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Modifying the qualitative properties of print by surface treatment of flexographic printing plate

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Abstract

In the fast-pace technology development in graphic industry, modern flexography has found its domain mostly in the packaging sector and it is increasingly of interest for functional printing. Functional printing has a relatively low market value but greater interest in research. Due to the new qualitative requirements, workflows and materials used in flexography had to be updated and improved. The application of digitally controlled processes and procedures has taken the place of the analogue production, together with the new methods of material processing and improvements of the materials themselves. This research focuses on the functional modification of photopolymer flexographic printing plate's properties with the aim of achieving optimal output quality. During the transfer of the printing ink from the anilox to the printing plate and then to the printing substrate, surface properties of the printing plate influence the quality of the print. Therefore, surface properties of the printing plate should be compatible with the used printing ink and the printing substrate, which is especially important when using new formulations of inks and experimenting with different printing substrates and applications, for example in functional printing. In this research, samples of photopolymer flexographic printing plates were exposed to UV-ozone treatment in order to modify the surface properties of the photopolymer material. Results have displayed significant changes in surface free energy of the photopolymer material when the printing plate samples were exposed to the UV-ozone for periods up to 5 minutes. In order to analyze the quality of the prints produced with UV-ozoned flexographic printing plates, test prints were produced. Prints produced with printing plates with longer UV-ozone treatment have displayed the qualitative changes in the reproduction of fine printed elements, i.e. the width of fine lines, coverage values, ink volume on print and the definition of the shape and edges of printed elements. Changes of named properties of the print are significant for conventional, and in many cases for functional printing. Performed research proved that the functional modification of flexographic printing plates with the aim of improving the print quality is possible. The UV-ozone treatment is a procedure where the printing plate is exposed to significantly higher energy than with conventional UVA and UVC tubes. Therefore, the duration of the UV-ozone treatment must be precisely adjusted in order to maximize the quality of the print, while at the same time maintaining printing plate's functionality.

Keywords: flexography, photopolymer, UV-ozone, surface free energy, ink transfer

1. Background

Flexography is a printing technique mostly used in packaging and functional printing. Flexographic printing plates are made of photopolymer materials, formulated to meet mechanical and qualitative requirements in the graphic reproduction process. In the significant part of its domain, flexography is competing with gravure printing. In the past few years, there have been some gains in share over gravure printing because of the greater flexibility of the prepress in flexography, as well as for the jobs with shorter run lengths, frequent design changes and special functional applications (Bodwell and Scharfenberger, 2011; Phillips, et al., 2012).

Many parameters influence the quality of the final product in flexography: photopolymer material used for the printing plate production (Matsubara and Oda, 2013), quality of the file adjustment, type of anilox roller, type of tape placed under the printing plate to adjust the elastic deformation of the printing plate, properties of the printing ink and printing substrate (Bollström, et al., 2012; Bollström, et al., 2013; Aspler and Lepoutre, 1991), control of the printing process, and a set of parameters associated with the printing plate production (Mahović Poljaček, et al., 2013).

Flexographic printing process has achieved significant improvements in the quality of the printed product. The automation of the printing process ensured better control over the output. Printing inks and anilox technology improved in quality as well, but the main improvements have been made in the area of printing plates and imaging methods (Bodwell and Scharfenberger, 2011; Esko, 2012). New formulations of photopolymer materials enabled production of smaller dots on the printing plates, in some cases even being able to eliminate the bump curve, resulting in higher quality prints in the highlight area and expanded gamut. Photopolymer materials used nowadays have increased resistance to solvents and ozone, and are compatible with solvent-based, water-based and UV-curable inks. Furthermore, new technologies in the flexographic printing plate processing workflow enabled the production of "flat-top" dots (Esko, 2012). However, the debate about superiority of this shape of printing element over the "bullet-shaped" dots exists (Asahi, 2015).

Furthermore, new formulations of photopolymer materials used in flexographic printing plate production enabled increased ecological sustainability of the processing. Water-washable printing plates eliminated the use of the volatile organic solvents from the printing plate production process (Anderson & Vreeland Inc., 2017; Asahi Photoproducts, n.d.; Flint Group, n.d.). Mechanical (chemistry-free) process of engraving the polymer material in the printing plate production was re-introduced to flexography as well. In the graphic reproduction process, the transfer of the printing ink from the anilox to the printing plate and finally to the printing substrate depends on the surface properties of the materials used. Since the printing plate is in the middle of the ink transfer chain, its surface free energy (γ) must be adequate to achieve the optimal transfer of the printing ink from the anilox to the printing substrate (Mahović Poljaček, Cigula and Tomašegović, 2012; Page Crouch, 2005). Improvements of the flexographic printing plate's surface properties in the past decade have been made as well. Patterned textures have been applied to the surface of the printing elements on the printing plate in the plate making process (Kodak, 2014). The surface of the printing plate roughened in this way enables better adsorption of the printing ink to the printing plate, and better transfer of the ink to the printing substrate, reducing the fingering. However, flexographic printing plate manufacturers have several approaches to the cause-effect relation of the surface properties of the printing plate and the quality of the print (Asahi Photoproducts, n.d.; Flint Group Flexographic Products, n.d.).

Furthermore, γ of the printing plate can be modified in the standard printing plate production workflow if needed, during the post-treatment process (Mahović Poljaček, et al., 2014). Previous research (Tomašegović, Mahović Poljaček and Cigula, 2013; Tomašegović, Mahović Poljaček and Leskovac, 2016; Mahović Poljaček, Tomašegović and Gojo, 2012) has indicated that UVA and UVC post-treatments influence the printing plate's physico-chemical surface characteristics by changing the components of γ of the photopolymer material. This influences the transfer of the printing ink from the anilox to the printing plate and from the plate to the printing substrate (Mogg, et al., 2016).

In previous research (Mahović Poljaček, et al., 2014, Mahović Poljaček, et al., 2016), energy dispersive X-ray spectroscopy (EDS) analysis showed that the changes in contact angles of probe liquids and γ are caused by the increase of oxygen concentration in the surface layer of the printing plate, while FTIR-ATR analysis pointed specifically to the increased ratio of carbonyl and hydroxyl bonds (Tomašegović, Mahović Poljaček and Cigula, 2013). Therefore, duration and intensity of the post-treatment process must be strictly adjusted and regularly monitored. Modifications of the printing plate's properties during the UV post-treatment depend on the type of the photopolymer material and should be performed in the printing plate production workflow in accordance with the type of the printing ink and printing substrate used. Since standards in flexography are mainly focused on the process control concerning screen ruling and parameters connected to process colours, printing substrates and dot gain (International Organization for Standardization, 2012), further analysis and experiments are yet to be performed when considering the influences of the printing plate quality on the graphic reproduction process.

The aim of this research is to determine the influence of the printing plate's surface modification, precisely, the influence of the UV-ozone treatment, on the surface properties of the printing plate specifically related to the quality of the prints. The UV-ozone treatment of the flexographic printing plate, due to its higher energy, is a rapid method compared to the modification of the regular UVA and UVC post-treatments and presents a new method for adjusting the properties of the prints in relation to the specific printing system. Improvements and adjustments of qualitative properties of the print obtained by UV-ozone treatment have the potential to be useful in conventional and functional printing.

2. Experimental settings

For the purpose of this research, samples of Mac-Dermid LUX ITP 60 printing plate were received from MacDermid Printing Solutions. This plate is a solvent-washable, CtP flexographic printing plate with thickness of 1.14 mm. Printing plate samples used in this research were produced in the standard conditions by the printing plate manufacturer (MacDermid, 2014). The objective of the research was to determine the effect of the UV-ozone treatment on the surface properties of the printing plate, as well as the quality of the prints obtained by modified printing plates. Therefore, two sets of samples for each type of printing plate were produced:

- fields with 100 % surface coverage;
- samples with applied control elements which consisted of different fine elements, special elements and strips, as well as control wedges with halftones from 1 % to 100 % coverage value (Figure 1).

Motives were transferred on all printing plate samples with the application of the same compensation curve – FlexoSync 56. White opaque Melinex, with thickness of 350 ± 4 μm and γ of 42 mJ/m^2 was used as a printing substrate.

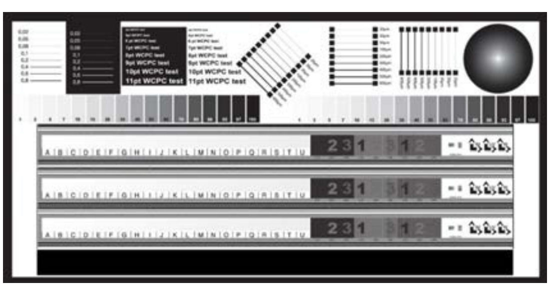

Figure 1: Set of control elements on tested printing plate samples

To ensure that the printing process was consistent in terms of the printing pressure (and other parameters), elements from three DFTA (2006) strips (Figure 1) were microscopically analyzed. After ensuring by microscopy that the transfer of the DFTA strip from the digital file to the printing plate was correct, three positive and negative lines surrounding the DFTA strip were observed and analyzed on the print, as well. These lines make it possible to check how stable thin lines are over various production runs. They enable to check the capability of the plate to hold straight the isolated line during the pressure in the printing process. Due to their sensitivity to the changes in the printing conditions, microscopic analysis of their shape was used to make sure that the deformations due to the variation of the pressure did not occur during the printing process and that the lines remained straight, with the similar and unchanged shape.

The UV-ozone treatment of the printing plate samples was performed in a NOVA SCAN PSD Pro Series Digital UV Ozone System; UV lamps in the NOVA SCAN PSD generate UV light at wavelengths of 185 nm and 254 nm, the instrument also produces O_3 and provides molecular excitation (NOVASCAN Technologies, n.d.).

All samples of printing plates were treated by UV-ozone for up to 5 minutes (0.5, 1, 1.5, 2, 3 and 5 minutes).

Topographic analysis of the printing plate samples and prints was performed by means of the white light interferometry using a WYKO NT – 2000 White Light Interferometer, which was also used to calculate the roughness parameters of the printing plate surface. The profile and surface of the structure can be measured without contacting the sample, which can greatly minimize the chance of destroying the fragile structures. Vision 32 software was used to calculate the width of printed fine lines, surface coverage and ink volume on the prints (Wyant, 2002).

Roughness of the solid-tone areas on prints was measured by portable roughness tester TR200 ten times on different spots on each sample, in order to identify the changes in the uniformity of the printed ink layer as a consequence of the UV-ozone treatment of the plate.

On the printing plate samples, contact angles of different probe liquids were measured by means of Fibro DAT 1100 Dynamic Contact Angle Measuring System. Contact angles of the probe liquids are the parameters which are then used to calculate the γ of the solid samples. Three probe liquids of known γ were used for the measurements: water, glycerol and diiodomethane. Contact angle was measured using sessile drop method, five times on each sample, on the different control elements on the printing plate. The shape of the probe liquid drops was a spherical cap, and the volume of the drops was 4 μl. All measurements of the contact angles on the samples were performed in the same moment after the drop touched the photopolymer surface (10 s), and the average value was calculated (ASTM International, 2003). After that, mean value of the contact angle for each sample was calculated and γ of printing plates was obtained using the Owens-Wendt-Rabel and Kaeble (OWRK) method, by means of the OCA20 software support (Dataphysics, n.d.). The OWRK method is applicable for the calculation of γ of polymers, aluminium and coatings (Owens and Wendt, 1969).

A Cooper Sheet Fed Flexo Press was used to produce the laboratory test prints by means of the UV-ozoned samples of MacDermid LUX ITP 60 printing plate. The Cooper Sheet Fed Flexo Press is a single colour printing machine for flexography, where the flexographic printing system can be tested throughout the complete print-

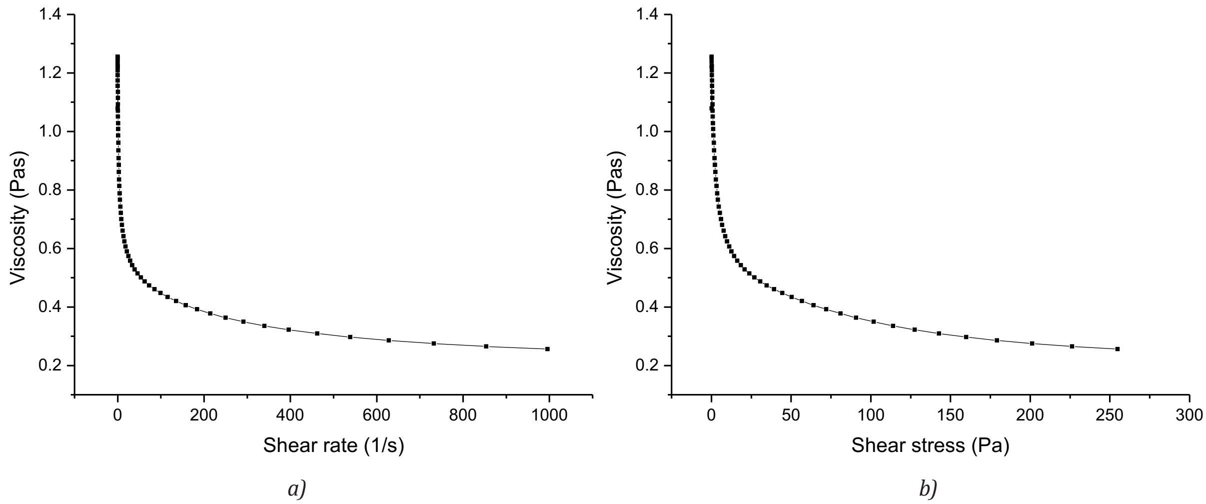

Figure 2: a) Viscosity vs. shear rate of the printing ink, b) viscosity vs. shear stress of the printing ink

ing process with all adjustments in the reproduction steps. Quartz Cationic UV DP1515/1 UltraC plus black from Mirage ink and ceramic anilox roll with cell volume of 2.27 cm^3/m^2, 1049 lpi were used in the printing process. Surface tension of the ink was 33.74 mN/m, with the rheological properties presented in Figure 2.

The pressure during the printing was set manually, following the standard operating procedure for the machine. Cooper press does not enable predefined numerical adjustment of the pressure. Kiss-print is achieved by inserting the printing substrate in the press and lowering the plate cylinder towards the printing substrate until the contact between the plate and the substrate is achieved, but the substrate can still be moved under the plate. Once set, the pressure was fixed throughout the printing process. After adding the printing ink to the ink chamber and wetting the plate with the ink, the first two prints were produced and discarded before producing the three prints that have been used for measurements. Printing speed was 24.17 m/min.

3. Results and discussion

3.1 Surface free energy of MacDermid LUX ITP 60 printing plate

Figure 3 presents the γ changes in total (γ^{total}) and its polar (γ^{p}) and dispersive (γ^{d}) components of UV-ozoned printing plate samples. It is evident that γ^{d} does not change distinctively throughout the variation in UV-ozone treatment. On the other hand, γ^{p} increases progressively from 6.55 mJ/m^2 to 23.13 mJ/m^2, while γ^{total} increases from 43.37 mJ/m^2 for non-treated printing plate sample up to 59.40 mJ/m^2 for the sample treated with the UV-ozone for 5 minutes.

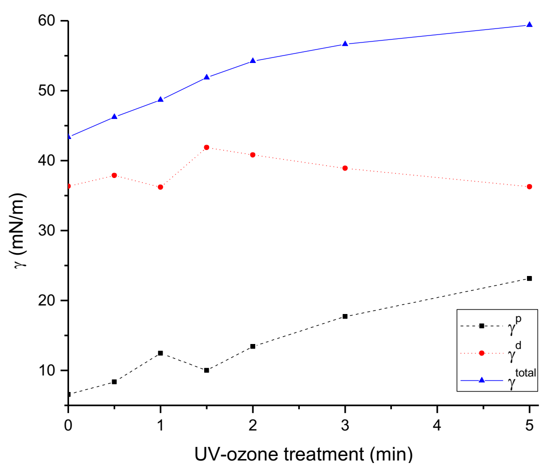

Figure 3: Surface free energy of UV-ozoned LUX ITP 60 printing plate samples

It can be seen that γ^{p} primarily influences the increase of the values of γ^{total}. The reason for this is the integration of the oxygen in the surface layer of the photopolymer material during the UV-ozone treatment, common to the UV treatments in the printing plate processing (Tomašegović, 2016). On the other hand, the decreasing trend of γ^{d} after 1.5 minutes of UV-ozone treatment points to the start of the material degradation, since γ^{d} can be directly related to the crosslinking degree (Tomašegović, 2016).

This means that prolonged UV-ozone treatment can result with shortened lifetime of the printing plate and decreased mechanical and chemical resistivity in the printing process. Therefore, maximal duration of the UV-ozone treatment should be adjusted to the specific photopolymer material and preliminary tests should be performed before the application of the treatment in the real system.

3.2 Test prints

Test prints of the motives transferred to MacDermid LUX ITP 60 printing plate were produced by means of the Cooper press. Several parameters were measured on test prints: width of the fine lines, coverage values of the halftones from 1 % to 100 % and the approximate ink volume in the halftone area. All parameters were measured and monitored in dependence on the duration of UV-ozone treatment.

3.2.1 White light interferometry and analysis of fine lines on test prints

Width of the fine lines on the prints produced by the Cooper press was measured by using a 2-dimensional analysis tool in Vision 32 software. Result of the measurement is displayed in Figure 4.

Figure 4: Cross section and width of the printed fine line measured by white light interferometry

In Figure 5, Δ*d* on *y*-axis presents the difference between width of the line on prints produced without the UV-ozone treatment and the width of the line on the print produced with specific duration of UV-ozone treatment (lines are labeled on the legend by their initial width on the motive without the UV-ozone treatment). The measurement results have shown that the width of the lines reduces with increased duration of UV-ozone treatment.

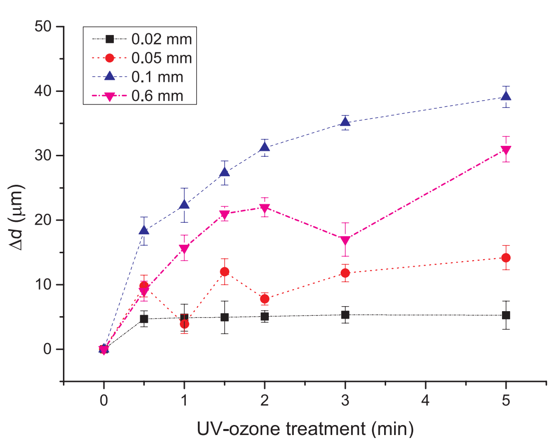

Figure 5: The change of width of the fine lines printed with UV-ozone treated plates

Previous research (Tomašegović, et al., 2016) showed that the UV-ozone treatment increases the hardness of the flexographic printing plate due to further crosslinking in the volume of the material and changes in the chemical bonds in the photopolymer material. Indeed, hardness of the MacDermid LUX ITP 60 printing plate samples was measured using a Shore A hardness tester, and the results showed the increase in hardness of approx. 4 Shore A between the non UV-ozoned sample and the sample UV-ozoned for 5 minutes. Therefore, printing elements on the plate become more mechanically stable and deform less in the printing process. Furthermore, the difference between the prints of the fine lines produced by means of non UV-ozoned and UV-ozoned printing plates amounts up to 35 % of the initial width of the line printed by means of the printing plate without the UV-ozone tretement. Greater mechanical stability would reduce the barreling and stretching mechanisms of halftone dot and track expansion and therefore UV- ozone treatment could be used to optimize printing fine elements in flexography.

Figure 6 presents the common test motive used in applications of various printed electronics. It consisted of the fine lines of different initial widths, which are connected to a “pad”. The crucial part considering the quality of the print is the “line-pad” joint. Because of the elastic deformation of the printing plate during the engagement, the shape of either pad or line near the joint can deform. The results are usually either correctly printed line, but poor quality of the connection between the line and pad, or vice versa, which both can result in problems with conductivity when printing conductors and other electronic components.

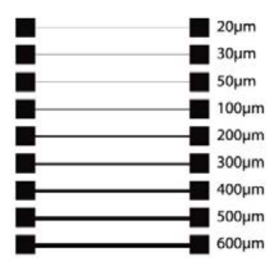

Figure 6: Motive for testing print quality in printed electronics

Figures 7.1–7.4 present the magnified white light interferometry measurements of fine lines connected to the pad on the printing plate and prints.

The printed area of the connection of line and pad improves both in the uniformity of the ink layer on the line, and the area of the connection between the elements with prolonged UV-ozone treatment. This is due to the changes in mechanical properties of the printing plate after UV-ozone treatment. As the hardness of the printing plate increases due to increased UV-induced

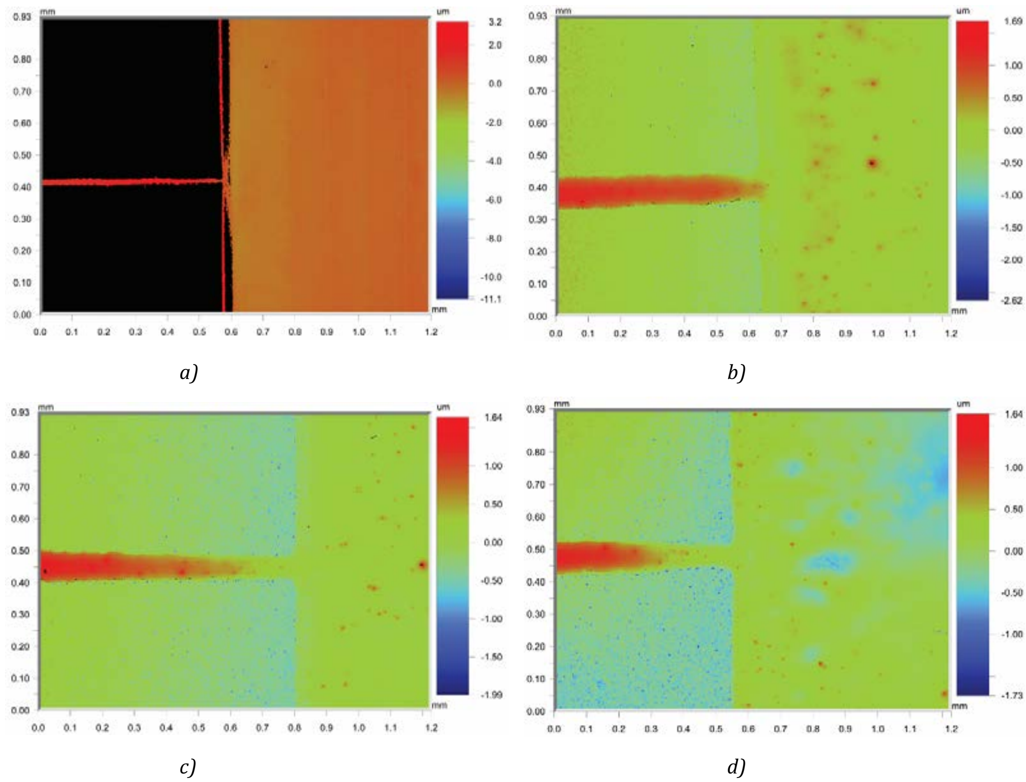

Figure 7.1: 20-μm line and pad joint on: a) printing plate, b) print without UV-ozone treatment of plate, c) print obtained by plate UV-ozoned for 2 minutes, d) print obtained by plate UV-ozoned for 5 minutes

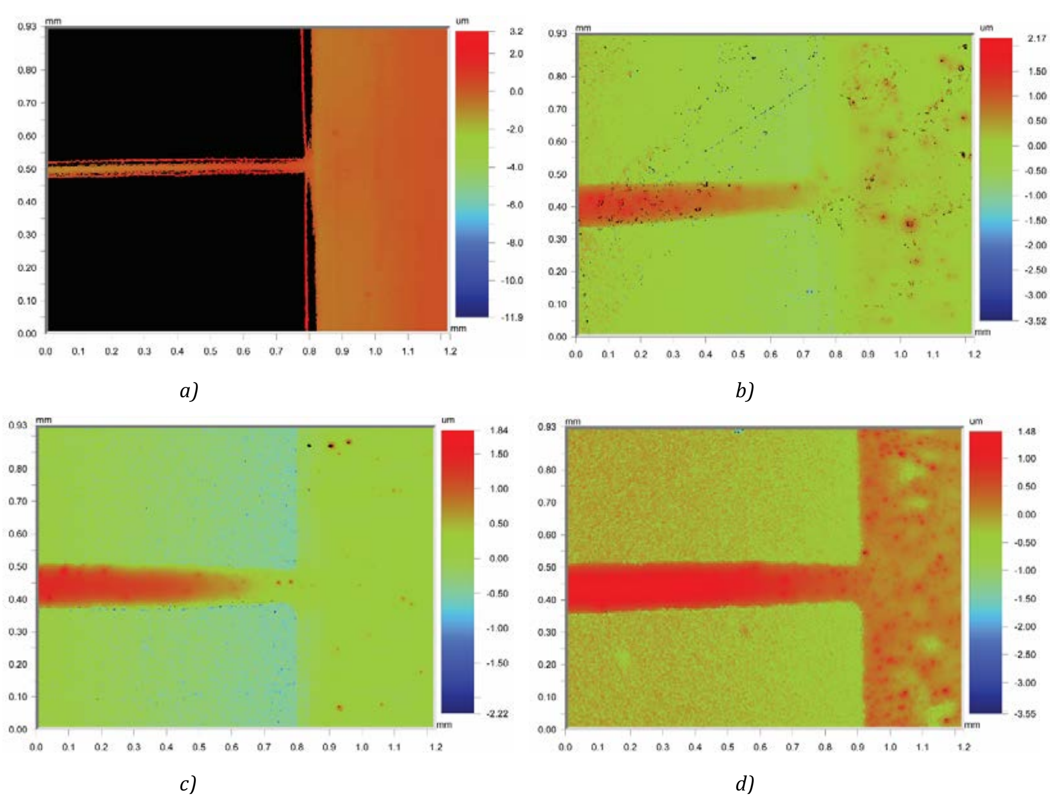

Figure 7.2: 50-μm line and pad joint on: a) printing plate, b) print without UV-ozone treatment of plate, c) print obtained by plate UV-ozoned for 2 minutes, d) print obtained by plate UV-ozoned for 5 minutes

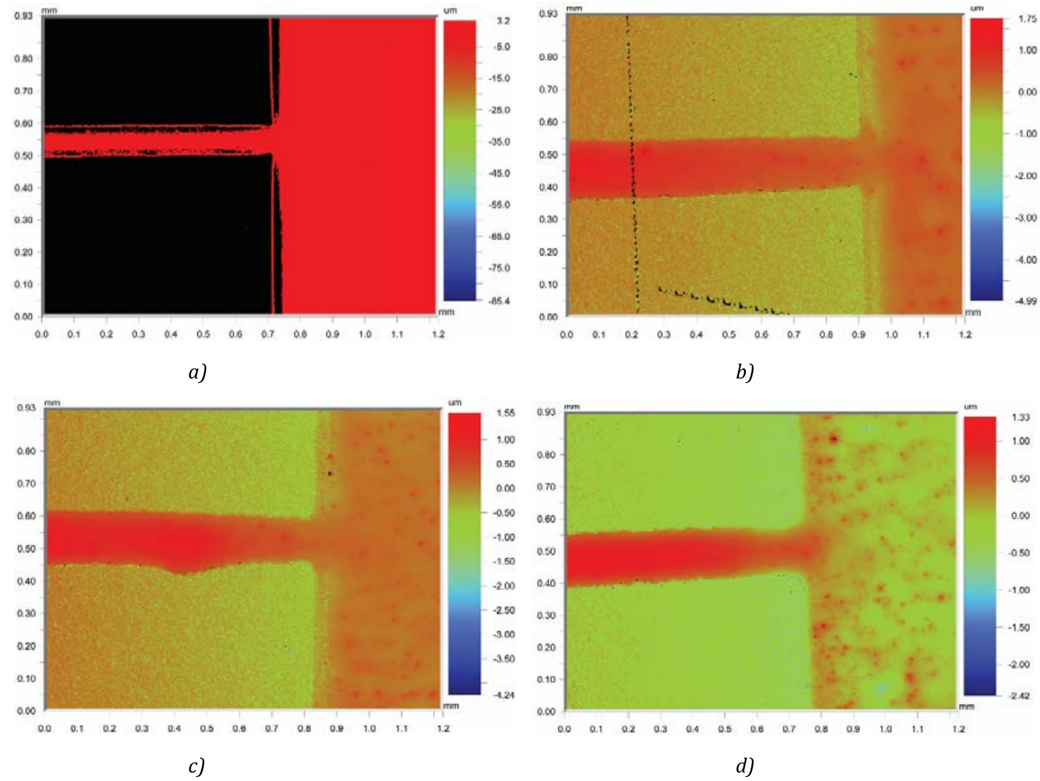

Figure 7.3: 100-µm line and pad joint on: a) printing plate, b) print without UV-ozone treatment of plate, c) print obtained by plate UV-ozoned for 2 minutes, d) print obtained by plate UV-ozoned for 5 minutes

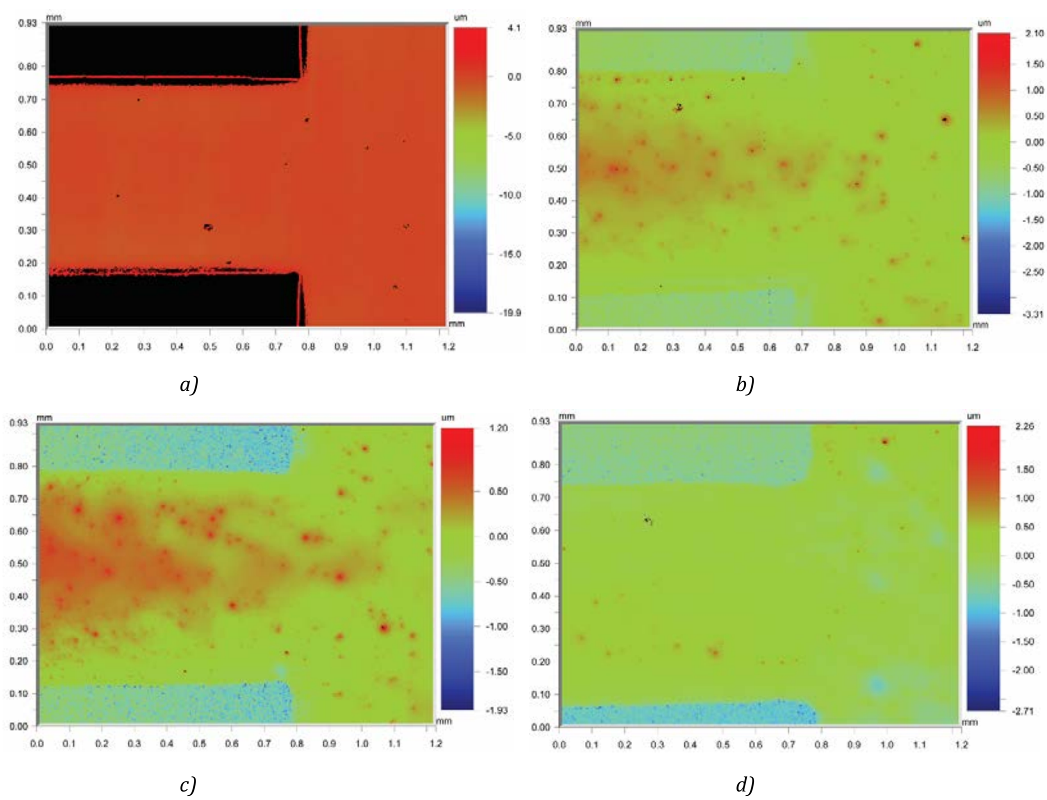

Figure 7.4: 600-µm line and pad joint on: a) printing plate, b) print without UV-ozone treatment of plate, c) print obtained by plate UV-ozoned for 2 minutes, d) print obtained by plate UV-ozoned for 5 minutes

crosslinking in the volume of the photopolymer, elastic deformation of the printing plate during the printing process decreases. However, UV-ozone treatment should be properly adjusted to obtain both improvement in the print quality and the required thickness of the ink layer, important in printed electronics domain, since previous research showed the decreased thickness of the ink layer on the print due to the increased γ and therefore improved wetting of the ink on the UV-ozoned printing plate samples (Tomašegović, et al., 2016).

3.2.2 Roughness of the solid printed surface

Changes in the R_a and R_z roughness parameters on the solid-tone areas on the prints after the UV-ozone treatment of the printing plates are presented in Figure 8, R_a parameter ranges from 0.037 µm to 0.050 µm, and R_z from 0.35 µm to 0.44 µm.

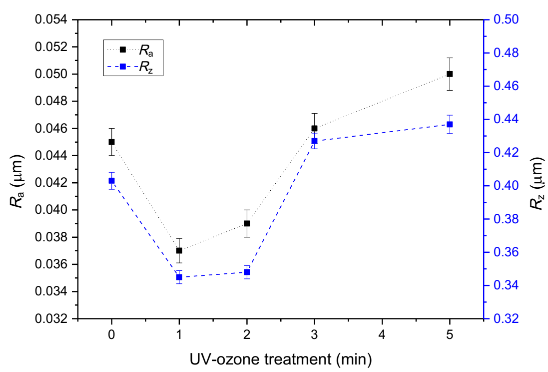

Figure 8: R_a and R_z parameters on solid-tone prints produced by UV-ozone treated plates

The measured changes in the roughness parameters are not as significant quantitatively, but they do point to the changes in the plate–ink interaction because of the UV-ozone treatment. Specifically, as roughness of the printing plate initially increases due to the UV-ozone treatment up to 2 minutes (Tomašegović, et al., 2016), roughness of the printed solid-tone decreases. After 2 minutes of the UV-ozone treatment, roughness of the printing plate samples starts to decrease, resulting with the increased surface roughness of the solid-tone areas of the print. Therefore, it can be concluded that the changes in the roughness of printing plate do not cause the changes in R_a and R_z parameters on the prints, since the trends of the changes are opposite. The effect of the roughness of the printing substrate is also not influencing significantly the roughness of the prints, since its mean R_a parameter equals 0.027 µm, and R_z 0.33 µm.

Therefore, the changes in the roughness parameters of the prints can be connected to:

- peaked γ^d of the printing plate samples and changes in the γ^d – γ^p ratio between 1 and 2 minutes of the UV-ozone treatment (Figure 3) and apparently to some extent altered interaction between the printing plate and the ink, resulting with the increased homogeneity of the printed layer in this timeframe of the duration of the UV-ozone treatment;
- increased hardness of the printing plate after the prolonged UV-ozone treatment (Tomašegović, 2016) and therefore decreased ability of the printing plate to conform to the substrate when printing. Therefore, the impaired uniformity of the transferred ink layer, in conjunction with its decreased thickness, will result with the decreased smoothness of the printed layer.

3.2.3 Surface coverage of halftones on test prints

The trend of printing ink transfer for the halftone reproduction in dependence on the UV-ozone treatment is presented in Figure 9. Due to changes in the mechanical properties of the photopolymer material caused by UV-ozone treatment, dot gain is less expressed with prolonged duration of the UV-ozone treatment. FlexoSync 56 compensation curve was applied to all samples of printing plates, but due to the features of laboratory printing process, dot gain is higher than expected. Nevertheless, 5 minutes of UV-ozone treatment decreased the coverage from 90 % to 80 %, on the field with 50 % nominal coverage value. Therefore, UV-ozone treatment can be used as a tool for optimizing dot gain; however, the level of treatment must be investigated for different printing inks and substrates.

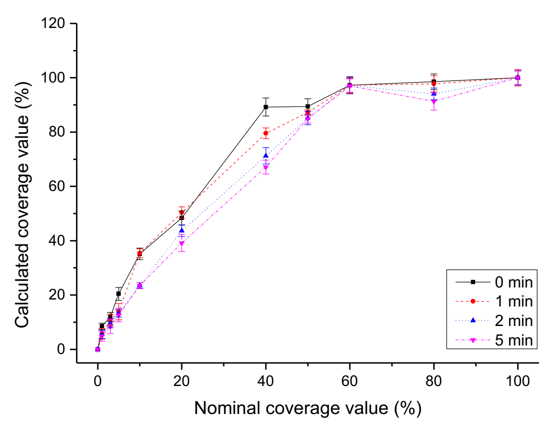

Figure 9: Coverage values of halftones on prints produced by UV-ozone treated plates

3.2.4 Ink layer volume on test prints

In Figure 10 the results of ink volume calculations on the halftone area are presented in µm^3 per area of 1 mm^2. Similar to the results of coverage value calculations, the volume of the ink on the halftone prints decreases with prolonged UV-ozone treatment.

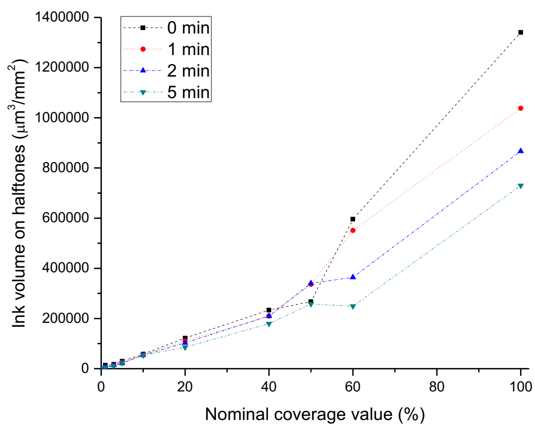

Figure 10: Ink volume on halftones on prints produced with UV-ozone treated plates

The results of the ink volume calculations are in direct relation with previously obtained results of the ink layer thickness on prints produced by means of the UV-ozoned printing plate samples (Tomašegović, et al., 2016). The decreased ink layer thickness both on 100 % coverage value and on halftone areas with prolonged UV-ozone treatment can be used for the fine adjustment of the ink layer features on the print by means of the printing plate, beside the anilox.

Since the cell count and volume on the anilox roller define only the amount of the ink available for the transfer to the printing plate, surface and mechanical properties of the printing plate modified by specific surface treatment can be used to regulate the ink transfer in the "printing plate–substrate" system.

4. Conclusions

The aim of this research was to modify the surface properties of photopolymer flexographic printing plate by means of UV-ozone treatment in order to influence the properties of the print. At the same time the printing plate needed to retain its functional properties.

The tested printing plate displayed a significant increase of γ after 5 minutes of the UV-ozone treatment. The difference in γ^{total} between non-exposed sample and sample exposed to the UV-ozone treatment for 5 minutes was cca 15 mJ/m^2. The main reason for the changes was the increase of γ^p due to integration of the oxygen in the composition of the photopolymer material.

The γ^d started to increase with shorter exposures to UV-ozone treatment, but decreased after longer exposure. This indicates the start of the degradation of the photopolymer material as a result of longer exposures to the UV-ozone treatment.

The UV-ozone treatment of the printing plates resulted in changes of the width of the fine lines on test prints, roughness of the printed layer, surface coverage of the halftones, and ink volume on test prints. Width of the fine lines decreased after the UV-ozone treatment, which was caused by the increased mechanical stability of the printing elements. This improvement resulted in lower dot gain on the halftones. Roughness of the printed layer displayed the lowest values for prints obtained by the printing plates treated by UV-ozone for a period of 1–2 minutes.

Due to the improved wetting on the printing plate, a thinner layer of the printing ink is transferred to the printing substrate, resulting in decreased ink volume in the halftone area after the prolonged UV-ozone treatment.

This research has proven that the surface treatment of flexographic printing plate, specifically UV-ozone treatment, affects significantly the properties and quality of the print and can be used to purposefully modify the properties of the printing elements, resulting in the improved quality of the specific print, whether conventional or functional.

With each new technology for printing plate production on the market, some qualitative properties of the flexographic prints increase providing new opportunities for the application of flexography in the printing industry. This research targeted some possibilities for further improvement of high-quality flexographic products in existing systems, with the aim of expanding the further potential for application of flexography, specifically in functional printing.

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