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Original scientific paper

THE INFLUENCE OF PRINTING SUBSTRATE PROPERTIES ON COLOR CHARACTERIZATION IN FLEXOGRAPHY ACCORDING TO THE ISO SPECIFICATIONS

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Abstract: Flexography is widely used in the packaging industry due to the fact that print can be adapted into various printing substrates, whose surface characteristics substantially affect the reproduction quality. Accordingly, this research comprises the comparison of the most important quality parameters of graphic reproduction in accordance with the ISO 12647-6 standard for three types of printing substrates: uncoated and coated paper and OPP film. The main goal is to examine the effect of the printing process in combination with various printing substrates on the color characteristics on the print. After the printing of a color-test form, the characterization of prints was carried out. The obtained results serve as the guidelines and recommendations for an easier and simpler control of reproduction. It has been concluded that the existing standard provides only basic recommendations. Accordingly, the characterization of the process should be adjusted to the customers' expectations.

Keywords: flexography; ISO specifications; print quality; printing substrate

1 INTRODUCTION

Flexography is a printing technique which uses photopolymer plates with elevated printing elements that leave a direct print on the substrate. The printing technique is very sensitive, and the printing plate is easily adjusted to all printing substrates. Due to its flexibility and softness, the substrate can cause, under pressure and low viscosity color, an extremely high Tone Value Increase (TVI). The printing plate makes a significant segment of the entire process which gives the flexography certain advantages. Due to the elastic printing elements, this printing technique enables printing in different absorbing and non-absorbing printing substrates such as: thin films, flexible and hard foils, all kinds of paper, cardboard of different thickness and strenghts, packaging material of corrugated surface and similar [1].

The surface characteristics of the printing substrate have a significant influece on the printing quality. On paper, the surface is additionally enriched by the finishing processes (coating, impregnating, parchmentization and laminating). The most common procedure of paper finishing is coating; therefore, the papers are divided into uncoated (raw) and coated papers [2].

The flexography process enables a high quality graphic reproduction which almost has a photo level quality. In the printing process, there have to be goal values and tolerances for the entire process, including the composition and ink viscosity, plate thickness and dot consistency, the self-adhering mounting tape and printing conditions (settings for printing pressure and speed) for the consistency in achieving the production goals [3].

The entire process of flexography consists of a large number of influential parameters that need to be standardized for specific printing conditions (Fig. 1). The concept of standardizing the reproduction process includes all the factors present in the production process which also influence the quality of the final printed product. Graphic prepress, printing platemaking, print and printing substrates used in the process have to be mutually aligned and optimized in order to get the best quality of the flexography reproduction. Therefore, all the phases of the technological process within a unique working order have to be characterized, which is the basic precondition for the standardization of the entire process.

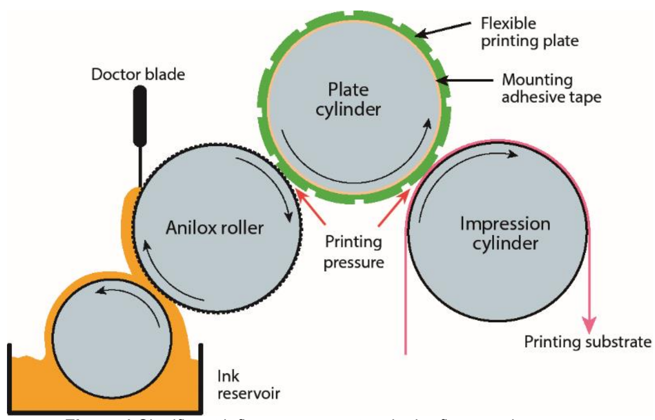

Figure 1 Significant influence parameters in the flexography process

The most common and at the same time the most efficient mode of achieving top print quality is coordination with the goal values in the ISO 12647-6 standard. However, many printing houses set their own standards by combining different line screens and volumes of the anilox roller, which in turn characterize specific printing processes in accordance with specific printing substrate classes [4].

2 METHODOLOGY

The following chapter describes the research methodology of the influence of the printing substrate on the characteristics of colour reproduction in three types of printing substrates with the objective of comparing the quality of reproduction and optimization of the production process. The research framework describing the research purpose and process is shown in Fig. 2.

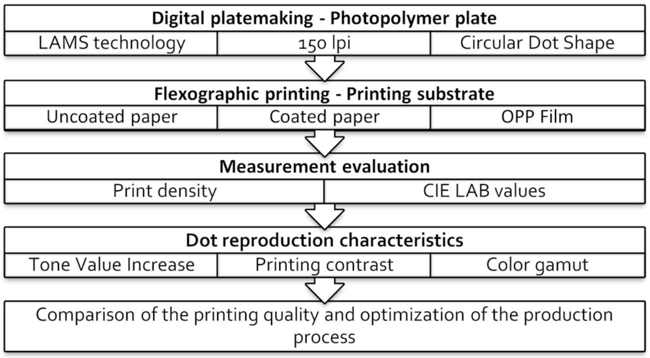

Figure 2 Research framework

2.1 Photopolymer platemaking

The experimental part of this paper begins with the design of the test form set up in a way which enables the evaluation of a quality dot reproduction by applying acceptable and established methods and research techniques. The test form used in the experiment is shown in Fig. 3.

Figure 3 Layout of the test form for printing

The color test form consists of the following elements:

- measuring patches with cascading transition in the range from 0 – 100 %,
- Ugra / Fogra test wedge for the evaluation of all the important color-reproduction characteristics,
- *flexo iO chart* for determining the print out colour gamut,
- elements for the evaluation of the text size (from 2 – 12 pt) and line thickness (from 0.05 – 0.50 mm),
- color-image for visual print evaluation.

The photopolymer plate was made by using the LAMS digital technology with the following settings defined: line screen 150 lpi, conventional AM round dot shape, screen angles (7.5°; 37.5°; 67.5° and 82.5°) and 2540 dpi resolution.

2.2 Printing

The polymer plate is mounted on the plate cylinder of a commercial, six-color flexography machine Nilpeter FB4200. The printing is performed by the principle "roll to roll" printing in the 60 m/min speed. In the course of the printing process, the printing substrate passes through the plate cylinder and impression cylinder. For an appropriate printing pressure, the distance between the two cylinders needs to be optimal. Light pressure is crucial for a good quality of reproduction since it prevents the halo effect and optimizes the Tone Value Increase [5]. It is often not easy to print when using light pressure, namely due to the characteristics of the printing substrate surface, the uneven height of the printing elements or the type of task which is being printed (full color printing, combined printing or process printing). Light pressure is the smallest needed pressure for the ink to transfer from the anilox roller to the printing plate and from the plate to the printing substrate [6].

Printing specifications:

- Flexo printing machine: Nilpeter FB4200
- Flexo ink: PULSE SLM UV Process CMYK
- Printing width: 330 mm
- Printing length: 490,00 mm
- Anilox line count: 405 lpi
- Anilox cell volume: 3.1 BCM
- Printing substrate: uncoated paper, coated paper, film.

The printing experiment is envisaged in a way that the test plate is printed by using the process CMYK UV ink on three different printing substrates, while other parameters are kept constant, including the speed and pressure in print, as well as the characteristics of the self-adhesive mounting tape and anilox roller. The chosen printing substrates are from different quality classes with different physical and optical characteristics (porosity, gloss, surface gloss, opacity, grammage).

Specification of the three selected printing substrates:

- Uncoated, white, machine-finished label paper HERMAwhite (601), grammage 72 g/m^2, opacity 83%.
- White label paper, semi-gloss coated on one side HERMAextracoat (242) grammage 80 g/m^2, opacity 86%, surface gloss 30%.
- White, high gloss, opaque OPP label film Treofan DECOR – LWD, thickness 38 µm, unit weight 23.5 g/m^2, opacity 82%, gloss 65%.

Films and foils are usually defined as a thin synthetic polymer layer. Therefore, it is necessary to prepare in advance the films and foils which have a significant influence on their surface tension and enable the ink to connect with the printing substrate which then decreases the level of difficulties in printing.

2.3 Printing evaluation

In order to compare the research results, it is important for the printing experiment to be set in controlled conditions. Each of the chosen types of printing substrates belongs to a separate qualitative group. The measured CIELCH values of process colors on prints must be matched with the goal values according to the ISO 12647-6 standard, i.e. within the limits of an acceptable deviation.

Densitometric and colorimetric values on printings are measured by using the spectrophotometer X-Rite Exact (geometry 45°/0°, standard type of lighting D50, neutral filter (No), measuring angle 2°, aperture size 2 mm). As a result of measuring, the mean value of the three measurements is taken in each patch for every basic print color.

The Tone Value Increase as the first indicator for the quality of reproduction is a difference between the measured area coverage on the print in relation to the nominal value of the coresponding test patch. The Tonal Value Increase is never completely compensated because color reproduction will be overly light. The Controlled Tone Value Increase in accordance with the standard is an entirely acceptable occurence.

The Print Contrast, as the second examined indicator of the reproduction quality, measures the ability of the printing process to reproduce shadow tones. The goal is to achieve a larger color gamut by using the optimal color density for a specific printing process [7].

3 RESULTS AND DISCUSSION

3.1 Color difference

Based on the measured CIELCH values for solid patch of primary CMY and secondary RGB colors on three types of printing substrates and the goal value defined according to ISO 12647-6:2012(E) standard [8], the hue difference is calculated and compared with the acceptable deviations in hue color (Tab. 1). The acceptable deviation for solid tone of the process colors according to the mentioned standard amounts to $\Delta h_{ab} < 6°$.

Results show that hue differences for all the process colors in all three types of printing substrates are within the acceptable tolerances, except for the *magenta* in OPP films where the value of hue differences is above the upper limit and amounts to $\Delta h_{ab,M}$ = 6,56°. The mean value of hue differences for process colors in all three types of printing substrates is significantly under the upper acceptable limits ($\Delta h_{ab} < 6°$) and for the uncoated paper it amounts to 1,93°, for the coated paper 2,12° and for OPP film 2,73°. Such values indicate to precisely the opposite from the hypothesis that the highest deviations would be those in uncoated paper due to its relatively poor surface characteristics in relation to other printing substrates. Generally speaking, the minimal values in hue differences are seen in *cyan*, and maximal values are seen in *magenta*. The values in hue differences for secondary colors are not listed in the calculation of average value and are shown only for informative purpose.

Table 1 Hue differences (Δh_{ab}) for CMY and RGB colors in line with the ISO 12647-6:2012(E) standard

DeltaH / Lch													
	h (ISO 12647-6)	Uncoated paper				Coated paper				OPP film			
		L (%)	C_{ab} (%)	h_{ab} (°)	Δh_{ab}	*L* (%)	C_{ab} (%)	h_{ab} (°)	Δh_{ab}	*L* (%)	C_{ab} (%)	h_{ab} (°)	Δh_{ab}
C	233.00	58.43	46.12	234.51	1.51	53.77	61.37	231.36	1.64	56.46	62.06	233.16	0.16
M	357.00	51.74	60.69	359.47	2.47	46.18	75.63	0.17	3.17	48.47	70.28	350.44	6.56
Y	93.00	87.11	74.64	91.20	1.80	88.03	96.04	91.46	1.54	87.38	84.19	94.46	1.46
R	36.00	50.19	69.78	31.92	4.08	45.25	89.35	36.37	0.37	45.91	80.69	33.47	2.53
G	160.00	54.14	49.06	150.47	9.53	47.67	72.14	157.01	2.99	50.24	71.49	155.68	4.32
B	296.00	32.19	36.01	296.60	0.60	18.84	50.51	298.49	2.49	22.97	55.62	294.56	1.44
		avg_{CMY} = 1.93°				avg_{CMY} = 2.12°				avg_{CMY} = 2.73°			

Table 2 CIE LAB values of the tested printing substrate and the recommended values according to the standard

Printing substrate	*L** (%)	*a**	*b**
Uncoated paper	91.55	1.48	2.80
Coated paper	93.55	0.76	3.25
OPP film	91.01	0.21	−4.44
ISO 12647-6	>88	–3 to +3	–5 to +5

According to the mentioned standard, ISO 12647-6, the recommended CIE $L^*a^*b^*$ values for the printing substrate are defined in the following gamut: for L^* (>88), for a^* (from –3 to +3) and for b^* (from –5 to +5). In Tab. 2, it is shown that all the examined printing substrates meet the mentioned criteria. The lightness value in all printing substrates is higher than 91%. Accordingly, it was to be expected that the reproduction of the process colors would be within the tolerance limits.

3.2 Color gamut

The comparison of color reproduction in the three tested printing substrates is presented by the color gamut of the print. Based on the measured CIELAB values of the primiary and secondary colors, three hexagones were constructed within the ab diagram that show the gamut of the reproduced colors for a specific type of printing substrates (Fig. 4).

The smallest color gamut was quite expectedly seen in the uncoated paper and it is significantly smaller than in the other two types of the printing substrates. Furthermore, the color gamut of the coated paper is higher than in the OPP film, which proved to be completely opposite from the set hypothesis. A larger gamut in the coated paper in relation to the OPP film was seen in the red and yellow area of the ab diagram, while in the green and blue area there are no significant deviations. Such gamut results in the coated

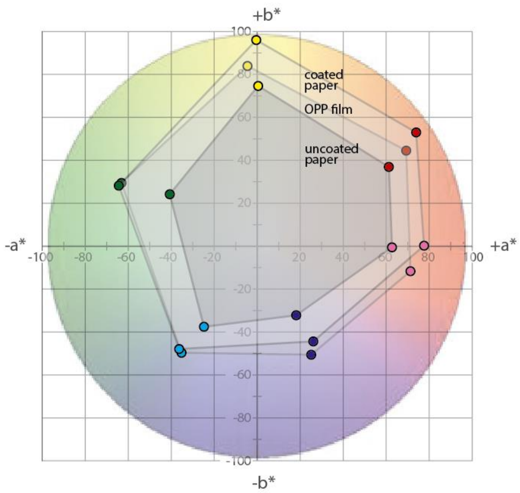

Figure 4 Overview of the color gamut in the ab diagram for three chosen printing substrates

paper and OPP film can be seen in the LAB values for the printing substrates.The difference in the coordinate b (Δb) between the mentioned printing substrates amounts to 7.69, which indicates a shift from the blue to the yellow area of the ab diagram (Fig. 4).

3.3 Tone Value Increase

The printing quality in modern graphical technology is related to the quality of dot reproduction, and by applying the densitometric method, all the significant characteristics of dot printing can be determined.

One of the key factors influencing the quality and accuracy of dot reproduction is the change of dot size which can result in tone and color shifts. Therefore, the definition of Tone Value Increase is a significant parameter in the characterization of production processes. Tab. 3 shows the Tone Value Increase of process colors measured in two characteristic measuring fields (40% and 80%) for all three types of printing substrates. Tab. 3 also shows recommended values in accordance with the ISO specifications serving as a point of comparison.

Table 3 Tone Value Increase in the process color for the three chosen printing substrates

Tone Value Increase CMYK@40% / 80%						
	Uncoated		Coated		OPP label film	
	40%	80%	40%	80%	40%	80%
C	22.50	10.20	21.00	11.30	20.30	13.10
M	23.30	10.40	22.20	13.10	21.60	12.10
Y	23.60	12.60	19.40	12.00	19.20	12.90
K	24.70	10.70	21.50	11.90	22.50	13.00
ISO 12647-6	18.2	11.0	18.2	11.0	18.2	11.0

The Tone Value Increase results in all the tested printing substrates show somewhat higher values from the recommended ones. The Tone Value Increase in the middle tones for the process colors (at 40%) is the highest in the uncoated papers (4-6% higher than the ISO recommendation), while in the coated papers and OPP film, it is expectedly lower (1-2% higher than the ISO recommendation). In shadow tones (at 80%), the values are higher for 1-2% in all printing substrates than in the ISO recommendation.

3.4 Relative printing contrast

As a rule, prints should have the highest possible printing contrast. In order to achieve this, solid tones should have a high color density, while the halftone screen is still open. By increasing the ink film, the printing contrast is increased only up to a certain limit. By further increasing the ink film, halftone dots are filled and the printing contrast falls down again. The optimal color density for a certain printing process can be determined by using the relative printing contrast based on measuring the three quarter halftone dot patch. In the process of CMY colors, it is measured at the 70% tone value, while for the color black it is measured at the 80% tone value.

The obtained results for the printing contrast indisputably show that the printing substrates with poorer substrate characteristics result in a lower printing contrast. Although unexpectedly, the highest printing contrast can be seen in the coated paper print (in *cyan* it amounts to 46.20%). A significantly lower printing contrast in relation to the coated paper, for 9-13%, was measured in the uncoated paper, while in the OPP film it is lower for 5-10%. This indicates that despite the better substrate characteristics as a key parameter for the quality of reproduction, the quality parameters in the OPP film show lower values in relation to the coated paper, which can also be seen in Tab. 4. Such results in the OPP film can be ascribed to the influence of surface tension between the ink and the printing substrate.

Table 4 Printing contrast of the process colors for the three chosen printing substrates

Print Contrast CMY@70%, K@80%			
	Uncoated	Coated	OPP film
C	34.50	46.20	36.10
M	35.7	41.40	36.10
Y	26.70	40.20	30.90
K	23.60	32.80	24.20

4 CONCLUSION

The purpose of characterizing the entire reproduction process is in the programmed printing mode, i.e. managing the process from one point with a predictable and repeatable quality product level. This point is a graphical prepress which is connected to the overall process by the application of the color managing system. In the graphical prepress, corrections are done in certain work phases in line with the obtained results of the specific measurable parameters of the reproduction quality. These adjustments depend on the different characteristics of the photopolymer plates, different characteristics of the printing substrates, different ink types and different anilox roller specifications. The design process has to be matched with the standard, i.e. it should be implemented within the framework of the prescribed tolerances. It is therefore crucial to understand the entire production process.

The ISO 12647-6 standard contains in its specification only certain values of the qualitative color reproduction parameter which serve only as a starting reference. The reason behind it is that the characterization of the production process depends on a certain combination of ink, anilox roller, printing plates, printing substrates and printing machine. Therefore, there are no appropriate modes of implementing characterization which would take all these parameters into account and define the specific values for all possible combinations. Hence, it is important for the group of qualitative data, i.e. the process characterization, to be aligned with the customers' expectations. The second reason for the inability to design an appropriate standard is the fast development of the flexographying industry and the application of advanced technological solutions in all the production process areas.

Hue differences (Δh_{ab}) are a basic parameter in the process colors defined by the ISO specifications. Hue difference values are in this research completely matched with the mentioned standard, which is a basic precondition for further characterization. Therefore, the values of the qualitative parameters in the three types of printing substrates, based on this research, can be taken as framework values in order to further specify the mentioned production processes.

The evaluation of qualitative reproduction parameters under the influence of different printing substrate characteristics showed significant indicators which can give a serious contribution to the advancement of production process and can also result in an increased quality. The definition of repeatable and exact parameters within the process results in a constancy of the reproduction quality. This presents the first step towards standardization.

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