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Influence of Some Flexographic Printing Process Conditions on the Optical Density and Tonal Value Increase of Overprinted Plastic Films

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Abstract: The print quality of prints performed with flexographic printing technology is influenced by various parameters such as viscosity of the printing inks, printing substrates, plates, anilox rolls, etc. The aim of this work is to analyze the influence of ink viscosity, printing plate and printing base on selected properties of print quality, such as optical density of full tone area and the increase of tonal value (TVI). Additionally, the printed dots on 5, 15, 30, 50 and 75% of half tone area were investigated using digital microscopy. The least square fitting method in a matrix form was successfully used in order to confirm the influence of printing process parameters on print quality. The results obtained reveal the significant influence of the printing plate and printing substrate characteristics and the lesser influence of printing ink viscosity for 40–100% coverage area. The values of the optical densities of full tone areas are mainly influenced by the properties of the printing plate and the printing base. Furthermore, the optical density decreases when the value of flow time decreases, which is related to the lower thickness of dried ink film. The TVI on light tones (0 to 20%) is mainly influenced by the ink viscosity.

Keywords: printing ink viscosity; print quality; optical density; tonal value increase

1. Introduction

Flexographic printing is a fundamental, well-established roll-to-roll printing technique used for printing products such as flexible packaging, multiwall bags, labels, corrugated packaging and even printed electronics, printing with ZnO inks and as well as gas and biosensors [1–10]. Nowadays, more than 75% of packaging products are printed with this technique [6]. In flexography, the following printing substrates may be used: paper, corrugated cardboard, and nonabsorbent materials such as plastic and biodegradable films and aluminum foils. This technology requires, in most cases, flexible, raised-image printing plates (rubber or photopolymer) and low-viscosity and rapid-drying fluid inks [11]. The printing ink is firstly transferred from the reservoir to an anilox roller where a large number of finely engraved cells are filled with printing ink. Next, the ink is transferred from the anilox roller onto a photopolymer printing plate, placed on a plate cylinder. In this stage, the printing ink is subjected to both shear and extensional stresses [7,12]. Then, the plate comes into contact with the printing substrate on the impression cylinder to complete the printing process. Finally, the printed image is consolidated by the drying of the ink.

Flexographic printing technology requires low-viscosity ink, which allows regular ink flow into the printing unit. There are three types of flexographic printing inks: solvent-based, water-based and

UV-curable inks. Printing plates, nowadays, predominantly use photopolymers. The printing inks typically contain a considerable amount of polymer resin that binds particles of dyes or pigments and eventually creates a film of printing ink, which is seen by the human eye as a printed image. These various types of particles lead to the exhibition of viscoelastic and non-Newtonian characteristics of printing inks [13].

The printed products are characterized by the print quality. In general, the assessment of print quality is a complex process which may be conducted through defining the optical properties of a print, i.e., gloss, color, thickness of dried ink film, tonal value increase (or dot gain), etc. [14,15]. Prior to optical parameter measurements, print quality is checked visually according to ISO standard [16], where minimum requirements of visual quality control and viewing conditions are specified. One of the fundamental print quality parameters is tonal value increase, which enables tone definition and color reproduction and additionally influences the image depth of field [17]. The tonal value increase is one of the most important measured values. It allows control of the printing process and is directly related to the quality of the printed image [18].

The quality of the print is greatly determined by the preparatory work in the prepress and printing processes. The type of printing machine, the pressure between cylinders in the printing unit, used materials—inks and printing substrate—and type and quality of the plate influence the final quality of print. Furthermore, properties of the anilox roller, type of mounting tape placed under the printing plate to adjust its deformation and control of the printing process [19–22] may have an impact on the quality. Moreover, the interactions between printing ink and printing substrate are influenced by properties of the printing ink, such as viscosity, surface tension and wettability. Additionally, uneven absorption and distribution of ink components are primary causes for defects such as unevenness and mottle [23] which may be observed by the customer as poor print quality.

Rheological properties of inks play a significant role in the printing process [24,25]. Hence, the viscosity, together with the flow behavior, has a major influence on the flow of the ink in the printing unit. During printing, the volatile solvents evaporate, causing a change in the viscosity and color of ink. Too low viscosity of the printing ink results in prints which are characterized by insufficient color intensity and inadequate optical density [26]. Moreover, the printing ink may flow from the printed image on the substrate, additionally may flood areas, and as a consequence raster circles may arise around the printed element. On the other hand, if the printing ink exhibits viscosity that is too high, the dried printing ink shows poor adhesion to the base.

The problem of the influence of ink viscosity of flexographic printing inks was studied previously in several works, i.e., [25,27,28]. Gu et al., has shown the influence of various parameters such as pH and temperature of the ink on ink viscosity and hence on the size of the printed dot [24]. When the ink viscosity is too high, the ink transfer is poor in the printing unit; when the ink viscosity is to low [24], the printing dots are bigger which is related to flooding of the ink. Furthermore, Gencoglu has investigated the influence of water-based and solvent-based ink viscosity on dot area on overprinted coated and uncoated papers and has shown that the same dot area was obtained when using a solvent-based or water-based flexography printing ink characterized by 17 s ink flow [27]. Wang et al., has presented the influence of viscosity in chitosan-based flexographic printing inks on the print quality of overprinted papers [28] and it was presented, that the molecular mass of chitosan affects the viscosity and print quality of an overprinted paper base. However, in this work, printing was performed using a laboratory printing machine, primarily IGT F1.

On the other hand, some researchers have investigated the influence of printing conditions on print quality. For instant, Tomašegović et al., analyzed the influence of printing base and printing plate on the TVI and optical density of prints [29]. Next, Olsson et al., observed the effect of surface polarity of the printing base on final dot gain [30]. Poljaček et al., deeply analyzed the properties of printing plates and the final impact on the print quality of the obtained prints [19,31].

In this paper, we narrow the analyses to the influence of the most relevant parameters for the printing process: changes in the optical density of the solid tone area and tonal value increase. In this regard, we have emphasized the impact of ink viscosity on selected properties of prints. In order to determine TVI, densitometric measurements of half-tone patches in the range between 2 and 100% were performed. The printing process was performed in industrial conditions using two different types of printing plates and two different printing substrates (plastic films). The printing was carried out with CMYK flexographic, solvent-based printing inks, characterized by different flow times (15, 25 and 35 s). It should be highlighted, that printing was performed in industrial conditions, not in the laboratory. The printing process parameters, such as speed, pressure, etc., were constant. Furthermore, we have performed microscopic analysis of the half-tone areas. Finally, we have used the least square fitting method in a matrix form in order to confirm our observations.

2. Materials and Methods

2.1. Materials

As printing inks, CMYK (color Cyan, Magenta, Yellow and Black) process solvent printing inks Solvaplast (Sun Chemicals) were used. These inks are used for printing flexible food packaging. The inks were characterized by maximum pigmentation (80%) according to the standards used in the Amerplast printing house. Furthermore, according to the supplier the best results are achieved at viscosities 16–25 s (according to cup with 4 mm outlet diameter [32]). The printing inks exhibited flow viscosity of 15, 25 and 35 s specified by the flow time in a flow cup (volume 100 mL, outlet diameter 4 mm). The measurements were performed at 23 ± 0.5 °C according to the ISO standard [32]. The relative error of measurement was less than 3%.

Two different photopolymer printing plates were used: DuPont Cyrel Fast DFR 45 and Kodak Flexcell NX with DigiCup structure. The properties of the printing plates are listed in Table 1. For the mounting of both plates, the same mounting tape was used. It was chosen according to its tack and cushion properties for the job being printed, in order to optimally correspond to both plates and both printing substrates as well.

Table 1. Properties of printing plates.

Property	DuPont Cyrel Fast DFR	Kodak Flexcell DigiCup NX
Thickness	1.14 mm (0.045 inch)	1.14 mm (0.045 inch)
Hardness	78–80 Sh A	71–77 Sh A
Linear reproduction	1–99% 54 L/cm	1–99% 60 L/cm
Minimum positive line	0.100 mm (4 mil)	0.020 mm (0.8 mil)
Minimum point size	300 µm	50 µm
Relief depth	0.55 mm (0.022 inch)	0.7 mm (0.03125 inch)

As a printing base, two white opaque plastic films were used: BoPP (35 µm thickness) and LDPE (40 µm thickness). The surface free energies of the BoPP and PE plastic films are 40 and 42 mJ·m^2, respectively, according to the ISO standard [33].

2.2. Ink Rheology Measurements

The rheological behavior of inks was studied using a Rheolab QC rotational rheometer (Anton Paar, Austria) with concentric cylinder geometry (CC39). The shear stress was measured while the controlled applied shear rate increased from 0 to 1000 s^{-1}. The standard volume (60 mL) of the sample was placed in a measuring cup. The measurements were repeated twice with new sampling at 23 ± 0.5 °C.

2.3. Printing

The printing was performed using an 8-color flexo printing machine Flexpress 6S-8 (Fischer & Krecke, Bielefeld, Germany) equipped with GTT laser engraved anilox rolls with patented Open Slalom Ink Channel geometry. The printing was performed with a constant printing speed of 300 m/min, and the plastic film web tension was 50 and 60 N for BOPP and PE, respectively. The drying temperature was 50 and 60 °C for BOPP and PE, respectively. The printing conditions were kept constant, regardless of the printing plate used or the viscosity of printing inks. The tests were carried out in very short periods of printing time—the printing machine was working about 1 min in each of the printed options.

A series of half-tone patches in increasing order (1, 2, . . . , 9, 10, 15, 20, 25, . . . , 95, 97, 98, 100%), as presented in Figure 1, was used in order to monitor reproducibility of the prints in ink coverage values, i.e., for the measurement of optical densities and the increase of tonal value. Additionally, it was also used for microscopic analysis.

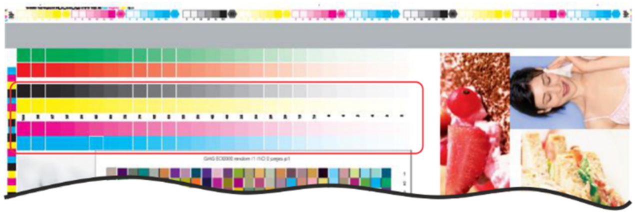

Figure 1. Printed test chart. The area used for the performed analysis is highlighted with a red rectangle.

2.4. Print Quality Measurements

The optical density (OD) and tonal value increase (TVI) were measured using X-Rite SpectroEye with the following settings: D50 illuminant using a 2° observer, DIN density standard and without polarization filter. Data collection was performed at six different positions on the samples, and the reported values are the average of these measurements.

The TPL digital microscope with 2 MPIX with 1/4″ CMOS sensor was used in order to generate microscopic images of the reproduction of the half-tone areas used for the visual assessments. The microscope is equipped with a physical matrix resolution of 1.3 million pixels. Microscopic images of the areas of interest were captured from both the plates and prints: 5, 15, 30, 50 and 75% of half-tone area.

2.5. Least Square (LS) Fitting

The collected results were used to build a matrix for the least square (LS) fitting model according to [34]. The input parameters were: type of printing plate, type of printing substrate and the flow time of the printing ink. The outlet parameters were: optical density of solid tone area and tonal value increase of 5, 40 and 80% of nominal coverage value.

3. Results and Discussion

3.1. Ink Rheology

Prior to industrial printing, the rheology, kinematic viscosity (flow time) and flow curve, of investigated CMYK printing inks were determined. The flexographic technique requires low-viscosity printing inks (viscosity in the range of 0.05−0.5 Pa·s) characterized by flow time in the range 18–35 s (outlet diameter of 4 mm) [35], thus we have chosen the following values of flow times: 15, 25 and 35 s as a viscosity below the required range, viscosity in the middle of the range and maximum value of viscosity, respectively. However, the highest values of flow time did not allow printing using the industrial machine. This tendency was observed for cyan printing ink. The flexographic printing inks are shear-thinning or pseudoplastic materials. Thus, the viscosity of the investigated inks decreased when the shear rate increased. The flow curves of the investigated magenta printing ink are shown on Figure 2 and Figure S1. The flow curves were fitted by the Ostwald–de Waele model, according to Equation (1) [36]:

$$\tau = c \cdot \gamma^{p}, \tag{1}$$

where c is a consistency coefficient, and the exponent p is a power-law index which characterizes the flow behavior: $p < 1$ for shear-thinning flow behavior; $p > 1$ for shear-thickening flow behavior and $p = 1$ for ideal viscous (Newtonian) flow behavior. The parameters c and p along with R-squared values of the fitting for the investigated printing inks are listed in Table 2; the flow curves of printing inks are shown on Figure 2. According to the Ostwald–de Waele model, the value of the exponent p was less than 1, so the investigated printing inks exhibited pseudoplastic flow behavior, as expected. However, the values of the exponent p decreased with the increasing viscosity of printing ink (flow time of printing ink).

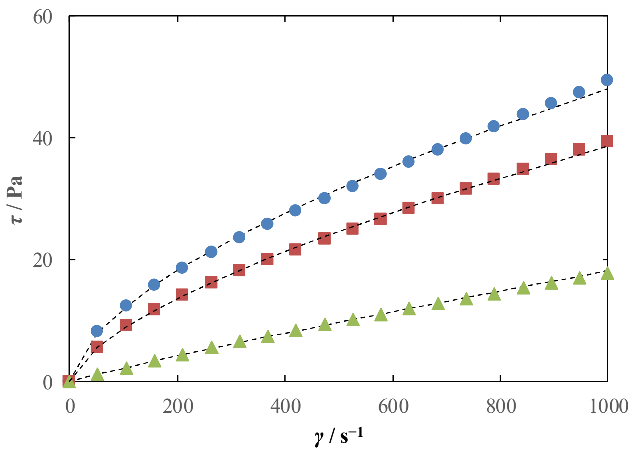

Figure 2. Shear stress (τ) versus shear rate (γ) dependencies measured for magenta printing ink characterized by various flow times 15 (green triangles), 25 (brown squares) and 35 s (blue dots). All experimental points are fitted by the Ostwald model.

Table 2. Ostwald–de Waele model parameters along with R-squared values of the fitting calculated for the flow curves of investigated printing inks.

Flow Time	c	p	R^2
Cyan			
15	0.17 ± 0.03	1.03 ± 0.01	0.999
25	0.03 ± 0.01	0.87 ± 0.01	0.999
Magenta			
15	0.04 ± 0.03	0.90 ± 0.01	0.999
25	0.45 ± 0.00	0.65 ± 0.02	0.999
35	0.75 ± 0.00	0.60 ± 0.03	0.999
Yellow			
15	0.03 ± 0.04	0.85 ± 0.02	0.988
25	0.14 ± 0.03	0.83 ± 0.01	0.999
35	0.28 ± 0.02	0.80 ± 0.00	0.999
Black			
15	0.06 ± 0.03	0.83 ± 0.00	0.999
25	0.59 ± 0.02	0.67 ± 0.00	0.999
35	0.85 ± 0.03	0.64 ± 0.02	0.999

3.2. Optical Density of Solid Tone Area

The printing was performed in industrial conditions. All factors were kept constant during printing: printing plate pressure, hardness of mounting tapes, anilox rolls, solvents used for diluting printing inks, pressure of the rouge chamber to the anilox roll or corona refreshing during the printing process, etc. The changing parameters were: type of printing plate, type of printing substrate and changes of ink viscosity.

The values of the optical densities (OD) of the solid tone areas are summarized in Table 3. The changes of values of the OD for magenta printing ink are shown in Figure 3. The values of optical densities of solid tone areas were mainly influenced by the properties of the printing plate and the printing base. It can be noticed the optical density for samples with the Kodak printing plate were higher regardless of the flow time of the printing ink and the printing base. The microstructure of the printing elements affected the ability of the plate to pick up and transfer more printing ink from the plate onto the printing base. The optical density was higher on PE plastic base than on BoPP. This may be related to the higher values of surface free energy (42 mJ/m^2) and greater wettability of the printing base by printing ink. Printing inks with high viscosities are more difficult to pull out of the cells of the anilox roll. On the other hand, low viscosity of the printing ink increases the amount transferred to the printing plates. However, lower viscosity of the ink is usually associated with higher solvent content. Hence, the optical density decreases when the value of flow time decreases, which is related to the lower thickness of dried ink film.

Table 3. Optical density of the solid tone area.

Plate:	**Fast**		**Kodak**	
Printing Base:	**BoPP**	**PE**	**BoPP**	**PE**
		Cyan		
25	1.29 ± 0.02	1.32 ± 0.05	1.65 ± 0.02	1.71 ± 0.03
15	1.20 ± 0.02	1.24 ± 0.01	1.53 ± 0.01	1.55 ± 0.02
		Magenta		
35	1.14 ± 0.02	1.21 ± 0.03	1.55 ± 0.02	1.60 ± 0.01
25	1.11 ± 0.02	1.15 ± 0.01	1.49 ± 0.02	1.57 ± 0.02
15	1.05 ± 0.01	1.12 ± 0.01	1.36 ± 0.01	1.35 ± 0.01
		Yellow		
35	1.18 ± 0.02	1.56 ± 0.01	1.56 ± 0.01	1.66 ± 0.03
25	1.18 ± 0.02	1.57 ± 0.01	1.57 ± 0.01	1.63 ± 0.01
15	1.06 ± 0.01	1.35 ± 0.01	1.35 ± 0.01	1.33 ± 0.01
		Black		
35	1.01 ± 0.03	1.02 ± 0.02	1.20 ± 0.02	1.25 ± 0.05
25	1.05 ± 0.02	1.00 ± 0.02	1.24 ± 0.01	1.37 ± 0.10
15	0.98 ± 0.01	0.92 ± 0.01	1.21 ± 0.02	1.16 ± 0.02

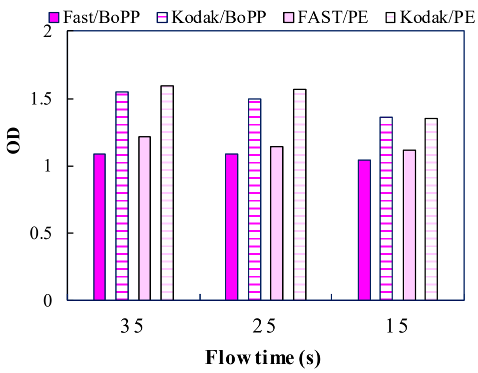

Figure 3. Optical density (OD) of the solid tone area as a function of printing ink flow time for magenta printing ink.

3.3. Tonal Value Increase

The TV of investigated inks exhibited similar values regardless of the color of the printing ink. None of the experimental curves show significant increase of tonal value. As an example, results of the reference and measured tone values for magenta printing ink are presented in Figure 4. No great differences of TV were observed for different ink flow viscosities. It can be concluded that the tonal value is dependent on the properties of the printing substrate and the type of printing plate and independent of, or only slightly dependent on, ink viscosity.

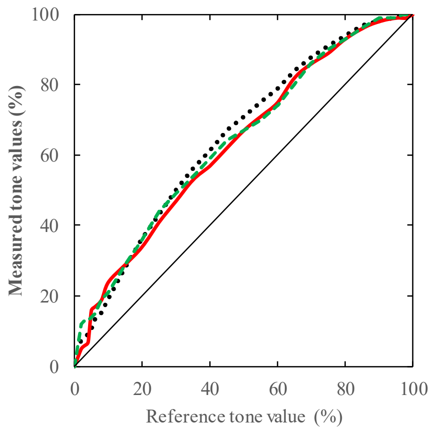

Figure 4. Dependency between the reference and measured tone values for magenta printing ink (BoPP printing base, FAST plate). Black dotted line: 35 s flow time; red solid line: 25 s flow time; green dashed line: 15 s flow time.

Generally, tonal value increase is positive due to the applied printing pressures [11]. Figure 5 shows the correlation between the reference tone value and the increase of tone value (TVI) for 35, 25 and 15 s magenta printed on BoPP using two different plates. Figures S2–S8 shows the correlation between the reference tone value and TVI for others investigated inks. The TVI for other investigated printing inks are presented in Supplementary Materials. The results of TVI for investigated inks were compared with the values of TVI according to the ISO standard (dashed line) [37]. For the FAST plate, the highest TVI values were recorded with 35 s flow time printing ink (black line), and the values of TVI were higher than the reference ISO TVI values (dashed blue line). On the other hand, TVI values for 25 and 15 s flow time of printing ink were higher in the range of 0–40% tone and lower or similar in the range 40–100% tone area. For the Kodak plate (see Figure 4), the TVI reproduction curve for the 35 s flow time of the printing ink almost matched the reference ISO TVI values. Additionally, the values of TVI for 25 and 15 s flow time of printing ink were higher than ISO TVI values. This was the opposite of what was observed for the FAST plate.

The analyses of microscopic images (see Figures 6 and 7, and Figures S9–S16 in Supplementary Materials) of prints reveal that they, in terms of light tones (0 to 20%), were improperly overprinted, particularly for the inks of 25 and 35 s of flow time. Not all dots were overprinted equally; microscopic observation reveals large irregularity in the appearance and shape of the dots. However, this effect was not observed for all half-tone dots and caused deviations in the TVI reproduction curve in the range of 0–10% (see Figure 5). It is interesting that, for the low-viscosity printing inks, 25 and 15 s flow time, in the range of 40–60% tone area using FAST plate, the TVI reproduction curve exhibited lower values than the ISO TVI values. The analysis of microscopic images of the 50% tone area for investigated prints overprinted with magenta ink may clarify this effect (see Figures 6 and 7). The shape of dots obtained using the FAST plate was round, but on the other hand the shape of dots obtained by Kodak plates was square. Furthermore, it can be seen that the lower viscosity of printing ink caused "flooding" of dots.

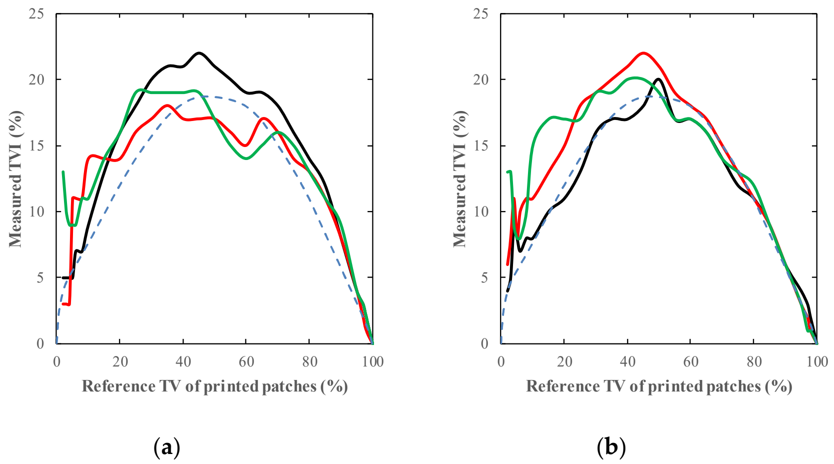

Figure 5. Measured TVI of the samples for overprinted BoPP with magenta printing ink using (**a**) FAST plate and (**b**) Kodak plate. Black line: 35 s flow time; red line: 25 s flow time; green line: 15 s flow time; dashed line: ISO TVI [37].

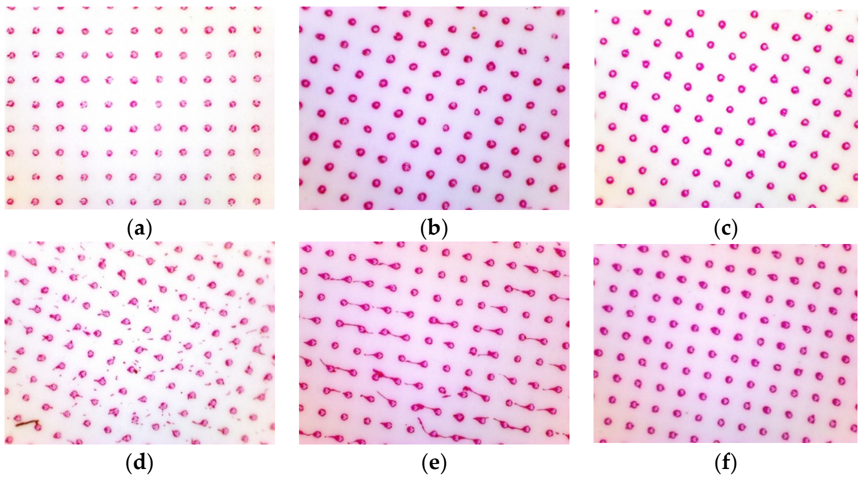

Figure 6. Microscopic images of 5% tone area for overprinted BoPP film with magenta printing ink for (**a**) FAST plate, 35 s flow time; (**b**) FAST plate, 25 s flow time; (**c**) FAST plate, 15 s flow time; (**d**) Kodak plate, 35 s flow time; (**e**) Kodak plate, 25 s flow time, (**f**) Kodak plate, 15 s flow time.

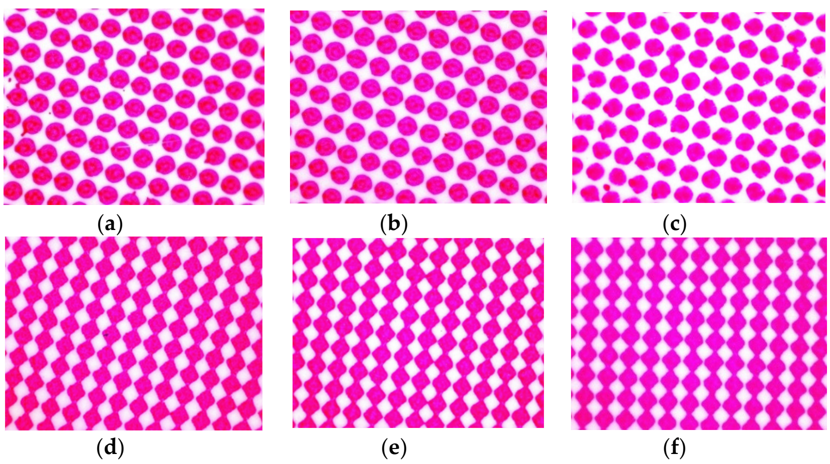

Figure 7. Microscopic images of 50% tone area for overprinted BoPP film with magenta printing ink for (**a**) FAST plate, 35 s flow time; (**b**) FAST plate, 25 s flow time; (**c**) FAST plate, 15 s flow time; (**d**) Kodak plate, 35 s flow time; (**e**) Kodak plate, 25 s flow time, (**f**) Kodak plate, 15 s flow time.

In order to confirm the observation regarding of the influence of printing plate on the OD and TVI, the least square analysis was performed. Influential parameters in the flexographic reproduction system can be quantified using the LS fitting method in matrix form [29]. This method was used in order to assign the weight coefficients of the printing process that affect the selected print quality parameters of prints—optical value and tonal values (80, 40, 5% half-tone).

Figure 8 shows the weight coefficients for the chosen parameters (printing base or printing plate) of the printing process and ink flow that influence the print quality of the prints. The influence of selected parameters may have a positive or negative sign, representing the proportional or inversely proportional connection, respectively [29]. Furthermore, a higher value of weight coefficient is related to a bigger influence of the corresponding parameter.

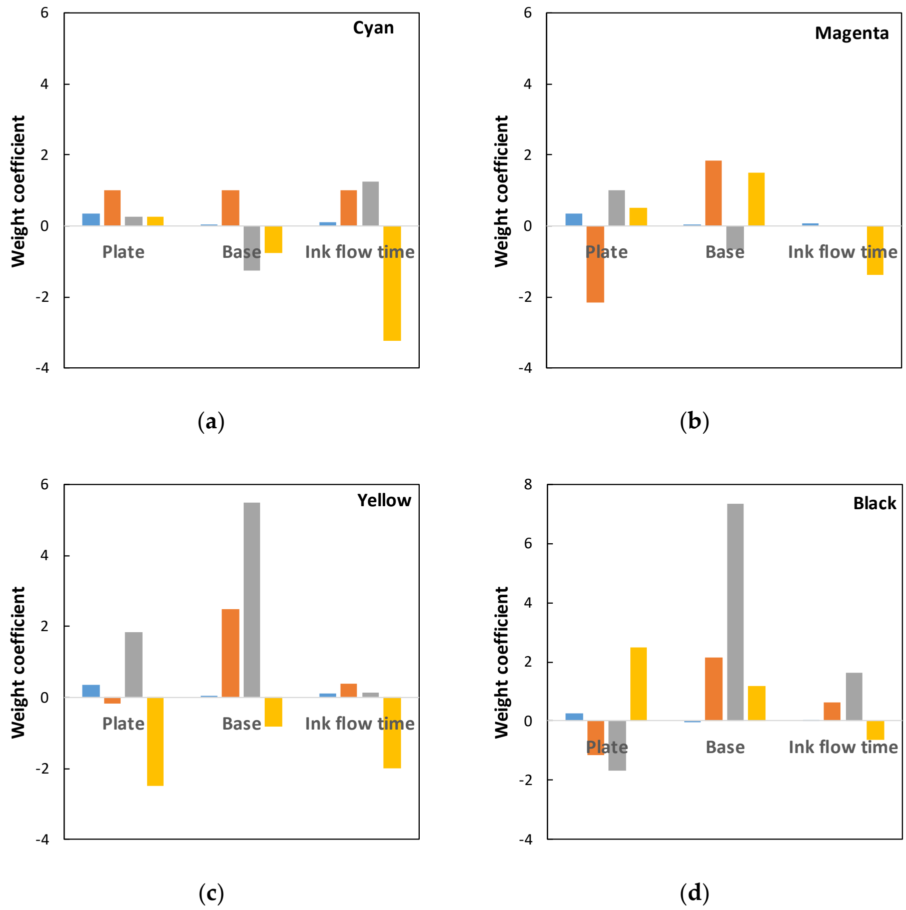

Figure 8. Weight coefficients of influential parameters for (**a**) cyan, (**b**) magenta, (**c**) yellow, (**d**) black printing inks. Color blue: 100%; color orange: 80%; grey 40% and light orange 5% measured tonal value.

The obtained results of the weight coefficients pointed to the dominant impact of the plate and base type on the analyzed properties of the print (optical density of solid tone area and TVI). The ink flow time generally had a negligible effect on the properties of print quality, except cyan printing ink, otherwise the effects of the three parameters were comparable.

The viscosity of the ink had the lowest influence on the quality of the print, which confirmed our observations. In this regard, the print quality depended mainly on the plate and the printing substrate being used. However, for the tone area in the range 40–100%, the impact of printing plate and substrate was higher. On the other hand, for the light tones, in the coverage of 5%, the influence of ink viscosity was greater—this may be related to the flooding of the ink from the overprinted dots prior to drying of the ink.

4. Conclusions

In this paper, we have analyzed the influence of selected printing conditions on the print quality of a printed plastic substrate. The objective of the present work was to analyze the influence of the printing ink viscosity, printing plate and printing substrate on the quality of the print expressed through optical density and TVI changes.

Our results reveal that the viscosity of the printing ink exhibited a lower influence on optical density of solid tone area and tonal value increase than that exhibited by the type of printing base and printing plate. However, based on our results, it can be concluded that higher viscosity of printing inks is related to higher optical density of solid tone. The optical density decreases when the value of viscosity decreases. Additionally, for the 15% tonal value area smaller tonal increase was observed. Further, we have successfully quantified the influence of these parameters using the least square fitting method. The results presented in this work, reveal that print quality is mainly influenced by the type of printing plate and the printing base used, so the interaction between the plate and the base is one of the most important factors. Hence, the optimization of the process should be in terms of the printing plate or base used and not of the printing ink. Furthermore, this research has underlined the importance of choice of printing plate and printing base in order to achieve satisfactory tonal value increase or optical density.

Supplementary Materials: The following are available online at http://www.mdpi.com/2079-6412/10/9/816/s1: Figure S1: Shear stress (τ) versus shear rate (γ) dependencies measured for (a) cyan, (b) yellow and (c) black printing ink characterized by various flow times 15 s (green dots), 25 s (brown dots) and 35 s (blue dots) All experimental points are fitted by the Ostwald model. Figure S2: Measured TVI of the samples for overprinted BoPP with cyan printing ink using (a) FAST and (b) Kodak plate. Red line: 25 s flow time; green line: 15 s flow time; dashed line: ISO TVI (ISO 12647-6). Figure S3: Measured TVI of the samples for overprinted PE with cyan printing ink using (a) FAST plate and (b) Kodak plate. Red line: 25 s flow time; green line: 15 s flow time; dashed line: ISO TVI (ISO 12647-6). Figure S4: Measured TVI of the samples for overprinted PE with magenta printing ink using (a) FAST plate and (b) Kodak plate. Black line: 35 s flow time; red line: 25 s flow time; green line: 15 s flow time; dashed line: ISO TVI (ISO 12647-6). Figure S5: Measured TVI of the samples for overprinted BoPP with yellow printing ink using (a) FAST plate and (b) Kodak plate. Black line: 35 s flow time; red line: 25 s flow time; green line: 15 s flow time; dashed line: ISO TVI (ISO 12647-6). Figure S6: Measured TVI of the samples for overprinted PE with yellow printing ink using (a) FAST plate and (b) Kodak plate. Black line: 35 s flow time; red line: 25 s flow time; green line: 15 s flow time; dashed line: ISO TVI (ISO 12647-6). Figure S7: Measured TVI of the samples for overprinted BoPP with black printing ink using (a) FAST plate and (b) Kodak plate. Black line: 35 s flow time; red line: 25 s flow time; green line: 15 s flow time; dashed line: ISO TVI (ISO 12647-6). Figure S8: Measured TVI of the samples for overprinted PE with black printing ink using (a) FAST plate and (b) Kodak plate. Black line: 35 s flow time; red line: 25 s flow time; green line: 15 s flow time; dashed line: ISO TVI (ISO 12647-6). Figure S9: Microscopic images of 15% tone area for overprinted BoPP film with magenta printing ink for (a) FAST plate, 35 s flow time; (b) FAST plate, 25 s flow time; (c) FAST plate, 15 s flow time; (d) Kodak plate, 35 s flow time; (e) Kodak plate, 25 s flow time, (f) Kodak plate, 15 s flow time. Figure S10: Microscopic images of 30% tone area for overprinted BoPP film with magenta printing ink for (a) FAST plate, 35 s flow time; (b) FAST plate, 25 s flow time; (c) FAST plate, 15 s flow time; (d) Kodak plate, 35 s flow time; (e) Kodak plate, 25 s flow time, (f) Kodak plate, 15 s flow time. Figure S11: Microscopic images of 75% tone area for overprinted BoPP film with magenta printing ink for (a) FAST plate, 35 s flow time; (b) FAST plate, 25 s flow time; (c) FAST plate, 15 s flow time; (d) Kodak plate, 35 s flow time; (e) Kodak plate, 25 s flow time, (f) Kodak plate, 15 s flow time. Figure S12: Microscopic images of 5% tone area for overprinted PE film with magenta printing ink for (a) FAST plate, 35 s flow time; (b) FAST plate, 25 s flow time; (c) FAST plate, 15 s flow time; (d) Kodak plate, 35 s flow time; (e) Kodak plate, 25 s flow time, (f) Kodak plate, 15 s flow time. Figure S13: Microscopic images of 15% tone area for overprinted PE film with magenta printing ink for (a) FAST plate, 35 s flow time; (b) FAST plate, 25 s flow time; (c) FAST plate, 15 s flow time; (d) Kodak plate, 35 s flow time; (e) Kodak plate, 25 s flow time, (f) Kodak plate, 15 s flow time. Figure S14: Microscopic images of 30% tone area for overprinted PE film with magenta printing ink for (a) FAST plate, 35 s flow time; (b) FAST plate, 25 s flow time; (c) FAST plate, 15 s flow time; (d) Kodak plate, 35 s flow time; (e) Kodak plate, 25 s flow time, (f) Kodak plate, 15 s flow time. Figure S15: Microscopic images of 50% tone area for overprinted PE film with magenta printing ink for (a) FAST plate, 35 s flow time; (b) FAST plate, 25 s flow time; (c) FAST plate, 15 s flow time; (d) Kodak plate, 35 s flow time; (e) Kodak plate, 25 s flow time, (f) Kodak plate, 15 s flow time. Figure S16: Microscopic images of 75% tone area for overprinted PE film with magenta printing ink for (a) FAST plate, 35 s flow time; (b) FAST plate, 25 s flow time; (c) FAST plate, 15 s flow time; (d) Kodak plate, 35 s flow time; (e) Kodak plate, 25 s flow time, (f) Kodak plate, 15 s flow time.

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