https://doi.org/10.24867/GRID-2020-p30 Professional paper

STATISTICAL ANALYSIS OF THE INFLUENCE OF PRINT RUN ON SURFACE ROUGHNESS OF DIGITAL FLEXO PRINTING PLATES' SOLID TONE AREAS

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Abstract: *In this study we have aimed to present statistical evaluation of changes in the surface roughness of the solid tone areas on CtP flexo printing plate in dependence of print run. Changes in flexo plate surface roughness is influenced by the plate-making process, printing pressure and speed, the interaction with the ink and printing substrate and by the wear of the printing plate due to long print-runs. Thus, the aim of this research was to evaluate the changes in the amplitude surface roughness parameters (Ra, Rp, Rv and Rz), between the printing plates used for different print runs. In the experiment, we have employed three sets of CtP flexo printing plates, for three colors-cyan, magenta and blue. The first set was not used for printing, the second was used to print 7 rolls of substrate and the third is used to print 11 rolls of printing substrate. The amplitude surface roughness parameters were compared by applying independent-samples t-test method using the software SPSS (Statistical Package for Social Science) with a 0.05 significance level. Statistical analysis revealed that the difference between the amplitude surface roughness parameters measured on CtP flexo printing plates are significant with a 95% confidence level, whereas the statistical significance pointed out that with the longer print runs, the difference will be strongly expressed.*

Key words: CtP flexo printing plate, solid tone area, surface roughness, long print run

1. INTRODUCTION

Flexography is a direct printing technique primarily recognisable due to its exceptional ability to print on the various substrates delivering high quality imprints. Due to its cost effectiveness, versatility and efficiency, it became growing printing process on a highly demandable graphic arts industry market.

The printing substrates which can be utilized in flexography are mainly used in the packaging industry and are different types of the absorbent and non-absorbent materials, coated and uncoated paper board, metalized foils, paper foils and plastic films (Kipphan, 2001; Rentzhog, 2006; Lanska, 2007).

Flexography is a high-speed printing process which uses relief printing plates. It means that the image areas on the printing plate are raised above the non-image areas. Image areas receive the printing ink which is, due to slight contact pressure, transferred onto the printing substrate. The ink transfer concept in flexography is simple, but still there is a wide diapason of variable parameters which directly influence ink transfer and consequently the quality of the final printed result (Dedijer et al., 2012).

For example, printing pressures which are required to print solids and halftones differ significantly, which may result in image distortion especially if printing is conducted on substrates with textured surface (Bould et al, 2004). The flexographic printing plate is also one of the key factors which highly influence the stability and quality of the printing process.

In light of ink transferring, especially from the large solid areas which are not rare in flexography, the controlled and uniform ink transferring from the printing plate onto the printing substrate is a must if the high-quality output is a goal. One of the parameters which are directly linked with the ink transferring rate is printing plate surface property. The analyses of surface topography give relevant information to make possible prediction of behaviour of the flexo plate surface during printing process (Barros et al, 2005). Moderate surface roughness of flexo printing plate is desirable since it enables optimal ink transfer, while excessive roughness of the solid areas cause low solid ink density due to failure to make contact between the printing plate surface and a given substrate (Choi and O'Brate, 2010). Too low surface roughness may lead to again insufficient ink transfer onto the printing plate.

There are a variety of methods proposed in order to quantify the surface roughness: profilometric methods, like MSP-mechanical stylus contact profilometry or non–contact laser profilometry or different imaging methods such as SEM (Scanning Electron Microscopy) or AFM method (Atomic Force

Microscopy) (Risović et al, 2009; Chappard et al, 2003). In direct contact profilometry, surface roughness is measured directly, where measuring unit's (sharp diamond tip) displacements are recorded and used for further surface roughness parameters calculation (Risović et al, 2009). Among many roughness parameters which can be used for the surface characterization, the most commonly used are amplitude ISO roughness parameters: Ra (average surface roughness), Rz (mean value of the single roughness depths Zi), Rp, the height from the highest profile peak and Rv, the height from the lowest profile peak (Mahović, 2007; Pavlović et al, 2010).
In this paper we have explored the influence of print run on changes in surface roughness of solid tone areas on three sets of CtP flexo printing plates consisting of cyan, magenta (process colors) and blue (spot color) plate. The first set represents the CtP flexo printing plates that were not used in printing process, the second one consists of printing plates that were used for printing of 53075 meters of printing substrate, while the third set represents flexo plates used for printing the 82025 meters of the substrate. The obtained data were compared by applying independent-samples t-test in software SPSS (Statistical Package for Social Science, version 20) with a 0.05 significance level.

2. METHODS

The printing plates utilized in the experiment were digital flexo plates (Table 1). For the purpose of the experiment, printing plates were processed according to manufacturer's recommendation: UVA back exposure 35 seconds, UVA main exposure 10 minutes (lamp temperature 40°C, intensity 19,6 mW/cm^2), developing speed 150 mm/min (developer temperature 32°C), drying 120 minutes (drying temperature 60°C) and UVA and UVC postexposure and finishing 9 and 10 minutes, respectively. For the laser ablation, we have used laser imager for direct exposure on flexo plates (energy 4 J/cm^2, resolution 2450 ppi). The printing process was performed on roll fed flexo printing machine on matte duplex cardboard 270 g/m^2 using water-based colors and printing speed of 600 m/min. During the experiment, 17 cardboard rolls, or 82025 meters, were printed with the same printing plates. The sampling was done at the beginning of the print, after 11 and after 17 printed rolls. The measurements were done on the solid tone area of each prewashed printing plates. Amplitude surface roughness parameters, Ra, Rp, Rv and Rz, were measured at 11 positions, in printing and cross printing direction, whereas 32 measurements for each parameter was used for further statistical one factorial ANOVA analysis in SPSSv20 statistical tool. For the surface roughness measurements, we have used hand held portable stylus roughness tester TR 200: cut-off 0.80 mm, sampling length 5xcut-off, Gauss filter, resolution 0.01 μm, measuring speed Vt= 0.5 mm/s.
In results presentation, the values measured from the printing plates before printing, after 1 and 17 rolls, will be noted as 1, 2 and 3, respectfully.

Table 1: Technical parameters of used flexo printing plates

Thickness	1.70 mm
Hardness	69 Shore A
Ton value reproduction	1-95%
Minimal line width	80 μm
Minimal single dot diameter	150 μm

3. RESULTS AND DISCUSSION

Direct profilometric measurements of flexo printing plates resulted in a range of profilometric parameters' values, providing a basis for a further statistical analysis (Table 2, Table 3 and Table 4). The measured roughness profiles, for all three colors, indicate a remarkable similarity in corresponding surface roughness parameters values.

Table 2: Surface roughness parameters of three flexo printing plates (cyan process color)

	Plate	Average value (μm)	Std. Dev.	Koef. of variation (%)
Ra	1	0.083	0.014	17.05
	2	0.082	0.048	12.24
	3	0.073	0.010	13.72
Rp	1	0.216	0.042	19.61
	2	0.223	0.048	21.54
	3	0.210	0.034	16.24
Rv	1	0.222	0.049	21.88
	2	0.213	0.034	15.90
	3	0.183	0.036	19.48
Rz	1	0.438	0.041465	23.33
	2	0.436	0.056480	16.45
	3	0.393	0.064211	14.62

Table 3: Sufrace roughness parameters of three flexo printing plates (magenta process color)

	Plate	Average value (μm)	Std. Dev.	Koef. of variation (%)
Ra	1	0.079	0.012	15.56%
	2	0.077	0.007	9.61%
	3	0.071	0.015	21.49%
Rp	1	0.291	0.071	24.37%
	2	0.246	0.052	21.01%
	3	0.213	0.045	21.34%
Rv	1	0.206	0.041	20.02%
	2	0.204	0.034	16.78%
	3	0.177	0.043	24.04%
Rz	1	0.496	0.101	20.37%
	2	0.450	0.073	16.17%
	3	0.390	0.092	23.66%

Table 4: Sufrace roughness parameters of three flexo printing plates (blue spot color)

	Plate	Average value (μm)	Std. Dev.	Koef. of variation (%)
Ra	1	0.080	0.008	9.81
	2	0.076	0.010	13.55
	3	0.072	0.013	18.11
Rp	1	0.185	0.039	21.03
	2	0.202	0.030	14.74
	3	0.240	0.046	19.00
Rv	1	0.217	0.034	15.56
	2	0.202	0.021	10.32
	3	0.181	0.035	19.45
Rz	1	0.402	0.065	16.10
	2	0.405	0.072	17.85
	3	0.421	0.079	18.69

According to values represented in Tables 2-4, we have detected decreeing tendency in average surface roughness parameter in dependence of print run. Namely, overall surface roughness expressed through the value of Ra parameter is decreased after printing 11 rolls of cardboard. It is clearly showing that the flexo plate surface is becoming smoother. This is also reflected through the values of Rp, Rv and Rz parameter for two process colors indicating that the longer interaction of printing plate, ink and printing substrate, followed with the applied printing pressure and printing speed, results in wearing the profile peaks and lowering valleys depth. The exception from this are Rp and Rz values for the printing plate for blue spot color, where, on contrary, we detect the mild increasing tendency with the print run. The changes detected in highest peak value may be due to possible higher granulation of printing ink, or their abrasive nature, where there is possibility that micro damages might occur on the flexo printing plate surface which might be detected as profile peaks. The value of coefficient of variation is below 25% which classifies the obtained measurement as stable and repeatable, with low variability (Papić, 2020).

3.1 Statistical analysis

In order to determine level of significance of changes in surface roughness parameters due to print run, statistical analysis method, independent-samples t-tests were performed. In Tables 5 - 13 are presented statistical test results carried out for a 5% significance level, i.e., for a 95% confidence level.

Table 5: Independent-samples t-test carried out for surface roughness parameters obtained on plate 1 and 2 (cyan process color)

Independent Samples Test							
			t-test for Equality of Means				
						95% Confidence Interval of the Difference	
	Partial Eta squared (η^2)	Sig.	t	df	Sig. (2-tailed)	Lower	Upper
Ra	0.002	.062	.327	62	.745	-.005107	.007107
Rp	0.002	.003	-.382	62	.704	-.040124	.027249
Rv	0.012	.551	.868	62	.389	-.011840	.030027
Rz	0.000	.017	.120	62	.905	-.041468	.046781

Table 6: Independent-samples t-test carried out for surface roughness parameters obtained on plate 2 and 3 (cyan process color)

Independent Samples Test							
			t-test for Equality of Means				
						95% Confidence Interval of the Difference	
	Partial Eta squared (η^2)	Sig.	t	df	Sig. (2-tailed)	Lower	Upper
Ra	0.163	.779	3.473	62	.001	.003686	.013689
Rp	0.008	.015	.688	62	.494	-.024465	.050152
Rv	0.098	.022	2.596	62	.012	.006876	.052936
Rz	0.047	.022	1.758	62	.084	-.005860	.091360

Table 7: Independent-samples t-test carried out for surface roughness parameters obtained on plate 1 and 3 (cyan process color)

Independent Samples Test							
			t-test for Equality of Means				
						95% Confidence Interval of the Difference	
	Partial Eta squared (η^2)	Sig.	t	df	Sig. (2-tailed)	Lower	Upper
Ra	0.139	.045	3.168	62	.002	.003575	.015800
Rp	0.001	.949	.290	62	.773	-.037781	.050593
Rv	0.126	.187	2.985	62	.004	.012881	.065119
Rz	0.042	.762	1.650	62	.104	-.009620	.100432

In Tables 5-7 are presented results of independent-samples t-test carried out for surface roughness parameters obtained on plates for cyan process color. The result presented in column Sig. (significance) and partial eta squared indicates the presence of the statistical significance and the degree of influence on the result. Statistical significance at level of <0.05 for the average surface roughness was denoted between 1 and 3 printing plate indicating that the changes in surface roughness influenced by print run are significant. The values of partial eta squared points out the high effect size and confirms determined statistical significance between mean values of roughness parameter Ra measured on printing plates used for different print runs (according to Cohen, if partial eta squared is higher than 0.14 than it can be denoted high effect size (Pallant, 2007). If we look at the expressed statistical significance for the other three parameters which reflects the changes in more specific surface attributes, peaks and valleys, we can see that the statistically significant result was obtained between 1 and 2, and 2 and 3 printing plate.

Table 8: Independent-samples t-test carried out for surface roughness parameters obtained on plate 1 and 2 (magenta process color)

Independent Samples Test							
			t-test for Equality of Means				
						95% Confidence Interval of the Difference	
	Partial Eta squared (η^2)	Sig.	t	df	Sig. (2-tailed)	Lower	Upper
Ra	0.003	.000	.411	62	.683	-.008216	.012466
Rp	0.032	.000	1.440	62	.155	-.017427	.107239
Rv	0.000	.000	.107	62	.915	-.026418	.029418
Rz	0.024	.000	1.227	62	.224	-.029172	.121984

Table 9: Independent-samples t-test carried out for surface roughness parameters obtained on plate 2 and 3 (magenta process color)

Independent Samples Test							
			t-test for Equality of Means				
						95% Confidence Interval of the Difference	
	Partial Eta squared (η^2)	Sig.	t	df	Sig. (2-tailed)	Lower	Upper
Ra	0.053	.000	1.868	62	.066	-.000393	.011643
Rp	0.055	.003	1.891	62	.063	-.001912	.068599
Rv	0.113	.426	2.808	62	.007	.007813	.046437
Rz	0.120	.195	2.906	62	.005	.018835	.101852

Table 10: Independent-samples t-test carried out for surface roughness parameters obtained on plate 1 and 3 (magenta process color)

Independent Samples Test							
			t-test for Equality of Means				
						95% Confidence Interval of the Difference	
	Partial Eta squared (η^2)	Sig.	t	df	Sig. (2-tailed)	Lower	Upper
Ra	0.029	.000	1.362	62	.178	-.003628	.019128
Rp	0.081	.001	2.342	62	.022	.011454	.145046
Rv	0.058	.001	1.952	62	.055	-.000685	.057935
Rz	0.107	.001	2.730	62	.008	.028571	.184929

In Tables 8-10 are presented results of independent-samples t-test carried out for surface roughness parameters obtained on plates for magenta process color.
Statistical significance at level of <0.05 for the average surface roughness was denoted between all printing plates indicating that the changes in surface roughness influenced by print run are significant. The values of partial eta squared points out the small to mild effect size (Pallant, 2007). If we look at the statistical significance values for the other three parameters it is noticed that the statistically significant result was not only obtained between 2 and 3 printing plate and Rv and Rz surface roughness parameters.

Table 11: Independent-samples t-test carried out for surface roughness parameters obtained on plate 1 and 2 (blue spot color)

Independent Samples Test							
			t-test for Equality of Means				
						95% Confidence Interval of the Difference	
	Partial Eta squared (η^2)	Sig.	t	df	Sig. (2-tailed)	Lower	Upper
Ra	0.049	.084	1.786	62	.079	-.000483	.008608
Rp	0.039	.284	-1.583	62	.118	-.040019	.004644
Rv	0.040	.352	1.614	62	.112	-.003615	.033928
Rz	0.000	.554	-.148	62	.883	-.036794	.031731

Table 12: Independent-samples t-test carried out for surface roughness parameters obtained on plate 2 and 3 (blue spot color)

Independent Samples Test							
			t-test for Equality of Means				
						95% Confidence Interval of the Difference	
	Partial Eta squared (η^2)	Sig.	t	df	Sig. (2-tailed)	Lower	Upper
Ra	0.025	.084	1.272	62	.208	-.002126	.009563
Rp	0.137	.819	-3.131	62	.003	-.061240	-.013510
Rv	0.046	.135	1.730	62	.089	-.003266	.045328
Rz	0.012	.466	-.866	62	.390	-.054080	.021392

Table 13: Independent-samples t-test carried out for surface roughness parameters obtained on plate 1 and 3 (blue spot color)

Independent Samples Test							
			t-test for Equality of Means				
						95% Confidence Interval of the Difference	
	Partial Eta squared (η^2)	Sig.	t	df	Sig. (2-tailed)	Lower	Upper
Ra	0.120	.001	2.903	62	.005	.002424	.013139
Rp	0.304	.125	-5.201	62	.000	-.076224	-.033901
Rv	0.139	.021	3.162	62	.002	.013312	.059063
Rz	0.017	.178	-1.048	62	.299	-.054868	.017118

In Tables 11-13 are presented results of independent-samples t-test carried out for surface roughness parameters obtained on plates for blue spot color. The result presented in column Sig. (significance) and partial eta squared indicates the presence of the statistical significance and the degree of influence on the result. Statistical significance, looking at the average surface roughness, was denoted between 1 and 3 printing plate indicating that the changes in surface roughness influenced by print run are significant. The value of partial eta squared value confirms high effect size (Pallant, 2007). If we look at the expressed statistical significance for the peaks and valleys, we can see that the statistically significant result was obtained only between 1 and 3 printing plate and only for the Rv surface roughness parameter. This may lead to the conclusion that during printing, statistically there are no significant changes in the average values of the highest peaks and lowest valleys.

4. CONCLUSIONS

In this paper detailed statistical surface roughness analysis of CtP flexo plates in correlation with print run was conducted. The conclusions derived from the conducted research are as follows:

- The changes in values of four amplitude surface roughness parameters (Ra, Rp, Rv and Rz) due to print run, obtained by the by direct stylus profilometric method, generally correspond to anticipated trend: longer print run will result in lowering the surface roughness of the flexo printing plate.
- The decreasing tendency is clearly expressed through changes of the average surface roughness value – Ra: the differences between average Ra values at the beginning of the printing and after 82025 meters of printed material were found to be statistically different in case of all printing plates utilized in the experiment.
- On the basis of values obtained for more specific surface roughness parameters – peaks and valleys (Rp, Rv and Rz), it is seen that the longer print run will, generally lead to in wearing the profile peaks and lowering valleys depth. The contradictory result was obtained only in case of Rp and Rz values for the printing plate for blue spot color. The noticed increasing tendency, may indicate that the abrasive nature of printing inks or substrate may lead to micro damages on the flexo printing plate surface which might be detected as profile peaks.
- Values of partial eta squared points out the mild to high influence of print run on the changes in surface roughness of digital flexo printing plates.
- The statistical analysis reveal that the influence of print run on changes of the peak and valleys surface roughness values may not be in case of all printing plates considered as statistically significant. This might be connected with the type of ink used (process vs. spot colors) and its characteristics in terms of granulation and influence on the printing plate surface.
- With further analysis, extended on other printing substrates and inks, as well as printing plates in terms of processing parameters, this research can be significantly upgraded and may deeply reveal the changes in surface roughness on the CtP flexo printing plates in dependace of print run.

5. ACKNOWLEDGMENTS

This research (paper) has been supported by the Ministry of Education, Science and Technological Development through the project no. 451-03-68/2020-14/200156: “Innovative scientific and artistic research from the FTS (activity) domain”.

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