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Quality of electrophotographic prints on foil substrates

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Abstract:
Electrophotographic printing uses many types of substrates, our study focuses on plastic substrates. Six types of regular and self-adhesive foil substrates were chosen to be printed using two electrophotographic presses: Xerox Colour 1000 Press and Canon imagePress C7000VP. A test chart containing tone value scales and a set of samples for profiling was created, spectrophotomety and densitometry was applied to obtain the optical and colorimetric properties of the substrates investigated. Xerox Color 1000 Press produced larger densities and tone value increase on every type of substrate. The largest TVI values and reproducible colour gamut was observed on the smoothest foil in case of both presses. Large colour differences were found between patches of full tone process colors on the different substrates investigated.
Key words: printability, electrophotography, plastic substrate, colour gamut *

Introduction

Electrophotography is one of the major digital printing technologies today. A unique virtual printing form is created during the nonimpact printing process on the surface of the photoconductor drum. Imaging is based on the photoelectric effect. The first step is the charging of the photo conductor drum, mostly corona treatment is applied, during air is ionized between the corona roll and the dielectric surface of the photo conductor drum. Ionized air is conductive, causing the migration of charged particles (electrons and ions) from the corona to the photo conductor. Laser light is used to illuminate the photo conductor drum. Simultaneous sheet-wide illumination is also possible by using a linear array of light emitting diodes. Irradiation causes the dissipation of charge on non-imaging surface areas. Modulation of the laser emission results varying charge density, usually 8 bits/pixel modulation is applied in colour electrophotographic process. The latent image generated by the charge distribution on the drum surface. Following the exposure of the latent image the charge attracts toner particles to form a toner-image on the drum (Schein 1992). Besides pressure, electrostatic attraction also plays a role in the transfer of the toner image to the substrate. In order to fix the toner image to the substrate heat and pressure is applied. Heat make toner particles to melt and bond to the substrate surface structure, pressure also increase temperature of the toner causing softening and penetration to the substrate

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material in case of absorptive substrates (Lahti and Tuominen, 2010).

In electrophotographic printing, as well as in other printing technologies, the quality of the prints is influenced by characteristics of the substrate, the ink (toner) and the specific technology (Sipi, 2003). The interaction between the toner and the substrate is an outstanding technological parameter for quality printing.

In case of multicolour printing transparent dyes are used the usual four process colours (CMYK) are used. Secondary colours (RGB) are produced by the mixture of two process colours, the first layer is fixed to the substrate, the next layer is put down onto the previously fixed layer (Johnson, 2003). In the print quality is primarily determined by toner characteristics in the electrophotographic printing process (Sastri and Sankaran 2003). Toner has to fix fast to the substrate and be printable. The appearance of the prints may vary significantly in case of different substrates. Particle size is usually 5-10 μm. Theoretically resolution increases with decreasing particle size, which is generally the fifth of pixel size, at 600 dpi resolution average particle size is about 8 microns (Malvern Instruments, 2011).

Toners are comprised of coloured pigment, thermoplastic resins to permit adhesion to substrate and additives to increase charging capacity. Quantitatively the largest fraction (about 90%) of it is resin. Electrical charging of powdered toners is a key factor. In quality colour printing two component toners are used, that contain toner particles and carrier beads, the latter are larger in size (Figure 1).

diameter ~ 80 μm diameter ~ 8 μm

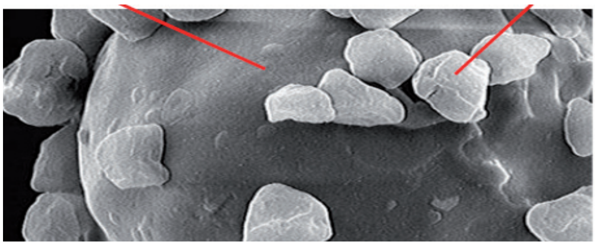

Figure 1. SEM image of two component solid toner particles

The carrier beads are metal particles with a thin layer of polymer. Toner particles are charged in contact with the carrier beads (triboelectric charge). Electrostatic control is applied in the transport process of the toner to the photo conductor drum (Hedvall et al., 1990). Important properties of the toner include particle size, charge to mass ratio, surface chemical properties, and viscoelasticity.

The advantages of small particle size are sharpness, high resolution but the printing process may become unstable due to sensitivity to the development parameters. Charge to mass ratio together with particle size may scatter toner particles near printed edges (a characteristic property of electrophotographic print appearance). Bonding (fusing) characteristics of the toner to substrate will influence the mechanical and surface texture properties of the print. Fusing depends on surface chemical and viscoelastic properties of the toner. Ideally all particles should transfer to the substrate to prevent accumulation of toner on the drum, which may cause a ghost image on the next sheet (Oittinen and Saarelma 1998).

The electrophotographic printing process requires substrates with special properties. Fortunately a wide range of such substrates are available. The type and surface properties of the substrate primarily determine the appearance of the prints (Mortimer, 1998). Properties of the substrates are classified into major groups of printability and runnability (Kipphan, 2001). Printability properties directly influence print quality. Printability properties include the physical and chemical properties of the structure and surface of the substrate and technological parameters, which are of utmost importance in case of plastic substrates (Maxwell, 1996). Electricity is applied in the printing process, making the runnability properties of such substrates critical. The conductivity of the substrate has to be in the appropriate range to prevent accumulation of charge, which may lead to jamming of the sheets. Resistivity of the substrate is important to keep the electric field during toner transfer. These two properties will determine the tolerance range for resistivity of the paper (Sirviö, 2003). Moisture content of the substrate is a critical parameter as well, a linear increase of moisture content will decrease resistivity exponentially in case of absorptive substrates. If the conductivity of the substrate is beyond the acceptable range the spread of toner may cause the loss of dots in image areas with fine details (Hakola at al. 2008) (Pettersson and Fogden 2005). Conditions of the heat transfer affect surface strength and dimensional stability of the substrate. Deformation of the substrate influence image quality in duplex printing (Mitsuya and Kumasaka 1992). Substrate and toner surface chemical compatibility is necessary for optimal surface adhesion. The smoothness of substrate surface gains importance with increasing resolution (decreasing particle size). Increased resolution improves print quality at the expense of having to keep the surface, thermal and electric properties of the substrate in a narrow range of tolerance (Sipi 2010).

During the last few years numerous studies investigated electrophotographic print quality. In most of these studies paper substrates were considered, the behavior of non-absorptive substrates in the electrophotographic printing process were seldom investigated.

The aim of our research work was to evaluate the applicability of plastic foils for electrophotographic printing. We used densitometry and spectrophotometry to determine optical tone value increase, colour difference and variation of gamut size on CMYK prints.

Experimental

Printing materials

In this study six different foil substrates were investigated, some of them were self-adhesive. Two of the substrates were polyolefin (#1 StarSet and #5 XEROX DURAPAPER LABEL, BOTH self adhesive) the other four were polyester (#2 PicoFilm #3 Premium Nevertear #6 WindowGraphix are regular, #4 Blizzard IS SELF-ADHESIVE). Substrate #2 (PicoFilm) was clear and strong PET. All foils were developed for electrophotographic printing, #6 is a special foil suitable for fixing onto glass surfaces electrostatically without adhesive.

Two types of electrophotographic presses were used to print the substrates XEROX COLOUR 1000 PRESS (TONER: Xerox EA Low Melt Toner) and Canon imagePress C7000VP (toner: Canon C-EXV 20). A test chart was created, it comprised of 12 step tone value scales for each of process colours (CMY), secondary colours (RGB), and chromatic grey, and a profiling chart with 323 colour patches.

Methodology

We measured apparent dot area to determine tone value increase (TVI) curves. Printable gamut and colour difference characteristics were obtained by spectrophotometric easurements. X-Rite SpectroEye and X-Rite Eye One pro spectrophotometers were used, both devices operate in the 380-780 nm spectral range, they have 4.5 mm aperture and 45°:0° measurement geometry.

Results and Discussion

Properties of foils

Physical properties of the substrates were measured first. We used Bekk measurement device to determine smoothness of the foil surfaces, conductivity values were obtained at 20º C ambient temperature using 10 x 10 mm copper electrodes and constant 100 kg/cm^2 pressure. Volume resistivity of the foil substrates exceeded 108 Ohm in every case. Substrate properties are summarized in Table 1. Large variations of smoothness values was observed.

Tone value increase of CMYK prints

Tone value is the relative area of the image covered by halftone dots. Theoretically this value may fall in the range of 0-100%. Printing technologies are usually unable to reproduce tones below 5%. Tone value increase is used to describe the difference between the requested tone value in the original application file and the final apparent tone value on the substrate as measured with a densitometer. The increase of tone values primarily affect midtones.

The printable tone range depends not only on the printing technology applied, but also on the surface properties of the substrate (Novotny, 2008). In electrophotographic printing improper generation of electric charge can be the primary cause of variations of tone values. Such electrostatic inaccuracies may cause the decrease of tone values typically in highlight areas (5-40% tone range). Figures 2-7 show tone values measured on process colour scales of the six plastic substrates printed with the two different presses.

Table 1. Physical properties of the studied foils

Property	#1	#2	#3	#4	#5	#6
Grammage, g/m^2	180	125	145	160	190	125
Caliper, µm	220	150	195	200	250	160
Bekk smoothnes, s	15.7	7.4	7.8	7.7	22.6	54.6

Table 2. Measured optical density values of CMYK process colours on substrates printed with both presses.

Substrate	Optical density							
	Xerox Color 1000 Press				Canon C7000VP			
	C	M	Y	K	C	M	Y	K
1	2.22	1.99	1.76	2.50	1.38	1.51	1.21	1.60
2	1.96	1.87	1.66	2.28	1.21	1.45	0.98	1.44
3	2.19	1.95	1.82	2.61	1.33	1.36	0.93	1.36
4	2.18	1.98	1.78	2.60	1.58	1.56	1.31	1.63
5	1.92	1.73	1.59	2.46	1.49	1.51	1.14	1.67
6	2.40	2.08	1.88	2.75	1.44	1.48	1.12	1.50

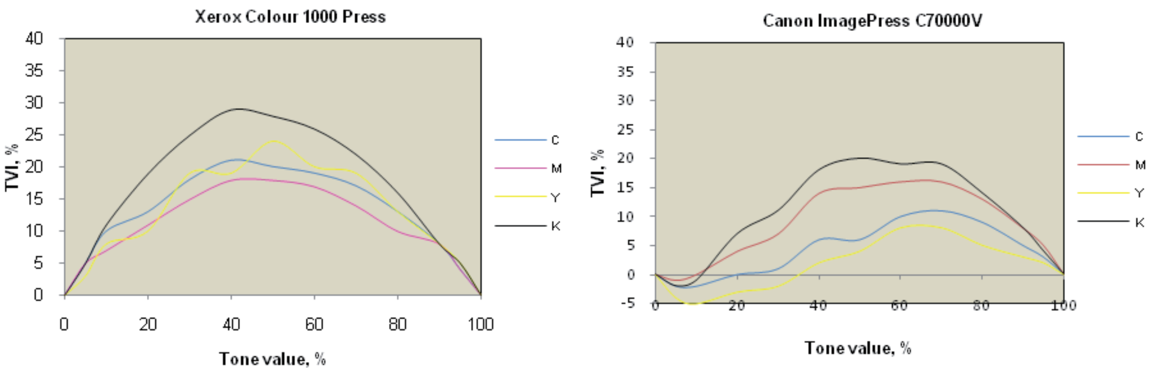

Figure 2: Optical tone value increase of CMYK prints at Foil 1.

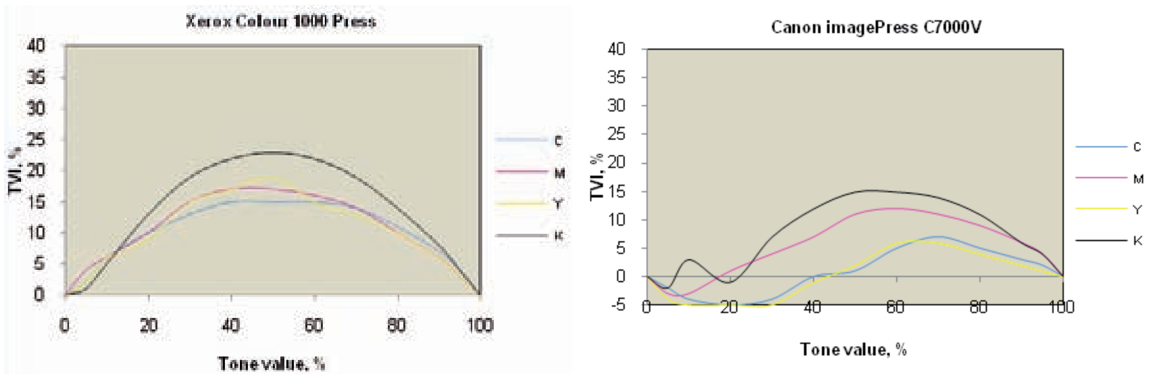

Figure 3: Optical tone value increase of CMYK prints at Foil 2.

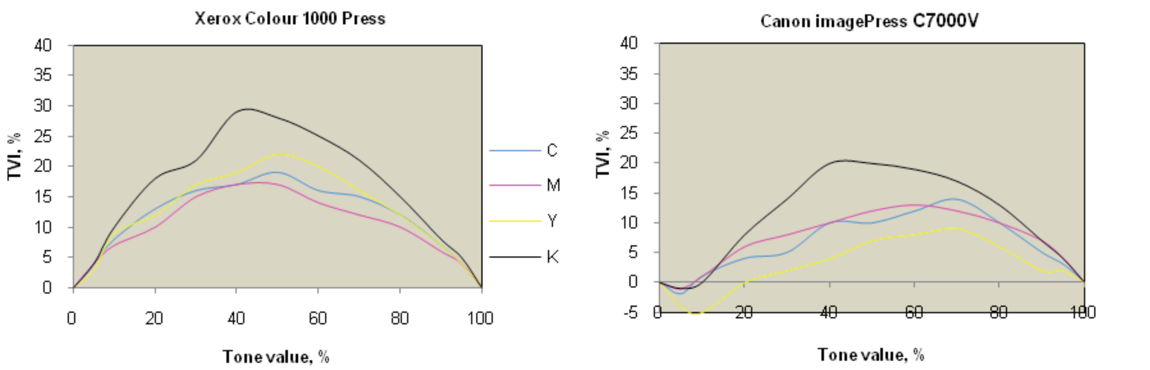

Figure 4: Optical tone value increase of CMYK prints at Foil 3.

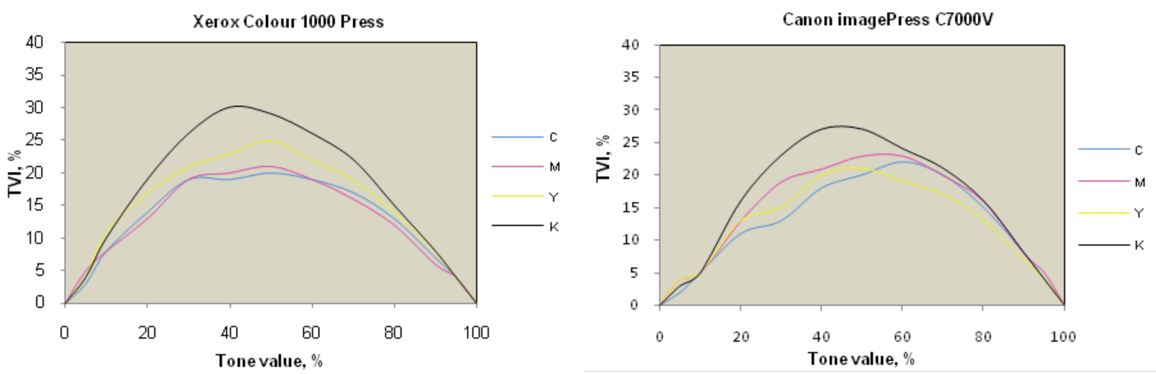

Figure 5: Optical tone value increase of CMYK prints at Foil 4.

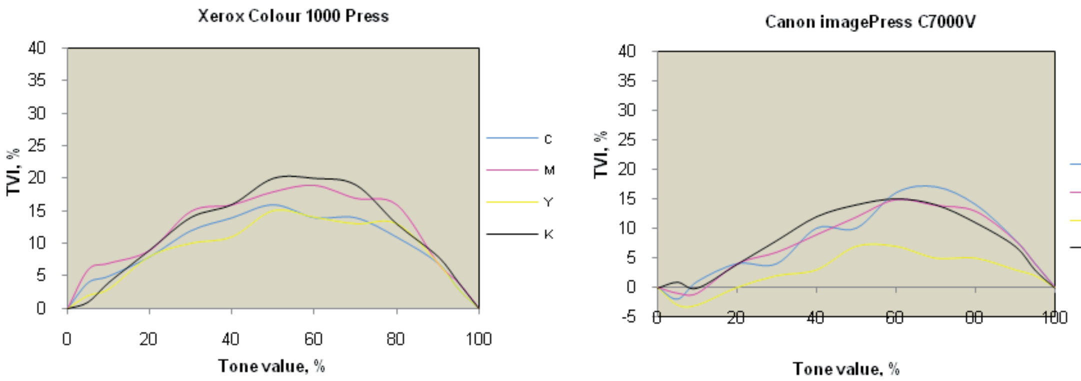

Figure 6: Optical tone value increase of CMYK prints at Foil 5.

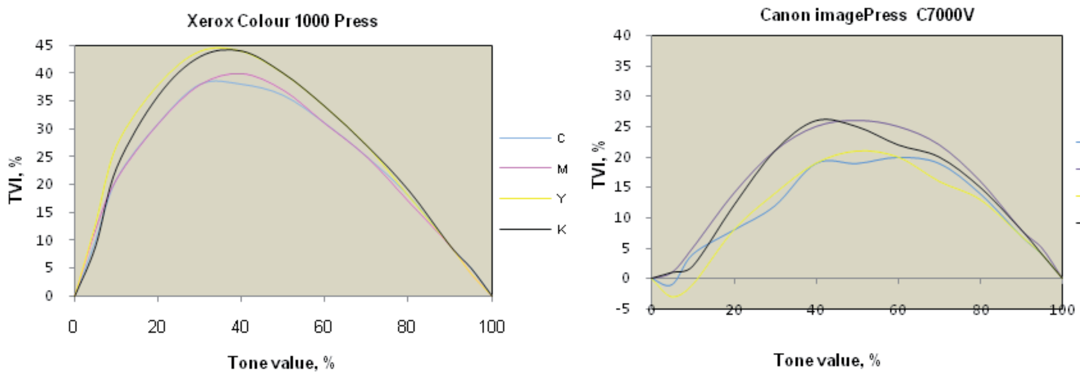

Figure 7: Optical tone value increase of CMYK prints at Foil 6.

XEROX COLOR 1000 PRESS produced higher density and larger TVI values on all substrates than the other press. Dot loss was observed on highlight areas of prints produced by the CANON C7000VP press on every type of substrate.

Investigation of printable colour gamut

The range of reproducible colours (gamut) depends on the printing process and the substrate and other printing materials used. We used a software tool commonly applied in proofing colour workflows to visualize and compare the colour gamut achievable on the substrates investigated. First, printer profiles were generated using X-Rite EyeOne Pro measurement device and profiling software.

A standard test chart with 323 patches was printed on the substrates of this study, by both printing presses to sample the printable colour solid.

The profiles were loaded to the gamut visualization tool, which calculated printable gamut in CIELAB colour space volume units. Relative printable gamut sizes are shown in Table 3, the largest gamut is taken as reference. Figures 8 and 9 illustrate reproducible colour solids in CIELAB space.

Table 3. Reproducible gamut volumes on foil substrates. In the first row of relative gamut sizes the reference is largest value for the given press, in the second row the largest value of all data served as a reference.

Printing press	Substrate #	Relative gamut (%)	Relative gamut (%)
Xerox Color 1000 Press	1	76	76
	2	78	78
	3	82	82
	4	83	83
	5	97	97
	6	**100**	**100**
Canon C7000VP	1	63	38
	2	64	38
	3	75	45
	4	91	54
	5	98	59
	6	**100**	60

Reproducible colour gamuts are significantly larger in case of the Xerox Color 1000 Press compared the Canon C7000VP. Within one press there are large variations between reproducible gamuts in case of the different plastic substrates.

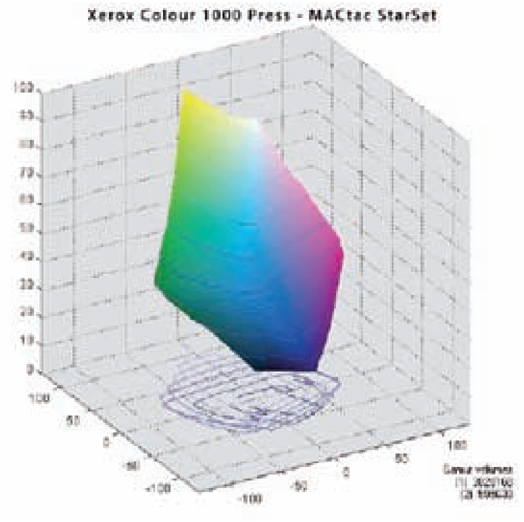

Figure 8: Colour gamut in CIELAB colour space on substrate #2, printed using XEROX COLOR 1000 PRESS.

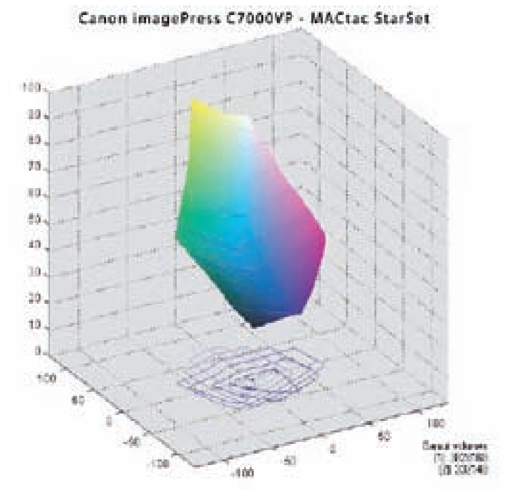

Figure 9: Colour gamut in CIELAB colour spacet on substrate #2, printed using CANON C7000VP.

Evaluation of colour differences

Being the lightest substrate (based on measured L*, a*, b* values) #2 was chosen as a reference for colour comparisons. Colour difference values (ΔEab*) between the chosen and the other substrates were calculated in case of all process colours (Table 4 and 5) (Figure 10).

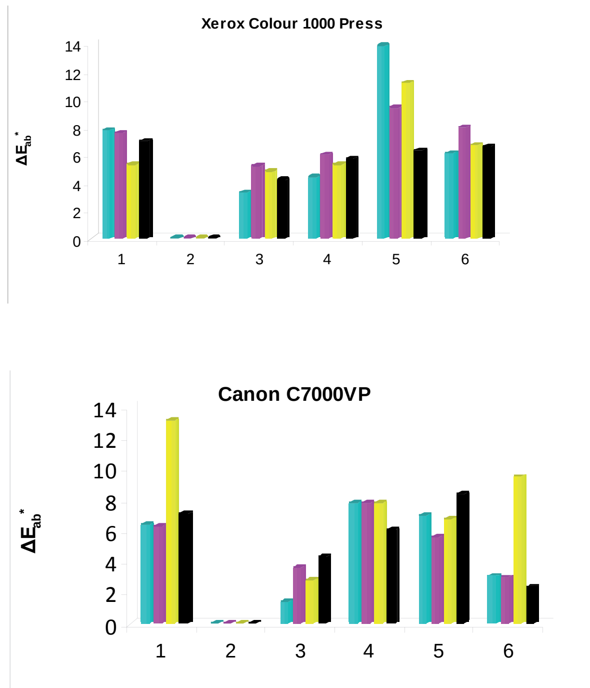

Figure 10: Colour differences of CMYK process colours compared to substrate #2

Conlclusions

In this study different types of plastic substrates printed using electrophotographic technology were investigated. Tone value increase, reproducible colour gamut and colour differences were determined on foils printed with Xerox Color 1000 Press and Canon imagePress C7000VP presses. The Xerox Color 1000 Press produced higher toner coverage on every foil substrates examined. The highest TVI values (35-40% in midtones) and largest colour gamut were measured on WindowGraphix type foil in case of both presses. This type of foil was the smoothest among the substrates and the only one with embedded electrostatic charge.

Table 4. Colour differences of CMYK process colors between reference substrate #2 and the other substrates printed with Xerox C1000Press

Substrate	ΔE_{ab}^*			
	C	M	Y	K
1	7.8	7.6	5.3	7.0
2	0.0	0.0	0.0	0.0
3	3.3	5.2	4.8	4.2
4	4.4	6.0	5.3	5.7
5	13.9	9.4	11.2	6.3
6	6.1	8.0	6.7	6.6

Table 5. Colour differences of CMYK process colors between reference substrate #2 and the other substrates printed with Canon C7000VP

Substrate	ΔE_{ab}^*			
	C	M	Y	K
1	6.4	6.3	13.2	7.1
2	0.0	0.0	0.0	0.0
3	1.4	3.6	2.8	4.3
4	7.8	7.8	7.8	6.1
5	7.0	5.6	6.8	8.4
6	3.1	3.0	9.5	2.4

Dot loss was observed in highlight areas on prints produced by the Canon imagePress C7000VP which is likely to be a consequence of improper setting of the applied electric field. No decrease of tone values were experienced in case of Xerox Color 1000 Press due to the high coverage, which, on the other hand, caused excessive TVI values. Large colour differences between patches of full tone process colours were measured most probably as a result of variations in tone transfer. Our findings may contribute to developments aimed at the improvment of the interaction of different toners and plastic foils.

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