noticeable for Sample 1 - cardboard with weight 250, and the smallest deviation is noticeable in Sample 3 - offset paper with weight 100 g/m^2. Based on that, it can be concluded that as the weight of the paper increases, so do the values of deviations of the area and perimeter of the line from the ideal values. Since the smallest deviations are noticeable in Sample 3, it can be concluded that in this case the surface roughness affects the surface quality parameters, because there are also the highest values of roughness noticeable in Sample 3.

When measuring the roundness of a dot, it can be noticed that the smallest deviations are present in Sample 2 - coated paper. The largest deviations from the ideal values for the roundness of the dot are noticeable in Sample 1 - cardboard 250 g/m^2. Based on the obtained results, it can be concluded that the substrate affects the roundness of the dot, i.e. that deviations from ideal values are lower when it comes to coated papers compared to uncoated ones, which can be related to roughness of paper surface as a feature of the substrate, because research has shown that coated papers have less roughness.

When it comes to text reproduction, it can be concluded that the substrate also affects the print quality. Deviations of the areas and perimeters of the text vary depending on whether the text is printed in positive or negative. It can be concluded that Sample 1 - offset paper has the smallest deviations of area in the text printed in positive, and the largest deviations in text printed in negative. When it comes to perimeter, smaller deviations from the ideal values are noticeable at coated paper, and larger deviations at uncoated paper. It can further be concluded that substrates with less surface roughness have more approximate perimeter values to the ideal values, compared to substrates with higher surface roughness.

The last measurement in this paper refers to the substrate roughness and based on the obtained results it can be concluded that substrate roughness affects print quality. The highest values of substrate roughness were obtained in the Sample 3 - offset paper with weight 100 g/m^2, and the lowest values of roughness were obtained in the Sample 2 - coated paper with weight 135 g/m^2.

Based on the results of the research, it can be concluded that the substrate with its characteristics, above all surface properties affect the parameters of print quality. Also, the obtained research results indicate that further research is needed in this area, in order to obtain more complete knowledge about the impact of substrates on print quality parameters. For these reasons, further research and testing of roughness impact on the quality of reproductions that are obtained using other process inks are planned, as well as examining the influence of different processing of the substrate surface on the print quality. Furthermore, parameters as line raggedness and line blurriness should be examined, as well as influence of different paper side i.e. feld paper side and wire paper side. The presented research is related to the prints obtained using electrophotographic printing technique, so it is desirable to expand future research to prints obtained by others printing techniques, and above all inkjet and offset printing techniques.

REFERENCES

Ataeefard, M., & Sadati Tilebon, S. M. (2021). Seeking a paper for digital printing with maximum gamut volume: a lesson from artificial intelligence. *Journal of Coatings Technology and Research*, *19*, 285-293. https://doi.org/10.1007/s11998-020-00393-6

Dedijer, S., Pal, M., Tomić, I., Poljak, S., Pavlović, Ž., Jurič, I. & Milić Keresteš, N. (2020, November 12-14). Statistical analysis of the influence of print run on surface roughness of digital flexo printing plates' solid tone areas [Conference session]. *10th International Symposium on Graphic Engineering and Design*, Novi Sad, Srbija. https://doi.org/10.24867/GRID-2020-p30

Devai, S., Kašiković, N., & Lilić, A. (2019). Analiza kvaliteta otisaka dobijenih postupkom elektrografije na grafičkom sistemu Konica Minolta C6000L [Quality analysis of prints obtained by electrography on the graphic system Konica Minolta C6000L]. *Zbornik radova Fakulteta tehničkih nauka*, *34*(12), 2168-2171. https://doi.org/10.24867/05EF05Devai

Eshbaev, U., Nishonov, A., & Saodatov, A. (2021, October 14-16). Development of mathematical models of print quality by Box-Wilson [E3S Web of Conferences 304]. *2nd International Conference on Energetics, Civil and Agricultural Engineering*, Tashkent, Uzbekistan. https://doi.org/10.1051/e3sconf/202130403023

Jeong, H., Ko, Y., & Kim, H. (2019). Effects of a stylus on the surface roughness determination in a contact method for paper and paperboard. *Nordic Pulp & Paper Research Journal*, *34*(4), 442-452. https://doi.org/10.1515/npprj-2019-0011

Karlovits, I., Lavrič, G., Kavčič, U., & Zorić, V. (2021). Electrophotography toner adhesion on agro-industrial residue and invasive plant papers. *Journal of Adhesion Science and Technology*, *35*(23), 2636-2651. https://doi.org/10.1080/01694243.2021.1894694

Knoll, M., & Carver-Kubik, A. (2019). In-field digital photography and the curation of associated records: Not all prints are created equal. *Advances in Archaeological Practice*, *7*(3), 302-310. https://doi.org/10.1017/aap.2019.17

Konica Minolta (2021, December 15). CO_2 Emissions from Product Usage. Polymerized toner. https://www.konicaminolta.com/about/csr/environment/global-warming/toner/index.html

Kuzmić, M. (2016). *Kontrola kvalitete obrađene površine na strojarskim elementima* [Quality control machined surface to the mechanical element]. [Završni rad] Varaždin, Sveučilište Sjever. https://urn.nsk.hr/urn:nbn:hr:122:415460

Kwon, K., Rahman, K., Huy Phung, T., Hoath, S., Jeong, S., & Sub Kim, J. (2020). Review of digital printing technologies for electronic materials. *Flexible and Printed Electronics*, *6*(1), [043003]. https://doi.org/10.1088/2058-8585/abd29e

Milošević, U., Kašiković, N., & Milošević, R. (2019). Kontrola kvaliteta otisaka u Ink jet štampi [Imprint quality control in Ink jet printing]. *Zbornik radova Fakulteta tehničkih nauka*, *34*(10), 1762-1765. https://doi.org/10.24867/04EF01Milosevic

Novaković, D., & Kašiković, N. (2013). *Digitalna štampa*. FTN izdavač (in serbian).

Petrović, S. (2020). *Karakterizacija kompozitnih nosioca flekso štamparskih formi i njihov uticaj na kvalitet štampe kartonske ambalaže* [Doctoral disseration University of Novi Sad]. University of Novi Sad.

Radić, A., Kašiković, N., & Milošević, R. (2020). Ispitivanje ponovljivosti štampe na otiscima dobijenim elektrofotografijom pomoću grafičkog sistema Xerox Versant 3100 [Testing of print reproducibility on prints obtained by electrophotography using the Xerox Versant 3100 graphics system]. *Zbornik radova Fakulteta tehničkih nauka*, *35*(10), 1707-1709. https://doi.org/10.24867/09EF01Radic

Smithers (2021, December 14). Roughness and Smoothness. https://www.smithers.com/industries/packaging/manufacturers-and-users/packaging-materials-testing/paper-testing-surface-properties/roughness-and-smoothness

Stančić, M., Novaković, D., & Kašiković, N. (2013). Uticaj procesnih boja na parametre kvaliteta digitalno štampanih tekstilnih podloga [Influence of process colors on quality parameters of digitally printed textile substrates]. *Glasnik hemičara, tehnologa i ekologa Republike Srpske*, *5*(9), 59-66. https://doi.org/10.7251/GHTE1309059S

Tomić, I., Pinćjer, I., & Miketić, N. (2020). *The influence of total base ink coverage on the uniformity of digital prints overprinted with pearlescent inks* [Conference session]. *10th International Symposium on Graphic Engineering and Design*, Novi Sad, Srbija. https://doi.org 10.24867/GRID-2020-p4