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THE INFLUENCE OF VARIABLE PARAMETERS OF FLEXOGRAPHIC PRINTING ON DOT GEOMETRY OF PRE-PRINTED PRINTING SUBSTRATE

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Original scientific paper
Flexography is widely used in the packaging industry because of its ability of print on various printing substrates and because of the use of digital platemaking technologies. However, there are some limits in the reproduction of smooth gradients which create the effect of sudden transition tones in the highlight area. Therefore, this research compares the parameters of print quality influenced by the dot geometry focusing on top dots shape, line rulings and printing pressures. The objective was to study how the various platemaking processes affect the dot geometry on the basis of influence of the most important variable parameters of flexographic printing. A test image was created and then printed with cyan UV ink on aluminium foil on the pre-printed opaque white ink. Based on the obtained research results, the guidelines and print conditions will be given about how to apply the studied influential parameters for better tone reproduction on aluminium foil that will result in a positive impact on the environmental sustainability of flexographic printing.

Keywords: *dot geometry, flexographic printing, print quality, top dots shape*

Utjecaj promjenjivih parametara fleksotiska na geometriju rasterskog elementa predotisnute tiskovne podloge

Izvorni znanstveni članak
Fleksografija se naširoko koristi u industriji ambalaže zbog sposobnosti tiska na različite tiskovne materijale te zbog primjene digitalnih tehnologija za izradu fleksotiskarskih ploča. Međutim postoje određena ograničenja u reprodukciji glatkih prijelaza koja stvaraju efekt naglog prijelaza tonova u svijetlim područjima. Stoga ovo istraživanje uspoređuje parametre kvalitete tiska utjecajem geometrije rasterskog elementa usredotočujući se na oblik vrha rasterskih elemenata, linijaturu i pritisak prilikom tiska. Cilj je bio proučiti kako različiti procesi izrade fotopolimerne ploče utječu na geometriju rasterskog elementa na osnovu utjecaja najvažnijih varijabilnih parametara fleksotiska. Kreirana je testna forma te potom otisnuta pomoću cijan UV bojila na aluminijsku foliju na predotisnutu pokrivnu bijelu boju. Na osnovu dobivenih rezultata definirat će se smjernice i uvjeti tiska o tome kako primijeniti istraživane utjecajne parametre za bolju reprodukciju tonova na aluminijskoj foliji koja će za posljedicu imati i pozitivan utjecaj na ekološku održivost kod fleksotiska.

Ključne riječi: *fleksotisak, kvaliteta tiska, geometrija rasterskog elementa, oblik vrha rasterskog elementa*

1 Introduction

Flexography is a high speed printing technology for various printing substrates mainly used in packaging industry [1]. By examining the process, a lot of variable parameters that affect the ink transfer can be noted [2]. A few years ago, it was not possible to print the full range of halftone with flexography. It was difficult to hold dots below 5 % and dot gain was often out of control [3]. Computer-to-plate technology with digital flexographic plate is dominant but the advanced digital platemaking method is developed. This advanced digital technology is relatively new to flexography and has room for further development.

One of the main differences between a dot made with standard digital technology and the dot made with new digital technology is the shape of top dots [4]. The oxygen effect during exposure of digital flexo plates is the main reason for top dot shapes. In most light sensitive photopolymers, oxygen can serve to stop the polymerization when light is present. Free radicals within the photopolymer will react with the oxygen in the system and stop polymerization within the material [5].

Fig. 1 shows the effect of advanced digital main exposure with thermal film and UV-A tubes and standard digital main exposure with LAMS-layer and UV-A tubes on the dot shape.

The lamination stage of advanced digital platemaking technology is critical because it removes all oxygen between the layer and the plate allowing the creation of high quality and consistent full-amplitude tones [4]. By comparing the dots of plates made with standard and advanced platemaking method, this study will determine which system can produce a more detailed image especially in highlight tones and increase the quality of printing.

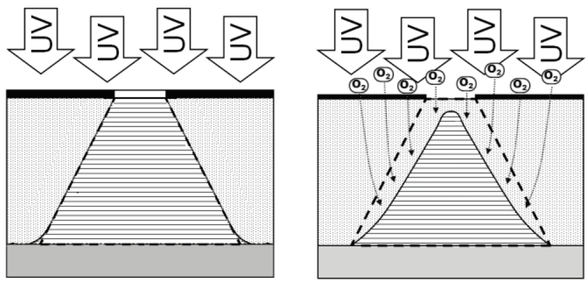

Figure 1 Two types of top dots shape

A pressure setting is critical in the flexographic process to promote good dots, prevent halo and control dot gain. The substrate passes between plate and impression cylinder and the gap, or nip, between these must be optimal to give the proper printing pressure [6]. The lightest pressure or "kiss impression" is ideal for printing. Kiss impression is clean print image created while applying the least amount of pressure possible (approx. 0,004 inch/0,1016 mm of nip engagement) against the paper with the plate [7]. However, if pressure is too low, some details in the highlight areas might not be transferred onto the substrate. A higher impression might produce smudged ink around the edges of the printed areas. On the other hand, if pressure is too high, dots would be squeezed more and could be deformed. The halftone dot extrudes the ink outwards resulting in higher dot gain [8]. The research of pressure on OPP substrate showed that printing plate to impression cylinder pressure has the greatest effect on tonal reproduction with the significant increase of density [9, 10].

2 Experimental methodology

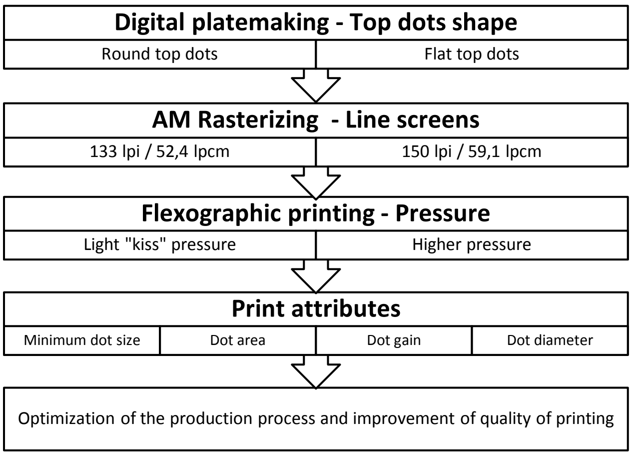

Figure 2 Research framework

The following section describes the effect of process variables on tonal reproduction in order to quantify the print quality. There are many variables that may be analysed, but it was decided to focus on top dots shape, line ruling and printing pressure. There are three locations on a press ink unit where it is possible to change pressure but this investigation was focused on pressure between printing plate and impression cylinder. The main question is how these variables will affect the printed result. The research framework to describe the purpose and process of the research is displayed in Fig. 2.

The first objective was to study how the various platemaking processes affect dot geometry including top dots shape and dot diameter. The second objective was to research the influence of three variables on the basic parameters of the print quality including minimum dot size, tonal range and tonal value increase. All parameters were analysed in three production stages (1-bit tiff, the printing plate and the print).

2.1 Test image

The test image which was used during the experiments is shown in Fig. 3. The test image consisted of a single colour control strips at two different line rulings (133 lpi and 150 lpi). The line rulings selected were chosen as common for foil substrate usually used for flexography. Each control strip consisted of halftone patches at specific coverage for flexography, minimum type and minimum line target in both positive and reverse prints. The conventional AM screening method with Euclidean dot shape and 37,5 degrees screen angle at resolution of 2540 dpi was used.

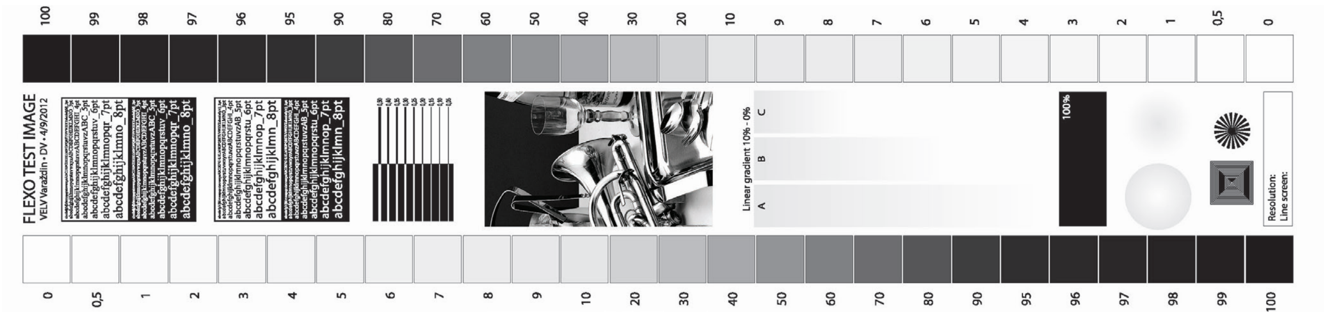

Figure 3 Single colour test image

2.2 Plate evaluation

There were two photopolymer plates of 1,14 mm thickness, 0,125 mm backing thickness used in the study. The first plate is a standard digital flexo plate with a laser ablative mask. Flint nyloflex ACE Digital plate (hardness acc. to DIN 53505, Shore A is 62) was used as a standard digital plate. After using the back exposure to create the floor of the plate it was directly imaged on Hell HelioFlex F1200 flexo CTP imagesetter. A laser ablated the carbon mask creating a negative image area (LAMS technology) and then the face side of plate was UV exposed [11].

The second plate was created by advanced digital flexographic system. Kodak Flexcel NX Digital Flexographic Plate (hardness acc. to DIN 53505, Shore A is 73) was created on the system of the same name. First, a thermal imaging film (thickness 0,165 mm) was imaged on the Trendsetter NX Imager and then laminated to the flexographic plate. After exposing the reverse and front side of plate, the film was removed.

In both processes, after main UV exposing, plates were processed with standard solvent process the same as an analogue photopolymer plate. A process ends with two final light exposures known as post-exposure.

The polymerization process starts when a flexo plate is UV exposed to the light source. Over-exposure of plates results in a larger dot than desired and poor print quality. The presence of oxygen in the exposure unit at standard digital technology eliminates the over-exposure of plates [5].

To quantify the physical dot area on the plate, the halftone patches at two line rulings and two types of photopolymer plates were measured. Every step of the halftone patches on both plates was captured as an image by using high resolution camera X-Rite vipFLEX2. Captured images were analysed by using PlateQuality Flexo software and all the important parameters including dot area, dot size and dot diameter were evaluated. All the parameters were calculated presenting the average value of all good dots on the entire captured imaged.

2.3 Press evaluation

Two finished plates (standard digital bumped and advanced digital linear) were mounted on the plate cylinder of the EDALE FL-350 6-colors commercial web flexographic printing press. The press was printing continuously at 60 m/min press speed. The substrate was an ALINVEST aluminium foil of 0,35 µm thickness with protective lacquer suitable for UV flexo printing commonly used for lids for yogurt cups. The aluminium foil was chosen for this study because it was a non-porous substrate and all ink transfer from the plate to the substrate remains on the surface, not in the substrate. In this way, it was ensured that the substrate porosity has no impact on designed experiment. Cyan UV ink was used during the experiment, as it traditionally provides good adhesion on films and has low odour content [9]. It was printed on-line on the pre-printed opaque white ink.

Ink was applied to the anilox roll via rubber ink-fountain roll. A 400 lpcm anilox roll with cell volume of 3,0 cm^3/m^2 was used for cyan and 280 lpcm anilox roll with cell volume of 4,5 cm^3/m^2 was used for opaque white. The target colorimetric CIELAB value for the solid cyan in accordance with ISO 12647-6:2006(E) for the printing substrate type four (film/foil) was used.

The print experiment was designed so that the pressure between printing plate and substrate was controlled, and other variables were held constant including press speed, sticky backing of the plate, anilox roll, substrate type and opacity of opaque white ink. Research of pressures showed that the percentage ink transfer from the plate increased with pressures increase [12] and when ink transfer reached a maximum, there was no further increase at higher pressures [7]. To achieve white opacity, anilox with higher volume and lower line screen was used.

Firstly, the correct colour of the solid cyan was achieved on the press and then the relative reflection density values were read with instrument from the OK print. The pressure settings were adjusted by measuring densities on solid patch. The target density of cyan ink was 1,20 ± 0,05 at kiss impression and 1,30 ± 0,05 at higher pressure settings. The tolerance between densities on both the operator side and the gear side may be ±0,05.

The physical dot area on the printing samples and other parameters of dot geometry were also measured using the same instrument to be quantified in the same manner as the plates were evaluated. This measuring method eliminates the optical dot area and the ink layer and gives a lower value than densitometry method whose calculation is based on the Murray-Davies equation [6]:

$$a = \frac{1-10^{-D_t}}{1-10^{-D_s}} \times 100, \quad (1)$$

where:
a – apparent dot area, %
D_t – density of tint – D_0
D_s – density of solid patch – D_0
D_0 – density of paper.

To determine the effect of line ruling and pressure in the press on printed dot gain, all combinations of two line rulings and two pressure settings were measured using densitometer X-Rite 520 with ISO status T response.

3 Results and discussion

The following section describes the results obtained by the measurement of the linear 1-bit TIFF at advanced technology and bumped 1-bit TIFF file at standard technology, measurement of the printing plate and of the printed samples, as shown in Tab. 1 to Tab. 4.

Table 1 Measurement at three production stage at round top dots at 133 lpi

RTD 2540 dpi/133 lpi		1-bit TIFF		Plate Flint ACE 1,14		Kiss pressure D_{cyan} = 1,20; D_{paper} = 0,34				Higher pressure D_{cyan} = 1,30; D_{paper} = 0,34			
Dot area / %	Dot diameter / µm	Dot area / %	Dot diameter / µm	Dot area / %	Dot diameter / µm	Relative density / –	Dot area / %	Dot diameter / µm	Dot gain / %	Relative density / –	Dot area / %	Dot diameter / µm	Dot gain / %
1	19,1	5,5	45	0,7	17	0,03	6,0	33	5,0	0,04	8,3	39	7,3
2	27,0	6,6	49	1,3	23	0,03	6,3	35	4,3	0,04	8,7	41	6,7
3	33,1	8,3	55	2,2	30	0,03	6,7	41	3,7	0,04	9,3	47	6,3
5	42,7	10,5	62	4,2	42	0,04	8,7	51	3,7	0,06	12,7	59	7,7
10	60,4	17	79	9,2	62	0,06	13,3	74	3,3	0,09	18,3	78	8,3
20	85,4	29,7	104	18,5	88	0,12	23,7	97	3,7	0,17	33,7	109	13,7
30	104,6	41,4	123	28,7	109	0,18	35,0	120	5,0	0,23	44,7	132	14,7
40	120,8	51,8	138	37,8	125	0,26	45,7	136	5,7	0,33	57,3	154	17,3

Table 2 Measurement at three production stage at round top dots at 150 lpi

RTD 2540 dpi/150 lpi		1-bit TIFF		Plate Flint ACE 1,14		Kiss pressure D_{cyan} = 1,20; D_{paper} = 0,34				Higher pressure D_{cyan} = 1,30; D_{paper} = 0,34			
Dot area / %	Dot diameter / µm	Dot area / %	Dot diameter / µm	Dot area / %	Dot diameter / µm	Relative density / –	Dot area / %	Dot diameter / µm	Dot gain / %	Relative density / –	Dot area / %	Dot diameter / µm	Dot gain / %
1	16,9	6,2	42	0,9	17	0,02	6,7	30	5,7	0,04	8,3	36	7,3
2	23,9	8,6	49	1,7	23	0,02	6,7	33	4,7	0,04	9,0	38	7,0
3	29,3	9,5	52	2,7	29	0,03	7,0	36	4,0	0,05	9,7	42	6,7
5	33,9	12,3	59	4,6	39	0,04	9,3	44	4,3	0,06	12,7	52	7,7
10	37,9	18,8	73	10	57	0,06	14,3	63	4,3	0,09	19,7	71	9,7
20	47,9	31,4	95	18,8	78	0,12	25,7	85	5,7	0,16	33,0	97	13,0
30	53,5	43,6	112	28,4	96	0,17	37,0	101	7,0	0,25	45,7	116	15,7
40	75,7	52,9	123	37,4	110	0,25	47,3	116	7,3	0,37	59,3	134	19,3

Table 3 Measurement at three production stage at flat top dots at 133 lpi

FTD 2400 dpi/133 lpi		1-bit TIFF		Plate Flexcel NX 1,14		Kiss pressure $D_{cyan} = 1,20$; $D_{paper} = 0,34$				Higher pressure $D_{cyan} = 1,30$; $D_{paper} = 0,34$			
Dot area / %	Dot diameter / µm	Dot area / %	Dot diameter / µm	Dot area / %	Dot diameter / µm	Relative density / –	Dot area / %	Dot diameter / µm	Dot gain / %	Relative density / –	Dot area / %	Dot diameter / µm	Dot gain / %
1,2	19,8	1,2	20	1,5	27	0,01	2,0	33	0,8	0,02	5,0	37	3,8
2	25,5	2	26	2,5	34	0,02	3,7	41	1,7	0,03	6,0	44	4,0
3	31,3	3	31	3,9	42	0,02	4,7	49	1,7	0,03	7,0	53	4,0
5	40,3	5	40	5,1	49	0,04	8,7	61	3,7	0,05	10,7	63	5,7
10	57,1	10	57	10,3	69	0,06	14,0	74	4,0	0,08	17,0	75	7,0
20	80,7	20	81	20,9	95	0,11	24,7	95	4,7	0,14	29,0	103	9,0
30	98,8	30	99	31,1	116	0,19	36,7	116	6,7	0,22	40,3	125	10,3
40	114,1	40	114	39,5	131	0,26	48,0	134	8,0	0,28	51,7	141	11,7

Table 4 Measurement at three production stage at flat top dots at 150 lpi

FTD 2400 dpi/150 lpi		1-bit TIFF		Plate Flexcel NX 1,14		Kiss pressure $D_{cyan} = 1,20$; $D_{paper} = 0,34$				Higher pressure $D_{cyan} = 1,30$; $D_{paper} = 0,34$			
Dot area / %	Dot diameter / µm	Dot area / %	Dot diameter / µm	Dot area / %	Dot diameter / µm	Relative density / –	Dot area / %	Dot diameter / µm	Dot gain / %	Relative density / –	Dot area / %	Dot diameter / µm	Dot gain / %
1,2	17,5	1,2	18	1,4	23	0,01	2,0	29	0,8	0,01	4,3	32	3,1
2	22,6	2	23	2,2	28	0,02	3,3	37	1,3	0,03	6,0	38	4,0
3	27,7	3	28	3,5	36	0,03	6,3	44	3,3	0,04	8,7	46	5,7
5	35,8	5	36	5	43	0,04	9,7	55	4,7	0,06	12,7	56	7,7
10	50,6	10	51	10	60	0,06	15,0	66	5,0	0,09	19,0	67	9,0
20	71,6	20	72	20,7	80	0,12	26,7	88	6,7	0,15	30,0	88	10,0
30	87,6	30	88	30,4	97	0,20	38,7	103	8,7	0,22	40,7	108	10,7
40	101,2	40	101	39,9	111	0,28	49,3	117	9,3	0,3	52,0	118	12,0

3.1 Plate measurement

The tone reproduction curve is very important in characterizing prepress. The photopolymer plates of two kinds of digital platemaking technologies with two different screen rulings were analysed. First, the photopolymer plates were measured to define the physical minimum dot that can be held on the printing plate [13].

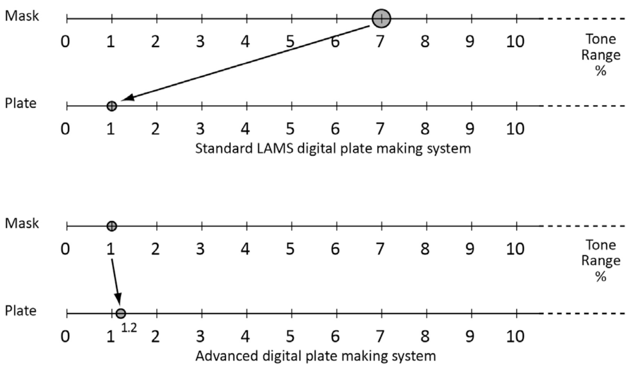

Figure 4 The minimum dot size on plate at 150 lpi at standard and advanced platemaking system

Fig. 4 shows that a 7 % dot in the mask makes 1 % dot on the plate at standard plate making system while the dot size in the mask and plate at advanced platemaking system are almost the same. The "bump-up" curve is dependent on many factors: plate material, line screen, exposure unit, imagesetter type and condition and press capabilities.

The tone reproduction of advanced digital technology at two screen rulings had almost identical and nearly linear result. The tone reproduction curve of standard digital technology was lowered in relation to the linear target and started with the minimum dot size, Fig. 5.

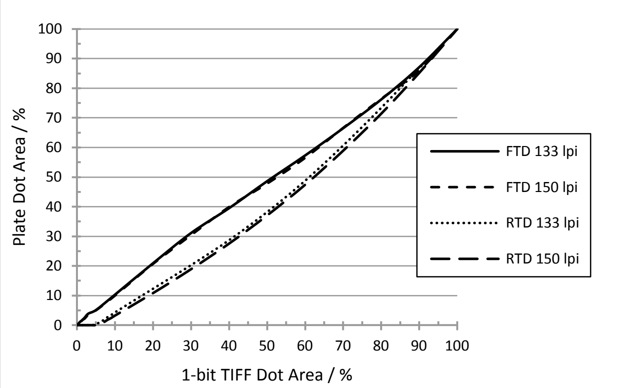

Figure 5 The comparison of the plate tone reproduction at two screen rulings on both digital platemaking systems using linear data

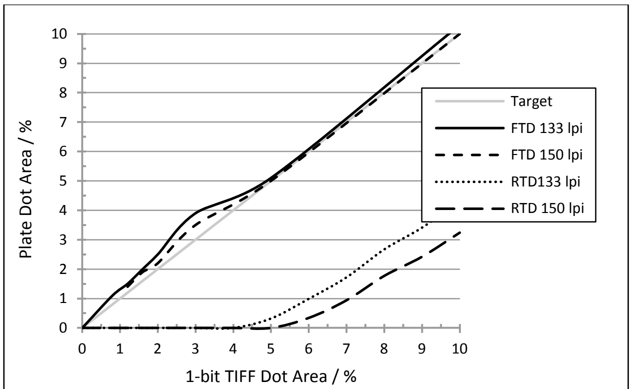

Figure 6 The plate tone reproduction in highlights area for both standard and advanced digital technology

Advanced digital technology allows imaging of all grey levels almost linearly, increasing the range of tones in the highlights and shadows. Small deviations are acceptable (up to 1 % up or down), and will be compensated by dot gain compensation (DGC) curves which will be applied in the ripping phase.

Standard LAMS digital plate loses highlights area while reducing printable grey level. The highlight areas below 6 % at 133 lpi and below 7 % at 150 lpi were not reproducible on the printing plate.

The standard digital platemaking process requires a "bump-up" curve to establish the minimum dot on the printing plate. The linear target is shown in Fig. 6 as a straight line at an angle of 45 degrees and it represents the ideal tone reproduction. The measured data of full tonal range was compared with the input data, and compensation curve was created. Fig. 7 shows that compensation curve for plate linearization was actually the "inverse" (or mirror) of the plate tone reproduction curve. This curve is also known as linearization or prepress curve.

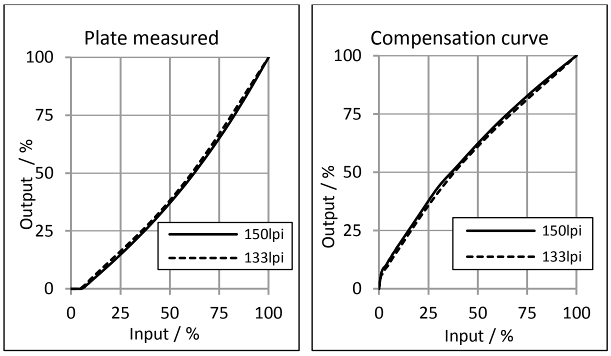

Figure 7 Actual tone reproduction on plate of standard digital system and its tone compensation curve

The minimum dot held on the advanced flexographic printing plate was 19 µm, which corresponds to 1 % at line ruling of 150 lpi. Standard digital LAMS technology at line ruling of 150 lpi can produce minimum dots size of 42 µm. For further research, the LAMS digital plate with prepress curve applied was used.

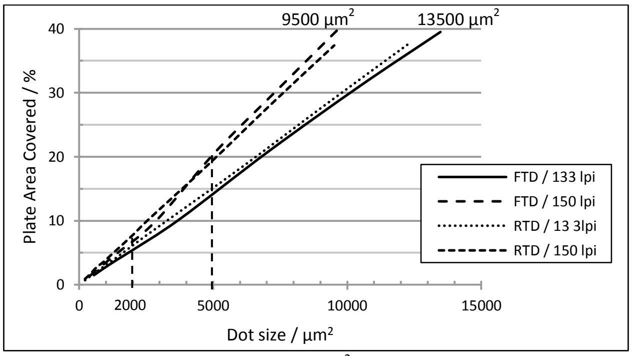

Figure 8 The plate dot size (µm^2) for different line ruling as a function of coverage in the range of 0 ÷ 40 %

The vertical lines on the chart in Fig. 8 show the dot size of 2000 µm^2 and 5000 µm^2. The identical dot size of 2000 µm^2 was for 5,4 % coverage at 133 lpi and 6,8 % coverage at 150 lpi at flat top dots technology. The same dot size of 2000 µm^2 was for 6,2 % coverage at 133 lpi and 7,8 % coverage at 150 lpi at round top dots technology. The difference between dot sizes for the same line screen at both digital platemaking systems is not significant and it is smaller than 1% in highlights. The graph shows that variation in dot area has a higher impact on coverage at a high line ruling than at low line ruling. Thus, the range of dot area for the 150 lpi displayed 9500 µm^2 and for the 133 lpi is 13 500 µm^{2,} which results in a low dot definition for the same coverage at higher line count. This fact indicates that if line screen increases, the printing system should reproduce smaller dots to get the same contrast. That means that higher line count results in lower contrast.

3.2 Tone reproduction at three production stages

Three phases of production are associated with ripping process, imaging process, and the printing process. Measurement of tone reproduction at the ripping stage was the measurement of the 1-bit TIFF file. The ripped file was output through CtP device and after solvent based processing, it created image areas on the flexible plate. The measurement of tone reproduction on the finished plate was created in the imaging stage. The final stage was the printing stage.

The targeted and measured value for solid cyan and opaque pre-printed white is shown in Tab. 5. CIELAB ΔE^*_{ab} deviation tolerance according to ISO 12647-6 for the solids of the process colours amounts to 8, therefore the deviation is within the limits.

Table 5 Colorimetric value for cyan and opaque white

		L^*	a^*	b^*	
Cyan	Reference	50	–33	–36	ΔE^*_{ab} =6,1
	Sample	53,6	–34,3	–40,8	
White	Reference	≥88	–5 to +5	–3 to +3	ΔL^*_{ab} =6,2
	Sample	81,8	–2,4	–2,9	

According to ISO 12647-6:2006(E), the print substrate colour ranges were defined for L^* (≥88), for a^* (–3 to +3) and for b^* (–5 to +5) [14]. A greater deviation of 6,2 in lightness can be observed.

The best way to express and analyse tone reproduction is the Jones diagram. This diagram consists of three quadrants representing each production stage, proceeding in the counter-clockwise direction. The output data from the graph in the first quadrant is transferred as the input to the graph in the second quadrant and so on.

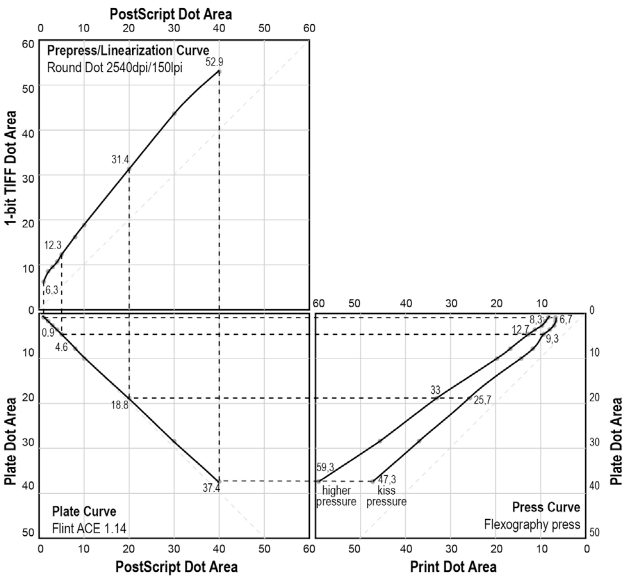

Figure 9 The multiple comparison of the tone reproduction at 150 lpi screen ruling with round top dots

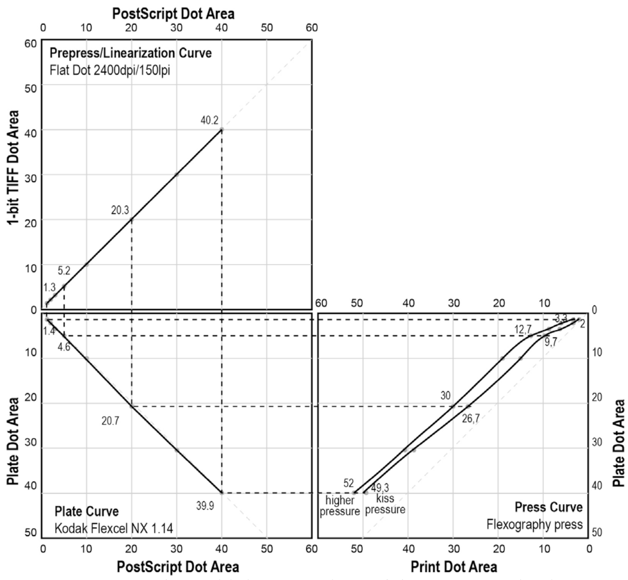

Figure 10 The multiple comparison of the tone reproduction at 150 lpi screen ruling with flat top dots

The entire tone reproduction curves of two line screen at standard digital process (Fig. 9) were higher than tone reproduction of advanced digital process (Fig.10), especially in the highlight areas. The highlight areas below 5 % were not reproducible on the printed sample, as shown in Fig. 9.

The most signifying differences between standard digital bumped dot and advanced digital linear dot is tone reproduction in highlights. For example, the 1 % dot on plate with round top created 8,3 % printed dot on substrate at round top dot, and the 1,4 % dot on plate with flat top created 4,3 % printed dot on substrate. The largest deviation from the ideal dot area occurred for the 150 lpi line ruling in the midtones region.

3.3 Density

The printing plate to impression cylinder pressure has significant effect on density depending on dots top shape and line rulings. Results are presented in Fig. 11 and Fig. 12. Density analysis shows that the highlight area is printed with small differences of the tint density. The density range up to 10 % coverage was 0,04 at kiss pressure at 150 lpi.

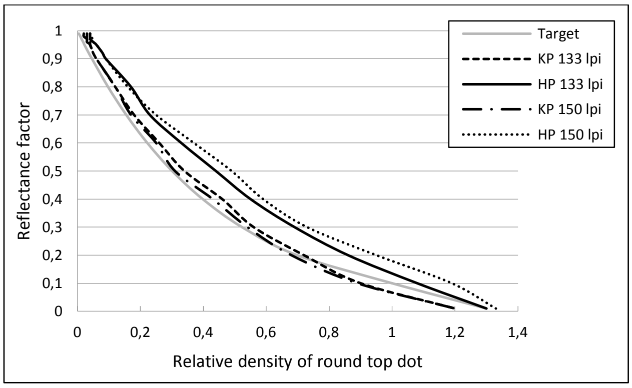

Figure 11 The effect of line screens and printing pressure on density for round top dots

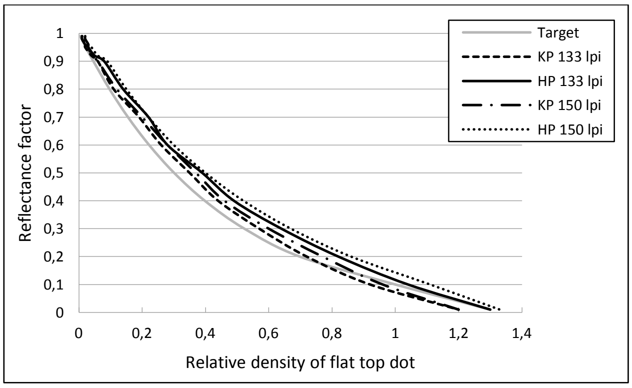

Figure 12 The effect of line screens and printing pressure on density for flat top dots

When the pressure is increased, the density at RTD is more increased than at FTD. Target density curve shows a proportional density increase according to reflectance factor. The RTD curve at higher pressure is straighter, which means that the density difference of individual tones in the midtones is smaller (Fig. 11) and it results in a darker reproduction and less print contrast, as shown in Tab. 6.

Print contrast is a density comparison of the solid area and a three-quarter tone screened area [15]. It indicates the ability of printed work to maintain detail in the shadow areas and a higher reading indicates better print quality and it is calculated using the following equation [6]:

$$C = \frac{D_\mathrm{s} - D_\mathrm{t}}{D_\mathrm{s}} \times 100, \qquad (2)$$

where:
C – print contrast, %
D_s – density of solid patch
D_t – density of tint (typically 75 % or 80 %).

Table 6 Print contrast

Print contrast (C) measured on 80 %			
Top dot shape	Line screen	Light pressure	Higher pressure
RTD	133 lpi	43,3	33,8
	150 lpi	39,2	28,5
FTD	133 lpi	40,0	36,9
	150 lpi	35,8	33,8

Higher printing pressure and higher line count results in lower print contrast. Print contrast is the highest at round top dots by using light pressure. However, it is decreased significantly at higher pressure and it is smaller than at flat top dots, as shown in Tab. 6.

3.4 Dot gain at two different pressure settings

Dot gain is an effect of halftone dots which always appears in the printing process. Dot gain is never entirely compensated because the print result will be too light. The reason for this is that the human eye expects to see some dot gain. The effect of line ruling on dot gain confirms previous research stating that dot gain increases as line ruling increases [7].

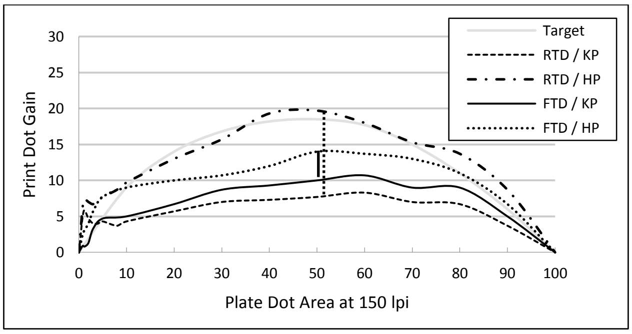

Figure 13 The influences of the two types of pressure and top dots shape on the dot gain for the 150 lpi

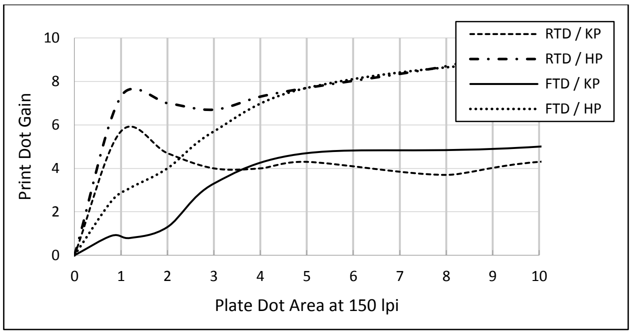

Figure 14 The influences of the two types of pressure and top dots shape on the dot gain for the 150 lpi – highlight detail

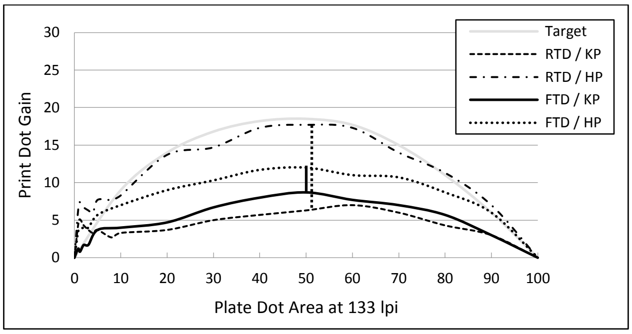

Figure 15 The influences of the two types of pressure and top dots shape on the dot gain for the 133 lpi

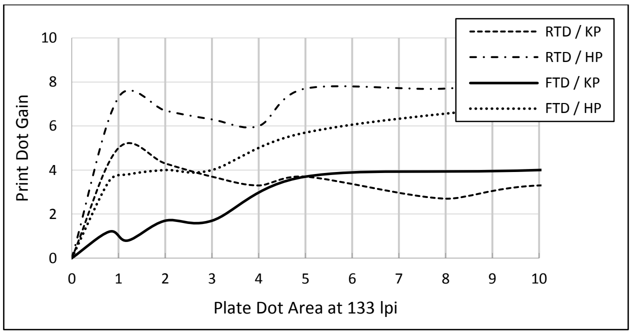

Figure 16 The influences of the two types of pressure and top dots shape on the dot gain for the 133 lpi – highlight detail

The printing press does not have a scale for pressure settings so the kiss pressure was evaluated by controlling the solid density. After the print with these settings, the press operator applies a higher pressure and printing is continued. The printing plate to impression cylinder pressure has the largest effect on dot gain and tonal reproduction and the reasons for this can be explained in terms of the ink spread, penetration into the paper, and the mechanical deformation of the plate.

The vertical lines on the chart in Fig. 13 and Fig. 15 show dot gain variation between kiss and higher pressure at 50 % coverage.

Through the experimental analysis, it was found that in the same printing conditions, with the printing pressure increased, dot gain at round top dots is higher than dot gain at flat top dots. However, the highlights area below 3 % coverage has the largest dot gain and it was difficult to hold dots stable in print, as shown in Fig. 14 and Fig. 16. This is the result of trying to hold a fine dot on the printing plate but the dots were collapsed. The printing plate dot is entered into the anilox cell, picking up excess ink. This effect is called "dot dipping" and can lead to very dirty printing [16]. It was found that a 1 % dot (Tab. 7) is smaller than the open cell width of anilox roller (22 μm for 400 lpcm), therefore poor reproduction was understandable.

Table 7 Plate dot diameter (μm) for 2540 dpi resolution

Plate line screen	Plate dot coverage			
	1 %	2 %	3 %	4 %
133 lpi	19	27	33	38
150 lpi	17	24	30	34

However, the 2 % and 3 % dots were also poorly reproduced. It is assumed that even if the dot size at these percentages is larger than the anilox open cell width due to round top shape, it partially enters the cell and picks up too much ink. Fig. 13 and Fig. 15 also show that flat top dots do not have a significant dot gain by increasing the pressure.

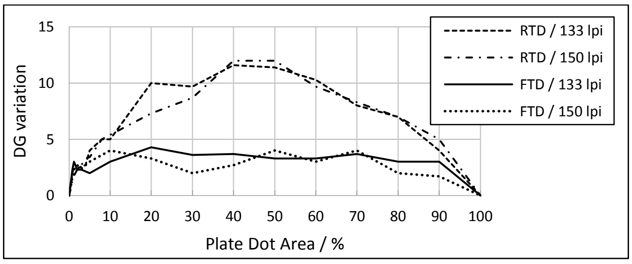

Figure 17 Dot gain variation between kiss and higher pressure

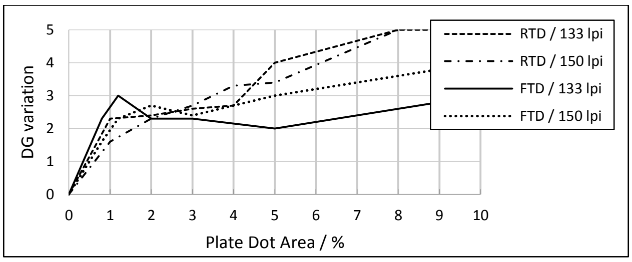

Figure 18 Dot gain variation between kiss and higher pressure – highlight detail

The results for dot gain variation between kiss and higher pressure are shown by the jagged lines in Fig. 17 and the highlight detail is shown in Fig. 18. The dot gain variation is significantly larger at round top dots, with the maximum of 12 % at 40 % coverage at 150 lpi. The dot gain variation at flat top dots is a more uniform and the maximum value was 4 %.

There are two causes of dot gain caused by printing pressure: the ink spreading after it was squeezed and mechanical deformation of the dot on the plate during printing. This mechanical deformation of the dot on the plate can be divided into two mechanisms: expanding of the dot surface and barrelling of the dot sides gain, as shown in Fig. 19. The balance of the factors is dependent on the configuration used, material properties and forces applied [7].

Significantly greater impact on dot gain of round top dots has a "barrelling" mechanism where deformation of the dot due to the pressure leads to the side shoulders becoming a part of the printable surface.

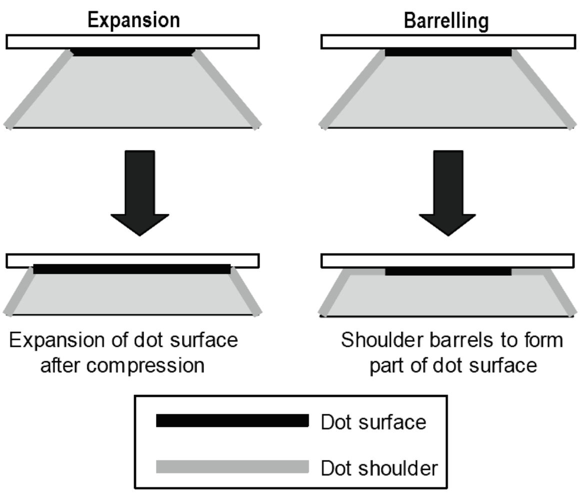

Figure 19 Two mechanisms of dot deformation [11]

3.4 Variation of the diameter

The dot diameter of the 1-bit TIFF document, flexographic printing plate and print samples was also quantified to analyse their variations.

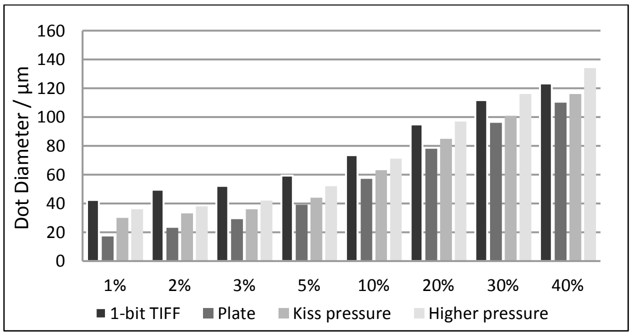

Figure 20 Variation of dot diameter at round top dots at 150 lpi

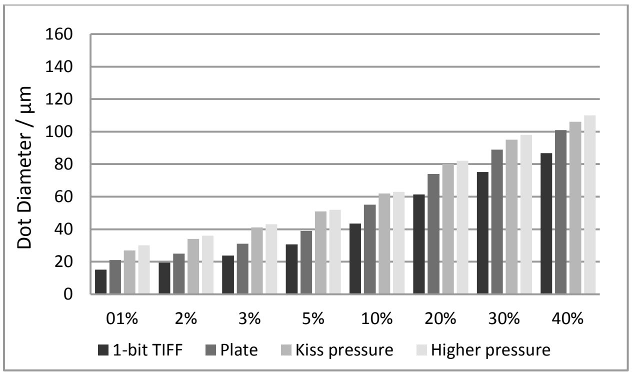

Figure 21 Variation of dot diameter at flat top dots at 150 lpi

By measuring the physical dot size a consistent method for analysis of the physical growth of the dot through all production stages is provided. Dot size and thus dot diameter depend on the screen count and are smaller at high screen count.

For example, the dot diameter at four stages for 10 % coverage of 150 lpi at round top dot was 73 µm/57 µm/63 µm/71 µm (Fig. 20) and at flat top dot was 50 µm/60 µm/66 µm/77 µm (Fig. 21). This indicates that the dot diameter at round top dots firstly reduces and then grows, which is not the case at flat top dots. A standard digital platemaking system requires applying a number of correction curves used for making printing plates (minimum dot size at plate and prepress compensation curve). This operating mode requires more work and may have some errors.

4 Conclusion

Traditional digital LAMS dots on plate are relatively smaller than the targeted size and have a round top. Advanced digital technologies produce a flat top dot structure and the dots size is almost the same as the target dot size. Standard digital platemaking system causes a large difference between nominal and actual coverage, therefore the compensation curve was used to correct the tonal values.

Minimum dot size grows as the line screen increases. Standard LAMS technology can reproduce dots as small as 40-50 µm, while advanced digital technology can reproduce dots as small as 19 µm using all grey levels. A bump curve is used at standard system to set the minimum dot size to 7 % at 150 lpi (to compensate highlight loss) and thus the tonal range is compressed to 7 % ÷ 100 %. The smallest dot a printing process can print is independent of the screen count used.

Coverage has no effect on dot gain as an individual parameter, but has through the interaction with line ruling and pressure settings during the printing process.

Line ruling proved to be a significant parameter because with line ruling increasing, dot gain is increased, too. Higher line rulings give a better image quality through the better dot definition, but the quality may be lost due to higher dot gain. Therefore, it is important to correctly apply compensation curve during prepress.

The pressure between printing plate and impression cylinder has the most significant influence on mechanical dot deformation (expansion and barrelling) and thereby on print quality. Round top dots show a high sensitivity to change in pressure, which leads to inconsistent printing, while flat top dots remain more consistent with over-pressure. However, the results show that dot gain at round top dot was closer to target curve. Dot gain was generally smaller than in other research in the similar conditions on the film substrate without pre-printed opaque white ink. These results might be associated with ink trapping of cyan on white ink, but it needs to be investigated in more detail.

Ink spreading on the substrate has a larger effect on the final dot size at round top dots because of bullet top shape. The pressure is larger at dot centre thus the ink is squeezed out and creates an outline of "halo" effect. However, full characterisation of the proportion of dot gain due to the dot deformation on the printing plate requires a further development.

Flat top dots have a better dot edge definition and therefore better define the print surface of the dot. It was not possible to reliably determine the impression level at round top dot and thus the interaction between top printable area and shoulder of a dot was larger.

The deviation of opacity of pre-printed opaque white ink was large according to specification of ISO 12647-6 and amounts to 6,2 %. However, the tolerance of cyan printed over white ink was within the limits of tolerance. The tolerance amounts to 6,1 and is located near the upper limits of deviation. For further research, it is needed to investigate how opacity of opaque white ink influences the colorimetric value of process colour.

Abbreviations

FTD – Flat Top Dots
RTD – Round Top Dots
KP – Kiss (light) Pressures
HP – Higher Pressures
LAMS – Laser Ablative Mask System.

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