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INFLUENCE OF PRINTING SURFACE ATTRIBUTES ON PRINT QUALITY IN ELECTROPHOTOGRAPHY

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Original scientific paper

This paper studies the influence of substrate roughness and thickness on the print quality in electrophotography. Mechanical dot gain in the printing process and the impact on the gloss change as a function of ink applied to various substrates were investigated. Printing on a digital printing machine HP Indigo 4500 was performed on three types of surfaces: Paper Fasson White Top Indi Centaure ALF606 S2030 weight 93 g/m^2, Polypropylene Digit Fasson PP Top White Indi 300 ALA S692N weight 58 g/m^2, and coated Fasson Digit Indi MP Gold Top S2000N weight 60 g/m^2. The dot gain measurements were carried out in the fields of 20 %, 40 %, 60 % and 80 % of black ink, and the data were analyzed using ImageJ software. The measurement of gloss was performed using a Gloss Master device, in the same fields of 20 %, 40 %, 60 %, 80 % and additionally in full-tone (100 %) for the four process colors (CMYK). Roughness and thickness measurements of the printed substrates were carried out to determine the impact of these parameters on the gloss.

***Keywords**: dot gain, electrophotography, image analysis, surface gloss*

Utjecaj podloge za tisak na kvalitetu otiska u elektrofotografiji

Izvorni znanstveni članak

U radu se predstavljaju istraživanja parametara utjecaja hrapavosti i debljine podloge na kvalitetu otisaka u elektrofotografiji. Istraživan je mehanički porast rasterske točke pri tisku i utjecaj na promjenu intenziteta sjaja u funkciji boje nanijete na različite podloge. Uzorci koji su korišteni za istraživanje tiskani su postupkom elektrofotografije na digitalnoj tiskarskoj mašini HP Indigo 4500. Korištene su tri vrste podloga za tisak: papir Fasson White Top Indi Centaure ALF606 S2030 gramature 93 g/m^2, polipropilen Digit Fasson PP Top White Indi 300 ALAS692N gramature 58 g/m^2 i oslojeni papir Fasson Digit Indi MP Gold TopS2000N gramature 60 g/m^2. Mehanički porast rasterske točke analiziran je uz pomoć softvera ImageJ na poljima 20 %, 40 %, 60 % i 80 % nanosa crne boje. Mjerenje sjaja vršeno je uz pomoć uređaja Gloss Master na poljima 20 %, 40 %, 60 %, 80 % i 100 % za četiri procesne boje (CMYK). Na podlogama vršeno je mjerenje hrapavosti, te mjerenje debljine podloge za tisak kako bi se utvrdio utjecaj ovih parametara na sjaj.

***Ključne reči**: analiza slika, elektrofotografija, porast rasterske točke, sjaj podloge*

1 Introduction

Printing process involves the interaction between the printing ink and printing surface (substrate), and the factors controlling the interaction determine the quality of the print. The development of printing technologies is currently a dynamic issue, especially in digital printing techniques. However, there is an apparent lack of knowledge about optimal properties of the printing surface for the application of these techniques within the area of liquid toner electrophotography [1].

Although electrophotographic technique offers significant advantages over other printing techniques, the literature survey shows that it has not received due attention of the researchers in the field. This prompted the authors to make a contribution to this interesting topic.

The ink-to-surface binding process is one of the final phases of the development of the print image. Print quality depends on the characteristics of the printing ink (viscosity, drying speed, pigment size, etc.), and the characteristics of the substrate used for print. Many factors, such as the absorption/soak properties, surface roughness and porosity affect the transmission of ink components into the surface of coated or non-coated papers [2].

Electrophotography is the most widespread non-impact printing technology. It is based on an invention by Chester Carlson from 1942. The process of electrophotographic printing can be subdivided into five stages: imaging, inking, toner transfer (printing), toner fixing, and cleaning (conditioning) [3].

Imaging is achieved by charging a suitable photoconductive surface, i.e. generating a homogeneous charge followed by subsequent charge removal or "imaging" via a controlled light source. This can be done by employing a scanning laser light or the light emitted by an LED array, and the position of the light impulses on the photoconductive drum corresponds to the printed image. Special inks are used for electrophotography, known as toners. These can be powder or liquid toners, which differ in their composition. The major element determining the printed image is the colorant contained in the toner in the form of pigments or dyes. Inking takes place by means of the systems (inking units) that transfer fine toner particles (around 8 μm) in a non-contact manner to the photoconductive drum through the generated electric potential difference (electric field). The toner charge is configured in such a way that the charged regions of the photoconductive surface take on the toner. After inking, the latent charge image on the photoconductive drum becomes visible due to the toner applied. The toner can be transferred directly to the paper, but also via intermediate systems, consisting, for instance, of a further drum or a belt. A fixing unit is required in order to anchor the toner particles and thus generate a stable printed image on the paper. To prepare the drum for printing the next image, mechanical and electrical cleaning of the surface is required [3].

The decisive factors influencing the quality and stability in electrophotographic printing are the quality of imaging, the uniformity and precision of ink transfer by the developing unit, the transfer onto the paper or the intermediate image carrier, and the conditioning of the imaging surface (and, where present, the intermediate image carrier) for the next printing process [3].

Hence, the aim of this study was to determine how different types of surfaces affect the quality of the electrophotographic printing process and behavior of surface print gloss as a function of the halftone coverage and surface roughness. In order to achieve this, measurements were performed of the thickness of printed surfaces, surface roughness, and mechanical dot gain in the areas of 20 %, 40 %, 60 % and 80 % of black color (K). Also, gloss measurements were performed in the areas of 20 %, 40 %, 60 %, 80 % and 100 % for the four process colors cyan, magenta, yellow and black (CMYK).

2 Materials and Methods

2.1 Substrates

Three types of surfaces were used: paper-Fasson Indi Centaure, White Top, ALF606 S2030, weight 93g/m^2 (hereinafter Sample 1), polypropylene-Fasson Digit Indi, PP Top White, ALA 300, S692N weight 58g/m^2 (hereinafter Sample 2) and paper-Fasson Digit Indi, MP Gold Top, S2000N, weight 60g/m^2 (hereinafter Sample 3). The upper layer of these kinds of paper provides a complete transfer of ElectroInk inks during one pass with the aid of the HP Indigo. The surface also provides good binding and above-average fastness and rub resistance of ElectroInk prints.

FASSON Indigo print surface structures have been developed and designed for the use on HP Indigo machines [4].

2.2 Mechanical dot gain

Dot gain is a phenomenon in printing and graphic arts whereby printed dots are perceived to be, and actually are printed bigger than intended with respect to the originally applied size. If dot gain is too great, it causes a darkening of the screened images or textures, especially in the mid tones and shadows, due to the viscosity of ink and its ability to spread through the paper as it is absorbed/soaked in. Dot gain also depends very much on the light scattering/ absorption properties of the paper, and this is known as optical dot gain. It also varies with paper type [5].

Dot gain also depends on the paper surface properties, absorption abilities, rheological properties and characteristics of the printing machines [3].

Measurements were carried out by transferring the images obtained with a Leica MZ 16 microscope to computer storage, after which the data were treated using ImageJ software (Fig. 1). Samples were 50 times magnified.

Figure 1 Flow chart of the mechanical dot gain measurement

2.3 Reflection models

Since few surfaces in the real world are ideally diffuse or perfectly specular, the dichromatic reflection model by [6] considers reflection at a surface patch of inhomogeneous dielectric objects as a linear summation of diffuse and specular reflections, as shown schematically in Fig. 2. The symbol $\boldsymbol{H}$ stands for the half-vector and represents the normalized vector sum between the illuminating vector $\boldsymbol{L}$

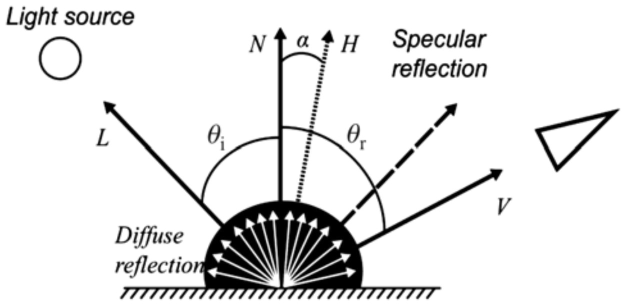


Figure 2 Diffuse and specular reflection at an object surface

and the viewing vector $\boldsymbol{V}$; α is the angle between the normal vector $\boldsymbol{N}$ of the surface patch and the half-vector $\boldsymbol{H}$, whereas θ_i and θ_r are the incident and reflection angles, respectively [7, 8].

2.4 Gloss measurements

Gloss measurements determine the amount of light reflected under certain angle range from the measured object surface. The incident and reflected light angles are equal, but are in the opposite direction. The amount of reflected light is essential in respect to the perception of the vision of glare from the surface of an object. So, the measurement of gloss determines how glossy (shiny) an object is.

A gloss measurement device is constructed so that the beam of light from the device falls under a certain angle to the perpendicular area from which gloss is measured. On the other side is placed a detector that measures the amount of reflected light under the same angle as the angle of incident light. Only the reflected light that has the same angle as the incident light is detected. In front of the detector, a green filter is placed to simulate human vision as closely as possible. The gloss measuring device measures three different angles of light reflection. The most common angle values are 20°, 60° and 85°. The angle of 60° can be used with most materials, while the angle of 20° is recommended when the gloss value at the angle of 60° is greater than 70° (which is a substrate with high reflectivity). The use of an angle of 85° is recommended when the gloss value at 60° is less than 10 (which is a matt surface). The device used for gloss measurements was a Master Gloss/Gloss Mate with three measurement angles: 20°, 60° and 85°, following the ISO 2814:2006 standard. The Gloss Mate measurement method is illustrated in Fig. 3. Three most common measurement angles are displayed.

Gloss measurements were performed on halftone fields 20 %, 40 %, 60 %, 80 % and 100 % for all three samples. Depending on surface gloss, a proper measuring angle was selected.

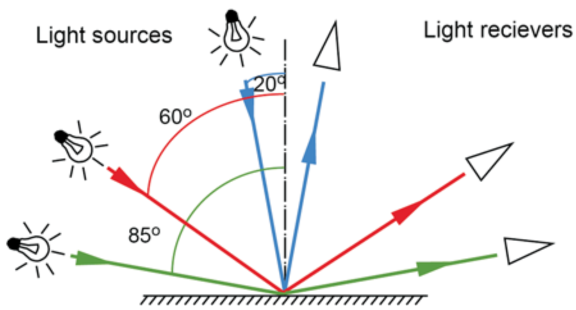


Figure 3 Illustration of the Gloss Mate measurement method

3 Results

The measurements provided the data about the changes of the paper surface characteristics in dependence of the type of surface printed by the electrophotographic technique. The analysis encompassed the data on surface features (roughness, gloss and Scanning Electron Microscopy (SEM) characteristics) of the three types of material, measured before and after the printing.

3.1 Printing surface properties

One of the most important characteristics of the surface reflection is surface roughness. Surface roughness (Ra) measurements were carried out using Portable Testers USA TR 200 surface roughness measurement device. Fig. 5 shows the corresponding surface roughness records for six specimens of the investigated materials. The measurements were performed on six different spots on the surface of all samples. Roughness measurements were performed to emphasize the difference between surface roughness of samples, which is presented in Fig. 5a, c, e in form of roughness measurement device sample outputs. Average paper thickness was calculated from the data taken for six specimens of the investigated materials. Dimensional characteristics of the materials are shown in Tab. 1.

Table 1 Paper thickness expressed in millimeters (S1 – Sample 1, S2 – Sample 2, S3 – Sample 3)

	1	2	3	4	5	6	Average value
S1	0,218	0,218	0,218	0,218	0,218	0,219	0,218
S2	0,126	0,124	0,123	0,123	0,125	0,125	0,124
S3	0,213	0,213	0,213	0,213	0,213	0,213	0,213

Paper thickness has been measured for information only to amendment sample dimensional characteristics information.

3.2 Dot gain

The results of the measurement of dot gain as a function of the chosen coverage values are graphically presented in Fig. 4.

Dashed line presents ink coverage for each of five halftone fields and solid line presents ideal coverage case.

In case of Sample 1 and Sample 2, the dot gain is observed in the halftone field of 20 % and 40 %, while in the halftone fields of 60 % and 80 % a "dot decrease" (negative dot gain) is present. The deviations for these two surfaces are in the range of 5 % to 10 %. In the case of Sample 3, a significant dot decrease is present in all halftone fields. The greatest difference of 86 % is in the 20 % halftone field, while for the other halftone fields it is 50 % or less.

3.3 Gloss values

Gloss measurements were also performed for all three samples (Figs. 6-8).

The average gloss value (expressed as gloss units or GU) for the non–printed Sample 1 was 6,03 GU. Polynomial curves and gloss-coverage (halftone field) for this surface are shown in Fig. 6.

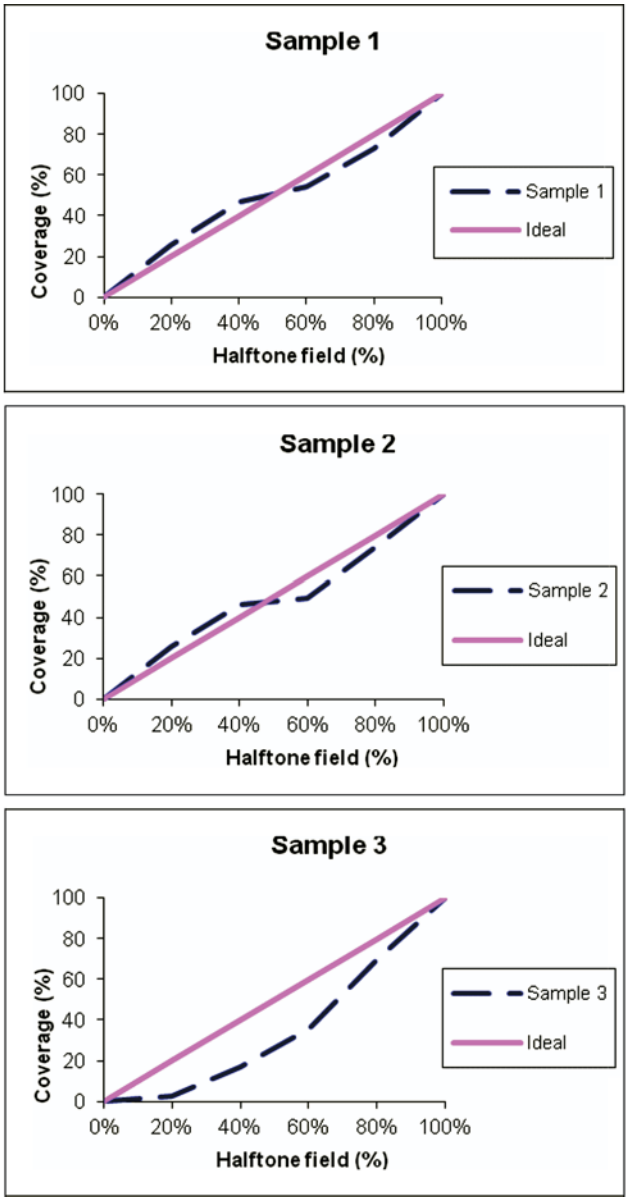


Figure 4 Dot gain for printed surfaces

The average gloss value for the non–printed surface Sample 2 was 34 GU (20°). Polynomial curves and gloss-coverage (halftone field) relation functions for this surface are shown in Fig. 7.

The average gloss value for the non–printed Sample 3 surface was 579,33 GU. Polynomial curves and gloss-coverage (halftone field) relation functions for this surface are shown in Fig. 8.

3.4 SEM analysis

SEM photomicrographs were taken using JEOL JSM 6460 LV Scanning Electron Microscope. Fig. 9 shows the SEM photomicrographs of the examined surfaces before printing, on which are clearly visible 3D features which present surface structure, while Figs. 10, 11 and 12 show SEM photomicrographs of printed samples of the examined materials. It is evident that the presence of printing ink on the tested surfaces affects the surface relief and thus also its gloss. Also, it can be seen that the surface gloss decreases after color being applied and the halftone dots contribute to

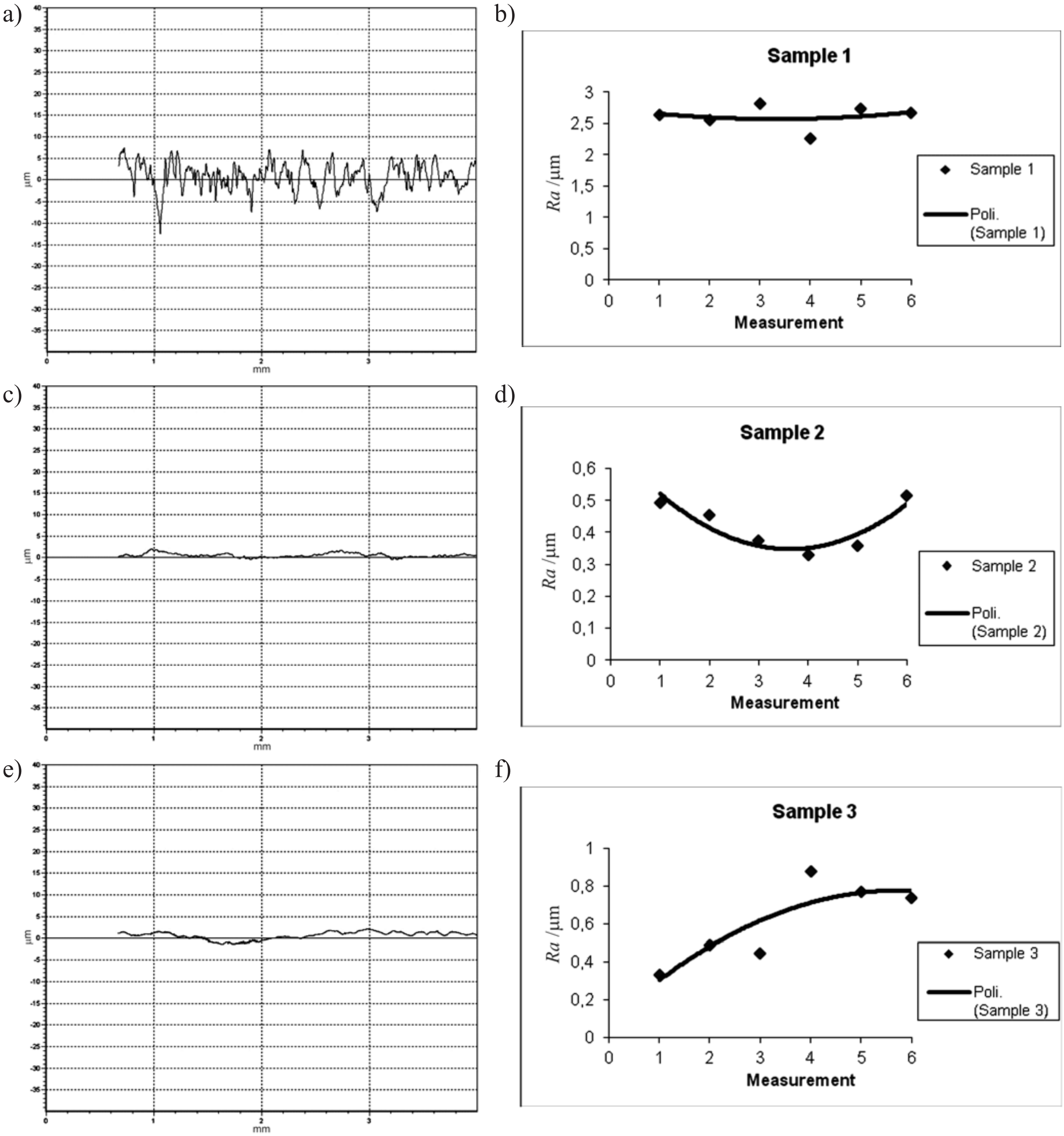


Figure 5 Surface roughness records for all three material types: Sample 1, Sample 2, and Sample 3 respectively. a), c) and e) present the roughness measuring device record samples, b), d) and f) present the roughness difference polynomial curves (Poly) obtained based on six measurements

an improper (diffuse) light scattering.

4 Discussion

Mechanical dot gain measured in the fields of 20 %, 40 %, 60 % and 80 % halftone value (Fig. 4) has a common trend for Sample 1 and Sample 2 surfaces. Namely, the dot gain in the lighter tones (up to 50 % halftone coverage) shows an increase, while the darker tones reveal a dot decrease (negative dot gain). On the other hand, the behavior of the Sample 3 shows a departure from this trend. Namely, a reduction in the dot gain is observed in both lighter and darker areas. This is also confirmed by the SEM recordings (Figs. 10, 11 and 12). However, these results differ from those obtained by [5], who found significant dot gain in all halftone fields. This points out to the difference between the electrophotography and UV Ink Jet printing techniques.

The average values of gloss, measured for the halftone fields 20 %, 40 %, 60 %, 80 % and 100 % were used to generate the corresponding polynomial curves (Figs. 6, 7 and 8) which show the gloss changes in dependence of the substrate surface coverage (halftone field).

In case of Sample 1 (Fig. 6), the gloss value declines from the 20 % to the 80 % field and then shows a constant growth. Such a trend is present in all four colors (CMYK). In case of cyan color (C), the gloss in the 100 % field is very strong, but the curve follows the same trend. Gloss values deviations are not large and vary within the range from 0 to 1.

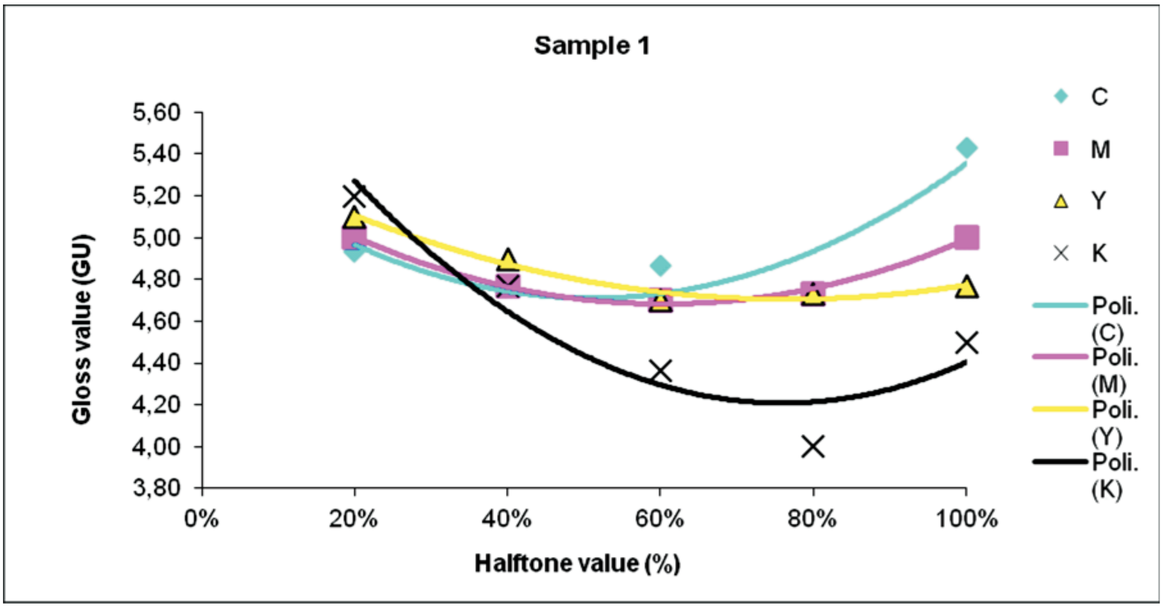


Figure 6 Polynomial curves and gloss-coverage (halftone field) for Sample 1

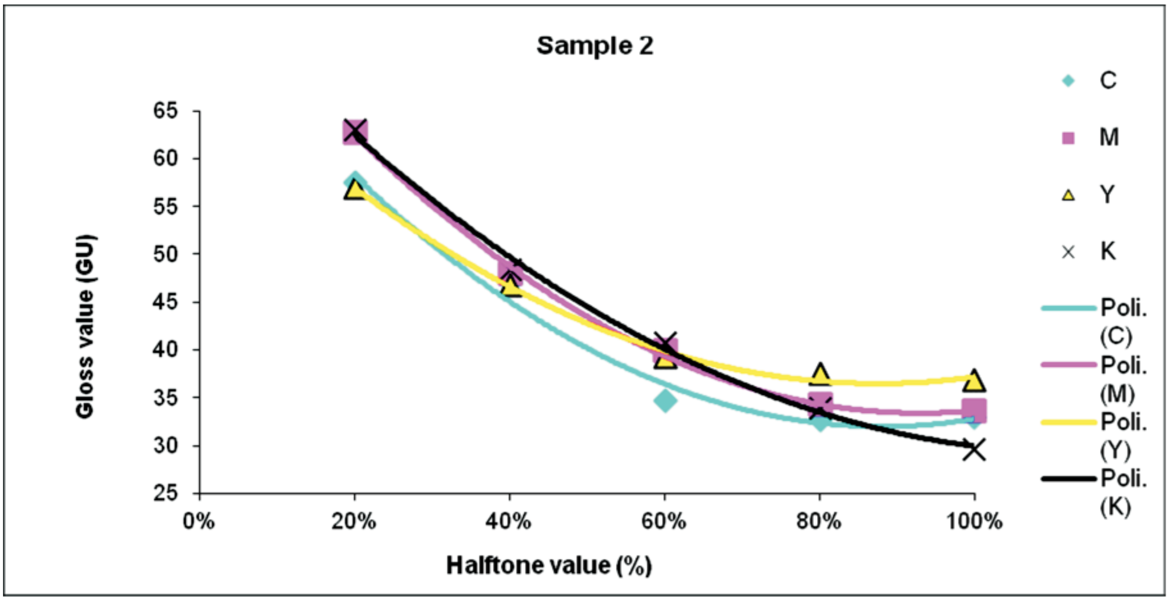


Figure 7 Polynomial curves and gloss-coverage (halftone field) for the surface Sample 2

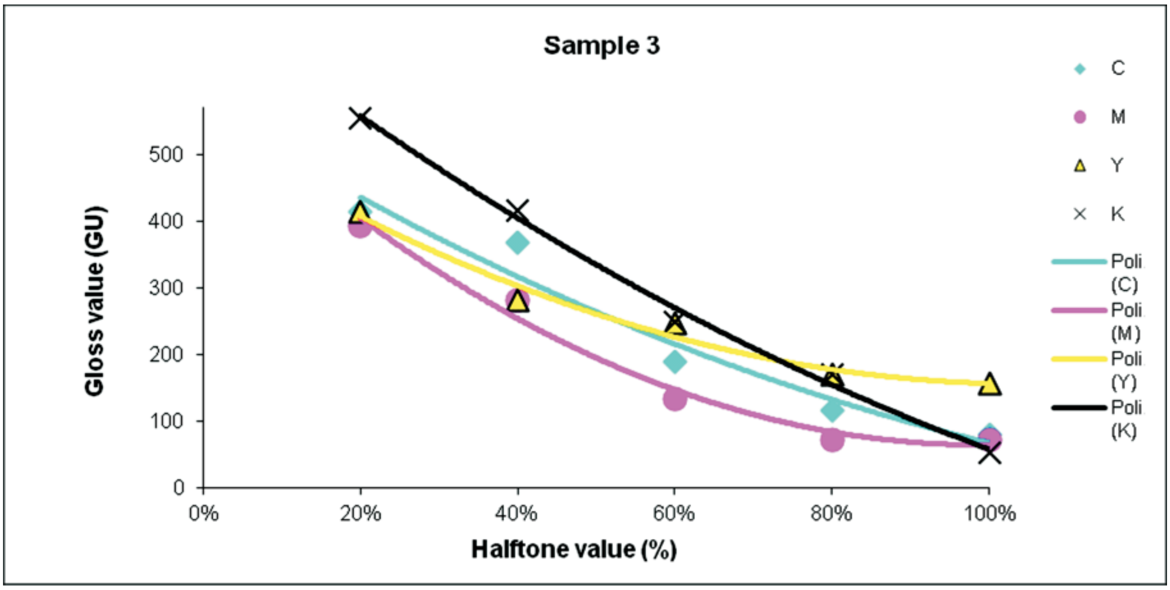


Figure 8 Polynomial curves and gloss-coverage (halftone field) for Sample 3

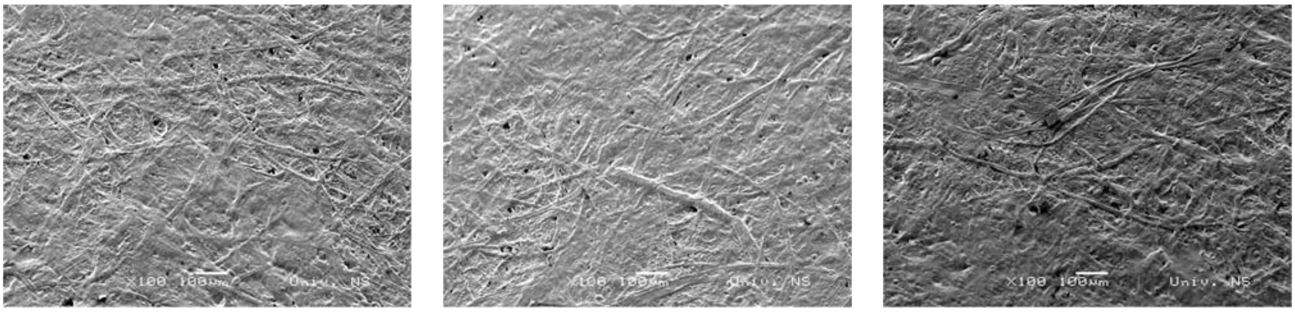
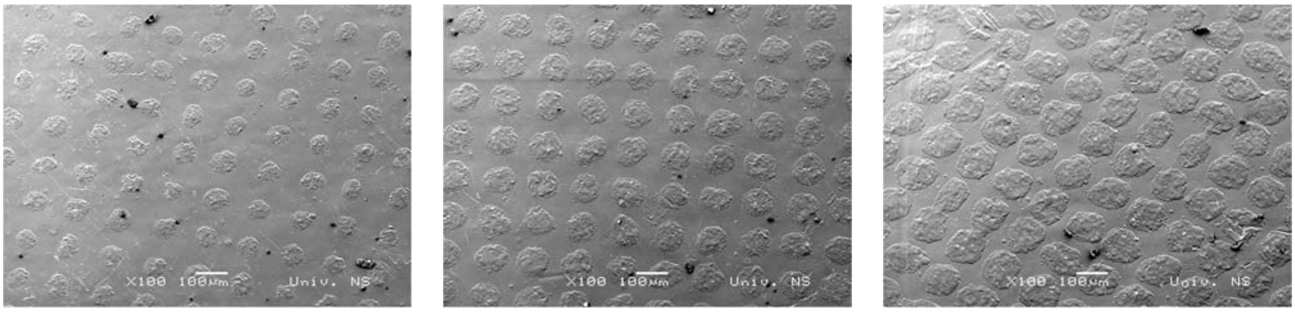
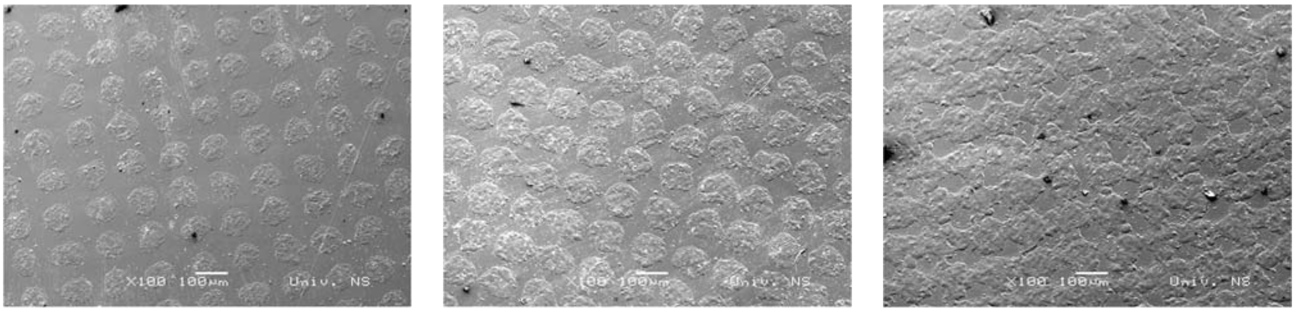


Figure 9 SEM photomicrographs of surfaces before printing: Sample 1, Sample 2 and Sample 3, respectively



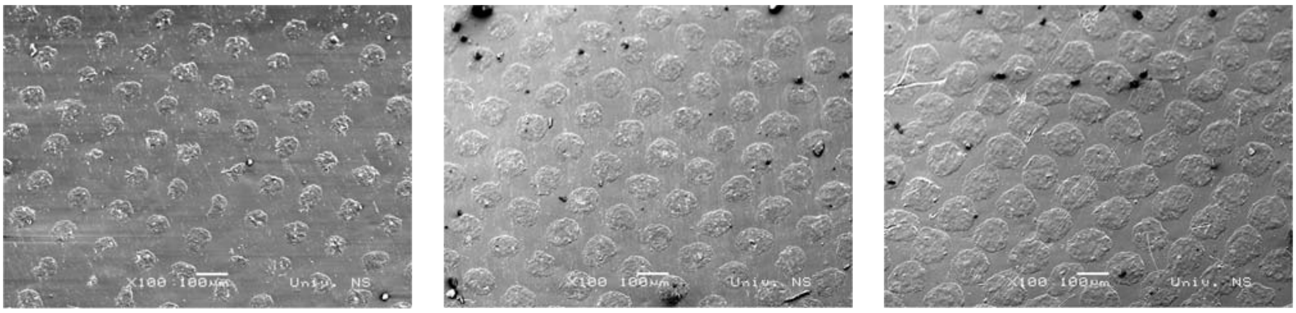
Sample 1 20 % Sample 1 40 % Sample 1 60 %

Figure 10 Printed surface - Sample 1



Sample 2 20 % Sample 2 40 % Sample 2 60 %

Figure 11 Printed surface - Sample 2



Sample 3 20 % Sample 3 40 % Sample 3 60 %

Figure 12 Printed surface - Sample 3

The measurement was carried out at an angle of 85°, and it can be concluded that the paper examined represents the surface with very little gloss – matt surface.

In case of Sample 2 (Fig. 7), smoother curves were obtained, showing a trend of gloss changes similar to the surface coverage (halftone field). For this surface, there is no pronounced gloss in the 100 % field like in the previous case. The curves show an increase in gloss with the decrease of printed surface coverage (halftone field). The measurement carried out at an angle of 60° shows that Sample 2 is a high glossy surface.

By examining Sample 3, a similar trend of gloss change was observed as for Sample 2. Also, there is no expressed gloss in the 100 % fields, and the curves show an increase in gloss with the decrease of printed surface coverage (halftone field). The measurement carried out at an angle of 20° indicates that the Sample 3 is an extremely high gloss surface.

Average gloss values for the non–printed surfaces are greater than those for the printed ones so it is obvious that surface gloss drops with ink appliance.

5 Conclusions

The study involving three different substrates showed that their properties play a very important role in obtaining high-quality print. Of the three substrates, the one denoted as Sample 1 appeared to have the smallest dot gain deviations, so that it is suitable for the prints which demand low gloss. Unlike that, Sample 2 has the best properties for the print observed from the point of all measured parameters, with very small dot changes, although the surface roughness is lowest compared to all the samples. Also, the printed surface gloss level is medium, which is very convenient for obtaining all kinds of prints. Sample 3 proved to be the worst for digital electrophotographic printing, with a very large mechanical dot reduction in the bright and dark tones, and with very high gloss due to the surface coat. The investigation provides important information about the characteristics of the substrate in the electrophotographic printing process. Overall conclusion is that application of printing ink (printing process) decreases surface gloss of all the examined surfaces. Reduction of the surface gloss occurs due to the changes in the surface properties (roughness) which is in concordance with the theory of [9]. Sample 2 and Sample 3 show that gloss is inversely connected to halftone value, gloss value drops while halftone value rises. Sample 1 results slightly deviate from this conclusion but further research might reverse the situation.

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