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Statistical analysis of printing elements reproduction on thermally developed CTP flexo printing plates

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Abstract:
This study presents statistical evaluation of the dot area and line width on thermally developed CtP flexo printing plates using image analysis software PerfectEye v4.03. The aim of the study was to determine whether the dot area and line width when different processing parameters are applied (different main exposure time and different number of rotations of developing drum during developing process) were statistically different from each other or not. Image analysis of dots and lines were performed with a VipTronic Vipdens measuring device using CCD camera and a PerfectEye image analysis software. The shape data, dot area and line width were compared by applying one way ANOVA (analysis of variance) method followed by post hoc Tukey's test using the software SPSS (Statistical Package for Social Science) and independent sample T-test with a 0.05 significance level. Statistical analysis revealed that the difference between the dot area and line width for different processing conditions are significant with a 95% confidence level.

Key words: CtP flexo printing plate, ANOVA, independent sample T-test, main exposure time, thermal development

Introduction

Today there are not many printing technologies such as flexography which can be labelled as constantly progressing and growing printing process. Due to its cost effectiveness for many applications, versatility and efficiency, it became growing printing process with constant improvements in quality of the produced imprints. One of the biggest advantages that flexography can offer is its capacity to print on a variety of the absorbent and non-absorbent substrates including coated and uncoated paper board, metalized foils, paper foils and plastic films, used especially in the packaging industry (Kipphan, 2001, Rentzhog, 2006, Lanska, 2007).

Flexography is a relief printing process meaning that the image areas on the printing plate are raised above the non-image areas. During the reproduction process

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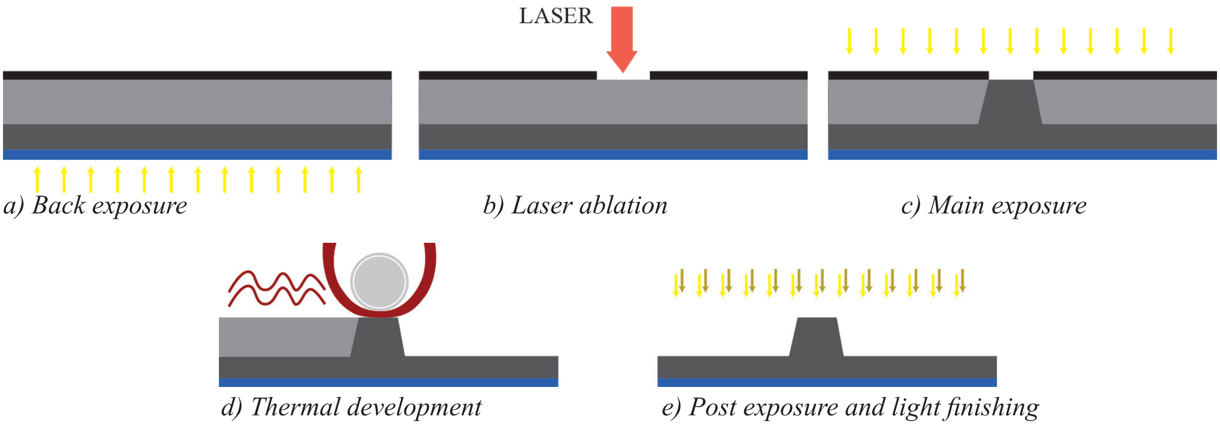
image areas receive the printing ink which is transferred directly to the printing substrate. Due to usage of flexible printing plates, the printing process requires only a slight contact pressure to enable reliable ink transfer from printing plate to substrate facilitating a high quality imprints (Novaković et al, 2010). Although it seems that the ink transfer concept is simple, there is a wide diapason of variable parameters which directly influence ink transfer and consequently the quality of the final printed result (Grirard-Leloup, 2000). Thus, it is necessary to have an extensive approach to the control of flexographic process. It means that the control should not start at the printing stage but has to be extended to overall production chain starting with control of input materials up to the control of the end product.
Printing plate making process is one of the essential and most impacting on the final imprint quality since in this phase printing elements are formed as well as relief depth and final plate hardness. Flexible flexographic printing plates are mainly made of rubber or photopolymer compounds. They vary in their hardness and thickness which has to be adapted to the particular substrate and specific process characteristics. For their production, there are two processes which can be applied: photographic/chemical processes or one of the digital laser-based computer to plate (CtP) technologies (Gilbert and Lee, 2008). Although, at the beginning point, the CtP technology was not generously accepted in flexography due to higher initial cost and lower productivity enhancement (Vanover, 2005, Hamilton, 2005, Hersey, 2010), today it is becoming standardised procedure since its inevitable positive influence on gaining stable, repeatable and high quality production process was recognised. CtP flexo plate making process includes computer controlled laser imaging of the black, sensitive coating (ablation mask) on the plate surface in accordance with the printing image (information). The remaining part of this coating forms a mask for the subsequent main exposure of the photopolymer coating with UV light which causes the cross linking reaction in the printing plate (Novaković et al, 2010). After main exposure, unexposed polymer has to be removed either by chemical or thermal processing method. After that, plates are dried (if chemical method is used), post-exposed and post-processed.

Probes in domain of CtP flexo printing plates include investigations of tone value reproduction, dot sharpness, dot shape, dot shoulder angle, dot surface, dot edge definition, dot valley depth, relief depth, and sharpness of line and text elements (Hamblyn et al, 2005, Gilbert and Lee, 2008, Johnson et al., 2008, Novaković et al., 2010, Hersey, 2010). The control over the CtP plate making procedure also includes the control of a surface roughness and surface free energy (Hamblyn et al, 2005, Johnson et al., 2008, Dedijer and Novaković, 2010, Choi and O'Brate, 2010) as well as its interaction with anilox roller and printing pressure (Johnson et al., 2003, Johnson et al., 2008,). It was established that duration of UVA exposure and UVC post exposure mainly influence previously mentioned printing elements characteristics. In the paper presented by Johnson et al., 2008 it was shown that extensive UVA radiation during plate making of CtP flexo plates leads toward lower dot area. In literature, this effect is known as oxygen inhibition (St. Clair et al., 2007, Schueneman and Obispo, 2009). It is direct consequence of oxygen presence during main exposure which leads to slower radical polymerization and in inhibition of polymerisation disabling main function of the photoinitiator (Schueneman and Obispo, 2009). From one point of view, this partial polymerisation can be considered as positive since it results in sharper and smaller printing elements as well as stepper dot shoulder angle (Hersey, 2010). But from the other side it may result in round-tipped dots rather than a traditional flat-tipped structure or in extreme cases, it can completely disable reproduction of dots in highlights. This can result in a loss of highlight detail, unpredictable dot gain, increased fluting and decreased plate longevity (Hersey, 2010). The extensive UVC exposure, on the contrary, results in higher dot area (Johnson et al., 2008). On the other side, longer UVA radiation causes also lower relief depth (Novaković et al., 2010). Thus, it is necessary to establish and obtain the adequate duration of each production phase during flexo plate making process if the goal is satisfactory final imprint quality.

The aim of this study was to evaluate the reproduction of printing elements (dots and lines) according to specific conditions of the processes in the plate making procedure based on thermal development defined within manufactures recommendations. In detail, the statistical analysis of dot area and line width in dependence of main exposure time and preformed rotations of developing drum during thermal developing were obtained. Furthermore, an object of this study was to show if the differences between the dot area and line width for different main exposure time and different developing conditions are significant with a 95% confidence level. The obtained data were compared by applying one way ANOVA (analysis of variance) method followed by post hoc Tukey's test using the software SPSS (Statistical Package for Social Science, version 15) and Student T test both with a 0.05 significance level.

Thermal technology

Thermal technology is relatively new technology in flexography domain. It is developing process which allows the removal of uncured polymer mechanically, without using any chemical solvents. Thus, it does not



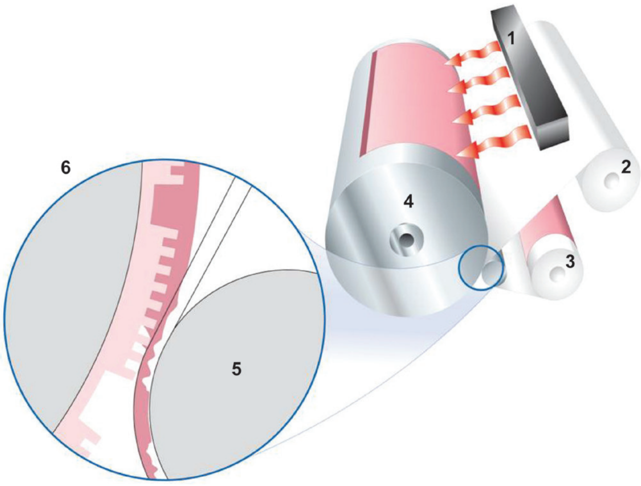
a) Back exposure b) Laser ablation c) Main exposure

d) Thermal development e) Post exposure and light finishing

Figure 1. CtP flexo plate making process with thermal development

require drying phase allowing the plate making process to be up to five times faster (Dupont, 2008). CtP flexo plate making process, based on thermal development, consists of back exposure, laser imaging, main exposure, thermal development process, post exposure and light finishing processes (UVA and UVC).

The plate making process begins with back exposure (Figure 1a), where photopolymer plate is treated with UV-A light. UV-A light is an electromagnetic radiation, a part of UV spectrum, with the wavelength in the range from 320 to 400 nm. The wavelength of 365 nm is usually used for the initiation of polymerisation reaction. Back exposure ensures forming adequate relief depth and allows the anchoring of printing elements in next processing phase. During laser ablation phase (Figure 1b), laser ablative mask (LAM) is removed with computer controlled laser beam according to printing image - revealing future printing areas and remaining on future non printing areas. During main exposure time, printing plate is treated with UV-A light (wavelength usually 365 nm) to form future image areas. In the next phase, the uncured monomer is removed using heat (Figure 1d). It is softened by passing over a heated roller (temperature at least about 70^{0}C). The temperature of a heated roller is set between the melt temperature of uncured polymer on the lower end and the melt temperature of cured polymer on the upper end. During development process, the heated printing plate is contacted with the material screen mesh or absorbent woven or non woven fabric, paper or polymer based) which will absorb or otherwise remove uncured polymer (Choi and O'Brate, 2010). Depending on the relief depth and thickness of the printing plates, the rotation has to be repeated 8 to 12 times (DuPont, 2008), in order to completely remove the melted material (Figure 2). The rotation speed of the drum, carrier of printing plate, cannot be changed and it is defined by the manufacturer; one rotation last approximately 1.12 minutes (DuPont, 2008). The last plate making phase is post exposure and light finishing (Figure 1e). It is carried out with UV-A and UV-C light in order to eliminate stickiness of the plate and to provide complete curing of polymers. UV-C light is the highest-energy UV rays with the wavelength from 100 to 280 nm, where for flexo plate processing wavelength of 254 – 256 nm is usually used.



1. IR source
2. Cylinder (carrier of fabric)
3. Cylinder (carrier of used fabric)
4. Drum (carrier of printing plate)
5. Pressure cylinder
6. Removal of untreated polymer

Figure 2. Thermal developing process (Dupont, 2008)

Methods and materials

For the purpose of the research digital (CtP) flexo printing plate DuPont TM Cyrel ® DFH 045 (1.14 mm thick) was used. The test chart contained half tone patches 8%, 30% and 50% of coverage and positive lines of initial width of 0.03 mm and 0.7 mm. Plate imaging was done on CDI Spark 4835 Esco Expoze imaging device applying AM screen ruling of 50 lines/cm (imaging resolution of 5080 ppi). Back exposure, main exposure, post exposure and light finishing were made by DuPont ™ Cyrel 1000 ECLF device. Thermal development process was made by DuPont ™ Cyrel ® FAST 1000 TD device. The radiation intensity of UV lamps (80 W) used for imaging of the printing plates was measured by Kühnast Stralungstechnick UV-A meter (315 – 400 nm, max. 360 nm). Results showed that the lamps had appropriate intensity; mean intensity per unit area was 20,2 mWcm^{-2}. According to research goal, the set of eight printing plates was made with following characteristics:

1. Back exposure time: 50 seconds;
2. Main exposure time: 8, 10, 12, 14 minutes;
3. Post exposure and light finishing: UVA – 7 minutes, UVC -7 minutes;
4. Developing conditions : 8 and 10 rotations of developing drum (for each variation of main exposure time – 8, 10, 12 and 14 minutes);

The analysis of a dot area and line width was done in PerfectEye software version 4.03 based on micrographs gained with VipTronic Vipflex 333 measuring device. A total of 360 measurements were made by image analysis (each element on each plate was measured 36 times) and later statistically evaluated.

Results and discussion

In order to observe the changes in dot area reproduction, precisely in single dot area, the results of preformed dot area measurements were presented in Figure 3. Presented graph depicts changes in dot area depending on main exposure time and used number of rotations of developing drum during thermal development.

As it can be seen from Figure 3 changes in dot area have polynomial character (of a second order) and are dependable on main exposure time as well as used rotations of developing drum. It can be denoted that higher main exposure time results in smaller dot area, regardless of examined half tone patch. It is noticed that in measuring point which corresponds to main exposure time of 14 minutes the dot area value has a growing tendency, with the exception of dot area measured on 8% field when 8 rotations of the developing drum were applied. It was expected that higher number of drum rotations during thermal developing process will result in smaller dot area. This trend was depicted in case of dots on 8% and 50% half tone patches but only for higher values of main exposure time (12 an 14 minutes).

In order to determine level of significance of changes in dot area depending on main exposure and developing, statistical analysis of variance - one way ANOVA followed by post hoc Tukey´s test and independent - samples T-test were performed. In Table 1 and Table

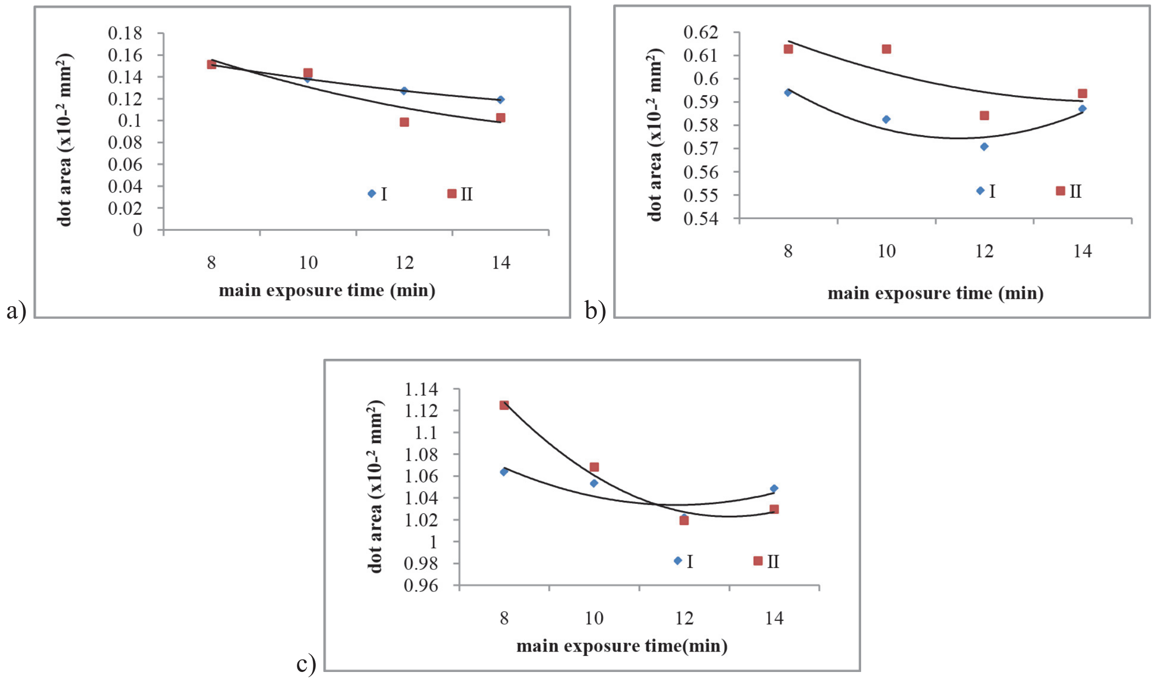


Figure 3. Changes in dot area depending on main exposure time using 8 (I) and 10 (II) rotations of developing drum; dot area measured on half tone patches a) 8%, b) 30% and c) 50%

Table 1. ANOVA results for dot area measured on half tone patches of 8%, 30% and 50% (developing with 8 rotations of rotating drum; main exposure time 8, 10, 12 and 14 minutes)

Development - 8 rotations							
Dot area on different half tone patches		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta squared
8%	Between Groups	0.021	3	0.007	56.946	0.000	0.550
	Within Groups	0.017	140	0.000			
	Total	0.038	143				
30%	Between Groups	0.010	3	0.003	16.760	0.000	0.260
	Within Groups	0.029	140	0.000			
	Total	0.039	143				
50%	Between Groups	0.035	3	0.012	36.090	0.000	0.440
	Within Groups	0.045	140	0.000			
	Total	0.080	143				

2 are presented the results of ANOVA carried out for a 5% significance level, i.e., for a 95% confidence level. The result presented in column Sig. (significance) and partial eta squared indicates the degree of influence on the result. As it can be seen, statistical significance at level of <0.05 was denoted in both cases, meaning that the changes in dot area influenced by changes in main exposure time are significant when the 8 rotations of the developing drum is used, as well as when 10 rotations is used. The extremely high value of partial eta squared points out the high effect size and confirms determined statistical significance between mean values of dot area measured when different main exposure time is performed (according to Cohen, if partial eta squared is higher than 0.14 than it can be denoted high effect size (Pallant, 2007)).

The results of post hoc Tukey's multiple comparison tests (Table 3) with a 0.05 significance level pointed out the differences between groups. The multiple comparisons by post hoc Tukey's test, support the significant influence of different main exposure time on dot area. Namely, when 8 rotations of a developing drum were used during thermal developing, dot area measured on a three different half tone patches were proved to be statistically different from each other on confidence level of 95%. The statistically significant difference was not noted only between mean values for dot area measured on the 30% and 50% tone patches between following groups: 8 minutes – 14 minutes, 10 minutes – 14 minutes (30% field) and 10 minutes – 14 minutes (50% field).

Table 2. ANOVA result for dot area measured on half tone patches of 8%, 30% and 50% (developing with 10 rotations of rotating drum; main exposure time 8, 10, 12 and 14 minutes)

Development - 10 rotations							
Dot area on different half tone patches		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta squared
8%	Between Groups	0.080	3	0.027	308.241	0.000	0.870
	Within Groups	0.012	140	0.000			
	Total	0.092	143				
30%	Between Groups	0.049	3	0.016	146.863	0.000	0.750
	Within Groups	0.016	140	0.000			
	Total	0.065	143				
50%	Between Groups	0.247	3	0.082	368.912	0.000	0.890
	Within Groups	0.031	140	0.000			
	Total	0.278	143				

Table 3. The results of multiple comparisons for dot area utilizing the post hoc Tukey's test (developing with 8 rotations of rotating drum; main exposure time 8, 10, 12 and 14 minutes)

Tukey HSD post hoc test - development 8 rotations							
Depen-dent Var.	(I) time (min)	(J) time (min)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
8%	8	10	0.0127111*	0.0025931	0.000	0.005969	0.019454
		12	0.0237639*	0.0025931	0.000	0.017021	0.030506
		14	0.0318750*	0.0025931	0.000	0.025132	0.038618
	10	12	0.0110528*	0.0025931	0.000	0.004310	0.017795
		14	0.0191639*	0.0025931	0.000	0.012421	0.025906
	12	14	0.0081111*	0.0025931	0.011	0.001369	0.014854
30%	8	10	0.0116389*	0.0033748	0.004	0.002864	0.020414
		12	0.0232778*	0.0033748	0.000	0.014503	0.032053
		14	0.0071083	0.0033748	0.156	-0.001667	0.015883
	10	12	0.0116389*	0.0033748	0.004	0.002864	0.020414
		14	-0.0045306	0.0033748	0.538	-0.013306	0.004244
	12	14	-0.0161694*	0.0033748	0.000	-0.024944	-0.007394
50%	8	10	0.0105250	0.0042209	0.065	-0.000450	0.021500
		12	0.0421139*	0.0042209	0.000	0.031139	0.053089
		14	0.0153167*	0.0042209	0.002	0.004342	0.026292
	10	12	0.0315889*	0.0042209	0.000	0.020614	0.042564
		14	0.0047917	0.0042209	0.668	-0.006183	0.015767
	12	14	-0.0267972*	0.0042209	0.000	-0.037772	-0.015822
*The mean difference is significant at the 0.05 level							

Table 4. The results of multiple comparisons for dot area utilizing the post hoc Tukey's test (developing with 10 rotations of rotating drum; main exposure time 8, 10, 12 and 14 minutes)

Tukey HSD post hoc test - development 10 rotations							
Depen-dent Var.	(I) time (min)	(J) time (min)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
8%	8	10	0.0074694*	0.0021949	0.005	0.001762	0.013177
		12	0.0525944*	0.0021949	0.000	0.046887	0.058302
		14	0.0484944*	0.0021949	0.000	0.042787	0.054202
	10	12	0.0451250*	0.0021949	0.000	0.039418	0.050832
		14	0.0410250*	0.0021949	0.000	0.035318	0.046732
	12	14	-0.0041000	0.0021949	0.247	-0.009807	0.001607
30%	8	10	0.0196056*	0.0024917	0.000	0.013127	0.026084
		12	0.0481750*	0.0024917	0.000	0.041696	0.054654
		14	0.0386750*	0.0024917	0.000	0.032196	0.045154
	10	12	0.0285694*	0.0024917	0.000	0.022091	0.035048
		14	0.0190694*	0.0024917	0.000	0.012591	0.025548
	12	14	-0.0095000*	0.0024917	0.001	-0.015979	-0.003021
50%	8	10	0.0566389*	0.0035198	0.000	0.047487	0.065791
		12	0.1055694*	0.0035198	0.000	0.096417	0.114722
		14	0.0952750*	0.0035198	0.000	0.086123	0.104427
	10	12	0.0489306*	0.0035198	0.000	0.039778	0.058083
		14	0.0386361*	0.0035198	0.000	0.029484	0.047788
	12	14	-0.0102944*	0.0035198	0.021	-0.019447	-0.001142
*The mean difference is significant at the 0.05 level							

Table 5. Independent-samples T-test results for dot area measured on half tone patches of 8%, 30% and 50% in the case of different developing conditions – 8 and 10 drum rotations (main exposure time 8, 10, 12 and 14 minutes)

Dependant variable	t	Sig.	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		Partial Eta squared
tone value					Lower	Upper	
comparing mean for development with 8 and 10 rotations/main exposure 8 minutes							
8%	-0.156	0.876	-0.0003889	0.0024915	-0.0053581	0.0045803	0.000
30%	-13.834	0.000	-0.0383917	0.0027752	-0.0439267	-0.0328566	0.732
50%	-18.697	0.000	-0.0613194	0.0032797	-0.0678819	-0.0547570	0.833
comparing mean for development with 8 and 10 rotations/main exposure 10 minutes							
8%	-2.425	0.018	-0.0056306	0.0023219	-0.0102614	-0.0009997	0.077
30%	-11.254	0.000	-0.0304250	0.0027034	-0.0358168	-0.0250332	0.644
50%	-4.738	0.000	-0.0152056	0.0032091	-0.0216301	-0.0087810	0.243
comparing mean for development with 8 and 10 rotations/main exposure 12 minutes							
8%	12.357	0.000	0.0274288	0.0022197	0.0230017	0.0318559	0.686
30%	-5.544	0.000	-0.0129767	0.0023405	-0.0176447	-0.0083087	0.305
50%	0.518	0.606	0.0021037	0.0040596	-0.0059928	0.0102002	0.004
comparing mean for development with 8 and 10 rotations/main exposure 14 minutes							
8%	-1.768	0.084	-0.0068250	0.0038613	-0.0145956	0.0009456	0.046
30%	5.975	0.000	0.0162306	0.0027163	0.0107934	0.0216677	0.338
50%	3.896	0.000	0.0186389	0.0047844	0.0090968	0.0281810	0.178

In the light of the pair-wise comparison results (Table 4), when 10 rotations of the developing drum were used during thermal developing, the mean values of dot area measured on three different half tone patches for four different main exposure times significantly differ from each other with the exception of a pair 12 minutes – 14 minutes for a 8% tone value field.

In Table 5 are presented the results of performed independent-samples T-test. The test was performed in order to determine whether the mean values of dote area differ from each other when the same main exposure time is performed but different number of rotations of developing drum during thermal developing process. The test was performed with the significance level of 0.05. Partial eta squared value is guideline to define the practical significance. As it can be seen from the results presented in Table 3, statistical difference followed by small effect size was not denoted for dot square on 8% tone value field and main exposure time of 8 and 14 minutes and dot area on 50% tone value field and main exposure time of 12 minutes. In all other cases, statistical significance at level of <0.05 was denoted including high effect size indicating high practical significance of main exposure time.

The changes in line printing elements, precisely the changes in line width, depending on main exposure time and used number of rotations of developing drum during thermal processing are graphically presented in Figure 4a and 4b.

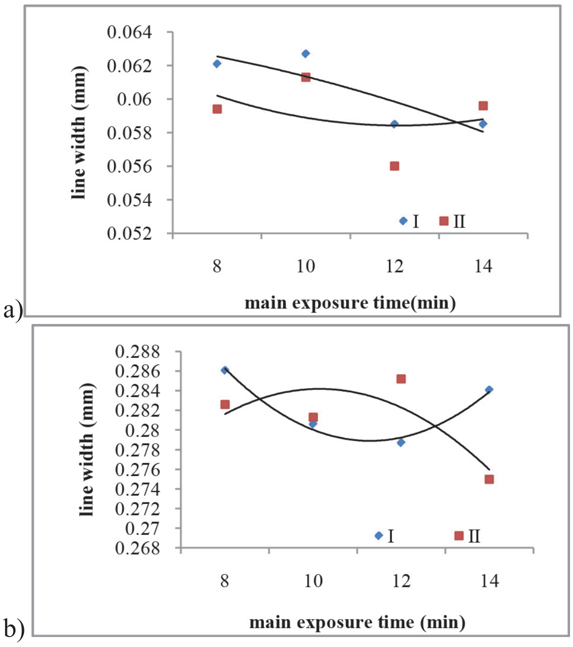


Figure 4. Changes in line width depending on main exposure time using 8 (I) and 10 (II) rotations of developing drum; initial line width a) 0.07 mm, b) 0.3 mm

Presented graphs (Figure 4) illustrate changes in line width in dependence of main exposure time described by polynomial function of a second order. It is not questionable that regardless of initial line width and main time exposure, measured width of printing line element is lowering from initially defined. This effect was ex-

Table 6. ANOVA results for lines of initial width of 0.07 mm and 0.03 mm (developing with 8 rotations of rotating drum; main exposure time 8, 10, 12 and 14 minutes)

Development - 8 rotations							
Line width		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta squared
0.07 mm	Between Groups	0.001	3	0.000	7.792	0.000	0.33
	Within Groups	0.002	140	0.000			
	Total	0.003	143				
0.3 mm	Between Groups	0.001	3	0.000	55.560	0.000	0.5
	Within Groups	0.001	140	0.000			
	Total	0.002	143				

Table 7. ANOVA results for line of initial width of 0.07 mm and 0.3 mm (developing with 10 rotations of rotating drum; main exposure time 8, 10, 12 and 14 minutes)

Development - 10 rotations							
Line width		Sum of Squares	df	Mean Square	F	Sig.	Partial Eta squared
0.07 mm	Between Groups	0.001	3	0.000	33.774	0.000	0.5
	Within Groups	0.001	140	0.000			
	Total	0.002	143				
0.3 mm	Between Groups	0.002	3	0.001	116.015	0.000	0.67
	Within Groups	0.001	140	0.000			
	Total	0.003	143				

Table 8. The results of multiple comparisons for line width utilizing the post hoc Tukey's test (developing with 8 rotations of rotating drum; main exposure time 8, 10, 12 and 14 minutes)

Tukey HSD post hoc test - development 8 rotations							
Dependent Variable	(I) time (min)	(J) time (min)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
0.07 mm	8	10	-0.0006222	0.0006559	0.779	-0.002328	0.001083
		12	0.0036028*	0.0006559	0.000	0.001897	0.005308
		14	0.0036028*	0.0006559	0.000	0.001897	0.005308
	10	12	0.0042250*	0.0006559	0.000	0.002520	0.005930
		14	0.0042250*	0.0006559	0.000	0.002520	0.005930
	12	14	0.0000000	0.0006559	1.000	-0.001705	0.001705
0.3 mm	8	10	0.0055083*	0.0006307	0.000	0.003869	0.007148
		12	0.0073583*	0.0006307	0.000	0.005719	0.008998
		14	0.0020250*	0.0006307	0.009	0.000385	0.003665
	10	12	0.0018500*	0.0006307	0.020	0.000210	0.003490
		14	-0.0034833*	0.0006307	0.000	-0.005123	-0.001844
	12	14	-0.0053333*	0.0006307	0.000	-0.006973	-0.003694
*The mean difference is significant at the 0.05 level							

Table 9. The results of multiple comparisons for line width utilizing the post hoc Tukey's test (developing with 10 rotations of rotating drum; main exposure time 8, 10, 12 and 14 minutes)

Tukey HSD post hoc test – development 10 rotations							
Dependent Variable	(I) time (min)	(J) time (min)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
0.07 mm	8	10	-0.0018417*	0.0005457	0.005	-0.003261	-0.000423
		12	0.0034917*	0.0005457	0.000	0.002073	0.004911
		14	-0.0001917	0.0005457	0.985	-0.001611	0.001227
	10	12	0.0053333*	0.0005457	0.000	0.003914	0.006752
		14	0.0016500*	0.0005457	0.016	0.000231	0.003069
	12	14	-0.0036833*	.0005457	0.000	-0.005102	-0.002264
0.3 mm	8	10	0.0012833	0.0005648	0.110	-0.000185	0.002752
		12	-0.0025667*	0.0005648	0.000	-0.004035	-0.001098
		14	0.0075583*	0.0005648	0.000	0.006090	0.009027
	10	12	-0.0038500*	0.0005648	0.000	-0.005319	-0.002381
		14	0.0062750*	0.0005648	0.000	0.004806	0.007744
	12	14	0.0101250*	0.0005648	0.000	0.008656	0.011594
*The mean difference is significant at the 0.05 level							

pected, due to the well known effect of oxygen inhibition of polymerisation process related to CtP flexo plate making process. It can be denoted that higher main exposure time results in lower line width with growing tendency in the last measuring point excluding 0.3 mm line when developing was performed with 10 rotations of rotating drum.

The same statistical method which was applied in dot area evaluation was also used for determination of level of significance for changes in line width depending on main exposure time and developing conditions.

In Table 6 and Table 7 are presented results of ANOVA carried out for a 5% significance level. As it can be seen, statistical significance at level of <0.05 was denoted in both cases, meaning that the changes in line width influenced by changes in main exposure time are significant when the 8 rotations of a developing drum is used, as well as when 10 rotations is used. High value of partial eta squared indicates high effect size.

The results of post hoc Tukey's multiple comparison tests with a 0.05 significance level pointed out the differences between groups (Table 8 and Table 9). Comparisons by post hoc Tukey's test support the statistical

Table 10. Independent-samples T-test results for line width in the case of different developing conditions – 8 and 10 drum rotations (main exposure time 8, 10, 12 and 14 minutes)

Dependant variable	t	Sig.	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference		Partial Eta squared
Line					Lower	Upper	
comparing mean for development with 8 and 10 rotations/main exposure 8 minutes							
0.07 mm	4.186	0.000	0.002678	0.00064	0.001402	0.003954	0.200
0.3 mm	4.467	0.000	0.003492	0.000782	0.001933	0.005051	0.222
comparing mean for development with 8 and 10 rotations/main exposure 10 minutes							
0.07 mm	2.499	0.015	0.001458	0.000584	0.000295	0.002622	0.082
0.3 mm	-1.375	0.173	-0.00073	0.000533	-0.0018	0.00033	0.026
comparing mean for development with 8 and 10 rotations/main exposure 12 minutes							
0.07 mm	4.766	0.000	0.002567	0.000539	0.001484	0.003649	0.245
0.3 mm	-14.027	0.000	-0.00643	0.000459	-0.00735	-0.00551	0.738
comparing mean for development with 8 and 10 rotations/main exposure 14 minutes							
0.07 mm	-1.731	0.088	-0.00112	0.000645	-0.0024	0.00017	0.041
0.3 mm	15.761	0.000	0.009025	0.000573	0.007879	0.010171	0.780

significant difference on confidence level of 95%. The statistically significant difference was not noted only between mean values for line 0.07 mm between following groups: 8 minutes – 10 minutes, 12 minutes – 14 minutes (development with 8 rotations of rotating drum), 8 minutes – 14 minutes (development with 10 rotations of rotating drum).

In Table 10 are presented results of performed independent-samples T-test with the significance level of 0.05. Statistically insignificant result with small effect size (partial eta squared 0.041) was denoted for 0.07 mm line in a case of main exposure time of 14 minutes. Also, statistically insignificant result with small effect size (partial eta squared 0.026) was given for 0.3 mm line when main exposure time was performed in duration of 10 minutes. In all other cases statistical significant difference on confidence level of 95% was denoted. In addition, high values of partial eta squared contribute to the gained results indicating high practical significance.

Conclusion

This study represents the research of changes in dot area and line width when different processing parameters are applied during flexo plate making process. The dot area and line width on thermally developed CtP flexo printing plates was successfully determined using image analysis software PerfectEye v4.03 and Vip-Tronic Vipdens 333 measuring device. It was shown that different main exposure time as well as different rotations of developing drum during thermal development significantly influence monitored shape parameters. It was shown that, due to well known effect of oxygen inhibition of polymerisation, longer main exposure time leads to smaller dot area and narrower line width. From one point of view, it can be considered as a positive effect knowing that during printing the dot gain can be expected (Johnson, 2003, Gilbert and Lee, 2008, ISO 12647-6:2006). But on the other side, main exposure time should be defined in the way that it does not affect the steady dot formation in the highlight areas. It must be denoted that for measured dots, with the exception of 8% dot in case of performed thermal developing with 8 rotations of developing drum, at the last measuring point values of dot area becomes higher. This may lead to the conclusion that if the main exposure time is long enough, previously mentioned effect can be partly compensated. The statistical analysis gives the contribution to this conclusion since insignificant statistical result was denoted between observed groups when main exposure time was 8 or 10 minutes and 14 minutes. But one must keep in mind that the extensive main exposure time can have undesirable effect on relief depth and surface properties of printing areas, especially surface roughness (Choi and O'Brate, 2010). Analysis of variance (ANOVA) and post hoc Tukey's test gave a good picture of dot area and line width changes and showed that when different main exposure time is applied, these parameters significantly differ from each other. The results of independent sample T-test also showed the significant difference in shape parameters when the same main exposure time was applied but different number of rotations of developing drum, meaning that even if the difference in drum rotation is 2 rotations, it might have significant impact on polymer removal and thus on the final shape of printing elements.

Conclusions obtained represent first step in predicting the forming of printing elements on flexo printing plate in dependence of main exposure time and thermal developing. With further analysis, extended on other plate processing parameters, the plate making process can be significantly upgraded.

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References

1. Choi, J., O›Brate, K. (2010). *Method of Controlling Surface Roughness of a Flexographic Printing Plate*, US patent 2010/0173135 A1, [Online] Available from: http://www.google.com/patents?id=QCXSAAAAEBAJ&printsec=abstract&zoom=4&hl=sr#v=onepage&q&f=false, [Accessed: 3rd April 2012]
2. Dedijer, S., Novaković, D. (2010). *Determination of surface roughness factors of solid printing areas on different flexo printing plates*, :In the proceedings of the 5th International Symposium on Novelties in Graphics, 27–29 May, Ljubljana, pp. 806 - 812
3. DuPont Cyrel (2008). *Fast thermal process*, CD lectures, DRUPA 2008
4. Gilbert, E.D., Lee, F.(2008). *Flexographic Plate Technology: Conventional Solvent Plates versus Digital Solvent Plates*, Journal of Industrial Technology , 24(3) , pp 2-7
5. Girard Leloup, L.(2000). *Statistical Analysis of the possibilities and limits of Flexographic Process Modelling,* In : Taga 2000 Conference Proceedings, 3-5th May 2000, Colorado Springs, USA, pp 469-486

6. Hamblyn, S., Bould, D., Bohan, M. F. J., Claypole, T. C., Gethin, D. T. (2005) *Consistency of flexographic plate making*, In: Taga Proceedings of the 57th Annual Technical Conference, 17-20 April 2005, Toronto, Canada
7. Hamilton, A. (2005). *Prepress primer*, Converting Magazine, July 5, 2007, [Online] Available from: http://www.convertingmagazine.com, [Accessed: 21st May 2012]
8. Hershey, J. (2010). *Dots Do It Right*, Package printing, [Online] Available from: http://printing.macdermid.com/pdf/Dots_Do_It_Right_Nov2010_PackagePrinting.pdf, [Accessed: 11th April 2011]
9. ISO 12647-6:2006 Graphic technology -- Process control for the production of half-tone colour separations, proofs and production prints -- Part 6: Flexographic printing
10. Johnson, J. (2003) The influence of moisture, temperature, pulse pressure, and substrate on print quality in flexographic printing, Karlstad University, Sweden, [Online] Available from: http://www.t2f.nu, [Accessed: 3rd April 2009]
11. Johnson, J., Andersson, C., Lestelius, M., Järnström, L., Rättö, P. and Blohm, E. (2008). *Degradation of Flexographic Printing Plates and Aspects of Print Quality*, submitted to Nordic Pulp and Paper Research Journal
12. Johnson, J. Rättö, P., Lestelius, M. and Järnström, L. (2003). *Dynamic Nip Pressure in a Flexographic CI-Printing Press*, In:TAGA Proceedings of the 55th annual conference, 14-17 April, Montreal, Canada, pp 357-374
13. Kipphan H.(2001). *Handbook of Print Media*, Springer, Berlin, pp. 503-626
14. Lanska D. J. (2007). *Common-Sence Flexography*, A User's Guide to Improved Pressroom Productivity, Printing Industries Press, Pittsburg
15. Novaković, D., Dedijer, S., Mahović – Poljacek, S. (2010). *A model for improving the flexographic printing plate making process*, Technical Gazette, Sveučilište u Osijeku, Osijek, 17(4), pp 403 – 410
16. Pallant, J. (2007). *Postupni vodič kroz analizu podataka pomoću SPSS-a za Windows* (verzija 15), prevod 3. Izdanja, Allen&Unvin, Mikro knjiga, Beograd
17. Rentzhog, M. (2006). *Water-Based Flexographic Printing on Polymer-Coated Board*, Doctoral Thesis, Royal Institute of Technology Stockholm, Sweden
18. Schueneman, N., Obispo, C. (2009). *Highlight Dot Shoulder Angle Using Bank Source Exposure &Point Source Exposure in Digital Platemaking for Flexography*, Flexo Global, pp 8- 20
19. St.Clair, D., Hansen, D., Dubois, D. (2007). *Photocurable compositions and flexographic printing plates comprising the same*, [Online] Available from: http://www.patentgenius.com
20. 7241540.html [Accessed: 15th June 2012]
21. Vanover, M. (2005). *Flexo platesetting: past, present and future*, Flexible Packaging, [Online] Available from: http://www.flexpackmag.com/Archives_Davinci?article=225, [Accessed: 10th June 2012]